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Department of Energy
Albuquerque Operations Office
Waste Isolation Pilot Plant Project Office
P.O. Box 3090
Carlsbad, New Mexico 88221

MAR 0 3 1992

Ms. Judith M. Espinosa, Secretary
New Mexico Environment Department
P.O. Box 26110
Santa Fe, NM 87502

Dear Secretary Espinosa:

This letter transmits the Resource Conservation and Recovery Act Part B Permit Application, Rev. 1. This is an augmented permit application prepared by the Waste Isolation Pilot Plant in response to discussions with the New Mexico Environment Department (NMED). The most significant revisions are in Chapters C, D, and I.

In Chapter C, Waste Analysis Plan (WAP), the revision has been prepared in accordance with Environmental Protection Agency guidance to include all of the critical elements of a WAP. Specifically, the WAP includes a description of the waste to be managed at the facility, the types of operations and processes which generate TRU waste, the facility process tolerance limits and boundary conditions, the waste parameters to be monitored, the sampling and analysis procedures, and the quality assurance/quality control requirements. In addition, the extensive appendices that were included in the initial permit application have been deleted since the revised waste analysis approach no longer requires these supporting documents as part of the permit application.

Chapter D, Facility Design, has been revised to include extensive design and engineering detail as requested by the NMED. This detail is provided for all systems that are used to handle waste or to provide protection to the facility, operators, public and the environment during routine waste management activities.

Chapter I, Closure/Post Closure Plans, has been revised. The chapter now focuses on the requirements for closure, should waste retrieval become a reality at the conclusion of the Test Phase. The application now describes a clean closure in which all of the waste and waste residues are to be removed from the facility. Once all waste residues are removed the Department of Energy will then evaluate the use of the facility for other applications.

Received March 4, 1992
Dr. G. Elizabeth Lindon

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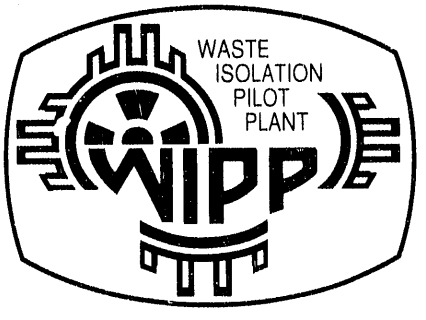
Revision 1.0

Resource Conservation and Recovery Act Part B Permit Application

Volume I of VII



Waste Isolation Pilot Plant
Carlsbad, New Mexico

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REVISION 1

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RESOURCE CONSERVATION AND RECOVERY ACT

PART B PERMIT APPLICATION

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WASTE ISOLATION PILOT PLANT
CARLSBAD, NEW MEXICO

MARCH, 1992

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B-1	General Description	Part IX, sec. 270.14(b)(1)
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B-1b	The Test Phase	Part IX, sec. 270.14(b)(1)
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B-2	Topographic Map	Part IX, sec. 270.14(b)(19)(i) Part IX, sec. 270.14(b)(19)(vi) Part IX, sec. 270.14(b)(19)(vii) Part IX, sec. 270.14(c)(3)
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B-3a	Seismic Standard	Part V, sec. 264.18(a) Part V, Appendix VI Part IX, sec. 270.14(b)(11)(i) Part IX, sec. 270.14(b)(11)(ii)
B-3b	Floodplain Standard	Part V, sec. 264.18(b) Part IX, sec. 270.14(b)(11)(iii)
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B-3b(1)(a)	Flood Proofing and Flood Protection Measures	Part V, sec. 264.18(b)(1)
B-3b(1)(b)	Flood Plan	Part V, sec. 264.18(b)(1)
B-3b(2)	Plan for Future Compliance with Floodplain Standard	Part V, sec. 264.18(b)(1)
B-3b(3)	Waiver for Land Storage and Disposal Facilities	Part V, sec. 264.18(b)(1)

[1] Regulatory citations are made using U.S. Environmental Protection Agency RCRA regulations current through July 1991.

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C	WASTE ANALYSIS PLAN	Part II, Appendix I Part V, sec. 264.13 Part X, sec. 270.14(b)(2) Part X, sec. 270.14(b)(3)
C-1	Facility Description	Part IX, sec. 270.14(b)(1)
C-1a	Containers	Part V, sec. 264.173
C-1b	Tank Systems	Part V, Subpart J
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C-2	Identification of Waste to be Managed	Part V, sec. 264.13(a) Part V, sec. 264.13(b) Part V, sec. 264.13(c) Part X, sec. 270.14(b)(2)
C-2a	Operations and Processes Generating TRU Waste	Part V, sec. 264.13(a)(2) Part V, sec. 264.13(b)
C-2b	Descriptions of Acceptable Waste Categories	Part V, sec. 264.13(a)(2) Part V, sec. 264.13(b)
C-2c	On-Site Generated and Derived Waste	Part V, sec. 264.13(a)(2) Part II, sec. 261, Appendix I Part V, sec. 264.13(b)
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C-3a	Facility-Established Boundary Conditions and Process Tolerance Limits	Part V, sec. 264.13 40 CFR, sec. 268.7
C-3b	EPA-Established Boundary Conditions	40 CFR, sec. 268.7

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C-4b	Parameters and Test Methods	Part V, sec. 264.13(b)(1) Part V, sec. 264.13(b)(2)
C-5	Waste Sampling Plan and Data Analysis	Part II, Appendix I Part V, sec. 264.13(b)(3)
C-5a	Sampling Plan	Part II, Appendix I Part V, sec. 264.13(b)(3) Part V, sec. 264.13(b)(4) Part V, sec. 264.13(b)(5)
C-5b	Sampling Method 1	Part II, Appendix I Part V, sec. 264.13(b)(3) Part V, sec. 264.13(b)(4) Part V, sec. 264.13(b)(5)
C-5c	Sampling Method 2	Part II, Appendix I Part V, sec. 264.13(b)(3) Part V, sec. 264.13(b)(4) Part V, sec. 264.13(b)(5)
C-5d	Data Analysis Methodology	Part V, sec. 264.13(b)(3)
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C-6a	Phase I Waste Shipment Screening and Verification	Part V, sec. 264.13(a)(1) Part V, sec. 264.13(a)(4) Part V, sec. 264.13(c)
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C-7	QA/QC Program	Part V, sec. 264.13(a)(1) Part V, sec. 264.13(a)(4) Part V, sec. 264.13(c)

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C-7b	Waste Shipment Screening QA/QC	Part V, sec. 264.13 (a)(1) Part V, sec. 264.13(a)(4) Part V, sec. 264.13(c)
C-7c	Waste Tracking QA/QC Restricted Waste	Part V, sec. 264.13(a)(1) Part V, sec. 264.13(a)(4) Part V, sec. 264.13(c)
D	FACILITY AND PROCESS INFORMATION	Part V, sec. 264.601 Part IX, sec. 270.14
D-1	Containers	Part IX, sec. 270.15
D-2	Tank Systems	Part V, Subpart J
D-3	Waste Piles	Part V, Subpart L
D-4	Surface Impoundments	Part V, Subpart K
D-5	Incinerators	Part V, Subpart O
D-6	Landfills	Part V, Subpart N
D-7	Land Treatment	Part V, Subpart M
D-8	Drip Pads	Part V, Subpart W
D-9	Miscellaneous Unit	Part V, Subpart X Part IX, sec. 270.23(a)(1) Part IX, sec. 270.23(a)(2)
D-9a	Description of the Miscellaneous Unit	Part IX, sec. 270.23(b)
D-9a(1)	Site Characteristics	Part V, sec. 264.601
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D-9a(1)(b)	Geology	Part V, sec. 264.601(a)(2) Part V, sec. 264.601(b)(4)
D-9a(1)(c)	Groundwater Hydrology	Part V, sec. 264.601(a)(2) Part V, sec. 264.601(a)(3) Part V, sec. 264.601(a)(4) Part V, sec. 264.601(b)(5) Part V, sec. 264.601(b)(6)

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D-9a(1)(e)	Soils	Part V, sec. 264.601(b)(8)
D-9a(1)(f)	Air Quality	Part V, sec. 264.601(c)(4) Part V, sec. 264.601(c)(5)
D-9a(1)(g)	Biological Community Structure	Not applicable.
D-9a(2)	Process Description	Part IX, sec. 270.14(8)(i)
D-9a(2)(a)	Description of Experimental Waste	Part V, sec. 264.601(a)(1) Part V, sec. 264.601(b)(1) Part V, sec. 264.601(c)(1)
D-9a(2)(b)	Waste Management Operations	Part V, sec. 264.173(b) Part IX, sec. 270.14(8)(i)
D-9a(3)	Facility Design and Construction	Part IX, sec. 270.14(8)(ii) Part IX, sec. 270.14(8)(iii) Part IX, sec. 270.14(8)(v) Part IX, sec. 270.23
D-9a(3)(a)	Site Security	Part V, sec. 264.14
D-9a(3)(b)	Waste Handling Building	Part V, sec. 264.31
D-9a(3)(c)	Waste Handling Equipment	Part V, sec. 264.31 Part IX, sec. 270.14(8)(i)
D-9a(3)(d)	Shafts and Subsurface Facilities	Part V, sec. 264.601
D-9a(3)(e)	Repository Subsurface Structures	Part V, sec. 264.601
D-9a(3)(f)	Containers	Part IX, sec. 270.15
D-9a(3)(f).1	Containers with Free Liquids	Part V, Subpart I
D-9a(3)(f).1a	Description of Containers	Part V, sec. 264.171 Part V, sec. 264.172
D-9a(3)(f).1b	Container Management Practices	Part V, sec. 264.173
D-9a(3)(f).1c	Secondary Containment System Design and Operation	Part V, sec. 264.175(a) Part V, sec. 264.175(d)
D-9a(3)(f).1d	Requirement for the Base or Liner to Contain Liquids	Part V, sec. 264.175(b)(1)

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D-9a(3)(f).1h	Removal of Liquids from Containment System	Part V, sec. 264.175(b)(5)
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D-9b	Waste Characterization	Part V, sec. 264.13 Part VIII, sec. 268.7
D-9c	Treatment Effectiveness	Part I, sec. 260.10
D-9d	Environmental Performance Standards for the Miscellaneous Unit	Part IX, sec. 270.23(c)
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D-9d(2)	Protection of Surface Water, Wetlands, and Soil Surface	Part V, sec. 264.601(b)(2) Part V, sec. 264.601(b)(6) Part V, sec. 264.601(b)(7) Part V, sec. 264.601(b)(10) Part V, sec. 264.601(b)(11)
D-9d(3)	Protection of the Atmosphere	Part V, sec. 264.601(c)(2) Part V, sec. 264.601(c)(3) Part V, sec. 264.601(c)(6) Part V, sec. 264.601(c)(7)
D-9e	Monitoring, Inspection, and Reporting	Part V, sec. 264.602 Part VIII, sec. 268.6 Part IX, sec. 270.31
D-9e(1)	Monitoring	Part V, sec. 264.90(b)(4) Part VIII, sec. 268.6
D-9e(2)	Inspection	Part V, sec. 264.15 Part V, sec. 264.33
D-9e(3)	Record Keeping	Part V, sec. 264.75 Part V, sec. 264.76 Part V, sec. 264.56(j) Part V, sec. 264.101 Part V, sec. 264.115 Part VIII, sec. 268.6

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E-1	Compliance with Groundwater Protection Requirements	Part V, sec. 264.90(b)(4) Part IX, sec. 270.14(c)
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E-1c	No Migration	Part V, Subpart F Part V, sec. 264.90(a)(2) Part V, sec. 264.90(b)(4) Part V, sec. 264.601 Part V, sec. 264.602
E-2	Interim Status Groundwater Monitoring Data	Part VI, sec. 264.60(c)
E-3	General Hydrogeologic Information	Part IX, sec. 270.14(b)(11)
E-4	Topographic Map Requirements	Part IX, sec. 270.14(b)(19)
E-5	Contaminant Plume Description	Part IX, sec. 270.14(c)(4)
E-6	General Monitoring Program Requirements	Part V, sec. 264.97 Part V, sec. 264.602
E-7	Detection Monitoring Program	Part V, sec. 264.98 Part V, sec. 264.602
E-8	Compliance Monitoring Program	Part V, sec. 264.601(a) Part V, sec. 264.602
E-9	Corrective Action Program	Part V, sec. 264.101
Appendix E1	RCRA Groundwater Protection Information Waste Isolation Pilot Plant	Part V, Subpart 1 Part V, sec. 264.601-603
F	PROCEDURES TO PREVENT HAZARDS	Part IX, sec. 270.14(b)(4) Part IX, sec. 270.14(b)(5) Part IX, sec. 270.14(b)(6) Part IX, sec. 270.14(b)(8) Part IX, sec. 270.14(b)(9) Part IX, sec. 270.15(c)
F-1	Security	Part V, sec. 264.14 Part IX, sec. 270.14(b)(4)

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F-1a	Security Procedures and Equipment	Part V, sec. 264.14(b) Part V, sec. 264.14(c)
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F-1a(2)	Barrier and Means to Control Entry	Part V, sec. 264.14(b)(2) Part IX, sec. 270.14(b)(19)(viii)
F-1a(2)(a)	Barrier	Part V, sec. 264.14(b)(2)(i)
F-1a(2)(b)	Means to Control Entry	Part V, sec. 264.14(b)(2)(ii)
F-1a(3)	Warning Signs	Part V, sec. 264.14(c)
F-1b	Waiver	Part V, sec. 264.14(a)
F-2	Inspection Schedule	Part V, sec. 264.15(b) Part V, sec. 264.33 Part V, sec. 264.174 Part V, sec. 264.193(i) Part V, sec. 264.195 Part V, sec. 264.226 Part V, sec. 264.254 Part V, sec. 264.273 Part V, sec. 264.303 Part V, sec. 264.602 Part V, sec. 264.1033 Part V, sec. 264.1052 Part V, sec. 264.1053 Part V, sec. 264.1058 Part IX, sec. 270.14(b)(5)
F-2a	General Inspection Requirements	Part V, sec. 264.15(b)(4) Part V, sec. 264.33 Part V, sec. 264.174 Part V, sec. 264.602
F-2a(1)	Types of Problems	Part V, sec. 264.15(b)(3)
F-2a(2)	Frequency of Inspections	Part V, sec. 264.15(b)(4) Part V, sec. 264.174 Part V, sec. 264.602
F-2b	Specific Process Inspection Requirements	Part V, sec. 264.15(b)(4) Part IX, sec. 270.14(b)(5)
F-2b(1)	Container Inspection	Part V, sec. 264.174

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F-2b(2)	Tank System Inspection	Part V, sec. 264.193(i) Part V, sec. 264.195
F-2b(3)	Waste Pile Inspection	Part V, sec. 264.254
F-2b(4)	Surface Impoundment Inspection	Part V, sec. 264.226
F-2b(5)	Incinerator Inspection	Part V, Subpart O
F-2b(6)	Landfill Inspection	Part V, sec. 264.303
F-2b(7)	Land Treatment Facility Inspection	Part V, sec. 264.273
F-2b(8)	Drip Pad Inspection	Part V, sec. 264.444
F-2b(9)	Miscellaneous Unit Inspection	Part V, sec. 264.602
F-3	Waiver or Documentation of Preparedness and Prevention Requirements	Part V, sec. 264.32 Part V, sec. 264.34 Part V, sec. 264.35 Part IX, sec. 270.14(b)(6)
F-3a	Equipment Requirements	Part V, sec. 264.32 Part V, sec. 264.34
F-3a(1)	Internal Communications	Part V, sec. 264.32(a) Part V, sec. 264.34(a)
F-3a(2)	External Communications	Part V, sec. 264.32(b) Part V, sec. 264.34(b)
F-3a(3)	Emergency Equipment	Part V, sec. 264.32(c)
F-3a(4)	Water for Fire Control	Part V, sec. 264.32(d) Part IX, sec. 270.14(b)(19)(x)
F-3b	Aisle Space Requirement	Part V, sec. 264.35
F-4	Preventive Procedures, Structures, and Equipment	Part IX, sec. 270.14(b)(8)
F-4a	Unloading Operations	Part IX, sec. 270.14(b)(8)(i)
F-4b	Runoff	Part IX, sec. 270.14(b)(8)(ii) Part IX, sec. 270.14(b)(19)(x) Part IX, sec. 270.14(b)(19)(xi)
F-4c	Water Supplies	Part IX, sec. 270.14(b)(8)(iii)
F-4d	Equipment and Power Failure	Part IX, sec. 270.14(b)(8)(iv)
F-4e	Personnel Protection	Part IX, sec. 270.14(b)(8)(v)

[1] Regulatory citations are made using U.S. Environmental Protection Agency RCRA regulations current through July 1991.

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F-5	Prevention of Reaction of Ignitable, Reactive, and Incompatible Wastes	Part V, sec. 264.17 Part IX, sec. 270.14(b)(9) Part IX, sec. 270.15(c)
F-5a	Precautions to Prevent Ignition or Reaction of Ignitable or Reactive Wastes	Part V, sec. 264.17(a)
F-5b	General Precautions for Handling Ignitable or Reactive Waste and Mixing of Incompatible Waste	Part V, sec. 264.17(b)
F-5c	Management of Ignitable or Reactive Waste in Containers	Part V, sec. 264.176 Part IX, sec. 270.15(c)
F-5d	Management of Incompatible Wastes in Containers	Part V, sec. 264.177 Part IX, sec. 270.15(c)
F-5e	Management of Ignitable or Reactive Wastes in Tank Systems	Not applicable.
F-5f	Management of Incompatible Wastes in Tank Systems	Part V, Subpart J
F-5g	Management of Ignitable or Reactive Wastes Placed in Waste Piles	Part V, Subpart L
F-5h	Management of Incompatible Wastes Placed in Waste Piles	Part V, Subpart L
F-5i	Management of Ignitable or Reactive Wastes Placed in Surface Impoundments	Part V, Subpart K
F-5j	Management of Incompatible Wastes Placed in Surface Impoundments	Part V, Subpart K
F-5k	Management of Ignitable or Reactive Wastes Placed in Landfills	Part V, Subpart N
F-5l	Management of Incompatible Wastes Placed in Landfills	Part V, Subpart N
F-5m	Management of Ignitable or Reactive Wastes Placed in Land Treatment Units	Part V, Subpart M
F-5n	Management of Incompatible Wastes Placed in Land Treatment Units	Part V, Subpart M
F-5o	Management of Ignitable or Reactive Wastes Placed on Drip Pads	Part V, Subpart W

[1] Regulatory citations are made using U.S. Environmental Protection Agency RCRA regulations current through July 1991.

NEW MEXICO HAZARDOUS WASTE MANAGEMENT REGULATIONS (HWMR-6) CROSS-REFERENCE TABLE[1] (CONTINUED)

Chapter	Title	HWMR-6, Part, Subpart or Section, or Appendix
F-5p	Management of Incompatible Wastes Placed on Drip Pads	Part V, Subpart W
G	RCRA CONTINGENCY PLAN	Part V, sec. 264.51(a) Part IX, sec. 270.14(b)(7)
G-1	General Information	Part V, sec. 264.50
G-2	Emergency Coordinators	Part V, sec. 264.52(d) Part V, sec. 264.55
G-3	Implementation	Part V, sec. 264.51(b) Part V, sec. 264.52(a)
G-4	Emergency Response Methods	Part V, sec. 264.52(a)
G-4a	Notification	Part V, sec. 264.56(a) Part V, sec. 264.56(d)
G-4b	Identification of Hazardous Materials	Part V, sec. 264.56(b)
G-4c	Assessment of the Nature and Extent of the Emergency	Part V, sec. 264.56(c)
G-4d	Control, Containment, and Correction of the Emergency	Part V, sec. 264.56(e) Part V, sec. 264.56(f)
G-4e	Prevention of Recurrence or Spread of Fires, Explosions, or Releases	Part V, sec. 264.56(e) Part V, sec. 264.56(f)
G-4f	Storage and Treatment of Released Material and Waste	Part V, sec. 264.56(g)
G-4g	Incompatible Waste	Part V, sec. 264.56(h)(1)
G-4h	Post-Emergency Facility and Equipment Maintenance and Reporting	Part V, sec. 264.56(h)(2) Part V, sec. 264.56(i)
G-4i	Container Spills and Leakage	Part V, sec. 264.171
G-4j	Tank Spills and Leakage	Part V, sec. 264.196
G-4k	Surface Impoundment Spills and Leakage	Part V, sec. 264.227
G-5	Emergency Equipment	Part V, sec. 264.52(e)
G-6	Coordination Agreements	Part V, sec. 264.52(c)
G-7	Evacuation Plan	Part V, sec. 264.52(f)

[1] Regulatory citations are made using U.S. Environmental Protection Agency RCRA regulations current through July 1991.

NEW MEXICO HAZARDOUS WASTE MANAGEMENT REGULATIONS (HWMR-6) CROSS-REFERENCE TABLE[1] (CONTINUED)

Chapter	Title	HWMR-6, Part, Subpart or Section, or Appendix
G-7a	Surface Evacuation On-Site Assembly Areas and Off-Site Staging Areas	Part V, sec. 264.52(f)
G-7b	Underground Assembly Areas	Part V, sec. 264.52(f)
G-7c	Plan for Surface Evacuation	Part V, sec. 264.52(f)
G-7d	Plan for Underground Evacuation	Part V, sec. 264.52(f)
G-7e	Further Site Evacuation	Part V, sec. 264.52(f)
G-8	Required Reports	Part V, sec. 264.56(j)
G-9	Location of the Contingency Plan and Plan Revision	Part V, sec. 264.53 Part V, sec. 264.54
H	PERSONNEL TRAINING	Part V, sec. 264.16 Part IX, sec. 270.14(b)(12)
H-1	Outline of the Training Program	Part V, sec. 264.16(a)(1) Part IX, sec. 270.14(b)(12)
H-1a	Job Title/Job Description	Part V, sec. 264.16(d)(1) Part V, sec. 264.16(d)(2)
H-1b	Training Content, Frequency, and Techniques	Part V, sec. 264.16(a) Part V, sec. 264.16(b) Part V, sec. 264.16(c) Part V, sec. 264.16(d)(3)
H-1b(1)	Training Content	Part V, sec. 264.16(a) Part V, sec. 264.16(d)(3)
H-1b(2)	Training Frequency	Part V, sec. 264.16(b) Part V, sec. 264.16(c)
H-1b(3)	Training Techniques	Part V, sec. 264.16(d)(3)
H-1c	Training Director	Part V, sec. 264.16(a)(2)
H-1d	Relevance of Training to Job Position	Part V, sec. 264.16(a)(2) Part IX, sec. 270.14(b)(12)
H-1e	Training for Emergency Response	Part V, sec. 264.16(a)(2) Part V, sec. 264.16(a)(3)
H-2	Implementation of Training Program	Part V, sec. 264.16(b) Part V, sec. 264.16(d)(4) Part V, sec. 264.16(e)

[1] Regulatory citations are made using U.S. Environmental Protection Agency RCRA regulations current through July 1991.

NEW MEXICO HAZARDOUS WASTE MANAGEMENT REGULATIONS (HWMR-6) CROSS-REFERENCE TABLE[1] (CONTINUED)

Chapter	Title	HWMR-6, Part, Subpart or Section, or Appendix
I	CLOSURE PLANS, POST-CLOSURE PLANS, AND FINANCIAL REQUIREMENTS	Part V, Subpart G Part IX, sec. 270.14(b)(13)
I-1	Test Phase Closure Plan	Part V, sec. 264.112 Part V, sec. 264.601 Part IX, sec. 270.14(b) Part IX, sec. 270.23(a)
I-1a	Closure Performance Standard	Part V, sec. 264.111 Part V, sec. 264.601
I-1b	Partial Closure and Final Closure Activities	Part V, sec. 264.112(b)(2)
I-1c	Maximum Waste Inventory	Part V, sec. 264.112(b)(3)
I-1d	Schedule for Closure	Part V, sec. 264.112(b)(6)
I-1d(1)	Time Allowed for Closure	Part V, sec. 264.113
I-1d(2)	Amendment of the Closure Plan	Part V, sec. 264.112(c)
I-1d(3)	Notification of Partial or Final Closure	Part V, sec. 264.112(d)
I-1e	Closure Procedures	Part V, sec. 264.112(b)(1)
I-1e(1)	Inventory Removal	Part V, sec. 264.112(b)(1)
I-1e(1)(a)	Bin-Scale Test Waste Retrieval	Part V, sec. 264.112(b)(1)
I-1e(1)(b)	Sampling and Quality Assurance	Part V, sec. 264.112(b)(4)
I-1e(1)(b).1	Sample Collection and Handling	Part V, sec. 264.112(b)(4)
I-1e(1)(b).2	Quality Assurance/Quality Control	Part V, sec. 264.112(b)(4)
I-1e(1)(b).3	Sample Analysis	Part V, sec. 264.112(b)(4)
I-1e(2)	Disposal or Decontamination of Equipment, Structures, and Soils	Part V, sec. 264.114
I-1e(2)(a)	Removal of Hazardous Waste Residues	Part V, sec. 264.112(b)(4)
I-1e(2)(b)	Decontamination of the Underground	Part V, sec. 264.112(b)(4)
I-1e(2)(c)	Decontamination of the Surface	Part V, sec. 264.112(b)(4)
I-1e(2)(d)	Waste Generated by Decontamination Activities	Part V, sec. 264.112(b)(4)
I-1e(2)(e)	Certification of Closure	Part V, sec. 264.115

[1] Regulatory citations are made using U.S. Environmental Protection Agency RCRA regulations current through July 1991.

NEW MEXICO HAZARDOUS WASTE MANAGEMENT REGULATIONS (HWMR-6) CROSS-REFERENCE TABLE[1] (CONTINUED)

Chapter	Title	HWMR-6, Part, Subpart or Section, or Appendix
I-1e(3)	Closure of Disposal Units/Contingent Closures	Part V, sec. 264.228(c)(1) Part V, sec. 264.258(c)(1)(i)
I-1e(4)	Closure of Containers	Part V, sec. 264.178
I-1e(5)	Closure of Tanks	Part V, sec. 264.197
I-1e(6)	Closure of Waste Piles	Part V, sec. 264.258
I-1e(7)	Closure of Surface Impoundments	Part V, sec. 264.228
I-1e(8)	Closure of Incinerators	Part V, sec. 264.351
I-1e(9)	Closure of Landfills	Part V, sec. 264.310
I-1e(10)	Closure of Land Treatment Facilities	Part V, sec. 264.280
I-1e(11)	Closure of Drip Pads	Part V, sec. 264.445
I-1e(12)	Post-Closure Care of Miscellaneous Units	Part V, sec. 264.603
I-2	Post-Closure Plan/Contingent Post-Closure	Part V, sec. 264.603
I-3	Decommissioning the WIPP Facility	Part V, sec. 264.112(b)(4)
I-4	Closure Cost Estimate	Part V, sec. 264.142
I-5	Financial Assurance Mechanism for Closure	Part V, sec. 264.143
I-6	Post-Closure Cost Estimate	Part V, sec. 264.144
I-7	Financial Assurance Mechanism for Post-Closure Care	Part V, sec. 264.145
I-8	Liability Requirement	Part V, sec. 264.147
J	CORRECTIVE ACTION FOR SOLID WASTE MANAGEMENT UNITS	Part V, sec. 264.90 Part IX, sec. 270.14(d)
J-1	Solid Waste Management Units	Part IX, sec. 270.14(d)
J-1a	Characterization of the SWMUs	Part IX, sec. 270.14(d)
J-2	Releases	Part V, sec. 264.90
J-2a	Characterization of Releases	Part V, sec. 264.90
J-2b	Corrective Actions	Part V, sec. 264.101(a)
K	OTHER FEDERAL LAWS	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)

[1] Regulatory citations are made using U.S. Environmental Protection Agency RCRA regulations current through July 1991.

NEW MEXICO HAZARDOUS WASTE MANAGEMENT REGULATIONS (HWMR-6) CROSS-REFERENCE TABLE[1] (CONTINUED)

Chapter	Title	HWMR-6, Part, Subpart or Section, or Appendix
K-1	Wild and Scenic Rivers Act	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-2	National Historic Preservation Act	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-3	Endangered Species Act	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-4	Coastal Zone Management Act	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-5	Fish and Wildlife Coordination Act	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-6	Clean Air Act	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-7	Clean Water Act (or Federal Water Pollution Control Act of 1972)	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-8	Safe Drinking Water Act	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-9	Comprehensive Environmental Response, Compensation, and Liability Act	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-10	Toxic Substances Control Act	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-11	National Environmental Policy Act	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-12	Resource Conservation and Recovery Act of 1976	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-13	Atomic Energy Act of 1954	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-14	Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-15	Hazardous Materials Transportation Act	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-16	Packaging and Transportation of Radioactive Materials	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)

[1] Regulatory citations are made using U.S. Environmental Protection Agency RCRA regulations current through July 1991.

NEW MEXICO HAZARDOUS WASTE MANAGEMENT REGULATIONS (HWMR-6) CROSS-REFERENCE TABLE[1] (CONTINUED)

Chapter	Title	HWMR-6, Part, Subpart or Section, or Appendix
K-17	Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-18	Waste Isolation Pilot Plant Land Withdrawal Act of 1991	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-19	Federal Land Policy and Management Act	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-20	Taylor Grazing Act	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-21	Public Rangelands Improvement Act	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-22	EO 12548—Grazing Fees	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-23	Materials Act of 1947	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-24	Federal Mine Safety and Health Act of 1977	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-25	The Wilderness Act	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-26	Bald and Golden Eagle Protection Act	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-27	Migratory Bird Treaty Act	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-28	Noise Control Act of 1972	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-29	Federal Insecticide, Fungicide, and Rodenticide Act	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-30	OSHA Regulations	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-31	National Defense Authorization Act -- Fiscal Year 1989	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-32	Protection and Enhancement of Environmental Quality	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)

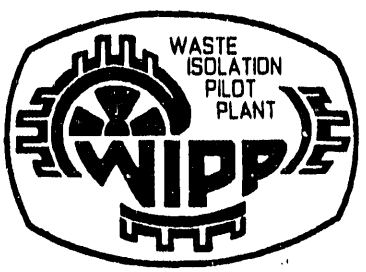
[1] Regulatory citations are made using U.S. Environmental Protection Agency RCRA regulations current through July 1991.

NEW MEXICO HAZARDOUS WASTE MANAGEMENT REGULATIONS (HWMR-6) CROSS-REFERENCE TABLE[1] (CONTINUED)

Chapter	Title	HWMR-6, Part, Subpart or Section, or Appendix
K-33	Protection and Enhancement of the Cultural Environment	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-34	Exotic Organisms	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-35	Floodplain Management	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-36	Off-Road Vehicles on Public Lands	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-37	Protection of Wetlands	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-38	Federal Compliance with Pollution Control Standards	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-39	Management of Federal Legal Resources	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-40	Environmental Safeguards on Activities for Animal Damage Control on Federal Lands	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-41	Naval Nuclear Propulsion Program	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
K-42	Superfund Implementation	Part IX, sec. 270.3 Part IX, sec. 270.14(b)(20)
L	NO-MIGRATION DETERMINATION	Part VIII, Part 268 Part IX, sec. 270.14(b)(21)
L-1	Compliance with Conditions of the Determination	Part VIII, Part 268
Appendix L1	Conditional and Proposed No-Migration Determinations for the Waste Isolation Pilot Plant	Part VIII, Part 268
M	CERTIFICATION	Part IX, sec. 270.11 Part IX, sec. 270.30(k)

[1] Regulatory citations are made using U.S. Environmental Protection Agency RCRA regulations current through July 1991.

Waste Isolation Pilot Plant
RCRA Part A Permit Application



United States Department of Energy

Waste Isolation Pilot Plant
Carlsbad, New Mexico

July 10, 1991

This material has been prepared by
Westinghouse WID for The
United States Department of Energy,
under Contract No. DE-AC04-86AL31950

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Please print or type with ELITE (12 characters per inch) in the unshaded areas only

OMB No. 2046-EPA-[illegible]

For EPA Regional Use Only		For State Use Only

Date Received
Month Day Year

EPA

United States Environmental Protection Agency
Washington, DC 20460

Hazardous Waste Permit Application Part A

(Read the Instructions before starting)

I. ID Number(s)

A. EPA ID Number	B. Secondary ID Number *(if applicable)*
NM4890139088	

II. Name of Facility

WASTE ISOLATION PILOT PLANT

III. Facility Location *(Physical address not P.O. Box or Route Number)*

A. Street

JAL HWY 30 MILES EAST

Street *(continued)*

City or Town	State	ZIP Code
CARLSBAD	NM	88221-

County Code *(if known)*	County Name
03	EDDY

B. Land Type *(enter code)*	C. Geographic Location		D. Facility Existence Date
	LATITUDE *(degrees, minutes, & seconds)*	LONGITUDE *(degrees, minutes, & seconds)*	Month Day Year
F	32 22 30 N	103 47 30 W	05 18 1981

IV. Facility Mailing Address

Street or P.O. Box

PO BOX 3090

City or Town	State	ZIP Code
CARLSBAD	NM	88221-

V. Facility Contact *(Person to be contacted regarding waste activities at facility)*

Name *(last)*	*(first)*
HUNT	ARLEN

Job Title	Phone Number *(area code and number)*
MANAGER	505-887-8101

VI. Facility Contact Address *(See instructions)*

A. Contact Address Location	A. Contact Address Mailing	B. Street or P.O. Box
	X	

City or Town	State	ZIP Code
		-

Please print or type with ELITE type (12 characters per inch) in the unshaded areas only

Form Approved. OMB No. 2050-0034 Expires 12-31-91
GSA No. 0246-EPA-OT

I. EPA I.D. Number (copy from page 1)

NM4890139088

II. Operator Information (see instructions)

Name of Operator

US DEPARTMENT OF ENERGY

P.O. Box

PO BOX 3090

City or Town

CARLSBAD

State

NM

ZIP Code

88221-

Area Code and Number

505-887-8101

B. Operator Type

F

C. Change of Operator Indicator

Date Changed (Month, Day, Year)

III. Facility Owner (see instructions)

Name of Legal Owner

US DEPARTMENT OF ENERGY

Mail or P.O. Box

PO BOX 3090

City or Town

CARLSBAD

State

NM

ZIP Code

88221-

Phone Number (area code and number)

505-887-8101

B. Owner Type

F

C. Change of Owner Indicator

Date Changed (Month, Day, Year)

IV. SIC Codes (4-digit, in order of significance)

Primary		Secondary	
4953	(description) REFUSE SYSTEMS		(description)
Secondary		Secondary	
	(description)		(description)

X. Other Environmental Permits (see instructions)

A. Permit Type	B. Permit Number	C. Description
E		Other: See Appendix A

EPA I.D. Number (enter from page 1)

N	M	4	8	9	0	1	3	9	0	8	8

XI. Nature of Business (provide a brief description)

The Waste Isolation Pilot Plant (WIPP) is a U.S. Department of Energy facility intended to demonstrate the technical and operational principles involved in the permanent isolation and disposal of defense-generated transuranic waste. WIPP operations entail receiving, unloading, and transferring radioactive-mixed waste from the surface of the site to the underground storage rooms. Waste will be emplaced in an underground storage horizon located in a deep-bedded salt formation approximately 2,150 feet beneath the surface.

XII. Process - Codes and Design Capacities

A. **PROCESS CODE** - Enter the code from the list of process codes below that best describes each process to be used at the facility. Twelve lines are provided for entering codes. If more lines are needed, attach a separate sheet of paper with the additional information. If a process will be used that is not included in the list of codes below, then describe the process (including its design capacity) in the space provided in Item XIII.

B. **PROCESS DESIGN CAPACITY** - For each code entered in column A, enter the capacity of the process.

1. **AMOUNT** - Enter the amount. In a case where design capacity is not applicable (such as for closure/post-closure or enforcement action) enter the total amount of waste for that process unit.
2. **UNIT OF MEASURE** - For each amount entered in column B(1), enter the code from the list of unit of measure codes below that describes the unit of measure used. Only the units of measure that are listed below should be used.

C. **PROCESS TOTAL NUMBER OF UNITS** - Enter the total number of units used with the corresponding process code.

PROCESS CODE	PROCESS	APPROPRIATE UNITS OF MEASURE FOR PROCESS DESIGN CAPACITY
	DISPOSAL:	
D79	INJECTION WELL	GALLONS; LITERS; GALLONS PER DAY; OR LITERS PER DAY
D80	LANDFILL	ACRE-FEET OR HECTARE-METER
D81	LAND APPLICATION	ACRES OR HECTARES
D82	OCEAN DISPOSAL	GALLONS PER DAY OR LITERS PER DAY
D83	SURFACE IMPOUNDMENT	GALLONS OR LITERS
	STORAGE:	
S01	CONTAINER (barrel, drum, etc.)	GALLONS OR LITERS
S02	TANK	GALLONS OR LITERS
S03	WASTE PILE	CUBIC YARDS OR CUBIC METERS
S04	SURFACE IMPOUNDMENT	GALLONS OR LITERS
	TREATMENT:	
T01	TANK	GALLONS PER DAY OR LITERS PER DAY
T02	SURFACE IMPOUNDMENT	GALLONS PER DAY OR LITERS PER DAY
T03	INCINERATOR	SHORT TONS PER HOUR; METRIC TONS PER HOUR; GALLONS PER HOUR; LITERS PER HOUR; OR BTU'S PER HOUR
T04	OTHER TREATMENT (Use for physical, chemical, thermal or biological treatment processes not occurring in tanks, surface impoundment or incinerators. Describe the processes in the space provided in Item XIII.)	GALLONS PER DAY; LITERS PER DAY; POUNDS PER HOUR; SHORT TONS PER HOUR; KILOGRAMS PER HOUR; METRIC TONS PER DAY; METRIC TONS PER HOUR; OR SHORT TONS PER DAY

UNIT OF MEASURE	UNIT OF MEASURE CODE
GALLONS	G
GALLONS PER HOUR	E
GALLONS PER DAY	U
LITERS	L
LITERS PER HOUR	H
LITERS PER DAY	V
SHORT TONS PER HOUR	D
METRIC TONS PER HOUR	W
SHORT TONS PER DAY	N
METRIC TONS PER DAY	S
POUNDS PER HOUR	J
KILOGRAMS PER HOUR	R
CUBIC YARDS	Y
CUBIC METERS	C
ACRES	B
ACRE-FEET	A
HECTARES	Q
HECTARE-METER	F
BTU's PER HOUR	K

EPA I.D. Number (enter from page 1)												Secondary ID Number (enter from page 1)											
N	M	4	8	9	0	1	3	9	0	8	8												

XII. Process - Codes and Design Capacities (continued)

EXAMPLE FOR COMPLETING ITEM XII (shown in line numbers X-1 and X-2 below): A facility has two storage tanks, one tank can hold 200 gallons and the other can hold 400 gallons. The facility also has an incinerator that can burn up to 20 gallons per hour.

Line Number		A. PROCESS CODE (from list above)			B. PROCESS DESIGN CAPACITY 1. AMOUNT (specify)	B. 2. UNIT OF MEASURE (enter code)	C. PROCESS TOTAL NUMBER OF UNITS			FOR OFFICIAL USE ONLY
X	1	S	0	2	600	G	0	0	2	
X	2	T	0	3	20	E	0	0	1	
	1				178,290	C	0	0	1	
	2				*See page 5 (this					
	3				form) for process					
	4				description -					
	5				miscellaneous unit					
	6									
	7									
	8									
	9									
1	0									
1	1									
1	2									

NOTE: If you need to list more than 12 process codes, attach an additional sheet(s) with the information in the same format as above. Number the lines sequentially, taking into account any lines that will be used for additional treatment processes in item XIII.

XIII. Additional Treatment Processes (follow instructions from item XII)

Line Number (enter numbers in sequence with item XII)	A. PROCESS CODE	B. TREATMENT PROCESS DESIGN CAPACITY 1. AMOUNT (specify)	B. 2. UNIT OF MEASURE (enter code)	C. PROCESS TOTAL NUMBER OF UNITS	D. DESCRIPTION OF PROCESS
	T 0 4				
	T 0 4				
	T 0 4				
	T 0 4				

NM 4 8 9 0 1 3 9 0 8 8

XII. PROCESS - CODES AND DESIGN CAPACITIES (continued)

The Waste Isolation Pilot Plant (WIPP) is defined as a "miscellaneous unit" under 40 CFR Part 260.10. "Miscellaneous unit" means a hazardous waste management unit where hazardous waste is treated, stored, or disposed of, and that is not a container, tank, surface impoundment, waste pile, land treatment unit, landfill, incinerator, boiler, industrial furnace, or underground injection well with appropriate technical standards under 40 CFR Part 146. WIPP is a geologic repository designed for the disposal of defense-generated transuranic waste. Some of the transuranic wastes disposed of at the WIPP contain hazardous wastes as co-contaminants. WIPP will be permitted as a "miscellaneous unit" under 40 CFR Part 264, Subpart X. This permit application does not include a code for "miscellaneous unit" and therefore, no code has been included in Sections XII A. and XIV D. of the form.

The process design capacity shown in this Section XII B. and the estimated annual waste quantities shown in Section XIV B. are for the expected life of the facility (25 years). During the initial Test Phase of the facility, which is expected to be less than 10 years, the total amount of waste received will be limited to 8,500 drums (about 1800 cubic meters). This limitation has been stipulated in the Conditional No-Migration Determination for the Waste Isolation Pilot Plant (WIPP) issued under 40 CFR 268.6 by the US EPA on November 14, 1990 (55 FR 47700).

EPA I.D. Number (enter from page 1)												Secondary ID Number (enter from page 1)												
N	M	4	8	9	0	1	3	9	0	8	8													

XIV. Description of Hazardous Wastes

A. EPA HAZARDOUS WASTE NUMBER - *Enter the four-digit number from 40 CFR, Part 261 Subpart D of each listed hazardous waste you will handle. For hazardous wastes which are not listed in 40 CFR, Part 261 Subpart D, enter the four-digit number(s) from 40 CFR, Part 261 Subpart C that describes the characteristics and/or the toxic contaminants of those hazardous wastes.*

B. ESTIMATED ANNUAL QUANTITY - *For each listed waste entered in column A estimate the quantity of that waste that will be handled on an annual basis. For each characteristic or toxic contaminant entered in column A estimate the total annual quantity of all the non-listed waste(s) that will be handled which possess that characteristic or contaminant.*

C. UNIT OF MEASURE - *For each quantity entered in column B enter the unit of measure code. Units of measure which must be used and the appropriate codes are:*

ENGLISH UNIT OF MEASURE	CODE	METRIC UNIT OF MEASURE	CODE
POUNDS	P	KILOGRAMS	K
TONS	T	METRIC TONS	M

If facility records use any other unit of measure for quantity, the units of measure must be converted into one of the required units of measure taking into account the appropriate density or specific gravity of the waste.

D. PROCESSES

1. **PROCESS CODES:**

   For listed hazardous waste: For each listed hazardous waste entered in column A select the code(s) from the list of process codes contained in item XII A. on page 3 to indicate how the waste will be stored, treated, and/or disposed of at the facility.

   For non-listed hazardous waste: For each characteristic or toxic contaminant entered in column A, select the code(s) from the list of process codes contained in item XII A. on page 3 to indicate all the processes that will be used to store, treat, and/or dispose of all the non-listed hazardous wastes that processes that characteristic or toxic contaminant.

   NOTE: THREE SPACES ARE PROVIDED FOR ENTERING PROCESS CODES - IF MORE ARE NEEDED:

   1. *Enter the first two as described above.*
   2. *Enter "000" in the extreme right box of item XIV-D(1).*
   3. *Enter in the space provided on page 7, item XIV-E, the line number and the additional code(s).*

2. **PROCESS DESCRIPTION:** *If a code is not listed for a process that will be used, describe the process in the space provided on the form (D.(2)).*

   NOTE: HAZARDOUS WASTES DESCRIBED BY MORE THAN ONE EPA HAZARDOUS WASTE NUMBER - Hazardous wastes that can be described by more than one EPA Hazardous Waste Number shall be described on the form as follows:

   1. *Select one of the EPA Hazardous Waste Numbers and enter it in column A. On the same line complete columns B, C, and D by estimating the total annual quantity of the waste and describing all the processes to be used to treat, store, and/or dispose of the waste.*
   2. *In column A of the next line enter the other EPA Hazardous Waste Number that can be used to describe the waste. In column D(2) on that line enter "included with above" and make no other entries on that line.*
   3. *Repeat step 2 for each EPA Hazardous Waste Number that can be used to describe the hazardous waste.*

EXAMPLE FOR COMPLETING ITEM XIV (shown in line numbers X-1, X-2, X-3, and X-4 below) - A facility will treat and dispose of an estimated 900 pounds per year of chrome shavings from leather tanning and finishing operation. In addition, the facility will treat and dispose of three non-listed wastes. Two wastes are corrosive only and there will be an estimated 200 pounds per year of each waste. The other waste is corrosive and ignitable and there will be an estimated 100 pounds per year of that waste. Treatment will be in an incinerator and disposal will be in a landfill.

Line Number		A. EPA HAZARD WASTE NO. (enter code)				B. ESTIMATED ANNUAL QUANTITY OF WASTE	C. UNIT OF MEASURE (enter code)	D. PROCESS (1) PROCESS CODES (enter)									D. PROCESS (2) PROCESS DESCRIPTION (If a code is not entered in D(1))
X	1	K	0	5	4	900	P	T	0	3	D	8	0				
X	2	D	0	0	2	400	P	T	0	3	D	8	0				
X	3	D	0	0	1	100	P	T	0	3	D	8	0				
X	4	D	0	0	2												Included With Above

EPA I.D. Number (enter from page 1)

N	M	4	8	9	0	1	3	9	0	8	8

XIV. Description of Hazardous Wastes (continued)

Line Number	A. EPA HAZARDOUS WASTE NO. (enter code)	B. ESTIMATED ANNUAL QUANTITY OF WASTE	C. UNIT OF MEASURE (enter code)	D. PROCESSES (1) PROCESS CODES (enter)	D. PROCESSES (2) PROCESS DESCRIPTION (If a code is not entered in D(1))
	F 0 0 1	1273	M		Miscellaneous unit; see Section XII
	F 0 0 2	1176	M		
	F 0 0 3	544	M		
	F 0 0 4	21	M		
	F 0 0 5	42	M		
	D 0 0 4	84	M		
	D 0 0 5	50	M		
	D 0 0 6	698	M		
	D 0 0 7	252	M		
	D 0 0 8	1133	M		
	D 0 0 9	160	M		
	D 0 1 0	13	M		
	D 0 1 1	13	M		
	P 0 1 5	67	M		
	D 0 1 2	30	M		
	D 0 1 3	30	M		
	D 0 1 4	30	M		
	D 0 1 5	30	M		
	D 0 1 6	30	M		
	D 0 1 7	30	M		
	D 0 1 8	30	M		
	D 0 1 9	30	M		
	D 0 2 0	30	M		
	D 0 2 1	30	M		
	D 0 2 2	30	M		
	D 0 2 3	30	M		
	D 0 2 4	30	M		
	D 0 2 5	30	M		
	D 0 2 6	30	M		
	D 0 2 7	30	M		

EPA I.D. Number (enter from page 1)												Section (enter from page 1)														
N	M	4	8	9	0	1	3	9	0	8	8															

XIV. Description of Hazardous Wastes (continued)

Line Number	A. EPA HAZARDOUS WASTE NO. (enter code)	B. ESTIMATED ANNUAL QUANTITY OF WASTE	C. UNIT OF MEASURE (enter code)	D. PROCESSES (1) PROCESS CODES (enter)	D. PROCESSES (2) PROCESS DESCRIPTION (If a code is not entered in D(1))
*	D028	30	M		Miscellaneous unit; see Section XII
	D029	30	M		
	D030	30	M		
	D031	30	M		
	D032	30	M		
	D033	30	M		
	D034	30	M		
	D035	30	M		
	D036	30	M		
	D037	30	M		
	D038	30	M		
	D039	30	M		
	D040	30	M		
	D041	30	M		
	D042	30	M		
	D043	30	M		

EPA I.D. Number (enter from page 1)												Secondary ID Number (enter from page 1)																	
N	M	4	8	9	0	1	3	9	0	8	8																		

XIV. Description of Hazardous Wastes (continued)

USE THIS SPACE TO LIST ADDITIONAL PROCESS CODES FROM ITEM D(1) OR D(2) ABOVE

Line Number	Appropriate Process Code (enter)																												

XV. Map

Attach to this application a topographic map of the area extending to at least one mile beyond property boundaries. The map must show the outline of the facility, the location of each of its existing and proposed intake and discharge structures, each of its hazardous waste treatment, storage, or disposal facilities, and each well where it injects fluids underground. Include all springs, rivers and other surface water bodies in this map area. See instructions for precise requirements.

XVI. Facility Drawing

All existing facilities must include a scale drawing of the facility (see instructions for more detail).

XVII. Photographs

All existing facilities must include photographs (aerial or ground-level) that clearly delineate all existing structures; existing storage, treatment and disposal areas; and sites of future storage, treatment or disposal areas (see instructions for more detail).

XVIII. Certification(s)

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to be the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Owner Signature	Date Signed **
Original signed by Arlen E. Hunt	July 9, 1991

Name and Official Title (type or print)

Arlen E. Hunt, Manager, DOE/WPO

Operator Signature *	CO-OPERATOR *	Date Signed **
Original signed by Arlen E. Hunt	Original signed by A. L. Trego	July 9, 1991

Name and Official Title (type or print) Operator * - Arlen E. Hunt, Manager, DOE/WPO

Co-Operator * - A. L. Trego, General Manager, Westinghouse

XIX. Comments

Section XVIII, Operator Signature - * See attached "RCRA Part A Application Certification"

** Date of submittal of additional data. See page 10 of 10 for date Part A was submitted.

Note: Mail completed form to the appropriate EPA Regional or State Office. (refer to instructions for more information)

RCRA PART A APPLICATION CERTIFICATION

The U.S. Department of Energy (DOE), through its Albuquerque Operations Office and WIPP Project Office, has signed as "owner and operator," and Westinghouse Electric Corporation, acting through its Waste Isolation Division (WID), has signed as "co-operator," this application for the permitted facility. The DOE has determined that dual signatures best reflect the actual apportionment of responsibility under which the DOE's RCRA responsibilities are for policy, programmatic, funding and scheduling decisions, WIPP requirements of DOE generator sites, the Waste Acceptance Criteria Certification Committee (WACCC), all other parties engaged in work at the WIPP facility pursuant to a direct contractual relationship with the DOE, as well as general oversight; the WID's RCRA responsibilities are for certain day-to-day operations (in accordance with general directions given by the DOE and in the M&O Contract as part of its general oversight responsibility), including but not limited to, the following responsibilities: certain waste handling, monitoring, record keeping, certain data collection, reporting, technical advice, and contingency planning. For purposes of the certification required by 40 CFR 270.11(d), the DOE's and the WID's representatives certify, to the best of their knowledge and belief, the truth, accuracy and completeness of the application for their respective areas of responsibility.

Owner and Operator Signature: Original signed by Arlen E. Hunt
Title: Project Manager, WIPP Project Office
for: Department of Energy
Date: January 18, 1991

Co-Operator Signature: Original signed by A. L. Trego
Title: General Manager
for: Westinghouse Electric Corporation
Date: January 18, 1991

PART A APPLICATION

APPENDIX A
OTHER ENVIRONMENTAL PERMITS

TABLE A-1

ACTIVE ENVIRONMENTAL PERMITS/APPROVALS

Granting Agency	Type of Permit/Approval	Permit Number	Date Granted	Date of Expiration
Department of the Interior, Bureau of Land Management	Right-of-Way for placement of raptor platforms	NM82212	09/12/89	09/12/92
As above	Right-of-Way for water pipeline	NM53809	08/24/84	N/A
As above	Right-of-Way for north access road	NM55676	08/24/83	N/A
As above	Right-of-Way for railroad	NM55699	09/27/83	N/A
As above	Right-of-Way for dosimetry and aerosol sampling sites	NM63136	07/03/86	N/A
As above	Same as above	NM77921	08/18/89	08/18/2019
As above	Right-of-Way for seven subsidence monuments	NM65801	11/07/88	N/A
As above	Right-of-Way for monument installation	NM88245	12/15/89	12/13/2019
As above	Withdrawal of public lands for the construction of the WIPP	PLO 6403, p. 1	06/29/83	06/29/91
U.S. Environmental Protection Agency	National Emissions Standards for Hazardous Air Pollutants (NESHAPS) (for radionuclides)	N/A (1)		
New Mexico Environmental Improvement Division	Open Burning Permit to train fire control crew	N/A	01/23/90	01/23/91
New Mexico Department of Game and Fish	Permit to collect biological samples	1894	01/08/90	12/31/90 (2)

(1) Notification of Start-up.
(2) A permit for 1991 has been applied for.
N/A Not Applicable

TABLE A-1

ACTIVE ENVIRONMENTAL PERMITS/approvals
(Continued)

Granting Agency	Type of Permit/ Approval	Permit Number	Date Granted	Date of Expiration
As above	Concurrence that construction of WIPP will have no significant adverse impact upon threatened or endangered species	N/A	04/07/80	N/A
New Mexico Commissioner of Public Lands	Right-of-Way for high volume air sampler	RW-22789	10/03/85	10/03/2020
New Mexico Department of Finance and Administration, Planning Division, Historic Preservation Bureau	Concurrence that the archaeological resources protection plan prepared by the DOE is adequate to mitigate any adverse impacts upon cultural resources resulting from construction of the full WIPP facility	N/A	07/25/83	N/A

N/A Not Applicable

PART A APPLICATION

APPENDIX B
MAPS

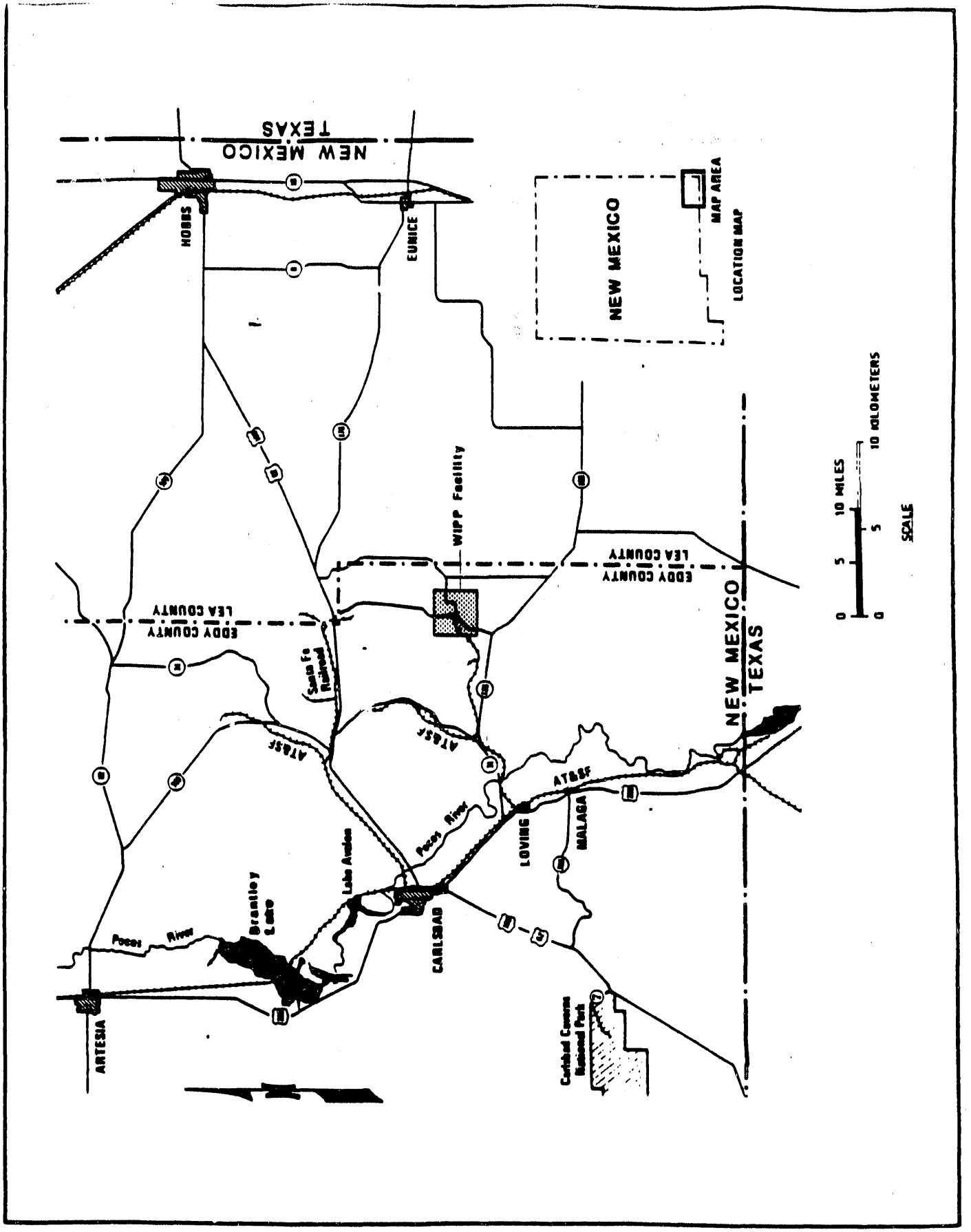


FIGURE B-1 GENERAL LOCATION OF THE WIPP FACILITY

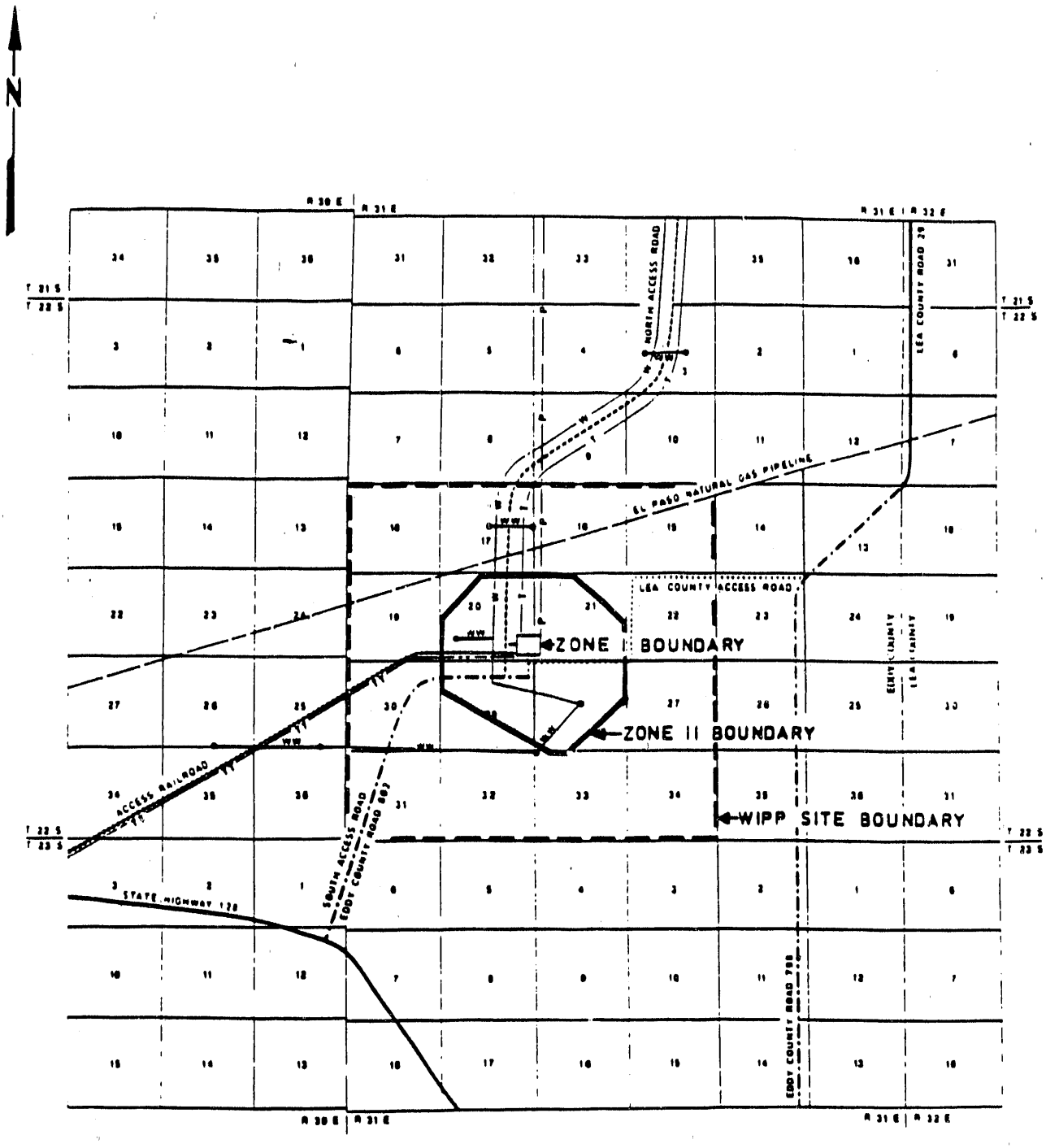


FIGURE B-2 PLANIMETRIC MAP - WIPP FACILITY BOUNDARIES

LEGEND

WIPP SITE BOUNDARY
10,240 ACRES.

U.S. DOE RIGHT OF WAY NUMBER NM-53809 , FOR WATERLINE, 50 FEET WIDE. THE DOE HAD AGREED WITH THE CITY OF CARLSBAD TO ALLOW THE INDIVIDUALS TO TAP THIS LINE LOCATED WITHIN THE NORTH ACCESS ROAD RIGHT OF WAY.

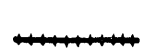
STOCK WATER TANKS AND TAP LINES CONNECTED TO THE MAIN WIPP WATERLINE.

SOUTHWESTERN PUBLIC SERVICE COMPANY RIGHT OF WAY NUMBER NM-43203 FOR POWERLINE 60 FEET WIDE.

GENERAL TELEPHONE OF THE SOUTHWEST RIGHT OF WAY FOR TELEPHONE LINE, 30 FEET WIDE, LOCATED WITHIN THE NORTH ACCESS ROAD RIGHT OF WAY.

GENERAL TELEPHONE OF THE SOUTHWEST RIGHT OF WAY NUMBER NM-60174 FOR TELEPHONE LINE, 30 FEET WIDE, LOCATED WITHIN THE RAILROAD RIGHT OF WAY.

U.S. DOE RIGHT OF WAY NUMBER NM-55675 FOR NORTH ACCESS ROAD, 170 FEET WIDE.



EL PASO NATURAL GAS COMPANY RIGHT OF WAY FOR GAS PIPELINE, 30 FEET WIDE IN SECTION 16, 50 FEET WIDE ELSEWHERE.

U.S. DOE RIGHT OF WAY NUMBER NM-55699 FOR ACCESS RAILROAD, 150 FEET WIDE.

EDDY COUNTY RIGHT OF WAY FOR ACCESS ROADS INCLUDES RIGHT OF WAY NUMBER NM-4130 FOR THE SOUTH ACCESS ROAD WHICH IS 150 FEET WIDE.

NOTES

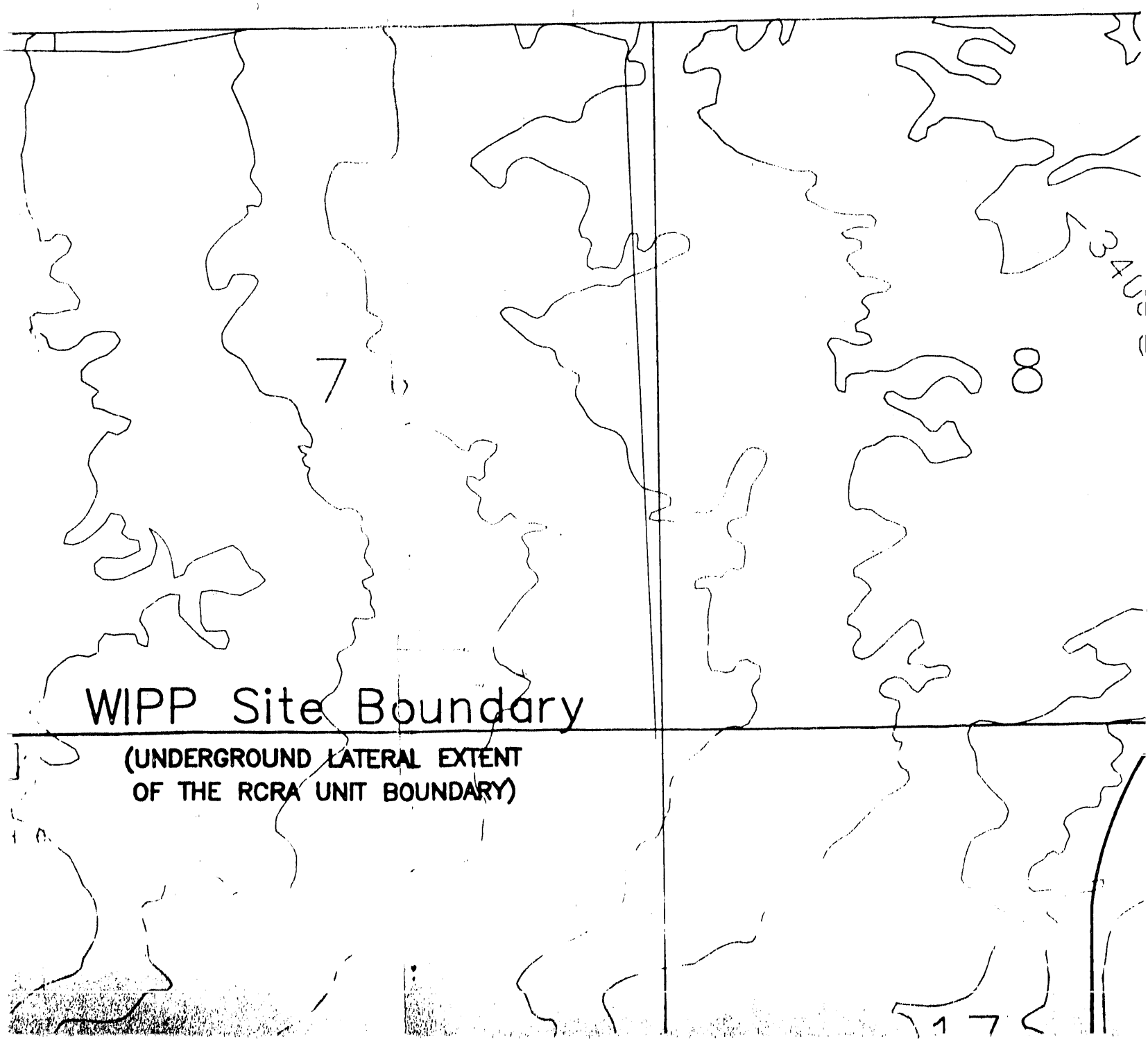
1. ZONE I IS A FENCED AREA OF APPROXIMATELY 35 ACRES. IT CONTAINS ALL SURFACE FACILITIES WITH THE EXCEPTION OF SALT STORAGE PILES, PARKING LOT, LANDFILL AND WASTE WATER STABILIZATION LAGOONS.

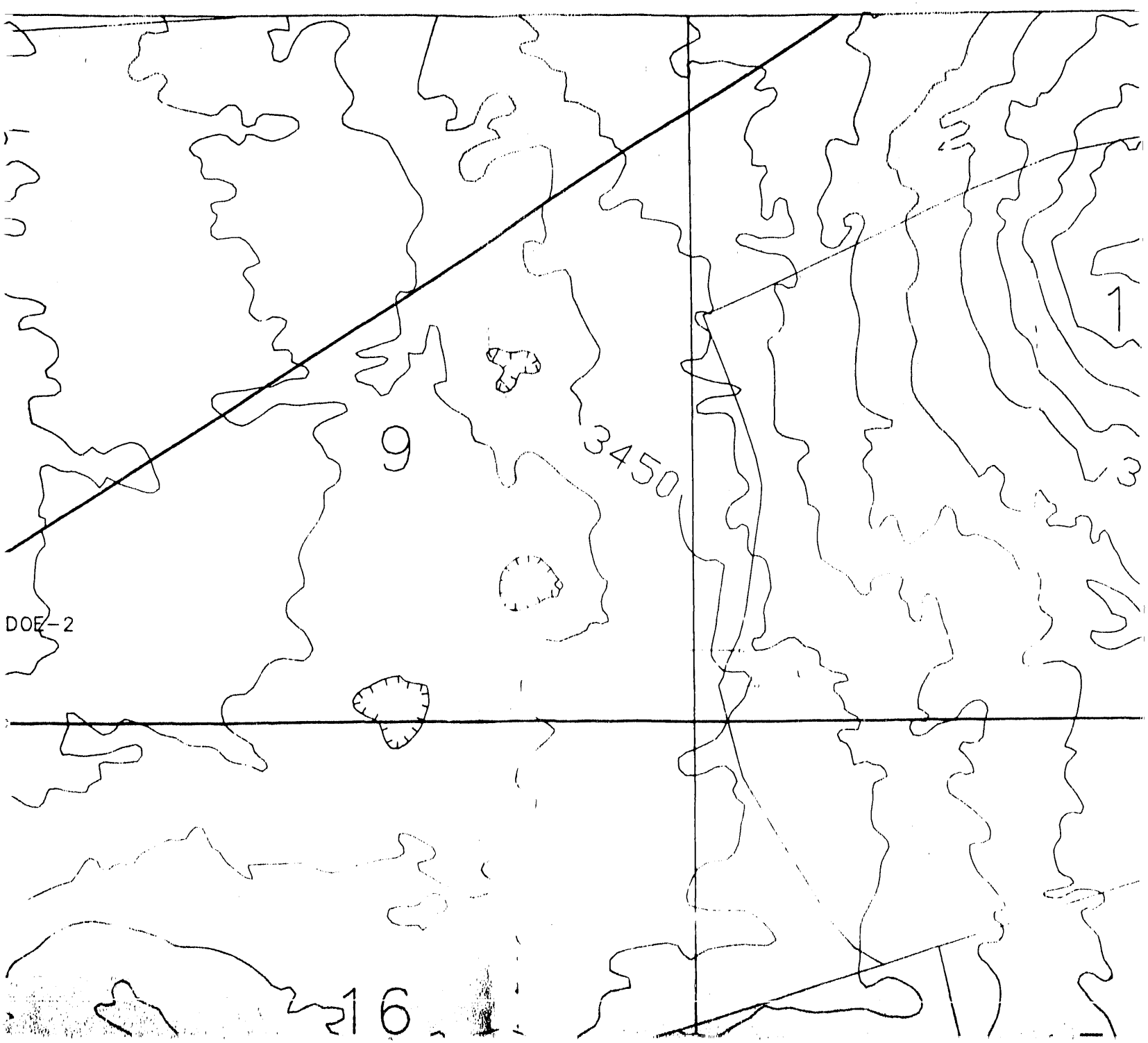
2. ZONE II OVERLIES THE MAXIMUM EXTENT OF THE AREA AVAILABLE FOR UNDERGROUND DEVELOPMENT. THE PORTION OF ZONE II LOCATED OUTSIDE THE DOE EXCLUSIVE USE AREA IS PRESENTLY MANAGED BY THE BLM.

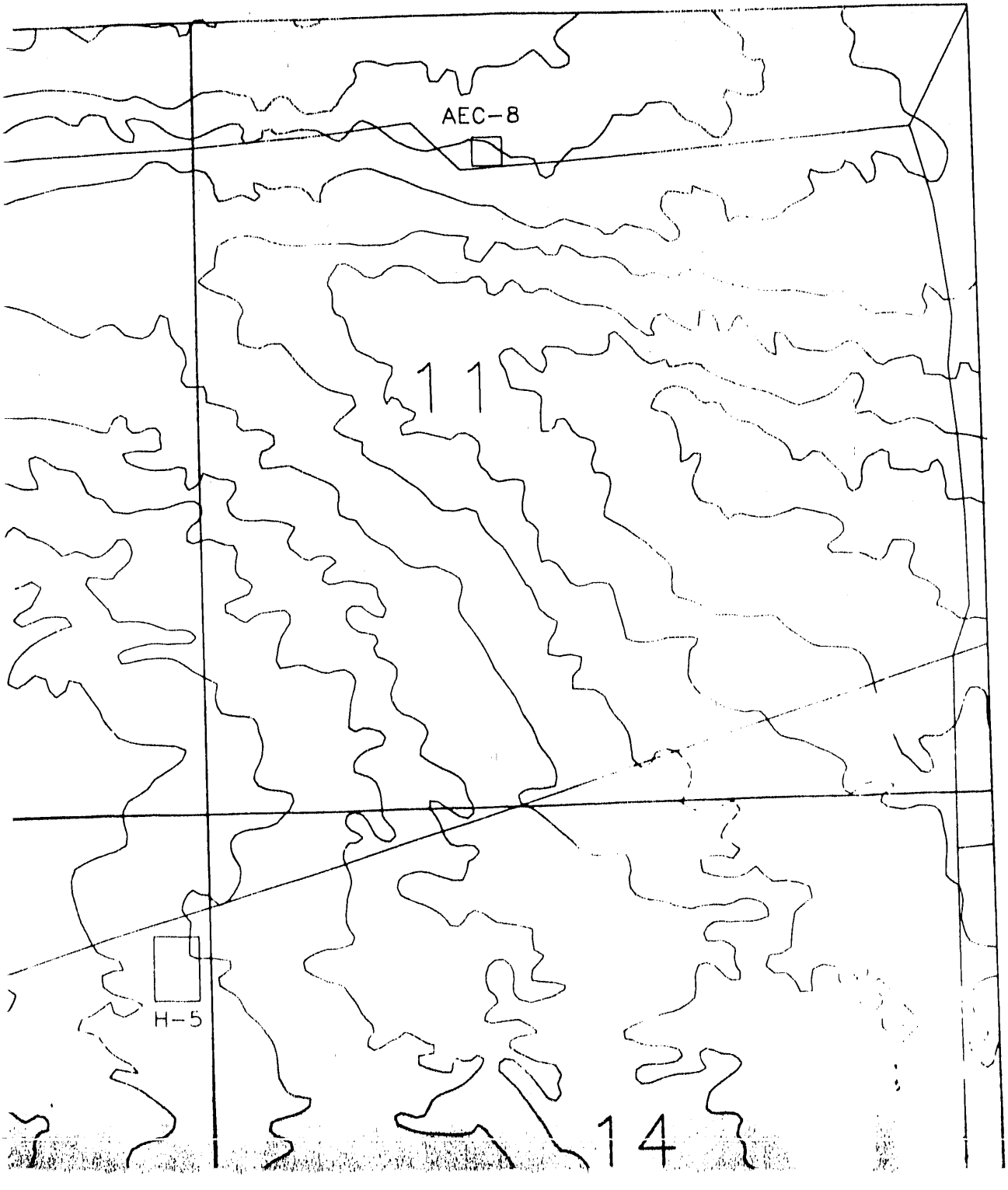
3. WIPP SITE BOUNDARY (WSB) PROVIDES A ONE MILE BUFFER AREA AROUND THE AREA AVAILABLE FOR UNDERGROUND DEVELOPMENT. PORTIONS OF WSB ARE PRESENTLY MANAGED BY THE BLM.

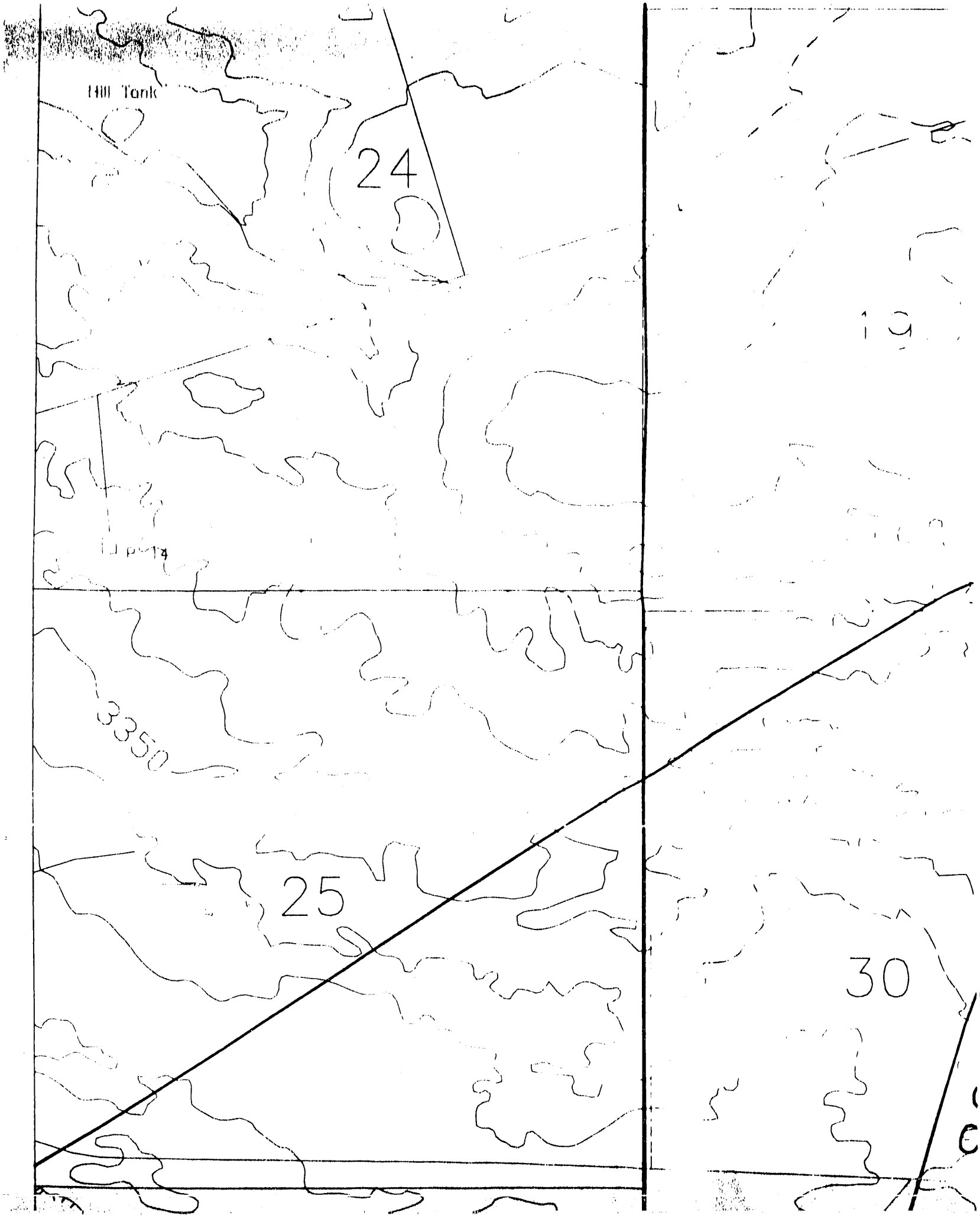
EXPLANATION TO FIGURE B-2

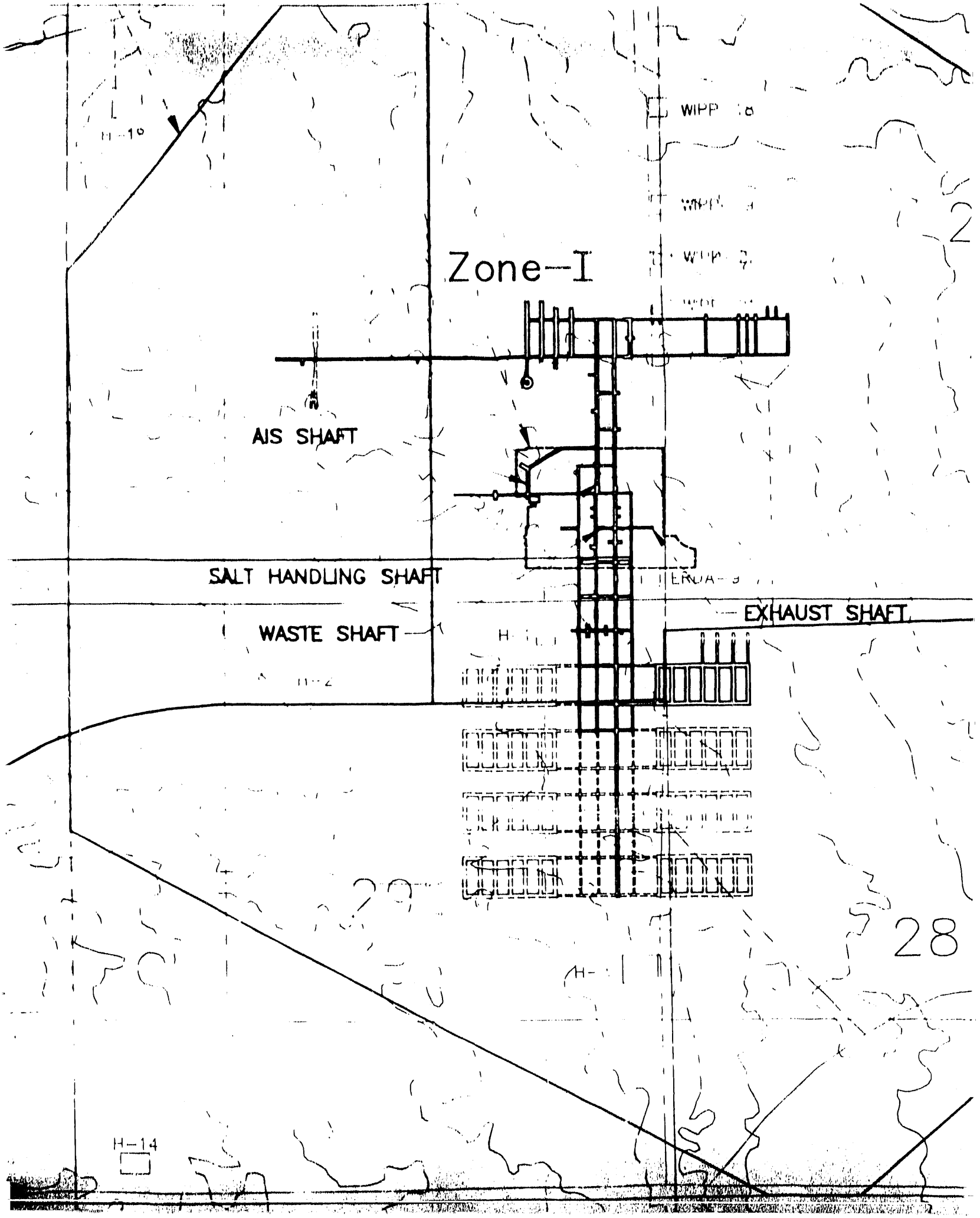
12
1 Z
H

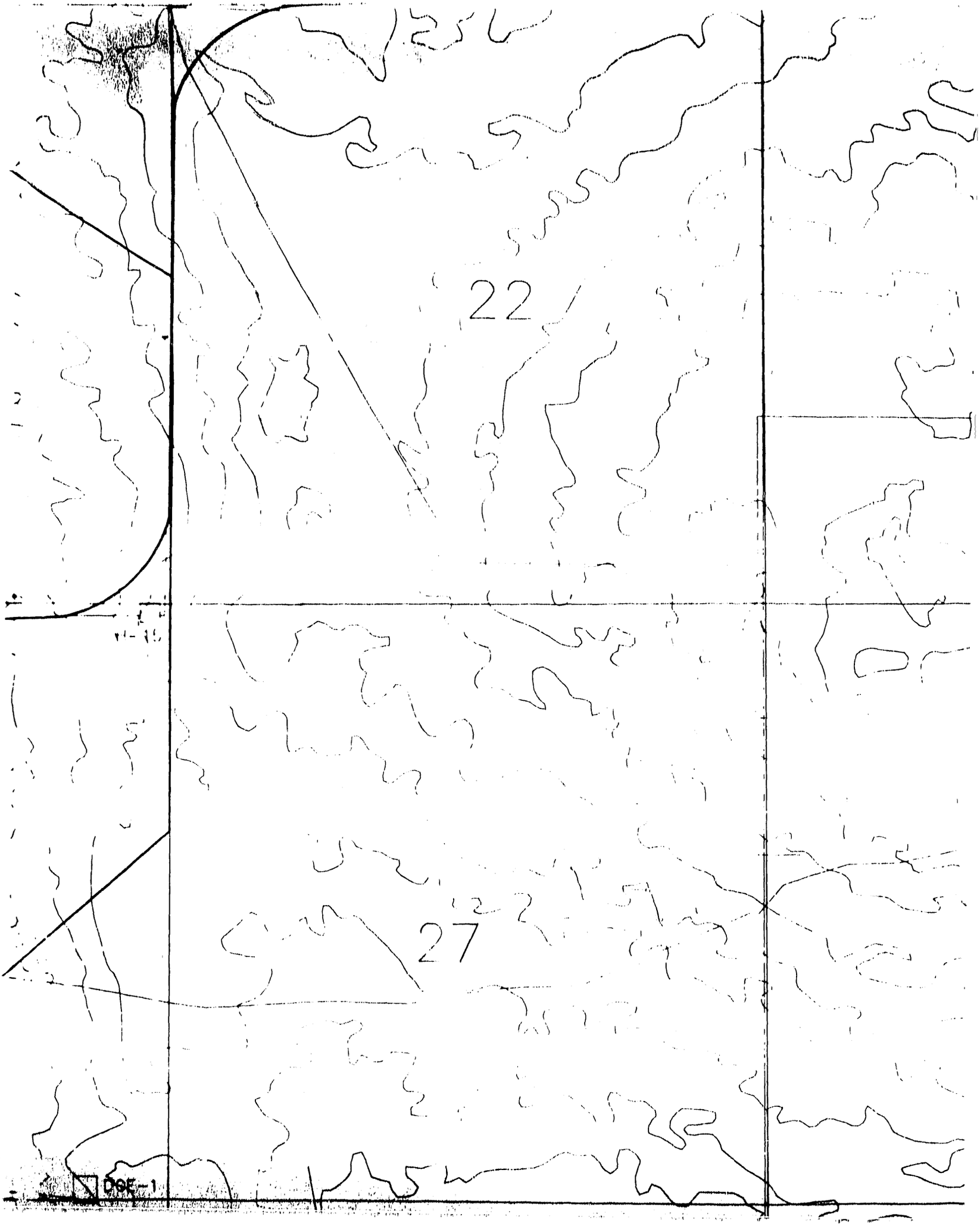

7
8
WIPP Site Boundary
(UNDERGROUND LATERAL EXTENT
OF THE RCRA UNIT BOUNDARY)


9
3450
DOE-2


AEC-8
11
H-5
14


Hill Tank
24
19
3350
25
30


Zone–I
AIS SHAFT
SALT HANDLING SHAFT
WASTE SHAFT
EXHAUST SHAFT
H–14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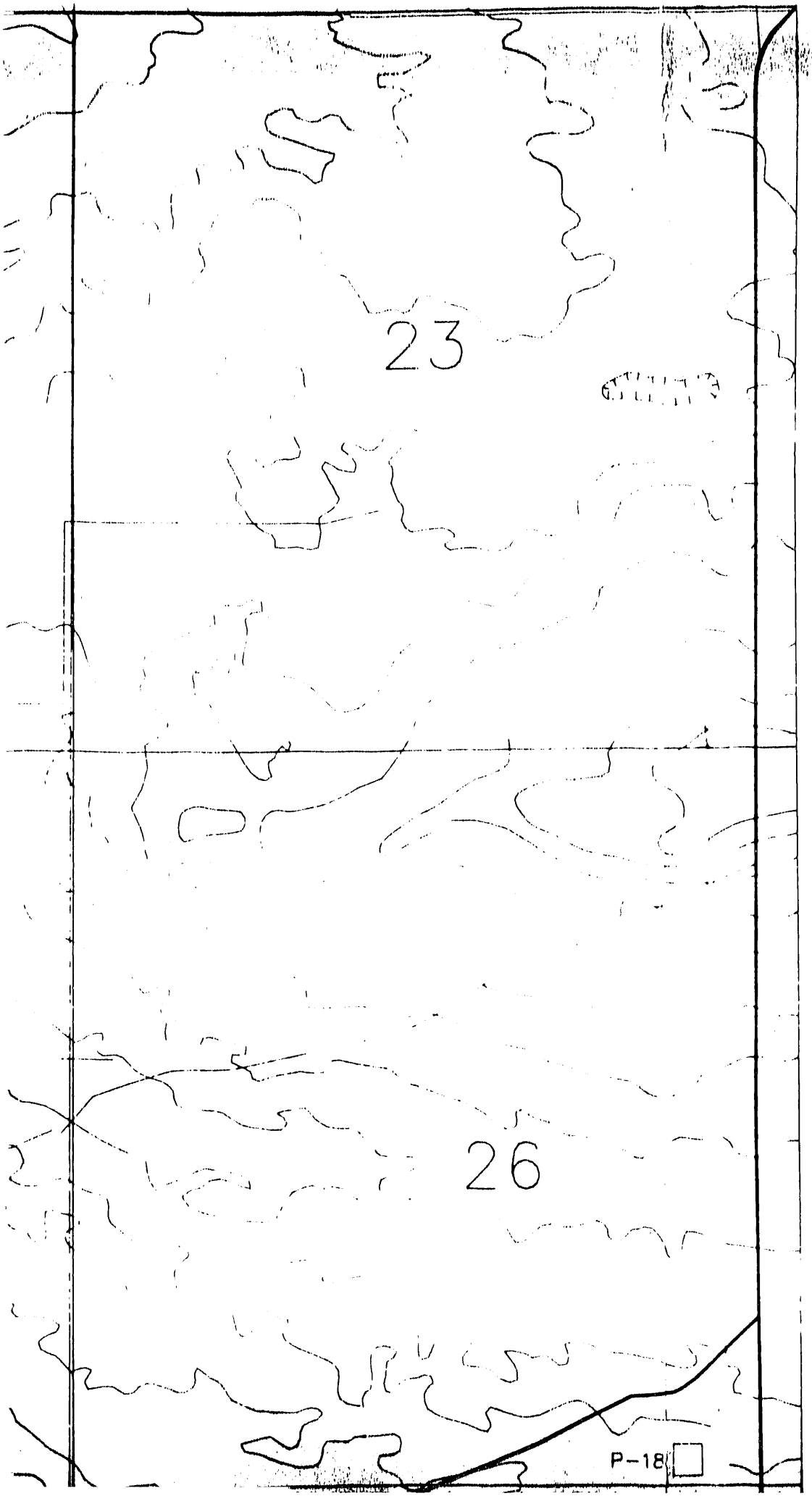
27
DOE-1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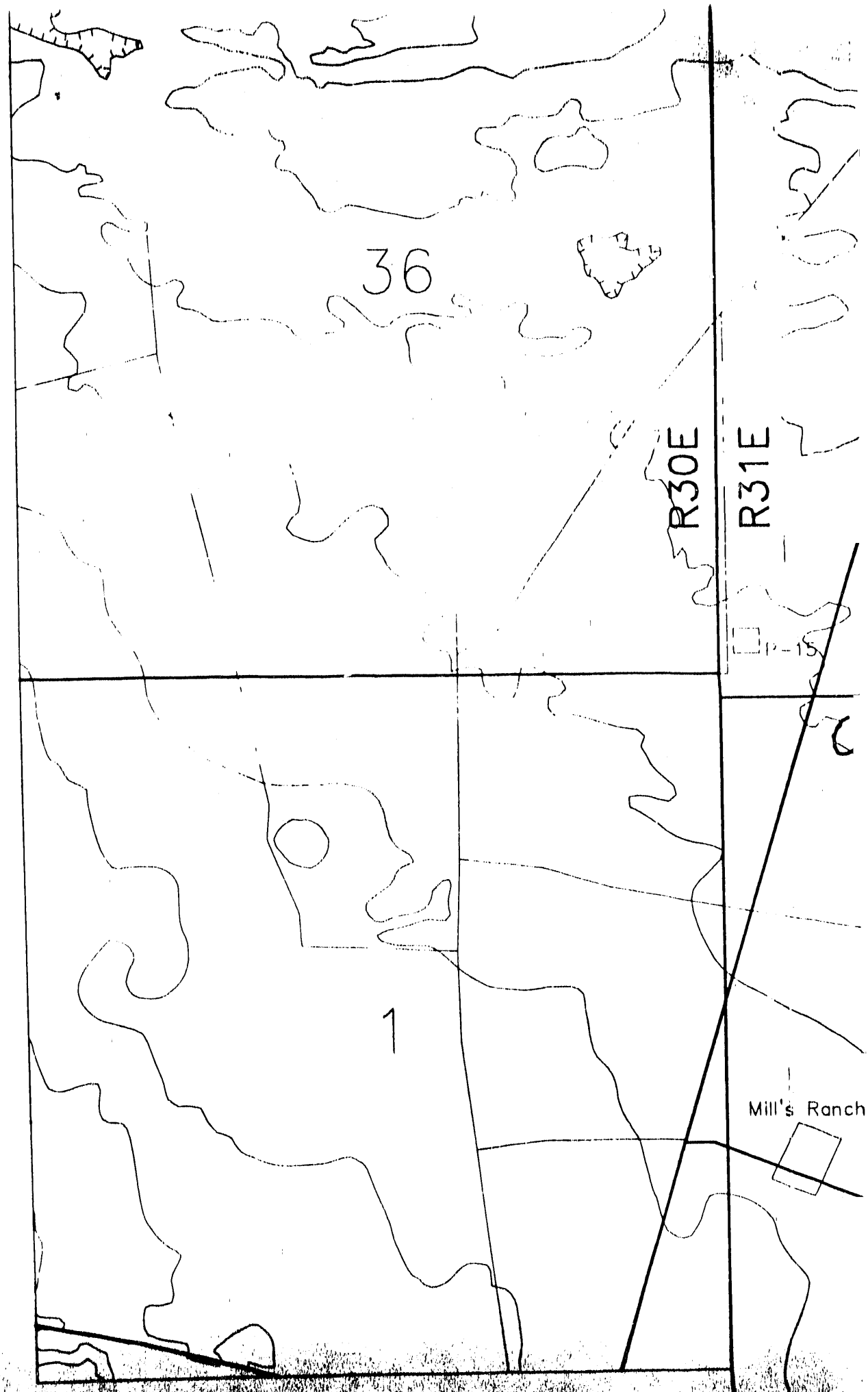
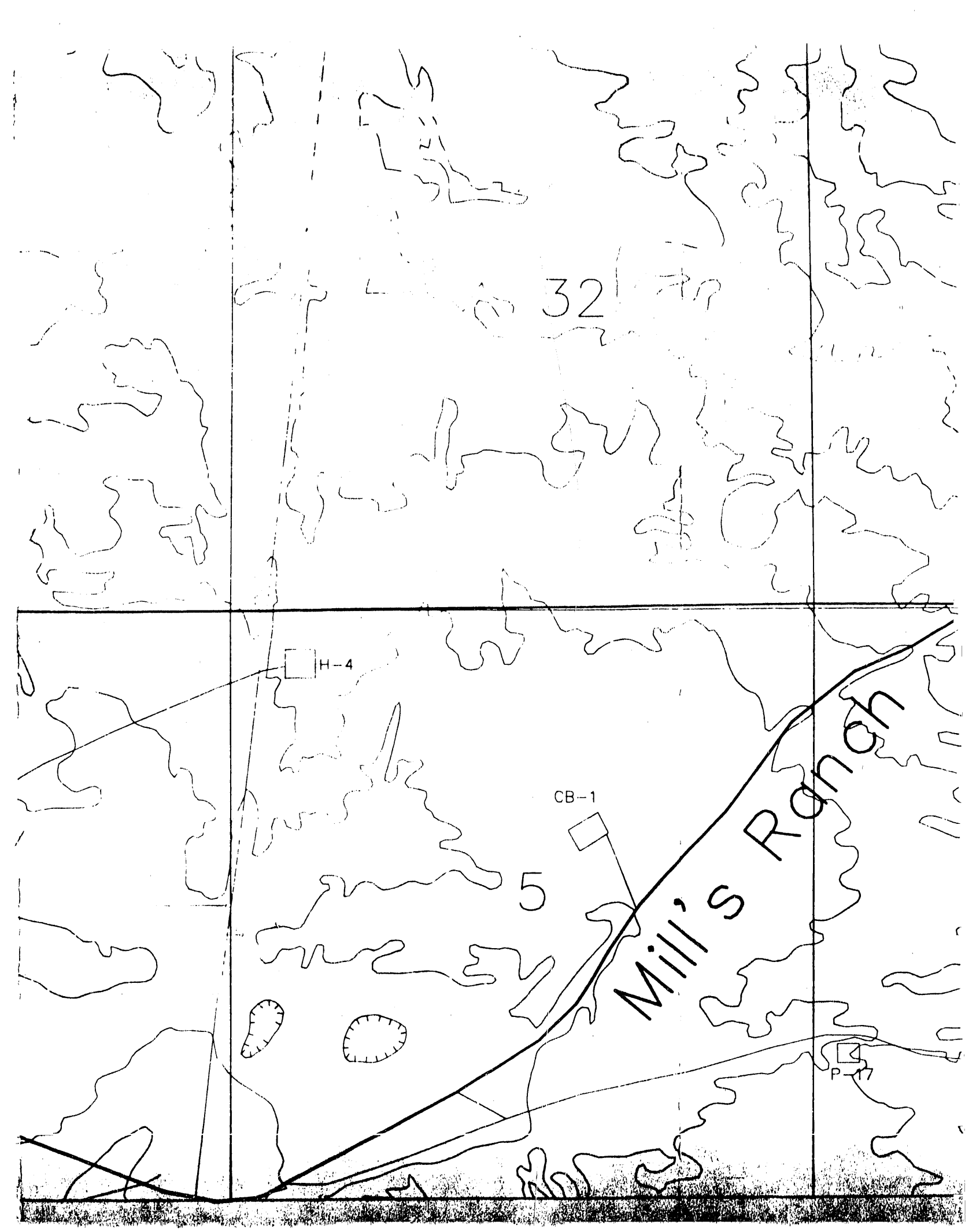
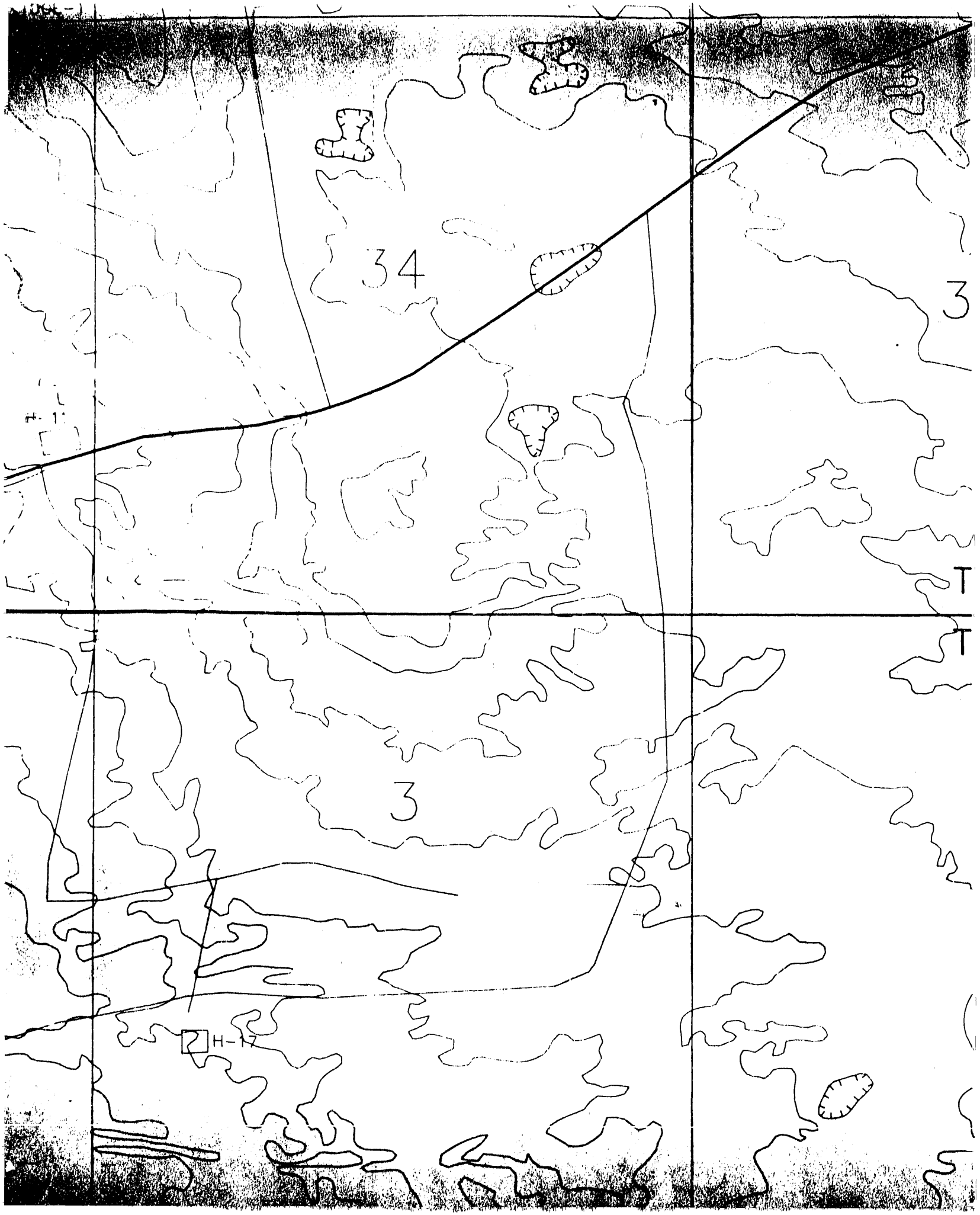
26
P-18


36
R30E
R31E
P-15
1
Mill's Ranch


32
H-4
CB-1
5
Mill's Ranch
P-17


34
3
T
T
3
H-17

ND:

FUTURE MINING

EXISTING MINING

CONTOUR INTERVAL = 10 FT.

UNDERGROUND FACILITIES ARE AT A DEPTH OF 2150 FT. BELOW THE SUR-

FIGURE B-3A

OCT 17-1991

TOPOGRAPHIC MAP WITH UNDERGROUND FACILITIES

BED WIRE FENCE
IN LINK FENCE

OUR INTERVAL = 10 FT. (EXCEPT THOSE WITHIN THE
1 FENCE WHICH EQUAL 1 FT.)

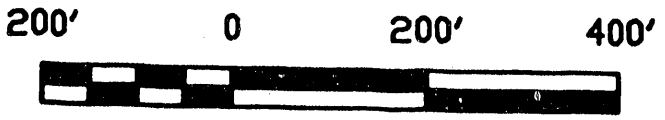


FIGURE B-3B

OCT 17-1991

TOPOGRAPHIC MAP WITH SURFACE FACILITIES

BARBED WIRE FENCE
CHAIN LINK FENCE

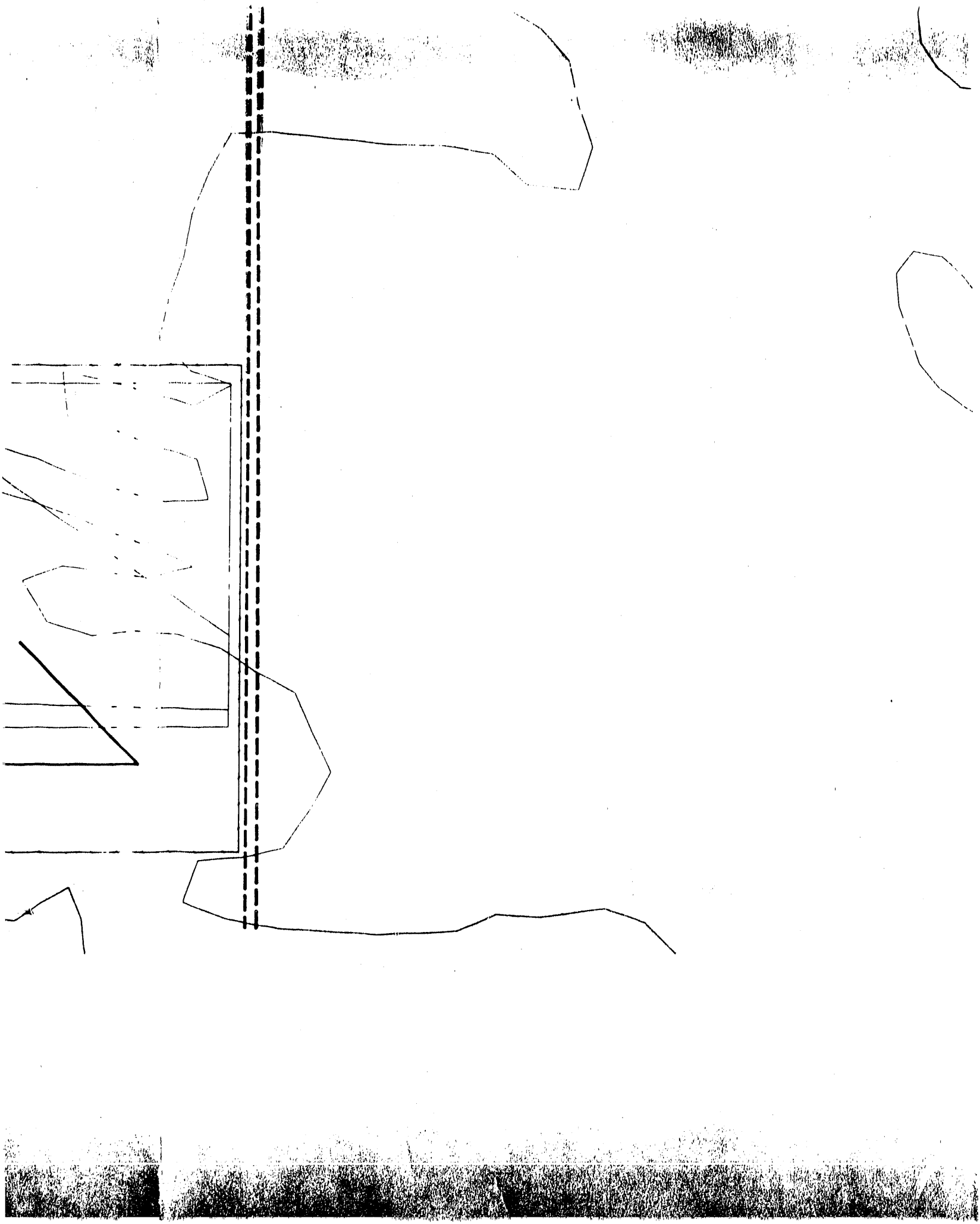
NOTE: CONTOUR INTERVAL = 10 FT. (EXC
ZONE 1 FENCE WHICH EQUAL 1 FT.

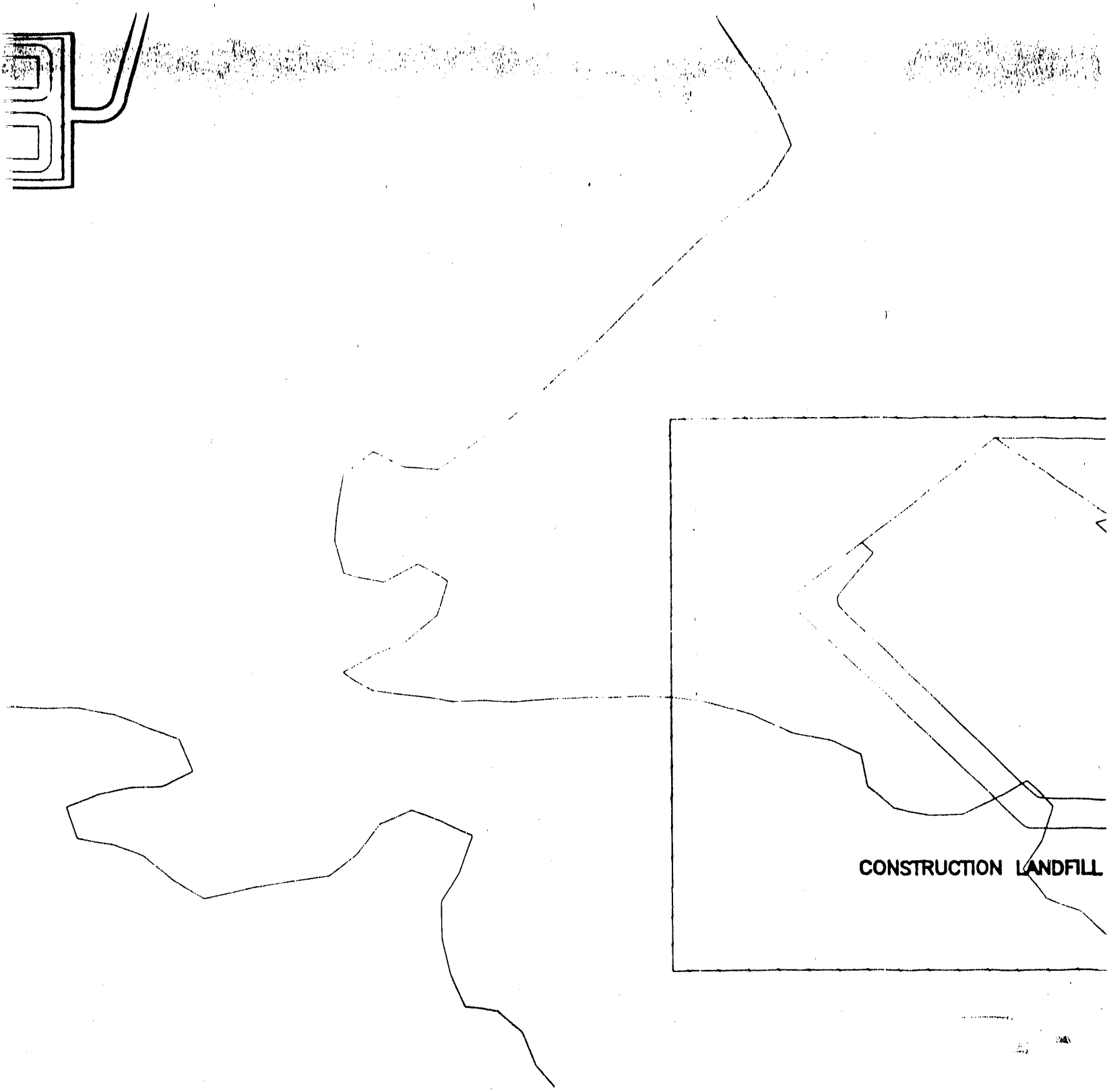
200' 0 200'

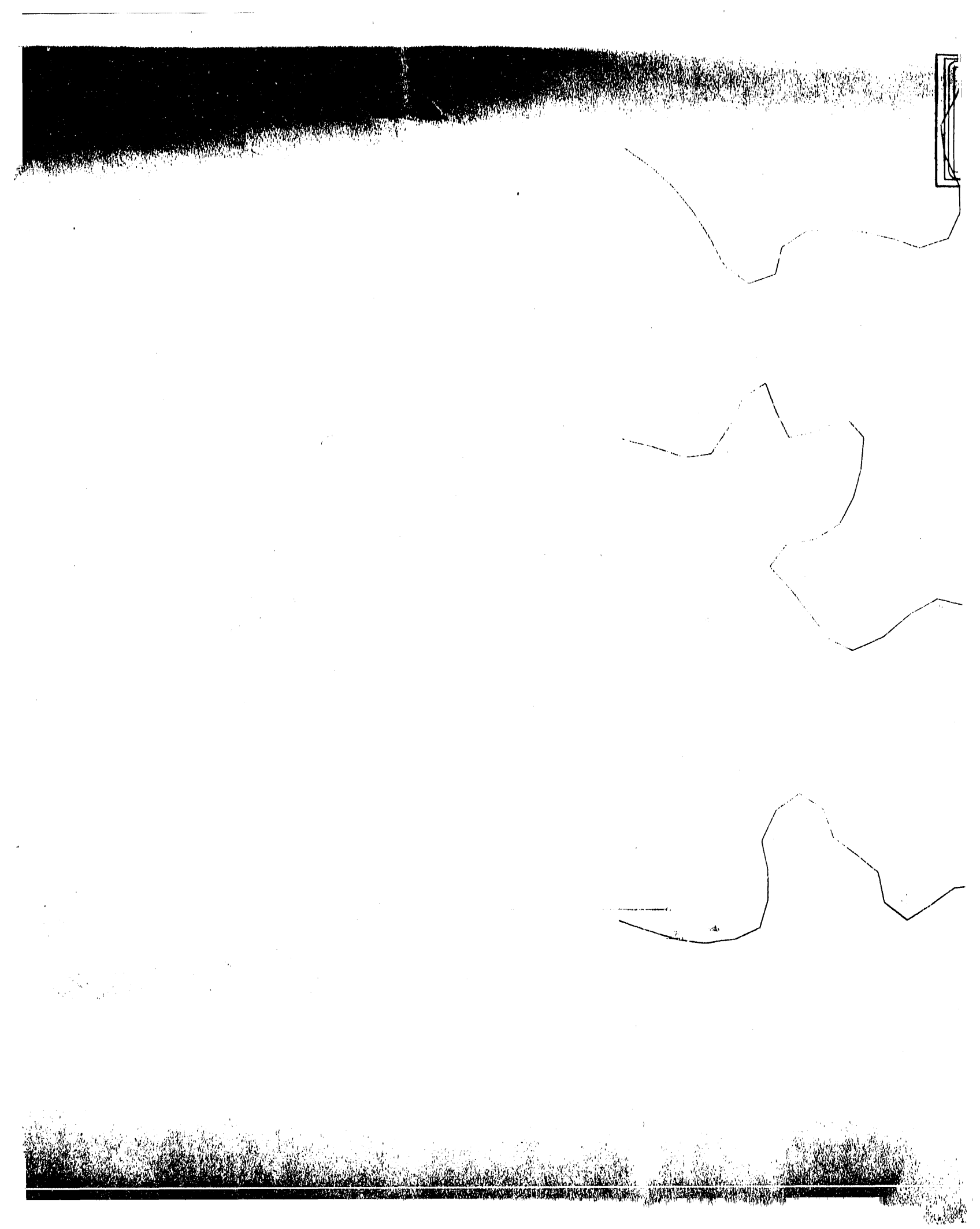
FIGURE B

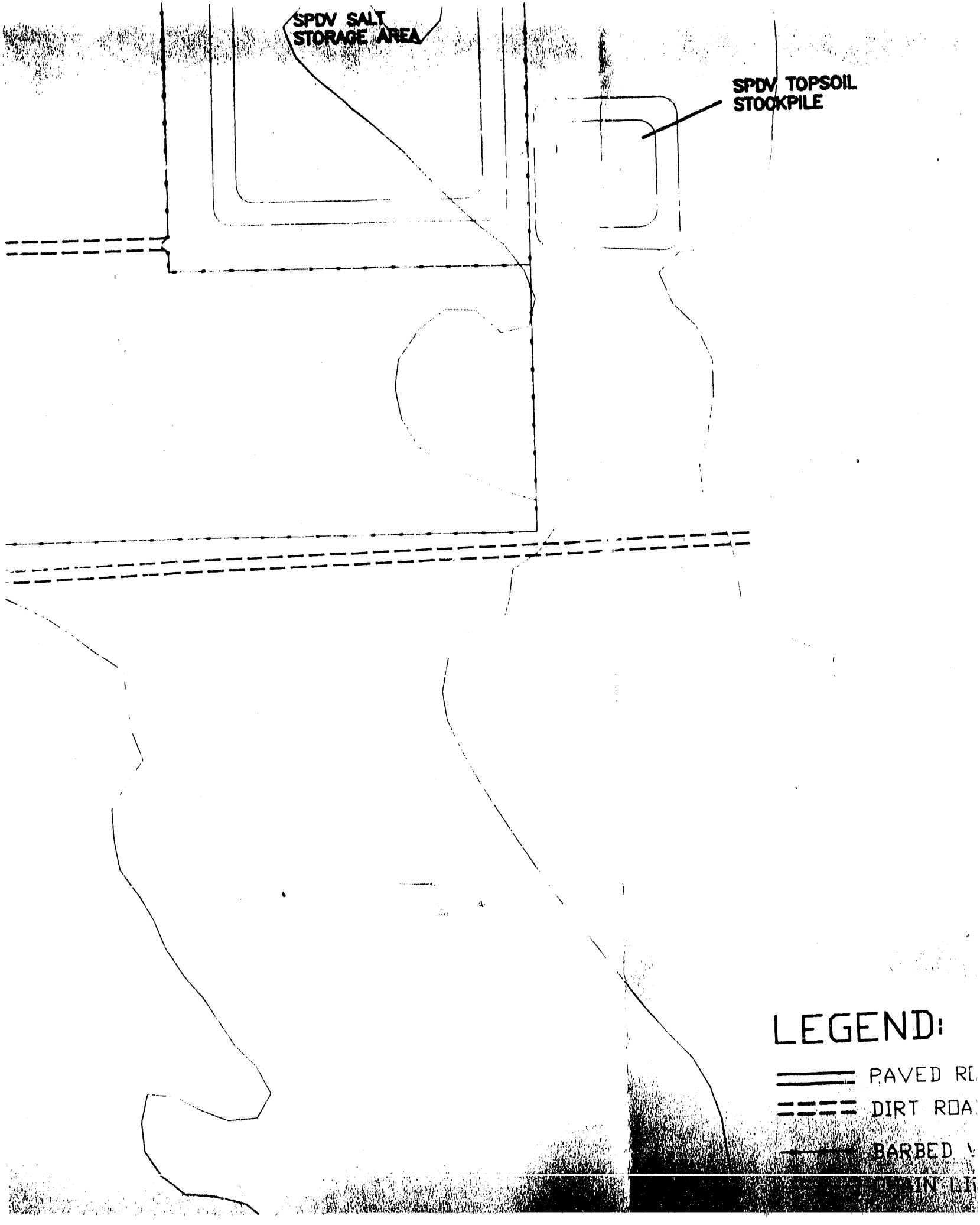
OCT 17-1991

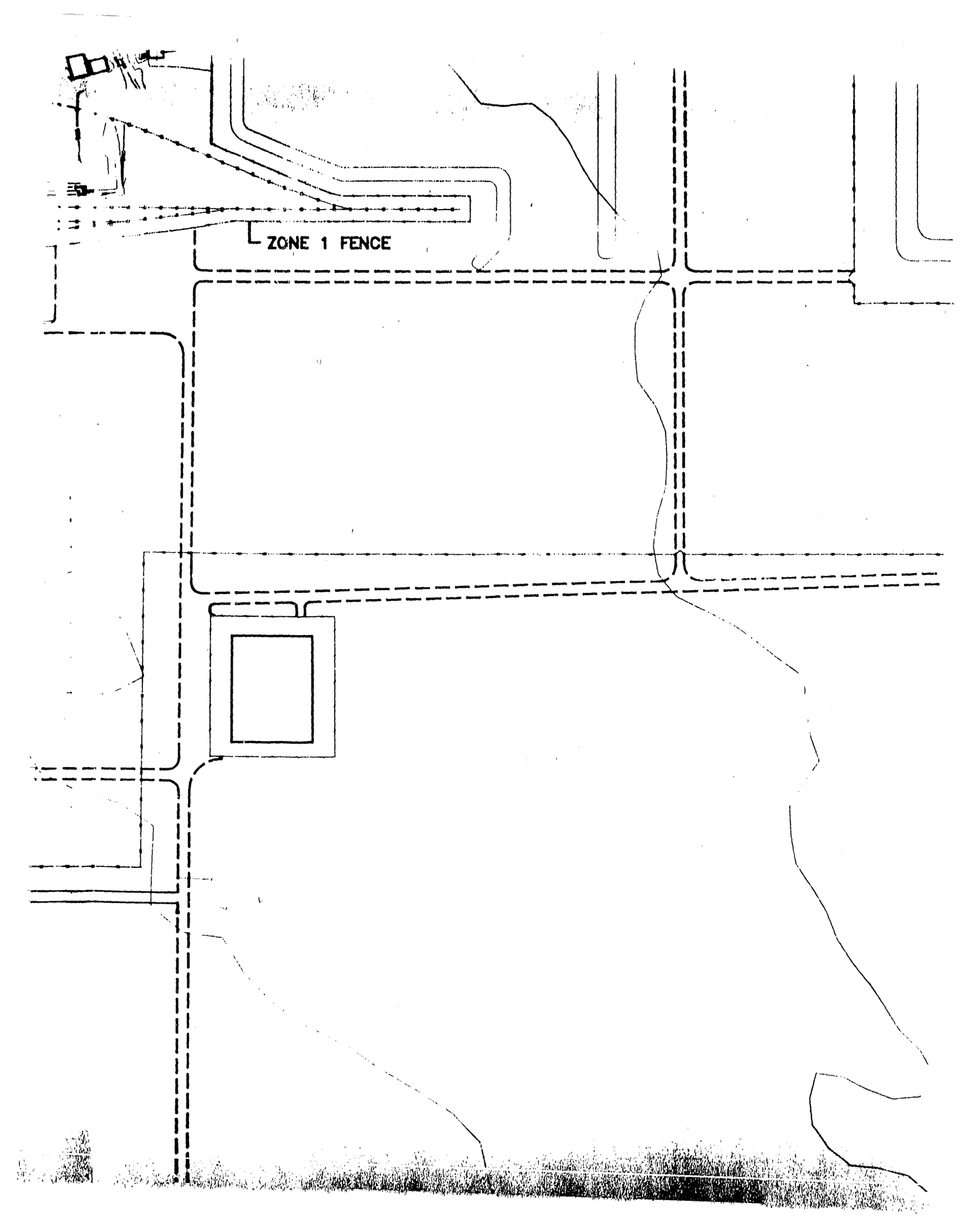
TOPOGRAPHI
WITH
SURFACE FAC

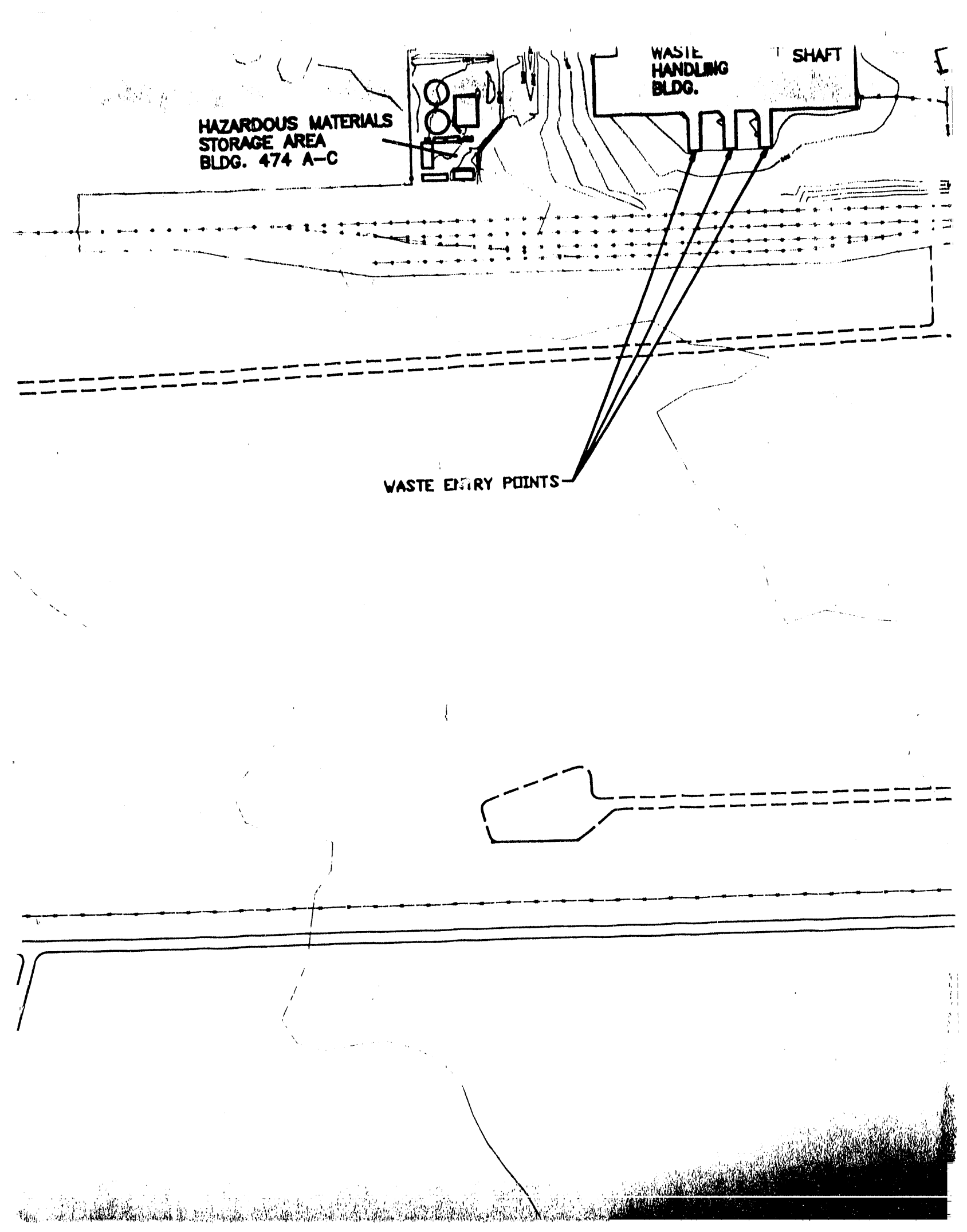


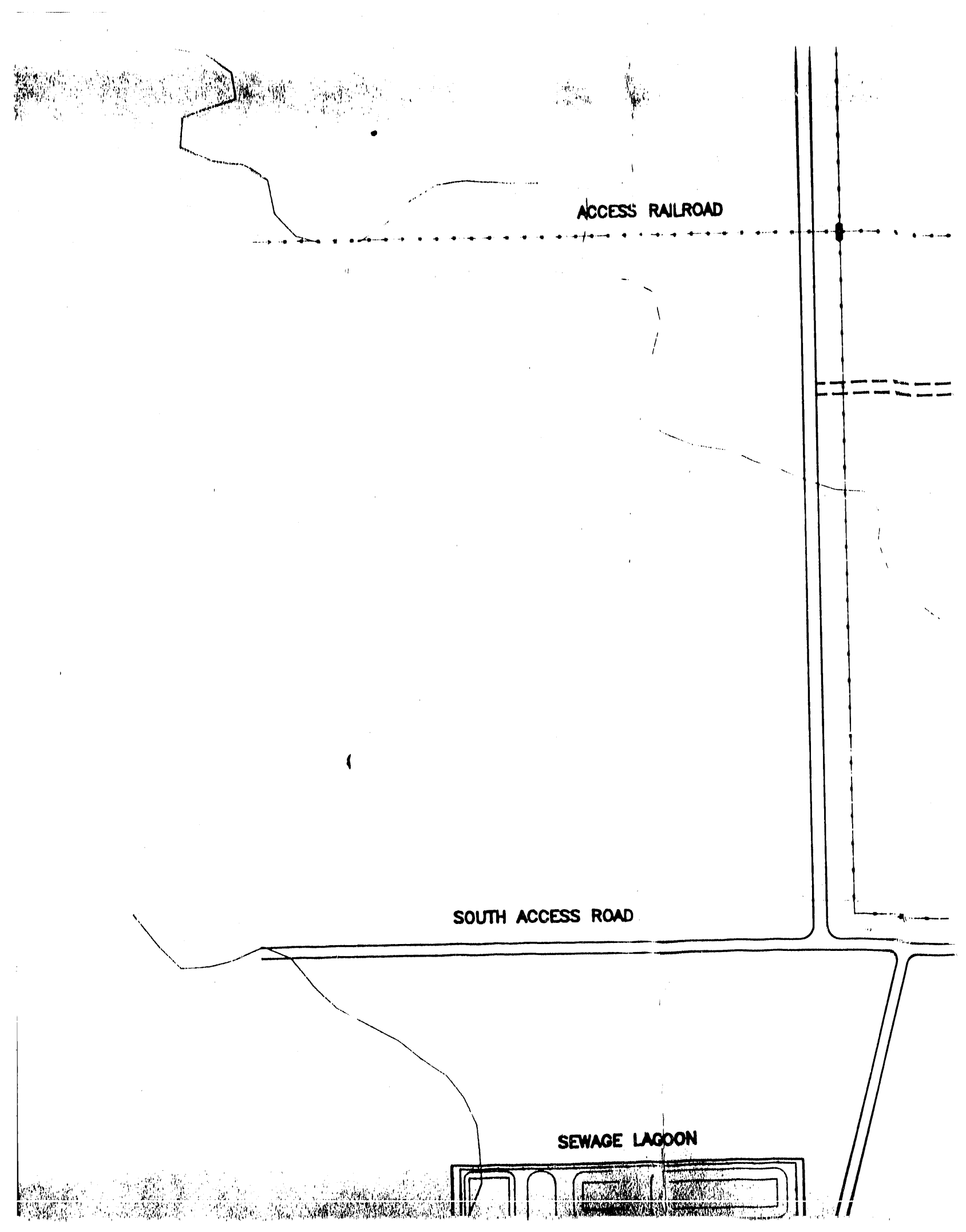

CONSTRUCTION LANDFILL

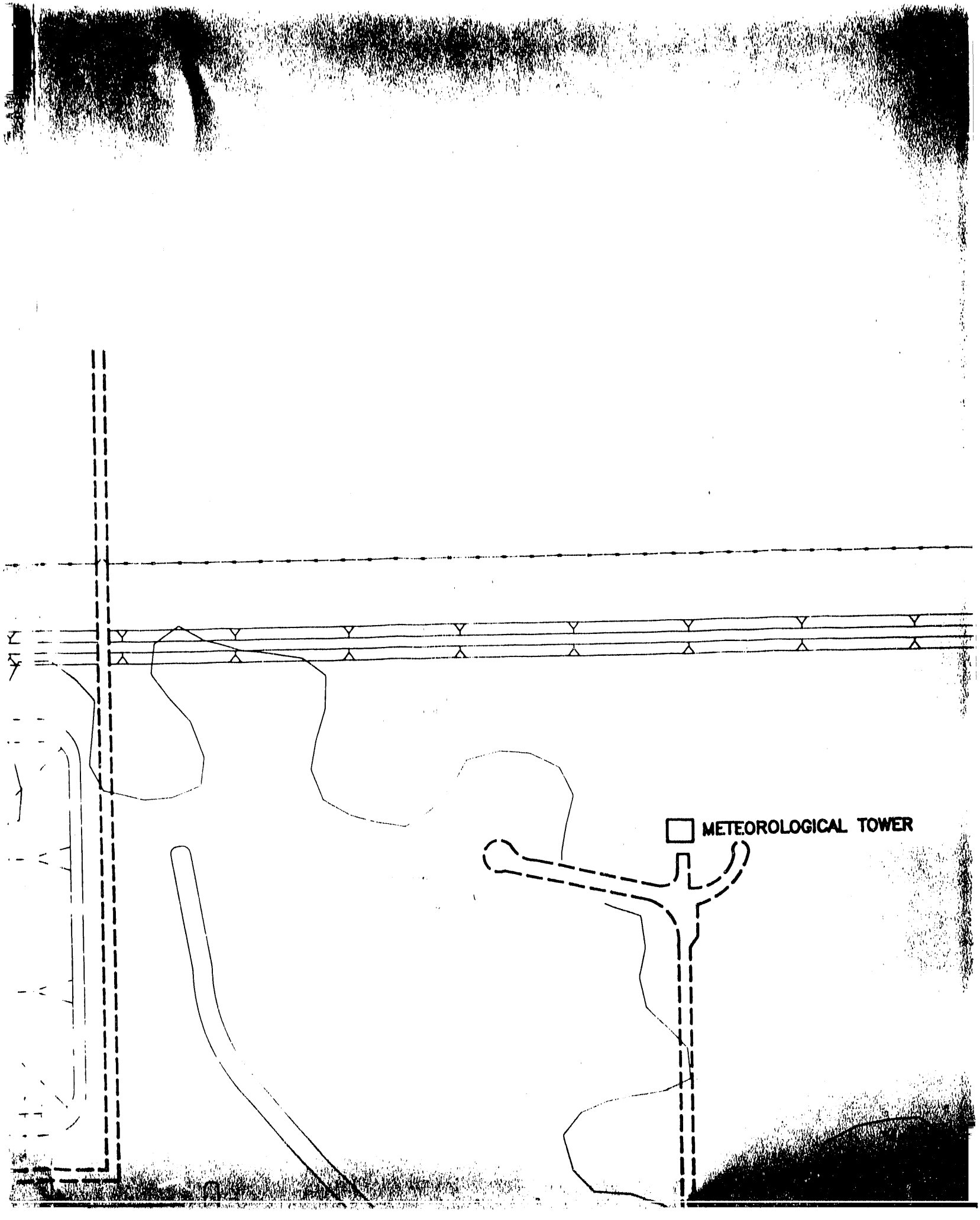


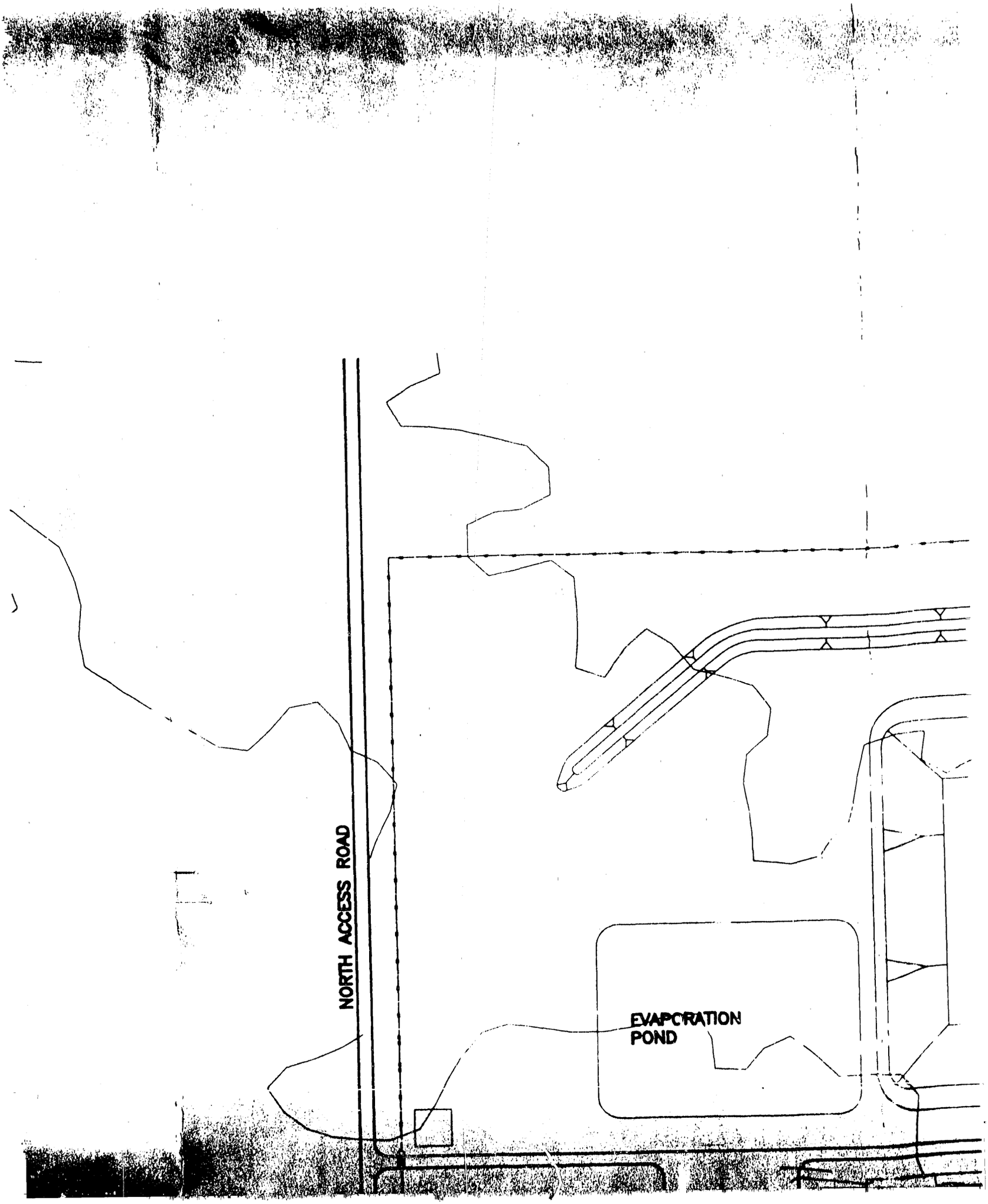

SPDV SALT STORAGE AREA
SPDV TOPSOIL STOCKPILE
LEGEND:
PAVED RO
DIRT ROA
BARBED

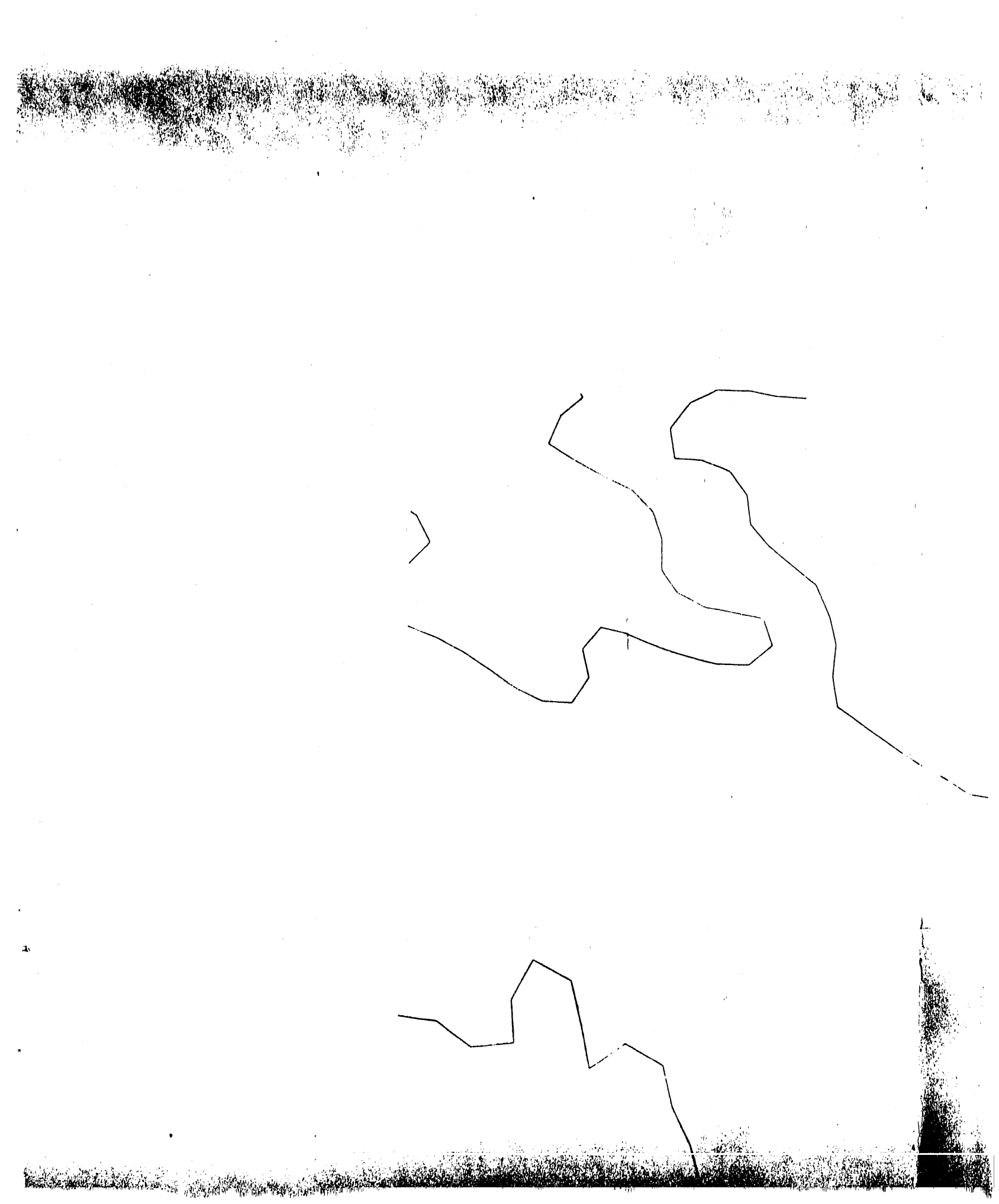

ZONE 1 FENCE


WASTE HANDLING BLDG.
SHAFT
HAZARDOUS MATERIALS STORAGE AREA BLDG. 474 A-C
WASTE ENTRY POINTS


ACCESS RAILROAD
SOUTH ACCESS ROAD
SEWAGE LAGOON


METEOROLOGICAL TOWER


NORTH ACCESS ROAD
EVAPORATION
POND



PART A APPLICATION

APPENDIX C
FACILITIES

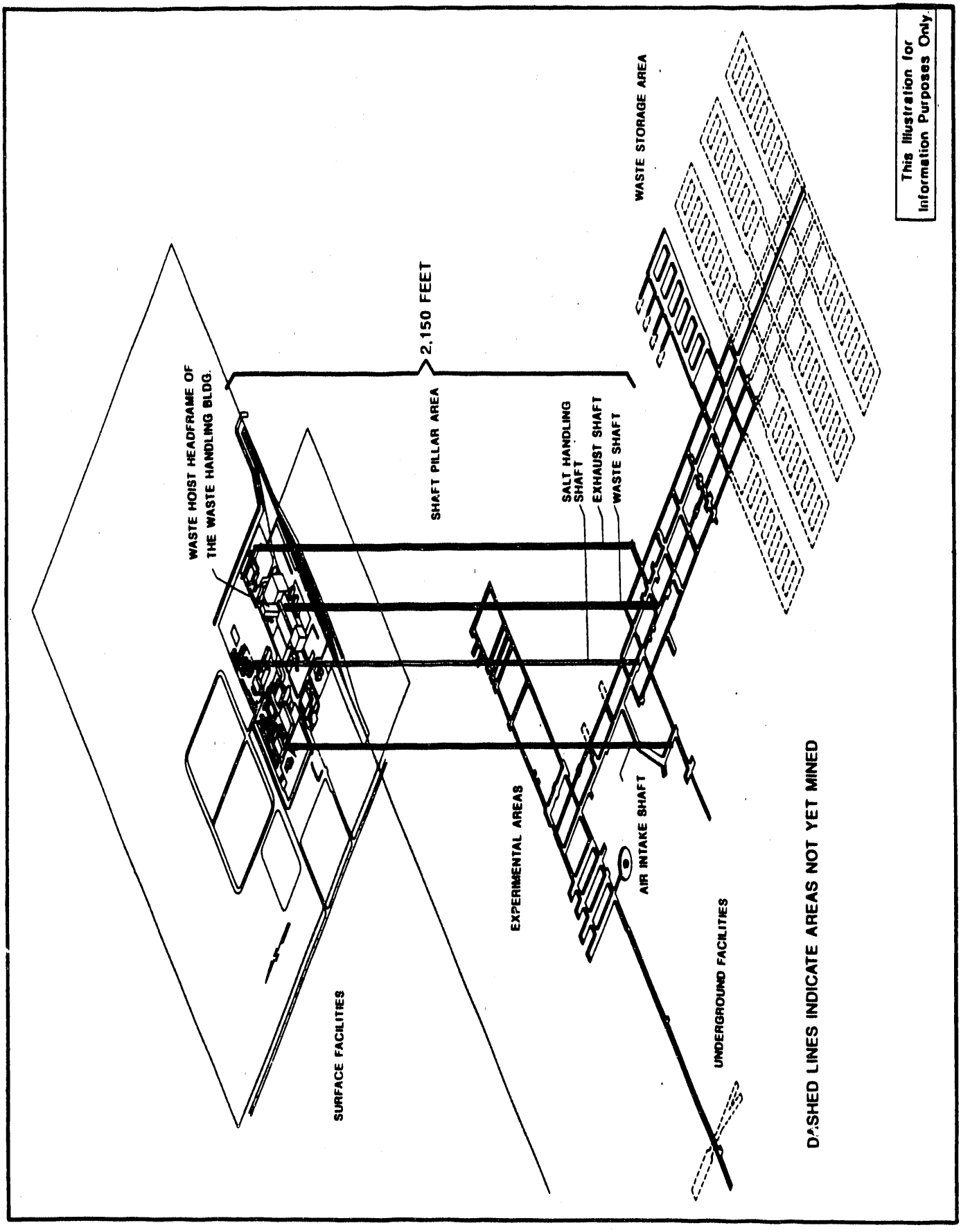


FIGURE C-1 SPATIAL VIEW OF THE WIPP FACILITY

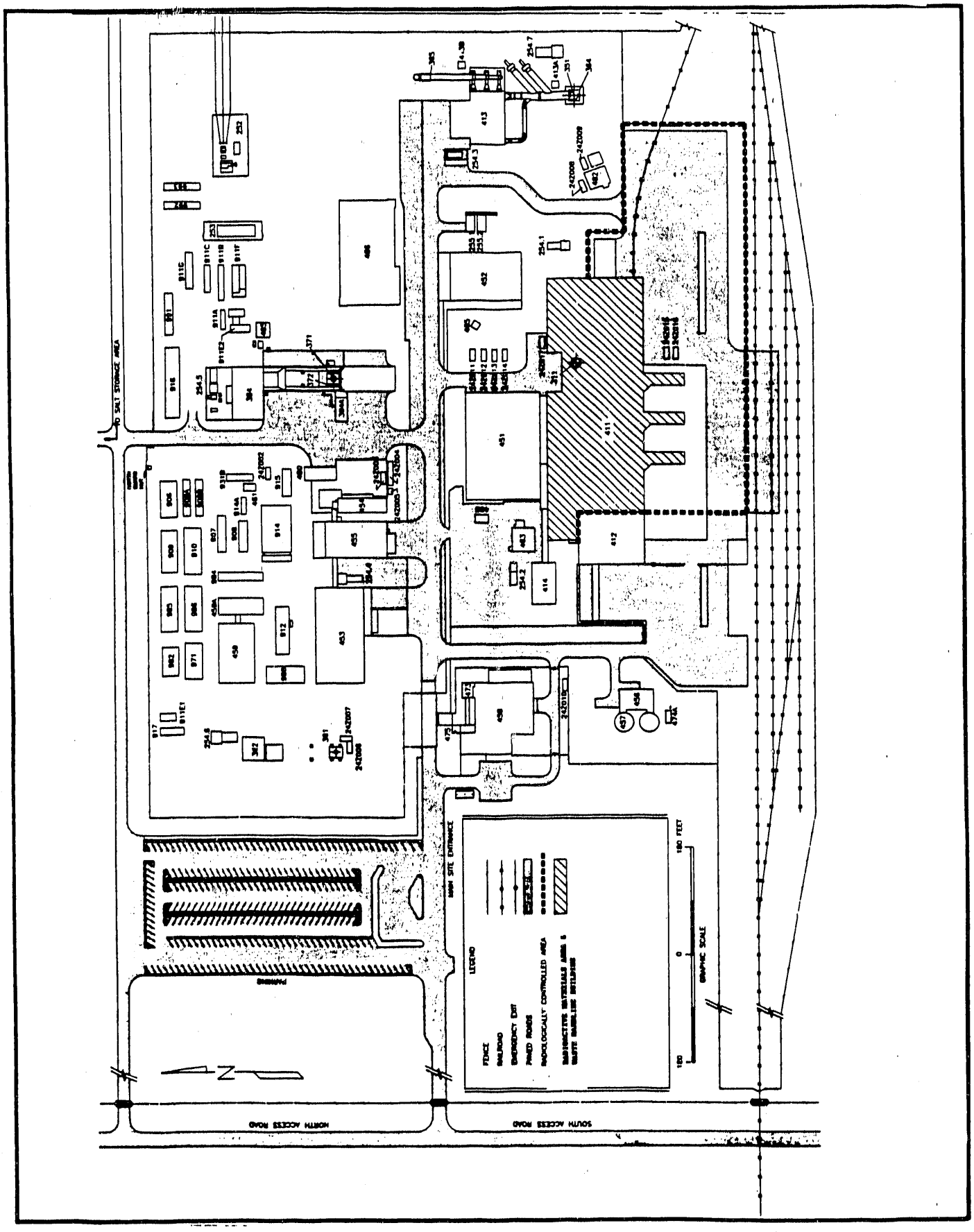


FIGURE C-2 WIPP SURFACE STRUCTURES

FACILITIES, USAGE AND STRUCTURE NUMBERS (FY 1990)

SPS UTILITY SUBSTATION	FAC 252	AUXILIARY AIR INTAKE	FAC 465
13.8 KV SWITCHGEAR 25P-SWG15/1	FAC 253	TELEPHONE HUT	BLD 468
AREA SUBSTATION NO.1 25P-SW15.1	FAC 254.1	ARMORY BUILDING - ARMORY AND LOCK SHOP	BLD 473
AREA SUBSTATION NO.2 25P-SW15.2	FAC 254.2	HAZARDOUS WASTE STORAGE BUILDING *	BLD 474
AREA SUBSTATION NO.3 25P-SW15.3	FAC 254.3	GATEHOUSE - MAIN SITE ENTRANCE/EXIT	BLD 475
AREA SUBSTATION NO.4 25P-SW15.4	FAC 254.4	VEHICLE FUEL STATION	FAC 480
AREA SUBSTATION NO.5 25P-SW15.5	FAC 254.5	EXHAUST SHAFT HOIST EQUIPMENT WAREHOUSE	BLD 482
AREA SUBSTATION NO.6 25P-SW15.6	FAC 254.6	SULLAIR COMPRESSOR BUILDING	BLD 485
AREA SUBSTATION NO.7 25P-SW15.7	FAC 254.7	ADMINISTRATION BUILDING	BLD 486
EMERGENCY GENERATOR #1 25-PE 503	FAC 255.1	DBL. WIDE TRAILER - VACANT - TO BE EXCESSED	TRL 906
EMERGENCY GENERATOR #2 25-PE 504	FAC 255.2	SINGLE WIDE TRAILER - OFFICE	TRL 907
WASTE SHAFT	FAC 311	SINGLE WIDE TRAILER - OFFICE	TRL 908
EXHAUST SHAFT	FAC 351	SINGLE WIDE TRAILER - CABLE FABRICATION	TRL 908A
AIR INTAKE SHAFT	FAC 361	SINGLE WIDE TRAILER - LAB AND CABLE FABRICATION	TRL 908B
AIR INTAKE SHAFT/WINCH HOUSE	FAC 362	DBL. WIDE TRAILER - OFFICE	TRL 909
EFFLUENT MONITORING INSTRUMENT SHED - "A"	FAC 364	DBL. WIDE TRAILER - OFFICE AND LAB	TRL 910
EFFLUENT MONITORING INSTRUMENT SHED - "B"	FAC 365	SINGLE WIDE TRAILER - VACANT - TO BE EXCESSED	TRL 911A
SALT HANDLING SHAFT	FAC 371	SINGLE WIDE TRAILER - OFFICE	TRL 911B
SALT HANDLING SHAFT HEADFRAME	FAC 372	SINGLE WIDE TRAILER - OFFICE	TRL 911C
SALT HANDLING SHAFT HOISTHOUSE	FAC 384	SINGLE WIDE TRAILER - AIS STAGING	TRL 911E1
UNDERGROUND SERVICES OFFICE	FAC 384A	SINGLE WIDE TRAILER - VACANT - TO BE EXCESSED	TRL 911E2
WASTE HANDLING BUILDING	BLD 411	DBL. WIDE TRAILER - COMPUTER CENTER	TRL 911F
TRUPACT MAINTENANCE BUILDING	BLD 412	SINGLE WIDE TRAILER - CABLE FABRICATION	TRL 911G
EXHAUST SHAFT FILTER BUILDING	BLD 413	DBL. WIDE TRAILER - OFFICE AND CLASSROOMS	TRL 912
MONITORING STATION A	BLD 413A	TRAILER COMPLEX (7) - OFFICE	TRL 914
MONITORING STATION B	BLD 413B	SINGLE WIDE TRAILER - OFFICE	TRL 915
WATER CHILLER FACILITY	FAC 414	TRAILER COMPLEX (4) - OFFICE	TRL 916
SUPPORT BUILDING - OFFICES, ETC.	BLD 451	SINGLE WIDE TRAILER - AIS DATA AQUISITION	TRL 917
SAFETY & EMERGENCY SERVICES FACILITIES	BLD 452	SINGLE WIDE TRAILER - CHANGE ROOM	TRL 931B
WAREHOUSE/SHOPS BUILDING	BLD 453	DBL. WIDE TRAILER - OFFICE	TRL 971
VEHICLE SERVICE BUILDING	BLD 454	DBL. WIDE TRAILER - OFFICE	TRL 982
AUXILIARY WAREHOUSE BUILDING - MAINTENANCE	BLD 455	SINGLE WIDE TRAILER - OFFICE	TRL 984
WATER PUMPHOUSE	BLD 456	DBL. WIDE TRAILER - OFFICE	TRL 985
WATER TANKS (2)	FAC 457	DBL. WIDE TRAILER - OFFICE	TRL 986
GUARD AND SECURITY BUILDING	BLD 458	DBL. WIDE TRAILER - OFFICE	TRL 988
CORE STORAGE BUILDING	BLD 459	SINGLE WIDE TRAILER - OFFICE	TRL 991
DBL. WIDE TRAILER - OFFICE	BLD 459A	SINGLE WIDE TRAILER - LAB	TRL 992
MAINTENANCE STORAGE	BLD 461	SINGLE WIDE TRAILER - LAB	TRL 993
COMPRESSOR BUILDING	BLD 463	MOBILE STORAGE BUILDINGS	242002 THRU 242017

* Non-Radioactive, less than 90 day storage; site-generated waste

EXPLANATION TO FIGURE C-2

This Illustration for Information Purposes Only.

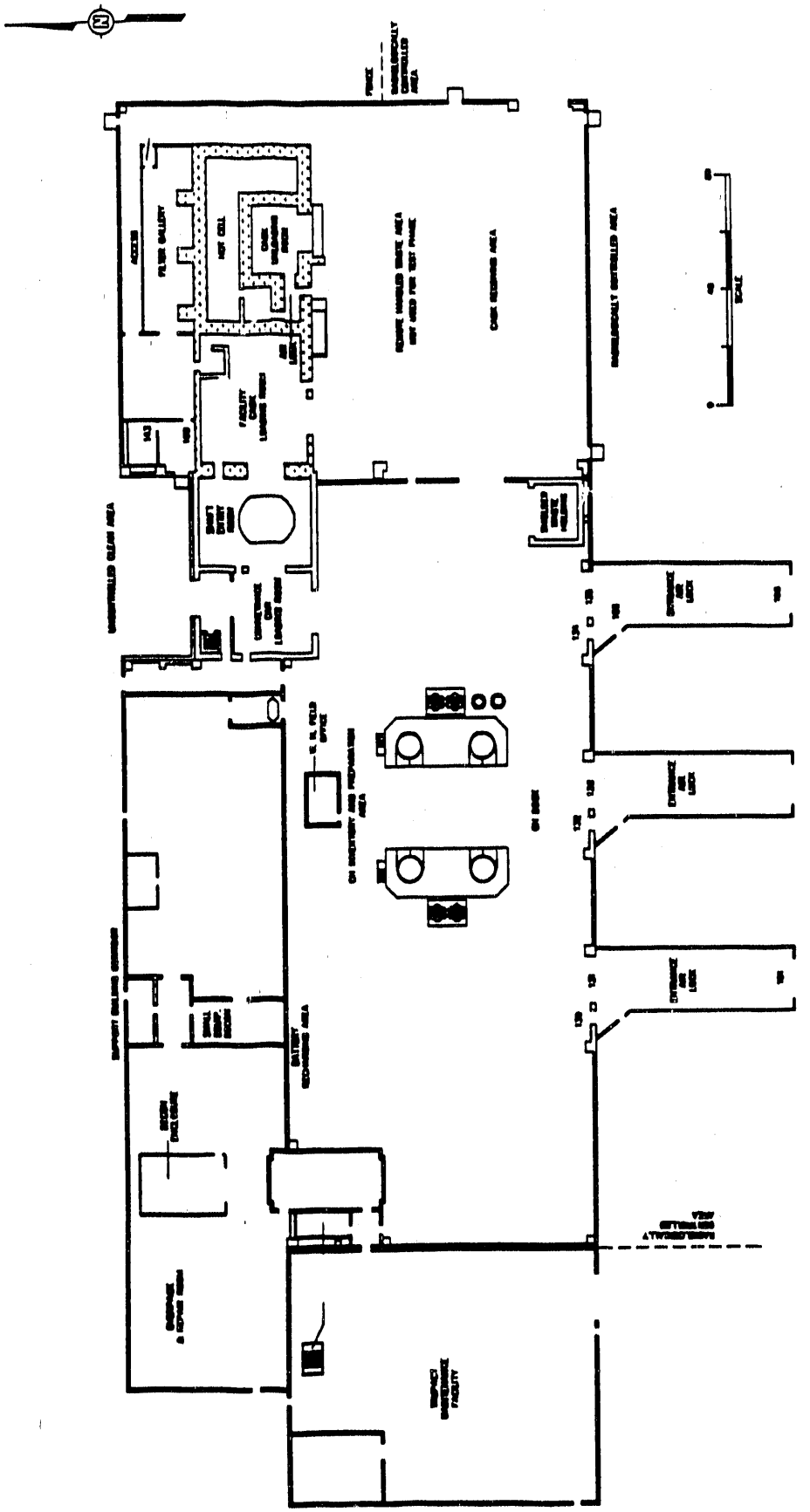


FIGURE C-3 WASTE HANDLING BUILDING PLAN

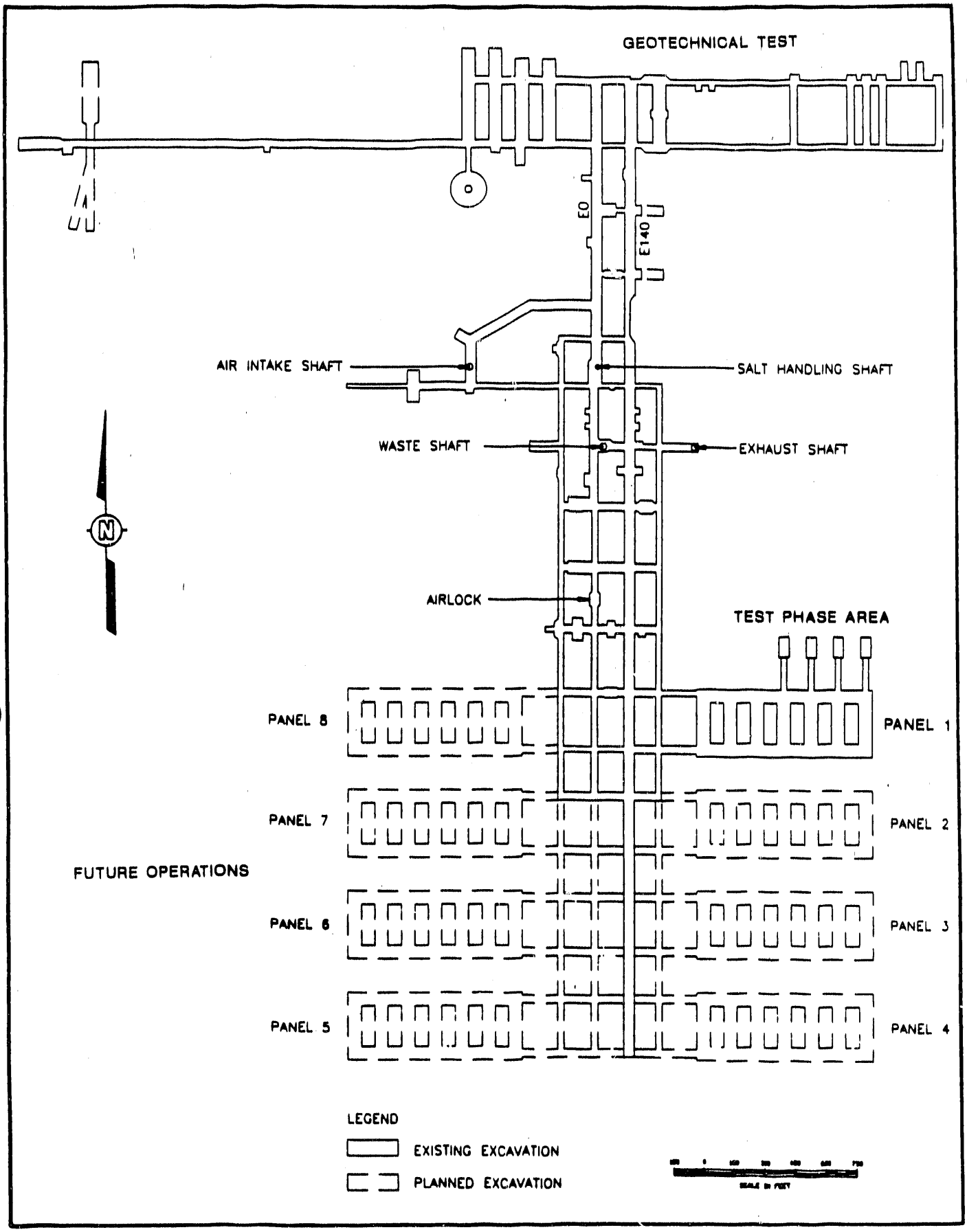
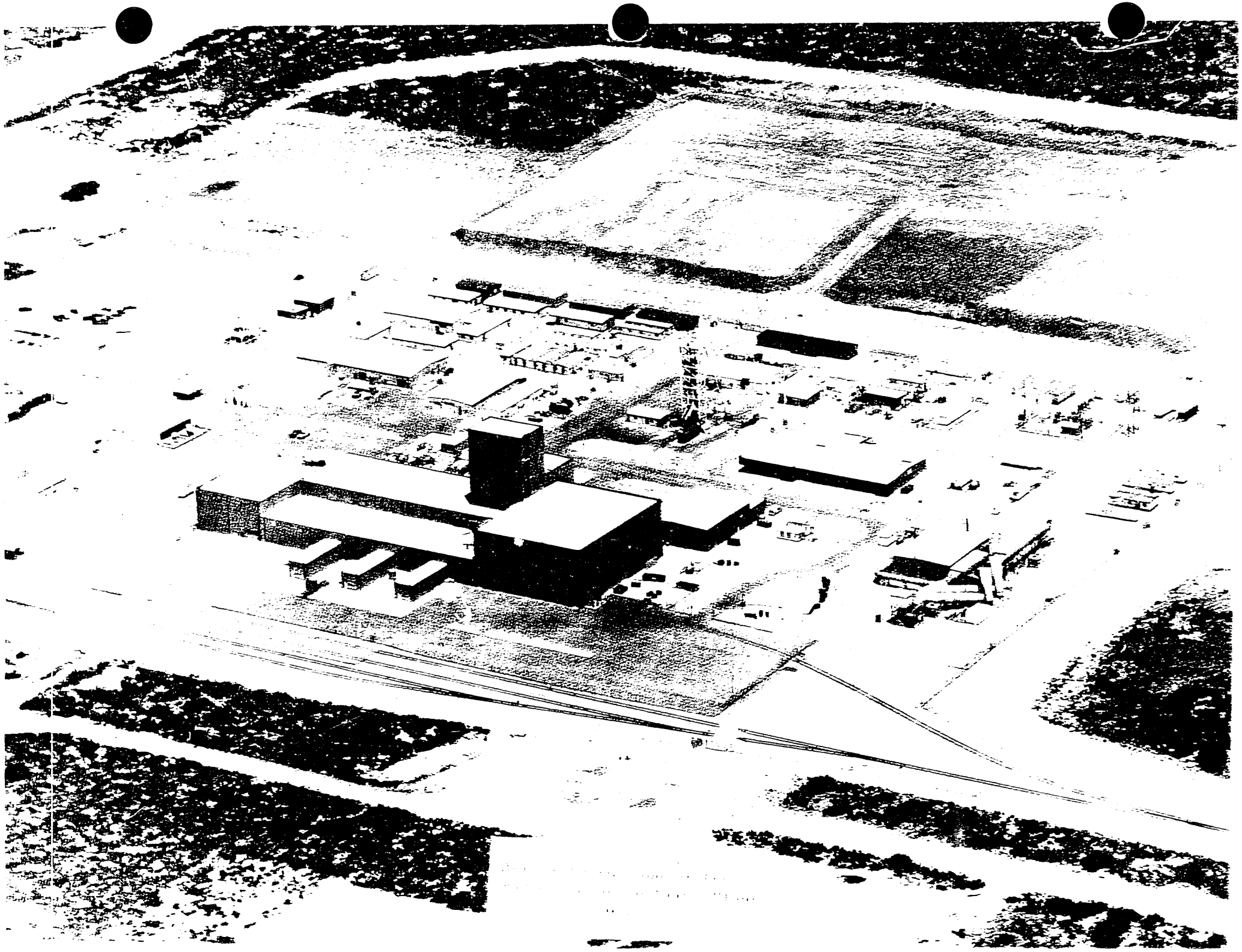


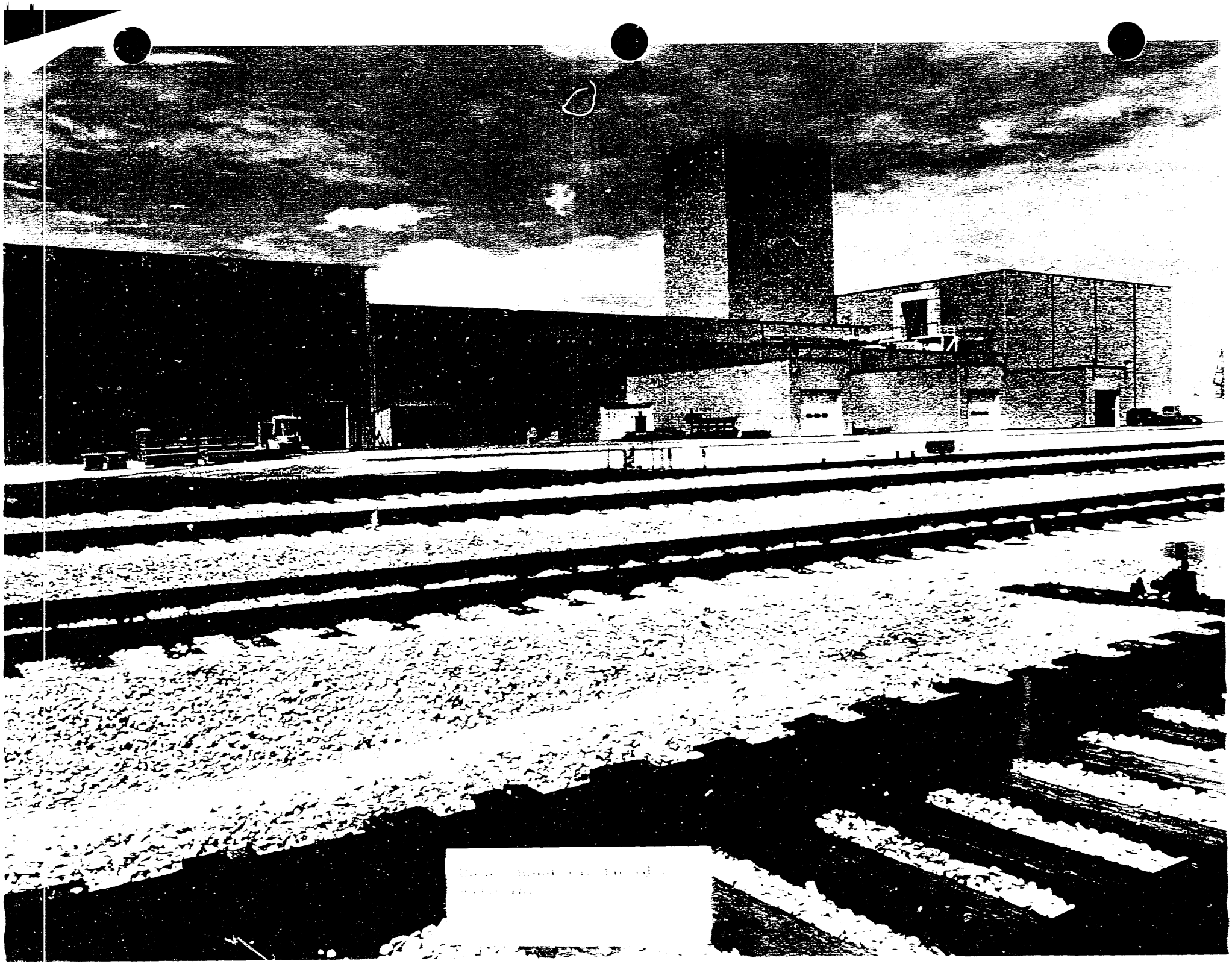
FIGURE C-4 REPOSITORY HORIZON

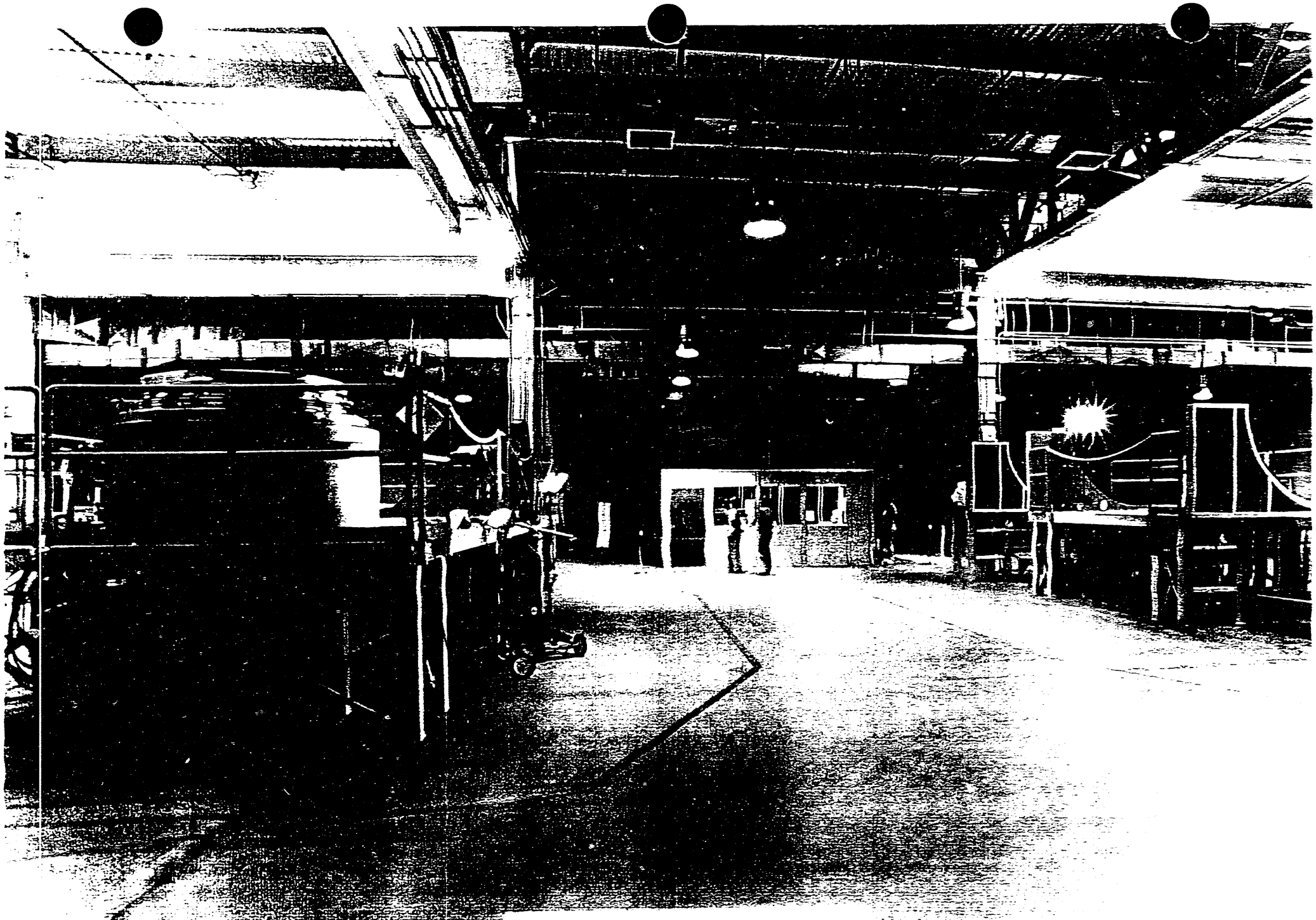
This Illustration for Information Purposes Only.

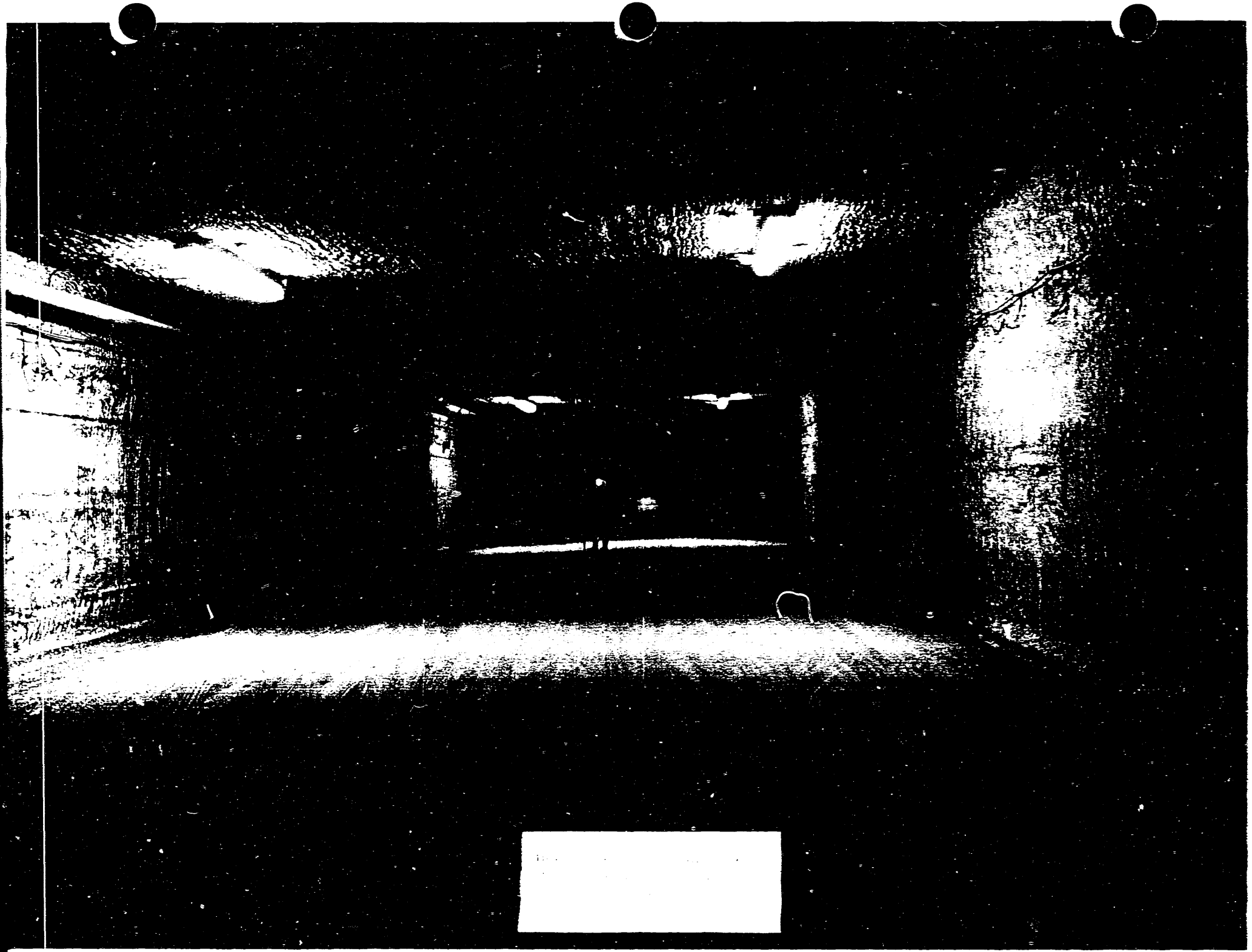
PART A APPLICATION

APPENDIX D
PHOTOGRAPHS









CHAPTER B

FACILITY DESCRIPTION

CHAPTER B
FACILITY DESCRIPTION
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CHAPTER B
FACILITY DESCRIPTION

B-1 General Description

The subject of this permit application is Test Phase activities at the Waste Isolation Pilot Plant (WIPP) facility (Figure B-1), which is defined as a miscellaneous hazardous waste management unit under New Mexico Hazardous Waste Management Regulations (HWMR-6), Part I, section 260.10. In order to facilitate the review of information presented herein, the format of this application is that of the U.S. Environmental Protection Agency's (EPA) RCRA [Resource Conservation and Recovery Act] Part B Application Completeness/Technical Evaluation Checklist (EPA, 1989). The WIPP Project was authorized by the Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980 (Public Law 96-164). Its legislative mandate is to provide a research and development facility to demonstrate the safe disposal of radioactive waste resulting from United States defense programs. The U.S. Department of Energy (DOE) is developing the WIPP facility as a deep geologic repository for transuranic (TRU) waste currently stored at or generated by DOE defense installations. At this time, DOE is seeking a permit to perform bin-scale tests. Detailed information on container design and operations during the bin-scale tests is presented to support this permit application.

The waste that will be emplaced at the WIPP facility results primarily from activities related to the reprocessing of plutonium-bearing reactor fuel and fabrication of plutonium-bearing weapons. This waste consists largely of such items as laboratory glassware and utensils, tools, scrap metal, shielding, and solidified sludges from the treatment of wastewater. Approximately 60 percent of this waste is also contaminated with substances that are defined as hazardous under HWMR-6, Pt. II, Subparts C and D, and subject to the Land Disposal Restrictions of HWMR-6, Pt. VIII, sec. 268.6 (DOE, 1990a). For example, trace amounts of degreasing solvents may remain on a tool or piece of glassware, and rubber aprons and gloveboxes are lined with lead.

Since Public Law 96-164 was enacted establishing the mission of the WIPP Project, program activities have focused on completion of major segments or phases of the project, thereby allowing significant progress to be made toward demonstrating the safety of the WIPP facility. Each major phase has provided an opportunity to study and evaluate the most recent information, individually and collectively, prior to proceeding with the next phase. The major phases of the WIPP Project began with Preliminary Design (Title I) in October 1979, followed by Detail Design (Title II), which started in September 1981. Following the successful completion of the Site and Preliminary Design Validation (SPDV) program in July 1983, the Construction Phase was initiated.

The Construction Phase of the project is complete (DOE, 1990b) and the project is ready to embark upon the next phase of development, the Test Phase. The Test Phase will be used to

gather data to support the performance assessment, which will determine the suitability of the site for long-term disposal of radioactive waste as required by EPA regulation 40 CFR Part 191[1], which implements the Nuclear Waste Policy Act. Information acquired during the Test Phase will also be used to verify data and assumptions that were used for modeling in the No-Migration Variance Petition, which was prepared to satisfy the requirements of the RCRA Land Disposal Restrictions, HWMR-6, Pt. VIII, sec. 268.6. The Test Phase is expected to last approximately five years. The Disposal Phase Decision, which will determine whether the WIPP facility is suitable to be a TRU waste repository, is not expected until near the end of the Test Phase (DOE, 1990c).

Both mixed and radioactive TRU waste from DOE generator sites will be used as the waste for the underground tests during the Test Phase (DOE, 1990c). Because the mixed waste is subject to the RCRA Land Disposal Restrictions, the WIPP Project has submitted a petition for a variance from treatment requirements based on a demonstration that the waste will not migrate beyond the unit boundary during the Test Phase (DOE, 1990a). On April 6, 1990, EPA published a public notice of the agency's intent to grant a "conditional" determination of no-migration (EPA, 1990a). EPA's decision to grant the conditional determination was published on November 14, 1990 (EPA, 1990b). Chapter L describes the conditions of the determination of no-migration in detail. EPA's approval of the conditional no-migration determination for the WIPP facility will allow the facility to accept waste which would otherwise be prohibited from land disposal during the Test Phase. Monitoring during the Test Phase will provide data to verify that migration has not occurred. Data gathered from other Test Phase activities will be used to support a WIPP Project demonstration of no-migration for operations and post-closure.

B-1a Definitions

Terms which have special regulatory interpretation are used in this permit to describe waste management activities at the WIPP facility. The following definitions are provided to assist the permit writer in understanding the intent of terms as they are used in this document.

Miscellaneous Unit

A miscellaneous unit is defined in HWMR-6, Pt. I, sec. 260.10, as "a hazardous waste management unit where hazardous waste is treated, stored, or disposed of and that is not a container, tank, surface impoundment, pile, land treatment unit, landfill, incinerator, boiler, industrial furnace, underground injection well with appropriate technical standards under 40 CFR Part 146, or unit eligible for a research, development, and demonstration permit under HWMR-6, Pt. IX, sec. 270.65." Miscellaneous units include salt bed formations in which hazardous wastes

---

[1] Subpart B of 40 CFR Part 191 was vacated and remanded to the EPA by the U.S. Court of Appeals for the First Circuit. However, in the 1987 Second Modification to the Agreement for Consultation and Cooperation, the DOE and the State of New Mexico (1981) agreed that the DOE should continue compliance planning activities in accordance with Subpart B as promulgated in August 1985 until a revised Standard is issued.

√ are managed. In the context of HWMR-6, Pt. IX, permitting requirements, and HWMR-6, Pt. V, technical requirements, waste management in the miscellaneous unit is subject to the same treatment, storage, or disposal requirements applicable to more typical RCRA-regulated hazardous waste management units.

Land Disposal

√ Under HWMR-6, Pt. VIII, sec. 268.2, the placement of hazardous waste in a salt bed formation is defined as "land disposal." The term "placement" does not differentiate between temporary
√ storage and permanent disposal. Because the management of waste in the WIPP facility technically constitutes "land disposal," the facility is subject to the RCRA Land Disposal Restrictions. However, because waste emplaced during the Test Phase may either be permanently disposed of or retrieved, based on the demonstration of repository performance,
√ some activities at the WIPP facility are described as waste management, subject to the
√ requirements for a miscellaneous unit in HWMR-6, Pt. IX.

B-1b The Test Phase

Tests with TRU waste are designed to provide information that can enhance the project's understanding of the effect and magnitude of potential gas buildup in the facility. Such a buildup
√ could become the mechanism for forcing hazardous constituents such as volatile organic compounds (VOCs) beyond the unit boundary. In addition, the effectiveness of various
√ engineered alternatives (such as waste compaction) will be evaluated so that the project can be ready to implement modifications to the waste form or repository design, should the need be
√ demonstrated.

The Test Phase will consist of a series of activities, including experiments with TRU waste, data collection, modeling, and calculations leading to a demonstration of compliance with the long-term
√ performance standard defined by 40 CFR Part 191 (DOE, 1990c). This permit application is for
√ waste management activities during the bin-scale tests involving the emplacement of TRU waste
√ underground at the WIPP facility.

√ Bin-scale tests will consist of up to 233 bins containing prescribed mixtures of TRU waste from Rocky Flats Plant and the Idaho National Engineering Laboratory. The wastes to be tested will be representative (from a performance assessment perspective) of the DOE TRU waste inventory
√ slated for disposal at the WIPP facility and will include high- and low-organic content waste and (relatively) old and new waste. Each bin will hold approximately six (55-gallon) drum-equivalents
√ of waste. The bins will be emplaced in Panel 1, underground at the WIPP facility (Molecke and Lappin, 1991). Experimental data to be gathered include pressure and gas composition. In addition to experimental data, the bins will be monitored to ensure that there is no migration of VOCs to the accessible environment. Section D-9e and Appendix D9 contain detailed

descriptions of the VOC monitoring system for bins. All test waste will be fully retrievable during the Test Phase.

Planning for the underground TRU waste tests is proceeding in a phased manner. The Integrated Systems Checkout program (DOE, 1990d) ensured that all systems, designs, and procedures required to emplace, monitor, and retrieve bins safely are in place and function correctly before any waste is received at the WIPP facility.

Detailed information pertaining to bin-scale tests is presented in Chapter D of this permit application.

B-1c The WIPP Site

The WIPP facility is located in the Pecos River Valley section of the Great Plains physiographic province in the north-central part of the Delaware Basin. The facility is north of the Jal Highway (State Highway 128) in Eddy County, New Mexico (Figure B-2), and consists of 16 sections of federal land under the jurisdiction of the DOE in Township 22 South, Range 31 East. These lands were withdrawn by Public Land Orders 6403 and 6826 (BLM, 1983, 1991), which authorized use of the land for the construction of the WIPP facility.

There are three basic groups of structures at the site: surface structures, shafts, and underground structures (Figure B-3). Surface structures accommodate the personnel, equipment, and support services required for the receipt, preparation, and transfer of waste from the surface to the underground. The surface structures are located within a perimeter security fence. Among surface buildings at the site are the Waste Handling Building, where all surface waste-handling activities will take place; the Exhaust Filter Building, which will filter contaminated air from the underground in the unlikely event of a release of radioactive particulates; the Support Building, which houses office space, change rooms, and the central monitoring system; and the Safety and Emergency Services Building, where the Emergency Operations Center is located (Figure B-4). There are also two salt piles, one of which is inactive, which store the salt that is mined from the underground until it is required for backfilling around the waste or for decommissioning the site (DOE, 1990e).

The WIPP facility consists of several zones. The legal boundaries of the waste management facility site are shown in Figure B-5. Zone I, surrounded by a chain-link fence enclosing 35 acres, includes all major surface structures. The Secured Area Boundary, enclosing 1,500 acres, includes other structures and areas associated with construction and operation. Zone II indicates the surface projection of the maximum extent of underground development. The WIPP site boundary extends at least 1 mile beyond any potential underground development and is defined on the surface by the 16-section (16-square-mile) land withdrawal area. The WIPP site boundary will be controlled both administratively and physically during the Test Phase and during operations (DOE, 1990e). After closure, if waste is disposed of underground at the WIPP facility, evidence

of the presence of the repository will be maintained by written records, shaft location markers, and site monuments, as described in the Closure Plan (see Chapter I). These controls are intended to prevent any undesirable intrusion into the surface structures in the near term and, in the long term, to prevent any inadvertent penetration into the subsurface repository.

Four vertical shafts connect the surface facility to the underground. These are the Waste Shaft, the Salt Handling Shaft, the Exhaust Shaft, and the Air Intake Shaft. The Waste Shaft will be used to transport waste to the underground. It is also used to transport materials and large equipment, and can transport personnel. The Salt Handling Shaft is the primary personnel hoist; removes mined materials from the underground; is a route for power, control, monitoring, and communication cables; and serves as the secondary air supply duct for the underground. The Exhaust Shaft serves as the exhaust air duct for the underground. The Air Intake Shaft is the primary supply of fresh air to the underground (DOE, 1990e).

√ The WIPP facility underground structures are located on the repository horizon, 2,150 feet under the surface, and consist of the waste management area, the shaft pillar area that contains the underground construction area, and the experimental area. The waste emplacement area will be mined as required for waste emplacement. Ultimately, it will consist of eight panels of seven disposal rooms each. The waste disposal rooms are 300 feet long, 13 feet high, and 33 feet wide. The experimental area, to the north, is reserved for activities that do not involve waste and that support salt repository technology development programs. Detailed descriptions of the surface and underground facilities are included in Chapter D.

B-2 Topographic Map

√ Topographic maps of the WIPP site and facility, as required by HWMR-6, Pt. IX, √ sec. 270.14(b)(19), are presented in Figures B-6 and B-7. In accordance with the note located √ at the end of HWMR-6, Pt. IX, sec. 270.14(b)(19), and due to the large size of the facility, the √ scale on Figure B-6 is 1 inch = 1,000 feet. Contour lines on Figures B-6 and B-7 are at intervals √ of 10 feet (except those within the Zone 1 fence on Figure B-7, which equal 1 foot), reflecting the flat, desert-plain topography at the WIPP site. In addition, a contour map at the approximate mid-height of the underground facility (corresponding to the Orange Marker Band) is presented in Figure B-8.

B-2a General Requirements

√ A map scale, date, and north arrow are on Figures B-6 and B-7. The WIPP facility is not in a √ 100-year floodplain nor are major surface water bodies within 10 miles of the site. Therefore, √ these requirements are not included on Figure B-6 or Figure B-7. See a discussion of the 100- √ year floodplain and Figure 2.4-1 which shows surface water features beyond the area represented √ in Figures B-6 and B-7 in Appendix B1. A wind rose showing prevailing windspeed and direction √ appears in Figure B-6. Additional wind roses for the WIPP site are presented in Figures B-9 and

B-13. While there are some potential production wells within the WIPP legal boundary, all are outside Zone II. The Zone II boundary delineates a minimum distance of 1 mile from the miscellaneous unit. Information regarding land uses on and near the WIPP facility is illustrated in Figures B-16 through B-21. The legal boundary of the WIPP site is shown in Figure B-6. Access control features such as fences and gates are illustrated in Figure B-7. Buildings, waste management areas, and other structures are illustrated in Figure B-7. More detailed information and figures concerning the waste management unit, buildings, structures, sewers, loading and unloading areas, fire control facilities, flood control and drainage barriers, runoff control systems, and waste handling areas are presented in Chapter D. Flood control and drainage barrier information is also included in Appendix B1. The underground waste emplacement area is shown in Figure B-6. Surface waste handling areas are shown in Figure B-7.

B-2b Additional Requirements for Land Disposal Facilities

The proposed point of compliance is the WIPP legal boundary, which encloses the 16 square miles of the WIPP site, and is shown in Figure B-6. Although there are water quality sampling wells (Figure B-22), no wells are proposed as RCRA groundwater monitoring wells. Chapter E addresses groundwater monitoring, and Appendix E1 presents RCRA Groundwater Protection Information. Chapter D appendices contain detailed descriptions of WIPP site characteristics, including geology and hydrology, and include maps of known water-bearing zones. No contamination has, and it is highly improbable that any contamination will, enter the groundwater from the regulated unit

B-3 Location Information

Selection of the WIPP site followed an extensive study of potential sites and was based on stringent site selection criteria. Investigation of the geographic area proposed for the WIPP facility, the Los Medanos region of southeastern New Mexico, began in 1972 with a careful review of the extensive geologic data base developed by potash and hydrocarbon industry exploration in the area. The results of this review were favorable, and detailed characterization of the present site was initiated in 1976 with drilling of a stratigraphic borehole, ERDA-9, at the center of the proposed site (DOE, 1990c). For details regarding WIPP site characterization, geology, and hydrology, see Appendices D6 and D7.

Between 1975 and 1988, over 95 boreholes were drilled and over 35,000 feet of core were retrieved specifically for geologic evaluation of the site. More than 40 of these boreholes have been used to acquire hydrologic data needed to establish models of local and regional hydrology. A detailed and exhaustive study of the geology of the WIPP vicinity was completed in 1978 (Powers et al., 1978). In addition, a variety of geophysical exploration techniques, including electrical resistivity, seismic reflection, gravity, and magnetic surveys, have contributed to and updated understanding of the many aspects of site geology (Lappin, 1988).

A comprehensive WIPP Project research and development program began in 1975 with investigations of salt creep properties and constitutive laws, gas generation from the degradation of TRU waste, corrosion behavior of TRU waste containers, and backfill behavior. From 1981 through 1983, field tests were conducted on waste package materials, large-scale salt deformation, and brine transport in a potash mine near the WIPP site. Investigations in the WIPP facility underground began in 1982 with the instrumentation of the Salt Handling Shaft and selected underground drifts. An extensive underground (in situ) test program for thermal/structural interactions, plugging and sealing, brine inflow, and waste package performance began in 1983 and is still in progress (Tyler et al., 1988).

The SPDV program (1981-1983) was developed and implemented to permit direct observation of geologic conditions at the proposed repository horizon and to allow determination of the geomechanical response of the salt beds after excavation of underground workings. Two shafts were drilled and a four-room test panel was excavated at the selected disposal depth. Extensive data from geologic investigations showed the geology of the disposal horizon to be consistent with predictions based on previous investigations (Westinghouse, 1983). The site's characteristics with respect to seismicity and flooding are discussed in the following sections.

B-3a Seismic Standard

The WIPP site is located in Eddy County, New Mexico. Eddy County, New Mexico, is not listed in HWMR-6, Pt. V, Appendix VI, Political Jurisdictions in Which Compliance With §264.18(a) Must Be Demonstrated. Therefore, the WIPP site is assumed to be in compliance with the requirements of HWMR-6, Pt. V, sec. 264.18(a).

WIPP facility structures and component systems that are designed to withstand the Design Basis Earthquake are functionally relied upon to confine, monitor, and control radioactive effluents or to provide permanent shielding (DOE, 1990e). The Design Basis Earthquake for the WIPP facility is defined as an event with maximum ground acceleration of 3.2 feet per second squared horizontally and vertically, with ten maximum stress cycles, and based on a 1,000-year recurrence interval (DOE, 1990e). Additional information regarding the seismicity and structural geology of the site is presented in Section D-9a(1), and additional information on Design Basis components of the WIPP facility is presented in Section D-9a(3).

B-3b Floodplain Standard

The WIPP site does not lie within a 100-year floodplain. There are no major surface water bodies within 10 miles of the site. It is approximately 14 miles from the nearest river, the Pecos River

(Figure B-2). The general ground elevation in the vicinity of the surface facilities (approximately 3,400 feet above mean sea level) is about 500 feet above the river bed and 400 feet above the 100-year floodplain. Further, although there are no flood protection requirements for the WIPP site, the WIPP facility drainage structures have been designed so that ponding resulting from a Probable Maximum Precipitation (PMP) event will not affect surface structures. The floor levels of all surface facilities are above the levels calculated for local flooding due to PMP events (DOE, 1990e). Detailed analysis of the surface hydrology, contained in Section 2.4 of the WIPP Final Safety Analysis Report, is included as Appendix B1 in this permit application.

B-3b(1) Demonstration of Compliance

The WIPP facility is not in a 100-year floodplain as defined in HWMR-6, Pt. V, sec. 264.18(b)(2)(i), and regulated under HWMR-6, Pt. V, sec. 264.18(b)(1). Floodplain regulations are not applicable to the WIPP facility.

B-3b(1)(a) Flood Proofing and Flood Protection Measures

The WIPP facility is not in a 100-year floodplain as defined in HWMR-6, Pt. V, sec. 264.18(b)(2)(i), and regulated under HWMR-6, Pt. V, sec. 264.18(b)(1). Floodplain regulations are not applicable to the WIPP facility.

B-3b(1)(b) Flood Plan

The WIPP facility is not in a 100-year floodplain as defined in HWMR-6, Pt. V, sec. 264.18(b)(2)(i), and as regulated under HWMR-6, Pt. V, sec. 264.18(b)(1). Flood plan regulations are not applicable to the WIPP facility.

B-3b(2) Plan for Future Compliance with Floodplain Standard

The WIPP facility is not in a 100-year floodplain as defined in HWMR-6, Pt. V, sec. 264.18(b)(2)(i), and as regulated under HWMR-6, Pt. V, sec. 264.18(b)(1). The plan for future compliance with the floodplain standard regulation is not applicable to the WIPP facility.

B-3b(3) Waiver for Land Storage and Disposal Facilities

The WIPP facility is not in a 100-year floodplain as defined in HWMRM-6, Pt. V, sec. 264.18(b)(2)(i), and as regulated under HWMR-6, Pt. V, sec. 264.18(b)(1). The waiver for land storage and disposal facilities regulation is not applicable to the WIPP facility.

B-4 Traffic Information

Access to the WIPP facility is provided by two access roads that connect with U.S. Highway 62/180, 13 miles to the north, and New Mexico Highway 128 (Jal Highway), 4 miles to the south (Figure B-2). The North Access Road, which connects the site to U.S. Highway 62/180, is the access road that will be used to transport waste from the highway to the site (Bechtel, Inc., 1981a). Access roads are Design Class IIIB. Road pavement materials and construction, as well as other road features, were designed in accordance with the Standard Specifications for Road and Bridge Construction, New Mexico State Highway Department (NMSHD-1976), if applicable (Bechtel; 1981a and 1981b). Signs and pavement markings are located in accordance with the manual on Uniform Traffic Control Devices (Bechtel, 1981a). Access road design designation parameters such as traffic volume are presented in Table B-1. Rail access may be provided from a spur of the Atchison, Topeka & Santa Fe railroad near the Western Ag-Minerals Corporation Nash Draw Mine, which is about 6 miles southwest of the WIPP facility.

WIPP employees and visitors park at the paved parking area, which lies west of the facility, outside of the security fence (Figure B-23). The parking lot is designed to accommodate 231 vehicles, including four buses. Access to the facility for personnel, visitors, and trucks carrying supplies and waste is provided through a security checkpoint. After passing through a security checkpoint (see Figures F-1 and F-2), Transuranic Package Transporter (TRUPACT-II) waste transport trucks will turn right (south) before reaching the Support Building and then left (east) to park either at the unloading docks or in the truck parking area just east of the docks (Figures F-4 and F-5). Salt transport trucks, which remove mined salt from the Salt Handling Shaft area, will not cross paths with waste transporters. They will proceed from the Salt Handling Shaft northward to the salt pile. Figure B-23 shows surface traffic flow at the WIPP facility.

The traffic circulation system is designed in accordance with American Association of State Highway and Transportation Officials (AASHTO) Site Planning Guides for lane widths, lateral clearance to fixed objects, minimum pavement edge radii, and other geometric features. Objects in or near the roadway are prominently marked in accordance with the standards contained in the Manual on Uniform Traffic Control Devices for Streets and Highways, as modified by the State of New Mexico (Bechtel, 1981c).

On-site roads, sidewalks, and paved areas are used for the distribution and storage of vehicles and personnel and are designed to handle all traffic generated by employees, visitors, waste shipments, and movements of operational and maintenance vehicles (Bechtel, 1981c). The facility entrance and waste haul roads are designed for AASHTO H20-S16 wheel loading (Bechtel, 1981c). Service roads are designed for AASHTO H10 wheel loading (Bechtel, 1981c). Access and on-site paved roads are designed to bear the anticipated maximum load of 80,000 pounds (the maximum allowable weight of a trailer carrying loaded TRUPACT-IIs).

The facility is designed to handle an average of 3.2 truck trailers per day, each carrying three TRUPACT-IIs (DOE, 1990d). This is equivalent to 810 vehicles per year for contact-handled TRU waste. However, during the Test Phase, bin-scale test shipments will not exceed a total of 250 truck trailers.

Underground traffic, with and without waste, will travel on separated paths. The ventilation and traffic flow in the waste handling areas underground are restricted and separate from those used for mining and haulage equipment.

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TABLE

TABLE B-1
WASTE ISOLATION PILOT PLANT SITE DESIGN DESIGNATION TRAFFIC PARAMETERS[1] (BECHTEL, 1981a)

Traffic Parameter	North Access Road (No. of Vehicles, unless otherwise stated)	South Access Road (No. of Vehicles, unless otherwise stated)	On-Site Waste Haul Roads (TRUPACT-II Traffic)
Average Daily Traffic (ADT)[2]	800	400	<1
Design Hourly Volume (DHV)[3]	144	72	NA[7]
Hourly Volume (Max. at Shift Change)	250	125	NA
Distribution (D)[4]	67%	67%	NA
Trucks (T)[5]	2%	0	100%
Design Speed[6]	70 mph	60 mph	25 mph
Control of Access	None	None	Full

[1]For WIPP personnel and waste shipments only.
[2]ADT - Estimated number of vehicles travelling in both directions per day.
[3]DHV - A two-way traffic count with directional distribution.
[4]D - The percentage of DHV in the predominant direction of travel.
[5]T - The percentage of ADT comprised of trucks (excluding light delivery trucks).
[6]Control of Access - The extent of roadside interference or restriction of movement.
[7]NA - Not Applicable.

FIGURES

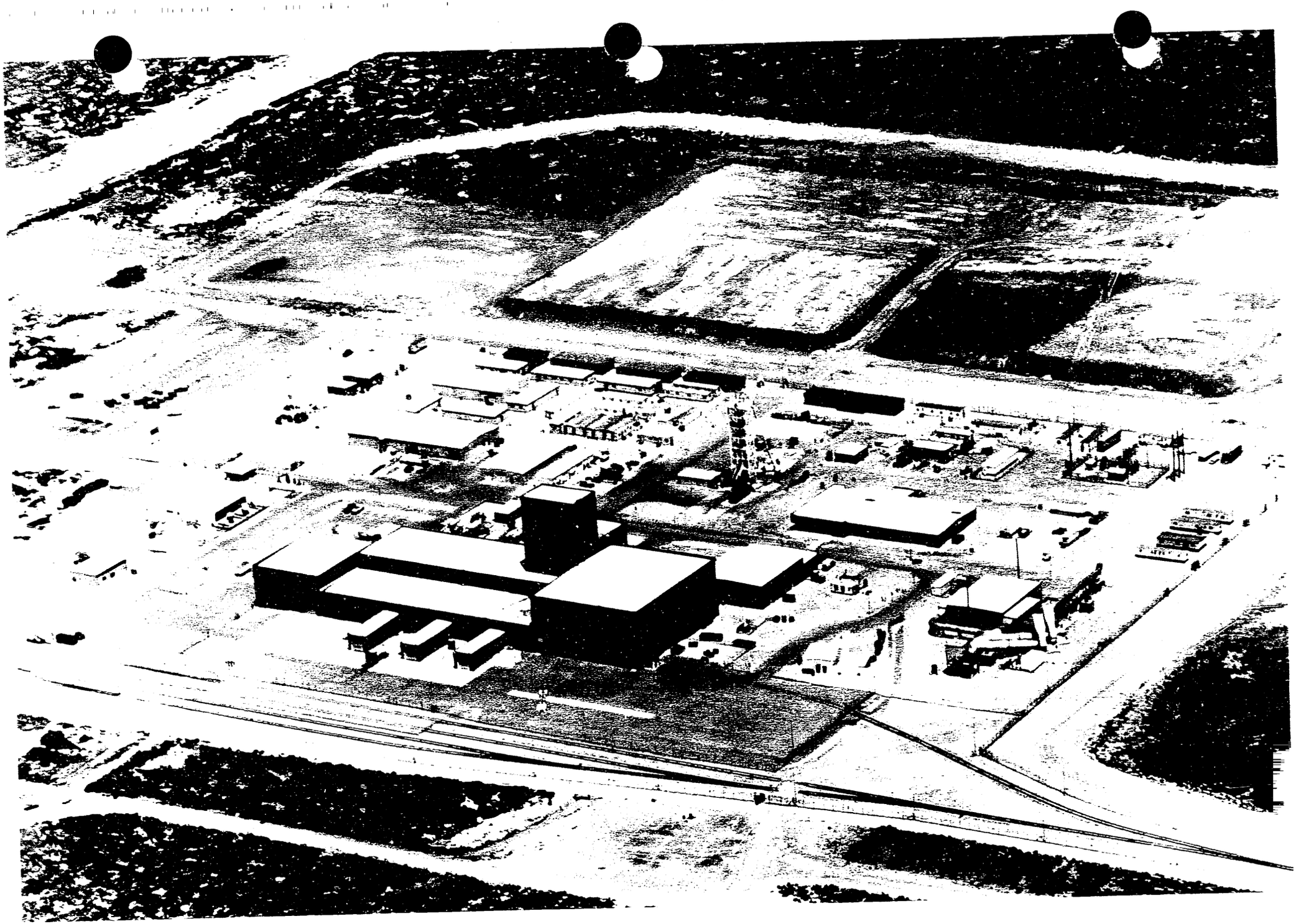
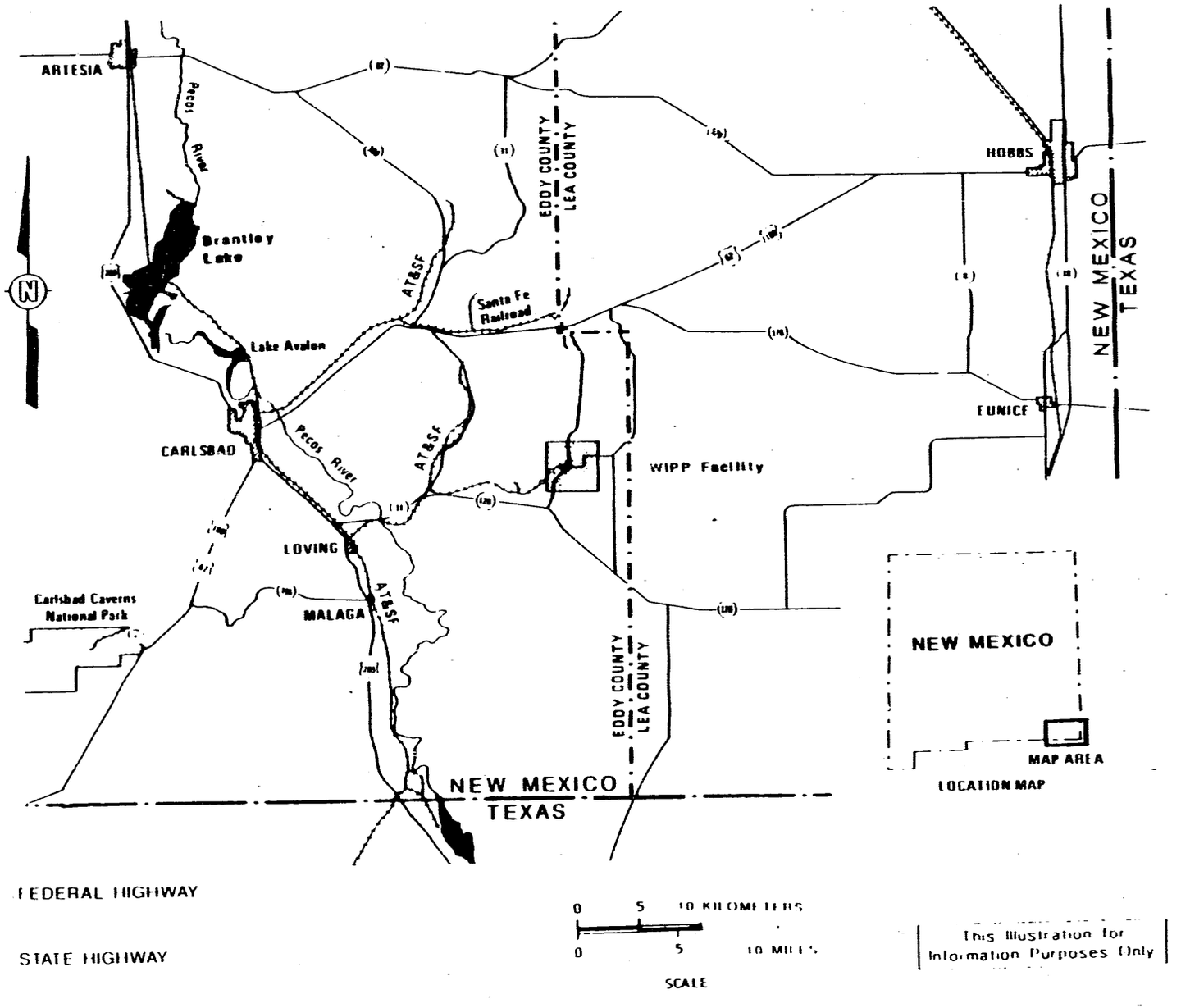
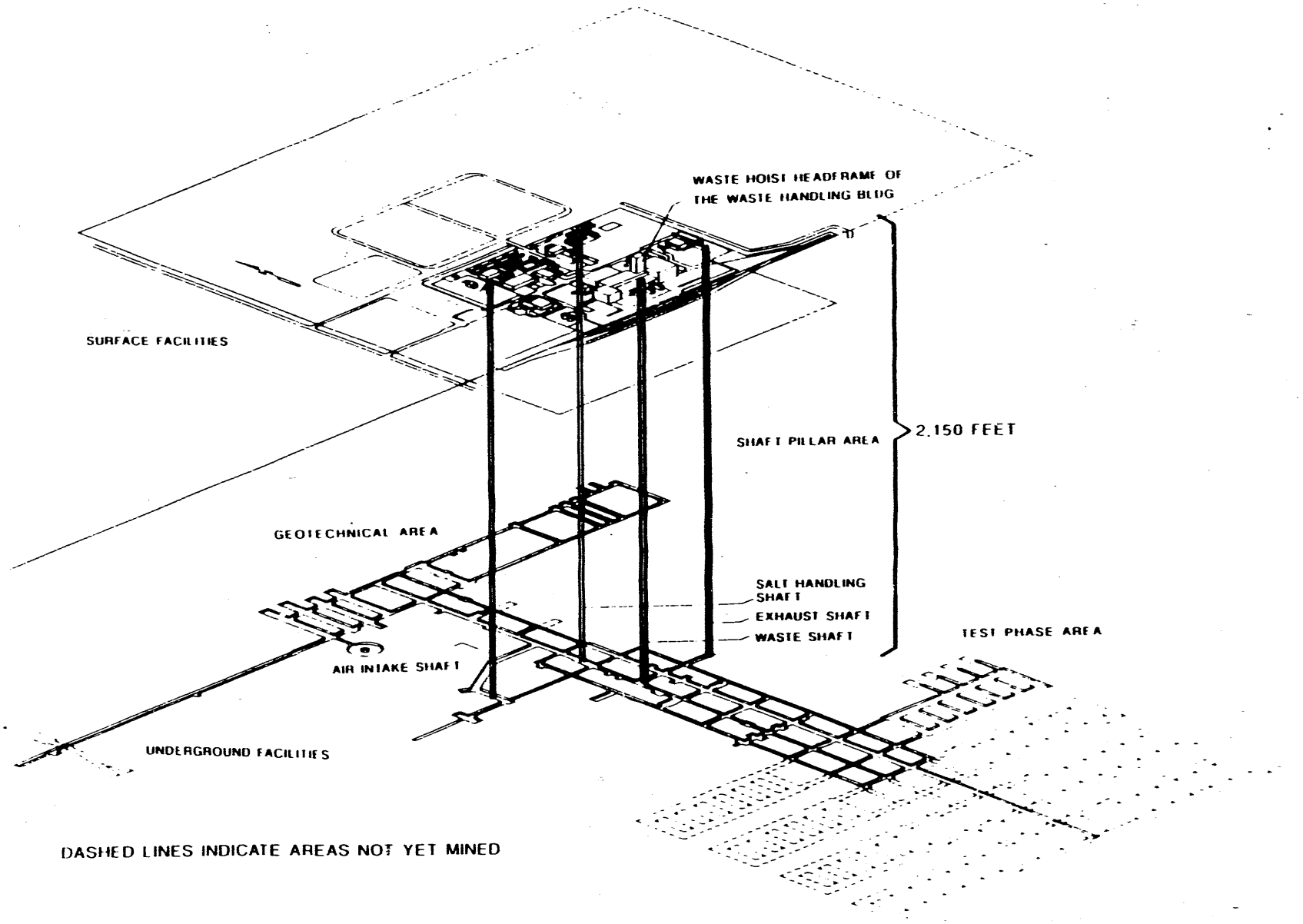


FIGURE B-1 AERIAL PHOTOGRAPH OF THE WASTE ISOLATION PILOT PLANT



DOE, 1990e

FIGURE B 2 GENERAL LOCATION OF THE WIPP FACILITY



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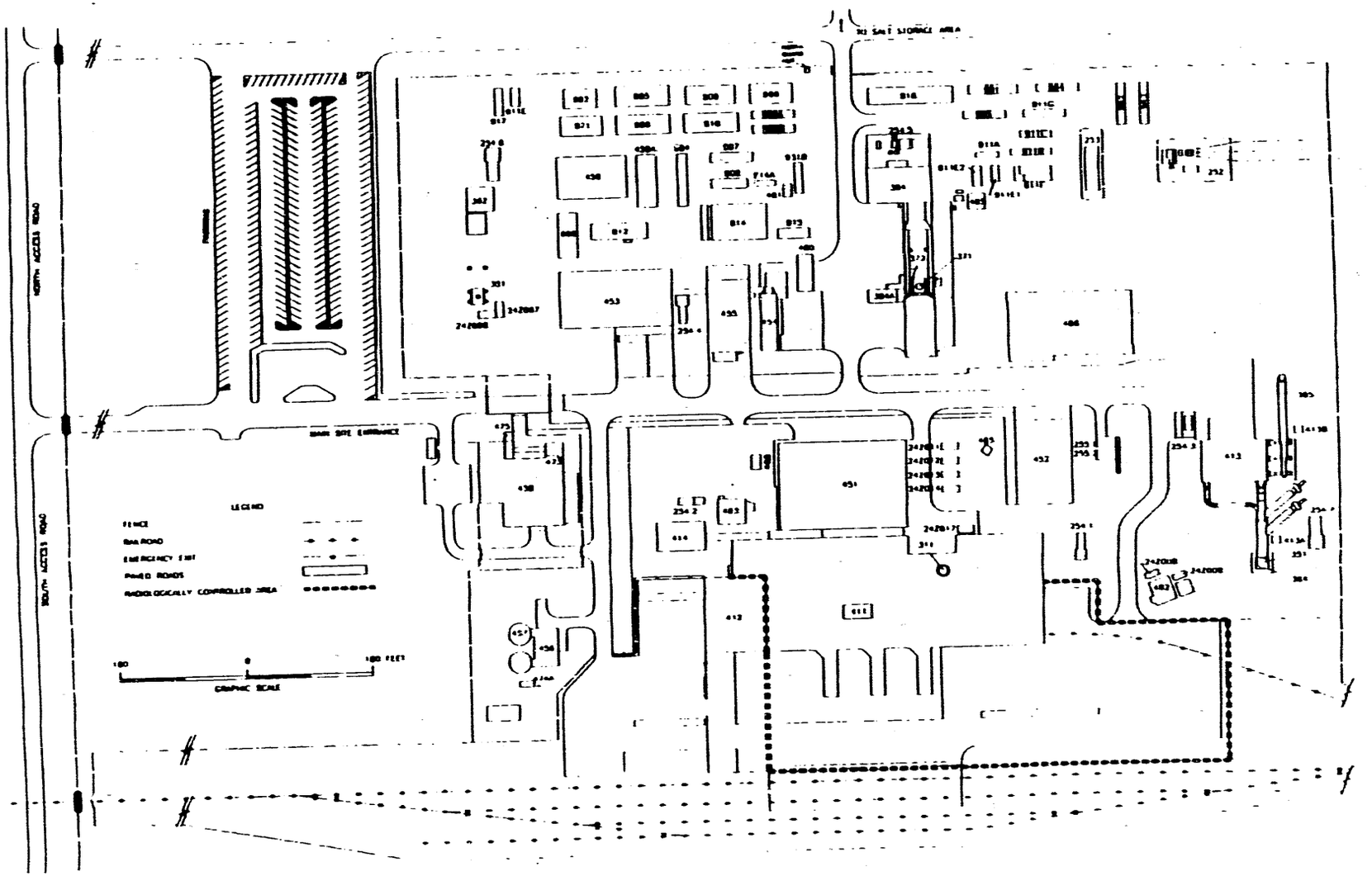
Information Purposes Only

FIGURE B 3 SPATIAL VIEW OF THE WIPP FACILITY



DOE, 1990e

FIGURE B 4 WIPP SURFACE STRUCTURES

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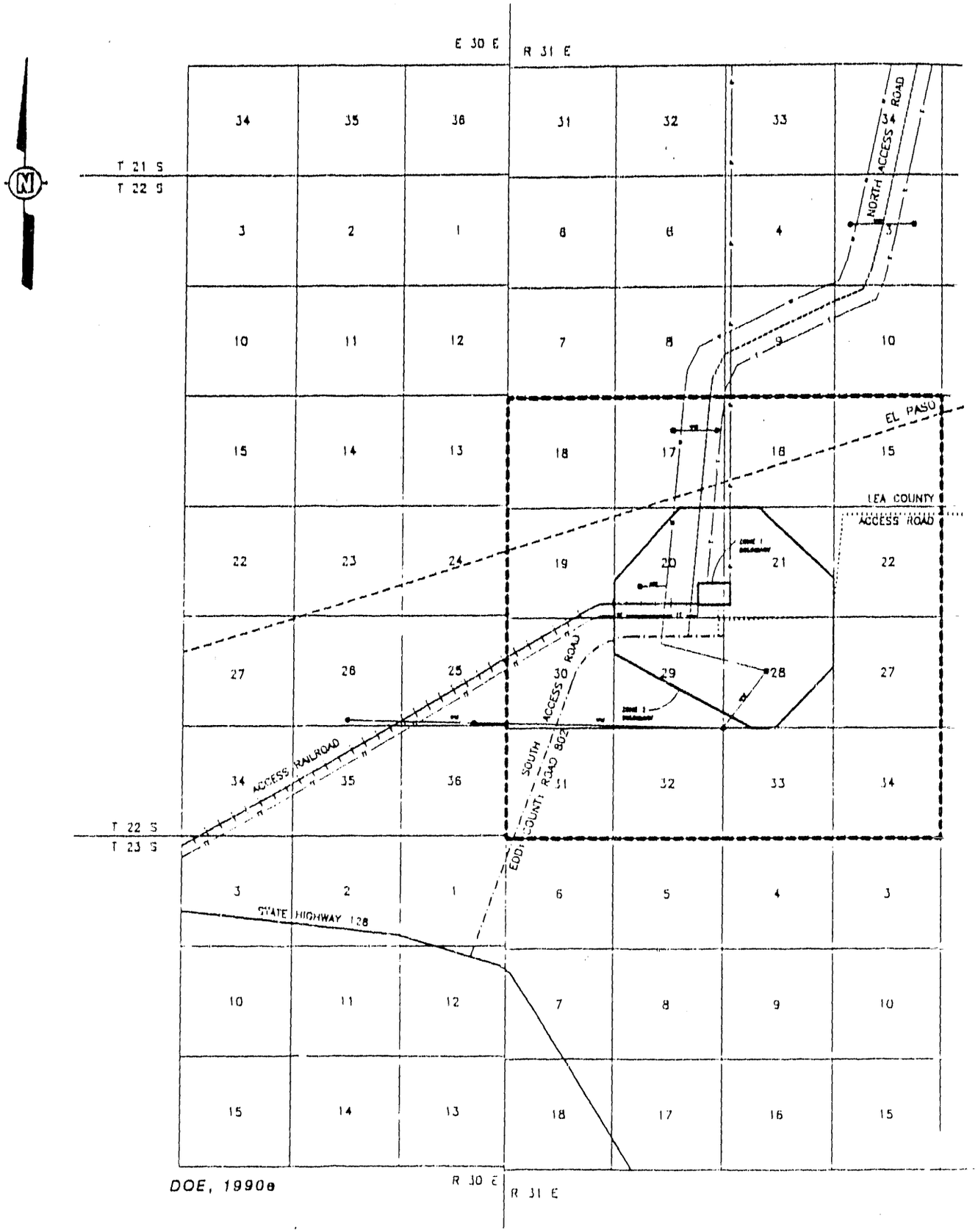
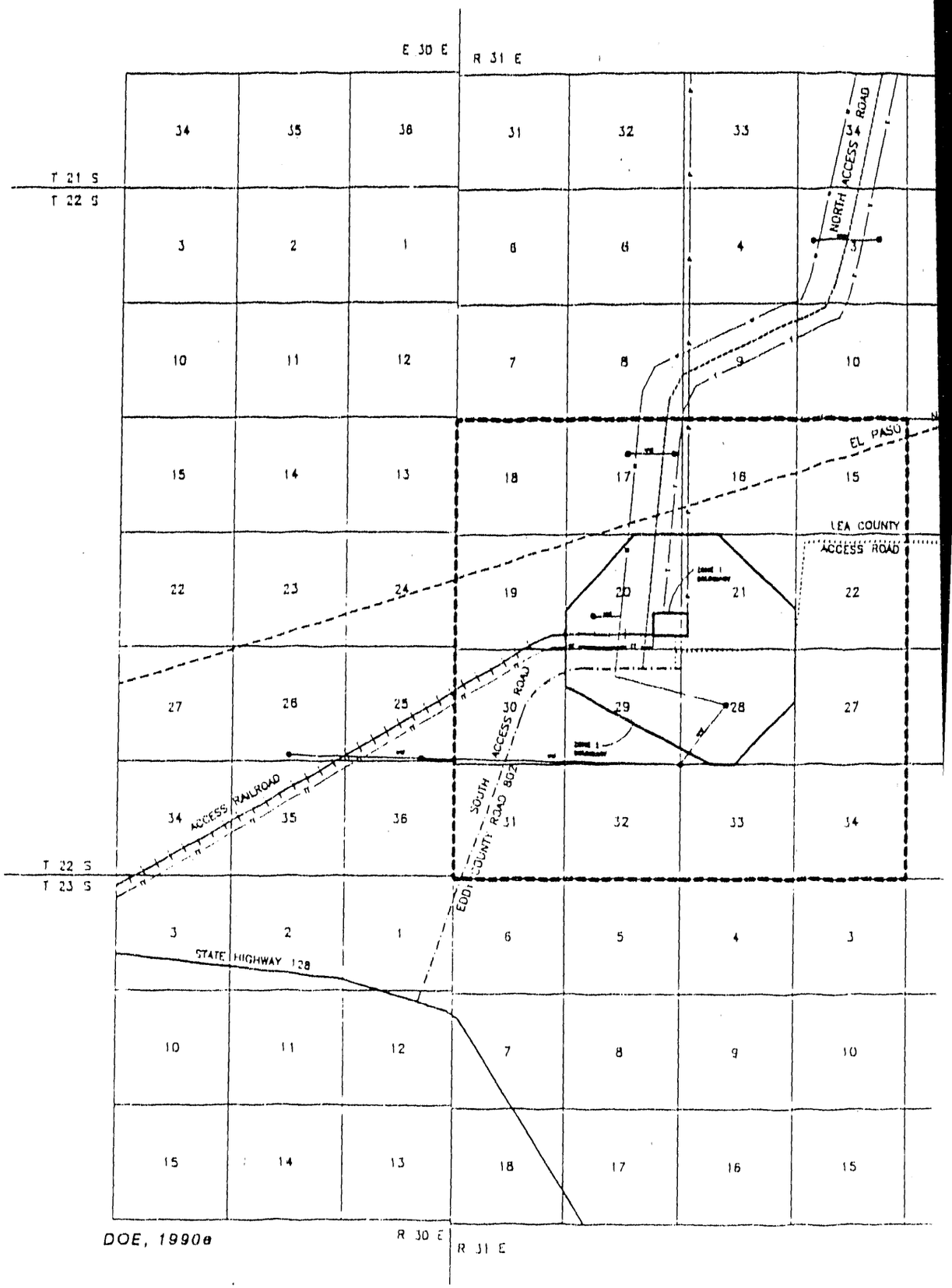

R 30 E
R 31 E
T 21 S
T 22 S
T 22 S
T 23 S
NORTH ACCESS ROAD
EL PASO
LEA COUNTY ACCESS ROAD
SOUTH ACCESS ROAD
EDDY COUNTY ROAD 802
ACCESS RAILROAD
STATE HIGHWAY 128
R 30 E
R 31 E

DOE, 1990a


R 30 E
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NORTH ACCESS ROAD
EL PASO
LEA COUNTY
ACCESS ROAD
SOUTH ACCESS ROAD
EDDY COUNTY ROAD 802
ACCESS RAILROAD
STATE HIGHWAY 128
34 35 36 31 32 33 34
3 2 1 6 5 4 3
10 11 12 7 8 9 10
15 14 13 18 17 16 15
22 23 24 19 20 21 22
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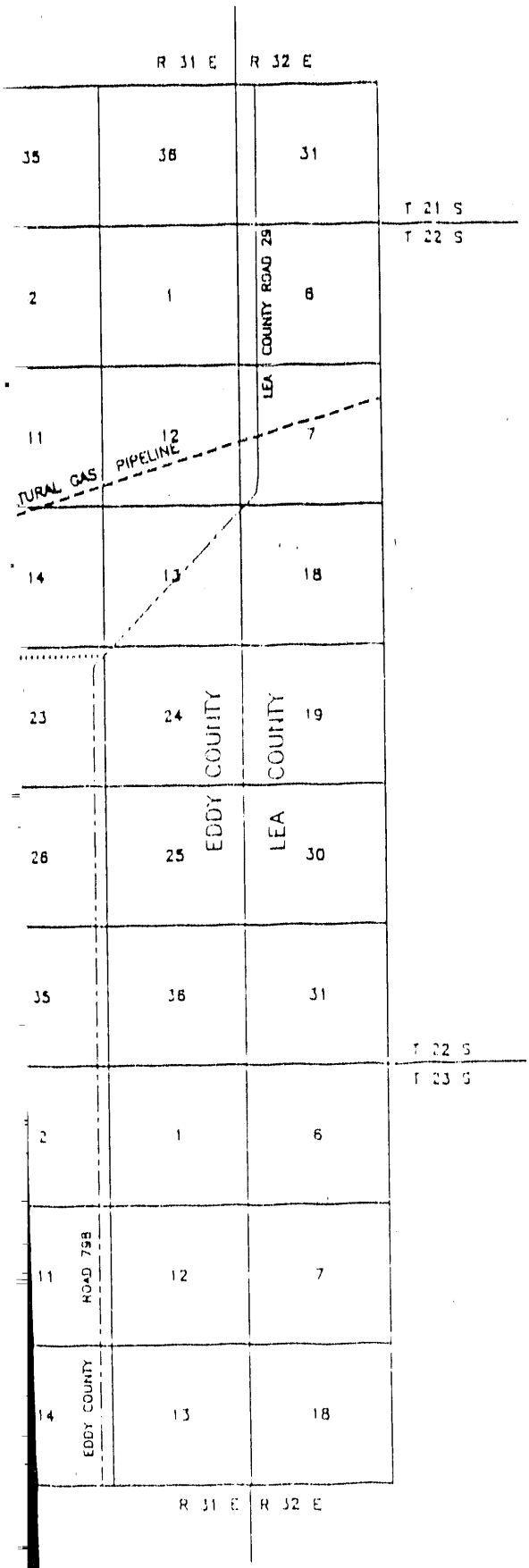
DOE, 1990a



LEGEND

WIPP SITE BOUNDARY

U.S. DOE RIGHT OF WAY NUMBER NM--5180B, FOR WATERLINE 50 FEET WIDE. THE DOE HAS AGREED WITH THE CITY OF CARLSBAD TO ALLOW INDIVIDUALS TO TAP THIS LINE LOCATED WITHIN THE NORTH ACCESS ROAD RIGHT OF WAY.

STOCK WATER LINES AND TAP LINES CONNECTED TO THE MAIN WIPP WATERLINE.

SOUTHWESTERN PUBLIC SERVICE COMPANY RIGHT OF WAY NUMBER NM--43253 FOR POWERLINE, 66 FEET WIDE.

GENERAL TELEPHONE OF THE SOUTHWEST RIGHT OF WAY FOR TELEPHONE LINE, 30 FEET WIDE, LOCATED WITHIN THE NORTH ACCESS ROAD RIGHT OF WAY.

GENERAL TELEPHONE OF THE SOUTHWEST RIGHT OF WAY NUMBER NM--60174 FOR TELEPHONE LINE, 30 FEET WIDE, LOCATED WITHIN THE RAILROAD RIGHT OF WAY

U.S. DOE RIGHT OF WAY NUMBER NM--55875 FOR NORTH ACCESS ROAD, 170 FEET WIDE.

EL PASO NATURAL GAS COMPANY RIGHT OF WAY FOR GAS PIPELINE, 30 FEET WIDE IN SECTION 18, 50 FEET WIDE ELSEWHERE.

U.S. RIGHT OF WAY NUMBER NM--55886 FOR ACCESS RAILROAD, 150 FEET WIDE.

EDDY COUNTY RIGHT OF WAY FOR ACCESS ROADS INCLUDES RIGHT OF WAY NUMBER NM--4130 FOR THE SOUTH ACCESS ROAD WHICH IS 150 FEET WIDE.

NOTES

1. ZONE 1 IS A FENCED AREA OF APPROXIMATELY 35 ACRES. IT CONTAINS ALL SURFACE FACILITIES WITH THE EXCEPTION OF SALT STORAGE PILES, PARKING LOT, LANDFILL AND WASTE WATER STABILIZATION LAGOONS.
2. ZONE 2 OVERLIES THE MAXIMUM EXTENT OF THE AREA AVAILABLE FOR UNDERGROUND DEVELOPMENT. THE PORTION OF ZONE 2 LOCATED OUTSIDE THE DOE EXCLUSIVE USE AREA IS PRESENTLY MANAGED BY THE BLM.
3. WIPP SITE BOUNDARY (WSB) PROVIDES A ONE MILE BUFFER AREA AROUND THE AREA AVAILABLE FOR UNDERGROUND DEVELOPMENT. PORTIONS OF THE (WSB) ARE PRESENTLY MANAGED BY THE B.L.M.
4. INFORMATION TO BE USED FOR PLANNING PURPOSES ONLY.

0 1 2 MILES

0 1 2 KILOMETERS

SCALE

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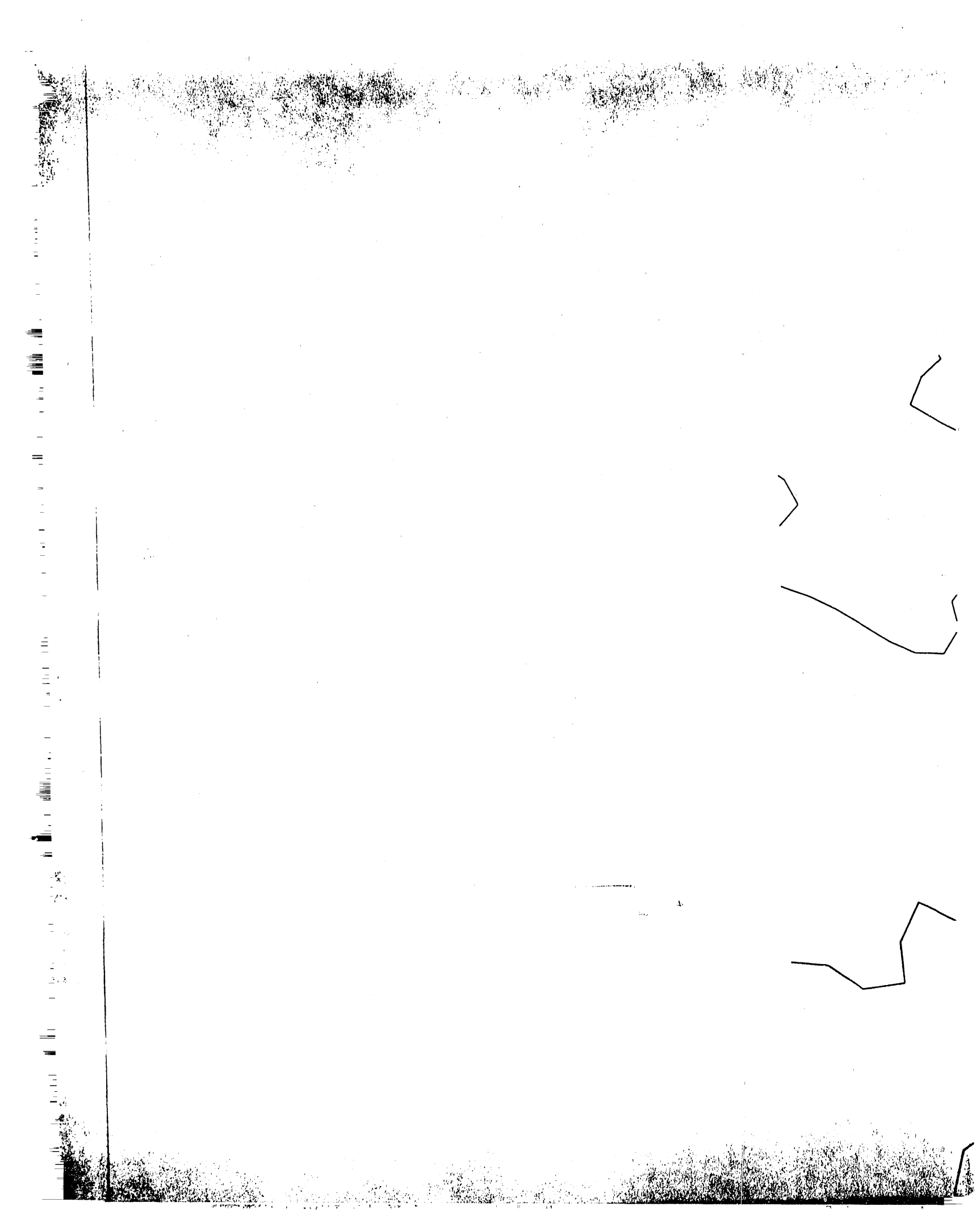
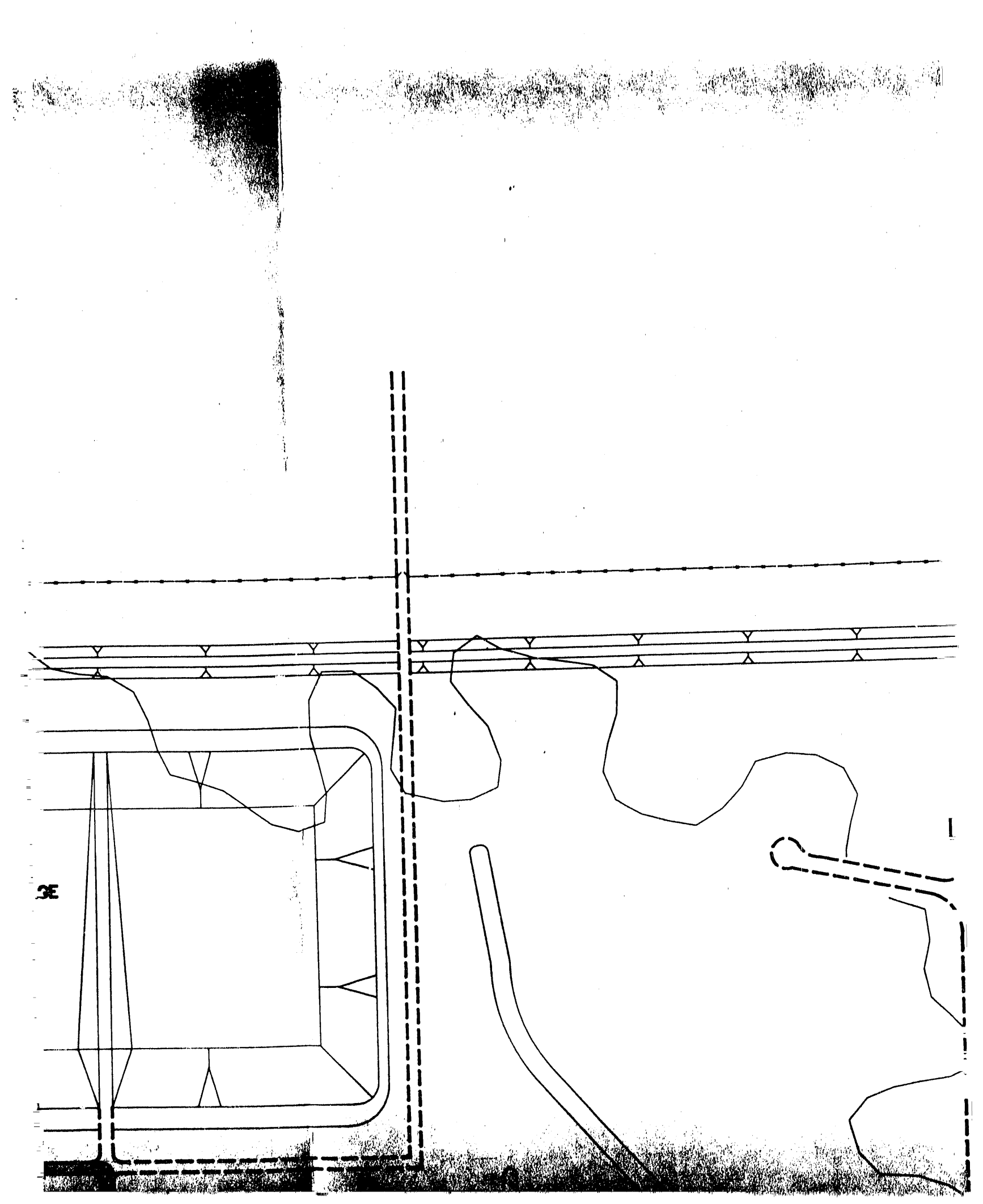
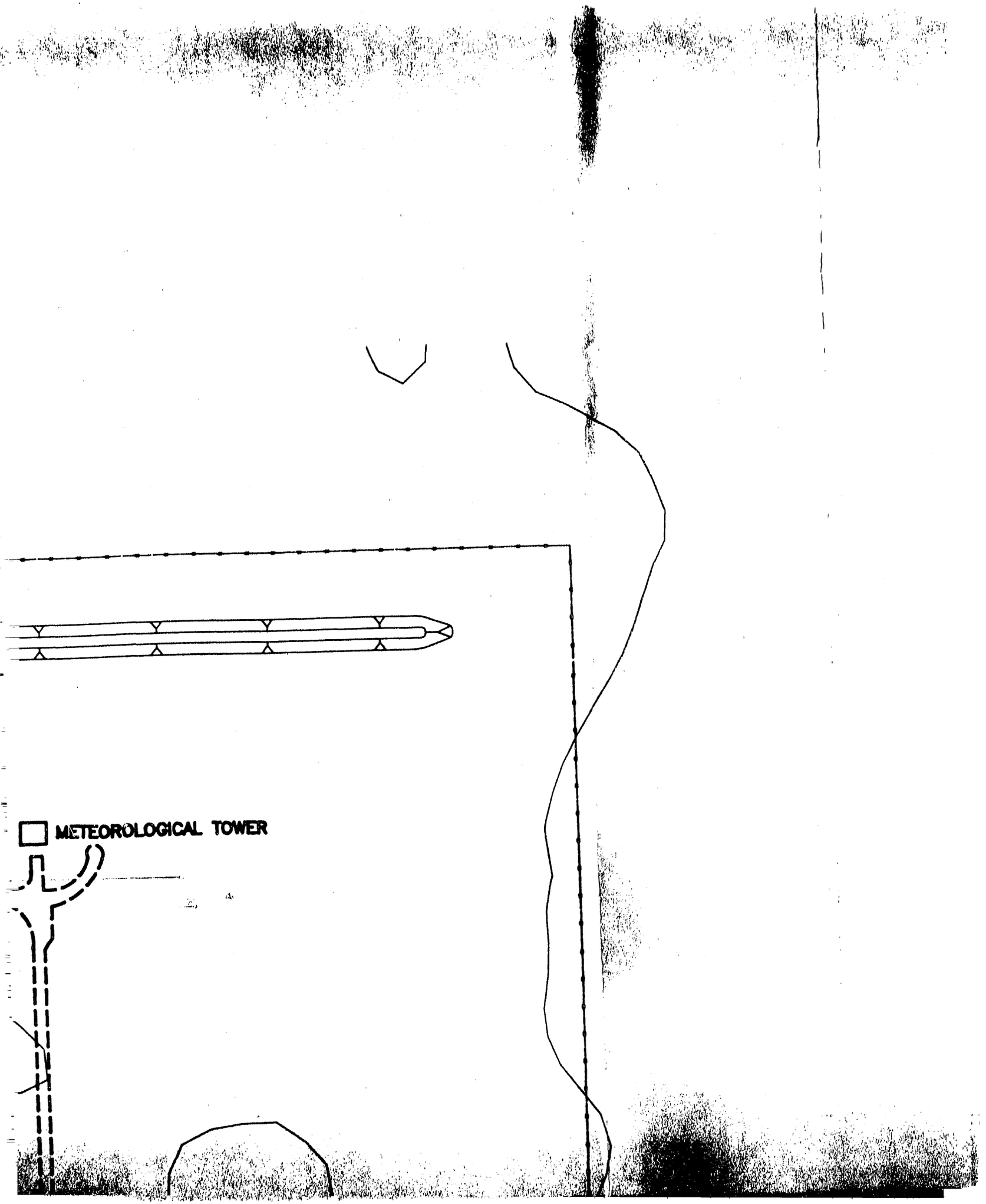
FIGURE B-5 SURFACE MAP SHOWING ZONES

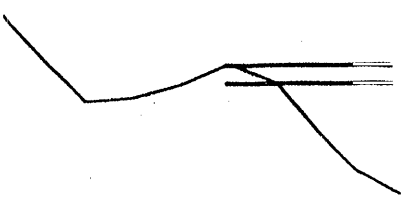


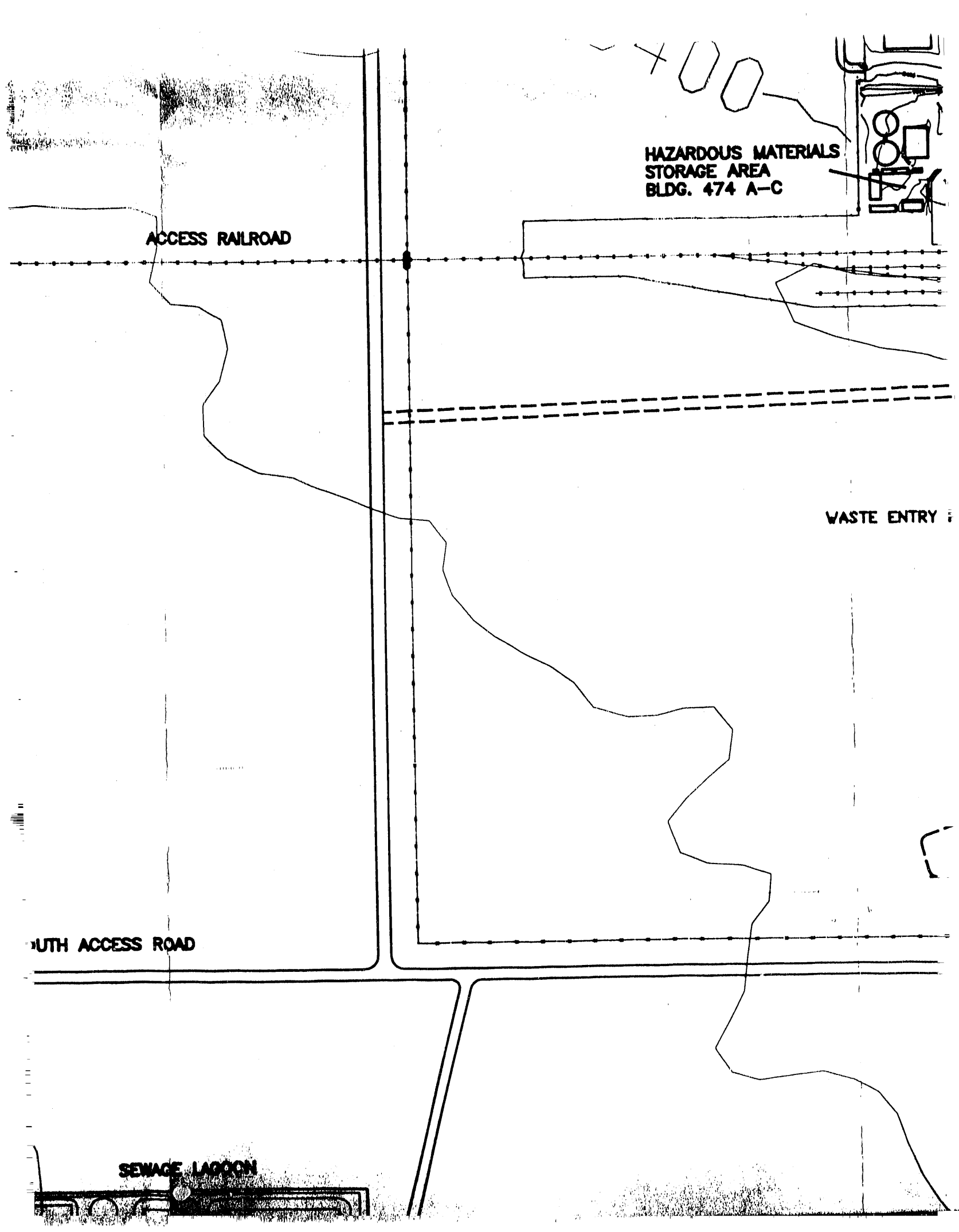
NORTH ACCESS ROAD
EVAPORATION
POND

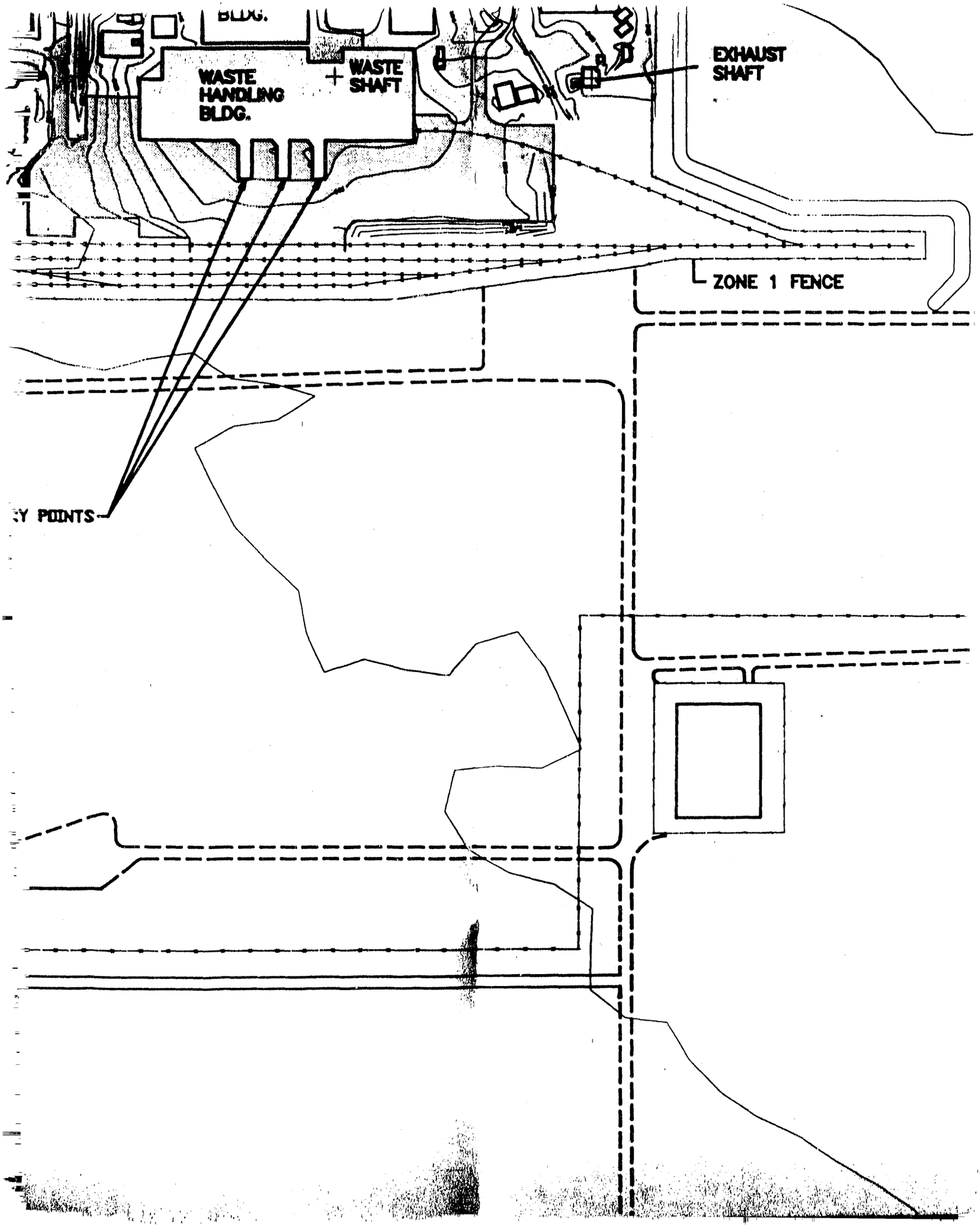


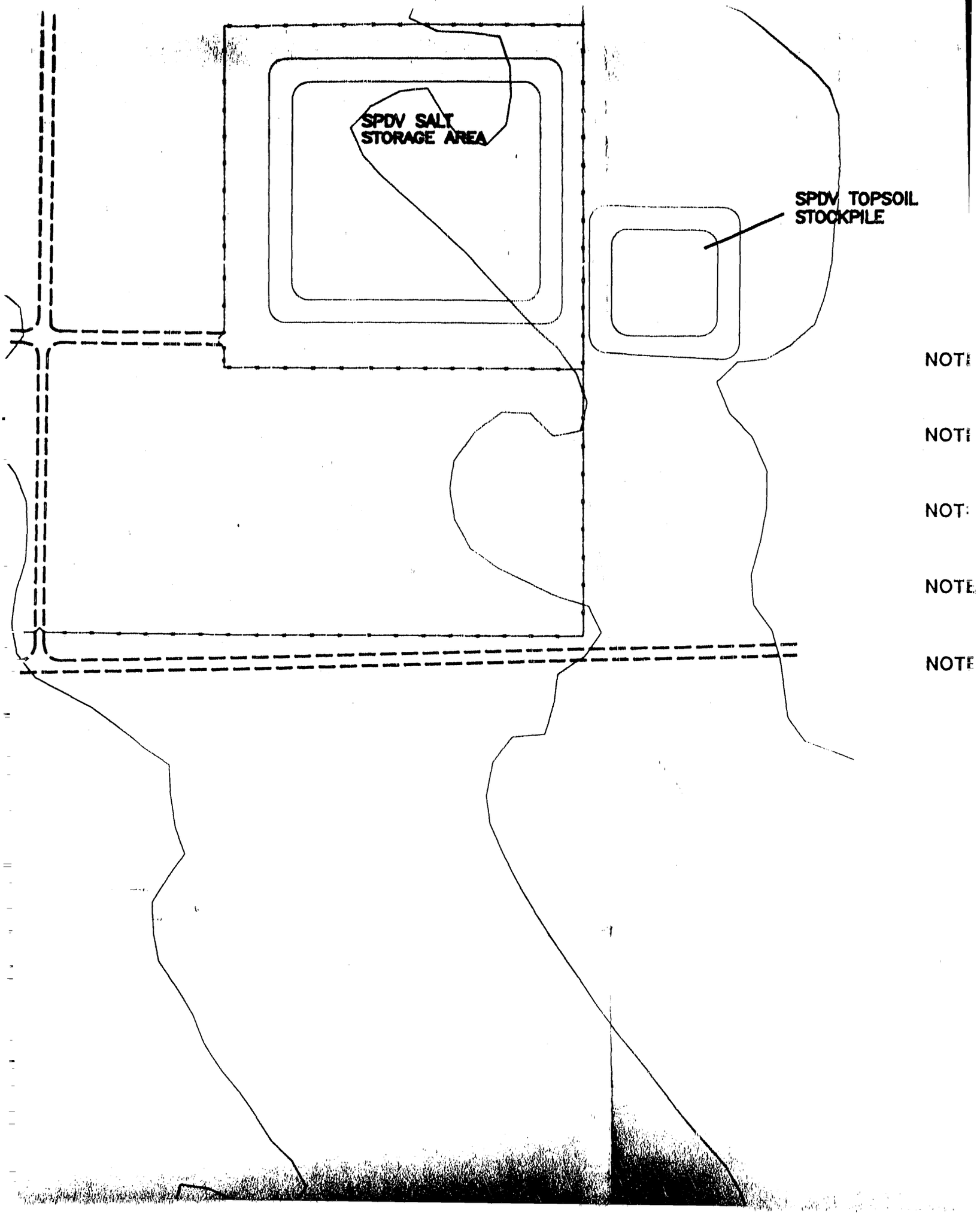

METEOROLOGICAL TOWER

LEGEND




HAZARDOUS MATERIALS
STORAGE AREA
BLDG. 474 A-C
ACCESS RAILROAD
WASTE ENTRY
UTH ACCESS ROAD
SEWAGE LAGOON


BLDG.
WASTE HANDLING BLDG.
WASTE SHAFT
EXHAUST SHAFT
ZONE 1 FENCE
Y POINTS



NOTE

NOTE

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NOTE

NOTE

SPDV TOPSOIL
STOCKPILE

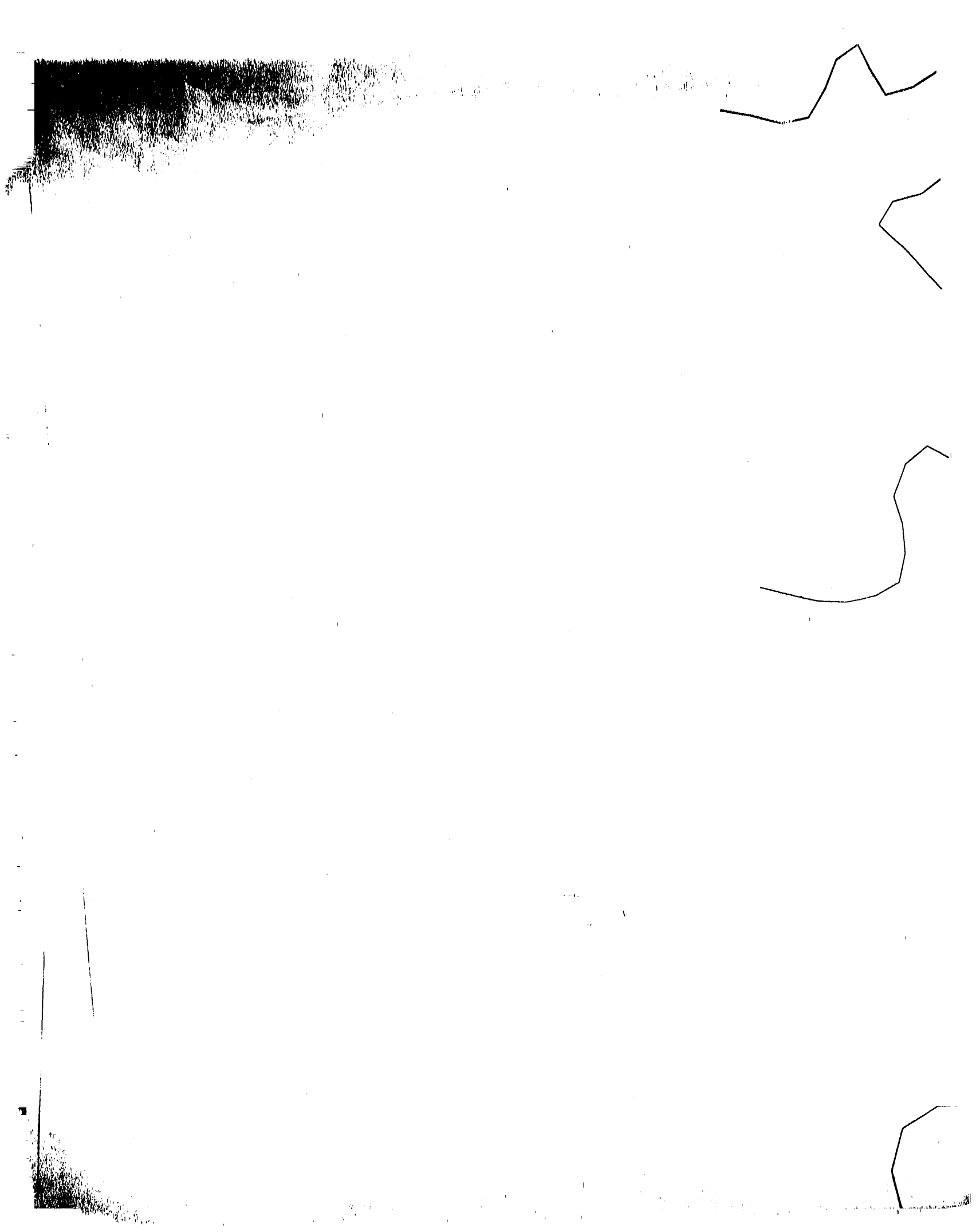
NOTE: CONTOUR INTERVAL = 10 FT. (EXCEPT THOSE WITHIN THE ZONE 1 FENCE WHICH EQUAL 1 FT.)

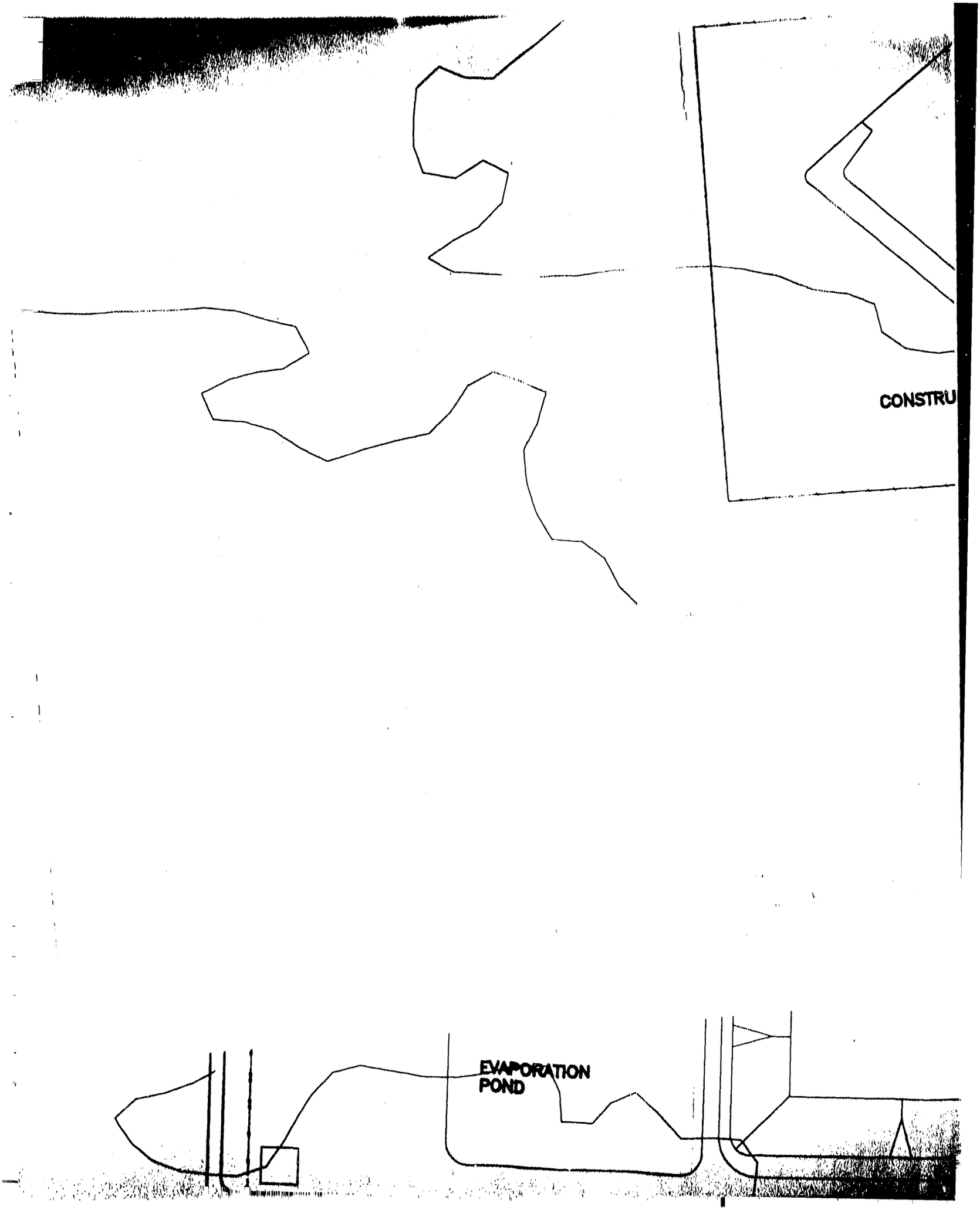
NOTE: FIRE CONTROL FEATURES ARE DISCUSSED AND ILLUSTRATED IN CHAPTER G.

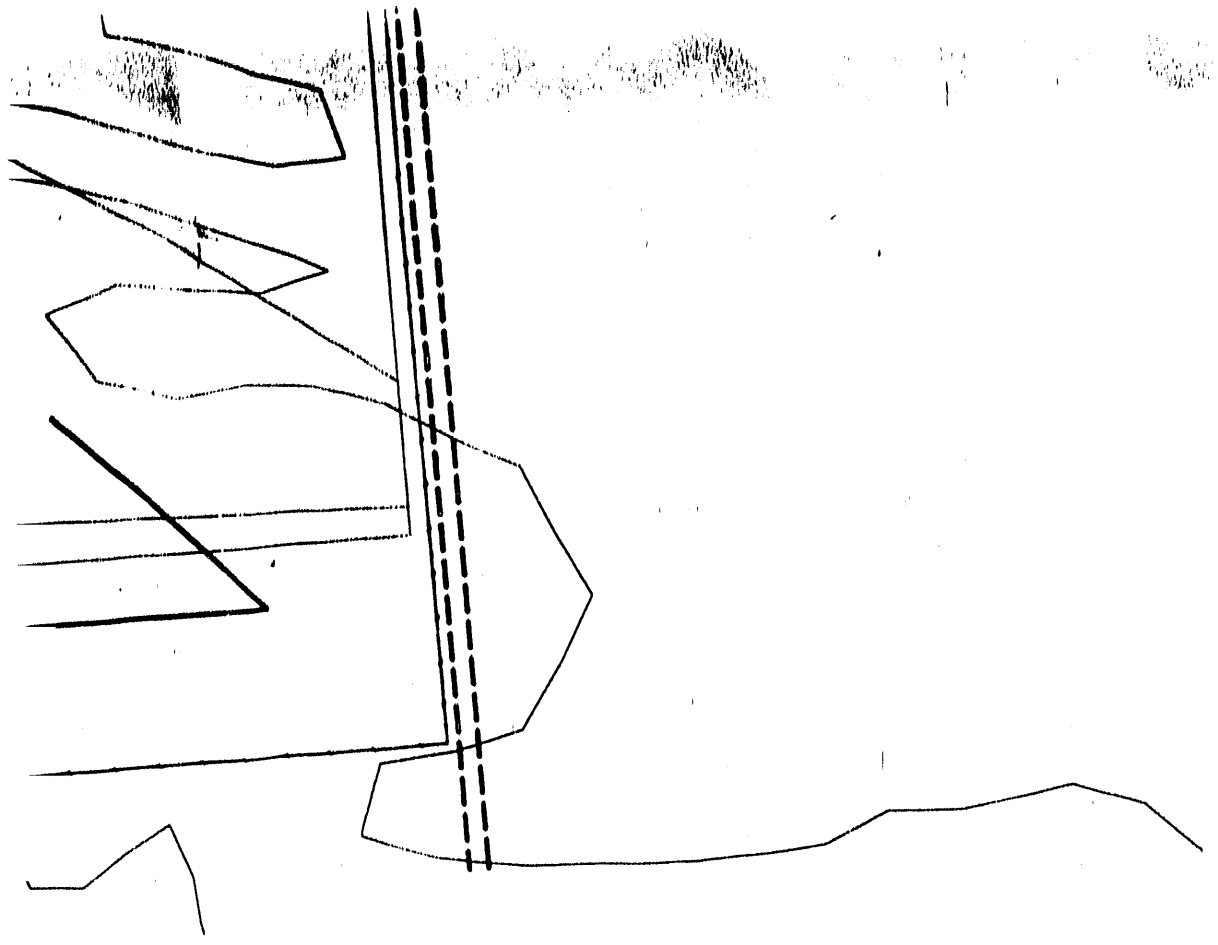
NOTE: ALL SURFACE TEST PHASE WASTE HANDLING ACTIVITIES OCCUR IN THE WASTE HANDLING BUILDING.

NOTE: MORE DETAILED INFORMATION AND FIGURES ARE PRESENTED IN CHAPTER D.

NOTE: SWMU LOCATIONS ARE ILLUSTRATED ON FIGURE J-1.




CONSTRU
EVAPORATION
POND



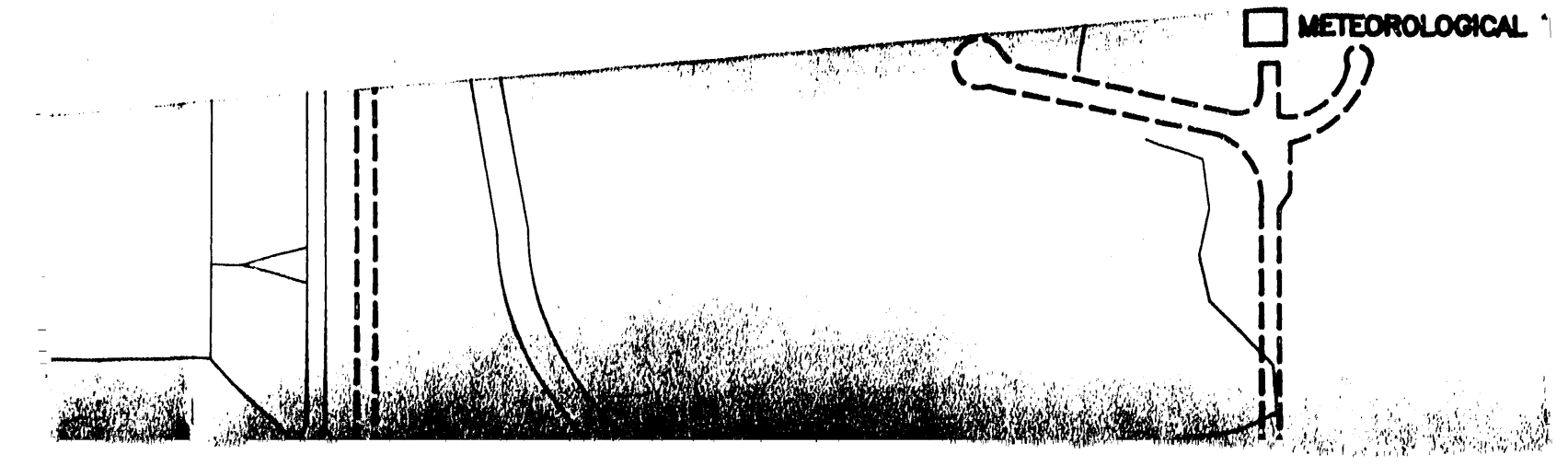

METEOROLOGICAL

FIGURE B-7
TOPOGRAPHIC MAP
WITH SURFACE FACILITIES

FEBRUARY, 1992

LEGEND

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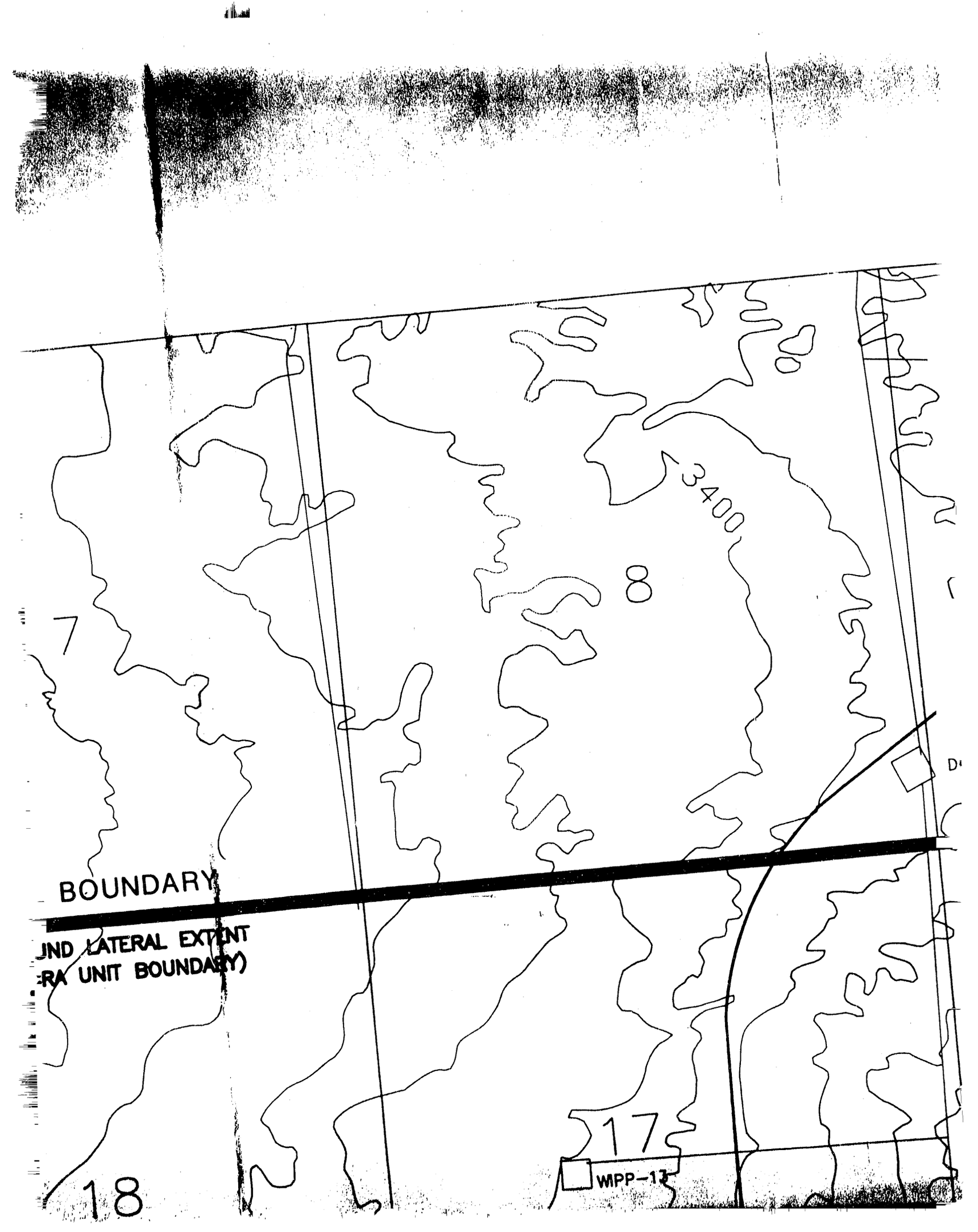
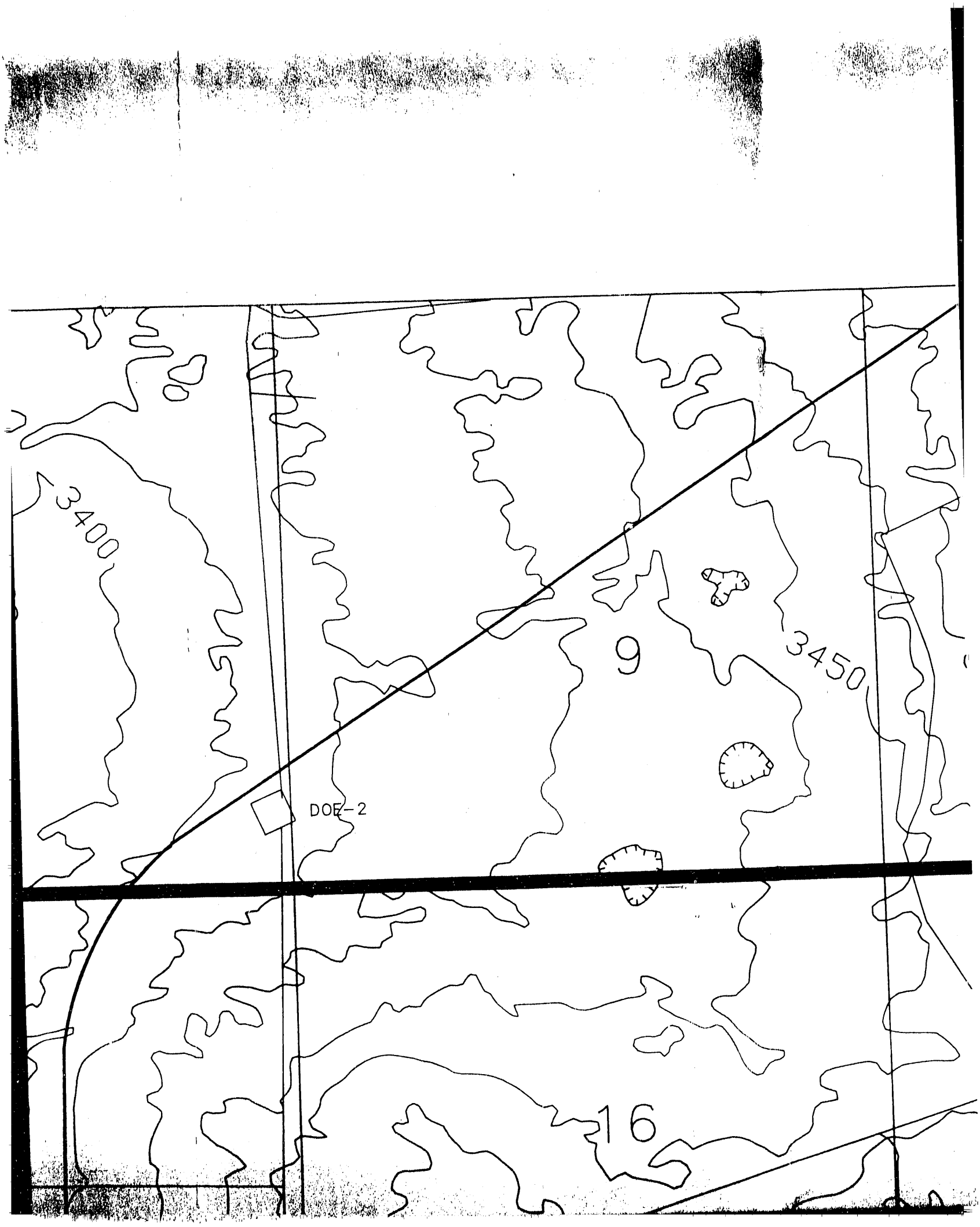
H-6
13


3400
8
7
BOUNDARY
JND LATERAL EXTENT
RA UNIT BOUNDARY)
17
WIPP-13
18


3400
9
3450
DOE-2
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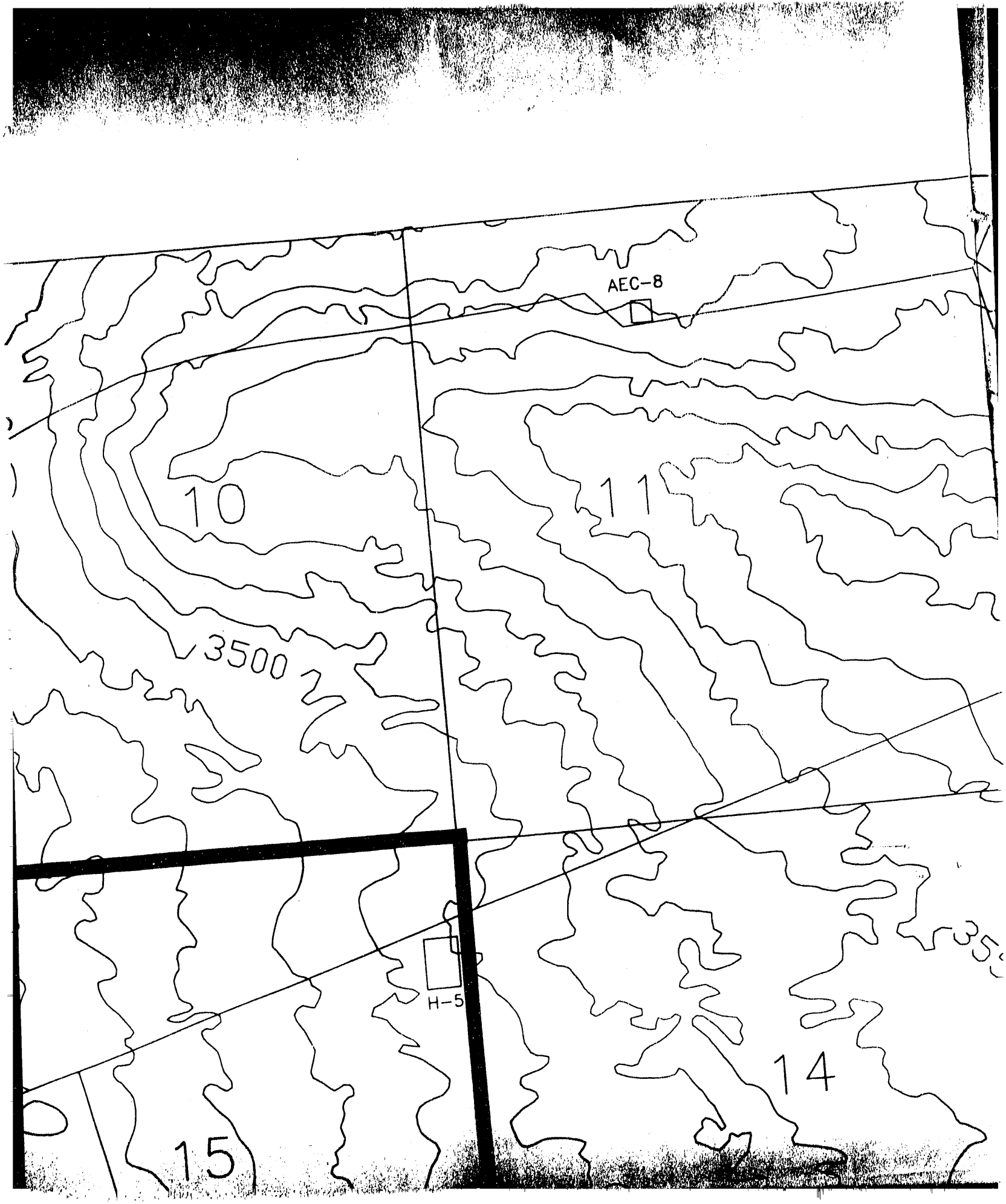
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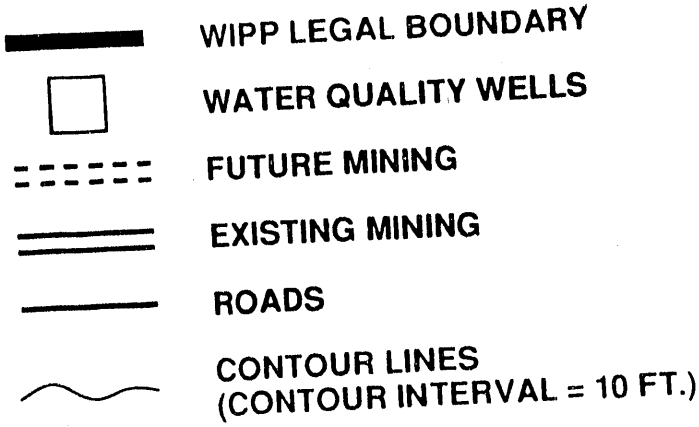

NOTE: UNDERGROUND FACILITIES ARE AT A DEPTH OF 2150 FT. BELOW THE SURFACE.

[illegible] SEE APPENDIX B1.

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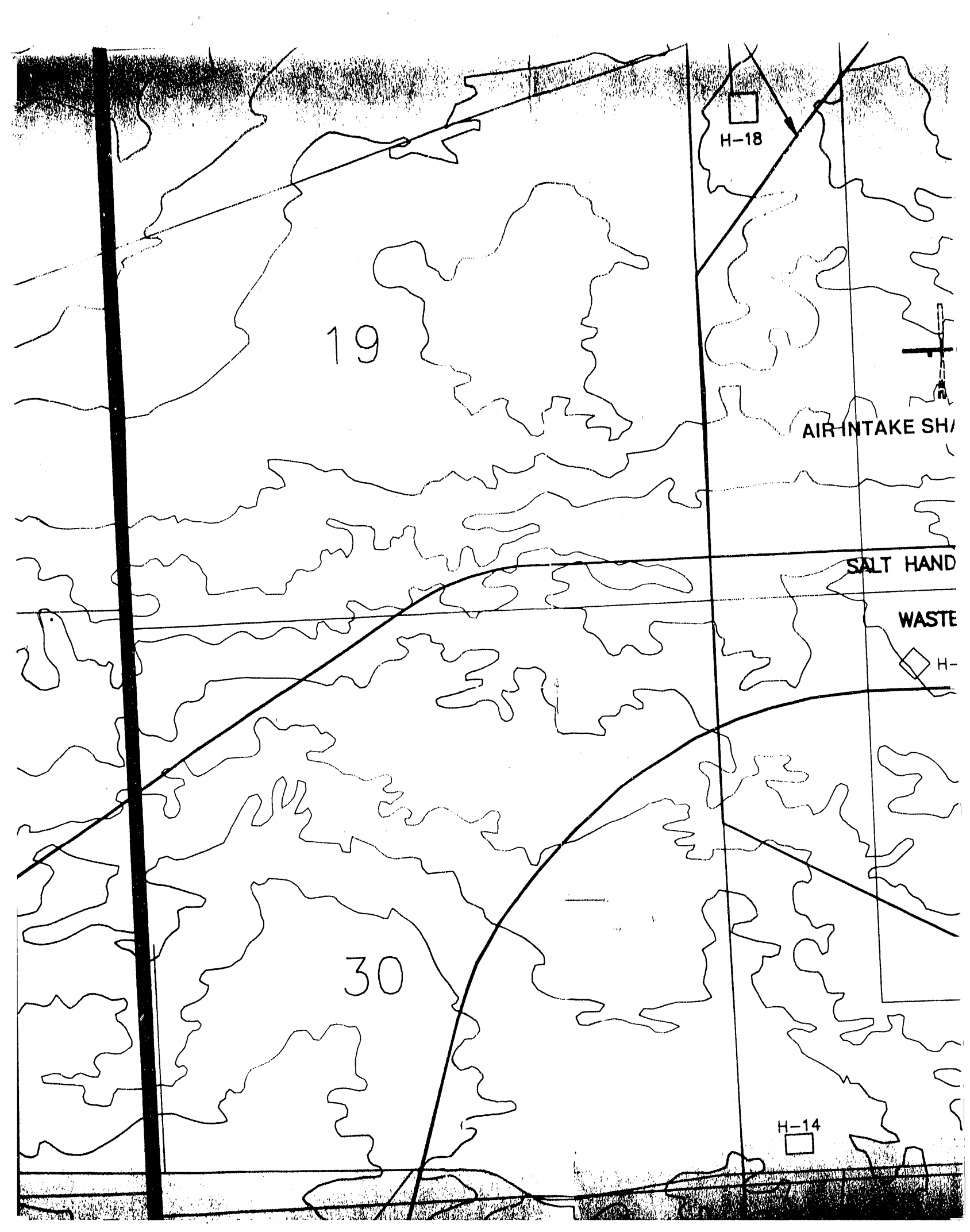
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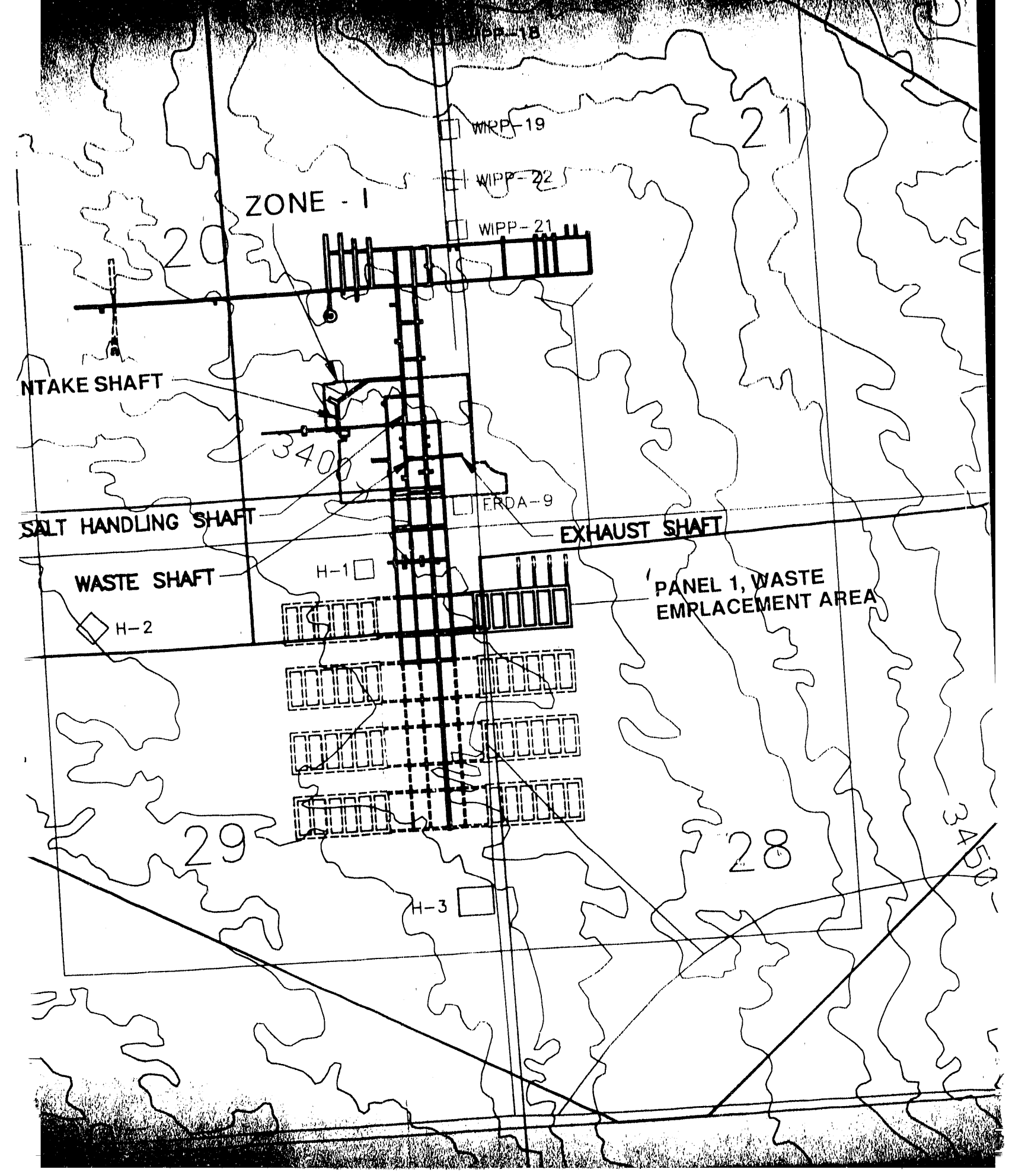
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SALT HANDLING SHAFT
WASTE SHAFT
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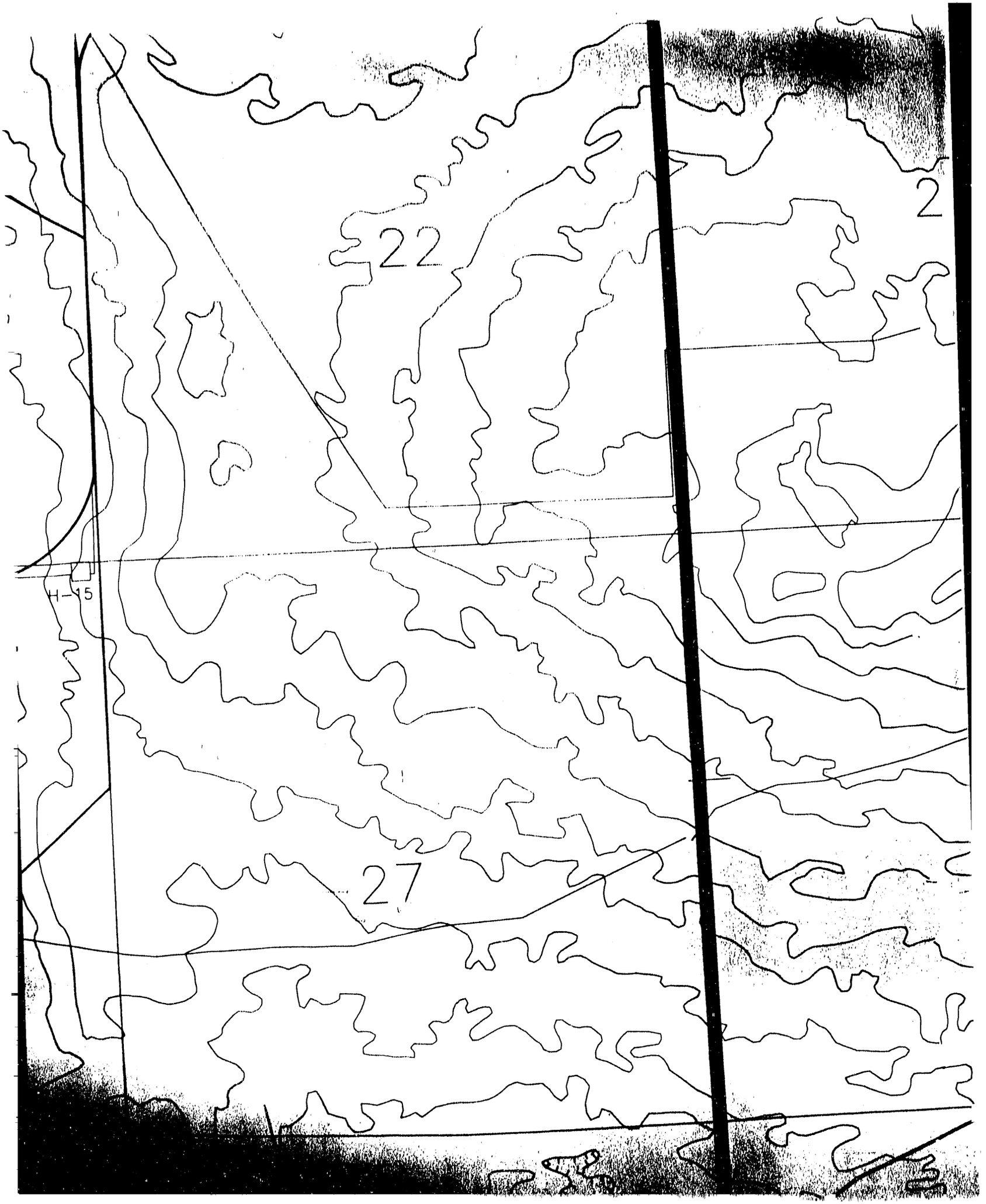
ERDA-9
EXHAUST SHAFT
H-1
PANEL 1, WASTE
EMPLACEMENT AREA
H-3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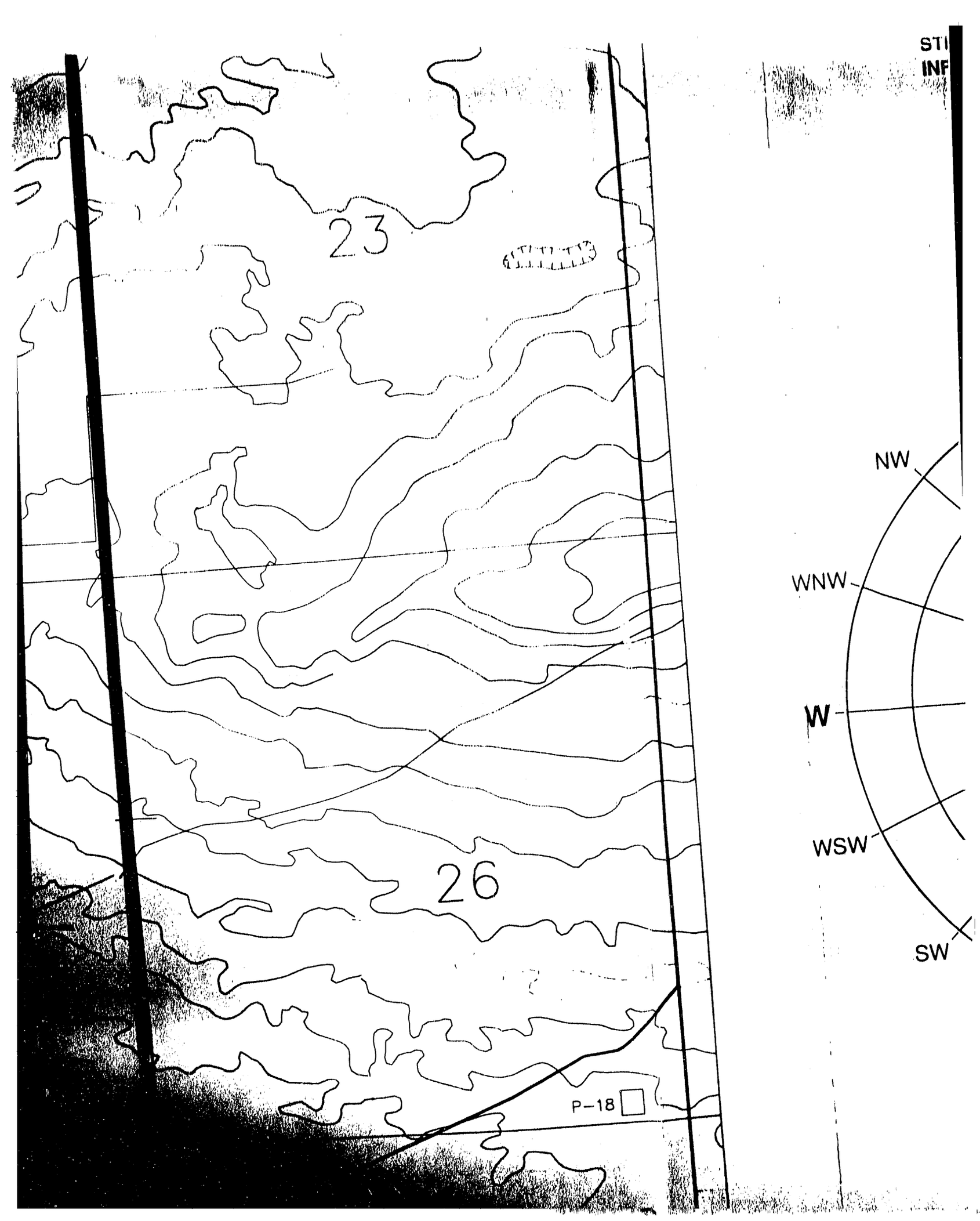
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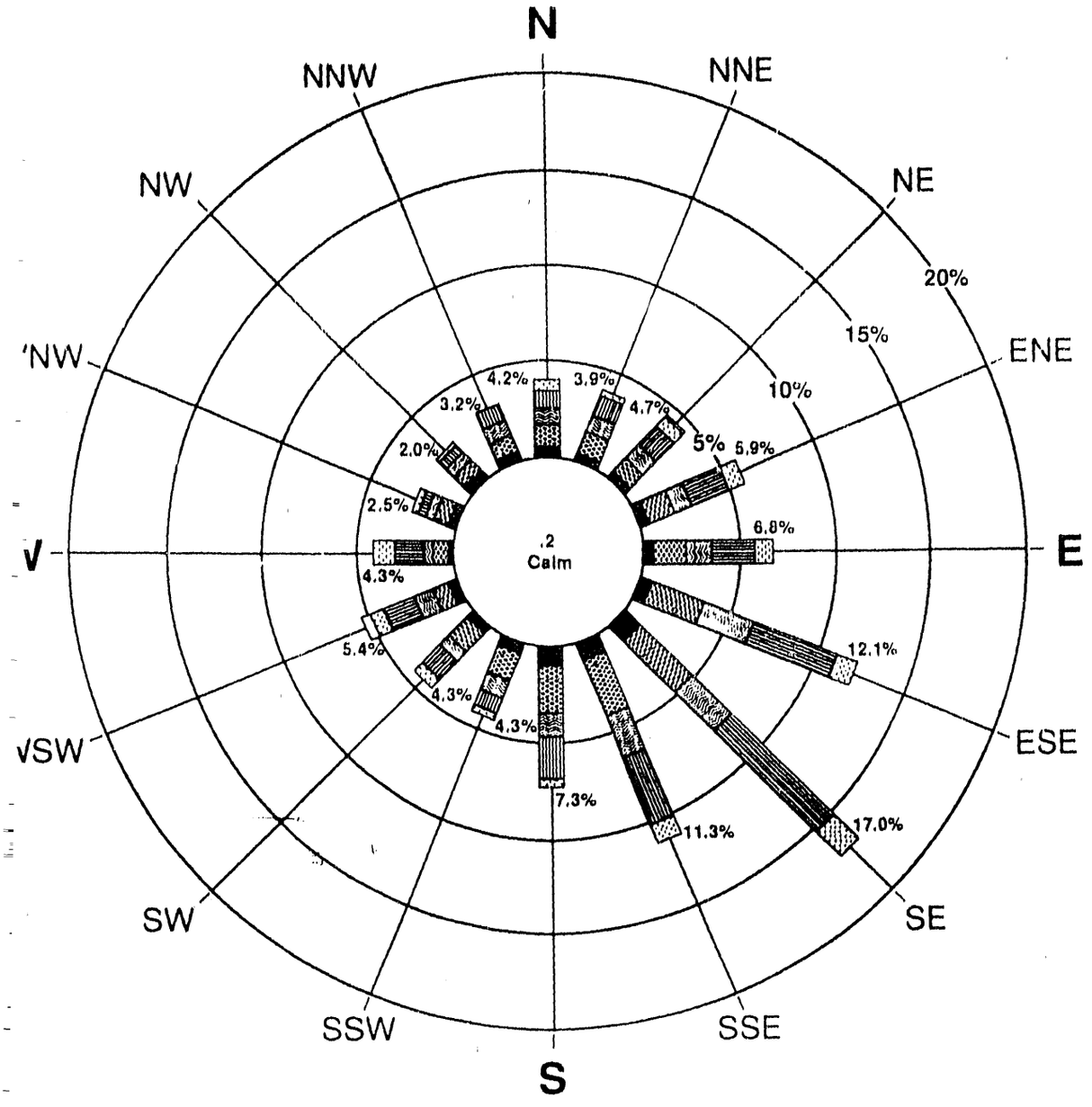
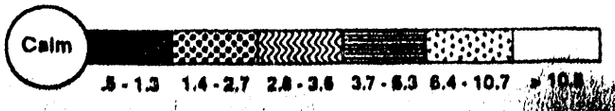
STRUCTURES ARE ILLUSTRATED IN FIGURE B-7. MORE DETAILED
INFORMATION IS ILLUSTRATED IN FIGURE 2.4-3, APPENDIX B1.





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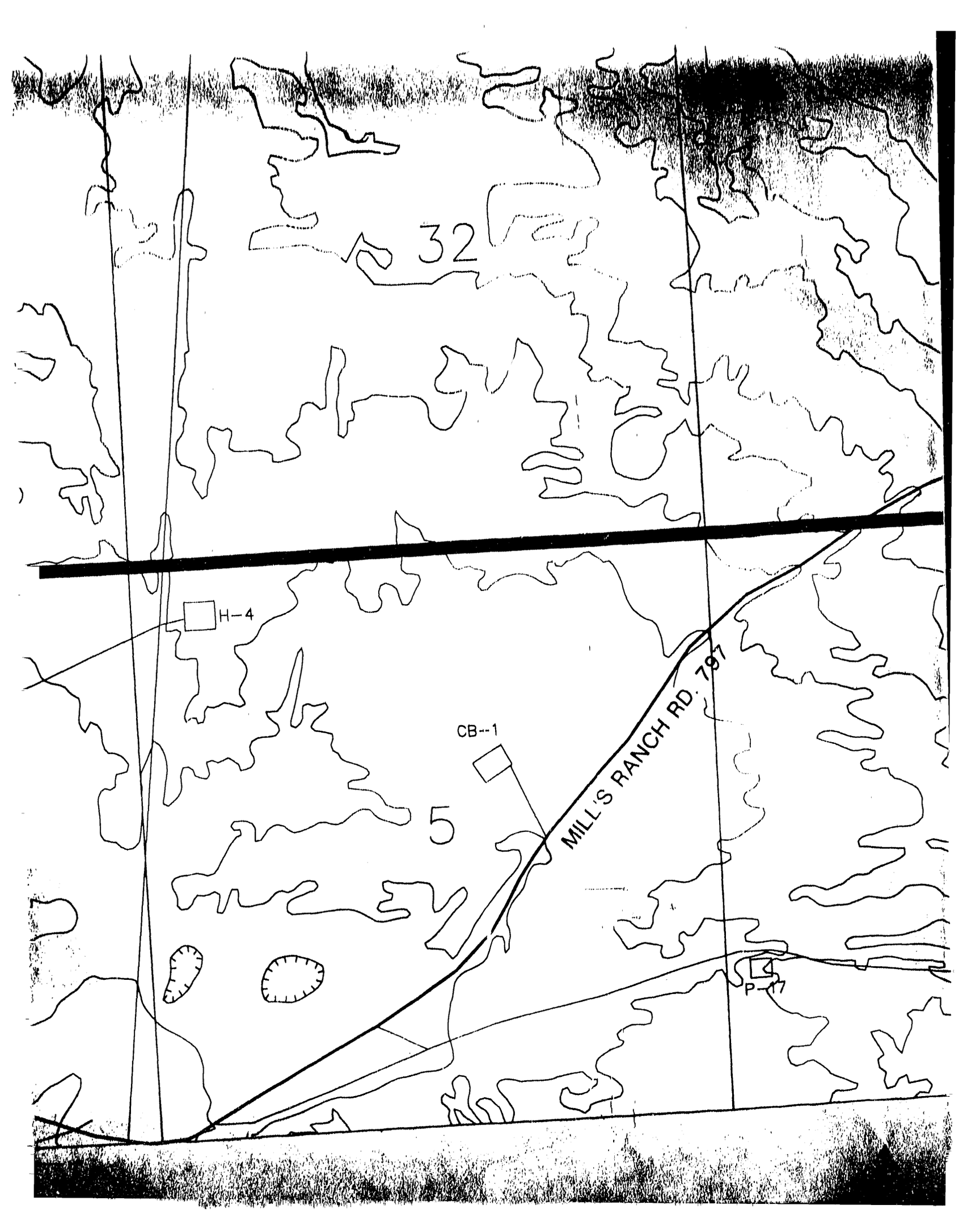
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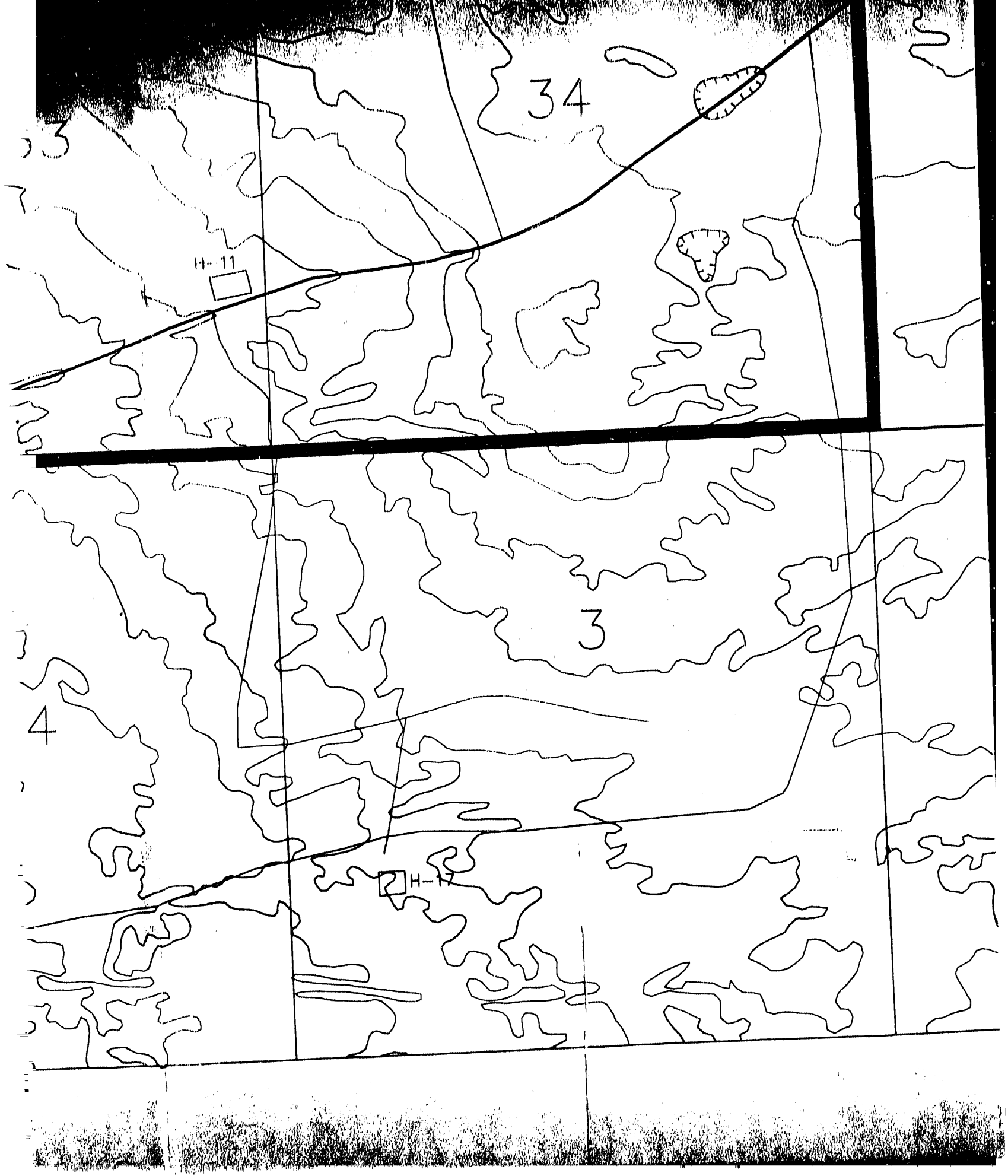
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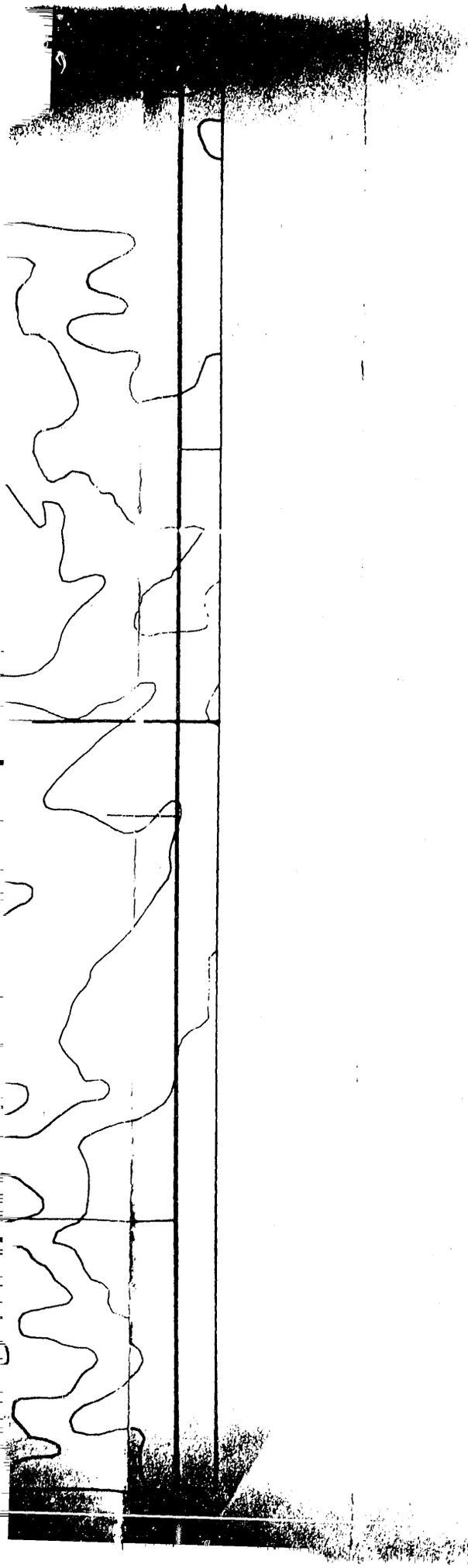


.56 - 1.3 1.4 - 2.7 2.8 - 3.6 3.7 - 6.3 6.4 - 10.7 > 10.8

Wind Velocity in Meters per Second

1989 ANNUAL WIPP WIND ROSE

FIGURE B-6
TOPOGRAPHIC MAP
WITH UNDERGROUND FACILITIE

FEBRUARY, 1992

Meters per Second

1989 ANNUAL WIPP WIND ROSE

FIGURE B-6
TOPOGRAPHIC MAP
ITH UNDERGROUND FACILITIES

FEBRUARY, 1992

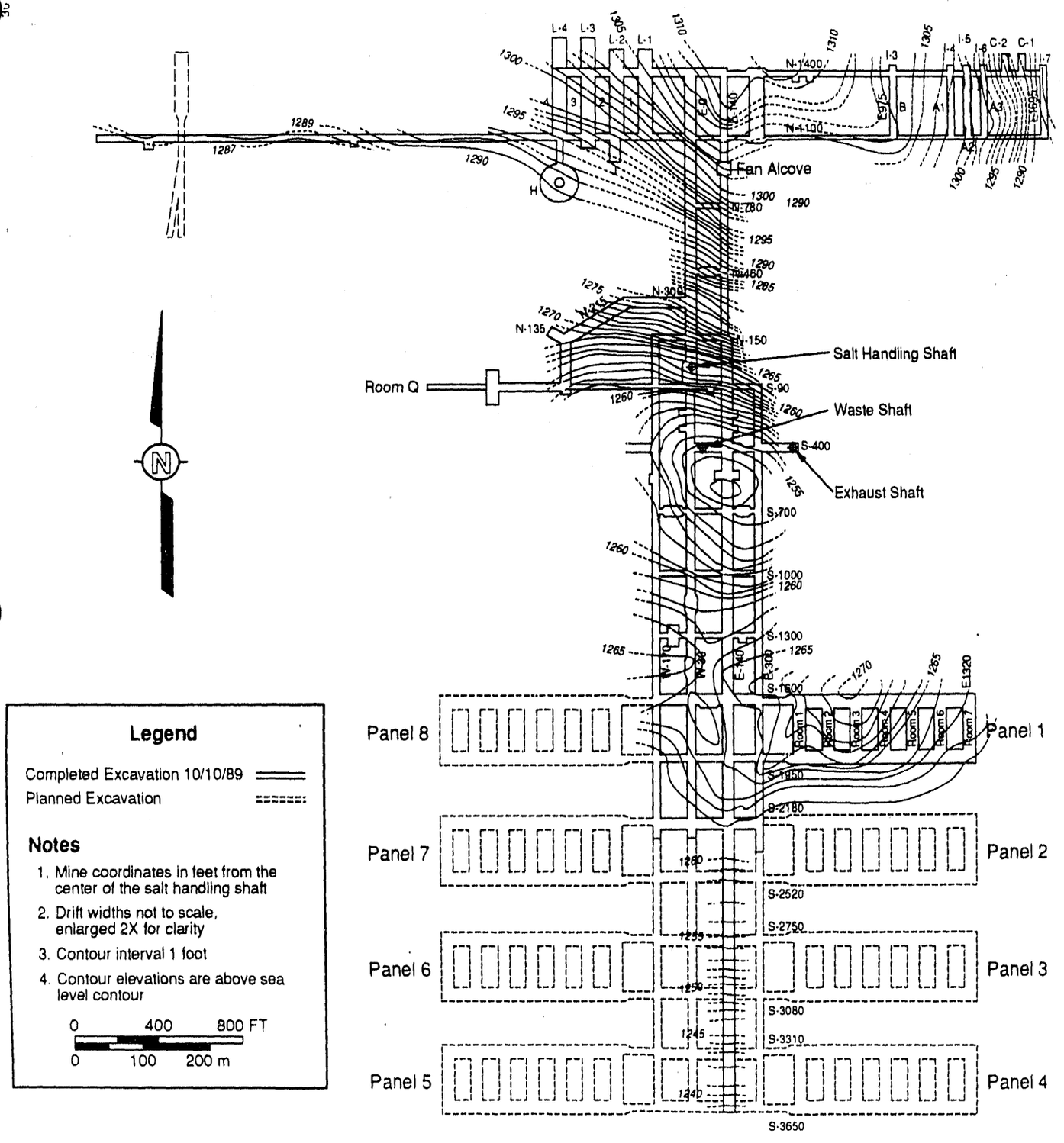
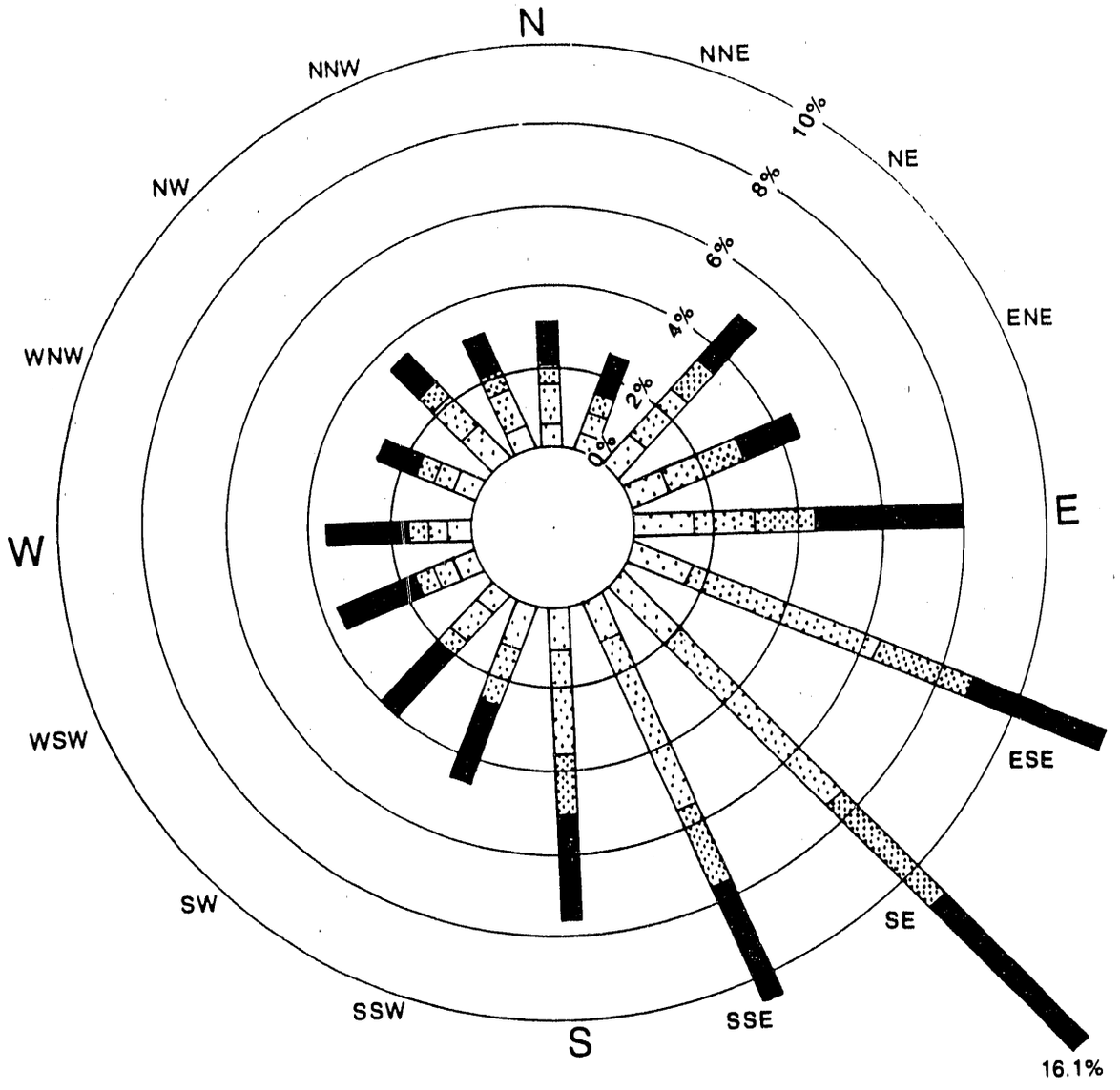


FIGURE B-8 PLAN VIEW OF THE UNDERGROUND SHOWING CENTERS OF THE ORANGE MARKER BAND

301486 01 ASJ



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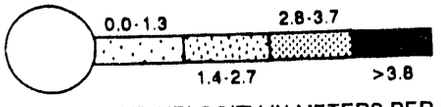

WIND VELOCITY IN METERS PER SECOND

BAR LENGTH SEGMENTS ARE PROPORTIONAL TO INDICATED SPEED INTERNAL OCCURRENCE

DOE, 1990e

FIGURE B-9 1985 ANNUAL WIPP WIND ROSE

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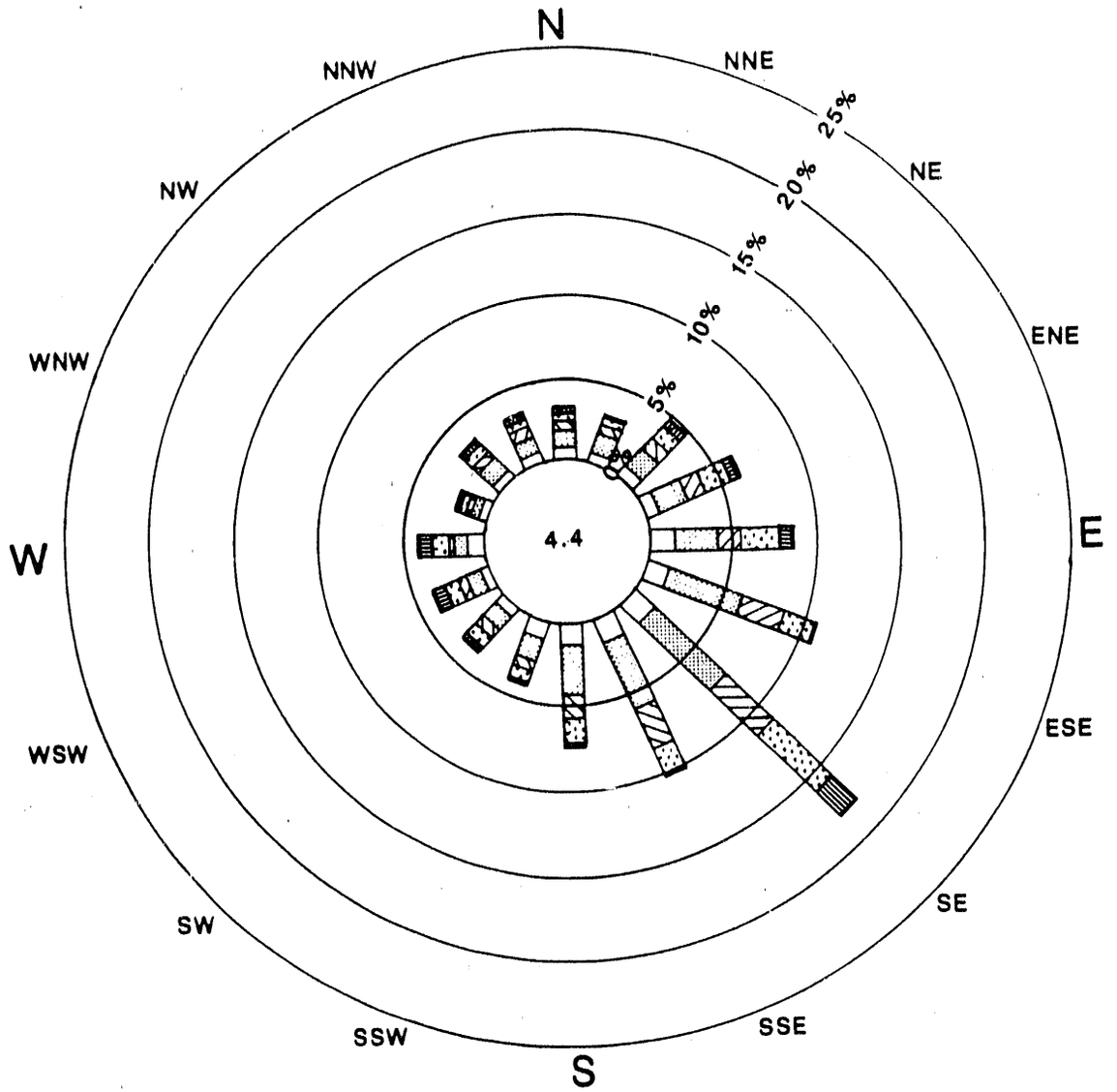

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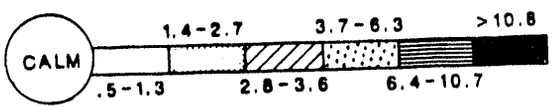

WIND VELOCITY IN METERS PER SECOND

BAR LENGTH SEGMENTS ARE PROPORTIONAL TO INDICATED SPEED INTERNAL OCCURRENCE

DOE, 1990e

FIGURE B-10 1986 ANNUAL WIPP WIND ROSE

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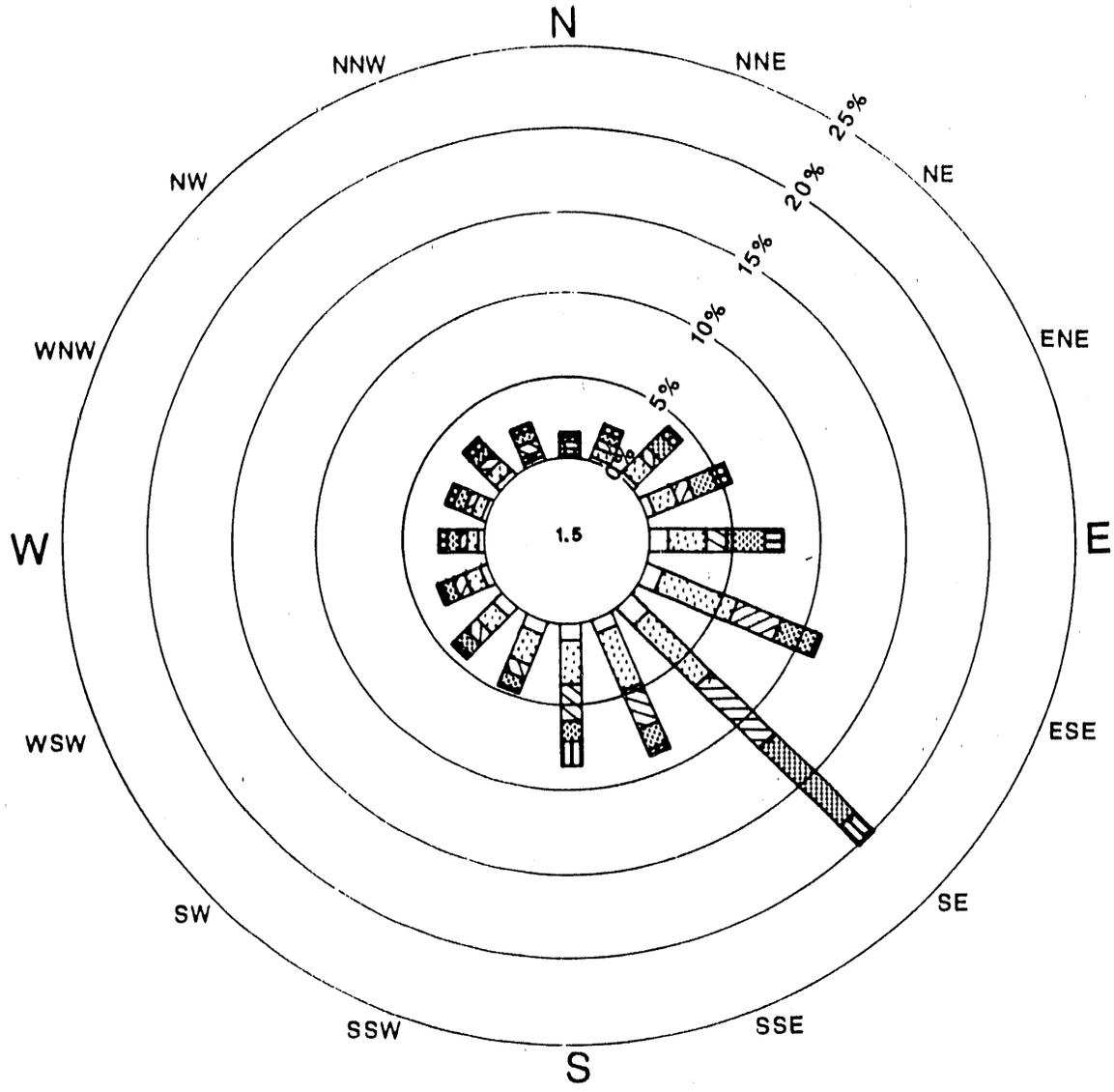

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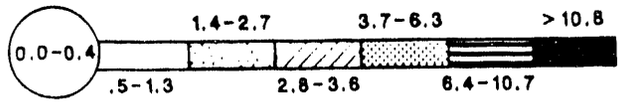
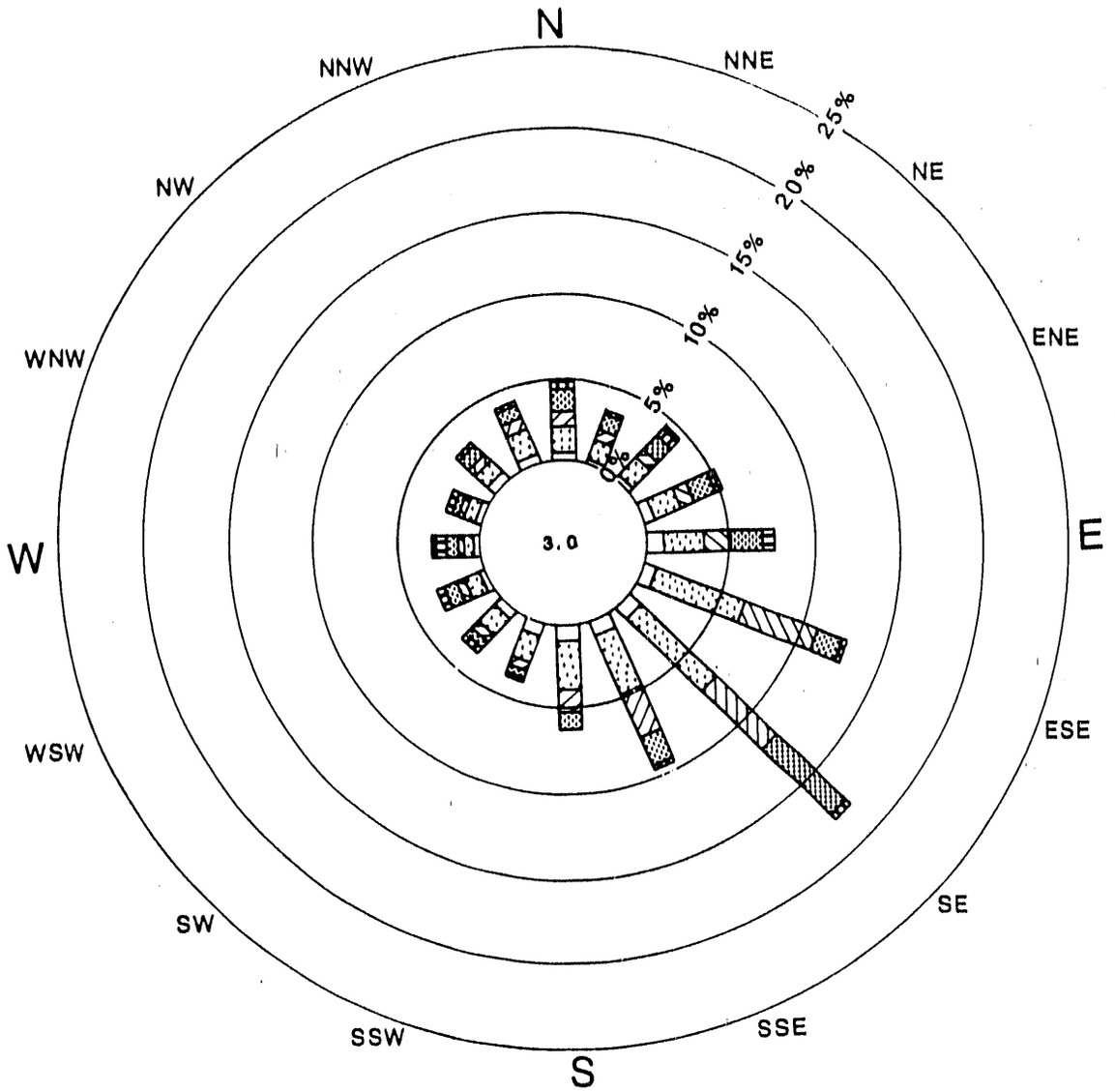


WIND VELOCITY IN METERS PER SECOND

BAR LENGTH SEGMENTS ARE PROPORTIONAL TO INDICATED SPEED INTERNAL OCCURRENCE

DOE, 1990e

FIGURE B-11 1987 ANNUAL WIPP WIND ROSE



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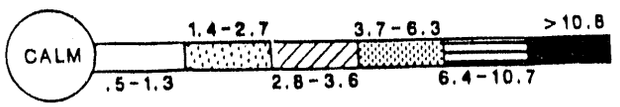

WIND VELOCITY IN METERS PER SECOND

BAR LENGTH SEGMENTS ARE PROPORTIONAL TO INDICATED SPEED INTERNAL OCCURRENCE

DOE, 1990e

FIGURE B-12 1988 ANNUAL WIPP WIND ROSE

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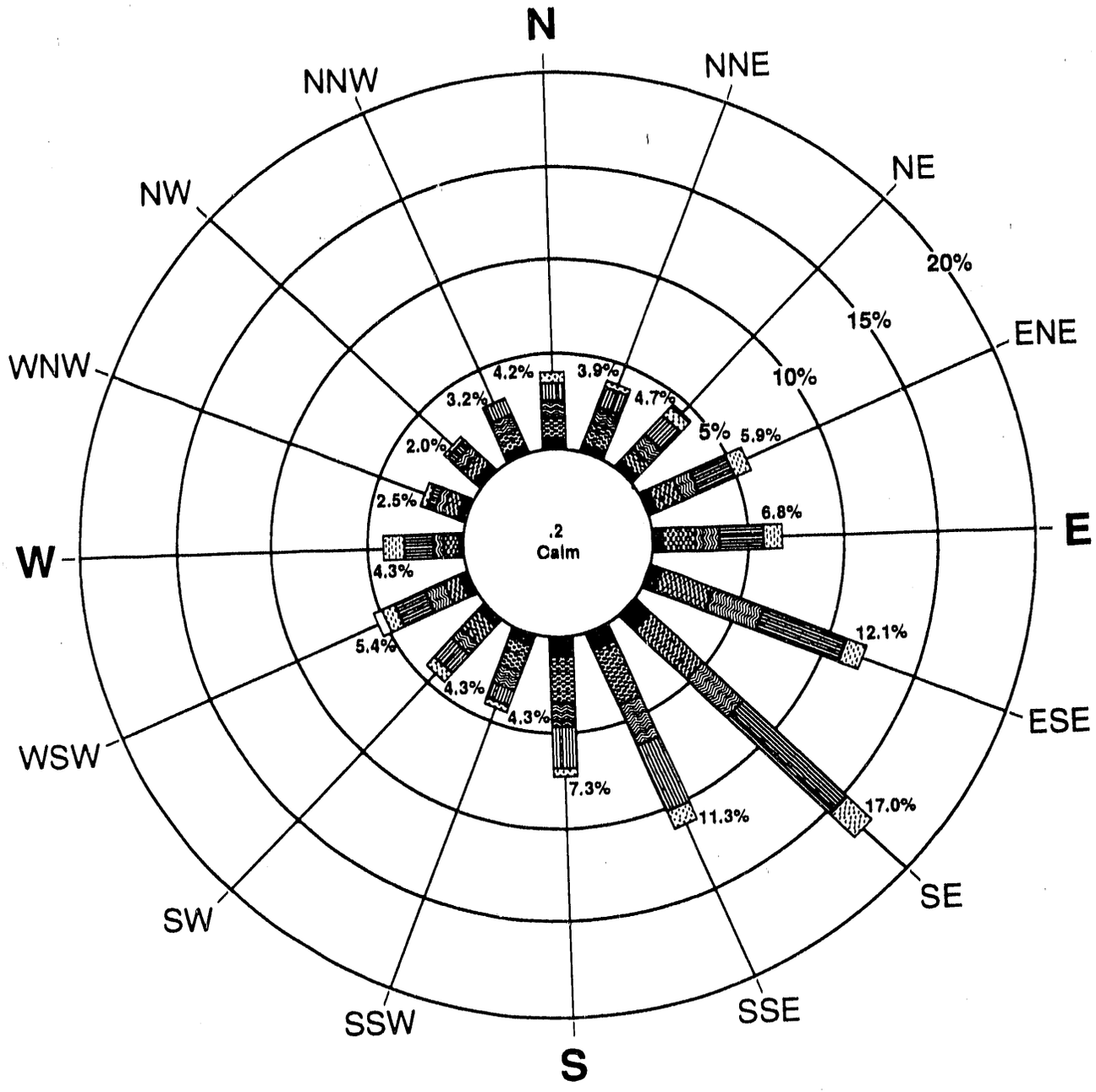
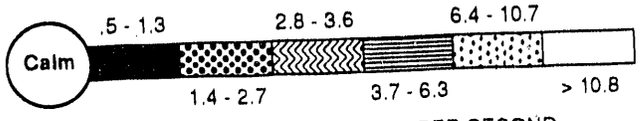




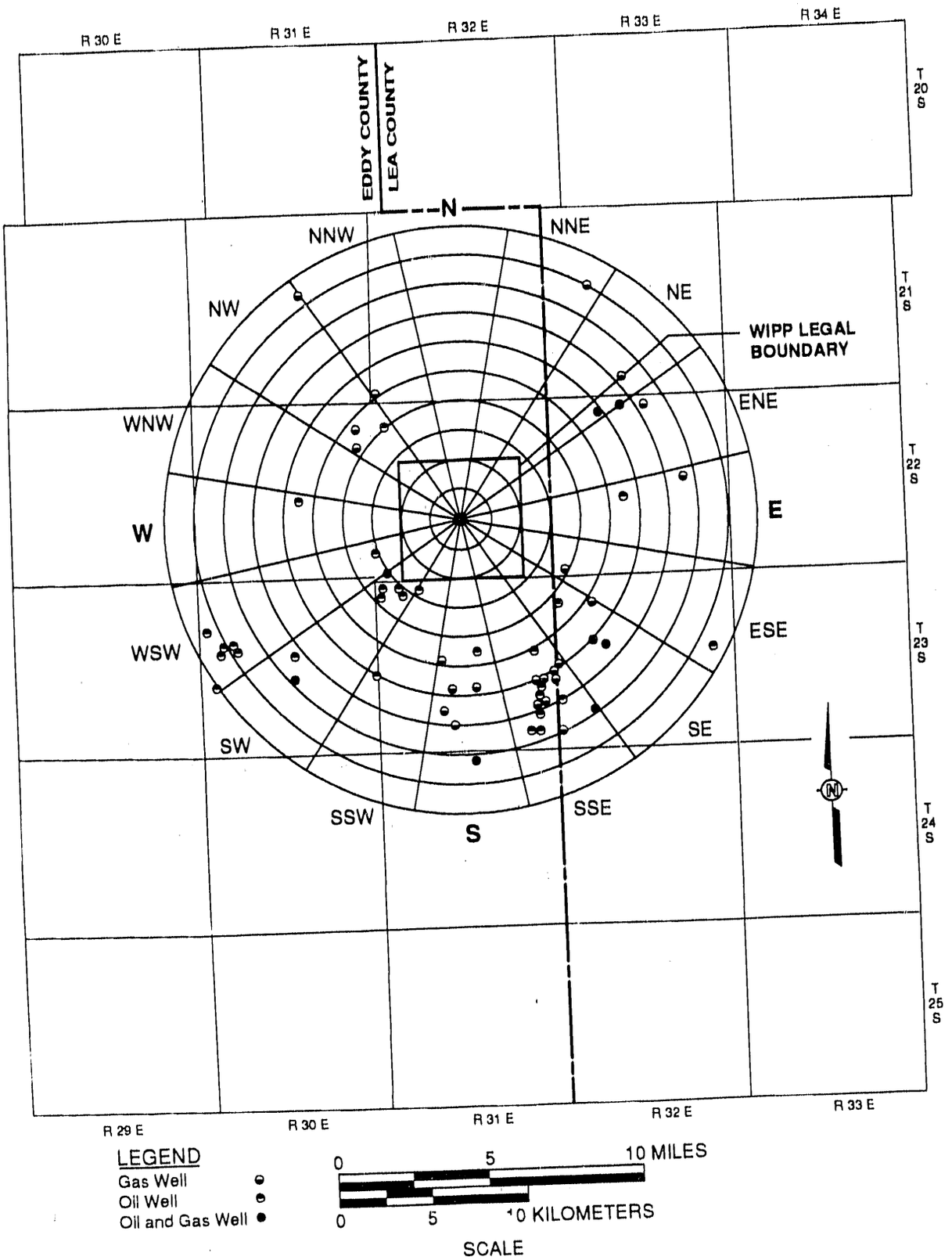
WIND VELOCITY IN METERS PER SECOND

BAR LENGTH SEGMENTS ARE PROPORTIONAL TO INDICATED SPEED INTERNAL OCCURRENCE

DOE, 1990e

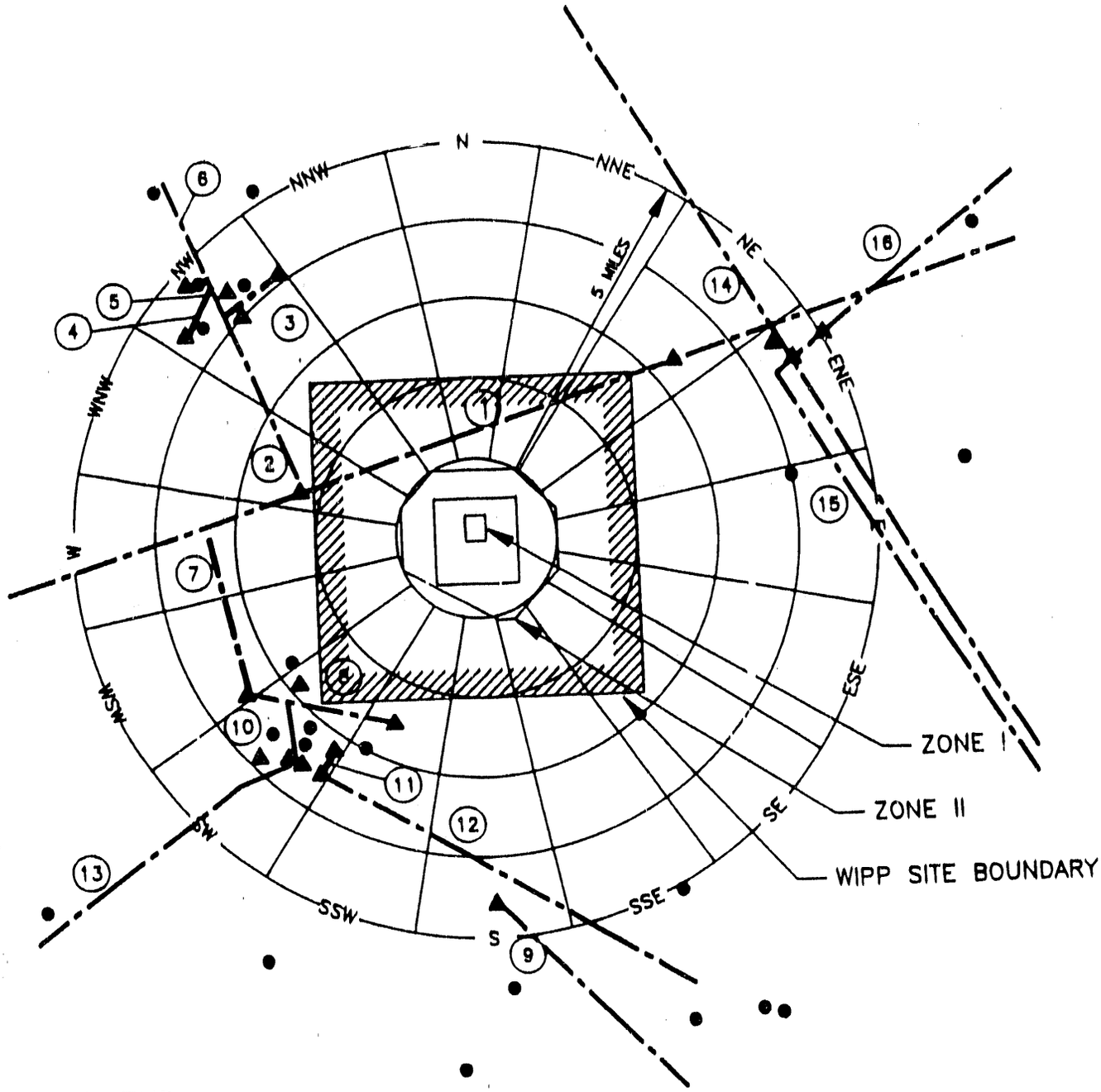
FIGURE B-13 1989 ANNUAL WIPP WIND ROSE

1436 01 A45



DOE, 1990e

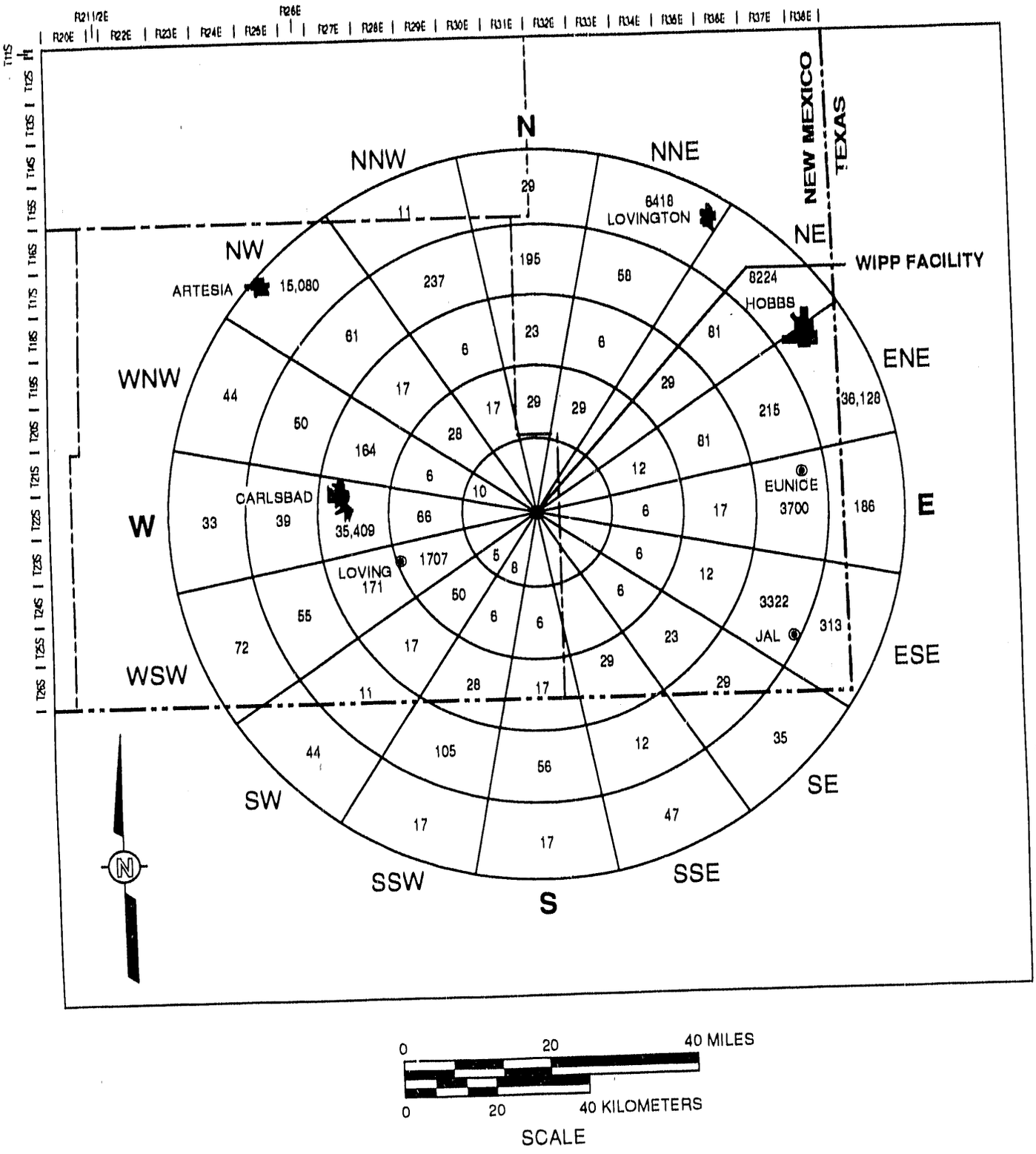
FIGURE B-14 1986 OPERABLE NATURAL GAS AND OIL WELLS WITHIN 10-MILE RADIUS OF THE WIPP FACILITY



DOE, 1990e

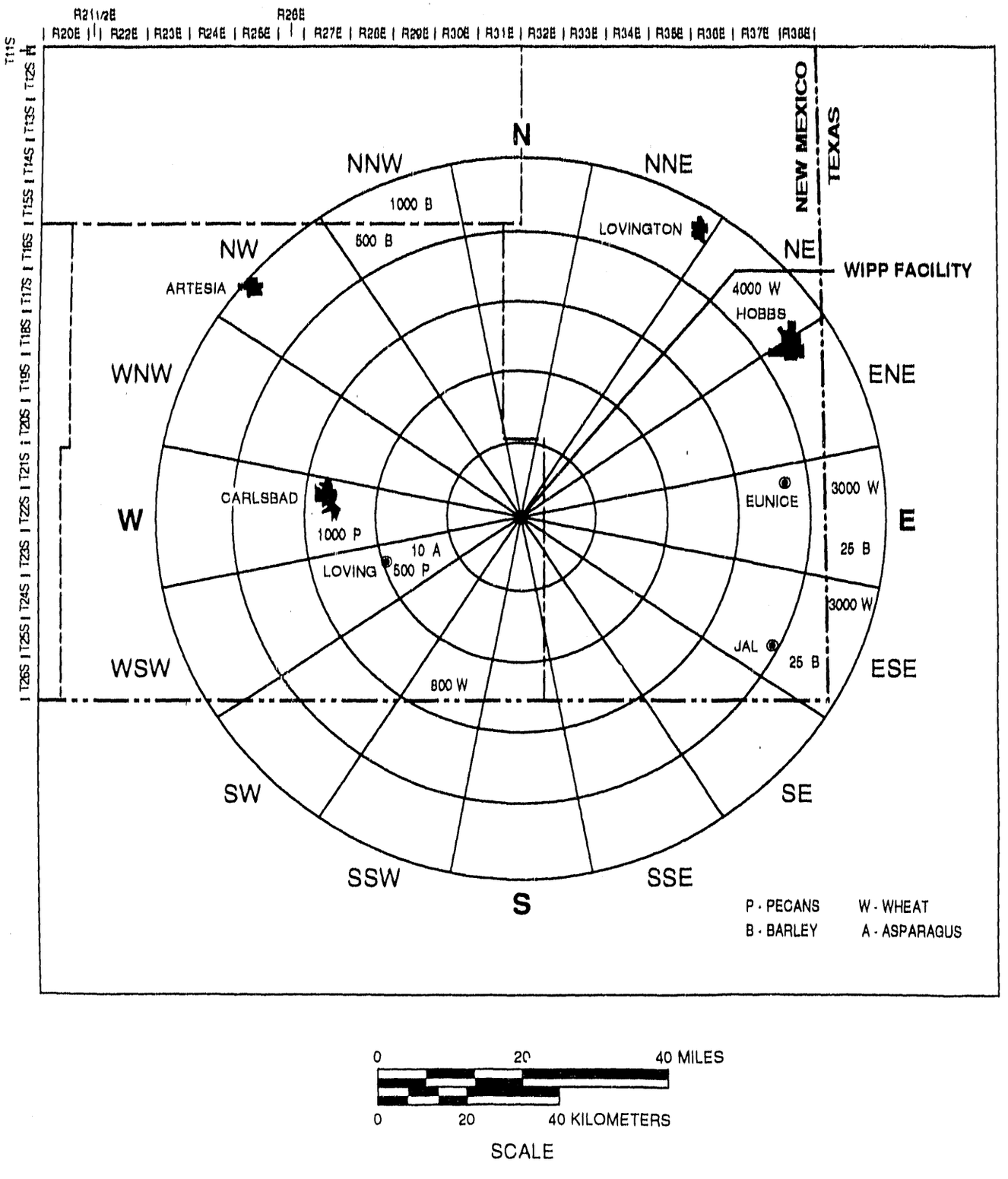
FIGURE B-15 NATURAL GAS PIPELINES AND WELLS WITHIN 5-MILE RADIUS OF THE WIPP FACILITY

1496 01 A46



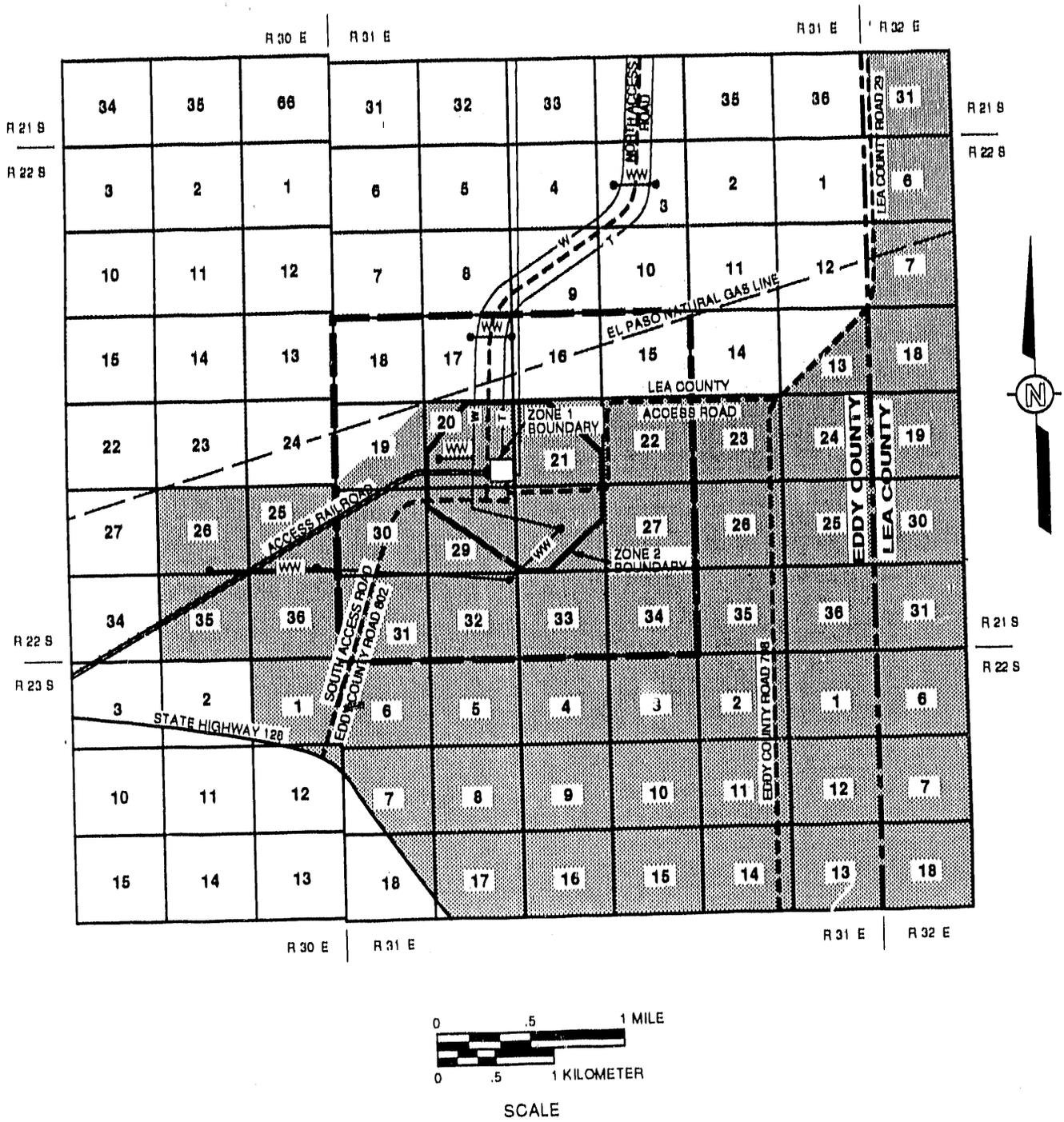
DOE, 1990e

FIGURE B-16 1985 POPULATION WITHIN 50-MILE RADIUS OF THE WIPP FACILITY



DOE, 1990e

FIGURE B-17 1985 ACRES PLANTED IN EDIBLE AGRIGULTURE AND COMMERCIAL CROPS WITHIN 50-MILE RADIUS OF THE WIPP FACILITY



DOE, 1990e

FIGURE B-18 GRAZING LEASES WITHIN THE WIPP BOUNDARY

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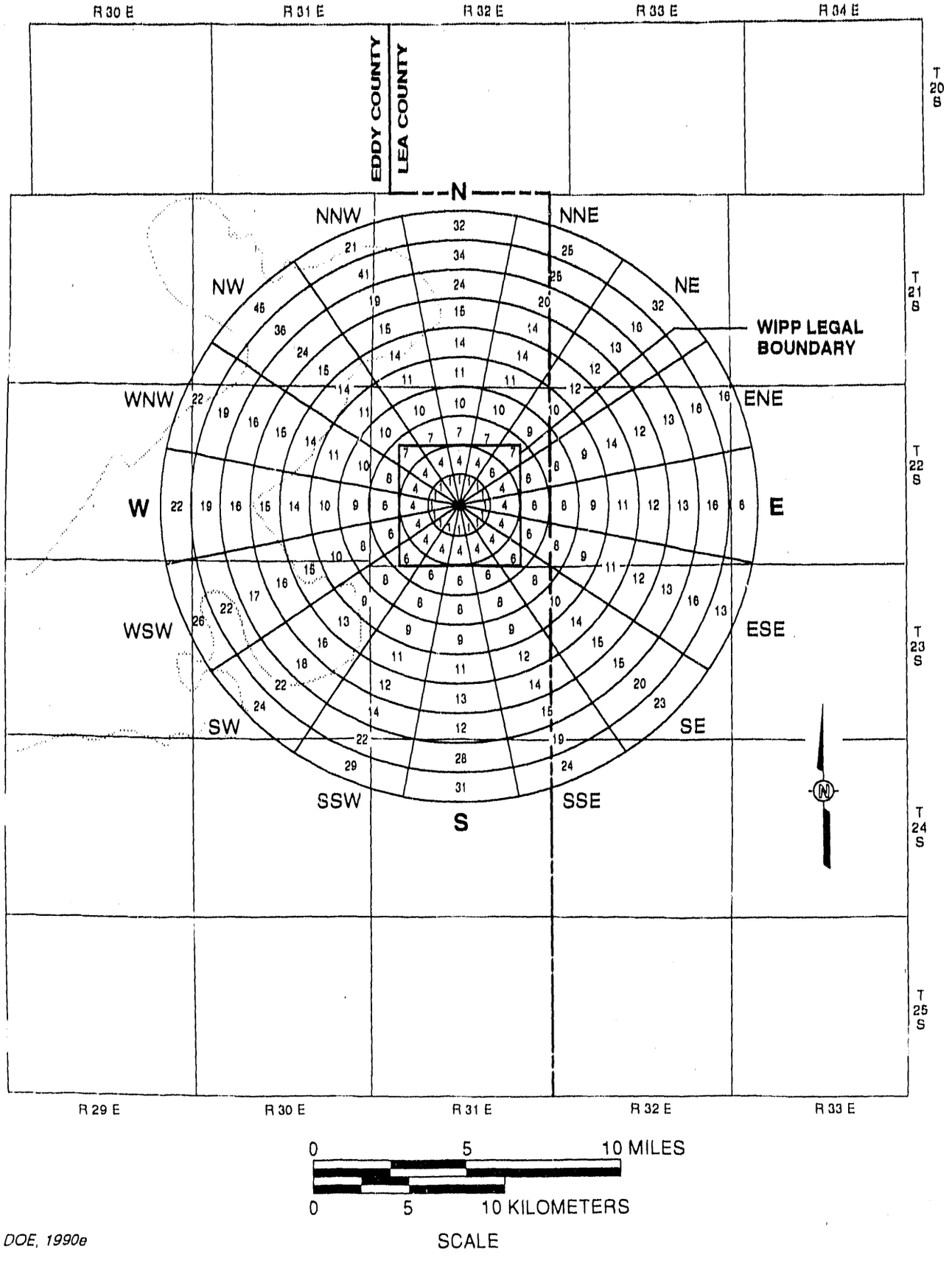
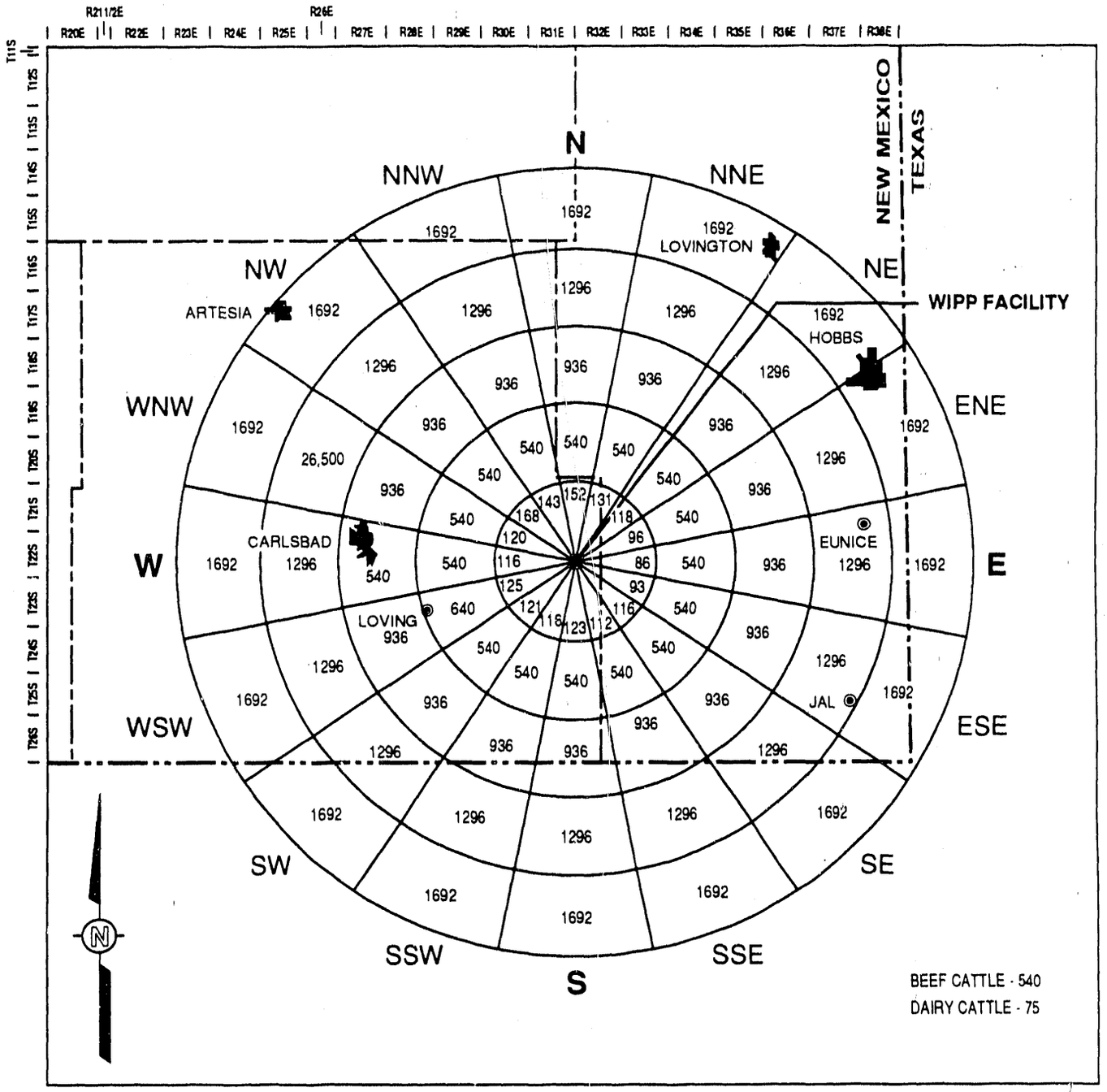


DOE, 1990e

FIGURE B-19 1985 AVERAGE YEARLY CATTLE DENSITY WITHIN 10-MILE RADIUS OF THE WIPP FACILITY



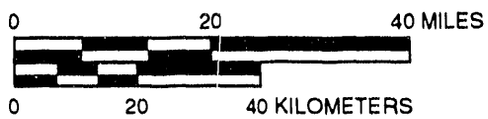


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FIGURE B-20 1985 AVERAGE YEARLY CATTLE DENSITY WITHIN 50-MILE RADIUS OF THE WIPP FACILITY

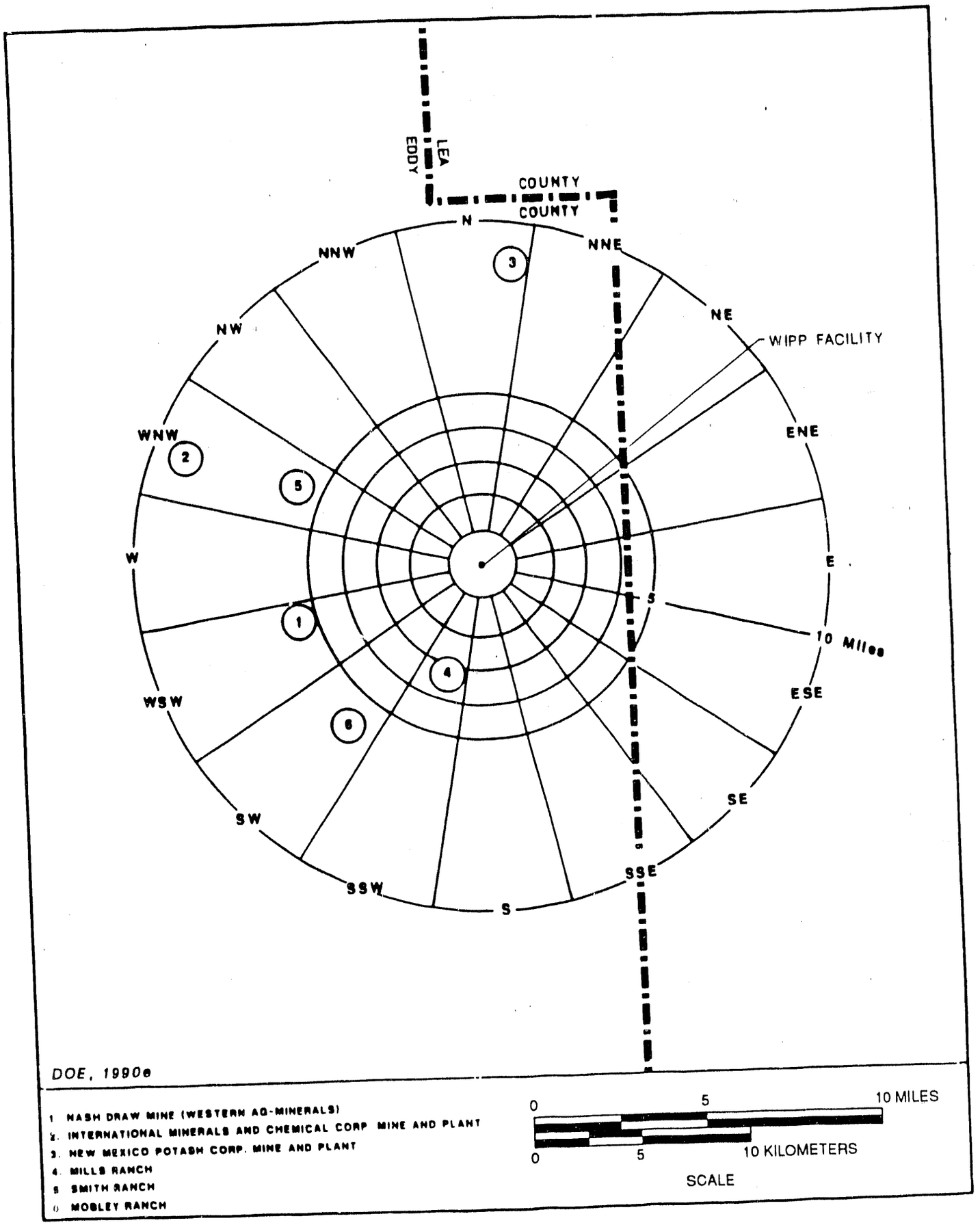
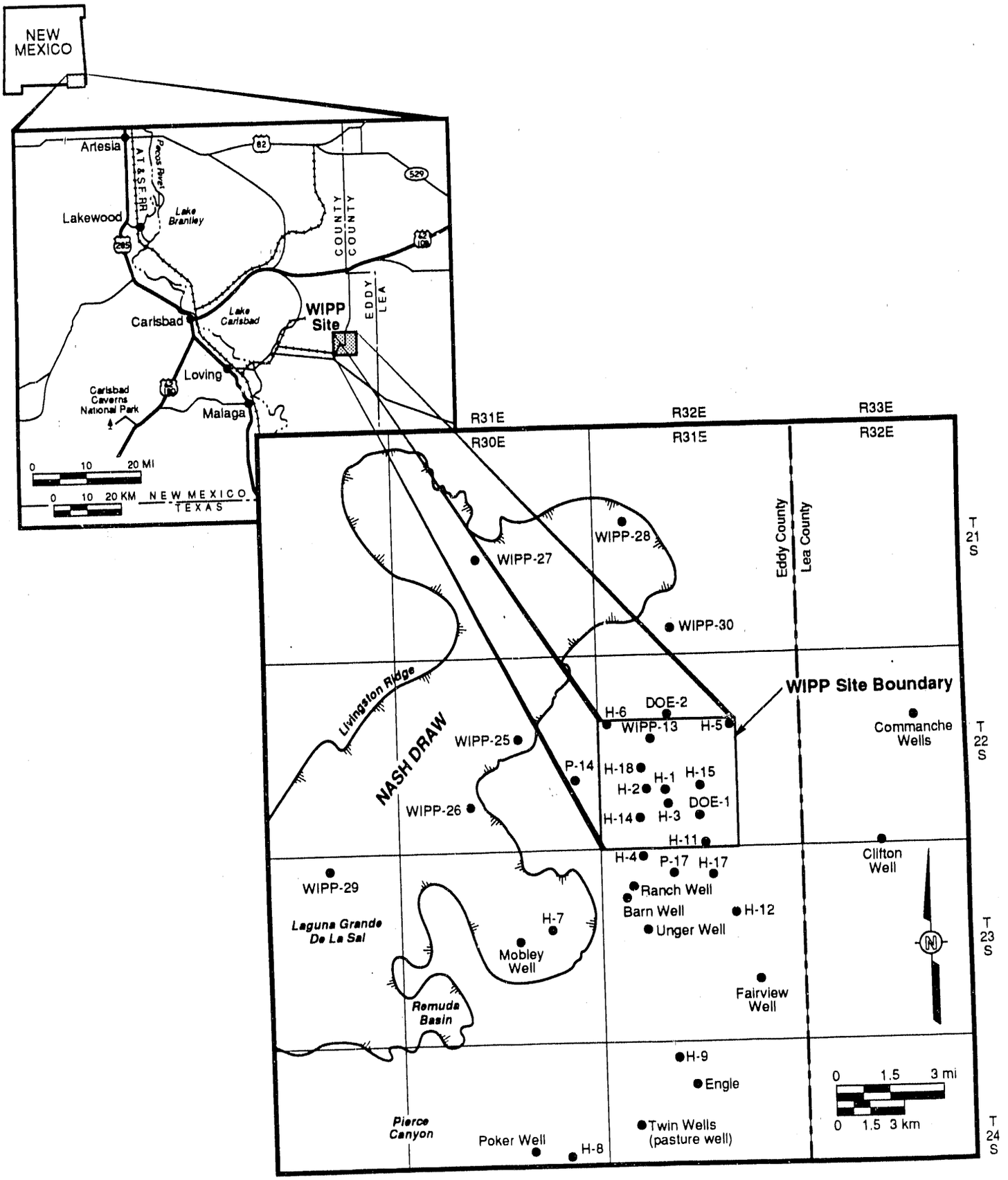


FIGURE B-21 MINES AND RANCHES WITHIN 10-MILE RADIUS OF THE WIPP FACILITY



Reference: Randall et al., 1988

FIGURE B-22 WATER QUALITY SAMPLING WELL LOCATIONS

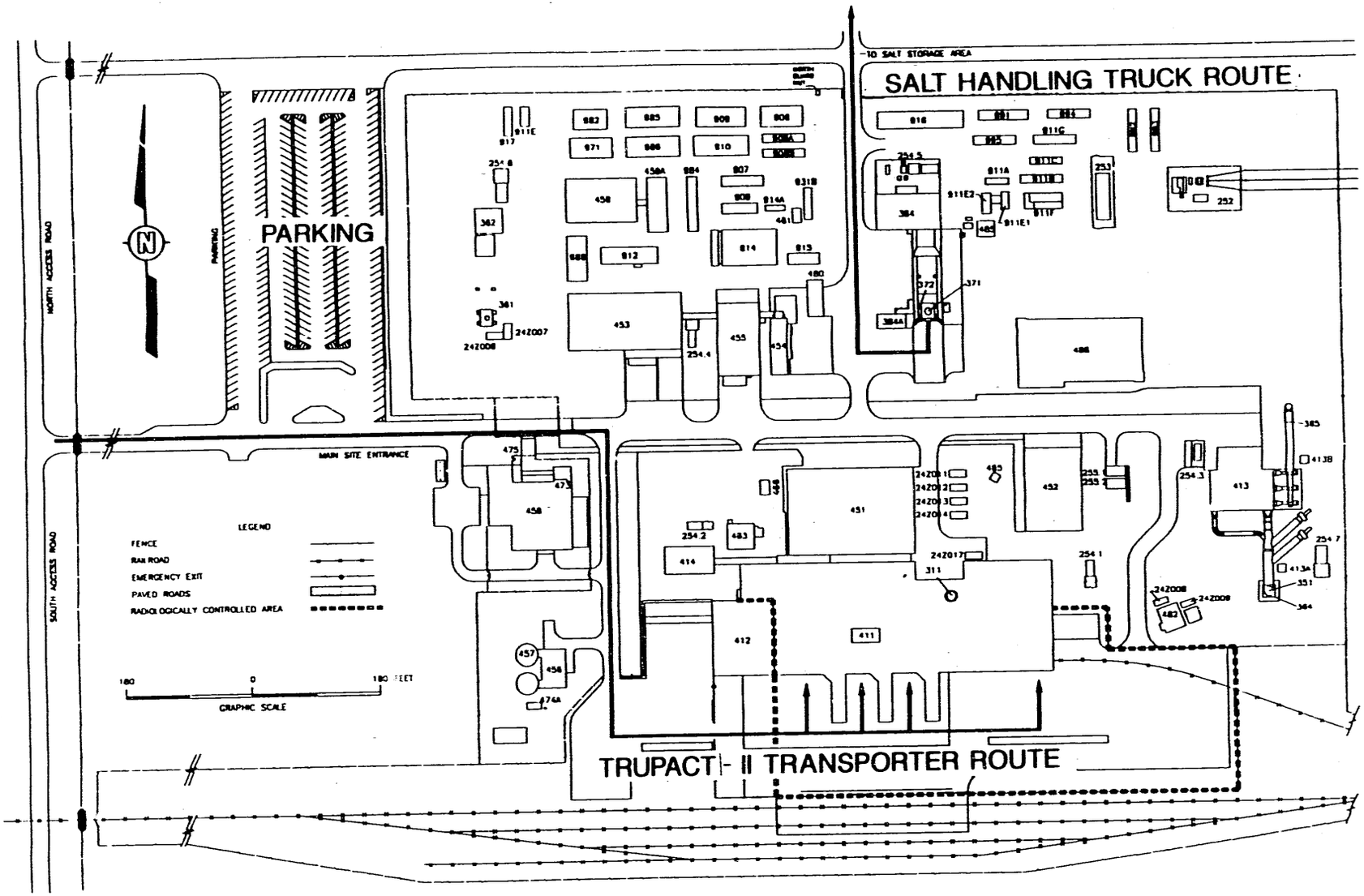


FIGURE B-23 WIPP TRAFFIC FLOW DIAGRAM

This Illustration for Information Purposes Only

CHAPTER C

WASTE ANALYSIS PLAN

CHAPTER C
WASTE ANALYSIS PLAN
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CHAPTER C
WASTE ANALYSIS PLAN

C-1 Facility Description

This waste analysis plan has been prepared in accordance with EPA/530-SW-84-012, Waste Analysis Plans, A Guidance Manual (EPA, 1984). Figures C-1 and C-2 contain an overview of the waste screening and acceptance process that is presented in this chapter.

The Waste Isolation Pilot Plant (WIPP) facility is a transuranic (TRU) radioactive waste disposal facility owned by the United States (U.S.) Government and operated by the U.S. Department of Energy (DOE). When utilizing this Waste Analysis Plan, the term "WIPP," when used in the context of requiring a duty or responsibility, means DOE as the facility owner and operator and the Westinghouse Electric Corporation Waste Isolation Division (WID) as the co-operator, as set forth in the WIPP Resource Conservation and Recovery Act (RCRA) Permit Application certification.

The mission of the WIPP Project, as established by Congress in 1979 (Public Law 96-164), is to provide a research and development facility to demonstrate the safe disposal of TRU waste resulting from the defense activities of the U.S. This mission will be fulfilled in a phased, step-wise approach. A Test Phase is currently planned prior to initiating operations as a permanent disposal site.

The WIPP facility is designed to safely dispose of both TRU and TRU mixed waste. The WIPP repository is located in a salt bed formation 2,150 feet below ground. The miscellaneous unit boundary is defined vertically by the upper and lower extent of the Salado Formation and, horizontally, by the downward projection of the 16-square-mile land withdrawal area perimeter. The repository is the only unit at the facility requiring a RCRA permit.

Mixed waste is that which contains both a radioactive and hazardous component, as defined in 51 FR 24504 (July 3, 1986). With regard to the radioactive component, TRU and TRU mixed waste are radiologically designated and separately packaged as either contact-handled (CH) or remote-handled, based on the dose rate at the surface of the waste container. During the Test Phase, only CH TRU waste will be received by the WIPP facility and, therefore, unless otherwise

√ Indicated, the term "TRU waste" throughout this document refers only to CH TRU and CH TRU
√ mixed waste, as appropriate.
√
√ The hazardous components of the TRU mixed waste have been designated on the facility's
√ Part A RCRA permit application. This plan describes the measures that will be taken to assure
√ that the wastes received at the WIPP facility are within the scope of the Part A as established by
√ New Mexico Hazardous Waste Management Regulations (HWMR-6) as amended 1991, Part V,
√ section 264.13), and comply with unit-specific requirements of HWMR-6, Pt. V, Subpart X, and
√ the conditions imposed by the WIPP No Migration Determination (55 FR 44700).
√
√ DOE's objective is to operate and maintain the WIPP as a "clean" facility, free of both chemical
√ and radiological contamination. Therefore, as allowed by HWMR-6, Pt. V, sec. 264.13, all waste
√ sampling and analyses will be conducted by the generator sites in accordance with the
√ procedures established herein. As shown in Figure C-1, the generator will conduct all the
√ required waste characterization activities and complete a Waste Profile Form (Figure C-3) for
√ each container of waste sent to the WIPP facility. The resulting data will be used to verify
√ process information describing the waste and subsequently will be reviewed for accuracy and
√ completeness at the WIPP facility prior to transport of the waste (Figure C-2).
√
√ The waste will arrive at the facility in U.S. Nuclear Regulatory Commission-certified,
√ U.S. Department of Transportation (DOT) Type B transportation packages (e.g., the TRansUranic
√ PACkage Transporter [TRUPACT-II]). Each TRUPACT-II, the current transportation package,
√ may carry up to two DOT Type A Standard Waste Boxes (SWBs).
√
√ Once the TRUPACT-IIs arrive at the WIPP facility, they are unloaded and taken inside the Waste
√ Handling Building where they are opened and their contents (SWBs) are removed. Routine
√ operating procedures require that these containers remain unopened during all facets of waste
√ handling. The containers are loaded onto a facility pallet, which is then transferred to a
√ conveyance loading car. The conveyance loading car is moved into the waste hoist cage, which
√ is lowered to the underground waste-receiving station through the Waste Shaft. At the
√ underground waste-receiving station, the loaded pallet is transferred to an underground waste
√ transporter. The underground waste transporter moves the loaded pallet to an underground room
√ where the TRU waste is removed from the pallet and emplaced. (A complete description of the
√ miscellaneous unit and waste handling operations are provided in Chapter D of this permit
√ application.)
√
√ C-1a Containers
√
√ Container handling is discussed as part of the process description for the WIPP facility in
√ Section D-9a(2). The container management regulations of HWMR-6, Pt. V, Subpart I, are
√ addressed in Section D-9a(3)(f) of this permit application.

C-1b Tank Systems

The WIPP facility does not manage hazardous or mixed waste using a tank system, as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart J. Tank system regulations are not applicable to the WIPP facility.

C-1c Waste Piles

The WIPP facility does not manage hazardous or mixed waste using a waste pile, as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart L. Waste pile regulations are not applicable to the WIPP facility.

C-1d Surface Impoundments

The WIPP facility does not manage hazardous or mixed waste using surface impoundments, as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart K. Surface impoundment regulations are not applicable to the WIPP facility.

C-1e Incinerators

The WIPP facility does not manage hazardous or mixed waste using an incinerator, as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart O. Incinerator regulations are not applicable to the WIPP facility.

C-1f Landfills

The WIPP facility does not manage hazardous or mixed waste using landfills, as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart N. Landfill regulations are not applicable to the WIPP facility.

C-1g Land Treatment

The WIPP facility does not manage hazardous or mixed waste using land treatment, as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart M. Land treatment regulations are not applicable to the WIPP facility.

C-1h Drip Pads

The WIPP facility does not manage hazardous or mixed waste using drip pads, as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart W. Drip pad regulations are not applicable to the WIPP facility.

C-2 Identification of Waste to be Managed

The mixed waste that may be accepted at the WIPP facility is listed in Part A of the RCRA permit application. This section provides an overview of the operations and processes that generate TRU mixed waste. Based on these operations and processes, as well as the materials used, descriptions are provided of the TRU waste that may be accepted at the WIPP facility.

C-2a Operations and Processes Generating TRU Waste

Examples of the major types of operations that result in the generation of TRU waste include:

- Production of nuclear products
- Plutonium recovery
- Research and development
- Decontamination and decommissioning.

TRU waste is not normally segregated with respect to the waste material type. However, segregation does occur as necessary to facilitate the recovery of plutonium. DOE facilities that use plutonium in the fabrication and manufacturing of nuclear products have more highly segregated waste because of the need to properly account for and recover plutonium. Other generator activities do not require such a high degree of waste segregation because of the nature of the processes or the fact that the residues and materials generated are below the radionuclide economic discard limits established by DOE. Independent of the site-specific operations or the degree of waste segregation, the general types of waste materials (e.g., combustibles, glass, and metal) are similar at all generator sites.

TRU waste may be packaged in one or more plastic bags or plastic, glass, or metal containers at the point where it is generated. Smaller inner containers may then, in some cases, be placed in larger plastic bags. The packaging helps prevent the spread of radioactive contamination during the handling and transfer operations that precede placement of the bagged waste into the waste container. The operations and processes that generate TRU waste are not fundamentally different from those that generate TRU mixed waste. TRU mixed waste results when TRU waste is co-contaminated with hazardous waste during the processes and operations described in this section. As required under RCRA, DOE evaluates its operations and uses material substitution and process modifications to minimize the quantities of TRU mixed waste that are generated.

Production of Nuclear Products

The production of nuclear products includes reactor operation, radionuclide separation/finishing, and weapons fabrication and manufacturing. These operations may result in the generation of many types of radioactive waste, including TRU waste. The operations that generate the majority of TRU waste are radionuclide separation/finishing and weapons fabrication. Radionuclide

separation/finishing operations are primarily chemical processes that result in the production of mixtures of radionuclides with specified purity. TRU waste is generated from the residue removed during the preparation of chemical solutions for reuse, sampling procedures to verify process quality assurance requirements, air filtration to maintain containment, filtration to remove residue from liquid processes, and maintenance and refurbishment of equipment and facilities.

The radionuclides that are chemically separated are used in fabrication and refurbishment operations. A portion of refurbishment operations includes removing daughter products and, therefore, is similar to the radionuclide separation/finishing operations. Weapons fabrication operations result in the generation of TRU waste from casting, machining, cleaning, and product quality sampling and analytical activities. The first step in these operations involves the forming and casting of plutonium components in foundry operations. Foundry operations include casting, rolling and forming, thermal cycling, and performing physical measurements of plutonium components. An intermediate step required before casting is solvent degreasing. The plutonium metal is melted in crucibles, cast in graphite or steel molds, and sent to the fabrication area. Oil-based coolants and fluids contact the plutonium in the fabrication process. The components are then sent to machining for final shaping. Machining operations use oils in cutting parts as well as lathe coolants. Parts are then cleaned with solvents, such as carbon tetrachloride. In addition, TRU waste is generated as a result of containment, filtration, facility modifications, and equipment and facility maintenance.

Plutonium Recovery Operations

Plutonium recovery operations result in the recovery of the product radionuclides, which are recycled. If the remaining material is below the economic discard limit, it becomes waste. Waste segregation is performed primarily to meet the treatment process requirements for radionuclide recovery. Depending on the physical form of the material and the chemical state of the plutonium, different recovery processes are used. Plutonium recovery operations may include scraping of molds, incineration of combustibles, leaching of metals and glass, washing of parts, and filtration of liquids.

Plutonium residues are generated during plutonium recovery processing, weapons fabrication and manufacturing, and research and development activities. These residues may require pretreatment to recover plutonium prior to declaring them waste. Residues may include casting crucibles and molds, reduction residues, gloves and plastics, paper and other combustible waste, and a variety of miscellaneous materials such as glass, scrap metal, and insulation. Residues are incinerated, leached, dissolved, scraped, and/or hand-washed in glove boxes to remove as much plutonium as possible. The treatment used depends upon the type of residue to be processed. Electrorefining, direct oxide reduction, and acid dissolution are common plutonium recovery processes.

Electrorefining techniques involve heating plutonium-containing materials in crucibles to a molten state in an enclosed furnace. Salts are used to help extract impurities from the molten material. Pure plutonium metal is recovered from residues by extraction in pyrochemical salts. This operation generates chloride effluents, spent ion exchange resins, pyrochemical salts, and combustible waste.

The direct oxide reduction process is another plutonium recovery technique that converts plutonium dioxide to plutonium metal using calcium metal as the reducing agent. The direct oxide reduction process is a pyrochemical salt system using high-temperature furnaces. Calcium chloride or calcium chloride/calcium fluoride mixtures are used to remove the calcium oxide, which is a byproduct of this process and to permit proper metal coalescence.

Residues, in either metal or oxide form, that cannot be recycled as metal are subject to plutonium recovery through acid dissolution processes. After being converted to the oxide form, these residues are dissolved in nitric acid containing small amounts of fluoride. The resulting solutions, if sufficiently pure, undergo a precipitation process to recover the plutonium.

The plutonium metal is recycled, and the filtrates from the precipitation process are evaporated. The concentrate produced by evaporation is processed using anion exchange resins to further extract any residual plutonium.

Items such as firebrick, soot, and off-gas filters become contaminated with plutonium and must also undergo plutonium recovery. The soluble plutonium in these residues is extracted through repeated contact with nitric acid. The resulting nitric acid solutions are passed through anion exchange columns to purify and concentrate any soluble plutonium. The anion exchange effluent is passed through the column until the concentration of the actinides is below the economic discard limit. The effluent is then processed through liquid treatment and converted to a solid form. The adsorbed plutonium is stripped from the ion columns and sent through precipitation processes for further purification. The insoluble portion from the leaching and dissolution operation is again recycled through acid dissolution until the plutonium concentration is below the radionuclide economic discard limits.

Research and Development Operations

Research and development projects are performed to develop the technology and equipment needed to improve the processes used to produce nuclear products, recover radionuclides, develop new products, and improve existing products. Research and development operations include a variety of hot cell or glove box activities. Chemical and physical tests are developed and conducted on a variety of sample types including plutonium-containing metals, salts, oils, acids, bases, and organic liquids. Research and development operations related to process chemistry include small-scale experiments that attempt to develop more effective chemical procedures for plutonium recovery. Development tests are performed using several processes,

including anion and cation exchange, calcination, liquid extraction, and peroxide precipitation. Research and development operations related to metallurgical research include metal casting in furnaces, heat treating, tensile testing, and high temperature or pressure testing. Successful small-scale research projects may be implemented as large-scale operations at various DOE facilities. The TRU waste generated from these operations are similar to waste from full-scale operations.

In addition, DOE facilities are involved in actinide separations research and process demonstrations for the production of fuel forms manufactured from plutonium. The custom fabrication of research materials from various isotopic materials, including small quantities of highly enriched actinides, involves vacuum, metallurgical, and ceramic technologies. In support of DOE missions, research and development operations also are conducted related to the chemical and physical properties of actinide elements and their compounds.

At the end of a research and development project the equipment may be removed and the facility area decontaminated or cleaned in preparation for a new project. Equipment that cannot be reused becomes waste. Operations in hot cells and glove boxes commonly result in a high percentage of combustible waste.

Decontamination and Decommissioning Operations

Facilities that are no longer needed to support DOE missions are decontaminated and decommissioned. Reusable or recyclable materials and equipment are removed for use in other programs. If the facility is needed for another program, it is cleaned and refurbished. If the facility is not needed, decontamination and decommissioning operations are conducted to make the area available for unrestricted use. Decontamination and decommissioning operations are conducted at all DOE generator sites and involve the strip-out of unusable equipment, glove box lines, and entire rooms or buildings. TRU waste generated in these operations include soil, building materials, and discarded equipment.

In addition, waste that may be generated as a result of the cleanup of spills or other nonroutine events is considered to be part of decontamination activities. Decontamination waste is generated within the plutonium-controlled areas and may be contaminated with TRU actinides. Soils and soils mixed with concrete, asphalt, and sand are common wastes generated from these nonroutine activities.

C-2b Descriptions of Acceptable Waste Categories

Information regarding TRU waste from all TRU waste generator sites was evaluated to establish the waste verification requirements for all past, present, and future generated TRU waste, and the WIPP Waste Analysis Plan Waste Categories (herein referred to as Waste Categories) were established. Waste Categories facilitate RCRA waste verification efforts and reflect the original

materials used in a process or operation (e.g., glass, metal, and filters); the mode of generation (e.g., glove box lines); the type of operation (e.g., plutonium recovery or research and development); or waste treatment or processing similarities.

It should be noted that, in other WIPP documents, TRU waste is commonly referred to by TRUPACT-II Content Codes (TRUCON) Codes and Item Description Codes (IDCs). TRUCON Codes were established primarily as a classification scheme for transportation purposes. IDCs are site-specific, internal codes to track and segregate waste for purposes of plutonium accountability, recovery, packaging, and handling. The intent of these designations and groupings was not to specifically describe TRU mixed waste or to provide a basis for RCRA waste verification methodologies.

The TRU waste generators have provided information describing past and currently generated waste. This information was used to establish the parameters of interest summarized in Table C-1. Additional past and current information for individual waste streams is available in Appendix B of the Waste Isolation Pilot Plant No-Migration Variance Petition (NMVP) (DOE, 1990a).

Waste Categories have been established based on the predominant material of a waste. All of the materials within a Waste Category are chemically compatible. Except as indicated for a specific Waste Category description, any of the EPA waste codes included in Part A of the permit application may apply to the wastes within each Waste Category. The following subsections provide a description of the acceptable Waste Categories.

Generators will use process knowledge and written records to determine the appropriate Waste Category for each waste. The waste will be characterized at the generator site according to the established sampling and analytical requirements associated with each Waste Category (Sections C-4 and C-5). These descriptions include the physical and chemical characteristics of the predominant material in a Waste Category, and the waste generation processes and operations that illustrate the potential mechanisms for co-contamination of hazardous wastes with these materials.

Combustibles and Noncombustibles

Combustible and noncombustible waste is generated at all DOE facilities and is common to waste generated in hot cells and glove boxes. This waste may include a mixture of any of the solid materials used by DOE facilities. This Waste Category contains various mixtures of combustible waste, such as paper, and noncombustible waste, such as metal. When no one material is predominant, the Waste Category is identified as Combustible and Noncombustible. The project-specific nature of the operations that generate many of the Combustibles and Noncombustibles make the detailed segregation of various waste materials unnecessary. Small-scale projects that

use specific radionuclides do not require extensive segregation of waste materials for plutonium accountability or recovery.

The hazardous metals in this Waste Category are associated with specific items in the waste (e.g., lead in equipment parts, leaded tape, or glass). Based on the original materials comprising this waste and waste generation operations, only residual concentrations of RCRA-regulated volatile organic compounds (VOCs) are expected to be present.

Combustibles

Combustible waste is generated at all of the TRU waste generator sites. Combustible wastes are not ignitable, as defined under HWMR-6, Pt. II, Subpart C. For example, cellulose is combustible as a textile fabric or as paper. Combustible plastics, such as polyethylene and polyvinyl chloride, will melt and decompose when exposed to fire but do not propagate flames.

Combustibles consist of paper, plastics, cloth rags and clothing, and wood resulting from almost all plutonium operations. Cloth and paper wipes are used to clean parts and wash down glove boxes during virtually all operations. Depending on the operations, damp combustibles are generally used and then wrung out, drained or dried. A small quantity of noncombustible waste, such as concrete, scrap metal, and equipment, may also be present in this Waste Category.

Combustible waste consists of waste material generated during a variety of processes and may contain trace organics from cleaning operations or from the absorption of spills in glove boxes. RCRA-regulated metals are typically a minor component of this Waste Category.

Graphite

Graphite is an inert carbon material used in foundry and metallurgical research and development operations. It has a high electrical and thermal conductivity. Common commercial products containing graphite include pencils, molds, bricks, crucibles, and electrodes.

Because of the inert properties of graphite, it is used at DOE facilities working with pyrophoric, radioactive metal to help maintain a reducing environment necessary during plutonium melting operations. Graphite that consists of graphite molds, cleaned or scraped graphite chunks, and coarse graphite pieces which have been used for casting molten plutonium. Graphite molds are cut from solid blocks, logs, or slabs. Graphite molds are cleaned or scraped in glove boxes to remove excess plutonium and then inspected to ensure that recoverable plutonium has been removed.

Graphite waste consists of a uniform, well-defined material that has specific uses in weapons fabrication and manufacturing operations. Plutonium casting operations include the use of solvents from the cleaning of graphite molds and, thus, residual spent solvents may be present

on the surfaces of graphite pieces. In addition, residual metals may be present from impurities in plutonium metal.

Filters

Filter waste includes the following types of filters:

- High efficiency particulate air (HEPA) filters
- Ful-Flo® filters
- Fiter media
- Processed filter media
- Prefilters.

Prefilters and HEPA filters are used on all ventilation intake and exhaust systems associated with all plutonium operations. Filter frames can be either wood, aluminum,or stainless steel; the filter media may be Fiberglas®, Nomex®, or similar material. Fiberglas® is a trade name for a variety of products made of or with glass fibers or glass flakes. Commercial products include insulating wools, mats, yarns, curtains, electrical insulation, and reinforced plastics. Glass fibers are commonly made by heating equal parts of slate and limestone. The final material has a high resistance to alkalies and is a suitable substitute for asbestos. Nomex® is a trade name for an aramide fiber, a distinctive class of highly aromatic polyamide fibers, which are characterized by their flame-retardant properties. Aramide fibers are commonly derived from p-phenylenediamine and terephthaloyl chloride. Commercial uses of this material include dust-filter bags, tire cord, and bullet-resistant structures.

Ful-Flo® filters consist of fibrous polypropylene filter media and are used to remove particulates from aqueous streams. Polypropylene is a synthetic, crystalline, thermoplastic polymer. This material is insoluble in cold organic solvents and is resistant to strong acids and alkalies. Common uses of polypropylene include automobile parts, housewares such as food containers, and pipes.

Filter media are generated from splitting absolute dry box and HEPA filters apart in the plutonium process areas. Loose particulate materials that are dislodged from the filters are stabilized and packaged separate from the media. Filter media are packaged in 1-gallon plastic bottles or bags.

Processed filter media consist of Ful-Flo®, filter media, and whole filters removed from acid and non-acid environments. Filter media may be mixed with portland cement to neutralize residual nitric acid that may be present.

Filters are designed to remove and retain specific particulate materials from air or liquids. Although the filters associated with plutonium operations are not designed to retain organic vapors, they may contain these residues depending on the operations conducted in a glove box

√ or building. Airborne RCRA-regulated metals, resulting from grinding or machining operations, also may be trapped in glove box filters. However, based on knowledge of the original materials and the operations conducted, the concentrations of these metals are not expected to exceed regulatory threshold limits. Therefore, the filters are not classified as a characteristic hazardous waste.

√ Benelex® and Plexiglas®

√ Benelex® and Plexiglas® are manufacturer's trade names that are generically used to describe materials of the same or similar composition. Benelex® consists of large sheets of material used as neutron radiation shielding around glove boxes, tanks, and equipment. This waste is generated during strip-out operations as a part of decontamination and decommissioning activities. Benelex® is manufactured by compressing, at extremely high pressures, a number of pure wood plies with interstitial layers of phenolic resin used as an adhesive. It consists of approximately 99.5 percent wood, with residual amounts of the phenolic resin. Plexiglas® is a poly methyl methacrylate polymer used for glove box windows and is generated as waste during the change-out of the glove box windows. Commercial uses of Plexiglas® include lenses, chalkboards, windshields, and windows.

√ This Waste Category is composed of well-defined materials that are used as neutron shielding material and in glove box construction. Organic residues may be present as a result of glove box cleaning prior to disassembly. Because lead is present as part of glove box shielding or leaded glass, this waste may exhibit the toxicity characteristic for lead.

√ Firebrick and Ceramic Crucibles

√ Firebrick is a high-density refractory clay used as an insulating material. Firebrick is a ceramic material of low thermal conductivity that is capable of withstanding extremely high temperatures with essentially no change. Firebrick may be composed of silica, magnesite, and dolomite or alumina, carbon, and silicon carbide. The primary commercial use of firebrick is for lining steel furnaces, coke ovens, and other high-temperature applications.

√ Firebrick becomes TRU waste when plutonium processing furnaces or incinerators are dismantled or repaired. Firebrick is cleaned with dilute acids and then rinsed, dried, and scraped to remove excess plutonium before disposal. Oil-Dri®, an absorbent clay material, is usually placed in packages of damp firebrick. Depending on the operation, firebrick may be packaged in Fibre-Paks® or poly bags. Ceramic crucibles are included in this Waste Category because they consist of a similar, heat-resistant type of material. Ceramic crucible waste is generated by plutonium analytical laboratories.

√ The surfaces of firebrick or crucibles may have residual concentrations of metals; however, the predominant metals associated with this waste (e.g, magnesium, iron, aluminum, and titanium)

are not RCRA-regulated. Because the processes in which these materials are used involve very high temperatures, organic constituents are not typically associated with this Waste Category.

Leaded Rubber

Leaded rubber waste contains layers of Hypalon® and lead oxide-impregnated neoprene. Hypalon® is a trade name for chlorosulfonated polyethylene, a synthetic rubber. This material is resistant to oil, solvents, chemicals, and abrasion. Commercial uses of this material include insulation for wire, shoe soles, automobile components, and flexible tubing and hoses. Neoprene is also a synthetic rubber available commercially in solid form as a latex or as a flexible foam. It is resistant to oils and has a high flame resistance (e.g., less combustible than natural rubber). Commercial products include mechanical rubber products, coating for electric wiring, gaskets, carpet backing, and automobile accessories. Lead oxides are noncombustible, toxic materials that are insoluble in water but soluble in acids.

Sources of TRU-contaminated, leaded rubber waste include gloves removed from glove box lines and aprons. Leaded rubber from wet-chemistry glove box lines are washed with water to remove nitrate contamination associated with nitric acid environments. Leaded rubber is dried, drained, or packaged to ensure no free liquids are included. In addition, adsorbents may be added directly to the waste to sorb residual moisture that may be present. Leaded rubber waste also may contain a small portion of tools and equipment components that contain other metals.

Leaded rubber is often classified as hazardous because of its potential for exhibiting the toxicity characteristic for lead. In addition, leaded rubber gloves from glove boxes in which organic solvents have been used are often conservatively classified by the generator sites as listed spent solvent waste.

Metal

Metal waste includes "light" metals, "heavy" metals, equipment, tanks, and machinery formerly either in or attached to glove boxes. "Light" metals, in engineering terminology, are metals or alloys of low density that are strong enough for use in construction. "Light" metals include aluminum, magnesium, and beryllium. "Heavy" metals are metals whose specific gravity is approximately five or higher and include metals such as lead, cobalt, and iron.

TRU-contaminated metal waste that has economically recoverable amounts of plutonium associated with it is leached with nitric acid and/or hot water or mechanically treated for plutonium recovery prior to declaring it waste. Metal waste may include glove box parts, hand tools, sheet metal, trays, clamps, pipe, valves, nuts and bolts, wire, and equipment consisting of a variety of metals, such as iron, copper, aluminum, lead, tantalum, and stainless steel. Smaller items, such as nuts and bolts, are often packaged in metal cans or plastic wide-mouthed bottles prior to removing them from the glove box lines.

Large pieces of equipment, tanks, or machinery are disassembled or otherwise reduced in size to increase the waste container packaging efficiency. Gearbox oil, hydraulic fluid, or other liquids are drained from machinery. Sharp metal pieces are often taped to decrease the handling hazards and preclude containment punctures.

Depending on the operation in which the equipment or tools were used, this waste may have been in contact with organic solvents and have residual surface contamination. Predominant RCRA-regulated metals include lead, chromium, and cadmium from tools and metal-plated bolts and screws.

Glass

Glass is an inert, noncombustible material that consists of a uniformly dispersed mixture of silica, soda ash, and lime. These materials are often combined with metallic oxides, such as calcium, lead, lithium, or boron, depending on the specific desired properties. Pyrex®, a borosilicate glass, is a trade name that is common to analytical laboratories.

Glass waste is created during virtually all TRU operations at DOE generator sites. Two general types of glass waste are generated. Raschig rings, one type of glass waste, are borosilicate glass rings used as neutron absorbers in storage tanks holding liquid radioactive waste. The other type of glass waste consists of a variety of laboratory glassware, fluorescent lights containing small amounts of mercury, and glove box windows.

Glass waste may contain small quantities of oil and organic solvents that remain in emptied glassware or as residues on Raschig rings from the solvent present in storage tanks. Lead is the predominant metal reported in the Waste Category and is associated with leaded glass and lead tape.

Supercompacted Waste

Supercompacted waste includes those solid materials described above that are amenable to compaction. This treatment technology has been developed to decrease waste volumes and increase management efficiencies through reduction in required storage capacities. As required by this Waste Analysis Plan, all waste containers are scanned prior to supercompaction using Real-Time Radiography (RTR), a nondestructive x-ray technique, to verify the original Waste Category.

The Rocky Flats Plant is currently the only generator site that is implementing the supercompaction process. Although the following process description, provided as an example of this treatment process, is specific to the Rocky Flats Plant, similar processes may be initiated at the other generator sites. Volumes and types of waste that are compacted will depend on the treatment unit design.

Waste is retrieved from storage and segregated based on the type of material (i.e., hard versus soft waste), plutonium content, TRU versus TRU mixed waste, and final overpack drum weight (e.g., 800 pounds). Soft materials may include combustibles, filters, and leaded rubber, while hard materials may include metal, glass, and graphite. Waste is packaged or repackaged into 35-gallon drums prior to supercompaction. A maximum of four 55-gallon drums of soft waste can be precompacted into one 35-gallon drum. Hard waste is not precompacted. Each 35-gallon drum of precompacted soft waste as well as hard waste is pierced with four holes to allow entrapped air to escape during supercompaction. Each 35-gallon drum of waste is supercompacted into one puck. A maximum of four pucks are placed into one 55-gallon loadout drum to be sent to the WIPP facility.

Because supercompacted waste may consist of any of the above described Waste Categories, it may contain any or all of the hazardous waste associated with those categories. No additional hazardous waste will be added during the supercompaction process.

Inorganic Waste Water Treatment Sludge

Inorganic waste water treatment sludge results from the acid/base neutralization of aqueous waste slurries, the filtration of solids, and the subsequent solidification of oxide and hydroxide precipitated solids. The three physical forms of this waste are (1) dry, solid monoliths; (2) highly viscous gel-like solids; or (3) crumbly solids. Diatomaceous earth, a clay absorbent, is often included in the sludge as part of the filtration process and cements, Oil Dri®, or vermiculite may be added to create the final waste form. Consistent with similar industrial or municipal waste water treatment processes, the sludge is vacuum filtered. Sludge is stabilized with cements or other appropriate adsorbents prior to packaging. Using knowledge of the materials and processes generating the waste, generators determine the amounts and types of absorbent necessary to ensure proper solidification and then verify the final waste form using RTR.

The predominant chemical components of wastewater treatment sludge are silica, calcium, sodium, magnesium, and iron oxides resulting from the neutralization and stabilization process. Acidic waste waters are generated from a variety of processes, including cleaning and dissolution chemistry. As a result, generators have reported a variety of solvents and heavy metals as possible contaminants in the final waste water treatment sludge. Based on the input materials for the various processes generating this waste and the waste water treatment processes themselves (including sludge vacuum filtration and stabilization), volatile organic constituents, although reported, are expected to be a minor component of this Waste Category.

Inorganic waste water treatment sludge may include spent solvents that are listed under HWMR-6, Pt. II, Subpart D. In addition, this waste may exhibit toxicity characteristics for organic constituents included under HWMR-6, Pt. II, Subpart C. Depending on the source of the waste

water, RCRA-regulated heavy metals also may be present. Heavy metals are concentrated during the treatment process so that the final sludge may exhibit toxicity characteristics for metals.

Organic Liquid and Sludge

Organic sludge is produced by stabilization of organic liquids such as oils, solvents, and lathe coolants. Some organic liquid waste is converted to a sludge by using the Envirostone® process, which involves the addition of water, an oil and solvent emulsification agent, and finally the stabilization and solidification of the mixture with gypsum-based Envirostone®. TRU-contaminated organic liquid is collected at or near the point of origin in appropriate tanks or containers as they are generated. Older waste was mixed with calcium silicate to form a paste-like substance. Other organic liquids, primarily from research and development activities, may be absorbed on inert materials such as vermiculite.

This Waste Category is expected to contain relatively high concentrations of volatile organic compounds. In addition, metals may be present from machining operations. Because a portion of this waste has been generated prior to 1982, the potential exists for waste oils in this Waste Category to contain polychlorinated biphenyls (PCBs).

Solidified Liquid

Solidified liquid is composed of aqueous waste that is not compatible with the primary aqueous waste water treatment process because of the presence of complexing chemicals. This liquid waste is excluded from the production liquid waste because of the presence of potential complexing chemicals that would interfere with the recovery of actinides. Complexing chemicals include organic acids, alcohols, or other chelating agents. Batches of this waste may be as little as 1 liter or as much as several hundred liters and may be solidified with portland and magnesium cement. Other nonflammable aqueous waste is solidified with vermiculite. Similar to inorganic waste water treatment sludge, the chemical constituents reported in this waste include small quantities of spent solvents and RCRA-regulated metals.

Inorganic Process Solids and Soil

This Waste Category consists of solids that cannot be reprocessed or process residues from evaporator and other types of storage tanks, grit, firebrick fines, ash, salts, metal oxides, and filter sludge. This waste is typically solidified in portland or gypsum-based cements. Contaminated soil, asphalt, and sand is generated from the cleanup of spills, as well as decontamination and decommissioning activities at DOE generator sites and may also be present in this waste. This Waste Category includes materials from a variety of sources with the potential for an accumulation of metals or organics.

Pyrochemical Salt

Pyrochemical salt is comprised of salts used in molten salt and direct oxide reduction processes. [illegible] salt is a fused halide salt mixture of sodium, potassium, and magnesium salts. In molten salt extraction, the salt serves as a solvent for plutonium and americium. Plutonium and americium are removed from spent molten salt by the salt-scrub process to yield a waste salt and an aluminum-magnesium-plutonium-americium alloy.

Direct oxide reduction salt is a calcium chloride salt containing unreacted calcium metal (1 to 3 weight percent) and calcium oxide. The direct oxide reduction process is a one-step reduction of plutonium oxide to plutonium metal. The process employs a calcium metal reductant and a molten calcium chloride salt flux. The uncertainty in the quantities of unreacted calcium metal present in the salt results in the need to process the salt by air oxidization. Air oxidation ensures that residual calcium metal, a nonradionuclide pyrophoric material, is oxidized in the waste salt so that it will not exhibit the characteristic of reactivity. Molten and direct oxide reduction salts are packaged in metal cans prior to being placed in 55-gallon drums.

Because pyrochemical salts are used in a high temperature process, metals are the only hazardous constituents typically reported as present. The types and concentrations of metals present in the waste will depend on the impurities present in the feed-stock materials and the impurities retained in the salt after plutonium is recovered.

Cation and Anion Exchange Resins

This Waste Category consists of leached and unleached spent ion exchange resins. The resins, synthetic polymers, typically consist of polystyrene copolymerized with divinyl benzene. Nitrate and chloride anion exchange are used to separate and purify plutonium from nitric acid or chloride solutions, respectively. After the impurities have been removed from the effluent, the plutonium sorbed on the resin is eluted and precipitated.

Feed solutions requiring plutonium separation and purification may contain trace quantities of spent solvents from various operations. Metals may be present; however, the concentrations typically are expected to be below regulatory threshold limits.

Solid and Solidified Materials

This Waste Category consists of a mixture of solid materials, which include the following Waste Categories: Combustibles and Noncombustibles, Combustibles, Graphite, Filters, Benelex® and Plexiglas®, Firebrick and Ceramic Crucibles, Leaded Rubber, Metal, and Glass and solidified materials (which includes the Waste Categories of Inorganic Waste Water Treatment Sludge, Organic Liquid and Sludge, Solidified Liquid, Inorganic Process Solids and Soil, Pyrochemical Salt, and Cation and Anion Exchange Resins.

C-2c On-Site Generated and Derived Waste

All nonradioactive hazardous waste generated at the WIPP facility is characterized, placed in containers, and stored (for periods of less than 90 days) until it is transported off site for treatment and/or disposal. This waste generation and accumulation activity is not subject to RCRA permitting requirements and, as such, is not addressed in this permit application.

Administrative controls, which direct normal operations at the WIPP facility, will be implemented to ensure that no RCRA-regulated materials will be mixed with the radioactive waste. For this reason, any mixed waste generated through normal waste handling operations will be derived from the received waste. Since these site-generated wastes may contain only those RCRA-regulated materials present in the waste from which they were derived, no sampling and analysis of these derived wastes is proposed for characterization purposes.

Anticipated sources of derived mixed waste during the Test Phase include the following:

- Spent carbon from the bin gas discharge system carbon sorption system
- Any test bins subject to mechanical failure of sampling ports, pressure relief valves, or other associated devices to the extent that the bin may no longer be used to support the test program
- Any waste generated through non-routine events such as the cleanup of spills.

In the event of an off-normal or accident situation, it may be necessary to use RCRA-regulated materials (e.g., solvents) to decontaminate equipment or structures. In these situations the materials used will be well documented. The only materials to be used for this purpose are those that are chemically compatible with waste to be emplaced in the WIPP facility. Characterization requirements for any waste generated in an off-normal or accident situation will be developed on a case-by-case basis in cooperation with representatives of the New Mexico Environment Department (NMED).

C-3 Boundary Conditions and Process Tolerance Limits

The WIPP facility has both facility-established boundary conditions and process tolerance limits and boundary conditions established by the U.S. Environmental Protection Agency (EPA) in its Conditional No-Migration Determination for the Department of Energy Waste Isolation Pilot Plant (NMD) (EPA, 1990). Facility-established boundary conditions and process tolerance limits are summarized in Table C-2. EPA-established boundary conditions are summarized in Table C-3.

Boundary conditions are maximum values of waste properties that, if exceeded, would indicate that an incoming waste does not meet its established, acceptable values for these properties.

Process tolerance limits are those characteristics of a waste that a waste management process can handle while maintaining permit compliance. Wastes that exceed boundary conditions or process tolerance limits will not be accepted at the WIPP facility but upon receipt will be returned to the generator site (Section C-6).

C-3a Facility-Established Boundary Conditions and Process Tolerance Limits

Boundary conditions and process tolerance limits have been established to ensure compliance with the WIPP facility's RCRA waste management requirements. The following waste is unacceptable for management at the WIPP facility:

- Ignitable, reactive, and corrosive wastes, as defined under HWMR-6, Pt.III, sec. 61, Subpart C
- Incompatible wastes as defined under HWMR-6, Pt. V, Appendix V
- Waste not described by one of the Waste Categories in Section C-2b of this Waste Analysis Plan
- Wastes that do not meet the EPA-established boundary conditions.

Ignitability, Reactivity, and Corrosivity

The WIPP facility will not accept waste that exhibits the characteristics of ignitability, reactivity, or corrosivity. In accordance with DOE Order 5820.2A, Radioactive Waste Management (DOE, 1988), DOE has established the TRU Waste Acceptance Criteria (WAC) (DOE, 1991a) to control the chemical and physical forms of the TRU waste at the generator sites that will ultimately be emplaced at the WIPP facility. The WIPP WAC are implemented by DOE generator/storage sites through WAC waste certification programs. WAC certification programs are overseen by DOE through annual audits. DOE ensures that TRU waste received at the WIPP facility does not exhibit these characteristics through administrative and operational procedures at the generator sites. The WIPP WAC certification programs result in controlled and consistent chemical and physical waste properties and final packaging.

Compliance with the restrictions on characteristic TRU wastes will be verified by review of all Waste Profile Forms and all RTR data records by WIPP Project personnel. The Waste Profile Form (Section C-6) indicates that the TRU waste described in the Waste Profile Form has been WAC-certified. RTR data records are data report forms that contain all of the information to fulfill the RTR data reporting requirements established in the Quality Assurance Program Plan for the Waste Isolation Pilot Plant Experimental-Waste Characterization Program (QAPP) (DOE, 1991a). RTR analysis is required on all original containers of TRU waste. In the case of containers that are comprised of TRU waste from more than one original container, RTR analysis is not required

on the final, composited waste container. For example, during the Test Phase a SWB will contain a bin into which has been emptied the contents of four to six 55-gallon drums. RTR analysis is required on each of the 55-gallon drums emptied into the bin but not on the bin itself. Copies of RTR tapes will be obtained for review, as necessary.

The TRU waste received at the WIPP facility is not aqueous or liquid, contains no prohibited materials, and is capable of being handled at standard temperatures and pressures without reaction to oxygen or water (Table C-4). The WIPP facility cannot accept containers holding liquid waste or waste that would be considered a liquid waste if a representative sample of the waste (as defined in HWMR-6, Pt. II, sec. 260.10) was taken and examined. Therefore, every container holding TRU waste must contain as little residual liquid as is reasonably achievable and all internal containers (e.g., bottles and cans) must be well-drained. Additionally, TRU waste cannot contain explosives, compressed gases, oxidizers, or nonradionuclide pyrophoric materials.

Prior to the acceptance of a container holding TRU waste, WIPP Project personnel will examine the RTR data records to verify that it contains no unvented compressed gas containers and only residual amounts of liquids. If discrepancies or inconsistencies are detected during the RTR data record review, WIPP project personnel will request a copy of the RTR tape to verify the Waste Category and ensure that no prohibited materials are present in the waste.

To ensure that TRU waste contains no oxidizers, explosives, or nonradionuclide pyrophoric materials, WIPP Project personnel will review the Waste Profile Forms to verify that each container has been WAC-certified. WAC-certified waste contains no explosives, no oxidizers, and no nonradionuclide pyrophoric materials.

Compatibility

The WIPP facility is designed to manage only compatible waste. Using HWMR-6, Pt. VI, Appendix V and the EPA document, A Method for Determining the Compatibility of Hazardous Wastes (EPA, 1976), DOE has determined that all of the Waste Categories described in Section C-2 are mutually compatible. The EPA has concurred with DOE's determination of compatibility (EPA, 1990). To ensure waste compatibility, the WIPP facility cannot accept any Waste Category that, if mixed with one of the acceptable Waste Categories, would produce toxic fumes, generate a violent reaction, or initiate a fire or explosion. Therefore, the WIPP Project will accept only those Waste Categories described in Section C-2. The WIPP Project requires that RTR analysis be performed on each original container holding TRU waste and will review all RTR data records and the Waste Profile Form to ensure that each original container holds an acceptable Waste Category. If discrepancies or inconsistencies are detected, WIPP Project personnel will request a copy of the RTR tape from the generator to verify the Waste Category and ensure that no prohibited materials are present.

Waste Category

Waste Categories have been established based on the original materials used in an operation or the processes generating a waste (Section C-2). Analytical requirements are determined by Waste Category. Waste Categories also ensure that process tolerance limits are maintained. For example, pressurized containers, which are not present in any of the Waste Categories, are an unacceptable waste because they could contain compressed gases that may cause the waste to exhibit the characteristic of ignitability.

The WIPP facility will accept only those Waste Categories described in Section C-2. The Waste Category is determined by the generator sites. The WIPP Project requires that RTR analysis be performed on each original container holding TRU waste and will review all RTR data records and the Waste Profile Form to ensure that each original container holds an acceptable Waste Category. If discrepancies or inconsistencies are detected during the RTR data review, WIPP Project personnel will request a copy of the RTR tape to verify the Waste Category.

C-3b EPA-Established Boundary Conditions

In accordance with 40 CFR 268.6, boundary conditions have been established by the EPA NMD (EPA, 1990) and are effective at the WIPP facility until there is official notice from EPA indicating otherwise. The following determinations will be made to monitor the additional EPA-established boundary conditions (Table C-3):

- Concentration of VOCs in the headspace of containers holding TRU waste
- Flammability potential of the headspace of containers holding TRU waste.

Concentration of VOCs in the Headspace of Containers Holding TRU Waste

The boundary conditions for headspace VOC concentrations apply to containerized TRU waste. The boundary conditions are specific to the Waste Types as defined in the document, TRUPACT-II Content Codes (TRUCON) (DOE, 1990b).

For TRU waste containerized in drums, the concentrations of VOCs in the drum headspace cannot exceed maximum values for carbon tetrachloride, methylene chloride, 1,1,1-trichloroethane, trichloroethylene, and 1,1,2-trichloro-1,2,2-trifluoroethane. For TRU waste containerized in bins, the concentrations of VOCs in the bin headspace cannot exceed mean values for carbon tetrachloride, methylene chloride, and trichloroethylene. Generator sites determine the concentrations of the boundary condition VOCs (Table C-3) in the TRU waste and transmit the data to the WIPP facility. WIPP Project personnel verify that these data are within the range of acceptable boundary condition values. If a container holding TRU waste exceeds

the boundary conditions for headspace VOC concentrations, it will not be accepted at the WIPP facility.

Flammability Potential of the Headspace of Containers Holding TRU Waste

The boundary condition for flammable gases requires that containers holding TRU waste have no mixtures of gases that are potentially flammable at the time of emplacement. Flammable gases that may be associated with TRU waste include hydrogen, methane, and the flammable VOCs listed in Table C-5. A mixture of gases containing hydrogen and methane plus flammable VOCs at concentrations less than 500 parts per million by volume (ppmv) is considered flammable by the EPA if it exceeds 50 percent of the calculated lower explosive limit for the hydrogen and methane portion of the mixture. A mixture of gases containing hydrogen and methane plus flammable VOCs at concentrations greater than 500 ppmv is considered flammable by the EPA if a sample of the mixture propagates a flame during a flame test. Generator sites determine the concentrations of hydrogen, methane, and flammable VOCs (Table C-3) in the TRU waste and transmit the data to the WIPP facility, as discussed in Section C-7a. WIPP Project personnel verify that these data are within the range of acceptable boundary condition values. Any container holding TRU waste exceeding the boundary conditions for flammable gases will not be emplaced in the miscellaneous unit.

C-4 Parameters, Rationale, and Test Methods

To determine the sampling techniques and waste analysis parameters necessary to ensure that the TRU waste accepted at the WIPP facility is properly characterized and can be safely managed, the current waste characterization information provided by the generator sites (Section C-2) has been reviewed. The Waste Categories were grouped based on how the original materials were used, how the waste was generated, and the consistency of the physical waste form.

The analytical parameters of interest include RCRA-regulated metals (Table C-6), organic compounds (Table C-7), and headspace VOCs (Table C-8). A parameter was selected based on one or more of the following criteria:

- It is included for its toxicity characteristic as defined in HWMR-6, Pt. II, Subpart C
- It is listed as a spent solvent as defined in HWMR-6, Pt. II, Subpart D
- It is identified in the NMD (EPA, 1990)
- It is identified by a DOE generator site (Table C-1) and is listed as a hazardous constituent in HWMR-6, Pt. II, Appendix VIII.

The parameters of interest and the rationale for including each parameter in this plan are summarized in Table C-1. This section includes a description of the acceptable methods to evaluate these parameters for each Waste Category and the objective of each evaluation.

Total RCRA-regulated metal and organic analyses will be used instead of the Toxicity Characteristic Leaching Procedure (TCLP) to evaluate if a waste exhibits a toxicity characteristic as defined in HWMR-6, Pt. II, Subpart C. If the total concentration of a constituent is less than the limits specified in Table 1 of HWMR-6, Pt. II, sec. 261.24, the waste will not be considered hazardous. If the total concentration of a constituent is greater than the regulatory threshold limit, the waste will be evaluated based on an assumption of 100 percent dissolution of the constituent, if a TCLP extraction had been performed. The regulatory limits, which are based on concentrations of each hazardous constituent in a TCLP extract, would be expressed as a total concentration for each constituent based on a dilution factor of 20 (i.e., the ratio of solid to extractant as specified in the TCLP), and the results from a total analysis will be compared to those values.

In all cases, DOE facilities will use methods provided by the EPA as guidance in Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (SW-846) (EPA, 1986), or equivalent methods as required to properly analyze TRU waste. DOE has developed analytical protocols and procedures for analyzing headspace VOCs and gases and has included these in the QAPP (DOE, 1991a) and the WIPP Waste Characterization Program Sampling and Analysis Guidance Manual (Guidance Manual) (DOE, 1991b), respectively. SW-846 methods used to analyze solidified/stabilized TRU waste forms are currently being evaluated by DOE. Equivalency of a method will be demonstrated by meeting the quality assurance and quality control (QA/QC) requirements specified in SW-846 for a given method. All final analytical protocols for solidified/stabilized waste forms will be included in a future revision of the QAPP. Detailed analytical procedures specific to analyzing TRU waste will be provided as guidance in a future revision of the Guidance Manual.

In most cases, the differences in the hazardous chemicals reported by each generator for specific waste within a Waste Category do not justify establishing waste analysis requirements based on individual waste streams or generator sites. Thus, in some cases, the data may be used to verify that a waste is nonhazardous or contains certain constituents in concentrations below regulatory threshold limits.

C-4a Criteria for Selection of Waste Analysis Parameters

The WIPP Project has established a rationale by which to group the Waste Categories. This approach provides a consistent and logical basis for the identification of required waste analysis parameters for each group. The Waste Categories are divided into three groups (i.e., Group I, Group II, or Group III) based on the rationale provided in this section. The Waste Category

descriptions included in Section C-2 provide detailed waste information and illustrate the similarities among the Waste Categories within each group.

The following rationale was used for including a Waste Category in Group I:

- Primarily identified based on the original materials used in an operation or process
- The original materials are common components of industrial and commercial products and therefore are well-characterized materials
- The original materials have a consistent and well-defined use throughout the DOE complex
- The purpose and function of the original materials are similar at all DOE TRU waste generator sites.

The following rationale was used for including a Waste Category in Group II:

- Waste generation processes are specific and well-defined
- The sources of original material inputs (e.g., plutonium scrap or feedstock) used in a process may be diverse and variable
- Final waste reflects a mixture of residual solids or solidified liquids from a variety of sources
- Waste may include liquid waste that has been treated, solidified, or stabilized
- The waste generation process serves to remove or concentrate specific components (e.g., cation and anion exchange resins that concentrate plutonium).

The following rationale was used for including a Waste Category in Group III:

- The waste is a mixture of Group I and Group II Waste Categories
- The populations of solidified/stabilized waste may represent more than one Group II Waste Category and are potentially from more than one generating source
- The waste typically represents older, stored waste.

In summary, Group I includes those Waste Categories for which the original materials used are the predominant component of the final waste. Group II Waste Categories include waste that

√ results from a specific process or a final treatment operation. The Group III Waste Category
√ includes mixtures of Group I and Group II Waste Categories.
√
√ Group I, Group II, and Group III Waste Categories are compatible and therefore can be packaged
√ in the same waste container, transported, and accepted at the WIPP facility. However, for
√ purposes of compliance with the sampling and analytical requirements described in this plan, TRU
√ waste generator facilities managing Group III waste must either (1) segregate 100 percent of the
√ waste being sampled into the appropriate Group I and Group II Waste Categories and
√ characterize these wastes in accordance with each Waste Category or (2) sample and
√ characterize the entire waste population in accordance with the requirements for the Group III
√ Waste Category. The approach used will depend on the quantities of Group III waste and the
√ degree of process knowledge available. These options are provided to minimize the amount of
√ waste handling and processing that will be necessary to verify the waste is properly characterized.
√ In either case, the statistical sampling methods included in Section C-5 will dictate the number
√ of samples required to be analyzed in a given population.
√
√ C-4b Parameters and Test Methods
√
√ Each generator site will evaluate its waste using the Waste Category descriptions and determine
√ the appropriate Waste Category for each waste. Once the Waste Category is identified, waste
√ verification information is provided in accordance with the appropriate group. Generators must
√ provide data from the results of Phase I Waste Shipment Screening (Section C-6) for all Waste
√ Categories as well as the applicable analytical data described in this section. Figure C-1
√ diagrams the waste screening and waste characterization data collection process that is to be
√ performed by generator sites. The sampling and analytical requirements described in this Waste
√ Analysis Plan are a function of the selected Waste Category and grouping. The rationale for the
√ hazardous waste determinations will be provided by the generator using the Waste Profile Forms
√ (Section C-6). The applicable supporting data also will be included for review by WIPP Project
√ personnel. The WIPP Project requires generators to submit a Waste Profile Form that includes
√ a description of each waste for each waste container for review and approval by WIPP Project
√ personnel prior to waste shipment.
√
√ Group I
√
√ The parameters, test methods, and a summary of the rationale for Group I analyses are provided
√ in Table C-9. RCRA-regulated metals present in Waste Categories within Group I are associated
√ with specific waste materials (e.g., lead in leaded rubber, leaded glass, or lead shielding). Based
√ on the use and knowledge of the original materials that comprise this waste, other reported
√ metals may exist as residues on the surfaces of solid materials (e.g., residual metals on graphite
√ molds or crucibles). Knowledge of the materials and operations that generate this waste are
√ sufficient to determine if the waste exhibits a toxicity characteristic for the metals as defined under

HWMR-6, Pt. II, Subpart C (Table C-6). No additional information related to RCRA-regulated metals is necessary to properly manage this waste.

VOCs are used in many glove box operations to clean equipment or material surfaces. Listed spent solvents (EPA hazardous waste codes F001-F005) are commonly reported in waste included in Group I. The absorption capacity of the solid materials that comprise these Waste Categories is minimal. The use of highly volatile organics to clean or degrease materials in glove boxes is expected to result in waste that contains small or trace quantities of volatile, spent solvents. In addition, materials in this group may be processed for plutonium recovery prior to declaring them waste. Plutonium recovery may involve heating or leaching with acid. TRU waste generators have conservatively characterized items such as tools, disassembled equipment and glove boxes, or leaded rubber, which may be residually contaminated with solvents, as listed spent solvent waste. Semivolatile organic compounds are not commonly used in plutonium operations or processes. PCBs are not used in plutonium operations or processes. Knowledge of the original organics used and the operations that generate the waste is sufficient to determine if the waste is hazardous or contains PCBs and other hazardous constituents (Table C-9).

Headspace gas analyses for volatile organic compounds included in Table C-8 will be performed for all Waste Categories in Group I sent to the WIPP facility during the Test Phase. The data obtained from these analyses will provide an indication of the types and concentrations of volatile organics present in the headspace of containers. Results of headspace gas analyses will be used to demonstrate compliance with EPA-established boundary conditions prior to shipment to the WIPP facility (Section C-3).

Group II

The parameters, test methods, and rationale for Group II analysis are included in Table C-10. RCRA-regulated metals associated with Group II Waste Categories originate from numerous operations and processes. Group II includes solidified or treated particulate or liquid waste. Acidic processes, commonly used in plutonium recovery operations, tend to solubilize heavy metals that may be present. Depending on the initial concentrations of metals in a waste water, the final inorganic treatment sludge may contain concentrations of metals above or below the regulatory threshold limits. In addition, process solids consist of materials scraped or cleaned from firebrick, graphite, and other related items. The Waste Categories in this group may contain RCRA-regulated metals at concentrations above the regulatory threshold limits in HWMR-6, Pt. II, Subpart C. The Waste Categories in Group II will be sampled and analyzed for total RCRA-regulated metals (Table C-6) prior to transport to the WIPP facility. These metals, if present, represent hazardous constituents that are either (1) characteristic waste or (2) other hazardous constituents listed in HWMR-6, Pt. II, Appendix VIII, identified by the generator sites.

Similarly, the organic constituents associated with the Waste Categories in Group II are derived from a variety of sources including analytical laboratories, weapons manufacturing and fabrication

operations, and plutonium recovery operations. With the exception of pyrochemical salts, all Waste Categories in this group will be sampled and analyzed for the organic constituents in accordance with the requirements in Table C-7. Knowledge of the electrorefining processes, which involves high temperature molten salt extraction, is adequate to demonstrate that organic constituents are not associated with pyrochemical salts. If present, the organic compounds that may be associated with the other Waste Categories in Group II represent hazardous constituents that are included as (1) listed, spent solvent waste, (2) characteristic organic waste, (3) other hazardous constituents listed in HWMR-6, Pt. II, Appendix VIII, identified by the generator sites, or (4) potentially flammable organics identified by the generator sites.

Transformer oils containing PCBs have been identified in a limited number of wastes included in the Organic Liquid and Sludge Waste Category. Therefore, solidified waste oils included in this Waste Category will be analyzed for PCBs (Table C-7). Waste containing concentrations of PCBs greater than 50 parts pers million (ppm) will not be accepted at the WIPP facility. PCBs are identified as hazardous constituents listed in HWMR-6, Pt. II, Appendix VIII. In addition, waste containing concentrations of PCBs greater than 50 ppm are regulated under the Toxic Substances Control Act (TSCA), as well as under RCRA 40 CFR 268.32(a)(2). TRU waste generators will sample and analyze this waste to ensure that PCBs at TSCA-regulated levels are not shipped to the WIPP facility during the Test Phase.

Headspace gas analyses for VOCs are required for all waste included in Group II that will be sent to the WIPP facility during the Test Phase (Table C-10). These data will provide an indication of the types and concentrations of volatile organics that are present in the headspace of containers. Results of headspace gas analyses will be used to demonstrate compliance with EPA-established boundary conditions prior to shipment to the WIPP facility (Section C-3).

Group III

The parameters, test methods, and rationale for Group III analysis are included in Table C-11. Group III consists of only one Waste Category, which is a mixture of Group I and Group II Waste Categories. Because the wastes in Group I and Group II are compatible, this Waste Category does not require segregation. The potential exists for this Waste Category to contain RCRA-regulated metals, organic solvents, or PCBs as included in Group I and Group II Waste Categories. Therefore, the Group III Waste Category requires the complete analysis as summarized in Table C-11 for all solidified materials as well as the use of process knowledge to support the characterization information provided for the solid materials (e.g., glass or metal waste).

Headspace gas analyses for VOCs are required for all waste included in Group III that will be sent to the WIPP facility (Table C-11). These data will provide an indication of the types and concentrations of VOCs that are present in the headspace of containers. As described in

Section C-3, results of headspace gas analyses will be used to demonstrate compliance with EPA-established boundary conditions prior to transport of the waste to the WIPP facility.

C-5 Waste Sampling Plan and Data Analysis

A waste verification program, including sampling and analysis, is to be implemented by each DOE site that intends to send waste to the WIPP facility. Analyses will be provided to WIPP Project personnel for review prior to waste shipment. Data obtained from site-specific sampling and analysis programs will provide the estimates of waste population parameters within each Waste Category that are necessary to meet waste verification requirements.

Headspace Sampling

Waste Categories in all groups will be sampled and analyzed to determine the concentrations of headspace VOCs (Table C-8) and headspace gases. To obtain representative headspace VOC and gas data for waste intended for shipment to the WIPP facility, the statistical methods described in this section will be used and will parallel the methods used for sampling Group II and III solidified/stabilized waste. Results of the initial headspace sampling will be compared to maximum values reported in the NMD (Table C-3) to determine the number of additional headspace samples required to verify hazardous waste determinations. Sampling protocols, equipment, and QA/QC methods for headspace sampling are included in the QAPP (DOE, 1991a).

Solidified/Stabilized Waste Sampling

Group II and Group III solidified/stabilized waste forms will be sampled and analyzed to assess these wastes for hazardous constituent content. Representative samples of Group II and Group III solidified/stabilized waste will be obtained using guidance set forth in SW-846, Chapter 9.0 (EPA, 1986). Group II and Group III solidified/stabilized waste sampling frequencies will be determined in accordance with the equations specified in this sampling plan.

DOE is currently developing sampling protocols for solidified/stabilized TRU waste. Sampling frequencies are outlined in Table C-12. Due to the variety of waste characteristics of the waste matrix, as described in Section C-2, a number of sampling methods may be used. All sampling protocols will be described and documented, and records will be completed and maintained as described in future revisions of the QAPP (DOE, 1991a). Sampling procedures and guidance will be included in future revisions of the Guidance Manual (DOE, 1991b).

C-5a Sampling Plan

For the purposes of this sampling plan, all waste generated prior to the development and implementation of sampling and analytical capabilities at each generator site will be considered

as stored waste. Stored waste may be generated as either process or batch waste streams. For the purposes of this sampling plan, a "process" is defined as a system or series of continuous or regularly occurring actions taking place in a predetermined manner over extended periods of time resulting in a product that is substantially uniform. A "batch" is defined as an amount of material subjected to some unit chemical process, unit physical mixing process, or other short-term operation resulting in a final product that is substantially uniform. Generator sites may provide process input data or batch-specific data for current/future generated waste and obtain a sample once per year for process analysis or once per batch in accordance with Table C-12.

As related to solidified/stabilized waste, this waste sampling plan establishes a statistical foundation for determining chemical concentrations in Group I and Group III waste (by Waste Category) and verifying whether a waste is hazardous as defined in HWMR-6, Pt. II, Subpart C. Waste container populations considered in this section are a subset of a Waste Category and may be determined based on the date of waste generation. Classification of waste for sampling and analysis may be influenced by knowledge of specific waste generation processes. As outlined below, a two-tier approach will be used to verify hazardous waste determinations. Each generator site will evaluate its waste and determine the appropriate populations within each Waste Category.

Tier 1

The maximum population size analyzed in sampling conducted under this plan must not exceed 1,000 waste containers (ASTM, 1988). When a population of containers is assembled, process knowledge will be used to determine similarity in waste content within that population. This will be accomplished using waste stream information and other available records such as identification codes that indicate a population contains waste from a specific process or batch.

At each generator site sending waste to the WIPP facility, the goals of Tier 1 sampling are to determine baseline concentrations and variabilities of hazardous constituents for a population of waste containers. Tier 1 sampling consists of obtaining a random sample of ten waste containers from each population. Data to assess the statistical distribution type (e.g., normal and log normal) for chemicals within the waste are currently unavailable. Therefore, sufficient Tier 1 sampling and analysis [applying the Central Limit Theorem (Koopmans, 1986)] will be conducted to justify using a normal distribution for analyte concentrations. The appropriateness of using normal distributions for chemical concentrations within each population will be verified by statistical evaluation of data gathered in Tier 1. Statistical distribution types used for each waste will then be corrected as necessary.

Tier 2

The number of samples required for Tier 2 sampling will be based upon results of Tier 1 sampling and determined using equations from SW-846, Chapter 9.0 (EPA, 1986). If chemical

concentration variability is small from point-to-point within individual waste containers, and from waste container-to-waste container in a population, then the number of Tier 2 samples for that population will be greatly reduced. This reduction can be accomplished while maintaining an acceptable level of statistical confidence when comparing average concentrations to the regulatory thresholds set forth in HWMR-6, Pt. II, Subpart C. Tier 2 sampling will ensure that no significant differences exist in the average concentrations of chemicals within a population.

C-5b Sampling Method 1

Sampling Method 1 is used to obtain samples from bulk, stabilized, or solidified waste packaged in waste containers with no smaller inner containers.

Tier 1 Sampling

Method 1 sampling for Tier 1 consists of obtaining three core samples from ten randomly selected waste containers within a maximum population of 1,000 containers. Sampling ten randomly selected containers within a population of 1,000 containers is considered sufficient for bulk solidified/stabilized waste because of the following:

- Waste matrices for Waste Categories that this sampling method will apply to are expected to be some of the more uniform waste matrices in the DOE inventory (e.g., waste water treatment sludge).

- Process knowledge is more effective for grouping waste when a relatively uniform waste matrix is being considered, primarily because some of the larger identifiable populations of similar waste result from processes generating waste in these Waste Categories.

- When the waste is well-grouped and relatively uniform, the containers may be considered to be incidental barriers surrounding the waste matrix. This allows this more uniform waste to be approximated statistically as a monolithic object. Potential for statistical correlation exists in this approach. However, due to the waste matrix that this sampling method is applicable to, the correlation is expected to be insignificant and sample independence is expected to be preserved.

- Sampling ten containers will provide 30 core samples, three core samples per container (minimum for horizontal variance analysis). Also, the cores will be sampled across three strata—upper, middle, and lower—which will provide sufficient data to analyze vertical variance (e.g., gravitational settling).

- Although other numerical schemes are possible to obtain 30 core samples, this method will provide the necessary data to perform the statistical analyses while

reducing the number of containers opened, thus reducing exposure during the sampling process.

The core sampling is to be done using a sample trier as described in SW-846, Chapter 9.0, or equivalent device. Specific details of the coring procedure will be included in the Guidance Manual (DOE, 1991b). Core locations will be randomly selected.

From one of the ten Tier 1 waste containers in each population, a field duplicate core sample will be taken. For quality assurance purposes, the duplicate sample will be recorded as such in the sampling record. However, the duplicate sample will be identified and treated as a routine sample for analysis purposes and following analysis, and the duplicate sample data will be incorporated into the Tier 1 data pool.

Each core sample will be partitioned to obtain representative samples of the upper, middle, and lower thirds (strata) of the core, and an aliquot will be taken from each third. A three-way analysis of variance that examines core-to-core (horizontal), strata-to-strata (vertical), and waste container-to-waste container variability will be applied to this stratified data to determine if data from the three strata may be collapsed. Collapsing (combining into one similar population) data is appropriate when variability along the length of the core from strata-to-strata and variability from core-to-core within a container has been demonstrated to be insignificant using variance analysis equations and methods in this plan. Collapsing data from all strata will permit obtaining a single representative Tier 2 sample at any interval along a core sample at any horizontal location in a waste container, and will reduce the total number of Tier 2 samples required. The three-way analysis of variance will be performed using standard statistical software.

Tier 2 Sampling

Tier 2 sampling will permit WIPP Project personnel to verify with 90 percent confidence that values resulting from Tier 1 sampling are representative of the population being analyzed. The required number of waste containers to be sampled will be determined using Tier 1 and previous Tier 2 data, [Equation C-5(5)], and critical values from the Student's t-distribution for a 90 percent confidence level (Koopmans, 1986). Waste containers to be sampled will be randomly selected. At a minimum, one sample core will be collected from each waste container selected for sampling from the Tier 2 population. In addition, in accordance with SW-846, Chapter 1.0 (EPA, 1986), one field duplicate core sample will be taken from every 20 waste containers sampled or one per population, whichever is more frequent. For waste containers from which a field duplicate is taken, cores will be collected and identified as described above for Method 1-Tier 1 sampling.

C-5c Sampling Method 2

Method 2 sampling will be used to sample waste containers having smaller containers inside (e.g., Fibre-Paks®, cans, bottles, or jars). The contents of the inner containers are expected to be solidified/stabilized waste.

Tier 1 Sampling

Method 2-Tier 1 sampling requires sampling all inner containerized waste within ten randomly selected waste containers. The ten containers are to be randomly selected from a maximum population size of 1,000. The samples will be collected by opening the inner containers and obtaining one representative core sample or alternatively splitting the solidified mass held inside, and obtaining a representative sample of the solidified mass using a shovel, scoop, or equivalent tool. In all cases a representative sample shall be obtained in accordance with the intent of this plan to the best ability of the technician sampling the waste. An example of this situation is a one-gallon can containing only a single, solid mass of pyrochemical salt. A representative random sample of the solid mass may be obtained by core sampling or alternatively may be obtained by sampling the mass at a random distance (height) from the bottom of the can. For a can containing a number of pieces of waste, a random distance will be determined from the bottom of the can, and a representative sample of the waste existing at, or nearest to, that location will be taken regardless of the waste form.

From one of the ten Tier 1 waste containers in each population, a field duplicate core sample will be taken. For quality assurance purposes, the duplicate sample will be recorded as such in the sampling record. However, the duplicate sample will be identified and treated as a routine sample for analysis purposes and following analysis, and the duplicate sample data will be incorporated into the Tier 1 data pool.

Tier 2 Sampling

Analysis of data from Tier 1 sampling will be used to determine the number of Tier 2 samples [Equation C-5(5)] required to verify a hazardous waste determination for a population. Method 2-Tier 2 sampling will involve random sampling one third of the inner containers (e.g., cans, bottles, or jars) of waste from waste containers that are selected for sampling in Tier 2. Samples for Method 2-Tier 2 sampling will be obtained as described above for Method 2-Tier 1. As in Method 1-Tier 2 sampling, one field duplicate sample will be taken from every 20 waste containers sampled or one per population, whichever is more frequent. For waste containers from which a field duplicate is taken, both samples will be collected and identified as described above for Method 2-Tier 1 sampling.

Waste analysis data from Tier 2 sampling may be pooled, as appropriate (Section C-5e), with all previous Tier 1 data for that waste and with previous Tier 2 data as it becomes available, to

√ calculate updated mean and variance values for the total population for each Waste Category.
√ Qualifications for data pooling are described in Section C-5e.
√
√ C-5d Data Analysis Methodology
√
√ The goal of statistical waste verification is two-fold. First, enough representative data will be
√ collected from a waste population to provide estimates of that population's average chemical
√ concentrations. Second, these estimates will be compared to the applicable regulatory thresholds
√ to assess if a waste is hazardous as defined in HWMR-6, Pt. II, Subpart C. Verification of
√ hazardous waste determinations will be assessed through a statistical test of hypothesis.
√ Because the sample size was chosen so that the Central Limit Theorem applies, critical values
√ from the Student's t-distribution (Kooprnans, 1986) are used.
√
√ Hazardous Waste Verification
√
√ Sampling and analyses are required for all Group II and Group III solidified/stabilized Waste
√ Categories. Data collected will be used to verify that a waste does or does not exhibit a toxicity
√ characteristic, as defined in HWMR-6, Pt. II, Subpart C. Waste that is hazardous because of a
√ listing in HWMR-6, Pt. II, Subpart D, must be sampled but is not evaluated using this verification
√ method.
√
√ Let μ be the true but unknown average concentration of the analyte, and let RT denote the
√ regulatory threshold. To verify that a waste does or does not exhibit a toxicity characteristic for
√ a constituent of interest, test the null hypothesis (H_O) that the average concentration for that
√ constituent is equal to the regulatory threshold value versus the alternative hypothesis (H_A) that
√ the average concentration is below the regulatory threshold. The standard notation is:
√
√ $$H_O: \mu = RT \quad \text{versus} \quad H_A: \mu < RT.$$
√
√ Verifying that waste is not hazardous means rejecting H_O. The null hypothesis is rejected
√ whenever the sample's average analyte concentration is too low to have come from a
√ concentration distribution centered at the regulatory threshold.
√
√ The level of significance of the test, α, is the probability of concluding that a waste is not
√ hazardous, when in fact it is. An acceptable probability of an incorrect conclusion is chosen in
√ advance of data collection and will not be changed after data have been collected. The level of
√ significance will be chosen for a one-sided test to be 0.05. The corresponding critical values for
√ the one-sided test may be found in any standard statistical text (Koopmans, 1986) with the
√ degrees of freedom, n - 1, denoted as ν. The complete verification that a waste does or does
√ not exhibit a toxicity characteristic is conducted as follows. To test
√
√ $$H_O: \mu = RT \quad \text{versus} \quad H_A: \mu < RT$$

at a level of significance α, with $\nu = (n - 1)$. Verification that a waste does not exhibit a toxicity characteristic is demonstrated if

$$\left|\frac{\bar{x}-RT}{s/\sqrt{n}}\right| \geq t_{\alpha,\nu} \qquad \text{C-5(1)}$$

where

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \text{ , the sample mean} \qquad \text{C-5(2)}$$

and

$$s^2 = \frac{1}{(n-1)}\left(\sum_{i=1}^{n} x^2{}_i - \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n}\right) \text{ , the sample variance} \qquad \text{C-5(3)}$$

$$s = \sqrt{s^2} \text{ , the sample standard deviation} \qquad \text{C-5(4)}$$

n = sample size

$t_{\alpha,\nu}$ = t critical value.

Verifying Tier 1 Parameters

After Tier 1 sampling is completed, estimates of the average amount of a particular analyte and its standard deviation may be used to determine the number of Tier 2 samples.

For a particular analyte, there are three possible outcomes from the Tier 1 sampling. First, the average amount may be so far below the regulatory threshold that further sampling is not warranted because the probability of ever reaching or exceeding the threshold value is practically zero. Second, the average amount may be so far above the threshold that further sampling is not warranted because the probability of ever falling below the threshold value is nearly zero. In the third case, the average amount may be close to the threshold value (either above or below), so that further sampling is required to verify whether a waste should be classified hazardous or not.

The number of samples required (EPA, 1986) for Tier 2 will be computed using

$$n = \frac{t^2_{\alpha,\nu}\, s^2}{|\bar{x}-RT|^2} \qquad \text{C-5(5)}$$

When the sample average is far from the RT (either above or below it,) the denominator will be large. This, in turn, will reduce the number of samples for Tier 2 sampling.

C-5e Data Variability and Pooling Qualifications

The Tier 2 parameter averages and variances [Equations C-5(2) and C-5(3)] will be compared to those of the Tier 1 sample and previous similar Tier 2 samples to ensure that no significant changes in average concentrations or in variability exist within the population. This comparison will be performed by formally testing two hypotheses. The first test involves the sample variances. The second test involves the averages. If either test results in a conclusion that the Tier 2 sample statistic is different from that of Tier 1, then a significant difference exists, and data should not be pooled. Therefore, another Tier 1 random sample (30 or more) will be collected using the original Tier 2 data as part of the new sample.

The test for equal variances is based on the F-statistic and the hypotheses are

$$H_O: \sigma_1^2 = \sigma_2^2 \quad \text{versus} \quad H_A: \sigma_1^2 \neq \sigma_2^2$$

where σ_1 is the standard deviation for the Tier 1 sample and σ_2 is the standard deviation for the Tier 2 sample. The ratio of the variances is compared to a critical value (Koopmans, 1986) from the F-distribution with $\nu_1 = (n_1 - 1)$ and $\nu_2 = (n_2 - 1)$ degrees of freedom. The ratio of the variances is computed so that the larger variance appears in the numerator, and the ratio is compared to a critical value with the closest numerator and denominator degrees of freedom. A significant change in variance exists if

$$\frac{s_1^2}{s_2^2} \geq F_{\left(\frac{\alpha}{2},\nu_1,\nu_2\right)}. \qquad \text{C-5(6)}$$

If the variances are significantly different (reject null hypothesis), the Tier 2 sample will not be pooled with Tier 1 data. A significant waste analyte concentration difference exists, and the Tier 2 sample will be included as part of a new initial Tier 1 sample.

If the variances are equal as evaluated using Equation C-5(6), the next step is to compare the average of the Tier 1 sample (and previous similar Tier 2 samples) to the current Tier 2 sample. This comparison is made with a two-sample t-test as follows. The hypotheses are

$$H_O: \mu_1 = \mu_2 \quad \text{versus} \quad H_A: \mu_1 \neq \mu_2$$

where the averages are from the Tier 1 and Tier 2 samples, respectively. The sample's t-statistic is compared to a t-critical value with ν equal to $(n_1 + n_2 - 2)$. The two-sample t-statistic is

$$|t| = \left| \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{(n_1-1)\,s_1^2 + (n_2-1)\,s_2^2}{n_1 + n_2 - 2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \right| \qquad \text{C-5(7)}$$

and the null hypothesis of equivalent averages is rejected if the sample's t-value exceeds the critical value.

If the averages are significantly different, then the data will not be pooled. The Tier 2 data will be treated as part of a new Tier 1 sample. However, if both the two-sample t-test [Equation C-5(7)] and the F-test [Equation C-5(6)] conclude that there is no significant difference between the current Tier 2 data and the Tier 1 (and previous similar Tier 2) data, then the data may be pooled and updated values of the average and variance will be computed [Equations C-5(2) and C-5(3)]. Failure to pool data, when it is appropriate, will limit the precision of the estimates to what was achieved in Tier 1 sampling.

C-6 Waste Shipment Screening and Verification

All incoming waste shipments will be screened to ensure that the waste received meets the permitted boundary conditions and process tolerance limits. As described in Section C-7, stringent quality controls related to waste labelling, identification, transport, and screening will ensure that the waste arriving at the WIPP facility is identical to that transported from the generator sites and is correctly identified with the hazardous waste manifest.

Waste shipment screening is a two-phased process that involves the verification of process tolerance limits; the verification of boundary conditions; the examination of the Waste Profile Form; the examination of the hazardous waste manifest and associated waste tracking information; the examination of the land disposal restriction notice; and the visual inspection of the waste shipment. The waste shipment screening process is diagrammed in Figure C-2. Table C-13 lists all of the waste screening determinations, their origin (facility-established or EPA-established), and whether they affect the decision to transport or the decision to accept a waste

shipment. Tables C-14 and C-15 list all of the waste screening determinations and summarize the parameter(s) and method(s) for each determination.

C-6a Phase I Waste Shipment Screening and Verification

The first phase of the waste shipment screening process verifies the waste shipment screening data and information that is associated with process tolerance limits and boundary conditions. The data and information result from five determinations that are made at the generator sites; namely, (1) the determination of Waste Category; (2) the determination of ignitability, reactivity, and corrosivity; (3) the determination of compatibility; (4) the determination of the concentration of VOCs in the headspace of containers holding TRU waste; and (5) the determination of the flammability potential of the headspace of containers holding TRU waste. The first phase of the waste shipment screening process also verifies the results of one determination that is made at the WIPP facility; namely, the determination of Waste Profile Form completeness. WIPP Project personnel verify that each container in a potential waste shipment meets all of the boundary conditions and process tolerance limits before the waste shipment is transported to the WIPP facility. Generators cannot transport any container holding TRU waste that does not meet all of the boundary conditions and process tolerance limits.

Verification of Process Tolerance Limits

Three waste shipment screening data verifications are made by WIPP Project personnel on every container holding TRU waste before a shipment leaves the generator site for the facility. The three verifications are performed on data from the following determinations: (1) the determination of Waste Category; (2) the determination of ignitability, reactivity, and corrosivity; and (3) the determination of compatibility.

The determination of Waste Category is made by the generator site and verified by WIPP before a waste shipment is transported to the WIPP facility. For each container holding TRU waste, generator sites provide the RTR data records and indicate the Waste Category on the Waste Profile Form. The generator sites transmit the RTR data records and Waste Profile Forms to the WIPP facility in advance of a waste shipment. WIPP Project personnel verify all RTR data records and Waste Profile Forms to ensure that only acceptable Waste Categories are included in the waste shipment. If, in a waste shipment, each container holding TRU waste contains an acceptable Waste Category, WIPP Project personnel notify the generator that the waste shipment can be accepted at the WIPP facility. If not, the waste shipment cannot be transported to the WIPP facility. All aspects of QA/QC associated with the transmittal and approval of the RTR data records and the Waste Profile Forms are controlled by the waste shipment screening QA/QC program described in Section C-7.

The determination of ignitability, reactivity, and corrosivity is made by the generator site and verified by WIPP Project personnel for every waste container in every waste shipment before a

waste shipment is transported to the WIPP facility. Using RTR analysis, generator sites determine if compressed gases or significant quantities of liquids are present in any of the containers making up a waste shipment. Generators also determine if each container holding TRU waste in a waste shipment has been WAC-certified. The data from RTR analysis, which includes all of the RTR data records, and documentation of WAC-certification are transmitted to the WIPP facility in advance of a waste shipment. Documentation of WAC-certification is provided on the Waste Profile Form. Prior to the shipment of TRU waste, the RTR data records and the Waste Profile Forms are verified by WIPP Project personnel. This ensures that only acceptable Waste Categories and WAC-certified containers are included in the waste shipment. If all TRU waste is acceptable, WIPP Project personnel notify the generator that the waste shipment can be accepted at the WIPP facility. If not, the waste shipment must be reconfigured to contain only acceptable waste containers. All aspects of QA/QC associated with the transmittal and approval of data records and Waste Profile Forms are controlled by the waste shipment screening QA/QC program in Section C-7.

The determination of compatibility, as discussed in Section C-3a, is verified by WIPP Project personnel accepting only specific Waste Categories. The determination of compatibility is therefore made by determinating the Waste Category.

Verification of Boundary Conditions

Two waste shipment screening data verifications are made by WIPP Project personnel on every container holding TRU waste before a shipment leaves the generator site for the WIPP facility. The two verifications are performed on data from the following determinations: (1) the determination of the concentration of VOCs in the headspace of containers holding TRU waste and (2) the determination of the flammability potential of the headspace of containers holding TRU waste. Generator sites perform the requisite analytical work on each container in the waste shipment and transmit the data to the WIPP facility. The data are verified by WIPP Project personnel to ensure that boundary conditions are not exceeded. If each container in a waste shipment meets all of the boundary conditions, WIPP Project personnel notify the generator that the waste shipment is acceptable at the WIPP facility. If not, the generator can transport only those containers that have met the boundary conditions. All aspects of QA/QC associated with data acquisition, and data report transmittal and approval are controlled by the waste shipment screening QA/QC program in Section C-7.

Examination of the Waste Profile Form

A Waste Profile Form must be completed for each waste container. In the case of containers that are comprised of TRU waste from more than one original container, a Waste Profile Form is required for all of the original containers as well as another Waste Profile Form for the final, composite waste container. For example, during the Test Phase a SWB will contain a bin into which has been emptied the contents of four to six 55-gallon drums. A separate Waste Profile

Form is required for each of the 55-gallon drums emptied into the bin as well as a Waste Profile Form for the bin itself. An example of the Waste Profile Form is shown in Figure C-3.

Waste Profile Forms are transmitted to the WIPP facility before a waste shipment leaves the generator site. Upon receipt of the Waste Profile Forms, a determination of Waste Profile Form completeness will be made at the WIPP facility. WIPP Project personnel will use standard operating procedures to check the Waste Profile Form for the following information:

- The generator site name, technical contact, telephone number, and EPA generator identification number
- The waste container identification number and whether or not the waste container is a Test Bin
- A listing of the identification numbers for waste containers placed in the Test Bin, as appropriate
- The data report cross-reference number
- The waste category
- The waste type
- The date of waste container WAC-certification
- The analytical techniques used to characterize the waste
- The reference and date for each sampling procedure used
- The designation of the appropriate sampling tier
- The listing of all appropriate EPA Hazardous Waste Codes
- A signed statement of accuracy.

If any discrepancies arise as a result of this examination, the generator will be contacted to resolve the problem before the waste container is transported to the facility. If the discrepancy cannot be resolved, the waste container cannot be transported to the facility. All aspects of QA/QC associated with the determination of Waste Profile Form completeness are controlled by the waste shipment screening QA/QC program described in Section C-7.

C-6b Phase II Waste Screening and Verification

The second phase of the waste shipment screening process verifies the results of determinations that are made after a waste shipment has arrived but before it is accepted at the WIPP facility. The second-phase determinations are: (1) the determination of hazardous waste manifest completeness, (2) the determination of waste shipment completeness, (3) the determination of land disposal restriction notice completeness, and (4) the determination of waste shipment irregularities. WIPP Project personnel will only sign a hazardous waste manifest to accept an entire waste shipment if the results from all of the Phase II waste shipment screening determinations are acceptable; otherwise, the entire waste shipment will not be accepted by the WIPP facility. If a waste shipment has containers that fail one or more Phase II waste screening determinations, WIPP Project personnel may choose to accept only those waste containers that pass all Phase II waste screening determinations. In this case, WIPP Project personnel will first indicate the unacceptable containers on the hazardous waste manifest and then sign the hazardous waste manifest.

Entire waste shipments that have been rejected will be transported back to the generator with the hazardous waste manifest unsigned by WIPP Project personnel. Unacceptable waste containers that have been rejected will be transported to the generator site from the WIPP facility using a new hazardous waste manifest.

Examination of the Hazardous Waste Manifest and Associated Waste Tracking Information

Upon receipt of a waste shipment, a determination of hazardous waste manifest completeness will be made at the WIPP facility. Each hazardous waste manifest that accompanies a waste shipment will be checked for completeness. WIPP Project personnel will follow standard operating procedures to check the hazardous waste manifest for the following information:

- The hazardous waste manifest number
- The shipment identification number
- The generator's name, address, and EPA identification number
- The transporter's name and EPA identification number
- The destination of the waste shipment including the name of the hazardous waste management facility, address, and EPA identification number
- A DOT shipping name and number
- The quantity (weight) of waste in the shipment

- The number and type of containers in the shipment
- A signed and dated certification of the shipment's content.

If there are discrepancies, they will be resolved by contacting the generator before the hazardous waste manifest is signed by WIPP Project personnel. If the discrepancies cannot be resolved, WIPP Project personnel will either reject the entire waste shipment or reject only those containers associated with the discrepancies. Rejected waste will be returned to the generator. All aspects of QA/QC associated with the determination of hazardous waste manifest completeness are controlled by the waste shipment screening QA/QC program described in Section C-7.

Using standard operating procedures, WIPP Project personnel will make a determination of waste shipment completeness by checking the unique, bar-coded identification number found on each container holding TRU waste. The bar-coded identification number check will be performed on every SWB. The bar-coded identification number(s) will be noted and checked against the WIPP Waste Information System (WWIS) database. The WWIS mainframe computer system maintains the following information associated with each container holding TRU waste:

- Shipment identification number
- TRUPACT-II cask identification number
- Assembly number
- Package (container) identification number
- Overpack identification number (if appropriate)
- Package (container) receipt date
- Package (container) emplacement date
- Package (container) emplacement location
- Package (container) emplacement panel/room.

The WWIS links the bar-coded identification numbers of all containers in a specific waste shipment to the waste shipment identification number, which is written on the hazardous waste manifest. Generators use the WWIS to electronically transmit the waste shipment information above to the WIPP facility before the waste shipment is transported. Once a waste shipment arrives, WIPP Project personnel can verify the identity of each container using the WWIS. Any discrepancies will be resolved by contacting the generator before the hazardous waste manifest is signed by WIPP Project personnel. If the discrepancies cannot be resolved, WIPP will either reject the entire waste shipment or reject only those containers associated with the discrepancies. Rejected waste will be returned to the generator. All aspects of QA/QC associated with the determination of waste shipment completeness are controlled by the waste shipment screening QA/QC program described in Section C-7.

Examination of the Land Disposal Restriction Notice

The EPA has granted DOE a conditional variance for the land disposal of untreated, restricted TRU waste at the WIPP facility. The term of the variance is from November 14, 1990, to November 14, 2000. The WIPP Project may accept the restricted waste disclosed in the NMVP (DOE, 1990a). With each waste shipment of land disposal restricted waste, the generator must provide the WIPP facility with a land disposal restriction determination and a notice that the waste is not prohibited from land disposal because the EPA has granted DOE a conditional no-migration variance for the WIPP facility. WIPP Project personnel will review this notice for the accuracy and completeness of the following information:

- The EPA hazardous waste number(s)
- The corresponding treatment standards for wastes F001 - F005
- The treatment standards for other allowable restricted waste
- The applicable five-letter treatment code found in Table 1 of 40 CFR 268.42, where applicable treatment standards are expressed as specific technologies
- The hazardous waste manifest number associated with the waste shipment
- The date the waste is subject to the prohibitions.

If there are discrepancies, they will be resolved by contacting the generator before the hazardous waste manifest is signed by WIPP Project personnel. If the discrepancies cannot be resolved, WIPP Project personnel will either reject the entire waste shipment or reject only those containers associated with the discrepancies. Rejected waste will be returned to the generator. All aspects of QA/QC associated with the determination of land disposal restriction notice completeness are controlled by the waste shipment screening QA/QC program described in Section C-7.

Visual Inspection

Using standard operating procedures, WIPP Project personnel will make a determination of waste shipment irregularities. Each waste shipment arriving at the WIPP facility will be visually inspected noting:

- If the number and type of containers holding TRU waste match the hazardous waste manifest
- If the shipment labels and placards match the hazardous waste manifest

- Any irregularities with the shipment, as for example, packaging deformities.

If there are discrepancies, they will be resolved by contacting the generator before the hazardous waste manifest is signed by WIPP Project personnel. If the discrepancies cannot be resolved, WIPP Project personnel will either reject the entire waste shipment or reject only those containers associated with the discrepancies. Rejected waste will be returned to the generator. All aspects of QA/QC associated with the determination of waste shipment irregularities are controlled by the waste shipment screening QA/QC program described in Section C-7.

C-7 QA/QC Program

DOE operates a QA/QC program to ensure and maintain the integrity of data, documents, and information associated with the management of TRU waste. The QA/QC program also ensures that waste is tracked from the generator site to its final emplacement at the WIPP facility. The overall QA/QC program is divided into the areas of waste characterization, waste shipment screening, and waste tracking.

C-7a Waste Characterization QA/QC

Waste characterization is the detailed analyses of TRU waste that serves to monitor any changes in the concentrations of required parameters (Sections C-4 and C-5), the appearance of new parameters, or variations in physical properties of the waste. Sampling and analytical waste characterization requirements are established by the WIPP Project (Sections C-4 and C-5) and are implemented at the generator sites.

Waste characterization QA/QC ensures that the characterization data obtained at generator sites is suitable for regulatory compliance purposes. WIPP maintains stringent QA/QC over the generation, transmittal, and verification of data from waste characterization determinations. In addition, the WIPP Project extends QA/QC practices to the management of all records associated with waste shipment screening determinations.

Data Generation

As required by Chapter 1.0 of SW-846 (EPA, 1986), waste characterization QA/QC is controlled by quality assurance project plans (QAPjP). The generator site QAPjPs are in turn controlled by the QAPP (DOE, 1991a). The QAPP addresses the QA/QC requirements of both Chapter 1.0 of SW-846 (EPA, 1986) and the American Society of Mechanical Engineers NQA-1, Quality Assurance Program Requirements for Nuclear Facilities (ASME, 1989). The QAPP identifies the specific requirements for all QAPjPs, including data quality objectives; quality assurance objectives; sampling procedures; sample custody procedures; calibration procedures and frequencies; analytical procedures; data reduction, validation, and reporting requirements; internal QC checks and frequencies; performance and system audits and frequencies; preventive

maintenance; procedures for assessing data quality; and procedures for corrective actions. All generator site QAPjPs are reviewed by WIPP Project personnel and audited by the WIPP Waste Acceptance Criteria Certification Committee (WACCC). WACCC audits ensure that implementation of the QAPjPs is consistent with the intent of the requirements of the QAPP.

The WIPP Project further requires all analytical laboratories analyzing TRU waste samples for the generator sites to have established, written QA/QC programs. DOE periodically audits these laboratories and their QA/QC programs.

Analytical methods used must (1) satisfy all of the appropriate quality assurance objectives given in the QAPP and (2) be implemented through laboratory documented, standard operating procedures. If properly implemented, the analytical methods published in SW-846 (EPA, 1986) or their equivalents can be used to satisfy all data generation requirements. In addition, DOE has published a compendium of recommended analytical methods in the Guidance Manual (DOE, 1991b). The methods contained in the Guidance Manual will, if properly implemented, fulfill all of the QAPP requirements. The Guidance Manual methods are modifications of SW-846 (EPA, 1986) protocols and other EPA-approved methods.

Data Transmittal

The QAPP, through the generator site QAPjPs, controls all aspects of waste characterization data transmittal. Data reports document the analytical results from all of the required characterization analyses and contain all of the raw data plus documentation of all required QA/QC activities associated with the sampling and analyses.

The QAPP establishes requirements for maintaining the integrity of the data in data reports by requiring data validation at both the data generation level and the generator-site project level before the data are transmitted to the WIPP facility.

Data Verification

The WIPP facility maintains approved, document-controlled standard operating procedures for the verification of data and information from all waste characterization analyses. Only approved, document-controlled standard operating procedures will be used by WIPP Project personnel for the verification of waste characterization data and information. Use of controlled standard operating procedures assures that data verification is conducted consistently and that record of data verification is created that can be audited.

Records Management

All waste characterization data and documents that are part of the WIPP facility operating record are managed in accordance with approved, document-controlled standard operating procedures.

C-7b Waste Shipment Screening QA/QC

Waste shipment screening is a two-phase process at the WIPP facility (Section C-6). Waste shipment screening QA/QC ensures that the data obtained from waste shipment screening determinations are accurate and precise so that the WIPP facility accepts only the waste it is designed and authorized to properly manage. The WIPP Project accomplishes this by maintaining stringent QA/QC over the generation, transmittal, and verification of data from waste shipment screening determinations. In addition, the WIPP Project extends QA/QC practices to the management of all records associated with waste shipment screening determinations.

Data Generation

The detailed nature and magnitude of the waste shipment screening data that are obtained at generator sites requires that the WIPP Project provides the generator sites with specific, data generation QA/QC requirements. Therefore, all elements of QA/QC that affect data for (1) the determination of the Waste Category of the waste; (2) the determination of ignitability, reactivity, and corrosivity; (3) the determination of compatibility; (4) the determination of the concentration of VOCs in the headspace of containers holding TRU waste; and (5) the determination of the flammability potential of the headspace of containers holding TRU waste, are established in the QAPP. As discussed in Section C-7a, the QAPP establishes quality assurance objectives, data quality objectives, and instrument calibrations and frequencies, in addition to specifying the QA/QC requirements for sampler and analyst training, sample chain-of-custody, and data validation and reporting. The QAPP further requires analytical laboratories to participate in a regularly scheduled laboratory performance demonstration program.

Data Transmittal

Generators will transmit data reports and Waste Profile Forms to the WIPP facility, in accordance with the protocols specified in the QAPP. Together, this information documents the analytical results of all of the waste screening determinations required of a waste shipment.

The determination of waste shipment completeness requires waste shipment data that are transmitted to the WIPP facility using the WWIS. The WIPP facility maintains approved, document-controlled standard operating procedures for all functions affecting the WWIS, including accessing, protecting, and maintaining current waste shipment data. In addition, DOE has established a restricted access, computer network security system for the WWIS.

Data Verification

The WIPP Project has established approved, document-controlled standard operating procedures for the verification of data and information from all waste screening determinations performed at generator sites. Only approved, document-controlled standard operating procedures will be used for the verification of waste screening determination data and information.

The WIPP Project has established approved, document-controlled standard operating procedures for the determination of Waste Profile Form completeness. The determination of Waste Profile Form completeness is conducted at the WIPP facility prior to transporting the waste container listed in the Waste Profile Form to the WIPP facility.

The WIPP Project has established approved, document-controlled standard operating procedures for the following waste screening determinations that are conducted at the WIPP facility prior to the acceptance of a waste shipment: (1) the determination of hazardous waste manifest completeness, (2) the determination of waste shipment completeness, (3) the determination of land disposal restriction notice completeness, and (4) the determination of waste shipment irregularities.

Records Management

As part of the WIPP facility's operating record, all data and documents associated with waste characterization data are managed in accordance with approved, document-controlled standard operating procedures.

C-7c Waste Tracking QA/QC

The Transportation Tracking and Communications System (TRANSCOM) is a unique, waste shipment monitoring system that provides 24 hour-a-day feedback to the WIPP facility, via satellite, on the location and status of each waste shipment during transport. Each tractor-trailer transporting TRU waste to the WIPP facility is equipped with a two-way, TRANSCOM communications system. Every 15 minutes the system automatically signals the TRANSCOM Control Center with updated geographical location and status information. DOE can track a container holding TRU waste, via TRANSCOM, from the generator site to the WIPP facility. The TRANSCOM system, plus driver qualifications and training, provides greater waste shipment security than the waste shipment security of typical hazardous waste transporters. DOE maintains approved, document-controlled standard operating procedures for tracking TRU waste via the TRANSCOM system.

The WWIS is used for on-site waste tracking. After a waste shipment arrives at the WIPP facility, the WWIS is updated with the appropriate container emplacement information (emplacement coordinates and time) as well as the waste shipment's hazardous waste manifest number. After

entering all appropriate emplacement information and the hazardous waste manifest number, a WWIS database report is generated. The WWIS report is maintained as part of the WIPP facility operating record. DOE maintains approved, document-controlled standard operating procedures for all functions affecting the WWIS. Additionally, the WIPP Project has established a restricted-access computer network security system for the WWIS.

List of References for Chapter C

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TABLES

TABLE C-1
RATIONALE FOR SELECTION OF PARAMETERS OF INTEREST

Chemicals[1]	Listed Waste (HWMR-6,[2] Part II, section 261.31)	Characteristic Waste (HWMR-6,[2] Part II, section 261.24)	Hazardous Constituents (HWMR-6,[2] Part II, Appendix VIII)	Conditional No-Migration Determination (55 FR 47700)	Generator Information
Volatile Organic Compounds (VOC)					
Benzene	•	•	•	•	•
Bromoform			•		•
Carbon disulfide	•		•		•
Carbon tetrachloride	•	•	•	•	•
Chlorobenzene	•	•	•	•	•
Chloroform		•	•		•
Cyclohexane				•	•
1,1-Dichloroethane			•	•	•
1,2-Dichloroethane		•	•	•	•
1,1-Dichloroethylene		•	•	•	
(Z)-1,2-Dichloroethylene			•	•	
Ethyl benzene	•			•	•
Methylene Chloride	•		•	•	•
2-Nitropropane	•		•		•
1,1,2,2-Tetrachloro-ethane			•		•
Tetrachloroethylene	•	•	•		•
Toluene	•		•	•	•
1,1,2-Trichloroethane	•		•		•
1,1,1-Trichloroethane	•		•	•	•
Trichloroethylene	•	•	•	•	•
Trichlorofluoromethane	•		•		•
1,3,5-Trimethylbenzene				•	
1,2,4-Trimethlybenzene				•	

TABLE C-1
RATIONALE FOR SELECTION OF PARAMETERS OF INTEREST (CONTINUED)

Chemicals[1]	Listed Waste (HWMR-6,[2] Part II, section 261.31)	Characteristic Waste (HWMR-6,[2] Part II, section 261.24)	Hazardous Constituents (HWMR-6,[2] Part II, Appendix VIII)	Conditional No-Migration Determination (55 FR 47700)	Generator Information
1,1,2-Trichloro-1,2,2-trifluoroethane	•		•	•	•
Vinyl chloride		•	•		
Xylenes	•			•	•
Non-Halogenated VOCs					
Acetone	•			•	•
n-Butyl alcohol	•			•	•
Cyclohexanone	•				•
Diethyl ether	•			•	•
2-Ethoxyethanol	•				•
Ethyl acetate	•				•
Formaldehyde					•
Hydrazine			•		•
Isobutanol	•				•
Methanol	•			•	•
Methyl ethyl ketone	•	•	•	•	•
Methyl isobutyl ketone	•			•	•
Semi-VOCs					
Cresols	•	•	•		•
ortho-Dichlorobenzene	•		•		•
1,4-Dichlorobenzene		•	•		
2,4-Dinitrotoluene		•	•		
Hexachloroethane		•	•		
Nitrobenzene	•	•	•		•

TABLE C-1
RATIONALE FOR SELECTION OF PARAMETERS OF INTEREST
(CONTINUED)

Chemicals[1]	Listed Waste (HWMR-6,[2] Part II, section 261.31)	Characteristic Waste (HWMR-6,[2] Part II, section 261.24)	Hazardous Constituents (HWMR-6,[2] Part II, Appendix VIII)	Conditional No-Migration Determination (55 FR 47700)	Generator Information
Polychorinated Biphenyls			•		•
Pyridine	•	•	•		•
Metals					
Arsenic		•	•		•
Barium		•	•		•
Beryllium			•		•
Cadmium		•	•		•
Chromium		•	•		•
Lead		•	•		•
Mercury		•	•		•
Nickel			•		•
Selenium		•	•		•
Silver		•	•		•
Thallium			•		•

1. The following chlorinated pesticides and herbicides: 2,4-D; Endrin; Heptachlor; Hexachlorobenzene; Hexachlorobutadiene; Methoxychlor; Pentachlorophenol; Toxaphene; 2,4,5-Trichlorophenol; 2,4,6-Trichlorophenol and 2,4,5-TP (Silvex) are conservatively listed in the Part A to this Permit Application, however these chemicals are not used at the generator sites and are not present in the waste.

2. New Mexico Hazardous Waste Management Regulations (HWMR-6), as amended 1991.

TABLE C-2
BOUNDARY CONDITIONS AND PROCESS TOLERANCE LIMITS ESTABLISHED BY THE WASTE ISOLATION PILOT PLANT

Determination	Parameter	Boundary Condition or Process Tolerance Limit
Ignitability, reactivity, and corrosivity	Liquids or Aqueous Waste	Residual liquid only with all internal containers well-drained
	Oxidizers	No oxidizers
	Explosives	No explosives
	Compressed gases	No compressed gases
	Pyrophoric materials	No nonradionuclide pyrophoric materials
Compatibility	Waste Category	Only those Waste Categories described in Section C-2
Waste Category	Waste Category	Only those Waste Categories described in Section C-2

TABLE C-3
BOUNDARY CONDITIONS ESTABLISHED BY THE U.S. ENVIRONMENTAL PROTECTION AGENCY FOR THE WASTE ISOLATION PILOT PLANT

Determination	Parameter	Boundary Conditions								
		Waste Type[a]	Maximum Allowable Volatile Organic Compound (VOC) Headspace Concentrations (Volume Percent)					Maximum Allowable Mean VOC Headspace Concentrations (Volume Percent)		
			CCl_4[b]	CH_2Cl_2[c]	TCA[d]	TCE[e]	Freon 113[f]	CCl_4[b]	CH_2Cl_2[c]	TCE[e]
Concentration of VOCs in waste container headspace	Headspace VOCs	I	0.08	0.44	1.88	0.08	0.05	0.24	0.39	0.25
		II	0.18	0.84	5.68	0.34	1.62	0.26	0.42	0.28
		III	0.58	0.50	2.12	0.28	5.74	0.30	0.33	0.29
		IV	8.18	1.42	14.96	0.28	20.80	6.90	0.93	0.38
Flammability potential of waste container headspace	Hydrogen and methane plus flammable VOCs[g]	If the headspace concentration of flammable VOCs is <500 parts per million by volume (ppmv), the calculated[h] lower explosive limit for hydrogen and methane must be < 0.5. If the headspace concentration of flammable VOCs is >500 ppmv, the flammability of the headspace gas mixture must be determined by a flame test[i].								

[a] As established in TRUPACT-II Content Codes (TRUCON) (DOE, 1990b)
[b] Carbon Tetrachloride
[c] Methylene chloride.
[d] 1,1,1-Trichloroethane
[e] Trichloroethylene
[f] 1,1,2-Trichloro-1,2,2-trifluoroethane
[g] Flammable VOCs are listed in Table C-5.
[h] The procedure for calculating lower explosive limit values is detailed in the Quality Assurance Program Plan for the Waste Isolation Pilot Plant Experimental-Waste Characterization Program (DOE, 1991b).
[i] The flame test procedure is detailed in the WIPP Waste Characterization Program Sampling and Analysis Guidance Manual (DOE, 1991c).

TABLE C-4
RATIONALE FOR COMPLIANCE WITH PROHIBITED CHARACTERISTIC WASTES

Prohibited Characteristics	Rationale for TRU Waste Compliance
Ignitability - Liquid waste. - Under standard temperature and pressure, capable of causing fire through friction, absorption of moisture or spontaneous chemical changes. - Contains ignitable compressed gases as defined in 49 CFR 173.300. - Contains oxidizers as defined in 49 CFR 173.151.	Ignitability - Waste is not a liquid. Verified by Real Time Radiography (RTR). - Generator waste handling and storage under standard temperature and pressure. - Prohibited by the Waste Acceptance Criteria (WAC). Verified by RTR. - Knowledge of processes and final Waste Category.
Corrosivity - Aqueous or liquid waste.	Corrosivity - A representative sample is not a liquid or aqueous waste. Verified by RTR.
Reactivity - Unstable and will readily undergo violent change without detonating. - When mixed with water, will react violently, form a potentially explosive mixture, or generate harmful toxic gases, vapors or fumes. - If subjected to a strong initiating force or if heated under confinement, will detonate or explode. - Cyanide or sulfide bearing waste. - Capable of detonation or explosive decomposition at standard temperature and pressure. - A forbidden explosive as defined in 49 CFR 173.51, a Class A explosive as defined in 49 CFR 173.53, or a Class B explosive as defined in 49 CFR 173.88.	Reactivity - Generator waste handling and storage under standard temperature and pressure. - Knowledge of processes and final Waste Category. - Knowledge of processes and final Waste Category. - Knowledge of processes and final Waste Category. - Generator waste handling and storage under standard temperature and pressure. - Explosives prohibited in plutonium areas at generator sites.

TABLE C-5
FLAMMABLE VOLATILE ORGANIC COMPOUNDS[a] (VOCs) AND THEIR LOWER EXPLOSIVE LIMIT (LEL) VALUES[b,c]

VOCs	LEL (v/v%)
Acetone	2.5
Benzene	1.3
n-Butyl alcohol	1.4
Chlorobenzene	1.3
Cyclohexane	1.3
1,1-Dichloroethane	5.6
1,2-Dichloroethane	6.2
1,1-Dichloroethylene	6.5
(Z)-1,2-Dichloroethylene	5.6
Diethyl ether	1.9
Ethyl benzene	1.0
Methanol	6.0
Methyl ethyl ketone	1.4
Methyl isobutyl ketone	1.2
Toluene	1.2
1,2,4-Trimethylbenzene	0.9
1,3,5-Trimethylbenzene	1.4
o-Xylene	1.0
m-Xylene	1.1
p-Xylene	1.1

[a] VOCs identified as flammable by the U.S. Environmental Protection Agency (EPA) for the No-Migration Determination (EPA 1990). The EPA determined flammability by assessing potential fire hazards under Waste Isolation Pilot Plant conditions on a compound by compound basis.

[b] The LEL is also refered to as the lower flammable limit (ASTM, 1989 and NFPA, 1986)

[c] LEL values are reprinted from NFPA, 1986 and GPC, 1988.

TABLE C-6
SUMMARY OF SAMPLE PREPARATION AND ANALYTICAL METHODS FOR TOTAL METALS

Parameters	Analytical Methods[a]
Total Arsenic	6010, 6020, 7060, 7061 or equivalent
Total Barium	6010, 6020, 7080, 7081 or equivalent
Total Beryllium	6010, 6020, 7090, 7091 or equivalent
Total Cadmium	6010, 6020, 7130, 7131 or equivalent
Total Chromium	6010, 6020, 7190, 7191 or equivalent
Total Lead	6010, 6020, 7420, 7421 or equivalent
Total Mercury	6010, 7471 or equivalent
Total Nickel	6010, 6020, 7520 or equivalent
Total Silver	6010, 6020, 7760, 7761 or equivalent
Total Selenium	6010, 7740, 7741, 7742 or equivalent
Total Thallium	6010, 6020, 7840, 7841 or equivalent

[a] "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods," SW-846, Third Edition, (EPA, 1986). Equivalent methods are demonstrated by meeting the quality assurance/quality control requirements specified in SW-846 protocols.

TABLE C-7
REQUIRED ORGANIC ANALYTES AND TEST METHODS ORGANIZED BY ORGANIC ANALYTICAL GROUPS

Organic Analytical Group	Required Organic Analytes	Analytical Method[a]
Volatile Organic Compounds	Benzene; Bromoform; Carbon disulfide; Carbon tetrachloride; Chlorobenzene; Chloroform; Cyclohexane[b]; 1,1-Dichloroethane; 1,2-Dichloroethane; 1,1-Dichloroethylene; (Z)-1,2-Dichloroethylene; Ethyl benzene; Methylene chloride; 2-Nitropropane; 1,1,2,2-Tetrachloroethane; Tetrachloroethylene; Toluene; 1,1,2-Trichloroethane; 1,1,1-Trichloroethane; Trichloroethylene; Trichlorofluoromethane; 1,3,5-Trimethylbenzene[b]; 1,2,4-Trimethylbenzene[b]; 1,1,2-Trichloro-1,2,2-trifluoroethane; Vinyl chloride; Xylenes	8240, 8260 or equivalent
Non-Halogenated, Volatile Organic Compounds	Acetone; n-Butyl alcohol; Cyclohexanone; Diethyl ether; 2-Ethoxyethanol; Ethyl acetate; Formaldehyde; Hydrazine; Isobutanol; Methanol; Methyl ethyl ketone; Methyl isobutyl ketone	8015, 8240, 8260, or equivalent
Semi-Volatile Organic Compounds	Cresols; ortho-Dichlorobenzene; 1,4-Dichlorobenzene; 2,4-Dinitrotoluene; Hexachloroethane; Nitrobenzene; Pyridine; Polychlorinated biphenyls (PCB)[c]	8250, 8270 or equivalent for all compounds 8080, 8081 or equivalent for PCBs

[a] "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods," SW-846, Third Edition (EPA, 1986). Equivalent methods are demonstrated by meeting the quality assurance/quality control requirements specified in the SW-846 protocols.

[b] Although not hazardous constituents, listed wastes, or characteristic wastes, these compounds must be analyzed because of the U.S. Environmental Protection Agency established, flammability boundary condition.

[c] Polychlorinated biphenyls (PCBs) analysis for Group II waste is required only for waste oils within the Organic Liquid and Sludge Waste Category. PCB analysis is required for all Group III waste.

TABLE C-8
VOLATILE ORGANIC COMPOUNDS (VOC) HEADSPACE TARGET COMPOUND LIST[a]

Volatile Organic Compounds
Acetone
Benzene
Bromoform
n-Butyl alcohol
Carbon tetrachloride
Chlorobenzene
Chloroform
Cyclohexane
1,1-Dichloroethane
1,2-Dichloroethane
1,1-Dichloroethylene
(Z)-1,2-Dichloroethylene
Diethyl ether
Ethyl benzene
Ethyl ether
Formaldehyde
Hydrazine
Methanol
Methylene chloride
Methyl ethyl ketone
Methyl isobutyl ketone
1,1,2,2-Tetrachloroethane
Tetrachloroethylene
Toluene
1,1,1-Trichloroethane
Trichloroethylene
1,1,2-Trichloro-1,2,2-trifluoroethane
1,3,5-Trimethylbenzene
1,2,4-Trimethylbenzene
Xylenes

[a] In accordance with the Quality Assurance Program Plan (DOE, 1991b), tentatively identified compounds shall also be reported.

TABLE C-9
SUMMARY OF PARAMETERS, RATIONALE, AND TEST METHODS FOR WASTE CATEGORIES IN GROUP I[a]

Group I Waste Categories	Parameters	Methods	Rationale
Combustibles and Noncombustibles Combustibles Graphite Filters Benelex® and Plexiglas® Firebrick and Ceramic Crucibles Leaded Rubber Metal Glass Supercompacted Waste	Total Metals listed in Table C-6 of this document	Process Knowledge	Hazardous Waste Determination
	Volatile Organic Compounds (VOCs) and Semi-VOCs listed in Table C-7	Process Knowledge	Hazardous Waste Determination Determine if polychlorinated biphenyls (PCBs) are present
	Headspace VOCs listed in Table C-8 of this document	WIPP Guidance Manual[b] Methods 430.1, 430.2, 440.1 or equivalent	Screen to assess concentrations of VOCs and verify process knowledge Determine the VOC hazardous constituent source term to assess the potential for migration in air

[a] This information is required in addition to the boundary condition and process tolerance limit data required in Section C-3.
[b] WIPP Waste Characterization Program Sampling and Analysis Guidance Manual (DOE, 1991c).

TABLE C-10
SUMMARY OF PARAMETERS, RATIONALE, AND TEST METHODS FOR WASTE CATEGORIES IN GROUP II[a]

Group II Waste Categories	Parameters	Methods	Rationale
Inorganic Waste Water Treatment Sludge Organic Liquid and Sludge	Total Metals (Table C-6 of this document)	See Table C-6 of this document	Determine Characteristic Metals Quantify Hazardous Constituents
Solidified Liquid	Volatile Organic Compounds (VOC) and Semi-VOCs[b] (Table C-7 of this document)	See Table C-7 of this document	Determine Characteristic Organics Quantify Hazardous Constituents Determine if polychlorinated biphenyls (PCBs) are less than 50 parts per million
Inorganic Process Solids and Soil Pyrochemical Salt[c] Cation and Anion Exchange Resins	Headspace VOCs (Table C-8 of this document)	WIPP Guidance Manual[d] Methods 430.1, 430.2, 440.1 or equivalent	Determine the VOC hazardous constituent source term to assess the potential for migration in air

[a] This information is required in addition to the boundary condition and process tolerance limit data required in Section C-3.
[b] PCB analysis is required for waste oils associated with the Organic Liquid and Sludge Waste Category only.
[c] Based on the knowledge of process generating the waste, VOC analyses, semi-VOC analyses and PCB analysis are not required.
[d] WIPP Waste Characterization Program Sampling and Analysis Guidance Manual (DOE, 1991c).

TABLE C-11
SUMMARY OF PARAMETERS, RATIONALE, AND TEST METHODS FOR THE WASTE CATEGORY IN GROUP III[a]

Group III Waste Category	Parameters	Methods	Rationale
Solid and Solidified Materials	Total Metals (Table C-6 of this document)	See Table C-6 of this document	Determine Characteristic Metals Quantify Hazardous Constituents
	Volatile Organic Coumpounds (VOCs) and Semi-VOCs (Table C-7 of this document)	See Table C-7 of this document	Determine Characteristic Organics Quantify Hazardous Constituents Determine if polychlorinated biphenyls (PCBs) are less than 50 parts per million
	Headspace VOCs (Table C-8 of this document)	WIPP Guidance Manual[b] Methods 430.1, 430.2, 440.1 or equivalent	Determine the VOC hazardous constituent source term to assess the potential for migration in air

[a] This information is required in addition to the boundary condition and process tolerance limit data required in Section C-3.
[b] WIPP Waste Characterization Program Sampling and Analysis Guidance Manual (DOE, 1991c).

TABLE C-12
SAMPLING FREQUENCIES FOR GROUP I, GROUP II, AND GROUP III HEADSPACE SAMPLING AND FOR GROUP II AND GROUP III SOLID WASTE SAMPLING

Retrievably Stored Waste		Current/Future Generated Waste	
Process Waste Stream	Batch Waste Stream	Process Waste Stream	Batch Waste Stream
Frequency determined by using Tier 1 and Tier 2 from Method 1 and/or Method 2 from this plan, as applicable	One sample per batch[a]	One sample per year or when process has changed[b]	One sample per batch[a]

[a] Additional supporting documentation required to qualify a group of drums as a batch.
[b] Either process material input or final waste sample required.

TABLE C-13
THE ORIGIN AND PHASE[a] OF ALL WASTE SCREENING DETERMINATIONS

Waste Shipment Screening Determination	Origin	Waste Shipment Screening Phase Level
Waste Category	Facility-established determination	Phase I
Ignitability, reactivity, and corrosivity	Facility-established determination	Phase I
Compatibility	Facility-established determination	Phase I
Concentration of Volatile Organic Compounds (VOCs) in waste container headspace	U.S. Environmental Protection Agency (EPA) established determination	Phase I
Flammability potential of waste container headspace	EPA-established determination	Phase I
Waste Profile Form completeness	Facility-established determination	Phase I
Hazardous waste manifest completeness	Facility-established determination	Phase II
Waste shipment completeness	Facility-established determination	Phase II
Land disposal restriction notice completeness	Facility-established determination	Phase II
Waste shipment irregularities	Facility-established determination	Phase II

[a] Phase I determinations are made before a generator can transport a waste shipment. Phase II determinations are made before the U.S. Department of Energy signs the hazardous waste manifest.

TABLE C-14
PHASE I WASTE SCREENING PARAMETERS AND APPROPRIATE DETERMINATION METHODS

Phase I Waste Shipment Screening Determination	Parameter	Method	Rationale
Waste Category	Waste Category	Real-time radiography per QAPP[a] and generator QAPjPs[b]	Determine acceptable Waste Categories.
Ignitability, reactivity, and corrosivity	Liquids and compressed gases	Real-time radiography per QAPP[a] and generator QAPjPs[b]	Determine acceptable transuranic (TRU) waste.
	Oxidizers, explosives, and pyrophoric materials	WP 02-6 and WP 02-7[c]	
Compatibility	Waste Category	Real-time radiography per QAPP[a] and generator QAPjPs[b]	Determine compatible TRU waste.
Concentration of volatile organic compounds (VOCs) in waste container headspace	Headspace VOCs	WIPP Guidance Manual[d] Methods 430.1, 430.2, 440.1 or equivalent	Test Phase no-migration and waste comparability demonstration.
Flammability potential of waste container headspace	Hydrogen and methane	WIPP Guidance Manual[d] Methods 510.1, 520.1, or equivalent	No-migration determination verification.
	Flammable VOCs	WIPP Guidance Manual[d] Methods 430.1, 430.2, 440.1 or equivalent	
	Lower explosive limit	QAPP[a] Equation 12-9	
	Flame Test	Guidance Manual[d] Method 810.1	
Waste Profile Form Completeness	Completeness of the Waste Profile Form	WP 02-6 and WP 02-7[c]	Determine acceptable TRU Waste

[a] Quality Assurance Program Plan, DOE, 1991b
[b] Quality Assurance Project Plans. QAPjPs are generator site-specific.
[c] Resource Conservation and Recovery Act (RCRA) Compliance Manual, Westinghouse, 1992b
[d] DOE, 1992

TABLE C-15
PHASE II WASTE SCREENING PARAMETERS AND APPROPRIATE DETERMINATION METHODS

Phase II Waste Shipment Screening Determination	Parameter	Method	Rationale
Hazardous waste manifest completeness	Manifest completeness	WP 02-06 and WP 02-7[a]	Waste shipment verification.
Waste shipment completeness	Waste container bar-code identification number	Waste Handling Normal Operations Procedures Manual, WP 05-NO[b]	Waste shipment verification.
Land disposal restriction notice completeness	Completeness and accuracy of the notice	WP 02-6 and WP 02-7[a]	Determine acceptable transuranic waste.
Waste shipment irregularities	Packaging deformities or irregularities	Waste Handling Normal Operations Procedures Manual, WP 05-NO[b]	Waste shipment verification.

[a] Resource Conservation and Recovery Act (RCRA) Compliance Manual, Westinghouse, 1992b
[b] Westinghouse, 1991

FIGURES

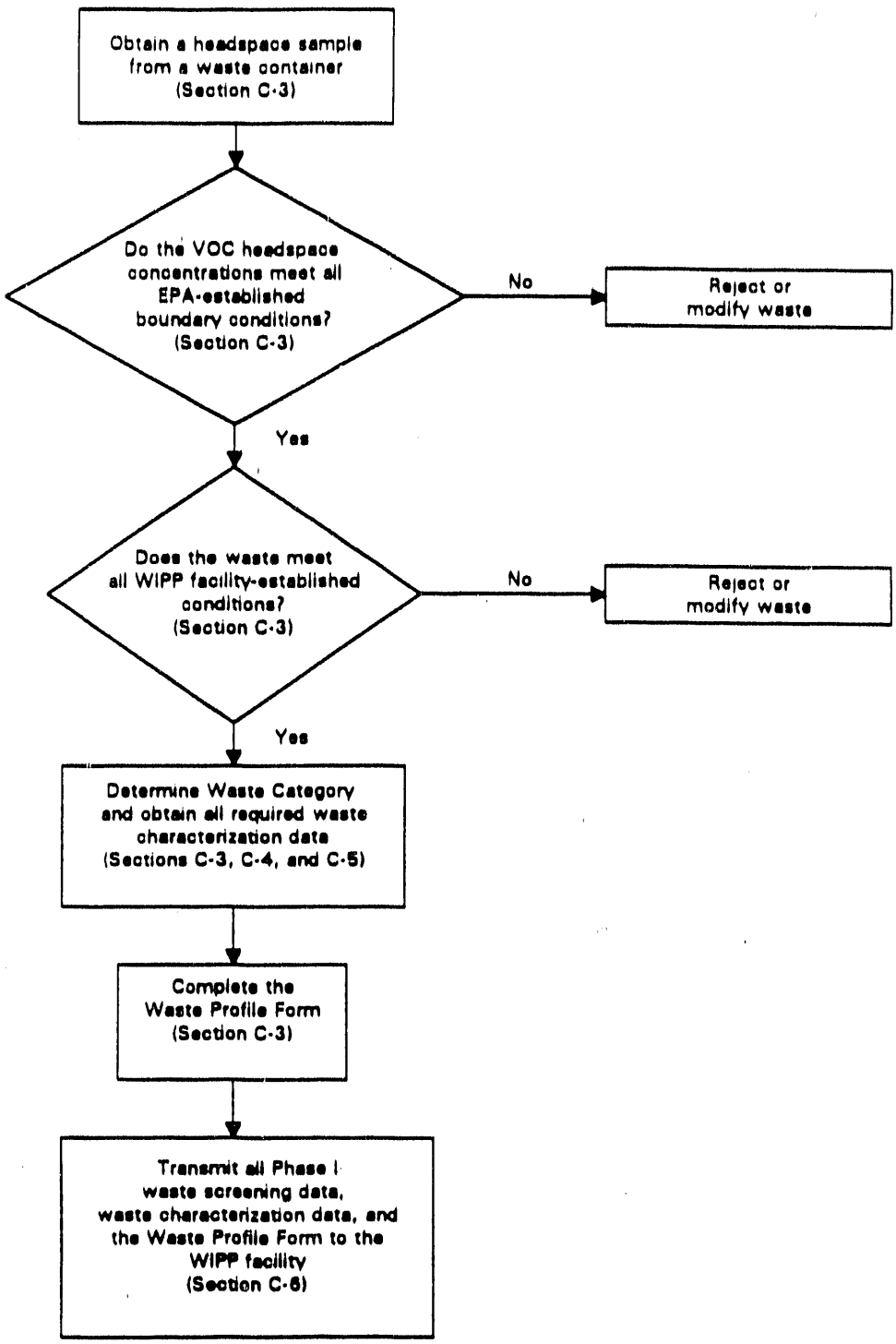

FIGURE C-1. GENERATOR WASTE SCREENING AND WASTE CHARACTERIZATION DATA COLLECTION FLOW DIAGRAM

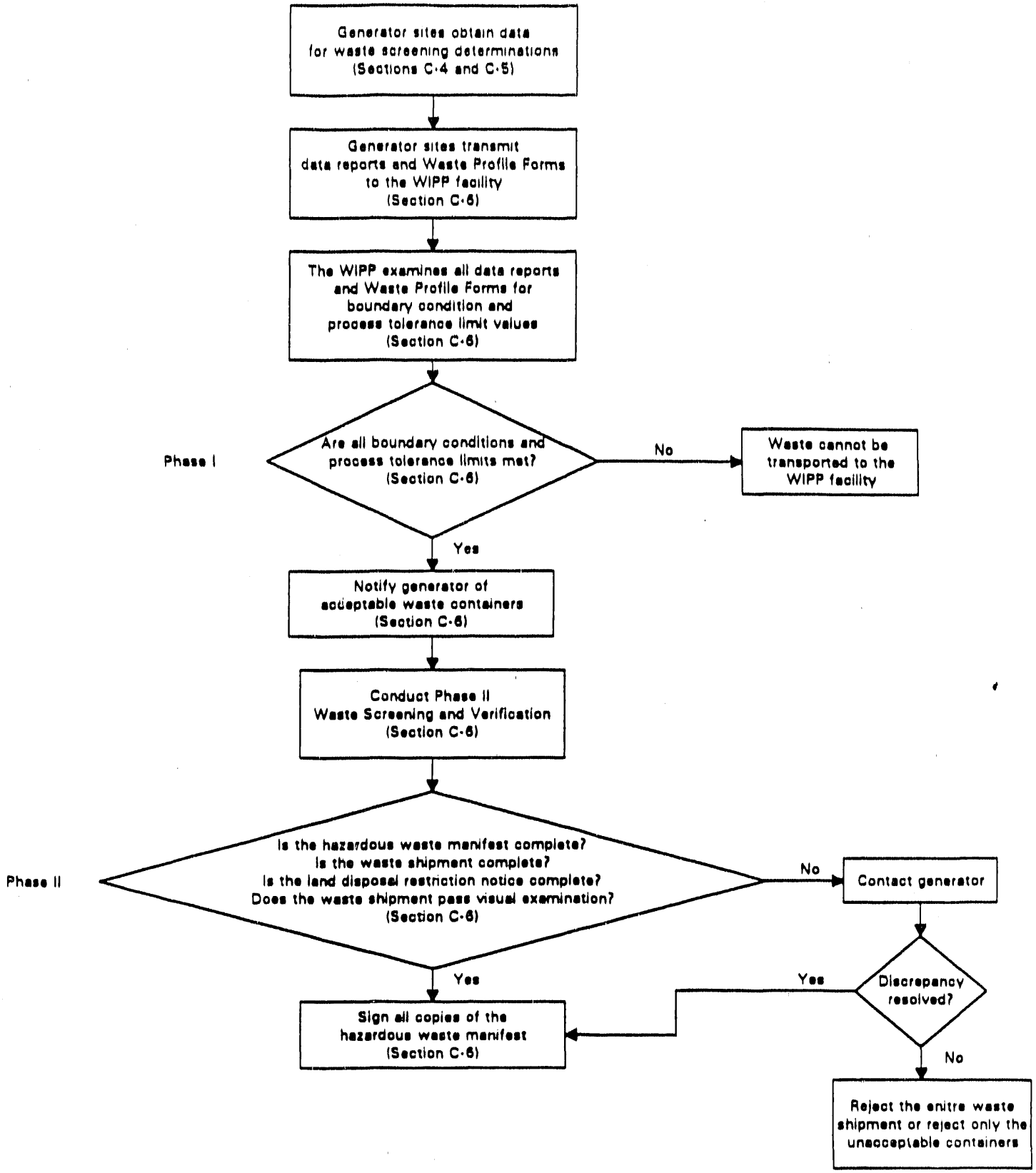

FIGURE C-2. WASTE ISOLATION PILOT PLANT FACILITY
WASTE SCREENING FLOW DIAGRAM

WIPP Waste Profile Form[a]

1. Generator Site Name:_____

2. Technical Contact:_____

3. Telephone Number:_____

4. EPA Generator ID Number:_____ _____

5. Waste Container ID Number:_____

6a. Is this Waste Container a Test Bin? ☐ Yes ☐ No (If yes, complete 6b. Special instructions apply.)

6b. List the ID Number of each Waste Container Placed in this Test Bin:_____

_____

_____

7. Data Report Cross-Reference Number:_____

8. Waste Category:_____

9. Waste Type:_____

10a. Date of WAC-Certification:_____

10b. Title, Revision Number, and Date of Document(s) Used for WAC-Certification:

_____

_____

_____

11. Indicate the techniques used to characterize this waste:

☐ Knowledge of Materials and Process - Reference(s) and Date(s) of Supporting Document(s) Used:

_____

_____

☐ RTR - Reference and Date of Procedure Used:_____

☐ Total Metals - Reference and Date of Procedure Used:_____

☐ VOCs - Reference and Date of Procedure Used:_____

☐ Non-Halogenated VOCs - Reference and Date of Procedure Used:_____

☐ Semi-VOCs - Reference and Date of Procedure Used:_____

[a] Waste Profile Forms and detailed instructions for completing them can be obtained from the Waste Isolation Pilot Plant (WIPP) facility.

FIGURE C-3. THE WIPP WASTE PROFILE FORM

Waste Container ID Number: _____

☐ PCBs - Reference and Date of Procedure Used:_____

☐ Headspace VOCs - Reference and Date of Procedure Used:_____

☐ Headspace Gases - Reference and Date of Procedure Used:_____

12a. Sampling of Group I Waste Categories - Reference(s) and Date(s) of Procedure(s) Used:_____

12b. Sampling of Group II Waste Categories - Reference(s) and Date(s) of Procedure(s) Used:_____

12c. Sampling of Group III Waste Category - Reference(s) and Date(s) of Procedure(s) Used:

13. Was This Container Sampled as Part of Tier I Sampling? ☐ Yes ☐ No
(If yes, enter the date sampled:_____)

14. Was This Container Sampled as Part of Tier II Sampling? ☐ Yes ☐ No
(If yes, enter the date sampled:_____)

15. Does this waste container hold hazardous waste? ☐ Yes ☐ No

If yes, list all appropriate EPA Hazardous Waste Codes and the rationale for the designation(s). If no, provide rationale.

16. Waste Profile Form Certification.

I hereby certify that I have reviewed the information in this Waste Profile Form and it is complete and accurate to the best of my knowledge.

Signature of Technical Contact Date

FIGURE C-3. THE WIPP WASTE PROFILE FORM
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CHAPTER D

FACILITY AND PROCESS INFORMATION

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CHAPTER D
FACILITY AND PROCESS INFORMATION

Introduction

Emplacement of waste in the Waste Isolation Pilot Plant (WIPP) facility during the Test Phase is subject to regulation under New Mexico Hazardous Waste Management Regulations (HWMR-6), Part V, Subpart X. As required by HWMR-6, Pt. V, section 264.601, the U.S. Department of Energy (DOE) must demonstrate that the environmental performance standards for a miscellaneous unit will be met. In addition, technical requirements of other subparts of HWMR-6, Pt. V, are applied to the operation of the WIPP facility, as appropriate. This chapter of the permit application describes the miscellaneous unit, waste-handling facilities and operations, and compliance with the environmental performance standard. As required by HWMR-6, Pt. V, sec. 270.23, engineering reports on siting and location of the repository are provided in Appendix D1. Engineering design basis reports are provided in Appendix D2. Detailed plans and design drawings for the repository and associated waste handling facilities and equipment are in Appendix D3. For those drawings undergoing revision, the engineering change orders are also included in Appendix D3. For the convenience of the reader, a list of drawings is shown in Table D-1.

Test Phase Overview

The Test Phase will consist of a series of activities, including experiments with transuranic (TRU) mixed waste, sampling and data collection, modeling, and calculations, leading to a demonstration of compliance with the long-term performance standard as defined by 40 CFR Part 191 (DOE, 1991b). Information acquired during the Test Phase will also be used to verify data and modeling assumptions in the No-Migration Variance Petition, which demonstrates that migration of hazardous waste or hazardous constituents from the WIPP underground repository during the Test Phase is unlikely, as required under HWMR-6, Pt. IX, sec. 268.6, and is the basis for the U.S. Environmental Protection Agency's (EPA) No-Migration Determination (EPA, 1990a).

At this time, the DOE is seeking a permit to perform bin tests only. Detailed information on container design and operations during the bin tests is presented in Appendices D2 and D3 to support this permit application.

Bin-Scale Test Summary

Three representative waste types have been selected for testing:

- High organic waste, both noncompacted and supercompacted
- Low organic waste, both noncompacted and supercompacted
- Solidified processing sludges.

The test bins will be prepared at Rocky Flats Plant and the Idaho National Engineering Laboratory to meet test plan requirements and to comply with the WIPP Waste Acceptance Criteria (WAC) (DOE, 1991a).

At the beginning of the bin tests, bin internal atmospheres will be controlled. Subsequently, gas generation rates will be monitored and gas composition studied. Bins are expected to generate hydrogen, methane, nitrogen, and oxygen through the processes of radiolysis, microbial decomposition, and corrosion. Small quantities of volatile organic compounds (VOCs) which are present in the waste may also be present in bin off-gases. Bins will be emplaced in Panel 1 of the WIPP repository (Molecke, 1990).

Both dry (i.e., containing no more than 1 percent free liquid by volume) and wet (i.e., up to 120 liters of brine per test bin injected after emplacement) bins will be monitored during the Test Phase. Brine, compositionally similar to that present naturally in the WIPP vicinity, will be injected into some test bins to enhance understanding of the effect and magnitude of potential gas buildup in the repository. The test program will proceed in distinct phases. Initially, bin-scale tests will evaluate the representativeness of waste forms under experimental conditions (Molecke and Lappin, 1991). This permit application is for the performance of bin-scale tests only.

D-1 Containers

Container handling is discussed as part of the process description for the WIPP facility in Section D-9a(2). Physical descriptions of the containers and management practices that address requirements of HWMR-6, Pt. V, Subpart I, are presented in Section D-9a(3)(f).

D-2 Tank Systems

The WIPP facility does not manage hazardous or mixed waste using a tank system as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart J. Tank system regulations are not applicable to the WIPP facility.

D-3 Waste Piles

The WIPP facility does not manage hazardous or mixed waste using a waste pile as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart L. Waste pile regulations are not applicable to the WIPP facility.

D-4 Surface Impoundments

The WIPP facility does not manage hazardous or mixed waste using surface impoundment as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart K. Surface impoundment regulations are not applicable to the WIPP facility.

D-5 Incinerators

The WIPP facility does not manage hazardous or mixed waste using an incinerator as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart O. Incinerator regulations are not applicable to the WIPP facility.

D-6 Landfills

The WIPP facility does not manage hazardous or mixed waste using landfills as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart N. Landfill regulations are not applicable to the WIPP facility.

D-7 Land Treatment

The WIPP facility does not manage hazardous or mixed waste using land treatment as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart M. Land treatment regulations are not applicable to the WIPP facility.

D-8 Drip Pads

The WIPP facility does not manage hazardous or mixed waste using drip pads as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart W. Requirements for drip pads are not applicable to the WIPP facility.

D-9 Miscellaneous Unit

The WIPP facility is a geologic repository. As such, it is defined as a miscellaneous unit in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart X.

D-9a Description of the Miscellaneous Unit

The WIPP repository is constructed within a 2,000-foot-thick bedded salt formation. The underground waste emplacement horizon is 2,150 feet beneath the ground surface. Waste management activities underground will be confined to a portion of the 15-acre mined area that will be used for experimental purposes during the Test Phase. Waste will be emplaced in Panel 1 within the 15-acre mined area.

The miscellaneous unit boundary, as defined in EPA's No-Migration Determination, is the entire area below ground defined by the upper and lower extent of the Salado Formation and the vertical projection of the 16-square-mile land withdrawal boundary on this underground volume (EPA, 1990a). The miscellaneous unit boundaries are shown in Figure D-1.

Waste handling activities will occur on the surface above the miscellaneous unit. Waste will be received, unloaded from the Transuranic Package Transporter (TRUPACT-II) shipping container, inspected, and moved to the Waste Shaft for transfer underground. The specific surface facilities associated with waste handling include an outdoor truck off-loading and loading area on the south side of the Waste Handling Building (WHB) and the WHB itself. Inside the WHB, the area where waste is handled is designated as a Radioactive Materials Area (RMA). Within this area are the inventory and preparation area, where TRUPACT-IIs are opened and waste containers removed, and an overpack and repair room.

Shafts connect the underground area with the surface. The Waste Shaft is located within the WHB and is used to transport TRU mixed waste, equipment, and materials to the repository horizon. The waste hoist can also be used to transport personnel. Other shafts leading to the unit are the Air Intake Shaft and the Exhaust Shaft, which connect underground ventilation systems to the surface. The Salt Handling Shaft is used to hoist mined salt to the surface and serves as the principal personnel transport shaft.

Further information on the waste handling facilities and the repository is given in Section D-9a(3). The WIPP surface facility, shafts, and repository horizon are shown in Figure D-2.

D-9a(1) Site Characteristics

The physical attributes of the WIPP site and adjacent vicinity contribute to the ability of the WIPP facility to isolate waste and assure that human health and the environment are protected.

Geologic disposal of TRU wastes has been studied intensively for more than 30 years. The National Academy of Sciences recommended that salt beds and salt domes be used for the disposal of TRU wastes. These salt formations were created millions of years ago by the evaporation of ancient seas. Geologic studies indicate that these formations are free of unsaturated water which could cause dissolution and create openings within the formation (NAS/NRC, 1970). The beneficial lack of openings and water eliminates an otherwise potential transport mechanism for waste migration to the surface or to groundwater.

Another advantage of salt is that it behaves as a plastic; that is, under heat and the lithostatic pressure found in deep geologic repositories salt will flow to heal any openings created by excavation or natural causes. Wastes emplaced in such a medium will become completely encased in a few decades, and in tectonically stable areas are expected to remain in place and isolated from the biosphere for geologically lengthy periods of time.

Detailed studies and evaluations of the natural environmental setting of the repository area have been part of the siting process. The following sections describe the climatic, geologic, and hydrologic characteristics of the WIPP facility and local vicinity. This information also provides the basis for evaluation of potential migration pathways in Section D-9d, Environmental Performance Standards for the Miscellaneous Unit.

D-9a(1)(a) Climate

The WIPP facility is located on the edge of the Chihuahuan Desert, a region of arid to semiarid climate. The average annual precipitation is about 12 inches, half of which is received during summer thunderstorms. Prevailing winds are from the southeast; however, strong winds are frequent, especially in spring, and can blow from any direction creating windstorms that carry large volumes of dust and sand (Fischer, 1987). Detailed meteorological data on the site has been collected (Fischer, 1990) and published in WIPP Annual Site Environmental Reports since 1985. The report for calendar year 1990 is provided as Appendix D4. Figure D-3 summarizes wind data collected during 1989. Additional historical wind rose data are provided in Figures B-9 through B-13. Appendices D5 and D6 also provide more detail on the climate.

D-9a(1)(b) Geology

Geologic History

The WIPP site is situated within the Delaware Basin, which is part of the larger Permian Basin, located in the southwestern part of the central region of North America. During the Permian period, which came to a close about 225 million years ago, ancient seas covered the basin. Their later evaporation resulted in the deposition of a thick sequence of salt and other marine sediments. A detailed discussion of the regional geologic history is presented in Appendices D6, D7, and D8. Three major evaporite-bearing formations were deposited in the Delaware Basin in this manner (Figure D-4):

- The Castile Formation, formed through evaporation of the Permian Sea, consists of interbedded anhydrites and halite (salt). Its upper boundary is at a depth of about 2,825 feet below ground surface (BGS), and its thickness near the WIPP facility is 1,500 feet (Appendix D7).

- The Salado Formation, in which the repository is located, overlies the Castile Formation and resulted from prolonged desiccation that produced cycles containing some carbonates and anhydrites, but predominantly halite. Its upper boundary is at a depth of about 850 feet BGS, and it is about 2,000 feet thick in the repository area (Appendix D7).

- The Rustler Formation was deposited in a lagoonal environment during a major freshening of the basin and consists of carbonates, anhydrites, and halites. Its beds are comprised mostly of clay and anhydrite and contain small amounts of brine. The Rustler Formation's upper boundary is about 500 feet BGS, and it ranges up to 560 feet in thickness in the area (Appendix D7).

These evaporite-bearing formations lie between two other formations significant to the geology and hydrology of the WIPP site. The Dewey Lake Redbeds overlying the Rustler Formation are dominated by non-marine sediments and consist almost entirely of mudstone, claystone, siltstone, and interbedded sandstone (Appendix D7). This formation forms a 540-foot-thick barrier of fine-grained sediments that retard the downward percolation of water into the evaporite units below. The Bell Canyon Formation is the first water-bearing unit below the Salado (Appendix D7). It is confined by the thick evaporite sequences of the Castile Formation above. It consists of 1,500 feet of interbedded sandstone, shales, and siltstones.

The Salado Formation was selected to host the WIPP repository for several reasons. The Salado is regionally extensive, underlying an area of more than 36,000 square miles. Its permeability is extremely low, and fluids within it are effectively immobile. Mechanically, salt behaves in a plastic manner under pressure (the pressure at the facility horizon is more than 2,000 pounds per square inch) and readily recrystallizes to heal cracks or openings). Any fluid remaining in small fractures or openings is saturated with salt, is incapable of further dissolution, and has remained in place for millions of years. Finally, the Salado is sandwiched between the Rustler and the Castile Formations (Figure D-5), which themselves are highly impermeable and will act to further confine and isolate waste within the WIPP repository (Appendices D6 and D7).

Geomorphology

The terrain of much of southeastern New Mexico is characterized by a gentle, southwesterly slope and a rolling surface marked by karst features, caliche, and sand dunes. The Pecos River, 14 miles west of the WIPP facility, is the nearest major perennial stream and receives almost all the surface drainage in this region and a large part of its subsurface drainage (Appendices D6 and D7).

Nash Draw is the nearest major geomorphic feature, located 5 miles west of the WIPP facility. It is an undrained physiographic depression resulting from the differential dissolution of portions of the Rustler Formation and the upper part of the Salado Formation. Dissolution has also produced numerous small sinkholes within Nash Draw. In the immediate area of the WIPP facility, however, post-depositional dissolution in the Rustler has been minor, reducing its thickness by, at most, a maximum of 30 feet. There has been no dissolution of the Salado within the WIPP facility area.

Most, if not all, of the depressions in the immediate vicinity of the WIPP facility resulted from the erosion and deposition of wind-blown sand, not from the dissolution of underlying evaporites. Evaporite dissolution in the area is not active at the WIPP site today, and its future occurrence is highly improbable under foreseeable climatic conditions because:

- There is relatively little rainfall and evapotranspiration consumes at least 96 percent of the precipitation.

- Geologic units above the Salado are confining layers with extremely low transmissivity, which virtually prevent any infiltration of water from the surface.

In addition, a thick layer of Mescalero caliche is found near the surface across the entire area, except Nash Draw. Formed during the mid-Pleistocene time, the presence of the caliche indicates the absence of significant erosion or deeper intrusion of rainwater, creating one of the most stable landscapes in the world. At the WIPP facility, the caliche is about 10 feet thick and, where it is well developed, most available porosity in its upper zone is plugged with calcium carbonate to form a nearly-continuous additional barrier to the downward infiltration of the small amount of precipitation that falls in the area. (Appendices D6, D7, and D9 provide an in-depth discussion of the existing and future dissolution features of the WIPP site area.)

Geologic Stability

No surface faults have been mapped within 5 miles of the center of the WIPP facility, and those beyond are related to the dissolution and collapse of soluble materials rather than to tectonic activity. Deep-seated faults of tectonic origin are present throughout the Delaware Basin, but movement along these faults ceased well before deposition of the evaporite units. The Bell Lake Fault, which is in Lea County, New Mexico, and 15 to 20 miles east of the site, is the closest such structure to the WIPP facility with approximately 500 feet of displacement (Haigler, 1962; Haigler and Cunningham, 1972). There are no folds of tectonic origin in the area of the WIPP site, although some thickening of the Salado associated with gravity-driven salt movement in the Castile has been observed. (Appendix D7 describes in detail the local and regional geologic structure and faulting in the Delaware Basin and a complete discussion of seismology in the vicinity of the WIPP facility.)

D-9a(1)(c) Groundwater Hydrology

The Salado Formation was selected as the host geologic unit because it is hydrologically isolated and because the plastic nature of the salt causes any fractures to close and heal. The general hydrogeology of the area surrounding the WIPP facility is described in this section in ascending order of geologic units. More detailed discussions of the local and regional hydrogeology are given in Appendices D5, D6, and D7.

Bell Canyon Formation

The uppermost sandstones of the Bell Canyon Formation, the Ramsey Sandstone Member, contain unsaturated brine with sufficient equivalent freshwater head to reach the Rustler Formation overlying the Salado. However, there is no natural hydrologic connection between the Bell Canyon Formation and the Rustler Formation. The sandstones of the Bell Canyon Formation are surrounded by siltstones of very low permeability, and the Bell Canyon Formation itself is confined by the overlying thick evaporite deposits of the Castile (Appendices D7 and D10).

Castile Formation

The Castile Formation is a basin-filling evaporite sequence of sediments that is surrounded by the Capitan Reef and was deposited within the basin outlined by the reef. The Castile represents a major regional groundwater aquiclude that effectively prevents any water from moving up from the underlying Bell Canyon Formation. Any fluid present in the Castile is very restricted because evaporites do not readily maintain pore space, solution channels, or open fractures at depth. Drill stem tests conducted in the Castile during construction of the WIPP facility found its permeability too low to be measured; however, the hydraulic conductivity has been conservatively estimated to be less than 10^{-8} foot per day.

It has been suggested that dissolution of the Salado salts could occur if a flow path were to develop through the Castile which would allow the upward movement of unsaturated brines from the Ramsey Sandstone Member of the Bell Canyon Formation (Anderson, 1978). However, detailed studies of the logs and cores from drilling in the vicinity of the WIPP facility have failed to identify fractures or other evidence indicating that water has moved vertically through the evaporite sequences. On the basis of numerical modeling, it has been suggested that, should such an event occur, salt removal from the Castile would occur at a rate of about 0.1 inch in 10,000 years (Lappin, 1988).

Another issue associated with the hydrology of the Castile Formation is the presence of isolated zones of pressurized brine found in fractured anhydrite beds. Two brine reservoirs were encountered by drillholes ERDA-6 and WIPP-12 during WIPP site characterization activities. The volumes of the ERDA-6 and WIPP-12 brine reservoirs are estimated to be 98,100 and 2,616,000 cubic yards, respectively. (Boreholes have not been drilled through the repository; site characterization boreholes have been sealed.)

The brine is pressurized and capable of discharging to the surface under artesian conditions. Most of the brine is stored in low-permeability microfractures, with only about 5 percent of the fluid present in large, open fractures. Brines have been encountered in fractured Castile anhydrites in other holes drilled for hydrocarbon exploration in the northern Delaware Basin both north and northeast of the WIPP facility in the Belco Well, approximately 6.5 kilometers from the center of the site (Lappin, 1988). A geophysical survey using transient electromagnetic techniques was

conducted directly over the WIPP facility waste-emplacement panels in 1987 (Earth Technology Corporation, 1987). The survey was conducted to determine the presence or absence of Castile brines beneath the facility. The results, based on a conservative interpretation, indicate that Castile brines are present beneath at least the northern, experimental excavations of the WIPP repository (Lappin, 1988).

There are two theories regarding the origin of these brine reservoirs. One theory is that the fluids originated from ancient seawater; the other is that they were transmitted to the Castile through an episodic connection with the Capitan Reef (Lappin, 1988).

Brine reservoirs within the Castile are inactive and isolated. According to a detailed study by Lambert and Carter (1984), the residence or isolation times for the Castile brines at ERDA-6 and WIPP-12 are between 360,000 and 880,000 years. The ERDA-6 and WIPP-12 brine reservoirs were also studied in detail by Popielak et al. (1983). They concluded that the brine chemistries are distinctly different for each reservoir, indicating an isolated and distinct separate origin for each reservoir with no regional interconnection. Hydraulic pressures within the reservoirs are higher than other regional groundwater systems, and have been maintained for at least a million years. The brine occurrences are described in several reports (Popielak et al., 1983; Mercer, 1983; Griswold, 1980; DOE, 1990b, 1990c). In any event, it has been concluded that the brines are saturated with respect to halite, are not increasing in volume or pressure, are unconnected with other aquifers or the surface, and have no further dissolution potential. It has also been concluded that neither of the proposed mechanisms are likely to generate significant additional brine beneath the WIPP facility within the next 10,000 years (Appendices D7, D9, and D10).

Salado Formation

The Salado Formation is an evaporite sequence that completed the filling of the Delaware Basin and lapped extensively over the Capitan Reef and the back-reef sediments beyond. The Salado Formation consists of approximately 2,000 feet of bedded halite with interbeds of seams of anhydrite, clay, and polyhalite. It acts hydrologically as a regional confining bed and does not contain any circulating fluids. The porosity of the Salado halite is very low, and interconnected pores are virtually nonexistent at the depth of the facility horizon. Fluids associated with the Salado occur mainly as very small fluid inclusions in the halite crystals and also between crystal boundaries ("interstitial" fluid) of the massive crystalline salt formation. Published values for permeabilities measured from the surface in the area of the WIPP facility are in the range of 0.01 to 25 microdarcies (Lappin, 1988). The most reliable value, 0.3 microdarcy, was obtained from well DOE-2 (Mercer, 1983). The results of permeability testing at the facility horizon are within the range of 0.001 to 0.01 microdarcy (Lappin, 1988). As a comparison, the permeability of the Salado is roughly a thousand times more restrictive than the lower clay liner required of surface impoundments and landfills, assuming similar thicknesses. The results of recent testing suggest that permeabilities in undisturbed rock salt may approach zero (Appendices D6, D7, and D10).

Several features of the Salado Formation have been extensively evaluated with regard to their potential impacts on repository integrity:

- Pressurized Gas - Pressurized gas has been encountered within the Salado in surface boreholes, local mines, and WIPP facility excavations. Because gas has been encountered only in disturbed rock associated with drilling and excavation, it is likely the gas exsolved from brine as surrounding pressure was relieved (Lappin, 1988; Deal and Case, 1987) (Appendix D7).

- Brine Seepage - The brine seeps observed in the WIPP facility excavations have received considerable attention. While the Permian salt beds of the Salado Formation are considered to be dry in that the inflow of brine is virtually nonexistent, very small volumes of brine have been observed to weep from exposed surfaces in the WIPP facility excavations (Deal and Case, 1987; Deal et al., 1987). The moisture readily evaporates, leaving behind thin salt crusts that build up over time. The brine is not derived from inclusions, but from interstitial fluid that, prior to disturbance, had been in place for at least several million years. Brine has also been observed to accumulate in drillholes, with measured inflow rates ranging from less than the rate of evaporation to 0.13 gallon per day. The rate of inflow is noted to decrease with time (Appendix D6).

  Sandia National Laboratories has modeled the rate of brine seepage (Nowak et al., 1988) and estimates that the expected brine accumulation in a waste disposal room after closure will be in the range of 141 to 1,518 cubic feet, the maximum value representing 1.2 percent of the initial room volume. This is within the range of the amount of brine easily released by the excavated salt. The WIPP facility disposal rooms, after backfilling, are expected to reconsolidate to virtually the same density as the surrounding host rock in about 100 years. The backfill materials will readily absorb the maximum expected brine accumulation while maintaining their mechanical strength. The small amounts of brine that will seep into the excavations are not postulated as a potential for any significant problem to the safe operation of the WIPP facility.

- Marker Bed Undulations - Marker Bed 139 (MB 139) directly underlies the WIPP facility and is characterized as a layer of polyhalite, anhydrite, and halite slightly more than three feet in thickness. Investigation of MB 139 was prompted by concern that its undulating surface developed in response to some late-stage stress which might affect the integrity of the WIPP facility. Studies have concluded that the undulations did not result from stress; rather, the upper surface of the marker bed was unevenly deposited (Borns, 1985).

- Marker Bed Fractures - Pre-existing fractures in MB 139, partially to wholly filled with halite, were formed in response to loading or, less likely, structural deformation in the Castile Formation (Borns, 1985). These pre-existing fractures provide planes of weakness that reactivate in response to the near-field stresses generated by the excavations. Separation along these fractures in the floors of WIPP facility rooms and drifts has occurred, with the amount of separation measuring up to several inches in width. The fracture separations are temporary, short-term responses to stress relief and are expected to close over time as the repository excavations creep shut and repressurize (Appendix D10). Hydrologic testing of MB 139 in one area of the repository suggested that separate fracture systems have developed within the marker bed due to excavation-induced stress relief and have yielded transmissivity values of 1 to 2 square feet per day (DOE, 1991c).

- Disturbed Rock Zone - Following the excavation of underground openings at the WIPP disposal horizon, a disturbed rock zone (DRZ) forms in the wall rock. The DRZ is defined as the zone of rock in which mechanical and hydrologic properties have changed in response to the excavation. The marker bed fractures described above are part of the DRZ, which also includes an area of macrofracturing and microfracturing of the walls and roof of the excavations and extends into the surrounding rock mass to a depth of up to 5 meters (16.4 feet). The potential impacts of the DRZ have been investigated and will continue to be examined during the Test Phase, particularly with regard to the maintenance of excavated openings during operations, behavior at the seal/rock interface for long-term isolation, and brine inflow. During the Test Phase, only the macroscopic aspects of the DRZ are of importance. Ground control measures (rockbolting and openings maintenance) have been implemented to minimize any adverse impacts from the DRZ. Appendices D6 and D8 provide more information on the DRZ.

Rustler-Salado Contact

Away from the WIPP site in the vicinity of Nash Draw, the contact of the Rustler and Salado Formations is evidenced by a layer of thinly-bedded clay and brecciated gypsum averaging 24 feet in thickness and containing brine. The hydraulic gradient in this layer is southwest across the region to Nash Draw. Transmissivity ranges from $3x10^{-5}$ to $5x10^{-2}$ square feet per day (Mercer, 1983). The water contained in this unit is saturated with respect to halite and is incapable of further dissolution. This brecciated water-bearing zone is not seen in the shafts at the WIPP facility and is not a factor affecting the containment of waste at the WIPP facility. Appendices D-6 and D7 present a detailed discussion of the hydrogeology of the Rustler-Salado contact in the WIPP site area.

Rustler Formation

The Rustler Formation has been the subject of extensive characterization activities because it contains the most transmissive hydrologic units overlying the Salado Formation. Within the Rustler, five hydrologic units have been identified. Of these, the Culebra Dolomite Member is the most transmissive and has been the focus of most of the Rustler hydrologic studies (Appendices D6, D7, and D10).

The Culebra Dolomite Member is the first continuous water-bearing zone above the Salado, and ranges up to 30 feet in thickness (Mercer, 1983; Lappin, 1988). Water in the dolomite is usually present in fractures and is confined by overlying gypsum or anhydrite and underlying clay and anhydrite beds. Its hydraulic gradient in the area of the WIPP facility is approximately 20 feet per mile and becomes much flatter south and southwest of the site (Figure D-6) (Crawley, 1988). Transmissivities in Nash Draw range up to 1,250 square feet per day; closer to the WIPP facility they are as low as 0.007 to 74 square feet per day (Lappin, 1988). The Culebra is hydrologically confined, and testing indicates no leakage between it and other units (Appendices D6, D7, and D10).

Use of water from the Culebra Dolomite is quite limited because of its varying yields and high salinity. The Culebra Dolomite is not used for water supply in the immediate WIPP site vicinity. Its nearest use is approximately 7 miles southwest of the WIPP facility, where salinity is low enough to allow its use for stock watering as shown in Figure D-7. Detailed discussion of the hydrologic characteristics of the other Rustler Formation members and the Dewey Lake Redbeds are provided in Appendix D7.

D-9a(1)(d) Surface Water Hydrology

A detailed discussion of the local and regional surface water hydrology and water quality is presented in Appendices D5, D6, and D7.

The mean annual precipitation in the region is approximately 12 inches, and mean annual runoff is up to 0.2 inch. The maximum recorded 24-hour precipitation at Carlsbad was 5.12 inches in August 1916. The potential evaporation is much greater than the annual precipitation. Almost all water that infiltrates the soil's surface is retained above the extremely impervious Mescalero caliche and then is lost through evapotranspiration (DOE, 1990c).

No natural drainage features exist at the WIPP site, which is situated more than 400 feet above and 14 miles east of the 100-year floodplain of the Pecos River (Figure D-8). A few small unnamed drainage channels constitute all the tributaries to the Pecos River within 50 miles north or south of the site.

There are no major surface water bodies located within ten miles of the WIPP facility. Beyond 10 miles, several water bodies lie to the north and south of the site. The largest of these, Laguna Grande de la Sal, located south of the site, is several square miles in area and is a catchment basin for limited surface drainage and artesian saline springs (Robinson and Lang, 1938).

Although large floods have occurred on the Pecos River (USGS, 1986), probable maximum flood calculations predict maximum flood levels on the Pecos near the WIPP facility to be near the levels of the modern floodplain (DOE, 1990d). The horizontal and vertical separations between the Pecos River floodplain and the WIPP facility are great enough that the Pecos River cannot affect the surface structures of the WIPP facility.

The drainage patterns at the WIPP facility are such that normal surface runoff from areas north, south, and west of the surface facilities drains westward into Nash Draw without affecting the site structures. Surface runoff during intense precipitation events could potentially pass through the site from the east; however, storm-water runoff is diverted away from the surface facilities by a system of berms and ditches. The WIPP facility drainage system is designed so that storm runoff due to the probable maximum precipitation event would not flood the WIPP facility (DOE, 1990d).

D-9a(1)(e) Soils

Regionally, soils in southeastern New Mexico developed from Quaternary and Permian parent material. The parent material from the Quaternary system is represented by alluvial deposits of major streams, dune sand which is the dominant surficial deposit in the immediate area of the facility, and other surface deposits. These are mostly loamy and sandy sediments containing some coarse fragments. Parent material from the Permian system is represented by limestone, dolomite, and gypsum bedrock.

There are three soil associations within 5 miles of the facility. Of these, only the Kermit-Berino association occurs at the facility in control Zones I and II. Generally, a hard caliche layer occurs at 7 to 13 feet below the surface. The Berino series, which covers about 50 percent of the area, consists of deep, noncalcareous, yellow-red to red sandy soils that developed in wind-worked material of mixed origin. These soils occur as gently sloping (up to 3 percent slope), undulating to hummocky areas and are the most extensive of the deep, sandy soils in the Eddy County area.

The Kermit series is made up of deep, lightly colored, noncalcareous, excessively drained loose sands, typically fine and yellowish-red in color. The surface is undulating (up to 3 percent slope) and consists primarily of stabilized sand dunes. Kermit soils are slightly to moderately eroded. Permeability is very high, and the potential for wind erosion is very high in denuded areas. Additional information concerning the area's soils is given in Appendices D5, D6, and D7.

D-9a(1)(f) Air Quality

An air monitoring program was initiated at the WIPP facility in 1985 (Fischer, 1985) to establish baseline air quality data. The Operational Environmental Monitoring Program (Mercer et al., 1989) continues to monitor air quality to document changes in air quality compared to the baseline period prior to waste receipt. At a sampling site located 0.6 mile northwest (downwind) of the Exhaust Shaft, five atmospheric gases are monitored continually: carbon monoxide, hydrogen sulfide, ozone, oxides of nitrogen, and sulfur dioxide. In addition, total suspended particulates are measured at several locations surrounding the site. Air quality data from the WIPP facility monitoring station have been reported in the Annual Site Environmental Reports for 1988 (Flynn, 1989), 1989 (Fischer, 1990), and 1990 (DOE, 1991b, Appendix D4). The Ecological Monitoring Program Annual Report for 1987 (Fischer, 1988) also gives air quality data (Appendix D5). The reports present a detailed discussion of the WIPP site air quality as monitored during the past four years.

Although the WIPP facility is not subject to regulation as an emission source for EPA-criteria pollutants, the measured concentrations of monitored gases are compared with New Mexico air quality standards, which serve as a trigger point for further investigation of possible emission sources. The data provided in Appendices D4 and D5 show periodic increases in concentrations of three of the monitored gases (sulfur dioxide, hydrogen sulfide, and ozone). Hydrogen sulfide and ozone concentrations were regularly higher during the spring and summer months of 1988 and 1989. Sulfur dioxide concentrations were also elevated from April 29 through May 20, 1987. The air quality data have been analyzed against concurrent wind direction data to determine the direction of the source. No source of these gases was identified at the WIPP facility (Fischer, 1988). The apparent increases are attributable to instrument error.

D-9a(1)(g) Biological Community Structure

In general, the biota of the region represents a transition between the northern Chihuahuan Desert and the southern Great Plains, and is dominated by shinnery oak (Quercus havardii), sand sage (Artemisia filifolia), honey mesquite (Prosopis glandulosa), and perennial grasses. Extensive root systems of the dominant species provide stability to the erodible dune soil. Mammal species counted during Ecological Monitoring Program trapping sessions include the Ord's kangaroo rat (Dipodomys ordii), the Plains pocket mouse (Perognathus flavescens), the northern grasshopper mouse (Onychomys leucogaster), the Southern Plains woodrat (Neotoma micropus), the white-footed mouse (Peromyscus leucopus), and the deer mouse (Peromyscus maniculatus).

This area of southeastern New Mexico is unusual in that it supports a large population of raptors (birds of prey), particularly Harris' Hawks, which reproduce more successfully here than in other parts of their range. A DOE-supported project was initiated in March 1985 to study the population dynamics, behavior, and strategies for management of raptors in the area around the WIPP facility (Bednarz and Hayden, 1988). Consultations with the U.S. Fish and Wildlife Service and

the New Mexico Department of Game and Fish regarding threatened and endangered species in the WIPP vicinity were held in 1979 and again in 1989 (DOE, 1990c). These consultations resulted in the conclusion that no state or federally listed threatened or endangered species nor critical habitat is projected to be impacted by the construction and operation of the WIPP facility (DOE, 1990c).

Detailed discussions of the local biological community and the results of monitoring by the Ecological Monitoring Program are given in Appendices D4 and D5.

D-9a(2) Process Description

Overview

Hazardous waste is not processed at the WIPP facility. Activities subject to this permit application are waste handling and management of TRU mixed waste used in experiments during the Test Phase. The bin-scale tests are described in Section B-1(b). TRU mixed waste handling and management practices during the Test Phase operations are summarized in this section. A detailed description of the facilities and systems associated with managing this waste is provided in Section D-9a(3). Specific container management practices in the miscellaneous unit are discussed in D-9a(3)(f).

D-9a(2)(a) Description of Experimental Waste

TRU mixed waste used for Test Phase experiments will be placed in test bins at the Rocky Flats Plant and Idaho National Engineering Laboratory generator sites. The total volume of waste which may be emplaced during the Test Phase is limited to a volume equivalent to 8,500 55-gallon drums (EPA, 1990a). Waste types and compositions have been determined by DOE's scientific advisor, Sandia National Laboratories (Molecke, 1990) and are described in Chapter C of this permit application.

At this time, DOE is requesting a permit to perform bin tests only. Bin-scale test waste will be contained in specially prepared bins. During the bin-scale tests, a maximum of 233 test bins will be emplaced. Each bin may contain a waste volume equivalent of four to seven 55-gallon drums. The average volume per bin is estimated to be equivalent to six 55-gallon drums or less. Bins will be contained inside standard waste boxes (SWBs). Detailed container descriptions may be found in Section D-9a(3)(f). All bin-scale tests will be conducted within the scope of the Test Plan and Test Plan Addendum (Molecke, 1990; Molecke and Lappin, 1991).

Derived Waste

All nonradioactive hazardous waste generated at the WIPP facility is characterized, placed in containers, and stored (less than 90 days) until it is transported off site for treatment and/or

disposal. This generation and accumulation is not subject to RCRA permitting requirements and, as such, is not addressed in this permit application.

The WIPP facility operational philosophy is to introduce no new hazardous chemical components into mixed waste which could potentially be generated in the RMA. This will be accomplished through administrative controls and the use of Safe Work Permits procedures in WP 12-1, WIPP Safety Manual (Westinghouse, 1991a), and Radiation Work Permits in WP 12-5, WIPP Radiation Safety Manual (Westinghouse, 1991b).

Some additional volume of mixed waste, such as used personnel protective clothing, swipes, or tools, may result from decontamination operations, VOC Monitoring System maintenance, bin failure, or other off-normal events. Such waste will be assumed to be contaminated with the same RCRA materials contained in the waste from which it was derived. Derived waste will be contained in standard U.S. Department of Transportation (DOT) approved 55-gallon drums, or other approved containers, and emplaced underground in a vented condition. Carbon sorption beds will be capped and stored in the derived waste area underground. Only wastes described in Chapter C will be emplaced in the repository during the Test Phase. No other RCRA-regulated wastes will be treated, stored, or disposed of in the miscellaneous unit.

D-9a(2)(b) Waste Management Operations

Prior to receipt of any experimental waste at the WIPP facility, waste operators will be thoroughly trained in the safe use of waste handling and transport equipment. Their training includes both procedural training and on-the-job training.

Bin-Scale Test Waste Handling

Waste will arrive by truck at the WIPP facility in sealed TRUPACT-II containers (Figure D-9) that have been certified by the U.S. Nuclear Regulatory Commission. A forklift will remove TRUPACT-II containers from the trucks at the TRUPACT-II unloading area and transport them a short distance through an airlock into the WHB. The forklift will deposit the shipping containers at one of the two unloading docks inside the WHB.

Inside the WHB Inventory and Preparation Area, the TRUPACT-II will be surveyed for radiological contamination. As the outer containment vessel lid is lifted, a survey of the TRUPACT-II inner vessel will be performed to minimize the potential for spreading external radioactive contamination, should it be present. The inner vessel lid will be lifted under the hood ventilation system (HVS), and the SWBs will be surveyed during and after this lift. If contamination is detected, the containers will be assumed to be potentially contaminated with hazardous constituents as well. Decontamination using non-RCRA regulated solutions may proceed when contamination is detected at any point in the waste receipt process.

Decontamination procedures are outlined in the WP 05-1, Waste Handling Operations Manual (Westinghouse, 1991c), and WP 12-5, WIPP Radiation Safety Manual (Westinghouse, 1991b). Waste products from decontamination will be managed as derived waste. Decontaminated containers may be placed back into the normal test waste program.

For inventory control purposes, waste container assembly identification numbers (bar codes on the exterior surfaces of the SWBs) will be verified against the WIPP Waste Information System (WWIS) data base, discussed in Chapter C of this permit application, and against the Uniform Hazardous Waste Manifest. The manifest identification codes will be checked against the identification codes of the containers received. Inconsistencies will be resolved with the generator before waste is accepted for emplacement.

The TRUPACT-II shipping container may hold two SWBs, each containing a test bin. After a survey for radiological contamination, an overhead bridge crane will be attached to SWB lift fittings, and the SWBs will be removed. The SWB/bin combinations will be set on the WHB floor, and the SWBs will be surveyed for radiological contamination. The strapping holding the two SWBs together will be disconnected. Each SWB will be surveyed in order to detect any radioactive contamination, and decontaminated if necessary. The test bin is hoisted clear of the SWB and rechecked for contamination. The SWB HVS is removed, and the bin is placed on a stand for inspection. Hoses, filters, and thermocouples are then installed and proper bin assembly is verified. Proper bin assembly is verified by checking the torque applied to bin lid bolts and ensuring that fittings have been properly assembled. After inspection and a contamination survey, the bin is placed back into the SWB.

The SWBs containing bin-scale test wastes will be modified in the WHB to form a Radiological Control Boundary (RCB) to provide containment for the test waste bins, while allowing access to test port connections. The RCB consists of the bottom of the SWB and a special lid that replaces the shipping lid. The special lid is designed to accommodate the leak tight connections between the test bin and test monitoring and support equipment. When the new lid has been bolted to the SWB, the entire outer container is considered a layer of containment and is a RCB.

The RCB/bin unit is placed in the SWB HVS and purged to achieve an anaerobic environment inside the test bin. An anaerobic environment is intended to represent the long-term atmosphere in the repository. To achieve this environment, an internal purge will be performed to obtain an oxygen level of 1,000 parts per million (ppm) or less. An oxygen gettering system may then be installed and operated until internal oxygen content is about 1 ppm. If a bin oxygen inleakage rate of 2 ppm per year or less cannot be verified, an oxygen gettering system may be installed to maintain the bin atmosphere in an anaerobic condition. The bin will be slightly pressurized and all isolation valves closed. Once the RCB/bin unit passes all external radiological contamination surveys, it will be placed on a facility pallet. A forklift will transport the loaded facility pallet to the conveyance loading car inside the air lock at the Waste Shaft. The conveyance loading car will

be driven onto the waste hoist deck where the loaded facility pallet will be transferred to the waste hoist (Figure D-10).

The waste hoist will lower the loaded facility pallet to the underground. At the waste station, the underground waste transporter will back up to the waste hoist cage, and the facility pallet will be winched onto the transporter. The transporter will then move the facility pallet to the appropriate waste management room for emplacement.

A forklift will be used to off-load the RCB/bin units from the underground waste transporter. The RCB/bin units will be emplaced in the Panel 1 test rooms approximately in order of receipt, based on the bin identification numbers, starting at the northern end of the test room and progressing southward. Panel 1 at the WIPP facility is reserved for emplacement of RCB/bin units for the bin-scale tests.

RCB/bin units will be placed on steel platforms approximately 6 inches off the floor in an off-set configuration to allow access to ports (Figure D-11). Container management in the repository is discussed in Section D-9a(3)(f). Internal pressure in the bins will be monitored throughout the bin-scale tests.

Grab samples of the gases and volatile components will be collected periodically as specified by the Test Plan for analysis by gas chromatography and mass spectroscopy to verify that this condition of operation is met (Molecke and Lappin, 1991). All RCBs and test bin platforms will be visually inspected each week to monitor for any physical deterioration, as described in Chapter F of this permit application.

If a test bin or a major component of the test system (e.g., seals, valves, filters) requires repair during the Test Phase, the RCB/bin unit may be transported to the WHB or repaired in place. The bin will remain contained within the RCB to prevent the release of hazardous waste. Repairs will be limited to those actions that can be performed without violating the primary confinement boundary of the test bin. When possible, a RCB/bin unit will be repaired and then transported back to the underground to continue as part of the bin-scale tests. If the RCB/bin unit is no longer useful for test purposes, it will remain in place, but be withdrawn from the test program and vented continuously to the underground exhaust ventilation airflow atmosphere via the VOC manifold system.

Each bin will be vented into a manifold system that will direct gas flow through a carbon sorption system used to remove VOCs. Each bin will be equipped with mechanical pressure relief to provide overpressure protection.

D-9a(3) Facility Design and Construction

The WIPP facility has been sited and designed to ensure safe operations during the Test Phase and throughout its anticipated 25-year operational lifetime and be protective of human health and the environment through the post-operational period.

√ Geomechanical testing of the WIPP repository rock salt core was conducted by Sandia National Laboratories (Powers et al., 1978). The host rock characteristics with respect to physical and chemical properties, geomechanical properties, stability, and strength have been evaluated and validation investigations have been conducted (DOE, 1986). These activities served as the basis √ for repository siting and design. The Geological Characterization Report describing the repository √ location is included in Appendix D1.

√ The main underground entries for the WIPP repository were designed based upon empirical data; site characterization data, including information from boreholes; surface geophysical measurements and laboratory tests; and mining and engineering standards universally applied √ to underground projects (DOE, 1986). The room and pillar design concept for the WIPP facility was based primarily on mining experience gained from general potash mining practice in the same local vicinity and under similar lithologic conditions, although modifications were made to √ account for the differences in depth between potash mines and the WIPP facility repository horizon. Since the extraction ratio (the ratio of the area of salt removed by mining to the total √ area) at the WIPP facility is significantly lower than that used in potash mining, design parameters also reflected this difference (DOE, 1986).

√ Design validation efforts for the WIPP facility began in 1981 with the Site and Preliminary Design Validation (SPDV) program which was implemented to further characterize and validate the WIPP site geology and to provide preliminary validation of the underground opening design (DOE, 1983a). The SPDV program involved the excavation of a test panel consisting of four full-sized rooms. The four SPDV test rooms were excavated 13 feet high, 33 feet wide, and 300 feet long and are separated by 100-foot-wide pillars similar to the proposed repository design. Data obtained from geologic field activities and geomechanical instrumentation were subjected to preliminary analysis and evaluation to determine the suitability of the design criteria and design bases and to provide initial confirmation of the underground opening reference design (Bechtel, 1983).

Additional information was gathered, analyzed, and evaluated after completion of the SPDV √ Program. The summary report Summary of Site Characterization Studies Conducted from 1983 √ through 1987 at the Waste Isolation Pilot Plant Site is included in Appendix D1. The final report √ on design validation is also included in Appendix D1. It was recognized that the vertical and horizontal closure rates in the underground facility were higher than expected by a factor of approximately three (DOE, 1986). Formal reviews were performed by WIPP Project participants and an outside Peer Review Panel. The reviews concluded that modifications to the reference

design were necessary. Five alternative design modifications were proposed and subsequently evaluated by DOE with respect to regulatory constraints, radiological safety, cost, and schedule (Tillman, 1987). The decision was made to accept a combination of alternatives that recommended deleting the crushed-salt backfill requirement during the Test Phase, mining the rooms to the near-maximum allowable design dimensions of 14 feet by 34 feet, and enlarging the rooms as necessary just before the transition to waste handling operations to remove a portion of the primary creep component (Tillman, 1987).

As a part of the design validation process, geomechanical tests were conducted in SPDV test rooms. During the tests, salt creep rates were measured. Separation of bedding planes and fracturing were also observed. A support system consisting of patterned rockbolting and light steel-beam supports with wire mesh and wire cable lacing was installed in Panel 1 in response to observed conditions and to satisfy the requirement that the structural integrity necessary for safe retrieval of waste from Panel 1 areas be maintained throughout the Test Phase and retrieval period (DOE, 1991c). The underground support system is not expected to prevent salt creep or to stop the fracturing and separation that have been observed underground. Rather, the system will maintain or suspend the fractured or separated material in place and prevent the roof rock from falling once it has become fully detached. Shields or guards will be placed over the bins and valves to prevent small pieces of rock, which may not be held by the support system, from damaging the waste containers. Normal mine maintenance will also be performed in the bin-scale test rooms during the Test Phase as needed. Thus, additional ground control support or removal of fallen rock from the top of the waste stack would not be required for retrieval operations if repository performance cannot be demonstrated.

Geologic and geomechanical information continues to be gathered in the WIPP facility underground on a regular basis and bin-scale test rooms in Panel 1 are specifically monitored (DOE, 1989). Geologic mapping and observational boreholes are used to characterize the host rock and to assess the effects of excavation. Displacement data are gathered from manually and remotely read instruments to measure closure rates and to evaluate rock-mass behavior. This information is used to further validate design criteria and to monitor the stability of underground openings to ensure safety and operational reliability.

The WHB has been designed to meet DOE design and quality assurance requirements specified in DOE Order 6430.1, General Design Criteria (DOE, 1983b), for Design Class II structures and components for non-reactor nuclear facilities. The design class designations are defined for structures, systems and components in accordance with the importance of their function relative to health and safety of the public and on-site personnel during plant operations (DOE, 1990d). The underground area is classified as a Design Class IIIB nonreactor nuclear facility. Table D-2 summarizes basic design requirements, principal codes, and standards for the WIPP facility. Engineering design-basis earthquake and tornado reports are provided in Appendix D2. The design-basis earthquake report provides the basis for seismic design of WIPP facility structures,

√ including the WHB foundation. A flood design basis report is not available because flooding is
√ not a credible phenomenon at the WIPP facility (see Appendix B1).

The specific systems and facilities related to environmental, safety, and health protection during waste handling and management operations are discussed in the following subsections.

D-9a(3)(a) Site Security

The WIPP site has extensive security protection including physical access control, fencing, lighting, warning signs noting potential hazards, security protection personnel, alarms, and
√ communication systems. Site security is described in Chapter F of this permit application. Details
√ on the design of access control fencing is provided in Appendix D3.

D-9a(3)(b) Waste Handling Building

The WHB has an area of approximately 84,000 square feet. The concrete floors are sealed with an impermeable coating which resist all but strong oxidizing agents. Such oxidizing agents are
√ not currently Waste Acceptance Criteria Certification Committee certifiable and are not present
√ in waste coming to the WIPP facility. Therefore, test waste poses no compatibility problems with
√ respect to the WHB floor. Figure D-12 is a plan view of the WHB, showing areas where waste
√ handling activities discussed in this section take place. Detailed design drawings for the WHB
√ and waste handling systems are provided in Appendix D3.

The TRUPACT-IIs are received through one of three air lock entries to the WHB. The air locks maintain the interior of the WHB at a pressure lower than that of ambient atmosphere. The doors at each end of the air lock are interlocked to prevent both from opening simultaneously. The air locks ensure that air flows into the WHB to prevent the inadvertent release of any radioactive particles, potentially contaminated with hazardous constituents, from the WHB. Bays on either side of the central air lock in the Inventory and Preparation Area (IPA) are equipped with a dock and a 5-ton overhead crane for opening and unloading the TRUPACT-II shipping container. The
√ overhead crane is rated to lift both the TRUPACT-II lids as well as palletized waste containers. The crane is designed to remain on its tracks and hold its load even in the event of a Design Basis Earthquake. The IPA is maintained at a lower air pressure than the WHB to minimize the spread of potential contamination.

Additionally, waste-holding space is available should off-normal events occur, such as the interruption of waste hoist operations. The waste-holding space is shielded to reduce radiation exposure to personnel in the WHB. Pallets loaded with waste containers can be stacked there, if required.

An Overpack and Repair Room (OPRR) provides space and facilities for opening, unloading, and
√ decontaminating TRUPACT-II shipping containers. The OPRR is also used for decontaminating

and/or overpacking SWBs or drums. The OPRR is maintained at a negative pressure relative to the IPA and the WHB for contamination control.

To specifically support the bin scale tests, an on-site laboratory has been developed to perform the analysis of gas samples taken from the bins. Ventilation for this laboratory is exhausted through the WHB ventilation system.

The other primary WHB support area is the heating, ventilation, and air conditioning area for the WHB. This equipment is contained within the main mechanical equipment room of the WHB, located on a second level above the OPRR. This area houses the exhaust fans and associated ducting that control ventilation flow within the WHB.

Ventilation

The WHB ventilation system provides a filtered air exhaust path consisting of one stage of prefilters and two stages of High Efficiency Particulate Air (HEPA) filters to remove radioactive particulate contamination. These filters are tested to American National Standards Institute requirements ANSI-N-510 and have a 99.95 percent removal efficiency.

The WHB ventilation exhausts through a single stack at a nominal flow of 55,000 cubic feet per minute with a design maximum of 90,000 cubic feet per minute. A schematic airflow diagram for the WHB is shown in Figure D-13. The final exhaust from the stack is continuously monitored for radioactive particulate contamination. Airflow reversal during the passage of a tornado is prevented by tornado dampers. If necessary, the exhaust systems can be powered from the backup power system if off-site power is lost, thus maintaining negative pressures in potentially contaminated areas.

The HVS and SWB HVS (a design extension of the HVS) function as local exhaust systems to control radiologically contaminated airborne dust particles through the use of HEPA filters during the initial opening phases of a TRUPACT-II container and SWB. The HVS and SWB HVS draw headspace gases and convey them through the CH-TRU WHB heating, ventilation, and air conditioning system.

Fire Protection

The design of the fire protection system satisfies the applicable sections of the National Fire Protection Association codes, DOE Orders, and federal codes. Fire barriers protect the cage loading area and shaft areas, within the WHB, and separate the overpack and repair room, shielded waste-holding area, support areas, and walls enclosing stairwells. In addition, the mechanical equipment room has fire barriers that separate this room from other areas of the WHB.

A sprinkler system is installed throughout the contact-handled TRU waste handling areas of the WHB. The design of the fire-suppression water-collection system is described in a revision to the Final Safety Analysis Report. Fire suppression water will be collected and held for hazardous (or radioactive) contamination verification, and its management will be determined by the test results. The waste handling area is provided with interior fire hose connections and portable extinguishers. Chapter F discusses fire protection.

D-9a(3)(c) Waste Handling Equipment

TRUPACT-II Type B Shipping Container

The TRUPACT-II is a double-contained cylindrical shipping container measuring 8 feet in diameter and 10 feet high. It meets DOT Type B shipping container requirements and is certified by the U.S. Nuclear Regulatory Commission after passing rigorous container integrity violation tests. The payload consists of two SWBs stacked on top of the other, which rest on a TRUPACT-II pallet (Figure D-14).

Unloading Dock

Each unloading dock is designed to accommodate up to two TRUPACT-II shipping containers. The unloading dock functions as a work platform, providing waste handling personnel easy access to the container during unloading operations (Figure D-15).

Forklifts

Electric-powered forklifts are used to transfer the TRUPACT-II shipping containers into the WHB and are used to transfer palletized waste to the conveyance loading car. Another forklift is used for general purpose transfer operations. This forklift has attachments and adapters to handle individual waste containers, if required.

Crane and Adjustable Center-of-Gravity Lift Fixture

A 5-ton traveling overhead crane is attached to the lift fixture to disassemble the TRUPACT-IIs. Separate lifting attachments have been specifically designed to couple with SWBs. The lift fixture has a built-in level indicator and two counterweights which can be adjusted to compensate for uneven loads to keep them level. The lift assembly is shown in Figure D-16.

Facility Pallet

The facility pallet is a fabricated steel unit designed to hold two TRUPACT-II pallets of waste. The facility pallet has a rated load of 28,000 pounds. The upper surface of the facility pallet has two recesses sized to accept SWBs. The facility pallet will accommodate a maximum of two

RCBs side by side or four SWBs stacked two-high to a total weight of 15,000 pounds. Two rectangular tube openings in the pallet bed allow the facility pallet to be lifted and transferred by a forklift to prevent direct contact between waste containers and forklift tines. This arrangement minimizes the potential for puncture accidents.

Conveyance Loading Car

The conveyance loading car is an electric vehicle. It is designed with a flat bed of adjustable height and is used to transfer the facility pallets on or off the pallet support stands in the waste hoist cage (Figure D-17). The car operates on rails.

Waste Hoist Cage

The hoist systems in the shafts and all shaft furnishings are designated as Design Class IIIA and are designed to resist the dynamic forces of the hoisting system and withstand a design-basis earthquake (defined in Chapter B). A control system detects malfunctions or abnormal operations of the hoist system, such as overtravel, overspeed, power loss, circuitry failure, or starting in a wrong location, and triggers an alarm that automatically shuts down the hoist.

The waste shaft hoist operates in the Waste Shaft and is a multi-rope, friction-type hoist. The conveyance car is 9 feet deep by 15 feet wide by 24 feet high (inside dimensions) and contains an upper and lower deck with personnel being carried on the upper deck. The waste hoist conveyance (outside dimensions) is 30 feet high by 10 feet wide by 14 feet deep and carries a payload of 45 tons. During loading and unloading operations it is steadied by fixed guides. The hoist's maximum rope speed is 500 feet per minute. A counter weight of 50 tons is used to balance the waste hoist conveyance.

The waste shaft hoist system has two sets of brakes. Each is designed so that either brake acting alone can stop a fully loaded conveyance under all emergency conditions. In the event of a power failure, the brakes will set automatically. The hoist is protected by a fixed automatic fire suppression system. Portable fire extinguishers are also provided at several points in the hoist station and hoist house.

Underground Waste Transporter

The underground waste transporter is a commercially available diesel-powered tractor and trailer designed specifically for transporting palletized waste from the waste hoist to the underground-facility pallet platform. This transporter is shown in Figure D-18.

Underground Forklift

√ Underground waste containers are removed from the underground-facility pallet platform using
√ a forklift. The RCBs are equipped with lift pockets to minimize the potential for puncture by the
√ forklift tines. RCBs are stacked two-high on 6-inch platforms in bin-scale test rooms.

D-9a(3)(d) Shafts and Subsurface Facilities

Shafts

The WIPP facility utilizes four shafts: the Waste Shaft, the Salt Handling Shaft, the Air Intake Shaft, and the Exhaust Shaft. These shafts are vertical openings which extend from the surface
√ to the repository level. Figure D-19 shows the location of the shafts relative to surface features.

The Waste Shaft is located in the WHB and is nominally 19 feet in diameter. The Salt Handling Shaft is located north of the Waste Shaft beneath the Salt Handling headframe and is nominally 10 feet in diameter. Salt mined from the repository horizon is removed through this shaft. It is the main personnel and materials hoist, and also serves as a secondary supply air duct for the underground areas. The Air Intake Shaft is located northwest of the WHB. It is a 16-foot-diameter shaft and is the primary source of fresh air underground. The Exhaust Shaft, east of the WHB, is nominally 14 feet in diameter and serves as the exhaust air duct for the underground areas.

Experience in salt mining has shown that excavated openings in salt, which are under overburden pressure, experience closure movement. The closure rate affects the design of all of the openings discussed in this section. Underground excavation dimensions, therefore, are nominal since they are dependent on the results of the ongoing salt creep. The unlined portions of the shafts have larger diameters than the lined portions, which allows for closure caused by salt creep. Each shaft includes a shaft collar, a shaft lining, and a shaft key section. Shafts and shaft components are discussed in greater detail in Appendix E1.

The reinforced concrete shaft collars extend from the surface to the top of the underlying consolidated sediments. Each collar serves both to retain adjacent unconsolidated sands and soils and to prevent surface runoff from entering the shafts. The shaft linings extend from the base of the collar to the top of the salt beds approximately 850 feet below the surface. The shaft lining serves to retard water from seeping into the shafts from water-bearing formations, such as the Magenta and Culebra Dolomite Members of the Rustler Formation, and is designed to withstand water pressure associated with the full piezometric head in these formations. The liners are also designed to retain loose rock. The shaft liners are concrete except in the Salt Handling Shaft, in which a steel shaft liner has been grouted in place.

The shaft key is a circular reinforced concrete section emplaced in each shaft below the liner in the base of the Rustler Formation and extending about 100 feet below and into the Salado Formation. The key functions to resist lateral pressures and to support the shaft liner. The key assures the liner will not separate from the host rocks or fail under tension. This prevents the shaft from becoming a conduit for groundwater flow into the underground facility.

Two water-seal rings are incorporated in each key. The rings are separated by an 11-foot interval into which eight 2-inch-diameter pipes are inserted to monitor any water that may penetrate the upper ring. If groundwater is detected flowing past the upper ring, this condition is corrected by injecting chemical sealants or cement grouts to stop the leakage.

On the inside surface of each shaft, excluding the Salt Handling Shaft, there are three water collection rings. The first is located just below the Magenta Dolomite interval, the second just below the Culebra Dolomite interval, and the last at the lowermost part of the key section. These collection rings function to collect any groundwater that may seep into the shaft through the liner. At the present time, the Air Intake Shaft has not been grouted. Groundwater seepage from the Rustler Formation is collected by water rings and routed to mobile water holding tanks. These tanks are inspected and emptied on a daily basis. Therefore, overfilling and leakage from these tanks is not a source of water underground which could come into contact with the waste. Recent inflow measurements from the Air Intake Shaft indicate that total seepage is approximately 1.24 gallons per minute.

The Waste Handling Shaft is protected from precipitation by the roof of the WHB. The Exhaust Shaft is sealed at the top by a 14-foot-diameter duct which diverts air into the exhaust ventilation system. Other shaft collars are open except for the headframes.

D-9a(3)(e) Repository Subsurface Structures

The subsurface structures in the repository, located at 2,150 feet below the surface, include the experimental waste, geotechnical experiment, and support areas. Access to all active waste management areas is restricted. All normal access to and from these areas is via a check station. Details of underground layout are provided in Appendix D3.

The status of important underground equipment, including fixed fire protection systems, the ventilation system, and contamination detection systems are monitored by a central monitoring system. Backup power is provided, as discussed in Chapter F. The subsurface support areas are constructed and maintained to conform to federal mine safety codes.

Panel 1 Waste Experiment Areas

The repository has been designed for the emplacement of 6.2 million cubic feet of contact-handled waste. During the Test Phase the volume of waste emplaced in the repository will not exceed that equivalent to the volume of 8,500 55-gallon drums. This represents less than 1 percent of the design capacity.

There are four main entries and cross-cuts in the repository that provide access and ventilation for waste management rooms. The main entries link the shaft pillar/service area with the waste management area and are separated by pillars. Normal entries are 12 feet high; one is 25 feet wide and the remaining three are 14 feet wide. Drifts and waste emplacement areas are structurally reinforced with rockbolts. The underground area is shown in Figure D-20.

Panel 1 of the repository has seven rooms. Rooms 1, 2, and 3 are reserved for the bin-scale tests. The location of these test rooms is shown in Figure D-21. The rooms have initial dimensions of 13 feet high by 33 feet wide by 300 feet long and are supported by 100-foot-wide pillars. There will be 42 platforms made of carbon steel which will hold RCB/bin units in the test rooms.

Panel 1 was excavated in 1986 through 1988. The rooms and access drifts of Panel 1 have been rockbolted to assure stability for the duration of the Test Phase and retrieval period. Panel 1 test rooms are typically pattern bolted with 10-foot mechanical bolts on a center-spacing pattern 3.9 feet by 3.9 feet through the middle third of each room. The outer third of each room has the same type and length of roof bolt, but uses a center-spacing pattern 3.9 feet by 6 feet (DOE, 1991c). Light steel crossbeams in an inverted channel configuration are installed in bin-scale test rooms to provide additional roof support. The roof area between the crossbeams is covered by an interlaced wire rope underneath a mat of steel mesh to contain the rock between the cross channels and distribute the load more evenly, reducing scaling and breakup of the roof beam. Figure D-22 provides an isometric view of the support system for Room 1, Panel 1. Figure D-23 depicts the wire mesh and lacing detail, while roof bolt detail is shown in Figure D-24. Detailed engineering drawings of roof support systems are provided in Appendix D3.

An underground support monitoring system will measure continuing creep and deformation in and around the room, loads on the rock bolts, stress loads on the rocks, and deflection of the steel crossbeams. This monitoring system allows loads in the rock bolts to be adjusted to accommodate room creep and will provide early indications of any unusual closure activity.

Bin Emissions Control

All test bin gas-sampling ports are equipped with HEPA particulate filters to prevent release of radioactive contamination. The RCBs which contain test bins are electrically grounded.

Figure D-25 shows the instrumentation and piping necessary to support a typical test system installation.

Gas discharges from the test bins are through gas flow valves, pressure relief valves and/or rupture disks. For safety reasons, bin pressure should not exceed 4.0 pounds per square inch differential (psid); therefore not approaching the calculated design pressure of 6.1 psid. Rupture disks will be set to open at pressures at or above 1.2 + 0.6 or -0.4 psid to prevent buildup of internal pressure. The rupture disks will operate independently of any electrical power supply.

Gaseous emissions from the test bins will be controlled by a manifold which will route emitted gases to the VOC sampling equipment. The manifold consists of 2-inch-diameter stainless-steel tubing. Gases will be directed through an activated carbon sorption system designed to remove VOCs with an efficiency of 95 percent or more, as required as a condition of the No-Migration Determination (EPA, 1990a). The design basis is discussed in Appendices D11 and D12 and will be verified during operations as described in Section D-9e. The carbon sorption system schematic is shown in Figure D-26 and in Appendix D3 (Drawing Number 52-2-001-W) and is further described in Section D-9d(3). Detailed design drawings related to this system are provided in Appendix D3.

Underground Fire Protection

The ventilation systems are designed to eliminate the recirculation of hot gases and smoke by venting these products of combustion to the outside. The result is improved visibility for safe egress and fire-fighting operations, and the evacuation of high-temperature gases.

The fire protection and suppression systems for underground support areas include:

- Automatic dry chemical extinguishing system (actuated by thermal detectors).
- Manual pull stations.
- Portable fire extinguishers.

Escape routes are designated by reflectors on the sides of the drift; green reflectors denote the primary escape route and red the secondary escape route. The back of each reflector is white denoting travel away from the escape route.

Ventilation

The ventilation system for the underground facilities is designed to provide a suitable environment for personnel and equipment during normal activities. It is also designed to provide confinement and channeling of potential airborne radioactive material in the event of an accidental release or fumes from an underground fire. Schematic diagrams of the underground ventilation system are

√ presented in Figures D-27 and D-28. Detailed engineering drawings of the ventilation system and
√ underground air flow control are provided in Appendix D3.

The main underground ventilation system is divided into three separate flows. One flow serves the mining areas, a second flow serves the geotechnical experiment areas, and the third flow serves the Panel 1 waste experiment areas. The three flows are recombined near the bottom of the Exhaust Shaft that serves as a common exhaust route from the underground level to the surface.

The underground ventilation system is designed as an exhaust system in which the working environment is maintained below atmospheric pressure in Panel 1. A small quantity of air is drawn down the Waste Shaft to offset natural updraft convection currents and minimize the potential of any radioactive contamination escaping up the shaft. This small quantity of air is immediately routed to the bottom of the Exhaust Shaft, so as to avoid mixing potentially contaminated air with air being circulated throughout the underground.

The design airflow quantities are based upon standard local, state, and federal industrial and mining laws and practices. Air quantities supplied to all the underground areas were determined to meet or exceed the criteria specified in the Mine Safety and Health Administration code.

The system is designed to perform under three modes of operation: normal mode (HEPA exhaust filtration system bypassed), filtered mode (exhaust filtered through HEPA filtration system if the concentrations of radioactive contaminants exceed pre-set limits), and air reversal mode.

The ventilation system consists of five centrifugal exhaust fans arranged in parallel, two identical HEPA filter assemblies arranged in parallel, isolation dampers, filter bypass arrangement, and associated ductwork.

The five fans are divided into two groups. One group consists of two fans which are used during normal operation to provide the required underground flow of 425,000 cubic feet per minute. These fans are located near the Exhaust Shaft. The remaining three fans, rated at 60,000 cubic feet per minute each and located at the Exhaust Filter Building, form the other group and are used during the filtered mode of operation.

The ventilation path for the Panel 1 area is separated from the mining area by means of air locks, bulkheads, and salt pillars. A pressure differential is maintained between the mining area and the Panel 1 area to assure that any releases exhaust through the waste management areas. A pressure chamber has been added to the west side of the Waste Shaft Station to ensure that no potential for leakage from the Panel 1 area to the mining area occurs.

In the normal mode, the two main surface exhaust fans, located near the Exhaust Shaft, provide continuous ventilation of the underground areas. All underground flows join at the bottom of the

Exhaust Shaft before rising to the surface for discharge to the atmosphere. In this mode, the filter assemblies are isolated and bypassed.

Outside air is supplied to the mining areas, the Panel 1 areas, and the geotechnical experimental complex via the Air Intake Shaft, the Salt Handling Shaft, and access entries. A small quantity of outside air flows down the Waste Shaft to ventilate the waste shaft station. Fan failure is monitored by a flow sensing device on the suction side and is statused in the Central Monitoring System.

In the filtration mode, the exhaust air passes through two identical filter assemblies at reduced flow (60,000 cubic feet per minute). The filtration mode is activated automatically at predetermined detection levels of the airborne radioactive particles by the radiation monitoring system. This system also provides a means for removing the airborne radioactive contaminants in the reduced exhaust flow before they are discharged through the exhaust stack to the atmosphere. The reduced exhaust flow is diverted to the HEPA filters by isolation and diversion dampers on the exhaust fans and duct work.

The system provides for an air reversal mode, designed primarily for fire emergencies. In this mode, the air flow direction is reversed by opening and closing certain ventilation doors and air regulators and, in some cases, by reversing the underground booster fans. The surface exhaust fans can be operated normally or can be deactivated, as required, to control the balance of the underground airflow.

Electrical System

The WIPP facility uses electrical power (utility power) supplied by Southwestern Public Service. On loss of utility power, waste handling and related operations cease.

Backup alternating current power for non-waste handling activities is provided on site by two 1,100-kilowatt diesel generators. These units provide 480-volts power with a high degree of reliability. Each of the diesel generators can carry predetermined equipment loads while maintaining additional power reserves. Predetermined loads include lighting and ventilation for underground facilities, lighting and ventilation for the waste handling areas, and the Air Intake Shaft hoist. The diesel generator can be brought on line within 30 minutes either manually or from the control panel in the Central Monitoring Room.

Uninterruptable power supply units are also on line providing power to predetermined monitoring systems. This ensures that the power to the radiation detection system for airborne contamination, the local processing units, the computer room, and the central monitoring room is always available, even during the interval between the loss of off-site power and initiation of backup diesel generator power.

D-9a(3)(f) Containers

Containerized experimental waste for the WIPP Test Phase will be received at the WIPP surface facilities and emplaced in the underground test area. Bin-scale test containers of mixed waste will be managed in accordance with the applicable regulations of HWMR-6, Pt. V, Subpart I.

D-9a(3)(f).1 Containers With Free Liquids

The WIPP WAC precludes waste in free-liquid form. However, minor liquid residues remaining in well-drained bottles, cans, and other containers are acceptable (DOE, 1991a). Since the WIPP WAC method of determining the presence of free-liquid is not consistent with the required method of HWMR-6, Pt. II, Appendix III (Paint Filter Test), all test waste containers received at the WIPP facility will be considered to contain potential free liquids. The liquid will constitute no more than 1 percent by volume of the waste for the dry bin-scale tests. A maximum of 120 liters (about 127 quarts) of brine solution may be injected into containers for wet bin-scale tests (Molecke, 1990; Molecke and Lappin, 1991).

D-9a(3)(f).1a Description of Containers

Waste containers to be received for the bin-scale tests will be test bins that are contained in SWBs (which are converted to RCBs by changing lids). Only new and clean containers will be used. A summary description of each container type is provided below.

Test Bins

Test bins are waste containers used to confine individual waste experiments for the bin-scale tests. There will be a maximum of 233 test bins managed at the WIPP facility during the Test Phase. Test bins have a gross internal volume of 42.4 cubic feet (DOE, 1991c). See Figure D-29 for detailed drawings including test bin dimensions.

Test bins are constructed of mild steel plate and contain a polyethylene liner. The bin material and liner will not react with, and are otherwise compatible with, the test waste so that the ability of the container to contain the waste is not impaired. Appendix D13 provides a discussion of compatibility.

Standard Waste Boxes

SWBs are DOT Type A shipping containers used for the bin-scale tests to contain individual test bins. The SWBs are fitted with a standard carbon composite filter as required for shipment in a TRUPACT-II. SWBs have an internal volume of 64 cubic feet (DOE, 1990d). Detailed design drawings for the SWBs are provided in Figure D-30 and Appendix D3. Up to 233 SWBs will be required for the bin-scale tests.

After arrival at the WIPP facility, each SWB that contains a test bin will be modified by replacing the SWB lid with a RCB lid. The RCB lid accommodates test connections and, like the SWB, is constructed of carbon steel. SWBs/RCBs containing test bins will not have an inner liner. Although waste should not be in contact with the SWB/RCB at any time, the SWB/RCB material will not react with, and is otherwise compatible with, the test waste so that the ability of the container to contain the waste in the event of a test bin leak is not impaired. Appendix D13 provides a discussion of compatibility.

SWBs meet all the requirements of DOT regulations contained in 49 CFR, including the structural requirements of 49 CFR 173.412 for Type A shipping containers. SWBs are also required to have a nominal life of 20 years from the date of waste certification to allow for intact container retrieval (DOE, 1991c).

Standard 55-Gallon Drums

Standard 55-gallon drums are used as waste containers for the collection of derived experimental waste (any waste generated in support of the Test Phase experiments). A standard 55-gallon drum has a gross internal volume of 7.4 cubic feet (DOE, 1990d). Figure D-31 shows a standard waste drum.

Standard 55-gallon drums are constructed of mild steel and may also contain a rigid, molded polyethylene liner. The drum material and liner will not react with, and are otherwise compatible with, the test waste so that the ability of the container to contain the waste is not impaired. Appendix D13 provides a discussion of compatibility.

Standard 55-gallon drums (e.g., DOT 17-C, DOT 17-H) meet all requirements of 49 CFR including the structural requirements of 49 CFR 173.412 for Type A shipping containers. The drums are also required to have a nominal life of 20 years from the date of waste certification to allow for intact container retrieval (DOE, 1990c).

D-9a(3)(f).1b Container Management Practices

Bin-Scale Container Management

Test bins of experimental waste received during the Test Phase remain closed throughout the Test Phase. SWBs containing bins are opened under a hood ventilation system only for inspection and preparation. Waste container handling practices are summarized below.

All waste handling operators will be thoroughly trained in the safe use of waste handling and transport equipment to minimize the potential for a rupture or leak of a test bin or SWB/RCB. Their training includes both procedural training and on-the-job training.

When the waste is received, the overhead bridge crane and specially designed Center-of-Gravity Lift fixture (Figure D-16) will be attached to the SWB(s) contained in the TRUPACT-II. The SWB(s) will be lifted out of the TRUPACT-II and placed on the WHB floor. All lifting devices and container fixtures are designed in accordance with engineering specifications and standards, and operated in accordance WP 10-4, WIPP Hoisting and Rigging Manual (Westinghouse, 1991d).

The SWB container lid will be unbolted and opened so that a different lid, which has been modified to accommodate bin test instrumentation connections, can be attached and bolted closed. The SWB with the new lid is a RCB. The RCB is placed on the facility pallet, conveyed by forklift to the waste hoist deck, and transported to the repository horizon on the waste hoist. The pallet is equipped with lift pockets to minimize the potential for the container to be punctured with the forklift tines. The waste hoist is maintained and inspected regularly, as described in Chapter F of this permit application, to assure its safe functioning.

The waste hoist will lower the loaded facility pallet to the repository horizon. At the waste station, the underground transporter will back up to the waste hoist cage, and the facility pallet will be winched onto the transporter. This transporter is shown in Figure D-18.

The transporter will then move the facility pallet to the appropriate underground waste test room. The underground drifts are continuously maintained to ensure a safe, level surface for the "roads," as are test room entrances in Panel 1. In the test rooms, RCBs are removed from the transporter using a forklift.

RCBs will be stacked two high on 6-inch-high platforms on 12-foot centers set back from the east and west ribs (walls) of the bin-scale test room in an alternating pattern (Figure D-32). Each RCB will be emplaced approximately 3 feet from the rib or adjacent wall leaving a 17-foot aisle between rows. This spacing allows personnel access between the RCBs to install instrumentation and perform inspections.

Post-Test Phase RCB removal operations are the reverse of emplacement and utilize the same waste container handling equipment.

D-9a(3)(f).1c Secondary Containment System Design and Operation[1]

Bin-Scale Secondary Containment System

Each individual bin is contained within a SWB/RCB (Figure D-33). The SWB/RCB provides adequate secondary containment in the event of a rupture or leak of a test bin, as demonstrated

[1]Containment discussed in this section relates to Pt. V, sec. 264.175, requirements rather than the DOE definition of radiological containment found in Order DOE 6430.1, General Design Criteria (DOE, 1983b).

In D-9a(3)(f).1f, Containment System Capacity. Any leak from an emplaced bin will be indicated by a drop in gas pressure, which is monitored continuously as part of the tests.

D-9a(3)(f).1d Requirement for the Base or Liner to Contain Liquids

Each test bin will be contained within a low carbon steel RCB. The RCBs are leak-tested, DOT-approved containers free of cracks or gaps. The physical integrity of the RCBs will be confirmed weekly by a visual inspection to check for leaks, rupture, and container corrosion. The required lifetime for the containers is 20 years.

D-9a(3)(f).1e Containment System Drainage

Each bin is provided with a dedicated secondary containment, its RCB. Only the failed bin would be affected by the rupture. As such, a bin need not be elevated within a RCB or otherwise protected from contact with accumulated liquids.

D-9a(3)(f).1f Containment System Capacity

RCBs have a net volume of 64 cubic feet. The net volume of an enclosed test bin is 42.4 cubic feet. There are 21.6 cubic feet (612 liters) of secondary containment capacity. The bins will contain no more than 120 liters (about 127 quarts) of brine and 12 liters (about 12.7 quarts) of liquids. The SWB is more than adequate to contain the contents of the test bin if a rupture or leak occurs.

D-9a(3)(f).1g Control of Run-On

Surface run-on during intense precipitation events could potentially pass through the WIPP site from the east, but is diverted by a system of culverts and drainage ditches designed to protect the WIPP facility from flooding, as depicted in Figure D-34, Site Work Finish Grading and Paving, Overall Plan. Therefore, run-on will not affect the underground test areas. Additional WIPP site grading and paving drawings are included in Appendix D3.

D-9a(3)(f).1h Removal of Liquids from Containment System

All liquid which could leak from a bin would be completely contained within the test bin's SWB/RCB. Since there exists no potential for overflow, removal of liquids will not be required.

D-9a(3)(f).2 Containers Without Free Liquids

All waste containers to be shipped to the WIPP facility are limited to no greater than 1 percent residual liquids by volume and are managed as such.

D-9b Waste Characterization

Waste characterization is described in Chapter C.

D-9c Treatment Effectiveness

Waste treatment, as defined in HWMR-6, Pt.I, sec. 260.10, is not performed at the WIPP facility.

D-9d Environmental Performance Standards for the Miscellaneous Unit

The WIPP miscellaneous unit has been designed, sited, and constructed, and will be operated, maintained, and closed, in a manner that will ensure protection of human health and the environment, in accordance with HWMR-6, Pt. V, sec. 264.601. The WIPP facility is located in a sparsely populated area with site conditions favorable to isolation of waste from the biosphere. Geologic and hydrologic characteristics of the site related to its waste isolation capabilities are discussed in Section D-9a(1). The WIPP facility has been designed to facilitate safe handling and disposal in order to prevent adverse human health and environmental impacts. Operating requirements minimize the potential for any release. Further, during the Test Phase, the monitoring programs described in Section D-9e have been designed to detect and measure any release of hazardous waste or constituents. Hazard prevention programs are described in Chapter F of this permit application. Contingency and emergency response actions to minimize impacts of unanticipated events, such as spills, are described in Chapter G of this permit application. The closure plan for the WIPP facility is described in Chaper I of this permit application.

D-9d(1) Protection of Groundwater and Subsurface Unit

Exposure of humans or environmental receptors to hazardous waste or hazardous constituents via the groundwater or subsurface environment is unlikely. This conclusion is supported by the following considerations:

- The total volume of waste to be emplaced during the Test Phase has been limited by EPA's No-Migration Determination to a volume equivalent to 8,500 55-gallon drums, or about 62,500 cubic feet (EPA, 1990a). Waste will be containerized throughout the Test Phase. The physical form of the WIPP facility waste is predominantly solid.

- Secondary containment of bin-scale test waste is provided to ensure that any release is contained within the unit, as discussed in Section D-9a(3)(f).1c.

- The WIPP facility repository is hydrologically and geologically isolated. As discussed in Section D-9a, the permeability of the Salado Formation, which hosts the repository, is extremely low, and fluids within it are effectively immobilized. No viable pathway

exists for waste to migrate into groundwater or the subsurface environment beyond the unit.

This conclusion is also supported by EPA's No-Migration Determination (EPA, 1990a). EPA states:

> After a review of DOE's petition, supporting information, and public comment, EPA finds that DOE has demonstrated, to a reasonable degree of certainty, that hazardous constituents will not migrate from the WIPP repository as a result of its planned test activities. . . . Because of the nature of the tests that will be conducted at WIPP and their relatively short duration, EPA has concluded that releases of hazardous constituents from the unit through brine, salt or other geological media is implausible during the test phase. . . . Waste will be containerized during the test period, and even if it were released from a container, there is no possibility that waste could migrate from the unit by groundwater or directly through the salt rock within the test period. No commenters questioned this conclusion. . . .

D-9d(2) Protection of Surface Water, Wetlands, and Soil Surface

Exposure of humans or environmental receptors to hazardous waste or hazardous waste constituents via surface water, wetlands, or the soil surface is unlikely. This conclusion is supported by the following considerations.

- All waste will be containerized throughout the Test Phase. As described above, the small volume of waste; limited quantity of liquid; provisions for containment of any release within the unit; and location of the unit deep within a stable, isolated geologic formation effectively precludes any potential for contamination of surface water, wetlands, or soil surface.

- The site is 14 miles northeast from and 500 feet above the Pecos River. It is 400 feet above the 100-year floodplain. The site has been graded to provide interceptor diversions to channel storm runoff away from the surface structures (Figure D-34). The site drainage system has been designed to handle a probable maximum storm (DOE, 1990d). Local surface water drainage and precipitation patterns are addressed in Section D-9a, Site Characteristics.

- In the vicinity of the WIPP facility, there is no hydrologic communication with any surface-water source. There is no driving mechanism which will allow waste to migrate through the salt into any below-surface water-bearing unit which discharges to surface water during the Test Phase.

√ This supports the conclusion that the potential for adverse effects to human health or the
√ environment via surface water, wetlands, or soil surface pathways is implausible.

D-9d(3) Protection of the Atmosphere

√ Release of hazardous waste or hazardous constituents to the air that may have adverse effects
√ on human health or the environment is unlikely. Although VOCs could be present in the waste emplaced within the unit and could potentially be a source of release to the air, provisions have been made to control such emissions to prevent any adverse effects to human or environmental receptors.

Lead and other heavy metals (presumed to have the characteristic of toxicity) will also be present in some waste forms. Metal in the waste, most of which is lead in monolithic form, is present in bricks and shielding rather than in particulate form (DOE, 1990c). The primary sources of other metals are in the form of sheets, rods, parts of equipment, or solidified sludges. Since all waste will be containerized and waste container vents employ particulate filters, there will be no routine releases of particulate metals to the atmosphere.

Performance Standard

√ The environmental performance standards for the WIPP facility described in the April 6, 1990,
√ Federal Register, Conditional No-Migration Determination for the Department of Energy Waste
√ Isolation Pilot Plant (WIPP) (55 FR 47700) for airborne emissions are protective of human health
√ and the environment, in accordance with HWMR-6, Pt. V, sec. 264.601. Concentrations of VOCs
√ in air emissions waste will be below EPA regulatory concern for the most restrictive constituent, carbon tetrachloride. EPA criteria for establishing levels of regulatory concern are determined by calculating the concentration of a carcinogenic chemical that would pose a risk of one excess cancer in a population of 1 million people ($1x10^{-6}$ risk level), assuming that the person remains at the unit boundary for a 70-year lifetime (EPA, 1990b). The unit boundary relevant to air emissions is the top of the Salado Formation within the repository.

Air Emissions Controls

Air emissions from the underground Panel 1 waste management areas have been studied in detail and the results presented to the EPA in the WIPP No-Migration Variance Petition (DOE,
√ 1990b). As a result of these studies, a bin-exhaust manifold and carbon sorption system have
√ been designed and installed to limit the potential for releases during the Test Phase.

Exhaust from the experimental bins is routed through the manifold system into a carbon sorption
√ bed designed to be greater than or equal to 95 percent effective in removing VOCs. Each test room will have an independent collection manifold and sorption system. The carbon sorption material for the system is loosely packed Calgon-type BPL granular carbon. The sorption system

design was based on the maximum quantity of VOCs that may be released from the experimental bins over a one-year period, estimated to be 5 moles per drum equivalent volume per year (Molecke, 1990). The design specification for the carbon sorption system recommends using 26.5 pounds (12 kilograms) of carbon per room per year and represents a 400 percent overdesign safety margin for a room containing 116 bins, to assure that the VOC removal efficiency will exceed 95 percent. Appendix D11 describes the type of calculation made to assure that the carbon sorption system is adequate to provide the desired safety margin. The rate for replacement of the carbon bed will be verified using Volatile Organic Sampling Train (VOST) tubes containing identical carbon sorption material. A VOC sampling system is located downstream of the carbon sorption system and just prior to the manifold exhaust.

Health Risk Evaluation

Health and environmental risks resulting from air emissions from the WIPP facility have been estimated using conservative assumptions which tend to overestimate the consequences of releases to the environment (Appendix D12). The source terms, assumptions, and risk assessment methodology are described below.

Based on characterization of newly-generated waste from the Rocky Flats Plant which is currently stored at the Idaho National Engineering Laboratory (Table D-3), five VOCs have been selected as indicators for environmental performance based on their toxicity and prevalence in the waste (DOE, 1990c). These are the only RCRA-regulated hazardous chemicals that may potentially compose greater than 1 percent by weight of the waste emplaced during the Test Phase:

- Carbon tetrachloride
- Methylene chloride
- Trichloroethylene
- 1,1,1-Trichloroethane
- 1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113).

With regard to their toxicity characteristics, carbon tetrachloride, methylene chloride, and trichloroethylene are considered potential carcinogens, while 1,1,1-trichloroethane and Freon 113 are known to produce adverse somatic effects when present in sufficient concentrations.

The average void volume was used to calculate the total grams of a volatile organic in the gas phase of each drum. The "void volume" or "headspace" is the total volume of a drum occupied by gases. The average void volume within the drums sampled was calculated to be 5.2 cubic feet (147 liters) (Clements and Kudera, 1985).

Information obtained from studies conducted at the Idaho National Engineering Laboratory on gas generation rates (Clements and Kudera, 1985) provides the basis for estimating the concentration of selected volatile organics in the waste drums used for experiments at the WIPP facility and for

postulating release fractions. The studies were conducted as part of a TRU waste sampling program undertaken by the Idaho National Engineering Laboratory to evaluate various types of TRU waste received from the Rocky Flats Plant for temporary storage. A total of 13 waste forms (combustibles, sludges, metals, etc.) were selected from those that were expected to comply with the requirements of the WIPP WAC.

The average concentrations of the selected volatile organics in the headspace of the drums are given in Table D-4. Although it is assumed that this concentration of gases is present in every drum, analytical results indicate that the VOCs are often below detection limits for many drums. Thus, the use of these average concentrations represents a conservative assumption (DOE, 1990b).

Releases of Hazardous Chemicals from Underground

Total gas generation rates for each bin have been calculated. Molecke (1990) estimates that a credible maximum rate of 23.7 cubic feet (670 liters) of gas will be released from each bin in one year through radiolysis, microbial decomposition, and corrosion. It is assumed that the average concentrations of VOCs found in the headspace gases of Rocky Flats drums (Table D-4) are continuously present.

The total grams of each of the five predominant VOCs in the headspace of the bins (Table D-5) were calculated using the following equation:

$$\frac{g\ VOC}{dayroom} = \text{Av. headspace Gas Concentration} \frac{g/\ell}{bin} \times \frac{116\ bins}{room} \times \frac{670\ liters}{bin\text{-}year} \times \frac{1\ bin\text{-}year}{365\ days}$$

This calculation is based on an earlier estimate that each room would contain 116 bins. The present plan includes only 76 bins per room, making this a conservative estimate. The volumetric air flow through the underground facility is 425,000 cubic feet per minute, or 1.73×10^7 cubic meters per day. Dividing the total grams of VOC generated per room by the volumetric air flow per day gives average daily concentration of VOCs that would be exhausted at the facility unit boundary. Table D-6 shows the calculated concentrations of VOCs at the facility unit boundary resulting from each Panel 1 waste experiment room assuming 95 percent removal efficiency by the VOC manifold exhaust controls. These concentrations are compared with concentrations established by EPA which are below regulatory concern for health protection (EPA, 1990b).

Potential for Health Risks

Based on calculations, the daily average concentrations of VOCs from each test room are a minimum of 25 times lower than those of regulatory concern to EPA prior to their release to the aboveground atmosphere (EPA, 1990a). Since there will be no more than 233 test bins (conservatively assumed to be a maximum of 116 per room), total emissions from bin off-gasing

will not exceed twice the concentrations calculated per room. Atmospheric dispersion will be expected to substantially further reduce the VOC concentrations at the WIPP site boundary. Since concentrations are at least an order of magnitude below EPA's health-based levels of regulatory concern at the unit boundary prior to atmospheric dispersion, no adverse health or environmental impacts are associated with this level of emissions.

D-9e Monitoring, Inspection, and Reporting

The following section describes the activities at the WIPP facility that are undertaken to satisfy the regulatory requirements in HWMR-6, Pt. V, secs. 264.601 and 264.602.

D-9e(1) Monitoring

Groundwater Monitoring

In the development of the WIPP Project monitoring programs, potential pathways for release of hazardous materials to the environment were evaluated. This evaluation indicated no credible release pathway via surface water. Release through groundwater is also believed to be implausible. In view of this, DOE has prepared groundwater monitoring information consistent with HWMR-6, Pt. V, sec. 264.90(b)(4). This information is included as Chapter E of this permit application.

VOC Monitoring

To meet the conditions of EPA's No-Migration Determination, an extensive VOC sampling and analysis program has been developed. WP 12-6, VOC Monitoring Plan for Bin-Room Tests (Westinghouse, 1991e), is provided as Appendix D12. This plan is responsive to the HWMR-6, Pt. VIII, sec. 268.6, Monitoring Requirements. Table D-7 relates specific monitoring requirements to portions of the plan.

The monitoring program is designed to verify that VOCs emitted from bin-scale tests are effectively removed prior to discharge into the Exhaust Shaft. VOC concentrations are monitored by means of samplers located at each bin-exhaust system manifold release point, downstream of the carbon sorption system. In addition, for the bin-scale tests, VOC samples are collected at two other locations underground and two above ground to verify that concentrations of the target constituents due to the waste area measured at the unit boundary as defined in the No-Migration Determination (EPA, 1990a) are below the levels of regulatory concern. Further, as required by the No-Migration Determination, any VOC which is detected in average estimated concentrations of one part per million or more at the point of sampling during any four-month period and is detected in at least 10 percent of the samples from the bin gas discharge system must be targeted for routine quantification.

The sampling and analysis method selected for the WIPP VOC Monitoring Program is EPA Compendium Method TO-14 (EPA, 1988). The method describes a procedure for determining VOC concentrations in ambient air using the SUMMA® passivated canister sampling and gas chromatographic/mass spectroscopy (GC/MS) analysis. Hazardous constituents targeted for quantification have been successfully collected in pressurized canisters and measured by this method at the part per billion by volume level.

The target VOCs have been proven to be stable in the SUMMA® canisters. Samples will be analyzed using GC/MS to quantify the VOCs.

The VOC sampler for each bin-scale test room will be located immediately downstream of the carbon sorption system (Figure D-35). The VOC sampling equipment for bin test rooms consists of a self-contained, canister air sampler, Programmable Logic Controller, and a helium make up gas system. This sampler operates using an internal neoprene diaphragm pump which fills one or more SUMMA® passivated stainless-steel sample canisters. The sampling flow rate (rate at which the canisters are filled) is controlled by an adjustable flow controller which can control the flow from 0 milliliters per minute up to 100 per minute into the canister. Samples of the gas that has passed through the sorption bed will be collected daily after waste emplacement. These samples will be 24-hour integrated samples and will be representative of the total emission stream being released to the atmosphere of Panel 1.

In order to provide confirmatory data that the calculated capacity of the carbon sorption VOC removal bed is adequate, a sampling loop consisting of three modified VOST tubes is included in the monitoring system design (Figure D-35). Each tube is packed with 8 grams (approximately 2.8×10^{-1} ounce) of carbon sorption material identical to that used in the carbon sorption system. Bin-gas discharge will be periodically routed through these tubes. These tubes will be used and analyzed based on a modification of EPA Test Method 0030, as described in the document Test Methods for Evaluating Solid Waste (SW-846) (EPA, 1986). The analytical data from these samples, coupled with system mass flow data, will provide a basis for estimating more accurately the lifetime of the carbon in the main sorption bed.

Eleven locations may be used for monitoring VOCs at the WIPP site (Figure D-36). Sampling at these locations will measure concentrations of VOCs at the point of potential release in the underground, the ambient air drawn into the underground, the air drawn into and exhausted from the Panel 1 experimental area, and the point of emission into the atmosphere. Sampling locations include the bin-scale stations, the Panel 1 Intake and Outlet, the Air Intake Shaft, and the Exhaust Shaft in Station A (DOE, 1990d).

The Panel 1 outlet station will monitor any VOC emissions potentially released from any leaks in the bin ducting and manifold systems. Subtraction of VOC target compound concentrations in the Panel 1 air intake passageway (background) from those measured in the air outlet will yield an estimate of VOCs that may have been released from the bin rooms.

The station deployed at the Air Intake Shaft is designed to measure detectable background quantities of the target compounds in the ambient air drawn into the underground. However, there will be additional sources of VOCs located in the underground which will contribute to the overall background concentrations of VOCs found at the facility.

The unit boundary sampling site will be the sampler located in Station A, at the top of the Exhaust Shaft. This VOC sampler will be integrated with the existing radioactive particulate monitoring system to measure detectable quantities of the VOC target compounds in the exhaust airstream that leaves the underground disposal facility.

Gases released by the VOC removal system should have very low or no measurable VOC concentrations. The quantity of VOCs measured at the top of the Exhaust Shaft will primarily be the result of contributions from sources other than the waste stored in the test bins. Numerous background sources of VOCs exist at the WIPP site. These include lubricants, solvents, paint, and other materials not related to the waste. These materials used both above and below ground at the WIPP facility will contribute VOCs to the underground atmosphere. Air drawn into the underground facility will also be a potential source of VOCs. All sources of VOCs will be well mixed by the mine ventilation airflow. Background sources will be monitored and evaluated prior to waste being emplaced in the WIPP facility underground.

The EPA has determined that in no event shall the monitoring frequency for the bin discharge system be reduced to less than 20 percent of the minimum time required for the consumption of the total working capacity of the carbon sorption system (EPA, 1990a). Following this requirement will ensure that, should the total working capacity of the sorption system be exceeded prematurely and breakthrough occur, the event will be detected in sufficient time to take corrective action and replace the used carbon bed with a new unit. Initially after waste emplacement, samples from the bin monitoring system will be collected daily. Sampling at this frequency will quickly detect any measurable concentrations of the target compounds that may have passed through the carbon sorption bed. Early detection of any higher than normal concentration in a sample would indicate that breakthrough of the carbon sorption bed was beginning to occur. If any sample shows significantly increased VOC concentrations, it will be assumed that the sorption bed is near saturation and will be immediately replaced with a new unit.

To determine if any VOC migration has occurred (i.e., any of the targeted compounds exceeded health-based levels at the unit boundary), the EPA has proposed that concentrations be averaged over an annual time period. To define at the earliest possible time if migration is occurring, the DOE is required to report to the EPA within ten days if, during any three-month period, the average concentration of any hazardous constituent measured or calculated in the Exhaust Shaft above background levels exceeds a health-based level. The sampling frequency at the release point and the reporting requirements will allow early determination of potential failure of the VOC control system and rapid corrective action.

√ Operation of the VOC monitoring stations is in progress at VOC-1, VOC-2, VOC-8, and VOC-9
√ and will have been in progress for more than 30 days prior to the receipt of waste at the WIPP
√ facility. This preliminary monitoring will better define background concentrations of the target compounds before the start of the bin-scale experiments.

√ Procedures in WP 12-6 outline the requirements and daily operating procedures to ensure that equipment and samples are not contaminated by exposure to background sources of VOCs (Westinghouse, 1991e). The WIPP VOC Monitoring Program staff are trained and have procedures in place addressing sampler operation, sample collection, and proper handling of samples and equipment. The VOC Monitoring Program is carried out in accordance with
√ WP 12-7, Volative Organic Compounds Monitoring Quality Assurance Program Plan (Westinghouse, 1991f).

Geomechanical Monitoring

Waste experiment rooms, drifts, and geomechanical test rooms are monitored to provide confirmation of structural integrity. Geomechanical data on the performance of the repository shafts and excavated areas are collected as part of the geotechnical field monitoring program. The results of the geotechnical investigations are reported annually (DOE, 1989). The report describes monitoring programs and geomechanical data collected during the previous year.

Convergence of rock walls in the repository Panel 1 rooms is continuously monitored using geomechanical instrumentation. Convergence stations, consisting of horizontal and/or vertical measurement points, were installed at the room midpoints at 25-foot intervals and selected
√ locations along the drifts. Locations of the convergence stations are shown in Figure D-37. At these stations, vertical closure at midspan and horizontal closure at mid-rib height is being monitored. At the other stations shown in the figure, additional closure points have been installed to better define the cross-sectional closure. Borehole extensometers were installed on each rib near the center of the room to monitor salt creep and deformation rates. Rockbolt supports, installed throughout the panel area, are visually inspected as part of the monitoring program to assure that structural stability is maintained.

Operational Environmental Monitoring Program (OEMP)

During the preoperational phase, measurements of environmental parameters were made to
√ establish the baseline conditions in the WIPP facility vicinity prior to waste receipt. Monitoring programs included air quality, surface and groundwater quality, soil chemistry, and ecological characterization (Reith et al., 1985). The radiological baseline for the site was also established (Reith and Daer, 1985).

During the Test Phase, an operational environmental monitoring program incorporating elements of the preoperational monitoring program will be undertaken (Mercer et al., 1989). This program

is designed to detect hazardous chemical or radiological releases to the environment and to assess trends in environmental parameters which may be the result of WIPP facility operations. Radiological environmental monitoring program elements are described in the permit application for information only and comply with DOE monitoring program requirements and objectives. Annual reports will be published with monitoring data and analyses during the Test Phase.

As required by the OEMP, measurements are taken of ambient radiation levels, atmospheric conditions, air and water quality, soil properties, and the status of the local biological community. Ecological portions of the program tend to focus on the immediate area surrounding the facility, whereas radiological surveillance will generally cover a broader geographic area including nearby ranches, villages, and cities. Environmental monitoring will continue at the site throughout project operations and decommissioning.

Tables D-8 and D-9 summarize typical OEMP sampling and analysis schedules. The tables list the sample types, the number of sampling stations, the approximate sampling schedule, and the environmental/ecological parameters to be monitored or analyzed. Additional or different types of samples will be collected and analyzed as necessary to investigate and explain trends or anomalies that may have a bearing on the environmental impacts of the WIPP Project. The OEMP will be reviewed annually, and the scope and intensity of the program will be adjusted in response to changing facility processes, environmental parameters, and program results.

Sampling and related activities (record keeping, packaging, and shipping) will be conducted in accordance with the procedures and instructions described in WP 02-3, Environmental Procedures Manual (Westinghouse, 1991g). Most samples will be analyzed by a commercial laboratory selected through the use of a prequalifying program. Sample splits will be made available to the State of New Mexico for independent verification of the DOE environmental surveillance program and some will be archived. Quality assurance/quality control will be established within the framework of WP 13-1, WIPP QA Program Manual (Westinghouse, 1991h).

D-9e(2) Inspection

As required in HWMR-6, Pt. V, secs. 264.15 and 264.33, the WIPP facilities and systems are inspected on a regular basis and in accordance with written procedures to assure their integrity, maintenance, and safe operation. Inspections focus on identifying malfunctions, signs of deterioration, operator errors, and discharges or spills. Inspections are undertaken on a regular schedule based on the likelihood of component failure and associated consequences.

Chapter F of this permit application describes the inspection program at the WIPP facility. Monitoring equipment, safety and emergency equipment, security devices, and operating and structural equipment related to waste management activities are inspected to insure that human health and the environment will be protected.

D-9e(3) Record Keeping

Biennial Report

√ In accordance with HWMR-6, Pt. V, sec. 264.75, a biennial report on facility activities will be
√ prepared and submitted to the Secretary of the NMED and to the Administrator, EPA Region VI.
√ The report will be prepared and submitted in accordance with procedures in WP 02-6 and 02-7
√ (Westinghouse, 1992) and will cover facility activities during the previous year. The EPA identification number, name, and address of the facility will be included in the report. A description and the quantity of each RCRA-regulated waste received at the facility will be listed
√ by the EPA identification number of each waste generator from whom the WIPP facility received the waste. The method of treatment, storage, or disposal for each RCRA-regulated waste will be
√ described. (Experimental waste received at the WIPP facility will be emplaced in the repository without any on-site treatment.) The report will also describe both the efforts undertaken at the
√ WIPP facility during the year to reduce the volume and toxicity of waste, including derived waste, generated at the site and the effectiveness of those efforts in comparison with prior years.
√ Proposed methods of waste minimization at the WIPP facility are described in the Draft Waste
√ Minimization and Pollution Prevention Awareness Program Plan for the Waste Isolation Pilot
√ Plant. (Westinghouse, 1991i). The report will be certified correct and signed by the authorized
√ official (Westinghouse, 1992).

Unmanifested Waste Report

The WIPP facility will not accept any unmanifested hazardous waste. All waste shipments will
√ be accompanied by a hazardous waste manifest that satisfies all the requirements of HWMR-6, Pt. V, Subpart E. The manifest will be reviewed upon receipt of the shipment. Discrepancies in the hazardous waste manifest will be resolved with generators before waste will be accepted. No unmanifested waste will be accepted.

Additional Reports

√ In compliance with HWMR-6, Pt. V, sec. 264.56(j), and HWMR-6, Pt. VI, sec. 265.56(j), any
√ release, fire, explosion, or other unusual occurrence will be noted in the WIPP facility operating
√ record and reported in writing within 15 days to the Secretary of the NMED and the Administrator
√ of EPA Region VI. Details of unusual occurrence reporting are in Chapter G of this permit application.

√ In addition, annual reports will be provided to the Administrator, EPA Region VI, in accordance
√ with HWMR-6, Pt. V, sec. 268.6, reporting requirements. The reports will describe monitoring
√ activities and the extent, if any, of migration from the miscellaneous unit. Copies of the report will
√ also be provided to the Secretary of the NMED. Additional information on reporting requirements associated with EPA's No-Migration Determination are provided in Chapter L.

No corrective actions for Solid Waste Management Units as described in HWMR-6, Pt. V, sec. 264.101, are necessary for the site. Chapter J discusses Solid Waste Management Units. Final closure of the site will be reported within 60 days of completion in accordance with HWMR-6, Pt. V, sec. 264.115, and as described in the WIPP Closure Plan, Chapter I of this permit application.

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TABLES

TABLE D-1
List of Drawings[1] in Appendix D3, Detailed Plans and Drawings

Drawing[1] Number	Title
DOE-WIPP 91-059 (Report)	WIPP Underground Storage Area, Panel 1, Room 1
WP-04-ED1341 (Report)	Site Backup Power System
23-C-001-022	Project Location Maps
23-C-003-003	North Access Road, Orientation Plan (Sh 01 of 02)
23-C-004-003	North Access Road, Orientation Plan (Sh 02 of 02)
23-C-014-003	Access Roads, Details
23-C-161-05A	Access Railroad, Plan & Profile
24-C-140-022	Site Work, Finish Grading & Paving, Overall Plan
24-C-145-022	Site Work, Finish Grading and Paving Plan
24-C-147-022	Site Work, Fencing Plan
24-C-149-022	Site Work, Finish Grading and Paving Sections & Details
25-J-015-W1	Yard Electrical, Area Sub No 3 and On Site Power, 480V SWGR 25P-SWG04/3, Electrical Diagrams & Details
25-J-020-W1	WIPP Site Primary Power Distribution-One Line Diagram
25-J-020-W6	Selected Load System Operations-Surface & U/G
25-F-003-W	Yard Piping - Fire Water System Plan
41-F-082-014	Waste Handling Building 411, Fire Protection Floor Plan (Sh 1 of 4)
41-F-087-014	Waste Handling Building 411, Firewater Collection System, Flow Diagram
41-S-003-W1	Waste Handling Building 411, Fire Protection Sprinkler System P&ID
41-S-003-W2	Waste Handling Building 411, Fire Protection Sprinkler System P&ID
41-S-003-W3	Waste Handling Building 411, Fire Protection Sprinkler System P&ID
41-S-003-W4	Waste Handling Building 411, Fire Protection Sprinkler System P&ID
53-S-002-W	Underground Fuel Stations 1 & 2, Dry Chemical Fire Suppression Systems P&ID
53-J-039-W	Underground Utilities, Fire Panel 534-FP-0320

[1]Unless otherwise specified.

TABLE D-1 (Continued)
List of Drawings[1] in Appendix D3, Detailed Plans and Drawings

Drawing[1] Number	Title
53-J-040-W	Underground Utilities, Fire Panel 534-FP-14001
53-J-041-W	Underground Utilities, Fire Panel 534-FP-14002
53-J-042-W	Underground Utilities, Fire Panel 534-FP-00601
53-J-051-W	Underground Utilities, Fire Panel 534-FP-033
53-J-054-W	Underground Utilities, Fire Panel 534-FP-0315
41-E-008-019	Exhaust Filter Building No. 413, Architectural, Plan Elevation & Schedules
41-F-026-019	Exhaust Filter Building 413, Underground Exhaust System, Flow Diagram
41-D-002-014	Waste Handling Building 411, Foundation Plan
41-D-003-014	Waste Handling Building 411, Foundation Plan
41-D-006-014	Waste Handling Building 411, Ground Floor Slab, Plan El. 100'-0"
41-D-010-014	Waste Handling Building 411, Foundation Details
41-D-016-014	Waste Handling Building 411, Hoist Tower Foundation, Plans El. 76'-0" & 89'-0"
41-D-017-014	Waste Handling Building 411, Hoist Tower Floor Slab, Plan El. 100'-0"
41-D-117-014	Waste Handling Building 411, Steel Framing, Elevation Line F
41-D-118-014	Waste Handling Building 411, Steel Framing, Elevation Line "E"
41-D-119-014	Waste Handling Building 411, Steel Framing, Elevation Lines 3, 5, and 7
41-E-003-014	Waste Handling Building No. 411, Architectural, C.H. Area-Plan at El. 100'0"
41-E-005-014	Waste Handling Building No. 411, Architectural, RH Area - Plan at El. 100'-0"
41-E-006-014	Waste Handling Building No. 411, Architectural, Mech. Equip. Rm. Plan at El. 123'-0"
41-E-063-014	Waste Handling Building 411, Architectural, Plans at Tower
41-F-022-014	Waste Handling Building 411, CH Area HVAC, Flow Diagram

[1]Unless otherwise specified.

TABLE D-1 (Continued)
List of Drawings[1] in Appendix D3, Detailed Plans and Drawings

Drawing[1] Number	Title
41-F-025-W	TRUPACT Dock Vacuum/Monitoring, Equipment Location, Drawing Equipment No. 41-D-047
41-A-001-W	Exhaust Filter Bldg 413, Underground Exhaust and Ventilation System P&ID
41-B-001-W1	Waste Handling Bldg 411, CH Area HVAC Piping and Instrument Diagram
41-B-001-W2	Waste Handling Bldg 411, CH Area HVAC Piping and Instrument Diagram
41-B-001-W3	Waste Handling Bldg 411, CH Area HVAC Piping and Instrument Diagram
41-B-003-W	Exhaust Filter Bldg 413, HVAC System Piping & Instrument Diagram
31-R-001-O1D	Waste Shaft 311, Shaft Development Sections
31-R-002-O1D	Waste Shaft 311, Shaft Lining and Key, Section and Details
31-R-006-O1D	Waste Shaft 311, Geomechanical Instrumentations, Installation Details
35-R-001-01D	Exhaust Shaft 351, Shaft Development, Plan, Sections and Detail
35-R-004-01D	Exhaust Shaft 351, General Arrangement, Plans and Sections
41-D-011-W	Waste Handling Facilities, Facility Pallet Assembly, Eqpt. No. 52-Z-002- C,D
165-F-001-W	TRUPACT II Standard Waste Box Assembly
54-W-001-W	Underground Mine, Ventilation System
54-W-002-W	Underground Ventilation Plan, Waste Handling Mode
54-W-004-W	Underground Ventilation Plan, Filtration Mode
54-W-009-W	Underground Mine Plan, Shaft and Drift Dimensions
24-D-001-W	Tech Devel. Trailer, Base for Radio Antenna Tower
73-E-001-W	Underground Utilities, Evacuation Warning Layout (2 sheets)
73-J-010-W	Underground Utilities,Public Address System Layout
73-J-011-W	Underground Utilities, Mine Paging System Layout

[1]Unless otherwise specified.

TABLE D-1 (Continued)
List of Drawings[1] in Appendix D3, Detailed Plans and Drawings

Drawing[1] Number	Title
73-J-014-W	Surface Layout, Plant Communications
73-J-025-W	Public Address and Intercom, Block Diagram and Master Control Console Wiring Diagram 73-P-006
51-W-102-W	Underground Development
54-D-003-W1	Supplementary Roof Support, Room 1, Panel 1 General Arrangement
54-D-003-W2	Supplementary Roof Support, Room 1, Panel 1 Steel Set Locations & Details
54-D-003-W3	Supplementary Roof Support, Room 1, Panel 1 Steel Set Fabrication
54-D-003-W4	Supplementary Roof Support Room 1, Panel 1 Cross Section
54-D-003-W5	Supplementary Roof Support Room 1, Panel 1, Wire Mesh and Lacing Detail
412-F-017-W	Bin-Scale Tests, Dry Test Bin Details (2 sheets)
412-N-002-W	Bin-Scale Tests, Dry Test Bin Assembly
412-N-009-W	Bin Scale Tests, SWB Lid Modification for RCB Lid Assembly and Details
52-L-001-W	Bin-Scale Tests, VOC Monitoring System P & I Diagram
52-L-002-W1	Bin-Scale Tests, VOC Monitoring and Helium Stations, Details
52-L-002-W2	Bin-Scale Tests, VOC Monitoring and Helium Stations, Details
52-L-002-W3	Bin-Scale Tests, VOC Monitoring and Helium Stations, Details
52-L-002-W4	Bin-Scale Tests, VOC Monitoring and Helium Stations, Details
52-L-002-W5	Bin-Scale Tests, VOC Monitoring and Helium Stations, Details
52-L-002-W6	Bin-Scale Tests, VOC Monitoring and Helium Stations, Details
52-L-002-W7	Bin-Scale Tests, VOC Monitoring and Helium Stations, Details
52-L-002-W8	Bin-Scale Tests, VOC Monitoring and Helium Stations, Details
52-L-002-W9	Bin-Scale Tests, VOC Monitoring and Helium Stations, Details
52-L-002-W10	Bin-Scale Tests, VOC Monitoring and Helium Stations, Details

[1]Unless otherwise specified.

TABLE D-1 (Continued)
List of Drawings[1] in Appendix D3, Detailed Plans and Drawings

Drawing[1] Number	Title
105-F-013-W	VOC (10) Monitoring System, Air Sampler Unit Assembly 105-S-008
412-M-003-W	Bin Scale Tests, VOC Monitoring System, Carbon Sorption System

[1]Unless otherwise specified.

TABLE D-2
BASIC DESIGN REQUIREMENTS(1)
Principal Codes and Standards

	STUCTURE/SUPPORTS			LIQUID AND PROCESS AIR HANDLING PROCESSING AND STORAGE EQUIPMENT						AIR HDLG DUCTING & FANS	HVAC FILTERS		MECHANICAL HANDLING EQUIPMENT			INSTRUMENTATION AND ELECTRICAL			QUALITY ASSURANCE PROGRAM	
	DBE DBT ACI-318 AISC	USC ANSI A58.1	SITE SPEC REQUIRE-MENTS	VESSEL — ASME VIII NFPA (5)	PIPING & VALVES — ANSI B31,1 NFPA (5)	UPC	PUMPS — API-610 NFPA (5)	STORAGE TANKS API-650 OR API-620	HEAT EXCHGRS ASME VIII TEMA	ALL OTHER EQUIP MFR'S STD	ARI SMACNA AMCA	PRE FILTERS ASHRAE 52.68	HEPA FILTERS MIL F 51068C ANSI N 509 ANSI N 510	CRANE AND RELATED EQUIP CMAA	CMAA AISC AWS	MFR'S STD	IEEE-NE	ANSI STDS OR NAT'L ELEC-TRICAL CODE	ISA/ MFR'S STD	INTENT OF ANSI/ASME NQA-1 1979 & SUPP-LEMENTS	COMM. AND INDUSTRY PRACTICES
DESIGN CLASS I	X		(1)	X (6)			X	X	X		X, (3)	X, (3) (4)	X, (3)	X	X		X	X		X	
DESIGN CLASS II	(1), (2)	X	(1)	X	X		X	X	X		X, (3)	X, (3)	X, (3)	X	X			X	X	X	
DESIGN CLASS IIIA	(1)	X	(1)	(1)	X		(1)			X	X, (3)	X, (3)	X, (3)	(1)	(1)	X		X	X	X	
DESIGN CLASS IIIB		X	(7)		(1)	X				X	X	X	X			X		X	X		X

X – Minimum Requirements

NOTES
(1) Requirements to be determined on case by case basis.
(2) Required for structure and supports needed for confinement and control of radioactivity.
(3) Except structures and supports that are designed to withstand DBE/DBT when specified in column 1 of this table.
(4) Underwriter's Laboratory (UL) Class I Listed.
(5) For fire protection systems.
(6) ASME III for other Class I vessels.
(7) Design of underground structures, mining equipment, and facilities are basically governed by Mine Safety and Health Administration and the experience in local mines.

Source: DOE, 1990c

TABLE D-3
ESTIMATED CONCENTRATIONS OF HAZARDOUS CONSTITUENTS IN TRANSURANIC MIXED WASTE FROM THE ROCKY FLATS PLANT

HAZARDOUS CONSTITUENT	MINIMUM (milligrams per kilogram)	MAXIMUM (milligrams per kilogram)
1,1,1-Trichloroethane	15	150,000
Carbon Tetrachloride	25	50,000
1,1,2-Trichloro-1,2,2-trifluoroethane	75	50,000
Trichloroethylene[1]	15	150,000
Methylene Chloride	50	750
Methyl Alcohol	0	25
Xylene	0	50
Butyl Alcohol	0	10
Cadmium	0	10
Lead	0	1,000,000

[1] No estimates were available on the total concentration of trichloroethylene. Based on knowledge of past industry practice, the concentration was assumed to be equivalent to that of 1,1,1-trichloroethane.

Source: DOE, 1990c

TABLE D-4
AVERAGE CONCENTRATION OF SELECTED VOLATILE ORGANIC COMPOUNDS IN THE HEADSPACE OF TRANSURANIC WASTE DRUMS

SELECTED VOC	AVERAGE CONCENTRATION (grams per liter)
Carbon Tetrachloride	1.85×10^{-3}
1,1,1-Trichloroethane	13.2×10^{-3}
Methylene Chloride	0.47×10^{-3}
1,1,2-Trichloro-1,2,2-trifluoroethane	1.22×10^{-3}
Trichloroethylene	6.99×10^{-4}

Source: Clements and Kudera, 1985

TABLE D-5
TOTAL QUANTITY OF VOLATILE ORGANIC COMPOUNDS AVAILABLE FOR RELEASE FROM A BIN-SCALE EXPERIMENT ROOM

CHEMICAL	(grams/room/year)[1]
Carbon Tetrachloride	144
1,1,1-Trichloroethane	1,026
Methylene Chloride	37
1,1,2-Trichloro-1,2,2-trifluoroethane	95
Trichloroethylene	54

Source: DOE, 1990b

(1) These quantities are based on the assumption of 116 bins in each experimental room. At the present time, each room is expected to contain 76 bins. ✓ ✓

TABLE D-6
ESTIMATED MAXIMUM DAILY CONCENTRATIONS OF VOLATILE ORGANIC COMPOUNDS AT THE UNIT BOUNDARY FOR EACH WASTE EXPERIMENT ROOM

CHEMICAL	CONCENTRATION[1] ($\mu g/m^3$)	EPA LEVELS OF REGULATORY CONCERN ($\mu g/m^3$) [2]
Carbon Tetrachloride	0.0012	0.03
1,1,1-Trichloroethane	0.0081	10,000
Methylene Chloride	0.0003	0.3
1,1,2-Trichloro-1,2,2-trifluoroethane	0.0008	30,000
Trichloroethylene	0.0005	0.3

√ (1) Emissions per room. These calculations are based on the assumption that there will be a maximum of 233 bins,
√ or two rooms. At the present time, each room is expected to contain 76 bins.
(2) EPA, 1990b

TABLE D-7
CROSS REFERENCE OF NEW MEXICO HAZARDOUS WASTE MANAGEMENT REGULATIONS (HWMR-6), PART VIII, SECTION 268.6 REQUIREMENTS

HWMR-6 CITATION	REQUIREMENT	MONITORING PLAN SECTION(S) RESPONSIVE TO REQUIREMENT ✓
268.6(a)(4)	"A monitoring plan that detects migration at the earliest practicable time . . ." must be provided.	Entire document
268.6(b)(6)(1)(i)	"The media monitored . . ." must be described.	6.1.1.1
268.6(b)(6)(1)(ii)	"The type of monitoring conducted at the unit . . ." must be described.	6.1.3
268.6(b)(6)(1)(iii)	"The location of the monitoring stations . . ." must be described.	6.1.3.1
268.6(b)(6)(1)(iv)	"The monitoring interval (frequency of monitoring each station) . . ." must be described.	6.1.3.3
268.6(b)(6)(1)(v)	"The specific hazardous constituents to be monitored . . ." must be described.	6.1.3.2
268.6(b)(6)(1)(vi)	"The implementation schedule for the monitoring program . . ." must be described.	6.1.3.3
268.6(b)(6)(1)(vii)	"The equipment used at the monitoring stations . . ." must be described.	6.1.3.3
268.6(b)(6)(1)(viii)	"The sampling and analytical techniques employed . . ." must be described.	6.1.3.3, 6.1.5
268.6(b)(6)(1)(ix)	"The data recording/reporting procedures . . ." must be described.	6.1.5.5, 6.1.6.10
268.6(b)(6)(2)	"Where applicable, the monitoring plan . . . must be in place for a period of time specified by the Administrator . . . prior to receipt of prohibited waste at the unit."	6.1.3.3
268.6(b)(6)(4)	"A copy of the monitoring data . . . must be kept on-site at the facility in the operating record."	6.1.6.10, 6.1.6.11, 6.1.6.14

TABLE D-7
CROSS REFERENCE OF NEW MEXICO HAZARDOUS WASTE MANAGEMENT REGULATIONS (HWMR-6), PART VIII, SECTION 268.6 REQUIREMENTS (CONTINUED)

√ HWMR-6 CITATION	REQUIREMENT	MONITORING PLAN SECTION(S) RESPONSIVE TO REQUIREMENT
268.6(b)(6)(3)	"The monitoring data . . . must be sent to the Administrator according to a format and schedule specified and approved in the monitoring plan."	6.1.5.5
268.6(b)(6)(5)(i)	"All sampling, testing, and analytical data must be approved by the Administrator and must provide data that is accurate and reproducible."	6.1.6
268.6(b)(6)(5)(ii)	"All estimation and monitoring techniques must be approved by the Administrator."	Entire document
268.6(b)(6)(5)(iii)	"A quality assurance and quality control plan addressing all aspects of the monitoring program must be provided to and approved by the Administrator."	6.1.4, 6.1.5, 6.1.6

Source: DOE, 1990b

TABLE D-8
TYPICAL SAMPLING SCHEDULE

TYPE OF SAMPLE	SAMPLING LOCATIONS	SAMPLING FREQUENCY
Liquid Influent	1	Semiannually
Liquid Effluent	1	Semiannually
Airborne Effluent	3	Continuously
Meteorology	2	Continuously
Exposure Rate Meter	1	Continuously
Atmospheric Particulate	7	Weekly
Air Quality	1	Continuously
Vegetation Radioanalysis	2-4(1)	Annually
Beef	2	Annually(1)
Game Birds	2	Annually
Rabbits	2	Annually
Soil-Radioanalysis	7	Biennially
Surface Water	8	Annually
Ground Water	14	Annually
Fish	2	Annually
Sediments	6	Biennially
Aerial Photography	1	Annually
Environmental Photography	7	Semiannually
Soil Chemistry	7	Quarterly
Soil Microbiota	7	Semiannually
Vegetation Survey	7	Biannually
Wildlife Survey	4	Annually

(1)If available.

Source: Mercer et al., 1989

TABLE D-9
TYPICAL ENVIRONMENTAL SURVEILLANCE ANALYSIS SCHEDULE

TYPE OF SAMPLE	ANALYSIS
Liquid Influent	Gross Alpha (α), Gross Beta (β), pH, Total Suspended Solids (TSS), Specific Radionuclides
Liquid Effluent	Gross α, Gross β, pH, TSS, Specific Radionuclides, Chemical Constituents
Airborne Effluent	Gross β, Specific Radionuclides
Meteorology	Temperature, Wind Speed, Wind Direction, Precipitation, Dew Point, Barometric Pressure
Exposure Rate Meter	Penetrating Radiation
Air Quality	Ozone, Carbon Monoxide, Hydrogen Sulfide, Sulfur Dioxide, Nitrous Oxides, Total Suspended Particulates
Vegetation-Radionuclides	Specific Radionuclides
Beef	Specific Radionuclides
Game Birds	Specific Radionuclides
Rabbits	Specific Radionuclides
Soil Radioanalysis	Gross α, Gross β, Specific Radionuclides
Surface Water	Gross α, Gross β, Specific Radionuclides, TSS, pH
Ground Water	Gross α, Gross β, Specific Radionuclides, TSS, pH
Fish	Gross α, Gross β, Specific Radionuclides
Sediments	Gross α, Gross β, Specific Radionuclides
Aerial Photography	Area of Land Disturbed
Wildlife Survey	Bird and Small Mammal Population Densities

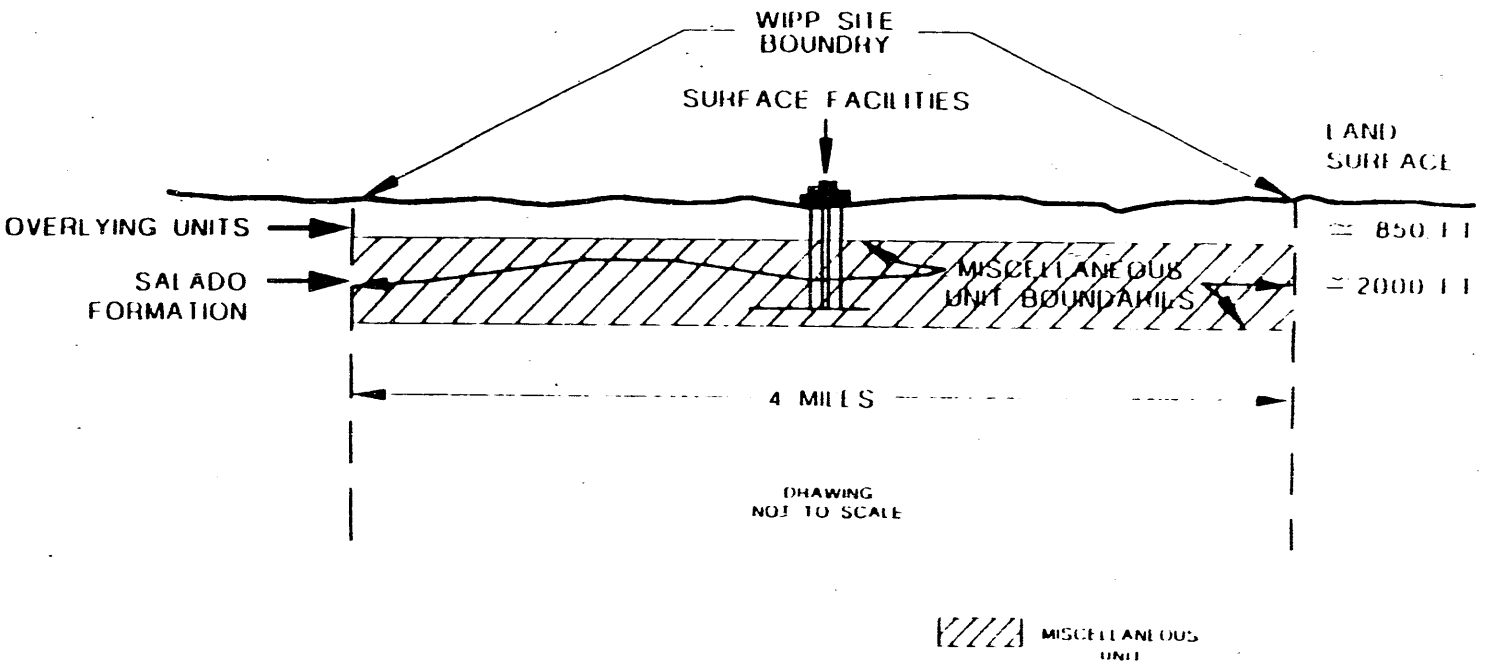
Source: Mercer et al., 1989

TABLE D-9
TYPICAL ENVIRONMENTAL SURVEILLANCE ANALYSIS SCHEDULE (CONTINUED)

TYPE OF SAMPLE	ANALYSIS
Salt Impact Study:	
Surface Photography	Visual Impacts
Soil Chemistry	pH, Electrical Conductivity, Sodium, Chloride, Magnesium, Calcium, Potassium
Soil Microbiota	Microbial Activity, Litter Decomposition
Vegetation Survey	Foliar Coverage, Species Richness, Annual Plant Density
Specific Radionuclides =	Pu^{238}, Pu^{239}, Pu^{240}, Pu^{241}, Pu^{242}, U^{233}, Am^{241}, Am^{243}, Cm^{244}, Th^{232}, Np^{237}, Ra^{226}, Cs^{137}, Sr^{90}, Co^{60}, U_{nat}, Th_{nat}
Chemical Constituents =	Chloride; iron; manganese; phenols; sodium; sulfate; pH; specific conductance; total organic carbon; total organic halogen; arsenic; barium; cadmium; chromium; fluoride; lead; mercury; nitrate; selenium; silver; endrin; methoxychlor; toxaphene; 2,4-D; 2,4,5-TP silvex; radium; turbidity; coliform bacteria.

Source: Mercer et al., 1989

FIGURES



DOE, 1990b

FIGURE D 1 SCHEMATIC SHOWING MISCELLANEOUS UNIT BOUNDARIES

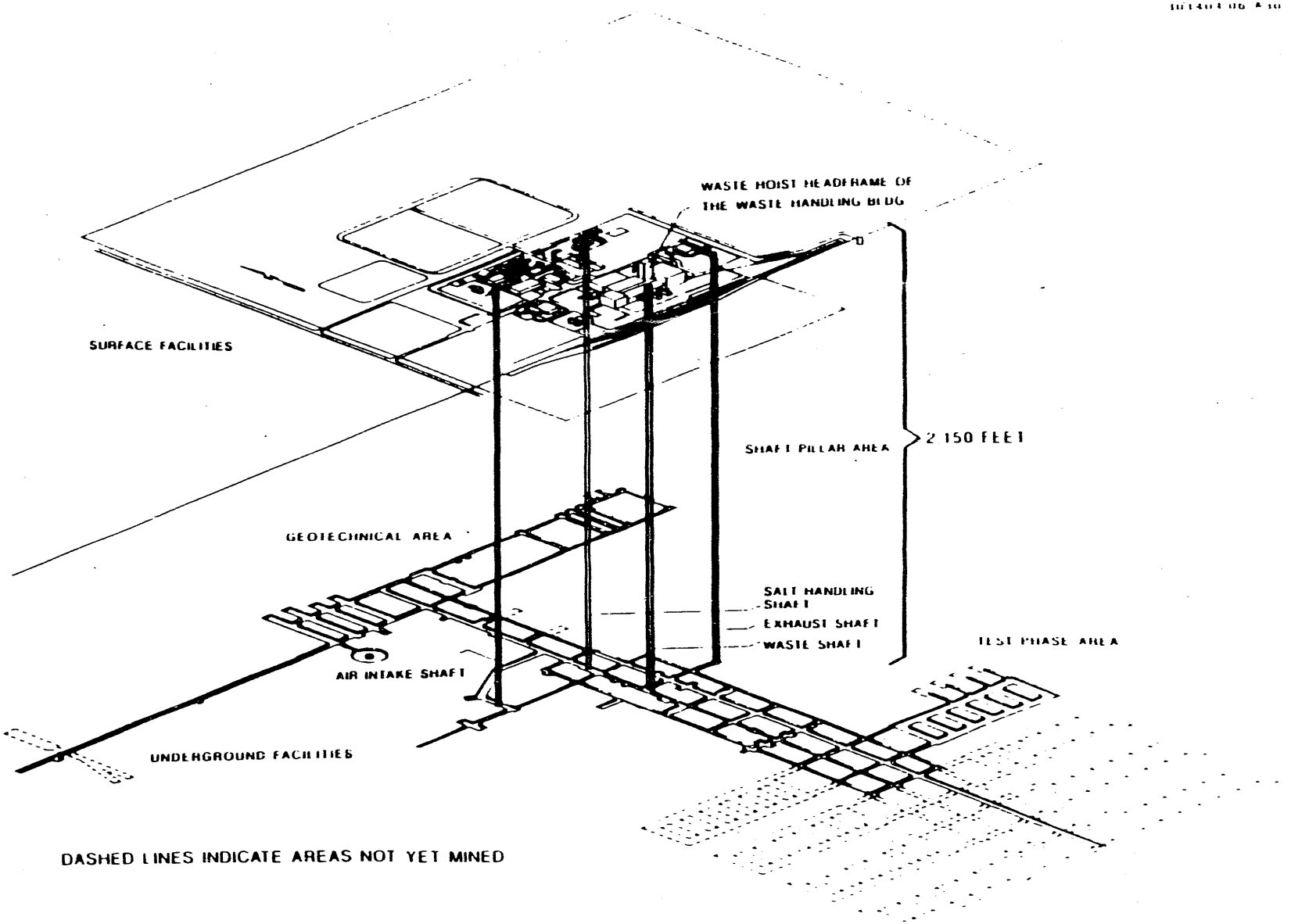
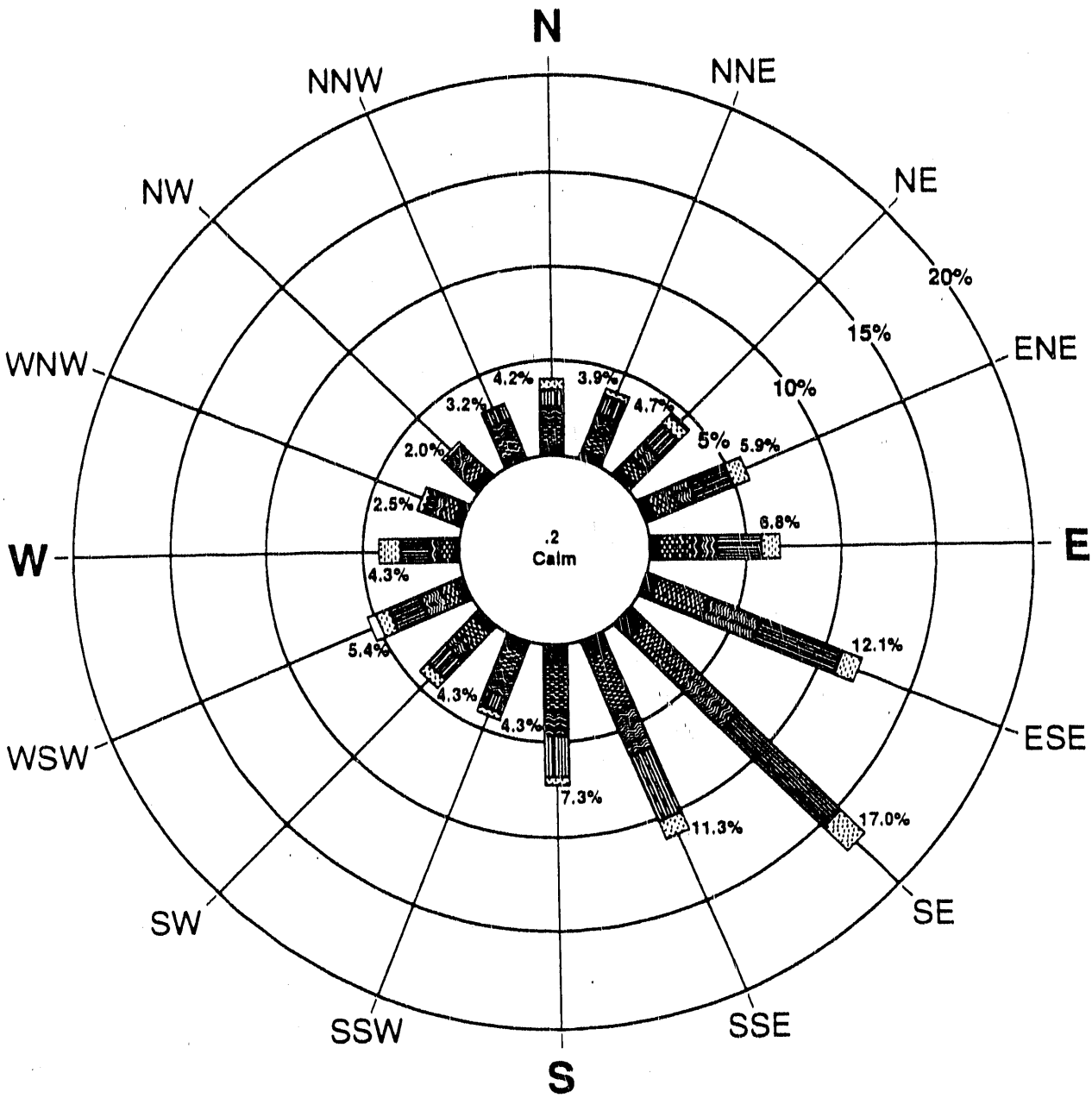
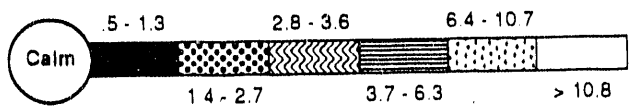


FIGURE D 2 SPATIAL VIEW OF THE MISCELLANEOUS UNIT AND WASTE HANDLING FACILITY

301486 01 A43





WIND VELOCITY IN METERS PER SECOND

BAR LENGTH SEGMENTS ARE PROPORTIONAL TO INDICATED SPEED INTERNAL OCCURRENCE

FIGURE D-3 1989 ANNUAL WIPP WIND ROSE

SYSTEM	SERIES	GROUP	FORMATION	MEMBER
RECENT	RECENT		SURFICIAL DEPOSITS	
QUATER-NARY	PLEIST-OCENE		MESCALERO CALICHE	
			GATUNA	
TRIASSIC		DOCKUM	UNDIVIDED	
PERMIAN	OCHOAN		DEWEY LAKE RED BEDS	
			RUSTLER	Forty-Niner
				Magenta
				Tamarisk
				Culebra
				Unnamed
			SALADO	Upper
				McNutt
				Lower
			CASTILE	
	GUADALUPIAN	DELAWARE MOUNTAIN	BELL CANYON	
			CHERRY CANYON	
			BRUSHY CANYON	

COOPER AND GLANZMAN, 1971
POWERS ET AL., 1978

FIGURE D-4 GEOLOGIC COLUMN REPRESENTATIVE OF WIPP FACILITY AREA

301486 01 A23

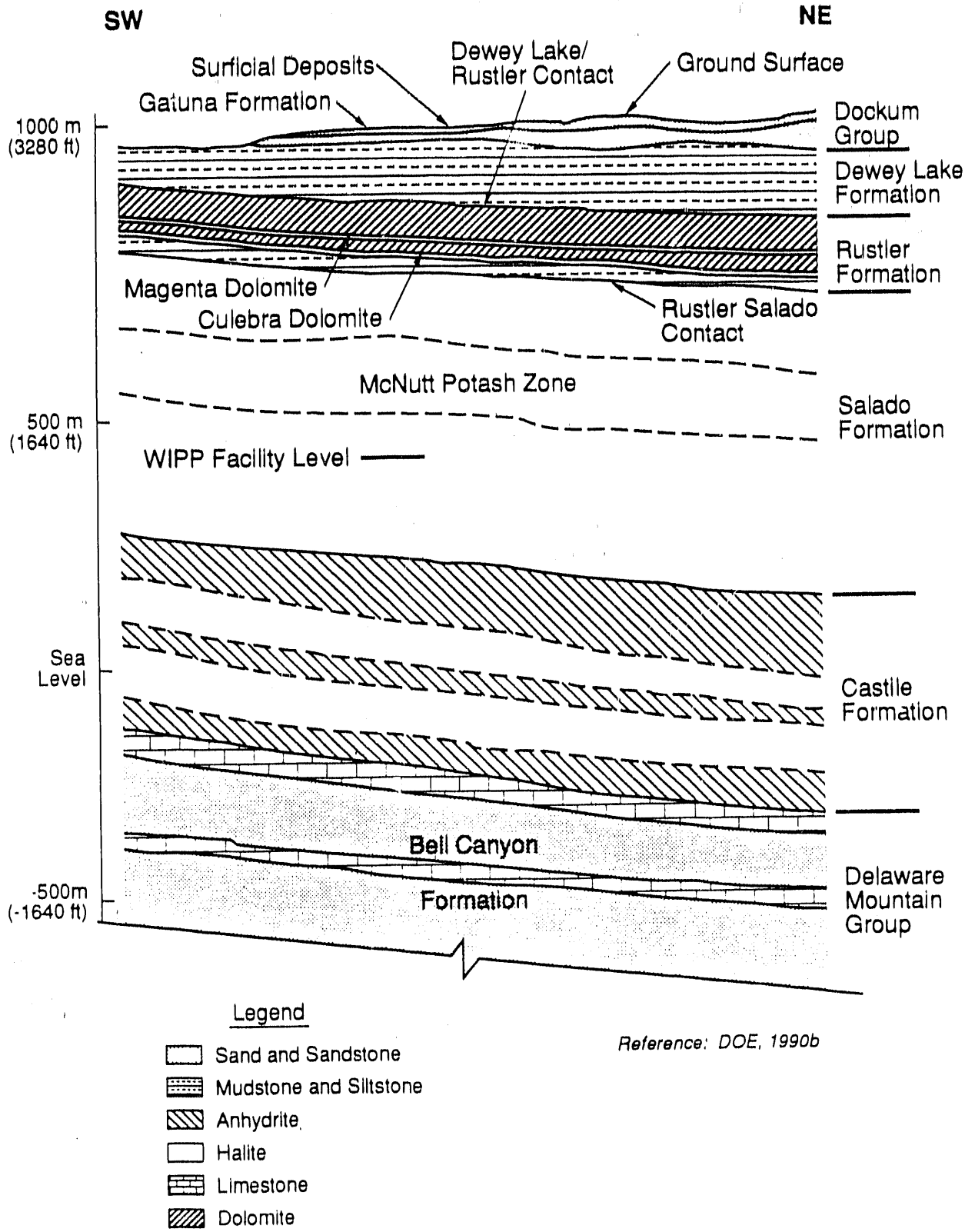


FIGURE D-5 GENERALIZED STRATIGRAPHIC CROSS SECTION

301486 01 A32

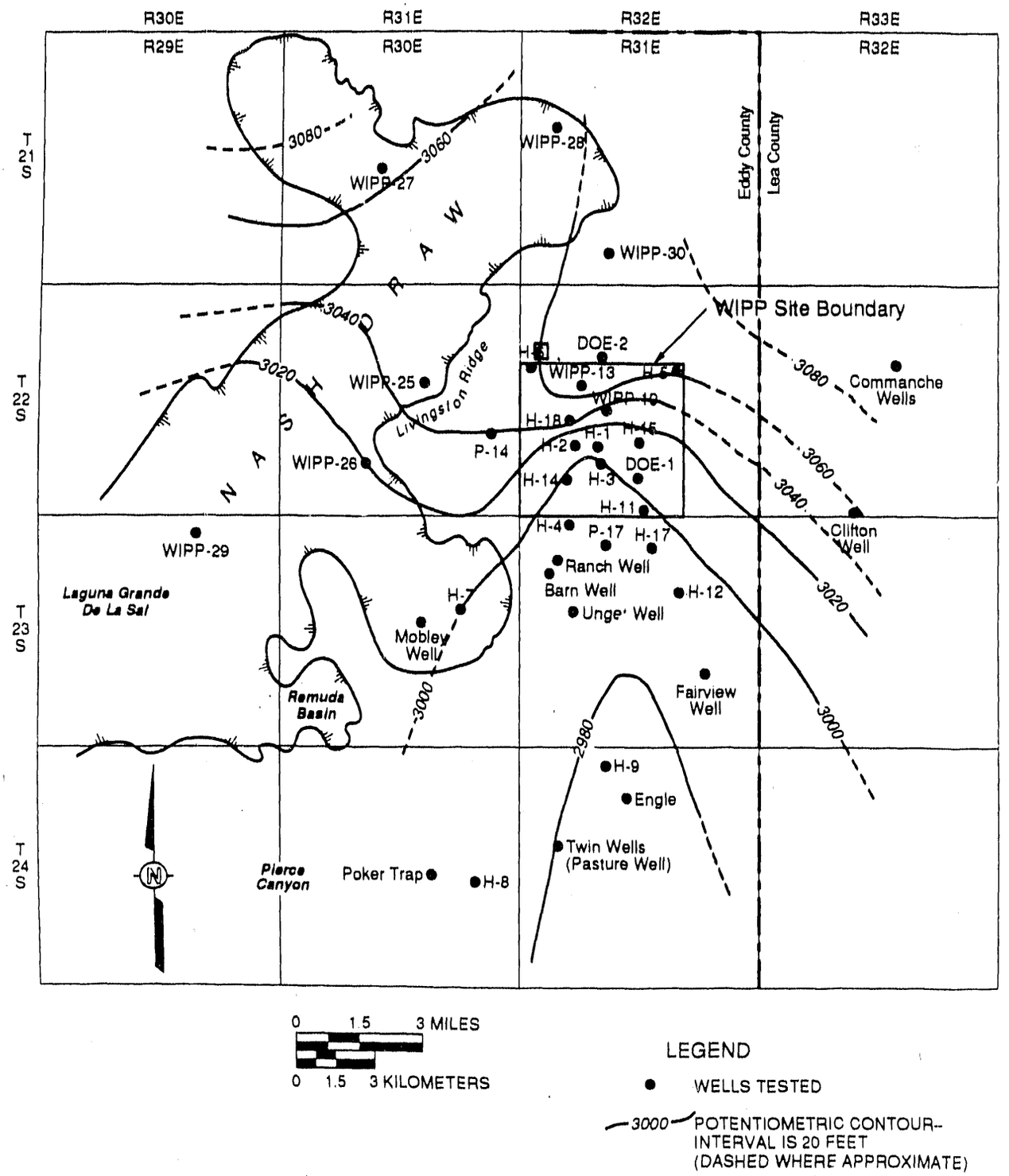


FIGURE D-6 CULEBRA FRESHWATER HEAD POTENTIOMETRIC SURFACE

301486 01 A16

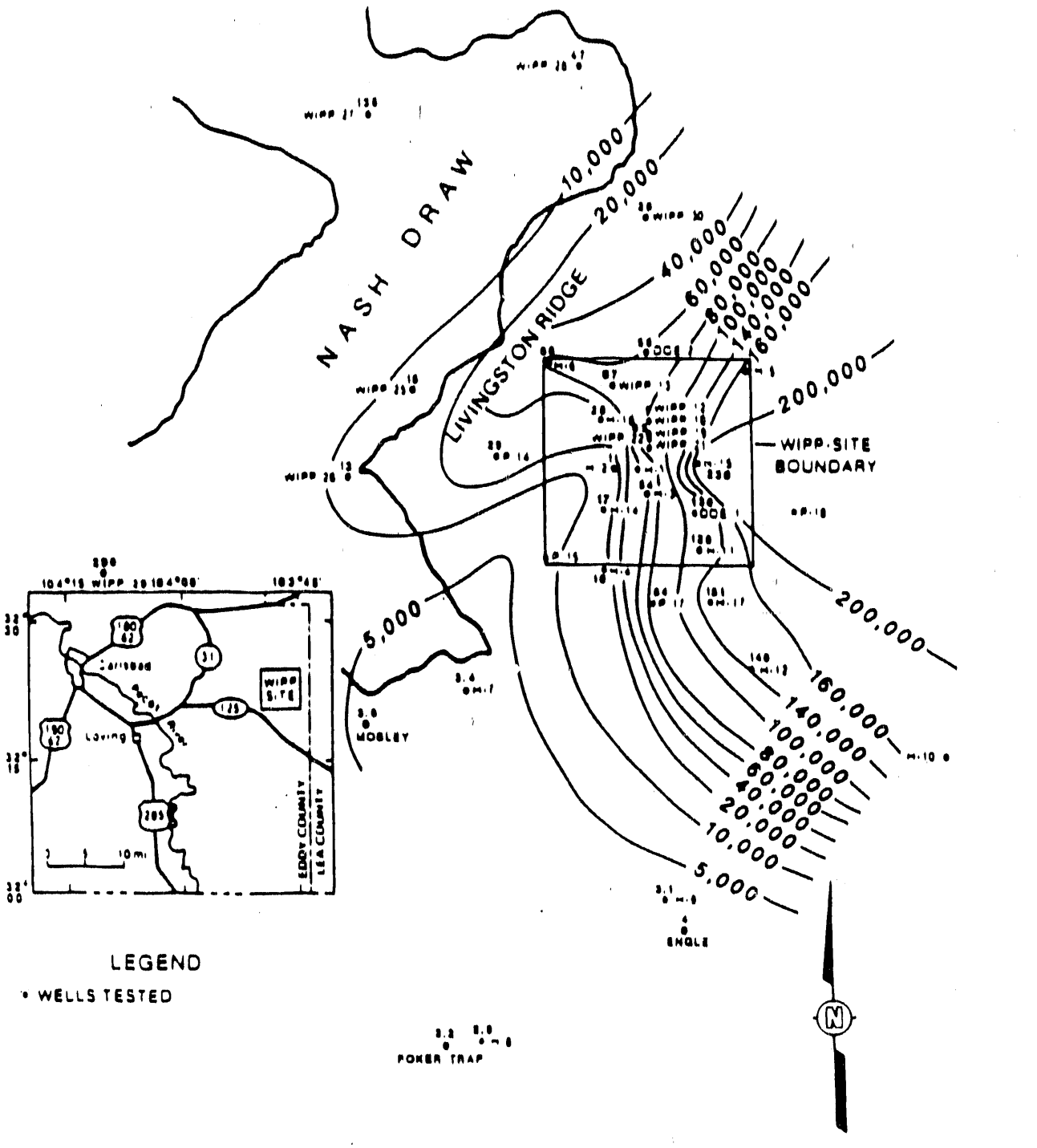
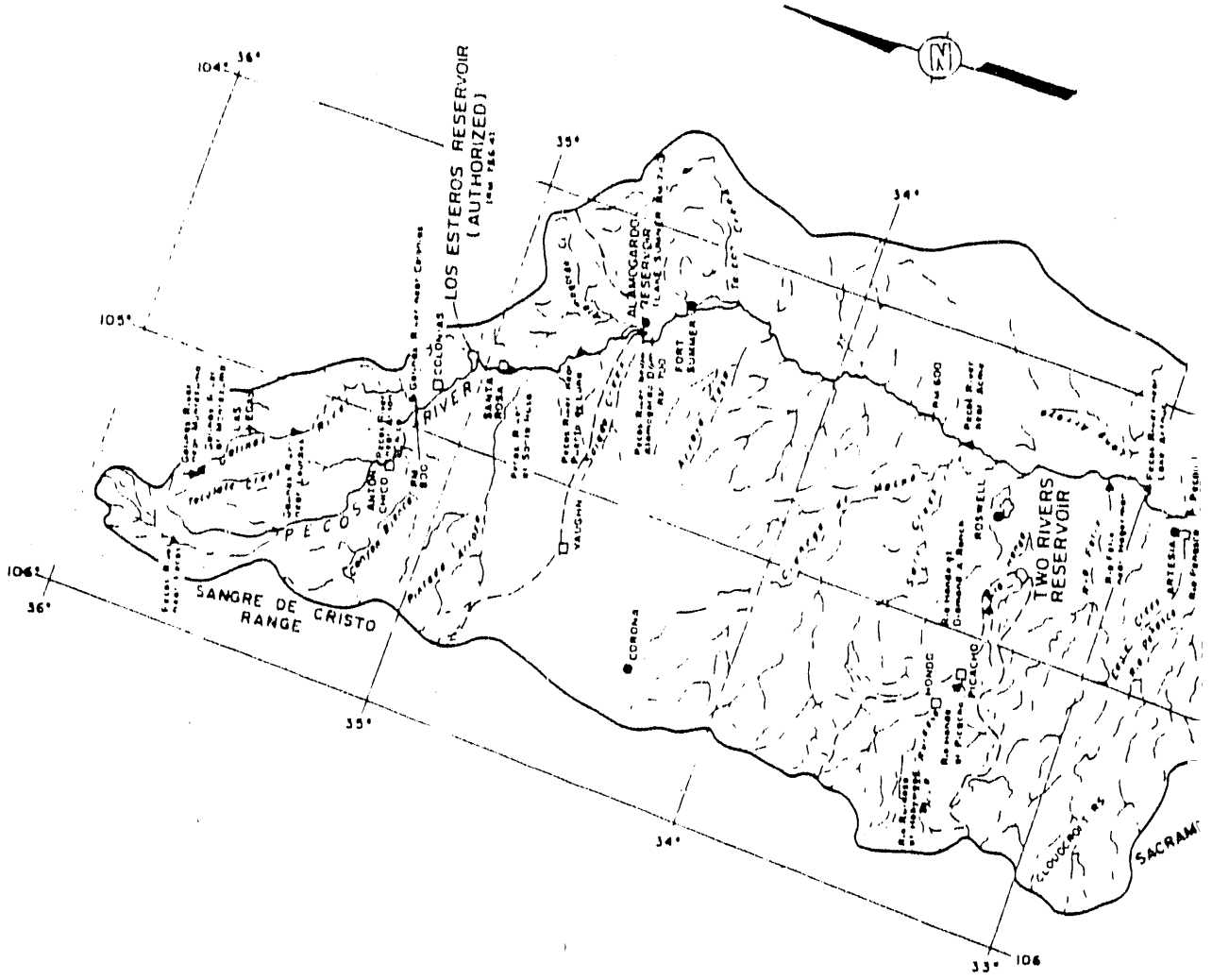


FIGURE D-7 TOTAL DISSOLVED SOLIDS DISTRIBUTION IN THE CULEBRA DOLOMITE

301486 01 82



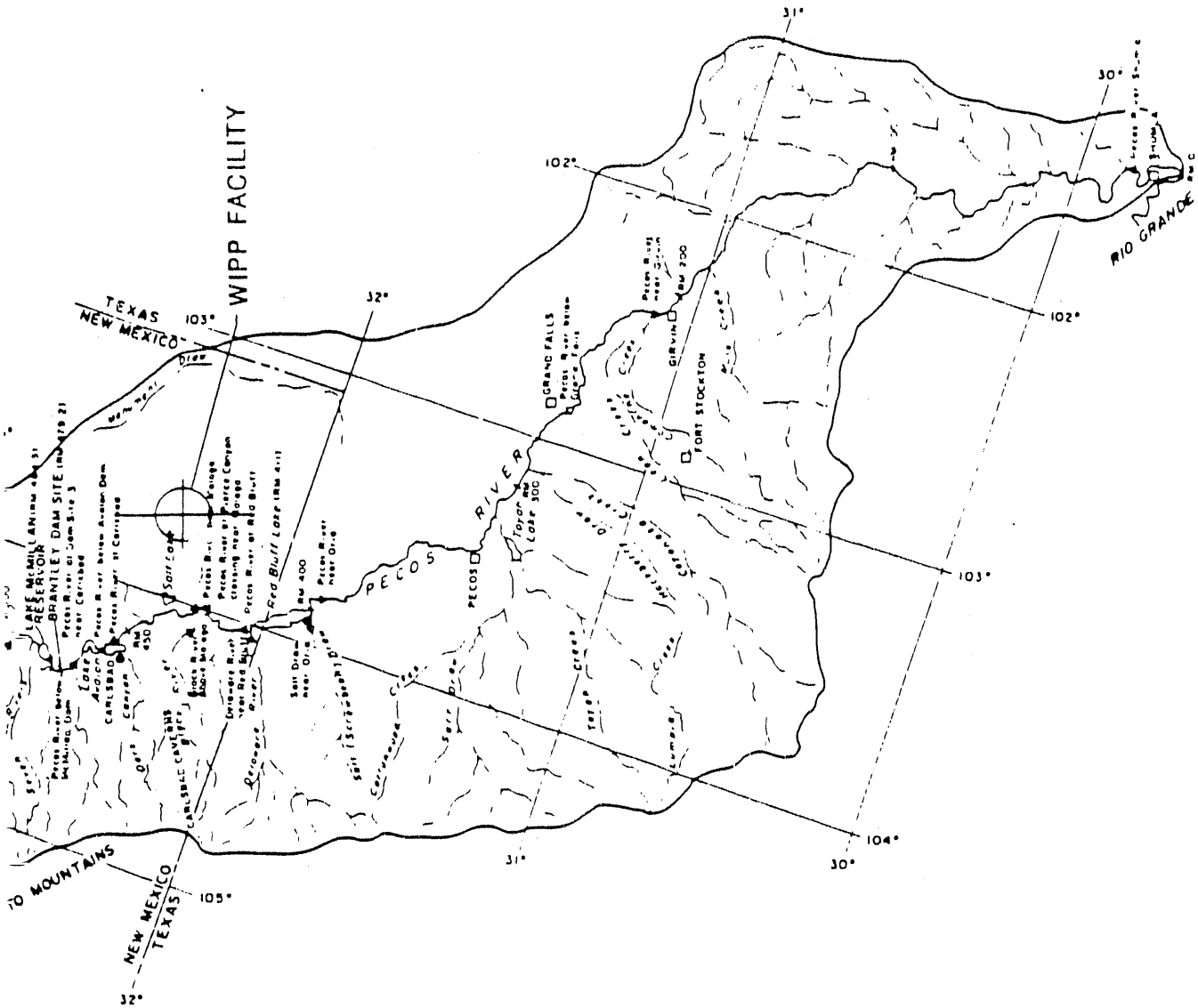
LEGEND

INTERMITTENT ST
PERENNIAL STRE
WATERSHED BOUN
SUB WATERSHED
STREAM GAGING S
STREAM GAGING ST
MUNICIPALITY
RESERVOIR AREA
PRECIPITATION STA
RIVER MILE

45 0 45 MILES

30 15 0 30 KILOMETERS

SCALE



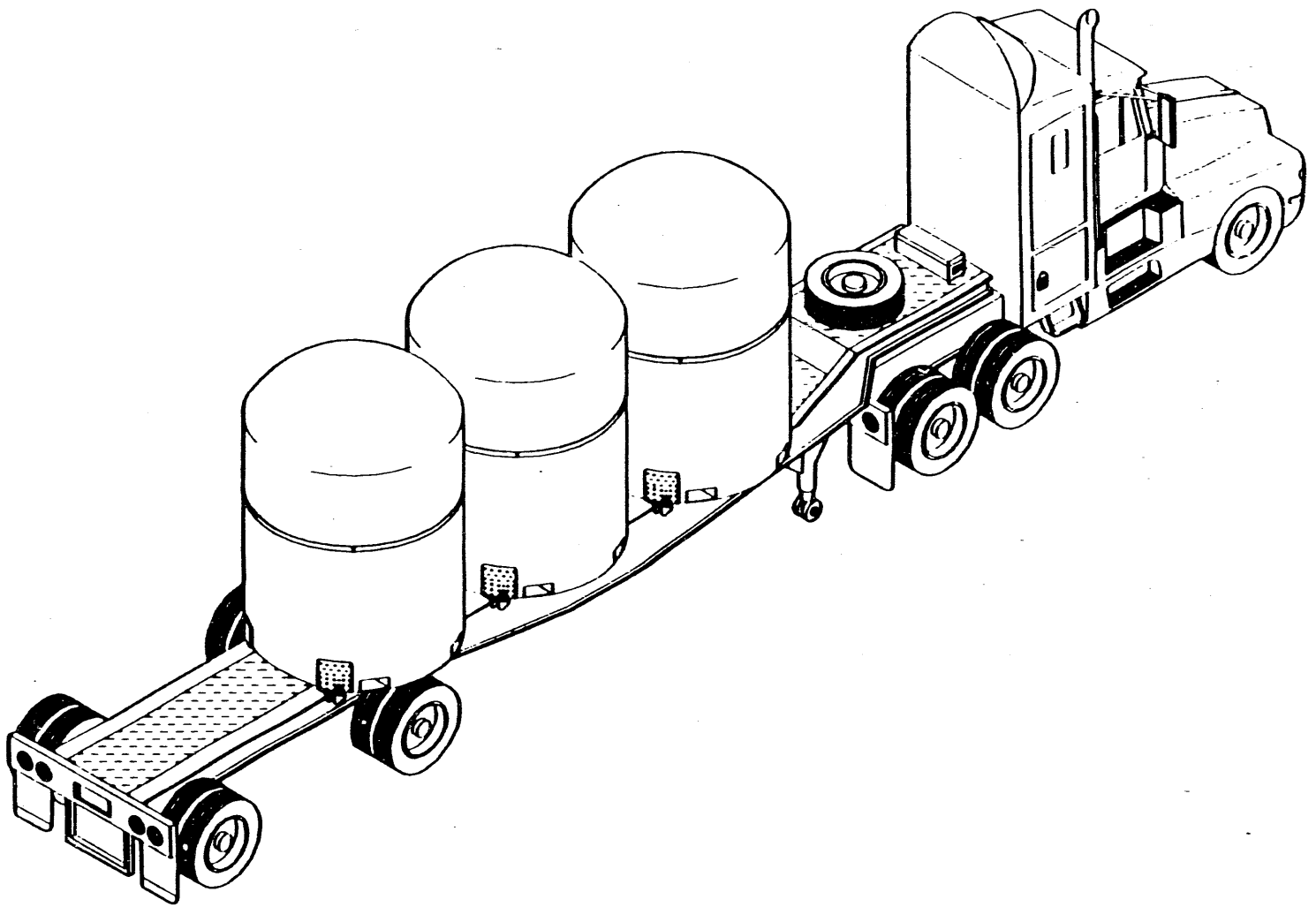
AMS
S
RY
UNDARY
TION (ACTIVE)
TION (INACTIVE)
ONS

Reference:

Flood Control, Brantley Dam and Reservoir Pecos River, New Mexico, U.S. Army Engineer District, Albuquerque, New Mexico (July 1964)

FIGURE D-8

DRAINAGE PATTERN AND GAGING STATIONS, PECOS RIVER BASIN



DOE.1990d

This illustration for information purposes only

FIGURE D.9 TRUPACT II CONTAINERS ON TRAILER

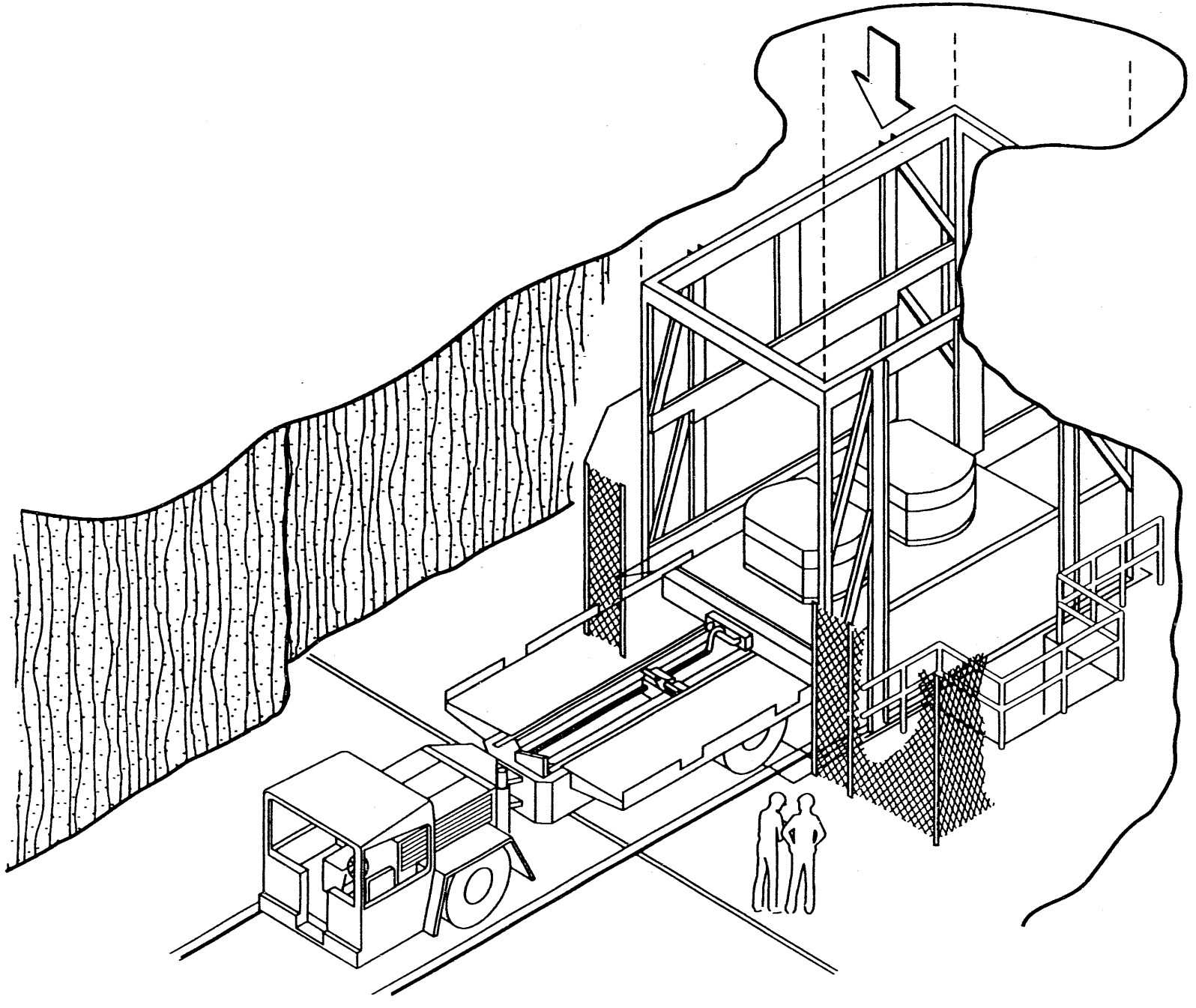
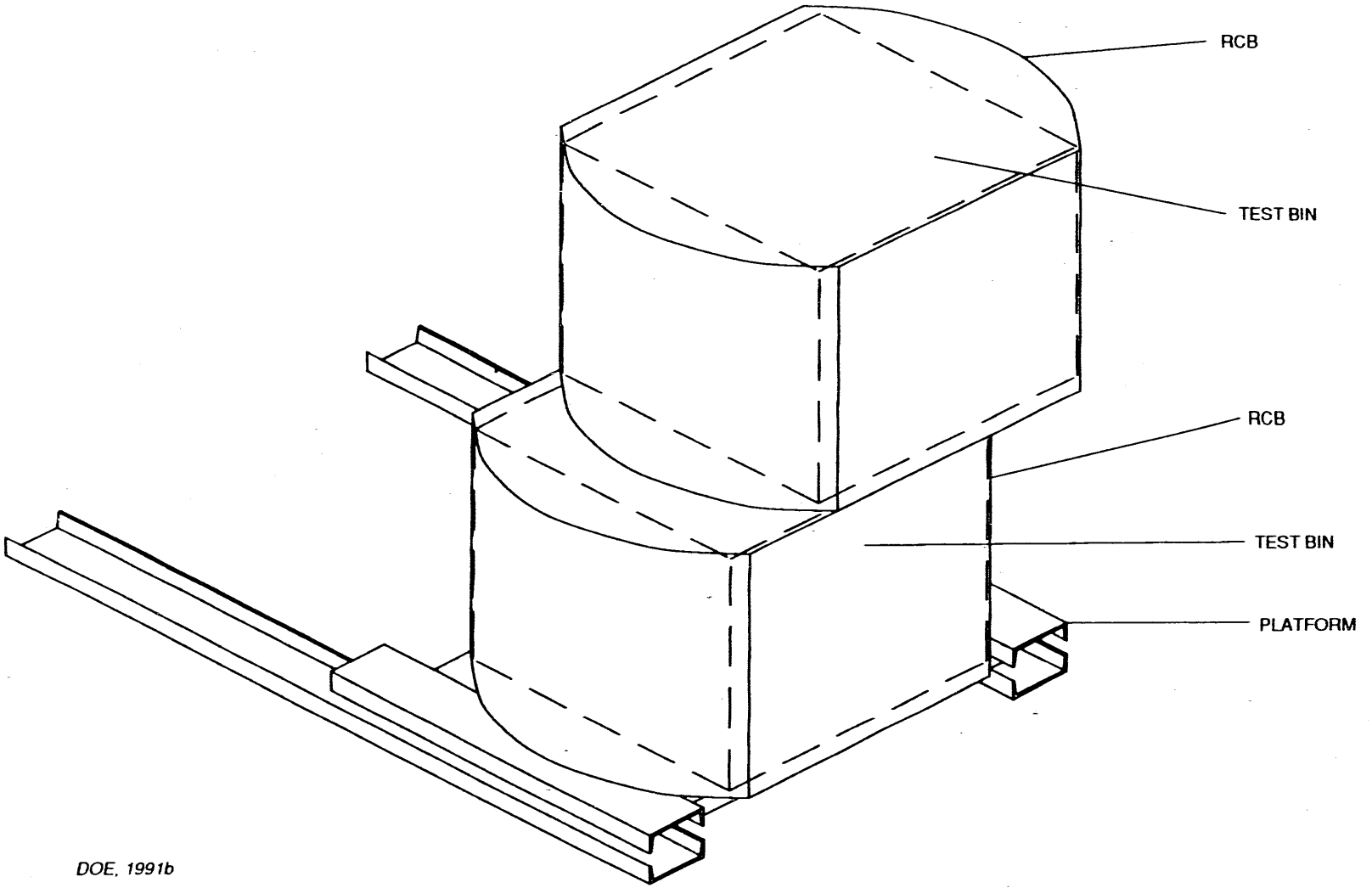


FIGURE D-10 WASTE TRANSFER CAGE TO TRANSPORTER



DOE, 1991b

FIGURE D-11 BIN, RCB PLATFORM CONFIGURATION

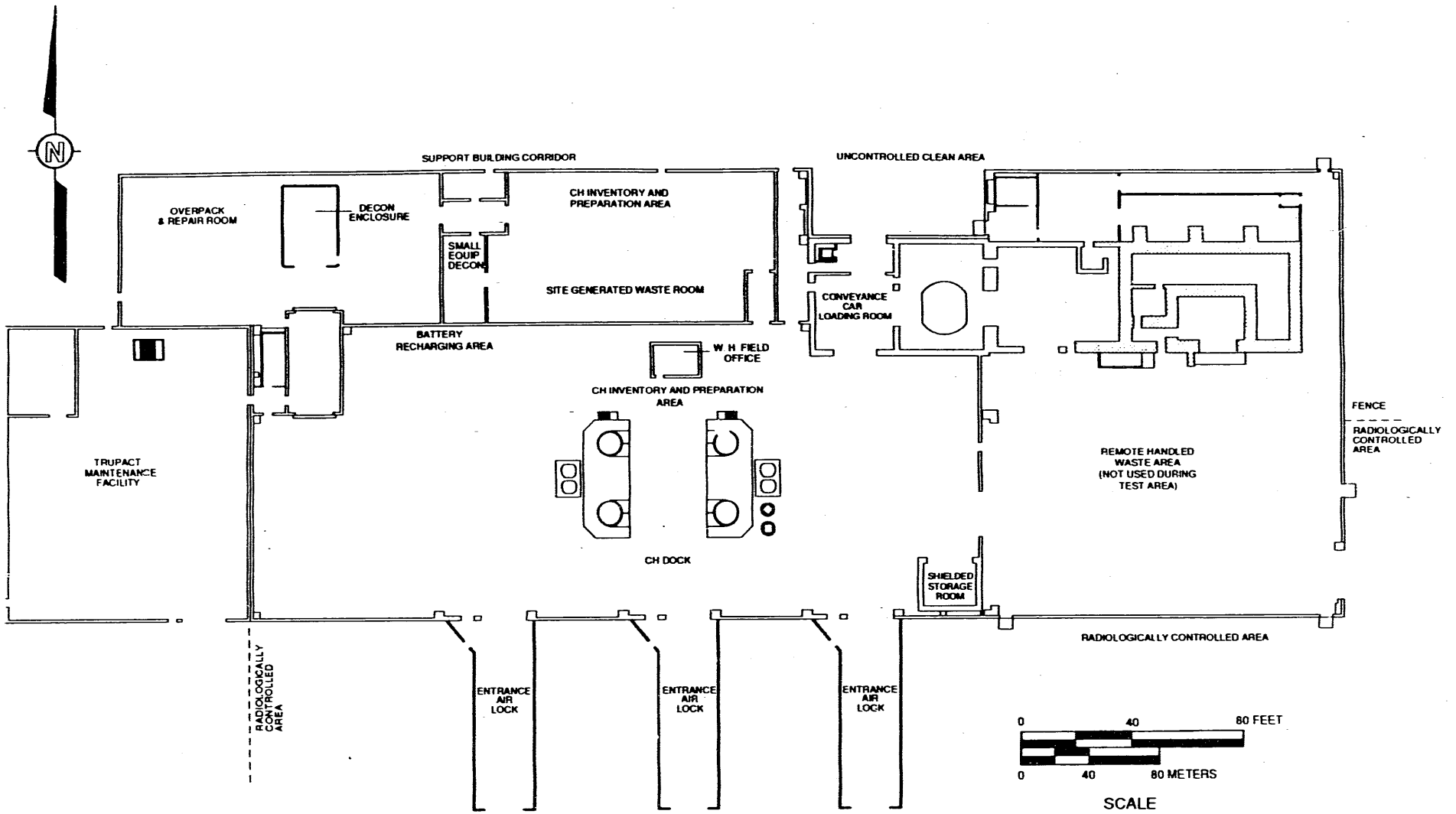
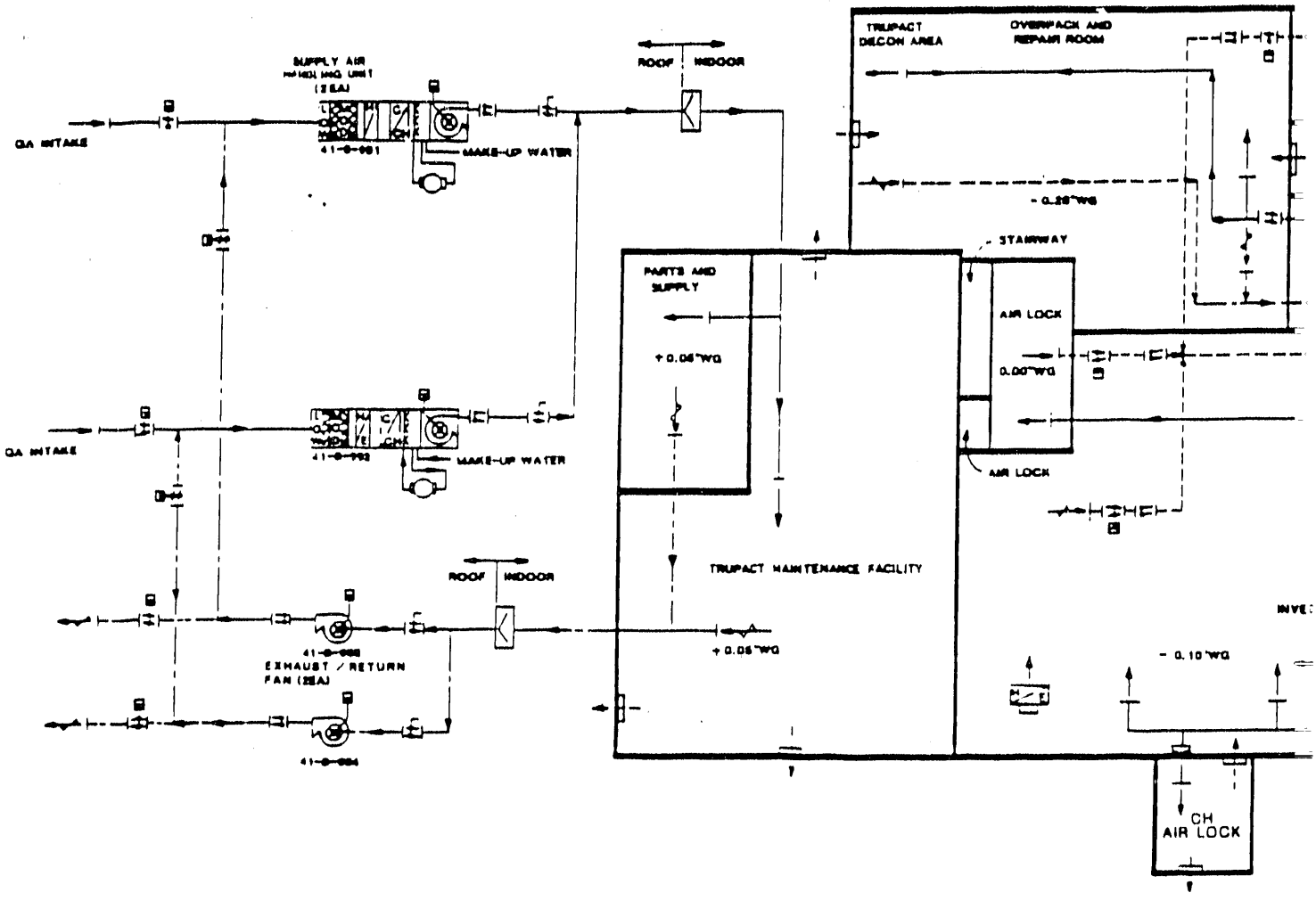
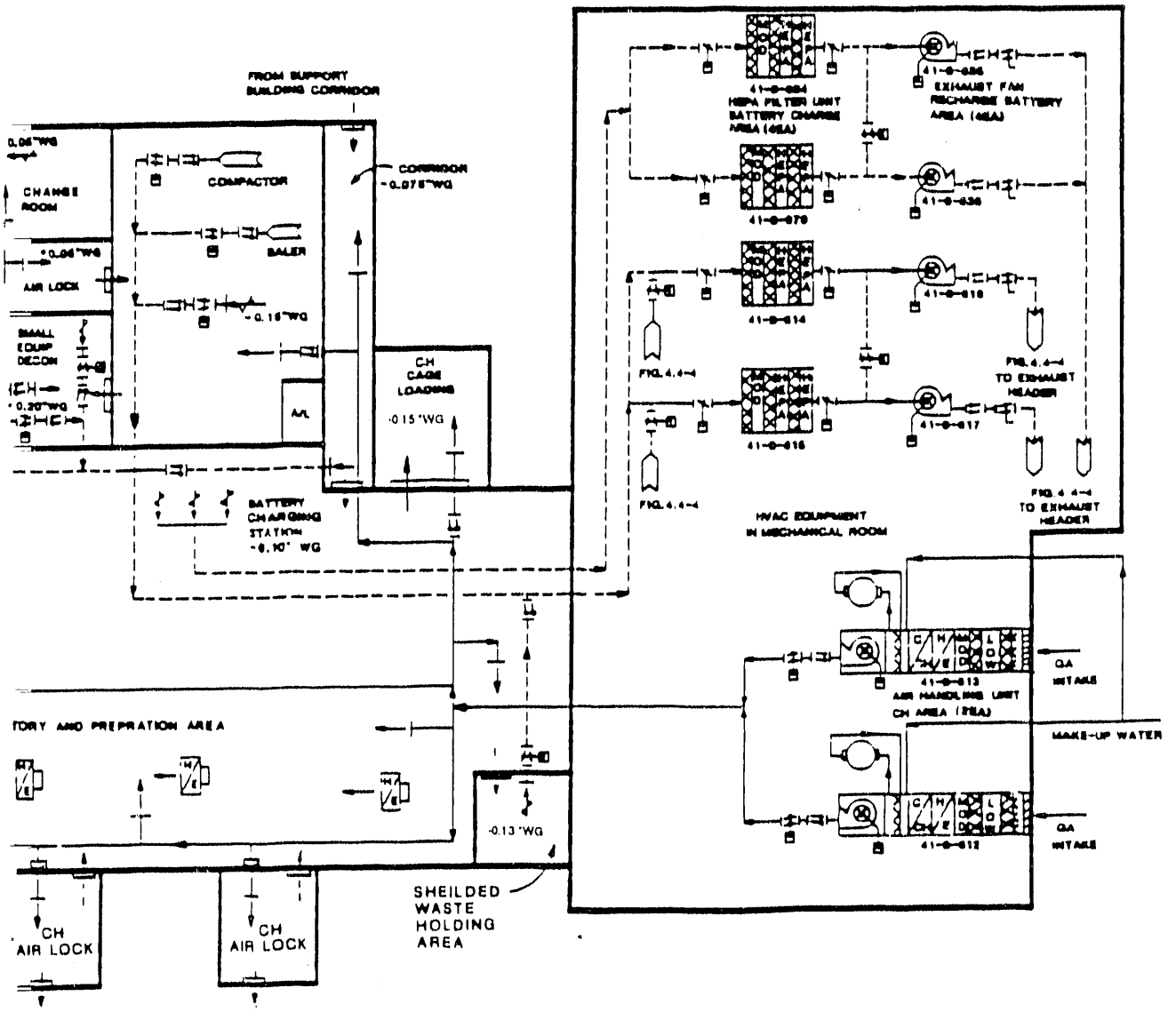


FIGURE D-12 WASTE HANDLING BUILDING PLAN (GROUND FLOOR)

3014660181



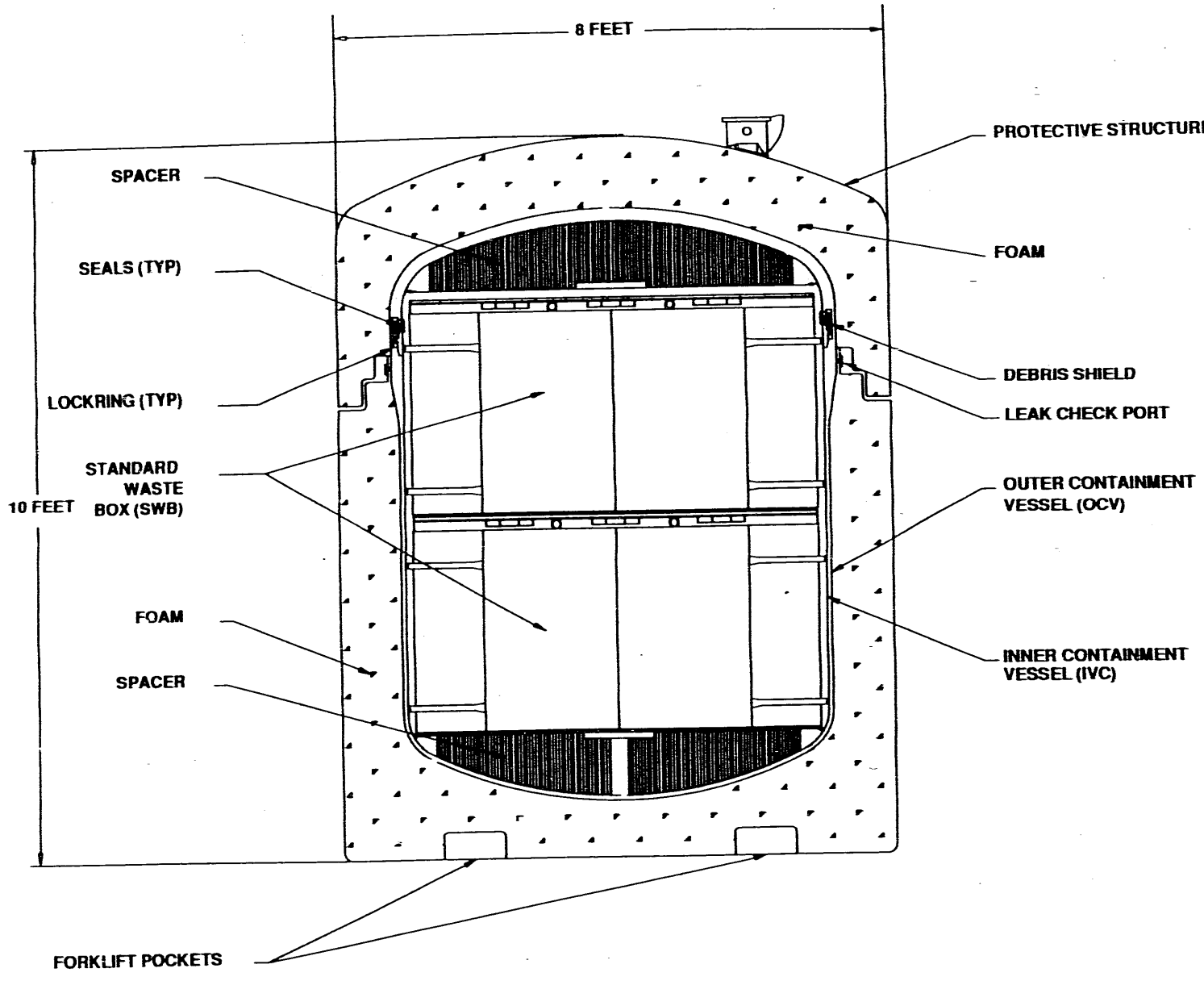
DOE,1990d



This illustration for information Purposes only.

FIGURE D-13

WASTE HANDLING BUILDING HVAC FLOW DIAGRAM



DOE, 1991b

FIGURE D-14 TRUPACT II CONFIGURATION

This Illustration for Information Purposes Only

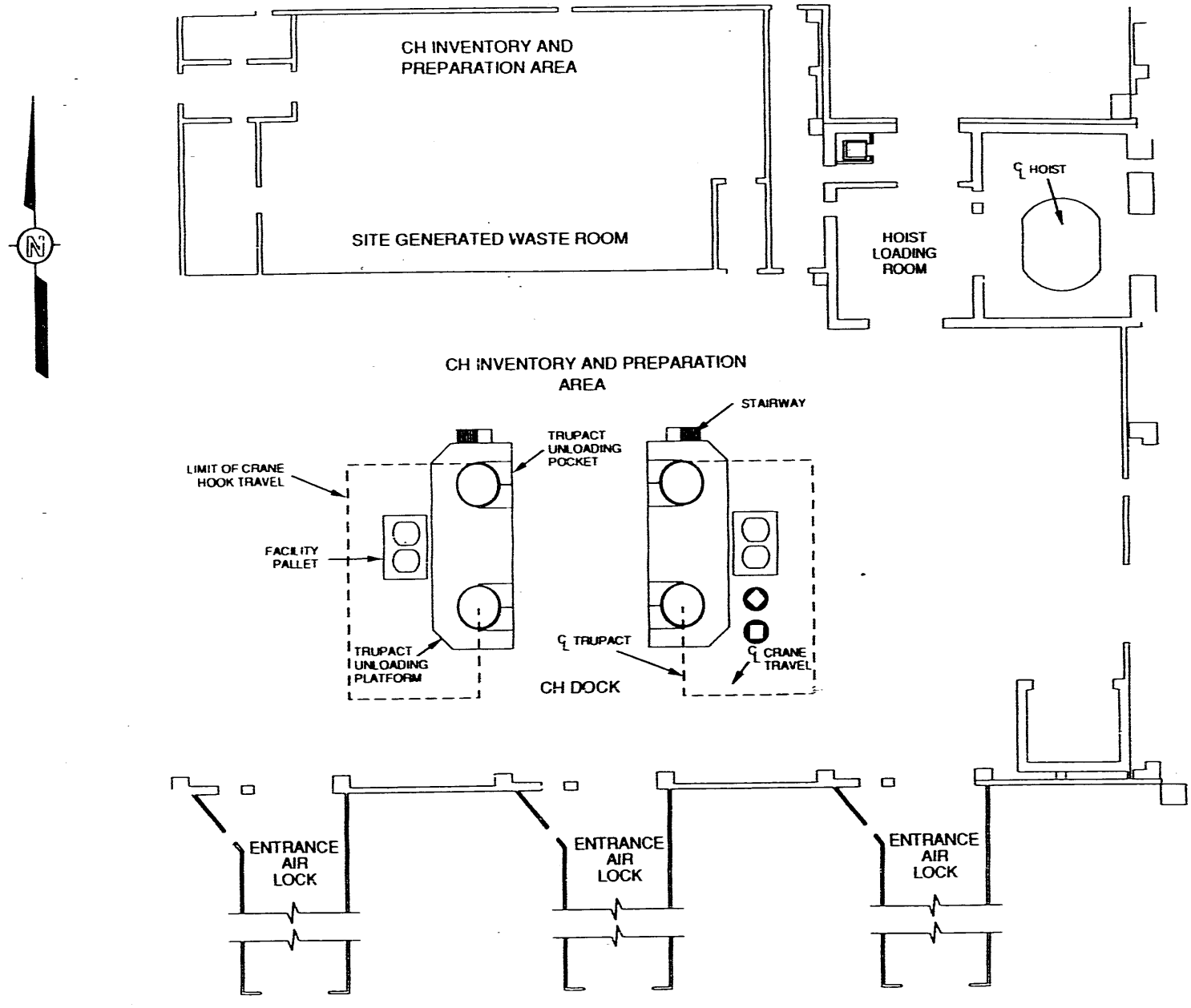


FIGURE D-15 CONFIGURATION OF CH TRU WASTE UNLOADING DOCKS IN WASTE HANDLING BUILDING

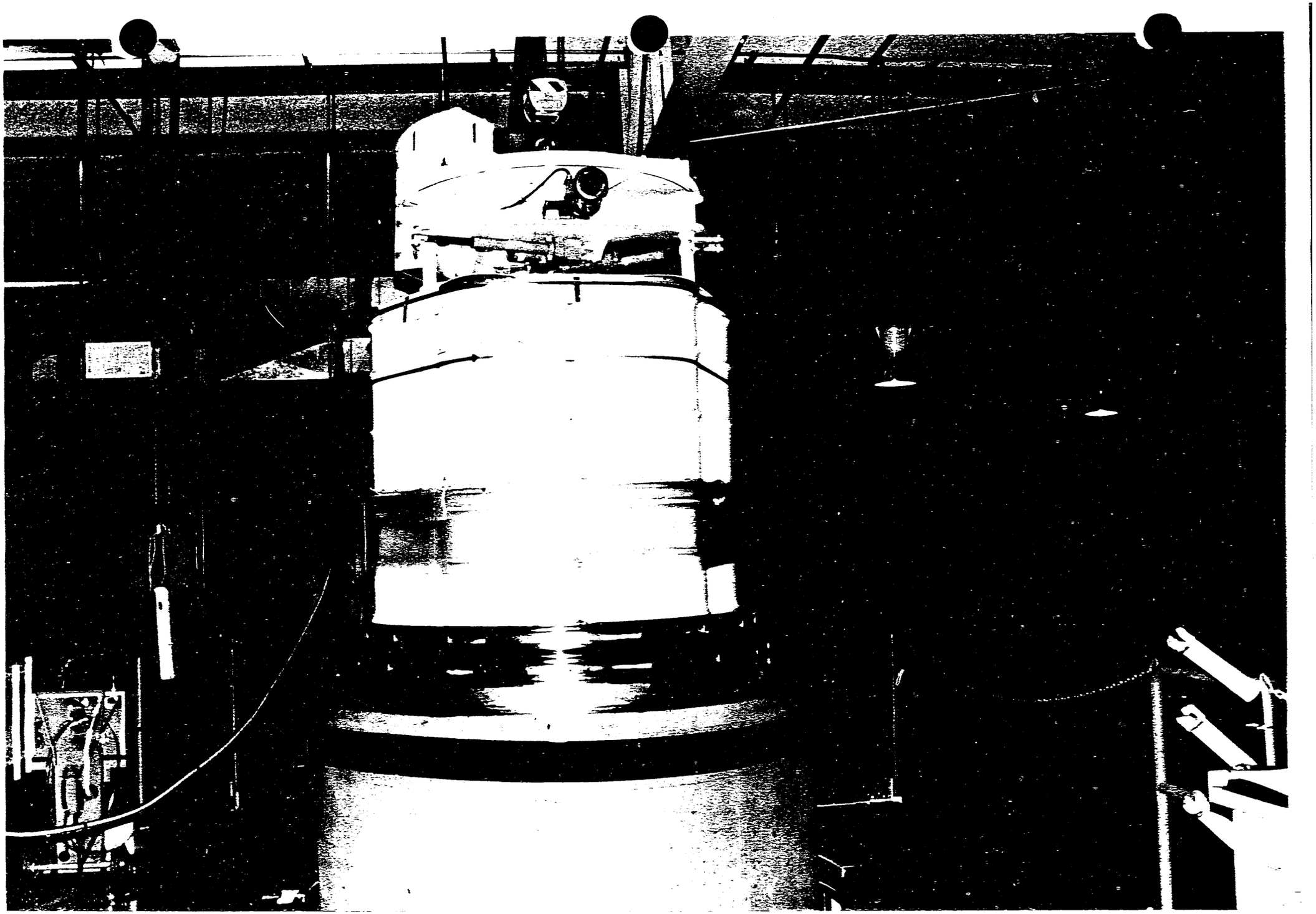


FIGURE D-16 CRANE AND CENTER OF GRAVITY LIFT ASSEMBLY

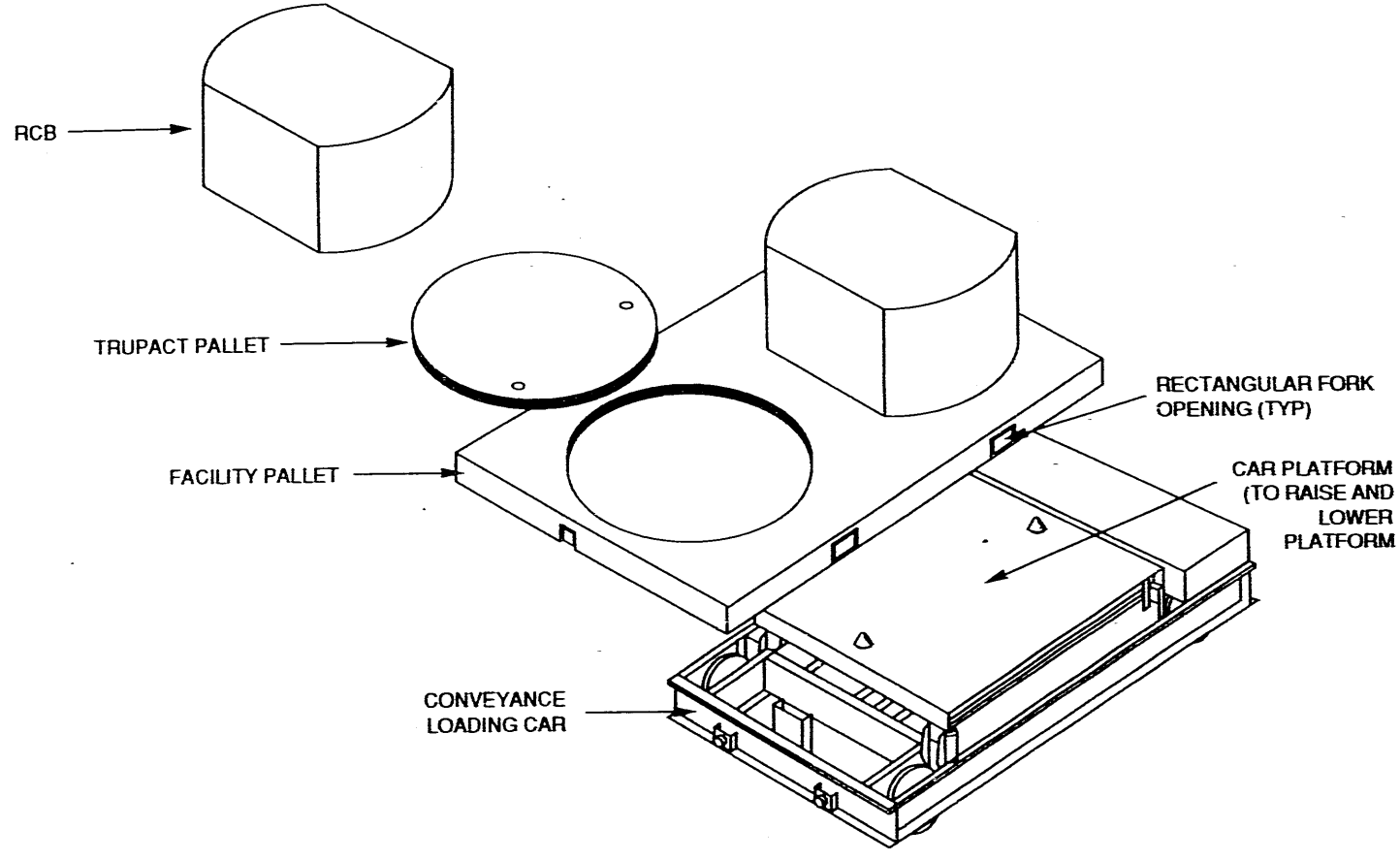
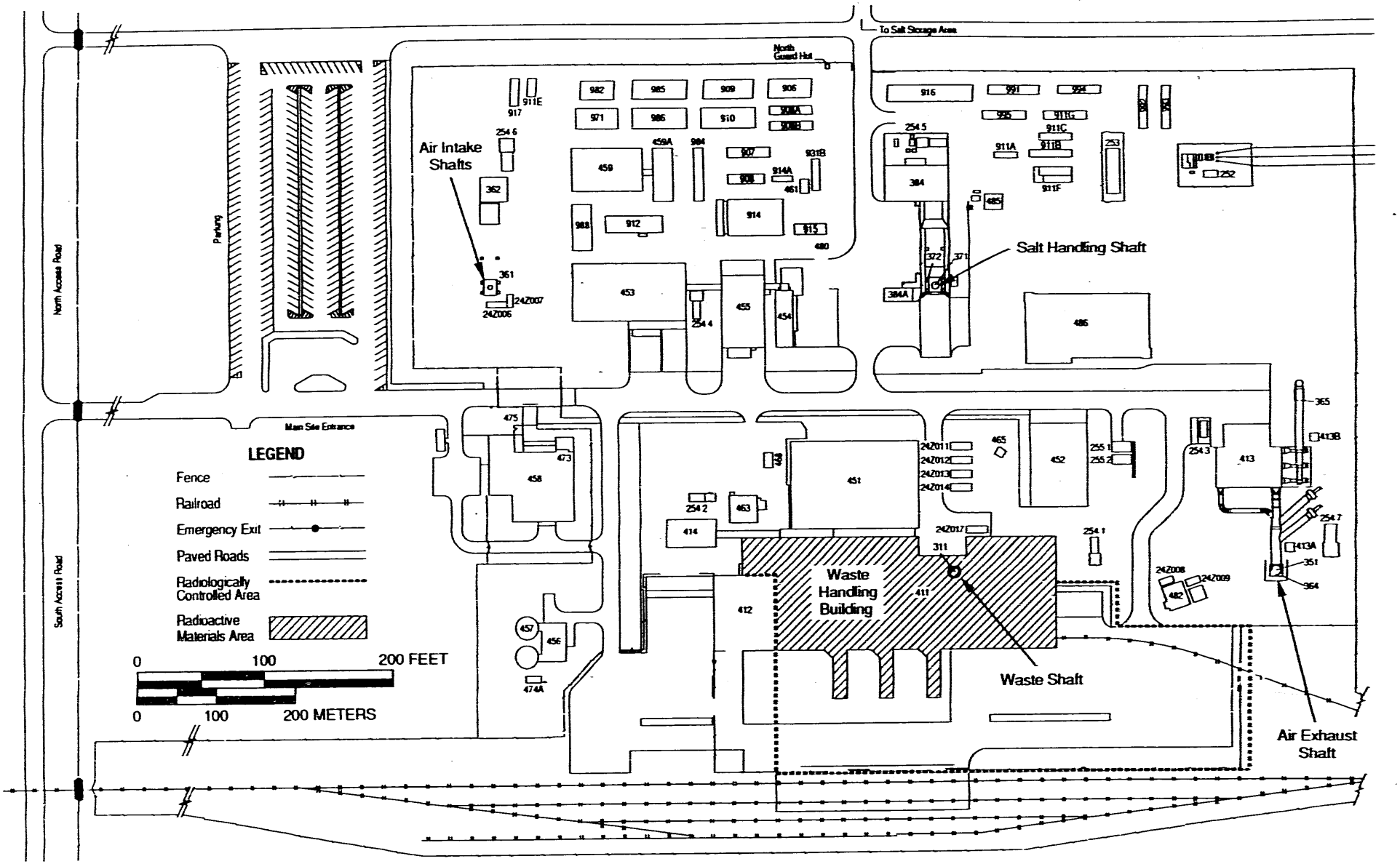


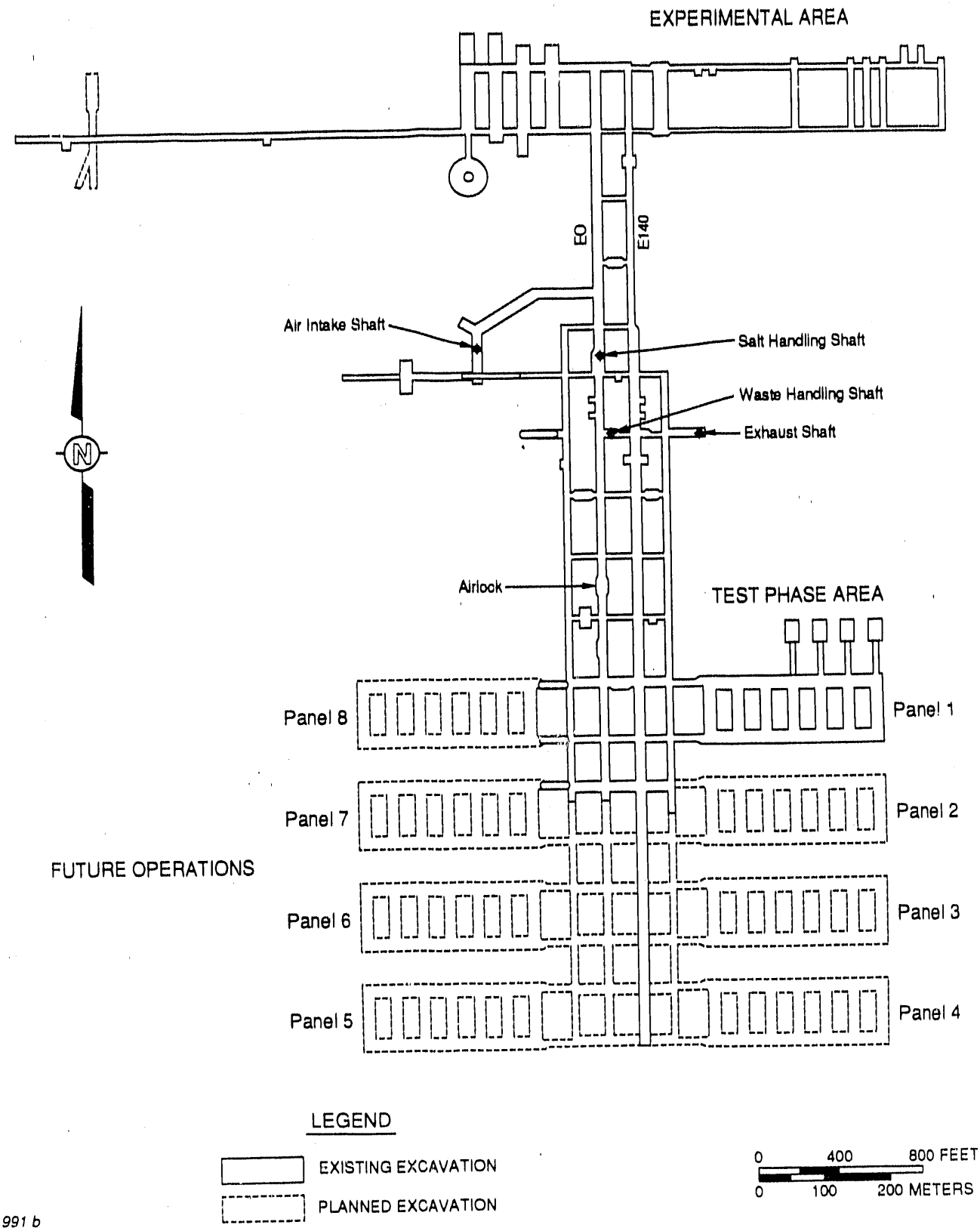
FIGURE D-17 CH WASTE PALLET ON CONVEYANCE LOADING CAR

FIGURE D 18 UNDERGROUND WASTE TRANSPORTER



Reference: DOE, 1990d

FIGURE D-19 RELATIONSHIP OF SHAFTS TO SURFACE FACILITIES



DOE, 1991 b

FIGURE D-20 REPOSITORY HORIZON

This illustration for Information Purposes Only

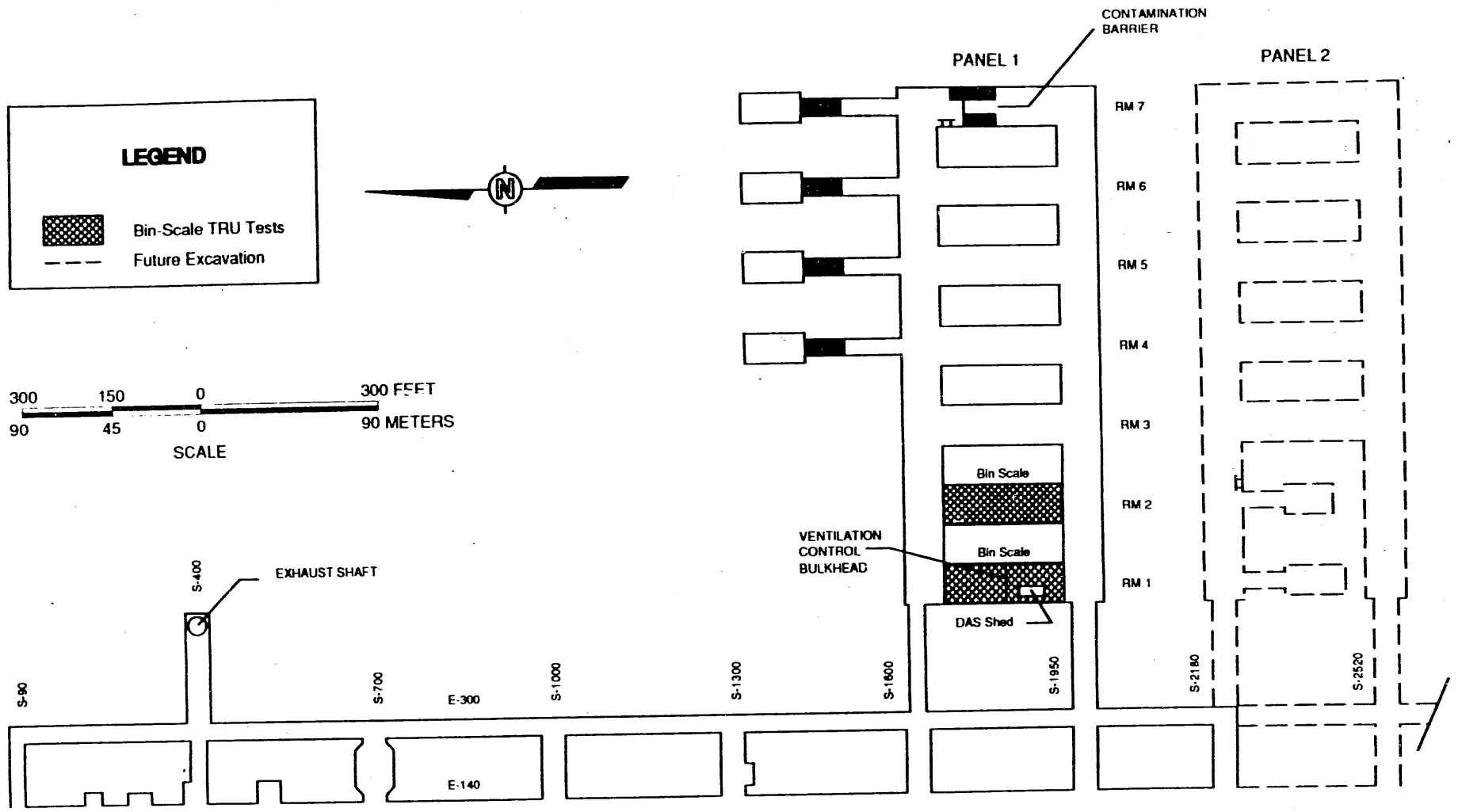


FIGURE D-21 WIPP CH TRU WASTE BIN SCALE TEST LOCATIONS PRELIMINARY LAYOUT

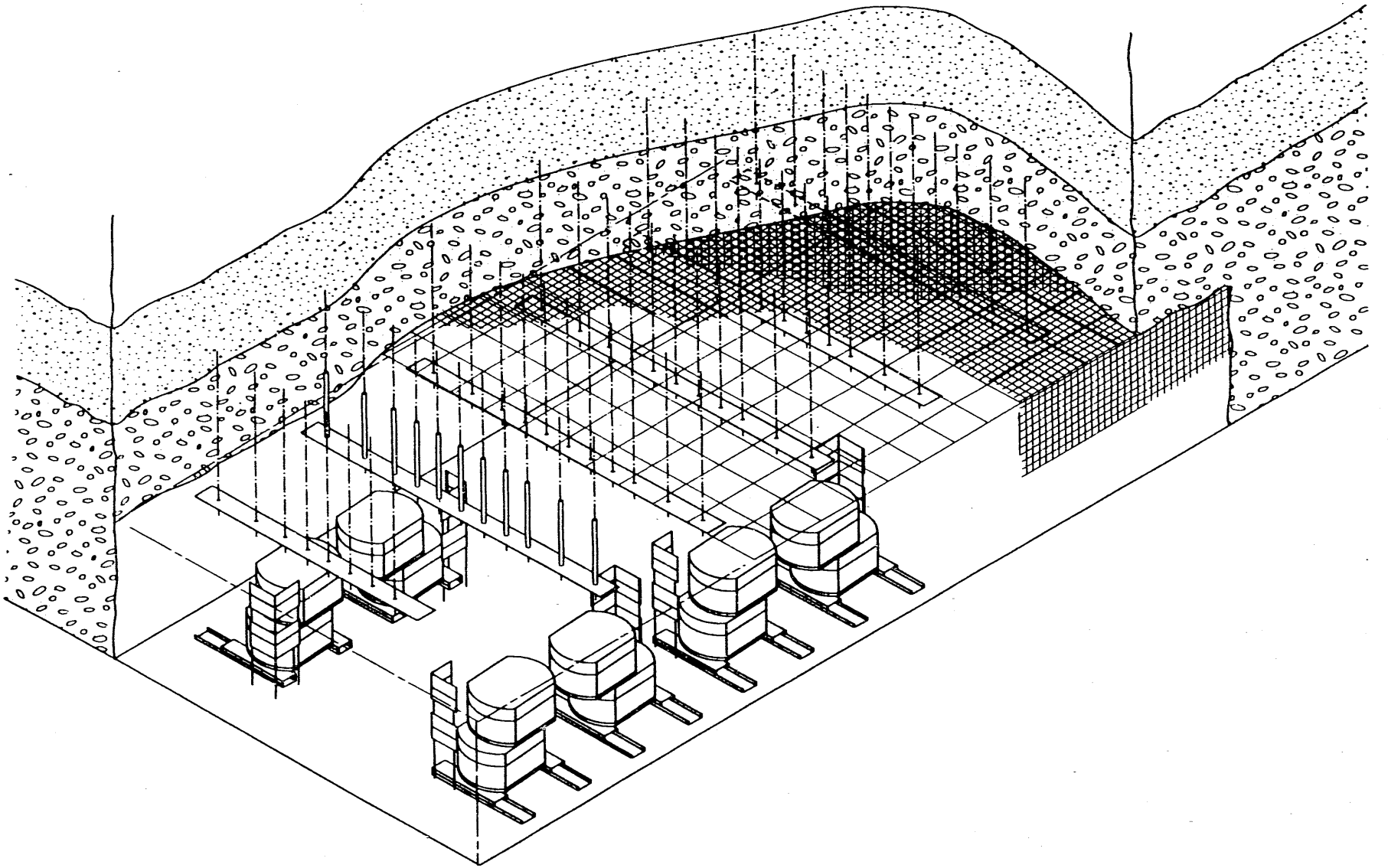


FIGURE D-22 ROOM 1, PANEL 1 CONCEPTUAL ROOF SUPPORT

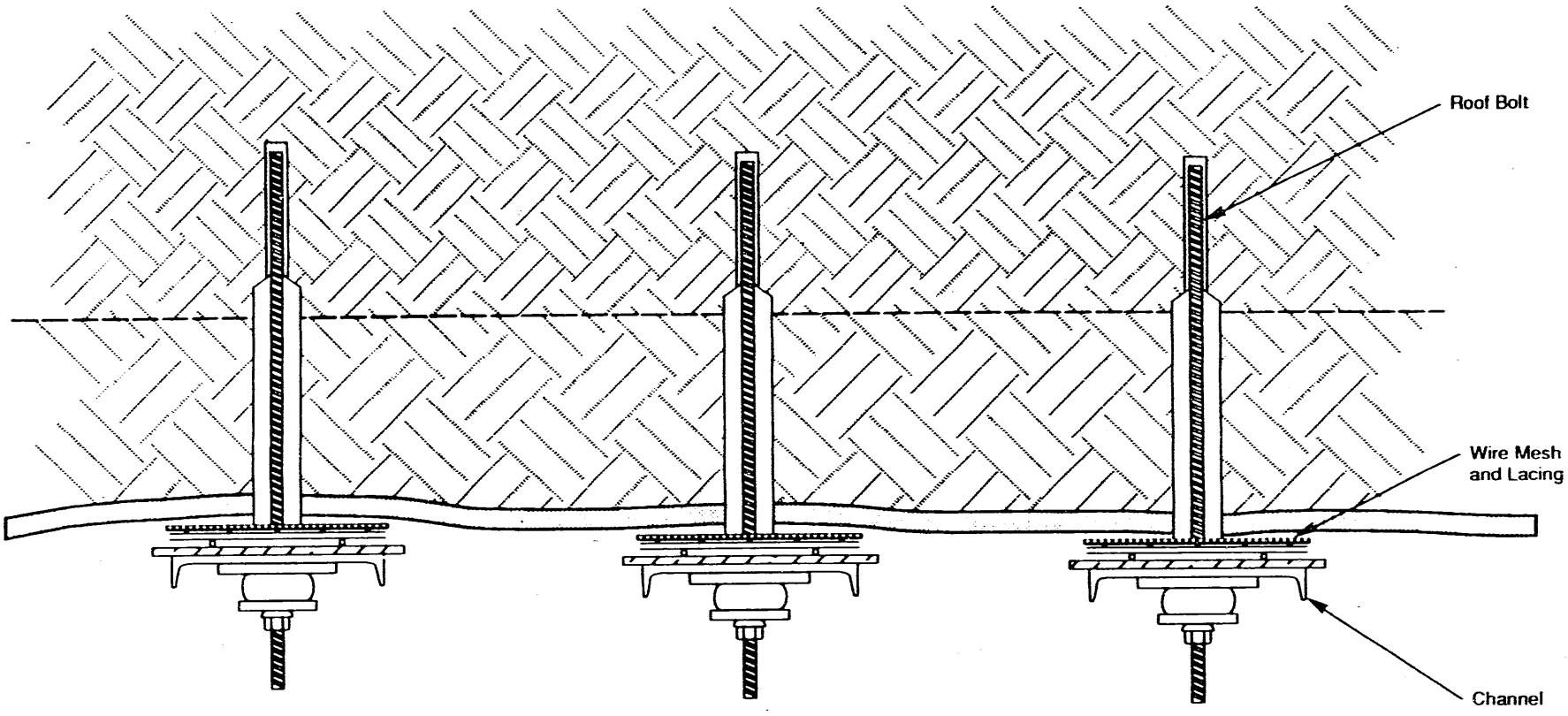


FIGURE D-23 ROOM 1, PANEL 1 - ROOF SUPPORT, WIRE MESH AND LACING

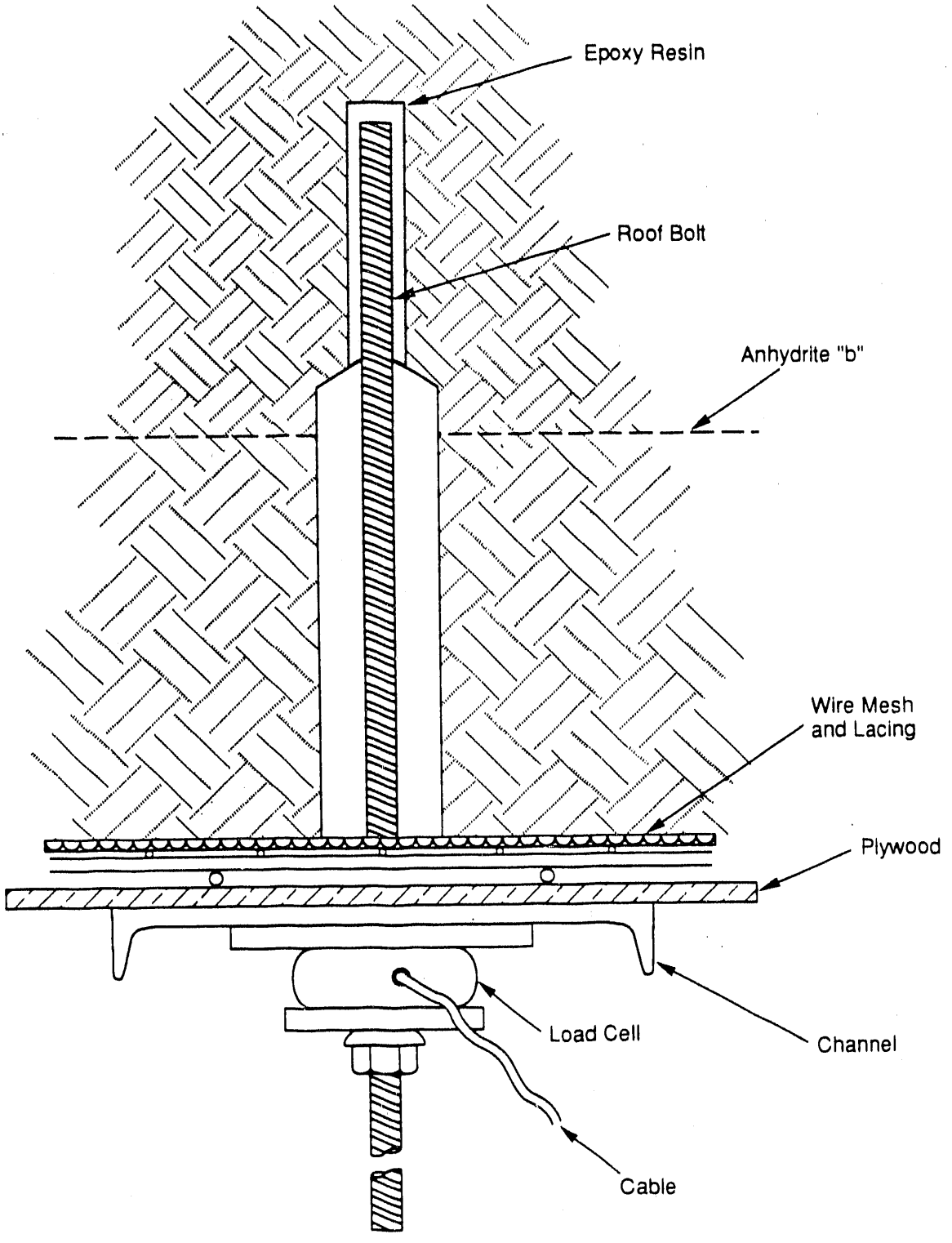


FIGURE D-24 ROOFBOLT DETAIL

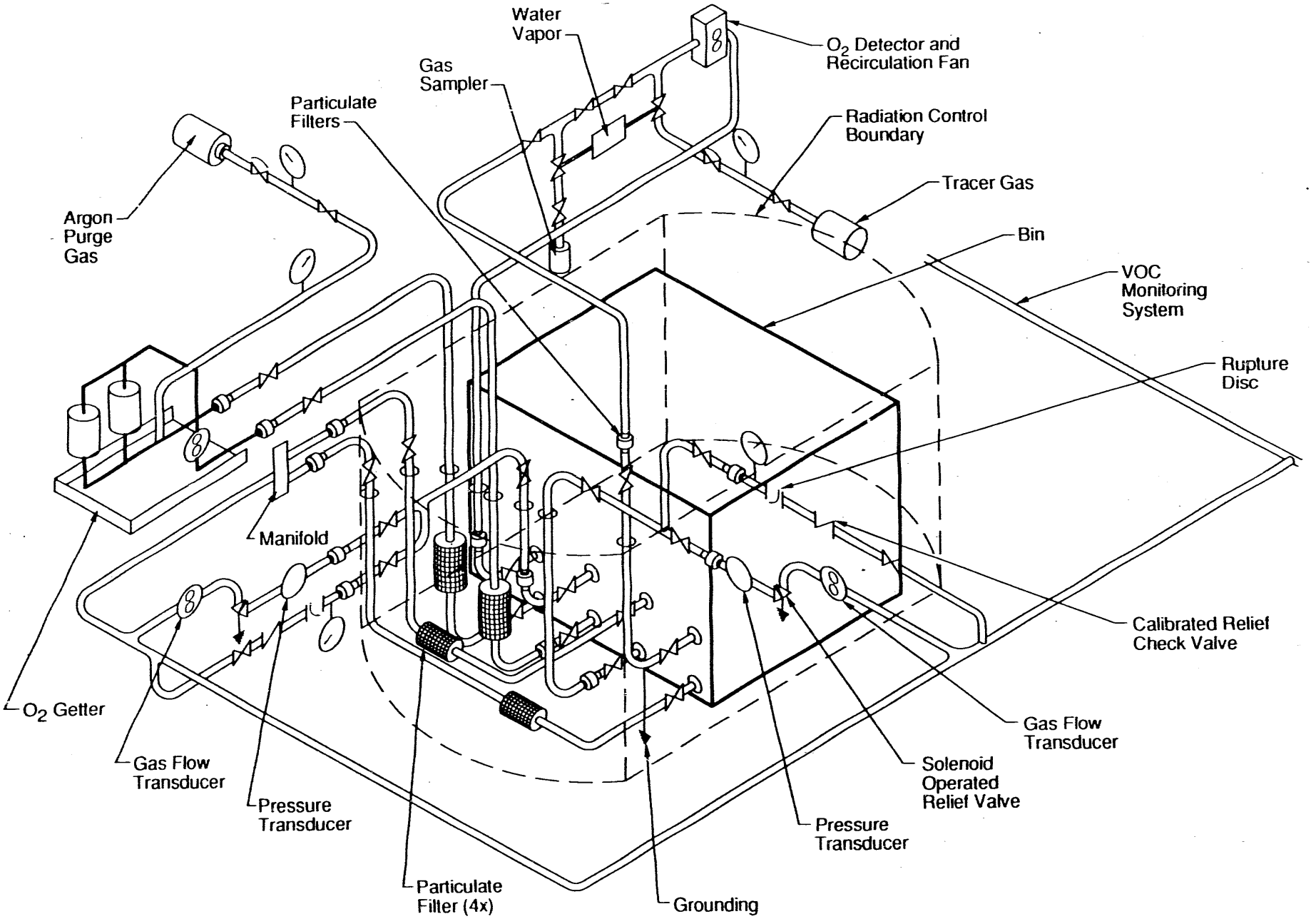


FIGURE D-25 SWB/BIN CONFIGURATION

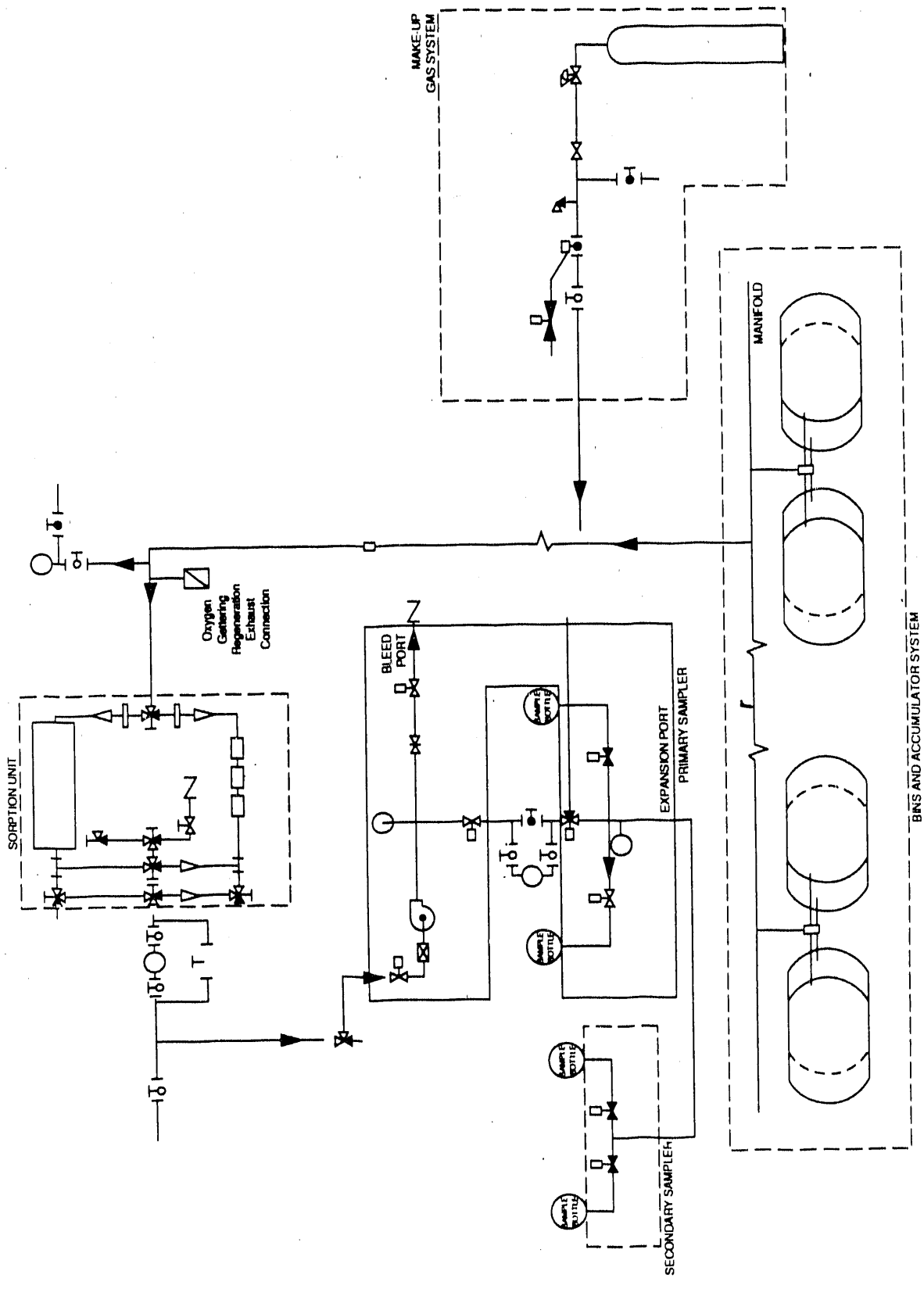
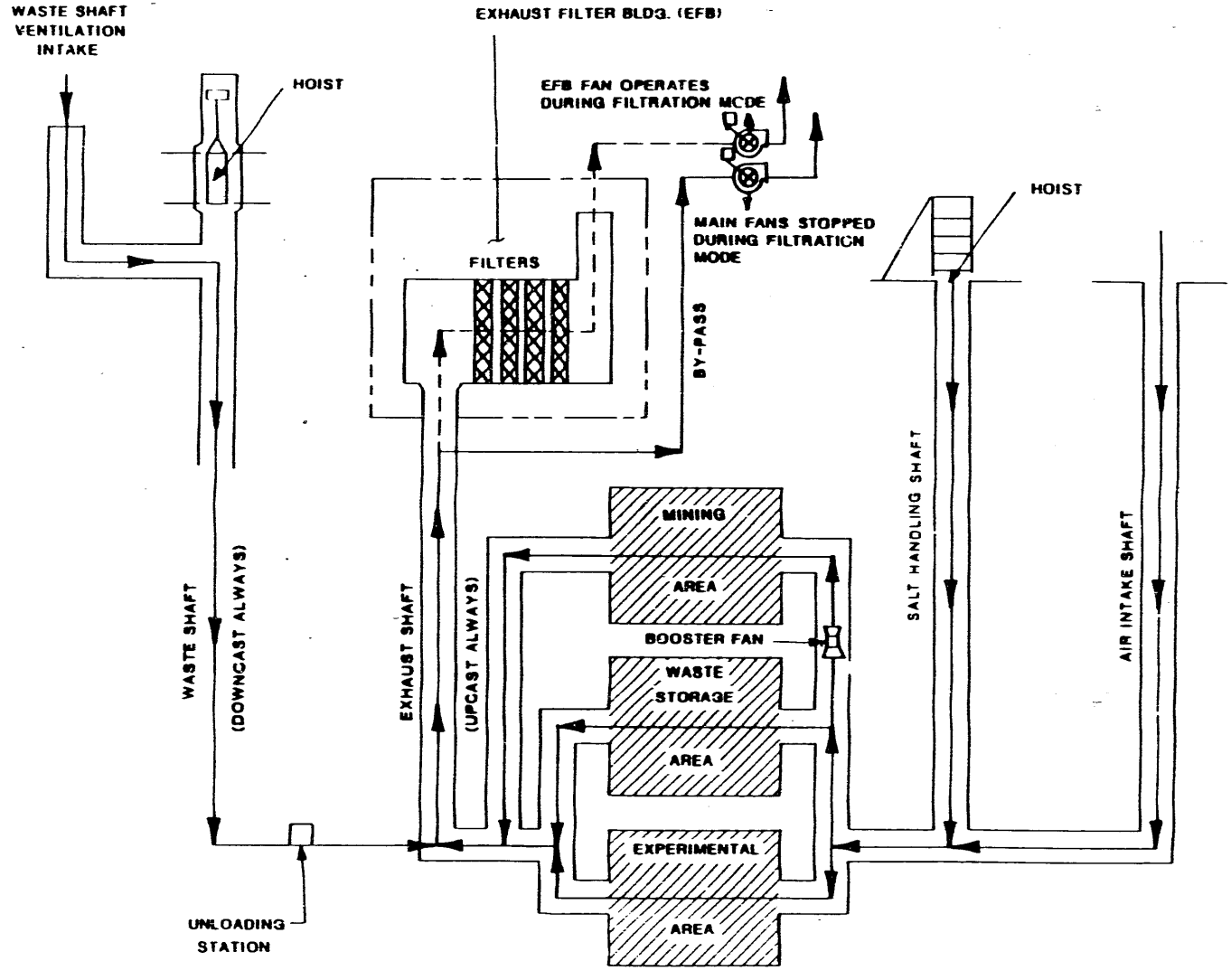


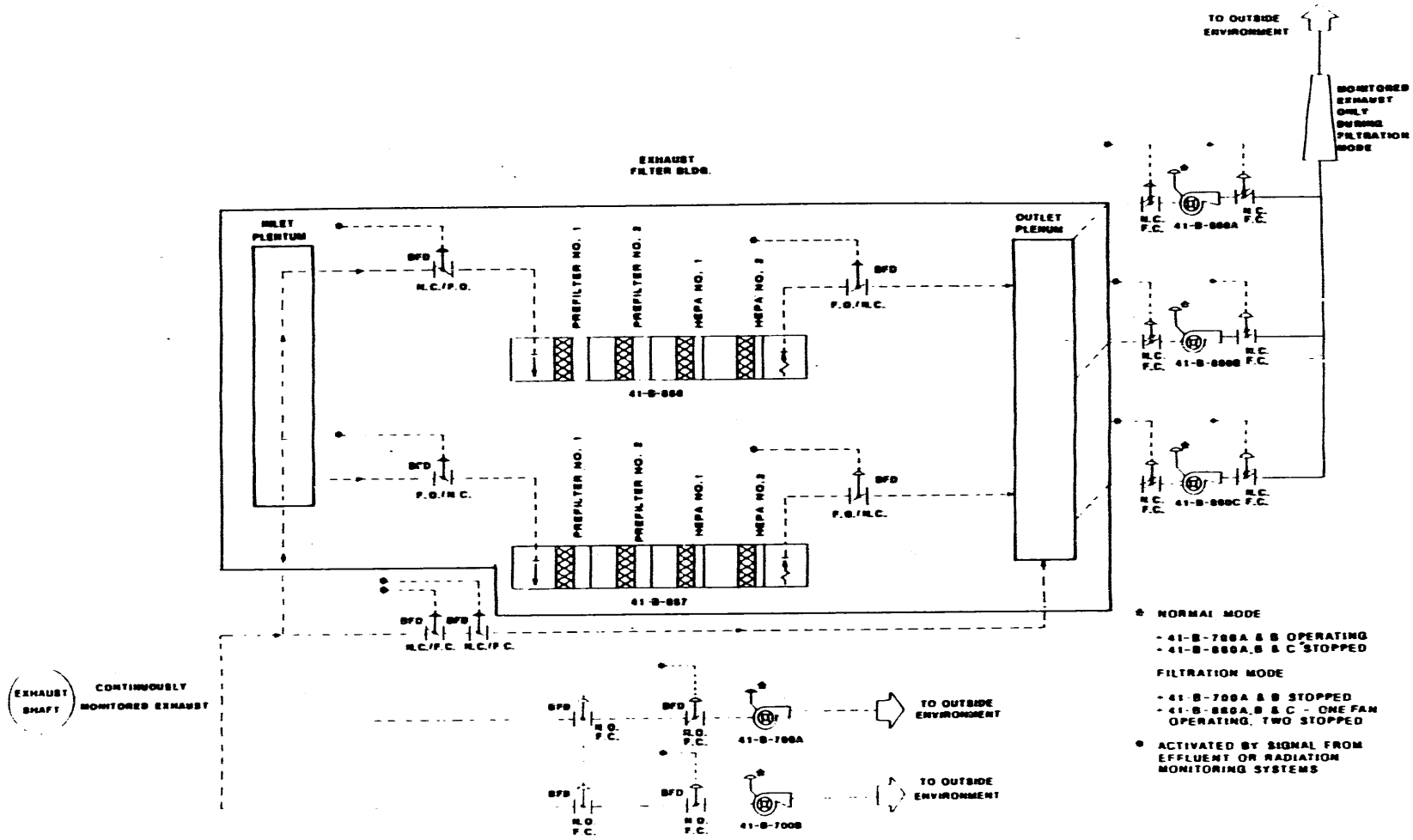
FIGURE D-26 VOC MONITORING SYSTEM



DOE. 1990d

This Illustration for Information Purposes only

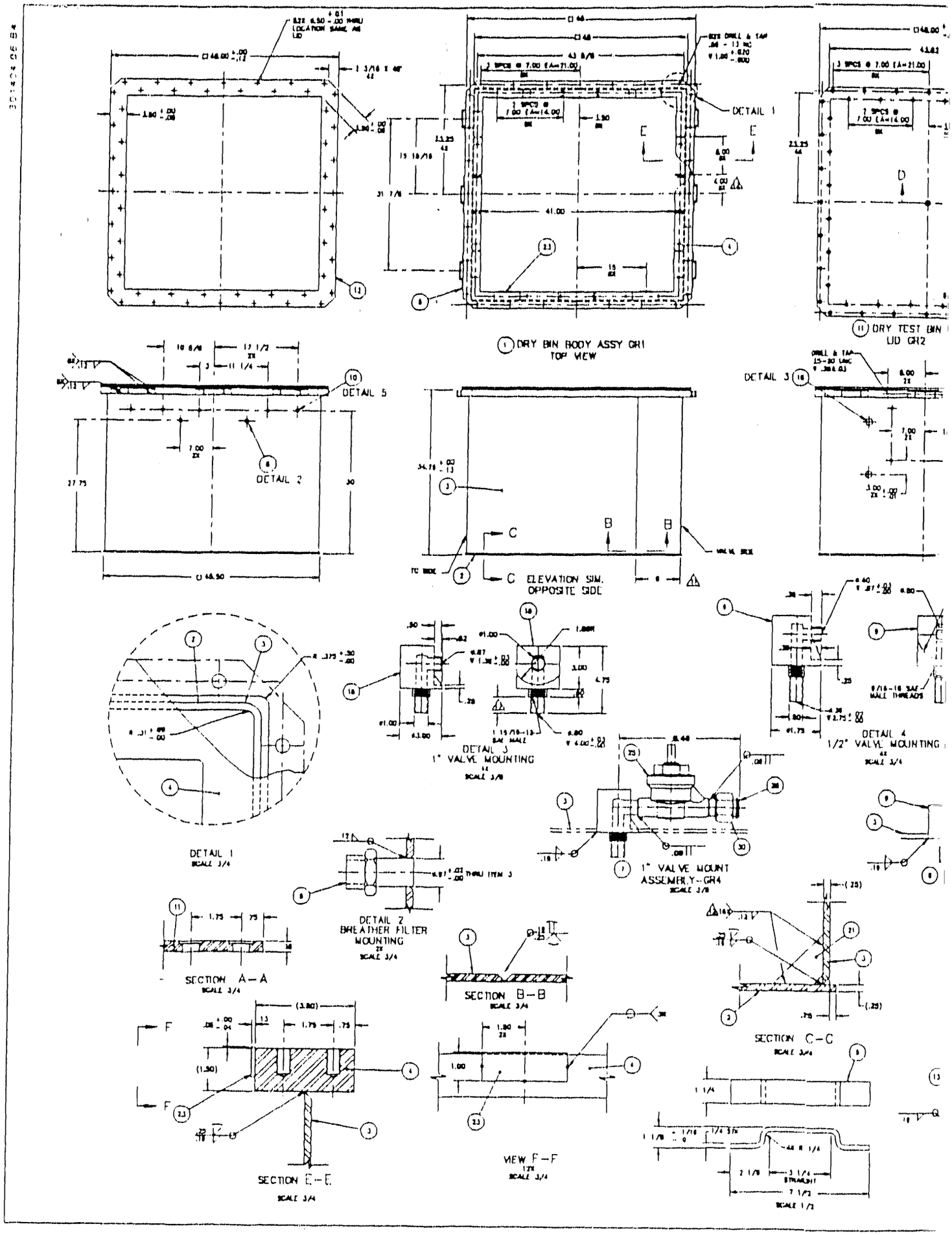
FIGURE D-27 UNDERGROUND VENTILATION SYSTEM AIR FLOW



DOE,1990d

This Illustration for Information Purposes only

FIGURE D-28 UNDERGROUND VENTILATION MODES


DETAIL 1
DETAIL 2
DETAIL 3
DETAIL 4
DETAIL 5
1 DRY BIN BODY ASSY GR1
TOP VIEW
11 DRY TEST BIN
LID GR2
C ELEVATION SIM.
OPPOSITE SIDE
1" VALVE MOUNTING
1/2" VALVE MOUNTING
1" VALVE MOUNT
ASSEMBLY-GR4
BREATHER FILTER
MOUNTING
SECTION A-A
SECTION B-B
SECTION C-C
SECTION E-E
VIEW F-F

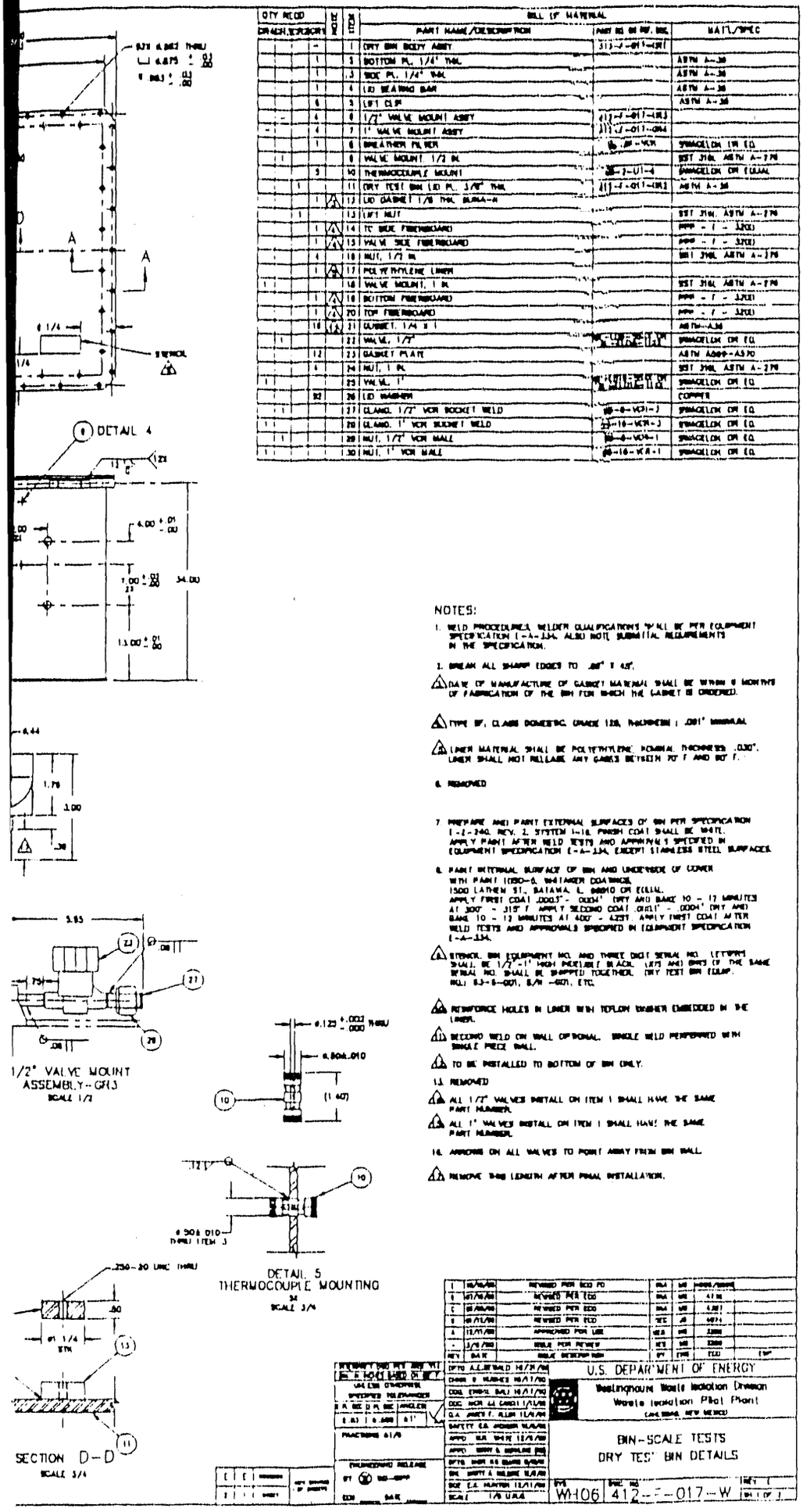
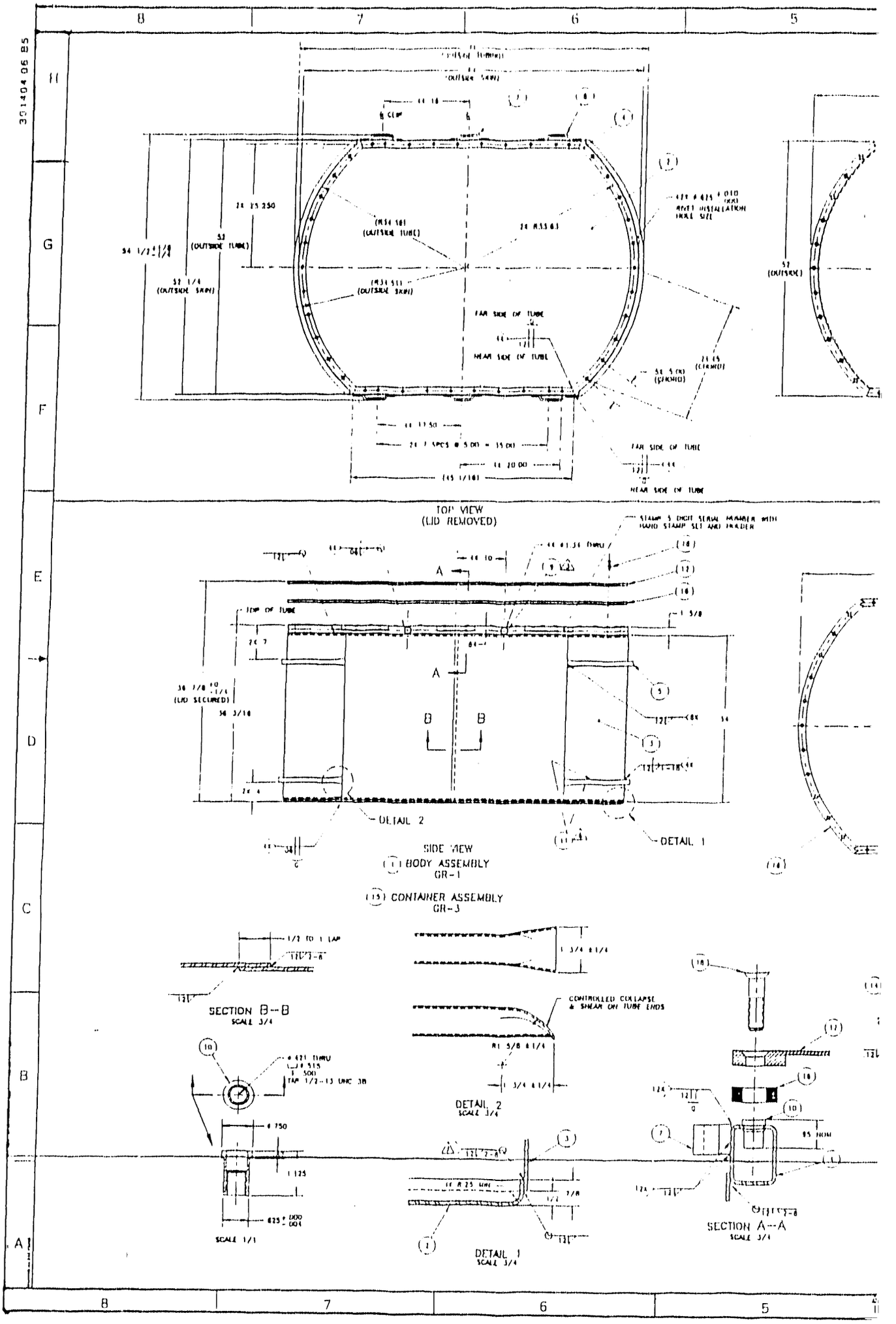


FIGURE D-29 BIN-SCALE TESTS DRY TEST BIN DETAILS


TOP VIEW
(LID REMOVED)
SIDE VIEW
(1) BODY ASSEMBLY
GR-1
(15) CONTAINER ASSEMBLY
GR-3
DETAIL 1
DETAIL 2
SECTION B--B
SCALE 3/4
SECTION A--A
SCALE 3/4
DETAIL 1
SCALE 3/4
DETAIL 2
SCALE 3/4
SCALE 1/1
CONTROLLED COLLAPSE & SHEAR ON TUBE ENDS
FAR SIDE OF TUBE
NEAR SIDE OF TUBE
(LID SECURED)
(OUTSIDE SKIN)
(OUTSIDE TUBE)

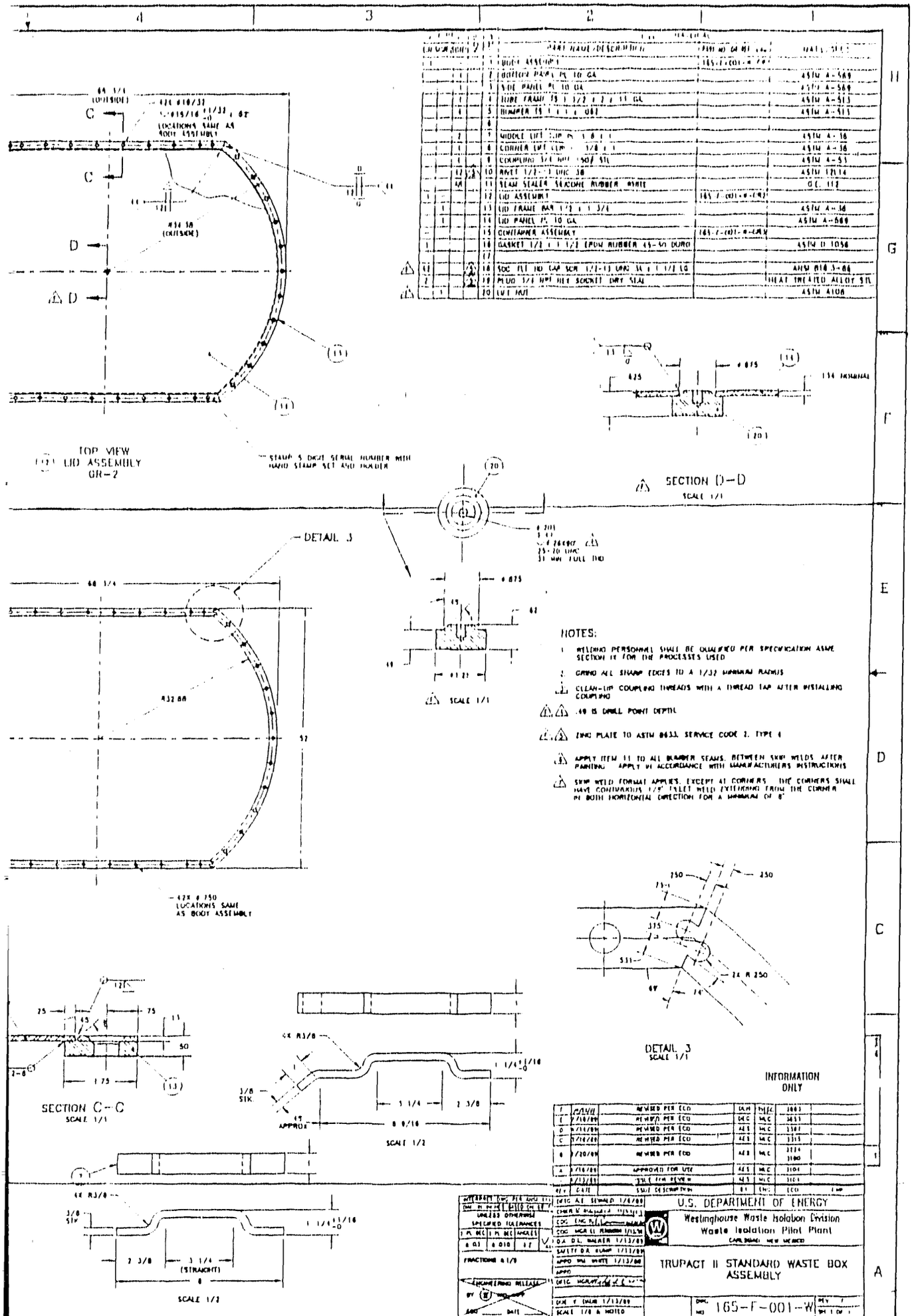


FIGURE D-30 TRUPACT II STANDARD WASTE BOX ASSEMBLY

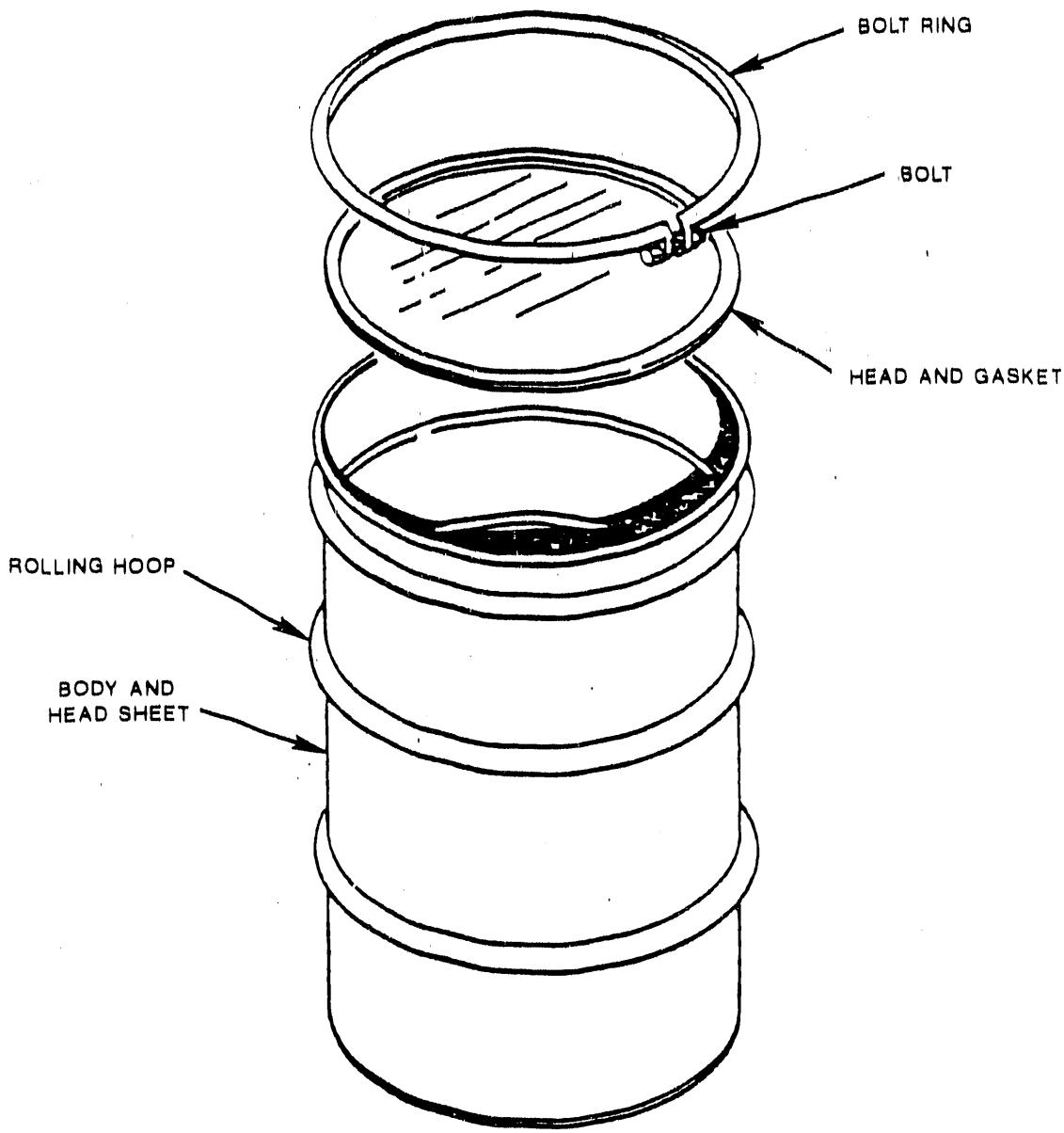
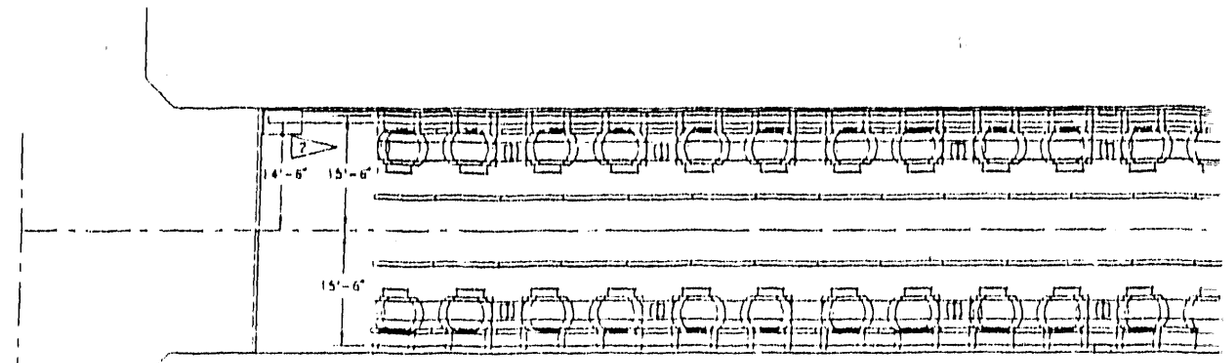
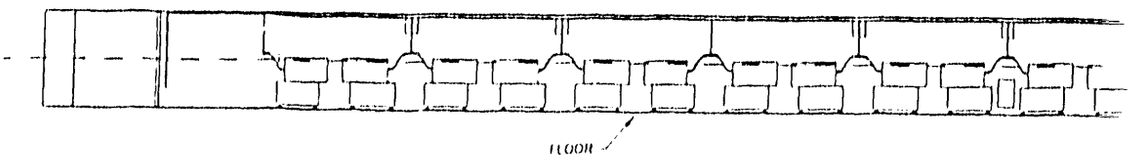


FIGURE D-31 TYPICAL DOT APPROVED 55-GALLON DRUM

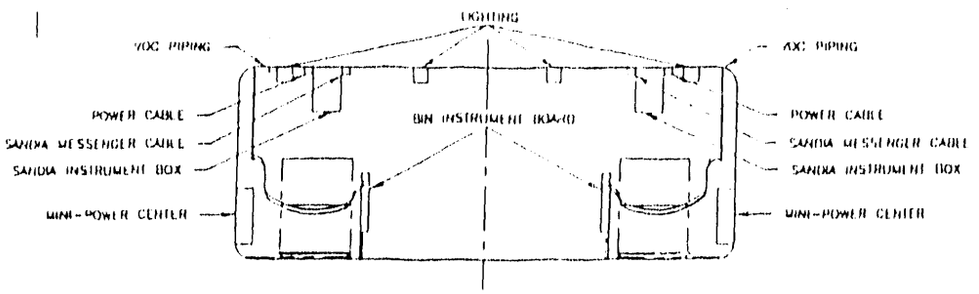
3014046 86



PLAN VIEW
VOC Mon

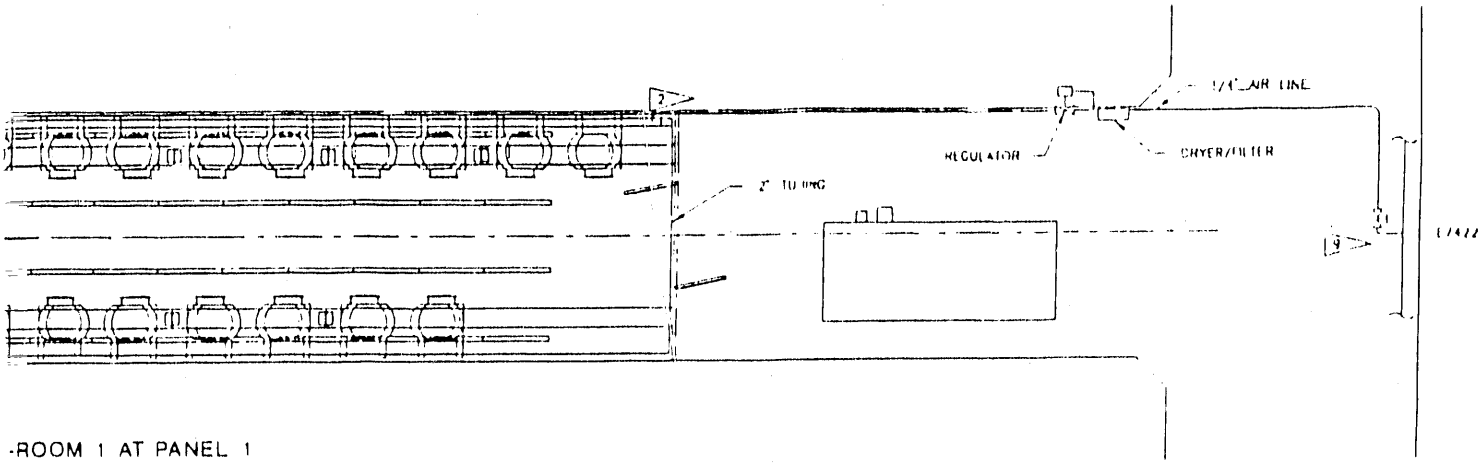


PROFILE
(Vie
VOC Mon

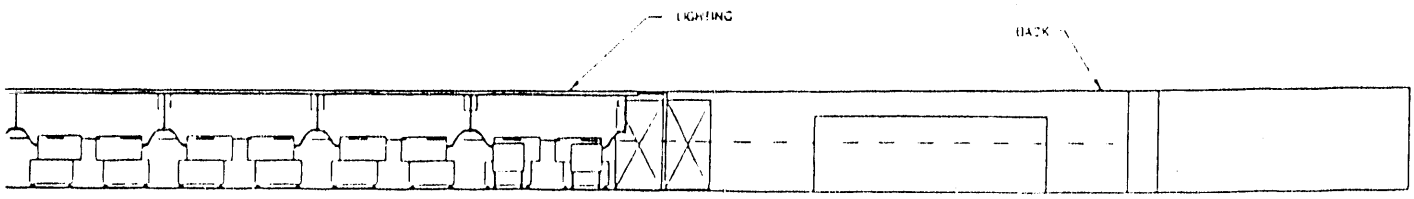


END VIEW – ROOM 1 AT PANEL 1

DRAWING NOT TO SCALE



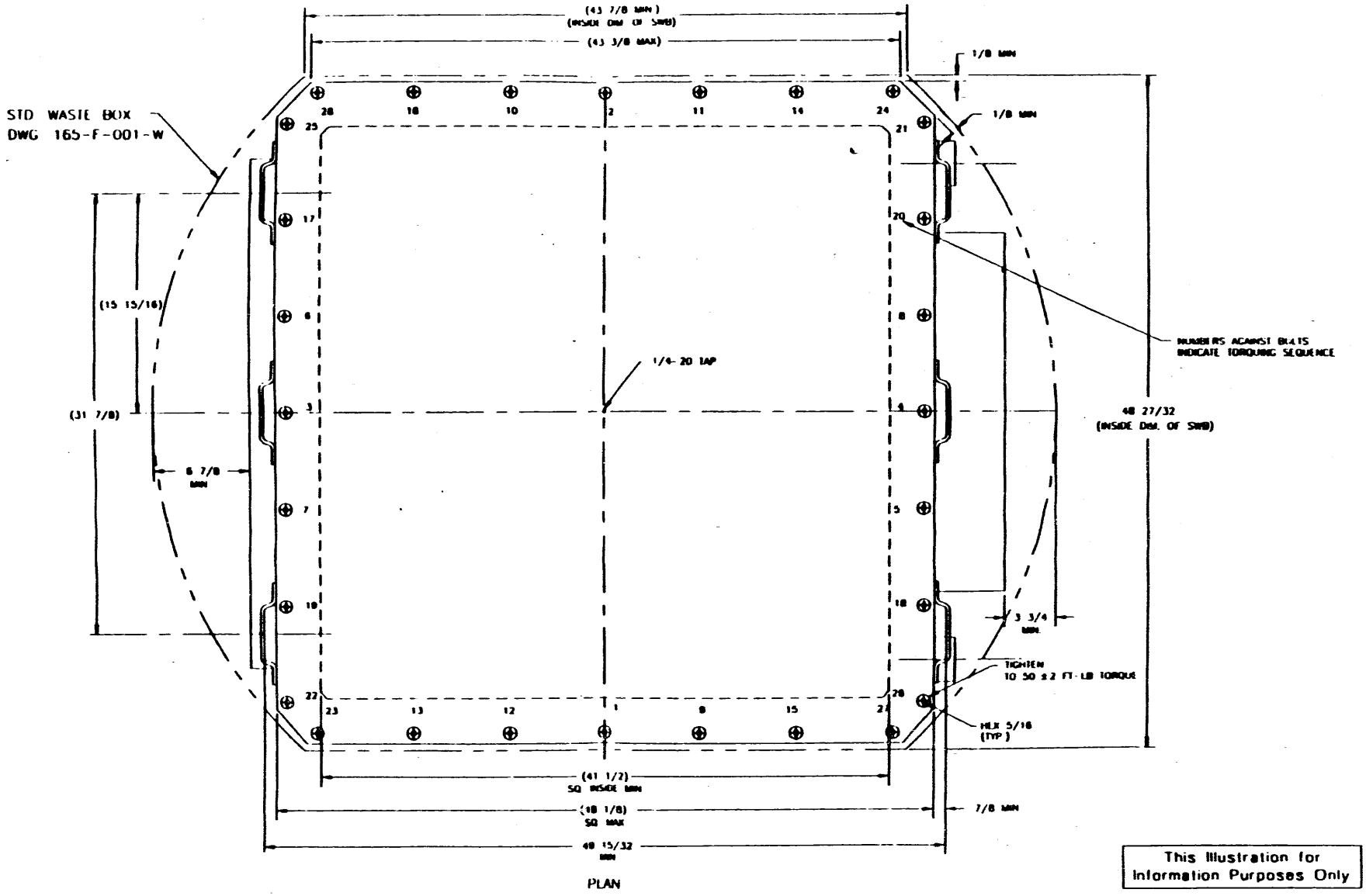
-ROOM 1 AT PANEL 1
toring System Piping



OOM 1 AT PANEL 1
Looking East)
oring System Piping

FIGURE D-32 BIN LAYOUT

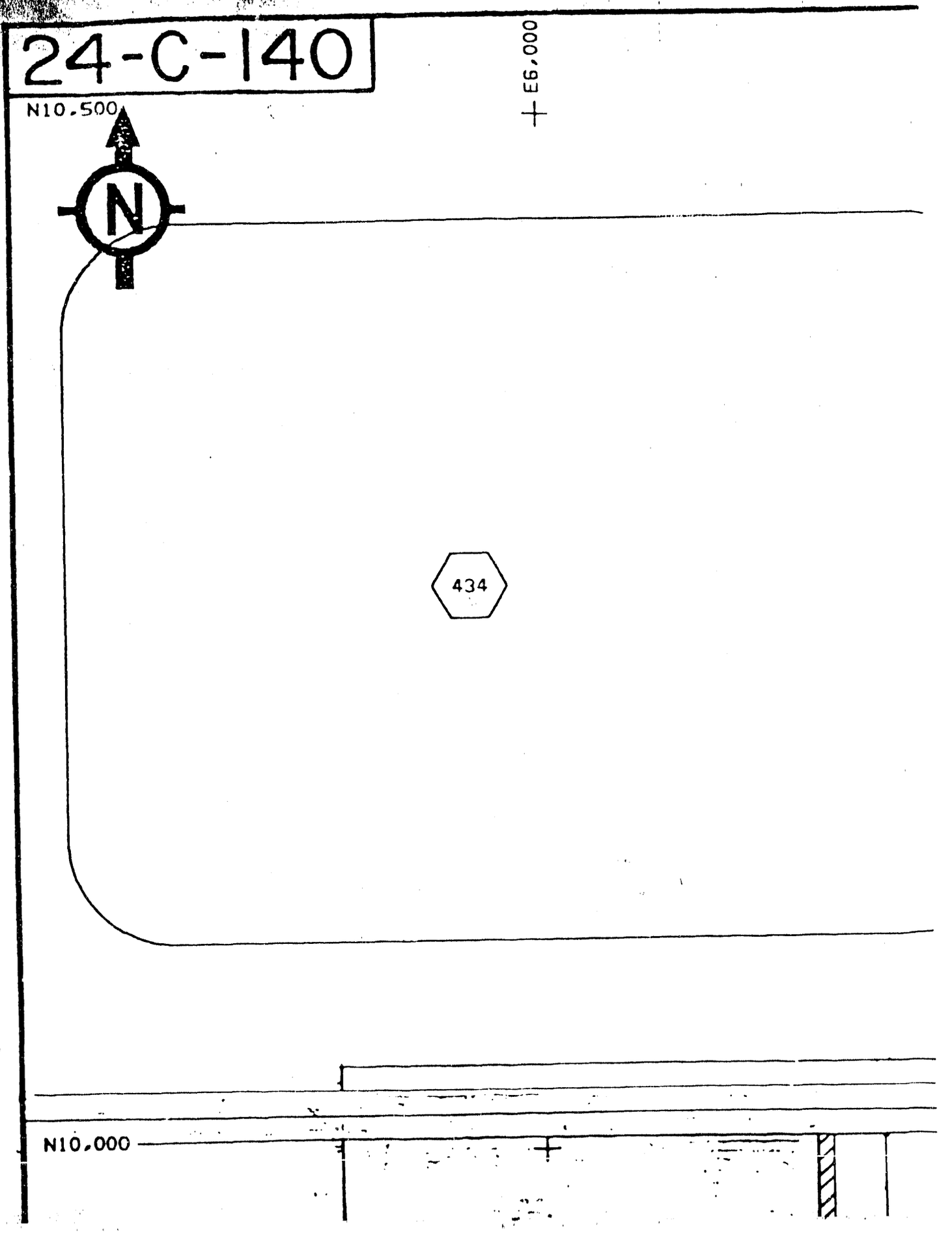
This Illustration for Information Purposes Only.

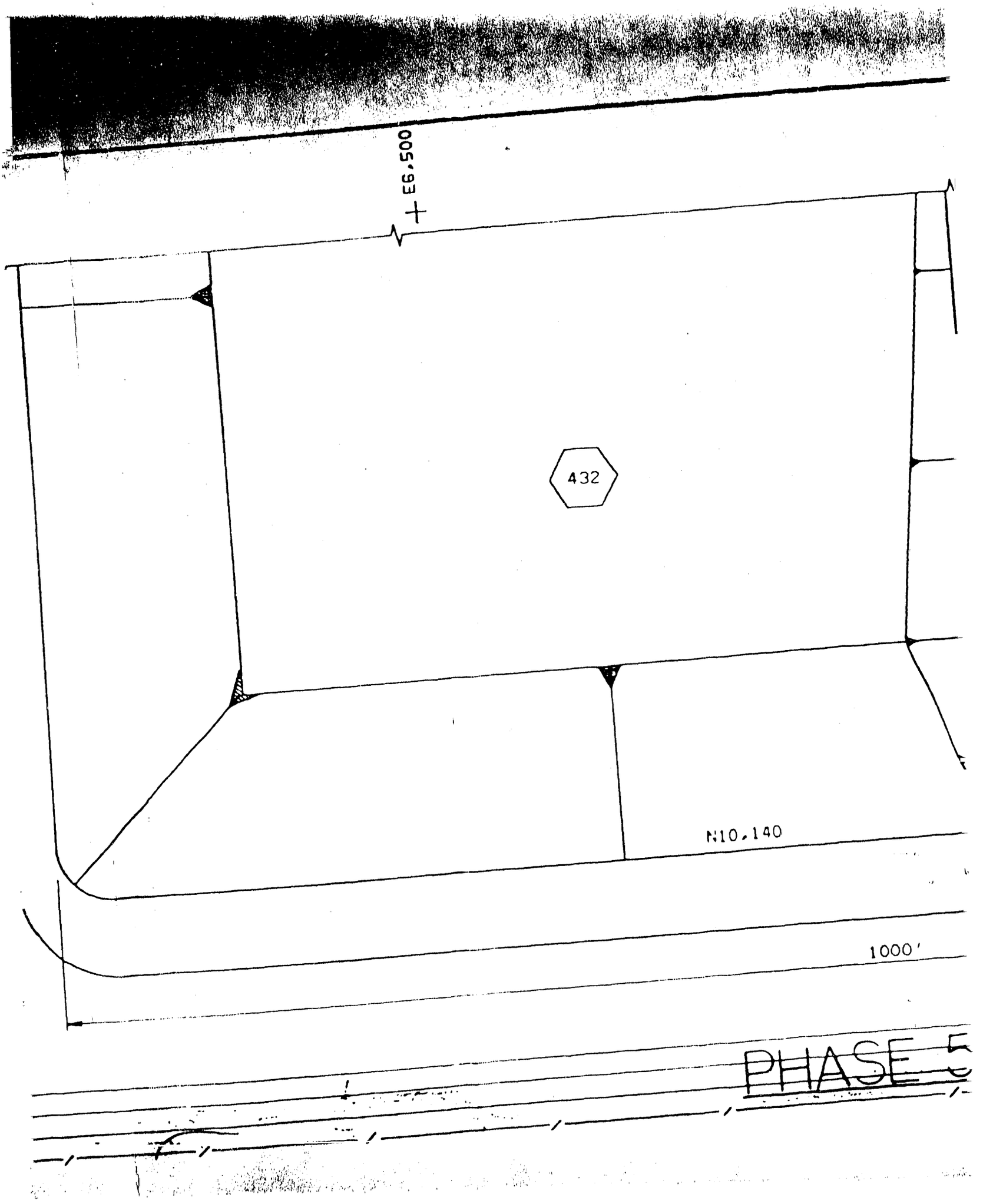


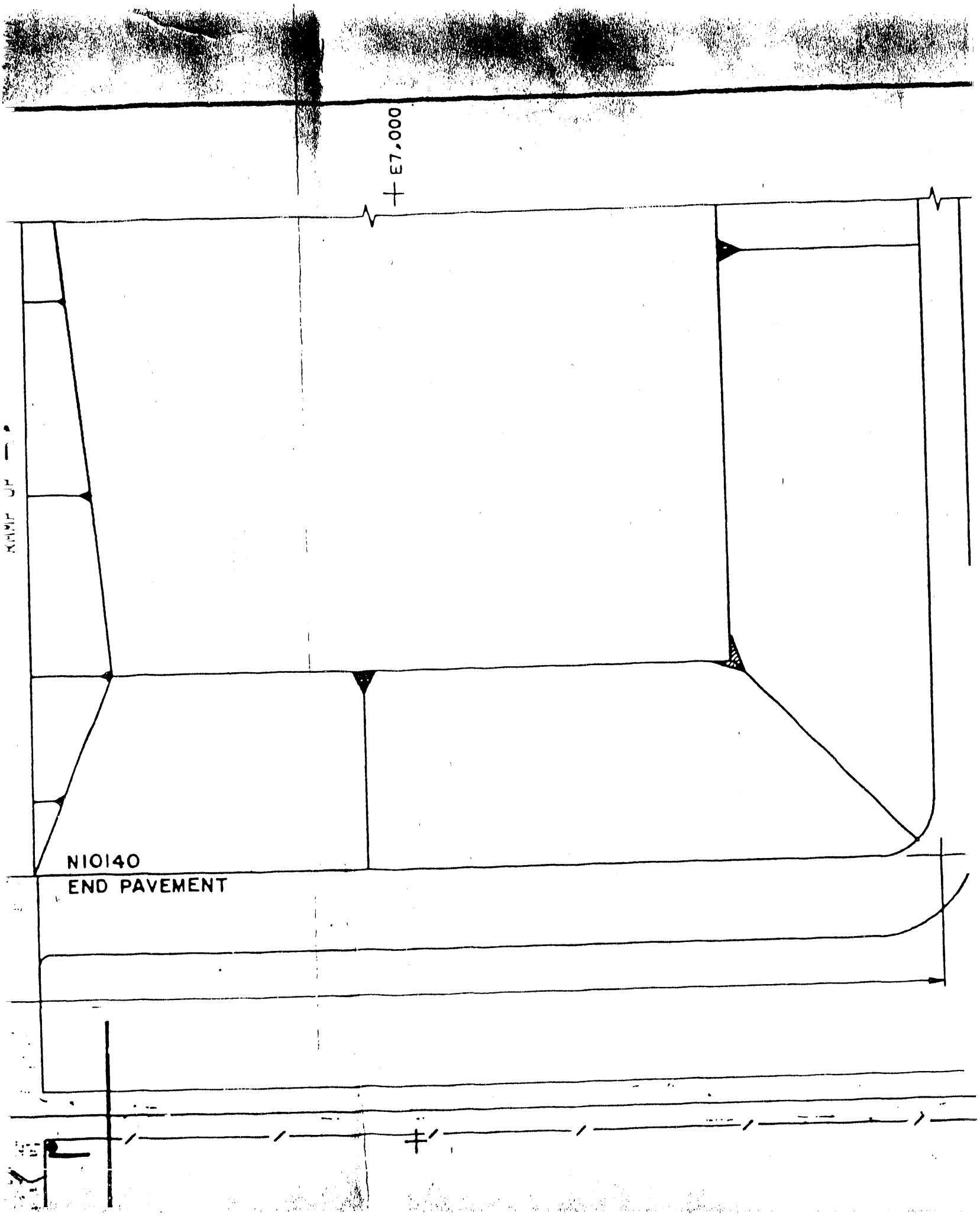
DOE, 1991

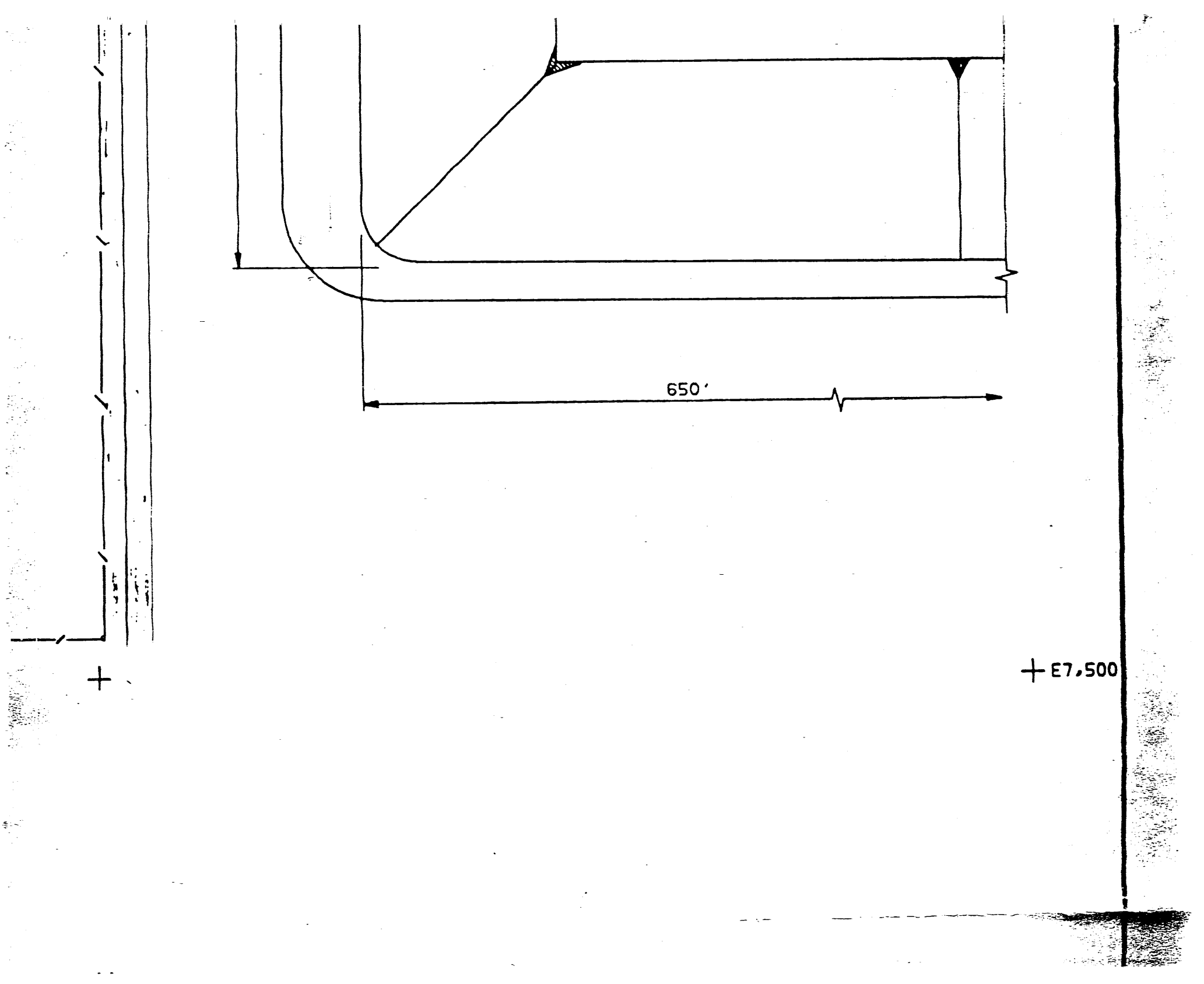
This Illustration for Information Purposes Only

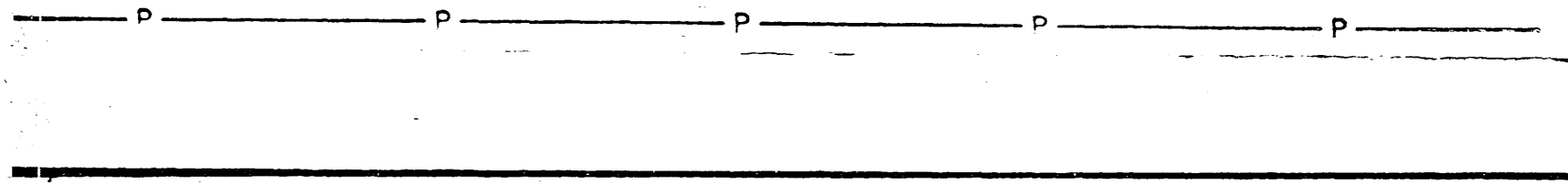
FIGURE D-33 WIPP TEST BIN-SWB INTERFACE DRAWING


24-C-140
N10,500
E6,000
N
434
N10,000


E6,500
432
N10,140
1000'
PHASE


E7,000
N10140
END PAVEMENT


650'
E7,500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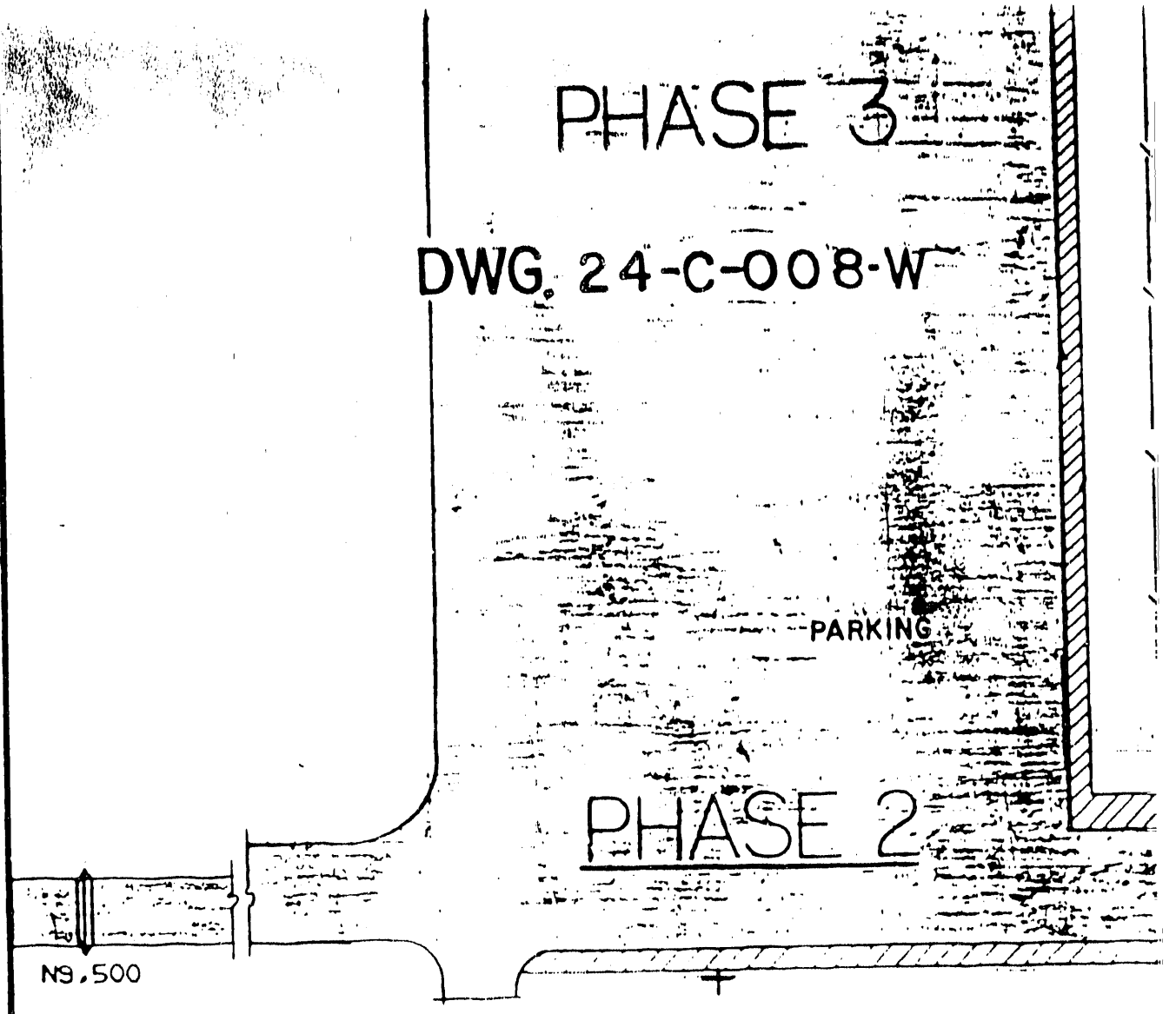
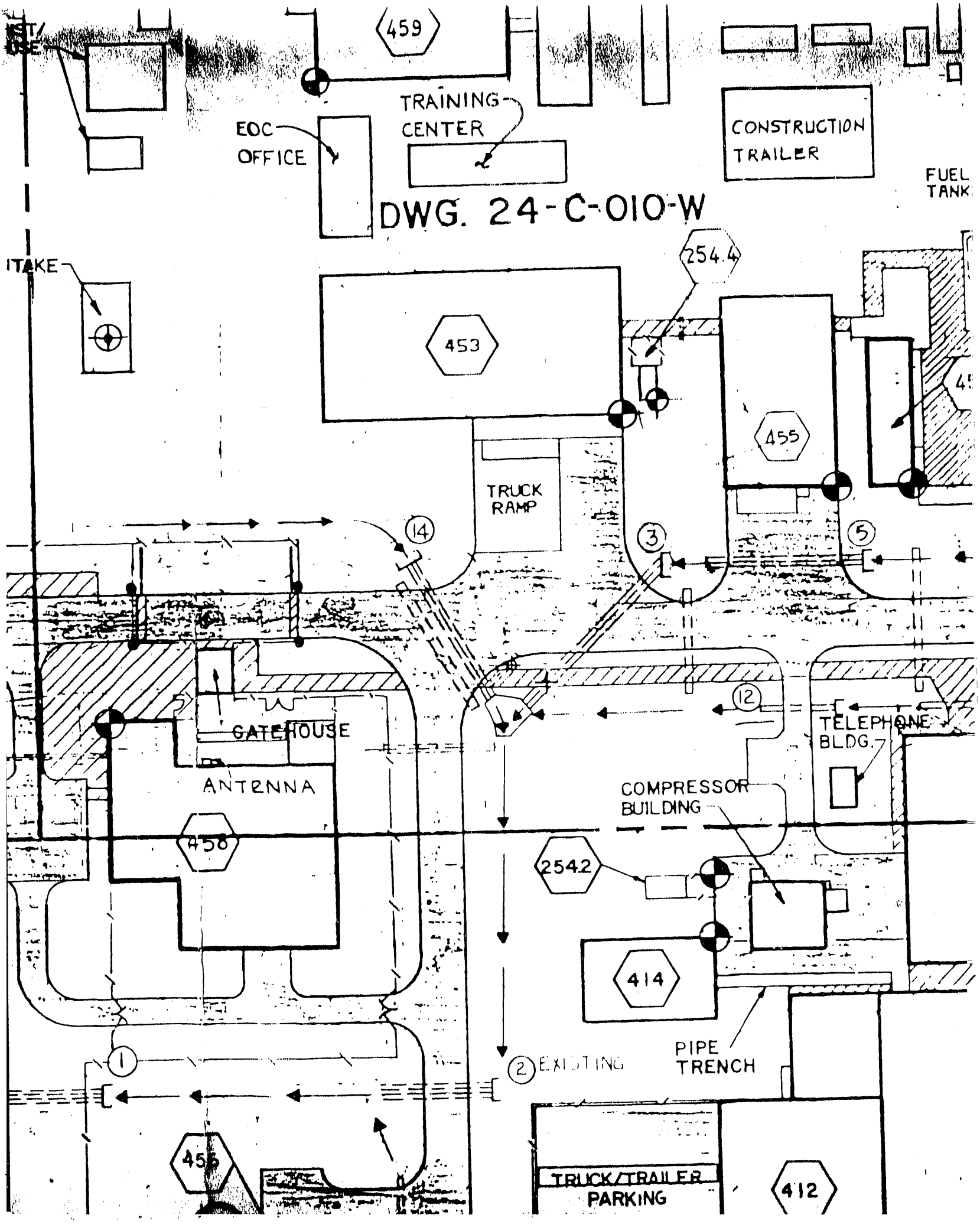
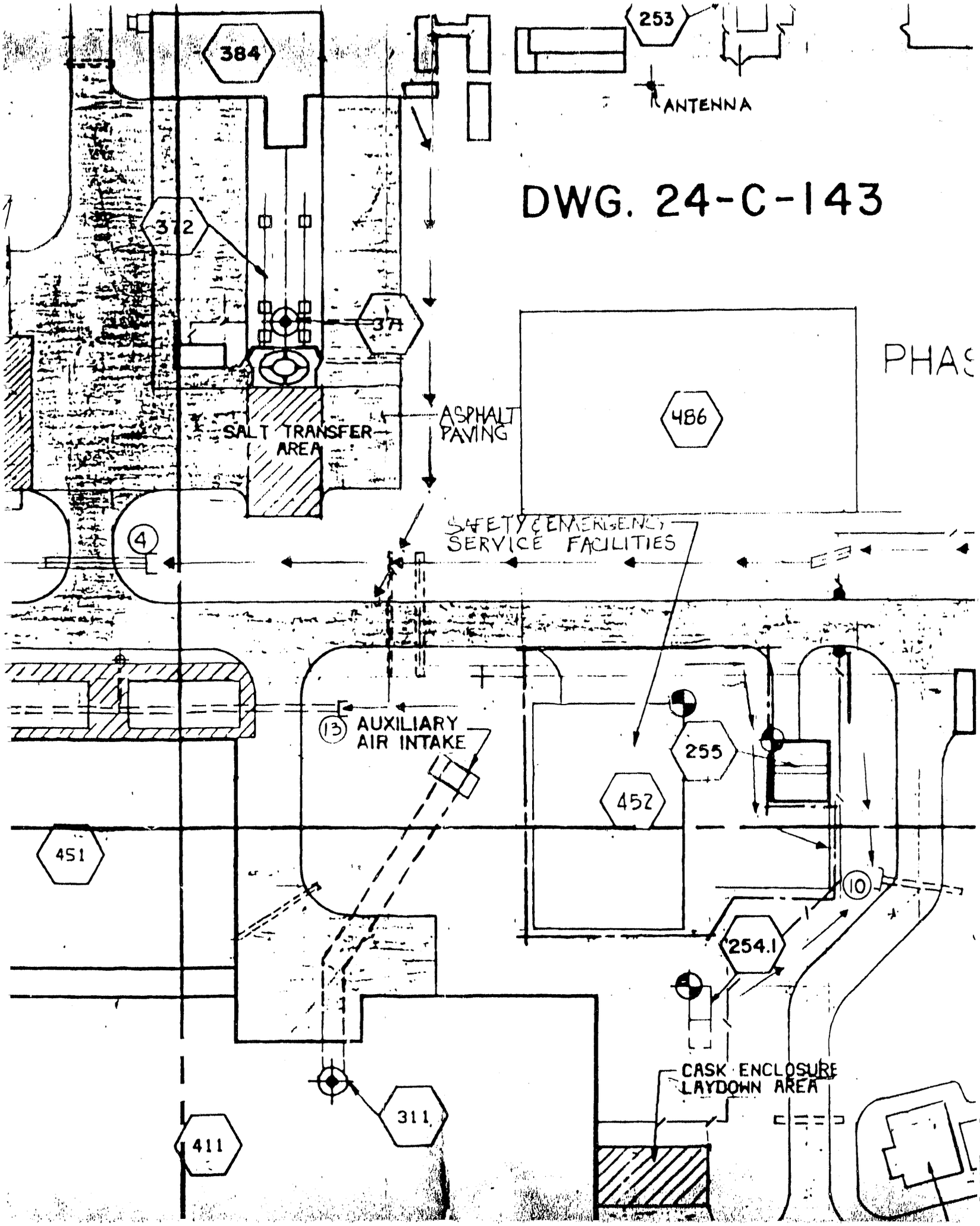
P
P
P
P

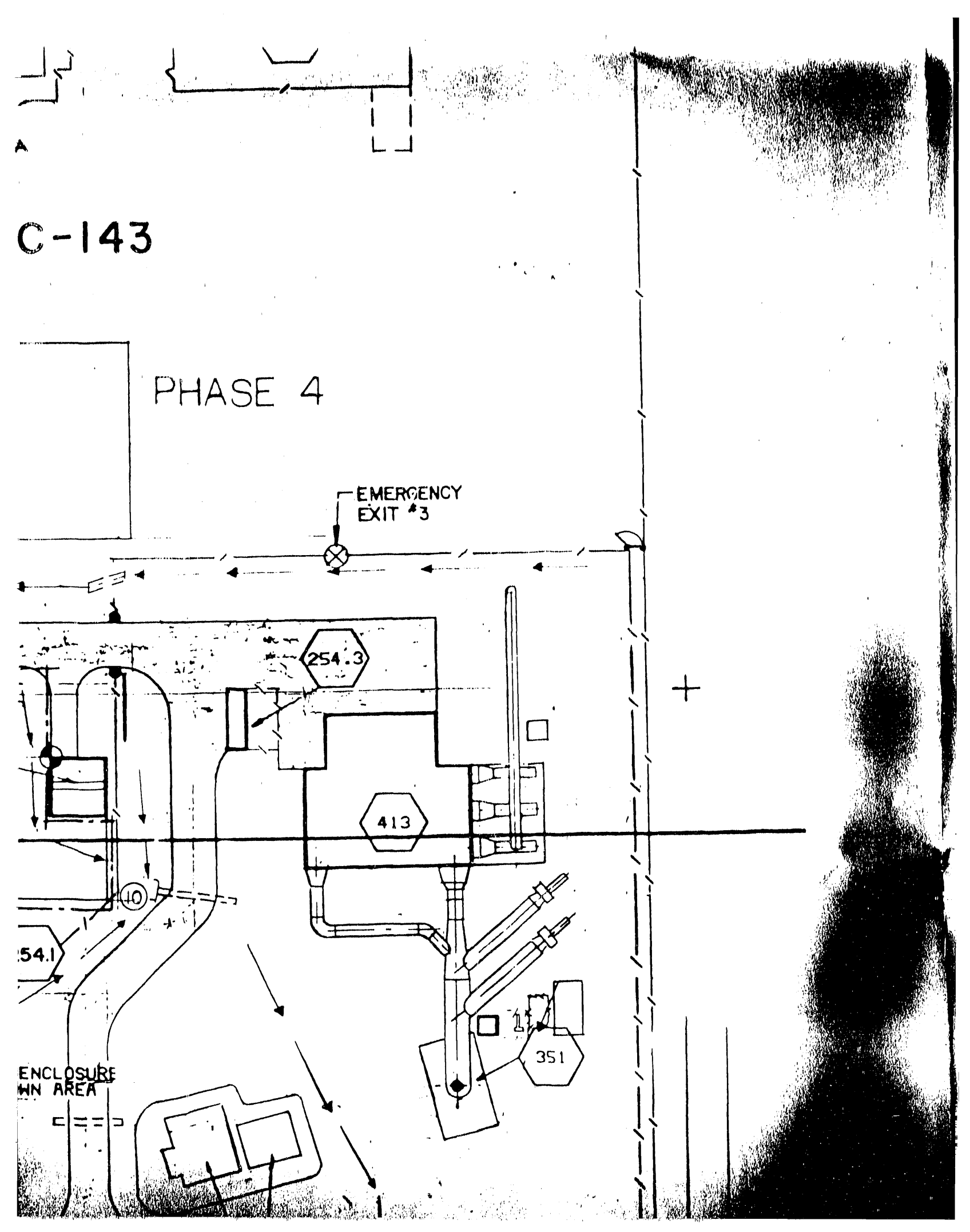


FLAG

V.I.P. PARKI


459
TRAINING CENTER
EOC OFFICE
CONSTRUCTION TRAILER
FUEL TANK
DWG. 24-C-010-W
INTAKE
254.4
453
455
TRUCK RAMP
14
3
5
12
GATEHOUSE
ANTENNA
458
TELEPHONE BLDG.
COMPRESSOR BUILDING
2542
414
1
2 EXISTING
PIPE TRENCH
456
TRUCK/TRAILER PARKING
412

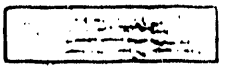

253
ANTENNA
384
DWG. 24-C-143
372
371
PHAS
ASPHALT PAVING
SALT TRANSFER AREA
486
SAFETY & EMERGENCY SERVICE FACILITIES
4
13
AUXILIARY AIR INTAKE
255
452
451
10
254.1
CASK ENCLOSURE LAYDOWN AREA
311
411


C-143
PHASE 4
EMERGENCY
EXIT #3
254.3
413
10
54.1
11
351
ENCLOSURE
WN AREA

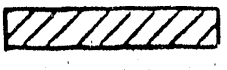
N

1. FOR NOTES SEE DWG

LE



ROADS



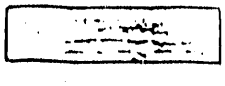
CONCRET
(THIS CC

EL

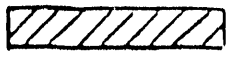
NOTES

1. FOR NOTES SEE DWG. 24-C-008-W

LEGEND



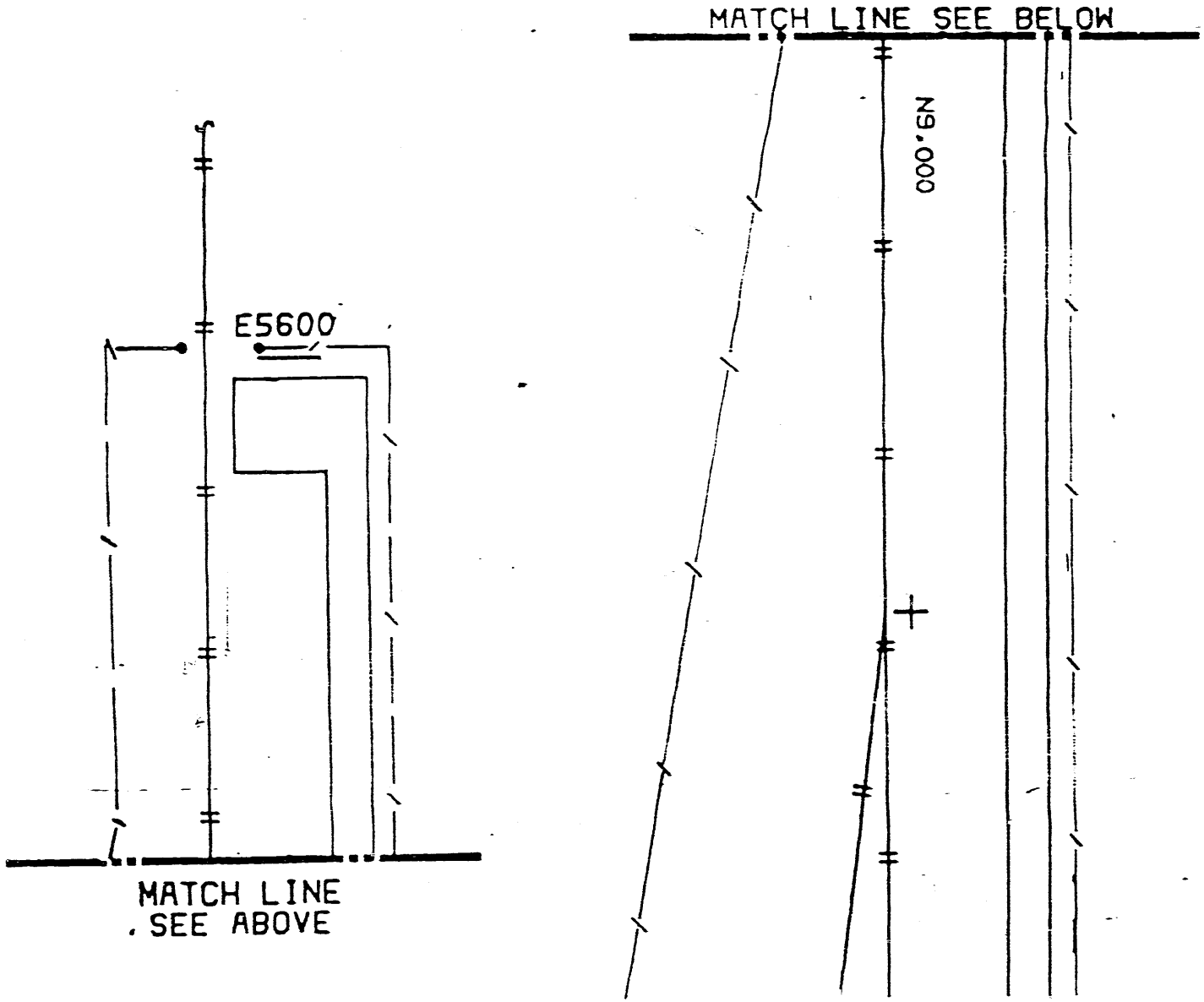
ROADS & PAVING (THIS CONTRACT)

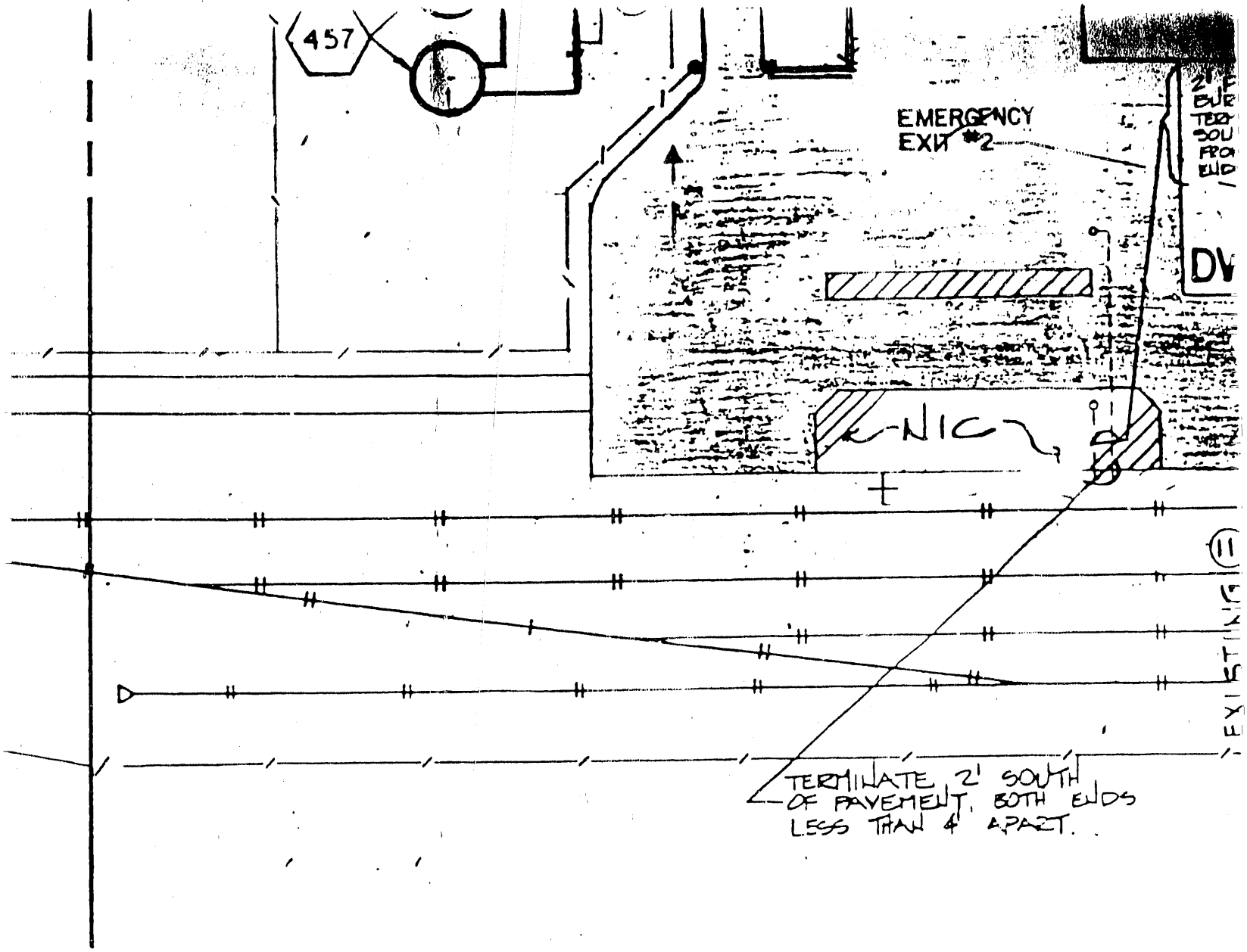


CONCRETE PADS & WALKS
(THIS CONTRACT)

FLOW LINE OF DRAINAGE DITCH

GRAPHICS FILE # NPC001




457
EMERGENCY
EXIT #2
-NIC-
TERMINATE 2' SOUTH
OF PAVEMENT, BOTH ENDS
LESS THAN 4' APART.

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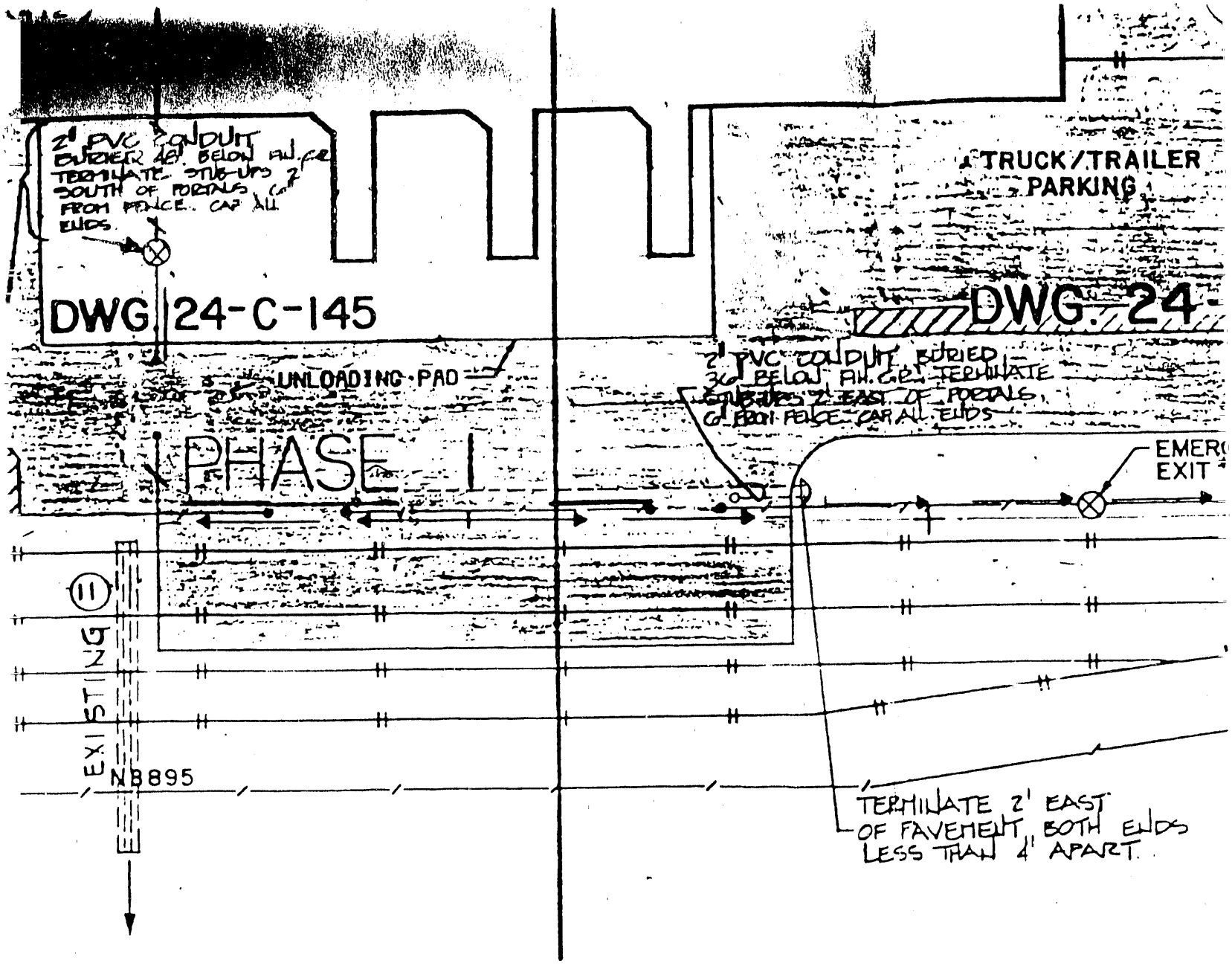
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TRUCK/TRAILER PARKING
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UNLOADING PAD
2" PVC CONDUIT BURIED 36" BELOW FH. GR. TERMINATE STUB-UPS 2' EAST OF PORTALS & 6' FROM FENCE. CAP ALL ENDS
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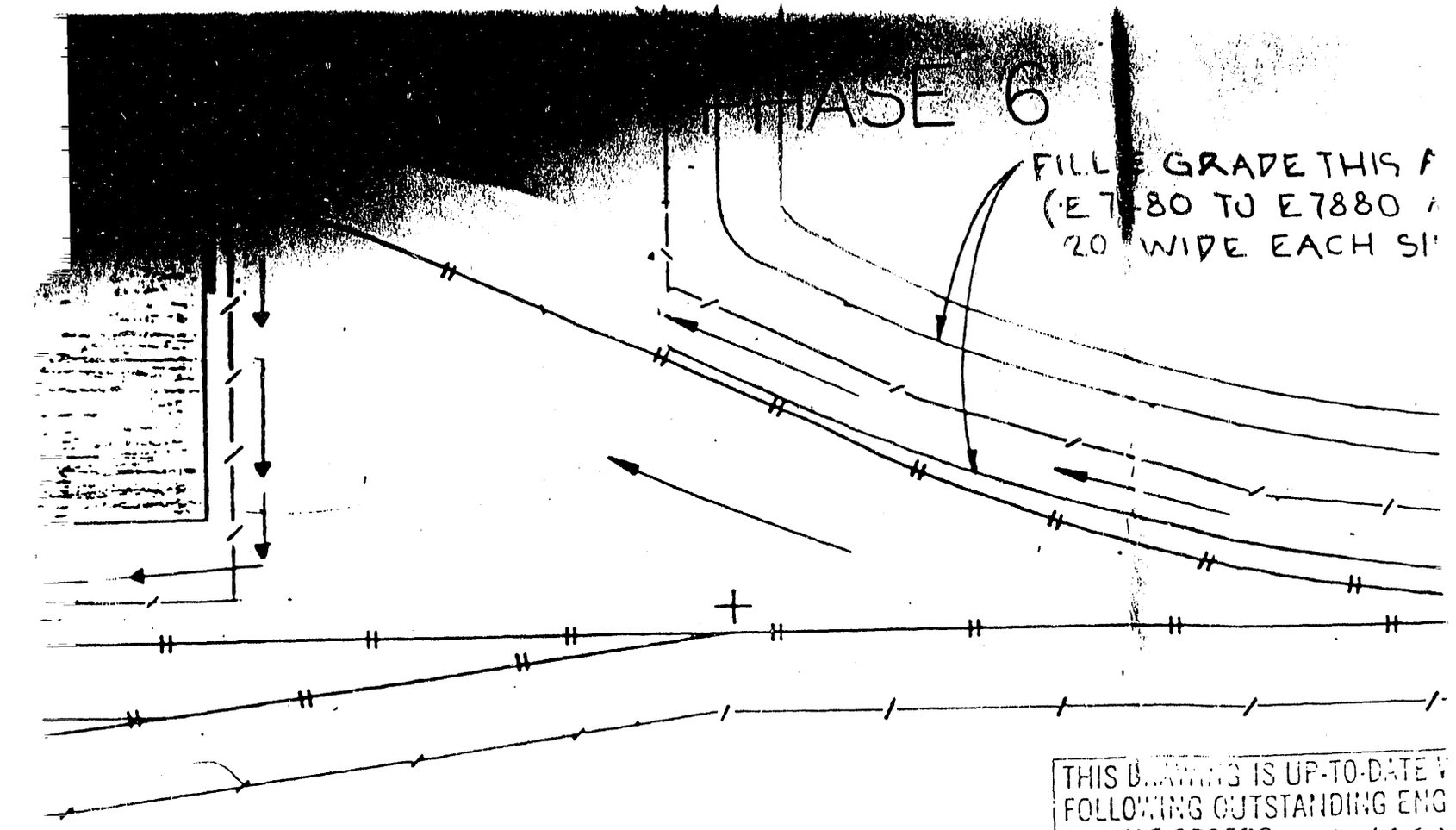

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		DATE	DATE	DATE	DATE
K	REVISED PER ECO	PA	—	JMK	—
		10-5-90	—	10-5-90	—
L	REVISED PER ECO/FO	DLH	AES	JHK	PA
		5/14/91	5/16/91	5/17/91	5/17/91

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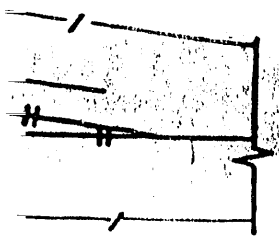

CE	REV	DATE	ISSUE DESCRIPTION	BY	CKD	SUPV	PE	PEM	DOE
NR	5	10/24/83	ISSUED FOR CONSTRUCTION	EB					
NR	4	7/7/83	REVISED AS [illegible] FOR APPROVAL	[illegible]					
NR	3	7/1/83	ISSUED FOR [illegible]						
NR	2	2/25/83	ISSUED FOR [illegible]						
NR	1	10/7/82	GENERALLY REVISED AND ISSUED FOR PROGRESS REVIEW	LJH	GNC				
NR	0	5/20/82	ISSUED FOR PROGRESS REVIEW	LJH		DW JMR	RB	[illegible]	

U.S. DEPARTMENT OF ENERGY
WASTE ISOLATION PILOT PLANT

BECHTEL

SAN FRANCISCO

SITE WORK
FINISH GRADING & PAVING
OVERALL PLAN

JOB NO. 12484	DRAWING APPROVED BECHTEL — DATE 2/17/84
DOE CONTRACT NUMBER DE-AC04-79AL10751	DRAWING APPROVED DEPARTMENT OF ENERGY — DATE 2/17/84

DRAWING NO.	CCP	REV	PAGE NO.
24-C-140-022		L	06

FIGURE D-34 WIPP SITE [illegible]

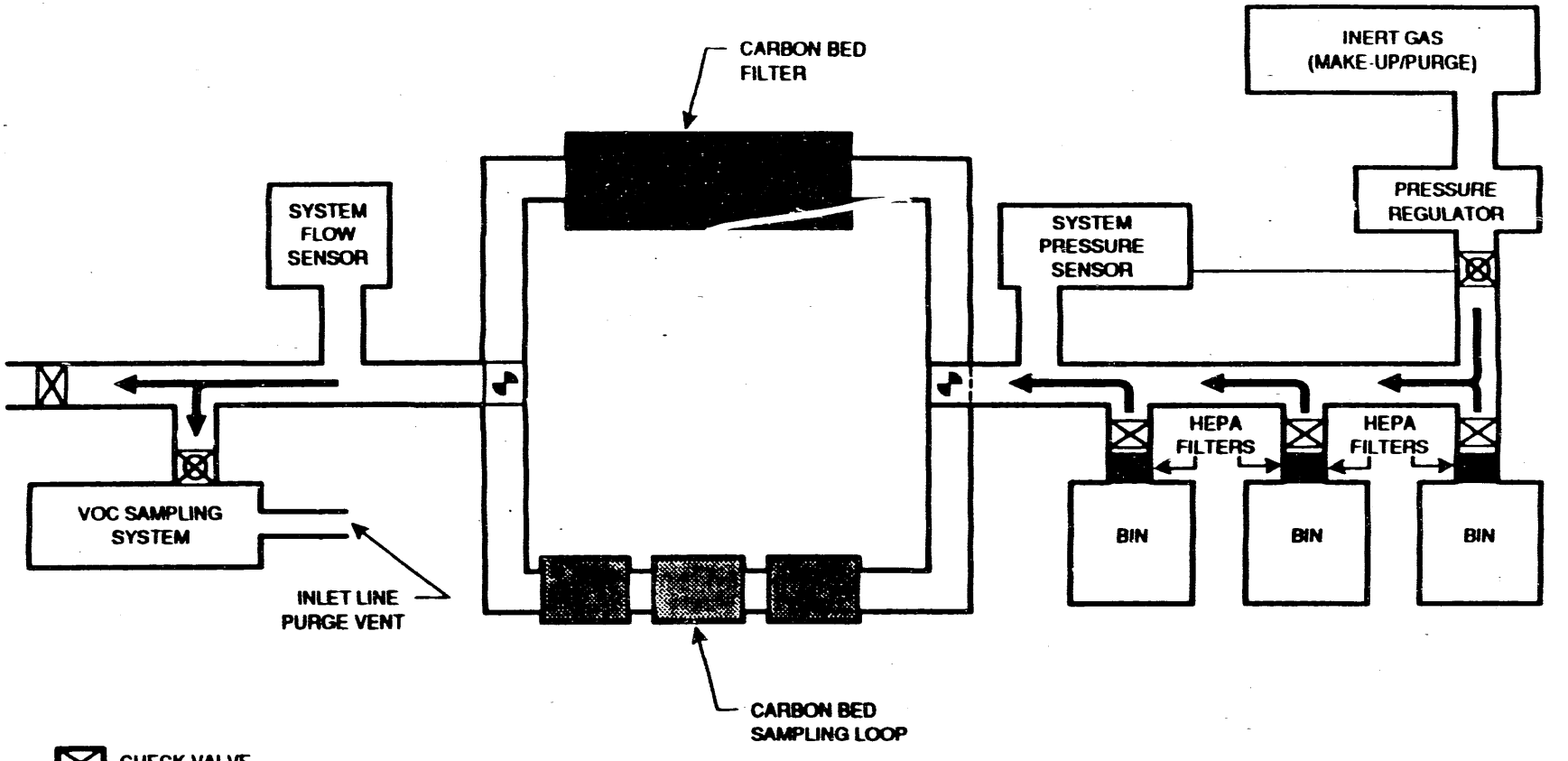

FIGURE D-35 CONCEPTUAL DIAGRAM OF BIN GAS DISCHARGE SAMPLING

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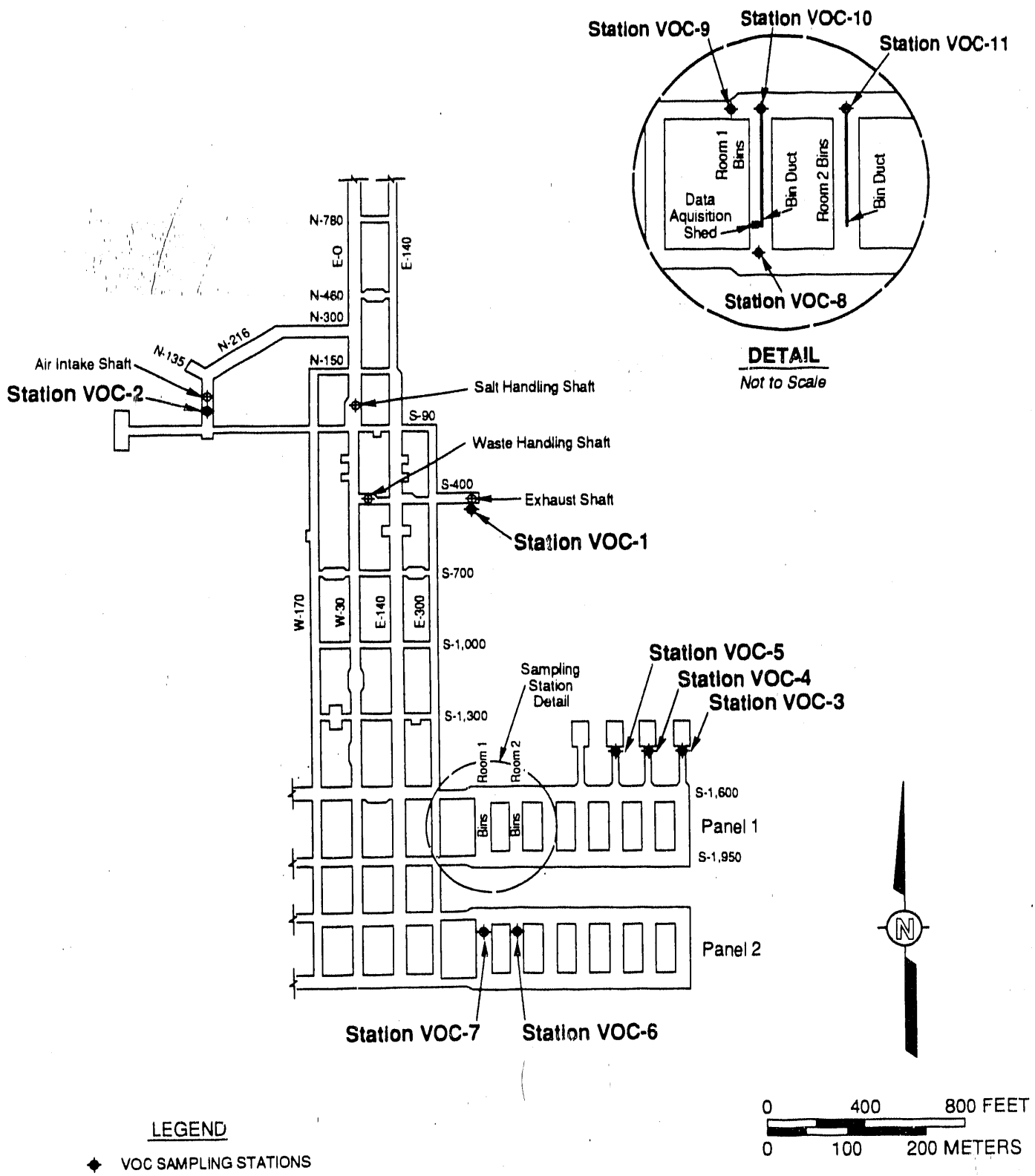

NOTE:

STATIONS VOC-1 AND VOC-2 ARE ON THE SURFACE.
STATIONS VOC-3 THROUGH VOC-11 ARE BELOW GROUND, IN THE REPOSITORY.

This illustration for Information Purposes Only

FIGURE D-36 VOC MONITORING STATION LOCATIONS

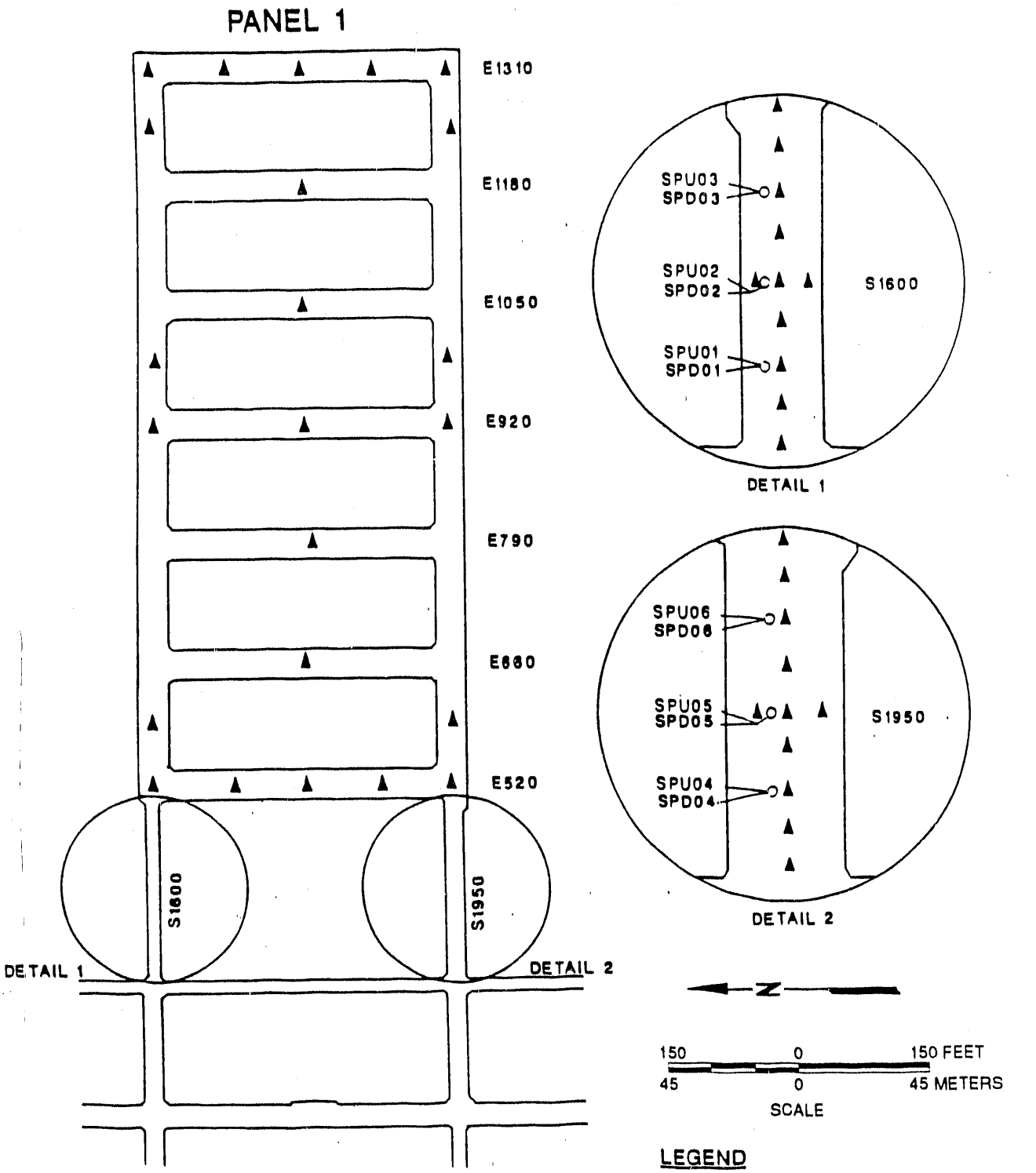

FIGURE D-37 PANEL 1 INSTRUMENTATION

CHAPTER E

GROUNDWATER MONITORING

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GROUNDWATER MONITORING
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CHAPTER E
GROUNDWATER MONITORING

E-1 Compliance with Groundwater Protection Requirements

E-1a Waste Piles

The Waste Isolation Pilot Plant (WIPP) facility includes no waste piles in which hazardous waste is treated or stored, as defined in New Mexico Hazardous Waste Management Regulations (HWMR-6), Part I, section 260.10, and regulated under HWMR-6, Pt. V, Subpart L. This section does not apply to the WIPP facility.

E-1b Landfill

The WIPP facility includes no landfills managing hazardous waste as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart N. This section does not apply to the WIPP facility.

E-1c No Migration

It is the position of the U.S. Department of Energy (DOE) that the migration of hazardous waste or hazardous constituents from the WIPP Test Phase activities to the environment through groundwater is unlikely. For this reason, DOE is submitting the demonstration contained in Appendix E1 to determine the applicability of the groundwater monitoring regulations contained in HWMR-6, Pt. V, Subpart F, and HWMR-6, Pt. V, sec. 264.602, during the Test Phase. Pending the outcome of the Test Phase, permit modifications, if required, will discuss DOE's position regarding groundwater monitoring for possible future operations at the WIPP facility.

Appendix E1, RCRA Groundwater Protection Information, Waste Isolation Pilot Plant, of this permit application summarizes the geological, hydrological, and climatological features of the WIPP site which, along with the nature of the WIPP Test Phase activities, determine the applicability of RCRA groundwater monitoring requirements. The protection information demonstrates that there is no potential for migration of liquid from the regulated unit to the nearest aquifer during the Test Phase. Therefore, it is DOE's position that the requirements of HWMR-6, Pt. V, sec. 264.602, for monitoring, testing, inspections, etc., are not applicable because the stipulations provided in HWMR-6, Pt. V, sec. 264.601(a), are met.

DOE Order 5400.1, General Environmental Protection Program (DOE, 1988), requires that all DOE facilities prepare a Groundwater Protection Plan and report groundwater monitoring data annually to the Office of Operational Safety as part of an Annual Site Environmental Report. This

plan is documented in the Waste Isolation Pilot Plant Groundwater Protection Management Plan (DOE, 1990).

E-2 Interim Status Groundwater Monitoring Data

An interim status groundwater monitoring waiver was prepared and is located at the WIPP facility. As indicated in the monitoring waiver, the WIPP facility is to be operated without RCRA groundwater monitoring, in accordance with the provisions made in HWMR-6, Pt. VI, sec. 265.601(a). Appendix E1 contains similar information that demonstrates very low potential for migration of hazardous waste or hazardous constituents from the WIPP site via groundwater. Therefore, this section does not apply to the WIPP facility.

E-3 General Hydrogeologic Information

A description of the general hydrogeologic conditions at the WIPP site is included in Sections 4.0, 5.0, and 6.0 of Appendix E1.

E-4 Topographic Map Requirements

The topographic and geomorphological features that may affect groundwater flow at the WIPP site are described in Sections 3.0 and 4.0 of Appendix E1.

E-5 Contaminant Plume Description

No contaminant plume is present at the WIPP site; therefore, this section is not applicable to the WIPP facility.

E-6 General Monitoring Program Requirements

The requirements of HWMR-6, Pt. V, Subpart F, do not apply, as stated in HWMR-6, Pt. V, sec. 264.97(d). Groundwater monitoring is not required to assure the performance standards in HWMR-6, Pt. V, sec. 264.601, are being met.

E-7 Detection Monitoring Program

The requirements of HWMR-6, Pt. V, Subpart F, do not apply because, as stated in HWMR-6, Pt. V, sec. 264.97(d), the groundwater detection monitoring program is not required to assure the performance standards in HWMR-6, Pt. V, sec. 264.602, are being met.

E-8 Compliance Monitoring Program

√ DOE is providing groundwater protection information to demonstrate compliance with HWMR-6,
√ Pt. V, secs. 264.601(a) and 264.602; therefore, compliance monitoring is not required at the WIPP
√ facility.

E-9 Corrective Action Program

√ DOE will institute corrective actions for all releases of hazardous waste or hazardous constituents
√ from solid waste management units at the WIPP facility that are necessary to protect human
√ health and the environment. Solid waste management units are described in Chapter J of this
√ permit application. Corrective actions will be performed in compliance with HWMR-6, Pt. V,
√ sec. 264.101.

List of References for Chapter E

U.S. Department of Energy (DOE), 1990, "Waste Isolation Pilot Plant Groundwater Protection Management Plan," DOE/WIPP 90-008, U.S. Department of Energy, Carlsbad, New Mexico.

U.S. Department of Energy (DOE), 1988, "General Environmental Protection Program," DOE Order 5400.1, U.S. Department of Energy, Washington, D.C.

CHAPTER F

PROCEDURES TO PREVENT HAZARDS

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PROCEDURES TO PREVENT HAZARDS
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CHAPTER F

PROCEDURES TO PREVENT HAZARDS

Introduction

The purpose of this chapter is to describe the measures taken during the Test Phase to prevent hazards. It describes the security equipment and procedures in place at the Waste Isolation Pilot Plant (WIPP) facility that continuously monitor and control entry onto the active portion of the facility, including 24-hour security surveillance, fencing, and signs. The chapter discusses the facility inspections (including container inspections) that are conducted to detect malfunctions and deterioration, operator errors, and discharges that may be causing or may lead to releases of hazardous waste or hazardous constituents to the environment or that could be a threat to human health. Preparedness and prevention procedures, structures, and equipment are also documented, including those related to ignitable, reactive, and incompatible waste.

F-1 Security

The security requirements contained in the New Mexico Hazardous Waste Management
√ Regulations (HWMR-6), Part V, section 264.14, and HWMR-6, Pt. IX, sec. 270.14(b)(4), require that security be provided by 24-hour surveillance or a barrier and means to control entry; if these requirements cannot be met, a waiver may be requested. The following sections demonstrate that the WIPP facility fully complies with the requirements and that a waiver is not requested.

F-1a Security Procedures and Equipment

The design and operation of the WIPP facility are specifically planned to fully meet the security
√ requirements contained in HWMR-6, Pt. V, secs. 264.14(b) and (c). Because the WIPP facility
√ is not requesting a waiver under HWMR-6, Pt. V, sec. 264.14(a), it must have 24-hour security surveillance or a barrier and means to control entry. In addition, warning signs must be provided. The WIPP facility meets the criteria for all three, as discussed below.

F-1a(1) 24-Hour Surveillance System

√ The WIPP facility fully complies with the requirements of HWMR-6, Pt. V, sec. 264.14(b)(1), for a 24-hour surveillance system (i.e., television monitoring or surveillance by guards or facility personnel who continuously monitor and control entry onto the active portion of the facility).

The responsibility for security surveillance rests with the armed security guard force, which provides protection 24 hours per day, 365 days per year, and with designated receptionists, who log in all visitors, contractors, and vendors before they proceed to the Main Gate for access into Zone I.

Figure B-5 in Chapter B, Facility Description, shows the relationship of the WIPP facility site boundary (which provides a 1-mile buffer around the area available for underground development), Zone II (which overlies the maximum extent of the area available for underground development), and Zone I (the fenced area containing all major surface buildings). Figure B-4 in Chapter B of this permit application shows the WIPP facility surface structures, their usage and structure numbers, and their relation to the fence. Figure F-1 shows the WIPP facility security gate, and Figure F-2 shows the Guard and Security Building where the security guard force is stationed.

The major duties of the security guard force are personnel, vehicle, and material access/egress control during work hours. During nonwork hours, the guard force conducts documented security patrols inside the facility as well as outside the security area. The security guard force consists of employees of the WIPP Management and Operating Contractor (MOC).

In addition to the security guard force, WIPP facility employees are called upon to challenge any person in WIPP facilities who is not wearing a badge or who is not under escort when an escort is required. Further physical protection is provided by fences, protective lighting, and closed-circuit television systems. The closed-circuit television system is monitored by the security guard force 24 hours per day.

F-1a(2) Barrier and Means to Control Entry

The existence of a barrier and means to control entry demonstrates compliance with HWMR-6, Pt. V, sec. 264.14(b)(2). Each is discussed in detail in the following sections.

F-1a(2)(a) Barrier

Primary WIPP facilities (Zone I) are contained within a 35-acre fenced area. This area is surrounded by a permanent 8-foot-high chain-link fence and topped by three strands of barbed wire for a total height of 9 feet. The fence encloses major surface structures. The plant substation is surrounded by an additional chain-link fence for security. The regularly inspected chain-link fencing at the WIPP facility completely surrounds the active portion of the facility, thereby complying with HWMR-6, Pt. V, sec. 264.14(b)(2)(i). Figure F-3 shows the fence and signs that surround Zone I.

F-1a(2)(b) Means to Control Entry

Entrance to Zone I, whether by personnel or vehicles, is through controlled gates and doors (Figures F-1, F-2, F-4, and F-5). WIPP facility access control procedures are designed to ensure that only properly identified and authorized persons, vehicles, and property are allowed entrance to and exit from the facility. A personnel identification and access control system is maintained within the facility. Employees identify themselves with an identification badge when entering or leaving the premises. The reception/protective force personnel require proper authorization before admitting visitors to the facility. In addition, visitors are required to wear a temporary badge and to be accompanied by an authorized escort. The protective force is on duty 24 hours per day, 365 days per year. Because the WIPP facility controls entry to the active portion of the facility at all times, the requirements of HWMR-6, Pt. V, sec. 264.14(b)(2)(ii), are met.

F-1a(3) Warning Signs

The permanent chain-link fence surrounding Zone I is posted at approximately 50-foot intervals with U.S. Department of Energy's (DOE) "No Trespassing" signs and with "Danger: Authorized Personnel Only" signs in English and Spanish (Figure F-3). The signs are legible from a distance of 25 feet and can be seen from any approach to the facility. These same signs, plus security and traffic signs, are also located on the controlled gates (Figures F-4 and F-5). The fence and gate signs at the WIPP facility fully comply with HWMR-6, Pt. V, sec. 264.14(c).

F-1b Waiver

The WIPP facility fully complies with all three of the requirements of HWMR-6, Pt. V, secs. 264.14(b) and (c), as described in Sections F-1a(1), F-1a(2)(a), and F-1a(2)(b) of this chapter. Therefore, no demonstration under HWMR-6, Pt. V, secs. 264.14(a)(1) and (2), is required.

F-2 Inspection Schedule

The WIPP facility has a series of manuals that include all the detailed inspection procedures and forms necessary to comply with HWMR-6, Pt. IX, sec. 270.14(b)(5), and HWMR-6, Pt. V, sec. 264.33, during the Test Phase. Table F-1 lists the inspection procedures for each item or system requiring inspection under these regulations. HWMR-6, Pt. IX, sec. 270.14(b)(5), lists requirements that are specifically contained in HWMR-6, Pt. V, secs. 264.15(b), 264.174, and 264.602, which are applicable to the WIPP facility. HWMR-6, Pt. IX, sec. 270.14(b)(5), also lists requirements for facilities that are not present at the WIPP facility or for operations not performed at the WIPP facility. As discussed in Sections F-2b(2) through F-2b(7) of this chapter, the WIPP facility does not manage mixed waste using tanks, surface impoundments, waste piles, land treatments, landfills, or drip pads. Therefore, HWMR-6, Pt. V, secs. 264.193(i), 264.195, 264.226,

264.254, 264.273, 264.303, and 264.574 are not applicable to the WIPP facility. In addition, HWMR-6, Pt. V, secs. 264.1033, 264.1052, 264.1053 and 264.1058, are not applicable to the WIPP facility because the WIPP facility does not perform distillation, fractionation, thin-film evaporation, solvent extraction, or air or steam stripping operations and does not have routine operations where equipment comes in contact with waste with organic concentrations of at least 10 percent by weight. Compliance with the specific requirements is discussed below and in the following sections, and the manuals that contain the relevant inspection information are cited where appropriate.

The WIPP facility maintains operational manuals detailing the inspections required under HWMR-6, Pt. V, secs. 264.15(a) and (b). Table F-1 lists the operational manuals containing the inspection procedures. The facility is inspected for malfunctions and deterioration, operator errors, and discharges that may cause, or potentially cause, releases to the environment or threaten human health. Frequency of inspections is discussed in detail in Section F-2a(2). Inspections are conducted often enough to identify problems in time to correct them before they pose a threat to human health or the environment and may also be based on regulatory requirements. The operational manuals assign responsibility for conducting the inspection, the frequency of each inspection, the types of problems to be watched for, what to do if items fail inspection, directions on routing for record keeping, and inspector signature, date, and time. The operational manuals are maintained at the WIPP facility.

Inspection procedures include identifying malfunctions or deteriorating equipment and structures. The equipment tagout/lockout procedures in WP 04-3, Operations Administration Manual (Westinghouse, 1992a), describe the steps taken to tag or lock an item that requires repair or replacement. Items that are operational with restrictions are tagged with those restrictions. Items that are not operational are tagged and locked to prevent their use. Tagged and locked items are listed on the Tagout/Lockout Index. The work authorization procedures in WP 04-3 outline the work request controls for repetitive or one-time tasks. [An exception is routine mine openings maintenance, including wire meshing and rockbolting, which are covered in WP 04-2, Mining Operations Manual (Westinghouse, 1991a).] Once a scheduled repair or replacement is accomplished in accordance with the work authorization procedures, the tag and lock are removed from the item in accordance with the equipment tagout/lockout procedures. If an item is being tested under the procedures in the controlling document for that piece of equipment, then the scheduled test will be noted on the Plan of the Day or the Daily Release Sheet maintained in the Facility Operations Shift Supervisor's Office. These procedures allow the persons conducting the inspections listed below to verify the status of items that have previously been identified for repair or replacement and to enter that information into the appropriate inspection form or log. Implementation of these procedures constitutes compliance with HWMR-6, Pt. V, sec. 264.15(c).

√ Requirements of HWMR-6, Pt. V, sec. 264.15(d), are met by the inspection procedures for each item or system included in Table F-1. The results of the inspections are maintained for at least three years in accordance with WP 02-6 and WP 02-7, Resource Conservation and Recovery Act √ (RCRA) Compliance Manual (Westinghouse, 1992b). The inspection logs include the date and time of inspection, the name of the inspector, a notation of the observations made, and the date and nature of any repairs or other remedial actions.

F-2a General Inspection Requirements

Table F-1 lists the major categories of monitoring equipment, safety and emergency systems, security devices, and operating and structural equipment that are important to the prevention or detection of, or the response to, environmental or human health hazards caused by hazardous materials. These systems may include numerous subsystems. These systems are inspected according to the frequency listed in Table F-1, a copy of which is maintained at the WIPP facility. The frequency of inspections is based on the nature of the equipment or hazard or meets frequency requirements when these are specified. When in use, daily inspections are made of √ areas subject to spills, such as loading and unloading areas, in accordance with HWMR-6, Pt. V, sec. 264.15(b)(4). Bin-scale test rooms and derived waste emplacement areas are √ inspected weekly as waste container storage areas, in accordance with HWMR-6, Pt. V, sec. 264.174. Volatile organic compound (VOC) monitoring is conducted daily and equipment is inspected daily until statistical standards are met, allowing the frequency to be reduced to weekly in accordance with the U.S. Environmental Protection Agency's (EPA) Conditional No-Migration Determination (EPA, 1990). The EPA's requirement is made in √ accordance with HWMR-6, Pt. V, sec. 264.602. As required in HWMR-6, Pt. V, sec. 264.33, the WIPP facility inspection procedures for communication and alarm systems, fire protection equipment, and spill control and decontamination equipment include provisions for testing and maintenance to ensure that the equipment will be operable in an emergency.

F-2a(1) Types of Problems

The inspection manuals for the systems subject to this Part B permit application and listed in Table F-1 include the types of problems (e.g., malfunctions or deterioration) to be looked for √ during the inspection of each item or system, if applicable, and are in compliance with HWMR-6, Pt. V, sec. 264.15(b)(3).

F-2a(2) Frequency of Inspections

Table F-1 lists the inspection frequency for equipment and systems subject to the Part B permit application. The frequency is based on the rate of possible deterioration of the equipment and the probability of an environmental or human health incident if the deterioration or malfunction, or any operator error, goes undetected between inspections. Areas subject to spills, such as

loading and unloading areas, are inspected daily when in use, consistent with the requirements of HWMR-6, Pt. V, sec. 264.15(b)(4).

The EPA's Conditional No-Migration Determination (EPA, 1990) contains an additional requirement to monitor for VOCs. DOE will operate a carbon adsorption device designed to achieve a control efficiency of at least 95 percent in the discharge system of the bin experiment rooms. Initially, the control device outlet airstream will be inspected and sampled on a daily schedule. Once statistical standards are met, inspection and sampling may be reduced to weekly. The VOC monitoring and the inspection of the monitoring equipment are part of the additional EPA requirements for the miscellaneous unit in accordance with HWMR-6, Pt. V, sec. 264.602.

Bin-scale test rooms and the site of emplacement of derived waste will be in Panel 1. [Section D-8a(2)(a) in Chapter D of this permit application contains a detailed explanation of derived waste.] The bin-scale test rooms and derived waste emplacement room will be inspected weekly in accordance with HWMR-6, Pt. V, sec. 264.174, to determine if containers are leaking and to monitor for deterioration of either the containers or the containment system. If deterioration is found, the type and extent will be noted during the inspection. Figure D-20 shows the location of the bin-scale Test Phase area; derived waste will be emplaced in an unused room in Panel 1.

F-2b Specific Process Inspection Requirements

The regulations listed in HWMR-6, Pt. IX, sec. 270.14(b)(5), and HWMR-6, Pt. V, sec. 264.15(b)(4), require inspections of specific portions of a facility, rather than the general facility. These include container storage areas, tank systems, waste piles, surface impoundments, incinerators, landfills, land treatment facilities, and miscellaneous units. Each is addressed below.

F-2b(1) Container Inspection

Inspection of container storage areas in the miscellaneous unit at the WIPP facility is addressed in Section F-2a(2) above and demonstrates that the WIPP facility is in compliance with HWMR-6, Pt. V, sec. 264.174.

F-2b(2) Tank System Inspection

The WIPP facility does not manage hazardous or mixed waste using a tank system as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart J. Tank system regulations are not applicable to the WIPP facility.

F-2b(3) Waste Pile Inspection

The WIPP facility does not manage hazardous or mixed waste using a waste pile as defined in
√ HWMR-6, Pt. I, sec. 260.10, and regulated under Pt. V, Subpart L. Waste pile regulations are
not applicable to the WIPP facility.

F-2b(4) Surface Impoundment Inspection

The WIPP facility does not manage hazardous or mixed waste using a surface impoundment as
√ defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart K. Surface
impoundment regulations are not applicable to the WIPP facility.

F-2b(5) Incinerator Inspection

The WIPP facility does not manage hazardous or mixed waste using an incinerator as defined
√ in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart O. Incinerator
regulations are not applicable to the WIPP facility.

F-2b(6) Landfill Inspection

The WIPP facility does not manage hazardous or mixed waste using a landfill as defined in
√ HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart N. Landfill regulations
are not applicable to the WIPP facility.

F-2b(7) Land Treatment Facility Inspection

The WIPP facility does not manage hazardous or mixed waste using land treatment as defined
√ in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart M. Land treatment
regulations are not applicable to the WIPP facility.

F-2b(8) Drip Pad Inspection

The WIPP facility does not manage hazardous or mixed waste using drip pads as defined in
HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart W. Drip pad
regulations are not applicable to the WIPP facility.

F-2b(9) Miscellaneous Unit Inspection

√ HWMR-6, Pt. V, sec. 264.602, requires that inspections contained in HWMR-6, Pt. V,
√ secs. 264.15 and 264.33, as well as any additional requirements needed to protect human health
√ and the environment as specified in the permit, be met. The requirements of HWMR-6, Pt. V,

secs. 264.15 and 264.33, are discussed in Section F-2 of this chapter, along with how the WIPP facility complies with those requirements for standard types of inspections.

The EPA's Conditional No-Migration Determination (EPA, 1990) requires VOC monitoring for the Test Phase. The details of this monitoring program are contained in Section D-8e(1) and Appendix D12. As required in HWMR-6, Pt. V, sec. 264.15, inspections must be conducted where there is a potential for release of hazardous waste or hazardous constituents to the environment or a threat to human health. As discussed in Section F-2a, the WIPP facility includes the VOC monitoring and inspection of the equipment used for the VOC monitoring as part of its RCRA inspection/monitoring schedule. VOC monitoring is conducted daily and VOC monitoring equipment is inspected daily until statistical standards are met, allowing the frequency to be reduced to weekly, in accordance with the EPA requirements. VOC monitoring and equipment inspection frequencies and the manuals that contain the procedures for the monitoring and inspections are listed in Table F-1.

F-3 Waiver or Documentation of Preparedness and Prevention Requirements

As described in the following sections, the WIPP facility has a variety of communications systems and emergency response equipment and possesses a continuous water supply to meet emergency situations. In addition, procedures are in place for maintaining sufficient aisle space in which to respond to emergencies involving hazardous waste or hazardous constituents. These systems and procedures fully meet the preparedness and prevention requirements of HWMR-6, Pt. V, secs. 264.32, 264.34, and 264.35, and therefore, no waiver under HWMR-6, Pt. IX, sec. 270.14(b)(6), is requested.

F-3a Equipment Requirements

The WIPP facility is well-equipped with internal and external communications systems, emergency equipment, and water for fire control. As shown in the following sections, the facility fully meets the requirements of HWMR-6, Pt. V, secs. 264.32 and 264.34.

F-3a(1) Internal Communications

HWMR-6, Pt. V, sec. 264.32(a), requires a facility to have an internal communications or alarm system capable of providing immediate emergency instructions (voice or signal) to facility personnel. In addition, HWMR-6, Pt. V, sec. 264.34(a), requires that employees have immediate access to an internal alarm or emergency communication device when handling waste. The following discussions show that the WIPP facility is well-equipped for internal communications and fully complies with the regulations.

The intraplant communication systems, designed to provide immediate emergency instructions to facility personnel, include two-way communication by the public address (PA) system and its intercom phones and paging channels, an intraplant telephone system, mine phones, pagers and plectra, portable two-way radios, and local and facilitywide alarm systems. The procedures for notifying facility personnel in an emergency and the locations of these communication systems are contained in the Contingency Plan, Chapter G of this permit application.

The PA and intercom system consists of handset stations and loudspeaker assemblies, each with its own amplifier. The system has multiple channels: one for public address and paging and the others for independent party lines. The handsets are hard-wired, hand-held transmitter-receivers that are capable of transmitting to other independent handsets or to the PA loudspeakers. Initial communication between parties within the plant can be established by using the paging channel. Each designated location has a single set of electrically isolated speakers and a handset. Multiple sets are provided in large open areas. In order to cover most areas in the plant, loudspeakers are properly oriented and volume levels are adjusted. If one station fails, the remaining stations are isolated from the out-of-service unit to prevent a failure in the remaining system.

Private automatic branch exchange (PABX) two-way communication is provided between any two telephones located above or below ground. Direct dialing to outside telephones and direct dialing to WIPP facility telephones are provided by this system. Failure of a single telephone station does not affect the balance of the telephone system. If the telephone system should fail, the PA system and the portable two-way radios provide backup surface communications.

The Site Notification System (SNS) consists of 50 pagers in the possession of office wardens and 40 plectra located in various buildings. The SNS pagers and plectra are tone-activated radio receivers that are activated by the two-way radio system. To generate a tone on the pagers and plectra or to send a verbal message, the radio operator enters a security code into the two-way radio system and begins broadcasting. The SNS pagers are portable and battery-operated. The plectra are portable and can be plugged into a standard electrical circuit or powered from internal batteries that are continuously recharged when connected to the electrical circuit. The two-way radio system is supplied with power from the uninterruptible power supply if the off-site power supply fails.

A plant radio station in the Guard and Security Building and one located in the Emergency Operations Center in the Safety and Emergency Services Building allow two-way radio communication with on-site personnel and with mobile/portable WIPP facility units operating on and off the WIPP site. The two-way radio also allows one-way emergency notification on the portable SNS pagers and plectra.

There are various alarm systems at the WIPP facility. The evacuation alarm system is used for, and limited to, situations requiring immediate, rapid, and complete or selective area evacuation. Its signals are produced by a tone generator and are transmitted plantwide over the paging channel of the PA speakers, overriding its normal use. The signals are high-intensity, intermittent signals that last about ten seconds. The plantwide alarm signals are initiated manually for radiation problems and automatically by underground fire detection and alarm systems for underground areas. Underground fire alarms also initiate the underground evacuation alarm. These alarm signals take priority over other signals on the paging channel but do not affect the intercom channels. Evacuation alarms using the PA system, local and plantwide, also can be initiated manually from the Central Monitoring Room (CMR) in the Support Building. The audible alarm signals are supplemented by warning lights in high ambient noise areas underground. These alarms are supplied with power from the uninterruptible power supply if the off-site power supply fails.

Whenever mixed and/or derived waste are handled, two persons, at a minimum, are involved in the operation. The Waste Handling Building (WHB) contains telephones and public address stations in the contact-handled waste bay and outside the Overpack and Repair Room. The mine phones are the main means of communication underground, although the public address system is also available. The mine phones are moved periodically so that they are maintained in close proximity to the work areas.

Table G-1 in the Contingency Plan, Chapter G of this permit application, describes the capabilities and locations of the various internal communication systems.

F-3a(2) External Communications

HWMR-6, Pt. V, sec. 264.32(b), requires that a communications device be available for contacting outside agencies for emergency assistance. In addition, HWMR-6, Pt. V, sec. 264.34(b), requires that if just one employee is on the premises, the employee must have immediate access to a device capable of summoning outside help. Waste handling operations are not conducted at the WIPP facility when only one person is present on the premises. Waste handling operations are conducted by two or more persons. The security guard force is also present on the premises during waste handling operations. When no waste handling operations are being conducted, at a minimum, the security guard force is present on the premises. As discussed below, the WIPP facility has the required external communication devices and operates in a manner that fully complies with these regulations.

The external communication systems, designed to provide two-way communication with outside agencies or for summoning emergency assistance from off site, include the commercial telephone system and two-way radios.

Direct dialing through any telephone located above or below ground allows contact with outside agencies. Failure of a single telephone station does not affect the balance of the telephone system. Sixty percent of the direct-dial incoming and outgoing lines are routed via a microwave located on the edge of the parking lot. The remaining 40 percent of the direct-dial lines are routed to Carlsbad by means of a buried cable. This diverse routing allows for continued direct-dial capability if either of the routing modes fails.

A plant radio station in the Guard and Security Building and one located in the Emergency Operations Center in the Safety and Emergency Services Building allow two-way radio communication with the Eddy County and Lea County Sheriff's Departments, the Hobbs Fire Department, the New Mexico State Police, the Guadalupe Medical Center, and the Otis Fire Response Teams.

Table G-1 in the Contingency Plan, Chapter G of this permit application, describes the capabilities and locations of the various external communication systems.

F-3a(3) Emergency Equipment

Table G-1 of the Contingency Plan, Chapter G of this permit application, describes the capabilities and locations of the fire suppression equipment and systems. Table G-2 lists the types of fire suppression systems by structure. Figure G-4 displays the underground locations of emergency equipment. Figure G-5 shows the fire-water distribution system on the surface. Figure G-6 shows the underground fuel area fire protection system. The information contained in these tables and figures demonstrates that the WIPP facility has the portable fire extinguishers, fire-control equipment (including special extinguishing equipment that use foam, inert gas, or dry chemicals), spill control equipment, and decontamination equipment needed for full compliance with the requirements of HWMR-6, Pt. V, sec. 264.32(c).

F-3a(4) Water for Fire Control

HWMR-6, Pt. V, sec. 264.32(d), requires that the facility be equipped with water at adequate volume and pressure to supply water hose streams, foam-producing equipment, automatic sprinklers, or water-spray systems. The following discussion on fire control systems at the WIPP facility demonstrates compliance with this requirement.

The primary function of the WIPP facility water system is to supply water for domestic use and fire protection. Water is furnished by the Double Eagle Water Company, owned by the City of Carlsbad. Wells located 30 miles north of the WIPP facility are the source of the water. Water is supplied by gravity flow through a 24-inch-diameter pipeline to a junction point about 13 miles north of the site at U.S. Highway 62/180. This line is sized to provide 6,000 gallons per minute for use by others, in addition to the peak flow rate required by the WIPP facility. Controls at the

junction point give the WIPP facility priority over flows to all other users. A 10-inch-diameter pipeline supplies water by gravity flow from the tie-in point to the WIPP facility.

At the WIPP facility, the water enters a pair of 180,000-gallon above-ground storage tanks located adjacent to the Pumphouse (Figure F-3). These tanks are 32 feet in diameter and are constructed of welded steel. The water level in each tank is monitored in the CMR. Of the 360,000-gallon total capacity, about 160,000 gallons (80,000 gallons per tank) is designated for storage of a two-day supply of domestic water. The remaining 200,000 gallons of water is dedicated to fire suppression and is sufficient to handle the maximum credible fire (DOE, 1990a). Separate sets of pumps for the domestic water and fire water systems are provided in the Pumphouse. During a fire, the fire-water pump is automatically started, and available domestic water is used first. Upon depletion of the domestic-water inventory, the domestic-water pumps are automatically shut off, and the dedicated fire-water reserve is available for fire suppression use only. The primary fire-water pump is a 100-percent-capacity electric pump. A 100-percent-capacity diesel fire-water pump provides backup in case of a power failure or when maintenance is required on the electric pump. Each fire-water pump is rated at 1,500 gallons per minute at 125 pounds per square inch. Fire-water pressure is maintained by an electric pump.

The following buildings are connected to and protected by the central sprinkler system: the Pumphouse, the Guard and Security Building, the Support Building, the WHB, the Exhaust Filter Building, the TRUPACT Maintenance Facility, the Engineering Building, and several other warehouse and maintenance buildings. The Pumphouse, the Support Building, the WHB, and several other warehouse and maintenance buildings also have hose reels. There is no fire-fighting water supply system underground. Instead, the underground is equipped with fire extinguishers of various types and in various locations (including vehicles) and a fire truck with a 300-gallon-capacity tank, 350-gallon-per-minute pump, 30-gallon foam tank, and 125-pound dry chemical extinguisher. Underground fuel stations are equipped with automatic, 1,000-pound dry chemical extinguishing systems.

Table G-1 of the Contingency Plan, Chapter G of this permit application, describes the capabilities and locations of the fire-suppression equipment and systems. Table G-2 lists the types of fire-suppression systems by structure at the WIPP facility. Figure G-4 displays the underground location of emergency equipment. Figure G-5 shows the fire-water distribution system on the surface. Figure G-6 shows the underground fuel area fire-protection system.

F-3b Aisle Space Requirement

HWMR-6, Pt. V, sec. 264.35, requires that a facility maintain sufficient aisle space to allow the unobstructed movement of personnel, fire protection equipment, spill control equipment, and decontamination equipment to any area of the facility during an emergency. The portions of the

WIPP facility included in this permit application have sufficient aisle space for emergency response, thereby complying with the regulations.

Waste Handling Building

During waste handling operations, sufficient room is maintained for unobstructed movement of personnel, fire protection equipment, spill control equipment, or decontamination equipment to areas in the WHB.

✓ Standard Waste Boxes (SWBs) will remain inside the Transuranic Package Transporter (TRUPACT-II) containers on the trailers parked outside the WHB until waste handlers are
✓ prepared to handle them. The TRUPACT-II is a double-contained cylindrical shipping container specially designed to meet U. S. Department of Transportation (DOT) Type B requirements for
✓ the transportation of mixed waste to the WIPP facility. The TRUPACT-II payload consists of up
✓ to two SWBs, one of which may be dunnage. Figures D-9 and D-14 illustrate the TRUPACT-II and its load.

✓ SWBs are unloaded from the TRUPACT-II container in the Inventory and Preparation Area (IPA) or the Overpack and Repair Room in the WHB (see Figure D-12). The IPA can handle the
✓ unloading of two TRUPACT-II containers at one time. The Overpack and Repair Room accommodates one TRUPACT-II container.

✓ After preparation, bin-scale test waste in Radiological Control Boundaries (RCBs) is placed onto facility pallets for transportation to the experimental rooms. Figure D-17 contains an illustration
✓ of a facility pallet. The facility pallet can accommodate two RCBs or two SWBs.

✓ In the event of a prolonged cessation of waste handling operations, bin-scale test waste can be
✓ placed in areas of the WHB that would be designated as temporary holding areas. These areas
✓ and the waste containers in them would be located so that sufficient aisle space would be
✓ maintained for unobstructed movement of personnel and equipment in an emergency. Shielded
✓ waste holding space for one facility pallet is available in the WHB (see Figure D-12).

✓ At all times, administrative controls ensure that TRUPACT-II containers, facility pallets, and SWBs or RCBs are managed in the WHB in a manner to prevent obstructing the movement of personnel, fire protection equipment, spill control equipment, and decontamination equipment.

Bin-Scale Test Rooms

RCBs in the bin-scale test rooms will be stacked two-high on platforms, with stacks alternately spaced 2 and 4 feet apart. Two rows of RCBs will run lengthwise in the room, with each row approximately 3 feet from a room wall (rib), leaving a 17-foot aisle between rows. The RCB

stacking will provide sufficient aisle space for movement of personnel, fire equipment, or spill control equipment to any area of operations during an emergency. Figures D-11 and D-32 illustrate the RCB stacking and bin-scale room layout.

Derived Waste Emplacement Area

Derived waste emplaced in Panel 1 will be arranged so that there is sufficient aisle space for movement of personnel, fire equipment, or spill control equipment to any area of operations during an emergency.

F-4 Preventive Procedures, Structures, and Equipment

The design and operation of the WIPP facility fully meet each of the requirements of HWMR-6, Pt. IX, sec. 270.14(b)(8), to prevent hazards associated with unloading operations, prevent runoff from hazardous waste handling areas, prevent contamination of water supplies, mitigate the effects of equipment and power failures, prevent undue exposure of personnel to hazardous waste, and prevent releases to the atmosphere. The individual regulatory requirements are discussed below.

F-4a Unloading Operations

The following description of procedures, structures, or equipment used at the facility to prevent hazards in unloading operations is required by HWMR-6, Pt. IX, sec. 270.14(b)(8)(i).

The WIPP facility's equipment, structures, and procedures are specially designed for the safe handling of mixed waste. Section D-8a(2)(b) details how mixed waste is handled, including unloading operations. These waste handling methods and the equipment and structures at the WIPP facility address the unloading of the unique TRUPACT-II from the transport vehicle, transfer of the TRUPACT-II via forklift to the IPA or Overpack and Repair Room, and the unpacking of the specially designed SWBs from the TRUPACT-II. Unloading hazards could stem from the fact that the containers being handled are of unusual design and from the need to avoid handling the containers whenever possible, due to the radiation hazard. The following is a summary of the unique system of procedures, structures, and equipment that were specially developed to prevent hazards in unloading of mixed waste.

The TRUPACT-II shipping container has a gross loaded weight of 19,250 pounds. The TRUPACT-II shipping container has forklift pockets at the bottom of the container specifically for lifting the container with a forklift (see Figure D-9). The 13-ton electric forklift unloads the TRUPACT-II from the trailer and transfers it to an unloading dock in the WHB (see Figure D-15). The unloading dock is specially designed to accommodate the TRUPACT-II container and

functions as a work platform, providing waste handling and health physics personnel with easy access to the container during unloading operations.

√ An overhead 5-ton crane and adjustable center-of-gravity lift fixture (see Figure D-16) transfer each layer of waste containers to the prepositioned, specially designed facility pallet (the facility pallet can be seen in Figure D-17). The facility pallet is a fabricated steel structure designed to securely hold four sets of waste containers. Each facility pallet has a rated load capacity of 25,000 pounds. The upper surface of the facility pallet has two recesses sized to accept the √ waste containers, ensuring that the SWBs or RCBs can be removed easily. Two SWBs or RCBs √ may be placed side by side on a facility pallet for a maximum load of 7,000 pounds. Two rectangular tube openings in the bed allow the facility pallet to be securely lifted by forklift.

Palletized waste is transferred by the 13-ton forklift to the conveyance loading car (the conveyance loading car can be seen in Figure D-17), an electric vehicle designed with an adjustable bed height that is used to transfer the facility pallets to the special pallet support stands in the waste hoist cage.

Once underground, the facility pallet is removed from the hoist cage by the underground waste transporter (see Figures D-10 and D-18), a commercially available diesel vehicle modified to interface with an integral tractor trailer. The trailer is designed specifically for transporting palletized waste and is sized to accommodate the facility pallet.

√ RCBs will be placed onto the bin-scale test room platforms using a forklift.

F-4b Runoff

The following description of procedures, structures, or equipment used at the WIPP facility to prevent runoff from mixed waste handling areas to other areas of the facility or environment, or √ to prevent flooding, is required by HWMR-6, Pt. IX, sec. 270.14(b)(8)(ii).

√ The Waste Handling Building (WHB) is a physical barrier that would prevent waste spills from √ reaching the environment before a cleanup could be initiated and completed. A detailed √ description of the WHB is contained in Section D-8a(3)(b). The WHB floor plan is shown in √ Figure D-12. Appendix D3 contains engineering drawings showing additional WHB details (e.g., √ fire protection, ventilation). Waste handling operations are described in Section D-8a(2)(b). Waste containers remain in the TRUPACT-II container until removed at the unloading dock or in the Overpack and Repair Room, both of which are inside the WHB.

√ Mixed waste received for emplacement at the WIPP facility must be certified under the Waste √ Acceptance Criteria (WAC) as containing less than 1 percent residual liquids in free-liquid form. √ The WAC are procedural controls that must be met at the generator or storage site and verified

by the WIPP facility staff prior to waste shipment to the WIPP facility and acceptance for the Test Phase. Chapter C contains information regarding WAC requirements for shipping. Chapter D discusses receipt and verification of the waste at the WIPP facility. One percent liquid content in two experimental bins, each containing a maximum of six drum-equivalents of waste, is approximately 6.6 gallons of liquid. In the event of a breached waste container, this small amount of liquid would travel no more than a short distance from the vicinity of the breached container. Calculations have been made to estimate the release of liquid from waste containers in the WHB after removal from the TRUPACT-II.[1] The bounding case release of the 1 percent free liquids in two experimental bins (one complete TRUPACT-II load) would involve less than 6.60 gallons spread 0.0033 foot (1 millimeter) thick over approximately 268 square feet. For comparison, the WHB is 84,000 square feet. Therefore, because of waste-handling operations, the characteristics of the waste, and the size of the waste-handling facilities, waste is not anticipated to reach the outside environment or other areas of the facility under expected conditions.

As discussed in Section B-3b, Floodplain Standard, of this permit application, the WIPP facility does not lie within a 100-year floodplain. There are no major surface water bodies within 10 miles of the site, and the nearest river, the Pecos River, is approximately 14 miles away. The general ground elevation in the vicinity of the surface facilities (approximately 3,400 feet above mean sea level) is about 500 feet above the riverbed and 400 feet above the 100-year floodplain. Protection from flooding or ponding caused by Probable Maximum Precipitation events is provided by the diversion of water away from the WIPP facility by a system of peripheral interceptor diversions. Additionally, grade elevations of roads, tracks, and surface facilities are designed so that storm water will not collect on the site under the most severe conditions. Repository shafts are elevated at least 6 inches to prevent surface water from entering the shafts. The floor levels of all surface facilities are above the levels calculated for local flooding due to Probable Maximum Precipitation events (DOE, 1990b). Section D-9a(1)(d), Surface Water Hydrology; Section D-9a(3)(f).1g, Control of Run-On; and Section D-9d(2), Protection of Surface Water, Wetlands, and Soil Surface, of this permit application, also discuss this subject. Figure D-34, in Chapter D of this permit application, displays the water diversions that have been constructed at the WIPP facility. Therefore, flooding of WIPP facility roads, tracks, and surface structures is not expected from the flooding of surface waters as a result of probable maximum precipitation events or because of site-runoff design.

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[1]The bounding case is based on the following calculations (International Technology Corporation, 1991):

a. Assume two bins, each containing 6 drum-equivalents that contain 1 percent free liquids (amounting to 0.55 gallons of liquid per drum-equivalent), are breached: (2 bins) x (6 drum-equivalents/bin) x (0.55 gallons of liquids/drum-equivalent) = 6.60 gallons total volume of liquid spilled.

b. Convert gallons to feet^3: 6.60 gallons x 0.1337 = 0.88242 feet^3.

c. Assume spill is 1 millimeter thick and convert to feet: (1 millimeter) x (1 centimeter/10 millimeter) x (1 inch/2.54 centimeter) x (1 foot/12 inches) = 0.0033 foot thick.

d. Divide total volume of liquid spilled by thickness of spill material: (0.88242 feet^3) ÷ (0.0033 foot) = 268 feet^2, rounded.

√ Waste is not expected to reach the outside environment or other parts of the facility from the
√ waste-handling facilities in nonflood circumstances; no flooding of the waste-handling facilities is
√ expected that might transport waste to the outside environment between parts of the WIPP
√ facility; and no waste is expected to find its way to an area of the WIPP site where it would be
√ carried off site by flood or precipitation waters.

F-4c Water Supplies

The following description of procedures, structures, or equipment used at the facility to prevent
√ contamination of water supplies is required by HWMR-6, Pt. IX, sec. 270.14(b)(8)(iii).

√ Section E-1, Groundwater Protection Information, in Chapter E of this permit application, notes that there are no waste piles or landfills at the WIPP facility that manage mixed waste, and that DOE and the EPA have determined that the WIPP facility will not affect groundwater quality during the Test Phase because there is no potential for migration of liquid from the regulated
√ waste management unit. Therefore, DOE is providing groundwater protection information in
√ accordance with HWMR-6, Pt. V, sec. 264.60. Appendix E1 of this permit application, RCRA
√ Groundwater Protection Information, Waste Isolation Pilot Plant, summarizes the geological, hydrological, and climatological features of the WIPP site which, along with the procedures,
√ structures, and equipment used during the Test Phase activities, to demonstrate groundwater
√ performance standards. The groundwater protection information demonstrates that groundwater will not come in contact with the waste, and the possibility that any contaminated groundwater can migrate from the disposal horizon to the accessible environment, including water supplies, during the Test Phase is unlikely. The Water Quality Sampling Program is characterizing area wells during the Test Phase, and the results are issued in the annual WIPP Site Environmental Report. The 1990 WIPP Site Environmental Report is provided in Appendix D4 of this permit application.

The primary function of the WIPP facility water system is to supply water for domestic use and fire protection. Water is furnished by the Double Eagle Water Company, owned by the City of Carlsbad. Wells located 30 miles north of the WIPP facility are the source of the water. Water is supplied by gravity flow through a 24-inch-diameter pipeline to a junction point about 13 miles north of the site at U.S. Highway 62/180. This line is sized to provide 6,000 gallons per minute for use by others, in addition to the peak flow rate required by the WIPP facility. Controls at the junction point give the WIPP facility priority over flows to all other users. A 10-inch-diameter pipeline supplies water by gravity flow from the tie-in point to the WIPP facility. At the WIPP facility, the water enters a pair of 180,000-gallon aboveground storage tanks located adjacent to the Pumphouse (Figure F-3). The 360,000-gallon combined capacity of the tanks is used as the potable water source and for fire control. These tanks are 32 feet in diameter and are constructed of welded steel. The water level in each tank is monitored in the CMR. Potable water is piped to the site and stored in tanks until distributed by pipe to the fire hydrants and

buildings. Managing the potable water supply in this manner prevents the contamination of the supply by mixed waste.

F-4d Equipment and Power Failure

The following description of procedures, structures, or equipment used at the facility to mitigate effects of equipment failure and power outages is required by HWMR-6, Pt. IX, sec. 270.14(b)(8)(iv).

In the event that normal utility power is lost, on-site diesel generators will provide alternating current (AC) power to important WIPP facility electrical loads. Uninterruptible power supply (UPS) units are also on line providing power to important monitoring systems. If utility power fails, the exhaust filter system goes into the fail position and the system is placed into filtration mode when power is restored by the diesel generators. Waste handling and related operations cease upon loss of utility power.

In case of a loss of utility power, backup power to predetermined loads can be supplied by either of the two on-site diesel generators. These units provide 480 volt (V) power with a high degree of reliability and are sized to feed the selected loads. Each of the diesel generators can carry all preselected monitoring loads plus operation of the Air Intake Shaft hoist for personnel evacuation and other selected backup loads in accordance with WIPP facility procedures in WP 04-NO, WIPP Facility Operations Normal Operations Procedures Manual (Westinghouse, 1991b). The diesel generators can be brought on line within 30 minutes.

Upon loss of normal power, the diesel generators are manually started from the local control panel or from the CMR. The starter system is a 24-V battery system with a 300-ampere-hour capacity. Although it is standard practice to start the diesel generators from the local control panel, each unit can be remotely started from the CMR when the generator start switch is left in the "remote" position. The diesel generators and associated breakers can be monitored in the CMR, thus providing the ability to feed selected facility loads from the backup power source, in sequence, without exceeding generator capacity. The on-site fuel storage capacity is sufficient for the operation of one generator at an expected load of 62 percent for three days. Additional fuel supplies are readily available within a few hours by tank truck, allowing on-line refueling and continued operation.

There is a central UPS, located in the Support Building, that supplies power to predetermined equipment located in the Support Building and WHB. The central UPS provides power to radiation monitoring, local processing units, and communications in the Support Building and WHB and to the central monitoring system, including the computer, located in the Support Building. In addition, individual UPSs supply transient-free power to strategically located local processing units for the Radiation Monitoring System on the surface, and in underground areas.

In case of loss of AC power input to the UPSs, the dedicated batteries can supply power to a fully loaded UPS for 30 minutes. It is expected that the AC power input to the UPS will be restored ✓ within 30 minutes via operator action. The CMR is connected to the UPS.

F-4e Personnel Protection

The following description of procedures, structures, or equipment used at the facility to prevent ✓ undue exposure of personnel to hazardous waste is required by HWMR-6, Pt. IX, sec. 270.14(b)(8)(v).

Procedures used at the WIPP facility to prevent undue exposure of personnel to hazardous waste and the sections in this permit application where these procedures are discussed in detail are listed below.

- The WAC are procedures designed to prevent the shipment (see Section C-3) or acceptance (see Sections C-6, D-9a[2][b] and D-9e[3]) of waste exhibiting the characteristics of ignitability, corrosivity, or reactivity. Section F-5 contains a general discussion of the prevention of the reaction of ignitable, reactive, and incompatible wastes.

- Administrative controls to prevent the addition of materials to the waste that could exhibit the characteristics of incompatibility, reactivity, and ignitability are discussed in Sections F-5 and D-8a(2)(a).

- ✓ ✓ Waste handling operations are conducted so that the need for waste handling personnel to touch the waste containers during unloading and emplacement operations, overpacking, repair, or retrieval (if necessary) is minimized. See a discussion of waste handling operations in Sections D-9a(2)(b) and D-9a(3)(f).1b and secondary containment in Section D-9a(3)(f).1c.

- ✓ Lockout/tagout and work authorization procedures, discussed in Section F-2, prohibit WIPP facility personnel from utilizing waste handling equipment that is temporarily out-of-service, prevent inappropriate use of waste-handling equipment that is not operational for all uses, and provide safety instructions for conducting nonroutine operations on the equipment.

- A system for monitoring and inspecting monitoring equipment, safety and emergency systems, security devices, and operating and structural equipment is in place to prevent, detect, or respond to environmental or human health hazards caused by hazardous materials. The inspection/monitoring requirements are described in Section F-2a.

- Adequate aisle space is maintained for emergency response purposes, as discussed in Section F-3b.

- Internal pressure in the experimental bins will be monitored throughout the bin-scale tests (Section D-9a[2][b]).

- Procedures to protect personnel from hazardous and/or mixed waste during nonroutine events are detailed in the Contingency Plan, Chapter G.

Structures and equipment at the WIPP facility to prevent undue exposure of personnel to hazardous waste and hazardous constituents and the sections in this permit application where these structures and equipment are discussed in detail are listed below.

- The WIPP facility was sited and designed to be protective of human health and ensure safe operations during the Test Phase (Sections D-9a[3], D-9a[3][b], D-9a[3][d], and D-9a[3][e]).

- Waste containers are required to meet shipping/structural requirements (D-9a[3][f].1a).

- The TRUPACT-II, forklifts, unloading dock, crane, facility pallets, conveyance loading car, waste hoist cage, and underground waste transporter were designed or selected for use in order to minimize the need for waste handling personnel to come into contact with waste. Each of these items is discussed in detail in Section D-9a(3)(c); Section F-4a discusses prevention of hazards to personnel during unloading operations.

- The hood ventilation system, used during the initial opening of the TRUPACT-II shipping container and SWB and in the laboratory, is used to vent any potential release of VOCs into the ventilation system of the Waste Handling Building (Section D-9a[3][b]).

- The carbon sorption system in the underground, discussed in detail in Sections D-9d(3) and D-9e(1) and Appendix D12, is designed to remove a minimum of 95 percent of the VOCs released from the bin test rooms. Section D-9d(3) explains that the remaining emissions are at a level where adverse effects on human health are not predicted.

- The WIPP facility has internal and external communications and alarm systems to notify personnel of emergency situations and provide instructions for response, evacuation, etc. (Section F-3a and Section G-5).

- The WIPP facility is well-equipped with spill-response equipment, transport vehicles, emergency medical equipment and rescue vehicles, fire detection, fire-suppression and fire-fighting equipment (including water for fire control), personnel protection equipment, emergency lighting and backup power, and showers and eye wash fountains. These are discussed in Sections F-3a, F-4c, F-4d, and F-4e and listed in Section G-5.

- The surface and underground ventilation systems, discussed in Sections D-9a(3)(b), D-9a(3)(d), and G-5 are designed to provide personnel with a suitable environment during routine operations.

F-4f Releases to Atmosphere

The following description of procedures, structures, or equipment used at the facility to prevent releases to the atmosphere is required by HWMR-6, Pt. IX, sec. 270.14(b)(8)(vi).

✓ Lead and other heavy metals (presumed to have the characteristic of toxicity) may be present in some waste forms. Metal in the waste, most of which is lead in monolithic form, is present in bricks and shielding rather than in particulate form (DOE, 1990b). The primary sources of other metals are sheets, rods, parts of equipment, or solidified sludges. Since all waste will be containerized and waste container vents employ particulate filters, there will be no potential releases of particulate metals to the atmosphere.

A release of hazardous waste or hazardous constituents to the air that may have adverse effects on human health or the environment is unlikely. Although VOCs could be present in the waste emplaced within the unit and could potentially be a source of release to the air, provisions have been made to control such emissions to prevent any adverse effects to human or environmental receptors.

See Section D-9e(1) and Appendix D12 for more detailed information on the VOC monitoring program (including the carbon sorption system) and Section D-8d(3) for a discussion of protection of the atmosphere, including performance standards, air emissions controls, health risk evaluation, releases of hazardous waste or hazardous constituents from the miscellaneous unit, and potential for health risks.

F-5 Prevention of Reaction of Ignitable, Reactive, and Incompatible Waste

✓ HWMR-6, Pt. IX, sec. 270.14(b)(9), requires a description of precautions taken to prevent accidental ignition or reaction of ignitable, reactive, or incompatible waste as required to
✓ demonstrate compliance with HWMR-6, Pt. IX, sec. 270.15(c), and HWMR-6, Pt. V, sec. 264.17.
✓ Because the experimental waste (including the container) received at the site during the Test

Phase, and any waste (including its container) that may be created as a result of handling the waste or from the experiments (derived waste), has been demonstrated to be compatible and does not exhibit the characteristics of ignitability, reactivity, or corrosivity, the WIPP facility is in full compliance with these regulations. Sections F-5a, F-5b, F-5c, and F-5d describe that HWMR-6, Pt. V, secs. 264.17(a) and (b), HWMR-6, Pt. IX, secs. 270.15(c) and (d), and HWMR-6, Pt. V, secs. 264.176 and 264.177, are not applicable to the WIPP facility.

F-5a Precautions to Prevent Ignition or Reaction of Ignitable or Reactive Waste

The mixed waste (including the container) received at the WIPP facility will not exhibit characteristics of ignitability, corrosivity, or reactivity. In addition, administrative procedures will prevent the introduction of materials into the waste that would cause the derived waste (including its container) to exhibit these characteristics. Therefore, there are no precautions specific to preventing the ignition or reaction of ignitable or reactive waste, and HWMR-6, Pt. V, sec. 264.17(a), is not applicable to the WIPP facility.

F-5b General Precautions for Handling Ignitable or Reactive Waste and Mixing of Incompatible Waste

The mixed waste (including the container) at the WIPP facility will not exhibit characteristics of ignitability, corrosivity, or reactivity. Section C-3, Boundary Conditions and Process Tolerance Limits, and Section C-6, Waste Shipment Screening and Verification, discuss the criteria and procedures used to preclude the shipping or acceptance of waste that exhibits these characteristics. Administrative procedures will prevent the introduction of materials into the waste that would cause it to exhibit these characteristics. Therefore, derived waste (including its container) also will not exhibit these characteristics. The addition of brine to the experimental waste does not affect exhibition of the characteristics of ignitability, corrosivity, or reactivity.

There will be no mixing of incompatible waste or mixing of incompatible waste with other materials. Compounds found within the waste are classified as "incompatible" if the potential for a reaction exists that might result in an explosion, heat generation, gas generation, pressure buildup, or the generation of toxic byproducts. Because the WIPP facility will not accept any waste form that is incompatible, only those physical waste forms described in Section C-2, Identification of Waste to be Managed, will be accepted. Only DOT 7A Type A containers are allowed within the miscellaneous unit. Further information on compatibility is in Section C-3a, Facility-Established Boundary Conditions and Process Tolerance Limits. In addition, the concentration of VOCs in experimental and derived waste container headspace and flammability potential of experimental and derived waste container headspace will not exceed boundary conditions discussed in Section C-3b, EPA-Established Boundary Conditions.

✓ Therefore, there is no treatment, storage, or disposal of waste exhibiting the characteristics of ignitability, corrosivity, or reactivity and no mixing of incompatible waste or materials, and HWMR-6, Pt. V, sec. 264.17(b), is not applicable to the WIPP facility.

F-5c Management of Ignitable or Reactive Waste in Containers

✓ Mixed and derived waste (including the containers) do not exhibit the characteristics of ignitability, corrosivity, or reactivity. Therefore, HWMR-6, Pt. IX, sec. 270.15(c), and HWMR-6, Pt. V, sec. 264.176, are not applicable to the WIPP facility. Although the regulations containing storage distances are not applicable at the WIPP facility, all waste containers at the WIPP facility are handled, transported, and emplaced within the Radioactive Materials Area, which is more than 15 meters (50 feet) from the WIPP facility boundary.

F-5d Management of Incompatible Waste in Containers

✓ No chemical incompatibilities will exist in waste (including the container) arriving at the WIPP facility, and no material will be added to the waste for experimental or cleanup purposes that are incompatible with the waste. Therefore, HWMR-6, Pt. IX, sec. 270.15(c), and HWMR-6, Pt. V, sec. 264.177, are not applicable to the WIPP facility.

As a result, no procedures are needed to prevent incompatible waste and materials from being placed in the same container or for having waste placed in an unwashed container that previously held an incompatible waste or material. Containers for derived waste and overpacking are the ✓ same as those approved to transport the mixed waste to the site -- SWBs or other approved ✓ containers such as 55-gallon drums.

Because incompatible waste will not be handled or emplaced in the miscellaneous unit, dikes, ✓ berms, walls, or similar barriers are not needed to separate waste types. Therefore, HWMR-6, Pt. V, sec. 264.177(c), does not apply to the WIPP facility.

F-5e Management of Ignitable or Reactive Waste in Tank Systems

The WIPP facility does not manage hazardous or mixed waste using a tank system as defined ✓ in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart J. Tank system regulations are not applicable to the WIPP facility.

F-5f Management of Incompatible Waste in Tank Systems

The WIPP facility does not manage hazardous or mixed waste using a tank system as defined ✓ in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart J. Tank system regulations are not applicable to the WIPP facility.

F-5g Management of Ignitable or Reactive Waste in Waste Piles

The WIPP facility does not manage hazardous or mixed waste using a waste pile as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart L. Waste pile regulations are not applicable to the WIPP facility.

F-5h Management of Incompatible Waste in Waste Piles

The WIPP facility does not manage hazardous or mixed waste using a waste pile as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart L. Waste pile regulations are not applicable to the WIPP facility.

F-5i Management of Ignitable or Reactive Waste in Surface Impoundments

The WIPP facility does not manage hazardous or mixed waste using a surface impoundment as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart K. Surface impoundment regulations are not applicable to the WIPP facility.

F-5j Management of Incompatible Waste in Surface Impoundments

The WIPP facility does not manage hazardous or mixed waste using a surface impoundment as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart K. Surface impoundment regulations are not applicable to the WIPP facility.

F-5k Management of Ignitable or Reactive Waste in Landfills

The WIPP facility does not manage hazardous or mixed waste using a landfill as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart N. Landfill regulations are not applicable to the WIPP facility.

F-5l Management of Incompatible Waste in Landfills

The WIPP facility does not manage hazardous or mixed waste using a landfill as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart N. Landfill regulations are not applicable to the WIPP facility.

F-5m Management of Ignitable or Reactive Waste in Land Treatment Units

The WIPP facility does not manage hazardous or mixed waste using land treatment as defined
√ in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart M. Land treatment
regulations are not applicable to the WIPP facility.

F-5n Management of Incompatible Waste in Land Treatment Units

The WIPP facility does not manage hazardous or mixed waste using land treatment as defined
√ in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart M. Land treatment
regulations are not applicable to the WIPP facility.

F-5o Management of Ignitable or Reactive Waste on Drip Pads

The WIPP facility does not manage hazardous or mixed waste using drip pads as defined in
HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart W. Drip pad
regulations are not applicable to the WIPP facility.

F-5p Management of Incompatible Waste on Drip Pads

√ The WIPP facility does not manage hazardous or mixed wastes using drip pads, as defined in
√ HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart W. Drip pad
√ regulations are not applicable to the WIPP facility.

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TABLE

TABLE F-1
INSPECTION/MONITORING SCHEDULE

System/Equipment Name	Inspection/ Monitoring Frequency	Manual(s)
Air Intake Shaft	weekly	WP 04-2, Mining Operations Manual (Westinghouse, 1991a)
Air Intake Shaft Hoist	preoperational[1]	WP 04-2
Ambulances	weekly	WP 12-1, WIPP Safety Manual (Westinghouse, 1992c)
Adjustable Center of Gravity Lift Fixture	preoperational	WP 05-1, Waste Handling Operations Manual (Westinghouse, 1991c)
Backup Diesel Generators - Operational Safety Requirement (OSR)	monthly	WP 04-7, WIPP Operational Safety Requirements Administrative Plan (Westinghouse, 1991d)
Bin-Scale Test Room Volatile Organic Compound (VOC) Monitoring and Carbon Sorption Bed Equipment Inspection	daily/weekly[2]	WP 12-VC, WIPP VOC Operating Procedures Manual (Westinghouse, 1991e)
Contact-Handled (CH) Underground Transporter	preoperational	WP 05-1
Conveyance Loading Car	preoperational	WP 05-1
Dry Chemical Fire Suppression System	semiannually	WP 04-AD, Waste Isolation Pilot Plant Operations Administration Manual (Westinghouse, 1992d)
Eye Washes	monthly	WP 12-1
Facility Pallet	preoperational	WP 05-1
Fire Detection and Alarm System - OSR	semiannually	WP 04-AD
Fire Extinguishers	monthly	WP 12-1
Fire Hoses	annually	WP 12-1
Fire Hydrants	quarterly	WP 12-1
Fire Pumps	weekly, annually	WP 12-1
Fire Sprinkler Systems - OSR	quarterly	WP 04-AD
Fire Trucks	weekly	WP 12-1
Flood Showers	monthly	WP 12-1

1 "Preoperational" signifies that inspections are required prior to the first use during a calendar day. For calendar days in which the equipment is not in use, no inspections are required.

2 Initially, bin-scale test room VOC monitoring and equipment inspection will be performed daily; frequency may be reduced to weekly when statistical standards are met.

TABLE F-1
INSPECTION/MONITORING SCHEDULE
(CONTINUED)

System/Equipment Name	Inspection/ Monitoring Frequency	Manual(s)
Forklifts Used for Waste Handling	preoperational	WP 05-1
Mine Pager Phones (underground to surface)	quarterly	WP 04-2
√ √ √ Non-First Aid Medical Supplies (not otherwise contained in emergency vehicles)	monthly	WP 12-2, WIPP Occupational Health Manual (Westinghouse, 1990)
√ Pagers (Emergency Response Personnel)	monthly	WP 12-1
√ Panel 1 Rooms Containing Waste	weekly	WP 05-1
√ √ Perimeter Fence, Gates, Signs	monthly	WP 11-2, Security Plan (Westinghouse, 1989)
√ √ Personnel Protective Equipment (not otherwise contained in emergency vehicles or issued to individuals):		WP 12-1 and WP 12-8, Industrial Hygiene Procedures Manual (Westinghouse, 1991f):
√ --negative pressure respirator	monthly	WP 12-8
√ --positive pressure respirator	monthly	WP 12-8
√ --Self-Contained Breathing Apparatus (SCBA)	monthly	WP 12-1
√ Public Address and Intercom System	monthly	WP 04-AD
√ Radios (2-way; used by Emergency Response and Security Personnel)	weekly	WP 12-1
√ Rescue Truck	weekly	WP 12-1
Salt Handling Shaft	weekly	WP 04-2
Salt Handling Shaft Hoist	preoperational	WP 04-2
Self-Rescuers	quarterly	WP 12-1
√ √ √ √ √ Spill Control Equipment	weekly	WP 02-6 and WP 02-7, WIPP Resource Conservation and Recovery Act (RCRA) Compliance Manual (Westinghouse, 1992b)
√ √ Surface CH TRU Waste Handling Area and Radiological Control Area (RCA)	postoperational[3]	WP 05-1
√ Underground Openings	monthly	WP 04-2

[3] "Postoperational" signifies that inspections are required after the last use during a calendar day. For calendar days in which the equipment is not in use, no inspections are required.

TABLE F-1
INSPECTION/MONITORING SCHEDULE
(CONTINUED)

System/Equipment Name	Inspection/ Monitoring Frequency	Manual(s)
√ √ √ Ventilation Exhaust Fan Flow Check[4]	quarterly	Preventive Maintenance Instructions (Westinghouse, 1991g)
√ VOC Samplers	quarterly	WP 12-VC
Waste Handling Cranes	preoperational	WP 05-1
Waste Handling Shaft	weekly	WP 04-2
Waste Handling Shaft Hoist	preoperational	WP 04-2
√ Water Tank Level	daily	WP 04-3

√ [4] This flow check is in accordance with the EPA's Conditional No-Migration Determination (EPA, 1990).

FIGURES

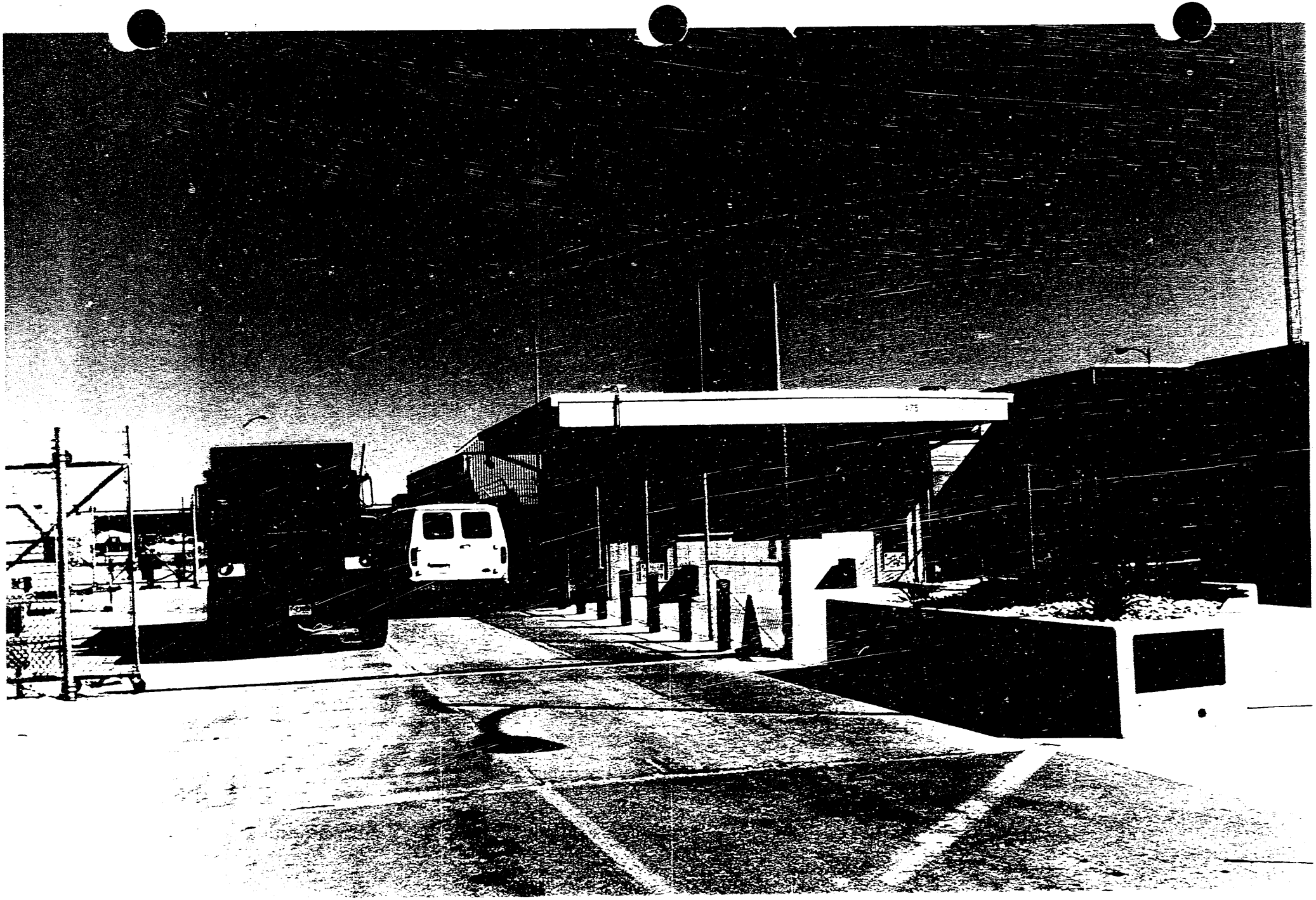

FIGURE F-1 WIPP SECURITY GATE AND GUARD AND SECURITY BUILDING

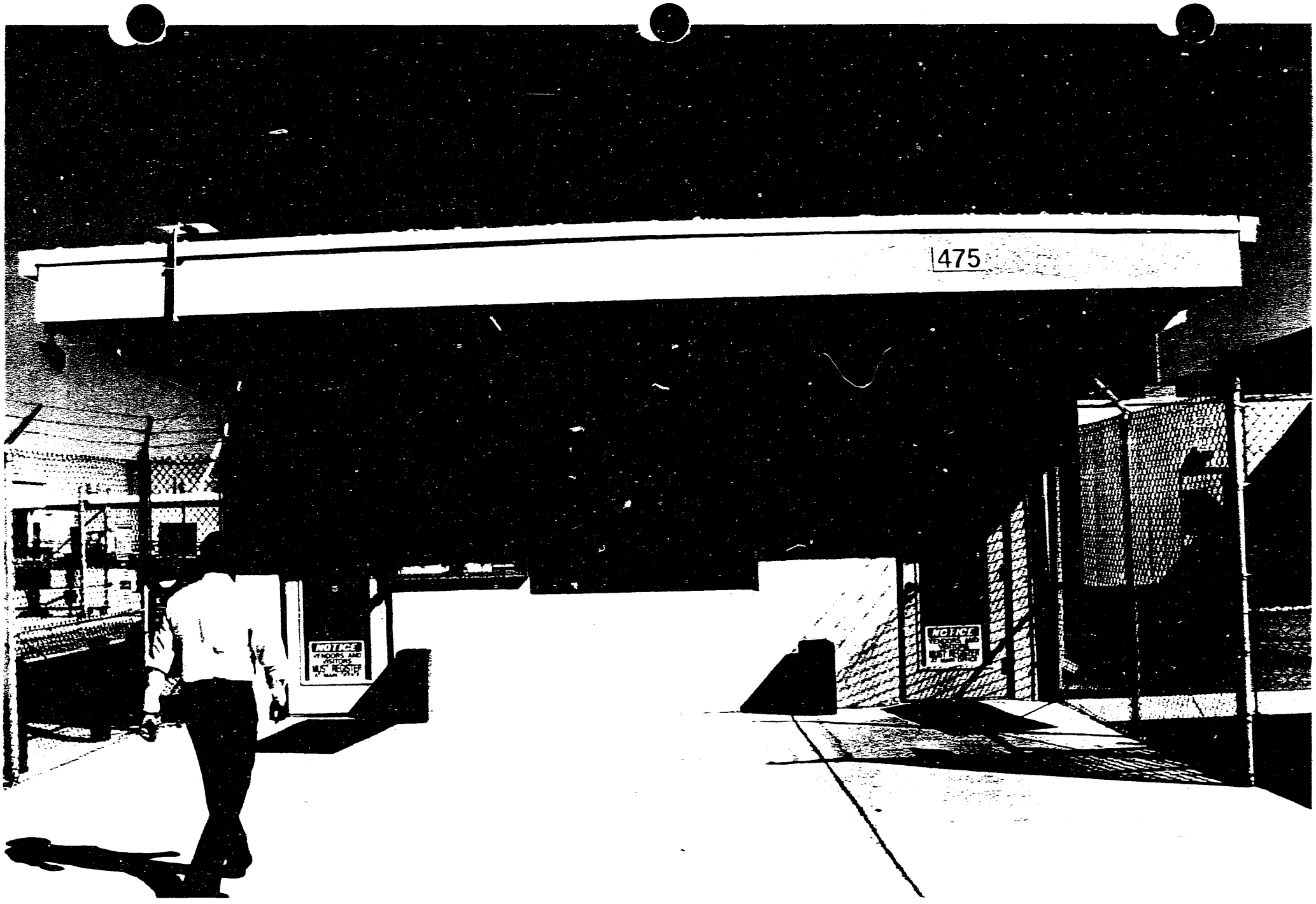

FIGURE F-2 WIPP GUARD AND SECURITY BUILDING

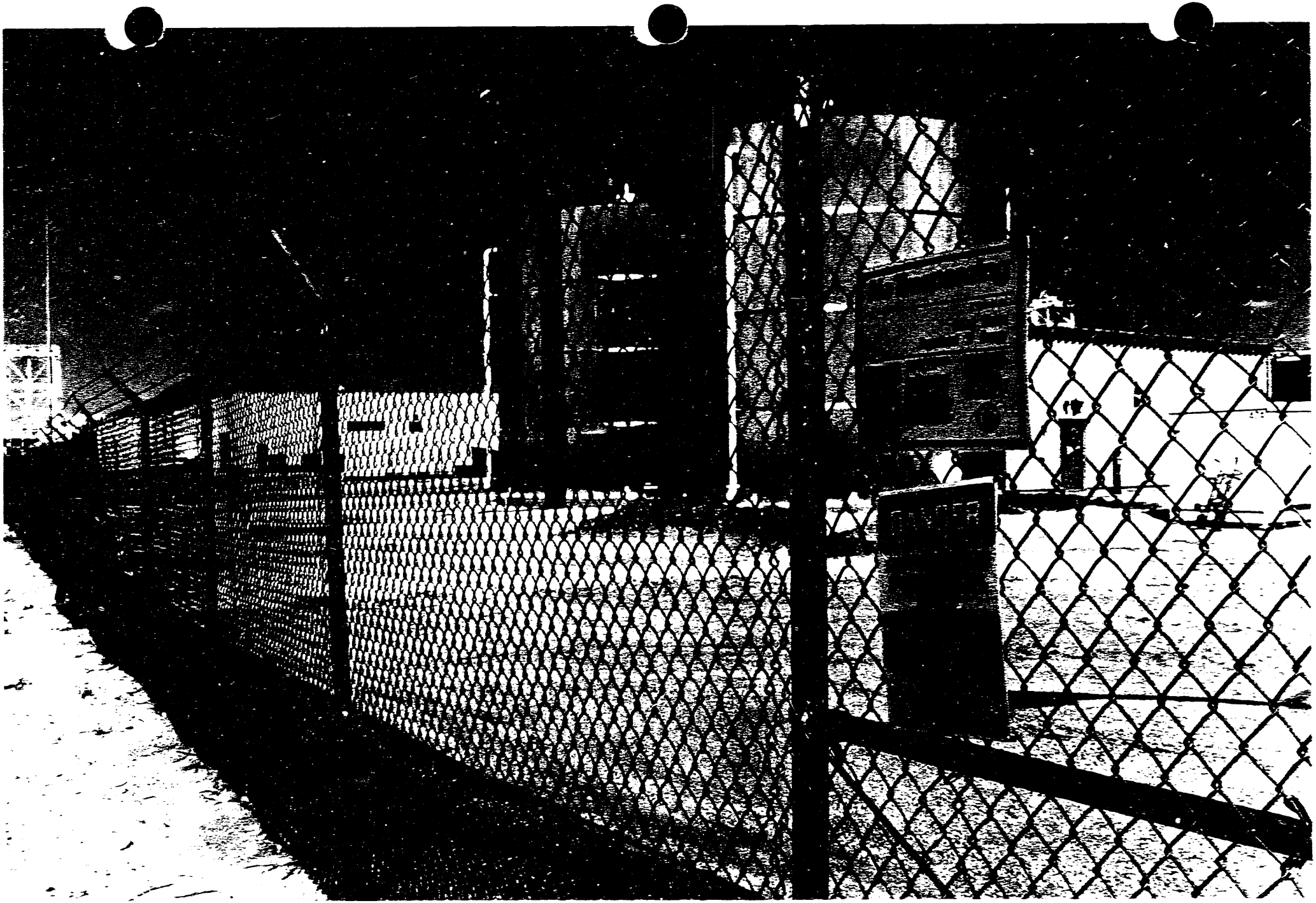

FIGURE F-3 WARNING SIGNS ON SECURED AREA FENCE. PAIR OF 180,000-GALLON WATER STORAGE TANKS IN BACKGROUND

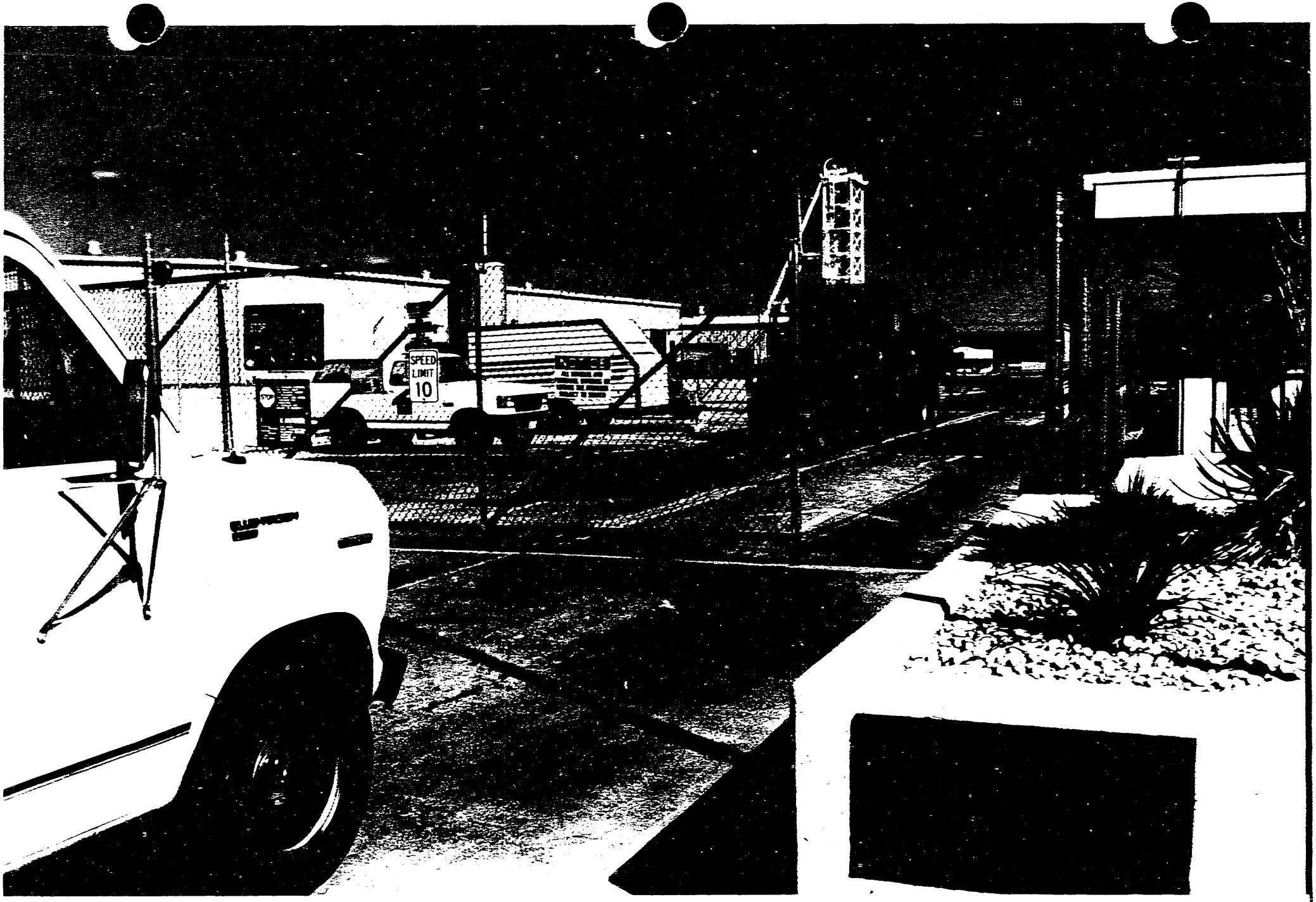

FIGURE F-4 WIPP SECURITY GATE

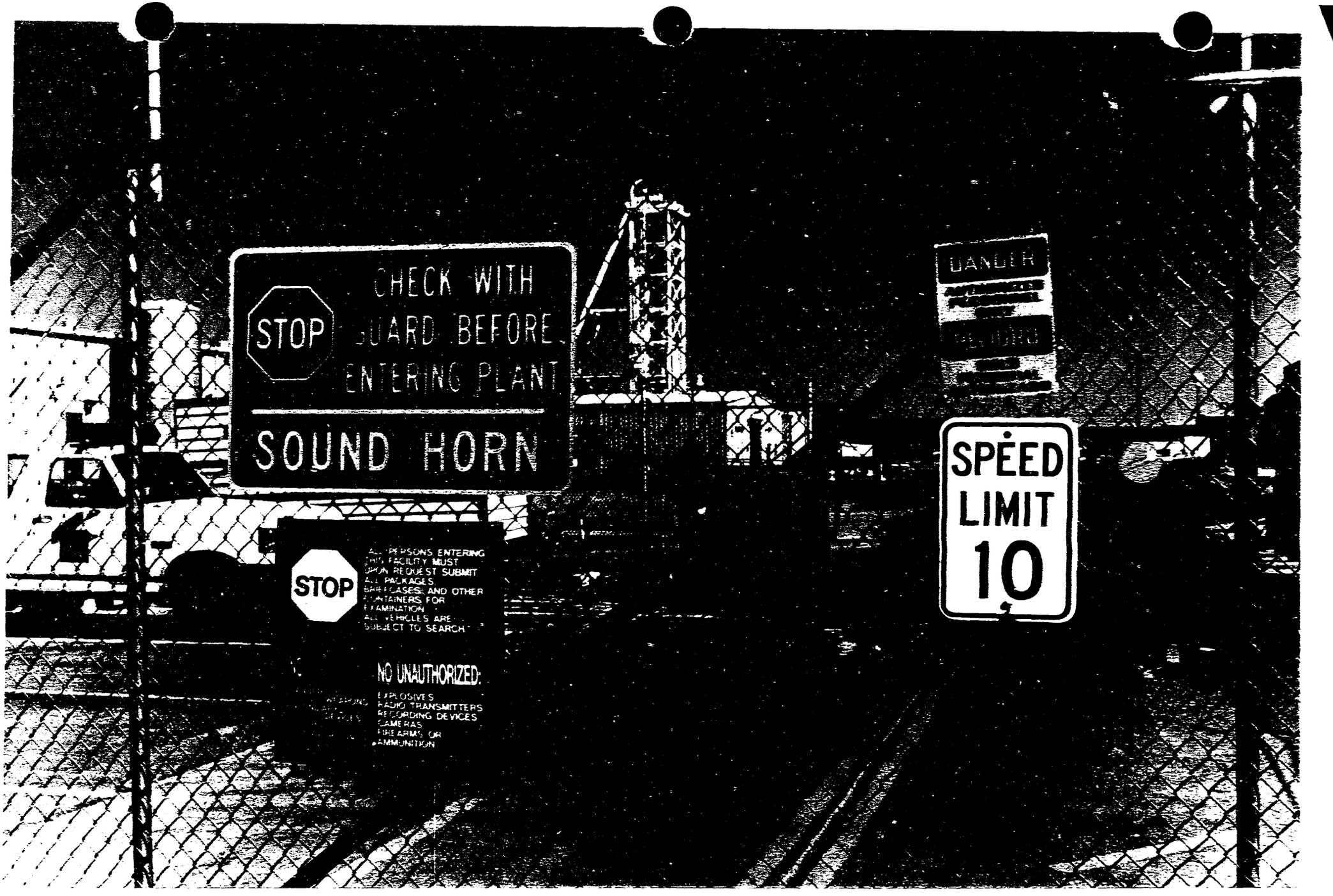

FIGURE F-5 WARNING SIGNS ON WIPP SECURITY GATE

RCRA CONTINGENCY PLAN
Waste Isolation Pilot Plant

March 1992

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RCRA CONTINGENCY PLAN
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CHAPTER G
RCRA CONTINGENCY PLAN

Introduction

The Waste Isolation Pilot Plant (WIPP) Project was authorized by the Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980 (Public Law 96-164) as a research and development facility to demonstrate the safe, environmentally sound disposal of transuranic (TRU) radioactive wastes derived from the defense activities of the United States (U.S). The WIPP facility is owned and operated by the U.S. Department of Energy (DOE). The TRU waste to be received at the WIPP facility consists largely of such items as laboratory glassware and utensils, tools, scrap metal, shielding, personnel protection equipment, and solidified sludges from the treatment of waste water. Approximately 60 percent of this waste is "mixed," that is, it is also contaminated with hazardous waste or hazardous constituents as defined by the Resource Conservation and Recovery Act (RCRA) and by the New Mexico Hazardous Waste Management Regulations (HWMR-6), Part II, Subparts C and D. Therefore, emplacement of TRU mixed waste in the WIPP repository is subject to regulation under HWMR-6 and RCRA. This Contingency Plan is prepared in accordance with the requirements of RCRA stated in HWMR-6, Pt. V, Subpart D, Contingency Plan and Emergency Procedures.

In addition to HWMR-6 and RCRA contingency plan requirements, WIPP facility emergency planning and notification are subject to DOE Order 5000.3A, Occurrence Reporting and Processing of Operations Information (DOE, 1990a); DOE Order 5500.1A, Emergency Management System, (DOE, 1990b); DOE Order 5500.2A, Emergency Notification, Reporting, and Response Levels (DOE, 1990c); and DOE Order 5500.3A, Emergency Planning and Preparedness for Operational Emergencies (DOE, 1990d). DOE Orders for a non-reactor facility specify emergency personnel and reporting requirements that differ from, but do not conflict with, RCRA requirements. Development of WIPP facility emergency planning and notification to satisfy DOE Orders augments the planning needed to comply with RCRA. The RCRA Contingency Plan is an integral part of the overall WIPP facility emergency plan.

G-1 General Information

The WIPP facility is located 26 miles east of Carlsbad in Eddy County in southeastern New Mexico and includes an area of 10,240 acres. The facility is located in an area of low population density with fewer than 30 permanent residents living within a 10-mile radius of the facility. The area surrounding the facility is used primarily for grazing, potash mining, and mineral exploration. As a result of land use restrictions imposed by the U.S. Bureau of Land Management (BLM) and administrative action by DOE to purchase lease holdings, no resource development that would affect WIPP facility operations or the long-term integrity of the facility is allowed within the 10,240 acres that have been set aside for the WIPP Project.

The WIPP facility is designed to receive containerized TRU and TRU mixed waste which are transported to the WIPP facility from ten DOE generator and storage sites in the U.S. The waste will be emplaced in bedded salt of the Salado Formation 2,150 feet below ground surface. Details of the project and its mission can be found in Public Law 96-164, the Final Environmental Impact Statement (DOE, 1980), the WIPP Final Safety Analysis Report (DOE, 1990e), and the WIPP Final Supplement Environmental Impact Statement (DOE, 1990f).

As a geologic repository for the management of mixed waste, the WIPP repository is regulated as a "miscellaneous unit" as defined under HWMR-6, Pt. V, Subpart X. The miscellaneous unit at the WIPP facility subject to RCRA regulation is the entire area below ground defined by the upper and lower extent of the Salado Formation, and the lateral projection of the 16-square-mile land withdrawal boundary.

On the surface, in the Waste Handling Building (WHB) area, waste will be received, unloaded from Transuranic Package Transporter (TRUPACT-II) shipping containers, inspected, and moved to the Waste Shaft for transfer underground. Figure G-1 shows the WIPP facility surface structures. The surface facilities that support the WHB include an outdoor truck loading and off-loading area, a TRUPACT-II handling area where TRUPACT-IIs are opened and waste containers removed, an inventory and preparation area, an overpack and repair room, and the cage loading area where waste is loaded onto the waste hoist for transport underground through the Waste Shaft. Four shafts connect the underground area with the surface (Figure G-2). The Waste Shaft is located within the WHB.

The WIPP facility includes other surface structures, shafts, and underground areas (Figures G-1, G-2, and G-3). Surface structures accommodate the personnel, equipment, and support services required for the receipt, preparation, and transfer of mixed waste from the surface to the underground. In addition to the WHB, these structures consist of warehouses, the Exhaust Filter Building, and several support buildings.

The WIPP facility is designed to handle 500,000 cubic feet per year of contact-handled and 10,000 cubic feet per year of remote-handled TRU and mixed waste. The operational life of the facility is 25 years. The initial operations at the WIPP facility will involve a Test Phase during which experiments will be conducted using contact-handled TRU and mixed waste. The Test Phase will support a performance assessment activity that is being carried out by the scientific advisor to the WIPP Project to determine the long-term isolation capabilities of the facility. The Test Phase is expected to last approximately five years. Depending on the results of the performance assessment which is supported by data collected during the Test Phase, DOE will make a decision to retrieve wastes emplaced for testing and close the WIPP facility; to modify the waste form or engineered designs of the WIPP facility; or to continue on to the Operations Phase, based on the ability of the WIPP facility to comply with 40 CFR Part 191, Subpart B, and HWMR-6, Pt. IX, section 268.6. A RCRA Part B permit is sought only for Test Phase waste management activities in the miscellaneous unit.

The provisions of this Contingency Plan apply to the miscellaneous unit, the Waste Shaft, the WHB, and supporting mixed waste handling areas. The remainder of the facility will not handle mixed waste and is not subject to the permitting requirements of RCRA; however, hazardous substances, hazardous materials, and hazardous wastes resulting from the use of these materials at the WIPP facility are present. These materials include:

- Hazardous Substances: As defined by the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA) means: any substance designated pursuant to Section 311(b)(2)(A) of the Clean Water Act (CWA); any element, compound, mixture, solution, or substance designated pursuant to Section 102 of CERCLA; any hazardous waste having the characteristics identified under or listed pursuant to Section 3001 of the Solid Waste Disposal Act (but not including any waste the regulation of which under the Solid Waste Disposal Act has been suspended by an Act of Congress); any toxic pollutant listed under Section 307(a) of the CWA; any hazardous air pollutant listed under Section 112 of the CAA; and any imminently hazardous chemical substance or mixture with respect to which the U.S. Environmental Protection Agency (EPA) Administrator has taken action pursuant to Section 7 of the Toxic Substances Control Act. The term does not include petroleum, including crude oil or any fraction thereof, which is not otherwise specifically listed or designated as a hazardous substance, and the term does not include natural gas, natural gas liquids, liquified natural gas, or synthetic gas usable for fuel (or mixtures of natural gas and such synthetic gas). As defined by the New Mexico Emergency Management Act, means: flammable solids, semi-solids, liquids or gases, poisons, corrosives, explosives, compressed gases, reactive or toxic chemicals, irritants or biological agents, but does not include radioactive materials.

- Hazardous Materials: As defined by the New Mexico Emergency Management Act means: hazardous substances, radioactive materials, or a combination of hazardous substances and radioactive materials.

CERCLA applies to the release of any substance listed in Table 302.4 of 40 CFR Part 302 and to any site where such substances are deposited, stored, disposed, or placed, including buildings and structures. At the WIPP facility, these substances may be in the TRU waste handled as part of the experimental program, as well as substances used or stored at the site in support areas of the facility. Spills and releases of hazardous substances and materials outside the miscellaneous unit will also be responded to in a responsible manner. Therefore, while this Plan applies directly to the miscellaneous unit and supporting mixed waste handling areas, it also serves as the single, facility-wide Contingency Plan.

G-2 Emergency Coordinators

Persons qualified to act as the Emergency Coordinator (primary and alternates), as required by HWMR-6, Pt. V, sec. 264.55, are listed below:

EMERGENCY COORDINATORS

PRIMARY				
NAME	ADDRESS*	OFFICE PHONE	HOME PHONE*	PAGER NUMBER**
John Lee, Assistant General Manager, Operations		(505) 887-8206		117
ALTERNATES				
Harry Bibby, Deputy Manager, Operations		(505) 887-8266		103
Les L. Reed, Manager, Environment, Safety, and Health		(505) 887-8489 Mobile phone: (505) 887-9443		165

*NOTE: Home addresses and phone numbers are proprietary and should not be released beyond the regulatory and emergency personnel.

**NOTE: To reach pager numbers, WIPP Security is called at 887-8324.

The Emergency Coordinator is equivalent to the WIPP facility Crisis Manager. The on-call Emergency Coordinator will be on the premises or on-call (i.e., available to respond to the emergency by reaching the facility within a short period of time) 24 hours a day, seven days a week, with the responsibility for coordinating all emergency response measures. The identity and means to reach the on-call Emergency Coordinator is maintained on a site call-out list maintained in several locations at the WIPP site, including the Central Monitoring Room (CMR) and WIPP Security, and by several individuals in the emergency notification chain (Section G-4, below). This call-out list is revised weekly to reflect assignment changes.

The named Emergency Coordinators are thoroughly familiar with the WIPP Contingency Plan, mixed waste and hazardous waste operations and activities at the WIPP facility, the locations of mixed waste and hazardous waste activities, locations on the site where hazardous materials are stored and used, and locations of waste staging and accumulation areas. They are familiar with the characteristics of mixed waste and hazardous waste handled at the WIPP facility, the location of mixed waste and hazardous waste records within the WIPP facility, and the facility layout. In

addition, the named Emergency Coordinators have the authority to commit the necessary resources to implement this Contingency Plan.

G-3 Implementation

The provisions of this Contingency Plan will be implemented immediately whenever there is an emergency event such as a fire, explosion, or release of hazardous waste or hazardous constituents in the miscellaneous unit as defined in Chapter B or waste handling areas that could threaten human health or the environment, or when the potential for such an event exists, as required under HWMR-6, Pt. V, sec. 264.51(b). Section G-4 describes the provisions of the Contingency Plan that facility personnel will take in the event of a fire, explosion, or any unplanned sudden or non-sudden release of hazardous material to the air, soil, surface water, or ground water at the WIPP facility; within the miscellaneous unit and waste handling area; and the support areas where other hazardous materials may be used or stored. The implementation of the Plan, in the course of communicating emergencies, is described in Section G-4a, Notification, below.

G-4 Emergency Response Methods

Methods that describe how and when the WIPP Contingency Plan will be implemented cover eleven implementation areas. These are:

(1) Notification (Section G-4a)

- Initial emergency response and alerting of the on-call Emergency Coordinator.
- Communication of the emergency conditions to facility employees.
- Notification of local, state, and federal authorities.
- Notification of the general public.

(2) Identification of hazardous materials (Section G-4b).

(3) Assessment of the nature and extent of the emergency (Section G-4c).

(4) Control, containment, and correction of the emergency (Section G-4d).

(5) Prevention of recurrence or spread of fires, explosions, or releases (Section G-4e).

(6) Storage and treatment of released material and waste (Section G-4f).

(7) Incompatible waste (Section G-4g).

(8) Postemergency facility and equipment, maintenance, and reporting (Section G-4h).

(9) Container spills and leakage (Section G-4i).

(10) Tank spills and leakage (Section G-4j).

(11) Surface impoundment spills and leakage (Section G-4k).

G-4a Notification

Notification requirements in the event of an emergency at a RCRA hazardous waste management facility are defined by HWMR-6, Pt. V, secs. 264.56(a) and (d). Methods to provide all needed notifications in case of an emergency at the WIPP facility are described in this section. The notification procedure meets the requirements of DOE Order 5000.3A (DOE, 1990a). Emergency notification described below is in accordance with WIPP emergency procedures contained in WP 12-9, Emergency Plan and Procedures (Westinghouse, 1992a). All facility personnel are trained in emergency notification procedures.

Initial Emergency Response and Alerting the On-Call Emergency Coordinator

All on-site emergencies will be reported immediately to the CMR Operator at extension 8111. All notifications shall include the following information as appropriate:

- Name and telephone number of the caller
- Location of the incident and the caller
- Time and type of incident
- Severity of the incident
- Magnitude of the incident
- Cause of the incident
- Assistance needed to deal with or control the incident
- Areas or personnel affected by the incident.

In addition to receiving the incident phone reports, the CMR Operator, who is located in the Support Building, Building 451 (Figure G-1), continuously monitors alarm status. These alarms indicate an abnormal mechanical, electrical, and/or radiological condition at selected points on the site both above and below ground. Alarms and fire suppression equipment are located throughout the WIPP facility. The alarm(s) may be the first notification of an emergency situation received by the CMR Operator. As a communications center, the CMR is effective in monitoring incoming alarms, telephone calls, and radio messages, and is a center for initiating outgoing calls to emergency staff and outside agencies.

Once the CMR Operator is notified of a fire, explosion, or uncontrolled release anywhere in the facility (by either an eye witness or an alarm), the Operator will proceed to notify emergency personnel and report the receipt of the call to WIPP Security. In addition the CMR Operator may use the public address (PA) system to notify emergency response teams (below). The CMR Operator reports the situation to the Facility Operations Shift Supervisor (FOSS). WIPP Security, using pagers and, if needed, telephones, is also able to notify emergency response personnel. WIPP Security maintains a call-out list containing key instructions, and the identities, phone numbers, and pager numbers of on-call emergency response personnel. The call-out list is updated weekly.

If the emergency is above ground, the CMR Operator or WIPP Security will notify the Emergency Response Team (ERT). If the emergency is below ground, the CMR Operator or WIPP Security will notify the underground supervisor and the First Line Initial Response Team (FLIRT). Means to communicate with on-site emergency response personnel are maintained in the CMR and at WIPP Security at all times.

✓ The response to an unplanned event will be performed in accordance with the applicable federal,
✓ state, or local regulations and/or guidelines for that response. These include HWMR-6 and RCRA for emergencies in the miscellaneous unit and waste handling areas; CERCLA; Chapter 74, Article 4B NMSA 1978, New Mexico Emergency Management Act; and agreements between the DOE and/or the WIPP Management and Operating Contractor (MOC) and local authorities
✓ (Section G-6) for emergencies throughout the WIPP facility. In addition, the Mine Safety and
✓ Health Act (MSHA) governs underground response to an unplanned event.

The FOSS is in charge of operations during a specified shift at the WIPP facility. The FOSS will contact the appropriate Facility Manager (FM) who will evaluate the incident and determine if an actual or potential emergency exists; i.e., the incident constitutes a real or potential threat to human health or the environment. The identity of the WIPP FM(s) and the means to communicate with the FM(s) are on the call-out list maintained by the FOSS. The list is kept current weekly. The FM is that individual, or his or her designee, who has direct-line responsibility for classifying the incident and notifying DOE in an emergency.

The nature of any incident potentially involving hazardous materials or waste will undergo assessment, as described in Section G-4c. The Emergency Coordinator will not be notified if the incident does not constitute an emergency requiring notification of public safety and regulatory agencies (i.e., if a fire, explosion, or release does not constitute a potential threat to human health or the environment, if a spill is contained in secondary containment, and/or if the spill or release is less than a reportable quantity, specified under CERCLA in 40 CFR sec. 302.4). Reportable quantities under CERCLA apply to the release of any substance listed in Table 302.4 of 40 CFR Part 302.

If the incident constitutes an emergency, the FOSS will notify the on-call Emergency Coordinator (phone numbers listed above), and the FM will notify the DOE facility representative. The identity and means to communicate with the DOE facility representative and the on-call Emergency Coordinator at all times are listed on the site call-out list, which is kept current weekly.

The WIPP facility maintains its own emergency response capabilities on site including the ERT, FLIRT, Emergency Services Technicians (ESTs), a registered nurse, security personnel, and Mine Rescue Teams. Coordination and mutual aid agreements with the local outside agencies make additional emergency personnel and equipment available (Section G-6, below). In addition, as a DOE facility, the staff at the WIPP facility can call upon the resources of DOE to assist.

Communication of Emergency Conditions to Facility Employees

The procedures for notifying facility personnel are dependent upon the type of emergency and level of response required. Options to accomplish this are:

- Local Fire Alarms
  - In the event of a fire, these may also be activated automatically or manually.
- Surface Evacuation Signal
  - The evacuation signal is a yelp[1] tone and is manually activated by the CMR Operator when needed. The CMR Operator shall follow the evacuation signal with verbal instructions and ensure the Site Notification System has been activated.
- Underground Evacuation Warning System
  - The evacuation signal is a yelp tone and flashing light. In the event of an evacuation signal, underground personnel will proceed to the nearest assembly areas (Section G-7b, Underground Assembly Areas) to be apprised of the nature of the emergency and the evacuation route to take.
- Contingency Evacuation Notification
  - If the primary warning system consisting of alarms and signals fails to operate when activated (as in a total power outage and failure of the redundant power systems), WIPP Security will be notified by the CMR Operator to initiate the contingency evacuation plan. In this procedure:
  - Security personnel will drive through the WIPP site with sirens oscillating.

[1] The yelp tone increases from 500 to 1000 hertz and drops to 500 hertz

- Security personnel will use voice amplifiers to alert personnel to evacuate the area.

The CMR Operator has the ability to notify facility personnel of an emergency using the PA system.

✓ WIPP facility personnel are trained and given instruction during general employee training, emergency preparedness classes, and during 40-hour safety training to recognize the various
✓ alarm signals and the significance of each alarm. All WIPP facility employees and site visitors are required to comply with directions from emergency personnel and alarm system notifications and to follow instructions concerning emergency equipment, shutdown procedures, and emergency evacuation routes and exits.

Notification of Local, State, and Federal Authorities

✓ If it is determined that the facility has had a fire, explosion, spill, or release of hazardous waste
✓ or hazardous waste constituent (included in HWMR-6, Pt. II) in the miscellaneous unit or mixed waste handling areas or an emergency resulting in a release of a hazardous substance (included in 40 CFR sec. 302.4 or the New Mexico Emergency Management Act, Sections 74-4B-3 and 74-4B-5) that could threaten human health or the environment inside or outside the facility, the
✓ Emergency Coordinator will assure that local authorities are notified by telephone and/or radio, including:

- Local Emergency Planning Committee [telephone number: (505) 887-1191]
- Carlsbad Police Department [telephone number: (505) 885-2111 or 911]
- Carlsbad Fire Department [telephone number: (505) 885-2111 or 911]
- Eddy County Sheriff [telephone number: (505) 887-7551]

✓ After local authorities are notified, the Emergency Coordinator will assure notification of:

✓ New Mexico Environment Department (NMED)
24-Hour Emergency Reporting telephone number: (505) 827-9329
FAX number: (505) 827-9368

Hazardous Materials Emergency Response, New Mexico State Police (State Emergency Response Commission)
Telephone number: (505) 827-9223
FAX number: (505) 829-3434

National Response Center
Telephone number: 1-800-424-8802
FAX number: (202) 479-7181

The first notification of public safety and regulatory agencies will include:

(1) Name and address of the facility and the name and phone number of the reporter.

(2) The type of incident: fire, explosion, release.

(3) The date and time of the incident.

(4) The type and quantity of hazardous material(s) involved.

(5) The exact location of the incident.

(6) The source of the incident.

(7) The extent of injuries, if any.

(8) Possible hazards to human health and the environment (air, soil, water, wildlife, etc.) outside the facility.

(9) The name, address, and telephone number of the party in charge of or responsible for the facility or activity associated with the incident.

(10) The party at the spill site who is in charge of emergency operations (the on-duty Emergency Coordinator) at the site and the telephone number of this party.

(11) The identity of any surface and/or ground waters involved or threatened and the extent of actual and potential water pollution.

(12) The steps being taken or proposed to contain and clean up the material involved in the incident.

The Emergency Coordinator will also be available to help the appropriate local, state, or federal officials decide whether local areas should be evacuated.

Notification of the General Public

Notification of the general public through the public safety and emergency agencies listed above will be made by or under the direction of the Emergency Coordinator following consultation with the DOE field representative. DOE policy is to provide accurate and timely information to the public by the most expeditious means possible concerning emergency situations at the WIPP site that may affect off-site personnel, public health and safety, and/or the environment.

G-4b Identification of Hazardous Materials

The identification of hazardous wastes or hazardous constituents involved in a fire, explosion, or release to the environment from the miscellaneous unit and mixed waste handling areas is a necessary part of the assessment of an incident, as described in HWMR-6, Pt. V, sec. 264.56(b). RCRA hazardous waste and hazardous substances and materials listed in 40 CFR sec. 302.4 or New Mexico Emergency Management Act, Sections 74-4B-3 and 74-4B-5, involved in any release at the WIPP facility will also be identified. Approaches available to identify the hazardous wastes, substances, or materials involved in an fire, explosion, or release at the WIPP facility include reference to the WIPP Waste Information System (WWIS), waste manifests, materials safety data sheets (MSDS), and materials inventories for buildings and operating groups at the WIPP facility. All mixed waste received by the WIPP facility during the Test Phase will be characterized for hazardous constituents prior to receipt, so that information required for identifying hazardous waste and hazardous constituents in case of an emergency in the miscellaneous unit or mixed waste handling areas is readily available through the WWIS. The identification of waste is one step in the emergency assessment which is described in Section G-4c, Assessment of the Nature and Extent of the Emergency.

G-4c Assessment of the Nature and Extent of the Emergency

Once personnel safety is ensured, the Emergency Coordinator will ensure that the identity, exact source, amount, and areal extent of any released materials are determined, as required under HWMR-6, Pt. V, sec. 264.56(b). The on-duty FOSS will be responsible for identifying immediate and potential hazards, using the services of ESTs and health physics technicians, and providing the WIPP Environment, Safety, and Health Department (ES&H) with the information necessary to determine: (1) the identity of hazardous wastes, hazardous constituents, and other hazardous materials involved, as described in Section G-4b; (2) whether the release involved a reportable quantity of a hazardous substance; (3) the areal extent of the release; (4) the exact source of the release; and (5) the potential hazards to human health or to the environment.

After the materials involved in an emergency are identified, the specific information on the associated hazards, appropriate personnel protective equipment, decontamination, etc., will be obtained from MSDSs, Dangerous Properties of Industrial Materials (Sax, 1989), and similar reference materials. This information is accessed through Safety and Plant Protection, Environmental Analysis and Compliance, and Transportation and Hazardous Materials Handling.

The emergency assessment requires determination of hazards involving evaluation of several criteria, including:

- Exposure: magnitude of actual or potential exposure to employees, the general public, and the environment; duration of human and environmental exposure; pathways of exposure.

- Toxicity: types of adverse health or environmental effects associated with exposures; the relationship between the magnitude of exposure and adverse effects.

- Uncertainties: considerations for undeterminable or future exposures; uncertain or unknown health effects, including future health effects.

If the assessment indicates that there is a real or potential threat to human health or the environment, the Emergency Coordinator will ensure that emergency information is communicated to facility employees and local, state, and federal authorities (see above).

G-4d Control, Containment, and Correction of the Emergency

The WIPP facility is required to control an emergency and to minimize the potential for releases, recurrences, or spreading of the emergency situation, as described in HWMR-6, Pt. V, secs. 264.56(e) and (f).

Immediate Response

As described in Section G-4a above, once the CMR Operator is notified (by either an eye witness or alarm) of a fire, explosion, or release, the Operator will immediately report the situation to the FOSS and take action to notify the appropriate emergency response personnel. The response will be in accordance with WP 12-9 (Westinghouse, 1992a).

Above Ground Emergencies

The ERT will respond to above ground emergencies at the WIPP facility in accordance with WP 12-9 (Westinghouse, 1992a).

Underground Emergencies

The FLIRT will respond to underground emergencies according to the following procedures in WP 12-9 (Westinghouse, 1992a): WIPP Underground Emergency Procedure, Nonradioactive Hazardous Materials Spill Control Procedure, and Response to Contamination Events.

The WIPP facility maintains two Mine Rescue Teams which are trained in compliance with 30 CFR Part 49 in areas of surface organization, mine gases, ventilation, exploration, mine fires and fire fighting, rescue and recovery, and mine recovery. A Mine Rescue Team is activated if the underground emergency exceeds the capabilities of the FLIRT in these areas of mine rescue; however, the Mine Rescue Teams are not designated to respond to spills or releases of hazardous wastes or materials in the underground.

Each Mine Rescue Team consists of five members, one alternate, one trainer, and one benchman. The teams are trained by a trainer who is certified by the U.S. Department of Labor Mine Safety and Health Administration. Their rescue equipment is supplied and maintained in accordance with federal regulations (30 CFR Part 49).

The first option in fighting mine fires will be to apply mechanical methods to stop fires (e.g., cut electrical power). In general, the use of emergency personnel to fight a mine fire, such as the Mine Rescue Team(s) or the FLIRT, will be avoided. If manpower is required, the Mine Rescue Team(s) would be able to respond to a mine fire; the FLIRT, although trained in fire fighting, will not usually be called on to fight mine fires. The last option in fighting mine fires will be to reconfigure ventilation.

G-4e Prevention of Recurrence or Spread of Fires, Explosions, or Releases

During an emergency, the Emergency Coordinator will ensure that reasonable measures are taken so that fires, explosions, and releases do not occur, recur, or spread to mixed waste or other hazardous materials at the facility, as required under HWMR-6, Pt. V, secs. 264.56(e) and (f). These measures include:

- Stopping processes and operations.
- Collecting and containing released wastes and materials.
- Removing or isolating containers of waste or hazardous materials.
- Ensuring that wastes managed during an emergency are handled, stored, or treated with due consideration for compatibility with other wastes and materials on site, and with containers utilized (Section G-4f, below).
- Restricting personnel not needed for response activities from the site of the incident.
- Evacuating the site.
- Curtailing nonessential activities in the area.
- Conducting preliminary inspections of adjacent facilities and equipment to assess damage.
- Overpacking and/or removing damaged containers/drums from affected areas. Damaged equipment and facilities will be repaired as appropriate.
- Constructing, monitoring, and reinforcing temporary dikes as needed.

- Maintaining fire equipment on standby at the incident site in cases where ignitable liquids have been or may be released and ensuring that all ignition sources are kept out of the area. Ignitable liquids will be segregated, contained, confined, diluted, or otherwise controlled to preclude inadvertent explosion or detonation.

If the facility (or portion of the facility) stops operations in response to a fire, explosion, or release, the Emergency Coordinator will ensure that appropriate systems are monitored by cognizant Operations or ES&H staff and that the following occurrences are immediately identified:

- Leaks
- Pressure build-up
- Gas generation
- Ruptures in valves or pipes.

No operation that has been shut down in response to the incident will be restarted until authorized by the Emergency Coordinator. Sections G-4g, Incompatible Waste, and G-4h, Post-Emergency Facility and Equipment Maintenance and Reporting, address specific issues related to decreasing the possibility of a recurrence or spread of a release, fire, or explosion.

G-4f Storage and Treatment of Released Material and Waste

Once initial spill containment has been completed, the Emergency Coordinator will ensure that recovered hazardous materials and waste are properly stored, treated, and/or disposed, as required by HWMR-6, Pt. V, sec. 264.56(g). For spills of liquid, the perimeter of the spill will be diked with an absorbent material that is compatible with the material(s) released. Free-standing liquid will be transferred to a labeled compatible container. The remaining liquid will be absorbed with an absorbent material and swept or scooped into a labeled compatible container. Spill residue will be removed. Spills of dry material will be swept or shoveled into a labeled compatible recovery container. Material recovered from the spill will be transferred to clean-washed containers or tanks or to containers or tanks that have held a compatible material. All containers will meet U.S. Department of Transportation (DOT) specifications for shipping the wastes and materials recovered.

Nonradioactive hazardous waste resulting from the cleanup of a fire, explosion, or release involving a nonradioactive hazardous waste or hazardous substance at the WIPP facility will be contained and managed as a hazardous waste until such time that it can be determined that the waste is not hazardous, as defined in HWMR-6, Pt. II, Subparts C and D. In most cases, hazardous materials inventories for the various buildings and areas at the facility will allow a determination of the hazardous materials present in any cleanup of a release or of the residues from an emergency condition. When necessary, however, samples of the waste will be collected and analyzed to determine the presence of any hazardous characteristics and/or constituents; this information is needed to evaluate disposal options. Sampling and analytical methods such as those detailed by the EPA (EPA, 1986) will be utilized. Hazardous wastes will be transferred to

√ the Hazardous Waste Staging Area per WP 02-6 and WP 02-7, Resource Conservation and
√ Recovery Act (RCRA) Compliance Manual (Westinghouse, 1992b), for transfer to an off-site disposal facility in accordance with applicable regulations (e.g., HWMR-6 and DOT regulations).

√ Administrative controls described in WP 02-5, Non-radioactive Hazardous Materials Environmental
√ Compliance Manual (Westinghouse, 1991a), and WP 05-1, Waste Handling Operations Manual
√ (Westinghouse, 1991b), will be implemented to ensure that no RCRA-regulated materials (not associated with the mixed waste itself) will be introduced to the radioactive materials area of the
√ WIPP facility during mixed waste handling operations. For this reason, mixed waste resulting
√ from the cleanup of a fire, explosion, or release in the miscellaneous unit and the mixed waste handling area will be derived from the received waste. It will be treated and handled according
√ to the radioactive waste handling procedures contained in WP 05-1 (Westinghouse, 1991b).

The contaminated area will be decontaminated. If the release is not contained on an impermeable surface, such as a secondary containment structure, contaminated soil, asphalt, concrete, or other surface will be removed and placed in DOT-approved shipping containers. Contaminated soil, asphalt, concrete, or other surface material, as well as materials used in the cleanup, e.g., rags and absorbent material, will be containerized and disposed of in the same manner as dictated for the contaminant. Clean soil, new asphalt, or new concrete will be replaced at the spill location.

If the spill occurred on an impermeable surface (such as a secondary containment structure), the surface will be decontaminated with water and/or a detergent. In the event that the spilled material is water reactive, a nonhazardous cleaning solution will be used. Contaminated wash water or cleaning solution will be transferred to an appropriate container, labeled, and disposed of as described above for nonradioactive and radioactive liquid wastes.

√ In the event of a hazardous material or waste release, waste that may be incompatible with the released material will not be received, treated, stored, or disposed of in the affected areas until cleanup operations have been completed.

For small nonemergency liquid spills, spill control procedures will be used to contain and absorb free-standing liquid. The contaminated absorbent will be swept or shoveled into a compatible container, and handled and stored as described above.

G-4g Incompatible Waste

Implementation of the TRU Waste Acceptance Criteria for the Waste Isolation Pilot Plant (DOE,
√ 1989a) ensures that incompatible TRU mixed waste will not be shipped to the WIPP facility.
Nonradioactive waste at the WIPP facility is carefully segregated during handling, storage (less
√ than 90 days), and transport within and off the facility. HWMR-6 requires separation of waste
√ managed that is incompatible with any materials released in an emergency [HWMR-6, Pt. V,

sec. 264.56(h)(1)]. Using guidelines provided in WP 02-6 and WP 02-7 (Westinghouse, 1992b), the Emergency Coordinator will not allow hazardous or mixed waste operations to resume in a building or area in which incompatible materials have been released prior to ensuring that necessary post-emergency cleanup operations to remove potentially incompatible materials have been completed.

G-4h Post-Emergency Facility and Equipment Maintenance and Reporting

The Emergency Coordinator will ensure that emergency equipment that is located or used in the affected area(s) of the facility and listed in the Contingency Plan is cleaned and ready for its intended use before operations are resumed, as specified in HWMR-6, Pt. V, sec. 264.56(h)(2). The WIPP facility is committed to replacing any needed equipment or supplies that cannot be reused following an emergency.

Cleaning and decontaminating equipment will be accomplished by: physically removing gross or solid residue; rinsing with water or another nonhazardous liquid, if required; and/or washing with detergent and water. Decontamination and cleaning will be conducted in a confined area, such as a wash pad or building equipped with a floor drain and sump isolated from the environment; e.g., the WHB. Care will be taken to prevent wind dispersion of particles and spray. Liquid or particulates resulting from cleaning and decontamination of equipment will be placed in clean, compatible containers. Waste produced in an emergency cleanup in the miscellaneous unit or waste handling areas is derived waste and will be managed as described in the liquid radioactive waste handling procedure incorporated in WP 05-1 (Westinghouse, 1991b). Waste resulting from decontamination operations elsewhere in the WIPP facility will be analyzed for hazardous waste constituents and/or hazardous characteristics to ensure proper management.

When the WIPP facility has completed any post-emergency cleanup of waste and hazardous residues from areas where waste management operations are ready to resume and all emergency equipment used in managing the emergency has been cleaned or replaced and is fit for service, the Emergency Coordinator will ensure that the following notifications are made: the EPA Regional Administrator; the Secretary of the NMED; and any relevant local authorities, such as emergency personnel in Carlsbad and Hobbs. This post-emergency notification complies with HWMR-6, Pt. V, sec. 264.56(i).

G-4i Container Spills and Leakage

The waste received at the WIPP facility must meet stringent waste acceptance criteria (i.e., less than 1 percent residual liquids and stabilized particulates) (DOE, 1989a) which will minimize the chances of waste container degradation and the possibility of liquid or particulate spills in the miscellaneous unit and mixed waste handling areas. During the test phase, up to 120 liters of brine may be added to certain test bins. The WIPP facility does manage drum quantities of lubricants, solvents, and recyclable spent solvents elsewhere at the facility. Should a spill or

release occur from a container, the WIPP facility will take the following actions in compliance with
√ HWMR-6, Pt. V, sec. 264.52(a) and HWMR-6, Pt. VI, sec. 264.171:

- Assemble the required response equipment, such as protective clothing and gear, heavy equipment, absorbent material, empty drums, overpack drums, plugging material, and hand tools.

- Transfer the released material to a container that is in good condition, or overpack the leaking container into another container that is in good condition.

- Once the release has been contained, determine the areal extent of migration of release and proceed with appropriate cleanup action, such as chemical neutralization, vacuuming, or excavation.

G-4j Tank Spills and Leakage

√ The miscellaneous unit and mixed waste handling areas at the WIPP facility do not include tank
√ storage or treatment of hazardous waste, as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart J. At the WIPP facility, tanks are used to store water and petroleum fuels only. The petroleum tanks store diesel and unleaded gasoline. In the event of
√ a spill from a petroleum product tank, actions are taken in accordance with WP 02-6 and WP 02-7
√ (Westinghouse, 1992b).
√

G-4k Surface Impoundment Spills and Leakage

√ The WIPP facility does not manage hazardous or mixed waste using a surface impoundment, as
√ defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart K. Surface impoundment regulations are not applicable to the WIPP facility.

G-5 Emergency Equipment

A variety of equipment is available at the facility for emergency response, containment, and cleanup operations in both the miscellaneous unit and the facility in general. This includes equipment for spill control, fire control, personnel protection, monitoring, first aid and medical attention, communications, and alarms. This equipment is immediately available to emergency response personnel. Listings of major emergency equipment available at the WIPP facility, as
√ required by HWMR-6, Pt. V, sec. 264.52(e), are shown in Tables G-1 and G-2. Locations of the underground emergency equipment are shown in Figure G-4. The fire water distribution system map is shown in Figure G-5. The underground fuel area fire protection system is shown in Figure G-6.

G-6 Coordination Agreements

The WIPP Project Office (WPO) has established Memoranda of Understanding (MOUs) with off-site emergency response agencies for fire fighting, hazardous material response services, medical assistance, and law enforcement. In the event that on-site response resources are unable to provide all the needed response actions during either a medical, fire, or security emergency, the appropriate off-site response agency will be notified for assistance.

The MOUs with off-site cooperating agencies are available from the DOE Contracting Officer. A listing and description of the MOUs with state and local agencies and mining operations in the vicinity of WIPP, as required by HWMR-6, Pt. V, secs. 264.37 and 264.52(c), are:

- Agreement among DOE, the WIPP MOC, AMAX Chemical Corporation, Mississippi Chemical Corporation, Western Ag-Minerals Company, and Eddy Potash, Inc., (January 22, 1990) provides for the mutual aid and assistance in the form of Mine Rescue Teams in the event of a mine disaster or other circumstance at any of the five facilities. This provision ensures that the WIPP MOC will have two Mine Rescue Teams available at all times when miners are underground, as required by DOE Order 5480.4, Environmental Protection, Safety, and Health Protection Standards (DOE, 1989b).

- Joint Powers Agreement among DOE; the City of Carlsbad, New Mexico; Eddy County, New Mexico; and the New Mexico Energy, Minerals, and Natural Resources Department for Alternate Emergency Operations Center (June 15, 1988) provides for the coordination of emergency plans, including the WPO emergency radiological response plans; provides for participation in periodic exercises, drills, and training; provides for establishing and maintaining an alternate Emergency Operations Center at the Living Desert State Park; and assigns responsibilities to the participants.

- Memorandum of Agreement between the City of Carlsbad, New Mexico, and the WIPP MOC for ambulance service assistance (August 13, 1981) provides that, upon notification by the WIPP MOC, the Carlsbad Fire Department will be dispatched from Carlsbad toward the WIPP site by a designated route and will accept the transfer of patient(s) being transported by the WIPP facility ambulance at the point both ambulances meet. If the patient(s) is not transferrable, the Carlsbad Ambulance Service will provide equipment and personnel to the WIPP facility ambulance, as necessary.

- MOU between the WPO and the Guadalupe Medical Center Emergency Radiological Treatment Center for the Waste Isolation Pilot Plant (October 5, 1988) provides for the treatment of radiologically contaminated personnel who have incurred injuries beyond the treatment capabilities at the WIPP facility. The WPO will provide transport of the patient(s) to the Guadalupe Medical Center Emergency Radiological Treatment Center for decontamination and medical treatment.

- MOU between the WPO and the Lea Regional Hospital Emergency Radiological Treatment Center for the Waste Isolation Pilot Plant (June 3, 1988) provides for the treatment of radiologically contaminated personnel who have incurred injuries beyond the treatment capabilities at the WIPP facility. The WPO will provide transport of the patient(s) to the Lea Regional Hospital Emergency Radiological Treatment Center for decontamination and medical treatment.

- MOU between the WPO and the U.S. Department of the Interior, New Mexico Office, BLM (June 29, 1983) provides for the development of the WIPP facility on BLM lands under an administrative land withdrawal. The MOU permits DOE to enter adjacent BLM land for emergency decontamination and assigns initial management of any wildland fire in the WIPP site area to DOE whereas BLM retains overall wildland fire suppression responsibility.

- Mutual Aid Fire-Fighting Agreement between the Eddy County Commission and the DOE (December 7, 1983) provides for the assistance of the Otis Fire Department (a volunteer fire district created under the Eddy County Commission and the New Mexico State Fire Marshall's Office), including equipment and personnel, at any location within the WIPP Fire Protection Area upon request by an authorized representative of the WIPP Project. These responsibilities are reciprocal.

- Mutual Aid Agreement between the City of Hobbs and DOE (March 6, 1990) provides for mutual ambulance, medical, fire, rescue, and hazardous material response services; provides for joint annual exercises; provides for use of WIPP facility radio frequencies by the City of Hobbs during emergencies; and provides for mutual security and law enforcement services, within the appropriate jurisdiction limits of each party.

G-7 Evacuation Plan

If it becomes necessary to evacuate the WIPP facility, the assigned staging area and assembly areas have been established. The WIPP facility has implementation procedures for both surface and underground evacuation in WP 12-9 (Westinghouse, 1992a). The following sections describe the evacuation plan for the WIPP facility, as required under HWMR-6, Pt. V, sec. 264.52(f).

G-7a Surface Evacuation On-Site Assembly Areas and Off-Site Staging Areas

Figure G-7 shows the aboveground on-site assembly areas and off-site staging areas. Personnel report to their Office Wardens at designated on-site assembly areas. The FOSS will decide which off-site staging area is to be used and will advise Office Wardens of the selection. The FOSS will communicate the off-site staging area location to Office Wardens via radio, WIPP Security, or telephone, as appropriate. Office Wardens will direct personnel to the selected off-site staging area. Personnel who are working in a contaminated area when site evacuation is announced will

minimize contact with other personnel during the evacuation. Each off-site staging area contains an area for the mustering of any potentially contaminated personnel.

G-7b Underground Assembly Areas

In the event of an underground evacuation, underground personnel will muster in the nearest assembly area (Figure G-8) to be accounted for and to await directions for evacuation to the surface. Assembly areas have mine pagers, telephones, evacuation maps, first-aid kits, and procedures available to assist workers in responding to the emergency.

G-7c Plan for Surface Evacuation

Notification for site evacuation will be made using the employee notification procedures in Section G-4a, above. Evacuation of surface facilities will occur upon sounding the evacuation alarm or upon instruction from the Office Warden(s). Evacuation routes and instructions are posted throughout the site.

Designated Office Wardens will be notified of site evacuation by WIPP Security or evacuation alarms. Office Wardens instruct all personnel to leave the work station in an orderly manner and to muster at the designated on-site assembly area (Figure G-7). The Office Warden is an individual assigned responsibility for assuring that personnel are evacuated from the Office Warden's assigned area or building during evacuations. Responsibilities include:

- Maintaining order during the evacuation
- Directing personnel to the staging area from the outside assembly area
- Accounting for personnel at the staging area
- Reporting results of personnel accounting to the Chief Warden.

Employees are to ensure that visitors they are escorting accompany them to the on-site assembly and off-site staging areas. The Chief Warden is a pre-assigned individual with responsibilities during evacuations at the staging area. These duties include:

- Maintaining order at the staging area
- Directing Office Wardens at the staging area
- Receiving reports from the Office Wardens regarding personnel accounting
- Reporting to the FOSS
- Accounting for personnel at the staging area.

During an evacuation all personnel will remain in the staging area until given further instructions. Personnel with assigned duties that prevent their immediate departure from the site during an evacuation (e.g., FOSS, ERT personnel, FLIRT personnel) will report to their supervisor/duty stations for instructions. These personnel will not evacuate until released by their supervisor.

G-7d Plan for Underground Evacuation

Notification for underground evacuation will be made using the underground PA evacuation alarm and strobe light signals. This notification equipment is battery-powered and will continue to operate in the event of a power outage.

Personnel evacuate to the nearest assembly area (Figure G-8). If the incident requires immediate evacuation of the underground (e.g., power outage, surface or underground fire), underground personnel are instructed to go to any hoist for transport to the surface. Primary underground evacuation routes (identified by green reflectors on the rib) will be used, if possible. Secondary underground evacuation routes (identified by red reflectors on the rib) will be used if necessary (Figure G-4). Brass tags are collected from personnel at the hoist collar on the surface and numbers are reported to the Underground Dispatcher to account for personnel.

If the incident does not require immediate evacuation of the underground, the supervisors record the numbers of brass tags from employees at the assembly areas and report all numbers to the Underground Dispatcher on the surface. Personnel await further instructions at the assembly area.

In either case, upon reaching the surface, personnel report to their assembly area to receive further instructions.

G-7e Further Site Evacuation

If the Emergency Coordinator concludes that site personnel evacuation beyond the location of the personnel staging area would be prudent, the most favorable evacuation route will be selected by the Emergency Coordinator.

In the event of an evacuation involving the need to transport employees, the following transportation is available:

- Buses -- WIPP facility buses are available for evacuation of personnel. The buses are stationed in the employee parking lot.

- Privately Owned Vehicles -- Because many employees drive to work in their own vehicles, these vehicles may be utilized in an emergency. Personnel may be directed as to routes to be taken when leaving the facility.

These vehicles may be used to transport personnel who have been released from the site by the Chief Warden.

G-8 Required Reports

ES&H must note in the operating record the time, date, and details of any incident that requires implementing this Contingency Plan. In compliance with HWMR-6, Pt. V, sec. 264.56(j), within 15 days after the incident, the Emergency Coordinator will ensure that a written report on the incident will be submitted to the EPA Regional Administrator and the Secretary of the NMED. The report must include:

(1) Name, address, and telephone number of the Owner/Operator.

(2) Name, address, and telephone number of the facility.

(3) Date, time, and type of incident (e.g., fire, explosion, release).

(4) Name and quantity of material(s) involved.

(5) The extent of injuries, if any.

(6) An assessment of actual or potential hazards to human health or the environment, where this is applicable.

(7) Estimated quantity and disposition of recovered material that resulted from the incident.

In addition to the above report, the Emergency Coordinator will ensure that ES&H submits reports to the appropriate agencies as listed in Tables G-3 and G-4.

In accordance with HWMR-6, Pt. V, sec. 264.56(l), DOE will notify the Secretary of the NMED and EPA Regional Administrator that the WIPP facility is in compliance with requirements for the cleanup of areas affected by the emergency, and that emergency equipment used in the emergency response has been cleaned or replaced and is fit for its intended use prior to the resumption of waste management operations in affected areas. The means the WIPP facility will utilize to meet these requirements is described in Sections G-4f, G-4g, and G-4h.

G-9 Location of the Contingency Plan and Plan Revision

The Owner/Operator of the WIPP facility will ensure that copies of this Contingency Plan are present at controlled-document locations throughout the facility and are, consequently, available to all emergency personnel and organizations described in Section G-4. In addition, the owner/operator will make available copies to the following outside agencies:

- New Mexico Energy, Minerals, and Natural Resources Department for Alternate Emergency Operations Center at the Living Desert State Park Office, Carlsbad

✓ • Carlsbad Fire Department

- Guadalupe Medical Center, Carlsbad
- Lea Regional Hospital, Hobbs
- Otis Fire Department, Otis
- Hobbs Fire Department, Hobbs
- BLM, Carlsbad
- Public Safety Department, Carlsbad
- New Mexico State Police.

✓ The Owner/Operator of the WIPP facility will ensure that this plan is reviewed annually and amended whenever:

- Applicable regulations are revised.
- The RCRA Part B permit for the WIPP facility is revised in any way that would affect the Contingency Plan.
- This Plan fails in an emergency.
- The WIPP facility design, construction, operation, maintenance, or other circumstances change in a way that increases the potential for fires, explosions, or releases of hazardous waste or hazardous constituents or change the response necessary in an emergency.
- The list of Emergency Coordinators changes.

✓ • The list of WIPP facility emergency equipment changes substantially.

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√ Recovery Act (RCRA) Compliance Manual," WP 02-6 and WP 02-7, Westinghouse Waste Isolation Division, Carlsbad, New Mexico.

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TABLES

TABLE G-1
EMERGENCY EQUIPMENT AND PERSONNEL MAINTAINED AT THE WASTE ISOLATION PILOT PLANT

Equipment	Description and Capabilities	Location
Communications		
Building Fire Alarms	manual and automatic; activation of automatic sprinkler system triggers fire alarm; locally audible, visual display and alarm in Central Monitoring Room (CMR)	Guard and Security Building, Pumphouse, Warehouse/ Shops, Exhaust Filter Building, Support Building, CMR/ Computer Room, Waste Handling Building, TRUPACT Maintenance Facility, Salt Handling (SH) Shaft Station, Waste Handling Shaft Station, Fuel Station No. 1 and 2, SH Hoisthouse, Maintenance Shops*, Guard Shack*, Auxiliary Warehouse*, Construction Management Trailer*, Core Storage Building* *local alarms; not connected to the CMR
Underground Fire Alarms	automatic; have priority over other paging channel signals but don't override intercom channels; alarms sound in the general area of the control panel; interface with CMR	Fire detection and control panel locations: Waste Shaft, Salt Handling Shaft, Panel 1 (outside room 1), E-O/N 1200, Fuel Station #1, Fuel Station #2
✓ ✓ ✓ ✓ Site-wide Evacuation Alarm	transmitted over paging channel of the PA system, overriding its normal use; manually initiated according to procedures requiring evacuation for radiation; automatically initiated by underground fire alarm systems for underground areas; audible alarm produced by tone generator at 10 decibels above ambient noise level (or at least 75 decibels); flashing strobe lights supplement audible alarm in high ambient noise areas; radios and/or pagers are used to notify facility personnel outside alarm range.	site-wide
✓ Vehicle Siren	manual; oscillating	WIPP emergency vehicles
Voice Amplifiers	manual; portable	Security Control Center
Still Video Transceiver System	a multiple component system for transceiving, recording, and developing images; non-secure or secure transmission and receipt of images from predesignated location in the U.S.	Emergency Operations Center (EOC), located in the Safety and Emergency Services Building
Public Address (PA) System	includes intercom phones; handset stations and loudspeaker assemblies, each with own amplifiers; multi-channel, one for PA and pages, and others for independent party lines.	surface and underground
Intraplant Phones	private automatic branch exchange; direct dial; provide communication link between surface and underground operations	throughout surface and underground
Mine Phones	battery-operated paging system	CMR, mining office, safety office, and underground

TABLE G-1
EMERGENCY EQUIPMENT AND PERSONNEL MAINTAINED AT THE WASTE ISOLATION PILOT PLANT (CONTINUED)

Equipment	Description and Capabilities	Location
Commercial, Off-Site Phones	local, long distance and emergency telephone service; direct dial; six dedicated off-site lines and 18 that operate through the Emergency Operations Center switchboard; diverse routing of service: 12 of the 20 direct inward dial (DID) and 12 of the 20 outward dial (DOD) are routed through microwave; the remaining DID and DOD are routed in the buried copper cable to Carlsbad	surface and underground
Pagers	manual; broadcast high-intensity, intermittent alarm signals for up to 60 seconds	issued to individuals
✓ Plectra	tone-alert radio receivers placed in areas not accessible by the public address system	site-wide
Portable Radios	two-way, portable; transmits and monitors information to/from other transmitters	issued to individuals
Plant Base Radios	two-way, stationary, UHF/ VHF-FM; linked to Eddy County and Lea County Sheriffs' Departments, NM State Police, Carlsbad Emergency Radio (Carlsbad ambulance, fire, HAZMAT and police, Guadalupe Medical Center and Otis Fire Department), and WIPP Channels 1-4 (Site Security and Safety, Site Operations, Site Emergency, repeater to Carlsbad)	Guard and Security Building and EOC
Repeater	a 50' high tower enabling the transmission of radio frequency waves; UHF-FM, two-way radio/ telephone repeater link	"C" Hill, Carlsbad, NM
✓ Personal Computer Data Link	personal computer with printer; personal computer with data link to DOE-Albuquerque	EOC
STU-III Telephone	for normal and secure modes; provides unsecured and secured direct dial on- and off-site telephone access	EOC
Mobile Phones	provide communications link between WIPP Security and key personnel	Issued to individuals plus emergency vehicles, environmental truck, PA van
Telecopier	facsimile (FAX); two; interfaced with existing telephone lines, capable of sending "hard copy" information to other FAX machines; one of the two is capable of sending and receiving secure FAXs	EOC
SATNET Communications System	maritime communications system; through satellite for worldwide communication	EOC
Spill Response		
SPILL-X-S Guns and Recharge Powder	containment; SPILL-X model SC-30-C XC-30-S SC-30-A; includes A-Acid, S-Solvent, C-Caustic	Rescue Truck and Emergency Services Storage
Absorbent Sheets	containment or cleanup; 3' x 100'	Rescue Truck
Absorbents	Grab and Go container; spill control bucket; for solvents and neutralizing absorbents; for acids/caustics	Emergency Services Storage

TABLE G-1
EMERGENCY EQUIPMENT AND PERSONNEL MAINTAINED AT THE WASTE ISOLATION PILOT PLANT (CONTINUED)

Equipment	Description and Capabilities	Location
Absorbent Sock	containment or cleanup; general liquid and oil "Pig"	various combinations in Emergency Services Storage and Rescue Truck
Air Bag System	12-ton, 21.8-ton, 17-ton with tank kit	Rescue Truck
Air Chisel	capable of cutting 3/16" steel	Rescue Truck
85-Gallon Overpack Drum	containment; poly overpack salvage drum; plastic with lid	Emergency Services Storage
Steel Salvage Drums	containment or cleanup; 20-, 30- and 55-gallon drums with lids	Emergency Services Storage and Rescue Truck
Drum Transfer Pumps and Drum Opener	containment or cleanup; jack rabbit pump; hand operated pumping	Rescue Truck
Floor Squeegee	containment or cleanup; straight rubber blade, wood handle	Rescue Truck
Foam Concentrate	AFFF 6%, ATC 3/6%, high expansion; 5-gallon pail	Emergency Services Storage, Fire Truck # 1, Rescue Truck
Gas Cylinder Leak Control Kit	Series A Hazardous Material Response Kit; contains non-sparking equipment to control and plug leaks	Rescue Truck
Portable Generator	emergency power; 5,000 watt; 120 or 240 volt	Rescue Truck
Hand Tools	containment and cleanup; hammers, saws, pliers, wrenches, etc.	Rescue Truck
Come-a-longs	4-ton; cable type	Rescue Truck
Porta-power	10 ton	Rescue Truck
Jugs	containment or cleanup; 1-gallon plastic	Emergency Services Storage and Rescue Truck
Pails	containment or cleanup; 5-gallon plastic with lid	Emergency Services Storage and Rescue Truck
Portable Lighting	emergency lighting; 120 volts; 500-watt bulbs, suitable for wet location	Rescue Truck
pH Meter	acid/base detection; electronic	Rescue Truck
Oxygen & Combustible Gas Meter	detects explosive levels of gas; electronic; portable	Rescue Truck
Multi-Gas Detection System	Hazardous Materials Kit; Precision Gas Detector	Rescue Truck

TABLE G-1
EMERGENCY EQUIPMENT AND PERSONNEL MAINTAINED AT THE WASTE ISOLATION PILOT PLANT (CONTINUED)

Equipment	Description and Capabilities	Location
Patching Kit	Series A Hazardous Response Kit; Class A	Rescue Truck
Scoops and Shovels	cleanup; plastic; various sizes; non-sparking	Rescue Truck
Transportation		
WIPP Buses	emergency transportation away from site; in use immediately before and after normal working hours	parking area
Medical Resources		
Ambulance #1	equipped as per Federal Specifications KKK-A-1822 and New Mexico Emergency Medical Services Act General Order 35; equipped with a radio to Guadalupe Medical Center in Carlsbad, VHF radio, UHF medical frequency, cellular phone	surface (Safety and Emergency Services Building)
Ambulance #2	electric cart; equipped with first aid kit, 2 stretchers, and other associated medical supplies	underground
Rescue Truck	special purpose vehicle; light and heavy duty rescue equipment; transports 1 litter patient, medical oxygen and supplies for mass casualties, fire suppression support equipment (rescue tool, air bag, K-12 Rescue Saw, 5,000-watt generator, self-contained breathing apparatus (SCBAs), and much more equipment	surface (Safety and Emergency Services Building)
Fire Detection and Fire Fighting Equipment		
Building Smoke and Thermal Detectors	ionization and photoelectric or fixed temperature/ rate of rise detectors; visual display and alarm in CMR	Guard and Security Building, Pumphouse, Warehouse/Shops, Exhaust Filter Building, Support Building, CMR/Computer Room, Waste Handling Building, TRUPACT Maintenance Facility, SH Shaft Station, Waste Handling Shaft Station, Fuel Station Nos. 1 and 2, SH Hoisthouse, Guard Shack
Fire Truck # 1	equipped per Class "A" fire truck per National Fire Protection Act; pump capacity 750 gallons per minute, booster tank capacity 500 gallons	surface (Safety and Emergency Services Building)
Fire Truck # 2	industrial pumper; 300-gallon capacity, 350-gallon-per-minute pump, 30-gallon foam tank, 125-pound dry chemical extinguisher	underground
Extinguishers	individual fire extinguisher stations; include dry chemical, Halon; 3-, 5-, 10-, 15-, 17-, 20-, 22-, 25-, 30-, 125-pound; AMEREX--AFF, -H AND -D/C, ANSUL-D/C, -P/K AND DUMP, HALON DUMP, BADGER-D/C AND -H, GENERAL-D/C, CO2 AND -P/K, SENTRY-H, -PK AND -D/C, KIDDE-D/C, -DUMP, PEMALL-D/C AND -H, AMLAFR-D/C, BUCKEY-D/C, and other similar styles	buildings, underground, and vehicles

TABLE G-1
EMERGENCY EQUIPMENT AND PERSONNEL MAINTAINED AT THE WASTE ISOLATION PILOT PLANT (CONTINUED)

Equipment	Description and Capabilities	Location
Automatic Dry Chemical Extinguishing Systems	automatic; 1,000-pound system (Purple K); actuated by thermal detectors or by manual pull stations	underground fuel stations # 1 and 2
Sprinkler Systems	fire alarms activated by water flow	Pumphouse, Guard and Security Building, Support Building, Waste Handling Building (contact- and remote-handled transuranic waste area only), Warehouse/Shops Building, Auxiliary Warehouse Building, TRUPACT Maintenance Facility
Water Tanks, Pipelines, Hydrants	fire-fighting water supply; two 180,000-gallon capacity	tanks are at southwest edge of WIPP facility; pipelines and hydrants are throughout the surface
Fire Water Pumps	fire-fighting water supply; 125 pounds per square inch, 1,500 gallons per minute centrifugal pump, one with electric motor drive, the other with diesel engine; small jockey pump	pumphouse
Hose Reels	fire-fighting water supply	Pumphouse, Guard and Security Building, Support Building, Waste Handling Building (contact- and remote-handled transuranic waste area only), Warehouse/Shops Building, Auxiliary Warehouse Building, TRUPACT Maintenance Facility
Personnel Protection Equipment		
Headlamps	mounted on hard hat; battery operated	each person underground
Underground Self-Rescuer Units	short-term rebreathers; approximately 300	each person underground
Self-Contained Breathing Apparatus (SCBAs)	oxygen supply; 4-hour units; approximately 14 Mine Rescue Team Draeger units	Mine Rescue Training Room
Chemical and Chemical-Supported Gloves	body protection; inner-cloth, outer-pvc, outer-viton	Warehouse, Rescue Truck
Suit, Acid	body protection; green	Rescue Truck
Suit, Fire Proximity	body protection; aluminized	Rescue Truck

TABLE G-1
EMERGENCY EQUIPMENT AND PERSONNEL MAINTAINED AT THE WASTE ISOLATION PILOT PLANT (CONTINUED)

Equipment	Description and Capabilities	Location
Suit, Fully Encapsulated	body protection; used with SCBAs; full outerboot; 4 Level A; viton; tyvek-saranex	Rescue Truck
Emergency Medical Equipment		
Anti-Shock Trousers	shock treatment; inflatable	Ambulance # 1 and # 2
Blankets	patient care; wool	Ambulance # 1 and # 2, Health Services (HS), Rescue Truck
Life Pack 5	monitor/defibrillator	Ambulance # 1 and # 2
Life Pack 6	monitor/defibrillator	Health Station
Oxygen	patient care; Size D, Size M, Size E	Ambulance # 1 and # 2, HS, Rescue Truck
Pillows and Cases	patient care; regular and small first aid	Ambulance # 1, HS, Rescue Truck
Resuscitators (Bag)	disposable bag resuscitation	Ambulance # 1, HS
Sheets	patient care; paper and cloth	Ambulance # 1, HS, Rescue Truck
Splints	immobilize limbs; hare traction, air splints, Thomas half ring, Keds, sandbags, fracture aid kit, padded board	Ambulance # 1 and # 2, HS, underground cabinets
Stretchers	patient transport; stretchers, basic life support litter, aluminum back board, portables, scoop stretcher, rescue blankets; one person capacity	various combinations in Ambulance # 1 and # 2, Rescue Truck, Auxiliary Warehouse, HS, Underground Conference Room, First Aid Room, underground cabinets
Suctions	portable and stationary	various combinations in Ambulances #1 and #2, HS
Trauma Kits	assorted one-use medical supplies; trauma and I-V	various combinations in Ambulances #1 and #2, HS, Rescue Truck
Cardiopulmonary Resuscitation (CPR) Board	flat surface; use to perform cardiopulmonary resuscitation	Ambulance # 1

TABLE G-1
EMERGENCY EQUIPMENT AND PERSONNEL MAINTAINED AT THE WASTE ISOLATION PILOT PLANT (CONTINUED)

Equipment	Description and Capabilities	Location
General Plant Emergency Equipment		
Fire Fighters	Emergency Services Technician (ESTs) respond to above ground fires as part of Emergency Response Team; Mine Rescue Teams and First Line Initial Response Team (FLIRT) may be used if manpower is required to fight underground fires; cross-trained backup personnel are also available; certification by New Mexico State Fire Marshal; handle fire fighting, rescue, spill and hazardous substance response at WIPP site; on call	based in the Safety and Emergency Services Building
Emergency Medical Technicians (EMTs)	state-licensed Emergency Medical Technician (EMT); titled ESTs; 4 full-time EMTs: 3 rotate on 24-hour shifts, 365 days/year; 4th on site Mon-Fri and works shifts on demand; 24-hour first-aid and emergency response coverage	based in the Safety and Emergency Services Building
First Aid Room	staffed by one full-time registered nurse from 0730 to 1600 hours five days per week; first aid for minor medical emergencies	Safety and Emergency Services Building
Mine Rescue Team	volunteer employees certified by U.S. Department of Labor Mine Safety and Health Administration trainer and equipped in accordance with 30 CFR regulations; two 5-member teams, one alternate, one trainer, one benchman; may also perform underground fire fighting duties, if manpower is required; used when emergency exceeds the capabilities of the FLIRT	on-site
Ventilation	for air circulation, smoke, heat and noxious gas removal, and in reversal mode for some systems, used as a fire-fighting tool; linked to main power supply, and selectively linked to back up diesel power supply; CMR tracks status	surface and underground
Emergency Lighting	for employe rescue and evacuation, and fire/spill containment; linked to main power supply, and selectively linked to back up diesel power supply and/or battery-backed power supply	surface and underground
Backup Power Sources	2 diesel generators, and battery-powered uninterruptible power supply (UPS); use limited to essential loads; manual or remote starting 1,100-kilowatt diesel generators with on-site fuel for 62% load for 3 days for selected loads; 30-minute battery capacity for essential loads	generators are east of Safety and Emergency Services Building; UPS is located at the essential loads
Central Monitoring Room (CMR)	central location to monitor all vital plant parameters and alarm functions, and provide reliable communications; on UPS; monitors electrical, Waste Shaft hoist, Salt Handling Shaft hoist, fire protection alarms, pumps, sprinklers, water levels, ventilation, radiation monitors, meteorological data, and communications	Support Building
Emergency Operations Center (EOC)	base of operations during emergency situations; equipped with primary and redundant communications system for Crisis Management Team	Safety and Emergency Services Building
Emergency Egress	color-coded signs in underground showing direction to exits (green= main route, red= secondary route) to hoists	throughout underground

TABLE G-1
EMERGENCY EQUIPMENT AND PERSONNEL MAINTAINED AT THE WASTE ISOLATION PILOT PLANT (CONTINUED)

Equipment	Description and Capabilities	Location
Hoists	hoists in Waste Handling Shaft, Air Intake Shaft and Salt Handling Shaft, and one portable diesel hoist	Waste Handling Shaft, Air Intake Shaft, Salt Handling Shaft
Emergency Evacuation Gates	one full-time manned gate; two unmanned gates that can be opened by authorized personnel only	perimeter fence: west side (manned), north and south sides (unmanned)
Earth-moving Equipment	operational equipment available in an emergency; loaders, backhoes, trucks	Auxiliary Warehouse
Support Equipment	operational equipment available in an emergency; generators, compressors, pumps, tools, tanks	Auxiliary Warehouse
Radiation Monitoring Equipment	stationary continuous air monitors and air samplers; portable samplers; detect alpha, beta, gamma, and neutron radiation and particulate contamination	over-radiation detectors are located throughout applicable handling areas; air samplers are outdoors both on site and off site; portable samplers operated by radiological team
Emergency Shower	for emergency flooding of contaminated individual; stationary and portable	surface and underground
Eye Wash Fountains	for emergency flooding of affected eyes; stationary and portable	surface and underground

TABLE G-2
TYPES OF FIRE SUPPRESSION SYSTEMS BY LOCATION

LOCATION/EQUIPMENT	AS[1]	AH[1]	AD[1]
Waste Handling Building[2]			
Inventory and Preparation	X		
Battery Recharge	X		
Interior Air Lock	X		
Exterior Air Locks	X		
Overpack & Repair Room	X		
Overpack Storage Room	X		
Compaction Area	X		
Change Room	X		
Small Equipment Decontamination	X		
Air Locks	X		
Site-Generated Waste Room	X		
Solidification Area	X		
Access Corridor (area 15)	X		
Remote Handling Area	X		
Cask Receiving Area	X		
Mechanical Equipment Room	X		
Standing Operator Room	X		
Manipulator Repair Room	X		
Operating Gallery	X		
Cage Loading Room/Lock	X		
Shaft Entry Room	X		
Cask Loading Room	X		
Vestibule	X		
Filter Gallery	X		
Access Corridor (area 28)	X		
Access Aisle	X		
Waste Hoist Room	X		
Waste Hoist Motor	X		
Deflection Sheave Room	X		
Crane Maintenance Room	X		
Traveling Platform	X		

TABLE G-2
TYPES OF FIRE SUPPRESSION SYSTEMS BY LOCATION
(CONTINUED)

LOCATION/EQUIPMENT	AS[1]	AH[1]	AD[1]
Support Building[2]			
General Office Areas	X		
Laboratory Areas	X		
Electrical Rooms	X		
Computer Room & Offices	X	X	
Central Monitoring Room Vault & Storage	X	X	
Mechanical Equipment Rooms	X		
Exhaust Filter Building[3]			
Filter Chamber	X		
Access Corridor	X		
Exhaust Equipment Room	X		
Mechanical Room	X		
Underground Facilities[3]			
Fuel Stations			X
Warehouse Shops/Building[3]			
Office	X		
Storage Warehouse	X		
General Shops Area	X		
Water Pumphouse[3]			
Pumphouse	X		
SH Hoist House & Headframe[3]			
SH Hoist House	X		
SH Hoist Motor	X		
SH Hoist Drum Sump	X		

[1]Symbols for WIPP Fire Protection Systems:

AS Automatic Wet Pipe Sprinkler System
AH Automatic Halon 1301 Extinguishing System
AD Automatic Dry Chemical Extinguishing System

TABLE G-2
TYPES OF FIRE SUPPRESSION SYSTEMS BY LOCATION
(CONTINUED)

(2)The Waste Handling Building and the Support Building contain the following:

- automatic wet pipe sprinklers in all areas
- interior fire hose connections
- fire detection in the Heating, Ventilation and Air Conditioning instrumentation (Support Building, only)
- Halon fire suppression in the Central Monitoring Room and Vault Storage and the Computer Room (Support Building, only)
- manual pull stations
- portable fire extinguishers

√ The Safety and Emergency Services Building contains the following:

√
- automatic wet pipe sprinklers
- manual pull stations
- portable fire extinguishers

The Core Storage Building contains the following:

- automatic wet pipe sprinklers
- portable fire extinguishers
- fire detection

(3)The Exhaust Filter Building, Underground Facilities, Warehouse/Shops Building, Water Pumphouse, and Salt Handling Hoist House and Headframe also have portable fire extinguishers and manual pull stations.

TABLE G-3
HAZARDOUS RELEASE REPORTING, FEDERAL

Statute	Chemical Releases Covered	To Whom Report Must Be Made	What Must Be Reported	
			Immediately (Oral)	Subsequently (Written)
Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)/Superfund Amendments and Reauthorization Act (SARA) (40 CFR Part 302)	"Reportable quantities" of CERCLA/SARA "hazardous substances."	National Response Center: (800) 424-8802; State Emergency Response Commission: (505) 827-9223 (New Mexico State Police, Hazardous Materials Emergency Response); and Local Emergency Planning Committee: (505) 887-1191.	(1) Chemical identification; (2) what hazardous substance; (3) quantity released; (4) time, location and duration of release; (5) media of release; (6) health risks and medical advice; (7) proper precautions (e.g., evacuation); and (8) name and phone number of reporter and facility.	As soon as practicable, update of oral notice and response action taken. Send report to: New Mexico State Emergency Response Commission, Department of Public Safety, Title III Bureau, P.O. Box 1628, Santa Fe, New Mexico, 87504-1628; and Chairman, Local Emergency Planning Committee, City of Carlsbad, P.O. Box 1569, Carlsbad, New Mexico, 88220. National Response Center will contact the U.S. Environmental Protection Agency (EPA). EPA may request a written report.
Emergency Planning and Community Right-to-Know Act (SARA Title III) (40 CFR Parts 302 and 304)	SARA Title III "extremely hazardous substances."	National Response Center: (800) 424-8802; State Emergency Response Commission: (505) 827-9223 (New Mexico State Police, Hazardous Materials Emergency Response); and Local Emergency Planning Committee: (505) 887-1191.	(1) Chemical identification; (2) what extremely hazardous substance; (3) quantity released; (4) time, location and duration of release; (5) media of release; (6) health risks and medical advice; (7) proper precautions (e.g. evacuation); and (8) name and phone number of reporter and facility.	As soon as practicable, update of oral notice and response action taken. Send report to: New Mexico State Emergency Response Commission, Department of Public Safety, Title III Bureau, P.O. Box 1628, Santa Fe, New Mexico, 87504-1628; and Chairman, Local Emergency Planning Committee, City of Carlsbad, P.O. Box 1569, Carlsbad, New Mexico, 88220. National Response Center will contact the U.S. Environmental Protection Agency (EPA) for an address if a written report is requested by EPA.

TABLE G-3
HAZARDOUS RELEASE REPORTING, FEDERAL
(CONTINUED)

Statute	Chemical Releases Covered	To Whom Report Must Be Made	What Must Be Reported	
			Immediately (Oral)	Subsequently (Written)
RCRA, 40 CFR §§264.56(a) and 265.56(a)	Any imminent or actual emergency situation.	State or local agencies with designated response roles, if their help is needed: Local Emergency Planning Committee: (505) 887-1191; Carlsbad Police Department: 885-2111; Carlsbad Fire Department: 885-2111; Eddy County Sheriff: 887-7551.	What assistance is required.	Not Applicable (N/A)
RCRA, 40 CFR §§264.56(d), 264.56(i), 265.56(d), and 265.56(i)	RCRA "hazardous waste" release (regardless of amount), fire, or explosion, which could threaten human health or environment outside the facility.	National Response Center: (800) 424-8802; State Emergency Response Commission: (505) 827-9223 (New Mexico State Police, Hazardous Materials Emergency Response); and Local Emergency Planning Committee: (505) 887-1191.	(1) Name and telephone number of reporter; (2) name and telephone number of facility; (3) time and type of incident; (4) name and quantity of materials involved; (5) extent of injuries, if any; and (6) possible health or environmental hazards outside the facility.	Prior to resumption of operations, notify that: (1) no waste that may be incompatible with released material is treated, stored, or disposed of until cleanup is complete, and (2) all emergency equipment listed in the Contingency Plan is cleaned and fit for its intended use. Send to Secretary, New Mexico Environment Department, 525 Camino de los Marquez, Santa Fe, New Mexico, 87503.

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TABLE G-3
HAZARDOUS RELEASE REPORTING, FEDERAL
(CONTINUED)

Statute	Chemical Releases Covered	To Whom Report Must Be Made	What Must Be Reported	
			Immediately (Oral)	Subsequently (Written)
RCRA, 40 CFR §§264.56(i), 264.56(j), 265.56(i), and 265.56(j)	Any incident which triggers implementation of Contingency Plan.	New Mexico Environment Department, Emergency Response Office, 24-hour telephone: (505) 827-9329 or Monday to Friday, 8am to 5pm: (505) 827-2915 or (505) 827-0188.	N/A	Within 15 days: (1) name, address and telephone number of owner/operator; (2) name, address and telephone number of facility; (3) date, time and type of incident (e.g. fire, explosion); (4) name and quantity of materials involved; (5) extent of injuries, if any; (6) possible hazards to human health or the environment; (7) estimated quantity of material that resulted from the incident. Prior to resumption of operations, notify that: 1) no waste that may be incompatible with released material is treated, stored, or disposed of until cleanup is complete, and 2) all emergency equipment listed in the Contingency Plan is cleaned and fit for its intended use. Send to Secretary, New Mexico Environment Department, 525 Camino de los Marquez, Santa Fe, New Mexico, 87503.

TABLE G-4
HAZARDOUS RELEASE REPORTING, STATE OF NEW MEXICO

Regulations	Chemical Releases Covered	To Whom Report Must Be Made	What Must Be Reported	
			Immediately (Oral)	Subsequently (Written)
New Mexico Hazardous Waste Management Regulations-6 (HWMR-6), Part V and Part VI	RCRA "hazardous waste" releases (regardless of amount), fire, or explosion, which could threaten human health or environment outside the facility.	National Response Center: (800) 424-8802; State Emergency Response Commission: (505) 827-9223 (New Mexico State Police, Hazardous Materials Emergency Response); and Local Emergency Planning Committee: (505) 887-1191	(1) Name and telephone number of reporter; (2) name and telephone number of facility; (3) time and type of incident; (4) name and quantity of material involved; (5) extent of injuries, if any; and (6) possible health or environmental hazards outside the facility.	Prior to resumption of operations, notify that: (1) no waste that may be incompatible with released material is treated, stored, or disposed of until cleanup is complete, and (2) all emergency equipment listed in the Contingency Plan is cleaned and fit for its intended use. Send to Secretary, New Mexico Environment Department, 525 Camino de los Marquez, Santa Fe, New Mexico, 87503.

TABLE G-4
HAZARDOUS RELEASE REPORTING, STATE OF NEW MEXICO
(CONTINUED)

Regulations	Chemical Releases Covered	To Whom Report Must Be Made	What Must Be Reported	
			Immediately (Oral)	Subsequently (Written)
(HWMR-6), Part V and Part VI	Any incident which triggers implementation of Contingency Plan.	New Mexico Environment Department, Emergency Response Office, 24-hour telephone: (505) 827-9329 or Monday to Friday, 8am to 5pm: (505) 827-2915 or (505) 827-0188.	(1) Name and telephone number of reporter; (2) name and address of facility; (3) name and quantity of materials involved, to extent known; (4) extent of injuries, if any; (5) possible hazards to human health or the environment, outside the facility.	Within 15 days: (1) name, address and telephone number of owner/operator; (2) name, address and telephone number of facility; (3) date, time and type of incident (e.g., fire, explosion); (4) name and quantity of materials involved; (5) extent of injuries, if any; (6) possible hazards to human health or the environment; (7) estimated quantity of material that resulted from the incident. Prior to resumption of operations, notify that: (1) no waste that may be incompatible with released material is treated, stored or disposed of until cleanup is complete, and (2) all emergency equipment listed in the Contingency Plan is cleaned and fit for its intended use. Send to Secretary, New Mexico Environment Department, 525 Camino de los Marquez, Santa Fe, New Mexico, 87503.

TABLE G-4
HAZARDOUS RELEASE REPORTING, STATE OF NEW MEXICO
(CONTINUED)

Regulations	Chemical Releases Covered	To Whom Report Must Be Made	What Must Be Reported	
			Immediately (Oral)	Subsequently (Written)
√ New Mexico Emergency Management Act, Section 74-4B-5	Any accident (spill) involving hazardous materials (including hazardous substances, radioactive substances, or a combination thereof) which may endanger human health or the environment.	New Mexico Environment Department: (505) 827-9329; and State Emergency Response Commission: (505) 827-9223 (New Mexico State Police, Hazardous Materials Emergency Response).	(1) Name, address and telephone number of owner or operator; (2) name, address and telephone number of facility; (3) date, time and type of incident; (4) name and quantity of material(s) involved; (5) extent of any injuries; (6) assessment of actual or potential threat to environment or human health; (7) estimated quantity and disposition of recovered material.	Written submission within one week of time permittee becomes aware of discharge. Same as oral and description of noncompliance and its cause, the period of noncompliance including exact dates and times, and if the noncompliance has not been corrected, the anticipated time it is expected to continue; and steps taken or planned to reduce, eliminate, and prevent reoccurrence. Send reports to New Mexico Environment Department, Chief, Ground Water Bureau, 525 Camino del los Marquez, Santa Fe, New Mexico, 87503; and New Mexico State Emergency Response Commission Department of Public Safety, Title III Bureau, P.O. Box 1628 Santa Fe, New Mexico, 87504-1628.

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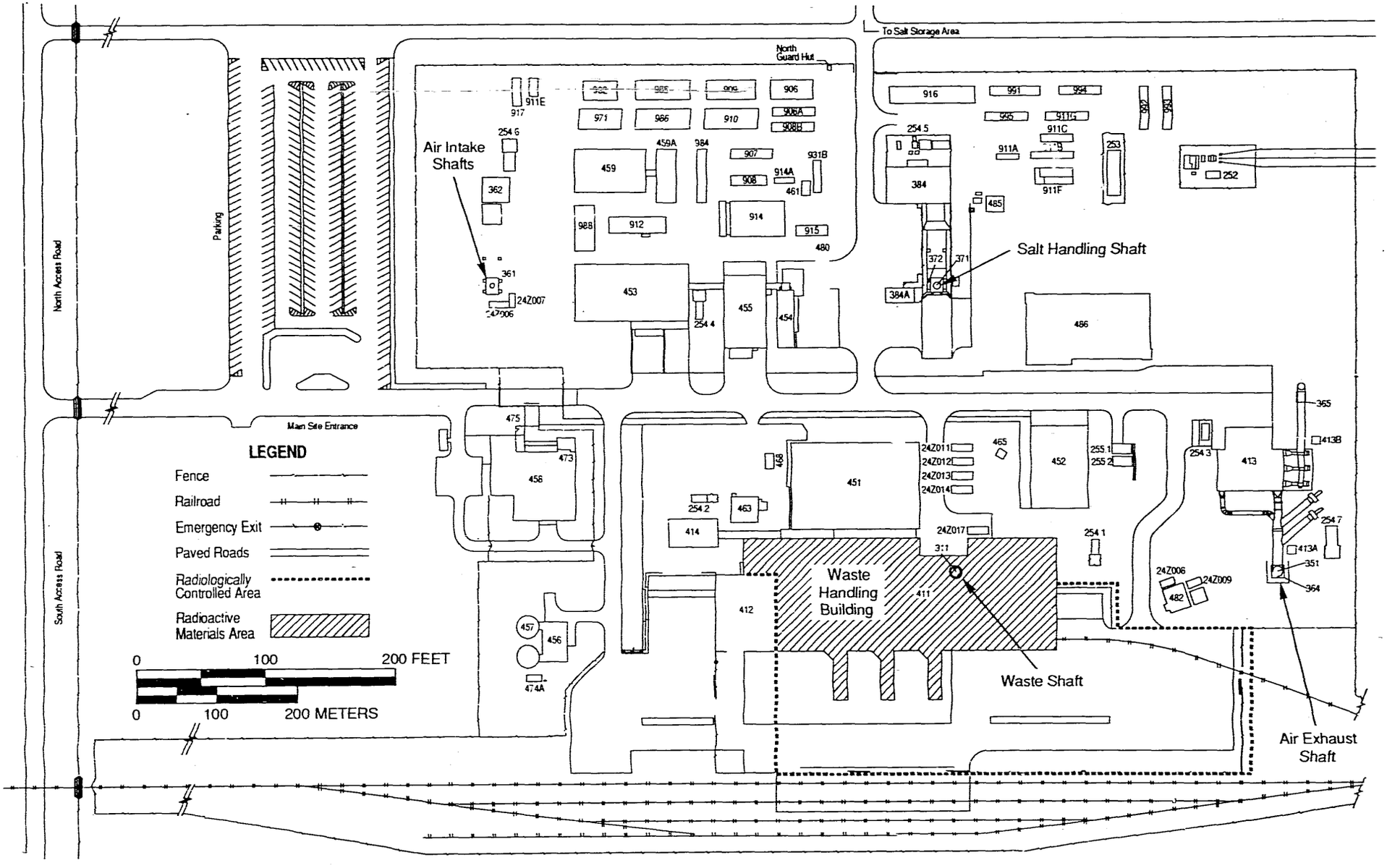
TABLE G-4
HAZARDOUS RELEASE REPORTING, STATE OF NEW MEXICO
(CONTINUED)

Regulations	Chemical Releases Covered	To Whom Report Must Be Made	What Must Be Reported	
			Immediately (Oral)	Subsequently (Written)
New Mexico Water Quality Control Commission, Part 1, Section 203	Any discharge from any facility of oil or any other water contaminant in such quantities as may, with reasonable probability, injure or be detrimental to human health, animal or plant life, or property.	Chief, Ground Water Bureau, New Mexico Environment Department, or his counterpart in any constituent agency delegated responsibility for enforcement of the rules as to any facility subject to such delegation (505) 827-2918.	Within 24 hours: (1) the name, address, and telephone number of the person or persons in charge of the facility; (2) the name, address, and telephone number of the owner/operator of the facility; (3) the date, time, location, and duration of the discharge; (4) the source and cause of the discharge; (5) a description of the discharge, including its chemical composition; (6) the estimated volume of discharge, and immediate damage from the discharge.	Submit within seven days: verification of the prior oral notification, also provide any appropriate additions or corrections to the information contained in the prior oral notification. Within 15 days: submit a written report describing any corrective actions taken and/or to be taken relative to the discharge. Send reports to Chief, Ground Water Bureau, New Mexico Environment Department, 525 Camino de los Marquez, Santa Fe, New Mexico, 87503.
New Mexico Underground Storage Tank Regulations-2	Any known or suspected release from an Underground Storage Tank (UST) system, any spill or any other emergency situation.	New Mexico Environment Department (Hazardous Waste Bureau): (505) 827-9329.	Within 24 hours: (1) the name, address, and telephone number of the agent in charge of the site at which the UST system is located, as well as the owner/operator of the system; (2) the name and address of the site and the location of the UST system on that site; (3) the date, time, location, and duration of the spill, release, or suspected release; (4) the source and cause of the spill, release, or suspected release; (5) a description of the spill, release, or suspected release, including its chemical composition; (6) the estimated volume of the spill, release, or suspected release; (7) action taken to mitigate immediate damage from the spill, release, or suspected release.	Mail or deliver within seven days of the incident, a written notice describing the spill, release, or suspected release and any investigation or follow-up action taken or to be taken. Send reports to Underground Storage Tank Program, New Mexico Environment Department, 525 Camino de los Marquez, Santa Fe, New Mexico, 87503.

FIGURES



Reference: DOE, 1990d

FIGURE G-1 WIPP SURFACE STRUCTURES

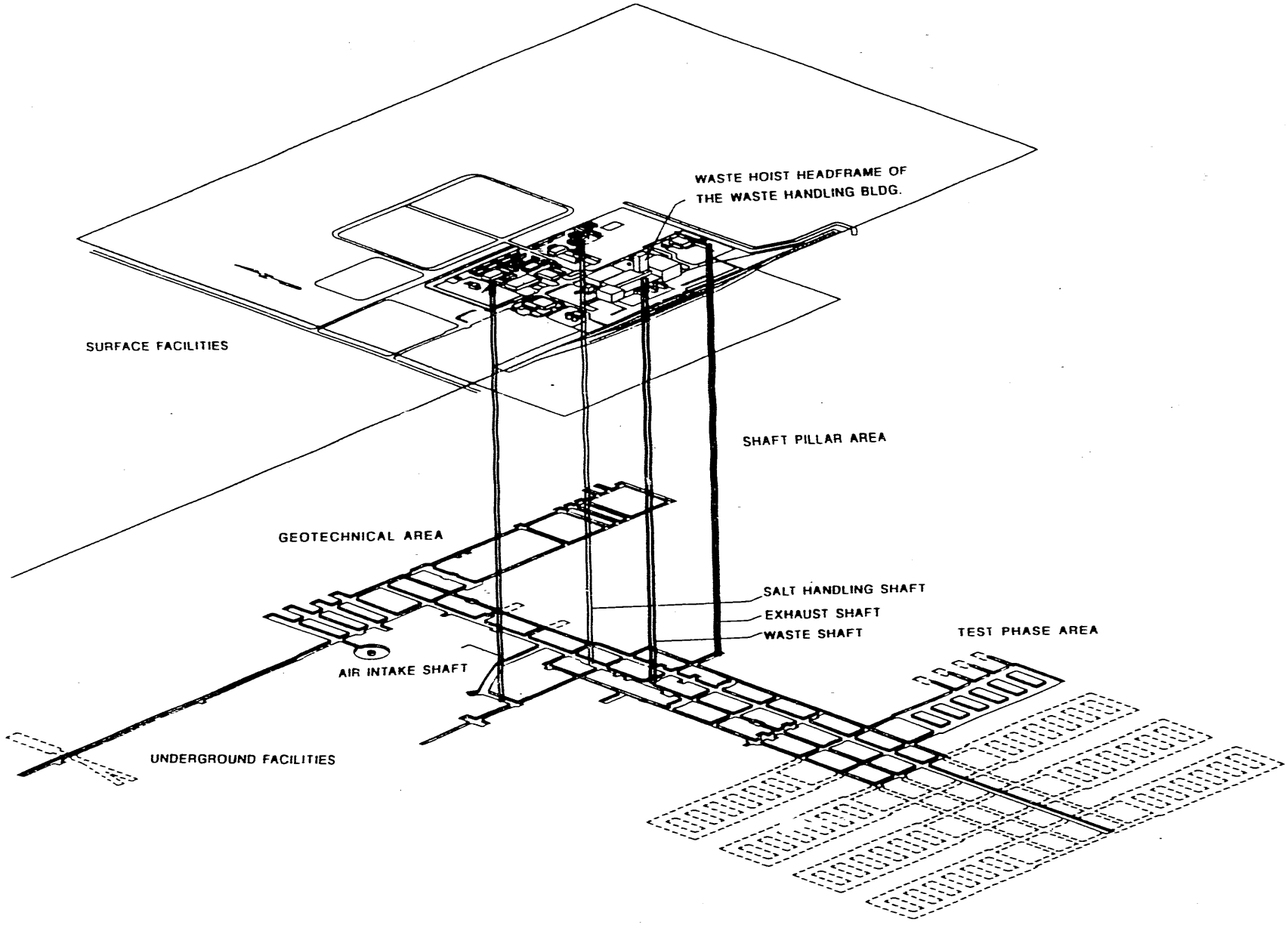
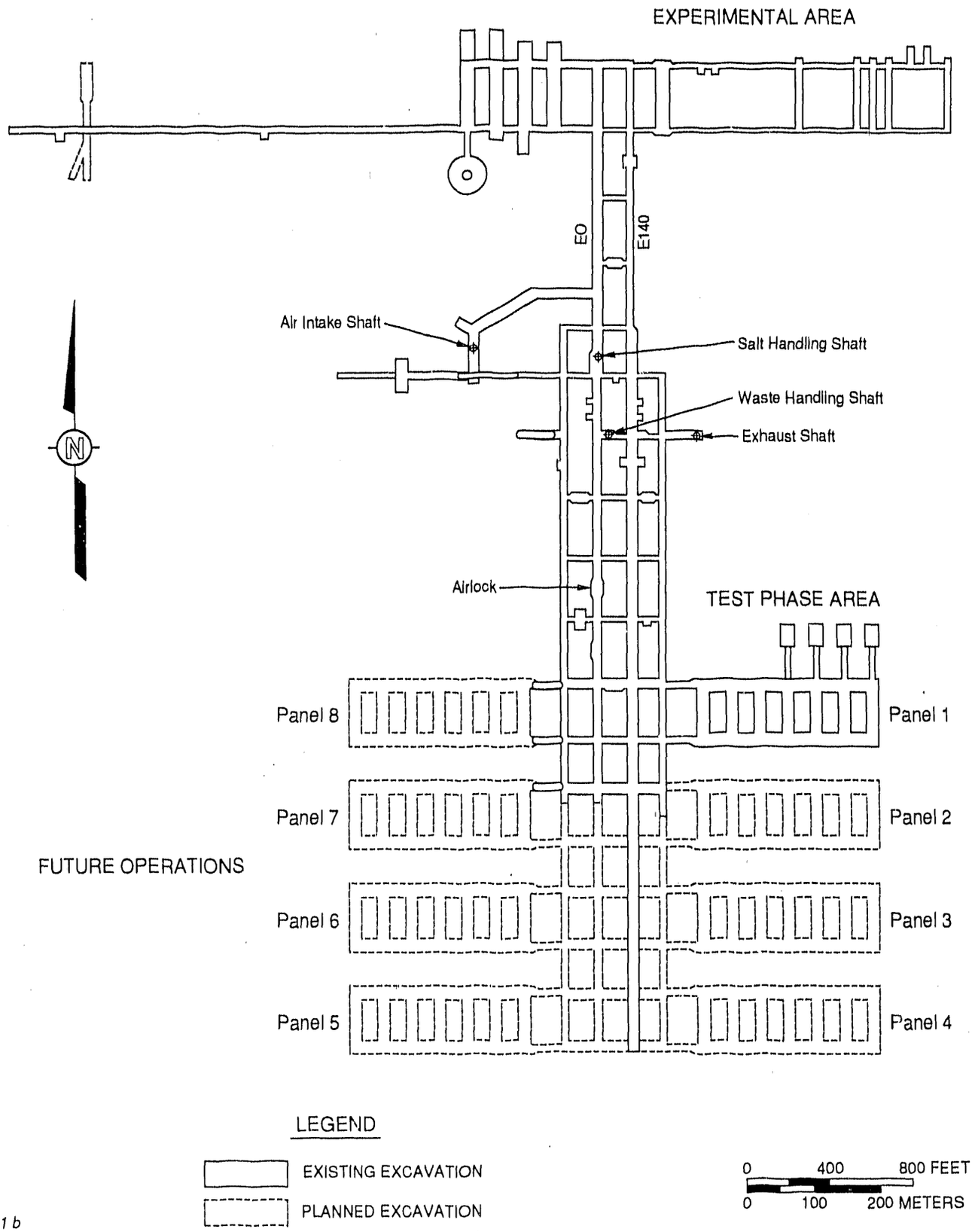


FIGURE G-2 SPATIAL VIEW OF THE WIPP FACILITY

This Illustration for Information Purposes Only.



DOE, 1991 b

FIGURE G-3 WIPP UNDERGROUND FACILITIES

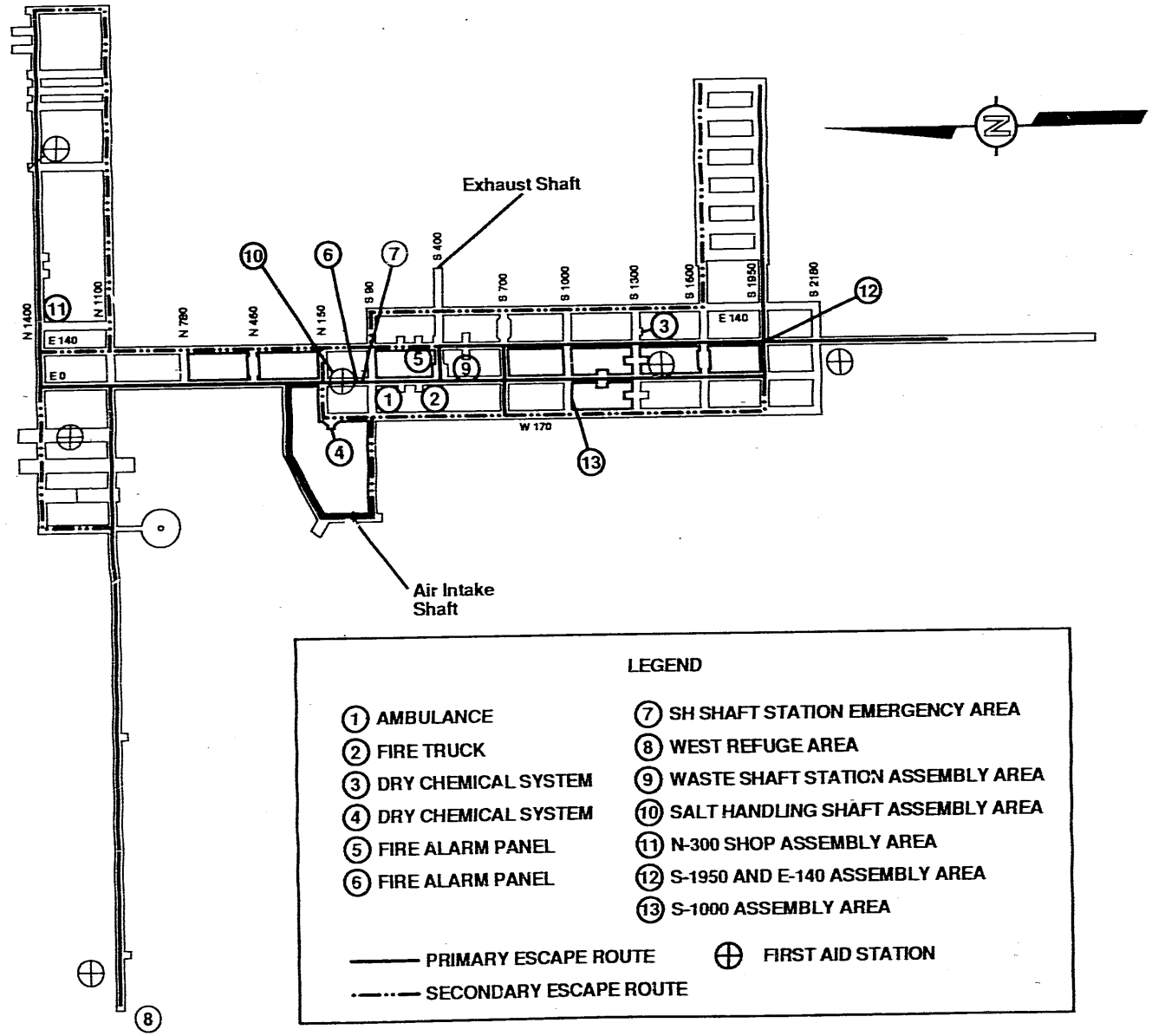


FIGURE G-4 UNDERGROUND EMERGENCY EQUIPMENT LOCATIONS AND UNDERGROUND EVACUATION ROUTES

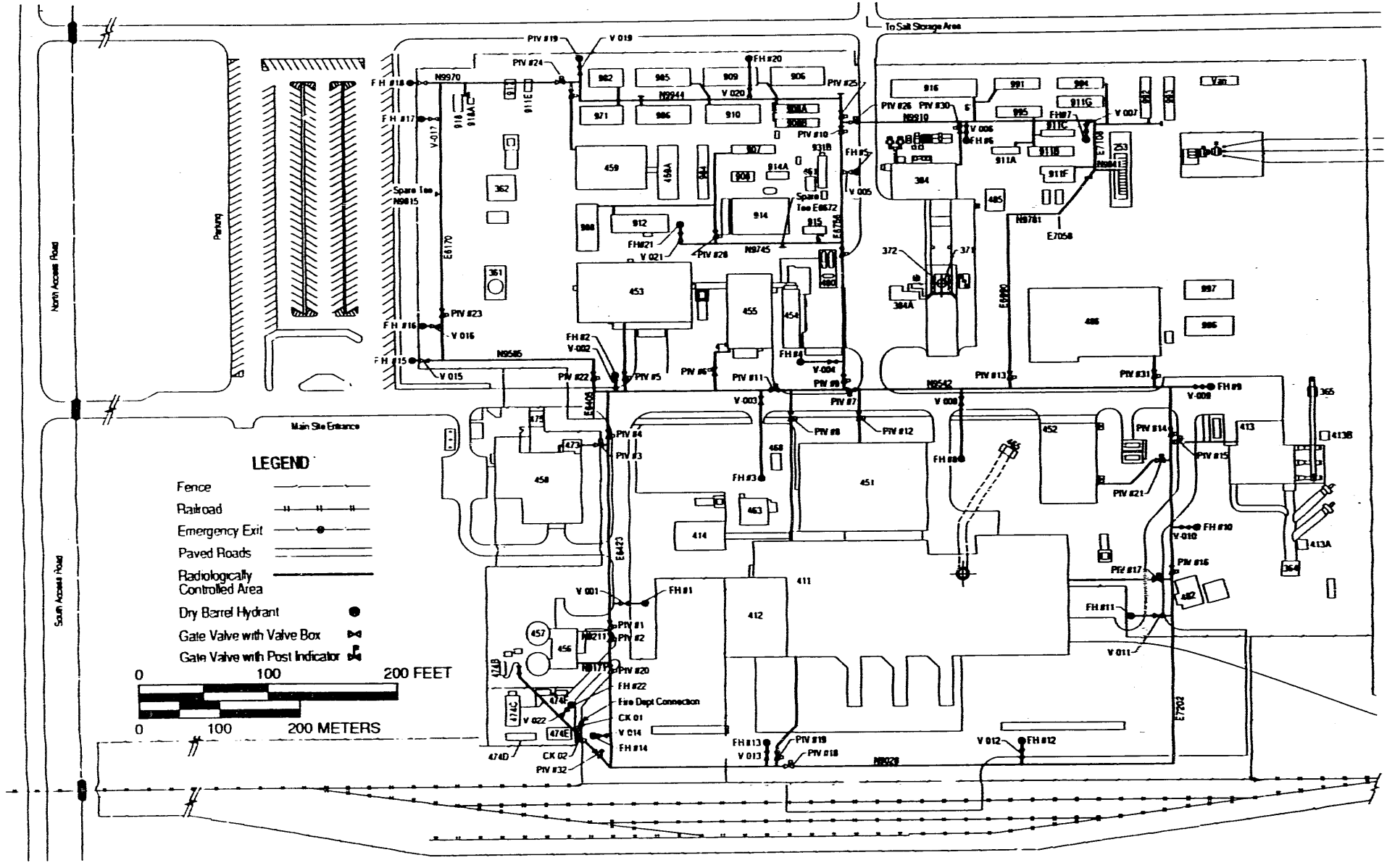


FIGURE G-5 FIRE WATER DISTRIBUTION SYSTEM

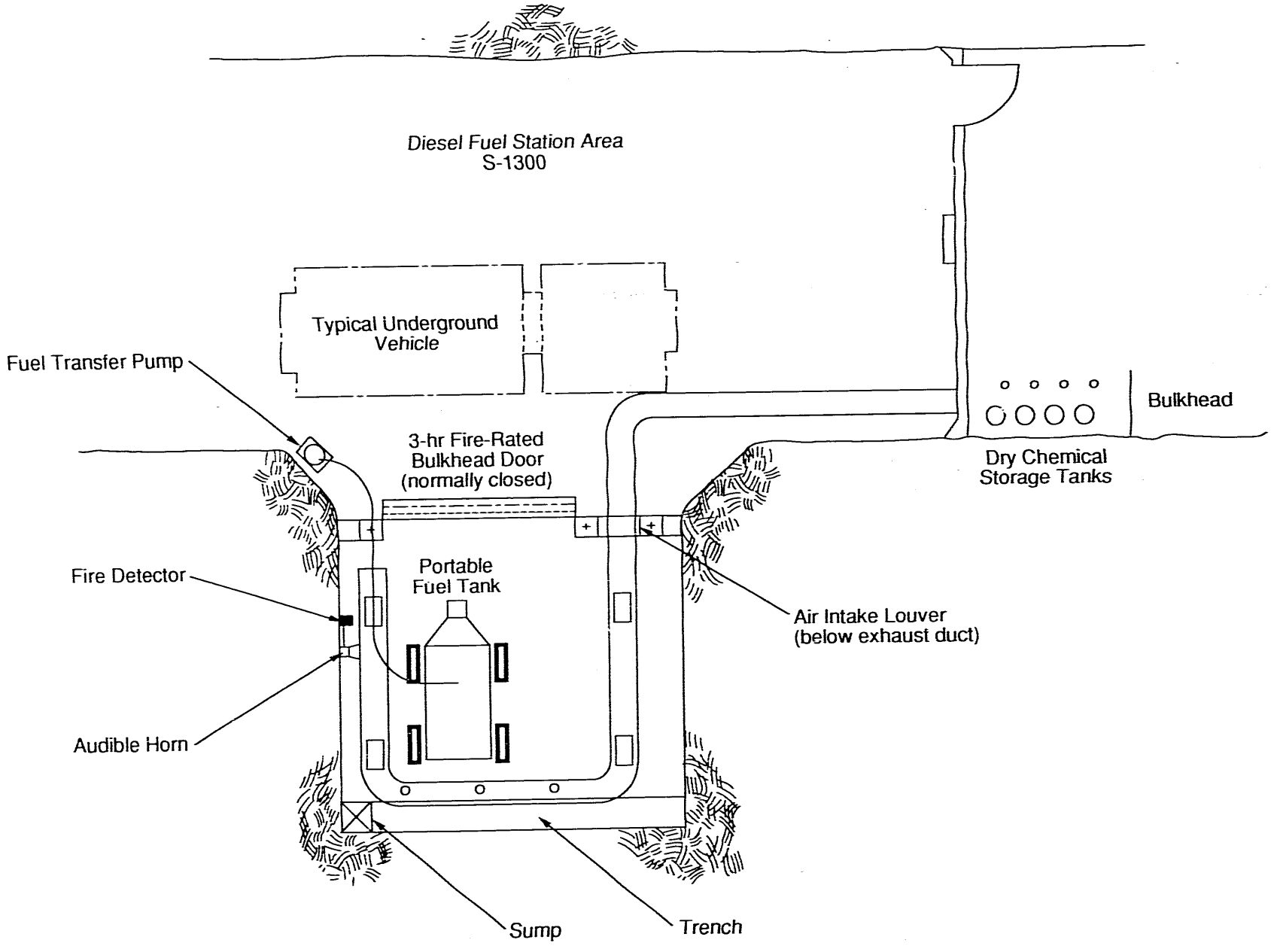


FIGURE G-6 UNDERGROUND FUEL AREA FIRE PROTECTION SYSTEM

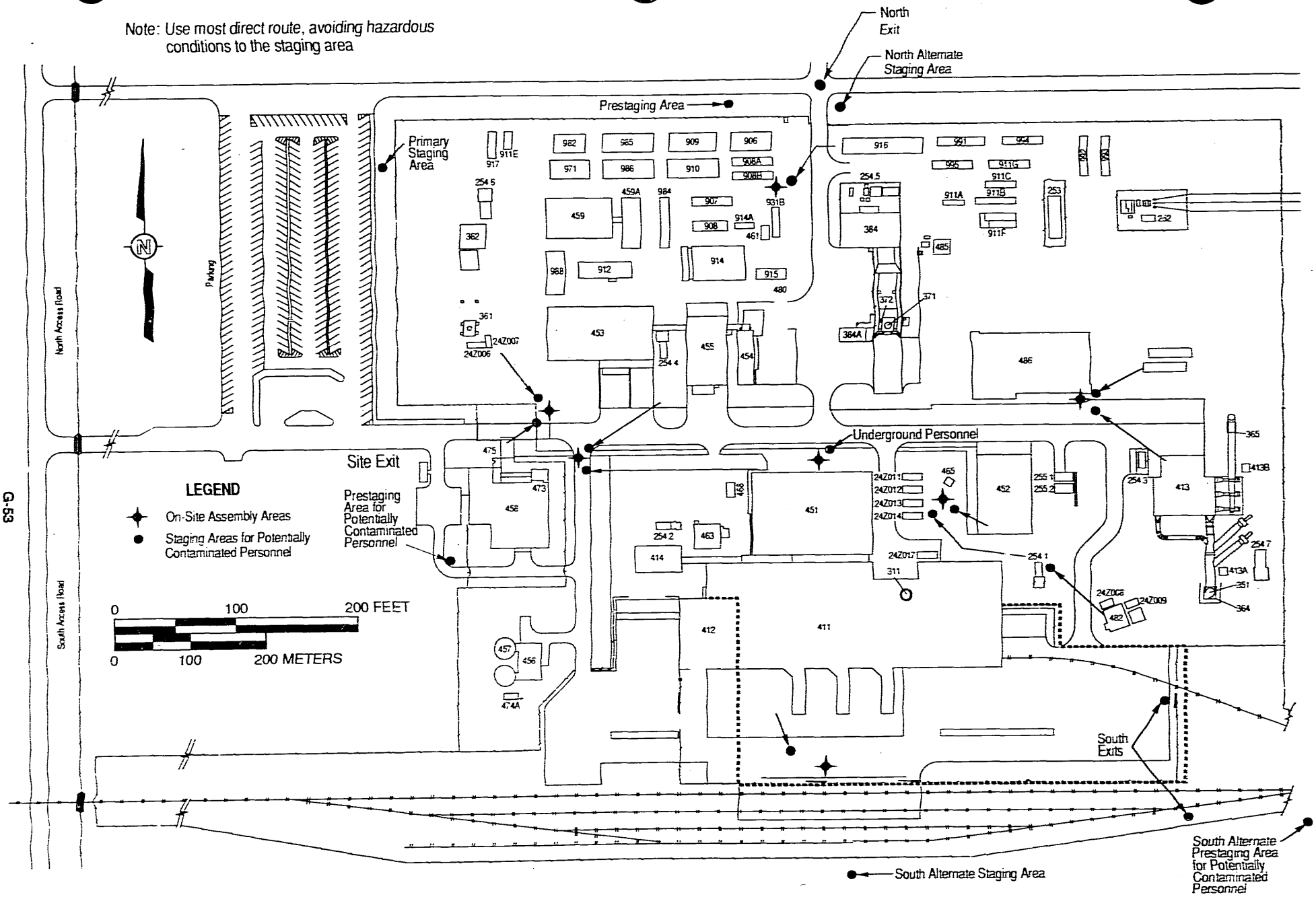


FIGURE G-7 WIPP ON-SITE ASSEMBLY AREAS AND WIPP OFF-SITE STAGING AREAS

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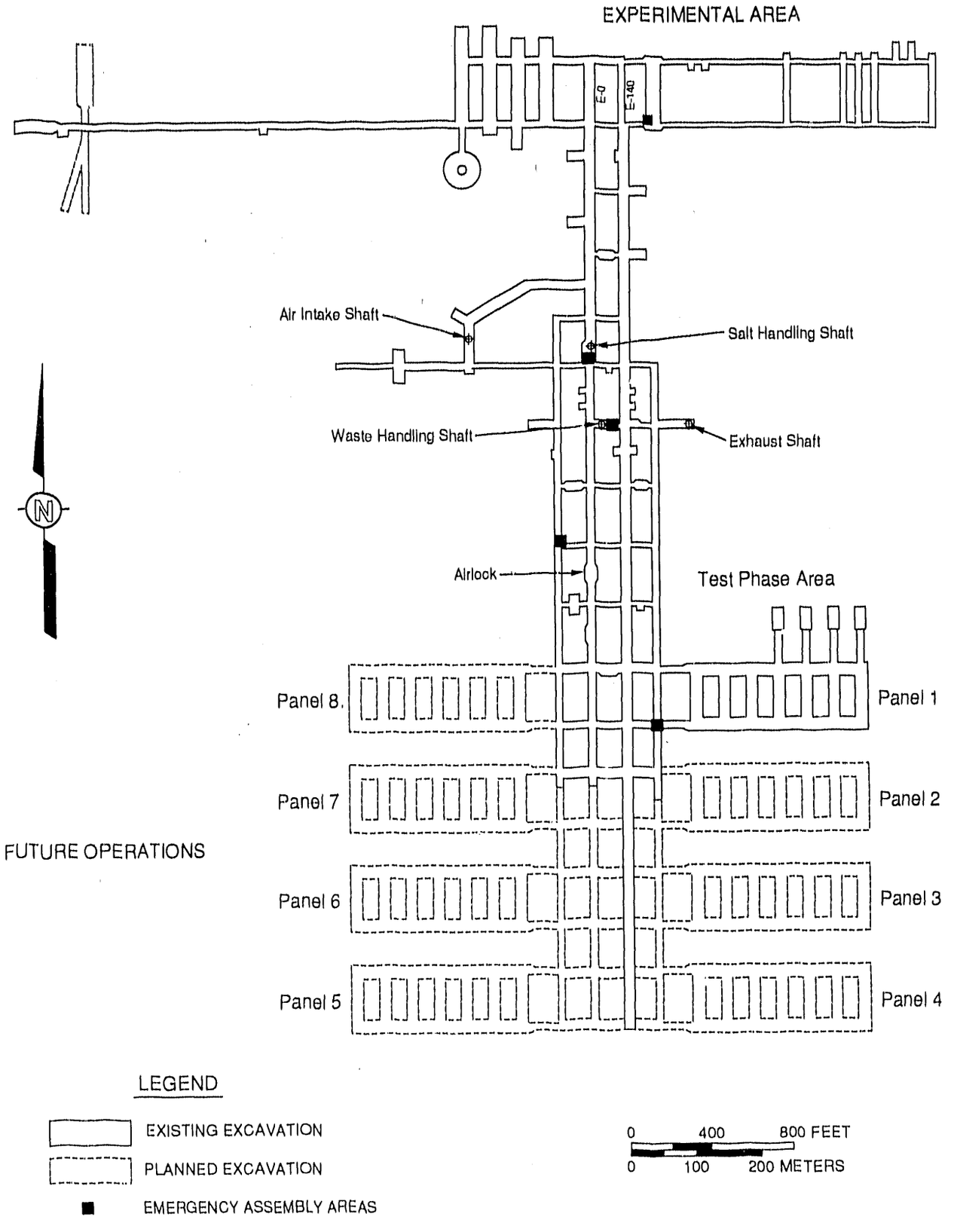

FIGURE G-8 DESIGNATED UNDERGROUND ASSEMBLY AREAS

CHAPTER H

PERSONNEL TRAINING

CHAPTER H
PERSONNEL TRAINING
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CHAPTER H
PERSONNEL TRAINING

Introduction

This chapter describes the personnel training program for the Waste Isolation Pilot Plant (WIPP) in accordance with the requirements of the Resource Conservation and Recovery Act (RCRA) and the New Mexico Hazardous Waste Act as described in the New Mexico Hazardous Waste Management Regulations (HWMR-6), Part V, section 264.16, and HWMR-6, Pt. IX, sec. 270.14.

The primary objective of the WIPP facility training program is to prepare personnel to operate the WIPP facility in a safe and environmentally sound manner. To achieve this objective, the program provides all employees with training relevant to their positions. Every WIPP facility employee, including those not directly involved in waste handling activities, receives an introduction to RCRA and emergency preparedness within 30 days of employment. In this way, everyone at the WIPP facility has, at a minimum, a basic understanding of the regulatory requirements and emergency procedures. Employees in waste management positions receive additional classroom and on-the-job training designed specifically to teach them how to perform their duties safely and in conformance with regulatory requirements. Waste management personnel receive the required training before being allowed to work unsupervised, and emergency response personnel receive the training before being called upon to respond to real emergencies.

The training requirements apply to all appropriate employees of the U.S. Department of Energy (DOE), the Management and Operating Contractor, the scientific advisor, and contractors who regularly work at the facility and who may come in contact with and/or manage hazardous waste. The WIPP Project training program, which is fully described in WP 14-1, WIPP Training Program Manual (Westinghouse, 1991), is comprehensive and applies to all areas of personnel performance and development. This chapter describes the introductory and continuing training provided to personnel who are directly involved with waste management at the WIPP facility that allows them to operate the facility safely and in compliance with hazardous waste regulations.

H-1 Outline of the Training Program

Employee training at the WIPP facility is the overall responsibility of the facility General Manager, with responsibility for implementation delegated to the Manager of the Human Resources Department. Members of the training staff are assigned to Technical Training within the Human Resources Department. The organizational structure of the Human Resources Department and its relationship to the line organizations is shown in an abbreviated organizational chart in Figure H-1.

The WIPP facility uses a modified version of the Performance-Based Training (PBT) approach to analyze, design, develop, implement, and evaluate training. Training needs are identified through the joint effort of Technical Training and line management. These groups then identify the appropriate training setting, either classroom instruction or on-the-job training. Specific procedures for identifying training needs are contained in WP 14-1 (Westinghouse, 1991).

All training is conducted by instructors certified by the Human Resources Department. On-the-job training is conducted by Level I trainers. Level I trainers are technically knowledgeable members of line organizations who have qualified on the related equipment and have attended the on-the-job training course. Classroom instruction is provided by Level II and Level III trainers. Level II trainers are members of Technical Training and line organizations who are qualified to conduct limited classroom training in their technical area of expertise. Level III trainers are members of Technical Training who are qualified to conduct classroom training, skills evaluation, and needs assessment. Levels II and III instructors are required to attend a train-the-trainer course and periodic refresher training.

Certified instructors develop the following, as required:

Classroom Instruction

- Objectives
- Lesson Plans
- Student Materials
- Examinations.

On-the-Job Training

- Qualification Cards
- Competency Statements.

All technical training materials are approved by the Technical Training Manager and cognizant line manager.

Following all technical training, trainees must successfully complete examinations to demonstrate competency. These examinations are based on objectives and/or competency statements. Trainees also provide feedback on the content and quality of instruction at this time in the form of course critiques and verbal input.

Training documentation is maintained by the Human Resources Development Section located at the WIPP facility. These training records include:

- Course Attendance
- Completed Qualification Cards
- Off-Site Training Documentation
- Completed Certification Cards.

A computer data base maintains records on training qualifications, certifications, and course attendance. The data base is used to identify course refresher and requalification dates. All training records on current personnel are kept in the Human Resources Development Section training files. Training records on former employees are kept by the Human Resources Development Section or at the Master Records Center for at least three years from the date of employment termination from the WIPP facility.

To ensure the safe and efficient operation of the WIPP facility, certain positions require formal certification. Department managers identify these positions based upon safety, complexity, and involvement with waste handling operations. A document known as a "certification card" is prepared to identify required training for each designated position. In the case of equipment and system/procedure qualification, a document called a "qualification card" is prepared that specifies the required knowledge and skills needed in such areas as equipment maintenance and safety. When the qualification card is completed, that particular qualification is recorded on the certification card. Successful completion of formal classroom training is verified by a qualified instructor by initialling the individual's certification card. When all requirements are met, both for classroom instruction and on-the-job training, the certification card is signed by the Department Manager certifying that the employee is fully competent to perform all aspects of the associated job position. Certification cards are included in the training records maintained by the Human Resources Development Section. Certification cards are living documents subject to change as the scope and content of training changes to meet new and revised regulatory requirements and modifications in job scope.

The waste management training program described in Section H-1b consists of a series of courses designed to ensure that waste management employees at the WIPP facility receive initial and continuing training relevant to their positions. These courses include instruction on the RCRA and Occupational Safety and Health Administration (OSHA) regulations, emergency procedures, and procedures for handling both site-generated hazardous waste and mixed waste.

Visitors, temporary personnel, and contractors are trained commensurate with the nature of the visit or duties.

H-1a Job Title/Job Description

Appendix H1 is a list of job titles for those positions at the WIPP facility that involve hazardous waste management. The job descriptions for these positions include hazardous waste

management job duties, required skills, qualifications, and experience, as well as educational requirements. These job descriptions are approved by the cognizant staff managers. A file of all waste management job titles and job descriptions and a list of employees for each job title are maintained at the WIPP facility by the Human Resources Department. The aforementioned files are maintained to reflect the changing scope of job titles or descriptions and are located in the Human Resources Department.

H-1b Training Content, Frequency, and Techniques

The WIPP training program includes a comprehensive combination of internal training courses and on-the-job training. Each training course is carefully developed and periodically reevaluated to ensure relevancy to the course objectives and to ensure its support of the goal of safe and environmentally sound operations at the WIPP facility. On-the-job training receives an equivalent amount of attention through the use of qualification cards. Before an employee is considered qualified to operate certain equipment, the person must pass a prescribed set of performance standards to the satisfaction of a Level I instructor.

H-1b(1) Training Content

All WIPP facility employees and subcontractors who will be on site longer than 30 days, including those not directly involved with hazardous waste management, receive facility-specific training in the following areas:

- General Employee Training (GET) Overview (procedures and policies)
- WIPP Facility Description
- Radiation Safety
- Emergency Preparedness (including Contingency Plan implementation)
- Security
- Fire Protection
- Quality Assurance
- Occurrence Reporting
- Industrial Safety
- RCRA/OSHA Overview
- Surface and Underground Facilities Tour.

This training is provided in GET-101, a three-day course conducted by certified WIPP facility instructors, and must be completed within 30 days of employment. Effective January 16, 1991, GET-101 was expanded to include the RCRA/OSHA Overview module. Consequently, all waste management personnel working at the WIPP facility prior to January 16, 1991, were required to take the RCRA/OSHA overview training as a separate course, RCRA/OSHA Overview (REP-107).

Annual refresher training on the topics taught in GET-101 (and REP-107 as applicable) is given in the General Employee Training Refresher course (GET-102). This provides current employees with a review and update of the topics covered in GET-101.

√ All WIPP facility employees involved in managing mixed waste will receive the Mixed Waste
√ Worker course (REP-109) prior to receipt of waste at the WIPP facility. All subsequent new hires into these positions will receive REP-109 before working unsupervised and within six months from date of employment. REP-109 will provide job-specific training concerning procedures for safely receiving mixed waste and transferring it to the underground for use in the Test Phase. The Mixed Waste Worker Refresher course (REP-111) will be given annually to provide a review and update of the initial training received in REP-109.

√ All WIPP facility employees involved in managing site-generated, nonradioactive hazardous waste receive the Site-Generated Hazardous Waste Worker course (REP-108). This course provides instruction regarding job-specific hazardous waste management procedures including emergency procedures. Review and update of REP-108 topics is provided annually by the Site-Generated Hazardous Waste Worker Refresher course (REP-110). To ensure consistent and current RCRA training, all hazardous waste workers were required to take REP-108 in January 1991.

√ The Hazardous Waste Transportation course (HMT-102) will be given to all WIPP facility
√ employees involved in transportation of hazardous waste at the WIPP facility. All employees receiving HMT-102 will be given annual refresher training by taking the Hazardous Waste Transportation Refresher course (HMT-103).

H-1b(2) Training Frequency

Waste management courses will be offered at a frequency that ensures new hires or transfers can receive relevant training within six months of assuming their new position. Employees do not work unsupervised in waste management positions until they have completed the required initial
√ training identified in Table H-1, Hazardous Waste Management Job Position Training Requirements. The Human Resources Department, Employee Relations Section, notifies the cognizant manager and training staff when any employee is transferred into or out of a position associated with waste management.

Personnel listed in the matrix are required to complete the indicated courses per the dates
√ established in the matrix and as provided in WP 14-1 (Westinghouse, 1991).

Because of the research and development nature of portions of this project, it is possible that not all training aspects have been identified at this time. In particular, future bin-scale testing is likely to require development of a specific training curriculum. Once details of bin-scale testing are established, a detailed analysis by training staff and appropriate line managers will be conducted

to determine the required training program. The final training program will incorporate all training elements that ensure safe and environmentally sound bin-scale testing as required by RCRA. This training program will be conducted prior to commencing bin-scale testing.

H-1b(3) Training Techniques

A variety of instructional techniques are used at the WIPP facility depending on the subject matter and the techniques that best suit the learning objectives. Many courses include a combination of lectures, demonstrations, visual aids (such as video tapes, slides, and viewgraphs), and exercises. Most equipment operation courses include hands-on practical instruction.

Written examinations are used as a technique to test the knowledge level of individuals participating in classroom training courses. The length and content of each exam varies according to its objective. Calculation, multiple choice, and fill-in-the-blank questions may be used. If individuals fail a written examination, they must be reexamined in identified areas of weakness.

On-the-job training at the WIPP facility follows a prescribed set of standards specific to the job to be performed. Typically, to become qualified to operate a piece of equipment or system, employees must be able to demonstrate the location and purpose of specified controls and gages, describe proper startup and shutdown procedures, describe specific safety features and limitations of the equipment, and perform maintenance functions. They must also demonstrate the ability to operate the equipment or system.

H-1c Training Director

The Technical Training Manager directs the training program and is responsible for establishing technical training requirements in cooperation with the line managers. Specifically, this includes analysis, design, development, implementation, and evaluation of technical training. The Technical Training Manager is required, at a minimum, to have a bachelor's degree and five years of nuclear experience or seven years of nuclear training experience. The incumbent is required to be trained in hazardous waste management procedures and to receive train-the-trainer and instructor training. The Technical Training Manager is also required to be knowledgeable of the applicable regulations, orders, and guidelines and the specific training process employed at the WIPP facility.

The name and qualifications of the current Technical Training Manager are documented at the WIPP facility.

Hazardous waste management training is provided by certified Level I, II, or III instructors that are knowledgeable and trained in hazardous waste management procedures.

H-1d Relevance of Training to Job Position

√ The WIPP facility training program provides employees with training relevant to their positions. The PBT process described in Section H-1 is a systematic method for determining the proper training for each waste management position. It compels managers and training staff to look critically at each position and to determine the necessary training program for each employee to fully develop their necessary expertise.

√ Several training courses are determined to be so basic to the WIPP Project mission that they are
√ considered relevant for all WIPP facility employees. The basic philosophy at the WIPP facility is that, as a RCRA-regulated facility, all employees must understand the basic regulatory
√ requirements under which the WIPP facility must operate. Therefore, all WIPP facility employees receive an introduction to RCRA during their introductory training.

Beyond these "umbrella" courses, training is designed and implemented relevant to the specific job functions being performed. For example, employees who operate key pieces of equipment
√ (such as forklifts, hoists, etc.) must be trained to operate and inspect equipment and recognize
√ maintenance problems before a specific job function is performed. These employees must receive classroom instruction and on-the-job training and demonstrate the ability to operate the equipment, as appropriate, before being certified. This process is controlled and documented by the certification/qualification process described in Section H-1. Descriptions of all training courses are on file in the Human Resources Development Section.

Supervisors who have direct responsibility for supervising waste management personnel receive waste management training relevant to their positions and are included in the matrix in Table H-1. Managers who do not have direct waste management supervisory responsibilities receive training sufficient to ensure their awareness of waste management requirements and procedures; however, they do not perform waste management duties and are not included in Table H-1. As
√ is the case with all WIPP facility employees, all managers receive RCRA/OSHA overview training.

Security personnel are an important element of the safe and secure operations at the WIPP
√ facility; however, they do not perform waste management functions and are not included in Table H-1.

H-1e Training for Emergency Response

√ The WIPP facility training program ensures that personnel are able to respond appropriately and
√ effectively to emergency situations. All WIPP facility employees receive GET-101, which includes instruction on hazard awareness, emergency preparedness, spill control, and the WIPP
√ Contingency Plan (Chapter G of this permit application). This training ensures that every

employee understands how to recognize real or potential emergencies and how to report such occurrences to the proper WIPP facility officials. It also ensures that employees will not endanger themselves or others by taking actions beyond their ability.

The WIPP facility emergency response organization consists of two units: the Emergency Response Team and the First Line Initial Response Team. The responsibilities of these two units are described in the WIPP Contingency Plan, Chapter G of this permit application. Members of these teams are security personnel and volunteers from the WIPP organization. They receive thorough emergency response training before they are called upon to perform in real emergencies. This training includes fire-fighting elements such as fire behavior, ladders, fire hose, fire streams, and ventilation; lifesaving elements such as rescue, cardiopulmonary resuscitation, and first aid; and self-contained breathing apparatus and hazardous materials.

Because these response teams are for unusual occurrences and not routine hazardous waste handling, a RCRA position title is not included in the matrix in Table H-1. Training records for these individuals are maintained in each individual's training file in the Human Resources Development Section located at the WIPP site.

Waste handling and emergency response personnel receive training that ensures their familiarity with emergency procedures, emergency equipment, and emergency systems including:

- Procedures for using, inspecting, repairing, and replacing facility emergency and monitoring equipment.
- Communications and alarm systems.
- Response to fires or explosions.
- Shutdown of operations.

As there are no automatic waste feed systems at the WIPP facility, training on parameters for waste feed cut-off systems is not required. Similarly, as there is no potential for ground water contamination incidents at the WIPP facility, training for responding to such incidents is not required.

H-2 Implementation of Training Program

The WIPP facility training program has been in place for over two years and is being implemented to ensure that all waste management personnel employed at the WIPP facility receive the training indicated in Table H-1 or equivalent course work. All personnel are trained on the Contingency Plan through their basic training. All recently hired employees and new-hires receive the

indicated training within six months of their date of hire or their transfer to a new position. Personnel do not work in unsupervised positions until they successfully complete the indicated training requirements. All waste management personnel attend annual refresher courses that review the initial training received.

√ Records relating to the WIPP facility training program for waste management personnel are
√ maintained by the WIPP Human Resources Department located at the WIPP facility. These records include the job titles and job descriptions for all waste management positions; a roster of employees in those positions; a list of courses required for each position; course descriptions; documentation that each employee has received and completed appropriate training; and all of the backup information regarding certification, qualification, and examination. Training records of current personnel are kept by the Human Resources Development Section until closure of the
√ WIPP facility. Records of former employees are kept by the Human Resources Development Section or at the Master Records Center for at least three years from the date the employee last worked at the facility.

List of References for Chapter H

Westinghouse Electric Corporation (Westinghouse), 1991, "WIPP Training Program Manual," WP 14-1, Westinghouse Waste Isolation Division, Carlsbad, New Mexico.

TABLE

TABLE H-1
HAZARDOUS WASTE MANAGEMENT JOB POSITION TRAINING REQUIREMENTS

RCRA Position Title	Section	Employment Status	INITIAL TRAINING					ANNUAL REVIEW			
			General Employee Training (GET-101)	RCRA/OSHA Overview (REP-107)	Mixed Waste Worker (REP-109)	Site-Gen. Haz. Waste Worker (REP-108)	Haz. Waste Transport. (HMT-102)	GET Refresher (GET-102)	Mixed Waste Refresher (REP-111)	Site-Gen. Haz. Waste Refresher (REP-110)	Hazardous Waste Transport. Refresher (HMT-103)
Shaft Tender	Hoisting Operations	New Current	A	B		C C		E F		H H	
Senior Shaft Tender	Hoisting Operations	New Current	A	B		C C		E F		H H	
Hoist Operating Specialist	Hoisting Operations	New Current	A	B		C C		E F		H H	
Supervisor, Hoisting Operations	Hoisting Operations	New Current	A	B		C C		E F		H H	
Manager, Hoisting Operations	Hoisting Operations	New Current	A	B		C C		E F		H H	
Senior Engineer	Hoisting Operations	New Current	A	B		C C		E F		H H	
Senior Operations Engineer 'B'	Facility Operations	New Current	A	B				E F			
Senior Engineer	Facility Operations	New Current	A	B				E F			
Shift Supervisor	Facility Operations	New Current	A	B				E F			
Manager, Facility Operations	Facility Operations	New Current	A	B				E F			
Waste Handling Technician	Waste Handling Operations	New Current	A	B	C D			E F	G G		
Senior Waste Handling Technician	Waste Handling Operations	New Current	A	B	C D			E F	G G		
Waste Handling Specialist	Waste Handling Operations	New Current	A	B	C D			E F	G G		
Senior Waste Handling Specialist	Waste Handling Operations	New Current	A	B	C D			E F	G G		
Senior Operations Engineer 'B'	Waste Handling Operations	New Current	A	B	C D			E F	G G		
Associate Operations Engineer	Waste Handling Operations	New Current	A	B	C D			E F	G G		
Manager, Waste Handling	Waste Handling Operations	New Current	A	B	C D			E F	G G		

TABLE H-1
HAZARDOUS WASTE MANAGEMENT JOB POSITION TRAINING REQUIREMENTS (CONTINUED)

RCRA Position Title	Section	Employment Status	INITIAL TRAINING					ANNUAL REVIEW			
			General Employee Training (GET-101)	RCRA/OSHA Overview (REP-107)	Mixed Waste Worker (REP-109)	Site-Gen. Haz. Waste Worker (REP-108)	Haz. Waste Transport. (HMT-102)	GET Refresher (GET-102)	Mixed Waste Refresher (REP-111)	Site-Gen. Haz. Waste Refresher (REP-110)	Hazardous Waste Transport. Refresher (HMT-103)
Health Physics Technician	Operational Health Physics	New Current	A	B	C D			E F	G G		
Senior Health Physics Technician	Operational Health Physics	New Current	A	B	C D			E F	G G		
Health Physics Specialist	Operational Health Physics	New Current	A	B	C D			E F	G G		
Senior Health Physics Specialist	Operational Health Physics	New Current	A	B	C D			E F	G G		
Manager, Operational Health Physics	Operational Health Physics	New Current	A	B	C D			E F	G G		
Quality Assurance Specialist	Inspection Services and QA Records	New Current	A	B	C D			E F	G G		
Senior Quality Assurance Technician	Inspection Services and QA Records	New Current	A	B	C D			E F	G G		
Quality Assurance Technician	Inspection Services and QA Records	New Current	A	B	C D			E F	G G		
Manager, Inspection Services & QA Records	Inspection Services and QA Records	New Current	A	B	C D			E F	G G		
Quality Assurance Analyst	Inspection Services and QA Records	New Current	A	B	C D			E F	G G		
Technical Assistant	Inspection Services and QA Records	New Current	A	B	C D			E F	G G		
Manager, Quality Assurance Engineering	Quality Assurance Engineering	New Current	A	B	C D			E F	G G		
Quality Assurance Engineer	Quality Assurance Engineering	New Current	A	B	C D			E F	G G		
Senior Quality Assurance Engineer	Quality Assurance Engineering	New Current	A	B	C D			E F	G G		
Senior Engineer	Quality Assurance Engineering	New Current	A	B	C D			E F	G G		

TABLE H-1
HAZARDOUS WASTE MANAGEMENT JOB POSITION TRAINING REQUIREMENTS (CONTINUED)

RCRA Position Title	Section	Employment Status	INITIAL TRAINING					ANNUAL REVIEW			
			General Employee Training (GET-101)	RCRA/OSHA Overview (REP-107)	Mixed Waste Worker (REP-109)	Site-Gen. Haz. Waste Worker (REP-108)	Haz. Waste Transport. (HMT-102)	GET Refresher (GET-102)	Mixed Waste Refresher (REP-111)	Site-Gen. Haz. Waste Refresher (REP-110)	Hazardous Waste Transport. Refresher (HMT-103)
Senior Engineer 'B'	Quality Assurance Engineering	New Current	A	B	C D			E F	G G		
Emergency Services Technician	Safety and Plant Protection	New Current	A	B	C D	C D	C D	E F	G G	H H	I I
Manager, Safety and Plant Protection	Safety and Plant Protection	New Current	A	B				E F			
Emergency Services Coordinator	Safety and Plant Protection	New Current	A	B	C D	C D	C D	E F	G G	H H	I I
Scientist, Environmental Permits and Programs	Environmental Permits and Programs	New Current	A	B				E F			
Senior Engineer	Environmental Strategic Planning	New Current	A	B				E F			
Principal Engineer	Environmental Strategic Planning	New Current	A	B				E F			
Engineering Technician	Environmental Analysis and Compliance	New Current	A	B	C D	C C	C D	E F	G G	H H	I I
Technical Assistant	Environmental Analysis and Compliance	New Current	A	B	C D	C C	C D	E F	G G	H H	I I
Experimental Technician	Environmental Analysis and Compliance	New Current	A	B	C D	C C	C D	E F	G G	H H	I I
Senior Engineer	Environmental Analysis and Compliance	New Current	A	B	C D	C C	C D	E F	G G	H H	I I
Senior Engineer "B"	Environmental Analysis and Compliance	New Current	A	B	C D	C C	C D	E F	G G	H H	I I

TABLE H-1
HAZARDOUS WASTE MANAGEMENT JOB POSITION TRAINING REQUIREMENTS (CONTINUED)

RCRA Position Title	Section	Employment Status	INITIAL TRAINING					ANNUAL REVIEW			
			General Employee Training (GET-101)	RCRA/OSHA Overview (REP-107)	Mixed Waste Worker (REP-109)	Site-Gen. Haz. Waste Worker (REP-108)	Haz. Waste Transport. (HMT-102)	GET Refresher (GET-102)	Mixed Waste Refresher (REP-111)	Site-Gen. Haz. Waste Refresher (REP-110)	Hazardous Waste Transport. Refresher (HMT-103)
Associate Scientist	Environmental Analysis and Compliance	New Current	A	B	C D	C C	C D	E F	G G	H H	I I
Senior Scientist 'B'	Environmental Analysis and Compliance	New Current	A	B	C D	C C	C D	E F	G G	H H	I I
Utility Technician	Maintenance Operations	New Current	A	B		C C		E F		H H	
Maintenance Technician	Maintenance Operations	New Current	A	B		C C		E F		H H	
Supervisor, Maintenance Operations	Maintenance Operations	New Current	A	B		C C		E F		H H	
Manager, Maintenance Operations	Maintenance Operations	New Current	A	B		C C		E F		H H	
Maintenance Specialist	Maintenance Operations	New Current	A	B		C C		E F		H H	
Senior Maintenance Specialist	Maintenance Operations	New Current	A	B		C C		E F		H H	
Assistant Engineer	Environmental Monitoring	New Current	A	B	C D	C C	C D	E F	G G	H H	I I
Training Coordinator	Technical Training	New Current	A	B	C D	C C	C D	E F	G G	H H	I I
Manager, Technical Training	Technical Training	New Current	A	B	C D	C C	C D	E F	G G	H H	I I
Associate Engineer	Quality Assurance Programs	New Current	A	B	C D			E F	G G		
Senior Quality Assurance Engineer	Quality Assurance Programs	New Current	A	B	C D			E F	G G		
Quality Assurance Specialist	Quality Assurance Programs	New Current	A	B	C D			E F	G G		

TABLE H-1
HAZARDOUS WASTE MANAGEMENT JOB POSITION TRAINING REQUIREMENTS (CONTINUED)

RCRA Position Title	Section	Employment Status	INITIAL TRAINING					ANNUAL REVIEW			
			General Employee Training (GET-101)	RCRA/OSHA Overview (REP-107)	Mixed Waste Worker (REP-109)	Site-Gen. Haz. Waste Worker (REP-108)	Haz. Waste Transport. (HMT-102)	GET Refresher (GET-102)	Mixed Waste Refresher (REP-111)	Site-Gen. Haz. Waste Refresher (REP-110)	Hazardous Waste Transport. Refresher (HMT-103)
Senior Engineer 'B'	Radiological Engineering	New Current	A	 B	C D			E F	G G		
Senior Engineer	Radiological Engineering	New Current	A	 B	C D			E F	G G		
Health Physics Specialist	Radiological Engineering	New Current	A	 B	C D			E F	G G		
Associate Operations Engineer	Hazardous Waste and Self Assessment	New Current	A	 B	C D	C D	C D	E F	G G	H H	I I
Senior Engineer 'B'	Hazardous Waste and Self Assessment	New Current	A	 B	C D	C D	C D	E F	G G	H H	I I
Senior Operations Engineer	Hazardous Waste and Self Assessment	New Current	A	 B		C D	C D	E F	G G	H H	I I
Maintenance Technician	Hazardous Waste and Self Assessment	New Current	A	 B		C D	C D	E F	G G	H H	I I
Utility Technician	Hazardous Waste and Self Assessment	New Current	A	 B		C D	C D	E F	G G	H H	I I
Manager, Trans. and Hazardous Materials Handling	Hazardous Waste and Self Assessment	New Current	A	 B	C D	C D	C D	E F	G G	H H	I I

A - 30 days following employment date
B - By January 22, 1991
C - 6 months following assignment date
D - By July 22, 1991
E - Within 12 months of GET-101 completion
F - Within 12 months of REP-107 completion
G - Within 12 months of REP-109 completion
H - Within 12 months of REP-108 completion
I - Within 12 months of HMT-102 completion

FIGURE

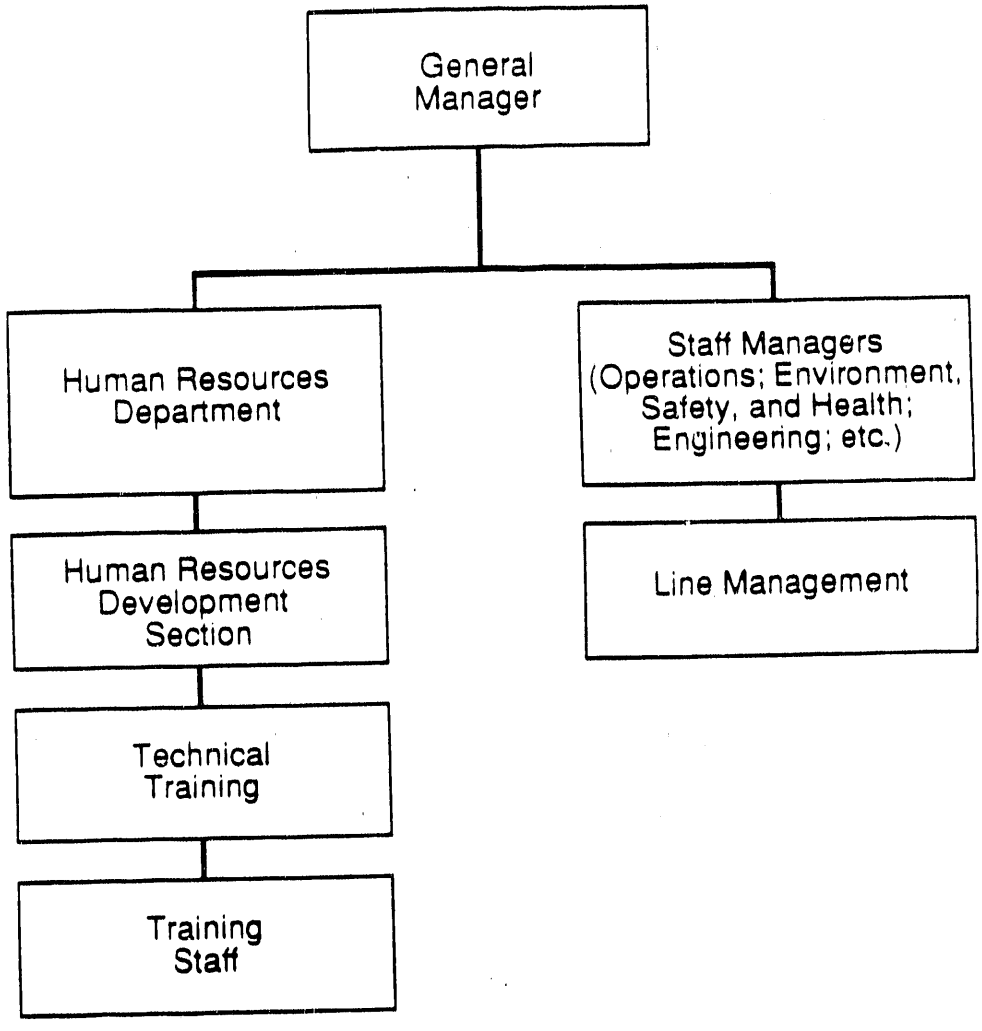

FIGURE H-1 ABBREVIATED WIPP FACILITY ORGANIZATIONAL CHART

CHAPTER I

CLOSURE PLANS, POST-CLOSURE PLANS, AND FINANCIAL REQUIREMENTS

CHAPTER I
CLOSURE PLANS, POST-CLOSURE PLANS, AND FINANCIAL REQUIREMENTS
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CHAPTER I
CLOSURE PLANS, POST-CLOSURE PLANS, AND FINANCIAL REQUIREMENTS

Introduction

This chapter contains the Test Phase Closure Plan, which describes the activities planned to close the Waste Isolation Pilot Plant (WIPP) facility at the end of the Test Phase should a decision be made not to proceed with the Operational Phase of the WIPP Project. If the WIPP facility is closed after the Test Phase, all waste emplaced during the Test Phase for in situ experiments will be removed from the underground and returned to the point of origin or transported to an interim treatment, storage, or disposal facility. The underground will be decontaminated, if necessary; routes of underground access will be sealed; all structures and equipment will be decontaminated and may be removed; and the site surface will be recontoured and revegetated. Current plans for Test Phase waste retrieval activities are described in the Waste Retrieval Plan (DOE, 1990). All closure activities and operations will maintain as low as reasonably achievable (ALARA) exposures as required by DOE Order 5480.11 (DOE, 1988a) to protect worker and public health and safety. The WIPP facility will "start clean-stay clean" throughout the Test Phase. Decontamination activities are discussed in this closure plan although it is highly unlikely that any decontamination will be necessary.

This plan is submitted to the NMED and the EPA with the Part B permit application in accordance with New Mexico Hazardous Waste Management Regulations (HWMR-6), Part IX, section 270.14(b)(13). The Closure Plan must be approved by the appropriate agency as part of the permitting procedure, and the approved plan will become a condition of the issued RCRA Part B permit. Until final closure is complete and has been certified in accordance with HWMR-6, Pt. V, sec. 264.115, a copy of the approved plan and all approved revisions will be on file at the WIPP facility and available to the Secretary of the NMED or the EPA Regional Administrator upon request.

I-1 Test Phase Closure Plan

This Test Phase Closure Plan is prepared in accordance with the requirements of HWMR-6, Pt. V, Subparts G and X. The New Mexico regulations incorporate 40 CFR Parts 260 through 270 by reference as HWMR-6 Parts I through IX. Regulatory citations in this plan reference the New Mexico regulations. Regulatory requirements that apply to the proposed closure activities are listed in Table I-1, with a cross-reference to the section of the plan where the requirement is addressed.

At the end of the Test Phase, waste will be retrieved from the underground test areas if the WIPP facility does not meet standards for long-term disposal of transuranic (TRU) waste established in the No-Migration Determination requirements of 40 CFR, Section 268. In addition, the WIPP facility must demonstrate the requirements of HWMR-6, Pt. V, sec. 264.601, as well as the requirements of 40 CFR Part 191. The DOE will identify an interim facility to accept the waste or the waste will be returned to its point of origin, as indicated on the waste shipping manifest. The steps involved in identifying an interim facility will depend on the scope of activity designated for the interim facility and include the following:

1. National Environmental Policy Act (NEPA) documentation will be prepared to describe and compare the environmental impacts of various alternatives, including the identification of a preferred alternative, a no action alternative, and other reasonable alternatives. This documentation will most likely involve the preparation of an environmental impact statement.

2. The NEPA documents will be reviewed by the public, and a final record of decision will be issued by DOE based on the review of the environmental impacts and the continued need for a solution to the TRU waste storage/disposal problem.

3. Facility and system designs and safety analyses will be prepared and reviewed.

4. Facility permits will be obtained, including a public comment period.

5. Facility construction would commence, followed by start-up testing, and subsequently, operations.

This process could take years, depending on the proposed activities at the interim facility. For example, a location merely to store the waste pending further disposition could be identified and permitted more quickly than an interim location designed for disposal where the waste may need to be modified through some process that could require extensive permitting.

A copy of this Closure Plan will be maintained at the WIPP facility and at the DOE-Albuquerque Field office. The primary contact person at the site is:

Arlen Hunt, Project Manager
U.S. Department of Energy
Waste Isolation Pilot Plant
P. O. Box 3090
Carlsbad, New Mexico 88221
(505) 887-8101

If, at the end of the Test Phase, the WIPP facility meets standards for long-term disposal of radioactive waste established by U.S. Environmental Protection Agency (EPA) regulations 40 CFR Part 191, Subpart B, implementing the Nuclear Waste Policy Act, waste will be moved from the underground test areas to the Waste Handling Building (WHB). The radiological control boundary/bin units will be reconfigured into standard waste boxes and placed underground for permanent disposal. Closure will begin at the conclusion of operations. After closure, evidence of the presence of the repository will be maintained by written records, shaft location markers, and site monuments to prevent any undesirable intrusion into the surface structures in the near term and, in the long term, to prevent any inadvertent penetration into the subsurface repository.

I-1a Closure Performance Standard

If, at the end of the Test Phase, the WIPP facility does not meet standards for long-term disposal of radioactive waste, the facility will be closed so as to minimize the need for further maintenance. In addition, the WIPP facility will control, minimize, or eliminate, to the extent necessary to protect human health and the environment, post-closure migration of hazardous waste, hazardous constituents, or hazardous waste decomposition products to ground or surface waters or the atmosphere. Clean closure, that is, the retrieval of all waste from the site will eliminate the need for further monitoring of regulated substances. The facility is not expected to require extensive decontamination at closure because any waste that is spilled or released during emplacement or removal will be contained and removed immediately. Decontamination activities will ensure the removal of waste residues to levels determined to be protective to human health and the environment, and further maintenance or post-closure care will not be necessary. The WIPP facility will be cleaned up to EPA health-based standards, calculated prior to closure.

The U.S. Department of the Interior, Bureau of Land Management (BLM), has minimal standards for closing an underground mine/shaft to protect groundwater. DOE will get approval from the District BLM Manager for any closure performed on the underground mined area. Final closure will be protective of the groundwater; therefore, all water-bearing geological units will be sealed in the shaft. At the time of closure, the WIPP facility will use experience in closure already developed in the Delaware Basin by the potash industries.

I-1b Partial Closure and Final Closure Activities

Partial closure of the test areas in which waste has been emplaced is not anticipated during the Test Phase. Waste will be retrievable throughout the Test Phase as specified in the land withdrawal legislation. An amendment to this closure plan will be submitted, if the Test Phase data indicates long-term disposal is unacceptable, and will describe in detail how final closure will be conducted. The maximum extent of operations which will be unclosed is limited to Panel 1 where testing of the waste will be conducted.

Currently there are no final engineering closure designs for the WIPP facility due to lack of criteria or guidelines for shaft closure of non-coal mines. However, there may be applicable criteria for closure from international sources, such as South Africa and Great Britain. DOE feels closure and groundwater protection is feasible; therefore, final engineering closure designs will be modeled after non-coal mines that have closed near the WIPP site in the Delaware Basin and from international sources.

I-1c Maximum Waste Inventory

The amount of waste emplaced during the Test Phase will not exceed one percent of the total volume of waste scheduled for emplacement at the facility. This is equivalent to the volume of 8,500 55-gallon drums. The Test Phase waste retrieval plan describes methods to be used for closure, including, but not limited to, methods for removing, transporting, treating, storing, or disposing of all hazardous waste.

I-1d Schedule for Closure

WIPP facility closure at the conclusion of the Test Phase, if required, is projected to be completed in approximately 67 months. A closure schedule is included in Table I-2. Twenty-eight months will be required to remove the waste emplaced during the Test Phase, decontaminate waste containers as necessary, and ship the waste to the origin as indicated on the shipping manifest or to an interim facility. Additional time may be needed if decontamination of waste handling equipment, the underground test areas, and above ground equipment and facilities is necessary. Closure at the end of the Test Phase may include dismantling the facility completely, including surface facility disassembly and removal from the site, surface paving and road mettle (caliche) removal, and recontouring and revegetating the disturbed surface areas in accordance with the BLM stipulations in the Memorandum of Understanding between DOE and the BLM (Appendix I1). A detailed closure schedule will be submitted, in writing, to the Secretary of the New Mexico Environment Department (NMED) along with the notification of closure.

I-1d(1) Time Allowed for Closure

As indicated by the proposed closure schedule in Table I-2, the closure activities required to close the facility will require more than 180 days to complete, and DOE requests a variance from the 180-day closure requirement in accordance with HWMR-6, Pt. V, sec. 264.113. During the closure period, DOE will continue to demonstrate compliance with applicable permit requirements and that all steps will be taken to prevent threats to human health and the environment. The closure period will take longer than 180 days, due to the management of the radioactive constituents within the waste and the complicated sealing of shafts/tunnels, remining of salt, and backfilling.

I-1d(2) Amendment of the Closure Plan

To amend the plan, DOE will submit a written notification of, or request for, a permit modification describing any change in the operating plan, facility design, or test designs which affect the approved Closure Plan, in accordance with HWMR-6, Pt. IX. The written notification or request will include a copy of the amended closure plan for approval by the NMED or the EPA. DOE will submit a written notification of, or request for, a permit modification to authorize a change in the approved Closure Plan if:

- Changes in operating plans or facility design affect the Closure Plan, or
- There is a change in the expected year of closure, or
- Unexpected events affect the closure plan, or
- Unanticipated changes in project philosophy require a modification of the approved Closure Plan.

DOE will submit a written request for a permit modification with a copy of the amended Closure Plan at least 60 days prior to the proposed change in facility design or operation, or within 60 days of the occurrence of an unexpected event that affects the Closure Plan. If the unexpected event occurs during final closure, the permit modification will be requested within 30 days of the occurrence. If the Secretary of the NMED requests a modification of the Closure Plan, a plan modified in accordance with the request will be submitted within 60 days of notification or within 30 days, if a change in facility condition occurs during final closure.

I-1d(3) Notification of Partial or Final Closure

Partial closure will not occur during the Test Phase period. DOE will notify the Secretary of the NMED in writing at least 60 days before the date on which final closure will commence.

I-1e Closure Procedures

Waste of known composition will be emplaced in the WIPP facility for Test Phase activities; therefore, potential hazardous constituents in the waste have been identified. In addition, all waste emplaced during the Test Phase will be packaged in Standard Waste Boxes (SWBs) with modified lids that enclose rectangular bins. Each retrieval action will be preceded by extensive monitoring to detect the presence of mixed waste contaminants. If radioactive contamination is detected on a container surface or in the air, it will be assumed that hazardous constituents may be present as well, based on waste profiling done prior to emplacement. If no radioactivity is detected in a room or work area, samples will not be collected and analyzed for potential hazardous constituents unless there is reason to suspect that hazardous constituent releases may have occurred (e.g., discoloration of pallet or salt, container corrosion). If unknown hazardous constituent releases are suspected, then a sample will be taken and analyzed for HWMR-6, Pt. II, Appendix VIII parameters. Prior to transport to the WIPP facility, Test Phase waste is

characterized in accordance with EPA requirements (EPA, 1990) and any additional waste characterization requirements defined in Chapter C (Waste Characteristics) of this permit application. Therefore, prior to Test Phase closure, information will be available to incorporate into detailed sampling, analysis, and closure plans. Based on analytical results, contaminated materials will be packaged according to applicable state and federal regulations; hazardous waste will be transported to a permitted RCRA treatment, storage, or disposal facility, and radioactive and mixed waste will be shipped off site with the retrieved waste. Prior to retrieval operations within any bin test room, the types and quantities of wastes that must be retrieved will be confirmed from records. If necessary, any liquids will be drained from the test bins and will be handled according to the appropriate regulations and procedures (if a process is needed). Treatment for the drained liquids will be determined prior to waste retrieval. The proposed retrieval process is based on the following conditions at the WIPP facility during the Test Phase:

- All retrieved waste bins will be overpacked in a SWB.

- Each bin will be contained within a SWB with a modified lid, referred to as a Radiological Control Boundary (RCB), and any release from a bin, therefore, will be contained. If, however, a bin releases some of its contents, the released material will be excavated, sampled, analyzed, and removed from the repository. Radioactively-contaminated salt and equipment will be sampled for the presence of hazardous constituents known to be present in the test waste, packaged, and handled appropriately as radioactive, mixed, or hazardous waste.

- During retrieval activities, the detection of radioactive contamination, either airborne or on bin surfaces, will indicate the need to sample and analyze for hazardous constituents. Samples will be analyzed for those hazardous constituents known to be present in the waste (EPA, 1990). If radioactive contamination is not detected, but a release is suspected, then samples will be collected and analyzed for HWMR-6, Part II, Appendix VIII, parameters.

- Waste container retrieval and shipping will be conducted concurrently to minimize the accumulation of waste at the WIPP facility awaiting transport. Therefore, retrieved waste will not require storage at the WIPP facility for longer than 90 days unless the state or the EPA determines an extension is consistent with the protection of human health and the environment.

I-1e(1) Inventory Removal

I-1e(1)(a) Bin-Scale Test Waste Retrieval

Bin-scale test waste and contaminated bins will be overpacked in SWBs. Bins will be emplaced in Panel 1 (Figure D-22) and will be arranged in rows stacked two high.

Underground Activities

Prior to retrieval, a sampling program to estimate the radiological and hazardous material contamination in each room will be conducted to identify and contain all areas of contamination. Each test room will be maintained as necessary to allow uninhibited operation of forklifts involved in retrieval activities. Adequate lighting and ventilation will be established in the work area. RCBs will be transferred by forklift to an underground waste transporter which can carry two RCBs at a time to the Waste Handling Shaft for transport to the WHB. All RCBs will be surveyed for surface contamination prior to removal.

Surface Activities

RCBs will be transferred from the waste hoist to the conveyance car and moved to the Inventory and Preparation Area, where each bin will be surveyed for radioactive contamination. To overpack test bins, the modified lid on each bin will be replaced with a SWB lid. Overpacked bins will be transported to the loading dock, surveyed for surface contamination, weighed, and placed in a Nuclear Regulatory Commission (NRC)-approved shipping container. An EPA hazardous waste manifest will accompany each shipment off site.

The NRC-certified container will be moved through an air lock to the trailer loading yard and placed on a trailer. Shipment documentation will be verified before the loaded trailer is released for transport off site.

I-1e(1)(b) Sampling and Quality Assurance

All closure-related sampling and analysis activities will follow EPA-approved procedures (EPA, 1986). Solids will be sampled with coring tools, trowels, or appropriate samplers. Radioactivity is measured by instruments applied directly to the object or to swipe samples collected using clean filter paper.

DOE Order 5480.11 (DOE, 1988a) requires that radiation exposure from DOE operations be ALARA to protect worker and public health and safety. Prior to conducting any sampling or analytical procedure, it may be necessary to obtain radioactivity measurements to assess exposure potential. The survey will be designed with respect to ALARA concerns to minimize exposure.

Samples will be analyzed by a certified laboratory. If analytical procedures included in "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods" (SW-846) (EPA, 1986) or its most recent version are inappropriate for analyzing mixed waste samples, equivalent analytical protocols will be used. The quality assurance requirements of SW-846 will be met for all sampling and analyses.

A sampling and analysis plan describing specific sampling and analysis protocols will be prepared prior to closure and will ensure that samples represent true conditions and are free of radiological or chemical contamination from external sources. ALARA principles will be followed to minimize exposures.

I-1e(1)(b).1 Sample Collection and Handling

The sample collection protocol for all samples of waste or environmental media will include:

- Appropriate sample containers and preservative
- Sample identification and labeling
- Documentation of sampling activities
- Sample handling and shipping
- Decontamination of sampling equipment.

These procedures are described below.

Appropriate Sample Containers and Preservative

Samples must be placed in containers compatible with the intended analysis and will be properly prepared and preserved to maintain sample integrity. The most recent version of SW-846 lists the proper container, preservative, and holding time for each chemical parameter of interest, and these requirements will be followed for all samples collected during the closure process.

Sample Identification and Labeling

Samples will be identified at collection with a label which must remain attached and legible through shipping and storage. Container labels list sample location and name, the unique sample number, and sample type. The names of sampling personnel and the preservation method are included on records traceable to the sample by the unique sample number. All labels will be marked with a permanent water-proof marker.

Documentation of Sampling Activities

Collection of each sample will be documented by a permanent sample record sheet. The following information will be entered in the record:

- Purpose of the sample collection
- Unique sample number
- Sampling location, date, and time
- Sampling personnel
- Type of waste (e.g., salt, brine, etc.)

- Number and volume of samples
- Description of sampling point and method
- Field observations or measurements
- Collector's signature.

Sample Handling and Shipping

Samples will be packaged and shipped in accordance with U.S. Department of Transportation (DOT) shipping requirements (49 CFR Part 173, Shippers--General Requirements for Shipments and Packagings). The type of packaging will depend on the protection that must be provided during handling, shipping, and storage, which varies with sample type, media, hazardous and radioactive substances present, analyses required, and handling and storage conditions.

Proper packaging will include consideration of:

- Type and composition of inner packing (e.g., plastic bags, metal cans, absorbent packing material, and frozen gel for preservation).
- Type and composition of overpacks (e.g., metal drum or plastic ice chest).
- Method of overpack sealing (e.g., custody tape).
- Marking and labeling of overpacks [e.g., laboratory address, any appropriate DOT Hazards Class Label(s), and handling instructions].
- Surface dose rates of sample.
- Activities of individual radionuclides.

√ All samples packages will be contact surveyed for beta-gamma and alpha radiation prior to placement in shipping containers and again after containers are sealed. Contaminated containers are decontaminated or repackaged before shipment. Decontamination information will be recorded and relayed to the receiving laboratory.

Decontamination of Sampling Equipment

To prevent cross contamination, clean sampling devices will be used to collect each representative sample. Procedures will be developed prior to closure for decontaminating sampling equipment based on detailed waste characterization information to be compiled by DOE in preparation for the Test Phase (EPA, 1990).

I-1e(1)(b).2 Quality Assurance/Quality Control

Because decisions about closure activities would be based in part on analyses of potentially contaminated surfaces and media, a program to ensure reliability of analytical data is essential. The WIPP will ensure data reliability by documenting sample management so that analyses are traceable to specific areas of potential contamination, and by following a quality assurance/quality control (QA/QC) program that mandates documentation of the precision and accuracy of laboratory analyses.

Blanks and duplicate samples will be collected in the field to determine errors introduced in the data from sample collection and handling activities. One rinseate blank will be collected each day for each piece of decontaminated sampling equipment to determine the potential for cross-contamination. One in every ten samples collected will be sent in duplicate to the analytical laboratory for analysis. These blanks and duplicate samples will be treated as separate samples. Acceptance criteria for QA/QC sample analyses will be compatible with the most recent version of SW-846 or other applicable EPA guidance.

Sample Management

DOE will use a chain-of-custody form to track samples from collection through analysis and to ensure that analytical results can be attributed to specific closure activities or specific areas. The procedures followed at the WIPP facility will be equivalent to those provided in SW-846 (EPA, 1986) or the edition current at closure. Important aspects of the procedures are presented below.

A chain-of-custody form will be prepared for all samples collected for laboratory analyses. The form includes:

- Sample number
- Signature of sample collector
- Date and time of sample collection
- Location at which sample was collected
- Type of waste (e.g., salt, brine, etc.)
- Signatures of persons who have samples in their possession
- Dates and times of possession.

This form will be initiated at the point of sample collection and will remain with the sample during transfer to the laboratory. The form will be completed upon receipt at the laboratory and returned to the WIPP facility for inclusion in facility records. The chain-of-custody form will include a request-for-analysis form which lists all analyses to be performed for the identified samples and all special instructions relating to sample management or analysis. Potential hazards posed by the samples will be listed in the request-for-analysis form; surface dose rates will be determined for all potentially radioactive samples and entered on the form.

Quality Control at Analytical Laboratories

Samples analyzed on site will be subject to the quality control procedures outlined in SW-846 (EPA, 1986) or equivalent procedures. Documentation demonstrating that these procedures are followed (e.g., tabulating results of blank analyses, calibration curves, etc.) are maintained in laboratory files.

QA/QC procedures not related to specific test methods in SW-846 will follow good laboratory practice and include proper maintenance and calibration of laboratory instruments; analyses of reference standards and quality control samples (matrix spike samples, matrix spike duplicates, blanks, and duplicates); sample tracking; and maintenance of all analytical records such as control charts, sample logs, etc. These practices will be part of the standard operating procedures of analytical laboratories responsible for analysis of mixed or hazardous waste samples generated by closure activities, as described in SW-846; contract laboratory program statements of work; and other guidelines.

I-1e(1)(b).3 Sample Analysis

All samples collected indicating radioactivity from field screening will be analyzed for the known hazardous constituents of the Test Phase waste. If no radioactivity is detected, but there is a reason to suspect that hazardous constituent releases may have occurred (e.g., discoloration of pallet or salt, container corrosion), then samples will be collected and analyzed for HWMR-6, Pt. II, Appendix VIII, parameters. Hazardous constituents are listed on the waste profile forms completed in accordance with EPA requirements for WIPP Test Phase activities by generator/storage sites prior to transport to and emplacement at the WIPP facility (EPA, 1990).

I-1e(2) Disposal or Decontamination of Equipment, Structures, and Soils

I-1e(2)(a) Removal of Hazardous Waste Residues

The WIPP facility was designed to simplify facility decontamination. The design includes consideration of:

- Ease of accessibility for decommissioning and dismantling material and equipment that may be reused.
- Surface finishes and materials that facilitate decontamination
- A minimum of dirt-catching spaces and corners to prevent contaminants from accumulating.
- Equipment that can be decontaminated without disassembly.

- Sealing cracks, crevices, and joints to prevent contamination from spreading to inaccessible areas.

- Placing exhaust filtering facilities at points of potential contamination to minimize contamination of long sections of duct work and downstream exhaust equipment

- Providing architectural or structural features that allow the dismantling and removal or equipment from areas of contamination or to other areas for decontamination, maintenance, or repair.

I-1e(2)(b) Decontamination of the Underground

Contaminated equipment will be transported to the surface for decontamination. After completion of detailed surveys and analyses of the mined areas and underground equipment, a decontamination plan and procedures that effectively address the as-found conditions will be developed. The plan and associated procedures will address the degree of decontamination required for mined surfaces and the disposal of contaminated rock salt generated by the decontamination process. The mined areas underground will be backfilled with salt and concrete; therefore, the effects on health will be negligible.

The protection of the health and safety of the public, WIPP facility employees, and the environment is the primary concern dictating the planning and procedural controls governing the decontamination effort. Structures will not be dismantled or equipment or waste disposed of until necessary precautions are identified and implemented, and employees are thoroughly trained in the techniques to be applied. Closure performance standards as required in HWMR-6, Pt. V, sec. 264.112(b)(5) are not applicable, as demonstrated in Chapter E of this permit.

I-1e(2)(c) Decontamination of the Surface

Decontamination of surface facilities will be preceded by extensive detailed contamination surveys to document the level of cleanliness for all surface structures and equipment. If areas or equipment are identified as contaminated, a decontamination plan and procedures will be developed and implemented to address the following questions:

- Should the component be decontaminated or disposed of as waste?

- What is the most cost-effective method for decontaminating the component?

- Would the decontamination procedures ensure that the contamination is adequately contained?

All radioactively contaminated material generated at the WIPP facility as a result of decontamination activities will be classified as TRU waste. Wastes will be managed and disposed

of in accordance with DOE Order 5820.2A, Radioactive Waste Management (DOE, 1988b), or the applicable DOE order in place at closure. All decontamination activities will be conducted in accordance with applicable RCRA requirements.

I-1e(2)(d) Waste Generated by Decontamination Activities

All radioactive waste generated by decontamination activities will be treated as mixed waste. Once the decision to retrieve has been made, the mixed waste generated by decontamination activities will be considered derivative waste and storage of the waste at the WIPP facility will be limited by statutory requirements to 90 days.

Hazardous waste will be handled in accordance with appropriate regulations and with the procedures in WP 02-6 and 02-7, Resource Conservation and Recovery Act (RCRA) Compliance Manual (Westinghouse, 1992). This waste is expected to be generated at approximately the same rate as during normal plant operations. Hazardous waste management is controlled at the WIPP through training, procedures, and inspections.

I-1e(2)(e) Certification of Closure

Within 60 days after completion of closure activities, DOE will submit to the Secretary of the NMED, via certified mail, a certification that the facility has been closed in accordance with the specifications of this Closure Plan, when approved. The certification will be signed by DOE and by an independent registered professional engineer. Documentation supporting the independent registered professional engineer's certification will be furnished to the Secretary of the NMED on request.

I-1e(3) Closure of Disposal Units/Contingent Closures

Because the miscellaneous unit contains no RCRA-regulated surface impoundments, waste piles, or landfills, closure of disposal units/contingency closures does not apply to the WIPP facility.

I-1e(4) Closure of Containers

Removal of waste containers and hazardous waste residues is addressed in I-1e(1)(a) and I-1e(2)(a).

I-1e(5) Closure of Tanks

The WIPP facility does not manage hazardous or mixed waste using a tank system, as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart J. Tank system regulations are not applicable to the WIPP facility.

I-1e(6) Closure of Waste Piles

The WIPP facility does not manage hazardous or mixed waste using a waste pile, as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart L. Waste pile regulations are not applicable to the WIPP facility.

I-1e(7) Closure of Surface Impoundments

The WIPP facility does not manage hazardous or mixed waste using a suface impoundment, as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart K. Surface impoundment regulations are not applicable to the WIPP facility.

I-1e(8) Closure of Incinerators

The WIPP facility does not manage hazardous or mixed waste using an incinerator, as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart O. Incinerator regulations are not applicable to the WIPP facility.

I-1e(9) Closure of Landfills

The WIPP facility does not manage hazardous or mixed waste using a landfill, as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart N. Landfill regulations are not applicable to the WIPP facility.

I-1e(10) Closure of Land Treatment Facilities

The WIPP facility does not manage hazardous or mixed waste using land treatment, as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart M. Land treatment regulations are not applicable to the WIPP facility.

I-1e(11) Closure of Drip Pads

The WIPP facility does not manage hazardous or mixed waste using drip pads, as defined in HWMR-6, Pt. I, sec. 260.10, and regulated under HWMR-6, Pt. V, Subpart W. Drip pad regulations are not applicable to the WIPP facility.

I-1e(11) Post-Closure Care of Miscellaneous Units

No post-closure plan is required for the Test Phase of the miscellaneous unit at the WIPP facility because the unit will be clean closed if closure is necessary. Therefore, this requirement does not apply.

I-2 Post-Closure Plan/Contingent Post-Closure

No post-closure plan is required for the Test Phase of the miscellaneous unit at the WIPP because the facility will be clean closed if closure is implemented. Therefore, this requirement does not apply.

I-3 Decommissioning the WIPP Facility

DOE Order 5820.2A, Radioactive Waste Management (DOE, 1988b), requires that facilities which handle radioactive or other hazardous materials be designed to simplify decommissioning and/or increase the potential for reuse. Decommissioning activities will be planned and implemented in accordance with the following:

- Maintaining employee and public health and safety.
- Protection of the environment.
- Compliance with applicable provisions of RCRA and the commitments included in the Final Environmental Impact Statement (DOE, 1980).
- Cost-effective program management.

√ After all unneeded certified radiologically clean or decontaminated underground equipment has been moved to the surface, the mine will be backfilled to the extent feasible with salt from the salt
√ storage pile. Shafts will then be plugged per the plug design specified in the WIPP Waste
√ Retrieval Plan (DOE, 1990).

√ Many aspects of the WIPP facility design are intended to facilitate decommissioning and closure. These include the following:

- Providing easy access to material and equipment that may eventually be recovered or dismantled.
- Smoothing the surfaces or equipment to make decontamination easier.
- Minimizing small dirt-catching spaces and corners to prevent the accumulation of radioactivity.
- Using modular construction for ease of dismantling.
- Using equipment that can be disassembled without cutting.
- Minimizing the weight of blocks of material that would be moved.

- To the extent possible, relying on standard equipment which can be decontaminated and used at other sites after decommissioning.

If decommissioning includes removal of surface facilities, the surface will be regraded to approximately its original contours. Any salt remaining on the surface will be removed and disposed of according to applicable regulatory requirements. Electrical power and telephone lines, railroad spurs, and roads may be removed depending on the possible future uses of the site. If removed, the rights-of-way will be regraded to original contours. Water will be shut off at the original connection point; however, water lines will not be removed unless removal is necessary to restore the natural terrain. The area will be revegetated in accordance with a revegetation plan currently in preparation.

I-4 Closure Cost Estimate

In accordance with HWMR-6, Pt. V, sec. 264.140(c), as a facility owned by the federal government, the WIPP facility is exempt from the financial requirements of HWMR-6, Pt. V, Subpart H.

I-5 Financial Assurance Mechanism for Closure

In accordance with HWMR-6, Pt. V, sec. 264.140(c), as a facility owned by the federal government, the WIPP facility is exempt from the financial requirements of HWMR-6, Pt. V, Subpart H.

I-6 Post-Closure Cost Estimate

In accordance with HWMR-6, Pt. V, sec. 264.140(c), as a facility owned by the federal government, the WIPP is exempt from the financial requirements of HWMR-6, Pt. V, Subpart H. In addition, post-closure requirements do not apply to a facility which is closed with no waste in place.

I-7 Financial Assurance Mechanism for Post-Closure Care

In accordance with HWMR-6, Pt. V, sec. 264.140(c), as a federal facility, the WIPP facility is exempt from the financial requirements of HWMR-6, Pt. V, Subpart H.

I-8 Liability Requirement

In accordance with HWMR-6, Pt. V, sec. 264.140(c), as a federal facility, the WIPP facility is exempt from the financial requirements of HWMR-6, Pt. V, Subpart H.

List of References for Chapter I

DOE, see U.S. Department of Energy.

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TABLES

TABLE I-1

PART B PERMIT APPLICATION CLOSURE PLAN CHECKLIST
NEW MEXICO HAZARDOUS WASTE MANAGEMENT REGULATIONS (HWMR-6), PART V, REGULATION CITATION

Part B Chapter I Reference	Section Citation
I-1 Test Phase Closure Plan	270.14(b)(13), 264.112
I-1a Closure Performance Standards	264.111
I-1b Partial and Final Closure Activities	264.112(b)(2)
I-1c Maximum Waste Inventory	264.112(b)(3)
I-1d Schedule of Closure	264.112(b)(6)
I-1d(1) Time Allowed for Closure	264.113
I-1d(2) Amendment of the Closure Plan	264.112(c)
I-1d(3) Notification of Partial or Final Closure	264.112(d)
I-1e Closure procedures	264.112(b)(1)
I-1e(1) Inventory removal	264.112(b)(1)
I-1e(2) Disposal and Decontamination of Equipment, Structures, and Soils	264.114, 264.115

TABLE I-2
TEST PHASE CLOSURE PLAN

	Action	Time
	Decision to Retrieve	-300 Days
	Complete Radiation Survey/Underground	-240 Days
√	Submit Detailed Closure Plan to the New Mexico Environment Department (NMED)	-180 Days
	Establish Radiation Protection Procedures	- 60 Days
√	Notify the NMED of Closure	- 60 Days
	Initiate Waste Retrieval	Day 0
	Complete Waste Retrieval	830 Days
	Decontaminate Underground	900 Days
	Decontaminate Surface Facilities	1000 Days
	Emplace Stored Salt Underground	1200 Days
	Remove Underground Equipment	1300 Days
	Emplace Salt in Shafts	1400 Days
	Plug Boreholes/Shafts	1600 Days
	Dismantle/Remove Surface Facilities	1800 Days
	Recontour and Revegetate	2000 Days
√	Submit Certification of Closure to the NMED	2020 Days

CHAPTER J

CORRECTIVE ACTION FOR SOLID WASTE MANAGEMENT UNITS

CHAPTER J
CORRECTIVE ACTION FOR SOLID WASTE MANAGEMENT UNITS
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CHAPTER J
CORRECTIVE ACTION FOR SOLID WASTE MANAGEMENT UNITS

Introduction

This chapter describes the solid waste management units (SWMUs) that have been identified in the 16-square-mile area within the Waste Isolation Pilot Plant (WIPP) legal boundary [New Mexico Hazardous Waste Management Regulations (HWMR-6), Part V, section 264.101(a)]. It includes descriptions of both active and inactive SWMUs. SWMU characterization sheets are presented in Appendix J-1 in response to regulatory requirements in HWMR-6, Pt. IX, sec. 270.14(d).

Corrective actions are only required for SWMUs from which releases of RCRA hazardous wastes or constituents have occurred. Hazardous waste is defined in HWMR-6, Pt. II, sec. 261.3. Hazardous constituents are listed in HWMR-6, Pt. II, Appendix VIII. Based on sampling and analysis data, visual site investigations, and document/record reviews, RCRA hazardous waste or hazardous constituents have not been released at the WIPP site; therefore, there have been no corrective actions.

The definition of a solid waste management unit has not yet been finalized by the U.S. Environmental Protection Agency (EPA). The most recent definition, presented in the proposed Subpart S to the RCRA regulations in 40 CFR Part 264 (EPA, 1990), has been used to define SWMUs at the WIPP facility. This definition states that SWMUs are "any discernible unit at which solid wastes have been placed at any time irrespective of whether the unit was intended for the management of solid or hazardous waste. Such units include any area at or around a facility at which solid wastes have been routinely and systematically released."

Applying the definition to units at the WIPP facility, the following are considered to be SWMUs:

- All units intended to store, treat, or dispose of waste materials, regardless of whether they have released hazardous waste or hazardous constituents, including tanks, sumps, septic systems, drain lines, waste container storage areas, landfills, surface disposal areas, surface impoundments, and wastewater treatment systems.
- Areas contaminated by releases from any of the above units.
- Product storage areas, only if there is documented evidence of routine (periodic and systematic) releases from these units.
- Existing structures that store waste.

- Soil under and around existing or former structures that were contaminated or have had documented routine releases.

The following units are not considered SWMUs:

- Active underground product storage tanks.
- One-time releases or spills.
- Product storage areas with no evidence of routine releases.
- Soil beneath existing or former buildings or structures with no evidence of contamination and no record of routine releases.
- The WIPP miscellaneous unit.

J-1 Solid Waste Management Units

The following logic was used to define a SWMU at the WIPP facility. All units used to store, treat, or dispose of solid waste (as defined in HWMR-6, Pt. I, Appendix I) are considered SWMUs, regardless of whether a release has occurred. All other types of units are considered SWMUs only if there have been routine and systematic releases. In these cases, the medium that received the release is considered to be the SWMU.

According to HWMR-6, Pt. V, sec. 264.90(d), the SWMU requirements of HWMR-6, Pt. V, Subpart F "*may apply* to miscellaneous units when necessary to comply with [HWMR-6, Pt. V, secs.] 264.601 through 264.603" (emphasis added). DOE believes compliance with the aforementioned sections is demonstrated in this permit application. Section D-9d(1), Chapter E, and Appendix E1 of this permit application address the requirements of HWMR-6, Pt. V, sec. 264.601(a). Sections D-9d(2) and D-9d(3) of this permit application address the requirements of HWMR-6, Pt. V, secs. 264.601(b) and (c), respectively. Chapter I of this permit application addresses the requirements of HWMR-6, Pt. V, sec. 264.603.

In addition, DOE will institute corrective actions for any releases of hazardous waste or hazardous constituents from SWMUs at the WIPP site that are necessary to protect human health and the environment. Corrective actions will be performed in compliance with HWMR-6, Pt. V, sec. 264.101.

The requirements of HWMR-6, Pt. V, secs. 264.601 through 264.603, including corrective actions, are addressed in this permit application. Therefore, the requirements of HWMR-6, Pt. V, Subpart F, are not necessary to show compliance and the WIPP miscellaneous unit is not considered a SWMU.

A SWMU is a discernible unit at which solid wastes have been placed at any time. To eliminate repetition of information, units that are similar in physical characteristics (e.g., salt and topsoil storage areas), use (e.g., drilling mud pits), or waste type (e.g., satellite storage areas) are grouped and described within a SWMU description for the particular type of discernible unit.

The following are descriptions of the areas encountered during this survey for which specific definitions apply.

Underground Storage Tanks

Two 8,000-gallon underground storage tanks (USTs) at the WIPP facility were used for holding gasoline and diesel fuel for vehicles and other equipment. These tanks are scheduled for replacement in 1992 to meet the technical requirements of the New Mexico Underground Storage Tank Regulations (USTR), as amended 1990, Pt. VI, sec. 600, which are similar to the federal regulations. New Mexico has the authority to administer the federal UST regulations. Although analysis of fuel inventories indicates that the tank systems have not leaked, a recent pressure test indicated a possible leak in the gasoline tank piping. In order to validate the test and comply with the USTR, Pt. VII, sec. 702, a site investigation of the tank facility was completed in December 1990. None of the soil samples collected for laboratory analysis showed levels of hydrocarbon contamination above USTR standards. Therefore, pursuant to USTR, sec. 1209 D.3.a, the State of New Mexico does not require further remedial action at the site at this time (NMEID, 1990). Releases of hydrocarbon fuels from USTs (if any did occur) are not regulated under RCRA (but separately under 40 CFR 280, Subparts F and G) and therefore are not included in this chapter.

Septic System (Decommissioned)

A septic system typically consists of a tank and associated waste lines that discharge to a leach field, seepage bed, or outfall. All components of a septic system are grouped as one unit. Sanitary wastes (domestic sewage), which are not chemically contaminated and managed in septic tanks, are exempt by definition from classification as solid waste [HWMR-6, Pt. II, sec. 261.4(a)(1)(i)]. Because of this and the fact that records indicate that the septic system at the WIPP facility received only sanitary waste, it is not included in this chapter.

Closed/Decommissioned Units

All closed or decommissioned SWMUs have been described, regardless of whether releases have occurred.

Container Storage Areas

All areas storing containerized wastes are described. Product, fuel, or raw material storage areas are included only if routine (periodic and systematic) releases have occurred.

J-1a Characterization of the SWMUs

SWMUs at the WIPP facility are identified by a unique number designation shown in the upper left-hand corner of the SWMU characterization sheets in Appendix J1. The SWMUs are sequentially numbered for the site. The individual units grouped within a SWMU are designated by a letter following the SWMU number. The locations of the SWMUs and individual units, if any, within SWMUs are shown in Figures J-1 through J-3.

The SWMU characterization sheets in Appendix J1 include the name, type, and period of operation for each unit. The unit description includes all available information on the unit, including location, size, dates of operation for the individual units within a SWMU, materials of construction, and waste descriptions. Information on the extent and nature of known releases is also included. The figure showing the location of each individual unit within a SWMU is indicated on the SWMU characterization sheet.

J-2 Releases

Four of the WIPP site SWMUs have recorded releases of nonhazardous materials. The SWMUs that have recorded releases are the mud pits (SWMU No. 001), the storage yards (SWMU No. 004), the concrete batch plants (SWMU No. 005), and the holding ponds (SWMU No. 006).

Releases from the mud pits (SWMU No. 001) occurred when holes were cut in the liner to allow drainage. Sodium- and potassium-saturated brines were released.

Small areas of stained soil under pallets in the storage yards (SWMU No. 004) indicate minor releases from drums. In addition to construction/maintenance materials and virgin petroleum products, drums of wastewater and used petroleum and oil products awaiting laboratory analysis are stored at the storage yard. Minor releases from the area for staging wastewater and waste oils are remediated as per the applicable WIPP facility procedure.

Material released from the concrete batch plants (SWMU No. 005) consisted of water mixed with sand, concrete and gravel, and trace amounts of motor oil, grease, and diesel fuel that may have leaked from trucks during loading. Minor releases of these non-RCRA regulated materials at the concrete batch plants are handled in accordance with procedures in WP 02-8, WIPP Spill Prevention, Control, and Countermeasures Plan (Westinghouse, 1991).

Releases from the holding ponds (SWMU No. 006) occurred when holes were cut in the liners after the water had evaporated. Material stored in the holding ponds and potentially released included saturated brine, drill cuttings, and trace amounts of hydraulic oil and grease that may have leaked from drilling equipment.

J-2a Characterization of Releases

The releases are characterized on the SWMU characterization sheets in Appendix J-1. In most cases, the characterization of the releases includes a description of the material released and the nature of the release. However, because the nature of the releases, the exact volume released is not known and the timing can only be estimated by the period of operation.

J-2b Corrective Actions

Based on sampling and analysis data, visual site investigations, and document/record reviews, releases of hazardous materials have not occurred at any of the WIPP facility SWMUs. According to HWMR-6, Pt. V, sec. 264.101(a), corrective actions are required only for releases of hazardous waste or hazardous constituents. There have been no releases of RCRA hazardous waste or hazardous constituents from WIPP facility SWMUs, so corrective actions are not required.

List of References for Chapter J

EPA, see U.S. Environmental Protection Agency.

NMEID, see New Mexico Environmental Improvement Division.

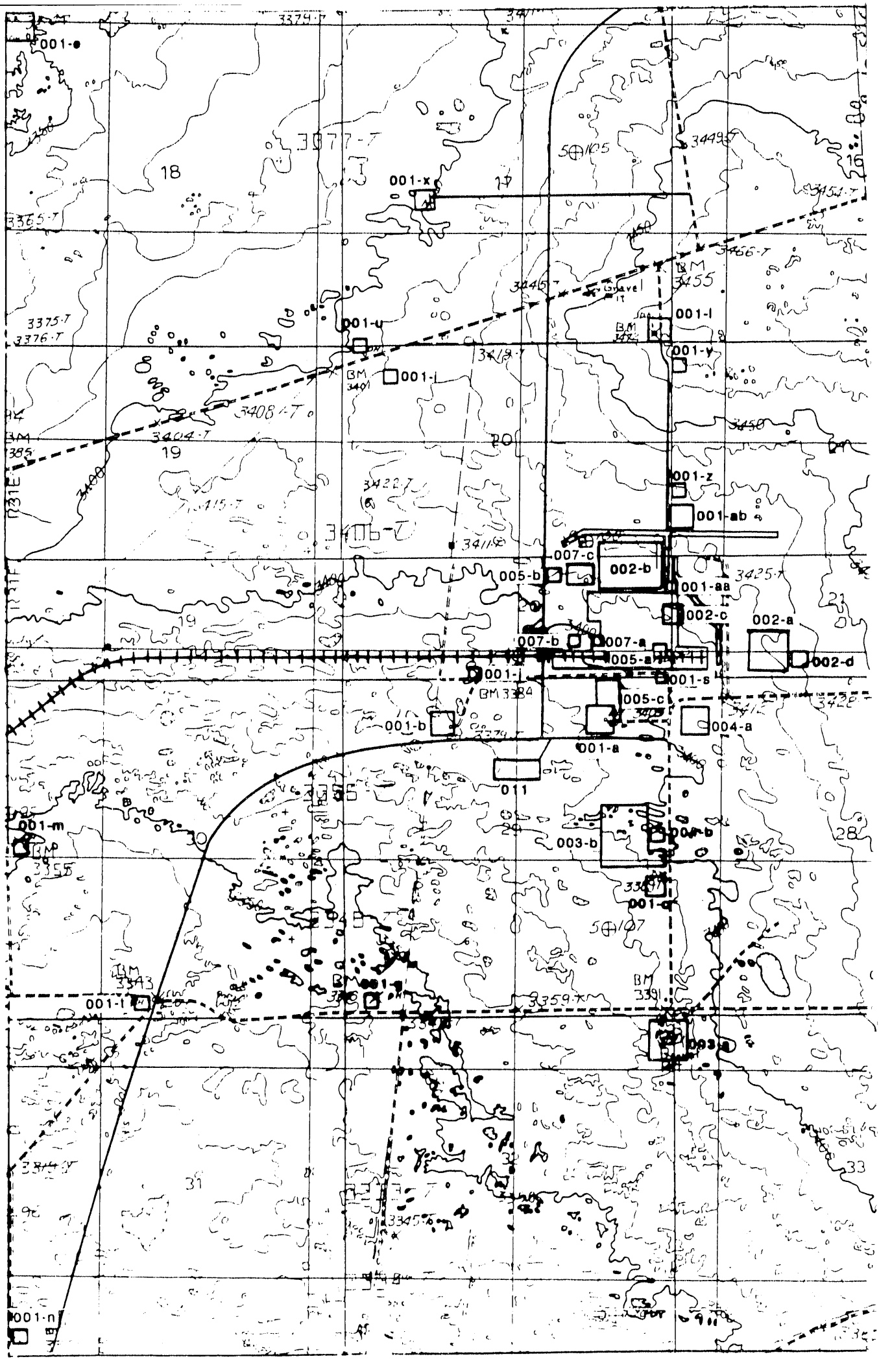
New Mexico Environmental Improvement Division (NMEID), January 16, 1990, "Hydrocarbon Release from Underground Storage Tank and Modification to Underground Storage Tank System at the WIPP Site, Carlsbad, New Mexico," Letter from Steve Wild (NMEID) to Bryan Howard (Westinghouse).

U.S. Environmental Protection Agency (EPA), 1990, "Corrective Action for Solid Waste Management Units (SWMUs) at Hazardous Waste Management Facilities" (EPA Regulations for Corrective Action under RCRA, Proposed Subpart S), Federal Register, Vol. 55, No. 145, pp. 30798-30884.

Westinghouse, see Westinghouse Electric Corporation.

Westinghouse Electric Corporation (Westinghouse), 1991, "WIPP Spill Prevention, Control, and Countermeasures Plan," WP 02-8, Westinghouse Waste Isolation Division, Carlsbad, New Mexico.

FIGURES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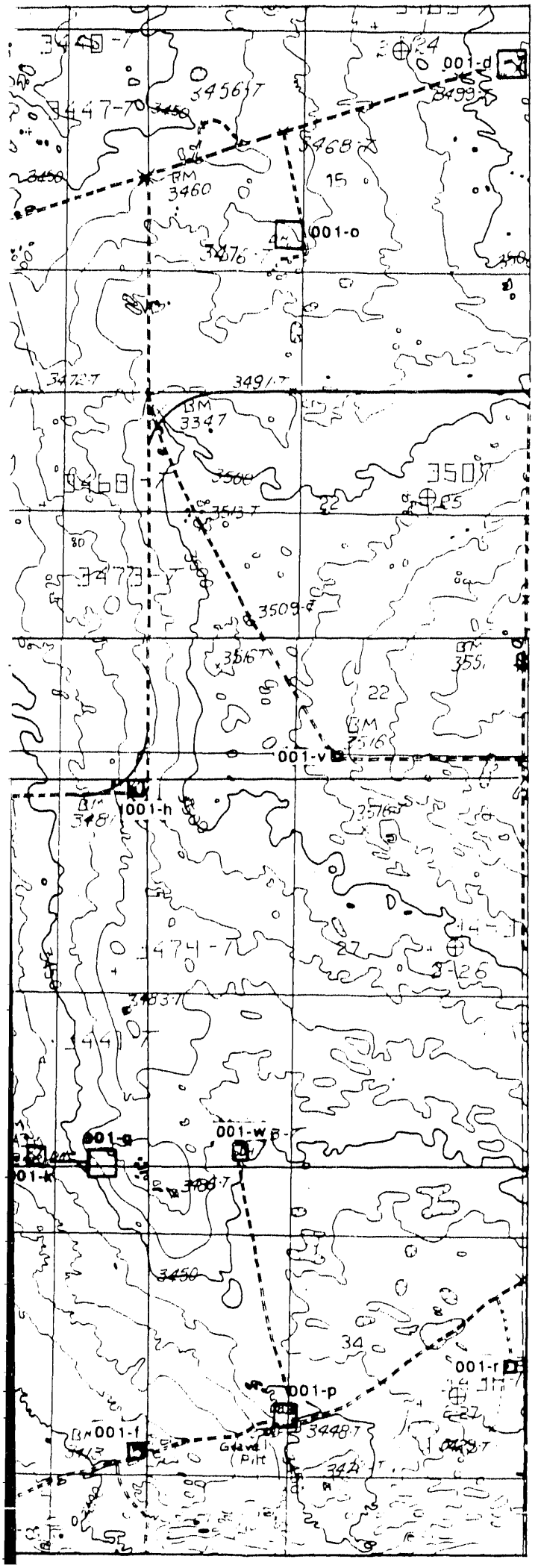

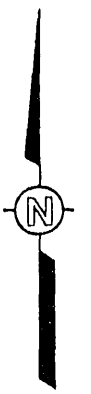

002-a SWMU IDENTIFICATION NUMBER WITH SUB-SWMU LETTER DESIGNATION

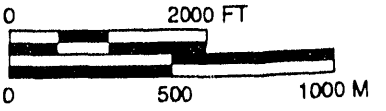

FIGURE J-1

LOCATION OF SWMUs
WITHIN THE 16 - SQUARE - MILE
WIPP LEGAL BOUNDARY AREA

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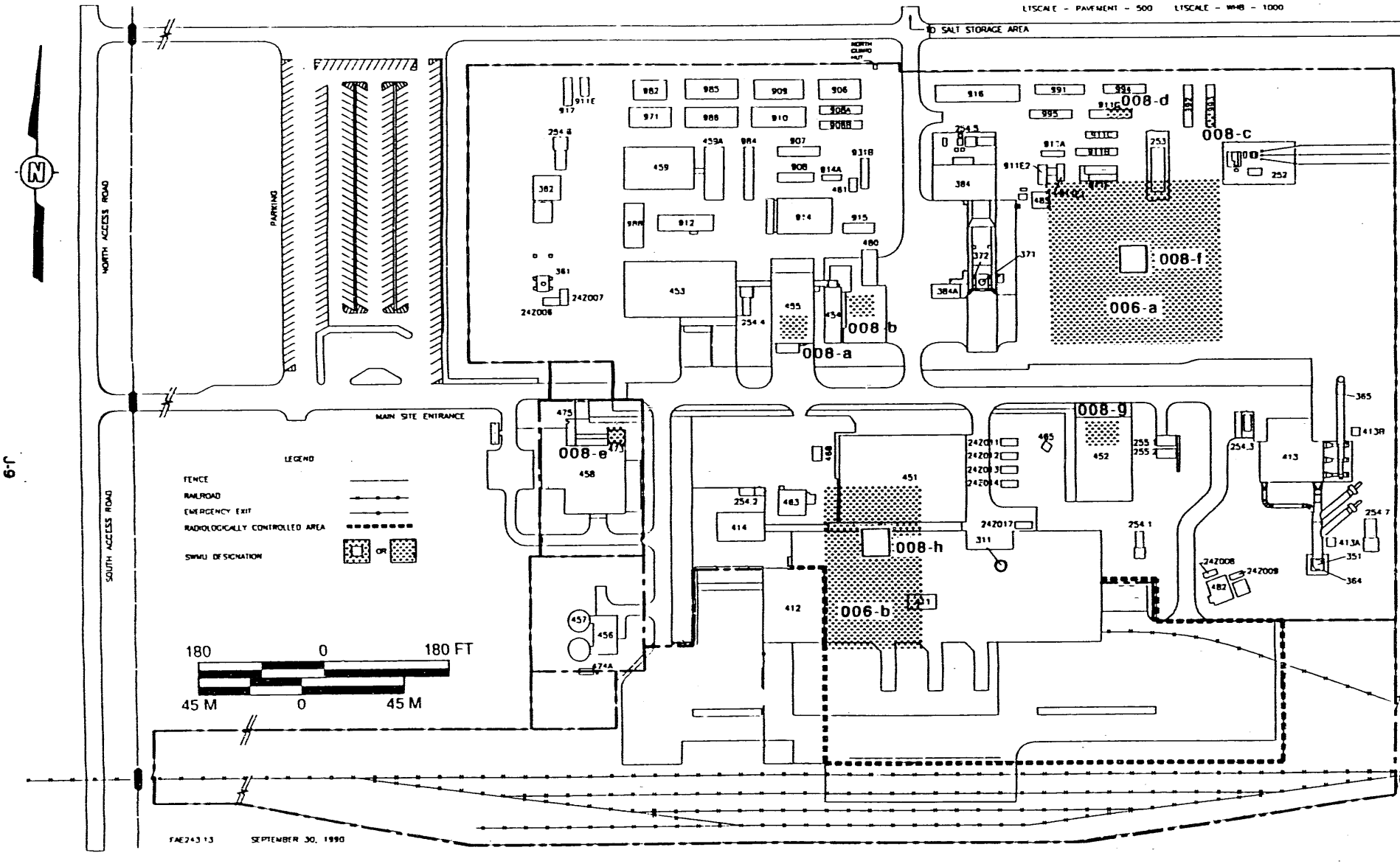
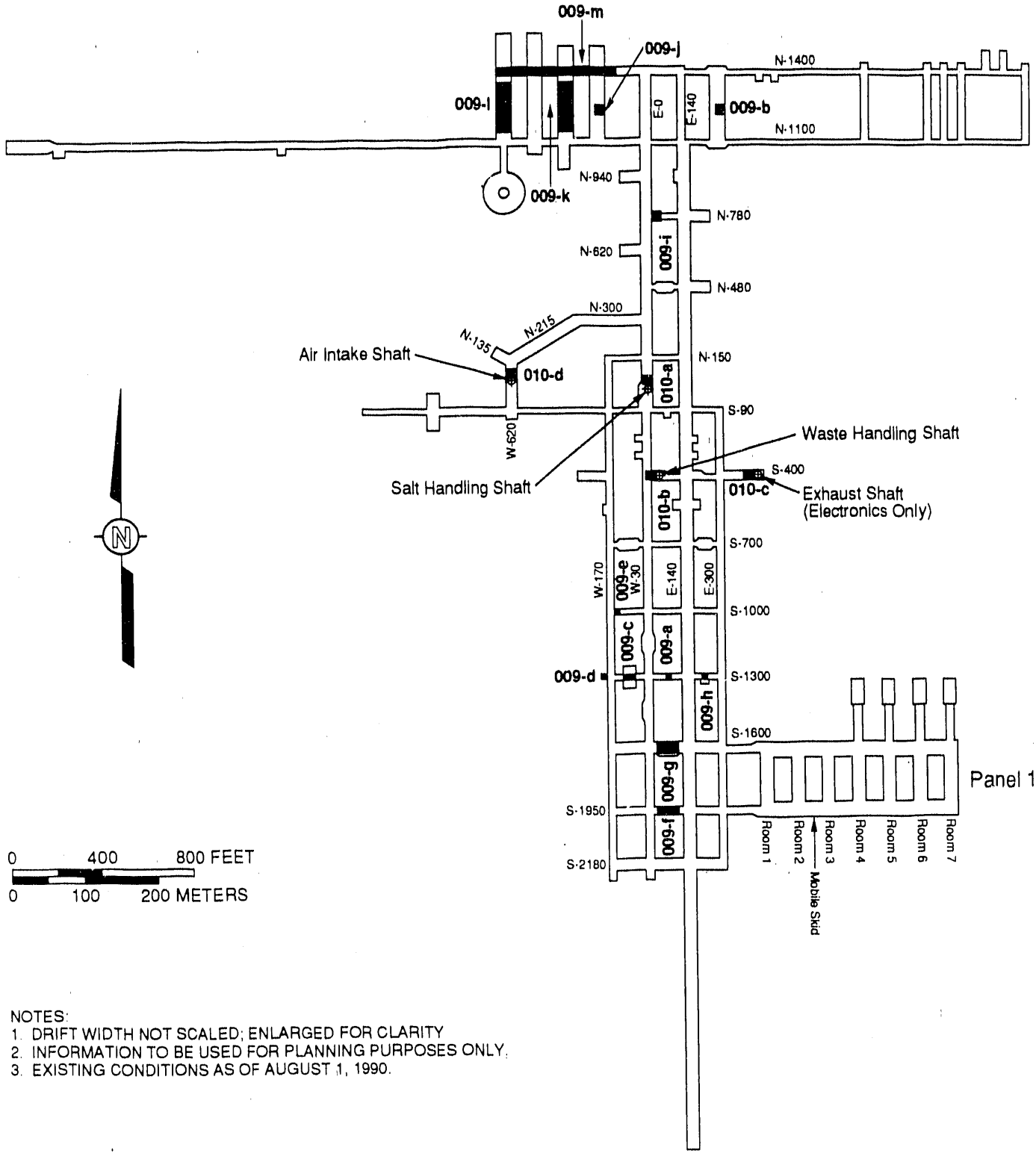


FIGURE J-2 SURFACE SATELLITE ACCUMULATION AREAS, HOLDING PONDS, AND SEPTIC LEACH FIELD



NOTES:
1. DRIFT WIDTH NOT SCALED; ENLARGED FOR CLARITY
2. INFORMATION TO BE USED FOR PLANNING PURPOSES ONLY.
3. EXISTING CONDITIONS AS OF AUGUST 1, 1990.

FIGURE J-3 UNDERGROUND SATELLITE ACCUMULATION AREAS AND SHAFT SUMPS

CHAPTER K

OTHER FEDERAL LAWS

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CHAPTER K
OTHER FEDERAL LAWS

Introduction

This chapter lists federal laws, Executive Orders (EOs), and regulations that either apply or potentially apply to the operation of the Waste Isolation Pilot Plant (WIPP) facility. The information provided may be necessary to enable the New Mexico Environment Department (NMED) and U.S. Environmental Protection Agency (EPA) to carry out their responsibilities according to the provisions of New Mexico Hazardous Waste Management Regulations (HWMR-6), Part IX, sections 270.3 and 270.14(b)(20). Each federal statute or EO that could potentially apply to the WIPP facility because of the nature of proposed activities and proposed land use is listed, the requirements are briefly summarized, and the possible applicability to the WIPP facility is discussed. With a few exceptions (e.g., 40 CFR Part 191), applicable federal regulations are not summarized. Instead, federal statutes, EOs, and regulations determined to contain environmental protection standards applicable to all U.S. Department of Energy (DOE) facilities (depending on the activity) are discussed in Appendix K1; those that actually or potentially apply to the WIPP facility are indicated by an asterisk. Agreements between DOE and the State of New Mexico that apply to the WIPP facility are summarized in Appendix K2.

K-1 Wild and Scenic Rivers Act (16 U.S.C. sec. 1273 et seq.)

The Wild and Scenic Rivers Act protects designated pristine segments of selected rivers of the United States from construction of water resources projects that would result in adverse impacts on wild and scenic river values. The Pecos River, the closest major river to the WIPP site at a distance of 14 miles, is not designated as a wild and scenic river. Also, the WIPP project does not involve any water resources project construction or development. Therefore, the Wild and Scenic Rivers Act does not apply to the facility.

K-2 National Historic Preservation Act (16 U.S.C. sec. 470 et seq.)

The National Historic Preservation Act (NHPA) was enacted to protect the nation's cultural resources and established, among other things, the National Register of Historic Places (National Register). Since 1976, cultural resources investigations have recorded approximately 98 archeological sites and numerous isolated artifacts within the 16-square-mile area enclosed by the WIPP site boundary. Thirty-three sites recorded within the central 4-square-mile area, including all of Zones I and II, were determined eligible for inclusion in the National Register as an archeological district. Investigations since 1980 have recorded

an additional 14 individual sites outside of the central 4-square-mile area that are considered eligible for inclusion in the National Register (DOE, 1990a). The average site density on WIPP facility lands, according to the WIPP Final Environmental Impact Statement (FEIS) (DOE, 1980), is 7.5 sites per square mile. A mitigation plan describing the avoidance and/or excavation of sites was submitted to the New Mexico State Historic Preservation Officer (SHPO) (Hart and Brausch, 1980; DOE and BLM, 1983). A determination of No Adverse Effect from WIPP facility activities on cultural resources was made by the SHPO in May 1980 (Merlan, 1980). A similar plan was submitted to the National Advisory Council on Historic Preservation. The Council concurred that the WIPP Mitigation Plan is appropriate to protect cultural resources (National Advisory Council on Historic Preservation, 1981).

The NHPA has been amended by the Archeological and Historic Preservation Act (16 U.S.C. sec. 469a et seq.), which directs federal agencies to recover and preserve historic and archeological data that would otherwise be lost as a result of federal construction or activities. It has also been amended by the Archeological Resources Protection Act (16 U.S.C. sec. 470aa et seq.), which requires a permit from the U.S. Department of the Interior for excavation or removal of archeological resources from public or Indian lands. Both of these statutes apply to known cultural resources or resources recorded in the future on WIPP facility lands. In accordance with the WIPP Mitigation Plan, four archeological sites that could have been or that were actually disturbed by construction activities have been excavated. The DOE avoids other sites so that there will be no adverse effects on known cultural resources from WIPP facility activities, and no additional archeological sites have been slated for excavation.

K-3 Endangered Species Act (16 U.S.C. sec. 1531 et seq.)

The Endangered Species Act provides protection for threatened or endangered species of flora and fauna. Under Section 7 of the Act and implementing regulations in 50 CFR Part 402, the EPA is prohibited from authorizing activities likely to jeopardize the continued existence of any threatened or endangered species or its critical habitat. The Section 7 process may involve a biological assessment and "formal consultation," followed by the issuance of a "biological opinion" by the U.S. Fish and Wildlife Service for any species that is determined to be in potential jeopardy. According to the WIPP FEIS (DOE, 1980) and the Final Supplement Environmental Impact Statement (SEIS) (DOE, 1990a), the U.S. Fish and Wildlife Service lists four threatened or endangered species of plants or animals that could occur at the WIPP site: the Lee pincushion cactus (*Coryphantha sneedi* var. *leei*); the peregrine falcon (*Falco peregrinis anatum*); the bald eagle (*Haliaeetus leucocephalus*); and a fish, the Pecos gambusia (*Notropis simus pecosensis*). The U.S. Fish and Wildlife Service has determined that WIPP facility activities will have no adverse impacts on these species (Stigman, 1979). In addition, no critical habitat for terrestrial endangered species has been identified at the WIPP site (Stigman, 1979). Consequently, neither formal consultation nor

biological opinion processes have been required for the WIPP project by the U.S. Fish and Wildlife Service under Section 7.

K-4 Coastal Zone Management Act (16 U.S.C. sec. 1451 et seq.)

The Coastal Zone Management Act was enacted to preserve, protect, develop, restore, and enhance the nation's coastal zones. As an inland state, New Mexico does not have a State Coastal Zone Management Program with which DOE must comply. Because the WIPP facility is not located in an affected area (i.e., a coastal zone), the Act does not apply to the WIPP facility.

K-5 Fish and Wildlife Coordination Act (16 U.S.C. secs. 661-666c)

The Fish and Wildlife Coordination Act provides for the protection of fish and wildlife resources potentially affected by development projects that modify any stream or other body of water 10 acres or greater in size. Because there are no natural bodies of surface water proposed for modification by WIPP facility-related activities, the Fish and Wildlife Coordination Act does not apply.

K-6 Clean Air Act (42 U.S.C. sec. 7401 et seq.)

The Clean Air Act provides for the preservation, protection, and enhancement of air quality, principally in areas of special natural, recreational, scenic, or historic value. Under the Clean Air Act, EPA has established the National Ambient Air Quality Standards (NAAQS) for six "criteria" pollutants: sulfur dioxide, particulate matter, carbon monoxide, ozone, nitrogen dioxide, and lead. These standards establish the maximum levels of each pollutant allowed in the air over a particular locality.

Hazardous air pollutant emissions are regulated under 40 CFR Part 61, the National Emission Standards for Hazardous Air Pollutants (NESHAPs) of the Clean Air Act. The WIPP Project has prepared an inventory to determine the presence and concentration of NESHAPs pollutants. The EPA has determined that 40 CFR Part 61, Subpart H, applies to the WIPP facility with respect to future emissions of radionuclides only. A revised standard for Subpart H radionuclide emissions was promulgated by the EPA in a final rule published in the Federal Register, effective December 15, 1989 (EPA, 1989). In the Final Safety Analysis Report (FSAR) for the WIPP facility (DOE, 1990b), the doses from future anticipated WIPP facility emissions were calculated to be less than 1 percent of the allowable effective dose equivalent of 10 millirem (mrem) per year to any one member of the public. DOE documented the expected emission levels in a data package submitted to the EPA. An emissions monitoring system was installed to comply with NAAQS NESHAPs and to meet monitoring compliance requirements; the system is described in the FSAR (DOE,

1990b). The emissions monitoring test results will be used to verify compliance. Thus, the WIPP facility will be in full compliance with the standards during the Test Phase.

The 1990 Clean Air Act amendments are not anticipated to impact WIPP Test Phase activities, because the WIPP facility is not a treatment facility and does not qualify as a major source of emissions.

K-7 Clean Water Act (or Federal Water Pollution Control Act of 1972) (33 U.S.C. sec. 1251 et seq.)

Section 402 of the Clean Water Act is the basis for regulating discharges of pollutants into navigable waters of the United States under the National Pollutant Discharge Elimination System (NPDES). The NPDES regulates discharges from point sources to navigable (surface) waters. There will be no discharges from point sources into navigable waters from the WIPP facility that would necessitate a NPDES permit. According to the WIPP FEIS, "best management practices" will be employed to eliminate the need for a NPDES permit for discharges resulting from unusual occurrences, such as flooding from a ten-year-recurrence rain. A request for a variance (based on zero discharge due to engineering controls) from NPDES permitting requirements will be submitted to the NMED by early 1992. Chapter D of this permit application discusses the management of possible sources of discharges such as decontamination wash water. Also, the NMED, under State Water Quality Control Commission regulations, has determined that the WIPP facility need not file a discharge plan (the state permit requirement for discharges of contaminants to water) for its domestic wastewater treatment lagoons (Castle, 1990).

K-8 Safe Drinking Water Act (42 U.S.C. sec. 300f et seq.)

The Safe Drinking Water Act of 1974 (SDWA), as amended, provides the regulatory strategy for protecting public water supply systems and underground sources of drinking water. As defined in implementing regulations in 40 CFR sec. 141.2, these are systems that provide water for human consumption and that have at least 15 connections or regularly serve at least 25 people.

The SDWA, in Part C, also protects underground sources of drinking water from underground injections of contaminated fluids. Underground injection, defined as "subsurface emplacement of fluids by well injection" in sec. 1421(d) of the SDWA, is governed by the Underground Injection Control (UIC) program under the Part C regulations in 40 CFR Part 144.

Because the WIPP facility receives water from an off-site supplier, the facility has neither developed nor does it maintain a public water supply system within the meaning of the

✓ SDWA and its implementing regulations. Also, the WIPP facility does not qualify for regulation under the UIC program because none of the transuranic (TRU) waste emplacement at the facility will be by well injection of fluids. The nearest underground ✓ source of drinking water to the WIPP facility is the Dewey Lake Redbeds, a perched water table located approximately 3.5 miles to the south with no hydrogeologic connection to the ✓ WIPP site. Therefore, the SDWA and its implementing regulations do not apply to the WIPP ✓ facility.

(Note: In NRDC (Natural Resources Defense Council) v. EPA [824 F.2d 1258 (1987)], the court linked deep geologic disposal of nuclear wastes to the UIC concept in the SDWA. The individual protection requirements of the EPA radiation protection standards in 40 CFR sec. 191.15 were remanded because the 25 mrem and 75 mrem individual dose limits were deemed inconsistent with the SDWA standard of 4 mrem for public drinking water supplies. These regulations have not yet been repromulgated.)

K-9 Comprehensive Environmental Response, Compensation, and Liability Act (42 U.S.C. sec. 9601 et seq.)

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), or "Superfund," and the Superfund Amendments and Reauthorization Act of 1986 (SARA) establish a comprehensive federal strategy for responding to, and establishing liability for, releases of hazardous substances from a facility to the environment. Hazardous substance cleanup procedures are specified in the National Contingency Plan (NCP) in 40 CFR ✓ Part 300. To date, no release sites have been identified at the WIPP facility that would ✓ require cleanup under the provisions of CERCLA. After the WIPP facility begins receiving waste shipments, any spills of hazardous substances of reportable quantities will be reported to the National Response Center under the provisions of CERCLA sec. 103 and 40 CFR Part 302. Under Title III of SARA, or the Emergency Planning and Community ✓ Right-to-Know Act of 1986, the WIPP facility is required to provide information, such as inventories of specific chemicals used or stored, to the State Emergency Response Commission and the Local Emergency Planning Committee to ensure that emergency plans ✓ are sufficient to respond to unplanned releases of hazardous substances. The WIPP facility will also report the storage inventory and annual release and disposal information to the EPA ✓ and the NMED as required under sec. 313 of SARA.

K-10 Toxic Substances Control Act (15 U.S.C. sec. 2601 et seq.)

The Toxic Substances Control Act (TSCA) applies primarily to manufacturers, importers, and ✓ processors of toxic chemicals for commercial purposes. The WIPP facility is not considered a manufacturer or processor of chemical products; therefore, most of the provisions of TSCA do not apply. Section 6(e) of TSCA regulates the use of polychlorinated biphenyls (PCBs)

and PCB-containing items. DOE policy prohibits the use of PCB items or equipment in DOE-installed equipment at facilities such as the WIPP facility. Therefore, TSCA would not apply to DOE-installed equipment. At the present time, TSCA does not apply to the WIPP repository because there are no plans to ship PCB-contaminated wastes to the facility. The WIPP facility will comply with TSCA regulations contained in 40 CFR secs. 761.60 and 761.65, with respect to any possible future storage or disposal of PCB-contaminated materials.

K-11 National Environmental Policy Act (42 U.S.C. sec. 4321 et seq.)

The National Environmental Policy Act (NEPA) was enacted to, among other things, "assure for all Americans safe, healthful, productive, and aesthetically and culturally pleasing surroundings." It directs the federal government to use "all practicable means" to improve and coordinate federal plans, functions, programs, and resources to that end. NEPA contains several "action-forcing" provisions, such as: utilizing an interdisciplinary approach in planning and decision making, ensuring appropriate consideration of unquantified environmental values, developing alternatives to proposals involving conflicts over use of resources, making environmental information generally available, and including a "detailed statement" on environmental impacts of "major federal actions significantly affecting the quality of the human environment." Because NEPA procedural objectives and extensive public involvement requirements are detailed in Council on Environmental Quality regulations implementing NEPA in 40 CFR Parts 1500-1508, the Act has often been referred to as a "public disclosure law."

The WIPP facility is in full compliance with NEPA. The WIPP FEIS was published in 1980. The DOE's Record of Decision (ROD), published on January 28, 1981 (DOE, 1981), concluded that the Los Medanos (WIPP) site in southeastern New Mexico would be acceptable for the long-term disposal of TRU waste with "minimal risk of any release of radioactivity to the environment." The ROD noted:

> "If significant new environmental data results from the SPDV [Site Preliminary and Design Validation] program or other WIPP project activities, the FEIS will be supplemented as appropriate to reflect such data, and this decision to proceed with phased construction and operation of the WIPP facility will be reexamined in the light of that supplemental National Environmental Policy Act (NEPA) review."

Consistent with this commitment, DOE prepared additional NEPA documentation to address changes in the proposed action and the development of new geologic and hydrologic information. Changes addressed in the SEIS (DOE, 1990a) included alterations in the composition of the waste inventory, the transportation of waste to the WIPP facility,

conducting a Test Phase, and management of TRU waste mixed with hazardous chemical constituents. The DOE's ROD to proceed with the Test Phase was published on June 22, 1990 (DOE, 1990c).

In accordance with the commitments made in the ROD for the WIPP SEIS, the DOE will issue another SEIS at the end of the Test Phase prior to deciding whether to proceed with the Operational Phase at the WIPP site.

K-12 Resource Conservation and Recovery Act of 1976 (42 U.S.C. sec. 3251 et seq.)

Under the requirements of HWMR-6, Pt. IX, sec. 270.14(b)(20), the Part B of a Resource Conservation and Recovery Act (RCRA) permit application must contain information on "other federal laws." While this requirement is generally construed to refer to laws other than RCRA, the WIPP facility presents some unique RCRA compliance dimensions that merit a brief mention. Also, some background on RCRA's applicability to the WIPP facility provides a context for the following discussion of how RCRA applies to activities and substances regulated under the Atomic Energy Act (AEA) of 1954.

On July 3, 1986, the EPA published a notice of its determination that waste containing both hazardous chemicals and radionuclides (radioactive mixed waste) was subject to regulation under RCRA (EPA, 1986). The EPA also notified those states, including New Mexico, that have EPA-authorized RCRA programs (authorized states) that they were required to obtain additional authority from the EPA to regulate the hazardous chemical constituents of radioactive mixed waste. The State of New Mexico received final EPA authorization to regulate radioactive mixed waste effective July 25, 1990 (EPA, 1990a).

DOE issued a final by-product interpretive rule on May 1, 1987 (DOE, 1987; 10 CFR Part 962) that also determined that the hazardous chemical constituents of DOE-generated mixed waste are subject to RCRA regulation. Thus, radioactive mixed waste destined for the WIPP facility is subject to dual regulation under both RCRA and the AEA.

Under the 1984 Hazardous and Solid Waste Amendments, the land disposal of hazardous wastes not meeting EPA-imposed treatment standards is prohibited unless it can be demonstrated "to a reasonable degree of certainty" that there will be "no migration of hazardous constituents from the disposal unit . . . for as long as the wastes remain hazardous" [RCRA sec. 3004(d)(1)]. HWMR-6, Pt. IX, sec. 268.6, provides for a "no-migration" variance from the land disposal restrictions when the applicant can make the required demonstration.

Because the WIPP facility qualifies as a land disposal unit, DOE submitted a petition to EPA headquarters for a no-migration variance in March 1989. On April 6, 1990, the EPA

published a public notice of the agency's intent to grant a Conditional No-Migration Determination (EPA, 1990b). EPA's decision to grant a conditional determination of no-migration was published on November 14, 1990 (EPA, 1990c).

K-13 Atomic Energy Act of 1954 (42 U.S.C. sec. 2011 et seq.)

The AEA establishes a national program for research, development, and utilization of atomic energy for both national defense and domestic civilian purposes. Section 161 of the AEA provides that the Atomic Energy Commission (succeeded for national defense purposes by the DOE) is authorized to prescribe regulations and orders to:

> "[G]overn any activity authorized pursuant to [the AEA], including standards, and restrictions governing the design, location, and operation of facilities used in the conduct of such activity, in order to protect health and to minimize danger to life or property."

The authority of DOE to develop policies, issue orders, and promulgate regulations addressing environmental, safety, and health protection aspects of radioactive waste and nuclear materials is derived directly from the AEA. However, the EPA has also derived its authority to establish radiation protection standards for TRU waste (40 CFR Part 191) partially from the AEA.

The DOE, under the authority of the AEA, and in accordance with various EOs, uses a system of Orders, Notices, and Directives to carry out the mandate to implement effective and consistent programs to protect the public, the environment, and employees from adverse consequences resulting from DOE operations. Implementation of those Orders dealing with environmental monitoring and surveillance is addressed in the Operational Environmental Monitoring Plan for the Waste Isolation Pilot Plant (Mercer et al., 1989).

RCRA contains (qualified) provisions making it inapplicable to activities or substances authorized by or regulated under the AEA. Two different sections of RCRA address these exclusions:

- The Solid Waste Exclusion. RCRA sec. 1004(27) defines a solid waste as a solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, agricultural operations, and community activities. However, the definition specifically excludes "source, special nuclear, or by-product material as defined by the Atomic Energy Act of 1954, as amended."

- The Inconsistency Exclusion. RCRA sec. 1006(a) provides the following: "Nothing in this Act shall be construed to apply to (or to authorize any state, interstate, or

local authority to regulate) any activity or substance which is subject to [listed acts] or the Atomic Energy Act of 1954 . . . except to the extent that such application (or regulation) . . . is not inconsistent with the requirements of such Acts." [Emphasis added.]

✓ Thus, radioactive mixed waste destined to be emplaced at the WIPP facility is subject to dual regulation under both the AEA and RCRA. The radioactive constituents of the waste are regulated under the AEA, while the hazardous constituents are regulated under RCRA. Nevertheless, there may be some circumstances under which RCRA regulation of the hazardous constituents would be found to be inconsistent with AEA health and safety requirements.

K-14 Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes (40 CFR Part 191)

The authority of the EPA to establish radiation protection standards for nuclear wastes is derived from the AEA, as amended; the Reorganization Plan No. 3 of 1970; and the Nuclear Waste Policy Act (NWPA) (Pub. L. 97-425). The standards apply to spent nuclear fuel, high-level radioactive waste as defined by the NWPA, and TRU waste that contains more than 100 nanocuries per gram of waste of alpha-emitting TRU isotopes with half-lives greater than 20 years. The standards, divided into two subparts (A and B), are described below.

Subpart A, Standards for Management and Storage, sets the operational term requirements limiting annual doses to members of the public from management and storage operations at disposal facilities that are operated by DOE and are not regulated by the U.S. Nuclear Regulatory Commission (NRC) or by agreement states. (The annual dose equivalent to any member of the public in the general environment cannot exceed 25 mrem to the whole body,
✓ 75 mrem to the thyroid, and 25 mrem to any critical organ.) Because the WIPP facility does not qualify as a disposal facility as defined by 40 CFR Part 191 during the Test Phase, Subpart A does not apply to management and storage operations during that period. However, in the Second Modification to the Agreement for Consultation and Cooperation,
✓ dated August 4, 1987, the DOE agreed with the State of New Mexico that the WIPP facility will comply with the standards of Subpart A upon the initial receipt of waste and thereafter.

Subpart B, Standards for Disposal, establishes several sets of long-term requirements for containment, assurance (that containment requirements can be met), individual protection, and groundwater protection and provides guidance for implementation. The containment provisions of 40 CFR sec. 191.14 require that radioactive waste disposal systems be designed to provide a reasonable expectation that cumulative releases of radionuclides from the repository over 10,000 years will not exceed levels specified in the standards. This degree of assurance is to be provided by performance assessments to be conducted by

DOE during a Test Phase of approximately five years following the first receipt of TRU waste at the WIPP facility.

As the result of a challenge to the EPA standards by the NRDC and others, the U.S. Court of Appeals for the First Circuit vacated and remanded Subpart B of the regulation (NRDC v. EPA, see Section K-8). Thus, legally, Subpart B portions of 40 CFR Part 191 are not now in effect. Nevertheless, the Second Modification to the Agreement for Consultation and Cooperation between DOE and the State of New Mexico, dated August 4, 1987, specifies that, while the standards are on remand, DOE will continue to guide its performance assessment planning efforts as though the vacated regulations are still in effect.

K-15 Hazardous Materials Transportation Act (49 App. U.S.C. sec. 1801 et seq.; 49 CFR Parts 106-179)

The Hazardous Materials Transportation Act (HMTA) provides for safe intrastate and interstate transportation of hazardous materials (including nuclear materials). The HMTA allows states to regulate the transport of hazardous/nuclear materials as long as such regulations are consistent with the HMTA or U.S. Department of Transportation (DOT) regulations. The DOT regulations for hazardous/radioactive materials are contained in 49 CFR Parts 171-177. Specifications for the kinds and design of packages to be used for the transport of various types of radionuclides are contained in 49 CFR Part 173, Subpart I (and parallel NRC regulations in 10 CFR Part 71). DOT regulations in 49 CFR Part 177 provide a routing and quantity rule for highway shipments of radioactive material; 49 CFR Part 174 contains segregation rules for shipment by rail. In the Second Modification to the Agreement for Consultation and Cooperation, dated August 4, 1987, DOE agreed to comply with all applicable DOT regulations and the corresponding regulations of the NRC.

K-16 Packaging and Transportation of Radioactive Material (10 CFR Part 71)

Regulations for shipping containers and the safe packaging and transportation of radioactive materials are under the authority of the NRC and DOT. In the Second Modification to the Agreement for Consultation and Cooperation, dated August 4, 1987, DOE agreed to comply with the applicable transportation regulations of the NRC. Packaging requirements for radioactive materials, including Type B packages to be used to transport waste to the WIPP facility, are detailed in DOT regulations (49 CFR Part 173, Subpart I), which reference the NRC regulations. In turn, the NRC regulations in 10 CFR Part 71 reference the DOT regulations in 49 CFR Part 173.

The NRC requirements for shipping containers apply to the certification of the TRUPACT-II shipping container by the NRC. The container will be used to transport radioactive waste to the WIPP facility. The TRUPACT-II container, to be used to transport transuranic waste,

was certified by the NRC on August 30, 1989, after compliance with 10 CFR Part 71 requirements for Type B packaging was demonstrated (NRC, 1990).

K-17 Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980 (Public Law 96-164)

This Act, which authorized the WIPP Project, provides as follows:

> "Notwithstanding any other provision of law, the Waste Isolation Pilot Plant is authorized as a defense activity of the Department of Energy . . . for the express purpose of providing a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States. . . ."

The statute provides for DOE consultation and cooperation with appropriate officials of the State of New Mexico with respect to the public health and safety concerns and for a written agreement between DOE and the appropriate officials of the State of New Mexico setting forth the procedures under which to carry out consultation and cooperation. In compliance, DOE has entered into two agreements with the State of New Mexico: the Consultation and Cooperation (C&C) Agreement and the Working Agreement for the C&C Agreement. Both agreements have been modified several times (see Appendix K2). The most recent modification of the C&C Agreement is the Second Modification to the Consultation and Cooperation Agreement, dated August 4, 1987. The Working Agreement for the C&C Agreement was last modified in March 1988. The agreements are implemented through DOE and the New Mexico Radioactive Waste Consultation Task Force. In addition, DOE interfaces regularly with the NMED and the New Mexico Legislature's Radioactive and Hazardous Waste Committee.

K-18 Waste Isolation Pilot Plant Land Withdrawal Act of 1991 (S. 1671; introduced to the 102d Congress, August 2, 1991)

The purpose of Senate Bill 1671 is to withdraw certain public lands from the jurisdiction of the U.S. Bureau of Land Management (BLM) for the operation of the WIPP Project. The bill provides for the transfer of the WIPP site lands from the Secretary of the Interior to the Secretary of Energy and would effectively withdraw the lands from entry, sale, or disposition; appropriation under mining laws; and operation of the mineral and geothermal leasing laws. The Secretary of Energy is directed to produce a management plan to provide for grazing, hunting and trapping, wildlife habitat, the disposal of salt tailings, and mining. Subject to the passage of S.1671 (or similar legislation), compliance with the following statutes or executive orders is required:

- Taylor Grazing Act
- Subchapter IV of the Federal Land Policy and Management Act
- Public Rangelands Improvement Act
- EO 12548 -- Grazing Fees
- Materials Act of 1947
- Federal Mine Safety and Health Act of 1977.

The bill further provides that the Secretary of Energy may enter into agreements with the Secretary of the Interior and the State of New Mexico in order to administer grazing, wildlife habitat, and mining programs. An experimental program for TRU waste, EPA standards, inclusion of engineered barriers, restrictions on TRU waste and high-level radioactive waste, retrievability, transportation, economic assistance and impact, decommissioning, and oil and gas leases are also addressed in S. 1671.

K-19 Federal Land Policy and Management Act (43 U.S.C. secs. 1701-1782)

The Federal Land Policy and Management Act was enacted to ensure, among other things, that:

> ". . . public lands be managed in a manner that will protect the quality of scientific, scenic, historical, ecological, environmental, air and atmospheric, water resource, and archeological values; that, where appropriate, will preserve and protect certain public lands in their natural condition; that will provide food and habitat for fish and wildlife and domestic animals; and that will provide for outdoor recreation and human occupancy and use. . . ."

The 10,240 acres occupied by the WIPP facility are now public lands under the jurisdiction of the BLM. DOE has conducted site validation investigations and construction under two successive administrative land withdrawals, but the withdrawals did not permit receipt and storage of TRU or TRU mixed waste. DOE has subsequently obtained an administrative modification of the latest land withdrawal to allow the Test Phase to proceed (BLM, 1991).

Under S. 1671, the Secretary of Energy is required to comply with Subchapter IV of the Federal Land Policy and Management Act. Subchapter IV establishes the authority for grazing fees, range betterment funds, grazing permits, and grazing advisory boards. Under the proposed WIPP facility land withdrawal act, or similar legislation, the Secretary of Energy would be empowered to administer these programs.

K-20 Taylor Grazing Act (43 U.S.C. sec. 315 et seq.)

This Act is intended to prohibit injury to public grazing lands by preventing overgrazing and soil deterioration. The Act promotes the orderly use of and improvement to public grazing lands by establishing grazing districts and a grazing permit system. Under the proposed land withdrawal legislation (S. 1671), DOE must allow grazing to continue on WIPP facility land where grazing districts had been established prior to the date of enactment of the withdrawal act. The Secretary of Energy is empowered to issue grazing permits on WIPP facility land.

K-21 Public Rangelands Improvement Act (43 U.S.C. sec. 1901 et seq.)

The Public Rangelands Improvement Act establishes a national policy and commitment to:

- Inventory and identify current public rangeland conditions and trends
- Manage, maintain, and improve the condition of public rangelands so that they become as productive as is feasible
- Continue the policy of protecting wild free-roaming horses and burros, while at the same time facilitating the removal and disposal of excess wild free-roaming horses and burros that pose a threat to themselves, their habitat, and other rangeland values.

Under the proposed land withdrawal act (S. 1671), DOE must inventory and administer WIPP facility lands as public rangelands.

K-22 EO 12548 -- Grazing Fees

EO 12548 orders the establishment of fees for grazing of domestic livestock on public rangelands. Under the proposed land withdrawal act (S. 1671), the Secretary of Energy is empowered to establish grazing fees.

K-23 Materials Act of 1947 (30 U.S.C. 601 et seq.)

The Materials Act of 1947 pertains to the disposal of mineral materials (including, but not limited to, sand, stone, gravel, pumice, cinders, and clay) on public lands. The disposal of vegetative materials (e.g., yucca, manzanita, mesquite, cactus, and timber or forest products) is also addressed. Under the proposed land withdrawal legislation (S. 1671), the WIPP facility must dispose of salt tailings in accordance with the bidding, advertising,

contract negotiation, and disposition of monies provisions (secs. 602-603) of the Materials Act.

K-24 Federal Mine Safety and Health Act of 1977 (30 U.S. C. sec. 801 et seq.)

Under the Federal Mine Safety and Health Act of 1977, the U.S. Department of Labor (DOL) is responsible for developing and enforcing regulations and standards to protect mine workers. Under a Memorandum of Understanding (MOU) between DOE and DOL (DOE and DOL, 1987), effective July 9, 1987, the Mine Safety and Health Administration (MSHA) conducts periodic health and safety compliance inspections of WIPP facility underground operations. Because the MSHA does not have formal regulatory jurisdiction over the WIPP facility, it advises DOE of appropriate actions to be taken to ensure the timely correction of any deficiencies noted during these inspections. MSHA also may, at the request of DOE, participate in investigations in the event of an accident or fatality at the WIPP facility. The MOU is included in Appendix K2 of this permit application.

K-25 The Wilderness Act (16 U.S.C. sec. 1131 et seq.)

The Wilderness Act provides for the establishment of the National Wilderness Preservation System. The Act defines a "wilderness" as "an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain." The Act also describes a wilderness as, among other things, an area of "undeveloped federal land . . . which is protected and managed so as to preserve its natural conditions." Numerous wilderness areas have been designated by the Congress. The closest designated wilderness area, the Gila, is located approximately 260 miles west of the WIPP facility. The Wilderness Act does not apply to the WIPP facility because the WIPP is not located within or adjacent to a designated wilderness area.

K-26 Bald and Golden Eagle Protection Act (16 U.S.C. secs. 668-668d)

The Bald and Golden Eagle Protection Act makes it unlawful to take (capture, kill, or destroy), molest, or disturb bald (American) and golden eagles, their nests, or their eggs anywhere in the United States. A permit must be obtained from the U.S. Department of the Interior to relocate a nest that interferes with resource development or recovery operations. The Act potentially applies to the WIPP facility because there is a possibility that bald and golden eagles could be present on WIPP facility lands.

Surveys to identify raptor nests on WIPP facility lands since 1985 have not recorded any bald or golden eagle nests near operational activities. Through the Cooperative Raptor Research and Management Program at the WIPP facility, DOE will continue to monitor for raptor nests on WIPP lands and near operational buildings.

✓ K-27 Migratory Bird Treaty Act (16 U.S.C. sec. 703 et seq.)

The Migratory Bird Treaty Act is intended to protect birds that have common migration patterns between the United States and Canada, Mexico, Japan, and Russia. The Act stipulates that it is unlawful to indiscriminately "kill . . . any migratory bird." It regulates the harvest of migratory birds by specifying the mode of harvest, hunting seasons, bag limits, ✓ etc. Although the WIPP facility is not located within a major migration corridor, there is the ✓ potential for migratory birds to be present on WIPP facility lands. As required by the Migratory Bird Treaty Act, DOE will consult annually with the U.S. Fish and Wildlife Service with respect to impacts on migratory birds from the hunting activities permitted on WIPP ✓ facility lands.

✓ K-28 Noise Control Act of 1972 (42 U.S.C. sec. 4901 et seq.)

According to the Act's policy clause in sec. 2(a)(3), the primary responsibility for noise control is vested in state and local governments. Federal regulation is deemed essential only for commercial noise sources requiring national uniformity of treatment (e.g., aircraft noise). However, federal agencies are required to comply with federal, state, interstate, and local requirements respecting control and abatement of environmental noise "to the fullest extent consistent with their authority" [sec. 4(a) and (b)(1), (2)].

DOE facilities are required to comply with the Occupational Safety and Health Administration (OSHA) standards in 29 CFR Part 1910, which include the Occupational Noise Exposure ✓ standards in 29 CFR 1910.95. Any WIPP facility noise sources that exceed these standards ✓ will be mitigated. For example, noise dampers have been installed in the WIPP facility underground air exhaust fans. There are no noise sources at the WIPP facility that would affect the general public.

✓ K-29 Federal Insecticide, Fungicide, and Rodenticide Act (7 U.S.C. sec. 136 et seq.)

The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) authorizes the EPA to regulate the registration, certification, use, storage, disposal, transportation, and recall of pesticides. The EPA, at its discretion, may exempt federal agencies from any FIFRA provisions if emergency conditions exist (40 CFR Part 166). Recommended procedures for storage and disposal of pesticides and pesticide containers are contained in 40 CFR Part 165. FIFRA standards are considered mandatory for DOE facilities. DOE will comply ✓ with the standards of FIFRA at the WIPP facility.

K-30 OSHA Regulations (29 CFR Parts 1900-1999)

Section 6(a) of the Williams-Steiger Occupational Safety and Health Act of 1970 provides that the DOL establish employee safety and health standards with which industries are generally familiar and that have been found to be national consensus standards or established federal standards. DOE voluntarily complies with OSHA standards for all WIPP facility activities. The WIPP facility has established safety procedures in accordance with DOE policy.

K-31 National Defense Authorization Act -- Fiscal Year 1989

DOE has entered into a contract with the New Mexico Institute of Mining and Technology to conduct independent reviews of the health and safety aspects of the design, construction, and operations of the WIPP facility, as required by the National Defense Authorization Act of 1989. The Environmental Evaluation Group (EEG) performs the reviews for the Institute. The DOE will cooperate, as appropriate, with the EEG reviews of health and safety practices at the WIPP facility.

K-32 Protection and Enhancement of Environmental Quality (EO 11514, as Amended by EO 11991)

EO 11514 directs federal agencies to:

- Monitor, evaluate, and control their agency's activities so as to protect and enhance the quality of the environment.
- Develop procedures to ensure public information and understanding of federal programs with environmental impact.
- Ensure that information regarding existing or potential environmental problems as a result of research, development, demonstration, test, or evaluation activities is made available to federal agencies, states, counties, municipalities, institutions, and other appropriate entities.
- Review their agency's statutory authority, regulations, policies, and procedures in order to identify any deficiencies or inconsistencies that limit compliance with NEPA.
- Comply with Council on Environmental Quality (CEQ) regulations except where such compliance would be inconsistent with statutory requirements.

DOE complies with CEQ regulations and public disclosure requirements by preparing NEPA documentation on WIPP Project activities as necessary. DOE also conducts continuing comprehensive environmental monitoring programs at the WIPP site, such as Operational Ecological Monitoring Program and the Cooperative Raptor Research and Management Program.

K-33 Protection and Enhancement of the Cultural Environment (EO 11593)

This EO directs federal agencies to (1) administer the cultural properties under their control in a "spirit of stewardship and trusteeship for future generations"; (2) initiate measures to preserve, restore, and maintain federally owned sites, structures, and objects of historical, archaeological, or architectural significance; and (3) institute procedures to assure that federal programs contribute to the preservation of nonfederally owned sites, structures, and objects of historical, architectural, or archaeological significance. DOE is required to initiate procedures to preserve cultural resources recorded on WIPP facility lands. (Procedures regarding cultural resources are discussed in Section K-2, National Historic Preservation Act.)

K-34 Exotic Organisms (EO 11987)

EO 11987 directs executive agencies to restrict the introduction of exotic species to and the exportation of native species from lands under their administration. DOE will comply with this EO at the WIPP site.

K-35 Floodplain Management (EO 11988)

EO 11988 directs federal agencies to avoid adverse impacts associated with the modification of floodplains, to consider alternatives to a proposed action, to provide early public review of proposed actions, and to propose mitigation measures for proposed actions within floodplains. Because the WIPP site is not located within a floodplain zone, EO 11988 does not apply to the WIPP facility.

K-36 Off-Road Vehicles on Public Lands (EO 11989)

This EO directs respective agency heads to close areas or trails on public lands where the use of off-road vehicles (ORVs) "will cause or is causing considerable adverse effects on the soil, vegetation, wildlife habitat, or cultural or historic resources." Consequently, the BLM and DOE will restrict the use of ORVs on WIPP facility lands to areas or trails suitable for such use.

K-37 Protection of Wetlands (EO 11990)

EO 11990 requires that federal agencies consider the effects of proposed actions in wetlands, determine whether wetlands are present, assess the impacts, consider alternatives to a proposed action, provide for early public review, and propose mitigation measures for proposed actions that could affect wetlands. It has been determined that, at the present time, the WIPP facility is not located within and will not impact a wetlands area; therefore, EO 11990 does not apply to the WIPP facility.

K-38 Federal Compliance with Pollution Control Standards (EO 12088)

EO 12088 directs the head of each federal agency to ensure that all necessary actions are taken for the prevention, control, and abatement of environmental pollution. Each agency is responsible for compliance with applicable pollution control standards established by such statutes as the Clean Water Act, the Clean Air Act, radiation guidances under the AEA of 1954, and others. Each agency must submit an annual plan for the control of environmental pollution at its facilities. This EO applies to DOE in controlling pollution at the WIPP facility. The Waste Minimization and Pollution Prevention Awareness Plan for the WIPP facility was submitted to DOE in September 1991.

K-39 Management of Federal Legal Resources (EO 12146)

This EO establishes the Federal Legal Council, which is composed of representatives from various federal agencies. It directs federal agencies to review the management and operation of their legal activities and to furnish reports to the Federal Legal Council so that the Council can perform effective management of federal legal resources. DOE is one of the agencies represented on the Council.

K-40 Environmental Safeguards on Activities for Animal Damage Control on Federal Lands (EO 12342)

This EO revokes EO 11643, which prevented the use of chemical toxicants for the purpose of killing a predatory mammal or bird. In order to permit effective predator control with environmental safeguards provided under federal statutory programs, DOE would be allowed to use chemical toxicants for primary or secondary poisoning of predators on WIPP facility lands.

K-41 Naval Nuclear Propulsion Program (EO 12344)

This EO establishes an integrated program for the management of the Naval Nuclear Propulsion Program by the U.S. Department of the Navy and DOE. DOE is responsible for

✓ the administration of naval nuclear reactors and nuclear propulsion plants. The WIPP facility is not involved in nuclear propulsion activities; therefore, EO 12344 does not apply to the ✓ WIPP facility.

✓ K-42 Superfund Implementation (EO 12580)

This EO revokes EO 12316 (Responses to Environmental Damages) and implements procedures for the coordination and response actions to releases of hazardous substances into the environment under the NCP of CERCLA. A National Response Team consisting of representatives of various federal agencies, including DOE, was established. The EO applies to DOE as a "federal trustee of natural resources" but does not apply directly to ✓ WIPP facility operations.

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CHAPTER L

NO-MIGRATION DETERMINATION

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CHAPTER L
NO-MIGRATION DETERMINATION

Introduction

The Waste Isolation Pilot Plant (WIPP) Project will be involved in land disposal, as defined in the New Mexico Hazardous Waste Management Regulations (HWMR-6), Part VIII, section 268.2. Land disposal includes, by definition, the placement of hazardous waste in a salt bed formation. The U.S. Department of Energy (DOE) plans to place waste in a land-disposal unit to conduct experiments during the Test Phase. Consequently, the use of waste subject to the U.S. Environmental Protection Agency's (EPA) land disposal restrictions in experiments and associated activities conducted underground during the WIPP Test Phase constitutes land disposal.

The land disposal of hazardous materials is restricted by the provisions of HWMR-6 Pt. VIII. However, in accordance with HWMR-6, Pt. VIII, sec. 268.6, land disposal facilities may, by virtue of site characteristics and/or the properties of the waste they will receive, be granted a variance from the land disposal restrictions. To be granted a variance, the owner/operator of the unit must successfully demonstrate "to a reasonable degree of certainty, that there will be no migration of hazardous constituents from the disposal unit . . . for as long as the wastes remain hazardous" [HWMR-6, Pt. VIII, sec. 268.6(a)]. A no-migration determination allows untreated restricted wastes to be emplaced in a land disposal unit, pursuant to the conditions and limitations of the determination.

In March 1989, DOE submitted to the EPA a No-Migration Variance Petition (NMVP) for the WIPP facility (DOE, 1990a). The document was subsequently expanded to include an addendum and resubmitted to the EPA in March of 1990. The addendum provides additional information specifically requested by the EPA. The petition demonstrates that site characteristics (i.e., the ability of the bedded salt to isolate emplaced wastes from ground water); operational practices, which will prevent releases to air, soil, and surface water; and waste characteristics are sufficient to prevent migration of hazardous constituents beyond the unit boundary.

On November 14, 1990, the EPA issued a Conditional No-Migration Determination for the WIPP facility (EPA, 1990a). This allows DOE to emplace untreated restricted wastes for limited uses in the facility. The notice provides information relevant to the no-migration determination; describes EPA's responses to comments provided on the proposed determination, published in the Federal Register on April 6, 1990 (EPA, 1990b); and specifies the conditions and limitations of the determination. The conditional and proposed determinations are included in Appendix L1.

L-1 Compliance with Conditions of the Determination

The EPA's specific and general conditions of the determination are presented in Section VI of the November 14, 1990, Federal Register notice. This chapter of the Resource Conservation and Recovery Act (RCRA) permit application identifies the EPA's conditions and describes DOE's approach to compliance with each condition. DOE intends to comply fully with all conditions and limitations of the No-Migration Determination.

Specific Condition 1

> "No wastes subject to this variance may be placed in the WIPP repository for purposes other than testing or experimentation to determine the long-term acceptability of the WIPP. In accordance with 40 CFR §268.6(e), the DOE must notify the EPA before it conducts any testing or experimentation not within the scope of the 'WIPP Test Phase Plan: Performance Assessment,' April 1990 (DOE/WIPP 89-011, Revision 0), as further explained in Section IV.B.1 of . . . [the November 14, 1990, Federal Register] . . . notice. Placement of waste for the purpose of conducting an operations demonstration is prohibited."

Compliance with Specific Condition 1

DOE has committed to emplace only waste for experimental or test purposes in the WIPP facility underground during the Test Phase. DOE will involve regulators in the decision-making process in the event that any beneficial tests not described in the WIPP Test Phase Plan: Performance Assessment (DOE, 1990b) are proposed.

Radioactive mixed waste may be generated as the result of routine handling of Transuranic Package Transporter (TRUPACT-II) containers and experimental waste and in the performance of air monitoring. Since these wastes will be derived from the experimental waste, they are not prohibited from placement underground during the Test Phase. Such placement is the action that is most protective of human health and the environment and the health and safety of workers. This approach is consistent with Section IV.B.1. of the November 14, 1990, Federal Register notice (EPA, 1990a), which specifies that:

> ". . . those wastes, which might no longer have any experimental purposes, could nevertheless be stored in the repository until a final determination on the site was made. Because the materials were originally placed in the WIPP for permissible testing, continued storage of the wastes in the repository would be consistent with the terms of EPA's decision."

Waste derived from the experiments and placed underground will be subject to the same retrieval requirements as experimental waste.

Specific Condition 2

"Wastes placed in the repository may not exceed 8,500 drums or 1 percent of the total capacity of the repository, as currently planned."

Compliance with Specific Condition 2

DOE commits to emplace no more than 8,500 drums or 1 percent of the total planned capacity of the WIPP facility during test phase activities conducted within the parameters of the No-Migration Determination.

Specific Condition 3

"All wastes placed in the WIPP must be removed if DOE cannot demonstrate compliance with the standards of 40 CFR 268.6, before the expiration of this petition approval, with respect to permanent disposal of mixed waste in the repository. DOE must submit a detailed schedule for retrieval of the waste, including times for completing retrieval as quickly as reasonably feasible, no later than six months after a determination that the repository cannot meet standards for long-term disposal under 40 CFR 268.6 or six months before the expiration of this petition approval, whichever occurs first."

Compliance with Specific Condition 3

During the Test Phase, all waste emplaced in the WIPP facility underground will be maintained in a manner that will ensure that wastes are readily retrievable. DOE has prepared the Waste Retrieval Plan (DOE, 1990c) to specify retrieval actions and to demonstrate the ability to retrieve waste. DOE will submit the required retrieval schedule no later than six months after it is determined that the repository cannot meet standards for long-term disposal or six months before the expiration of the petition approval.

Specific Condition 4

"All wastes placed in the WIPP must be placed in a readily retrievable manner, as described in Section IV.B.4 of . . . [the November 14, 1990, Federal Register] . . . notice."

Compliance with Specific Condition 4

"Readily retrievable" is defined by EPA in the Federal Register (EPA, 1990a) notice as the adoption of specific measures identified in the NMVP to maintain room stability (e.g., room size, rock bolting, and standoff walls) and the use of easily retrieved waste containers (i.e., boxes and

drums). This information and DOE commitments to maintain the waste in a readily retrievable manner are included in the Waste Retrieval Plan (DOE, 1990c) and Section 2.6.8 of the NMVP (DOE, 1990a). This information was reviewed by the EPA during its review of the NMVP.

Specific Condition 5

> "DOE must install and operate a carbon adsorption control device designed to achieve a control efficiency of 95 percent in the discharge system of the bin experiment rooms. DOE must monitor the control device outlet airstream in accordance with the monitoring plan described in Section IV.K of EPA's proposed decision (55 FR 13089) as amended by Section IV.B.7 of . . . [the November 14, 1990, Federal Register] . . . notice, and it must maintain design and operating records as described in Section IV.J of EPA's proposed decision, as amended by Section IV.B.6 of . . . [the November 14, 1990, Federal Register] . . . notice. Records must be maintained at the WIPP facility for the term of this determination or for three years after they are created, whichever is longer. Records must also be maintained during the course of any enforcement actions for which they are relevant."

Compliance with Specific Condition 5

The efficiency of the carbon adsorption systems is dependent upon the surface area of the carbon, the quantity of carbon used, the flow rate of air through the system, and the types and quantities of constituents to be adsorbed. Data will be maintained as specified in the EPA notice as part of the WIPP facility operating record to document that the carbon sorption systems are at least 95 percent efficient in removing volatile organic compounds (VOC). Specifically, the following data will be collected and maintained:

- "The date and time when the carbon in the control device is replaced with fresh carbon and when volatile organic sampling train (VOST) tube samples are collected for monitoring carbon breakthrough, along with records of monitoring results."

- "Engineering design analyses used to size the control device and to determine the frequency of carbon replacement."

- "A signed certification that all carbon removed from the control device is regenerated or reactivated by a process that minimizes the release of organics to the atmosphere or is disposed of in compliance with federal and State of New Mexico regulations."

A description of the WIPP Volatile Organic Compound (VOC) Monitoring Program is included in Appendix D12 of this permit application. Information pertaining to the design and sizing of the carbon system to be utilized for bin-scale tests is included in Appendix D11.

The bin-scale test VOC monitoring system will include three VOST tubes. Samples of carbon packed in the tubes will be analyzed, and test results, coupled with system mass flow data, will provide a basis for estimating the lifetime of the carbon in the main sorption unit. Details regarding the VOST tube sampling program are also included in Appendix D12.

Specific Condition 6

> "DOE must implement the air monitoring plan described in Section IV.K of EPA's proposed decision (55 FR 13089), as amended in Section IV.B.7 of . . . [the November 14, 1990, Federal Register] . . . notice. Records must be maintained at the WIPP facility for the term of this determination or for three years after they are created, whichever is longer. Records must be maintained during the course of any enforcement action for which they are relevant."

Compliance with Specific Condition 6

√ The VOC Air Monitoring Program described in the Addendum to the NMVP (Section 6.1 of
√ Volume VII) has been implemented. The program calls for the implementation of air monitoring
√ 30 days prior to the first receipt of waste at the WIPP facility. Air monitoring at Station VOC-1
√ was implemented August 25, 1991 (more than 30 days in advance of waste receipt). The overall program for monitoring emissions from the underground is described in Chapter D. Records
√ related to air monitoring will be maintained in the WIPP facility operating record as required by Specific Condition 6.

Specific Condition 7

Conditions related to waste analysis:

(a) "DOE must ensure that each waste container emplaced underground at the WIPP has no layer of confinement which contains flammable mixtures of gases or mixtures of gases that could become flammable when mixed with air. This prohibition must be implemented by analytical testing of a representative sample of headspace gases from each waste drum or individual container, as described in Section IV.B.7.a and V.F.1.a of . . . [the November 14,1990, Federal Register] . . . notice."

(b) "DOE must analyze representative samples of the headspaces of containers to be used in the bin-scale test and compare these results to the estimated compositions provided in its petition for each waste type, as detailed in Section IV.B.7.b of . . . [the November 14, 1990, Federal Register] . . . notice. If the waste is not compositionally similar, as defined in Tables 2 and 3 in Section IV.B.7.b, that waste cannot be shipped to the WIPP until the

waste has been treated or modified such that it is compositionally similar to the estimates provided in the no-migration petition. In addition, as prescribed in Section IV.B.7.b, the DOE must demonstrate the comparability of bin-scale wastes to wastes described in DOE's petition before placing waste in the WIPP for alcove tests."

(c) "Waste analysis records must be maintained for the term of this determination or for three years after generation, whichever is longer. Records must also be maintained during the course of any enforcement action for which they are relevant. The records may be maintained at the generating site or at the WIPP facility."

Compliance with Specific Condition 7

The WIPP Waste Analysis Plan (Chapter C of this permit application) addresses compliance with the provisions of this condition. The plan requires DOE waste generators to provide the required information to the DOE WIPP Project Office (WPO) prior to the shipment of the waste to the ✓ WIPP facility. The WPO will approve shipment to the WIPP facility of only those wastes for which the required information has been provided. Only waste meeting the criteria specified by the EPA in the November 14, 1990, Federal Register (EPA, 1990a) notice will be approved for shipment. Records of waste analysis will be maintained as required by Specific Condition 7.

Details of DOE compliance with each of the requirements of Specific Condition 7 are provided below:

✓ (a) ✓ Section C-2 specifies the waste characterization activities to be performed by generator sites to meet minimum information requirements. The minimum information requirements are identified in Section C-2 of this permit application.

The minimum requirements include testing the waste for flammability as specified in Table C-4 of this permit application. Table C-4 was developed to respond specifically to the requirements for flammability testing included in the EPA No-Migration Determination. Only those wastes tested for flammability in accordance with the requirements of Table C-4 and demonstrated to be within the EPA-specified flammability limits will be ✓ acceptable for shipment to the WIPP facility.

(b) Requirements to test container headspace gases to demonstrate that the gas compositions are comparable to those described in the NMVP are also addressed in Section C-2 of the RCRA permit application. This testing is included in the minimum information requirements identified. Table C-5 of this permit application was developed to respond to this requirement specifically.

√ (c) DOE commits to maintain waste analysis records in the WIPP facility operating record throughout the ten-year term of the No-Migration Determination, for three years, or during the course of any enforcement action for which they are relevant, whichever is longer.

Specific Condition 8

"DOE must provide to the EPA Office of Solid Waste and EPA Region VI annual written reports on the status of DOE's performance assessment during the test phase. These reports must include: a description of the tests to date and their results, modifications to the test plan, a summary of DOE's current understanding of the repository's performance, waste characterization data from pre-test waste characterization, and an annual summary of air monitoring data required in Item 6 above."

Compliance with Specific Condition 8

As included in the WIPP Test Phase Plan: Performance Assessment (DOE 1990b), DOE commits to report annually on results of the Performance Assessment and associated tests and data. In conformance with this condition and the requirements of DOE Order 5400.1, General Environmental Protection Program (DOE, 1988), the results of VOC monitoring will be reported
√ annually in the WIPP Site Environmental Monitoring Report and in an annual data summary report
√ submitted to the EPA.

General Condition 1

"Wastes placed by DOE in the WIPP and the DOE's activities under the variance must be consistent with those described in the petition."

Compliance with General Condition 1

√ Waste emplaced in the WIPP facility during the Test Phase will be consistent with those described in the NMVP (DOE, 1990a). Chapter C of this permit application describes methods to be employed to ensure that this condition is met. The WIPP Management and Operating Contractor (MOC) will use administrative controls to ensure that project activities are consistent
√ with those described in the NMVP.

General Condition 2

"DOE must notify EPA of any changes in conditions at the unit and/or environment that significantly depart from the conditions described in the variance and affect the potential for migration of hazardous constituents from the unit . . .' If the change

is planned, EPA must be notified in writing 30 days in advance of the change; if it is unplanned, the EPA must be notified within ten days."

Compliance with General Condition 2

✓ The WIPP MOC will use administrative controls to ensure compliance with this condition. The ✓ Environmental Safety and Health Department of the MOC organization will be responsible for ✓ notifying the WPO of any changes in conditions described in the NMVP affecting the potential for ✓ migration of hazardous waste or hazardous constituents from the unit. If it is determined that the ✓ change is significant and/or may affect the potential for the migration of hazardous waste or ✓ hazardous constituents, the EPA will be notified by the WPO, in accordance with specific ✓ requirements of this EPA condition. Any such notifications will also be provided to the New ✓ Mexico Environment Department (NMED).

General Condition 3

"If DOE determines that there has been migration of hazardous constituents from ✓ the repository in violation of Part 268, it must suspend receipt of prohibited wastes at the unit and notify EPA within ten days of the determination. [In the case of the WIPP, DOE must submit such a notice to both the EPA Office of Solid Waste and EPA Region VI.] Within 60 days, EPA is required to determine whether DOE may continue to receive prohibited waste in the unit and whether the variance should be revoked."

Compliance with General Condition 3

The NMVP (DOE, 1990a) demonstrates that during the Test Phase, the only credible pathway for the migration of hazardous constituents beyond the unit boundary in concentrations exceeding health-based standards is via airborne transport of volatile organics. The EPA has concurred with this demonstration (EPA, 1990a; EPA, 1990b).

The MOC has developed a procedure to implement the determination of airborne concentrations ✓ of VOCs in the underground exhaust air stream. In addition, another WIPP facility procedure specifies steps to be taken to notify regulatory authorities in the event of an environmental release of a hazardous material or in the event migration is determined to have occurred from the WIPP underground facilities.

General Condition 4

"Finally, under section 268.6(h), the term of . . . [the November 14, 1990] . . . petition approval runs for ten years, that is until November 14, 2000."

Compliance with General Condition 4

The determination is to apply to the Test Phase of the WIPP Project only. Because the Test Phase is expected to have a duration of less than ten years, the ten-year duration of the determination should be consistent with project requirements. In the event that the Test Phase is proposed to extend beyond the period for which the determination is valid, DOE will request an extension of this period or will file a petition to renew the determination, as appropriate.

Other Conditions of the Determination

In addition to the conditions and limitations identified above, EPA included several specific requirements within the body of the text of the April 6 and November 14, 1990, Federal Register notices (EPA, 1990a and 1990b). These pertain to specific conditions of VOC monitoring.

Compliance with Other Conditions

DOE proposes to comply fully with all of the additional conditions identified in the EPA Federal Register notices. Each of these conditions is identified in Table L-1, which also indicates the various monitoring program documents where the DOE response to the EPA requirement is located.

List of References for Chapter L

DOE, see U.S. Department of Energy.

EPA, see U.S. Environmental Protection Agency.

Molecke, M. A., 1990, Test Plan: WIPP In Situ Alcove CH TRU Waste Tests, Sandia National Laboratories, Albuquerque, New Mexico.

U.S. Department of Energy (DOE), 1990a, "Waste Isolation Pilot Plant No-Migration Variance Petition," DOE/WIPP 89-003, Revision 1, U.S. Department of Energy, Carlsbad, New Mexico.

U.S. Department of Energy (DOE), 1990b, "WIPP Test Phase Plan: Performance Assessment," DOE/WIPP 89-011, Revision 0, U.S. Department of Energy, Carlsbad, New Mexico.

U.S. Department of Energy (DOE), 1990c, "Waste Retrieval Plan," DOE/WIPP 89-022, U.S. Department of Energy, Carlsbad, New Mexico.

U.S. Department of Energy (DOE), 1988, "General Environmental Protection Program," DOE Order 5400.1, U.S. Department of Energy, Washington, D.C.

U.S. Environmental Protection Agency (EPA), 1990a, "Conditional No-Migration Determination for the Department of Energy Waste Isolation Pilot Plant (WIPP)," Federal Register, Vol. 55, No. 220, pp. 47700-47721.

U.S. Environmental Protection Agency (EPA), 1990b, "Notice Proposing to Grant a Conditional Variance to the Department of Energy Waste Isolation Pilot Plant (WIPP) from Land Disposal Restrictions," Federal Register, Vol 55, No. 67, pp. 13068-13094.

U.S. Environmental Protection Agency (EPA), 1989, "Report on Minimum Criteria to Assure Data Quality," EPA/530-SW-90-021, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C.

U.S. Environmental Protection Agency (EPA), 1986, "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods," SW-846, Third Edition, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C.

Westinghouse, see Westinghouse Electric Corporation.

List of References for Chapter L
(Continued)

Westinghouse Electric Corporation (Westinghouse), 1991, "Volatile Organic Compounds Monitoring Quality Assurance Project Plan WP 12-7, Westinghouse Waste Isolation Division, Carlsbad, New Mexico.

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TABLE

TABLE L-1
OTHER CONDITIONS OF THE NO-MIGRATION DETERMINATION AND LOCATIONS OF DOE RESPONSES

EPA CONDITION/LIMITATION	LOCATION OF DOE RESPONSE
1. Monitoring must begin 30 days prior to the emplacement of any experimental wastes underground (EPA, 1990b, p. 13090).	WP 12-6, VOC Monitoring Plan for Bin-Room Tests (Appendix D12), Section 3.3. Monitoring at Station VOC-1 was implemented on August 25, 1991.
2. Monitoring of bin-scale experiment rooms must commence prior to emplacement of any bins containing TRU waste (EPA, 1990b, p. 13090).	WP 12-6, VOC Monitoring Plan for Bin-Room Tests (Appendix D12), Section 3.3. Station VOC-10 has been installed in the underground facility, Panel 1. DOE is prepared to initiate monitoring prior to waste receipt.
3. Monitoring of alcoves must commence prior to initiation of alcove experiments, after alcoves are sealed, and prior to purging of alcove atmosphere (EPA, 1990b, p. 13090).	This permit application is for bin tests only. A permit modification or modification under interim status will be submitted for alcove tests prior to alcove test initiation.
4. The leakage rate of the sealed alcoves must be measured by means of the injection of tracer gases into the atmosphere within each alcove and monitoring the tracer gas levels (EPA, 1990b, p. 13090).	Test Plan: WIPP In Situ Alcove CH TRU Waste Tests (Molecke, 1990), Section 12.1.3.
5. After 30 days of daily sampling at all locations except the exhaust and air intake shafts, sampling frequency may be reduced from daily to weekly, at a minimum, if the monitoring results are relatively constant over time, as indicated by a relative standard deviation of not more than 25 percent over the last 30-day period for any targeted constituents (EPA, 1990b, p. 13090).	WP 12-7, Volatile Organic Compounds Monitoring Quality Assurance Project Plan (Westinghouse, 1991), Section 7.2.1.

6.	Exhaust shaft and air intake locations must be monitored weekly (EPA, 1990b, p. 13090).	WP 12-7, Volatile Organic Compounds Monitoring Quality Assurance Project Plan, Waste Isolation Pilot Plant (Westinghouse, 1991), Section 7.2.1.
7.	In no event shall the monitoring frequency for the bin discharge system be reduced to less than 20 percent of the minimum time required for the consumption of the total working capacity of the carbon adsorption system (EPA, 1990b, p. 13090).	WP 12-6, VOC Monitoring Plan for Bin-Room Tests (Appendix D12), Section 3.3.1; WP 12-7, Volatile Organic Compounds Monitoring Quality Assurance Project Plan, Waste Isolation Pilot Plant (Westinghouse, 1991), Section 7.2.1.
8.	In the event that weekly air monitoring results exhibit increased variability, daily air sampling must be resumed if the calculated relative standard deviation with a preceding 4-week period at the monitoring location exceeds 75 percent for any targeted constituent. Daily sampling would have to continue until such a time as the criteria for a reduction in frequency to weekly sampling are met again (EPA, 1990b, p. 13094).	WP 12-6, VOC Monitoring Plan for Bin-Room Tests (Appendix D12), Section 3.3.
9.	Any volatile organic compound (VOC) must be targeted for routine quantification if the average estimated concentration at the point of sampling is 1 ppm or more during any 4-month period and the compound is detected in at least 10 percent of the samples collected from the gas discharge system from either room containing bins or 50 percent of the samples collected from any alcove (EPA, 1990b, p. 13090).	WP 12-6, VOC Monitoring Plan for Bin-Room Tests (Appendix D12), Section 4.4; WP 12-7, Volatile Organic Compounds Monitoring Quality Assurance Project Plan, Waste Isolation Pilot Plant (Westinghouse, 1991), Section 9.4.2. Procedures have been developed by the contract laboratory, as specified by a Westinghouse scope-of-work.

10.	DOE must implement standard operating procedures that will provide positive identification of the following compounds: perchloroethylene, chloroform, bromoform, dichloroethane, dichloroethylene, toluene, and chlorobenzene (EPA, 1990b, p. 13091).	√ WP 12-6, VOC Monitoring Plan for Bin-Room √ Tests (Appendix D12), Section 4.2; Volatile Organic Compounds Monitoring Quality √ Assurance Project Plan (Westinghouse, √ 1991), Sections 9.2.1.6 and 9.2.1.7. Procedures have been developed by the contract laboratory, as specified by the Westinghouse scope-of-work.
11.	The average response factor for each target analyte, as determined by 5-point instrument calibration, must be used for quantification in high-resolution gas chromotography (EPA, 1990b, p. 13091).	√ WP 12-6, VOC Monitoring Plan for Bin-Room √ Tests (Appendix D12), Section 5.5; Volatile Organic Compounds Monitoring Quality √ Assurance Project Plan (Westinghouse, √ 1991), Sections 9.2.1.5 and 9.2.2.4. √ Procedures have been developed by the √ contract laboratory, as specified by the √ Westinghouse scope-of-work.
12.	Standard operating procedures must be adopted by DOE to ensure the validity of the monitoring data (EPA, 1990b, p. 13091).	√ WP 12-7, Volatile Organic Compounds Monitoring Quality Assurance Project Plan √ (Westinghouse, 1991), Section 12.0. WIPP √ Waste Isolation Division (WID) quality √ assurance procedures are in place to assure √ validity of monitoring data.
13.	Consistent with the SW-846 (EPA, 1986) Method 8240, instruments must be recalibrated by a full 5-point calibration if the response factor from the calibration check differs by greater than 25 percent of the average or expected response factor (EPA, 1990b, p. 13091).	√ WP 12-7, Volatile Organic Compounds Monitoring Waste Quality Assurance Project √ Plan (Westinghouse, 1991), Sections 9.2.1.5 √ and 9.3.2.3. Laboratory standard operating √ procedures and quality assurance plans √ completed and implemented in accordance √ with the Westinghouse scope-of-work.

14.	The method limit of quantification for each target analyte must be established prior to the initiation of the monitoring program and be reevaluated annually thereafter in accordance with EPA/530-SW-90-021, December 12, 1989 (EPA, 1989). This document has been revised and retitled "Quality Assurance and Quality Control" (August 1990) (EPA, 1990b, p. 13091).	WP 12-6, VOC Monitoring Plan for Bin-Room Tests (Appendix D12), Section 6.1.6; WP 12-7, Volatile Organic Compounds Monitoring Quality Assurance Project Plan (Westinghouse, 1991), Section 9.3.2.6.
15.	The method limit of quantification must be determined separately for the bin, alcove, and exhaust shaft monitoring locations (EPA, 1990b, p. 13091).	WP 12-6 VOC Monitoring Plan for Bin-Room Tests (Appendix D12), Section 6.1.6; WP 12-7, Volatile Organic Compounds Monitoring Quality Assurance Project Plan (Westinghouse, 1991), Section 9.3.2.6.
16.	Recovery samples must be collected from audit cylinders and analyzed at a frequency of 10 percent at each monitoring location (EPA, 1990b, p. 13092).	WP 12-6, VOC Monitoring Plan for Bin-Room Tests (Appendix D12), Sections 5.2.3 and 6.1; WP 12-7, Volatile Organic Compounds Monitoring Quality Assurance Project Plan (Westinghouse, 1991), Section 9.3.1.4. Method Relative Accuracy Sampling Procedures for audit cylinder sampling have been completed (WP-12 EM1641, 42, 43, 44, and 45).
17.	Duplicate samples must be collected and analyzed at a frequency of 10 percent in each monitoring location, including the exhaust shaft (EPA, 1990b, p. 13092).	WP 12-6, VOC Monitoring Plan for Bin-Room Tests (Appendix D12), Section 6.1.6.1; WP 12-7 Volatile Organic Compounds Monitoring Quality Assurance Project Plan (Westinghouse, 1991), Section 9.3.1.3. Duplicate sampling is discussed in Method Relative Accuracy Sampling Procedures (WP-12 EM1641, 42, 43, 44, and 45.)
18.	Data completeness must be evaluated by data validation audits of a frequency not less than 5 percent (EPA, 1990b, p. 13092).	WP 12-7, Volatile Organic Compounds Monitoring Quality Assurance Project Plan (Westinghouse, 1991), Sections 9.3.2.10 and 12.4.

19.	To ensure that any sampling analysis problems that may occur are detected and corrected, accuracy, precision, and completeness must be tracked and evaluated after every 10 quality control analyses (EPA, 1990b, p. 13092).	WP 12-7, Volatile Organic Compounds Monitoring Quality Assurance Project Plan (Westinghouse, 1991), Section 9.3.2.9.
20.	Systems audits must be performed not only prior to the initiation of the monitoring program but also semiannually thereafter to be consistent with good operating practice (EPA, 1990b, p. 13092).	WP 12-7, Volatile Organic Compounds Monitoring Quality Assurance Project Plan (Westinghouse, 1991), Section 12.3.
21.	Corrective action must be taken whenever a condition or practice is found that is outside systems specifications or standard operating procedures or that could reasonably be expected to compromise the ability of the monitoring program to meet established quality assurance objectives for data acceptability (EPA, 1990b, p. 13092).	WP 12-7, Volatile Organic Compounds Monitoring Quality Assurance Project Plan (Westinghouse, 1991), Section 11.0.
22.	Specific quality assurance objectives must be established for data acceptability for the WIPP facility air monitoring program consistent with method capability and good operating practice (EPA, 1990b, p. 13092).	WP 12-7, Volatile Organic Compounds Monitoring Quality Assurance Project Plan (Westinghouse, 1991), Section 9.3.2.
23.	Corrective action must be taken whenever quality assurance objectives for data acceptability are not being met (EPA, 1990b, p. 13092).	WP 12-7, Volatile Organic Compounds Monitoring Quality Assurance Project Plan (Westinghouse, 1991), Section 11.0.
24.	To determine whether migration has occurred, concentrations of targeted constituents must be averaged over an annual time period (EPA, 1990b, p. 13092).	WID Procedure WP-12 EM3203, Environmental Volatile Organic Compound Data Management, addresses data management and calculations.

25.	Annual data summaries and summaries of data accuracy, precision, and completeness at each monitoring location, together with calculated concentrations at the exhaust shaft and documentation of the actual method limit of detection achieved for each targeted analyte, must be submitted to EPA (EPA, 1990b, p. 13092).	WID Procedure WP-12 EM3203, Environmental Volatile Organic Compound (VOC) Data Management, addresses data management and calculations.
26.	Documentation on all aspects of quality assurance and quality control as described in EPA/530-SW-90-021 (as revised and retitled "Quality Assurance and Quality Control") must be maintained at the WIPP facility operating record and be available for inspection by EPA (EPA, 1990b, p. 13092).	WP 12-7, Volatile Organic Compounds Monitoring Quality Assurance Project Plan (Westinghouse, 1991), Section 13.1.
27.	To determine relative accuracy, DOE must conduct and analyze both a matrix spike and a concurrent matrix duplicate.	Procedures for conducting field sampling for relative accuracy in accordance with this requirement have been completed (WP-12 EM1641, 42, 43, 44, and 45).

CHAPTER M

CERTIFICATION

CHAPTER M
CERTIFICATION

The U.S. Department of Energy (DOE), through its Albuquerque Operations Office and its Waste Isolation Pilot Plant (WIPP) Project Office, has signed as "owner and operator," and Westinghouse Electric Corporation, acting through its Waste Isolation Division (WID), has signed as "co-operator" this application for the permitted facility. The DOE has determined that dual signatures best reflect the actual apportionment of Resource Conservation and Recovery Act (RCRA) responsibility for the WIPP facility The DOE's RCRA responsibilities are for policy, programmatic funding and scheduling decisions, WIPP requirements of DOE generator sites, the Waste Acceptance Criteria Certification Committee, all other parties engaged in work at the WIPP facility pursuant to a direct contractual relationship with the DOE, as well as general oversight. The WID's RCRA responsibilities are for certain day-to-day operations (in accordance with general directions given by the DOE and in the Contract as part of its general oversight responsibility) including, but not limited to, the following responsibilities: certain waste handling, monitoring, record keeping, certain data collection, reporting, technical advice, and contingency planning. For purposes of the certification required by New Mexico Hazardous Waste Management Regulations (HWMR-6), Part IX, section 270.11(d), the DOE's and the WID's representatives certify, to the best of their knowledge and belief, the truth, accuracy, and completeness of the application for their respective areas of responsibility.

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to be the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Owner and Operator Signature: *Original Signed by Arlen Hunt*
Title: Project Manager, WIPP Project Office
for: U.S. Department of Energy
Date: *March 3, 1992*

Co-Operator Signature: *Original Signed by A. LaMar Trego*
Title: General Manager
for: Westinghouse Electric Corporation
Date: *February 28, 1992*

ACRONYMS

ACRONYMS

1

AASHTO	American Association of State Highway and Transportation Officials	2
AC	Alternating Current	3
AEA	Atomic Energy Act	4
ALARA	As Low As Reasonably Achievable	5
BGS	Below Ground Surface	6
BLM	(U.S. Department of the Interior) Bureau of Land Management	7
C&C	Consultation and Cooperation	8
CEQ	Council on Environmental Quality	9
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act	10
CFR	Code of Federal Regulations	11
CH	Contact-Handled	12
CMR	Central Monitoring Room	13
CWA	Clean Water Act	14
DID	Direct Inward Dial	15
DOD	Direct Outward Dial	16
DOE	U.S. Department of Energy	17
DOL	U.S. Department of Labor	18
DOT	U.S. Department of Transportation	19
DRZ	Disturbed Rock Zone	20
EEG	Environmental Evaluation Group	21
EO	Executive Order	22
EOC	Emergency Operations Center	23
EPA	U.S. Environmental Protection Agency	24
ERT	Emergency Response Team	25
ES&H	WIPP Environment, Safety, and Health Department	26
EST	Emergency Services Technician	27
FAX	Facsimile	28
FEIS	Final Environmental Impact Statement	29
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act	30
FLIRT	First Line Initial Response Team	31
FM	Facility Manager	32
FOSS	Facility Operations Shift Supervisor	33
FSAR	Final Safety Analysis Report	34
GC/MS	Gas Chromatography/Mass Spectrometer	35
GET	General Employee Training	36
HEPA	High Efficiency Particulate Air (filter)	37
HMTA	Hazardous Materials Transportation Act	38
HS	Health Services	39
HVS	Hood Ventilation System	40

ACRONYMS
(CONTINUED)

1	HWMR	(New Mexico) Hazardous Waste Management Regulations
2	IDC	Item Description Code
3	IPA	Inventory and Preparation Area
4	MB	Marker Bed
5	MOC	(WIPP) Management and Operating Contractor
6	MOU	Memorandum of Understanding
7	MSDS	Materials Safety Data Sheet
8	MSHA	Mine Safety and Health Administration
9	MSL	Mean Sea Level
10	NAAQS	National Ambient Air Quality Standards
11	NCP	National Contingency Plan
12	NEPA	National Environmental Policy Act
13	NESHAPs	National Emission Standards for Hazardous Air Pollutants
14	NFPA	National Fire Protection Association
15	NHPA	National Historic Preservation Act
16	NMD	No-Migration Determination
17	NMED	New Mexico Environment Department
18	NMEID	New Mexico Environmental Improvement Division
19	NMVP	No-Migration Variance Petition
20	NPDES	National Pollutant Discharge Elimination System
21	NRC	U.S. Nuclear Regulatory Commission
22	NRDC	National Resources Defense Council
23	NWPA	Nuclear Waste Policy Act
24	OEMP	Operational Environmental Monitoring Program
25	OPRR	Overpack and Repair Room
26	ORV	Off-Road Vehicle
27	OSHA	Occupational Safety and Health Administration
28	PA	Public Address
29	PCB	Polychlorinated biphenyl
30	PBT	Performance-Based Training
31	PMP	Probable Maximum Precipitation
32	QA	Quality Assurance
33	QAPjP	Quality Assurance Project Plan
34	QAPP	Quality Assurance Program Plan
35	QC	Quality Control
36	RCB	Radiological Control Boundary
37	RCRA	Resource Conservation and Recovery Act
38	RMA	Radioactive Materials Area

ACRONYMS
(CONTINUED)

ROD	Record of Decision	1
RTR	Real Time Radiography	2
SARA	Superfund Amendments and Reauthorization Act	3
SCBA	Self-Contained Breathing Apparatus	4
SDWA	Safe Drinking Water Act	5
SEIS	Supplement Environmental Impact Statement	6
SH	Salt Handling	7
SHPO	State Historic Preservation Officer	8
SNS	Site Notification System	9
SPDV	Site and Preliminary Design Validation	10
SWB	Standard Waste Box	11
SWMU	Solid Waste Management Unit	12
TCLP	Toxicity Characteristic Leaching Procedure	13
TRANSCOM	Transportation Tracking and Communications System	14
TRU	Transuranic (waste)	15
TRUCON	TRUPACT-II Content Codes	16
TRUPACT-II	Transuranic Package Transporter	17
TSCA	Toxic Substances Control Act	18
UIC	Underground Injection Control	19
UPS	Uninterruptible Power Supply	20
US	United States	21
UST	Underground Storage Tank	22
USTR	Underground Storage Tank Regulations	23
V	Volt	24
VOC	Volatile Organic Compound	25
VOST	Volatile Organic Sampling Train	26
WAC	Waste Acceptance Criteria	27
WACCC	Waste Acceptance Criteria Certification Committee	28
WHB	Waste Handling Building	29
WIPP	Waste Isolation Pilot Plant	30
WPO	(DOE) WIPP Project Office	31
WWIS	WIPP Waste Information System	32

GLOSSARY

GLOSSARY

alluvial fan	a cone-shaped deposit of alluvium made by a stream where it runs out onto a level plain or meets a slower stream; generally formed where streams issue from mountains upon a lowland.
alpha particle	a charged particle emitted from the nucleus of an atom, having a mass and charge equal in magnitude to a helium nucleus, i.e., two protons and two neutrons.
alpha radiation	radiation composed of positively-charged particles emitted in the radioactive decay of certain nuclides. Each alpha particle is made up of two protons and two neutrons bound together and is identical to the nucleus of a helium atom.
analyte	a substance or parameter for which a sample is analyzed.
anhydrite	a mineral, $CaSO_4$, consisting of an anhydrous calcium sulfate that is massive and white or slightly colored.
aquiclude	a body of relatively impermeable rock that is capable of absorbing water slowly, but does not transmit it rapidly enough to supply a well or a spring.
aquifer	a body of rock that contains enough saturated permeable material to transmit ground water and to yield significant quantities of ground water to wells and springs. The opposite of an aquiclude.
bedded salt	consolidated layered salt separated from other layers by distinguishable planes of separation.
berm	a narrow ledge or shelf typically along the top or bottom of a slope.
beta radiation	radiation made up of negatively charged particles emitted in the radioactive decay of certain nuclides; free electrons.

calcite	a mineral, $CaCO_3$, which is the principal constituent of limestone.
caliche	a crust of calcium carbonate that forms in the stony soils of arid regions.
carcinogen	a substance which may cause or induce cancer.
Central Monitoring Room	a room at the WIPP facility equipped to monitor vital plant parameters and alarm functions and provide reliable communications.
certification	in this document, the process of verifying and denoting that specified employee qualification requirements have been satisfactorily completed.
certification card	a document specifying certification requirements for a particular job, and on which completion of the requirements is recorded.
chain-of-custody form	form used to track control of a sample from the time of collection to analysis.
conservative	when used with prediction or estimates, a conservative estimate is one in which the uncertain inputs are selected in the way that tend to overestimate potential negative impacts.
contact-handled waste	waste that does not require shielding other than that provided by its container.
containment	a base which underlies a hazardous waste container which is free of cracks or gaps and is sufficiently impervious to contain leaks and spills, and otherwise meets the conditions of New Mexico Hazardous Waste Management Regulations (HWMR-6), Part V, Subpart I (as opposed to a definition of radiological containment found in Order DOE 6430.1A, General Design Criteria).
contingency plan	a document setting out an organized, planned, and coordinated course of action to be followed in case of a fire, explosion, or release of hazardous waste or hazardous

	constituents that could threaten human health or the environment.
declivity	a descending slope; downward inclination.
decontamination	the removal of unwanted material (especially radioactive or hazardous materials).
decommissioning	the process of removing a facility or piece of equipment from operation, which is then either moth-balled, entombed, decontaminated, dismantled, or converted to another use.
derived waste	waste resulting from handling and management of mixed waste used for experiments during the Test Phase at the WIPP facility.
Design Basis Earthquake	for the WIPP site area, defined as an event with maximum ground acceleration of 3.2 inches per second squared horizontally and vertically, with 10 maximum stress cycles, based on a 1,000-year recurrence interval. Facility structures are designed and built to withstand these stresses.
dissolution	the process of dissolving or, more rarely, of melting.
dolomite	a common rock-forming mineral, $CaMg(CO_3)_2$; also, a sedimentary rock consisting primarily of the mineral dolomite.
drift	a horizontal mine passageway.
eolian	deposits arranged by the wind and erosive action of the wind, and which are due to the transporting action of the wind.
Emergency Coordinator	an employee at the WIPP facility or on call with responsibility for coordinating emergency response measures. The Emergency Coordinator is thoroughly familiar with all aspects of the facility's contingency plan, all operations and activities at the facility, the location and characteristics of waste handled, the location of all records within the facility, and the facility layout. The Emergency Coordinator has the authority

	to commit resources necessary to implement the contingency plan.
Emergency Operations Center	a room at the WIPP facility equipped with primary and redundant communications systems and is the base of operations during emergency situations.
evapotranspiration	that portion of the precipitation returned to the air through direct evaporation or by transpiration of vegetation, no attempt being made to distinguish between the two.
evaporites	a non-clastic sedimentary rock composed primarily of minerals produced by precipitation from a saline solution as a result of extensive or total evaporation of the solvent.
gamma radiation	short-wavelength electromagnetic radiation emitted in the radioactive decay of certain nuclides; high-energy photons.
getter (gas)	materials which have an ability to remove gases from the atmosphere by chemical means.
glauberite	a mineral, $Na_2Ca(SO_4)_2$, often found in evaporites.
gypsum	a mineral, $CaSO_4 \cdot 2H_2O$, common to evaporites.
halite	a naturally occurring mineral of sodium chloride (rock salt).
hazardous waste	solid waste that exhibits any of the characteristics of hazardous waste identified in New Mexico Hazardous Waste Management Regulations (HWMR-6), Part II, Subpart C; is listed in Part II, Subpart D; or is a mixture of a solid waste and a hazardous waste.
headspace gases	gases in the headspace of a container that are generated from biological, chemical, and radiolytic processes occurring in the waste. The head space of a container is the space between the container lid and the waste inside the container.
high efficiency particulate air filter	filter that captures entrained particulate material from an air stream, usually with efficiencies in the 99.95 percent and above range for particle sizes of 0.3 micron or greater. Filter

	material is usually a paper or fiber sheet that is pleated to increase surface area.
horizon	in this document, an underground level. The waste-emplacement horizon in the WIPP facility is the level about 2,150 feet deep at which openings would be mined for waste disposal.
hydraulic conductivity	a quantity defined in the study of ground water hydraulics that describes the rate at which water flows through an aquifer. It is measured in feet per day or equivalent units. It is equal to the hydraulic transmissivity divided by the thickness of the aquifer.
hydraulic gradient	in an aquifer, the rate of change of total head per unit of distance of flow at a given point and in a given direction.
isotopes	atoms having the same number of protons in their nuclei, but differing in the number of neutrons. Almost identical chemical properties exist between isotopes of a particular element.
Level I trainers	technically knowledgeable members of the WIPP facility line organization who are qualified to provide training on operation of specified equipment.
Level II trainers	members of Technical Training and the WIPP facility line organizations who are qualified to conduct limited classroom training in their technical area of expertise.
Level III trainers	members of Technical Training who are qualified to conduct classroom training, skills evaluation, and training needs assessment.
lithostatic pressure	the vertical pressure at a point in the earth's crust equal to the pressure exerted by the weight of the overlying rock and/or soil.
lower explosive limit	the minimum concentration of gas or vapor in air below which a substance does not burn when exposed to an ignition source.

magnesite	a mineral, $MgCO_3$.
Master Records Center	WIPP project record archive.
meteoric water	water which occurs in or is derived from the atmosphere.
microdarcy	a standard unit of permeability one-millionth of a darcy.
milli	a prefix meaning one-thousandth (1/1,000 or 10^{-3}).
miscellaneous unit	a hazardous waste management unit used to treat, store, or dispose of hazardous waste which does not fit any other unit definition such as container, tank, surface impoundment, landfill, etc. such as a geologic repository.
mixed waste	waste that meets the definition of hazardous waste under New Mexico Hazardous Waste Management Regulations (HWMR-6), Part II, section 261.3, and also is radioactive.
mrem	one one-thousandth of a rem, or Roentgen Equivalent Mean; a measure of radiation dose defined as 100 ergs of energy deposited in 1 gram of biological tissue multiplied by appropriate factors to account for relative biological damage associated with various types of radiation.
nano	a prefix meaning one-billionth (1/1,000,000,000 or 10^{-9}).
overpack	a container put around another container to confine or contain the contents of the inner container.
particulates	fine liquid or solid particles such as dust, smoke, or fumes found in the air or emissions.
perched water table	unconfined ground water separated from an underlying main body of ground water by an unsaturated zone.
performance assessment	[defined in 40 CFR §191.12(g)] an analysis that identifies the processes and events that might affect the disposal system; examines the effects of these processes and events on the performance of the disposal system; and estimates the cumulative releases of radionuclides, considering the

	associated uncertainties, caused by all significant processes and events. To the extent possible, these estimates shall be incorporated into an overall probability distribution of cumulative release.
permeability	the property or capacity of a porous rock sediment or soil for transmitting a fluid: it is a measure of the relative ease of fluid flow under unequal pressure.
petrocalcic horizon	a diagnostic subsurface soil horizon that is characterized by an induration with calcium carbonate, sometimes with magnesium carbonate.
playa	the shallow central basin of a desert plain, in which water gathers after a rain and is evaporated.
polyhalite	a mineral, $K_2MgCa_2(SO_4)_4 \cdot 2H_2O$, generally of evaporite origin; often brick-red due to iron oxide.
potable water	water that is safe and palatable for human use.
process tolerance limits	those characteristics of a waste or waste mixture that a waste management process can accommodate while achieving waste management objectives. In the case of the WIPP Project, these characteristics are important in regard to the near-term and long-term isolation of the waste.
qualification	the process of verifying that an individual possesses the knowledge and skills to properly accomplish a specified task.
qualification card	the document that specifies the knowledge and skill requirements for a specified task and on which completion of the requirements is recorded.
radiation	particles or energy emitted from an unstable atom as a result of radioactive decay.
radiological control boundary	a standard waste box with a modified lid.
radiolysis	chemical decomposition by the action of radiation.

radiolytic decomposition	the breakdown of material into simpler compounds or constituent parts by the action of radiation.
radionuclide	an unstable nuclide of an element that decays or disintegrates spontaneously, emitting radiation.
Real-Time Radiography	a non-intrusive screening method which allows examination of the contents of a waste drum or container without opening the drum or container.
remote-handled waste	radioactive waste that requires shielding in addition to that provided by its container in order to protect the people who handle it.
retrievable	storage of waste in a manner designed for recovery without loss of control or release of hazardous chemicals or radioactivity.
rockbolts	metal rods or pins emplaced in the ceiling of a waste disposal room to stabilize the ceiling.
seismic reflection	the return of a seismic wave incident upon a surface to its original medium.
solid waste management unit	[proposed 40 CFR §264.501] a discernible unit at which solid wastes have been placed at any time, irrespective of whether the unit was intended for the management of solid or hazardous waste.
specific conductance	a measure of the ability of sampled media to transmit an electric current.
standard waste box	a waste container measuring approximately four feet square by three feet high.
swipe samples	the presence of radioactive contaminants may be ascertained by applying a Kim-wipe^{R} or equivalent to the surface of the potentially contaminated item and measuring the radioactivity of the Kim-wipe^{R}.

Test Phase	a series of WIPP Project activities including experiments with TRU waste, data collection, modeling, and calculations leading to compliance with the long-term performance assessment standard defined by 40 CFR Part 191.
transmissivity	the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.
transuranic waste	waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes per gram with half lives greater than 20 years.
Transuranic Package Transporter	package designed to transport contact-handled TRU waste to the WIPP site. It is a cylinder with a flat bottom and a domed top that is transported in the upright position.
volatile organic compounds	organic compounds which vaporize at relatively low temperatures. Many are RCRA regulated.
WIPP Site Boundary	the boundary providing a one-mile buffer around Zone 2.
Zone 1	a fenced area of approximately 35 acres. Zone 1 contains all WIPP surface facilities with the exception of salt storage piles, parking lot, landfill, and wastewater stabilization lagoons.
Zone 2	a zone overlying the maximum extent of the area available for underground development at the WIPP site.

JUN 0 5 1992

DOE/WIPP 91-005
Revision 1.0

Resource Conservation and Recovery Act Part B Permit Application

Volume II of VII

Waste Isolation Pilot Plant
Carlsbad, New Mexico

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APPENDIX B1

SURFACE HYDROLOGY

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FROM PREVIOUSLY PUBLISHED WIPP FINAL SAFETY ANALYSIS REPORT SECTION 2.4

U.S. Department of Energy (DOE), 1990
WP 02-9, Revision 0, Carlsbad, New Mexico

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2.4 SURFACE HYDROLOGY

2.4.1 HYDROLOGIC DESCRIPTION

2.4.1.1 Site and Facilities

The WIPP facility lies within the Los Medanos area in the drainage basin of the Pecos River (Figure 2.4-1). The headwaters of the Pecos River are located northeast of Santa Fe, New Mexico; from there the river flows south through eastern New Mexico and western Texas until it discharges into the Rio Grande. The Pecos River has an overall length of approximately 500 miles, a maximum basin width of 130 miles and a total drainage area of roughly 44,500 square miles(mi^2). Of these, 20,500 $miles^2$ are classified as noncontributing.[1] Climatic characteristics of the basin vary from sub-humid in the mountains to semiarid at the lower elevations.

The Pecos River is about 14 miles west of the WIPP facility at its closest point (river mile 430 above the confluence with the Rio Grande), and has a drainage area of about 19,000 $miles^2$. The slope of the Pecos riverbed in this area is approximately 4.0 feet per mile.[2]

East of the river, near the WIPP facility, which includes the Los Medanos area, no outstanding natural drainage features exist. A few small unnamed drainage channels constitute all the tributaries joining the Pecos from the east within 50 miles north or south of the WIPP facility. From the west, the principal tributaries joining the Pecos north of Carlsbad are Rio Penasco with a drainage area (D.A.) of 1,060 $miles^2$ at river mile 496 (rounded to nearest mile), the Rocky Arroyo (D.A. = 64 mi^2) at river mile 475, and the Dark Canyon (D.A. = 451 mi^2) at river mile 459. Other smaller tributaries flowing from the west are the Little Walt Canyon, Willow Draw, Spencer Draw, and the North Seven, Middle Seven, and South Seven Rivers. Most of these tributaries originate in the Guadalupe Mountains.[2,3] Downstream from Carlsbad, the Black River (D.A. = 436 mi^2) joins the Pecos from the west at a point about 16 miles southwest of the WIPP facility at river mile 436. The Delaware River (D.A. = 689 mi^2) joins the Pecos from the west at river mile 406 and a number of other small creeks and draws join at various points between Carlsbad and Malaga.

In the reach between Carlsbad and Malaga (where the river is closest to the WIPP facility), the bed of the Pecos is made up of sand and gravel. The overbanks adjacent to the main channel consist of sandy soil dominated by mesquite and salt cedars. In general, the right (west) bank has a steeper slope than the left (east bank) and, at a few places, the banks are made up of bare rock. During major floods, river water spreads over a flood plain.

The Pecos River flow above Malaga (river mile 432) is regulated by storage in several dams, including Santa Rosa Lake (Los Esteros Dam-river mile 757), Lake Sumner (Alamogordo Dam - river mile 702), Lake Brantley (river mile 479), Lake Avalon (river mile 467) and several other smaller upstream dams that divert water for irrigation and power production. The locations of dams on the Pecos River and its tributaries are shown in Figure 2.4-1. Salient features of these structures are given in Table 2.4-1. Numerous stream gaging stations are located on the Pecos River and several of its tributaries. These gaging stations are shown in Figure 2.4-1. Information pertaining to several gaging stations, including average, maximum, and minimum recorded discharges, is contained in Table 2.4-2.

The stream gaging station at Malaga, New Mexico on the Pecos River is the nearest station to the WIPP facility. The maximum and minimum recorded flows at this station during the period 1938 to 1985 were 120,000 cubic feet per second (ft^3/s) (August 23, 1966) and 3.7 ft^3/s (October 20, 1976), respectively.[4]

There are no major surface water bodies located within 10 miles of the WIPP facility. Beyond 10 miles, several water bodies lie to the north including Laguna Gatuna, Laguna Tonto, Laguna Plata, and Laguna

Toston. All these lakes are situated at or above a mean sea level (MSL) elevation of 3,460 feet. As the floor elevation of the WIPP surface facilities is about 3,400 feet MSL, surface runoff from the WIPP facility would not flow north toward any of these lakes.

About four miles west of the WIPP facility, there is a topographical depression known as Nash Draw which contains an ephemeral drainage system. This drainage carries water only during very wet years and joins the Pecos River about a mile upstream from Malaga. At its nearest point to the WIPP facility, Nash Draw is about five miles wide. The general bed elevation of Nash Draw in the vicinity of the WIPP facility is 3,150 feet MSL, which is approximately 250 feet below the grade elevations of the WIPP surface facilities. Red Lake, located in Nash Draw about seven miles northwest of the WIPP facility, is at 3,160 feet MSL.[5]

Several brine lakes are located in southeastern Nash Draw. The largest of these, Laguna Grande de la Sal, is several square miles in area and is a downslope catchment basin for limited surface drainage and artesian saline water-bearing formations.[6] Emptying into its northern end are a large saline spring, Surprise Spring, and the much smaller, less saline Pupfish Spring. Only the northern third of the lake is perennial. The amount of water in the southern portion of the lake depends strongly on the amount of precipitation that falls.[7] The remaining brine lakes, including Laguna Tres, Laguna Quatro, Laguna Dos, Lindsey Lake, and Tamarisk Flat, lie northeast of Laguna Grande de la Sal. These lakes were formed between 1942 and 1979, apparently as a result of potash refining and oil brine disposal in Nash Draw.[7] These water bodies are located at elevations of approximately 3,000 feet MSL.[5]

Scattered throughout the area near the WIPP facility are livestock watering impoundments (tanks). Some of these include Hill Tank, Indian Tank, Red Tank, and Noye Tank.

There are no known domestic surface water users on the Pecos River downstream from Carlsbad. Most of the surface water is used for irrigation while less than one percent of the total water withdrawn is used for industrial purposes. The actual amount of water diverted by any user differs from year to year. Approximate quantities diverted in the years 1978 to 1985 from Carlsbad to the New Mexico-Texas border are listed in Table 2.4-3. Approximate allotments for 1986 in the reach from the New Mexico-Texas border to Girvin, Texas are shown in Table 2.4-4.

Water quality in the Pecos River Basin near the WIPP facility is strongly influenced by both man caused and natural factors. Man caused impacts on the Pecos River include irrigation water returned to the river and wastewater treatment plant discharges. Natural sources are from groundwater inflows and by water contact with the river banks and bottom causing dissolution of salts and other constituents.

In addition, wastewater from the potash and oil industries has been discharged into surface sediments, spoil piles and ponds contaminating the shallow brackish aquifers and recharging existing water bodies in Nash Draw. The land surface slope and shallow aquifer gradient around Nash Draw are toward the Pecos River.[1]

The water quality of the Pecos River between Carlsbad and Red Bluff has exhibited increasing concentrations of several analytes in a downstream direction. Selected water quality parameter concentrations per station are presented in Table 2.4-5. Especially noteworthy are the increases in sodium and chloride concentrations. Theories explaining these increases include contributions from groundwater inputs, irrigation return water, and dissolution of ions from river sediments.

Results of the chemical analyses of the Pecos River water at Malaga (river mile 432) for the 1985 water year are given in Table 2.4-6. The daily measured specific conductance and water temperatures at the same station for the 1985 water year are given in Tables 2.4-7 and 2.4-8, respectively.

2.4.2 PRECIPITATION IMPACTS

2.4.2.1 Local Precipitation Patterns

The WIPP facility is located in the Chihuahuan Desert with an arid to semiarid climate. Precipitation in this area varies between localities and years, but averages roughly 12 inches per year. Mean annual precipitation values at various locations in the region around the WIPP facility are given in Table 2.4-9. Precipitation amounts have also been recorded at the WIPP facility during the periods of May 1976 to February 1980, and June 1985 to February 1987. These data are noted in Table 2.4-10, which indicates that four complete years of precipitation data have been obtained at the WIPP facility. Using 12 inches of precipitation per year as an average, 1977 appeared to be a slightly dry year (9.3 inches), 1979 a normal year (11.8 inches), and 1978 and 1986 very wet years (19.4 and 23.0 inches, respectively).

The probable maximum precipitation (PMP) quantities during "all season" and "winter" for different durations within a 10 miles^2 drainage area in the vicinity of the WIPP facility are listed in Table 2.4-11. The corresponding intensities are shown in Figure 2.4-2. The PMP determinations have been used to design the drainage systems and roof loads for the surface structures at the WIPP facility (discussed in Sections 2.4.2.2 and 2.4.2.3, respectively).

2.4.2.2 Drainage Patterns

In the proximity of the WIPP facility, subsurface geologic formations are covered with smoothly rounded hills of dune sand. Surface drainage patterns in the area are not well defined, and rain that collects in pools between the sand dunes is lost through infiltration into the sand and evapotranspiration. Vegetation generally consists of mesquite, shinnery oak and other plants commonly found in the northern Chihuahuan Desert and southern Great Plains. Land is used primarily for cattle grazing; however, potash mining and petroleum extraction also occur in the area.

The general ground slope in the vicinity of the WIPP facility is about 50 ft/mi. downward from the east toward the west. The average ground slope from north to south is downward about 13 ft/mi. A topographic and surface water divide (Antelope ridge) exists about 10 miles east of the WIPP facility. The activities associated with operation of the WIPP facility are not expected to alter the existing drainage pattern of the area around the WIPP facility.

The local drainage pattern is such that normal surface runoff from contributing areas north, south, and west of the surface structures drains westward into Nash Draw without affecting the WIPP facility structures. Storm water runoff from areas around the surface structures, including that from the east, are diverted away from the structures by a system of peripheral interceptor diversions. As shown in Figure 2.4-3, this drainage system is designed so that storm runoff due to a PMP event on the contributing drainage areas does not flood the plant. In addition, the grade elevations of most roads, tracks, and surface facilities are designed so that storm water will drain away under the most severe conditions. For example, the floors of the Waste Handling Building (WHB) and other surface structures are 0.5 feet above the grade elevation.

2.4.2.3 Roof Load Design

In addition to designing the WIPP facility drainage system, precipitation impacts were considered for the roof load design of structures. To estimate the roof loads for the design of surface structures, the 100-year mean recurrence interval snow load of 10 pounds per square foot (lb/ft^2) is used, which is the value recommended by ANSI.[8] The adopted snow load is about 30 percent higher than the recorded monthly maximum snowfall in Carlsbad.[9]

To prevent the undesirable buildup of standing water on the roofs of confinement structures, they are designed without parapets. This limits the design roof load to the weight of the snowpack plus the weight of water required to bring the snowpack to threshold condition and the water depth necessary to begin flowing over the edges of the roof. The weight of water required to bring the snowpack (snow load of 10 lb/ft^2) to threshold condition is estimated to be seven lb/ft^2. The water depth required to initiate flow over the edges of the roof and discharge the PMP without any holdup on the roof is conservatively estimated at two inches. This provides an additional load of 10 lb/ft^2. Thus, the total roof load is estimated to be 27 lb/ft^2. Design loads of buildings are discussed further in Section 3.2.7.

2.4.2.4 Precipitation Losses

The maximum, average, and minimum mean monthly temperatures in Carlsbad (26 miles from the WIPP facility) over a period of 30 years (1951-1980) are given in Table 2.4-12. Generally, June, July, and August are the warmest months (average temperature for this period is 81.2F), and December and January are the coldest (average temperature for this period is 43.8F).[10] The record high temperature recorded in Carlsbad was 112F (June 1902), and the record low as -18F (January 1962). Wind speeds are usually moderate with the prevailing wind from the south. The maximum recorded wind in Roswell was a gust of 75 miles per hour. The average relative humidities at 5:30 a.m., 11:30 a.m., 5:30 p.m., and 11:30 p.m. in Roswell are 65, 36, 30, and 52 percent, respectively.

The potential evaporation in the vicinity of the WIPP facility is much greater than the average annual precipitation of about 12 inches. More than 90 percent of the mean annual precipitation at the WIPP facility is estimated to be lost by evapotranspiration.[7] National Oceanographic and Atmospheric Administration (NOAA) records show the average annual Class A pan evaporation rate at Lake Avalon to be 116 inches, with an average of 76 inches lost between May and October. The annual shallow lake evaporation for southeastern New Mexico is estimated at 80 inches. The maximum evaporation rate is typically in June while the minimum is typically in December or January.[11]

In the area around the WIPP facility, the natural soil material is comprised of loamy sand of depths of as much as 15 feet. A nearly continuous petrocalcic soil horizon (the Mescelaro caliche) that varies from zero up to 10 feet in thickness[12] underlies the surficial soil at the WIPP facility from a depth of a few inches to over 15 feet. The petrocalcic horizon forms by the precipitation of calcium carbonate at the limits of soil moisture penetration and forms an extremely impervious barrier. Thus, little, if any, soil moisture infiltrates beyond this horizon.[13] Preliminary investigations indicate that natural breaches of this horizon amount to only a very small percentage of the area underlain by it. Even under conditions of a rare, locally intense precipitation event which might cause deeper than average infiltration, the petrocalcic horizon is "an additional obstruction to infiltrating and recharging the underlying beds."[12] Where the petrocalcic horizon is close to the surface, a mat of plant roots forms on top of it. Almost all the infiltrating water that reaches the petrocalcic layer is retained above it and is typically lost by evapotranspiration.

The above discussion indicates that precipitation losses due to evaporation in the basin are high; therefore, the runoff coefficients are low. The mean annual runoff in the region is only 0.1 to 0.2 inch.[7]

2.4.3 PROBABLE MAXIMUM FLOOD (PMF) NEAR THE WIPP FACILITY

2.4.3.1 Flood History

Floods on the Pecos River can be generated by: (1) frontal storms that produce large runoff volumes and high flood peaks; (2) thunderstorms (convective storms) that produce small runoff volumes but very high peaks; and (3) snowmelt in the mountainous portion of the drainage area that produces large runoff volumes, but relatively low peaks.

Between the confluence of the Rio Hondo with the Pecos River (river mile 566) and river mile 484 (location of the former McMillan Reservior, now part of Lake Brantley), the channel capacity of the Pecos River, without any overbank flooding, is about 8,500 ft^3/s. In the reach between river mile 484 and the confluence of Dark Canyon near Carlsbad (river mile 459), the channel capacity is estimated to be 50,000 ft^3/s. From the confluence of Dark Canyon to Red Bluff reservoir (river mile 411), the channel capacity is approximately 20,000 ft^3/s.[2]

Large floods are reported to have occurred on the Pecos River in 1893, 1904, 1905, 1915, 1916, 1919, 1937, 1941, and 1966.[3,4,14] No data are available for the 1893 event. The earliest flood for which discharge information is available occurred on October 2, 1904 following the failure of Avalon Dam. This flood was caused by a storm that lasted five days and covered the upper catchments of the Pecos River, Rio Hondo, Rio Felix, and Rio Penasco. The runoff generated by that storm caused floods throughout the Pecos River basin, and during the flood, the peak flow at Avalon gaging station (river mile 466) probably exceeded 90,000 ft^3/s. The corresponding river stage is not available. The river stage at Red Bluff during this flood (river mile 411) is reported to have reached 28 feet (gage datum = 2,850.05 feet).

Based on the records of the gaging station at Carlsbad (river mile 459), there was another major flood on July 25, 1905, when the peak flow of the Pecos reached 54,900 ft^3/s. The fourth and fifth major floods of the Pecos were on April 17, 1915 and August 7, 1916, when the peak flows at the Carlsbad gaging station reached 80,000 and 85,700 ft^3/s, respectively, with regulation by the McMillan and rebuilt Avalon reservoirs. Another flood occurred in September 1919, when the river stage at the Malaga gaging station, approximately 27 miles downstream from Carlsbad (river mile 432), was recorded at 29.4 feet (gage datum = 2,895.64 feet). The corresponding discharge was 40,400 ft^3/s.

Another major flood on the Pecos River is reported to have occurred on May 30, 1937, when the peak flow at Artesia (river mile 504) and Lake Arthur (river mile 522) was 51,500 ft^3/s. The corresponding stage at Lake Arthur was 21.77 feet (gage datum = 3,327.07 feet). The area in the vicinity of Carlsbad was flooded again on May 22, 1941, when the peak flow at Dam site three (river mile 474) reached 60,000 ft^3/s with regulation by Alamogordo (Lake Sumner), McMillan, and Avalon reservoirs. This flood resulted from intense rainfall over the drainage area of the Pecos River upstream of Red Bluff reservoir. It produced a stage of 35.1 feet at Malaga.

The highest flood of record (through 1986) on the Pecos River occurred on August 23, 1966, when the discharge and stage at Malaga were 120,000 ft^3/s and 42.1 feet, respectively, with regulation by the Alamogordo, McMillan, and Avalon reservoirs. The water surface profile of the Pecos River in Carlsbad during this flood is shown in Figure 2.4-4.

The flood frequency curve of the Pecos River at Malaga is shown in Figure 2.4-5. An additional curve is included in this figure to show the attenuation at Malaga expected to be provided by the Brantley reservoir.

2.4.3.2 Flood Design Considerations

As noted earlier, the WIPP facility is approximately 14 miles from the Pecos River. The general ground elevation in the vicinity of the surface facilities (approximately 3,400 feet MSL) is about 500 feet above the riverbed and over 400 feet above the floodplain. As discussed in Sections 2.4.3.3 and 2.4.4, a probable maximum flood (PMF) or floods induced by potential dam failures on the Pecos River or its tributaries cannot raise the water level 500 feet to endanger the WIPP facility. Therefore, as far as the potential for flooding from the Pecos River is concerned, the WIPP facility is categorized as a "dry site."

In the past, the Pecos River has maintained a reasonably stable course in the vicinity of the WIPP facility and does not exhibit any marked tendencies to shift several miles east or west. This stability is demonstrated by the narrow width of alluvial deposits along the river's floodplain. Therefore, because the horizontal and vertical separations between the WIPP facility and the river are both large, any change in the river course accompanied by bank erosion during unprecedented future floods could not affect structures at the facility.

The nearest watercourse to the WIPP facility is Nash Draw, an irregular depression about four miles from the WIPP facility. Its bed is about 250 feet below the site grade. In view of the large horizontal and vertical separation, it is inconceivable that the PMF of Nash Draw could affect the WIPP surface structures.

As the WIPP facility is categorized as a dry site, it was not considered appropriate to develop a discharge hydrograph using complex basin and stream course response models. Developing detailed computations for providing a water surface profile were also not deemed necessary. However, brief discussions concerning PMF flow and water level determinations are contained in the following two sections.

2.4.3.3 Probable Maximum Flood (PMF) Flow

The peak flow of the Pecos River during a PMF near the WIPP facility was estimated using the conservative approach suggested in Appendix B of the NRC Regulatory Guide 1.59.[15] The WIPP facility lies just west of the 103rd meridian. The regional isolines of PMF peaks shown on the maps of Appendix B of the NRC Regulatory Guide extend slightly west of the 103rd meridian; however, they are recommended to be used for areas east of the 103rd meridian. In view of the proximity of the WIPP facility to the 103rd meridian, it is considered reasonable to use the extrapolated portions of these isolines. This gives a PMF peak flow for the Pecos River of 1,350,000 ft^3/s near the WIPP facility for a drainage area of 19,000 mi^2.

In Table B.1 of Appendix B to Regulatory Guide 1.59, the estimated PMF flow of the Pecos River at the Los Esteros Dam (D.A. = 2,430 mi^2) is shown as 352,000 ft^3/s. The same table indicates the PMF flow at Alamogordo Dam (D.A. = 4,390 mi^2) to be 277,000 ft^3/s. Both values are less than 60 percent of the values estimated from the extrapolated portions of the isoline maps from Appendix B of Reference 15. It is, therefore, concluded that the 1,350,000 ft^3/s value obtained from the extrapolated portion of the isoline maps for a drainage area of 19,000 mi^2 is conservatively large.

2.4.3.4 Water Level Determinations

The rating curve of the Pecos River at the United States Geologic Survey (USGS) gaging station 08406500 near Malaga, New Mexico is shown in Figure 2.4-6. Since this rating curve does not extend beyond a discharge of 25,000 ft^3/s, its extrapolation to the PMF peak flow of 1,350,000 ft^3/s is not appropriate. Therefore, the water surface elevation corresponding to the PMF peak flow was estimated by the slope area method using representative cross sections of the Pecos River applicable to the reach near Malaga. Three cross sections of

the Pecos River near Malaga are shown in Figure 2.4-7. The water surface elevations of the historic flood of August 23, 1966 are marked on these cross sections, which were used by the USGS to estimate the peak flow of 120,000 ft^3/s that passed down the Pecos on August 23, 1966.

To compute the conveyances of the cross sections shown in Figure 2.4-7, the USGS divided each of these cross sections into four subsections. The values of Manning's n used for each subsection are shown in Table 2.4-13. Based on a comparison of the photographs of the Pecos riverbed with those available in the literature[16] for known values of n, the USGS values of Table 2.4-13 are considered reasonable.

The average water surface slope of the Pecos River in Carlsbad during the flood of August 23, 1966 was 0.00095 (see Figure 2.4-4). The average water surface slope, based on high-water marks near Malaga recorded by the USGS for the same flood, is 0.00123. The energy slopes used by the USGS for its estimates of the flood discharge of August 23, 1966, for two consecutive reaches of 752 feet and 645 feet with beginning and ending cross section shown in Figure 2.4-7, are 0.00113 and 0.00161, respectively. In view of these values, it is assumed that the average energy slope during the PMF on the Pecos River would be about 0.001, i.e., 5.28 ft/mi. For the three cross sections of the Pecos River near Malaga (Figure 2.4-7), weighted average values of Manning's n are computed using the equation:

$$n = \frac{AR^{2/3}}{\sum_{i=1}^{m} \frac{A_i R_i^{2/3}}{n_i}}$$

where

A = total cross sectional area
R = hydraulic radius of cross section, in feet
m = number of subsections in which a cross section is divided
A_i = Area of the ith subsection
n_i = Manning's roughness coefficient applicable to the ith subsection
R_i = hydraulic radius of ith subsection, in feet

Using the average of the weighted roughness coefficients computed previously (Table 2.4-13) and an average energy slope of 0.001, the water surface elevation corresponding to the PMF peak flow of 1,350,000 ft^3/s near the WIPP facility is estimated to be 2,980 feet MSL.

2.4.3.5 Flooding Protection Requirement

As calculated in the previous section, a very conservative estimate of the highest water surface elevation in the Pecos River during a PMF is 2,980 feet MSL. This is about 420 feet below the floors of the surface structures at the WIPP facility, which have an elevation of approximately 3,400 feet MSL. The horizontal and vertical separations between the Pecos River floodplain and the WIPP facility are great enough that floods in the Pecos River cannot affect the surface structures at the WIPP facility. Accordingly, there are no flood protection requirements for the WIPP facility. In addition, as stated in Section 2.4.2.2, the WIPP facility drainage structures will be designed so that ponding during a PMP event does not affect the surface structures.

2.4.4 OTHER POTENTIAL DAMAGE CONSIDERATIONS

2.4.4.1 Potential Dam Failures (Seismically Induced)

Major dams on the Pecos River and its tributaries upstream of the WIPP facility (Table 2.4-1) are the Los Esteros Dam (Santa Rosa Lake) at river mile 757, Alamogordo Dam (Lake Sumner) at river mile 702, Brantley Dam at river mile 479, Diamond A and Rocky Dams on the Rio Hondo and Rocky Arroyo, and Avalon Dam at river mile 466.

Los Esteros is an earthfill dam with a storage capacity of 447,100 acre feet. It is an irrigation and flood control reservoir belonging to the U.S. Army Corps of Engineers, located about 327 miles upstream from the WIPP facility. Sumner Lake (Alamogordo Dam) is an irrigation and recreation reservoir with a storage capacity of 101,600 acre feet located about 272 miles upstream of the WIPP facility. A flood wave generated by the seismic failure of these dams would be greatly attenuated during its long passage over the wide floodplains of the Pecos River and is not likely to produce a flood peak comparable to the PMF at the WIPP facility. Also, such a flood wave is unlikely to retain sufficient energy to cause a domino type failure of the Brantley and Avalon Dams which are, respectively, 218, 223, and 235 miles downstream from the Alamogordo Dam.

Diamond A and Rocky Dams on the Rio Hondo and the Rocky Arroyo Rivers, respectively, have a combined capacity of 166,200 acre-feet and are more than 145 miles upstream from the WIPP facility. Downstream from the confluence of the Rio Hondo and the Pecos River is Brantley Lake. Brantley Dam, which is about 49 miles upstream from the WIPP facility, has a storage capacity of 340,360 acre-feet. Lake Avalon, located about 37 miles upstream from the WIPP facility, has a storage capacity of 4,330 acre-feet. The heights of these dams vary from 40 to 212 feet (Table 2.4-1). A flood wave generated by the failure of one or more of these dams would be attenuated by the valley storage over a river length of 37 miles or more before reaching the closest point to the WIPP facility. It is inconceivable that this attenuated wave could create a water depth of 420 feet and spread a distance of 14 miles laterally to affect surface structures at the WIPP facility. Thus, a detailed analysis of the effect of potential dam failures on the flood conditions at the WIPP facility is not considered necessary.

2.4.4.2 Coincident Wind Wave and Tsunamis Considerations

Since the PMF estimated elevation (2,980 feet, MSL) is about 420 feet below the floors of the surface structures (Section 2.4.3.5) and the WIPP facility is about 14 miles from the river, wind wave runup is not a concern. In addition, since the WIPP facility is far from any major lake or ocean, the consideration of surges or tsunamis is not relevant. Therefore, detailed calculations concerning either event are not considered necessary.

2.4.4.3 Ice Flooding

None of the historic floods described in Section 2.4.3.1 were caused by ice jams on the Pecos River or its tributaries. There are no records of prolonged water surface freezing or of major ice jams in the basin. Therefore, ice jam flooding is not considered relevant.

Temperature records over a period of 30 years (1951-1980) in Carlsbad indicate that, on the average, 74 days in a year have temperatures that drop below 32F. Days with subzero temperatures are extremely rare. The 50-percent probability for a freeze free period is 223 days in a year.[10] Thus, the possibility of major ice formation in the river near the WIPP facility is very improbable.

2.4.4.4 Environmental Releases of Effluents

Any liquid effluents identified as liquid radwaste to be disposed at the WIPP facility as site-generated waste are expected to have very low concentrations or levels of radioactivity (Section 5.4). Liquid radwaste will be stored in tanks located within the WHB and solidified for emplacement underground. There are no normal or credible accident scenarios that will result in a release of liquid radwaste into the groundwater or surface water environments. However, in the unlikely event of an accidental spill from any of the tanks, the effluents would be contained within spill walls inside the building. Also, no liquid effluents are to be discharged from the WIPP facility into the Pecos River. Thus, it is concluded that the accidental release of effluents from the WIPP facility will be contained and will not have an adverse effect on the groundwater or surface water environments.

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TABLE 2.4-1

SALIENT FEATURES OF DAMS UPSTREAM AND DOWNSTREAM OF THE WIPP FACILITY*

DAM NAME	RIVER/ APPROX. LOCATION	DRAINAGE AREA, mi2	TYPE OF DAM	YEAR OF COMPLETION	HEIGHT ft	MAX. STORAGE CAPACITY, acre-ft	PURPOSE
Santa Rosa Lake (Los Esteros)	Pecos (N.M.) River Mile 757	2,430	Earthfill	1980	212	447,100	Irrigation and flood control
Sumner Lake (Alamogordo)	Pecos (N.M.) River Mile 702	4,390	Earthfill	1937	164	101,600	Irrigation and recreation
McMillan**	Pecos (N.M.) River Mile 484	16,990	Earthfill	1893	40	33,620	Irrigation and recreation
Brantley	Pecos (N.M.) River Mile 479	10,800	Earthfill	1988	340,360***		Irrigation, flood control and recreation
Avalon	Pecos (N.M.) River Mile 467	18,070	Earthfill	1907	40	4,330	Irrigation
Red Bluff	Pecos (Texas) River Mile 411	20,720	Earthfill	1936	98	340,000	Irrigation and hydro power
Two Rivers Project	Rio Hondo (N.M.) River Mile 33	963	Earthfill	1963	93	166,200	Flood control
Diamond A Dam Rocky Dam	Rocky Arroyo (N.M.) 14 miles southwest of Roswell (N.M.)	64	Earthfill	1963	113		Flood control

*From Water Resources Data New Mexico, Water Year 1985, USGS Water-Data Report NM-85-1 (1986).

**The Lake McMillan Dam was breached in 1989 as part of the completion of Brantley Dam

***Flood Control, Brantley Dam and Reservoir, Pecos River, New Mexico, U.S. Army Engineer District, Albuquerque, New Mexico (July 1964).

TABLE 2.4-2

DISCHARGES IN THE PECOS RIVER BASIN*

RIVER	LOCATION	APPROXIMATE RIVER MILE	DRAINAGE AREA (MILES^2)	PERIOD OF RECORD	DISCHARGE (cfs) AVERAGE	MINIMUM	MAXIMUM
Pecos	Pecos, NM	897	189	1919-1985	99.3	2.0	4,500
Pecos	Anton Chico, NM	808	1,050	1910-1985[2]	129	0	40,300
Gallinas	Colonias, NM	789[1]	610	1951-1985	15.6	0	13,700
Pecos	Santa Rosa, NM	748	2,650	1906-1979[3] 1980-1985[4]	135	0.28	55,200
Pecos	Below Sumner Dam, NM	702	4,390	1937-1985	200	0	42,800
Pecos	Acme, NM	585	11,380	1938-1985	179	0	45,000
Rio Hondo	Roswell, NM	566	1,070	1981-1985	--	0	373
Pecos	Artesia, NM	504	15,300	1937-1985	240	0	51,500
Rio Penasco	Dayton, NM	496	1,060	1951-1985	5.34	0	29,800
Pecos	Dam Site 3, Carlsbad, NM	474	17,980	1940,1945-1985	155	4.3	69,000
Pecos	Below Dark Canyon Draw, Near Carlsbad, NM	459	18,550	1970-1985	45.7	0	28,200
Black	Above Malaga, NM	436	343	1948-1985	12.9	0.51	74,600
Pecos	Malaga, NM	432	19,190	1938-1985	166	3.7	120,000
Pecos	Red Bluff, NM	411	19,540	1938-1985	161	0.19	111,000
Delaware	Red Bluff, NM	406	689	1938-1985	12.9	0	81,400
Pecos	Girvin, TX	200	29,560	1939-1975[5]	96	2.2	20,000

Data from Water Resources Data, New Mexico, Water Year 1985, U.S. Geological Survey Water Data Report NM-85-1 (1986),

[1] At confluence with Pecos River

[2] Varied from 1910 to 1925

[3] Varied, before completion of Santa Rosa Dam

[4] After completion of Santa Rosa Dam

[5] Data from Water Resourceds Data, New Mexico, Water Year 1975, U.S. Geological Survey Water-Data report NM-75-1 (1976).

--No data available

TABLE 2.4-3

SURFACE WATER USERS ON THE PECOS RIVER (1978-1985)

Between Carlsbad and New Mexico - Texas Border*

DIVERSION, ACRE-FEET PER YEAR

USER	1978		1979		1980		1981		1982		1983		1984		1985	
	PUBLIC	WELL	PUBLIC	WELL	PUBLIC	WELL	PUBLIC	WELL	PUBLIC	WELL	PUBLIC	WELL	PUBLIC	WELL	PUBLIC	WELL
Irrigation																
Carlsbad Irrigation District	57,190.0		73,550.0		76,780.0		47,270.0		72,140.0		84,200.0		72,140.0		79,870.0	
City of Carlsbad Golf Course, North and South Pumps	307.3		374.5		393.9		393.0		393.0		350.2		373.0		303.8	
Dowling, Mrs. F. V.	15.8		0.0		15.7		3.0		11.0		1.7		18.0		40.5	
Hines, E. J.	0.6		0.7		0.7		0.5		0.3		0.0		0.0		0.0	
Moutray, Hugh (in 1978 changed to McDonald, Clarence, et al.)	469.9		846.8		676.5		261.0		557.9		583.1		359.0		2,062.4	
O'Chesky Estate, Fred (in 1978 changed to Lopez, Angel; in 1982 changed to Sibley, William C.)		74.6		6.6		82.7		5.0		0.0		2.2		37.7		1.2
Valley Land Company	8,603.3		8,785.9		7,965.8		8,541.1		9,343.5		7,322.6		7,429.1		10,657.1	
City of Carlsbad-Harroun Canal																
Total Irrigation	66,586.9	74.6	83,557.9	6.6	85,830.6	82.7	56,468.6	5.0	82,446.1	0.0	92,522.4	2.2	80,319.1	37.7	92,933.8	1.2
Commercial																
Mississippi Chem.Corp.	105.3		630.2		0.0		0.0		0.0		0.0		0.0		0.0	
City of Carlsbad (Tansil Dam)***	6,904.7		14,249.9		11,679.0		11,925.0		7,871.2		7,267.2		11,451.2		13,025.1	
Bataan Recreational Lake**	373.6		373.6		373.6		373.6		373.6		373.6		373.6		373.6	
Total Commercial	7,383.6		15,253.7		12,052.6		12,298.6		8,244.8		7,640.8		11,824.8		13,398.7	

*Data is from annual "Watermaster Report, Pecos Valley Surface Water District", Table 6, compiled by New Mexico State Engineer, Roswell Office, Supplied by Eddie Trujillo of the New Mexico Interstate Stream Commission, Santa Fe, New Mexico, January 1987.

**This is not a diversion. Water just passes through the lake.

NOTE: Well water is supplemental to basic surface right.

TABLE 2.4-4

SURFACE WATER USERS ON THE PECOS RIVER BETWEEN NEW MEXICO-TEXAS BORDER AND CONFLUENCE AT GIRVIN, TEXAS*

USER	APPROXIMATE ALLOTMENT (ACRE-FT/Y) (BASED ON 1986 FIGURES)	PURPOSE
Loving County Water Improvement District No. 1	620	Irrigation
Reeves County Water Improvement District No. 2	1,760	Irrigation
Ward County Water Improvement District No. 3	1,660	Irrigation
Ward County Irrigation District No. 1	4,740	Irrigation
Ward County Improvement District No. 2	5,500	Irrigation
Pecos County Water Improvement District No. 2	3,060	Irrigation
Pecos County Water Improvement District No. 3	2,660	Irrigation

*Information provided by personal communication with John Hayes of the Red Bluff Water Power Control District, Pecos, Texas

TABLE 2.4-5

SELECTED WATER QUALITY PARAMETERS FOR SAMPLING STATIONS ON THE PECOS RIVER*

BASED ON DATA OBTAINED DURING WATER YEAR OCTOBER 1985 - SEPTEMBER 1986

STATION NO.	APPROXIMATE RIVER MILE	FLOW (cfs)[2]	DISSOLVED SOLIDS CONCENTRATION (mg/l)[1]				
			CALCIUM	MAGNESIUM	SODIUM	SULFATE	CHLORIDE
Carlsbad[3]	459	30.7	350	120	350	1100	590
Malaga	432	67.8	500	180	770	1600	1400
Pierce Canyon Crossing	426	66.9	500	2101	600	1800	2700
Red Bluff[4]	411	70.5	510	220	1800	2000	3500

*Data from Water Resources Data, New Mexico, water Year 1985, U.S. Geological Survey Water-Data Report NM-85-1 (1986).

[1]Mean value. Samples collected 12 times during year; roughly every 30 days.

[2]Mean value for water year.

[3]Flow measured at a location 0.1 miles downstream from mouth of Dark Canyon Draw; water quality samples obtained 0.2 miles upstream from Dark Canyon Draw. This tributary had no flow for water year 1985.

[4]Mean value for dissolved solids concentrations of five or six collections made during the water year.

Table 2.4-6

WATER QUALITY DATA OF THE PECOS RIVER NEAR MALAGA, NEW MEXICO-BASED ON WATER SAMPLES COLLECTED DURING WATER YEAR OCTOBER 1984 TO SEPTEMBER 1985

(All Units in mg/l Unless Otherwise Indicated)

DATE	FLOW (cfs)	pH (FIELD)	DISSOLVED OXYGEN	HARDNESS AS $CaCO_3$	CALCIUM AS Ca*	MAGNESIUM AS Mg*	SODIUM AS Na*	POTASSIUM AS K*	SULFATE AS SO_4
10-04	75	8.0	8.6	1600	410	140	560	11	1300
10-30	69	8.2	10.3	1900	460	180	630	8.2	1500
12-11	59	8.3	14.2	2000	500	190	760	11	1600
12-31	69	8.4	13.9	1700	430	150	700	9.1	1600
2-05	130	8.2	11.6	1800	480	150	510	6.5	1400
3-13	49	8.3	13.2	2000	490	190	800	11	1600
4-02	64	8.6	12.8	2200	550	200	890	15	1900
4-30	53	8.5	8.9	2100	530	200	830	15	1400
5-30	45	8.2	8.6	200	490	190	720	11	1400
6-27	57	7.8	8.8	2200	550	210	840	15	1800
8-06	29	8.1	--	2000	530	160	740	14	1900
9-05	34	8.0	8.1	2500	630	220	1200	25	2200

DATE	FLOW (cfs)	pH (FIELD)	CHLORIDE AS CL*	FLUORIDE AS F*	SILICA AS SiO_2	NITRITE+ NITRITE AS N	TOTAL AMMONIA NITROGEN AS N	TOTAL ORGANIC NITROGEN AS N
10-04	75	8.0	1100	0.70	15	0.96	---	---
10-30	69	8.2	1200	0.80	13	1.4	0.180	0.52
12-11	59	8.3	1300	0.80	11	1.8	0.210	1.6
12-31	69	8.4	1200	0.70	13	2.1	0.230	1.3
2-05	130	8.2	950	0.70	12	1.5	0.210	0.79
3-13	49	8.3	1300	0.80	4.7	0.28	0.210	1.6
4-02	64	8.6	1600	0.80	5.7	0.94	0.290	0.11
4-30	53	8.5	1700	0.80	6.9	0.42	0.310	1.2
5-30	45	8.2	1200	0.80	12	0.25	0.210	1.4
6-27	57	7.8	1600	0.80	7.1	0.50	0.330	1.3
8-06	29	8.1	1400	0.80	16	0.58	0.200	1.9
9-05	34	8.0	2300	1.0	18	1.2	0.280	1.6

Data from Water Resources Data, New Mexico, Water Year 1985, U.S.G.S. Water-Data Report NM-85-1 (1986)

Specific Conductance and Temperature Data are presented in Tables 2.4-7 and 2.4-8, respectively.

*Dissolved component.

--Indicates no data available.

Table 2.4-6

WATER QUALITY DATA OF THE PECOS RIVER NEAR MALAGA, NEW MEXICO BASED ON WATER SAMPLES COLLECTED DURING WATER YEAR OCTOBER 1984 TO SEPTEMBER 1985

(All Units in mg/l Unless Otherwise Indicated)

DATE	FLOW (cfs)	pH (FIELD)	TOTAL PHOSPHOROUS AS P	ORTHO PHOSPHOROUS AS P*	BORON AS B*	IRON AS FE*
10-04	75	8.0	---		0.310	0.030
10-30	69	8.2			0.400	0.100
12-11	59	8.3	0.160		0.390	0.080
12-31	69	8.4	0.190	0.060	0.360	0.060
2-05	130	8.2	0.130	0.150	0.240	0.040
3-13	49	8.3	0.150		0.380	0.050
4-02	64	8.6	0.140		0.470	0.050
4-30	53	8.5	0.110		0.440	0.040
5-30	45	8.2	0.020	0.020	0.410	0.050
6-27	57	7.8	0.100	0.020	0.410	0.100
8-06	29	8.1	0.060	0.020	0.410	0.190
9-05	34	8.0	0.040	0.010	0.560	0.260

Data from Water Resources Data, New Mexico, Water Year 1985, U.S.G.S. Water-Data Report NM-85-1 (1986)

Specific Conductance and Temperature Data are presented in Tables 2.4-7 and 2.4-8, respectively.

*Dissolved component.

--Indicates no data available.

TABLE 2.4-7

SPECIFIC CONDUCTANCE (MICROSIEMENS/CM AT 25 °C) OF THE PECOS RIVER NEAR MALAGA, NEW MEXICO BASED ON ONCE-DAILY OBSERVATIONS FOR WATER YEAR OCTOBER 1984 TO SEPTEMBER 1985

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	5310	5950	5750	5740	4550	5360	7220	6990	6410	7570	7470	8410
2	4870	5790	5700	5720	4670	5570	7140	7080	6650	7680	7350	8500
3	5010	5780	5700	5720	4770	5610	6650	7110	6860	7640	7030	8320
4	5280	5790	5680	5700	4810	5740	6740	6930	6860	7360	5790	8360
5	5480	5770	5710	5740	4920	5720	5550	6170	6900	7580	6360	8110
6	5610	5750	5690	5730	4990	6000	6310	6050	6940	7830	7180	8000
7	5480	5740	5660	5740	4990	5780	6870	6220	6390	7860	6350	6990
8	5370	5730	5650	5790	4990	5870	7250	6420	6870	7830	6190	6620
9	5390	5820	5970	5830	4860	6120	7420	6610	7050	7790	7160	5200
10	5380	5770	6160	5900	4910	6100	7440	6360	7140	7850	7460	5850
11	5700	5760	6260	5750	4890	6030	6750	6430	7000	7780	7600	6080
12	5700	5750	6320	5800	4960	6180	7030	6940	6430	7640	8070	6600
13	5740	5730	6410	5740	4980	6310	7060	7220	6740	7660	7370	6740
14	5600	5740	6410	5740	5040	6370	6720	6940	7040	7940	7110	6310
15	5470	5740	6340	5680	5120	6420	6790	7060	7080	7820	6430	4460
16	5510	5720	5760	5690	5080	6450	6810	7500	7210	7840	5810	5620
17	5590	5710	5630	5580	4970	6610	6750	6900	7340	7920	6850	6040
18	5740	5770	5590	5480	4930	6870	6730	6690	7400	7910	6860	6350
19	5980	5760	5540	5380	4960	7060	6820	6750	7500	7950	6650	3430
20	5050	5800	55809	5240	4930	7090	6920	6110	6830	8080	7270	2630

Water Resources Data, New Mexico, Water Year 1985, U.S. G. S.

Water Data Report, NM-85-1 (1986)

--- Indicates no data available.

TABLE 2.4-7

SPECIFIC CONDUCTANCE (MICROSIEMENS/CM AT 25 ° C) OF THE PECOS RIVER NEAR MALAGA, NEW MEXICO BASED ON ONCE-DAILY OBSERVATIONS FOR WATER YEAR OCTOBER 1984 TO SEPTEMBER 1985

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
21	5410	5840	5520	5110	4930	6880	6910	5960	6920	7900	7290	2750
22	5490	5880	5540	4960	5030	6670	6980	6180	7330	8110	7740	2510
23	4820	5830	5580	4900	4960	6770	7160	6340	7270	8180	7870	3280
24	5400	5830	5580	4840	4930	6760	7320	6130	6740	8220	7500	3820
25	5430	5780	5580	4660	4900	6610	7440	6130	5800	8460	6770	4230
26	5440	5680	5590	4500	4810	6550	7520	6370	7260	8360	6410	4580
27	5670	5670	5690	4410	5110	6610	7210	6360	6740	6830	7290	4840
28	5760	5740	5780	4440	5200	6850	6840	6440	6920	---	---	5140
29	5810	5720	5790	4430	---	6980	7050	6550	7140	6930	6770	5370
30	5840	5750	5820	4490	---	7090	6980	6550	7350	7210	7200	5530
31	5960	---	5780	4600	---	7130	---	6550	---	7430	6440	---
MEAN	5490	5770	5800	5320	4940	6390	6950	6580	6949	7770	6990	5690

WATER YEAR 1985 MEAN 6220 MAX 8500 MIN 2510

Water Resources Data, New Mexico, Water Year 1985, U.S. G. S.

Water Data Report, NM-85-1 (1986)

--- Indicates no data available.

TABLE 2.4-8

DAILY TEMPERATURE WATER (° C), OF THE PECOS RIVER NEAR MALAGA, NEW MEXICO BASED ON ONCE-DAILY OBSERVATIONS FOR WATER YEAR OCTOBER 1984 TO SEPTEMBER 1985

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	19.0	18.0	9.0	10.0	6.0	12.5	15.0	25.5	23.0	24.0	27.0	26.0
2	17.5	17.0	10.0	7.0	5.0	13.0	15.0	23.5	26.0	25.0	28.5	25.0
3	19.0	15.0	9.5	7.0	5.5	15.0	16.0	21.0	27.0	25.0	28.0	30.0
4	19.0	15.5	8.5	8.0	6.0	12.0	18.0	23.5	27.0	26.0	32.5	29.0
5	19.0	15.0	8.0	8.0	7.0	12.0	17.0	24.0	25.5	27.5	27.0	25.5
6	20.0	15.0	7.0	8.5	6.5	13.0	17.0	23.0	22.0	25.0	27.5	24.0
7	19.5	15.0	7.0	8.5	7.0	17.0	19.0	26.0	24.0	29.0	30.0	24.0
8	22.0	15.0	9.0	10.0	7.0	15.0	17.5	28.5	25.5	28.0	31.0	25.0
9	19.5	16.0	10.0	10.5	8.0	15.5	16.0	25.0	26.5	29.0	28.0	25.0
10	21.0	14.0	10.0	8.5	9.0	17.0	16.5	24.0	27.0	27.0	26.0	28.0
11	21.0	13.5	10.0	9.0	9.0	17.5	19.0	21.0	27.0	26.0	25.5	25.5
12	20.5	13.0	11.0	7.0	8.5	16.0	22.0	21.0	25.0	30.0	25.5	25.5
13	20.0	13.5	12.0	6.0	9.0	17.0	20.0	21.0	23.0	27.0	26.0	25.0
14	18.5	14.0	10.0	7.0	9.0	15.0	20.0	24.0	28.0	27.5	29.0	25.0
15	19.0	13.5	8.0	7.0	9.0	14.0	19.5	24.5	27.0	28.0	26.0	23.5
16	19.5	13.0	8.0	8.0	9.5	13.0	25.0	22.0	26.5	27.0	25.5	23.
17	19.0	13.0	9.0	6.5	11.0	14.0	21.0	21.0	30.0	29.5	28.0	24.0
18	17.5	12.5	9.0	7.0	11.0	14.0	21.5	21.0	27.5	27.0	26.5	25.0
19	16.0	12.0	10.0	8.0	11.5	16.0	20.5	21.5	26.0	27.0	28.5	23.5
20	16.5	12.0	11.0	7.0	12.5	13.0	19.0	25.0	24.5	26.5	27.5	24.0

*Water Resources Data, New Mexico, Water Year 1985, U.S.G.S Water Data Report NM-85-1 (1986)

---Indicates no data available.

TABLE 2.4-8

DAILY TEMPERATURE WATER (° C), OF THE PECOS RIVER NEAR MALAGA, NEW MEXICO BASED ON ONCE-DAILY OBSERVATIONS FOR WATER YEAR OCTOBER 1984 TO SEPTEMBER 1985

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
21	16.5	11.0	11.5	6.0	13.5	12.0	20.0	21.0	27.0	25.0	27.0	22.0
22	16.0	10.0	10.0	4.5	14.5	14.5	20.0	22.5	26.0	28.0	30.0	---
23	14.0	10.0	9.5	6.5	14.0	14.0	20.0	22.0	25.5	26.0	29.0	23.0
24	13.0	10.5	10.0	6.0	13.0	15.0	21.0	23.0	27.0	26.0	26.5	22.0
25	13.0	9.0	9.0	7.5	12.0	18.0	20.0	24.0	26.5	27.0	26.0	22.0
26	13.5	11.5	9.0	8.5	12.5	17.0	20.0	24.0	25.5	26.0	25.0	22.0
27	13.5	10.0	9.0	9.0	12.0	16.0	19.0	24.0	25.0	26.5	26.0	22.0
28	15.0	9.0	10.0	8.5	12.0	16.5	21.0	26.0	26.5	---	---	21.5
29	15.0	10.0	12.0	8.5	--	16.5	19.0	24.0	24.0	26.0	28.0	20.5
30	18.0	9.0	10.0	9.5	---	14.0	20.0	25.0	23.5	29.0	28.0	17.5
31	18.0	---	10.0	7.5	---	14.5	---	22.0	---	31.5	26.0	---
MEAN	17.5	13.0	9.5	8.0	9.5	15.0	19.0	23.5	26.0	27.0	27.5	21.0

WATER YEAR 1985 MEAN 18.5 MAX 32.5 MIN 4.5

*Water Resources Data, New Mexico, Water Year 1985, U.S.G.S Water Data Report NM-85-1 (1986)

---Indicates no data available.

TABLE 2.4-9

AVERAGE PRECIPITAION AMOUNTS AT LOCATIONS NEAR THE WIPP FACILITY

1878 through 1982

STATION	MEAN ANNUAL PRECIPITATION (in)	YEARS OF RECORD THROUGH 1982
Chaves County		
Roswell	10.61	1878 through 1982
Eddy County		
Artesia	10.44 (N)	1905 through 1907, 1910 through 1982
Carlsbad	11.91 (N)	1889, 1891, 1894 through 1948, 1951, 1953 through 1982
Carlsbad FAA	11.25(M)	1949 through 1982 (1955 through 1980)
Duval Potash	14.21(M)	1955 through 1967, 1969 through 1982 (1955 through 1982)
Lake Avalon	11.01(N)	1914 through 1978
Lakewood	9.67	1912 through 1928
Loving	11.88(M)	1918 through 1939, 1945
Otis	11.84(M)	1901 through 1913
WIPP	13.53 (M)	1976 through 1980 (1977 through 1979)
Lea County		
Eunice	12.47(M)	1929 through 1935 (1931 through 1933)
Hobbs	14.36(N)	1913 through 1930, 1932 through 1935, 1938 through 1982
Jal	11.67(N)	1919 through 1921, 1923 through 1927, 1932 through 1933, 1941 through 1982
Maljamar	14.51(M)	1947 through 1982 (1955 through 1982)
Ochoa	11.17(N)	1943 through 1946, 1949 through 1950, 1953 through 1982
Pearl	13.32(N)	1906 through 1908, 1917, 1919 through 1922, 1927, 1930 through 1948, 1950, 1952 through 1982

N = Normal precipitation (i.e., mean of years 1941 through 1970, given by NOAA).

M = Mean precipitaion for the years indicted in parentheses or for total years of record.

Adapted from Hunter (1985). Compiled from Geohydrology Associates, 1978; National Resources Planning Board, 1942; and NOAA.

TABLE 2.4-10

MONTHLY AND ANNUAL PRECIPITAION SUMMARY FOR THE WIPP FACILITY (INCHES)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1976[1]	--	--	--	1.5	0.2	1.9	1.1	3.3	0.7	0.1	0.0	--	
1977[1]	0.2	0.1	0.4	0.5	1.4	1.1	0.7	0.6	2.1	.20	0.2	0.0	9.3
1978[1]	0.1	0.4	0.1	0.2	1.6	3.7	0.6	2.0	5.2	1.3	3.5	0.7	19.4
1979[1]	0.1	0.6	0.1	0.2	2.2	1.7	3.2	2.0	0.3	0.0	0.2	1.0	11.6
1980[1]	0.8	0.2	--	--	--	--	--	--	--	--	--	--	--
1981-1984	--	--	--	--	--	--	--	--	--	--	--	--	--
1985[2]	--	--	--	--	--	1.9	2.0	1.1	7.4	1.6	0.1	0.0	--
1986[2]	0.1	0.4	0.0	0.0	0.9	7.6	1.9	2.2	3.8	0.4	0.9	1.1	19.3
1987[2]	0.1	0.1	0.7	1.2	3.5	1.0	0.1	4.5	0.7	0.8	0.3	0.7	13.6
1988[2]	0.0	0.0	1.3	1.7	2.8	0.1	3.4	3.4	2.8	0.0	0.0	0.1	16.5
1989[2]	0.1	1.5	0.1	0.0	0.1	3.6	1.0	2.6	1.0	0.0	0.0	0.4	9.8

--Indicates precipitation data was not collected.

[1]Adapted from Hunter (1985). Based on data from Matejka, 1977; Pocalujka, Babj, and Church, 1979a, b, c; and Pocalujka, Babij, Catizone, and Church, 1980a, b; 1981a.

[2]Data from Annual Site Environmental Reports for the Waste Isolation Pilot Plant for the applicable year.

TABLE 2.4-11

ALL SEASON AND WINTER PMP FOR A DRAINAGE AREA OF 10 SQUARE MILES AROUND WIPP FACILITY

	PMP DEPTH (INCHES)			INTENSITY (INCHES/HOUR)		
DURATION	ALL SEASON (1)	ALL SEASON (2)	WINTER (2)	ALL SEASON (1)	ALL SEASON (2)	WINTER (2)
48 Hours	36.9	36.3	21.5	0.8	0.8	0.5
24 Hours	34.0	32.5	18.4	1.4	1.4	0.8
12 Hours	29.8	30.5	14.9	2.5	2.5	1.2
6 Hours	25.0	25.5	11.8	4.2	4.3	2.0
1 Hour	14.5	---	---	14.5	---	---
30 Minutes	11.0	6.9	3.2	22.0	13.8	6.4
15 Minutes	8.4	5.0	2.3	33.6	19.8	9.2
10 Minutes	6.9	3.9	1.8	41.4	23.6	10.9
5 Minutes	5.0	2.6	1.2	60.0	30.6	14.2

(1)Probable Maximum Precipitation Estimates--United States Between the Continental Divide and the 103rd Meridian, Hydrometeorological Report No. 55, U.S. Department of Commerce, (National Weather Service), U.S. Deparetment of Army (Corps of Engineers), and U.S. Department of Interior (Bureau of Reclamation), Silver Spring, MD. 1984 (revised 1987).

(2)Seasonal Variation of the Probable Maximum Precipitation East of the 105th Meridian for areas from 10 to 1,000 Square Miles and Durations of 6, 12, 24, and 48 hours, Hydrometeorological Report No. 33, U.S. Department of Commerce, Weather Bureau and U.S. Dept. of Army, Corps of Engineers, Washington, DC (April, 1956).

---Indicates no data available.

TABLE 2.4-12

MAXIMUM, AVERAGE, AND MINIMUM TEMPERATURES AT CARLSBAD, NEW MEXICO*

(Period of Record 1951-1980)

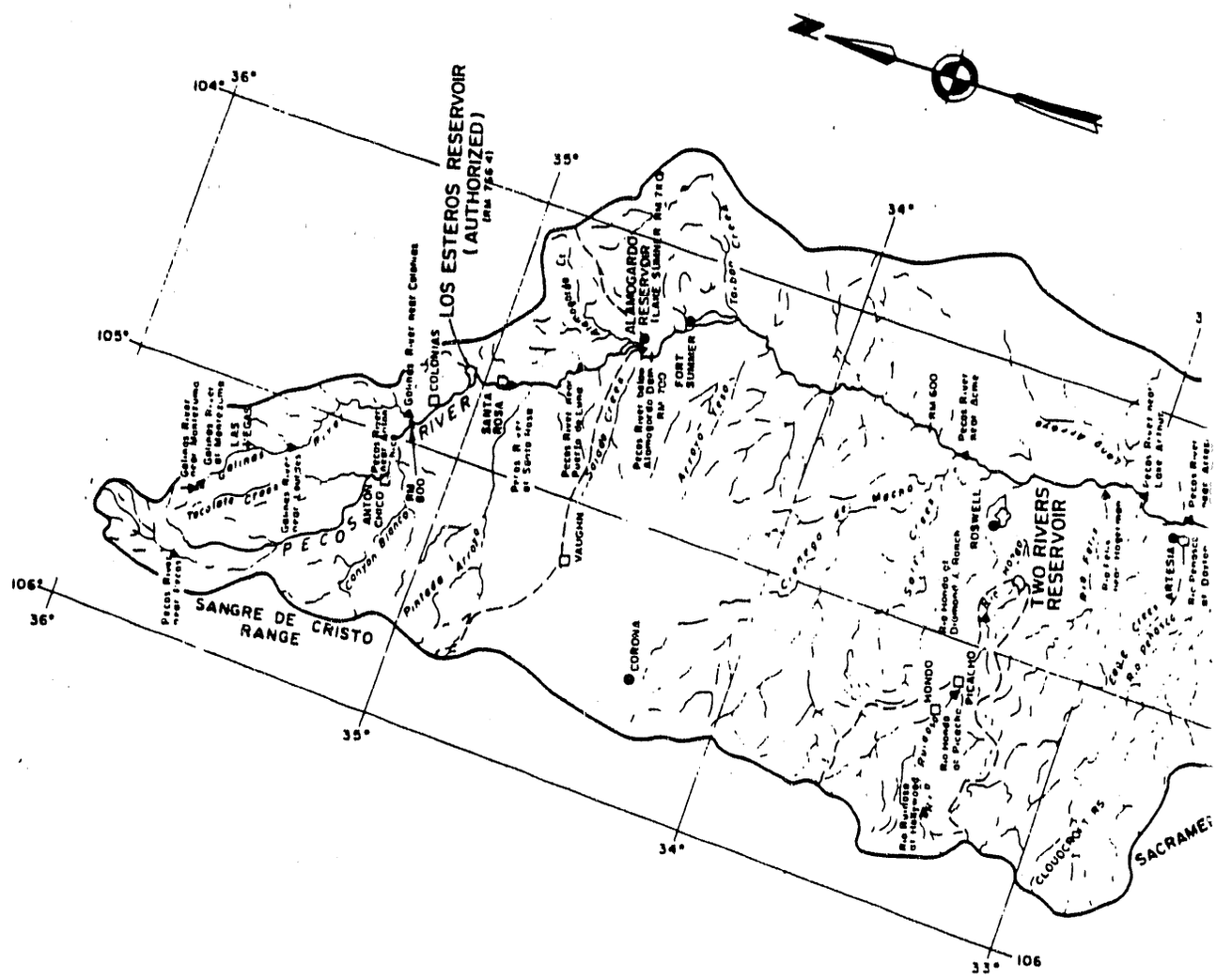
MONTH	TEMP., °F	TEMP., °F	TEMP., °F
January	57.1	43.2	29.2
February	61.9	47.4	32.8
March	69.4	54.3	39.1
April	79.1	63.7	48.2
May	87.4	72.2	57.0
June	95.5	80.6	65.6
July	95.6	82.5	69.3
August	93.6	80.6	67.6
September	86.9	73.9	60.9
October	77.5	63.2	48.8
November	64.8	50.8	36.7
December	58.3	44.3	30.3
Annual	77.3	63.1	48.8

*Climatological Summary, Means and Extremes for Period of Record 1951-1980, U.S. Department of Commerce, National Climatic Data Center (1986). Station: Carlsbad FAA Airport, New Mexico.

TABLE 2.4-13

VALUE OF MANNING'S n USED BY THE U.S.G.S.

SECTION NO. REFER FIG. 2.4-7	SUBSECTION	DISTANCE, FT	n
1	1	68 - 590	0.100
1	2	590 - 822	0.080
1	3	888 - 1185	0.040
1	4	1185 - 1318	0.045
2	1	360 - 725	0.090
2	2	725 - 859	0.060
2	3	859 - 1093	0.040
2	4	1093 - 1142	0.050
3	1	37 - 300	0.090
3	2	300 - 450	0.075
3	3	450 - 782	0.045
3	4	782 - 810	0.045



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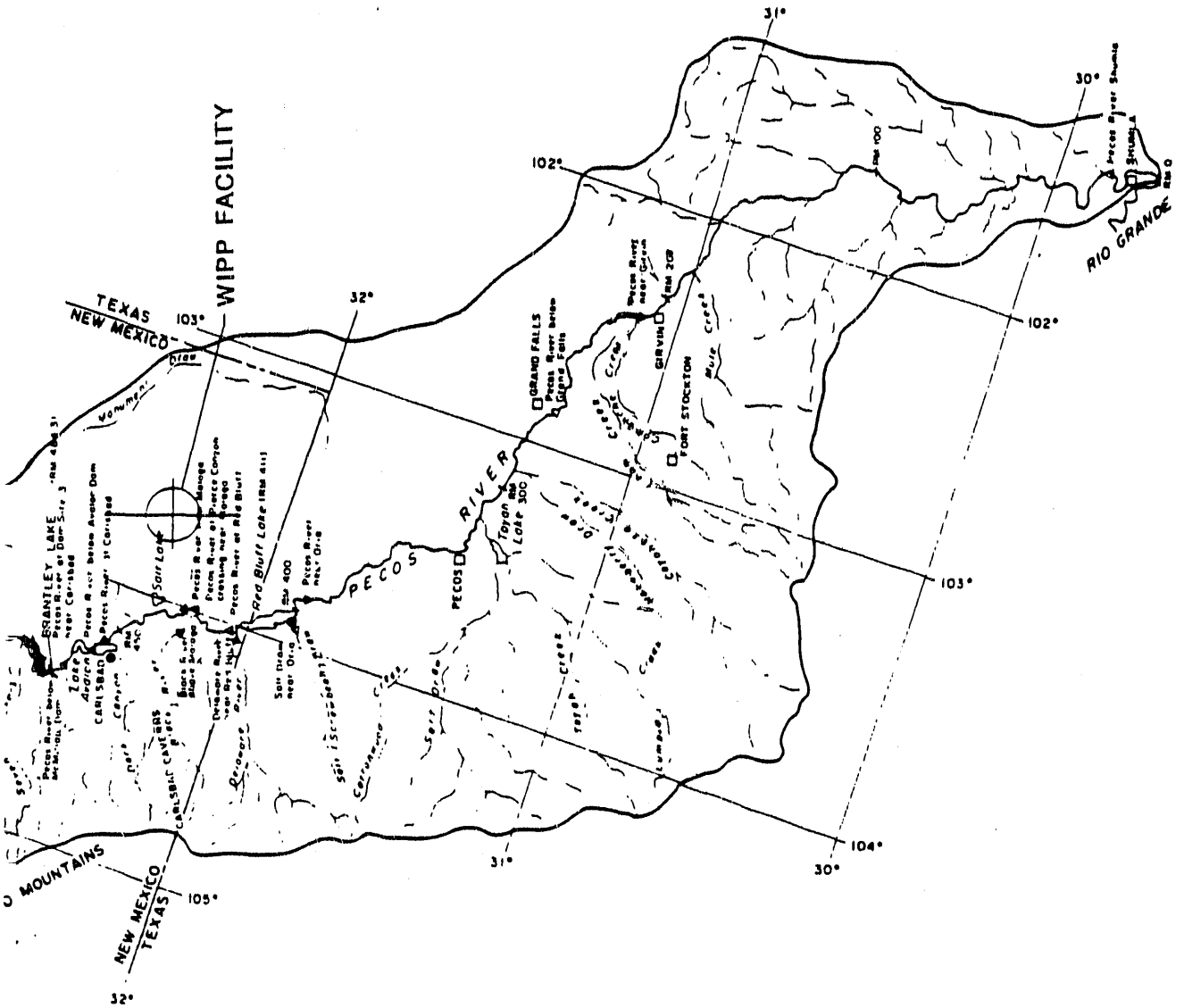
WATERSHED BOUND
SUB WATERSHED B
STREAM GAGING ST
STREAM GAGING ST
MUNICIPALITY
RESERVOIR AREA
PRECIPITATION STA
RIVER MILE



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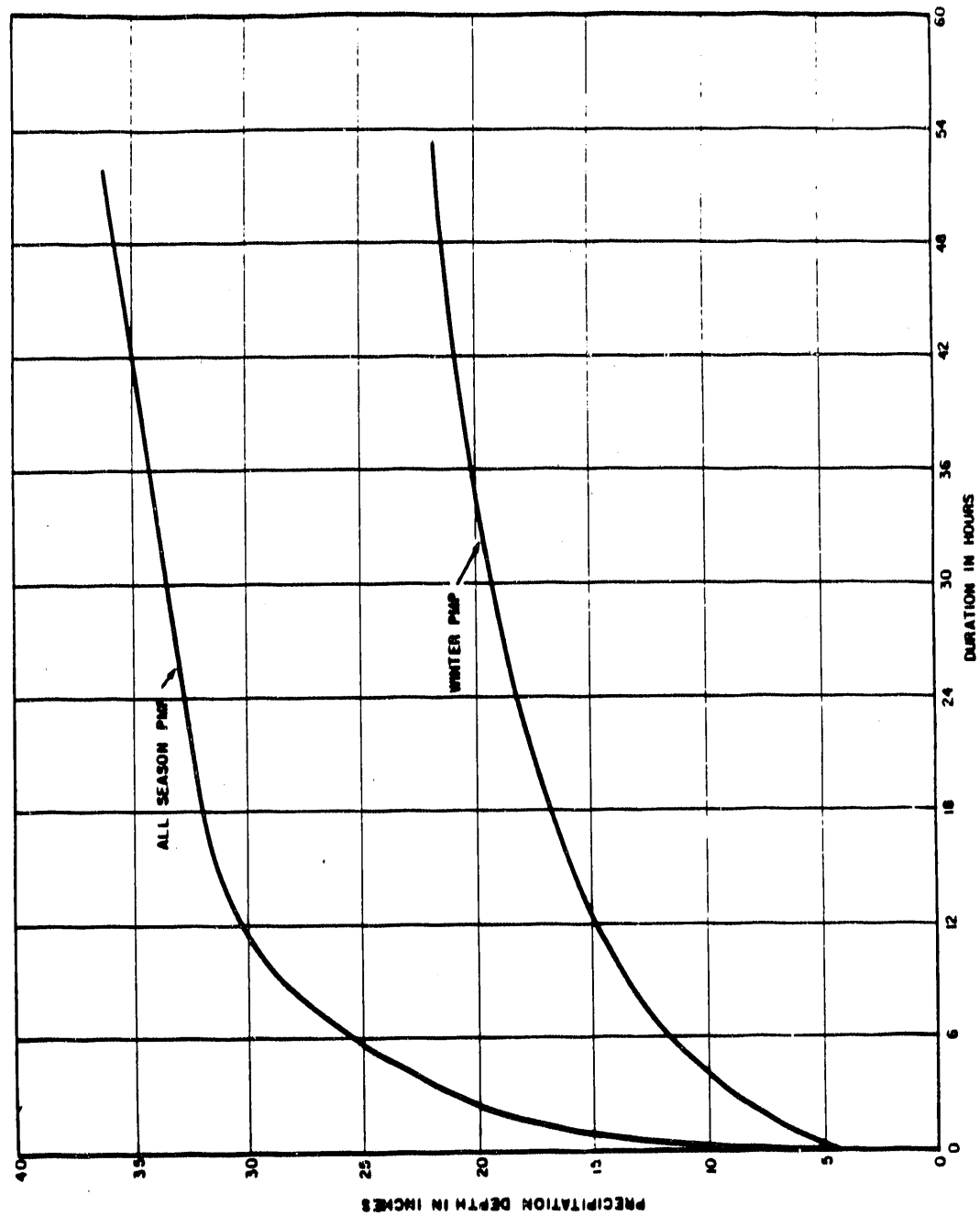
Reference:

Flood Control, Brantley Dam and Reservoir Pecos River, New Mexico, U.S. Army Engineer District, Albuquerque, New Mexico (July 1964)

FIGURE 2.4-1
Drainage Pattern and Gaging Stations, Pecos River Basin



REFERENCE:

Seasonal Variation of the Probable Maximum Precipitation East of the 105th Meridian for Areas from 10 to 1,000 Square Miles and Durations of 6, 12, 24, and 48 Hours, Hydrometeorological Report No. 33, U.S. Dept. of Commerce, Weather Bureau and U.S. Dept. of Army, Corps of Engineers, Washington, D.C., (April 1956).

FIGURE 2.4-2
Winter and All-Season PMP for a Drainage Area of 10 Sq. Mi. Around the WIPP Facility

GG78

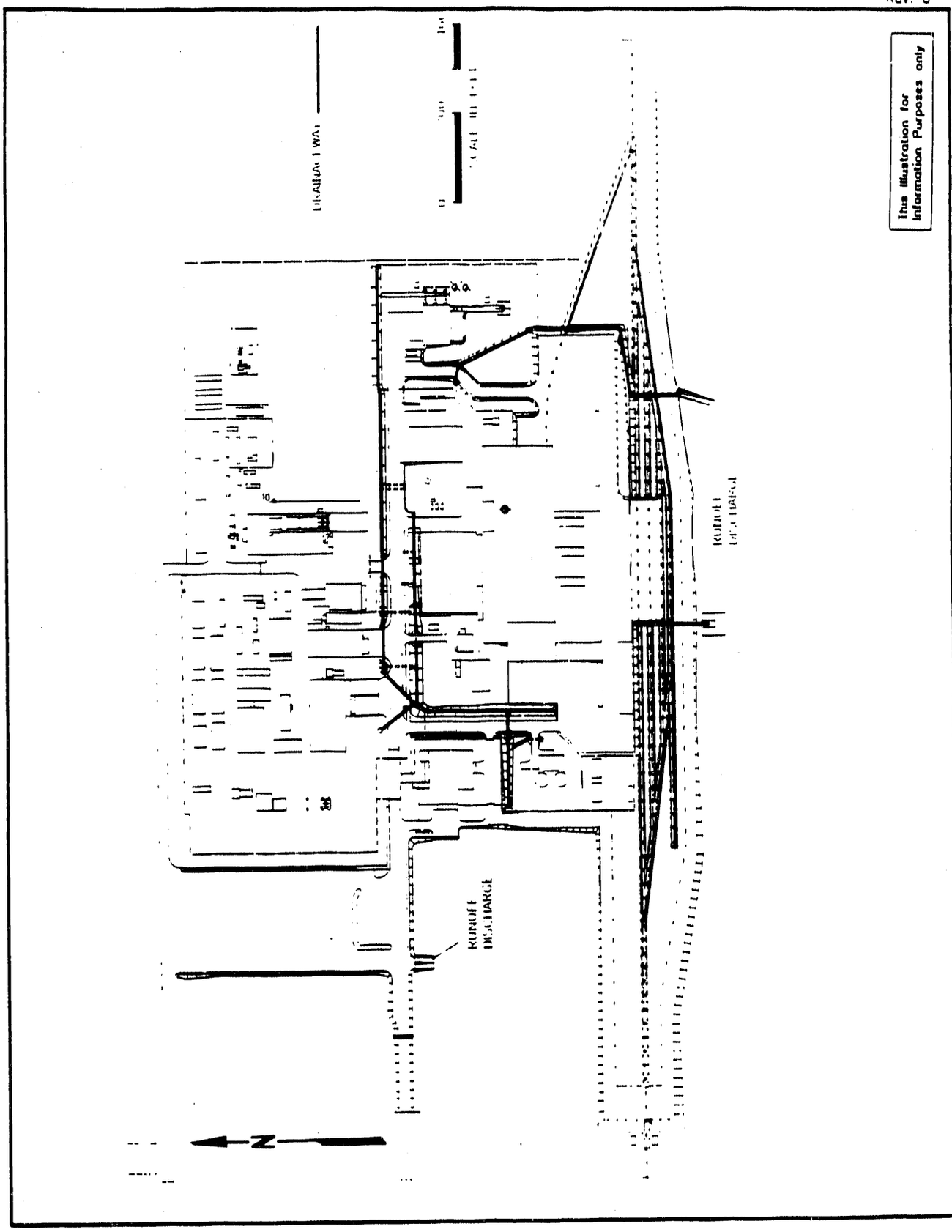


FIGURE 2.4-3
WIPP Facility Drainage

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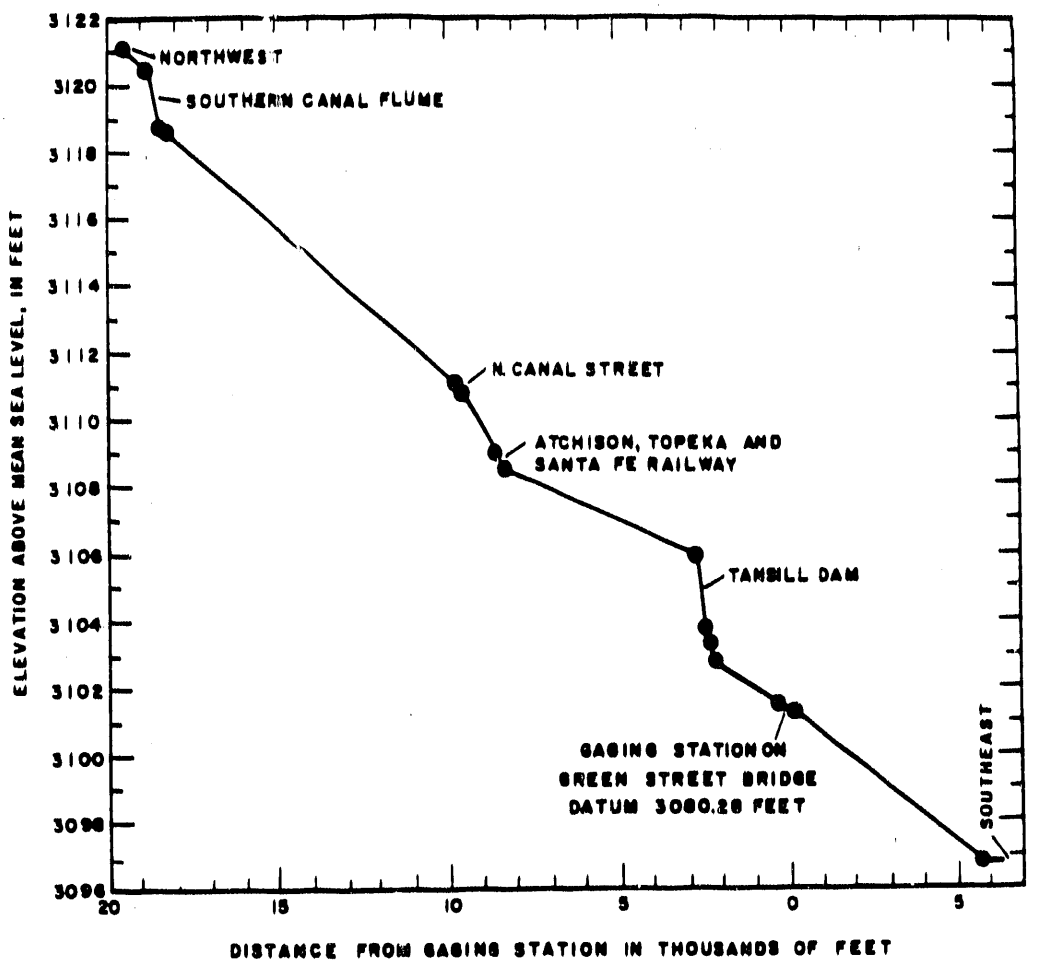

REFERENCE:

Flood of August 1966 at Carlsbad, New Mexico, Hydrologic Investigations Atlas HA-318, U.S. Geological Survey, Washington, D.C., (1968).

LEGEND

● FLOODMARK ELEVATION

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FIGURE 2.4-4
Water-Surface Profile of August 23, 1966 Flood on Pecos River in Carlsbad

GG78

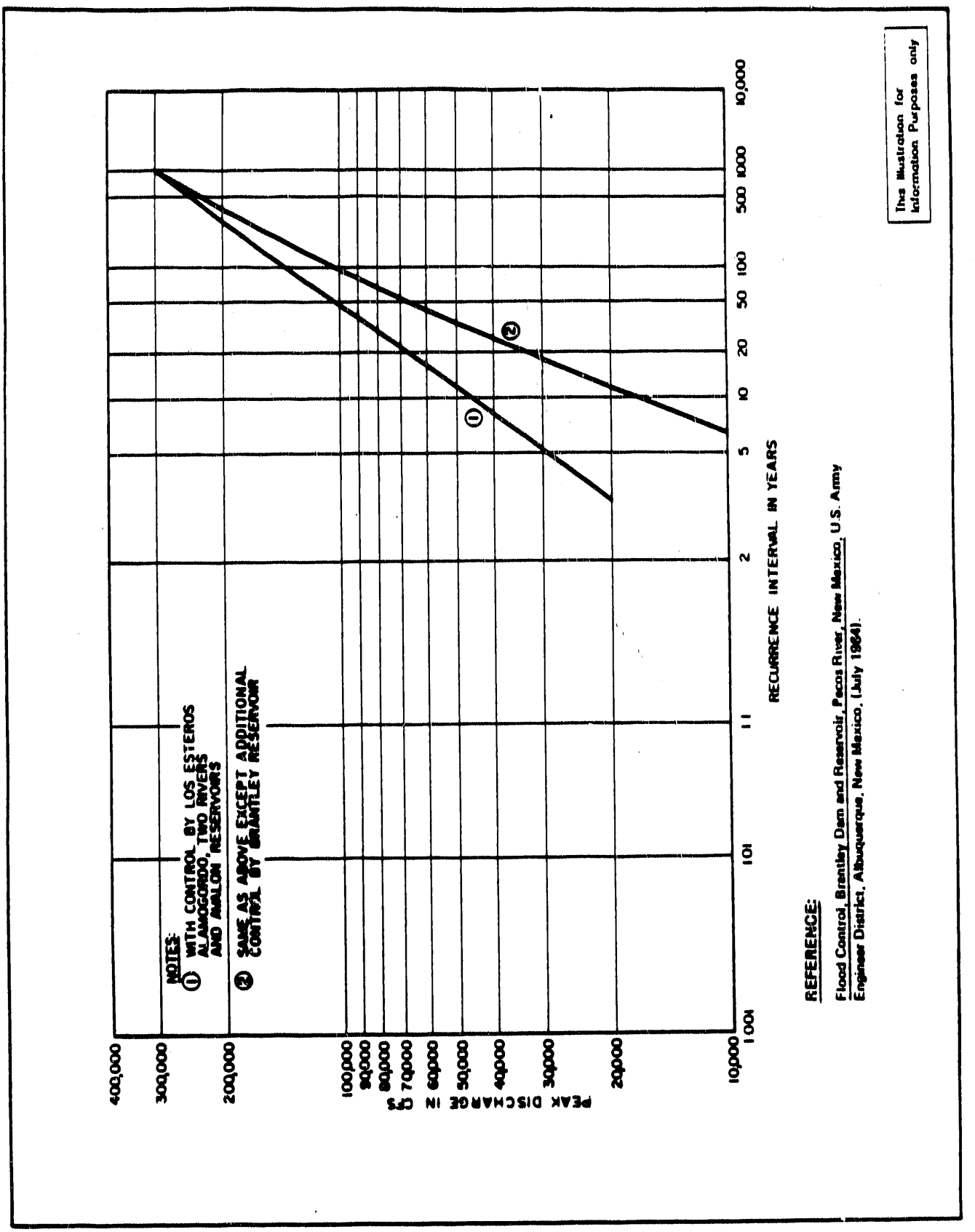

FIGURE 2.4-5
Flood Frequency Curve of the Pecos River in Malaga, N.M.

GG79.1

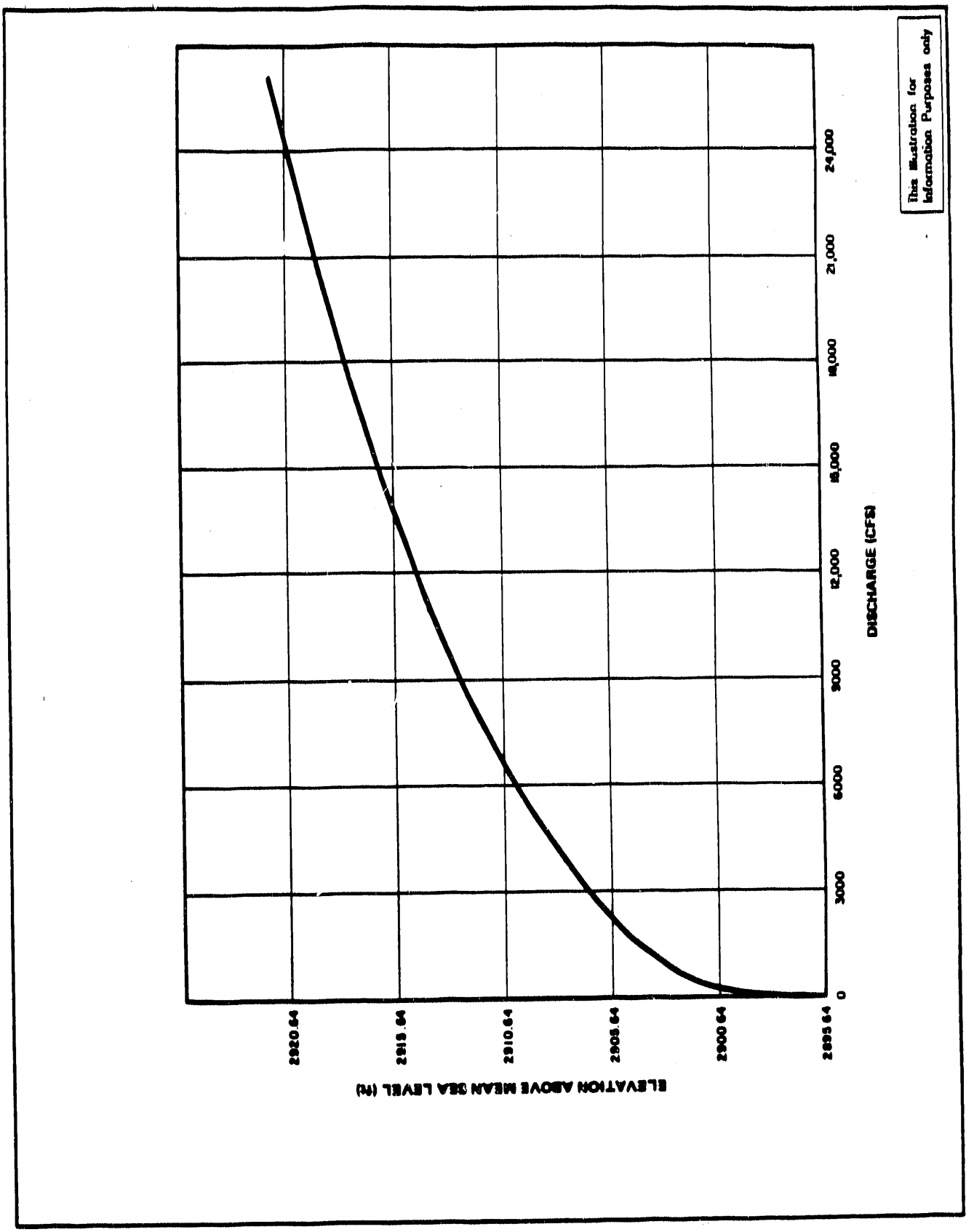

FIGURE 2.4-6
Rating Curve of Pecos River near Malaga, N.M.
USGS Sta. 08406500

GG66

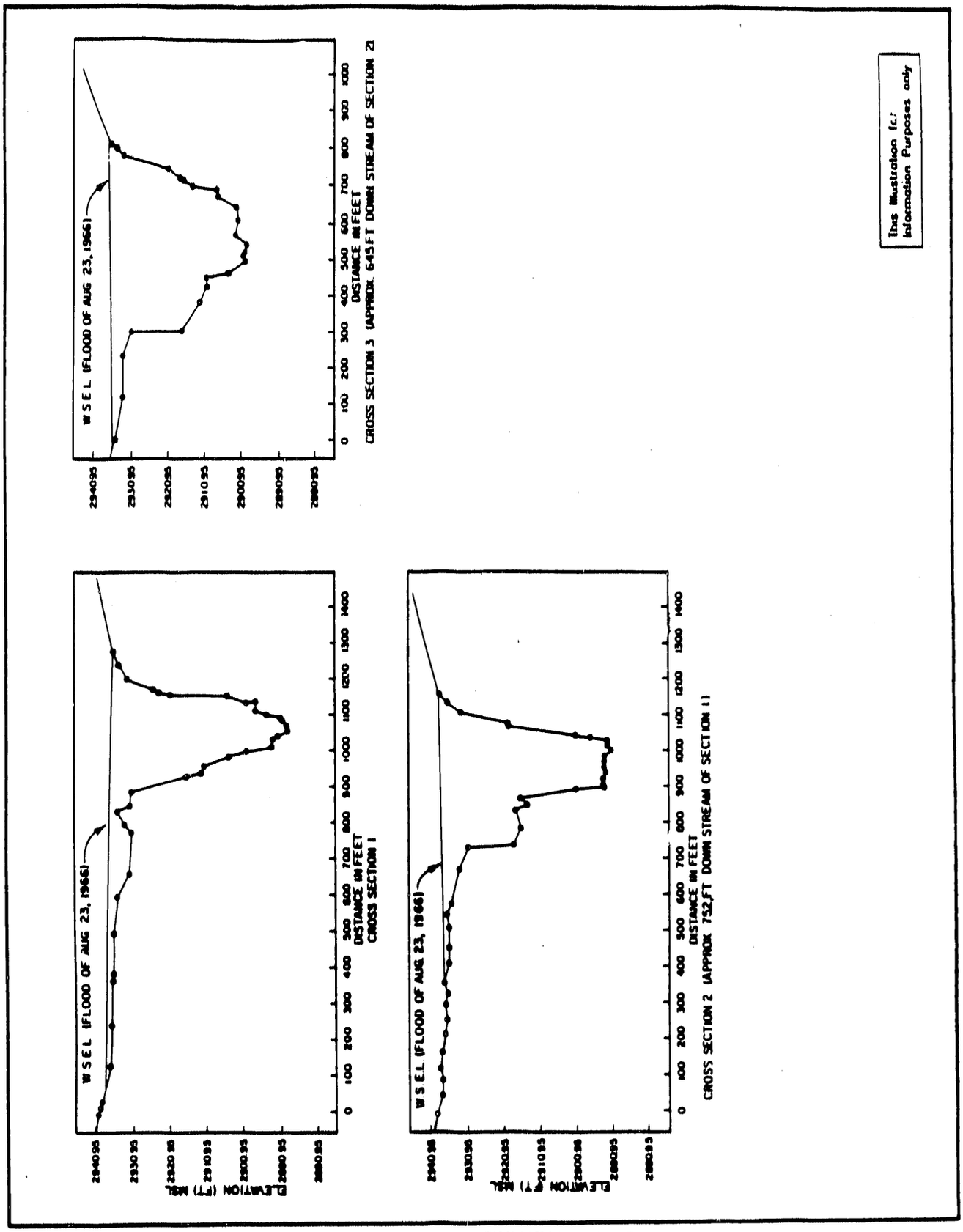

FIGURE 2.4 -7
Cross Section of Pecos River near Malaga, N.M.

GG91

APPENDIX D1

SITING REPORTS

SUMMARY OF SITE CHARACTERIZATION STUDIES CONDUCTED FROM 1983 THROUGH 1987 AT THE WASTE ISOLATION PILOT PLANT (WIPP) SITE, SOUTHEASTERN NEW MEXICO

(Lappin, A. R.)

SANDIA REPORT

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Summary of Site-Characterization Studies Conducted From 1983 Through 1987 at the Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico

A. R. Lappin

Prepared by
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SUMMARY OF SITE-CHARACTERIZATION STUDIES CONDUCTED FROM 1983 THROUGH 1987 AT THE WASTE ISOLATION PILOT PLANT (WIPP) SITE, SOUTHEASTERN NEW MEXICO

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Albuquerque, NM 87185

ABSTRACT

The Waste Isolation Pilot Plant (WIPP) is being constructed at a depth of 650 m in bedded halites of the Salado Formation. The geologic setting of the WIPP site has been active for at least 250 million years, and is presently responding to the end of the last pluvial period, within the 10,000-year time scale of regulatory interest. Both construction of the WIPP facility and WIPP site-characterization activities impose additional transient effects, some of which will last until the hydrologic and structural closure of the facility.

The Bell Canyon Formation beneath the WIPP facility contains shales, siltstones, and sandstones. Studies suggest that no channel sandstone is present in the Bell Canyon beneath the WIPP site. Fluid movement would be downward if drilling interconnected the Bell Canyon with the Rustler Formation, the first water-bearing zone above the WIPP facility.

The Salado and Castile Formations contain abundant bedded halites and anhydrites, and deform in response to gravity. Fluids play a major role in this deformation, although the regional permeabilities of both units are extremely low. Pressurized brines may be present within the Castile Formation 200 m or more beneath the WIPP waste-emplacement panels. The hydrologic and structural characteristics of the Salado change within an altered zone extending a few meters from the WIPP underground workings.

The permeability within this altered zone is enhanced, and deformation includes local opening of preexisting fractures in anhydrite and formation of new fractures in halite. Within a few meters of the facility the Salado characteristics become those of the far field, in which permeability is extremely low and deformation is dominated by creep. Brine seepage into the WIPP facility is extremely slow, and involves transient behavior resulting from the combined effects of deformation, low permeability, and ventilation.

At the WIPP site, the hydrology and geochemistry of the Rustler Formation and younger units overlying the Salado are dominated by confined flow within the Culebra dolomite. Rustler karst is not present at the WIPP site, but is present in and near Nash Draw. The combination of modern heads and transmissivities of units other than the Culebra indicates the potential for limited vertical flow within the Rustler, and from the Salado into the Rustler, but is not consistent with infiltration of water from the surface to the Rustler carbonates at the WIPP site. Isotopic studies indicate that surficial water was required for formation of secondary gypsum veins within the Dewey Lake Red Beds overlying the Rustler. The distribution of hydrochemical facies in Culebra groundwaters and the results of stable-isotope, radiocarbon, and uranium-disequilibrium studies are all consistent with the interpretation that there is no modern recharge to the Rustler at the WIPP site, and that a change of flow directions in the Culebra dolomite has occurred over approximately the last 10,000 years.

The transmissivity of the Culebra dolomite varies by approximately 6 orders of magnitude at and near the WIPP site. The transmissivity in the central portion of the site, including the locations of all four WIPP shafts, is low (less than 10^{-6} m^2/s). Higher Culebra transmissivities are found south, northwest, and west of the site, especially in Nash Draw. Fracturing within the Culebra affects local hydrology and contaminant transport, but is not significant in regional-scale behavior at and near the site, at least so long as the present distribution of head potentials is not significantly disturbed.

SUMMARY

The Waste Isolation Pilot Plant (WIPP), which is designed for receipt, handling, storage, and permanent isolation of defense-generated transuranic wastes, is being excavated at a depth of approximately 655 m in bedded halites of the Permian Salado Formation of southeastern New Mexico. Site-characterization activities at the present WIPP site began in 1976. Full construction of the facility began in 1983, after completion of "Site and Preliminary Design Validation" (SPDV) activities and reporting. Site-characterization activities since 1983 have had the objectives of updating or refining the overall conceptual model of the geologic, hydrologic, and structural behavior of the WIPP site and providing data adequate for use in WIPP performance assessment.

This report has four main objectives:

1. Summarize the results of WIPP site-characterization studies carried out since the spring of 1983 as a result of specific agreements between the U.S. Department of Energy and the State of New Mexico.

2. Summarize the results and status of site-characterization and facility-characterization studies carried out since 1983, but not specifically included in mandated agreements.

3. Compile the results of WIPP site-characterization studies into an internally consistent conceptual model for the geologic, hydrologic, geochemical, and structural behavior of the WIPP site. This model includes some consideration of the effects of the WIPP facility and shafts on the local characteristics of the Salado and Rustler Formations.

4. Discuss the present limitations and/or uncertainties in the conceptual geologic model of the WIPP site and facility.

The objectives of this report are limited in scope, and do not include determination of whether or not the WIPP Project will comply with repository-performance criteria developed by the U.S. Environmental Protection Agency (40CFR191). When combined, the results of recent and previous geologic studies of the WIPP site form a conceptual model, summarized below. The model presented is limited to aspects relevant to WIPP site characterization and, ultimately, performance assessment.

The overall geologic and hydrologic setting of the WIPP site area has been transient (not steady-state) since before the beginning of deposition of the Bell Canyon Formation, approximately 250 million years ago, and will continue to be transient after effective closure of the WIPP facility. Some events, such as crystallization of secondary minerals within the Salado Formation approximately 200 million years ago and formation of the Mescalero caliche 400,000 to 500,000 years ago, have taken place on a very long time scale relative to WIPP performance assessment, which must consider only a 10,000-year time frame. Two types of transient response

have occurred or are occurring at and near the WIPP site within the 10,000-year time frame of regulatory interest. These are: a) the continuing natural response of the geologic and hydrologic systems to the end of the last pluvial period (period of decreased temperatures and increased precipitation) in southeast New Mexico; and b) the continuing responses to hydrologic, geochemical, and structural transients resulting from WIPP site characterization and facility construction. The transient responses induced by the presence of the WIPP underground workings will continue until reequilibration following effective structural and hydrologic closure of the facility.

The Bell Canyon Formation, consisting largely of shales, siltstones, and sandstones, contains the first relatively continuous water-bearing zone beneath the WIPP facility. In some parts of the northern Delaware Basin, the unit contains permeable channel sandstones that are targets for hydrocarbon exploration. Recent studies suggest that the upper Bell Canyon at the WIPP site does not contain any major channel sandstone. This decreases the probability of the Bell Canyon serving as a source of fluids for dissolution of overlying evaporites at the WIPP. These same studies indicate that the final direction of fluid flow following interconnection of the Bell Canyon, Salado, and Rustler Formations within a drillhole would be downward into the Bell Canyon, after accounting for density increases in the fluids due to dissolution of halite within the Salado. It is assumed here that the measured hydrologic characteristics of the Bell Canyon Formation are more significant to WIPP performance assessment than those of underlying units. The head distribution within the upper Bell Canyon near the WIPP site indicates flow towards the northeast.

Both regional studies and studies within the WIPP facility indicate that the Castile and Salado Formations, both of which are made up predominantly of layered anhydrites and halites, should be considered as low-permeability units that deform regionally in response to gravity. In general, permeabilities and fluid-flow rates in both units are very low and are insensitive to stratigraphy. Formation permeabilities in the Castile and Salado Formations remote from the WIPP excavations are generally less than 0.1 microdarcy, and the regional water content of Salado halites is up to 2 weight percent. Exceptions include local brine occurrences in Castile anhydrites and gas occurrences in the Salado Formation, both of which are fracture-controlled, can be large in volume, and can be under pressures high enough to cause fluid flow to the surface. No major gas occurrence within the Salado Formation has been encountered at the WIPP site. In fact, where it has been possible to measure far-field brine pressures within the Salado, the pressures, permeabilities, and available brine volumes combine to indicate the potential for only very limited fluid flow upwards into the overlying Rustler Formation. It is not certain that the Castile and Salado Formations are hydrologically saturated regionally.

Pressurized Castile brines have been encountered in Castile anhydrite in hole WIPP-12, approximately 1.5 km north of the center of the WIPP site. Geophysical studies indicate that Castile brines may be present beneath a portion of the WIPP waste-emplacement panels, consistent with earlier assumptions. These brines are stratigraphically 200 m or more below the

WIPP facility horizon and are not of concern except in the case of human-intrusion breach of the facility.

In the western part of the Delaware Basin, extensive halite dissolution has apparently taken place in both the Castile and Salado Formations. However, much of the variability in structure and internal stratigraphic thicknesses within the Castile and Salado Formations results from deformation and original depositional variability, rather than from evaporite dissolution. Regional or far-field deformation of the Castile and Salado Formations involves pressure solution as a major mechanism, due to the presence of intergranular fluids, but occurs too slowly to be of future concern to the WIPP Project. Structures within hole DOE-2 result from deformation rather than dissolution.

The hydrologic and structural characteristics of the Salado Formation in the disturbed zone generated by the presence of the WIPP facility are different than those in the far field. Formation permeability within a couple of meters of the underground workings at the facility horizon increases significantly. Near-field deformation of the Salado Formation involves both the opening of preexisting fractures in anhydrite beneath the facility horizon (Marker Bed 139) and generation of new fractures in halite. Fluid contents in the disturbed zone at the facility horizon decrease in response to facility ventilation and/or deformation. Within a few meters of the underground workings, both hydrologic and structural behavior of the Salado Formation become essentially those of the far field. Brine seepage into the WIPP facility includes a significant transient phase, which will probably last until effective facility closure. The results of preliminary hydrologic testing in the Salado Formation adjacent to the WIPP air-intake shaft indicate extremely low permeabilities, with no apparent stratigraphic variability. The results also indicate that development of a disturbed zone around the WIPP shafts is less extensive than at the facility horizon. The extent, characteristics, and importance of the disturbed-rock zones around the WIPP shafts and at the facility horizon remain to be determined in detail.

At and near the WIPP site, the Rustler Formation should be considered as a layered unit of anhydrites, siltstones, and halites, containing a thin and variably fractured carbonate unit, the Culebra dolomite. The Culebra dolomite is the first continuous water-bearing unit above the WIPP facility and, at the WIPP site, is at least an order of magnitude more permeable than other members of the Rustler Formation, including the Magenta dolomite. The transmissivities of Rustler anhydrites at the WIPP site are too low to measure. As a result, the Culebra dominates fluid flow within the Rustler Formation at the WIPP site and is the most significant pathway to the accessible environment from the WIPP facility, except for direct breach to the surface by human intrusion. The transmissivity of the Culebra varies by approximately six orders of magnitude in the region containing the WIPP site. The Culebra transmissivity in the central portion of the site, including the locations of all four WIPP shafts, is low. Higher Culebra transmissivities are found in areas southeast and northwest of the central part of the site. Fluid flow rates within the Culebra are very low at the site center and in regions to the east, but

relatively high within Nash Draw. Modern flow in the Culebra is confined and largely north-south in the area of the WIPP site.

Fluid flow and geochemistry within the Culebra dolomite and shallower units are in continuing transient response to the marked decrease or cessation of local recharge at approximately the end of the last pluvial period. Both bulk chemistry and isotopic relations within Culebra fluids are inconsistent with modern flow directions if steady-state confined flow is assumed. Because of the relative head potentials within the Rustler Formation at and near the WIPP site, there must be a small amount of vertical fluid flow between its members, even though the permeabilities of Rustler members other than the Culebra dolomite are quite low. Where measured successfully, the modern head potentials within the Rustler prevent fluid flow from the surface downward into the Rustler carbonates. These results do not prohibit either the modern movement of fluids from the underlying Salado Formation upwards into the Rustler Formation or the downward movement of Dewey Lake waters into the Rustler Formation during or even after the cessation of local recharge at the end of the last pluvial period. They do, however, suggest that recharge from the surface to the Rustler Formation is not now occurring at the WIPP site. The results of stable-isotope, radiocarbon, and uranium-disequilibrium studies are also consistent with the interpretation that there is no measurable modern recharge to the Culebra dolomite from the surface at and near the WIPP site. The transient hydrologic response of the Rustler Formation to the end of the last pluvial period has involved at least some change in flow directions in the Culebra dolomite. Although the modern flow is largely north-south, the results of uranium-disequilibrium studies suggest that flow was more easterly during previous recharge.

Within and near Nash Draw, evaporite karst is operative within the Rustler, as evidenced by the continuing development of small caves and sinkholes in near-surface anhydrites and gypsums of the Forty-niner and Tamarisk Members. There is no evidence of karstic hydrology in the Rustler at and near the WIPP site. However fracturing of some portions of the Culebra dolomite is sufficient at the site to strongly affect both hydraulic and transport behavior on the hydropad scale, i.e., over distances of approximately 30 m. Interpretation of multipad interference tests conducted both north and south of the center of the WIPP site indicates that this fracturing need not be incorporated into numerical modeling of the regional-scale hydraulic behavior of the Culebra east of Nash Draw. Similarly, detailed transport calculations indicate that effects due to fracturing are not significant in regional-scale transport within the Culebra dolomite at and near the WIPP site, at least as long as the modern head distribution is not significantly disturbed and the calculated flow directions and transport properties are representative.

The Dewey Lake Red Beds overlying the Rustler Formation consist largely of siltstones and claystones, with subordinate sandstones. In tested locations, the Dewey Lake may be hydrologically unsaturated, but is too low in permeability for successful hydrologic testing. South of the WIPP site, near an area where the unit may be receiving modern recharge, sandstones within the Dewey Lake locally produce potable water. In general, water

levels within the Dewey Lake Red Beds, like those in the underlying Rustler Formation, must be in transient response to the end of the last pluvial period. Isotopic relations suggest that surficial waters have been involved in the formation of secondary gypsum veins within the Dewey Lake, but that the Dewey Lake and Rustler hydrologic systems are largely separate.

The major near-surface units at the WIPP site are the Gatuna Formation and Mescalero caliche. The sandstones and stream-channel conglomerates within the Gatuna indicate that major changes in local climate have occurred over (at least) the last 600,000 years. The widespread preservation of the Mescalero caliche indicates not only the relative structural stability of the Livingston Ridge surface (on which the WIPP surface facilities are sited) over the last 400,000 years, but also that infiltration over this same time period has not been sufficient to dissolve a layer of carbonate 1 to 2 m thick.

ACKNOWLEDGMENTS

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SUMMARY OF SITE-CHARACTERIZATION STUDIES CONDUCTED FROM 1983 THROUGH 1987 AT THE WASTE ISOLATION PILOT PLANT (WIPP) SITE, SOUTHEASTERN NEW MEXICO

1.0 INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico (Figure 1.1) is designed for the receipt, handling, storage, and disposal of defense-generated transuranic (TRU) wastes. The WIPP underground facilities are currently being constructed at a depth of approximately 655 m in bedded halites in the lower portion of the Salado Formation (Table 1.1). First receipt of waste is scheduled for October 1988.

WIPP site-characterization activities began in 1976 with the drilling of hole ERDA-9 near the center of the site (Sandia National Laboratories and United States Geologic Survey, 1983) (Figure 1.2). As used here, the term "WIPP site" specifically refers to the sixteen square miles of T22S, R31E contained within WIPP Zone 3 and shown in Figure 1.2. This terminology is used for internal consistency within the report. Construction of the WIPP facility and monitoring of its underground structural and hydrologic behavior began in 1981, with construction of two shafts and limited underground workings.

WIPP site-characterization and facility-characterization studies through March 1983 are documented in several reports, including: 1) the WIPP Geologic Characterization Report (Powers et al., 1978); 2) the WIPP Final Environmental Impact Statement (FEIS) (U.S. Department of Energy, 1980); and 3) both summary and topical reports completed as part of the WIPP Site and Preliminary Design Validation (SPDV) effort (e.g., Beauheim et al., 1983a; Borns et al., 1983; Lambert, 1983; Popielak et al., 1983; Weart, 1983; Wood et al., 1982).

After the SPDV studies were completed and documented, the U.S. Department of Energy and the State of New Mexico agreed to several additional site-characterization activities, which, with one exception, were scheduled for completion by January 1988. The specific studies are described in Appendices I and II to the "Agreement for Consultation and Cooperation Between [the U.S.] Department of Energy and the State of New Mexico on the Waste Isolation Pilot Plant" (1981), and are referred to here as "C&C studies." Some non-C&C studies, such as a major regional-scale interference test of the Culebra dolomite, have also been carried out since 1983. A reactive-tracer experiment in the Culebra dolomite, originally a C&C study, was deleted during 1987, by agreement between DOE and the State of New Mexico. Studies agreed to in lieu of the reactive-tracer experiment should, with a few exceptions, be completed and reported by approximately December 1988.

Thus, formal WIPP site-characterization activities will end approximately December 1988. However, understanding of the geologic, hydrologic, and geochemical behavior of the WIPP facility (and site) will continue to

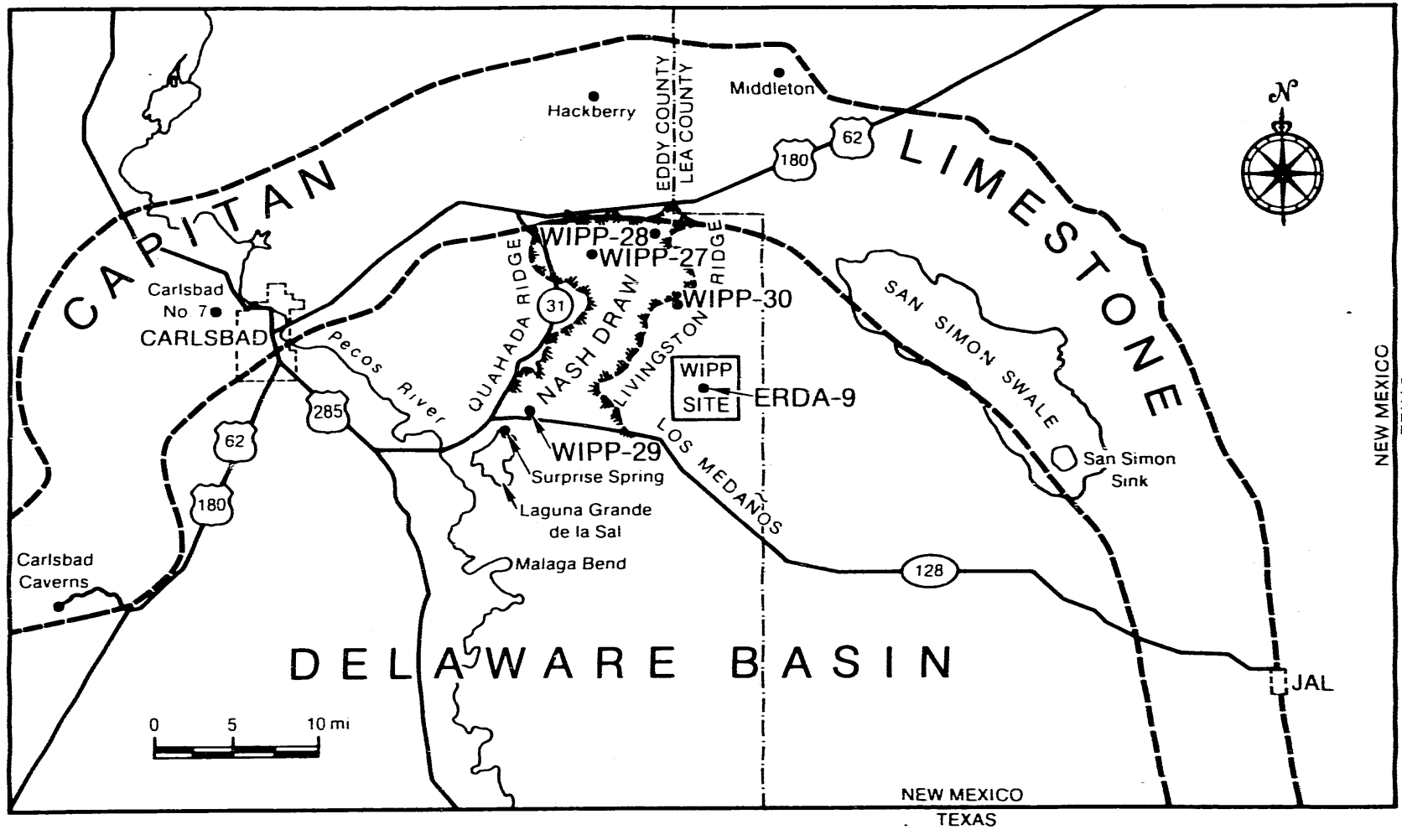


Figure 1.1: Setting of the WIPP site relative to the northern Delaware Basin. Selected geomorphic features and some holes referred to in text but not shown in Figure 1.2 are also included. Modified from Figure VI-1 of Lambert (1983).

Table 1.1: Generalized stratigraphic column of the Delaware Mountain Group and younger sedimentary rocks at and near the WIPP site. Figure 2-1 of Beauheim (1987c).

SYSTEM	SERIES	GROUP	FORMATION	MEMBER
RECENT	RECENT		SURFICIAL DEPOSITS	
QUATER-NARY	PLEISTO-CENE		MESCALERO CALICHE	
			GATUNA	
TRIASSIC		DOCKUM	UNDIVIDED	
PERMIAN	OCHOAN		DEWEY LAKE RED BEDS	
			RUSTLER	Forty-niner
				Magenta Dolomite
				Tamarisk
				Culebra Dolomite
				unnamed
			SALADO	
			CASTILE	
	GUADALUPIAN	DELAWARE MOUNTAIN	BELL CANYON	
			CHERRY CANYON	
			BRUSHY CANYON	

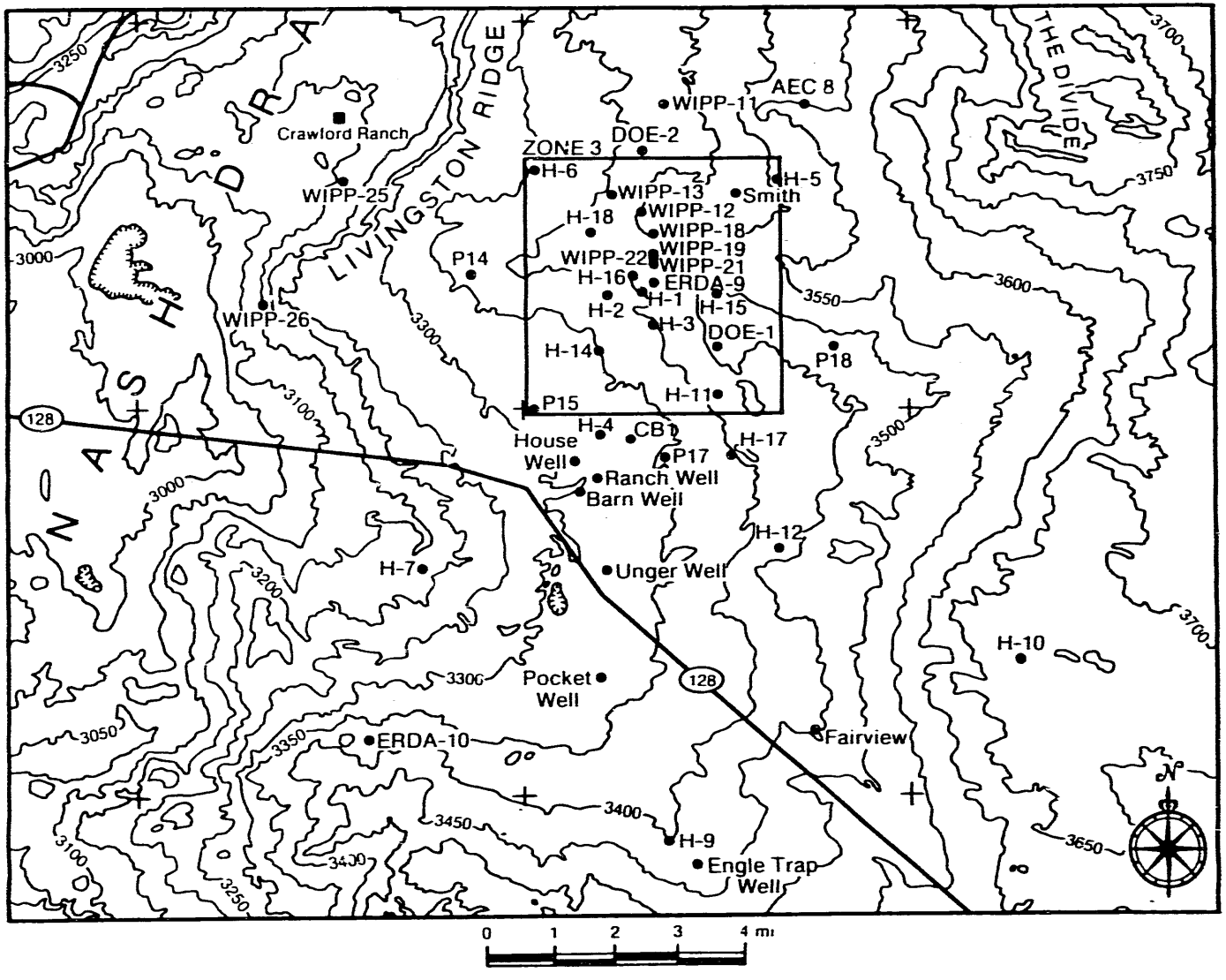


Figure 1.2: Boreholes at and near the WIPP site referred to in text. Holes were drilled as part of the site-characterization of the WIPP, as ranchers' wells, or as potash or hydrocarbon exploration holes. Only exploration holes which have been hydrologically tested are included.

develop after that time. Geotechnical work in and near the WIPP facility will extend into the period of operational demonstration, especially to complete characterization of the hydrologically and structurally disturbed zones around the underground workings and access shafts, in direct support of WIPP performance assessment. Data collected during these studies must support a full evaluation of expected facility performance against criteria developed by the U.S. Environmental Protection Agency (40CFR191) in their present or revised form. The structural, hydrologic, and nuclide-containment behavior of the WIPP facility, including potential far-field paths of nuclide release to the accessible environment, will be monitored throughout the WIPP operational period.

1.1 Report Objectives

This report has four main objectives. These are to:

1. Summarize the results of C&C studies carried out since the Spring of 1983.

2. Summarize the results and/or status of site-characterization and facility-characterization studies carried out since 1983 but not mandated by the C&C Agreement.

3. Compile the results of WIPP site-characterization studies into an internally consistent conceptual model for the geologic, hydrologic, geochemical, and structural behavior of the WIPP site. This model includes preliminary consideration of the local effects of the WIPP facility and shafts on the Salado and Rustler Formations.

4. Discuss the present limitations and/or uncertainties in the conceptual geologic model of the WIPP site and facility.

The objectives of the report are limited in scope and do not include determination of whether or not the WIPP Project will comply with repository-performance criteria developed by the U.S. Environmental Protection Agency (40CFR191). Whether or not the WIPP will comply with 40CFR191 must be demonstrated by the WIPP performance-assessment activity within five years following first emplacement of waste. The objective of this report is to develop as complete a conceptual model as possible for use in the required performance assessment.

1.2 Structure of Report

The remaining parts of this section (1.0) contain:

1. A general discussion of the stratigraphic setting and variability of sedimentary rocks within the northern Delaware Basin that have been of interest during WIPP site characterization (Section 1.3).

2. A general discussion of the technical issues of interest in WIPP site (and facility) characterization (Section 1.4). Emphasis in this discussion is on technical areas of site characterization which have been actively pursued since 1983.

The sections making up the body of the report (2.0 through 4.0) are generally ordered in stratigraphically upward sequence. This structure is a matter of convenience, and is not intended to imply relative priorities of the different issues and units discussed.

Within each technical section, recent studies in the formation(s) of interest are discussed in relation to the topics or issues outlined in Section 1.4. The final section of the report, Section 5.0, attempts to compile the results of the three preceding sections into an internally consistent conceptual model for the geologic, hydrologic, structural, and geochemical behavior of the WIPP site.

1.3 General Stratigraphic Setting of the WIPP Site and Facility

As shown in Figure 1.1, the WIPP site is located in southeastern New Mexico, in the northern portion of the Delaware Basin. The generalized stratigraphy in the vicinity of the WIPP is summarized in Table 1.1. Regional stratigraphic relationships and characteristics are discussed in detail in Powers et al. (1978).

The Delaware Basin became a distinct structure by the late Pennsylvanian Period to early Permian Period, approximately 280 million years ago. Approximately 250 million years ago, the reef now represented by the Capitan limestone began to grow around the margins of the developing basin, and the sandstones, shales, and carbonates now making up the Delaware Mountain Group (DMG) were deposited within the basin. Most of the Capitan limestone is relatively massive. Some portions of the unit are hydrologically active and support local karst hydrology, including the formation of large cavities such as Carlsbad Caverns. The Delaware Mountain Group, which is limited to the basin, contains three major subdivisions, the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations (in ascending stratigraphic order). Only the Bell Canyon Formation is considered here, as it is the first regionally continuous water-bearing formation beneath the WIPP facility. The hydraulic behavior of the Bell Canyon Formation is assumed to be more significant than that of any underlying units in WIPP breach scenarios.

The Bell Canyon Formation is divided into five informal members, the Hays sandstone, Olds sandstone, Ford shale, Ramsey sandstone, and Lamar limestone (in ascending stratigraphic order). The individual members vary in thickness and lithology. As shown in Figure 1.3, the upper Bell Canyon sandstones tend to be elongated and laterally discontinuous, in the nature of "channel sands." Individual sands are separated laterally by stratigraphically equivalent siltstones and/or shales. Near the WIPP site, the Bell Canyon Formation consists of a layered sequence of sandstones, shales/siltstones, and limestone 300 m or more in thickness (Powers et al., 1978).

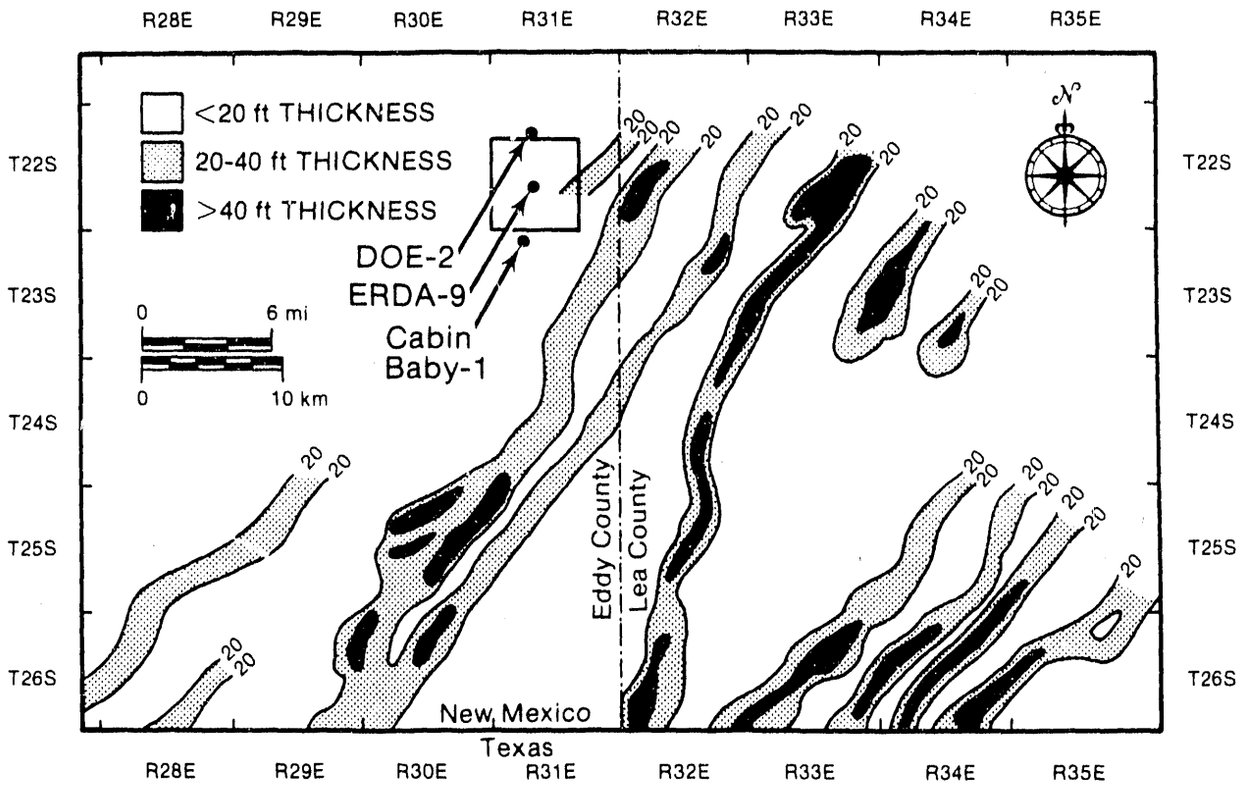


Figure 1.3: Lateral distribution and thicknesses of channel sands in the informal Ramsey member of the Bell Canyon Formation in the northern Delaware Basin, including holes DOE-2 and Cabin Baby-1. Simplified from Figure 2-2 of Davies (1983).

Within the northern Delaware Basin, the sandstones and shales of the Bell Canyon Formation are overlain by the thick-bedded sequence of anhydrites and halites of the Castile Formation, also of Permian age. As shown in Table 1.1, the Castile Formation near the WIPP site normally contains three relatively thick anhydrite/carbonate units and two thick halites. Both anhydrites and halites contain abundant anhydrite and/or carbonate laminae, may be strongly deformed internally, and are variable in local thickness. The thickness of the Castile Formation near the WIPP site is approximately 400 m.

The Salado Formation, of Late Permian (Ochoan) age, is 530 to 610 m thick at and near the WIPP site, and is generally bedded on a scale of 0.1 m to 1 m. It contains 45 numbered "anhydrite" marker beds of variable thickness (MB101 through MB145 with increasing depth). Between marker beds, the Salado consists of layered halites of varying purity and accessory mineralogy; anhydrite ($CaSO_4$), clays, and polyhalite ($K_2MgCa_2(SO_4)_4 \cdot 2H_2O$) are dominant accessory minerals. The WIPP facility horizon is between MB138 and MB139.

The Salado Formation is overlain by the Rustler Formation, also of Ochoan age. As shown in Table 1.2, the Rustler contains five members. Two, the Magenta and Culebra dolomites, are somewhat variable gypsiferous dolomites. The Culebra and Magenta dolomites vary mainly in the concentration of fractures and the local occurrence of silty zones. The other three members of the Rustler (unnamed lower member, Tamarisk Member, and Forty-niner Member in upward succession) consist of varying proportions of anhydrite, siltstone/claystone, and halite. The major mineralogical variability within the Rustler Formation as a whole is in the degree of alteration of anhydrite to gypsum and the presence or absence of halite, both generally interpreted to result from evaporite dissolution. Some of this variability, however, may reflect original depositional patterns. The Rustler ranges from 83 m to 130 m in thickness at the WIPP site, depending on the extent of evaporite dissolution and/or depositional variability.

The Culebra dolomite is the first laterally continuous unit above the WIPP facility to display significant permeability. Barring direct breach to the surface, the Culebra dolomite provides the most direct pathway between the WIPP facility and the accessible environment. The hydrology and fluid geochemistry of the Culebra dolomite are quite complex. The unit displays wide ranges in hydraulic properties, local flow and transport mechanisms, and geochemistry. As a result of these factors, the Culebra has received a great deal of study in WIPP site characterization, both before and since 1983.

The Rustler Formation at the WIPP is overlain by the Dewey Lake Red Beds (the uppermost unit of the Ochoan Series) consisting largely of siltstones and claystones, with subordinate sandstones. The unit is approximately 30 m to 170 m thick at and near the WIPP site, varying at least in part due to post-depositional erosion. Where relatively thick and hydraulically unsaturated, the Dewey Lake Red Beds form a low-permeability buffer zone between the surface and relatively soluble carbonates and/or sulfates in the underlying Rustler Formation. In some areas, however, the unit is

thinned by local erosion and/or is hydraulically saturated. Where sufficiently thin, the Dewey Lake may not present an effective barrier to vertical fluid movement from the surface into the Rustler, depending on the local fluid pressures within and above the Rustler Formation. Where saturated, the Dewey Lake may, in some areas, serve as a source of fluids to the underlying Rustler Formation. The depositional age of the Castile, Salado, and Rustler Formations, as well as the Dewey Lake Red Beds, ranges approximately from 245 million to 230 million years. Over approximately the eastern half of the WIPP site, the Dewey Lake Red Beds are overlain by the (undivided) Dockum Group of sandstones and shales of Triassic age.

Table 1.2: Generalized stratigraphy of the Rustler Formation at and near the WIPP site. Adapted from Snyder (1985).

Age	Member	Approximate Thickness (m)	Generalized Character in "Unaltered" Sections
Permian/ Ochoan	Forty-Niner	45±	Anhydrite Halite and Siltstone Anhydrite
	Magenta Dolomite	6-9	Thinly Laminated Gypsiferous Dolomite; Local Anhydrite
	Tamarisk	65±	Anhydrite Halite and Siltstone Anhydrite
	Culebra Dolomite	6-10	Finely Crystalline, Vuggy, Gypsiferous Dolomite; Local Siltstone
	Unnamed	44±	Alternating Halite, Siltstone, Anhydrite Laminated Siltstone

The shallowest and youngest stratigraphic units at the WIPP site proper, except for recent surficial sands, are the Gatuna Formation, the Mescalero caliche, and the Berino soil. The Gatuna Formation, the upper part of which is approximately 600,000 years in age, consists of siltstones, sands, and stream-laid conglomerates, deposited in a wetter climate than is now present in southeast New Mexico. The Mescalero caliche, 410,000 to 510,000 years in age, is relatively continuous in the vicinity of the WIPP site and supports the Livingston Ridge surface on which the site is located (Figure 1.1). The Berino soil, approximately 250,000 years old, is a thin horizon, and is much less widespread than either the Gatuna or the Mescalero. Together, the Gatuna Formation, Mescalero caliche, and Berino soil indicate

some of the variability of the climate in southeastern New Mexico over the last 600,000 years and the relative structural stability of the Livingston Ridge surface over the last 400,000 to 500,000 years.

Localized gypsite-spring deposits, approximately 25,000 years in age, occur along the eastern flank of Nash Draw, but are not currently active. Around the northwest margin of the Delaware Basin, packrat middens indicate that the climate approximately 10,500 years ago was significantly wetter than that at present. The recent surficial windblown sands at and near the WIPP site are almost all stabilized by vegetation. South of the site, however, there is an area in which surficial dunes appear to be active. It is from these dunes that the area has derived its name, "Los Medanos."

1.4 Technical Issues of Interest in WIPP Site and Facility Characterization

This section contains brief discussions of several technical issues of general interest in site characterization of the WIPP, including some consideration of the WIPP facility itself. The most general issues are discussed first. After that, the approach is generally stratigraphic, in parallel with the structure of the report as a whole. Detailed referencing of individual technical studies is not included here, but is included in Sections 2.0 through 4.0, where appropriate.

1.4.1 Transient Versus Steady-State Geologic, Hydrologic, and Geochemical Setting of the WIPP

In order for the expected behavior of the WIPP facility to be evaluated against the EPA's repository-performance guidelines (40CFR191), it must be demonstrated that the structural, hydrologic, geochemical, and transport behavior of the WIPP facility and environs are adequately understood to provide satisfactory predictions over at least the 10,000-year time frame of regulatory interest. "Structural behavior," as the term is used here, includes both far-field and near-field mechanical deformation of stratigraphic units. Far-field structural behavior is behavior independent of the presence of the WIPP facility, especially the underground workings. Near-field behavior is the behavior of the portions of the Salado and Rustler Formations that have been disturbed by the presence of the WIPP facility. "Hydrologic behavior" includes description of the distribution of hydrologic properties, fluid pressures, and directions of fluid flow. As the term is used here, however, it does not include investigation of chemical equilibrium between fluid and rock. "Geochemical behavior" includes both bulk chemistry and isotopic relations resulting from rock-water interaction, but is largely limited to consideration of natural chemical transport and reactions between rocks and fluids, independent of waste. "Transport behavior" includes consideration of the mechanisms of contaminant transport in Rustler groundwaters and the relative importance of different transport mechanisms; it does not include consideration of any specific radionuclides that will or will not be a part of the WIPP radionuclide inventory.

Two basic assumptions are possible concerning the overall geologic setting of the WIPP site. The simplest assumption, implicitly made in the WIPP FEIS (U.S. Department of Energy, 1980), is that the entire geologic system at the WIPP is at steady state on the time scale of regulatory interest. Under this assumption, the geology, hydrology, and geochemistry of the WIPP site should be constant with (or independent of) time for at least the period of regulatory concern to waste isolation.

However, the overall geologic and hydrologic settings of the WIPP site have been transient (not steady-state) since before the beginning of deposition of the Bell Canyon Formation, approximately 250 million years ago, and will continue to be transient long after effective closure of the WIPP facility. Some events, such as crystallization of secondary minerals within the Salado Formation approximately 200 million years ago and formation of the Mescalero caliche 400,000 to 500,000 years ago, have taken place on a very long time scale. Two types of transient response are occurring at and near the WIPP site within the 10,000-year time frame of regulatory interest. These are: a) the continuing natural response of the geologic and hydrologic systems to the end of the last pluvial period (period of decreased temperatures and increased precipitation) in southeast New Mexico; and b) the responses to man-induced hydrologic, geochemical, and structural transients resulting from site characterization and facility construction.

Thus, there is abundant evidence that the overall setting and behavior of the WIPP site are transient on at least three geologic and two human-induced time scales. The time scales of transient behavior range from at least tens of millions of years in the cases of secondary mineralization and fracture formation within the Salado Formation (independent of the WIPP facility) to tens of years in the case of pressure transients imposed on the Rustler Formation by shaft construction and hydrologic testing. The evidence for transient behavior of the WIPP site comes from a broad range of geologic, hydrologic, geochemical, and structural studies. The WIPP performance-assessment activity will ultimately determine which transient phenomena are significant to the long-term performance of the WIPP facility.

1.4.2 Dissolution of Evaporitic Rocks at and near the WIPP Site

Evaporite dissolution, i.e., dissolution or alteration of halite, anhydrite/gypsum, and/or the sulfatic carbonates of the Rustler, Salado, or Castile Formations by groundwaters, has been an issue of major interest in WIPP site characterization. The fundamental reason for this has been the need to evaluate the possibility that, although the Permian evaporites at the WIPP site have been in existence for approximately 240 million years, they might be regionally or locally dissolved on the 10,000-year time scale of regulatory interest. If this occurred, then evaporite dissolution could play a major role in breach of the WIPP facility, by short-circuiting the transport of radionuclides from the facility to the accessible environment.

There are four settings in which evaporite dissolution is or has been of interest in WIPP site characterization. These include:

1. Regional-scale stratabound dissolution of evaporites, especially halite, within the Castile and Salado Formations. In stratabound dissolution, fluid movement is predominantly parallel to bedding. Stratabound dissolution has probably taken place in the western part of the Delaware Basin, as indicated by the absence of halite from both the Castile and Salado Formations in Figure 1.4. If stratabound dissolution within the Castile reached the WIPP site, mechanical collapse of the overlying Salado Formation would occur, possibly resulting in direct breach of the facility. If stratabound dissolution within the Salado reached the WIPP, direct breach of the facility might result.

The possibility of stratabound dissolution reaching the WIPP site itself on the 10,000-year time scale of interest was evaluated as part of site-characterization activities prior to 1983. There is general agreement that stratabound dissolution of the Castile and/or Salado Formations will not reach the WIPP facility in the 10,000-year time frame of interest. In addition, recent interpretations indicate that much of the variability in the thicknesses of the Castile and Salado Formations is due to deformation and original depositional variability, rather than to evaporite dissolution. This should result in slower estimated dissolution rates.

2. Dissolution of Castile and/or Salado halites by localized upward intrusion of halite-unsaturated fluids from the upper portion of the Bell Canyon Formation into the overlying units. If such dissolution occurred immediately beneath the WIPP site, the resulting mechanical subsidence might directly breach the WIPP facility. If this dissolution mechanism is in fact feasible, the locations at which it might occur in the future are not predictable with the present understanding of hydrology in the northern Delaware Basin.

At the WIPP site, one basinal structure within the Salado Formation was proposed in 1983 as a possible result of subsidence resulting from point-source dissolution of Castile and/or Salado halites. This structure has since been investigated by the drilling, coring, and hydrologic testing of hole DOE-2 (Figure 1.2). No evidence of evaporite dissolution was found in hole DOE-2. The DOE-2 structure is the result of syndepositional and postdepositional deformation of the Castile and Salado Formations, rather than of evaporite dissolution. This conclusion, together with earlier studies indicating that the only proven "breccia pipes" in the northern Delaware Basin result from dissolution within the Capitan limestone and occur only directly above this unit (Snyder and Gard, 1982), indicates that point-source dissolution of Castile and/or Salado evaporites is not operative either within the main part of the basin or at the WIPP site.

3. Dissolution of halite from within the Rustler Formation by stratabound flow. East of the WIPP site, the Rustler Formation contains abundant halite (salt) in the Forty-niner, Tamarisk, and unnamed members. West of the WIPP site, for example in Nash Draw, the Rustler

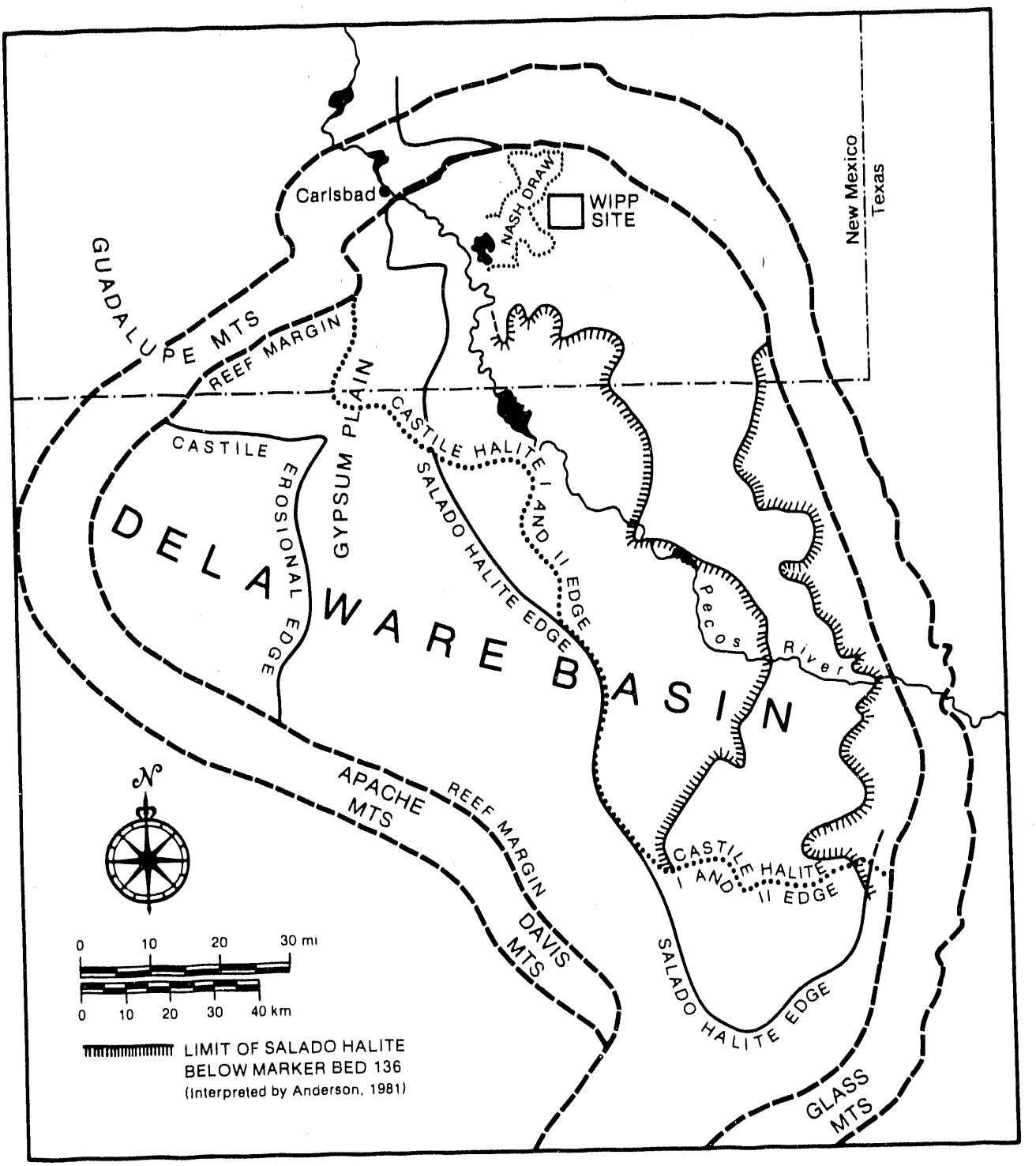


Figure 1.4: Generalized distribution of the Castile and Salado Formations in the Delaware Basin, with emphasis on distribution of halites. Slightly modified from Figure VII-1A of Lambert (1983) and including, in part, the interpretation of Anderson (1981).

Formation is totally devoid of halite (Figure 1.5). If Rustler variability is due to evaporite dissolution and if stratabound dissolution reached the WIPP site within 10,000 years, the overburden at the WIPP would be significantly reduced, perhaps leading to breach.

The variability within the Rustler Formation has conventionally been thought to result from regional-scale stratabound evaporite dissolution, based on the assumption that the distribution of halite was originally uniform. It has also traditionally been assumed that dissolution of Rustler evaporites was a recent phenomenon, linked to the growth of Nash Draw over the last 600,000 years. These two assumptions maximize both the total amount of halite dissolved from the Rustler and the rate at which this dissolution occurs. There is considerable disagreement concerning the uniformity and amount of stratabound evaporite dissolution within the Rustler Formation. However, even with the two "conservative" assumptions outlined above, i.e., assumptions thought to maximize the potential impact to the WIPP, it does not appear feasible for the Nash Draw structure to extend to the WIPP site on the time scale of regulatory interest.

4. Evaporite dissolution within the Rustler Formation as a result of vertical fluid flow. This second potential evaporite-dissolution mechanism involving the Rustler Formation at and near the WIPP site requires local recharge, from the surface to the Rustler Formation, of waters unsaturated in halite and anhydrite/gypsum. If this vertical movement of unsaturated fluids occurs to a significant degree, the resulting local evaporite dissolution within the Rustler might result in local high-permeability channels or pathways within the Rustler Formation. The final result of such dissolution would be the generation of a "karstic" hydrologic system. In such a system, the hydrology and transport behavior would be dominated by relatively narrow high-permeability pathways or channels, even though most of the unit would consist of low-permeability "blocks." The hydrology of at least part of the Rustler Formation within Nash Draw, where the Rustler is exposed at the surface, is known to be karstic, and includes the continuing formation of small caves and sinkholes in anhydrites of the Forty-niner and Tamarisk Members. Such a hydrologic and transport system within the Rustler Formation at the WIPP site itself might provide a means for rapid transport of nuclides from the WIPP facility to the accessible environment.

A comprehensive approach has been taken to the question of Rustler karst at the WIPP site. Field studies have evaluated the surface-geological evidence for and against significant surface infiltration and possible development of karstic cavities below. Hydrologic measurements, including regional-scale pumping tests, have characterized the present distribution of hydraulic properties and relative head potentials within the Rustler at and near the WIPP. Isotopic studies have estimated the isolation or residence times of Rustler waters, estimated the relative importance of vertical and stratabound fluid flow within the Rustler and Dewey Lake, and evaluated the extent to which the entire Rustler hydrologic setting is transient.

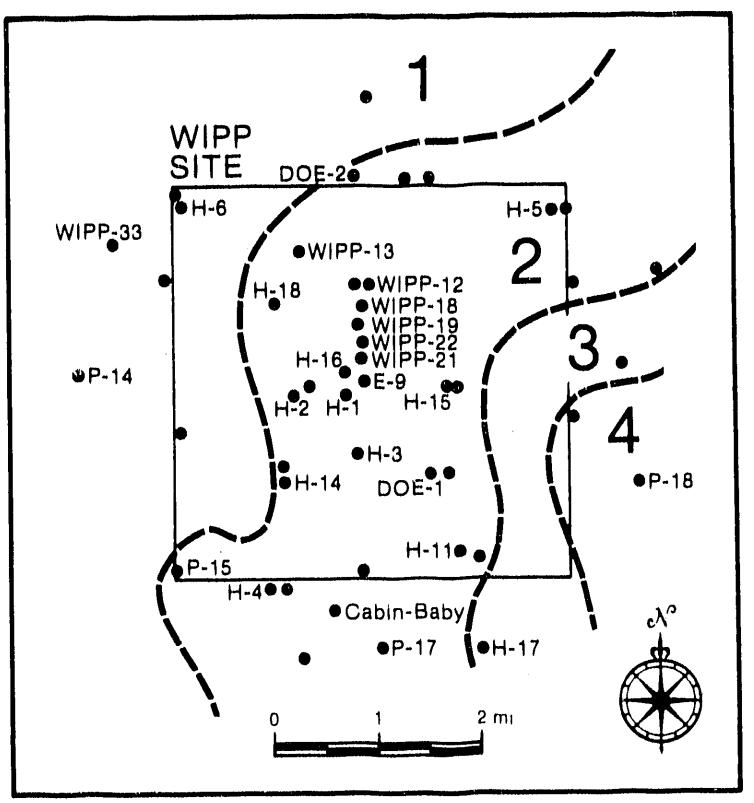


Figure 1.5: Generalized halite distribution within the Rustler Formation at and near the WIPP site. Slightly modified from Figure 9 of Chaturvedi and Channell (1985). Zone 1: no halite present within the Rustler Formation; Zone 2: halite present only below the Culebra Member; Zone 3: halite present between Culebra and Magenta Members; Zone 4: halite present above the Magenta Member.

The combined results of these studies indicate that vertical recharge from the surface to the Rustler is not active at the WIPP site. Where measured successfully, the calculated residence or isolation time of Rustler groundwaters at the WIPP site is greater than 10,000 years. There must have been changes in flow directions within the Culebra dolomite within the last (approximately) 10,000 years. The isotopic results do indicate that some vertical fluid flow has taken place, especially within the Dewey Lake Red Beds. In addition, local development of karstic channels or porosity within Rustler anhydrites does appear to have been a consequence of vertical infiltration of fluids from the surface in the WIPP-33 structure, approximately 1 km west of the western boundary of Zone 3. However, the WIPP-33 structure is unique at and near the WIPP site and is not now significantly active. Regional-scale pumping tests of the Culebra dolomite have not identified any major or dramatic high-transmissivity structures similar to those expected if Rustler karst involving the Culebra were present at the WIPP site.

1.4.3 Directions of Fluid Flow to Be Expected if the Rustler and Bell Canyon Formations Are Interconnected

In the effort to be "conservative," i.e., to not underestimate the impact of breaches of the WIPP facility, it was assumed in the WIPP FEIS (U.S. Department of Energy, 1980) that fluid flow in the event of interconnection of the Rustler and Bell Canyon Formations would be upward into the Rustler. This issue, as well as the distribution of hydrologic properties within the Bell Canyon Formation, has since been investigated in testing of the holes Cabin Baby-1 and DOE-2, near the southern and northern boundaries of the WIPP site, respectively (Figure 1.2).

The results of hydrologic testing in both Cabin Baby-1 and DOE-2 suggest that the WIPP site is not directly underlain by a high-permeability channel sand in the upper part of the Bell Canyon (Figure 1.3). If such a sand is present, it must be more narrow than those shown in Figure 1.3. This decreases the potential, already concluded by Wood et al. (1982) to be negligible, for any significant upward migration of Bell Canyon fluids into overlying evaporites in the absence of a drillhole. In addition, the fluid pressures and brine densities measured in both Cabin Baby-1 and DOE-2 indicate that, in the event of interconnection of the Bell Canyon, Salado, and Rustler Formations within a drillhole, the final direction of fluid flow would be downward into the Bell Canyon Formation. This conclusion assumes that both Bell Canyon and Rustler fluids become saturated as a result of local halite dissolution within the Salado Formation.

1.4.4 Distribution and Origin of Brine Occurrences within Castile Anhydrites

In the northern Delaware Basin, highly pressurized brines have been encountered locally in fractured anhydrites of the Castile Formation during drilling from the surface. The known distribution of these Castile brine occurrences as of 1983 is shown in Figure 1.6. Castile brines have been

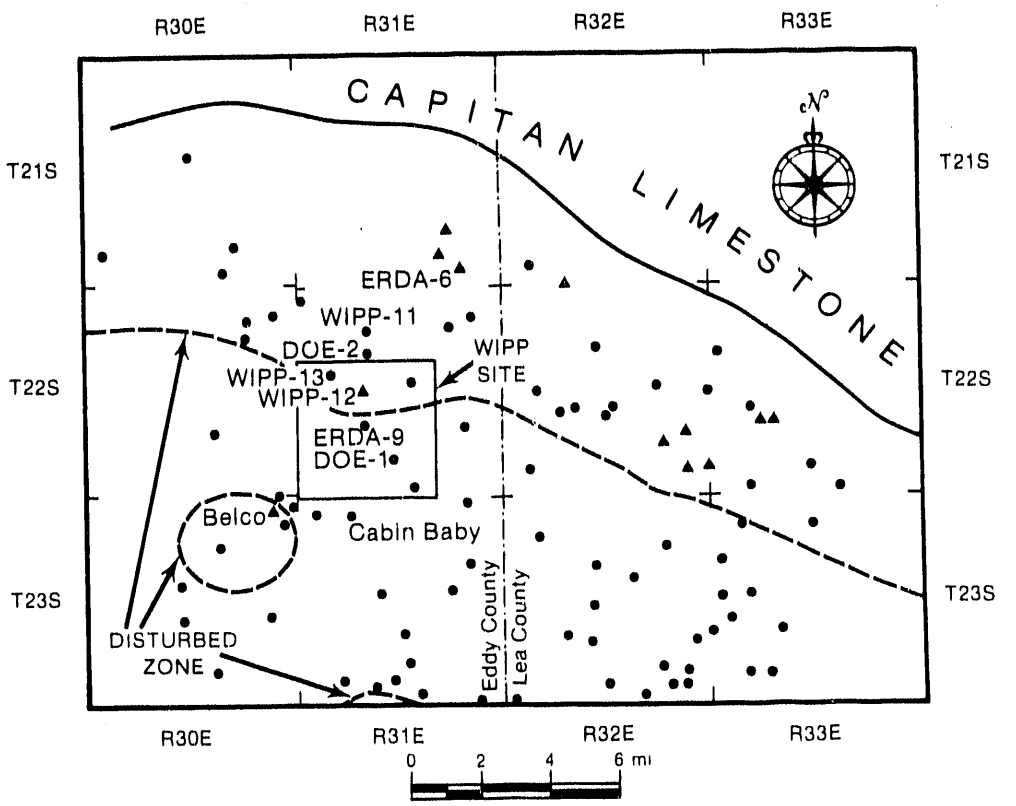


Figure 1.6: Generalized distribution of Castile brine occurrences and approximate extent of the Castile "Disturbed Zone" in the northern Delaware Basin. Distribution of Castile brines is simplified from Figure G-11 of Popielak et al. (1983). Approximate boundaries of Castile "Disturbed Zone" are from Figure 1-1 of Borns et al. (1983). Closed triangles represent holes in which Castile brines have been encountered. ERDA-9 is included for reference, but does not penetrate Castile Anhydrite III completely.

encountered largely in hydrocarbon-exploration drillholes both north and northeast of the WIPP site (i.e., between the WIPP site and the margin of the basin). However, brine was also encountered southwest of the WIPP site, at the Belco well. During WIPP site characterization, Castile brines have been encountered in hole WIPP-12, approximately 1.6 km north of the site center, and in ERDA-6, approximately 8 km northeast of the site center.

Two basic hypotheses have been put forward to explain the origin of Castile brines, namely that the occurrences are due to:

1. Migration of connate Castile fluids from halites into anhydrites fractured as a result of local deformation.

2. Isolation of meteoric waters within the fractured Castile anhydrites, following episodic lateral hydrologic connection of the Castile Formation and the Capitan limestone.

Because of the localized but widely distributed occurrence of Castile brines in the vicinity of the WIPP site, it has previously been assumed for purposes of performance assessment that Castile brine is present beneath the WIPP facility itself. Since the upper Castile anhydrite is stratigraphically 200 m or more beneath the WIPP facility horizon, this brine is of concern only in the event of a drilling intrusion which connects the brine occurrence with the facility. A recent surface-geophysical survey over an area including the WIPP waste-emplacement panels is consistent with the presence of Castile brines beneath a portion of the panels.

1.4.5 Deformation of the Castile and Salado Formations

Borns et al. (1983) define a structurally "Disturbed Zone" (DZ) (Figure 1.6) within the Castile Formation, based largely on the systematic loss of coherent seismic response. The deformation of the Castile Formation within the DZ involves both anhydrites and halites, and is associated with the known occurrences of Castile brines. Although the overall mineralogies of the Salado and Castile Formations are similar, the two units are layered on different scales. Regional deformation of the Salado Formation is largely in response to regional deformation of the underlying Castile Formation.

Recent results indicate that fluids and pressure-solution mechanisms play a major role in far-field deformation of both the Castile and Salado Formations. This has been investigated both theoretically and by examination of core collected in hole DOE-2. The time scale of regional deformation of the Salado and Castile Formations is from thousands to millions of years, too long to be of concern in evaluation of the future performance of the WIPP facility.

Construction of the underground WIPP facility, resulting in generation of a large void space at a depth of 650 m within a stratigraphic section that is predominantly halite, results in a strong local mechanical response within the Salado Formation. The near-field mechanical response of the Salado

Formation around the WIPP facility involves both higher stresses and deformation rates than expected in natural or far-field deformation. At least during early closure, near-field creep deformation appears to involve mechanisms such as dislocation climb. It is presently not known when, or if, pressure solution will become a dominant mechanism in creep closure of the WIPP facility.

Creep, however, is not the only near-field process involved in closure of the WIPP facility. Marker Bed 139 (MB139), approximately 1 m below the WIPP facility horizon, is fractured from pre-excavation processes, i.e., processes not related to excavation of the WIPP facility. The opening of these fractures, in addition to formation of fractures within Salado halites, plays a significant role in the near-field structural response to excavation of the WIPP facility.

Monitoring of these structural "excavation effects" is ongoing, and will continue through the operational phase of the WIPP. The time scale of near-field mechanical effects began with the beginning of construction of the WIPP facility and will continue until structural reequilibration following complete closure of the facility. Therefore, the time of interest may be 100 years or more, depending on both the long-term behavior of the facility and the types and amounts of both waste and backfill that are emplaced.

1.4.6 Fluid Flow within the Salado Formation

Salado halites were assumed to be anhydrous at the time of the WIPP FEIS and SPDV activities, with the exception of small amounts of fluid inclusions and water bound up in hydrous minerals. Fluid flow into the WIPP facility under this assumption would be very small in volume, directly stress-related, and transient. Long-term steady-state fluid flow would be zero.

Recent hydrologic measurements from the surface and within the WIPP facility, combined with geochemical studies within the facility, indicate that grain-boundary fluids are present within the Salado Formation, and that the unit should be considered as a very low-permeability material in which fluid residence times in the far field are on the order of millions of years. There are, however, major increases in both permeability and fluid-pressure gradients within the Salado Formation within a few meters of the WIPP facility at and near the facility horizon. The recent results suggest that, while there are major stress-related transient effects, long-term fluid flow into the facility will reach some very low but non-zero steady-state rate, and will continue until effective hydrologic closure of the facility. On the basis of preliminary hydrologic testing results, the development of an altered or disturbed zone around the WIPP shafts appears to be much more limited than at the facility horizon.

1.4.7 Present-Day Hydrology, Transport Behavior, and Geochemistry of the Rustler Formation

The Culebra Dolomite Member of the Rustler Formation is the first laterally continuous water-bearing zone above the WIPP facility. Transport within the Culebra dolomite constitutes the major transport mechanism from the WIPP facility to the accessible environment, except for direct transport to the surface. Therefore, there is great interest in determining the modern distribution of hydraulic and nuclide-transport properties within the Culebra.

The hydrologic characteristics of the Culebra dolomite are complex. The transmissivity of the unit varies by approximately four orders of magnitude at and near the WIPP site, with relatively high-transmissivity regions both southeast and northwest of the site center. However, the center of the WIPP site, including all four shaft locations, is in a region of low Culebra transmissivity (permeability). The relatively transmissive parts of the Culebra contain fractures that dominate both hydraulic and transport behavior on the scale of individual three-hole hydropads (approximately 30 m between holes). If these fractures were to dominate flow and transport behavior on the "regional" scale considered here, i.e., over the 3.2-kilometer distance between the center of the WIPP site and the boundary of WIPP Zone 3 (Figure 1.2), nuclide-transport times to the accessible environment would be greatly decreased relative to times estimated without considering fractures.

Numerical modeling of Rustler hydrology through 1983 was based on testing only at single holes and individual three-hole hydropads, and ignored possible fracturing. Since 1983, two regional-scale interference tests have been conducted in the Culebra, one centered at the H-3 pad and one at hole WIPP-13 (Figure 1.2). Hydraulic effects of fracturing have been evaluated in detail at the H-3 and H-11 hydropads. The interpretation of the regional-scale multipad interference tests indicates that fracturing need not be included in modeling simulation of Culebra hydrologic behavior at this scale, since test calculations with and without fractures have produced very similar results.

In addition, detailed calculations completed in 1987 indicate that although fracturing plays a major role in local or pad-scale contaminant transport within parts of the Culebra, radionuclide transport to the accessible environment can realistically be modeled using the porous-medium approximation, at least so long as the present pattern of head distributions within the Culebra is not significantly perturbed and the transport properties and flow paths assumed in the calculations are representative. This conclusion may or may not be valid in the case of a breach involving a Castile brine reservoir at high fluid pressures.

Through 1983, numerical modeling of Rustler hydrology also ignored both the geochemical variability of Rustler fluids and possible effects of variable fluid density on directions of fluid flow. Both numerical methods and data bases for evaluation of groundwater flow in the region of the WIPP site have developed significantly since that time. Recent groundwater-flow calculations, which include effects of variable brine density, indicate

that modern fluid flow within the Culebra dolomite is generally north-south in the vicinity of the WIPP site. Flow rates vary greatly, being rapid down the axis of Nash Draw, but extremely slow across the WIPP site proper. While the assumption of hydrologic steady state appears adequate for modeling of head potentials within the Culebra dolomite, groundwater flow across the WIPP site within the Culebra is sufficiently slow to make the assumption of hydrologic steady-state inadequate for detailed modeling of long-term flow directions and rates. However, the changes in flow rates and directions as a function of time appear not to be dramatic at the WIPP site itself. Groundwater flow is quite slow in this area.

As noted, Culebra fluids are quite variable. Recent work indicates that they can be broken into four distinct geochemical facies. The general distribution of fluid compositions is inconsistent with steady-state confined fluid flow in the present flow directions. The mineralogy of the Culebra dolomite is widely variable, but without sharp regional distinctions, since dolomite, clays, and gypsum/anhydrite are all widespread. Halite has not been reliably identified in Culebra core, except for that which may have been introduced during drilling. The analyzed Culebra fluid compositions form a variable but continuous population, all of which reflect exposure to evaporitic rocks.

2.0 BELL CANYON FORMATION

The Delaware Mountain Group is divided into the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations, all of which are predominantly of shales, siltstones, and sandstones. Only the Bell Canyon is considered here, since it is the first regionally continuous water-bearing zone beneath the WIPP facility. The hydraulic behavior of the Bell Canyon is assumed here to be more significant than that of underlying units in WIPP breach scenarios.

There have historically been two reasons for interest in the Bell Canyon Formation in WIPP site characterization. First, the Bell Canyon has been proposed by some as a source of fluids for local or point-source dissolution of halite in the overlying Castile and Salado Formations. This mechanism and general conclusions regarding its validity at the WIPP site are summarized in general terms in Section 2.1, based on work completed through 1983. Second, it must be assumed for purposes of performance assessment that at least one drillhole from the surface will penetrate the WIPP facility. It may then be important to estimate the distribution of permeable zones within the Bell Canyon at the WIPP site and to estimate directions of fluid flow that might result from an open borehole penetration that connected the Bell Canyon with fluid-bearing zones within the Rustler Formation, especially the Culebra dolomite. The character of the Bell Canyon and expected directions of fluid flow between the Culebra and the Bell Canyon at the WIPP site are discussed in Section 2.2.

2.1 Potential for the Bell Canyon Formation to Serve as a Source of Fluids for Dissolution of Evaporites in the Castile and Salado Formations

Anderson (1978, 1981) and Davies (1983) have proposed a major role for the Bell Canyon Formation in point-source dissolution of overlying evaporites. The proposed mechanism involves: 1) recharge of halite-unsaturated fluids to the Bell Canyon Formation from the Capitan limestone; 2) upward movement of these fluids into (at least) the lower halite of the Castile Formation; 3) halite dissolution within the Castile Formation; 4) subsidence and disruption of the Castile and overlying Salado Formations as a result of halite dissolution; 5) downward flow of halite-saturated brines back into the Bell Canyon Formation; and 6) removal of brines through the Bell Canyon Formation. An important characteristic of this hypothesis proposal is that it is not possible to predict localities of future point-source evaporite dissolution.

Wood et al. (1982), as part of the WIPP SPDV studies, addressed the potential for fluids within the upper Bell Canyon Formation to dissolve evaporites within the Castile Formation. For this evaluation, it is assumed that: 1) a permeable sandstone is present at the top of the Bell Canyon Formation, i.e., a Ramsey channel sand (Figure 1.3); 2) the effective thickness of the sandstone is 30 m; and 3) the transmissivity of the sandstone ranges from 1.0×10^{-6} to 2.8×10^{-6} m^2/s. Any decrease in sandstone permeability or shifting of the sandstone to positions below the

top of the Bell Canyon would reduce the potential for dissolution of overlying evaporites.

For the range of hydraulic properties and gradients considered, and assuming the Ramsey sand is at the top of the Bell Canyon, Wood et al. (1982) conclude that:

1. Except at locations adjacent to the Capitan limestone, only diffusional dissolution is possible directly above the Bell Canyon. Salt directly above the top of the Bell Canyon, assuming diffusional processes, is calculated to dissolve at a vertical rate of approximately 0.003 m per 10,000 years. This would have negligible effect on the WIPP facility.

2. Allowing for an order-of-magnitude increase in flow velocities within the Bell Canyon Formation, dissolution would still be too slow to maintain open cavities within Castile halites at depth. Such cavities are required to maintain the high-permeability pathways necessary for dissolution due to the density-flow mechanism outlined above.

3. Even allowing for the maximum potential dissolution rates at the top of the Bell Canyon from both diffusive and convective mechanisms, no significant evaporite dissolution as a result of fluid flow from within the Bell Canyon should be observed at the WIPP facility for at least 10,000 years.

In addition, Lambert (1983) concludes that the Bell Canyon Formation itself shows no evidence of either modern hydraulic connection with a source of halite-unsaturated fluids (such as the Capitan limestone) or any effective path for brines to exit the Delaware Basin. Instead, Lambert interprets the Bell Canyon fluids as having very long residence times and concludes that their compositions reflect extensive rock-water interaction, evolving isotopically and geochemically away from compositions representative of meteoric recharge.

Thus, studies at the end of the WIPP SPDV phase indicated that the Bell Canyon Formation was not dissolving evaporites near the WIPP site. As discussed in Section 3.0, however, this question was later investigated directly by the drilling, coring, and hydrologic testing of hole DOE-2, near the northern boundary of WIPP Zone 3 (Figure 1.2).

2.2 Expected Directions of Fluid Flow Between the Bell Canyon and Rustler Formations

The information on freshwater-equivalent heads in the Rustler and Bell Canyon Formations available through 1983 is summarized in Mercer (1983). At that time, the freshwater head within the Bell Canyon Formation at the center of the WIPP site, approximately 1040 m AMSL, was 120 m greater than the expected freshwater head in the Culebra dolomite at the same location,

approximately 920 m AMSL. (All elevations here are given relative to mean sea level.) This is consistent with the assumption made in the WIPP FEIS (U.S. Department of Energy, 1980) that fluid flow would be upwards into the Rustler if the Bell Canyon and Rustler were interconnected in an open hole. However, this "conservative" assumption, i.e., the assumption with most apparent impact to WIPP performance assessment, neglects: a) the original density of fluids in the Bell Canyon and Culebra; b) possible increases in both Bell Canyon and Culebra fluid densities due to dissolution of halite within the Salado Formation; c) possible effects of fluid potentials within the Salado Formation or elsewhere within the Rustler Formation; and d) possible changes in fluid density as a result of entrainment of waste from within the WIPP facility.

In the event of a drillhole breach interconnecting the Bell Canyon, Castile, Salado, and Rustler Formations, it is reasonable to assume that local dissolution of halite within the Salado Formation would take place, resulting in an average fluid density of approximately 1.2 g/cm^3, the approximate density of saturated NaCl brine. Under this assumption, Bell Canyon brine at the center of the WIPP site would stand to an elevation of approximately 835 m in an open hole, some 445 m above the WIPP facility, but approximately 210 m below land surface, and more than 200 m lower than the Bell Canyon freshwater-equivalent head of approximately 1040 m. Assuming that local halite dissolution within the Rustler or upper portion of the Salado Formations led to a final density of Culebra brine of 1.2 g/cm^3, the Culebra near the center of the WIPP site would support a column of brine to an elevation of approximately 900 m, 20 meters below the freshwater-equivalent head within the Culebra, but some 65 m higher than supported by the underlying Bell Canyon Formation.

Therefore, if brine saturation by halite dissolution is considered, the data available as of 1983 are consistent with the interpretation that interconnection of the Bell Canyon Formation and the Culebra dolomite in an open drillhole through the WIPP facility should result in downward movement of contaminated brine into the Bell Canyon Formation. However, the calculated direction of fluid flow depends on assumed fluid densities. Fluid might move upward until the Bell Canyon and Culebra fluids were saturated with halite, at which time downward flow would begin. In addition, these results depend on the assumption that no significant fluid or gas pressures are generated within the Salado Formation or WIPP facility. As of 1983, however, predicted directions of fluid flow were limited in reliability, because heads and fluid densities in the Culebra dolomite and Bell Canyon Formation had not been measured together in the same hole. Two holes penetrating the Bell Canyon Formation very near the WIPP site have since been drilled and/or hydrologically tested. The results from hole Cabin Baby-1 are discussed in Section 2.2.1, and those from hole DOE-2 in Section 2.2.2.

2.2.1 Results from Hole Cabin Baby-1

Cabin Baby-1, a hydrocarbon exploration hole, was originally drilled through the Castile Formation and the upper 35 m of the Bell Canyon

Formation in 1974 and 1975. At that time, all of the Ramsey and part of the Olds members of the Bell Canyon were penetrated. The hole depth at that time was 1265 m below land surface. As described in Beauheim et al. (1983b), the hole was deepened to a total depth of 1308 m in 1983 to allow hydrologic testing, fluid sampling, and monitoring of Bell Canyon fluid levels. The deepening allowed testing of most of the Hays sandstone member underlying the Olds, in addition to all of the Olds and Ramsey members.

The results of hydrologic testing of the Bell Canyon in Cabin Baby-1 and DOE-2 are summarized in Table 2.1. Only the lowermost "sand" member of the Bell Canyon, the Hays, is significantly permeable in Cabin Baby-1, with an interpreted transmissivity of between 1.7×10^{-7} and 5.1×10^{-7} m^2/s. The description of the Hays member by Beauheim et al. (1983b) indicates that it is siltstone. The estimated transmissivities of the overlying Olds and Ramsey members are less than 10^{-8} m^2/s. Core from the Ramsey member is not available from Cabin Baby-1.

Table 2.1: Summary of hydrologic test results from the Bell Canyon Formation in Cabin Baby-1 and DOE-2. Data from Table 6 of Beauheim et al. (1983b) and Table 7-2 of Beauheim (1986).

Effective Test Interval (m blg)	Unit	K(md)	T(m^2/s)
Cabin Baby			
1230-1246	Lamar	6×10^{-4}	5.7×10^{-11}
1247-1257	Ramsey	2.3×10^{-2} - 8.7×10^{-2}	1.7×10^{-9} - 6.3×10^{-9}
1259-1269	Olds	2.2×10^{-2} - 8.2×10^{-2}	2.1×10^{-9} - 7.9×10^{-9}
1271-1308	Hays	0.57 - 1.7	1.7×10^{-7} - 5.1×10^{-7}
DOE-2			
1263-1272	Ramsey	8.4×10^{-2} - 9.4×10^{-2}	5.8×10^{-9} - 6.5×10^{-9}
1276-1285	Olds	9.8×10^{-2} - 0.11	7.1×10^{-9} - 8.2×10^{-9}
1297-1318	Hays	2.3 - 2.4	5.7×10^{-7} - 6.0×10^{-7}

Fluid samples were successfully collected from the Hays and Olds members of the Bell Canyon in Cabin Baby-1, as was a mixed sample from the entire exposed Bell Canyon. The presence of the tracer added to the drilling

fluid indicates that all of the water samples are slightly contaminated with drilling fluid. Therefore, the reported specific gravity of fluid from the Hays sandstone (1.120 - 1.134) may be slightly too high (Beauheim et al., 1983b).

At the end of operations in 1983, the penetrated portion of the Bell Canyon in Cabin Baby-1 was isolated by a packer emplaced in the lower anhydrite of the Castile Formation, and a monitoring tube was installed to the surface to allow long-term monitoring of a composite Bell Canyon fluid level. As of October 1986, the composite Bell Canyon fluid level in Cabin Baby-1 was stabilized at an elevation of approximately 920 m (Saulnier et al., 1987). Assuming that a specific gravity of 1.12 represents Bell Canyon fluids in the hole, and that the fluid column is supported by the effective pressure at the top of the Hays member at an elevation of -255 m, the calculated pressure at this elevation is 12.81 MPa. This pressure in the Bell Canyon in Cabin Baby-1 would support a column of brine having a density of 1.20 g/cm^3 to an elevation of 842 m.

Culebra fluid pressures and properties in Cabin Baby-1 are contained in LaVenue et al. (1988). These results indicate a Culebra freshwater-equivalent head of approximately 913 m. At the elevation of the base of the Culebra in this hole, approximately 856 m, this requires a fluid pressure of approximately 0.55 MPa. Assuming a final brine density of 1.2 g/cm^3 after halite dissolution, this is equivalent to a brine column supported to an elevation of 903 m.

The expected saturated-brine head in the Culebra in Cabin Baby-1, 903 m, is 61 m higher than the composite saturated-brine head in the Bell Canyon in the same hole, 842 m. Thus, under the assumptions used here and consistent with extrapolations from regional data available as of 1983, the final direction of fluid flow in the event of an open drillhole interconnecting the Bell Canyon and Salado Formations with the Culebra dolomite at Cabin Baby-1 would be downward.

2.2.2 Results from Hole DOE-2

Hole DOE-2, located near the center of the northern boundary of WIPP Zone 3 (Figure 1.2), was drilled in two stages to a total depth of 1318 m, between August 1984 and June 1985 (Mercer et al., 1987). In addition to the shallower units in the hole, the Ramsey, Olds, and Hays "sandstone" members of the Bell Canyon Formation were hydrologically tested (Table 2.1), as described by Beauheim (1986).

The results of testing in DOE-2 are similar to those in Cabin Baby-1, in which the lower "sand," the Hays, is the only unit with appreciable permeability or transmissivity. Estimated transmissivities for the Hays in DOE-2 range from 5.7×10^{-7} to 6.0×10^{-7} m^2/s, similar to the upper estimate of transmissivity for the same zone in Cabin Baby-1. Estimated transmissivities of the Ramsey and Olds members in DOE-2 range only from 5.8×10^{-9} to 8.2×10^{-9} m^2/s, similar to the upper range of estimated transmissivities for the same members in Cabin Baby-1. The lithologic log

contained in Mercer et al. (1987) indicates that all three members are fine-grained sandstones, rather than siltstone.

After hydrologic testing, the Bell Canyon in DOE-2 was isolated for monitoring of a composite fluid level (Beauheim, 1986). As of March 1986, the composite fluid level had "stabilized" at an elevation of approximately 925 m. Assuming that the measured specific gravity of 1.10 (Mercer et al., 1987) is representative for the Bell Canyon fluids, and that the composite Bell Canyon head is controlled by fluid pressures at the top of the Hays member at an elevation of -243 m, this requires a fluid pressure of 12.5 MPa at this elevation. This pressure would support a column of brine having a density of 1.2 g/cm^3 to an elevation of approximately 827 m.

The Culebra freshwater-equivalent head in DOE-2 is approximately 934 m (LaVenue et al., 1988). Using the measured fluid density of 1.04 g/cm^3 (Uhland et al., 1987) for the Culebra in DOE-2, a freshwater-equivalent head of 934 m requires a pressure of 1.47 MPa at the base of the Culebra, at an elevation of 784 m. Assuming a final Culebra brine density of 1.2 g/cm^3 following halite dissolution, the Culebra fluid pressure at DOE-2 would support a brine column of density 1.2 g/cm^3 to an elevation of approximately 909 m, 82 m higher than supported by the composite Bell Canyon head in the same hole. Under the assumptions used here, the final direction of fluid flow in the event of an open hole interconnecting the Bell Canyon, Salado, and Culebra at DOE-2 would be downward.

Wood et al. (1982) estimate that the transmissivities of sandstones within the Bell Canyon Formation normally range from 1.0×10^{-6} to 2.8×10^{-6} m^2/s, although they report a maximum value of 1.7×10^{-5} m^2/s. This range is approximately one order of magnitude greater than the transmissivity of the Hays member in Cabin Baby-1 and DOE-2, and more than two orders of magnitude greater than the transmissivities measured in the Olds and Ramsey members in the same holes. Therefore, the Ramsey member in Cabin Baby-1 and DOE-2 does not appear to be part of one of the channel sands shown in Figure 1.3. Given that Cabin Baby-1 and DOE-2 are the only two holes very near to WIPP Zone 3 that penetrate the Bell Canyon, this result does not guarantee that no channel sandstone is present in the Bell Canyon beneath the WIPP site. Given the general trend of the channel sands shown in Figure 1.3, it does suggest that any channel sand present would have to be at least as narrow as the sand shown at the eastern edge of the WIPP site. Cabin Baby-1 lies along the trend of this sand, however, indicating that this channel is not continuous towards the southwest.

The recent results in both DOE-2 and Cabin Baby-1 are consistent with the conclusion that the final direction of fluid flow resulting from interconnection of the Bell Canyon Formation and the Culebra dolomite at or near the WIPP site would be downwards into the Bell Canyon, contrary to assumptions maintained in the WIPP FEIS. There are some limitations to this conclusion. There might be upward fluid movement until the Bell Canyon and Culebra fluids became essentially saturated with halite, at which time downward flow would begin. In addition, these results depend on the assumption that flow rates within the Bell Canyon and Culebra dominate any fluid pressures generated within the Salado Formation. This assumption appears generally valid, however, given the low fluid-flow rates normally encountered within the Salado Formation (Section 3.0).

3.0 CASTILE AND SALADO FORMATIONS

The major halite-bearing units at and near the WIPP site are the Castile and Salado Formations. Both units contain halites of varying purity and thickness. The two halites within the Castile Formation are normally thick, contain abundant sulfate/carbonate laminae, and are separated by two relatively thick anhydrites. The bedded halites within the Salado Formation contain accessory minerals such as polyhalite, clay, and anhydrite, and are separated by numerous anhydritic marker beds and related clay seams. Locally the middle portion of the Salado Formation contains commercial potash mineralization, at a level some 300 m stratigraphically above the WIPP facility horizon. The underground workings in the WIPP facility are being developed at a depth of approximately 655 m within bedded halites and anhydrites in the lower Salado. The halitic interval containing the WIPP facility horizon is approximately 8 m thick, and is situated between anhydrite marker beds MB138 and MB139. The Castile and Salado Formations are discussed together here, since halite is a major component of both, and many of the processes of interest involve both units.

The Castile Formation overlies the Bell Canyon Formation (Delaware Mountain Group). Near the WIPP site, the Castile normally contains a sequence of three thick anhydrites (Anhydrite I at the bottom and Anhydrite III at the top), separated by two thick halites (Halites I and II). The thickness of the Castile Formation at and near the WIPP site is approximately 400 m. Anderson et al. (1972) provide a general stratigraphic description of the Castile, including the more than 200,000 sulfate/carbonate laminae that occur throughout both halites and anhydrites within the unit. Bedding within Castile anhydrites ranges from massive (approximately 30 m) to laminar (see for example, Mercer et al., 1987). Individual beds in the Salado are often 1 m thick or less. The unit nominally contains 45 anhydrite marker beds, numbered from Marker Bed 101 (MB101) to MB145 with increasing depth. The Salado Formation is about 600 m thick at the WIPP site.

In some areas, both total thickness and the thickness of stratigraphic intervals within the Castile and Salado Formations are variable. The origin and timing of this variability are discussed in Section 3.1. This variability has played a significant role in WIPP site characterization, since variable halite (and anhydrite) thicknesses could have at least three origins:

1. Initial depositional variability (e.g., Lambert, 1983; Borns and Shaffer, 1985).

2. Gravity-driven deformation, in which dense anhydrites sink into less dense halites, with compensating formation of salt-cored domes or anticlines (Borns et al., 1983; Borns and Shaffer, 1985).

3. Evaporite dissolution, by which halites are preferentially dissolved by contact with unsaturated groundwaters (Anderson, 1978; Davies, 1983).

Significant volumes of fluid are not normally encountered in drilling either the Castile or Salado. There are exceptions, however. Highly pressurized brines have been encountered in the uppermost Castile anhydrite in some hydrocarbon-exploration and stratigraphic test holes near the WIPP site (Figure 1.6). These fluids are under sufficient pressure to flow to the land surface. The origin and distribution of Castile brines at and near the WIPP site is discussed in Section 3.2.

As mentioned previously, the WIPP facility is presently being developed within the bedded halites and anhydrites of the lower Salado Formation. In order to place the WIPP facility within a proper regional perspective, it is necessary to characterize the behavior of the Salado Formation on both the regional scale and adjacent to the WIPP facility itself. The characteristics of the Salado are locally different as a result of "excavation effects" from construction of the WIPP facility. These transient effects demonstrably occur on time scales of interest in performance assessment. Recent studies examining the structural, hydrologic, and geochemical characteristics of the Salado Formation in and near the WIPP facility are discussed in Section 3.3. These studies are progressing, and will play a critical part in monitoring the behavior of the WIPP facility during the operational phase. The discussion of these activities is preliminary.

3.1 Regional and Local Variability, Deformation, and Dissolution of the Castile and Salado Formations

3.1.1 Regional Relationships and Behavior

As mentioned above, both aggregate and internal thicknesses within the Castile and Salado Formations vary locally. The variability near the WIPP site is shown in Figure 3.1. Holes WIPP-12, DOE-2, and WIPP-11 lie within the southern part of the Castile "Disturbed Zone" (DZ) shown in Figure 1.6, while hole Cabin Baby-1 lies outside this zone. Since ERDA-9 penetrates only the upper portion of the Castile Formation, the possible extension of the DZ beneath the WIPP facility has not been determined by drilling. The Castile and Salado Formations in hole Cabin Baby-1 are assumed here to represent the "undisturbed" character of these units near the WIPP site.

In the cross section shown in Figure 3.1, the total thickness of the Castile is known only in holes Cabin Baby-1 and DOE-2. The Castile is 409 m thick in Cabin Baby-1 and 302 m thick in DOE-2. The apparent thickness of Anhydrite I is 72 m in Cabin Baby-1 and 80 m in DOE-2. Therefore, we assume here that the thickness of Anhydrite I is not significantly variable on the scale of the WIPP site, and that, south of DOE-2, Anhydrite I is not strongly involved in structures within the Castile and overlying Salado. Apparent stratigraphic thicknesses from the top of the Castile to the top of Anhydrite I range from 222 m at DOE-2 to 372 m at WIPP-11. The assumed undisturbed thickness, that at Cabin Baby-1, is 337 m.

Much of the variability within the Castile Formation in Figure 3.1 is in halite thickness. For example, the anomalously thick Castile at WIPP-11 includes a thickness of 311 m for Halites I and II, compared with a

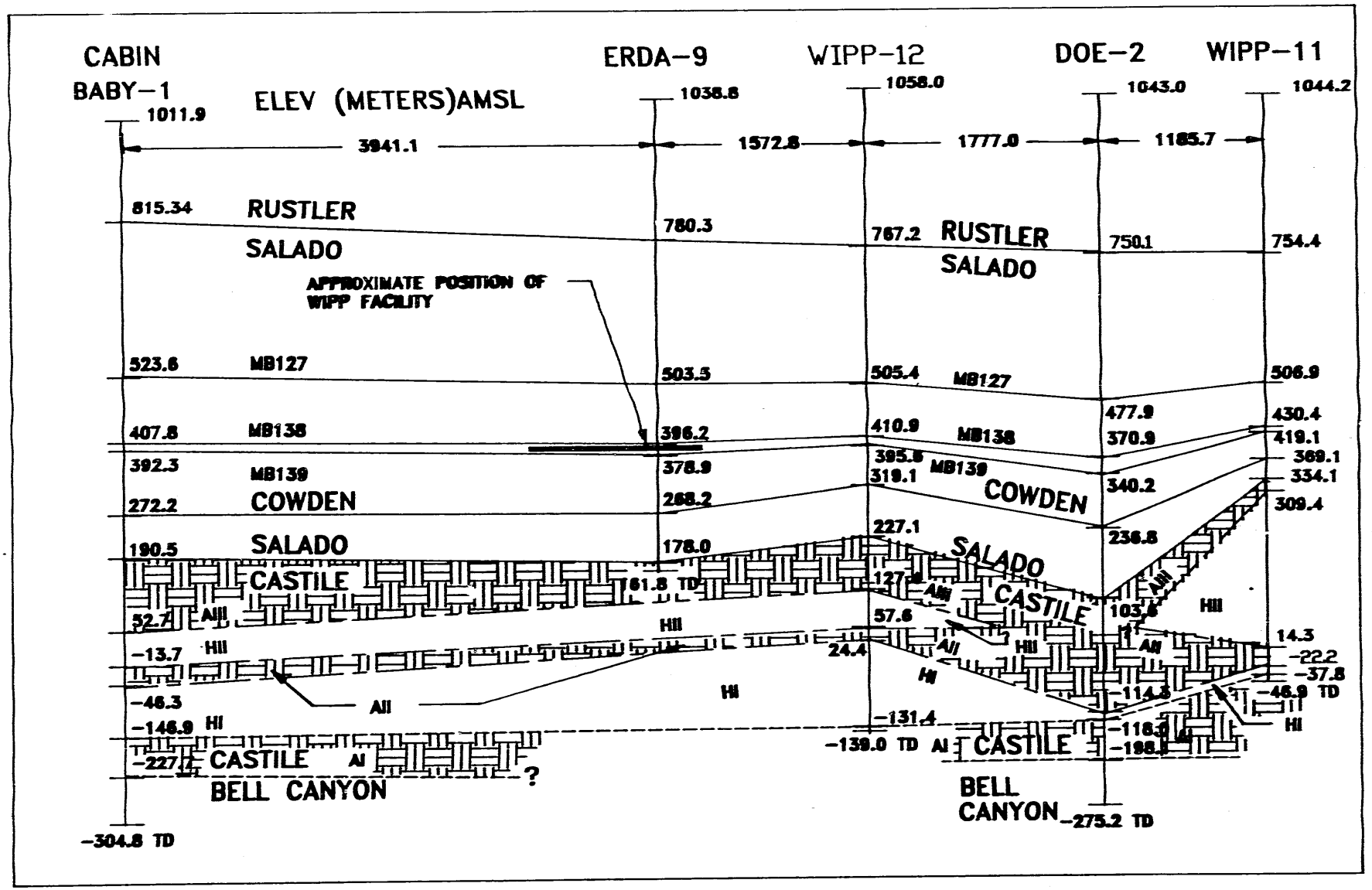


Figure 3.1: Generalized stratigraphic cross section of the Salado and Castile Formations between holes Cabin Baby-1 and WIPP-11. Hole locations used are shown in Figure 3.2. Elevations and hole spacings are in meters.

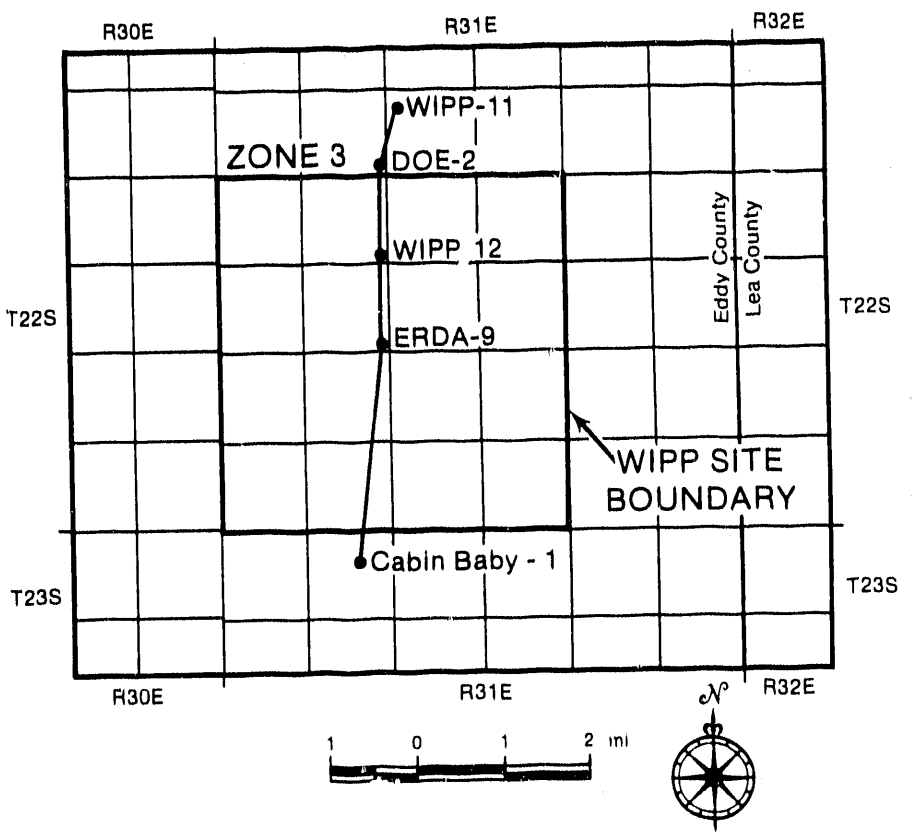


Figure 3.2: Hole locations used in Figure 3.1.

thickness of 167 m for the same units in Cabin Baby-1. At the other extreme, a total of only 2 m of Castile halite is present in DOE-2; Halite II is completely missing.

However, Anhydrites II and III also vary in thickness. Their total apparent thickness (drilled thickness, ignoring dip) in WIPP-11 is 61 m, compared to 219 m in DOE-2. Both values differ significantly from the total thickness of the two units in Cabin Baby-1, 170 m. These relationships indicate that, at least locally, anomalously thick halites within the Castile Formation are combined with anomalously thin anhydrites. Conversely, anomalously thin Castile halite, as in DOE-2, is combined with anomalously thick anhydrite. These results are inconsistent with halite dissolution being the only cause of variability in the thickness of the Castile Formation at the WIPP site.

Locally, the antithetic relations between anhydrite and halite thicknesses within the Castile are consistent with a similar relationship between overall thicknesses of the Salado and Castile Formations. The Salado is 625 m thick at Cabin Baby-1 and 602 m thick in ERDA-9. However, at WIPP-11 and WIPP-12, where the underlying Castile is anomalously thick, the Salado is unusually thin, 420 and 540 m, respectively. On the other hand, the Castile is relatively thin at DOE-2, and the apparent thickness of the Salado at DOE-2 is 647 m, greater than at either Cabin Baby-1 or ERDA-9.

Thus, the variable thicknesses of the combined Salado and Castile Formations at and near the WIPP site appear due to internally compensating variations in thicknesses of both anhydrites and halites. The origin of compensating anhydrite and halite thicknesses may be either depositional, as suggested by Lambert (1983) and Borns and Shaffer (1985), or a consequence of later gravity-driven deformation, as discussed in Borns et al. (1983). The Castile and Salado variability considered here at the WIPP site proper is very similar to that considered by Borns and Shaffer (1985) at the Poker Lake structures well south of the WIPP.

There is considerable evidence for both syndepositional and postdepositional deformation within the Castile Formation, as summarized by Borns et al. (1983) and Borns (1983). These authors distinguish three stages of deformation, listed in the sequence of development:

1. Formation of discontinuous isoclinal folds interpreted to be approximately syndepositional in age, i.e., to have occurred in soft sediments. These structures include displacive crystal growth in both anhydrites and carbonate laminae. Characteristically, the syndepositional structures are confined to a single layer, and may include disruption of the affected layer.

2. Asymmetric folding, including formation of crenulation cleavage, boudinage (separation) of carbonates, and convolute folding of anhydrite stringers within halites. Borns (1983) attributes a widespread subhorizontal fabric within Castile halites to folding at this stage. The axial planes of convolute folds in anhydrite stringers within Halites I and II are also subhorizontal. Borns (1983) interprets these relations to indicate that major deformation within the Castile often involves lateral movement of halite.

3. Late-stage near-vertical fractures and veins, which cross-cut earlier structures. These fractures may be either open, or filled with halite, anhydrite, and/or gypsum.

Syndepositional deformation was probably driven by gravity acting on original depositional slopes, or by responses to density contrasts within still-soft sediments. Borns et al. (1983) attribute later deformation to some combination of direct gravity-driven deformation resulting from deposition of dense anhydrites over less-dense halites and regional tilting of the Delaware Basin. On the large scale, the gravitic driving force for internal deformation of the Castile and overlying Salado Formations is clear. Above Anhydrite I, the Castile includes two thick anhydrites, with densities of approximately 2.95 g/cm^3. Each unit was deposited above thick halite with a density of 2.2 to 2.25 g/cm^3. Modeling discussed in Borns et al. (1983) indicates that, for the relatively thick-bedded Castile, these density contrasts should be sufficient to drive deformation in which the anhydrites effectively sink into underlying halites. Layering within the Salado is too thin to support such deformation; the Salado structures appear essentially to follow those in the underlying Castile as a relatively passive marker.

However, a driving force for deformation can be effective only if there are appropriate deformation mechanisms operating in the rocks involved. There have been three major studies into possible deformation mechanisms within the halites of the Castile and Salado. Munson (1979) assumed that deformation within the units is anhydrous. Munson concludes (Figure 3.3) that deformation under generic conditions for either a high-level-waste or TRU facility in halite would occur by an undefined mechanism, except at relatively high stress levels. At high stress levels, deformation would be dominated by creep mechanisms involving dislocation climb.

In contrast, Borns et al. (1983) associate structures within deformed portions of the Castile and Salado with the presence of fluids, and conclude that pressure solution plays a major role in controlling the regional deformation of both units. During pressure solution, deformation proceeds as a result of the migration of mineral constituents from regions of high stress to regions of low stress by means of diffusion through grain-boundary fluids. In the interpretation of Borns et al. (1983), the participation of fluids during deformation of the Castile and Salado Formations is indicated by veins containing both halite and anhydrite, as well as by anhydrite recrystallization in stress shadows. Recent studies of fluid contents within Salado halites indicate contents of as high as 2 weight percent (see Section 3.3), more than required for pressure solution to be operative (Borns, 1987b).

Borns (1987b) estimates deformation fields for halite, including pressure solution as a deformation mechanism (Figure 3.4). Field "C" in this figure includes the temperature and stress regimes estimated for regional deformation at and near the WIPP site by Borns et al. (1983), while field "B" is an analogous field for natural deformation of halites estimated by Carter and Hansen (1983) and Heard (1972). Pressure solution plays a major role in halite deformation within the conditions of both fields and assumed

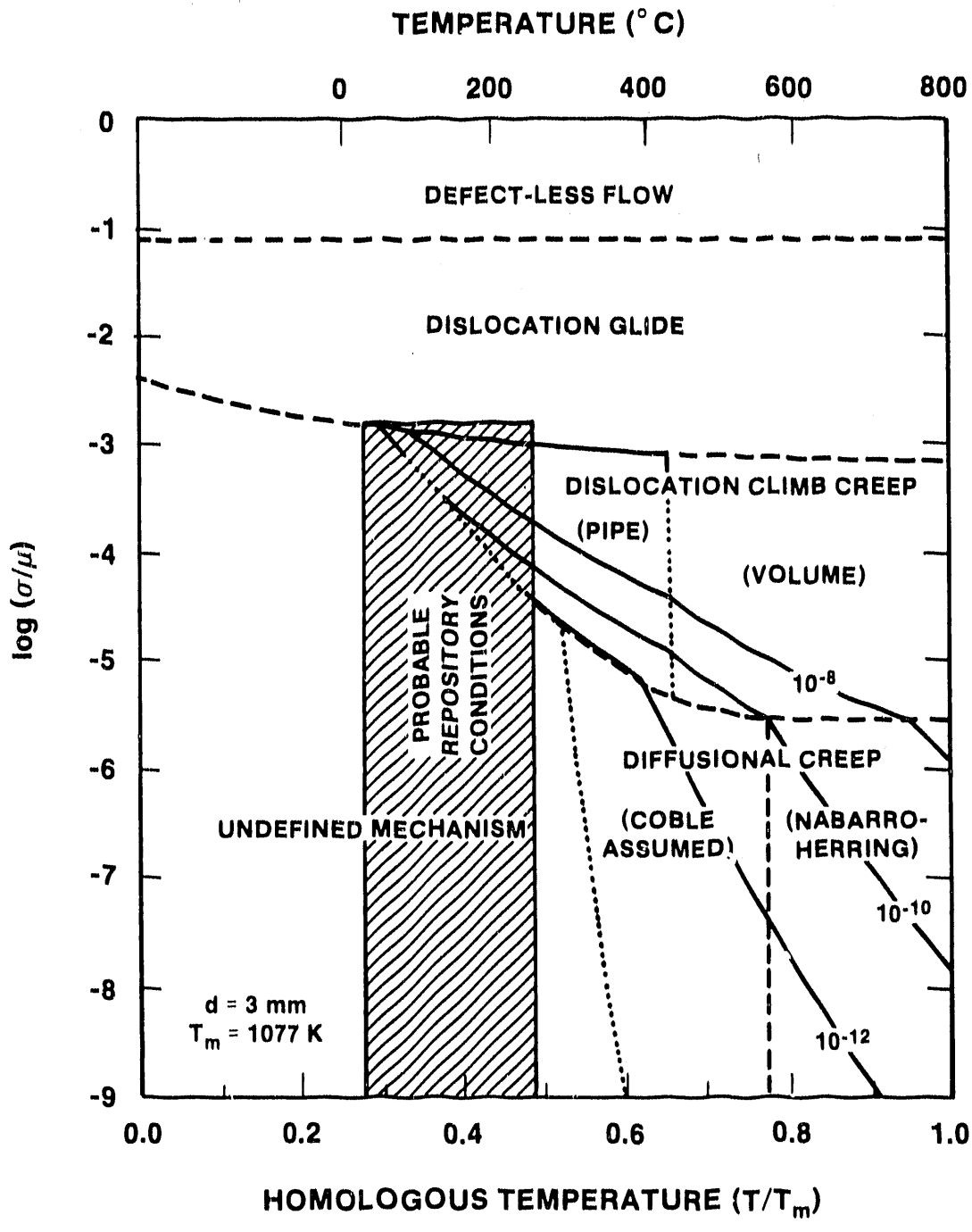


Figure 3.3: Deformation map for halite, assuming all deformation is anhydrous. Figure 2 of Borns (1987b). Homologous temperature (T/T_m) is the ratio between temperature and the dry melting temperature of halite. The stress axis is the log ratio of differential stress to halite shear modulus.

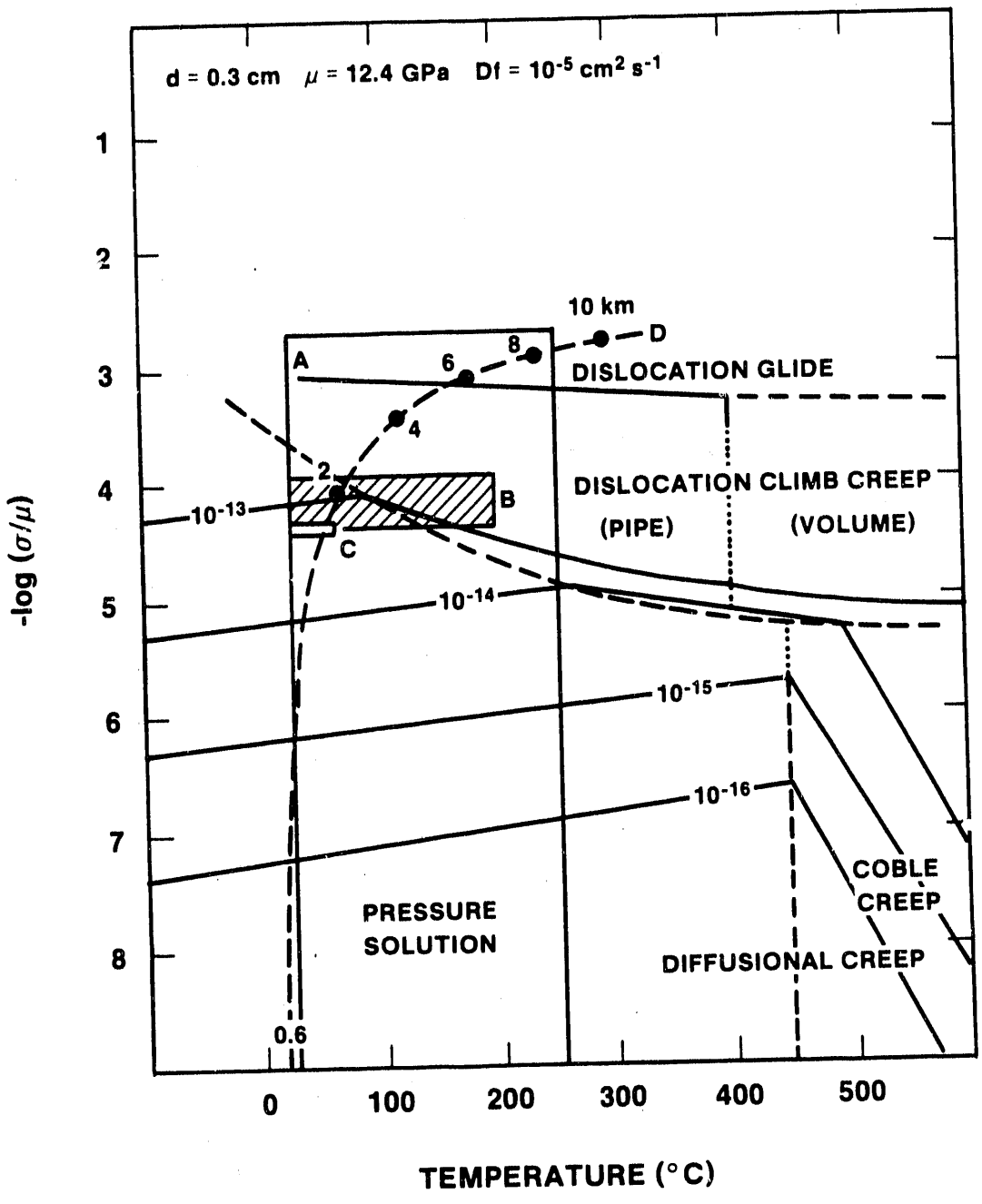


Figure 3.4: Deformation map for halite, assuming fluids present and considering pressure solution as a major deformation mechanism. Figure 4 of Borns (1987b). In this figure, viscous effects on grain boundaries are ignored. Field A is the field of "probable repository conditions" shown in Figure 3.3. Field B is the range of stress and temperature conditions estimated for natural rock-salt deformation (Carter and Hansen, 1983; Heard, 1972). Field C is the range of stress and temperature conditions for gravity-driven deformation at the WIPP site (Borns et al., 1983). Curve D is the estimated stress and temperature path for a Gulf Coast salt dome at the indicated depths (Carter and Heard, 1970).

material properties, so long as the volumetric strain rate is not greater than approximately 10^{-13} s^{-1}. As discussed by Borns (1987b), the maximum strain rates at which pressure solution is a dominant deformation mechanism depend on the character and thickness of the grain-boundary fluids.

The estimated strain rates for far-field deformation at the WIPP site, not including near-field deformation around the WIPP facility itself, are consistent with pressure solution. Based on a range of estimated strain rates of between 3×10^{-14} and 10^{-16} s^{-1}, the range of times calculated for formation of the WIPP-12 anticlinal structure, estimated to have undergone 1% volumetric strain, is 1.1×10^4 to 10^6 years (Borns et al., 1983). Near an underground facility such as the WIPP facility, however, early-time strain rates are probably too rapid for pressure solution to be a major deformation mechanism. Reported volumetric strain rates in such a setting are as high as 10^{-11} s^{-1} (Borns, 1987b), and may be even higher during initial transient closure.

In summary, the understanding of far-field deformation within the Castile and Salado Formations is consistent with the interpretations that:

1. Pressure solution, in which deformation results from mineral constituents being transported from high-stress to low-stress domains by means of an intergranular fluid or film, plays a major role in regional deformation of evaporites at and near the WIPP site. Since only approximately 0.2 volume percent (0.1 weight percent) fluid is required for pressure solution to be operative in halite, more than enough fluid is present within the Salado and Castile Formations at and near the WIPP site.

2. Much of the deformation within the DZ may have been effectively syndepositional (i.e., Permian) in age, although this is not the last period of deformation that has taken place.

3. The driving force behind regional-scale evaporite deformation at and near the WIPP is gravitational, due to the depositional emplacement of dense anhydrites over less dense halites. There is, however, a regional overprinting due to Pleistocene tilting of the entire northern Delaware Basin.

4. Deformation such as that known to occur within the DZ, even if it does progress toward the WIPP, is unlikely to reach the WIPP site within 10^4 years, the minimum estimated time required for formation of the WIPP-12 structure.

5. It is not known whether or when pressure solution will become an important mechanism in closure of the WIPP facility itself. At early times close to the facility, i.e., at relatively high stresses and deformation rates, mechanisms involving dislocation climb (and fracturing) should dominate. At later times and/or at greater distances from the underground workings, i.e., at lower stresses and deformation rates, pressure solution may dominate.

3.1.2 The DOE-2 Structure

The recognition of gravity as a driving force for regional-scale deformation of the Castile and Salado Formations and the probable role of pressure solution in such deformation does not rule out the possibility of halite removal by dissolution. The absence of halite within the Castile in the western part of the Delaware Basin (Figure 1.4) is interpreted as partly due to halite dissolution in response to regional tilting and uplift of the basin. However, as summarized by Neill et al. (1983), there is generally agreement that blanket or stratabound dissolution within the Castile and Salado Formations is not a feasible mechanism for breach of the WIPP facility on the regulatory time frame. Regional-scale evaporite dissolution within the Castile and Salado Formations is not discussed further here.

Both Anderson (1978, 1981) and Davies (1983) proposed that evaporites in the Castile and/or Salado Formations may be locally dissolved by halite-unsaturated fluids moving upwards from the Bell Canyon Formation (see Section 2.0). Subsidence of the overlying evaporites, especially the Salado Formation, would result. Hole DOE-2 was drilled specifically to investigate a depression in MB124 in the middle portion of the Salado Formation (Figure 3.1; see also Figure 2-2 of Mercer et al., 1987). However, the DOE-2 structure is interpreted as being due to lateral and vertical deformation of the Castile and Salado Formations, rather than evaporite dissolution.

The expected position of the top of the Castile Formation (Anhydrite III) in DOE-2 was at an elevation of between 230 and 260 m. However, the top of the Castile in DOE-2 was actually at an elevation of 102 m, more than 120 m lower. The base of the Castile in DOE-2, at an elevation of -199 m, is consistent with regional trends, indicating that the structure does not extend below the top of Anhydrite I.

Laminae within the upper Castile anhydrite in DOE-2 are strongly deformed, with vertical bedding and discontinuous folds at various depths (Mercer et al., 1987; Borns, 1987a). These structures are consistent with syndepositional deformation. Other structures seen in the Salado and Castile Formations in DOE-2, such as pull-apart structures and fibrous vein infillings, are interpreted by Borns as postdepositional. As noted by Borns (1987a), removal of Castile halite from DOE-2 by dissolution should have left in place many of the anhydrite "laminae" originally present in Halites I and II. No such dissolution residues were identified in core collected in hole DOE-2. The very thin Castile halite in DOE-2 (approximately 2 m) is compensated by unusually thick halites within the overlying Salado Formation. As shown in Figure 3.1 and noted in Table 3-3 of Mercer et al. (1987), halites within the informal lower member of the Salado Formation (from MB126 to the top of the Castile) in hole DOE-2 are 96 m thicker than in the same stratigraphic interval in hole WIPP-12, and 204 m thicker than in WIPP-11.

The DOE-2 structure is interpreted as being due to both lateral and vertical deformation of the Castile and Salado Formations, rather than to evaporite dissolution. The structural understanding of the Salado and

Castile does not allow prediction of where such a structure might develop in the future. Drilling and testing of hole DOE-2 indicates that no such structure remains unexamined at and near the WIPP site. Estimated times required for 1% strain in the structure at WIPP-12 indicates, however, that the time required for generation of a significant structure as a result of gravitationally driven deformation probably exceeds the 10,000-year time frame of regulatory interest.

3.2 Occurrence and Origin of Pressurized Brines within Anhydrites of the Castile Formation

Uncertainties about the original thicknesses, rates of gravity-driven deformation, and regional and local dissolution rates of Castile halites relate to natural phenomena affecting the reliability of long-term extrapolations of WIPP performance. One issue, the possible presence of pressurized Castile brines beneath the WIPP facility itself, plays a direct role in evaluation of the possible consequences of human intrusion into the WIPP facility. This is because, when encountered in drillholes, such brines can rise to the land surface; they would be capable of directly transmitting entrained waste to both the Rustler and the land surface. A geophysical survey conducted in 1987 indicates that Castile brines may be present beneath a portion of the WIPP waste-emplacement panels, consistent with previous assumptions made in WIPP performance assessment.

The known occurrences of Castile brines in the northern Delaware Basin as of 1983 (Figure 1.6) are taken from Popielak et al. (1983). Brines have been encountered in fractured Castile anhydrites in several hydrocarbon-exploration drillholes both north and northeast of the WIPP site, between the WIPP site and the margin of the Delaware Basin. In addition, Castile brines were encountered southwest of WIPP in the Belco well, approximately 6.5 km from the center of the site. During WIPP site characterization, pressurized Castile brines have been encountered in holes WIPP-12, approximately 1.6 km north of the site center, and ERDA-6, approximately 8 km northeast of the site center.

Brine volumes in the two occurrences have been estimated on the basis of flow tests and drillstem testing, but remain somewhat uncertain because of limited early flow data and the assumptions necessary concerning both fracture porosity and rock-mass compressibility in the absence of observation holes. Estimated brine volumes in the two occurrences range between 9.5×10^3 and 10^5 barrels for ERDA-6 and between 5×10^6 and 17×10^6 barrels for the WIPP-12 occurrence (Popielak et al., 1983; Neill et al., 1983).

Because of the apparent large volume of the WIPP-12 reservoir, it is reasonable to postulate that this reservoir extends beneath all or part of the WIPP facility. However, geophysical studies prior to 1983 were unsuccessful in determining whether or not Castile brines were present beneath the WIPP facility (Borns et al., 1983). Nonetheless, as a result of the occurrence of Castile brine in WIPP-12, it was assumed through 1983 that these brines were present beneath the WIPP facility (Channell, 1982; Bard, 1982; Case et al., 1982). A geophysical survey using transient

electromagnetic methods was made directly over the WIPP waste-emplacement panels in 1987 (Earth Technology, 1987), to determine the presence or absence of Castile brines beneath the facility. The results contained in Earth Technology (1987) are summarized in Figures 3.5 and 3.6.

As discussed in Section 2.0, the WIPP is underlaid by the Bell Canyon Formation. While the permeability of the upper portion of the Bell Canyon Formation is variable, the entire unit appears to be a good electrical conductor. Therefore, the dominant conductive layer beneath the WIPP facility appears to be the Bell Canyon. However, the apparent variations in depth to the first major conductor appear to exceed the estimated depth uncertainty for the geophysical method used, 75 m (Figure 3.6). At some of the locations, the interpreted depth to the first major conductor lies significantly above the depth of the top of the Bell Canyon Formation, i.e., within the Castile Formation. On the basis of this interpretation, brine may be present within the Castile Formation under part of the area outlined by the WIPP waste-emplacement panels (Earth Technology, 1987).

However, the combination of the depths to the first major conductor indicated in Figure 3.5 and stratigraphic depths indicated in Figure 3.1 suggests that the brine occurrence is limited. The depth to the top of the Bell Canyon is 1230 m in Cabin Baby-1 and approximately 1250 m in ERDA-9 (assuming linear variation between Cabin Baby-1 and DOE-2). Therefore, conductor depths greater than 1300 m in Figure 3.5 almost certainly reflect the Bell Canyon Formation. At the other limit, the depth to the bottom of the Salado is 861 m in ERDA-9 and 821 m in Cabin Baby-1. Since the minimum interpreted depth to the conductor is 988 m, the conductor does not appear to be within the Salado Formation anywhere in the surveyed area. The depth to the bottom of Anhydrite III is 959 m in Cabin Baby-1, and is assumed to be approximately 950 m in ERDA-9. Assuming 75 m vertical uncertainty in the geophysical soundings, this implies that apparent conductor depths of less than approximately 1025 m are consistent with brine occurrence within Anhydrite III. This interpretation suggests that brine is present within Anhydrite III under only the furthest northern and northeastern parts of the waste-emplacement panels. To date, pressurized Castile brines have been found only within fractured portions of the uppermost anhydrite present, Anhydrite II in ERDA-6 and Anhydrite III in WIPP-12.

The results shown in Figure 3.5 are based on one-dimensional modeling. Preliminary attempts at three-dimensional interpretation of the results indicate that the lateral resolution of the interpretation cannot be improved by more complex modeling approaches. Therefore, the "conservative" interpretation is that Castile brines are present beneath at least the northern portion of the WIPP waste-emplacement panels, consistent with both the most recent work and earlier assumptions.

Two basic hypotheses have been put forward to account for the occurrences of Castile brines:

1. Migration of connate Castile fluids into fractured anhydrites as a result of local deformation (Borns et al., 1983; Popielak et al., 1983).

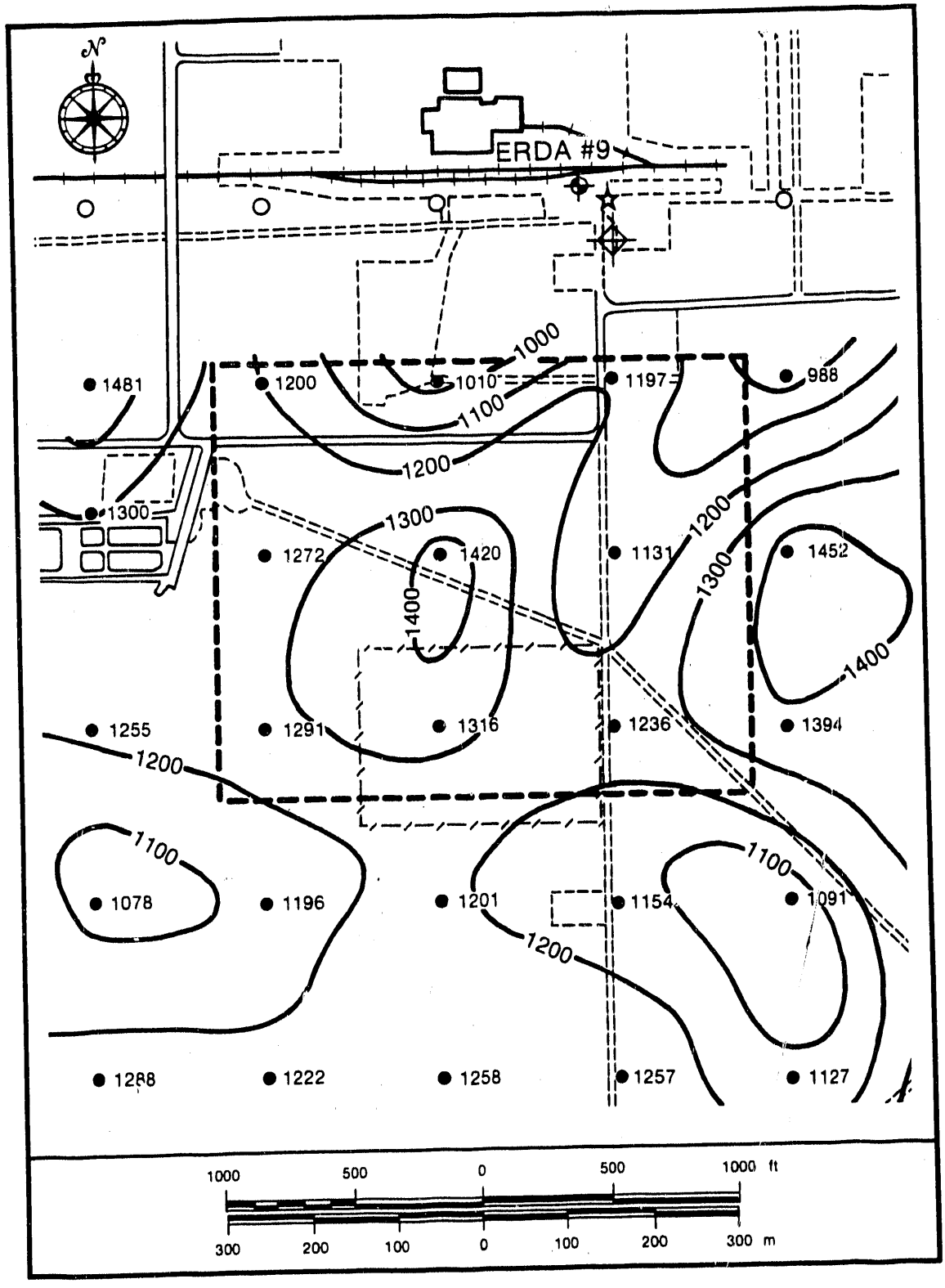


Figure 3.5: Contour map of apparent depth to first major deep conductor in survey including area of WIPP waste-emplacement panels, in meters. The heavily dashed rectangle outlines the surface projection of the WIPP waste-emplacement panels. Simplified from Figure 3-3 of Earth Technology (1987).

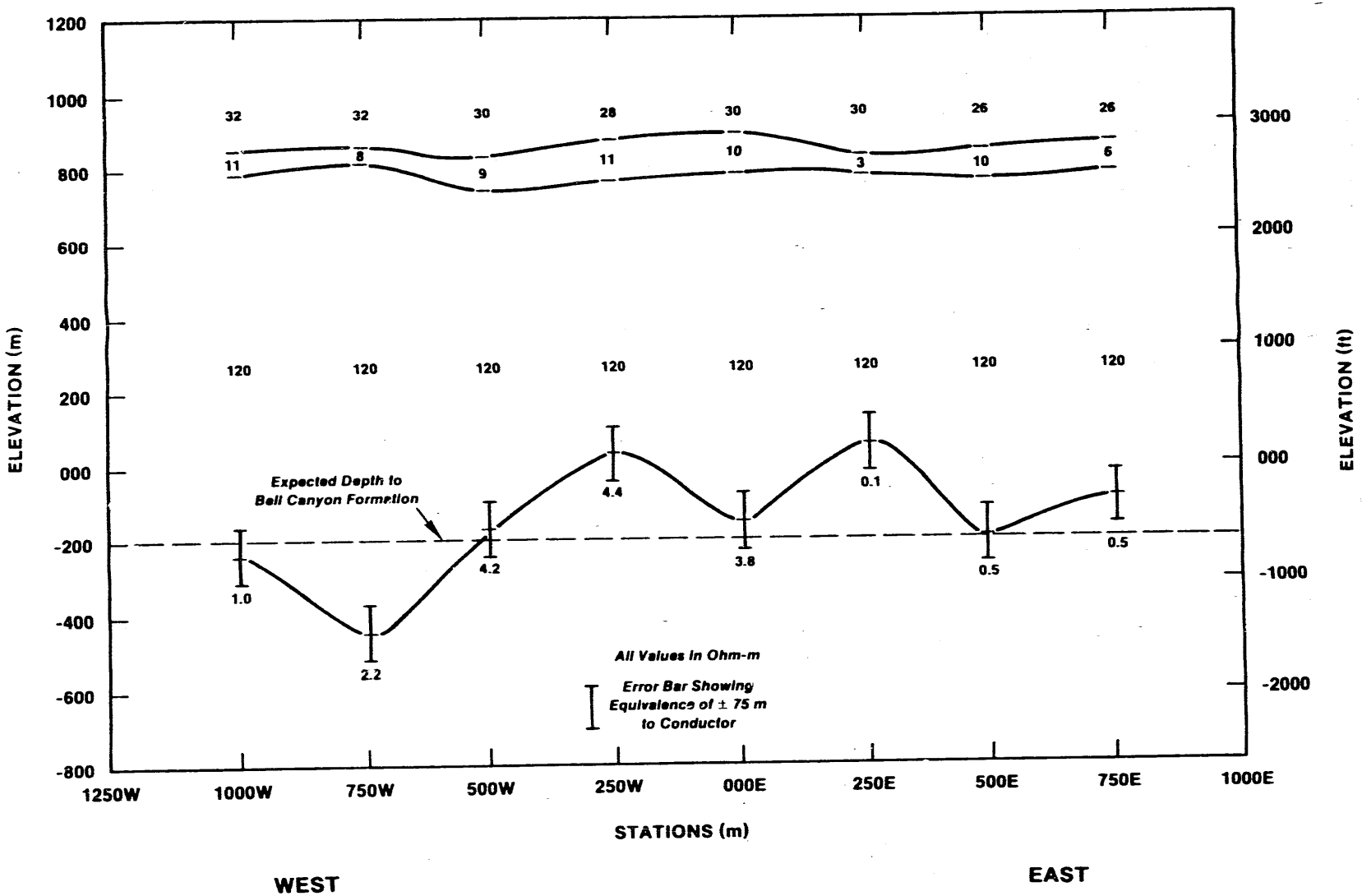


Figure 3.6: Cross section of apparent depth to first major deep conductor, showing brine locally present in both the Bell Canyon and Castile Formations. Line of section is along the north side of the WIPP waste-emplacement panels. Figure 4-11 of Earth Technology (1987).

2. Isolation of meteoric waters within fractured anhydrites following episodic hydrologic connection of the Castile with the Capitan limestone (Lambert and Carter, 1984).

According to the first hypothesis, the brines would be localized by deformation of the Castile Formation. The brines would occur in relatively low-pressure areas, such as the crests of domal or anticlinal structures similar to those encountered at WIPP-12 and ERDA-6. Such brines might continue to be generated by slow gravitationally driven deformation during and after the WIPP operational phase. Borns (1983) estimated that the reduction of porosity of the Castile halites by 0.2% required to generate the volumes of brine encountered in the WIPP-12 domal structure would likely be indistinguishable in bulk-property measurements. As pointed out by Borns (1987b), mechanical displacement and/or fluid movement during gravity-driven deformation need not be continuous. From a mechanical point of view, the emplacement of Castile brines appears consistent with either continuous or episodic deformation, and would result in indistinguishable changes in the properties of surrounding Castile halites. However, as discussed in Section 3.1, regional deformation within the Castile Formation is probably too slow to be of concern in the performance of the WIPP facility.

Lambert and Carter (1984) conclude, on the basis of uranium-disequilibrium studies, that the Castile brine occurrences were neither in-place nor remobilized connate Castile fluids. They conclude that the brine occurrences are the result of isolation of waters resulting from intermittent or episodic lateral hydraulic connection of the Capitan limestone and Castile anhydrites. Local fracturing of the Castile anhydrites is still required. Lambert and Carter (1984) specifically conclude that:

1. The residence or isolation times for the Castile brines at ERDA-6 and WIPP-12 are between 360,000 and 880,000 years.

2. The extent of buildup in $^{234}U/^{238}U$ ratios expected to result from continuous exposure of fresh rock to fluids during gravity-driven deformation is not seen.

3. Therefore, the mode of emplacement of the Castile brines must be episodic in character. The relevant episodic feature of the system is interpreted by Lambert and Carter (1984) to be hydraulic connection between the Castile anhydrites and the Capitan limestone. Any future brine generation, according to this interpretation, would require hydrologic reconnection of the Capitan and Castile.

In summary, recent geophysical studies indicate that brines are probably present within Castile anhydrites under a portion of the WIPP waste-emplacement panels. The brines are 250 m or more stratigraphically below the WIPP facility horizon. Although the detailed distribution of the brines remains unknown, this is not of special concern, since the presence of Castile brines beneath at least a portion of the WIPP facility has been and will continue to be assumed in WIPP performance assessment. The

mechanism(s) giving rise to Castile brine occurrences are not completely known. However, both mechanisms proposed, fluid migration in response to episodic deformation and isolation of fluids resulting from episodic interconnection of the Capitan limestone and Bell Canyon Formation, are unlikely to generate significant additional brine beneath the WIPP facility in the 10,000-year time scale of regulatory interest.

3.3 Recent Hydrologic, Geochemical, and Structural Studies of the Salado Formation

As mentioned above, the WIPP facility is presently being developed within bedded halites and anhydrites of the Salado Formation, at an average depth of approximately 655 m. This section attempts to place the WIPP facility within a proper perspective relative to both local and regional-scale hydrologic and structural behavior of the Salado Formation. Differences in Salado behavior as a result of the presence of the WIPP facility are considered as "excavation effects."

Section 3.3.1 discusses the hydrologic behavior of the Salado Formation as interpreted from testing conducted from the surface and within the WIPP facility. Section 3.3.2 describes the present understanding of the fluid geochemistry and mineralogy of the Salado Formation, based on recent and ongoing studies within the WIPP facility. Section 3.3.3 discusses the interim results of ongoing investigations into the structural behavior of the Salado Formation adjacent to the WIPP facility, with emphasis on Marker Bed 139 (MB139), a relatively thick anhydritic marker bed approximately 1 m below the WIPP facility horizon.

3.3.1 Regional-Scale and Near-Facility Hydrology of the Salado Formation

3.3.1.1 Hydrologic Testing from the Surface and at the Facility Horizon--Unlike the case in the Castile Formation, significant brine flows have not been encountered in hydrologic testing of the Salado Formation from the surface. However, two anomalous phenomena have been encountered in the Salado. First, pressurized gas has been encountered in some holes drilled from the surface and near the mining face in WIPP excavations. In the most dramatic case, nitrogen gas was encountered in the upper portion of the Salado in hole AEC-8, at a depth between 335 m and 391 m, during reworking of the hole approximately one year after original drilling (Table 3.1; Mercer, 1987). The gas pressure was sufficient to partially remove the drillstem from the borehole. A large volume of gas, approximately 6 x 10^5 m^3, was allowed to flow to the surface without apparent depletion of the reservoir (Mercer, 1987). Gas has also been locally encountered during construction of the WIPP facility, as described in Deal and Case (1987). To date, all gas occurrences within the WIPP facility have been small, although the largest such occurrence did result in a 0.4-m diameter disk being blown out of the face being mined. Second, as shown in Table 3.1, long-term monitoring at some holes penetrating the Salado Formation indicates a slow buildup of fluid pressure. The maximum pressure measured to date is 3.3 MPa (472 psig) at WIPP-12. This pressure is generated within the Salado, since it was measured before the hole was deepened into

Table 3.1: Summary of known Salado gas occurrences and measured wellhead pressures from surface drilling. Gas-occurrence data are modified from Table 2 of Mercer (1987). Fluid-pressure data are from the text of Mercer (1987).

A. Gas Occurrences

Hole	Comments
ERDA-9	At 430 m; trace of H_2S
ERDA-6	At 561 m; blew for 30 min.
AEC-7	At 491 m; blew for 1 hour
AEC-8	At 335-391 m; blew for several months
P-7	Many kicks
P-12	Hole unloaded fluid over weekend
P-20	Slight blow at TD of 608 m

B. Pressures Measured at Surface

Hole	Comments
Cabin Baby	1.4 MPa
WIPP-12	2.94 MPa, before deepening
WIPP-13	2.93 MPa, hole open to Castile and Salado
WIPP-11	0.12 MPa
DOE-2	0
AEC-7	0

the Castile Formation and intersected Castile brines (Section 3.2). The rate at which Salado brine pressures build up is very slow and, as noted by Mercer (1987), the pressures appear to be supported by only very small volumes of fluid. Complete reduction of the 1.6 Mpa (228 psig) pressure at the WIPP-12 wellhead in 1985 was achieved by release of approximately 5 gallons of brine. In some holes, for example DOE-2 and AEC-7, no long-term pressure buildup has been observed.

The published results of "successful" hydrologic tests of the Salado from the surface (Table 3.2) indicate permeabilities from approximately 0.01 microdarcy to a high of 25 microdarcies. Ongoing evaluation indicates that, as a result of instrumentation limitations, testing-time limitations or problems with pressure or flow stabilization, data from the Salado in DOE-2 are the most reliable, indicating a maximum permeability of 0.3 microdarcies. It has not been possible in testing from the surface to identify any discrete sources for this fluid or to determine any stratigraphic effects.

Table 3.2: Summary of Salado hydrologic properties interpreted in hydrologic testing from surface. Modified from Tables 3 through 9 of Mercer (1987). Ongoing interpretation indicates that only results from hole DOE-2 are reliable.

Hole	Comments
AEC-7	550.8-581-3 m; MB 126; gas perm. 3×10^{-6} D
AEC-7	672.7-703.2 m; MB 139; gas perm. $12\text{-}21 \times 10^{-6}$ D
ERDA-9	436.8-452.9 m; MB 118, 119; perm. $0.1\text{-}0.7 \times 10^{-6}$ D
ERDA-9	613.9-638.3 m; MB 136, 137; perm. $0.6\text{-}3.2 \times 10^{-6}$ D
ERDA-9	765.7-798 m; Cowden, lower Salado; perm. $1.6\text{-}2.2 \times 10^{-6}$ D
ERDA-9	799.5-876 m; lower Salado; perm $0.4\text{-}6.5 \times 10^{-6}$ D
ERDA-9	799.5-826.9 m; lower Salado; perm. $0.7\text{-}25 \times 10^{-6}$ D
Cabin Baby	230.7-828.2 m; entire Salado; perm. $0.01\text{-}0.1 \times 10^{-6}$ D
DOE-2	669-703.8 m; MB 138, 139; perm. $\leq 0.3 \times 10^{-6}$ D

However, there has been only limited "success" in field testing of the Salado from the surface. There appear to be two causes for this. First, the formation permeability appears in many cases to be below the testable minimum for the equipment used, approximately 0.01 to 0.1 microdarcy. For example, testing of all intervals in holes AEC-8, ERDA-10, and WIPP-12 was unsuccessful due to the low permeability and limitations to the test equipment. The most recent results included in Table 3.2, based on testing in Cabin Baby-1 in 1983 and DOE-2 in 1985, suggest an upper permeability

limit of approximately 0.3 microdarcies. As noted by Mercer (1987), it is not clear that any of the successful tests indicate the permeability of undisturbed halite, since the test intervals almost always include one or more interbeds. Second, in the case of hole WIPP-12, hole "ageing" during the seven years between hole completion and attempted testing of the Salado made it extremely difficult to find locations in the borehole that allowed successful setting of packers to isolate intervals for drillstem testing. The tentative interpretation is that this ageing involves loosening of grain boundaries in halites, with a concomitant increase in local permeability around the borehole.

Flow testing of the Salado Formation within the WIPP facility is still in its early stages. Preliminary results indicate that the presence of the WIPP facility has a strong impact on the hydrologic behavior of nearby portions of the Salado Formation. The results of initial gas-flow testing in the WIPP facility are described by Stormont et al. (1987). Interpretation of this testing indicated that apparent gas permeabilities are very low at distances of greater than approximately 2 m from the underground workings, with no distinguishable stratigraphic variability. Stormont et al. (1987) calculate a "far-field" permeability of less than 1 microdarcy for the Salado.

Stormont et al. (1987) identify a zone of markedly increased permeability within approximately 2 m of the underground workings, on the basis of marked increases in gas flow rates at constant injection pressure. The apparent increases in permeability are especially dramatic near room center lines, in both room roofs and floors. In addition, the magnitude of the local increases in permeability appear to be a function of both time and room width. Stormont et al. (1987) note that their measurements are consistent with time-dependent development of a dilatant or "damaged" zone around the underground workings, and that this zone may well be only partially saturated. Finally, Stormont et al. (1987) indicate that the interpretation of their tests was complicated by uncertainties in the degree of saturation of the Salado, pressure-threshold effects inherent in gas-flow testing in either a partially or fully saturated medium, and local flow inhomogeneities due to fracturing in the disturbed or altered zone near the facility.

Recent brine-flow testing within the WIPP facility described by Peterson et al. (1987) has eliminated some of the problems inherent in gas-flow testing. Peterson et al. (1987) describe the results of long-term (240-day) shut-in brine-flow tests in two holes. One hole penetrated "intact" halite and the other "intact" anhydrite in MB139, both at a distance of 8 to 9 m from the underground workings. Assuming complete saturation within the tested zones, the results indicate far-field permeabilities of approximately 0.001 microdarcy for intact halite, and 0.01 microdarcy for MB139. In addition, apparent steady-state "pore" pressures of 8.3 MPa and 10.3 MPa were measured in the two holes. Peterson et al. (1987) note that there is some uncertainty in both estimated permeabilities and fluid pressures, due to the long test times required.

Gas-flow testing of the same two holes prior to brine-flow testing, at a gas-injection injection pressure of 2.1 MPa, indicated halite and marker-bed permeabilities approximately one order of magnitude greater than

indicated in the later brine-flow testing. These higher permeabilities are similar to those reported by Stormont et al. (1987). Gas-flow testing after brine-flow testing indicated effectively zero permeability. The reasons for this complexity are not clear. It may well be that initial gas-flow testing utilized unsaturated flow paths resulting from near-hole dilatancy, and that these flow paths were later saturated during brine-flow testing.

However, it is not clear that the Salado Formation is completely saturated, even in the far-field. For example, the gas "blows" locally encountered in drilling the Salado from the surface (see Table 3.1) indicate that high-pressure gases occur locally within the unit. Unfortunately, it cannot be determined whether the initial pressures in these occurrences represent regional partial saturation or are a result of exsolution of dissolved gases as a result of stress release around drilled holes. The large gas flow in the Salado in hole AEC-8 occurred approximately one year after initial hole completion. Experience during the development of the WIPP facility also indicates the local occurrence of gas within the Salado at high pressure, perhaps approaching the local lithostatic pressure of 16 MPa. Release of gas concentrated along a fracture nearly parallel to the facility working face resulted in a small blowout during mining operations, as described by Deal and Case (1987). Later drilling in front of the same working face encountered gas at a depth of approximately 3 m. However, because gas occurrences within the WIPP facility have all been near faces being actively mined, it cannot be demonstrated that they were at lithostatic pressure before release. They may result from exsolution of dissolved gases during stress release near the excavation. Other observations by Deal and Case, such as the widespread exsolution of gas from brines collected within the WIPP facility and local bubbling of brine seeps on ribs within the facility, further suggest that gas may play a major role in at least the near-field hydrologic behavior of the Salado Formation.

Thus, the results of recent permeability testing within the Salado Formation, both within the WIPP facility and from the surface, are generally consistent with a far-field permeability of approximately 0.001 to 0.1 microdarcy. It is not certain whether the Salado is saturated or partially saturated regionally; in the altered zone near the WIPP facility, it appears to be partially saturated. There are marked near-field increases in Salado permeability near the WIPP facility, resulting from fracturing and possibly matrix dilatancy. The development of a hydrologically altered zone around workings at the WIPP facility horizon appears to depend on both time and geometry. The ultimate extent of this zone and the rate or extent of its elimination or reduction during the final stages of facility closure remain unknown at present, but will be examined carefully during the early operational phase.

3.3.1.2 Hydrologic Testing Adjacent to the WIPP Air-Intake Shaft--Barring a direct breach of the WIPP as a result of human intrusion, the successful long-term performance of the facility largely depends on the success with which the facility shafts are plugged or sealed. Present planning calls for emplacement of shaft seals in both the Salado Formation and the unnamed

lower member of the Rustler Formation. Therefore, it is important to know the distribution of hydrologic properties within both units adjacent to the WIPP shafts. A preliminary series of hydrologic tests was conducted at several levels in the WIPP waste-handling shaft during 1987. Additional testing and monitoring of the hydrologic characteristics of both the Rustler and Salado Formations adjacent to the WIPP air-intake shaft is planned.

The objectives of the preliminary hydrologic testing adjacent to the WIPP waste-handling shaft, results of which are described in Saulnier and Avis (1988), were to:

1. Determine if a significant fractured or altered zone had developed around the concrete shaft liner in the shaft since its completion.

2. Estimate the radial extent of the hydrologic cone of depression resulting from construction of the waste-handling shaft.

3. Determine "far-field" hydrologic properties for previously untested zones in the lower unnamed member of the Rustler Formation and levels in the Salado Formation at which it is anticipated that plugs might be placed at the end of the WIPP operational phase.

Testing in the waste-handling shaft was carried out in subhorizontal drillholes, using three distinct test zones. The detailed experimental instrumentation is described in Stensrud et al. (1988). Zone 1 extended from the hole "bottom" approximately 7.9 m outside the shaft to a depth of some 5.7 m, Zone 2 from approximately 4.8 m to 3.7 m, and Zone 3 from approximately 2.9 to 1.6 m. There was, however, some variability in both test-zone depths and the relationship between Zone 3 and the shaft liner. No shaft liner was present below the 850-foot level. The shaft liner was thin enough in the lower Rustler for Zone 3 to test entirely within the rock mass. At the 850 level, however, the thickened shaft liner in the keyway dictated that Zone 3 in one hole included the interface between rock and shaft liner. (English depth units are used here for consistency with depth records within the shaft).

The results of the preliminary testing in the waste-handling shaft are summarized in Table 3.3 and Figures 3.7 and 3.8. Tested lithologies include mudstone and claystone in the unnamed lower member of the Rustler (at the 782 and 805-foot depths, respectively) and halites, an anhydrite, and a polyhalite within the Salado Formation (850 and 1320-foot depths). All of the tested intervals are extremely low in permeability. Hydraulic conductivities listed in Table 3.3 range only from 10^{-14} to 10^{-13} m/s. This corresponds to an approximate range in permeability of one order of magnitude, from 0.001 to 0.01 microdarcy. There is no consistent increase in conductivity towards the shaft (from Zone 1 to Zone 3) in any of the rock types tested, except at the 850-ft level. In the 850W hole, pressurized fluids flowed into the borehole at the liner/rock interface. The precise origin of these fluids remains to be determined.

Table 3.3: Summary of results of 1987 hydrologic testing in the WIPP waste-handling shaft. From Saulnier and Avis (1988).

Borehole	Lithology	Test Zone Depth Int. (Feet from Shaft Wall)	Test Period	Pressure Pulse (psi)	Hydraulic Conductivity (m/s)	Formation Pressure (psi)
W782W	Silty Mudstone	1) 18.6-26.0	07/18-22/87	113.3	1.0 E-13	90
		2) 12.3-15.9	07/20-22/87	108.3	1.0 E-14	140
		3) 5.4- 9.5	07/21-22/87	99.4	1.0 E-14	140
W805W	Silty Claystone	1) 18.6-26.0	07/11-15/87	94.5	5.0 E-14	225
		2) 12.3-15.9	07/13-15/87	105.1	1.0 E-14	140
		3) 5.4- 9.5	07/14-15/87	97.8	1.0 E-14	110
W805SW	Silty Claystone	1) 18.6-26.5	08/28-31/87	102.9	6.0 E-15	275
		2) 12.3-15.9	Not Tested		1.0 E-14*	90*
		3) 5.4- 9.5	08/29-31/87	92.6	2.0 E-14	70
W850W	Halite	1) 18.6-26.0	07-30/08-03/87	97.6	1.0 E-13	40
		2) 12.3-15.9	08/2-3/87	116.5	1.0 E-13	40
		3) 5.4-9.5	07-31/08-3/87	90.39	Not Analyzable*	
W850SE	Halite	1) 23.2-36.0	08/19-24/87	103.5	3.0 E-14	50
		2) 16.8-20.5	08/21-24/87	103.1	3.0 E-14	30
		3) 10.0-14.1	08/22-24/87	100.7	2.0 E-14	90
W1320E	Halite/ Anhydrite Polyhalite	1) 18.6-41.8	08/11-17/87	17[illegible].3	2.0 E-14	550
		2) 12.3-15.9	08/14-17/87	52.6	3.0 E-14	450
		3) 5.4- 9.5	08/15-17/87	53.0	3.0 E-14	100

*Zone 2 analysis from pressure buildup after shut-in, August 28 to 31, 1987.

Physical limitations to the testing system dictated that Zone 3 not extend any closer than approximately 1.6 m from the inside of the shaft. Therefore, even if the one or two holes tested at each level are representative and adequately characterize the permeability at the tested levels, it can only be argued that the results indicate that no damaged zone presently extends more than 2 m into the rock mass. This includes any damage zone resulting from blasting during construction of the shaft. In addition, because of scheduling constraints, all of the testing was relatively short-term. Longer-term testing might identify changes in hydraulic properties near the shaft.

The permeabilities listed in Table 3.3 indicate no significant stratigraphic variability. All of the tests indicate extremely low permeability, roughly one order of magnitude less than estimated from measurements from the surface. One reason for this may be that the holes tested here were nearly horizontal; as a result, at least part of the fluid flow was vertical, perpendicular to layering. The results may imply that vertical

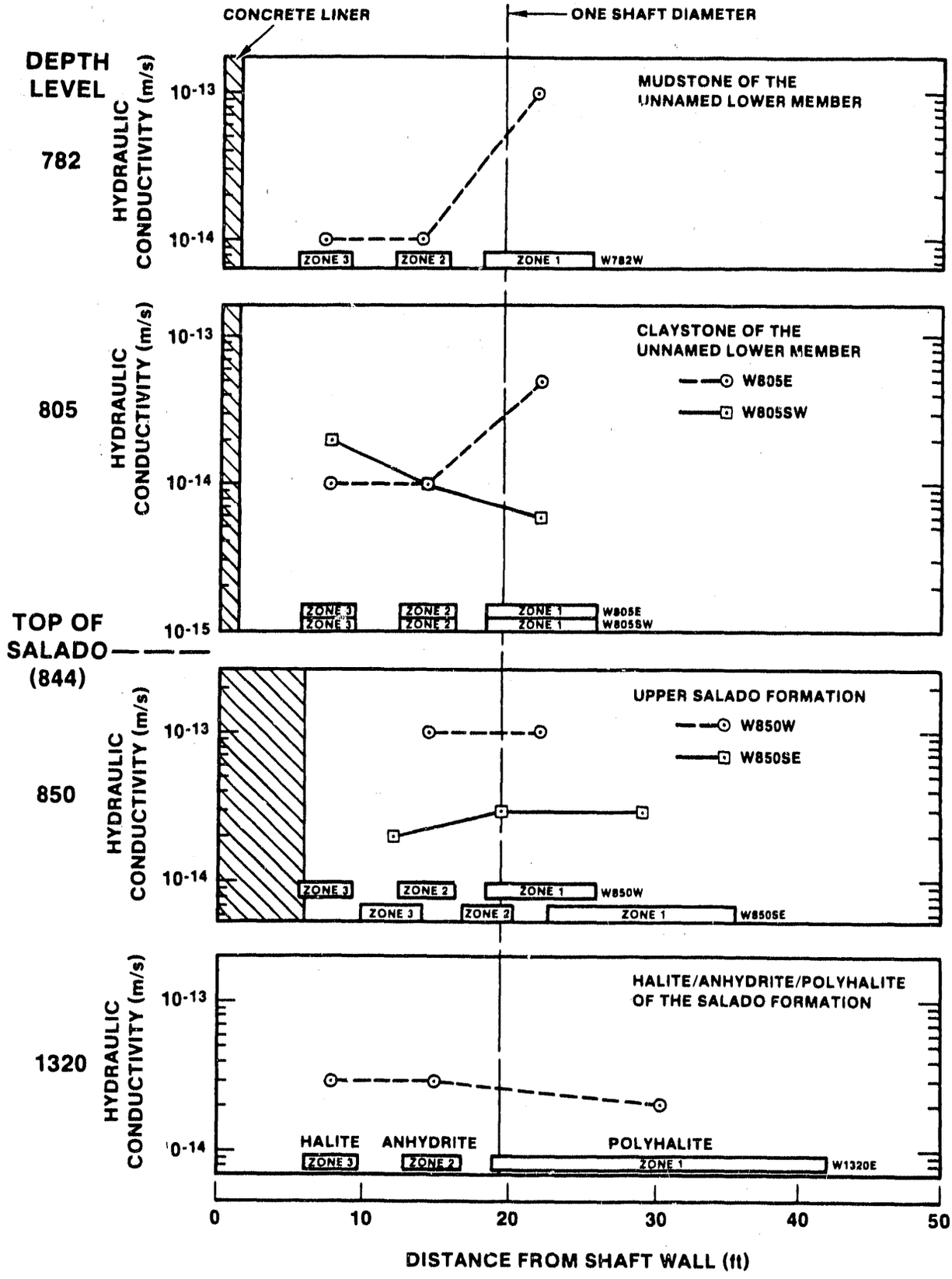


Figure 3.7: Summary of formation conductivities determined in 1987 testing in the WIPP waste-handling shaft. Figure 6.3 of Saulnier and Avis (1988).

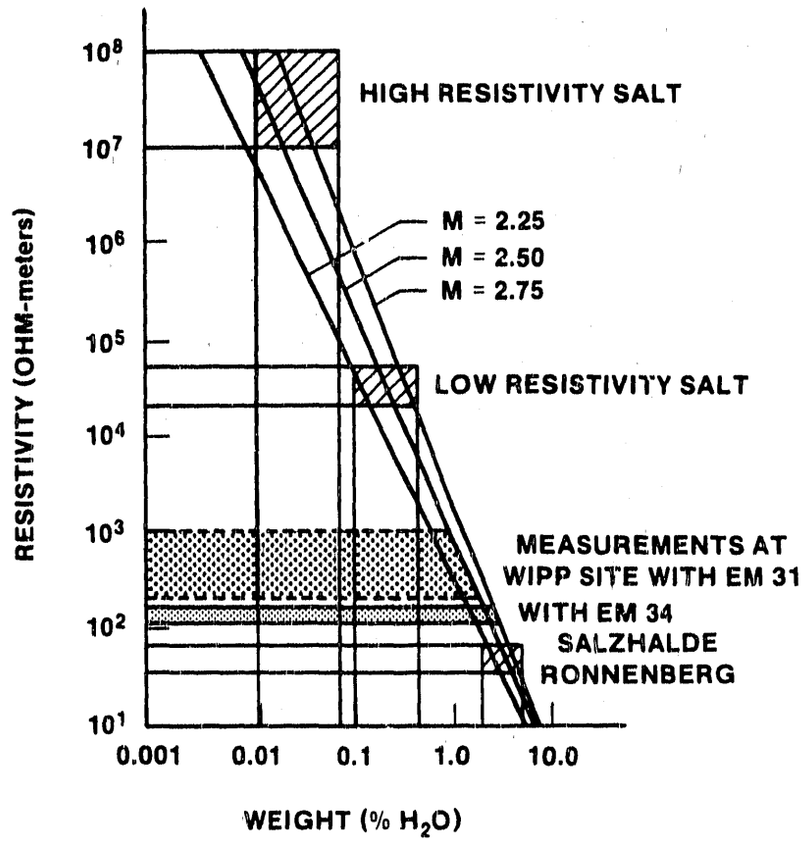


Figure 3.9: Apparent variation in water content of Salado halite at the WIPP facility horizon with depth into the wall. The EM31 survey investigates conductivity up to approximately 2 m depth and the EM34 survey to a depth up to 20 m. Figure 9 of Pfeifer (1987).

different instrumentation systems were used in these measurements. The EM31 system investigates the effective electrical conductivity to a depth of approximately 2 m, the EM34 system to a depth of up to 20 m into the adjacent rock mass. The apparent conductivity near the underground workings, measured with the EM31 system, is lower (resistivity is higher) than that measured at greater depth with the EM34 system. In Figure 3.9 this variation in resistivity is compared with a published correlation between water contents and resistivities of halites. The results are consistent with a water content of approximately 1% (by weight) near the mine opening and 2% or greater in the far field. Recent geophysical moisture and density measurements within the WIPP facility (Hudson, 1987) also are consistent with water contents of approximately 2 weight percent in Salado halite in the far field.

The recent results indicate that far-field water contents within the Salado Formation, estimated to average approximately 2 weight percent, are greater than previously expected. For example, estimated water contents of samples analyzed during SPDV activities ranged from a mean of 0.6 weight percent to a maximum of 1.8 weight percent, compared to mean and maximum values of 0.22 and 1.06 weight percent estimated from measurements on core from hole ERDA-9 (Beauheim et al., 1983a). The earlier estimates were made either on core material or on hand specimens collected during mining.

The combination of significant interconnected fluid contents and non-zero permeabilities within the Salado Formation in both the far-field and near the WIPP facility dictates that there be some fluid flow into the facility until effective hydrologic closure of the facility takes place. Two studies, both in their early stages, investigate the amounts and characteristics of fluid flow into the facility. One study, summarized in Deal and Case (1987), is a long-term study to characterize flow into the WIPP facility (exclusive of shafts) at ambient temperature. The second study, summarized in Nowak and McTigue (1987), is part of an experimental program using electrical heaters to simulate emplacement of defense-generated high-level waste (DHLW). A knowledge of ambient-temperature behavior is required in this study as a baseline for interpretation of later superimposed thermal effects.

Two lines of evidence summarized by Deal and Case (1987) indicate the complexity of ambient-temperature fluid flow into the WIPP facility from the Salado Formation. First, brine "seeps" often form within a few days on mined faces, and are indicated by the development of localized salt crusts or efflorescences on the walls. The seeps often appear to stop flowing after approximately one month. However, investigation of the salt deposits indicates that fluid flow may only decrease rather than ceasing entirely, and that the rate at which mine ventilation removes water locally exceeds the inflow rate at long times. Second, highly variable amounts of both brine and dissolved gas are intersected in drillholes within the WIPP facility. Minimum flow rates are apparently zero. The maximum flow rate was approximately 0.5 liter per day. One hole has produced approximately 235 liters of brine, and produced at a roughly steady-steady rate of 0.2 liters per day (Deal and Case, 1987). However, this hole apparently intersects numerous near-field fractures in MB139 related to the construction of the WIPP facility, and is unusual. Most of the measured

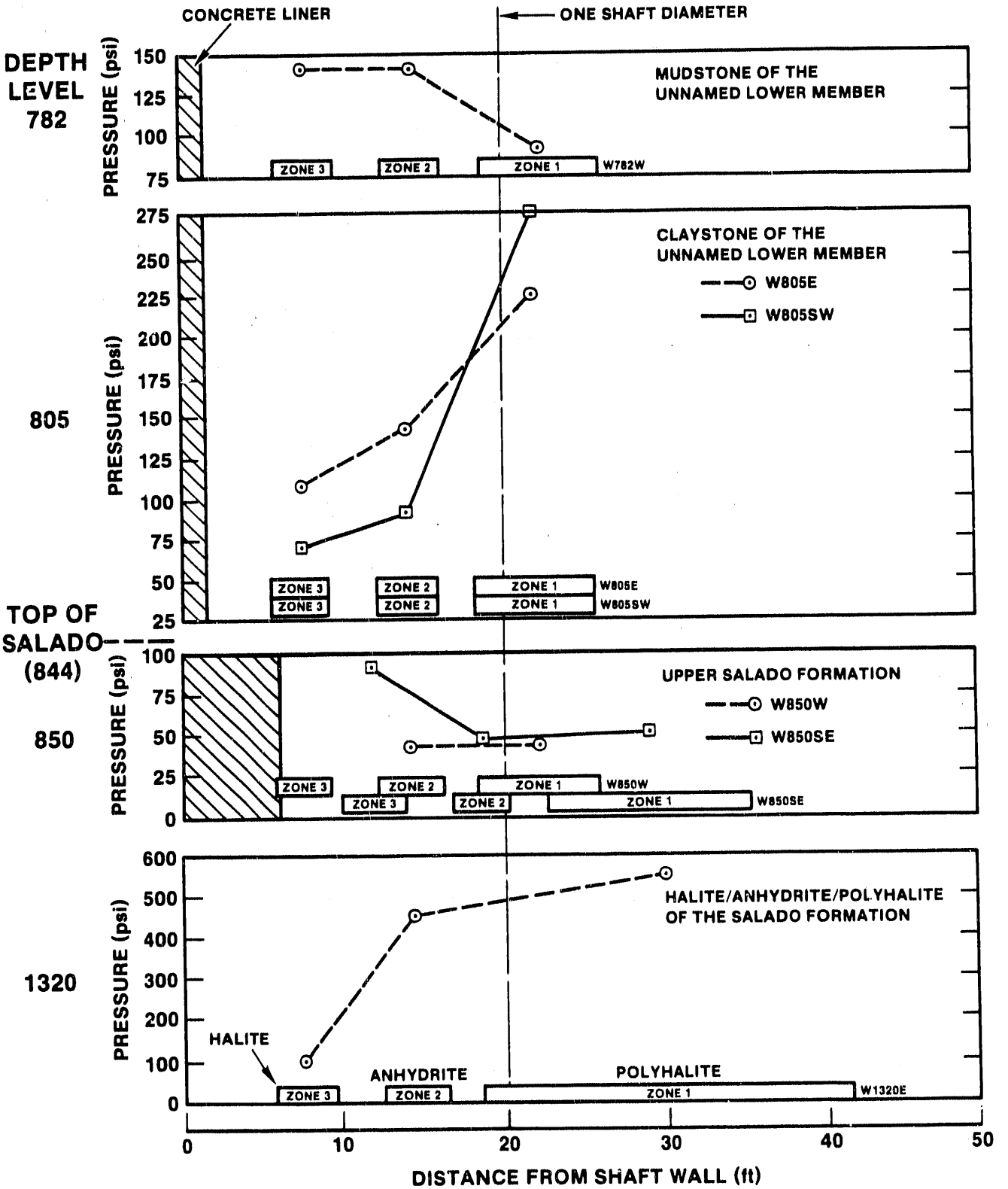


Figure 3.8: Summary of fluid formation pressures determined in 1987 testing in the WIPP waste-handling shaft. Figure 6.1 of Saulnier and Avis (1988).

permeability in both the lower part of the Rustler Formation and the Salado Formation is less than horizontal permeability, consistent with experience in other layered rock types.

Testing adjacent to the waste-handling shaft did indicate a distinct zone of decreased fluid pressures around the shaft at the 805-foot and 1320-foot levels, in claystone and halite/anhydrite/polyhalite, respectively (Figure 3.8). The cone of fluid-pressure depression apparently extends outward to greater than one shaft diameter at these levels. The fluid-pressure profiles at the 782-foot and 850-foot levels may be indeterminate because of effects of equipment compliance (Saulnier and Avis, 1988). The generation of a hydraulic cone of depression around the shaft was expected, consistent with responses noted earlier in the Culebra dolomite to construction of the WIPP exploratory shafts (see Haug et al., 1987). The behavior of this zone outside the Culebra as a function of time remains unknown.

Interpretation or prediction of long-term flow behavior into the shaft would require an observation hole, so that fluid storativities within affected units could be estimated. A nearby observation hole does not exist for the waste-handling shaft. However, hole H-16 was drilled and instrumented in 1987, approximately 17 m from the centerline of the WIPP air-intake shaft, specifically to investigate the near-field hydraulic response of all members of the Rustler Formation to construction of the shaft, and to provide monitoring data adequate for long-term predictions.

The hydrologic testing completed to date adjacent to the waste-handling shaft is preliminary, as is the interpretation of test results. The results to date allow limited fracturing, since only one or two holes was tested at each level. To better determine the presence or absence of fracturing by direct hydrologic measurement, arrays of three or more holes would be needed at each level. The fact that fluids were encountered at the liner/rock interface in one hole at the 850-foot level demonstrates that fluid movement at the shaft-liner/rock interface is possible locally, and that a single drillhole is not sufficient to characterize the source or behavior of these fluids. Non-intrusive geophysical methods similar to those described in Section 3.3.1.3 may aid in characterization of any altered zone around the WIPP shafts.

3.3.1.3 Brine Contents and Brine Seepage into the WIPP Facility--Geophysical studies within the WIPP facility aimed at characterization of the near-field disturbed rock zone are interim, and will continue during the early part of the WIPP operational phase. The presently available results, summarized in Borns and Stormont (1987) and Pfeifer (1987), indicate both that there is near-field variability in the water content and hydrologic properties of the Salado Formation and that water contents of Salado halites in the far-field are approximately twice that estimated at the time of the WIPP SPDV studies.

The results of a series of electrical conductivity measurements within the WIPP underground workings (Pfeifer, 1987) are shown in Figure 3.9. Two

flow rates range from a few hundredths to a few tenths of a liter per day. Deformation near the facility strongly influences fluid flow. Deal and Case (1987) note that fluid flow into most holes within the WIPP facility is initially zero or nearly zero. This phase is normally followed by a relatively rapid rise to some maximum flow rate, after which flow slowly reduces to some relatively steady-state but decreasing value.

Work summarized in Nowak and McTigue (1987) investigates flow into one 0.9-m (36-inch) and three 0.76-m (30-inch) diameter holes emplaced as part of experiments simulating and overtesting emplacement of DHLW. Water was continuously removed from the holes by use of dry nitrogen. A baseline ambient-temperature flow of 5 to 15 grams/day was collected in each hole after an initial transient phase. The average flow of 10 grams per day extrapolates to a steady-state flux of approximately 1.6 $cm^3/day/m^2$ of excavation wall. After the heaters were turned on, there was a rapid increase in flow rate to some peak value, followed by a reduction to near steady-state flow. Apparent steady-state flow rates were 50 to 80 g/day in the two holes containing 1.5 kW heaters, and 8 to 10 g/day in the two holes containing 470 W heaters. The integrated fluid flow into the most strongly heated holes was 36 to 38 kg of fluid after 600 days. This mass is significantly greater than the 0.1 kg collected after two years in similar experiments conducted in domal salts at the Asse Mine, Germany (Nowak and McTigue, 1987). The difference suggests a significant difference between fluid flow in domal salts and in bedded salts, such as those at the WIPP.

Parametric numerical modeling described by Nowak and McTigue (1987) indicates that:

1. Pore-pressure measurements in both the near-field and far-field domains of the Salado Formation are needed to determine far-field and near-field flow behavior, since the observed transient effects resulting from seepage appear at present to be limited to the very near-field domain.

2. The transient stage of flow into the WIPP waste-emplacement rooms will last until connected pore space in both the rooms and any altered zone around the facility is either effectively eliminated or comes to pore-pressure equilibrium with the surrounding Salado. The calculations indicate that transient flow, ignoring closure, might last for more than 5000 years.

3. The rock volume effectively involved in flow within the Salado may be limited, rather than a significant portion of the formation. However, the affected volume must increase with time.

In summary, recent hydrologic results in the Salado Formation indicate that the unit has a far-field permeability of less than 0.1 microdarcy. It has not been possible to determine either stratigraphic effects or the presence of effective fracturing in the far-field environment. The brine content of Salado halites appears to be up to 2 weight percent in the far-field, roughly twice that previously expected. Where it has been possible to measure Salado brine pressures, the calculated heads indicate very limited fluid flow upwards into the overlying Rustler Formation. The permeability

of the Salado locally increases markedly within two meters of excavations at the WIPP facility horizon. The increase in permeability appears to be both time-dependent and geometry-dependent, and to involve significant fracturing. The Salado Formation may be only partially saturated in both the near-field and far-field environments. The low permeability of the Salado Formation, mine ventilation, and rapid mechanical deformation near the WIPP facility result in markedly transient fluid flow into the underground workings. At present, the time-scale of transient flow, volume of the Salado involved in flow, and final fluid volumes to be expected within the WIPP facility remain to be precisely determined.

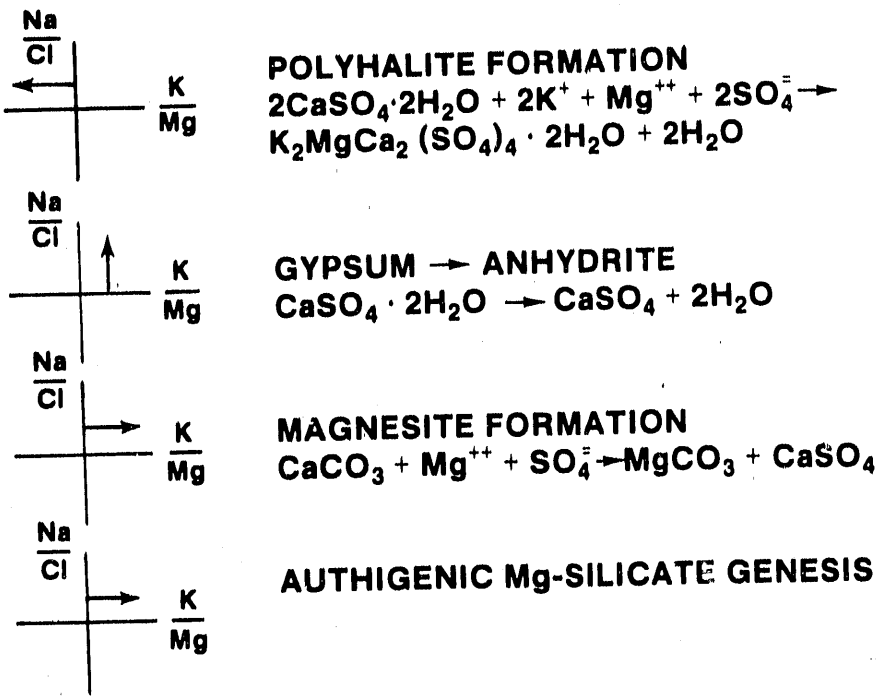
3.3.2 Geochemical and Mineralogical Studies of the Salado Formation Near the Facility Horizon

The mineralogy and stratigraphy of the Salado Formation are somewhat complex. The general mineralogy of the units is summarized by Bodine (1978), and mineralogy near the WIPP facility horizon by Stein (1985). Bodine (1978) noted that Salado clays were unusually depleted in aluminum and enriched in magnesium. The recent work by Stein (1985) does not include detailed clay mineralogy, but does indicate the nearly ubiquitous occurrence of authigenic quartz and magnesite near the WIPP facility horizon, in addition to widespread occurrence of anhydrite, gypsum, and polyhalite as accessory minerals within halites.

As mentioned in Section 3.3.1, it has not been possible to sample Salado fluids during drilling or testing from the surface. However, Salado fluids have been sampled within the WIPP facility, and are continuing to be collected, as described in Deal and Case (1987). The compositional results available to date for Salado fluids collected within the WIPP facility are described in Stein and Krumhansl (1986), and directly address both the character of fluids within the Salado Formation and the validity of assumptions held through 1983 concerning the types of fluids within the unit.

It was assumed through 1983 that Salado halites were anhydrous, with the exception of fluid inclusions and the water of hydration of hydrated minerals such as clays and polyhalites. Both the compositions and ages of fluid inclusions within Salado halites were poorly constrained. The compositional results for Salado fluid inclusions and macroscopic brine occurrences within the WIPP facility, summarized by Stein and Krumhansl (1986), are shown in Figure 3.10. The open and half-open squares in Figure 3.10 represent the compositions of individual fluid inclusions extracted from crystals of halite. The circles and crosses represent the compositions of macroscopic fluids collected from the WIPP facility, respectively from brine "seeps" on the walls and holes in the floor.

The fluid-inclusion compositions and compositions of fluids from seeps and holes form two distinct populations in terms of their respective Na/Cl and K/Mg weight ratios. Therefore, fluids encountered within the WIPP facility cannot primarily arise from the migration of fluid inclusions. Stein and Krumhansl (1986) relate the compositions of fluid-inclusion Groups I (half-open squares in Figure 3.10) and II (open squares) to alteration of brines



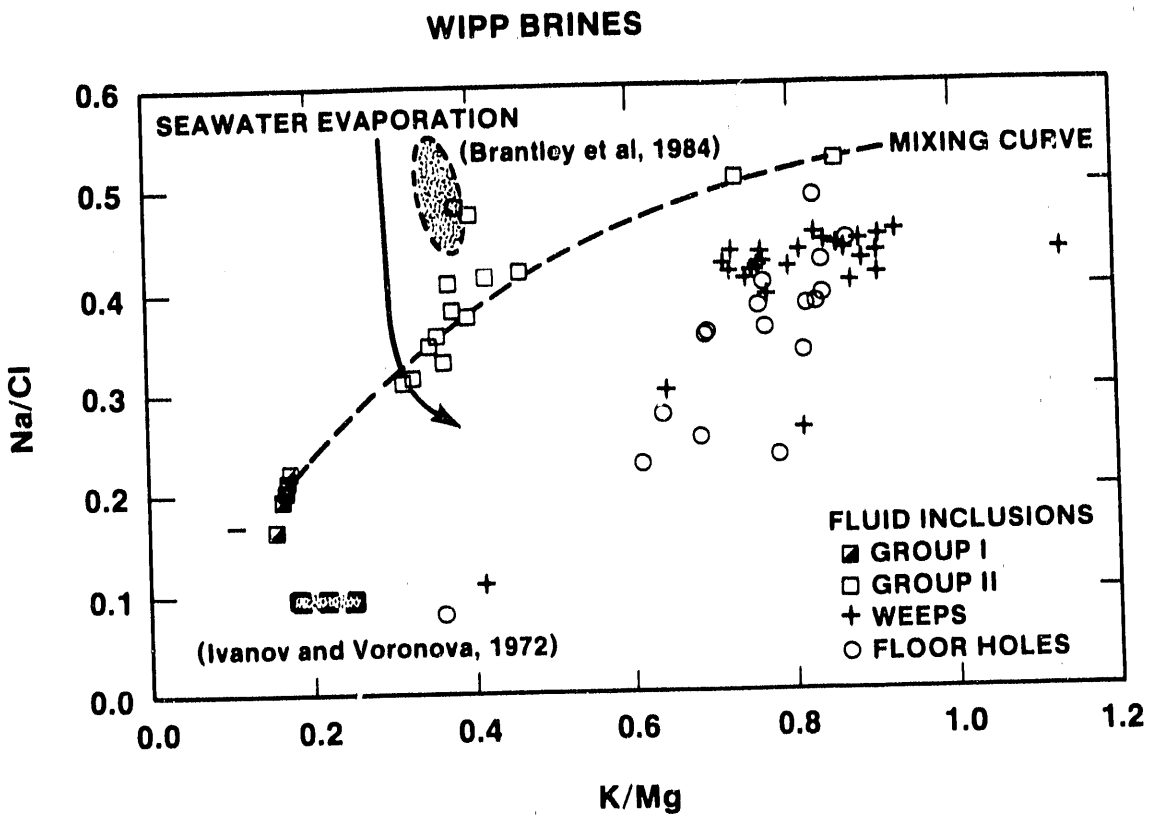


Figure 3.10: Compositional variability of Salado fluids from fluid inclusions and macroscopic brine occurrences in the WIPP facility. Figure 9 of Stein and Krumhansl (1986). Effects of individual reactions on fluid composition are also indicated.

originally resulting from evaporation of seawater. They interpret the controlling mechanisms to be crystallization of polyhalite and magnesite. Polyhalite formation drives fluid compositions to the left of the seawater-evaporation line in K/Mg space (Group I), while formation of magnesite drives fluid compositions to the right (Group II). The compositional effects of these reactions are summarized in the reactions included as part of Figure 3.10.

Both polyhalite and magnesite are widespread accessory minerals within Salado halites (Stein, 1985). Radiometric age dating of polyhalites from the WIPP (Brookins and Lambert, 1987) indicates crystallization ages of from 195 to 216 million years, i.e., from approximately 25 to 45 million years after deposition. The age of magnesite formation is unknown, but is assumed to be similar to that of polyhalite. On this basis, Stein and Krumhansl (1986) conclude that brines contained in fluid inclusions from samples near the WIPP facility horizon are roughly 200 million years old.

The fluids from weeps and seeps in the WIPP facility are enriched in potassium relative to both fluid inclusions and fluids expected from seawater evaporation (Figure 3.10). As discussed by Stein and Krumhansl and noted by Bodine (1978), the Salado clay-mineral assemblage is unusually Mg-rich. Stein and Krumhansl (1986) conclude that the relatively K-rich composition of fluids from weeps and seeps reflects the effects of the growth of these Mg-enriched silicates on grain-boundary fluids. While it is not possible to place a specific age on the grain-boundary fluids, it is known that the kinetics of such reactions are very slow. Therefore, Stein and Krumhansl (1986) conclude that the residence time of grain-boundary fluids within the Salado Formation must be at least several million years. The marked variability of fluids as a function of stratigraphy near the WIPP facility horizon, noted by Stein and Krumhansl, is consistent with there being little or no vertical fluid movement.

There is additional geochemical evidence for both the presence and timing of rock-water interactions involving fluids from the Rustler/Salado contact and deeper evaporite horizons at and near the WIPP. As summarized by Lambert and Harvey (1987), there is a body of consistent radiochronological evidence indicating the absence of any pervasive recrystallization of the evaporite section in approximately the last 200 million years. The internally consistent evidence consists of: a) K-Ar dating of polyhalites ($K_2MgCa_2(SO_4)_4 \cdot 2H_2O$); b) Rb/Sr isochrons on sylvites (KCl); and c) both Rb-Sr and K-Ar ages on langbeinite ($K_2Mg_2(SO_4)_3$). Apparent ages on leonite ($K_2Mg(SO_4)_2 \cdot 4H_2O$) are younger than ages on other minerals. Both Rb-Sr and K-Ar ages of clay minerals are significantly greater than the depositional age of the enclosing evaporites, suggesting that secondary reactions involving the clays have not completely altered their compositions. Thus, while the accessory magnesite near the WIPP facility horizon has not been dated, there is abundant radiometric evidence that the last major recrystallization of the Salado Formation occurred approximately 200 million years ago.

Available isotopic evidence for strong rock-water interactions in evaporitic rocks at and below the Rustler/Salado contact is summarized in Figure 3.11. These data and their implications for fluid flow are

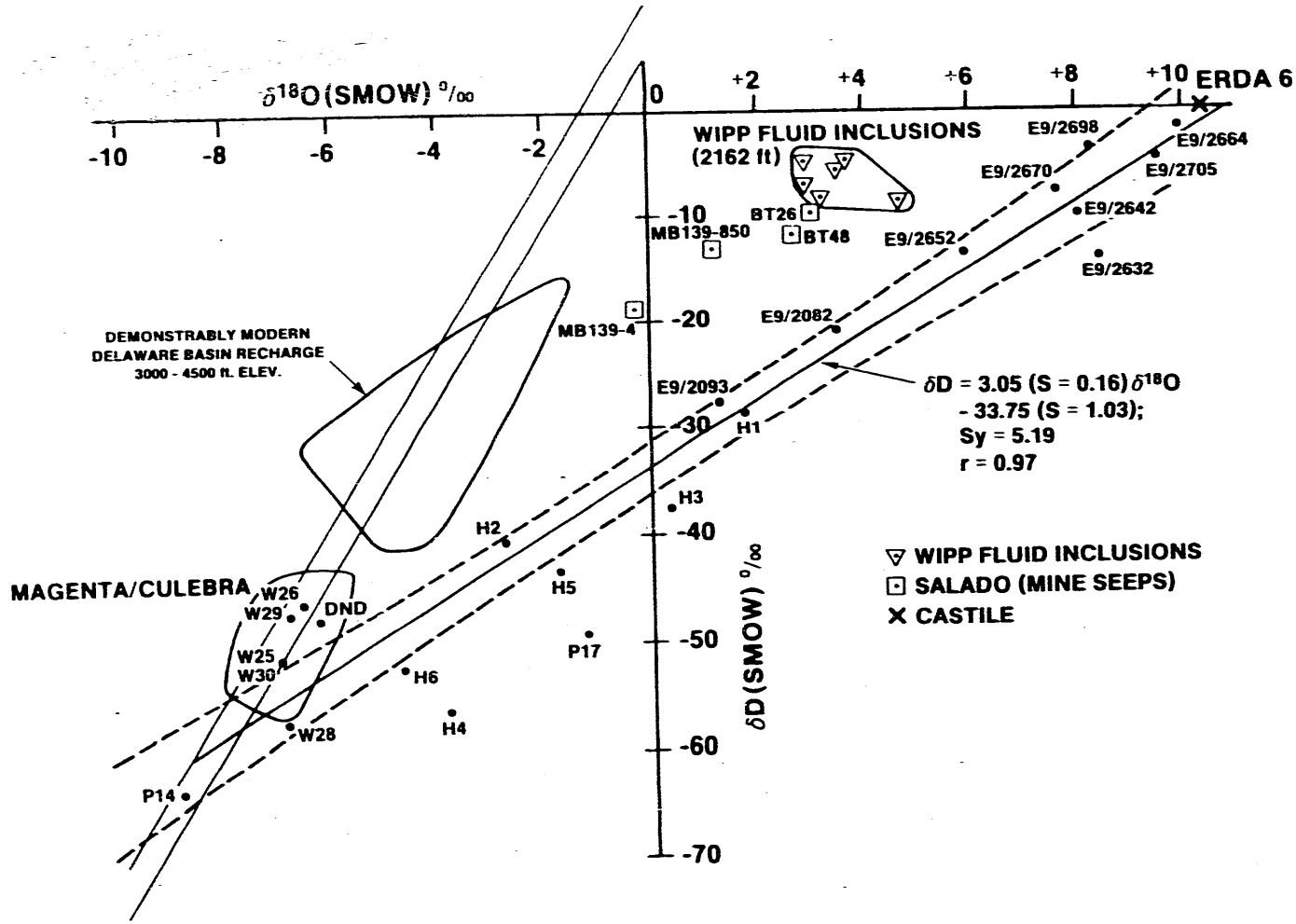


Figure 3.11: Stable-isotope composition of fluids from the Rustler/Salado contact and deeper evaporite zones at the WIPP site. Figure 25 of Lambert and Harvey (1987). Figure includes data from hole ERDA-9 (E9) of O'Neil et al. (1986) and fluid-inclusion data from the WIPP facility horizon (Knauth and Beeunas, 1986), in addition to original data from Lambert and Harvey. Lambert and Harvey data from the Rustler/Salado contact are indicated by hole designations, and those from MB139 by the appropriate prefix. Samples from seeps within the Duval Mine are indicated by the prefix BT (see Lambert and Harvey, 1987, for additional detail).

discussed by Lambert and Harvey (1987) relative to interpretations made by both O'Neil et al. (1986) and Knauth and Beeunas (1986).

O'Neil et al. (1986) consider the linear relationship between the isotopic composition of Castile brines (represented by brines from ERDA-6), fluid inclusions from the lower Salado in hole ERDA-9, and "modern meteoric water" (represented by fluids from Nash Draw and the western part of the WIPP site). They conclude that the trend reflects varying amounts of (vertical) mixing of Castile brines and modern near-surface waters. Lambert and Harvey (1987) conclude that large-scale mixing of fluids should involve major recrystallization of the evaporite section. They conclude, based on the radiometric-dating results discussed above, that such recrystallization has not taken place in the last 200 million years. Since they also concluded that large-scale mixing of fluids within an evaporite section would require recrystallization, the lack of significant recrystallization within the Salado is taken to indicate that there is no significant modern vertical mixing of Castile and surface fluids (Lambert and Harvey, 1987).

Instead, Lambert and Harvey (1987) consider the Castile fluids from ERDA-6, ERDA-9 fluid inclusions, and numerous fluids sampled from the Rustler/Salado contact as a single group (Figure 3.11). They conclude that these fluids form a variable population reflecting a mechanism by which increasing deviation of fluids from the meteoric compositional field results from increasing rock/water ratios, with resulting increasing interaction of fluids with hydrous minerals, especially clays, gypsum, and polyhalite. However, the isotopic character of rock-water reactions involving both gypsum and polyhalite are partially undefined at present.

One group of data shown in Figure 3.11 is not consistent with any single mechanism or trend of rock-water interaction within the Salado Formation. As noted, the trend including data from ERDA-6 brines, ERDA-9 fluid inclusions, and Rustler/Salado fluids appears to be continuous. However, fluids sampled directly in holes penetrating MB139 (samples MB139-850 and MB139-4) and in weeps within the nearby Duval Potash Mine (samples BT26 and BT48) are quite distinct. The isotopic composition of Salado fluid inclusions at the WIPP facility horizon reported by Knauth and Beeaunas (1986) are distinct and different from the character of inclusions from the Salado in ERDA-9. The reasons for the distinctions in fluid-inclusion analyses are not known, but may, as noted by Lambert and Harvey (1987), involve the different fluid-extraction techniques used by the different authors. The reason for the apparently distinct isotopic character of fluids from MB139 is not known at present. The available data indicate only a small isotopic distinction between fluid inclusions and macroscopic fluids collected at the WIPP horizon, in spite of the significant compositional differences between the two types of fluids noted by Stein and Krumhansl (1986).

In summary, the recent geochemical and hydrologic studies of the Salado Formation are generally internally consistent, but are incomplete at the present time. Hydrologic measurements indicate a far-field Salado permeability of less than 0.1 microdarcy. This indicates that, independent of local complications caused by the presence of the WIPP facility itself, fluid flow within the Salado is non-zero but extremely slow. The work by

Stein and Krumhansl indicates that the brine in fluid inclusions within Salado halites is on the order of 200 million years old, and is not the major source of fluid in the WIPP facility. Rather, the variable fluids in the WIPP underground workings appear to be grain-boundary fluids which have residence times within the Salado Formation of at least several million years. The variability in fluid compositions near the WIPP facility horizon is consistent with there being little or no vertical fluid movement. The isotope systematics and radiometric age dating of the Salado brines and minerals, considered together, are not consistent with derivation of Salado brines by modern large-scale vertical mixing of Castile and surficial waters.

3.3.3 Marker Bed 139 and the Structural Behavior of the Salado Formation near the WIPP Facility

Marker Bed 139, an anhydritic marker bed about 1 m in average thickness, occurs approximately 1 m or less below the WIPP facility horizon. Detailed study of MB139 began in 1983, because of concern that undulations on the top of the unit might be the result of deformation at some time after deposition or diagenesis (Jarolimek et al., 1983). If this were true, it is conceivable that such deformation might impact the WIPP facility during either the operational or regulatory time frames. The results of both Jarolimek et al. (1983) and Borns (1985) indicate, however, that the undulations on the upper surface of MB139 are depositional in origin.

Recent interest has focused on the mechanical and hydrologic fluid-flow behavior of MB139 near the WIPP underground workings. Observed behavior in room closure to date, especially in the oldest or "SPDV" rooms, indicates time-dependent opening of fractures in both MB139 and the halitic interval between MB139 and the room floors. It may be necessary to excavate MB139 in some areas before the end of operations, to provide an unaltered locality for emplacement of seals at the facility level. The mineralogy and structure of MB139 also provide information concerning long-term mechanical and fluid behavior within anhydritic portions of the Salado Formation, independent of the WIPP facility. Work examining MB139 and its role in excavation effects near the WIPP facility horizon is progressing; therefore, the discussion here is preliminary.

Borns (1985) investigated the stratigraphy and structure of MB139 in some detail, using core from a five-hole array drilled specifically for this purpose. The general level of internal complexity within MB139 is shown in Figure 3.12. The unit is bounded above and below by irregular contact zones. The lower contact zone (Zone V), often referred to informally as a "clay seam," is clay-rich and locally indicates some erosion and embayment of the top of the underlying polyhalitic halite. The upper contact zone (Zone I) is quite irregular in thickness, and contains structures indicative of shallow water deposition, such as mounds of halite hopper crystals. Borns (1985) concludes that the irregularities on the upper surface of MB139 are primary or depositional in origin, resulting from shallow-water depositional processes such as wave traction. This conclusion is in agreement with conclusions originally reached by Jarolimek et al. (1983).

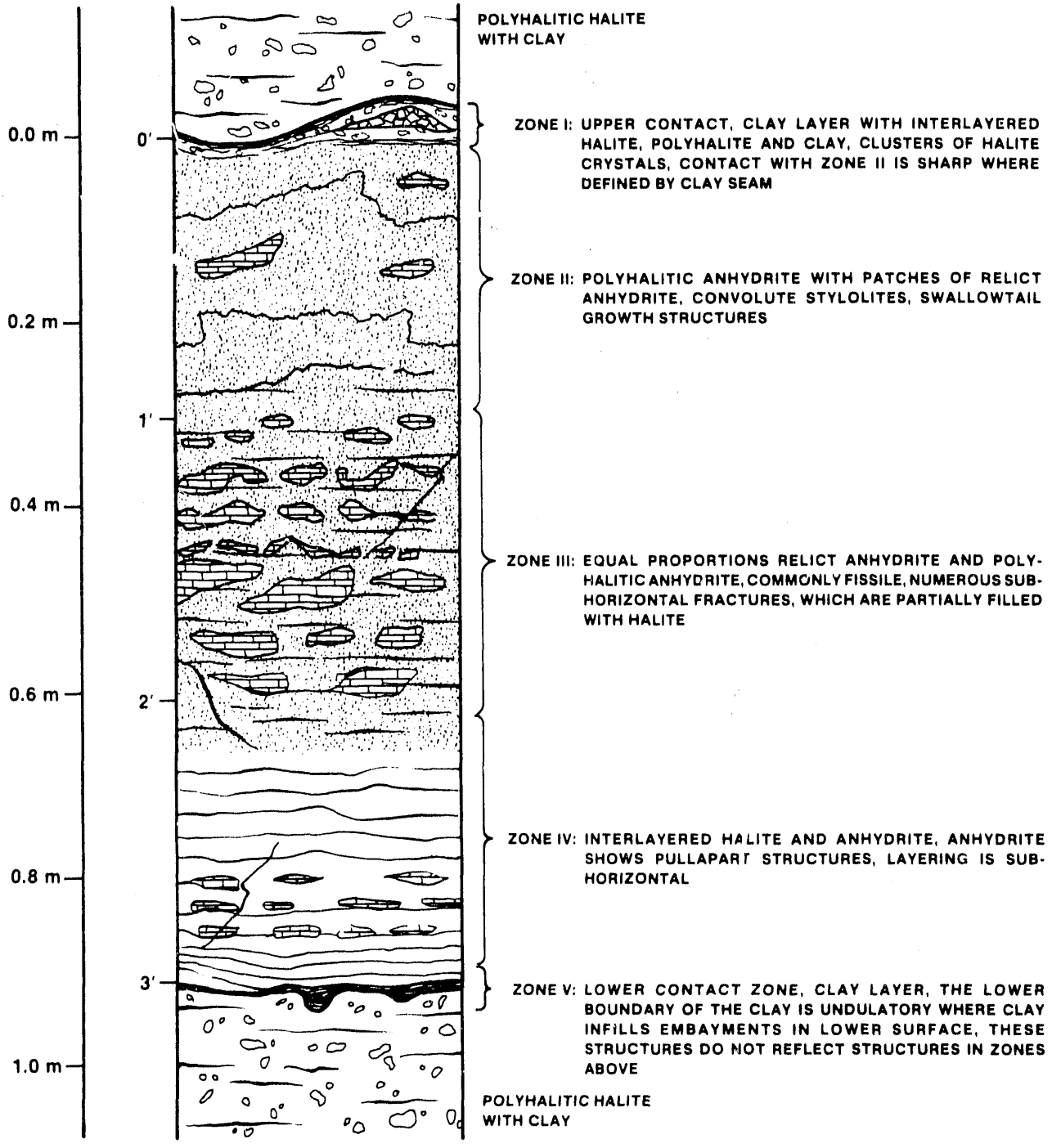


Figure 3.12: Generalized stratigraphic and structural cross section of MB139. The figure demonstrates the internal variability of the unit and the character of both upper and lower contacts. Figure 3 of Borns (1985).

The detailed investigations by Borns also revealed significant internal zonation and variability within the body of MB139. An upper zone within the unit (Zone II) is characterized by extensive replacement of original anhydrite by polyhalite (Figure 3.12), and by the presence of convoluted stylolites. Both features are interpreted to result from fluid movement after deposition. Based on the available radiometric ages on Salado polyhalites (Section 3.3.2), it may be that the formation of polyhalite MB139 occurred as much as 45 million years after deposition. However, polyhalites from within MB139 have not yet been dated. Zone IV, the internal zone directly above the basal contact, contains interlayered halite and anhydrite, with some replacement of anhydrite by later halite, again indicating fluid movement at some time. Anhydritic laminae in this zone show pull-apart structures with horizontal extension.

Within Zone III, the central portion of MB139, replacement of anhydrite by polyhalite is less complete than in Zone II. This zone also contains numerous sub-horizontal fractures, which are partially filled with halite and polyhalite. In some cases, inclined fractures extend from Zone III into or across the overlying Zones I and II. The cores investigated by Borns (1985) were drilled with air; halite was probably not removed from the fractures in Zone III during drilling. On this basis, Borns (1985) concludes that the partially healed subhorizontal fractures in the central part of MB139 predate the construction of the WIPP facility.

The time of formation of the fractures in MB139 is not known in detail. Borns (1985) suggests that they may have formed in response to long-term variations in the overburden pressure at the stratigraphic level of the WIPP facility. Alternatively, as noted by Borns (1985), the fractures may be a response to previous and/or ongoing gravity-driven deformation of the underlying Castile Formation. The horizontal orientation of most of the partially healed fractures favors an origin related to unloading.

An estimate of the variations in overburden pressure at the WIPP facility horizon, extrapolated from estimated variations in overburden at the contact between the Rustler and the Dewey Lake, is shown in Figure 3.13. The overburden pressure at the WIPP facility horizon is estimated to have varied between approximately 16 and 42 MPa since the end of deposition of the Dewey Lake Red Beds. The estimated overburden pressure at the end of the Cretaceous period, 42 MPa, is 2.6 times that at present. Based on stratigraphic interpretations, the reductions in overburden near the ends of the Cretaceous and Tertiary Periods appear to have been relatively sudden. If the interpretations of Borns (1985) are correct, and the sub-horizontal fractures within Zone III of MB139 formed by unloading in response to rapid erosion and removal of overburden, it follows that the formation of the fractures and at least initial movement of the halite-saturated fluids which resulted in their partial healing are probably either early Tertiary or early Pleistocene in age, i.e., that both fracture formation and fluid movement occurred either approximately 60 million or approximately 2 million years ago.

The mineralogical variability of MB139 and the occurrence of partially healed fractures within the central part of the unit have implications for both fluid flow and structural behavior of the unit. The widespread

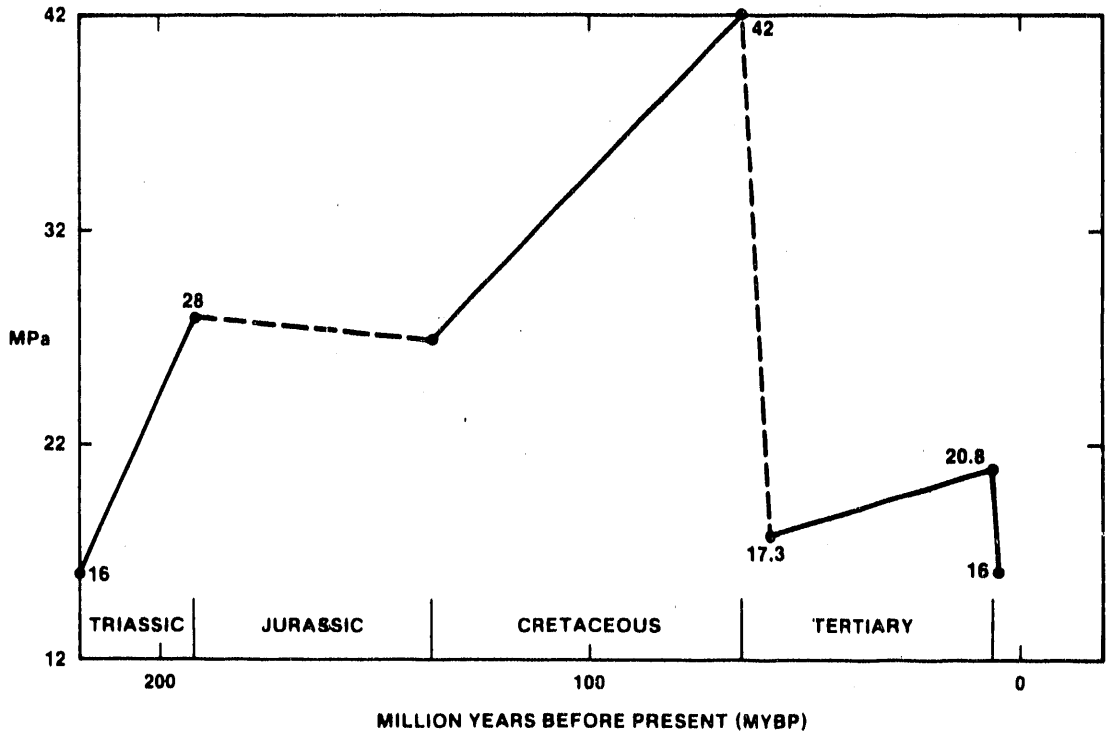


Figure 3.13: Variations in approximate overburden pressure at the WIPP facility horizon as a function of time. Overburden estimates (in MPa, 1 MPa = 145 psi) derived from Figure 10 of Borns (1985) by addition of constant 12 MPa overburden resulting from assumed constant thickness of interval between WIPP facility horizon and Rustler-Dewey Lake contact.

replacement of anhydrite by polyhalite indicates significant fluid movement, possibly some 45 million years after deposition. The replacement of anhydrite and partial healing of fractures by halite may indicate a second period of fluid movement at least 2 million years ago. The available hydrologic information for the Salado Formation at the WIPP site indicates that the far-field permeability within MB139 (and other anhydrite marker beds) is not significantly greater than that of the Salado halites themselves.

Pre-existing fractures within MB139 provide pre-existing planes of weakness that control or influence the near-field mechanical response around the WIPP excavation. Ongoing studies indicate that these fractures open locally in response to excavation. In the near-field altered zone, the resulting permeability is quite high. In the far-field, the permeability of MB139 appears no greater than that of surrounding halites. For confidence in plugging or sealing at the level of the WIPP facility horizon, it must ultimately be demonstrated either that fractures in MB139 will eventually reheal as a result of facility closure, or that damaged portions of the unit have been removed or grouted before seal emplacement. Characterization and delineation of the hydrologically and/or structurally altered zones around the WIPP facility horizon and shafts are ongoing, and will continue into the early operational phase of the facility.

4.0 RUSTLER FORMATION AND YOUNGER UNITS

As noted previously, much effort in WIPP site characterization has been focused on the Culebra Dolomite Member of the Rustler Formation, because this unit is the first laterally continuous water-bearing zone above the WIPP facility. The Culebra has continued to receive attention since 1983. However, work since 1983 has included other members of the Rustler Formation as well as shallower units. Section 4.0 discusses all units above the Salado as a group. Section 4.1 discusses hydrologic testing of the Rustler Formation and Dewey Lake Red Beds, and Section 4.2 discusses both field and numerical studies of the transport properties of the Culebra dolomite. Together, Sections 4.1 and 4.2 constitute a conceptual model of the modern flow and transport behavior within the shallow part of the WIPP stratigraphy, with emphasis on the Culebra dolomite. Section 4.3 discusses geochemical studies addressing both bulk-compositional and isotopic variability within the Rustler Formation and Dewey Lake Red Beds. Section 4.4 discusses studies into the overall geologic behavior of the Rustler and shallower formations at and near the WIPP site. Together, Sections 4.3 and 4.4 summarize available evidence concerning the transient geologic behavior in the region of the WIPP site for units above the Salado Formation.

4.1 Hydrologic Testing of the Rustler Formation and Dewey Lake Red Beds

The Rustler Formation at and near the WIPP site has been hydrologically tested and interpreted at three geometric scales, which are discussed sequentially from the smallest to the largest scale in this section. The smallest-scale of testing is conducted in single holes. Recent single-hole hydrologic testing has provided: 1) local or point transmissivity values for all members of the Rustler Formation except the Tamarisk Member, but with emphasis on the Culebra dolomite; 2) indications of the presence or absence of local hydraulically effective fracturing and wellbore damage within the Culebra; 3) information on relative head potentials within the Rustler; and 4) some indication of the distribution of properties and degree of hydraulic saturation within the Dewey Lake Red Beds. As discussed by Beauheim (1987b), single-hole testing is carried out by means of pumping, drillstem, slug-injection, slug-withdrawal, or pressure-pulse tests, depending on the local permeability or transmissivity. Single-hole testing is interpreted here in terms of transmissivities (in units of m^2/s). Use of this term assumes that the unit being tested is homogeneous across the tested interval. This assumption has been examined directly at hole H-14, in which two separate but overlapping intervals were tested in the Culebra dolomite. The results at H-14 indicate a factor of about 2 in vertical variability in transmissivity within the Culebra within a given hole. Recent single-hole testing of the Rustler Formation and Dewey Lake Red Beds is discussed in Section 4.1.1.

Single-hole tests do not indicate the extent to which either point transmissivity values or fracturing effects can be extrapolated laterally. Hydraulic behavior within the Culebra dolomite is, therefore, also examined at the "hydropad" scale. WIPP hydropads nominally contain three holes, located at the corners of an equilateral triangle 30 m on a side. Hydrologic information at the pad scale is collected by "interference"

testing. During this type of testing, at least two of the three holes on the pad are pumped sequentially in separate tests; the two unpumped holes in each test are used for observation. The objectives of interference hydrologic testing at the pad scale are to collect average or effective hydrologic-property data over distances of some 30 m, and to determine if fracturing effects are significant at this scale.

In the region of the WIPP site, single-pad hydraulic interference tests have been completed at the H-2, H-3, H-4, H-5, H-6, H-7, H-9, and H-11 hydropads. Detailed interpretation including evaluation of the effects of fracturing has been completed only for tests at the H-3 and H-11 hydropads, discussed in Section 4.1.2. Interference testing at the H-3 and H-11 pads has been interpreted using a "dual-porosity" approach, in which the Culebra is assumed to consist of an array of matrix blocks (primary porosity), separated by regularly spaced fractures (secondary porosity).

At some "large" scale, assuming that fracture spacing and properties are not too irregular, the effects of fracturing should become insignificant, i.e., it should become possible to model the flow and/or contaminant-transport behavior of a fractured rock unit such as the Culebra adequately using the porous-medium assumption. The scale at which this simplification is valid, however, may vary significantly with different rock types in different geologic or hydrologic settings. During WIPP site characterization, possible regional hydraulic effects of fracturing have been investigated by "multipad interference testing" of the Culebra dolomite. In this type of testing, one hole is pumped for a relatively long period of time, generally a month or more, while surrounding holes are used to observe hydraulic responses over an area of several square miles. Depending on the distances and extent of fracturing involved, effects due to fracturing may or may not be evident between the pumped hole and some of the observation holes.

Interpretation of multipad interference testing allows estimation of transmissivities and storativities within the tested area, provides information concerning the regional relationship between fluid densities and flow directions, and has allowed investigation of the interaction between WIPP shafts and the Culebra. Two major multipad interference tests, centered at the H-3 hydropad and at hole WIPP-13, have been carried out to date at the WIPP. Additionally, regional hydraulic information has been collected by observing hydrologic responses to WIPP shaft-sinking and shaft-sealing operations. Regional-scale hydrologic interpretation of the Rustler Formation, with emphasis on the Culebra dolomite, is discussed in Section 4.1.3. Interpretation on the regional scale indicates that fracturing need not be incorporated into regional-scale simulation of fluid pressures (head potentials) within the Culebra at and near the WIPP site, because pressure responses are relatively rapid, even on this scale. The assumption of steady state is adequate in modeling the modern Culebra head potentials. However, groundwater flow times are slow enough in the vicinity of the WIPP site to make the assumption of steady-state confined flow within the Culebra inadequate for simulation of long-term flow paths and flow times.

4.1.1 Single-Hole Hydraulic Testing and Interpretation

4.1.1.1 Transmissivity Distribution within Individual Units--Prior to 1985, hydrologic testing at and near the WIPP site was either interpreted using the porous-medium assumption or did not identify significant effects due to fracturing (e.g., Barr et al., 1983). More recently, Beauheim (1986, 1987b) has identified significant fracture effects in hydraulic testing of several holes, using the code INTERPRET. As described in detail by Beauheim (1986, 1987b), INTERPRET utilizes a "pressure-derivative" technique to determine whether or not significant pressure responses due to fracturing are present. In this approach, hydraulically effective fracturing is indicated by a flexure in the plot of dimensionless pressure derivative or drawdown versus dimensionless time (Figure 4.1.1). This flexure reflects a transition from "early" times, in which fluids are effectively produced only from within the fractures, to "late" times, in which fluid is produced from both fractures and matrix, but in which fluid release from the matrix to the fractures is generally the rate-limiting process. The transmissivity interpreted from behavior after this transition is referred to as "system" transmissivity.

At the time of the WIPP FEIS (U.S. Department of Energy, 1980) the suitability of the WIPP site was evaluated largely on the basis of possible releases from the site to Malaga Bend, on the Pecos River approximately 26 km from the WIPP site (Figure 1.1). Requirements for repository performance developed by the Environmental Protection Agency (40CFR191) were released in 1985. Although they may not be in their final form, these requirements place increased emphasis on evaluation of possible releases of radionuclides to the "accessible environment" near the facility. The definition of the accessible environment is not yet final. The WIPP Project has greatly increased the size and reliability of the hydrologic data base for the Rustler Formation since 1985, especially for the Culebra dolomite at and near the WIPP site. Table 4.1 contains the best local estimates of transmissivity used in modeling the hydrology of the Culebra dolomite from 1983 through 1987 and demonstrates the growth in this data base. Table 4.2 summarizes the results of recent single-hole testing in the Culebra dolomite.

Estimated Culebra transmissivities at the WIPP site area and within Nash Draw range over approximately six orders of magnitude, from 2.15×10^{-9} m^2/s at P-18 to 1.34×10^{-3} m^2/s at WIPP-26 (Tables 4.1 and 4.2). In addition to the growth in the Culebra data base evident in Table 4.1, many of the holes have been retested over the last five years. In some cases recent testing and interpretation have significantly changed earlier estimated transmissivities. However, the more recently estimated Culebra transmissivities are not consistently higher or lower than older values. At H-1 and DOE-2, recent data and interpretation indicate a significantly higher Culebra transmissivity. At H-3 and DOE-1, recent work indicates a lower local transmissivity than estimated earlier. In cases such as P-15, P-17, H-4, and WIPP-30, retesting and/or reinterpretation of earlier results has not resulted in any significant change in estimated Culebra transmissivity. In all cases, however, the more recent data and interpretations are better documented than older work, as a result of the

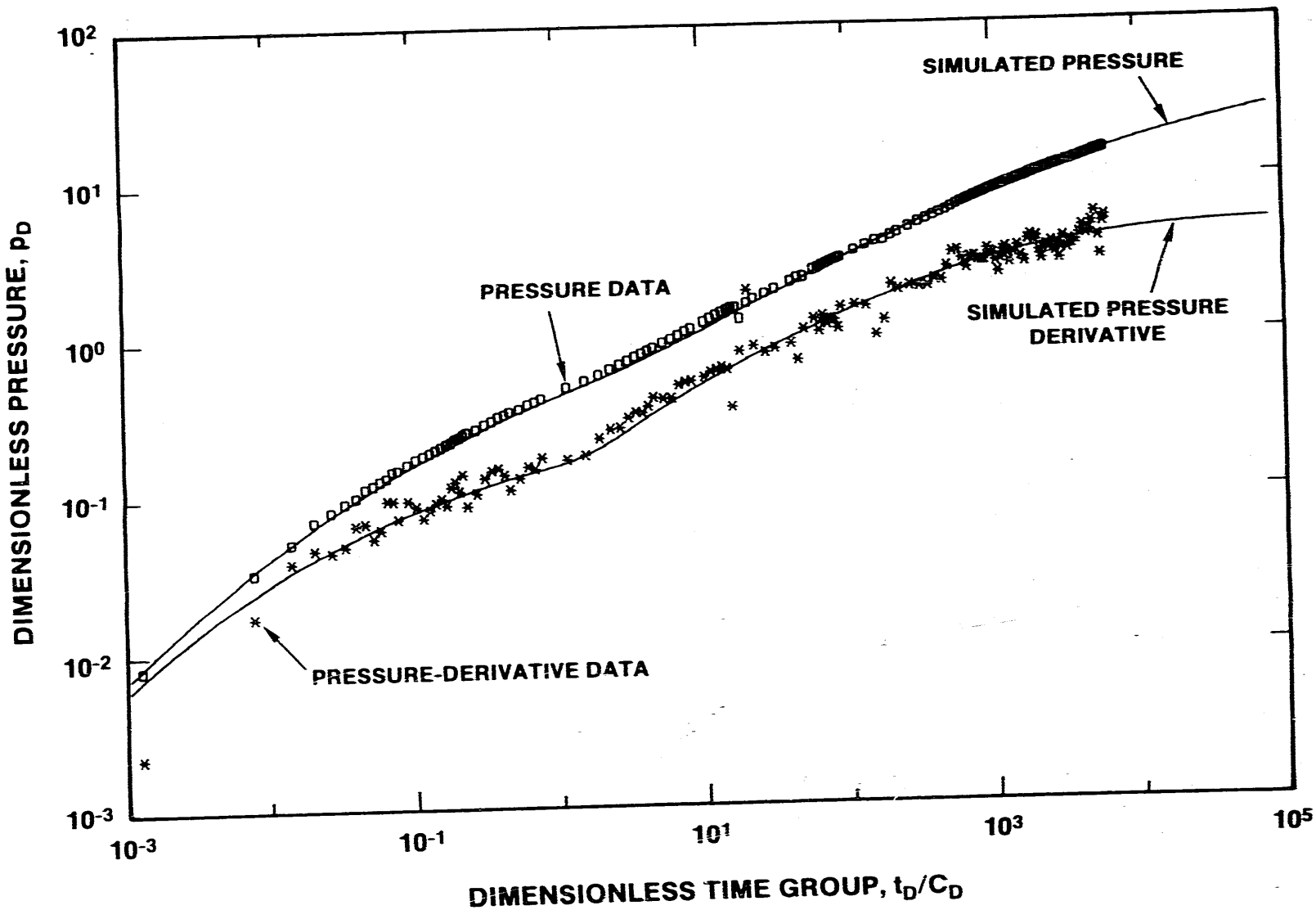


Figure 4.1.1: Measured and simulated response of H-3b1 to pumping of hole H-3b2. The presence of dual-porosity effects due to fracturing is indicated by the inflection in both measured and simulated pressure-derivative curves, in this case at a value of the dimensionless time group of approximately one. Simplified from Figure 6-11 of Beauheim (1987a).

Table 4.1: Transmissivity data bases used in numerical modeling of the Culebra dolomite in Barr et al. (1983), Haug et al. (1987), and LaVenue et al. (1988).

Well	Barr et al. (1983) Transmissivity (ft^2/day)	Haug et al. (1987) Transmissivity (ft^2/day)	LaVenue et al. (1988) Transmissivity (ft^2/day)	Transmissivity (m^2/sec)
H-1	0.07	0.07	0.8	8.60×10^{-7}
H-2	0.4	0.56	0.52	5.59×10^{-7}
H-3	19	3.7	2.3	2.47×10^{-6}
H-4	0.9	1.1	0.95	1.02×10^{-6}
H-5	0.2	0.16	0.14	1.51×10^{-7}
H-6	73	74	74	7.96×19^{-5}
H-7	>1000	1120	1030	1.11×10^{-3}
H-8	16	6.7	8.2	8.82×10^{-6}
H-9	230	170	160	1.72×10^{-4}
H-10	0.07	0.07	0.07	7.53×10^{-8}
H-11	--	10	26	2.80×10^{-5}
H-12	--	0.04	0.18	1.94×10^{-7}
H-14	--	--	0.31	3.33×10^{-7}
H-15	--	--	0.12	1.29×10^{-7}
H-16	--	--	0.7	7.53×10^{-7}
H-17	--	--	0.2	2.15×10^{-7}
H-18	--	--		
WIPP-12	--	--	0.03	3.23×10^{-8}
WIPP-13	--	--	69	7.42×10^{-5}
WIPP-18	--	--	0.3	3.23×10^{-7}
WIPP-19	--	--	0.6	6.45×10^{-7}
WIPP-21	--	--	0.25	2.69×10^{-7}
WIPP-22	--	--	0.37	3.98×10^{-7}
WIPP-25	270	270	270	2.90×10^{-4}
WIPP-26	1250	1250	1250	1.34×10^{-3}
WIPP-27	650	650	650	6.99×10^{-4}
WIPP-28	18	18	18	1.94×10^{-5}
WIPP-29	1000	1000	1000	1.08×10^{-3}
WIPP-30	0.3	0.3	0.3	3.22×10^{-7}
P-14	140	233	214	2.30×10^{-4}
P-15	0.07	0.08	0.09	9.68×10^{-8}
P-17	1	1.7	1.3	1.40×10^{-6}
P-18	0.001	0.002	0.002	2.15×10^{-9}
DOE-1	--	33	11	1.18×10^{-6}
DOE-2	--	36	89	9.57×10^{-6}
ERDA-9	--	--	0.47	5.06×10^{-7}
CABIN BABY	--	--	0.28	3.01×10^{-7}
ENGLE	--	--	43	4.62×10^{-5}
USGS-1	515	515	515	5.54×10^{-4}
	21 Values	25 Values	38 Values	38 Values

Table 4.2: Detailed summary of recent single-well test results in the Culebra dolomite. Slightly modified from Table 5-3 of Beauheim (1987b).

Well	Culebra Interval m (ft)	Interval Tested m (ft)*	Test Type	Transmissivity (ft^2/day)	Transmissivity (m^2/s)	Skin Factor
H-1	206-213.1 (676-699)	205.7-214.3 675-703)	slug #1	1.0	1.1×10^{-6}	--
			slug #2	0.83	8.9×10^{-7}	--
			slug #3	0.83	8.9×10^{-7}	--
			slug #4	0.83	8.9×10^{-7}	--
H-4c	149.4-157.3 (490-516)	150.6-158.5 (494-520)	slug	0.65	7.0×10^{-7}	--
H-8b	179.2-187.1 (588-614)	175.0-190.2 (574-624)	pumping	8.2	8.8×10^{-6}	-7.2
H-12	250.9-259.1 (823-850)	249.9-271.3 (820-890)	slug #1	0.18	1.9×10^{-7}	--
			slug #2	0.18	1.9×10^{-7}	--
H-14	166.1-174.3 (545-572)	162.5-167.9 (533-550.7)	DST/FBU	0.096	1.0×10^{-7}	-0.8
			DST/SFL	0.10	1.1×10^{-7}	--
			DST/SBU	0.10	1.1×10^{-7}	-1.3
H-14	166.1-174.3 (545-572)	162.5-175.0 (533-574)	DST/FBU	0.30	3.2×10^{-7}	-1.1
			DST/SBU	0.31	3.3×10^{-7}	-1.8
			slug	0.30	3.2×10^{-7}	--
H-15	262-4-269.1 (861-883)	260.0-271.3 (853-890)	DST/FBU	0.15	1.6×10^{-7}	2.6
			DST/SBU	0.15	1.6×10^{-7}	2.9
			slug	0.10	1.1×10^{-7}	--
H-16	213.4-221.0 (700-725)	212.4-223.7 (697-734)	DST/FBU	0.85	9.1×10^{-7}	0.0
			DST/SBU	0.85	9.1×10^{-7}	-0.3
			slug	0.69	7.4×10^{-7}	--
H-17	215.2-222.8 (706-731)	214.3-224.0 (703-735)	DST/FBU	0.21	2.3×10^{-7}	-1.5
			DST/SBU	0.22	2.4×10^{-7}	-1.2
			slug	0.22	2.4×10^{-7}	--

Table 4.2: Detailed summary of recent single-well test results in the Culebra dolomite. Slightly modified from Table 5-3 of Beauheim (1987b). (Continued)

Well	Culebra Interval m (ft)	Interval Tested m (ft)*	Test Type	Transmissivity (ft^2/day)	Transmissivity (m^2/s)	Skin Factor
H-18	210.3-217.3 (690-713)	208.8-217.6 (685-714)	DST/FBU	2.2	2.4×10^{-6}	-0.2
			DST/SBU	2.2	2.4×10^{-6}	-1.0
			slug	1.7	1.8×10^{-6}	--
WIPP-12	246.9-254.5 (810-835)	248.4-256.0 (815-840)	slug #1	0.10	1.1×10^{-7}	--
			slug #2	0.097	1.0×10^{-7}	--
WIPP-18	239.9-246-3 (787-808)	239.0-245-7 (784-806)	slug	0.30	3.2×10^{-7}	--
WIPP-19	230.4-237.4 (756-779)	229.8-237.7 (754-780)	slug	0.60	6.5×10^{-7}	--
WIPP-21	222.2-229.5 (729-753)	221.6-228.9 (727-751)	slug	0.25	2.7×10^{-7}	--
WIPP-22	226.2-232.9 (742-764)	228.0-234.7 (748-770)	slug	0.37	4.0×10^{-7}	--
WIPP-30	192.3-199.0 (631-653)	191.7-199.6 (629-655)	slug #1	0.18	1.9×10^{-7}	--
			slug #2	0.17	1.8×10^{-7}	--
P-15	125.9-132.6 (413-435)	125.0-133.5 (410-438)	slug #1	0.090	9.7×10^{-8}	--
			slug #2	0.092	9.9×10^{-8}	--
P-17	170.1-177.7 (558-583)	170.1-178.6 (558-586)	slug #1	1.0	1.1×10^{-6}	--
			slug #2	1.0	1.1×10^{-6}	--
P-18	277.1-285.9 (909-938)	277.1-286.5 (909-940)	slug	4×10^{-3}	7×10^{-5}	--
ERDA-9	214.6-221.6 (704-727)	214.9-221.9 (705-728)	slug #1	0.45	4.8×10^{-7}	--
			slug #2	0.47	5.1×10^{-7}	--

Table 4.2: Detailed summary of recent single-well test results in the Culebra dolomite. Slightly modified from Table 5-3 of Beauheim (1987b). (Concluded)

Well	Culebra Interval m (ft)	Interval Tested m (ft)*	Test Type	Transmissivity (ft^2/day)	Transmissivity (m^2/s)	Skin Factor
Cabin baby-1	153.3-161.2 (503-529)	153.3-161.2 (503-529)	slug #1	0.28	3.0×10^{-7}	--
			slug #2	0.28	3.0×10^{-7}	--
DOE-1	250.2-256.9 (821-843)	249.9-256.9 (820-843)	pumping/ drawndown	28	3.0×10^{-5}	-5.1
			recovery	11	1.2×10^{-5}	-6.0
Engle	200.9-207.6 (659-681)	197.5-208.2 (648-683)	pumping	43	4.6×10^{-5}	4.2

*Actual intervals open to the wells.

increase in documentation requirements over the ten-year span of WIPP site characterization. The interpreted test data from recent single-hole testing at and near the WIPP site are included in Beauheim (1987b). Raw data, test histories, and test instrumentation for all hydrologic testing at the WIPP for approximately the last five years are contained in a series of six hydrologic data reports: Hydro Geo Chem (1985); INTERA and Hydro Geo Chem (1985); INTERA (1986); Saulnier et al. (1987); Stensrud et al. (1987); and Stensrud et al. (1988).

Transmissivities listed in Tables 4.1 and 4.2 are not identical in all cases. Transmissivity estimates included in Table 4.1 from three-hole hydropads, such as the H-4 pad, are effective transmissivities. In single-hole tests, this is the same as the measured value. In the case of three-hole hydropads, however, the effective transmissivity is the square root of the product of the estimated maximum and minimum transmissivities on the pad. The calculated effective transmissivity, which is used in regional-scale modeling (Section 4.1.3), generally does not correspond directly to any of the measured single-hole values on the same pad.

As mentioned above, Culebra transmissivities at and near the WIPP site and within Nash Draw range over approximately six orders of magnitude, from more than 10^{-3} m^2/s to less than 10^{-8} m^2/s. However, this variability is not random. A large area of low transmissivities (less than approximately 10^{-6} m^2/s) is present near the center of the WIPP site, extending to the east, southeast, and southwest (Figure 4.1.2). This zone includes holes WIPP-12, 18, 19, 21, and 22; H-1, 2, 4, 5, 10, 12, 14, 15, 16, and 17;

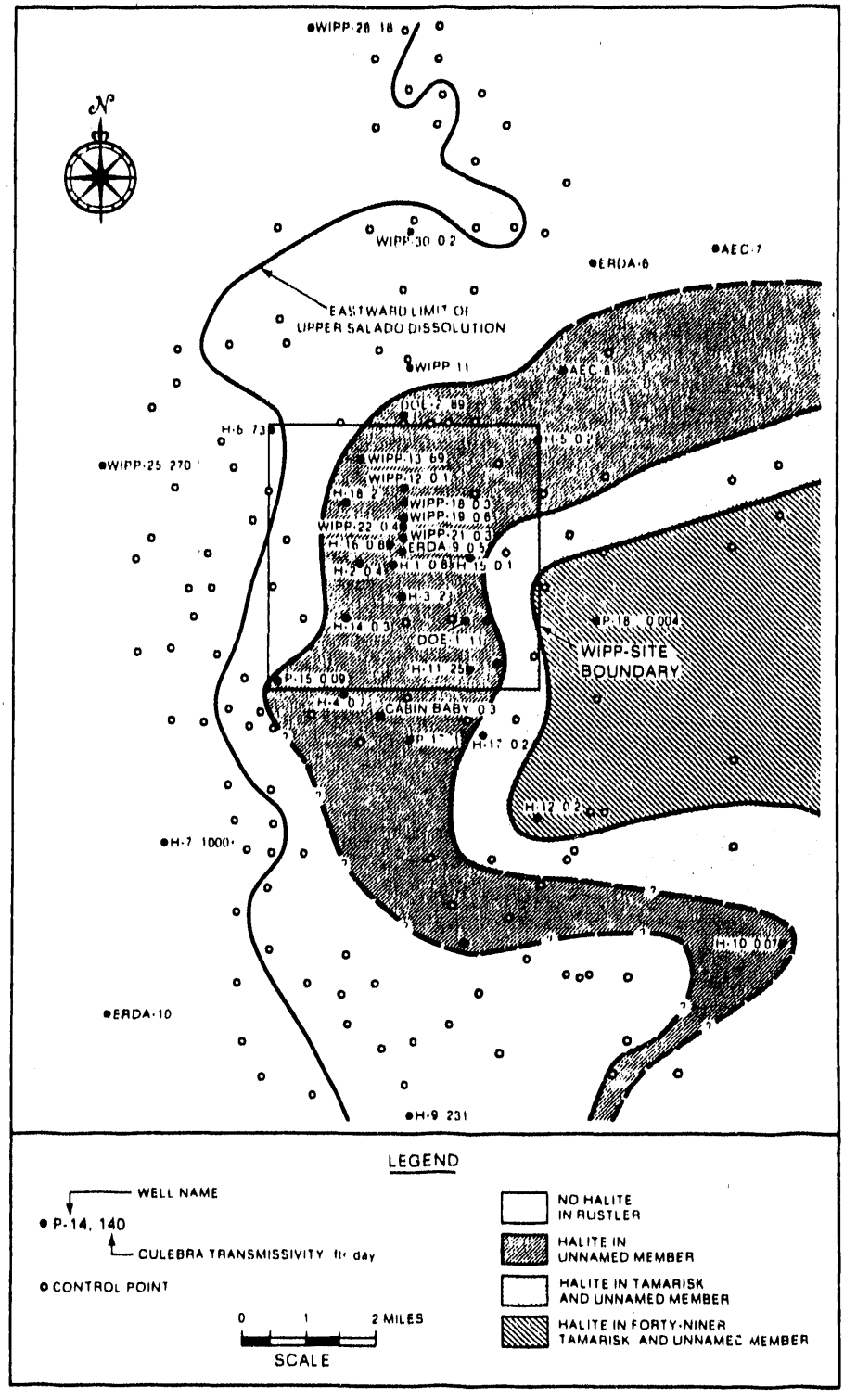


Figure 4.1.2: Transmissivity of the Culebra dolomite in relation to the distribution of halite within the Rustler Formation. Figure 6-2 of Beauheim (1987b). Halite distribution modified from Snyder (1985). Transmissivities in this figure are given in units of ft^2/day. Multiply by 1.075×10^{-6} to get transmissivities listed in Table 4.1 in m^2/s.

P-15, 17, and 18; ERDA-9, and Cabin Baby-1 (see also Figure 1.2). Within this low-transmissivity region, relatively high Culebra transmissivities (greater than approximately 10^{-5} m^2/s) have been measured southeast of the site center, in holes DOE-1 and H-11. The transmissivity measured on the H-3 pad (2.0×10^{-6} m^2/s) is transitional between transmissivities at H-11 and DOE-1 and those in the low-transmissivity domain north and southwest of H-3.

A continuous zone of variable but high Culebra transmissivity appears to be present northwest, west, and south of the site center. This zone includes holes H-6, 7, and 9; WIPP-13, 25, 26, 27, 28, and 29; DOE-2 and P-14; and the Engle well (see Figures 1.1 and 1.2). The Culebra transmissivity in hole H-18 (1.8×10^{-6} to 2.4×10^{-6} m^2/s) is transitional between those in adjacent higher-transmissivity and lower-transmissivity domains.

There are some limitations in the Culebra data base, in spite of the fact that Culebra transmissivities have now been estimated at 39 separate localities at and near the WIPP site and within Nash Draw. For example, although the low-transmissivity zone near the site center is interpreted here to be continuous to the southwest, there is no direct measurement of Culebra transmissivity in the interval between holes H-14 and H-2. At present there is also no direct field evidence of connection between the region containing holes DOE-1 and H-11 and the region to the south containing hole H-9. Quantitative integration of point data into a regional transmissivity pattern for the Culebra and evaluation of some of the uncertainties mentioned here are discussed in Section 4.1.3.

Single-hole Culebra tests in which the system transmissivity is less than 10^{-6} m^2/s generally do not show signs of fracturing, while holes with higher transmissivity do. To a first approximation, fracturing within the Culebra (and the Rustler as a whole) appears to be related to the removal of halite. As discussed by Mercer (1983), Snyder (1985), and Beauheim (1987b), there is a general correlation between the distribution of halite within the Rustler Formation (Figures 1.5 and 4.1.2) and transmissivity of Rustler members, especially the Culebra dolomite. The distribution of halite within the Rustler Formation is briefly discussed in Section 4.4.2.

However, the correlation between halite distribution and Culebra transmissivity is neither unique nor completely reliable. With the exception of WIPP-30 and possibly H-10, the Culebra in holes in which there is no halite in the unnamed lower member of the Rustler are highly transmissive. In WIPP-30, there is no halite within the Rustler, and the Culebra transmissivity is quite low. Without exception, the Culebra transmissivity is low if Rustler halite is present above the Culebra. Where there is Rustler halite present only beneath the Culebra, the correlation is not completely reliable, perhaps because of complications involving the response of the Culebra to evaporite dissolution in the upper part of the Salado Formation. For example, holes DOE-2 and WIPP-13, in the western part of the region in which halite is present beneath the Culebra (Figure 4.1.2), are highly transmissive, but hole H-18 is not. In the southeastern part of the WIPP site, holes P-17 and H-3 are relatively low in transmissivity, but the transmissivity at H-11 and DOE-1 is greater than 10^{-5} m^2/s. As discussed by Beauheim (1987b), examination of the detailed

Rustler isopachs summarized in Snyder (1985) does not indicate any consistent reason for the high transmissivities at H-11 and DOE-1.

The significance of the distinction between dual-porosity (fractured) and porous-medium behavior in single-hole hydraulic testing is not completely straightforward. The apparent absence of fracturing in a test does not indicate a total absence of fractures, nor does fracturing in single-hole hydraulic testing indicate that far-field or long-term hydraulic or transport behavior near a given hole is or would be dominated by fracture effects. At one extreme, very local fracturing in a very low-transmissivity test interval may play a role in the very early pressure responses, but may not be evident because of wellbore-storage and fluid-flow surge effects at the beginning of a test. Any low-transmissivity hole listed in Tables 4.1 and 4.2 may contain fractures which are not apparent because of the testing techniques and instrumentation used. However, the effects of these fractures should be extremely localized. At the other extreme, intense fracturing may lead to high transmissivity, but result in such small block sizes that fluid flow from the matrix blocks is "immediately" the rate-limiting step. Dual-porosity effects would not be evident during testing at such a site, and the tested interval would behave hydraulically as an equivalent porous medium. This type of behavior may be applicable, for example, in the highly-transmissive portions of the Culebra within Nash Draw; however, testing results in Nash Draw have not yet been investigated using INTERPRET. The hydraulic behavior of the highly-transmissive Culebra in the Engle well (4.6×10^{-5} m^2/s) does not show dual-porosity effects. However, this behavior is tentatively attributed by Beauheim (1987b) to wellbore and near-wellbore conditions, rather than to extreme fracturing of the test interval.

In addition, the fact that testing at a given hole does not indicate local fracturing does not guarantee that there is not fracturing nearby. Single-hole testing at WIPP-21 indicates a Culebra transmissivity of 2.7×10^{-7} m^2/s, with no dual-porosity effects. This hole responded strongly and rapidly to both the H-3 multipad interference test and activities in both the waste-handling and exhaust shafts. This behavior probably reflects the presence of a "low-storativity" structure, which could be a single fracture or fracture zone connecting the region near WIPP-21 with the two WIPP shafts, but not intersecting WIPP-21 itself.

Single-hole testing may also be strongly affected by drilling-induced near-well effects, which can make the test hole appear either more or less transmissive than the surrounding rock mass. As discussed by Beauheim (1986, 1987b), marked examples of such "skin" effects were found in testing in holes DOE-2 and WIPP-13. In the extreme example of hole DOE-2, the initial estimate of minimum transmissivity was 2.4×10^{-5} m^2/s. The calculated "skin factor" was +31 (Beauheim, 1986). For comparison, a hole so badly damaged that it would not produce fluid at all would have a skin factor of plus infinity. At the WIPP, positive skin factors have, in some cases, been reduced by acid treatment. Treatment of hole DOE-2 with hydrochloric acid removed the near-hole damage effects, and increased the interpreted transmissivity by a factor of 4, from 2.4×10^{-5} m^2/s, to 9.6×10^{-5} m^2/s (Table 4.1). The calculated skin factor at DOE-2 decreased from +31 to -4.7. A skin factor of less than zero indicates good connection of

the physical wellbore with fractures within the rock mass and results in an apparent well radius greater than that of the physical diameter of the hole. The Culebra in several holes listed in Table 4.2 exhibits negative skin factors, indicating good connection of the test hole with the surrounding rock mass.

As mentioned above, the presentation of data in terms of transmissivity explicitly assumes that the tested interval is vertically homogeneous. Data included in Table 4.2 indicate that Culebra transmissivity at H-14 varies with vertical position within the unit. While drilling this hole, it was possible to find a packer seat within the Culebra. Testing of the upper Culebra was then followed by testing of the entire unit. The calculated transmissivity of the upper 1.7 m of the Culebra is 1.1×10^{-7} m^2/s, while that of the entire 8.2 m thickness of the unit is 3.3×10^{-7} m^2/s. This indicates that the transmissivity of the lower 6.5 m of the Culebra in hole H-14 is approximately 2.2×10^{-7} m^2/s. The results at H-14 indicate that the Culebra cannot be assumed to be vertically homogeneous, since the transmissivity of individual zones within the unit vary by a factor of about 2. The results at H-14 are in qualitative agreement with the variability indicated by results of tracer-injection tests at holes H-1, H-2c, H-3, and P-14 (Mercer and Orr, 1979).

Because the Culebra dolomite is generally more permeable than the Magenta dolomite at and near the WIPP site, less testing of the Magenta has been completed at the WIPP. Older transmissivity data for the Magenta dolomite are contained in Mercer (1983) and Gonzalez (1983a). The results of recent testing of the Magenta dolomite in H-14, H-16, and DOE-2 are included in Table 4.3. Overall, reported Magenta transmissivities range from approximately 5.9×10^{-9} m^2/s in hole H-14 to 4.0×10^{-4} m^2/s in WIPP-25. Magenta transmissivities greater than approximately 10^{-6} m^2/s are known only in and near Nash Draw and the small valley south of the WIPP site (Figure 1.2).

As mentioned in Section 1.0, modeling of Rustler hydrology through 1983 assumed that the Culebra and Magenta dolomites were completely confined. This is equivalent to assuming that the unnamed lower, Tamarisk, and Forty-niner members of the Rustler have zero permeability. Indeed, standard hydrologic testing techniques are inapplicable to these units at the WIPP site because of their low permeabilities. Recent advances in testing, data-collection, and interpretation techniques have allowed meaningful examination of these units at three locations: DOE-2, H-14, and H-16 (Table 4.3). Even in the recent testing, however, it has only been possible to test the transmissivities of claystones and siltstones within the non-carbonate members of the Rustler. The claystones and siltstones in the Tamarisk and Forty-niner Members occur near the center of each unit, and are separated from the Magenta or Culebra by a zone of anhydrite/gypsum (Table 1.2). The anhydrites within the Rustler still cannot be tested from the surface, since their in situ transmissivities are less than approximately 10^{-11} m^2/s (Beauheim, 1986; 1987b). In addition, it still has not been possible to measure the transmissivity of the Tamarisk claystone, due to its low transmissivity.

Table 4.3: Summary of available transmissivity information for members of the Rustler Formation in holes H-14, H-16, and DOE-2. Slightly modified from data contained in Tables 5-2 and 5-3 of Beauheim (1987b) and Table 7-2 of Beauheim (1986).

	Zone depth (m)	Test interval (m)	Transmissivity (m^2/s)
H-14			
Forty-niner "claystone"	118.9 - 123.4	116.1 - 124.7	3.2×10^{-8} - 7.6×10^{-8}
Magenta	129.2 - 136.6	128.0 -136.6	5.7×10^{-9} - 6.0×10^{-9}
Culebra	166.1 - 174.3	162.5 - 175.0	3.2×10^{-7} - 3.3×10^{-7}
H-16			
Forty-niner "claystone"	171.6 - 175.0	170.7 - 177.1	2.4×10^{-10} - 6.0×10^{-9}
Magenta	179.8 - 187.8	179.5 - 189.3	2.6×10^{-8} - 3.0×10^{-8}
Culebra	213.4 - 221.0	212.4 - 223.7	7.4×10^{-7} - 9.1×10^{-7}
Unnamed member siltstone	237.1 - 256.6	225.2 - 259.4	2.4×10^{-10} - 2.9×10^{-10}
DOE-2			
Forty-niner "claystone"	204.2 - 207.5	202.4 - 209.1	2.7×10^{-9} - 1.2×10^{-8}
Magenta	213.1 - 220.1	213.4 - 220.1	1.1×10^{-9}
Culebra	251.2 - 257.9	251.2 - 257.9	9.6×10^{-5}

The transmissivity of the Magenta at H-14, H-16, and DOE-2 is 1.1×10^{-9} to 3.0×10^{-8} m^2/s (Table 4.3). The transmissivity of the claystone in the overlying Forty-niner in the same holes is comparable, 5.6×10^{-9} to 1.2×10^{-8} m^2/s. The siltstone within the unnamed lower member of the Rustler has been successfully tested only in hole H-16, in which it has an estimated transmissivity of between 2.4×10^{-10} and 2.9×10^{-10} m^2/s. The transmissivity of the Culebra in DOE-2, H-14, and H-16 ranges from 1.1×10^{-7} to 9.6×10^{-5} m^2/s, at least one order of magnitude greater than that of any of the surrounding units.

The results at H-14, H-16, and DOE-2 indicate that the Culebra is the most significant water-bearing unit within the Rustler at and near the WIPP site, consistent with earlier assumptions, although in some holes (H-10, WIPP-12, P-15) the Culebra transmissivity is similar to the Magenta transmissivities measured at H-14, H-16, and DOE-2. However, the recent results are inconsistent with previous assumptions, in that they suggest that stratabound fluid flow within the portion of the Rustler above the Culebra dolomite may occur as much through the Forty-niner claystone as through the Magenta, except where the Magenta is significantly fractured. At and near the WIPP site, both the Magenta and the Forty-niner claystone are more transmissive than the bounding anhydrites; no data are available concerning the transmissivity of the Tamarisk claystone. There must be a qualitative increase in the transmissivities of the Tamarisk and Forty-niner anhydrites somewhere between the WIPP site and Nash Draw, however, since evaporite karst in and near Nash Draw involves formation of small caverns and sinkholes within the Tamarisk and Forty-niner Members, as briefly discussed in Section 4.4.

4.1.1.2 Head Distribution within the Rustler Formation and between the Rustler, Dewey Lake, and Salado--As mentioned previously, numerical modeling of Rustler hydrology through 1983 assumed the Culebra and Magenta were completely confined, and that the transmissivities of other units within the Rustler were negligible. The results discussed in the preceding section indicate that the transmissivities of claystones or siltstones within the Rustler are locally measurable at the WIPP site, and are similar in magnitude to that of the Magenta dolomite, except where the Magenta is fractured. However, the transmissivity of the Culebra dolomite is normally at least one order of magnitude greater than that of other units within the Rustler at and near the WIPP site, and the transmissivities of Rustler anhydrites at and near the WIPP site are too low to measure. These results suggest that flow within the Culebra dolomite, parallel to layering, is the dominant factor in the hydrology of the Rustler Formation at the WIPP site. However, as discussed briefly in this section, fluid pressures and densities have been measured locally in units both above and below the Culebra.

Therefore, unless the Rustler anhydrites and/or Tamarisk claystone have absolutely zero permeability, there must be some vertical fluid flow within the Rustler. The amount of this flow is not known quantitatively, and cannot be measured directly in the field. At one extreme, vertical fluid flow may be completely negligible relative to stratabound flow within the Culebra dolomite. At the other extreme, "karstic" hydrology might occur within the Rustler Formation at the WIPP site, involving surficial recharge from the surface to the Rustler carbonates and/or anhydrites. In order for fluid flow to take place from the surface to the carbonate members of the Rustler Formation, the head potential within the Forty-niner must be greater than that within the underlying Magenta dolomite, regardless of the head potential or state of saturation within the Dewey Lake Red Beds. The relationships among the effective hydraulic heads of the various members of the Rustler Formation, the Salado, and the Dewey Lake in the central portion of the WIPP site are shown in Figure 4.1.3. The flow directions indicated include the expected effects due to variable brine densities.

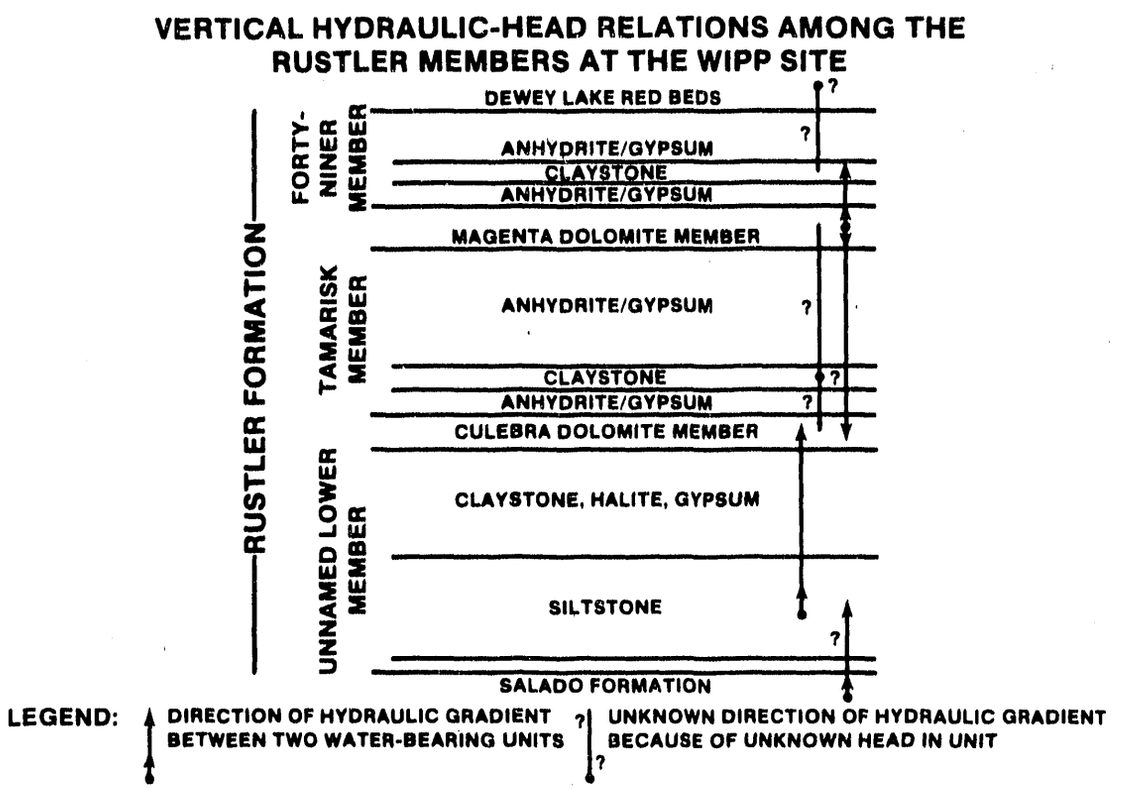


Figure 4.1.3: Head relations among units in the Rustler Formation and between the Rustler, Dewey Lake Red Beds, and Salado at the WIPP site. Figure 6-3 of Beauheim (1987b).

Figure 4.1.3 is based, in part, on testing of the Rustler and lower Dewey Lake Red Beds at H-14, H-16, and DOE-2. The transmissivity of the lower Dewey Lake was too low for successful testing, i.e., less than approximately 10^{-11} m^2/s. In fact, testing was unable to determine whether the Dewey Lake is hydraulically saturated. The regional pattern of hydrologic saturation within the Dewey Lake is not well known (Mercer, 1983); only very limited evidence has been found for local saturation at the WIPP site. South of the WIPP site, water is locally produced from the Dewey Lake, perhaps from lenticular sands within the unit (Mercer, 1983). Wells probably producing from within the Dewey Lake include the Pocket, Fairview, and Ranch wells indicated in Figure 1.2. As noted by Mercer (1983) the region east of the Ranch well includes thick active dune sands, and may serve as a location for local recharge to the Dewey Lake (see also Section 4.3.2).

In holes H-14 and H-16, consistent with the relationships shown in Figure 4.1.3, the Magenta head is greater than the head in the Forty-niner claystone (Beauheim, 1987b). Therefore, modern fluid flow between these two members is upward, rather than downward. Since water at these two holes is not moving from the top of the Rustler downwards into the Magenta, it cannot be moving from the surface down into the Magenta dolomite.

The Dewey Lake Red Beds at H-14 and H-16 may not be saturated. If not, fluid flow from the surface to the Forty-niner claystone is not likely. Given the uncertainty in regional saturation and head potentials within the Dewey Lake Red Beds the results at H-14 and H-16 do not rule out fluid movement from the surface downward into the Forty-niner claystone or the upper anhydrite in the Forty-niner and/or into the Magenta dolomite in some areas; i.e., where the Dewey Lake is saturated. Also, these results do not eliminate the possibility of flow between the Dewey Lake Red Beds and the Rustler carbonates in the past, if heads within the Dewey Lake Red Beds and Forty-niner were higher at that time relative to heads within the Magenta.

Magenta heads near the center of the WIPP site are greater than Culebra heads (Figure 4.1.3), consistent with downward flow between these two units. As indicated in Figures 17 and 18 of Mercer (1983), the difference in heads between the two units tends to increase towards the east and decrease towards the west, primarily due to a general east-to-west decrease in Magenta heads. Within and near Nash Draw, the heads within the two units are similar; in some places in and near Nash Draw, (H-7a, WIPP-26, WIPP-28), the Magenta is unsaturated (Mercer, 1983).

Vertical flow from the Magenta to the Culebra has been considered in regional-scale modeling of Culebra hydrology (Section 4.1.3.1). However, as noted above and indicated in Figure 4.1.3, it has not been possible to measure either transmissivities or head potentials within either the claystone or anhydrites in the Tamarisk at or near the WIPP site. Vertical flow between the Magenta and Culebra is discussed further by Mercer (1983) and Beauheim (1987b). The possible consequences of such flow, as considered in numerical modeling of Culebra hydrology (Haug et al., 1987), are briefly considered in Section 4.1.3.1.

As noted by Mercer (1983) and Beauheim (1987b), the head potentials in the silty portion of the unnamed lower member of the Rustler are greater than within the Culebra over much of the area of the WIPP site. Thus, fluid flow into the Culebra from the underlying unnamed member and possibly the Salado Formation is possible at both of these locations. However, as indicated in Figure 4.1.3, it has not been possible to measure either transmissivities or head potentials within the claystone, halite, or gypsum/anhydrite in the upper part of the unnamed lower member. The possible implications of vertical fluid flow from the unnamed member into the Culebra in numerical modeling of Culebra hydrology are briefly discussed in Section 4.1.3.1.

4.1.2 Single-Pad Interference Testing

Interference testing at the scale of a single hydropad is designed to provide data concerning the hydrologic effects of both fracturing and "anisotropy" at a geometric scale of some 30 m. If the test interval behaves as a porous medium at the hydropad scale, interference testing yields an "anisotropy tensor," which indicates local directions of maximum and minimum transmissivities. If, however, the porous-medium assumption is not valid at this scale, i.e., if fracturing effects are significant, testing at this scale normally provides average system transmissivities and storativities along the independent pairs of flow paths. Section 4.1.2.1 describes the detailed results of single-pad interference testing at the H-3 hydropad, and Section 4.1.2.2 the detailed results of testing at the H-11 pad. Detailed interpretation of pad-scale interference testing has only been completed to date for these two locations. Interpretation of results obtained at the H-2, H-4, H-5, H-6, H-7, and H-9 pads is ongoing.

4.1.2.1 Interference Testing at the H-3 Hydropad--Beauheim (1987a) interprets hydraulic data collected at the H-3 hydropad (Figure 4.1.4) during single-hydropad testing in 1984 and the H-3 multipad interference test conducted in 1985 and 1986. Hole H-3b3 was the pumped hole during the 1984 test, and H-3b2 the pumped hole during the H-3 multipad test.

The characteristic drawdown response in both pumped and observation holes at the H-3 pad is shown in Figure 4.1.1. As noted in Section 4.1.1, the inflection in dimensionless pressure at early dimensionless times indicates fracturing at H-3. In fact, the responses of observation holes on the H-3 pad to the beginning of pumping during both single-pad and multi-pad testing tests were practically instantaneous. Observation holes H-3b1 and H-3b3 responded within five seconds to the beginning of pumping in H-3b2 during the multipad test. The peak drawdowns in the observation holes were 90% or more of the drawdown in the pumped hole, even in the relatively short 1984 test. As a result, it was necessary to interpret the responses of observation holes on the H-3 pad as if these holes were a part of the pumped hole. This conclusion is supported by the fact that the calculated effective hydraulic radius of the pumped well in the 1984 testing (H-3b3) is approximately 146 m (Beauheim, 1987a). This interpretation, however, makes it impossible to determine storativities along the flow paths at the H-3 pad.

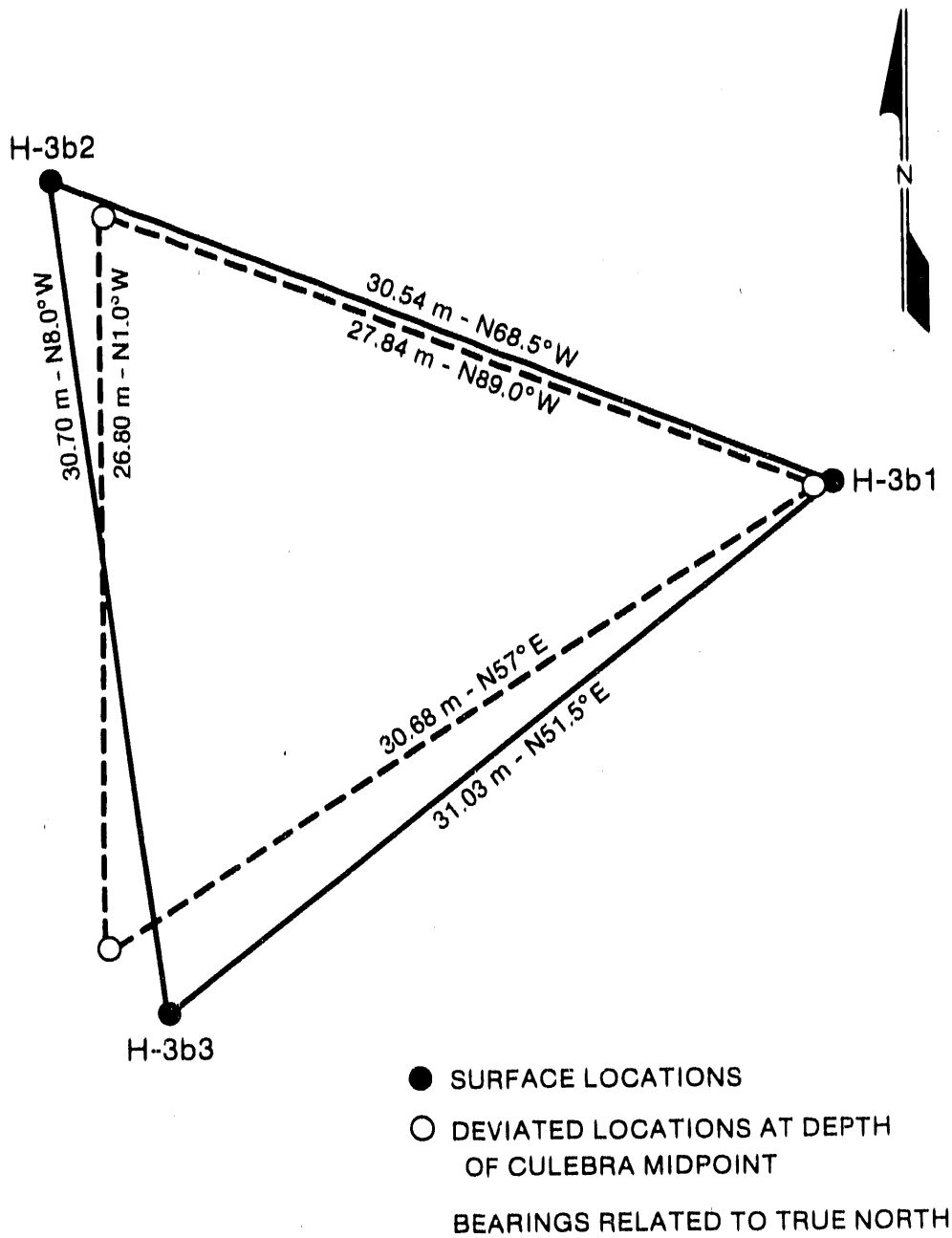


Figure 4.1.4: Physical layout of the H-3 hydropad. The figure is a plan view, showing positions and distances between wells both at the surface and where penetrating the Culebra dolomite. Figure 4.1 of Kelley and Pickens (1986).

The results of interference testing on the H-3 pad are summarized in Table 4.4. There is no significant difference between the interpreted transmissivities of the three holes on the H-3 pad, since the range in values is only from 3.1 to 3.2 x 10^{-6} m^2/s for the 1984 testing and 1.8 to 1.9 x 10^{-6} m^2/s for the multipad test. Therefore, there is no apparent anisotropy in the hydraulic properties at H-3. There is, however, a decrease of approximately 50% between the average transmissivity at H-3 interpreted from the 1984 testing, in which the pumping phase lasted 14 days at an average pumping rate of 4.0 gpm, and that interpreted from the H-3 multipad interference test, in which the pumping phase lasted 62 days, at an average rate of 4.8 gpm. Beauheim (1987a) attributes this difference to either a real difference in transmissivity between holes H-3b3 and H-3b2, the specific wells pumped in the two tests, and/or to the fact that the average transmissivity of the relatively large volume investigated during the long-term H-3 multipad test is lower than the average transmissivity of the volume investigated in the shorter-term 1984 testing. Consistent with this latter interpretation, the original H-3(b1) transmissivity of 2.0 x 10^{-5} m^2/s reported by Mercer (1983) is based on a combination of bailing/recovery and slug tests, both of short duration.

Table 4.4 includes estimates of both "skin factor" and the "storativity ratio" for individual holes on the H-3 pad. Calculated skin factors range from -7.3 to -8.1. As discussed by Beauheim (1987a), the strongly negative skin factors indicate direct connection of all three wellbores with fractures, consistent with the interpreted effective radius of 146 m for hole H-3b3. Although the storativities of the observation holes on the H-3 pad could not be calculated, Beauheim (1987a) does calculate "storativity ratios" (omegas), the ratio of fluid storativity within the fractures (secondary porosity) to that of the entire system of matrix plus fractures (primary plus secondary porosity). The calculated values range from 0.03 to 0.25. As noted by Saulnier (1987), most fractured-rock systems have a storativity ratio less than 0.1. The storativity ratios at the H-3 pad indicate unusually high storage within fractures, perhaps due to the vugginess of the Culebra.

4.1.2.2 Interference Testing at the H-11 Hydropad and Comparison with Results at the H-3 Pad--Saulnier (1987) summarizes the interpretation of pad-scale interference testing carried out at the H-11 hydropad (Figure 4.1.5) in 1984 and 1985. During 1984, holes H-11b1, H-11b2, and H-11b3 were each pumped in individual tests lasting from 12 to 21 hours. The 1985 test, in which H-11b3 was the pumped hole, lasted for 32 days. However, complications with instrumentation during the 1985 testing resulted in four distinct pumping and recovery periods. The resulting superposition of effects complicates interpretation of the 1985 results.

The results of interference testing at H-11 are included in Table 4.4. The interpreted transmissivities for pumped holes and for flow paths between pumped and observation holes on the H-11 pad range from 1.2 x 10^{-5} to 3.0 x 10^{-5} m^2/s. With the exception of the interpreted transmissivity of H-11b1 during 1984 pumping the range is only 2.5 x 10^{-5} to 3.0 x 10^{-5} m^2/s.

Table 4.4: Summary of single-pad interference testing results for the Culebra dolomite at the H-3 and H-11 hydropads. Slightly modified from data contained in Tables 6-1 and 6-3 of Beauheim (1987a) and Table 6.1 of Saulnier (1987).

	Transmissivity (m^2/s)	Skin Factor	Storativity	Storativity Ratio (ω)	Flow Ratio(λ)
H-3(1)					
H-3b3 (1984) pump	3.1×10^{-6}	-7.8	-	0.07	-
H-3b1 (obs.)	3.2×10^{-6}	-7.3	-	0.25	-
H-3b2 (obs.)	3.2×10^{-6}	-7.6	-	0.04	-
H-3b2 (1986) pump	1.8×10^{-6}	-8.1	-	0.03	-
H-3b1 (obs.)	1.9×10^{-6}	-7.7	-	0.25	-
H-3b3 (obs.)	1.9×10^{-6}	-8.0	-	0.10	-
H-11(2)					
H-11b1 (1984) pump	1.2×10^{-5}	-3.3	-	0.01	1.3×10^{-9}
H-11b2 (obs.)	2.5×10^{-5}	-	8×10^{-4}	0.35	2.0×10^{-6}
H-11b3 (obs.)	2.8×10^{-5}	-	5.5×10^{-4}	0.35	1.3×10^{-6}
H-11b2 (1984) pump	-	-	-	-	-
H-11b1 (obs.)	2.7×10^{-5}	-	6.1×10^{-4}	0.43	2.0×10^{-6}
H-11b3 (obs.)	2.6×10^{-5}	-	4.5×10^{-4}	0.40	3.8×10^{-6}
H-11b3 (1984) pump	2.8×10^{-5}	-4.4	-	0.01	2.3×10^{-6}
H-11b1 (obs.)	2.7×10^{-5}	-	6.3×10^{-4}	0.30	1.3×10^{-6}
H-11b2 (obs.)	2.6×10^{-5}	-	7.2×10^{-4}	0.30	1.3×10^{-6}
H-11b3 (1985) pump	3.0×10^{-5}	-4.6	-	0.01	3.7×10^{-7}
H-11b1 (obs.)	2.7×10^{-5}	-	2.9×10^{-3}	0.07	5.0×10^{-6}
H-11b2 (obs.)	2.8×10^{-5}	-	2.6×10^{-3}	0.07	5.8×10^{-6}

(1) All holes H-3 pad interpreted as part of pumped hole; therefore, storativities not available, but skin factors and point transmissivities available for all holes.

(2) Observation holes on H-11 pad well-behaved; therefore, transmissivities, except for pumped hole, are averages between observation and pumped hole.

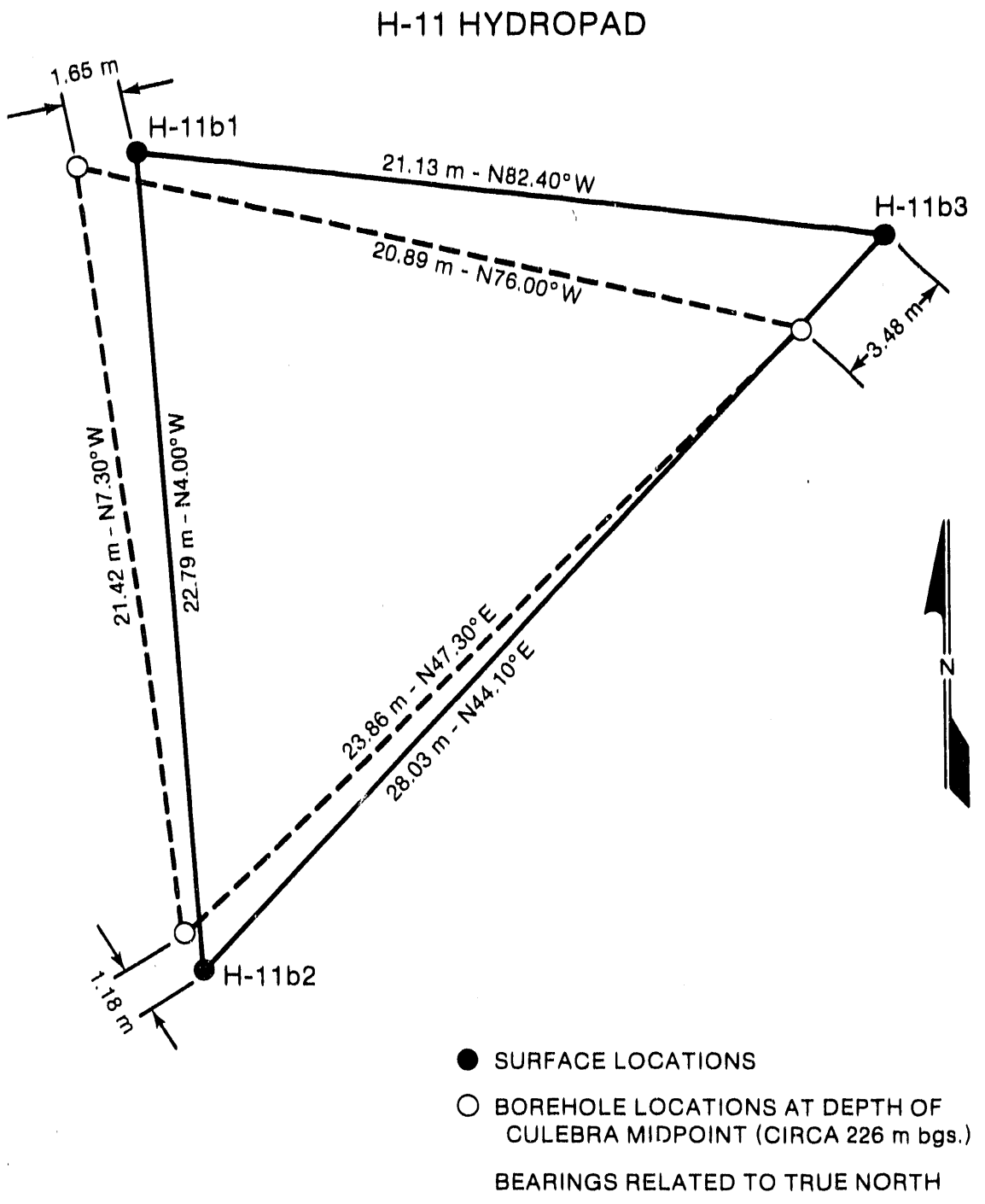


Figure 4.1.5: Physical layout of the H-11 hydropad. The figure is a plan view, showing positions and distances between wells both at the surface and where penetrating the Culebra dolomite. Modified from Figure 3.1 of Saulnier (1987).

The behavior of observation holes on the H-11 pad is consistently different than that observed on the H-3 pad. Although the observation holes on the H-11 pad displayed dual-porosity behavior, their response to the beginning and ending of pumping was sufficiently delayed to allow interpretation as observation holes, rather than as part of the pumped well. The calculated effective hydraulic radius of H-11b3, consistent with the behavior of the observation holes, is 4.9 m (Saulnier, 1987), as compared to an effective radius of 146 m at the H-3 pad (Beauheim, 1987a).

Comparison of the hydrologic behaviors at the H-3 and H-11 pads indicates that the hydraulic effectiveness of fracturing at a given site need not be proportional to the transmissivity. The interpreted transmissivity of H-11b3 during pumping of this hole in 1984 is 2.8×10^{-5} m^2/s, as compared to a transmissivity of 3.1×10^{-6} m^2/s for hole H-3b3 in 1984 testing at the H-3 pad. However, the effective radius of H-3b3 is 146 m, while that of H-11b3 is 5 m. In addition, the observation holes at the H-3 pad had to be treated as part of the pumped well, while observation holes at the H-11 pad behaved properly as observation wells. As shown in Table 4.3, the calculated skin factors at the H-3 pad, which range from -7.3 to -8.1, are consistently more negative than those at the H-11 pad, which range from -3.3 to -4.6.

Interpretation of behavior along the assumed radial flow paths between observation and pumped wells on the H-11 pads indicates average hydraulic storativities between 4.5×10^{-4} and 2.9×10^{-3}, with the higher values interpreted from testing in 1985. These storativities are higher than regional storativities calculated by Beauheim (1987a) from multipad testing at the H-3 pad (7.4×10^{-6} to 3.0×10^{-5}, see Table 4.6). As at the H-3 pad, calculated storativity ratios at H-11 range from 0.01 to 0.43, higher than normal for fractured media.

Calculated interporosity-flow parameters (lambdas) at H-11 range from 1.3×10^{-9} to 5.8×10^{-6} (Table 4.4). As noted by Saulnier (1987), the definition of the parameter lambda includes the ratio of the matrix permeability (permeability of the primary-porosity system) to permeability of the fractures (secondary-porosity system). Therefore, the calculated results indicate that there is a strong contrast between matrix and fracture permeabilities at the H-11 pad. As also indicated by Saulnier (1987), interpretation of the calculated lambda values at the H-11 pad is consistent with effective block or slab dimensions of 0.3 to 1.0 m. The available information on the effective block size in fractured portions of the Culebra dolomite is discussed further in Section 4.2, based on the results of testing with conservative tracers at the H-3 hydropad.

Using the system transmissivities interpreted from 1984 testing and an average storativity of 6.3×10^{-4}, Saulnier (1987) estimates the extent and orientation of hydraulic "anisotropy" at H-11. The calculated maximum transmissivity vector of 3.3×10^{-5} m^2/s is oriented 5.8 degrees north of east, and the calculated minimum transmissivity vector of 2.1×10^{-5} m^2/s 5.8 degrees west of north (Table 4.5). The calculated ratio of 1.6:1 between maximum and minimum transmissivities at H-11 indicates only a small degree of anisotropy. However, the presence of fractures at this site indicates that these results are only qualitative; because of the

fractures, directional variations in properties are almost certainly not continuous. Also, since the indicated directions of maximum and minimum transmissivity do not coincide with any direct flow paths on the H-11 pad, there is no guarantee that either the maximum or minimum values are reliable.

Table 4.5: Summary of apparent hydraulic anisotropy of the Culebra dolomite. Compiled from results contained in Saulnier (1987) and Gonzalez (1983b).

	T_{MAX} (m^2/s)	T_{MIN} (m^2/s)	T_{MAX}/T_{MIN}	Orientation of T_{MAX}
Site				
H-4(1)	2.9×10^{-6}	1.1×10^{-6}	2.6	N76W
H-5	2.4×10^{-7}	9.7×10^{-8}	2.5	N25W
H-6	1.1×10^{-4}	5.2×10^{-5}	2.1	N29W
H-11(2)	3.3×10^{-5}	2.1×10^{-5}	1.6	N84E

(1) Data for H-4, H-5, and H-6 from Gonzales (1983b).
(2) Data for H-11 from Saulnier (1987).

The available interpretations of anisotropy within the Culebra dolomite are summarized in Table 4.5. Earlier interpretations at the H-4, H-5, and H-6 pads all explicitly make the porous-medium assumption (Gonzalez, 1983b). The interpretation of Saulnier (1987) is based on the calculated system transmissivities. The available interpretations indicate transmissivity ratios between 1.6:1 and 2.6:1, with a direction of between N84E and N76W for the major transmissivity vector. For calculated major Culebra transmissivities between 2.4×10^{-7} m^2/s and 1.1×10^{-4} m^2/s and minor transmissivities between 9.7×10^{-8} and 5.2×10^{-5} m^2/s there appears to be less than a factor of three hydraulic anisotropy. The available results indicate that there is no consistent orientation of maximum Culebra transmissivity.

4.1.3 Multipad Interference Testing

As noted in the introduction to Section 4.0, the best method of estimating the regional distribution of properties within a variable hydrologic unit is by regional-scale testing and interpretation. At the WIPP site, two regional-scale multipad interference tests of the Culebra dolomite have been completed, centered at the H-3 hydropad and at hole WIPP-13. The H-3

multipad interference test and related analytical interpretation and regional-scale modeling of Culebra hydrology are discussed in Section 4.1.3.1. The WIPP-13 test and related interpretative and modeling studies are discussed in Section 4.1.3.2.

4.1.3.1 The H-3 Multipad Interference Test and the Regional Culebra Model of Haug et al. (1987)--The pumping phase of the H-3 multipad interference test (Figure 4.1.6) extended from October 15, 1985, to December 16, 1985. Recovery monitoring continued until April 16, 1986, when the data-acquisition system at the H-3 pad was turned off. Raw data from the test are included in INTERA (1986). Analytical interpretations of both detailed results at the H-3 pad and average or apparent transmissivities and storativities between H-3b2 (the pumped hole) and the numerous observation holes are reported by Beauheim (1987a). Analytical interpretation of regional flow patterns generated in response to the test, with emphasis on evaluation of a linear-flow regime at holes H-3, H-11, and DOE-1, is reported by Tomasko and Jensen (1987). Numerical calculation or simulation of Culebra transmissivities, heads, and fluid densities on the regional scale are reported by Haug et al. (1987), as well as modeling of the transient pressure responses to the H-3 multipad test.

Beauheim (1987a) describes the analytical (as opposed to numerical) interpretation of hydraulic data collected during the H-3 multipad interference test. Results on the H-3 pad itself are discussed in Section 4.1.2. The regional distribution of Culebra properties, based on Beauheim's analytical interpretation, is summarized in Table 4.6. The analytical approach used to interpret responses at observation holes necessarily assumes both radial flow into the pumped hole and homogeneous or average properties between pumped hole and individual observation holes (Beauheim, 1987a). Therefore, transmissivity values listed in Table 4.6 are apparent average values for an assumed radial flow path between H-3b2 and the listed observation hole. Beauheim (1987a) found it necessary to correct both pre-test and post-test heads for the relatively long-term transient behavior of some water levels at and near the WIPP site (Table 4.6). This transient behavior is in response to some combination of hydrologic testing, shaft sinking and sealing operations, and a possible regional transient.

Observation-hole responses to the H-3 multipad test fall into three general categories. First, on the H-3 pad itself, hydraulic fracturing was sufficient to require that Observation holes H-3b1 and H-3b3 be considered as part of the pumped hole (Section 4.1.2). Second, Observation holes DOE-1 and H-11b1, respectively 1606 and 2423 m southeast of H-3b2 (Figure 4.1.6), responded rapidly to both the beginning and ending of pumping. Drawdown in DOE-1 began 48 hours into the test, and that in H-11b1 only three hours later (Table 4.6). The average transmissivities interpreted along flow paths between H-3b2 and DOE-1 and H-11b1 are 5.9×10^{-6} m^2/s between DOE-1 and H-3b2 and 7.3×10^{-6} m^2/s between H-11b1 and H-3b2. Calculated apparent storativities along the same flow paths are 1.0×10^{-5} and 7.4×10^{-6}, respectively. Beauheim (1987a) concludes that the rapid responses at DOE-1 and H-11b1 and relatively high calculated transmissivities along flow paths between these holes and H-3b2 indicate a

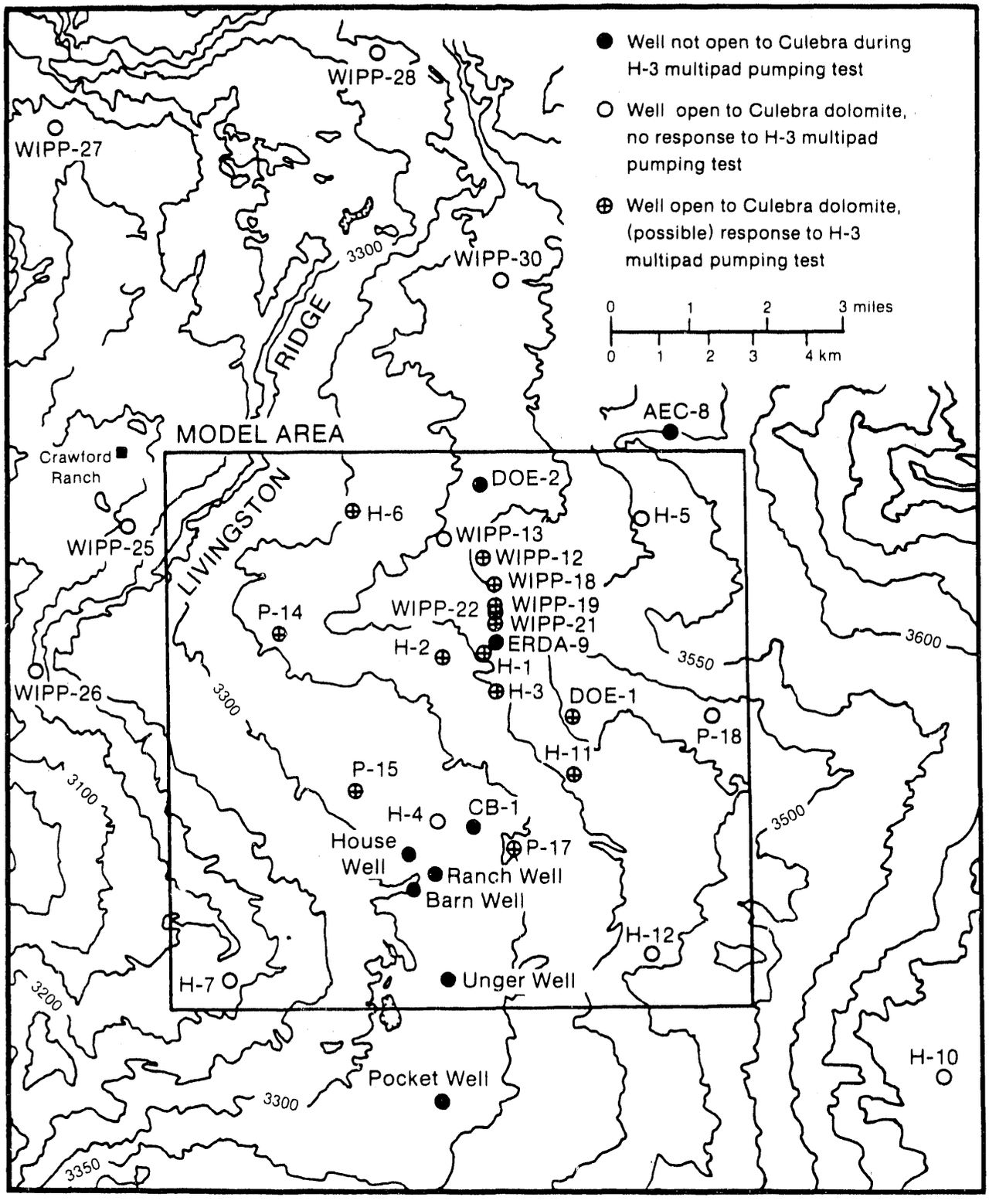


Figure 4.1.6: Pumping and observation wells for the H-3 multipad interference test. Figure 3.2 of Haug et al. (1987).

Table 4.6: Summary of results of analytical interpretation of H-3 multipad interference test. Slightly modified from data contained in Tables 3-1, 5-1, and 6-4 of Beauheim (1987a).

Well	Distance(m)[1]	Direction	First Obs.[2] Drawdown (hrs)	Delay in Max. Drawdown (hr)	Unmodified Interpretation		Modified Interpretation		
					T(m^2/s)[3]	S	T(m^2/s)	S	Head Modification (m/day)
H-11b1	2423	S42E	79	51	1.4×10^{-5}	6.6×10^{-6}	7.3×10^{-6}	7.4×10^{-6}	8.6×10^{-3}
DOE-1	1606	S68E	57	48	9.9×10^{-6}	9.2×10^{-6}	5.9×10^{-6}	1.0×10^{-5}	5.5×10^{-3}
H-1	815	N19W	488	1423	8.9×10^{-7}	3.9×10^{-5}	4.9×10^{-7}	2.7×10^{-5}	2.64×10^{-2}
H-2b2	1270	N54W	433	1393	2.7×10^{-6}	4.5×10^{-5}	1.3×10^{-6}	3.0×10^{-5}	1.16×10^{-2}
WIPP-19	1875	N2E	1207	1855	3.1×10^{-6}	2.9×10^{-5}	-	-	-
WIPP-21	1437	N3E	437	678	1.2×10^{-6}	9.0×10^{-6}	-	-	-
WIPP-22	1739	N2E	990	727	1.7×10^{-6}	1.7×10^{-5}	-	-	-

(1) Distances and directions measured from H-3b2 to the indicated well.
(2) First drawdown and delay in maximum drawdown are given relative to times at which pump was turned on and off, respectively.
(3) Unmodified and modified transmissivities (T) and storativities (S) are apparent average values between H-3b2 and indicated well, assuming radial flow to H-3b2.

preferential connection between the H-3 pad and the southeast portion of the WIPP site. He further concludes, consistent with single-pad interference testing at both H-3 and H-11 (see Section 4.1.2), that this connection is related to fractures. Third, holes north and northwest of H-3b2 were much slower to respond to the H-3 multipad test, indicating relatively poor and variable hydraulic connection in this direction. Hole H-1, 815 m from H-3b2, did not respond to pumping until approximately 488 hours into the test. The best estimate of the average transmissivity between H-3b2 and H-1 is 4.9×10^{-7} m^2/s. H-2b2, slightly further from H-3b2 than hole H-1, responded earlier (433 hours). The slightly higher apparent transmissivity between H-2b2 and H-3b2 (1.3×10^{-6} m^2/s) than between H-1 and H-3b2 indicates local variability within the Culebra dolomite, even in the low-transmissivity domain containing H-1, H-2, and H-3. In contrast to behavior at and southeast of the H-3 pad, there is no indication that regional-scale flow or pressure response between H-3 and either H-2b2 or H-1 involved fractures. Holes WIPP-19, 21, and 22 are north of the WIPP facility (Figure 4.1.6). Therefore, their response to any pumping test at H-3 will be influenced by the intervening WIPP shafts, unless the sealing of these shafts is perfect. There was, in fact, considerable uncertainty about the rates of leakage from the Culebra into the WIPP exhaust and waste-handling shafts during the H-3 test. As a result, interpreted transmissivities for flow paths extending north of the center of the WIPP site, i.e., between H-3b2 and holes WIPP-19, 21, and 22, may be inaccurate (Beauheim, 1987a).

Several observation holes did not respond measurably during the H-3 multipad test, including H-4, P-14, P-15, and P-17. Therefore, only minimal transmissivities could be calculated for areas south and southwest of H-3, based on the lack of response. Beauheim (1987a) estimates that the average transmissivity between H-4 and H-3b2 would need to be less than 1.0×10^{-6} m^2/s. As indicated in Table 4.2, drilling and testing of hole H-14 has since yielded results consistent with this bounding interpretation.

Tomasko and Jensen (1987) note a strikingly linear relationship between the observed drawdowns and the square root of time in holes H-3b2, H-11b1, and DOE-1 during the H-3 multipad test, and conclude from this that much of the response to the test in this area was a result of "linear flow," in which flow is largely confined to a linear high-transmissivity structure between less-permeable boundaries. Their interpretation is a second line of evidence for a high-transmissivity structure in the southeastern part of WIPP Zone 3. Figure 4.1.7 shows the nearly linear response of H-3b2 versus the square root of time during the pumping phase of the H-3 multipad test. Tomasko and Jensen (1987) interpret the limited curvature shown in Figure 4.1.7 to reflect the fact that the high-transmissivity structure containing H-3b2 is finite in width.

Figure 4.1.8 compares observed drawdowns and recoveries at H-11 and DOE-1 with those calculated assuming linear flow in a high-transmissivity structure oriented N29W. There is good agreement during the pumped phase, even with a model that used a simplified transmissivity distribution. Although calculated drawdowns exceed those measured, the shape of both drawdown and recovery curves agree well. This linear-flow approach yielded average transmissivities of 2.2×10^{-6}, 9.7×10^{-6}, and 2.0×10^{-5} m^2/s for

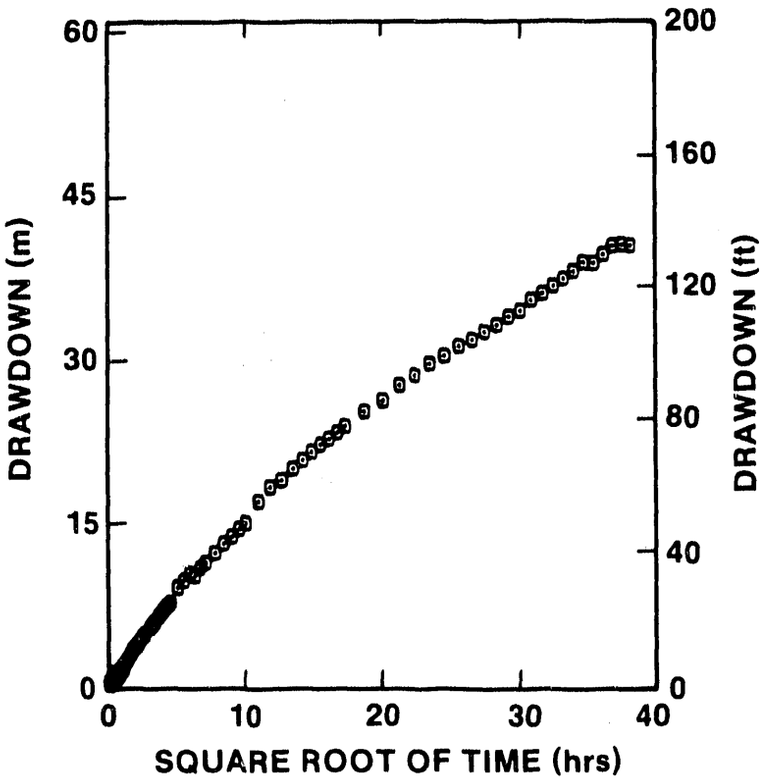


Figure 4.1.7: Observed drawdown versus the square root of time in hole H-3b2 during the H-3 multipad interference test. Slightly modified from Figure 15 of Tomasko and Jensen (1987).

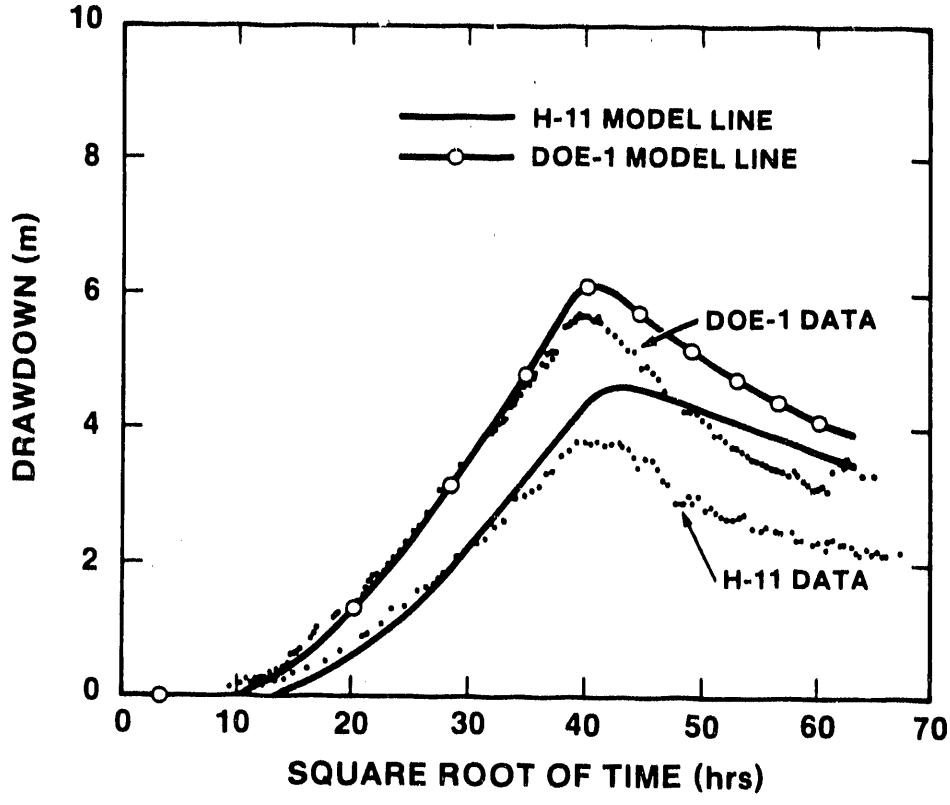


Figure 4.1.8: Comparison of measured and simulated responses at H-11 and DOE-1 during the H-3 multipad interference test, assuming perfectly linear flow. Figure 25 of Tomasko and Jensen (1987).

the H-3 pad and between H-3 and DOE-1 and H-11, respectively. These results are in qualitative agreement with the results of Beauheim (1987a) discussed above (2.0×10^{-6}, 5.9×10^{-6}, 7.3×10^{-6} m^2/s, respectively).

The analytical approaches discussed thus far involve specific assumptions, some of which pose real limitations in interpretation of testing on this geometric scale within a unit as complex as the Culebra dolomite. These include:

1. Regional-scale flow is assumed to be either perfectly radial or perfectly linear.

2. Transmissivities are either assumed uniform between pumped hole and observation hole, or a simplified transmissivity distribution is assumed.

3. Constant fluid density is assumed.

4. The Culebra dolomite is assumed to be completely confined.

In contrast, the approach taken by Haug et al. (1987), using the code SWIFT II (Reeves et al., 1986a; Reeves et al., 1986b), is fully numerical, and includes consideration of: a) a more complex pattern of regional flow, based on calculation of transmissivities between measurement points; b) variable fluid densities; and c) vertical fluid flux into or out of the Culebra. The modeling approach of Haug et al. (1987) assumes steady-state boundary conditions.

The results of non-directional kriging of the April 1986 Culebra-transmissivity data base (Figures 4.1.9 and 4.1.10) provide a quantitative indication of the statistical reliability of the data base at that time, independent of geologic and hydrologic judgement. The limited size of the data base resulted in the kriged transmissivity pattern consisting largely of "circles" around measured data points (Figure 4.1.9). The roughly circular areas within which the uncertainty in transmissivity (defined here as one standard deviation) was less than one order of magnitude were centered on individual hydro holes and approximately one kilometer in diameter (Figure 4.1.10). The only regions in which the areas of one-order-of-magnitude uncertainty overlapped was in the regions H-1 - H-2 - H-3 and H-11 - DOE-1. This finding provided strong impetus for testing of additional holes within WIPP Zone 3, as indicated by the large number of holes in Table 4.1 for which data have been collected or revised since April 1986.

One major emphasis of Haug et al. (1987) is consideration of the regional hydrologic behavior of the Culebra, independent of transient effects imposed by the WIPP facility. This required estimation of Culebra head potentials as they existed prior to the sinking of the WIPP shafts (Figure 4.1.11). Figure 4.1.12 shows the simulated or calculated Culebra transmissivity distribution resulting from calibration of downhole pressures within the Culebra against the "measured" pre-shaft freshwater-equivalent head potentials shown in Figure 4.1.11. The calibration effort

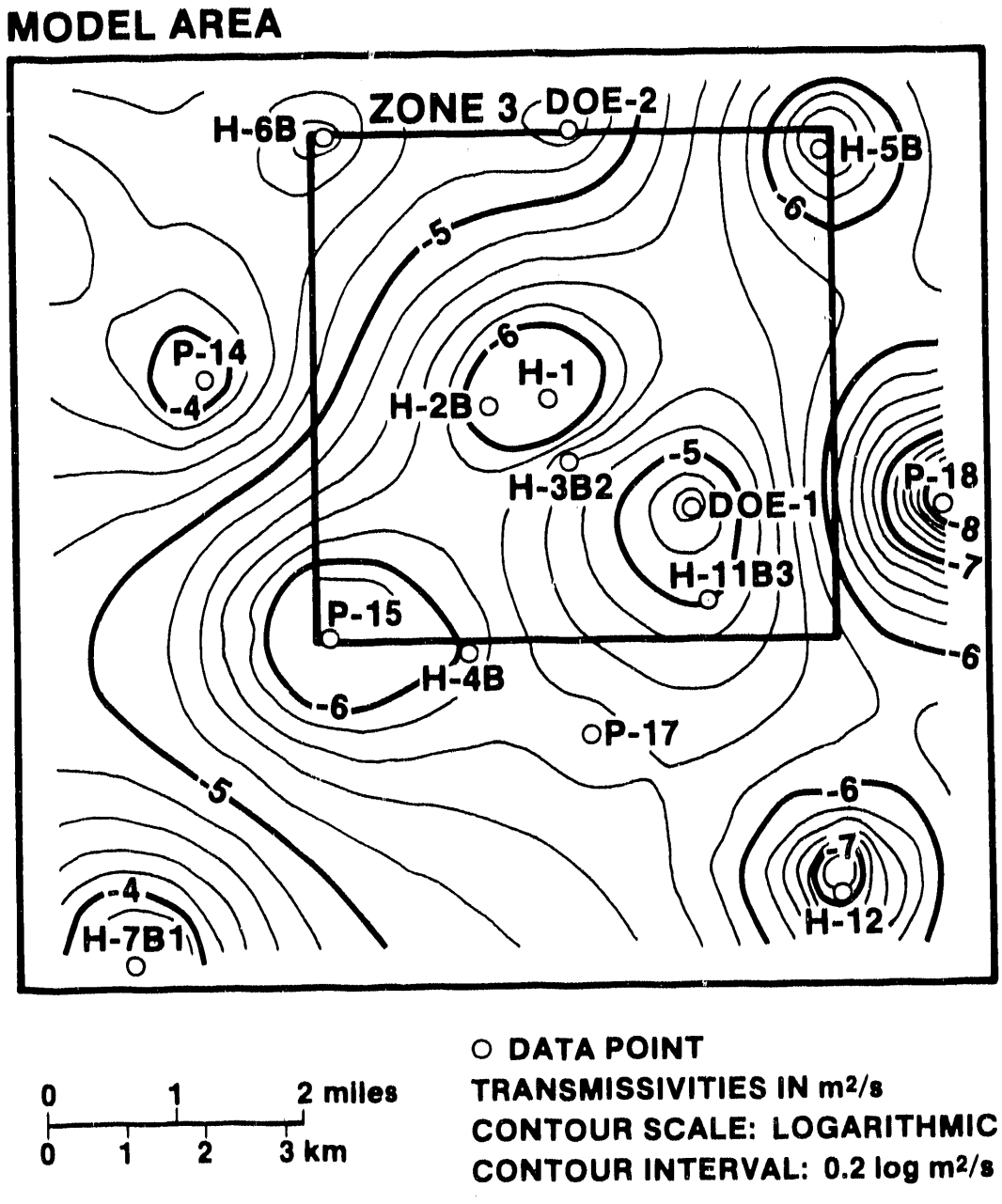


Figure 4.1.9: Initial kriged Culebra transmissivities, based on data available as of April 1986. Slightly modified from Figure 3.7 of Haug et al. (1987).

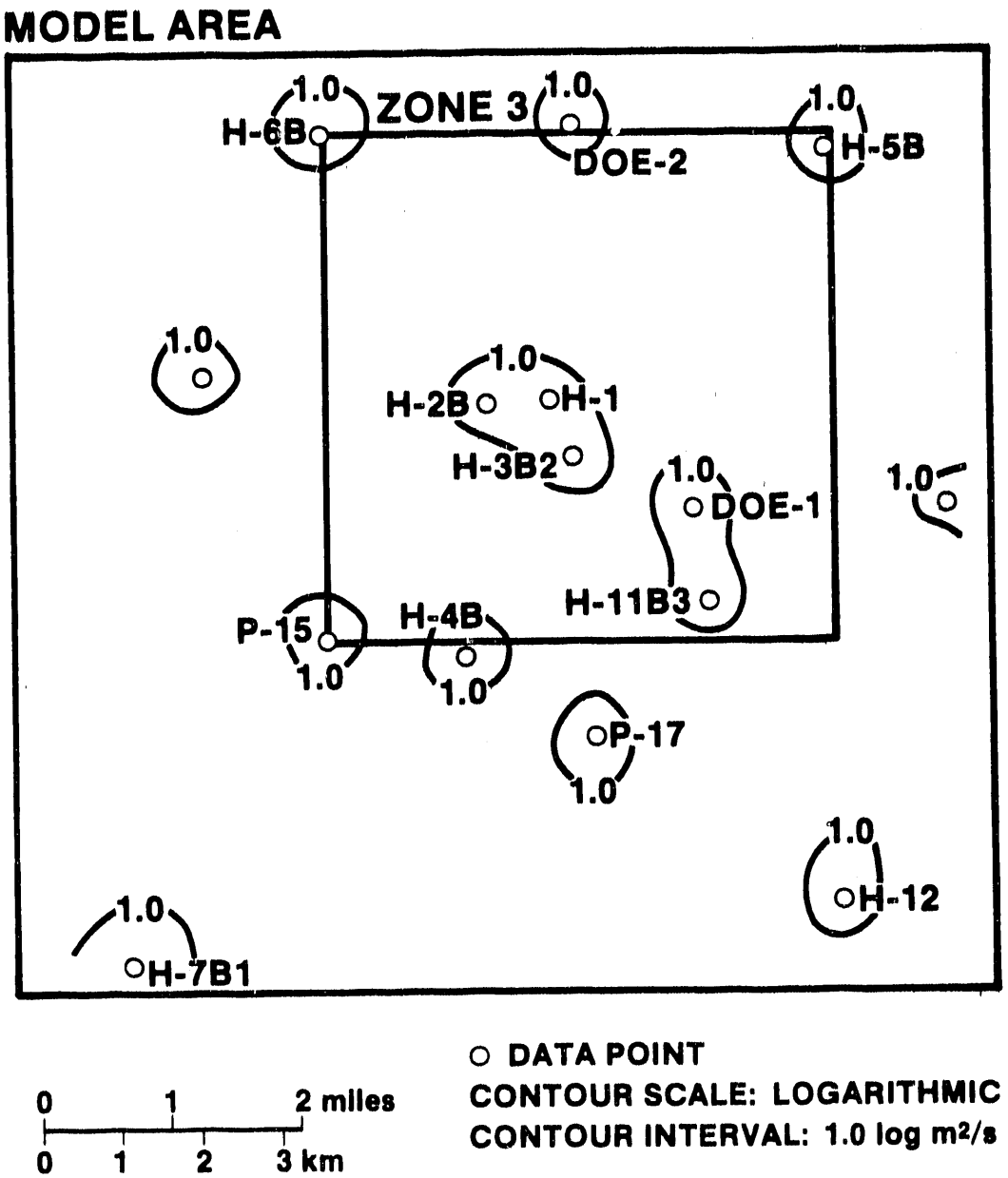


Figure 4.1.10: Estimation error in initial kriged Culebra transmissivities, based on data available as of April 1986. Slightly modified from Figure 3.8 of Haug et al. (1987).

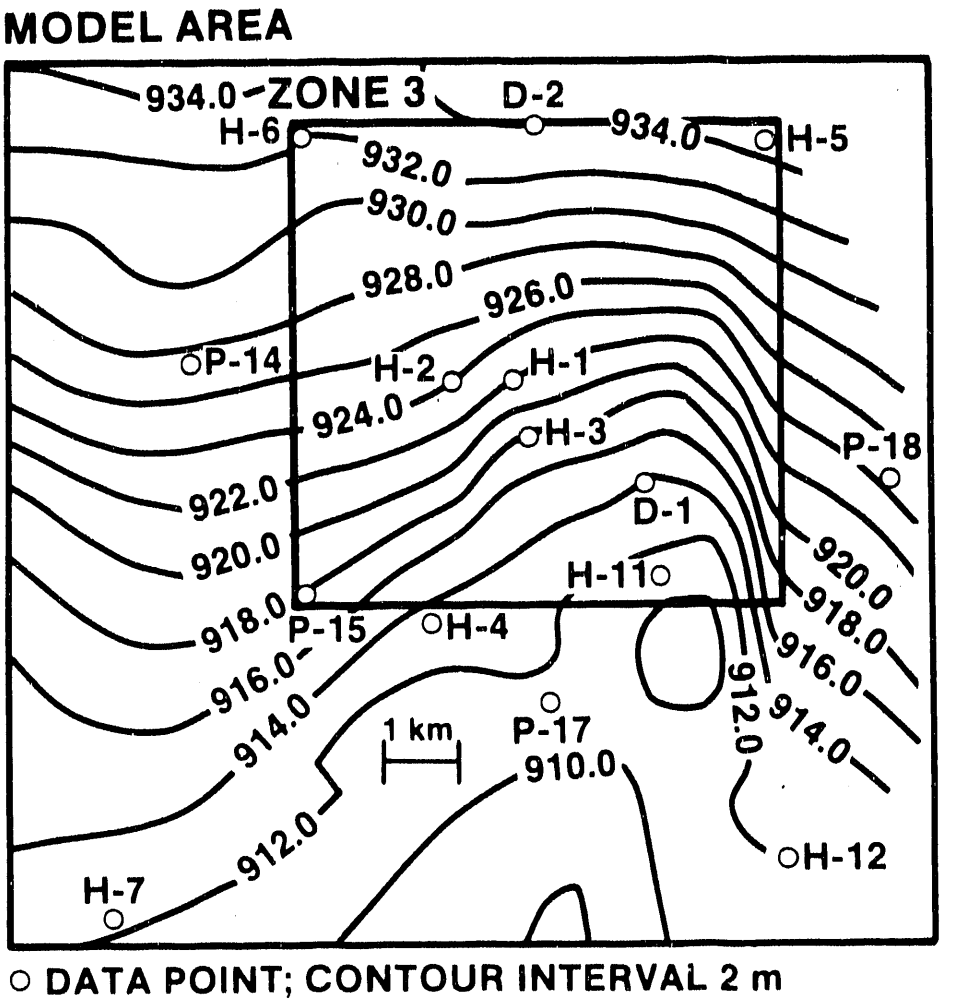


Figure 4.1.11: Best estimate of pre-shaft Culebra freshwater equivalent heads, based on data available as of April 1986. Slightly modified from Figure 3.9 of Haug et al. (1987).

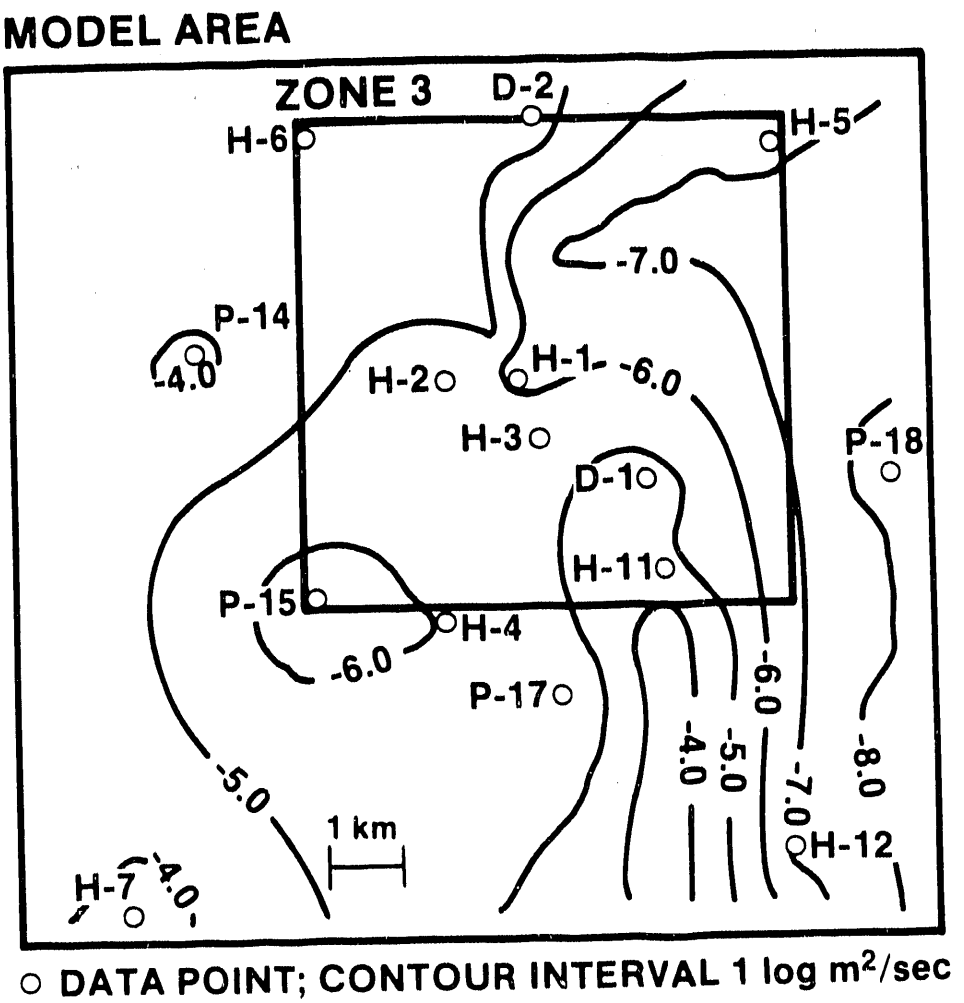


Figure 4.1.12: Best calculated distribution of Culebra transmissivities, based on pressure calibration to head distribution shown in Figure 4.1.11. Slightly modified from Figure 4.4 of Haug et al. (1987).

involved use of "pilot points" in some locations between measured data. At the pilot points, transmissivities were assigned, consistent with the uncertainty in initial kriged values. Evaluation of the statistical properties of the expanded data base including the pilot-point transmissivities indicated that the statistical properties of this data base were consistent with those of the measured data.

The transmissivity distribution in Figure 4.1.12 is marked by four main features:

1. A large and apparently continuous zone of relatively low transmissivity ($T<10^{-6}$ m^2/s) including the site center, the locations of the WIPP shafts, and extending to the east and northeast.

2. An apparently isolated region of low transmissivity in and near the southeastern portion of the site, in the region P-15 - H-4 - P-17. As noted in Section 4.1.1, it is not clear from existing point data whether or not this zone is connected to the low-transmissivity zone closer to the site center.

3. A narrow high-transmissivity zone ($T>10^{-5}$ m^2/s) in the region containing H-11 and DOE-1, and extending to the south. This zone was largely required in the model to account for the relatively low heads observed at H-11 and DOE-1 (Figure 4.1.11).

   The central portion of the high-transmissivity zone is defined in Haug et al. (1987) only by several pilot points, since no data from within the zone were available as of April 1986. The zone is consistent with results of both Beauheim (1987a) and Tomasko and Jensen (1987). Model transmissivities in the central part of the zone, approximately 3.0×10^{-4} m^2/s, are similar to the transmissivities at H-9b (1.7×10^{-4} m^2/s) and P-14 (2.3×10^{-4} m^2/s), but lower than the transmissivity at H-7b (1.1×10^{-3} m^2/s) (Table 4.1). The assigned value was chosen in the effort to be reasonably "conservative," i.e., to have the zone contain as high a transmissivity as was reasonable.

4. A relatively large and apparently continuous high-transmissivity zone in the western part of the modeled area. As of April 1986, the high-transmissivity zone included measured data only at holes H-6, DOE-2, P-14, and H-7. The need to define the relationship of this high-transmissivity zone to the low-transmissivity zone containing the center of the WIPP site was a major driving force behind multipad interference testing at WIPP-13 (Section 4.1.3.2).

The calculated transmissivity distribution (Figure 4.1.12) served as a basis for further model calibration (Haug et al., 1987). The distribution of Culebra fluid densities measured as of April 1986 is shown in Figure 4.1.13. Culebra fluids in the vicinity of the WIPP site range in density from approximately 1.00 to greater than 1.10 g/cm^3 (see Section 4.1.3.2). Two main features of Figure 4.1.13 are of note:

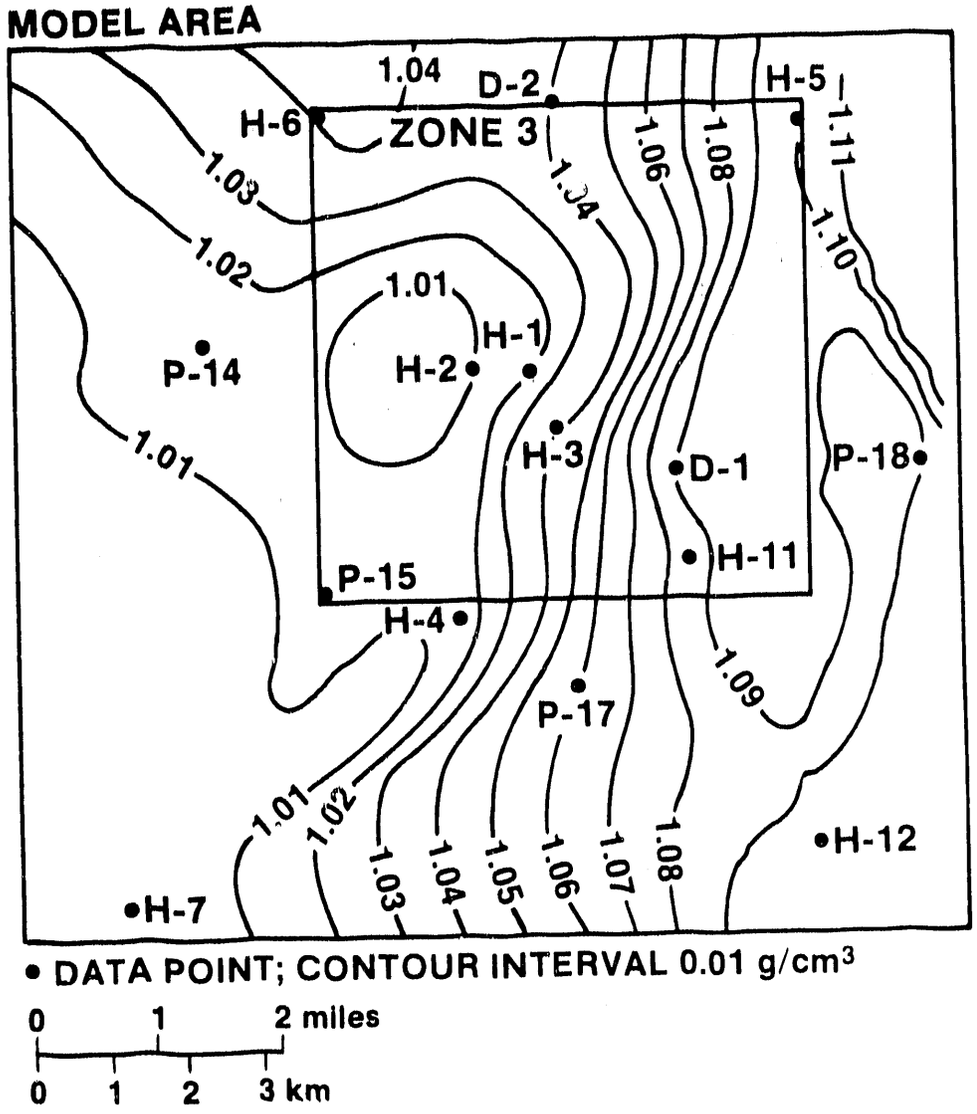


Figure 4.1.13: Best estimate of density distribution of Culebra fluids, based on information available as of April 1986. Figure 3.10 of Haug et al. (1987).

1. A linear zone of steep gradient in fluid density separates a large area of high fluid density (1.08 g/cm^3 or greater) east of the site center from an analogous area of relatively low fluid density (1.04 g/cm^3 or less) west of the site center.

2. Major curvature in the lines of fluid densities 1.01 through 1.04 g/cm^3 in the northwest part of the modeled area. As of April 1986, only measured density data from H-6, DOE-2, H-2, and P-14 provided control for this curvature.

During calibration of Culebra transmissivities against fluid densities, the interpolated brine densities near the boundaries of Figure 4.1.13 were first used as initial boundary conditions in simulation of assumed variable-density steady-state confined flow within the Culebra (Haug et al., 1987). The results of this approach were not satisfactory (Figures 4.1.14 and 4.1.15). Calculated brine densities at steady state are too low in the eastern portion of the model. The density contrasts in the eastern portion of the model (with the exception of the region near P-17) were adjusted successfully by slightly increasing the transmissivity in the northeastern portion of the model, without significantly changing fluid densities assigned at the boundaries. Over the western portion of the model, the problem was more severe. At steady state, a large area, including holes H-1, H-2, P-17, P-15, and P-14, was calculated to have fluid densities between 1.04 and 1.05 g/cm^3, compared to measured densities of 1.06 g/cm^3 at P-17 and less than 1.03 g/cm^3 at the other holes. The high calculated brine densities over the western portion of the site reflect the southward movement of the relatively dense brines at H-6 and DOE-2 required by steady-state confined flow (Haug et al., 1987).

These results are taken by Haug et al. (1987) to be consistent with at least three possibilities:

1. The interpolated brine densities along the northern boundary of the model are incorrect, except for the measured value at H-6. This possibility is considered in detail by Haug et al. (1987). Because of the recent increase in brine-density data in the northwest portion of the modeled area, the possibility is not considered further here (see Section 4.1.3.2).

2. There is enough vertical fluid leakage into and/or out of the Culebra to significantly affect fluid densities within the unit. This possibility is considered further by Haug et al. (1987), and is discussed below (see also Section 4.1.1).

3. The Culebra hydrologic regime is not at steady state on the time scale required for water flow across the modeled area. Transient boundary conditions for the hydrology of the Rustler Formation are consistent with recent geologic and isotopic results discussed in Sections 4.3 and 4.4, but have not yet been modeled directly, and are not considered further here.

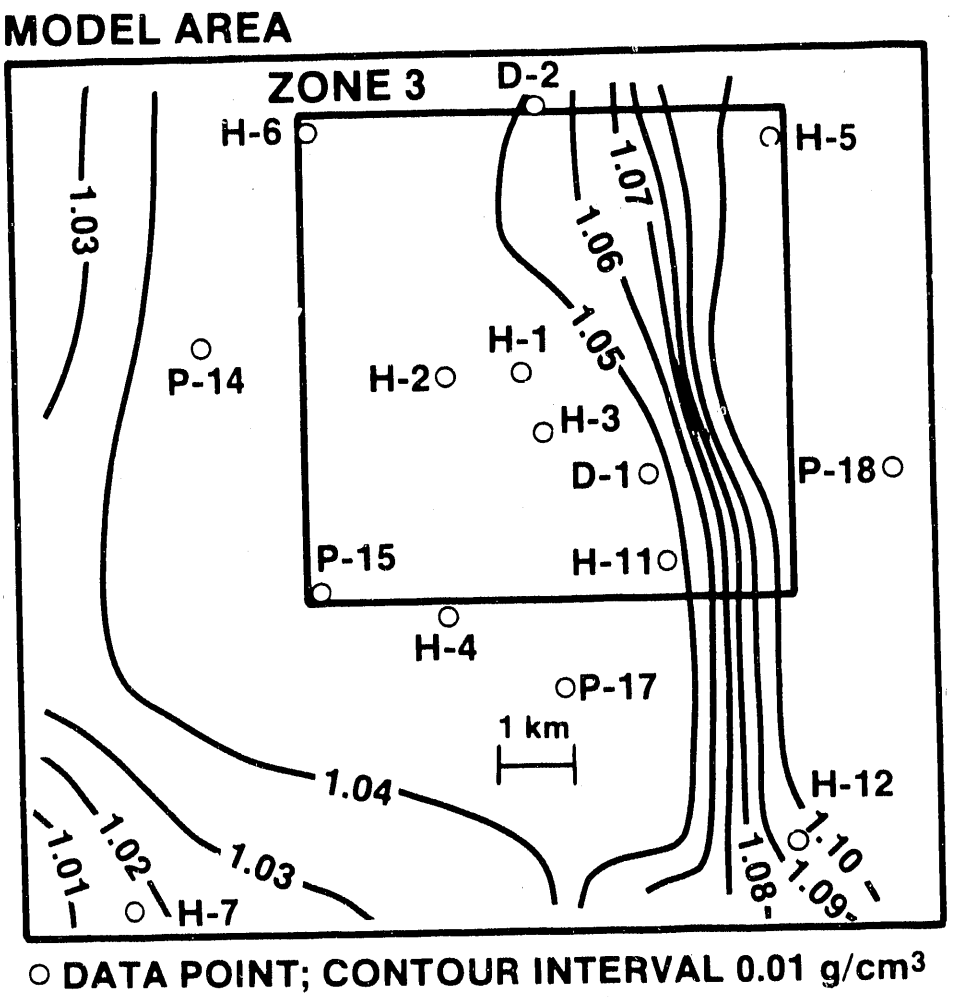


Figure 4.1.14: Calculated steady-state, brine-density distribution within the Culebra dolomite, based on data available as of April 1986. Slightly modified from Figure 4.7 of Haug et al. (1987).

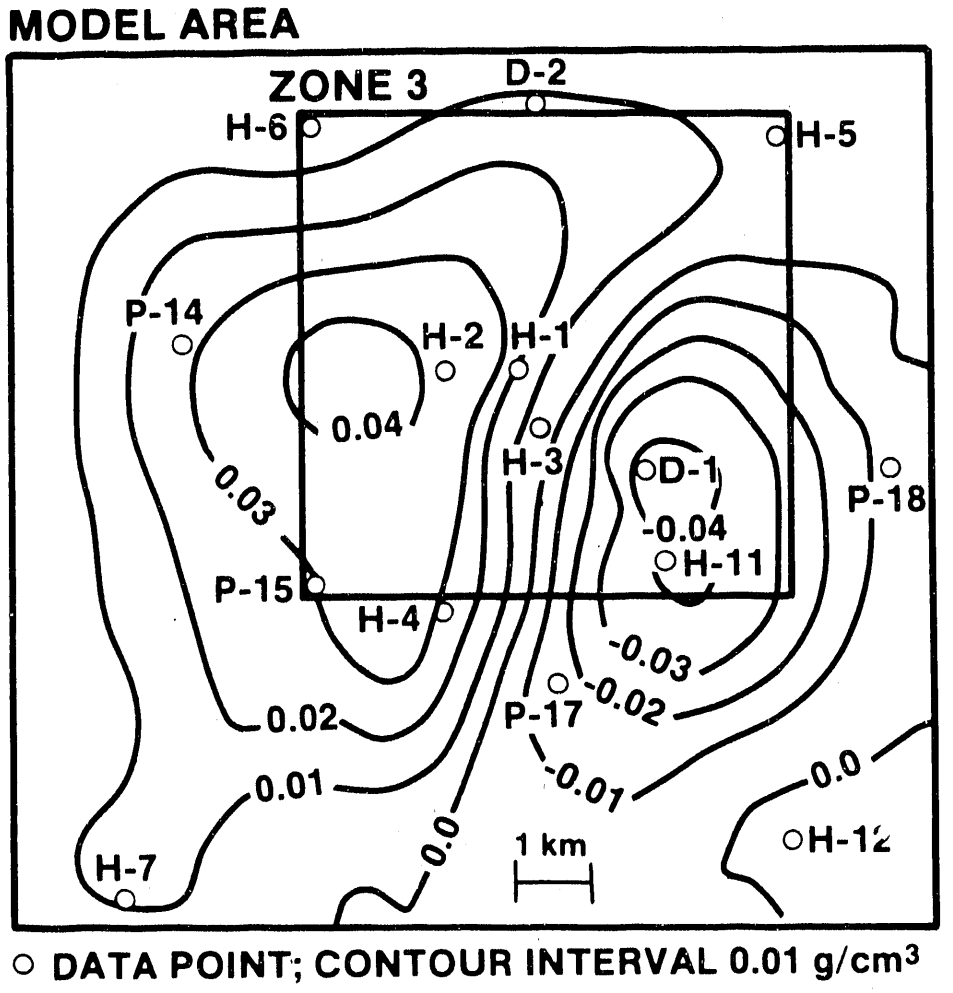


Figure 4.1.15: Difference between calculated steady-state brine density distribution within the Culebra (Figure 4.1.14) and the measured estimated distribution shown in Figure 4.1.13. Slightly modified from Figure 4.8 of Haug et al. (1987).

Haug et al. (1987) initially addressed the density contrast over the western portion of the modeled area by assuming that brine densities along the northern boundary of the model were incorrect; therefore, calibration against fluid density did not change interpolated transmissivities in this area. In the vicinity of hole P-17, however, better agreement between calculated and measured fluid densities was obtained by shifting the location of the southern high-transmissivity zone in Figure 4.1.12 closer to P-17.

Haug et al. (1987) then considered the possibility of vertical fluid flow into and/or out of the Culebra dolomite in two areas:

1. At and near P-17, where measured brine densities were 0.04 g/cm^3 higher than those calculated. Upward flow of relatively dense brine from the Rustler/Salado contact zone, through the unnamed lower member of the Rustler, into the Culebra dolomite was considered at this location, consistent with known head relationships (see Section 4.1.1).

2. Over the western and southwestern part of the modeled area, in which measured fluid densities are significantly less than modeled densities. Uniform downward flow of relatively fresh (low-density) fluids from the Magenta into the Culebra was considered in this area.

Assuming a brine density of 1.19 g/cm^3 for the Rustler/Salado contact zone and/or unnamed lower member of the Rustler in the region near P-17, Haug et al. (1987) estimate that a vertical flux of 10^{-12} m^3/m^2s would be sufficient to result in a calculated brine density within the Culebra of 1.06 g/cm^3, the measured value. Given the approximate vertical gradient of 0.18 m/m at this location, based on head relations shown in Mercer (1983), this flux would require a vertical hydraulic conductivity of 5.7 x 10^{-12} m/s in the unnamed member. This is within the range thought reasonable (Haug et al., 1987), but slightly higher than recently measured adjacent to the WIPP waste-handling shaft (Section 3.3.1.2). Thus, a very small upward flux into the Culebra in the vicinity of P-17 appears to be largely consistent with known data, and improves agreement between measured and calculated brine densities in the area. However, it is not feasible to measure the small flux in a reasonable time in the field.

In considering fluid flow from the Magenta dolomite downward into the Culebra over the western portion of the modeled area, Haug et al. (1987) assumed a brine density of 1.00 g/cm^3 for the Magenta. Addition of a small but constant vertical flux of 5 x 10^{-12} m^3/m^2s over the western portion of the model led to two qualitatively different responses:

1. In areas of low Culebra transmissivity, the resulting freshwater-equivalent heads were increased significantly, causing unacceptable disagreement between calculated and observed heads. In these areas, however, the assumed flux did significantly decrease the calculated brine densities within the Culebra.

2. In areas of high Culebra transmissivity, addition of the vertical flux did not significantly harm the agreement between calculated and

measured freshwater heads, nor did it significantly improve the agreement between measured and calculated brine densities within the Culebra.

Vertical flux from the Magenta downward into the Culebra dolomite over the western portion of the modeled area is consistent with known head and fluid-density relationships in some areas (Section 4.1.1.2). However, the flux, if real, must be laterally variable rather than constant, and the vertical conductivity of the Tamarisk claystone and anhydrites between the Magenta and Culebra may simply be too low at and near the site. The modeling results of Haug et al. (1987) suggest that vertical flow rates must be higher in regions in which the Culebra is more transmissive, and lower in regions where it is less transmissive. This amount of coupling of Culebra transmissivity with that of the overlying Tamarisk and Magenta members has not been identified in the regional variations in transmissivities of the different members of the Rustler at and near the WIPP site. For example, the transmissivity of the Tamarisk claystone, between the Magenta and Culebra, is too low for measurement at and near the site; the transmissivity of the Tamarisk anhydrites may be even lower. Given enough modeling time and effort, it appears that excellent agreement between measured and calculated brine densities within the Culebra dolomite could be obtained by calibration against both transmissivity distribution in the Magenta, Tamarisk, and Culebra and vertical flux, assuming steady-state boundary conditions. However, this agreement would not in any way be unique, and might not be consistent with the inability to measure properties within the Tamarisk. This is not to say that vertical flow is not occurring within the Rustler Formation (see Sections 4.1.1 and 4.4), simply that data are not adequate to model it precisely. The extremely low transmissivity of the Tamarisk claystone and anhydrites, relatively high transmissivity of the Culebra, and geochemical relationships within the Rustler (Section 4.4) suggest that transient confined flow within the Culebra dominates Rustler hydrology at and near the WIPP site.

In summary, model calibration to the Culebra pre-shaft head distribution by Haug et al. (1987) largely met with success, but also indicated uncertainties in the understanding of Culebra and Rustler hydrology. Calibration to the freshwater head distribution was successful to within one meter of measured values. Assuming steady-state confined flow, however, the resulting Culebra transmissivity distribution was not successful in simulating the measured brine-density distribution. In the eastern portion of the model, the required adjustment in transmissivity was minor. Over the western portion of the model, the results of Haug et al. (1987) indicated that: 1) the April 1986 understanding of brine densities may be qualitatively incorrect; 2) there may be regional-scale vertical flow within the Rustler Formation; and/or 3) the hydrologic setting of the Rustler Formation may be transient on the time scale required for groundwater flow across the modeled area.

The next step in model calibration by Haug et al. (1987) was simulation of transient stresses within the modeled area, assuming steady-state boundary conditions. Several transient activities were simulated, including: 1) sinking and grouting of the three existing WIPP shafts; 2) three pumping

tests and slug tests at H-2; 3) convergent-flow tracer testing at H-3; 4) a step-drawdown hydraulic test at H-3; and 5) the multipad interference test at H-3.

Responses to shaft sinking and grouting (both occurring before the H-3 multipad test) were well simulated using the density-calibrated transmissivity distribution estimated by calibration to the pre-shaft head distribution. From this, Haug et al. (1987) concluded that the transmissivity distribution in the region containing H-1, H-2, H-3, DOE-1, and H-11 was approximately correct.

Responses in the WIPP shafts and in holes WIPP-19, 21, and 22 during and after the H-3 multipad test could not be simulated closely unless additional leakage in the shafts was assumed to have occurred during the test. This conclusion, while coincidental, is supported by the fact that the hydraulic responses to sinking and initial grouting of the shafts were well simulated using the "steady-state" transmissivity distribution, while the later H-3 test itself was not.

The final calculated Culebra transmissivity distribution and fluid-flow velocities estimated on the basis of data available as of April 1986 and including adjustment for fluid-density effects in the eastern half of the model are shown in Figure 4.1.16. Four features are of note in this figure:

1. Fluid flow (presented as Darcy velocities) is extremely slow in the area H-12 - H-5 - WIPP-12. Calculated Darcy velocities in this area are 10^{-9} m/s or less.

2. Fluid flow in the southeastern portion of the model is strongly dominated by the high-transmissivity zone in the area H-11 - DOE-1 - P-17. Flow in this area is largely north-south, with Darcy velocities of approximately 10^{-8} m/s.

3. Flow in the northwest and western portions of the modeled area is rapid and largely north-south. Darcy velocities in this area range approximately from 5×10^{-9} to 1×10^{-8} m/s.

4. The region near the center of the WIPP site (WIPP-12 - P-15 - P-17) has relatively low Darcy velocities, approximately 1×10^{-9} to 3×10^{-9} m/s. The high-transmissivity zone to the southeast forces fluid flow in the region between H-4 and the center of the site to be northwest-southeast, in effect connecting the two high-transmissivity zones southeast and northwest of the site center. The control for this flow at the time of the H-3 multipad test was limited, since hole H-14 did not exist at that time.

As discussed in Section 4.1.2, interference testing at the H-3 and H-11 hydropads indicates the strong local influence of fracturing on hydraulic response. Haug et al. (1987) investigate whether or not a dual-porosity formalism is required to model regional-scale responses within the Culebra dolomite by examining times required for pressure equilibration between matrix blocks and fractures.

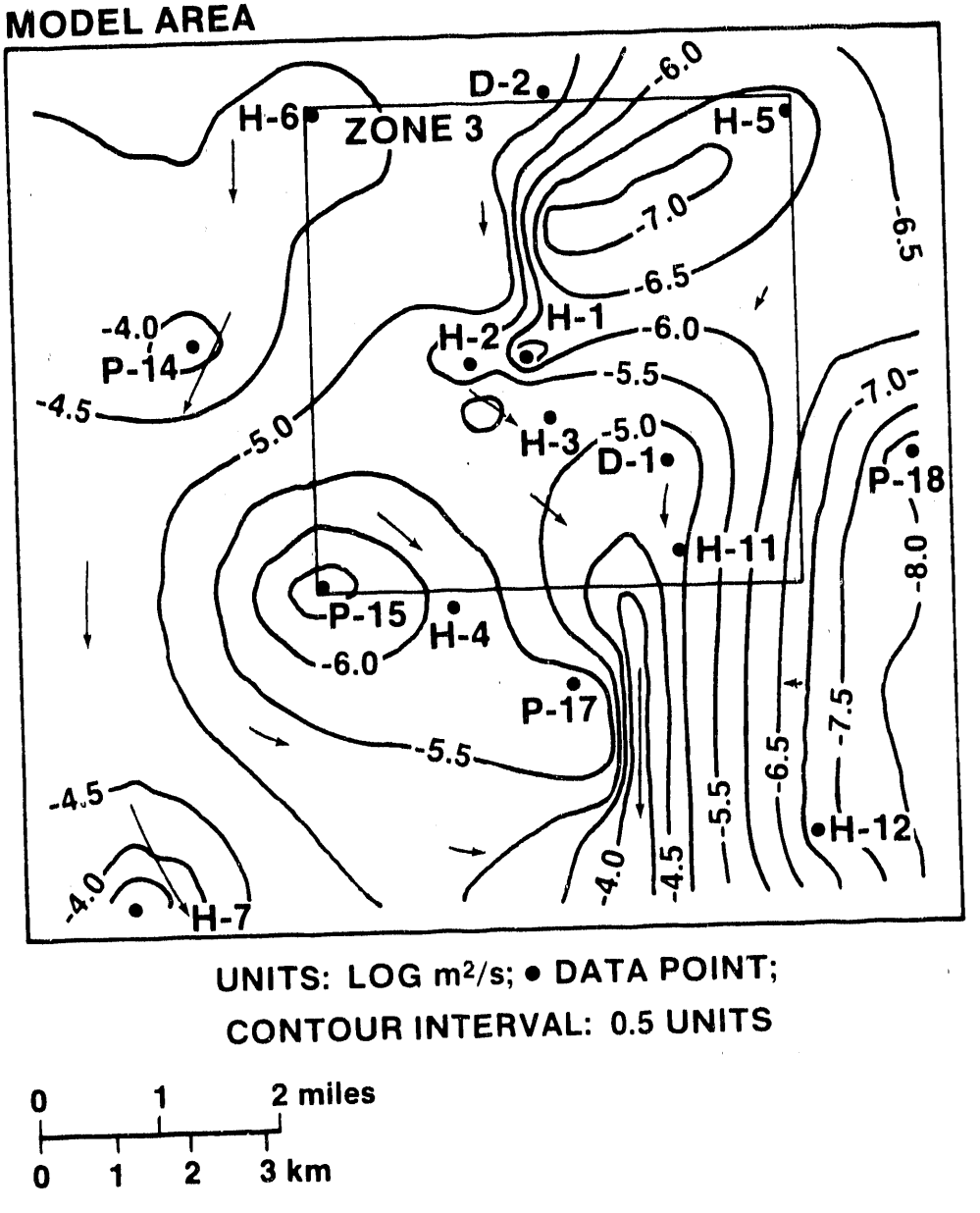


Figure 4.1.16: Final calculated Culebra transmissivities and flow directions, based on data available as of April 1986. Slightly modified from Figure 4.11 of Haug et al. (1987).

The time required for pressures in the fracture and matrix in a fractured medium to equilibrate to within 1% is proportional to the square of matrix block size and linearly proportional to the fluid diffusivity within the matrix. For a range of Culebra matrix block sizes (fracture spacings) between 1 and 8 m and a representative range of matrix compressibilities, matrix porosities, and matrix conductivities, Haug et al. (1987) calculate a maximum pressure-response time of 26 days. For the base-case properties interpreted from conservative-tracer testing at the H-3 pad (Section 4.2) the calculated pressure response time is only six hours. Based on these preliminary calculations, Haug et al. (1987) conclude that a dual-porosity formalism is not needed in modeling the regional-scale hydraulic responses within the Culebra dolomite at and near the WIPP site. Haug et al. (1987) modeled the transient hydraulic responses at the H-3 hydropad to both shaft sinking and sealing and the H-3 multipad interference test using both dual-porosity and porous-medium formalisms to examine this conclusion further. Consistent with their conclusion that use of the dual-porosity formalism is not needed at a regional scale, the maximum difference between the transient freshwater heads calculated using the two approaches is 0.02 m.

However, the validity of this conclusion is somewhat limited by the range of fracture spacings considered. The correlation between fracturing and transmissivity within the Culebra discussed in Section 4.1.1 indicates that fracturing is significant in areas of transmissivity greater than approximately 10^{-6} m^2/s. The approximate fracture spacing at the H-3 pad, with a transmissivity of 2×10^{-6} m^2/s, is 0.25 to 1 m (Section 4.2). Zones of higher transmissivity presumably have smaller effective block sizes. The preliminary calculations of Haug et al. (1987) indicate that it is in zones of otherwise low transmissivity, in which fracturing is not evident in single-hole testing, and in which fracture spacings may significantly exceed the thickness of the Culebra, that hydraulic behavior on something approaching the regional scale might be controlled by fracturing. However, there is no evidence of any discrete fracture structures within low-transmissivity portions of the Culebra dolomite at or near the WIPP site.

In summary, fielding and interpretation of the H-3 multipad interference greatly increased the understanding of the hydrology of the Culebra Dolomite Member of the Rustler Formation. It emphasized the role of fracturing and lack of hydraulic anisotropy within the H-3 hydropad. The analytical interpretation by Beauheim (1987a) indicated the presence of a high-transmissivity region in the vicinity of H-11 and DOE-1, suggested strong directional dependence of responses to the test, and suggested that transmissivities between H-3 and H-4 were probably less than 10^{-6} m^2/s, an interpretation later confirmed by drilling and testing of hole H-14. The interpretation of Tomasko and Jensen (1987) indicated that regional-scale flow in the southeastern portion of the WIPP site was probably controlled by a linear high-transmissivity zone. Numerical modeling of the site area by Haug et al. (1987) yielded a more complete estimate of the lateral distribution of Culebra transmissivities, qualitatively consistent with the interpretations of Beauheim (1987a) and Tomasko and Jensen (1987). A high-transmissivity region in the vicinity of H-11 and DOE-1 was interpreted to be present, in addition to a largely separate high-transmissivity zone west and northwest of the site center. Large areas northeast, east, and

southwest of the site center appeared to have low transmissivity. The interpretation of Haug et al. (1987) indicated both that fluid flow on the WIPP site proper was largely controlled by the high-transmissivity zone containing holes H-11 and DOE-1, and that the effects of this zone included northwest to southeast flow across the area including H-4 and the site center itself. Consideration of discrete fractures or inclusion of dual-porosity formalism appears not to be required to model the regional-scale hydrologic behavior of the Culebra dolomite at and near the WIPP site.

Limitations to interpretation of the H-3 multipad test strongly influenced hydrologic field activities in 1986 and 1987. On a regional scale, the information gained through the H-3 test supported fielding and interpretation of a test centered at WIPP-13, which is discussed in the next section. In preparation for this test, updated and more-reliable data on the Culebra were collected at DOE-2, and a series of WIPP holes (13, 18, 19, 21, and 22). The paucity of reliable data in the southern half of Zone 3 led to the drilling and testing of H-14 and H-15, as well as to reentry and testing of the Culebra in P-17, H-4c, P-14, P-15, Cabin Baby-1, and ERDA-9. The scarcity of head-potential and hydraulic-property data from members of the Rustler other than the Culebra led to testing of all members in holes H-14, and H-16. H-16 itself was sited primarily to address the problem of linkage between all five members of the Rustler Formation and the WIPP air-intake shaft.

4.1.3.2 The WIPP-13 Multipad Interference Test and the Regional Culebra Model of LaVenue et al. (1988)--The second regional-scale or multipad interference test of the Culebra dolomite was centered at hole WIPP-13 (Figures 1.2 and 4.1.17). The pumping phase of the WIPP-13 test lasted from January 12, 1987, to February 17, 1987. Water levels were monitored continuously in 17 surrounding wells, at distances ranging from 1280 to 6248 m. Analytical interpretation of the WIPP-13 multipad test is discussed by Beauheim (1987c). Numerical simulation of Culebra transmissivities and pre-shaft heads in an area including that examined in the WIPP-13 test is the primary focus of LaVenue et al. (1988). This effort includes evaluation of long-term transient hydrologic data at and near the WIPP site. Detailed modeling of transient effects of the WIPP-13 multipad test will be combined during 1988 with calibration of the transient effects of a planned multipad interference test at the H-11 hydropad and emplacement of the WIPP air-intake shaft.

The effects of dual-porosity behavior were quite strong in WIPP-13 during the pumping phase of the WIPP-13 test (Figure 4.1.18). The Culebra in WIPP-13 has an estimated transmissivity of 7.4×10^{-5} m^2/s (Beauheim, 1987c). The Culebra in and near WIPP-13 is best thought of as a double-porosity medium with unrestricted interporosity flow (Beauheim, 1987c).

The analytical interpretation by Beauheim (1987c) indicates that WIPP-13 lies within a relatively homogeneous fractured region, which includes WIPP-13 and DOE-2, as well as the H-6 hydropad (both H-6a and H-6b were monitored during the WIPP-13 test). DOE-2, at a distance of 1475 m from WIPP-13, responded within one hour to the beginning of pumping, while H-6b, at a distance of 2188 m, responded within 8 hours (Table 4.7). The

LOCATIONS OF THE WIPP SITE AND OBSERVATION WELLS

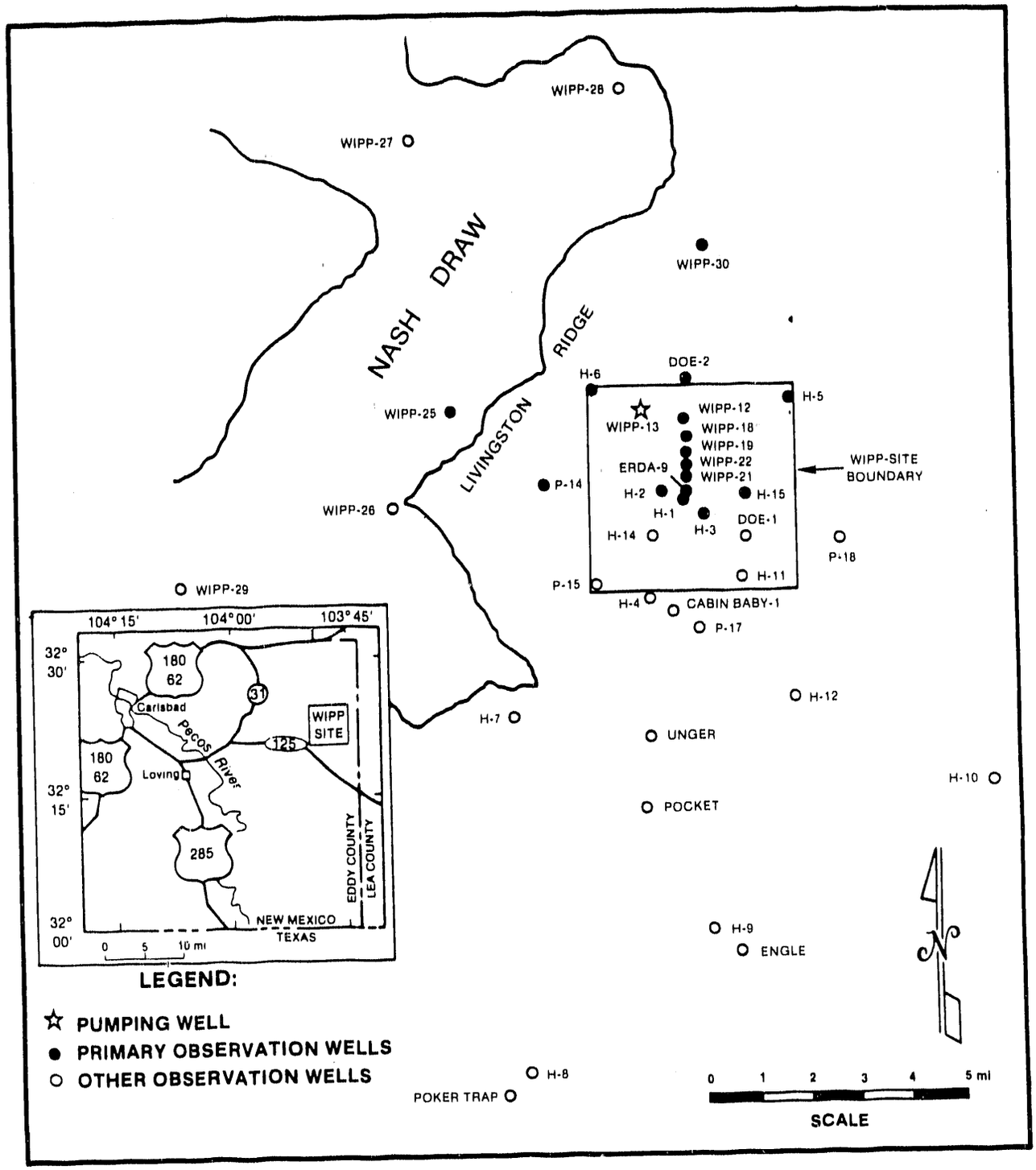


Figure 4.1.17: Pumped and observation wells for the WIPP-13 multipad interference test. Figure 1-1 of Beauheim (1987c).

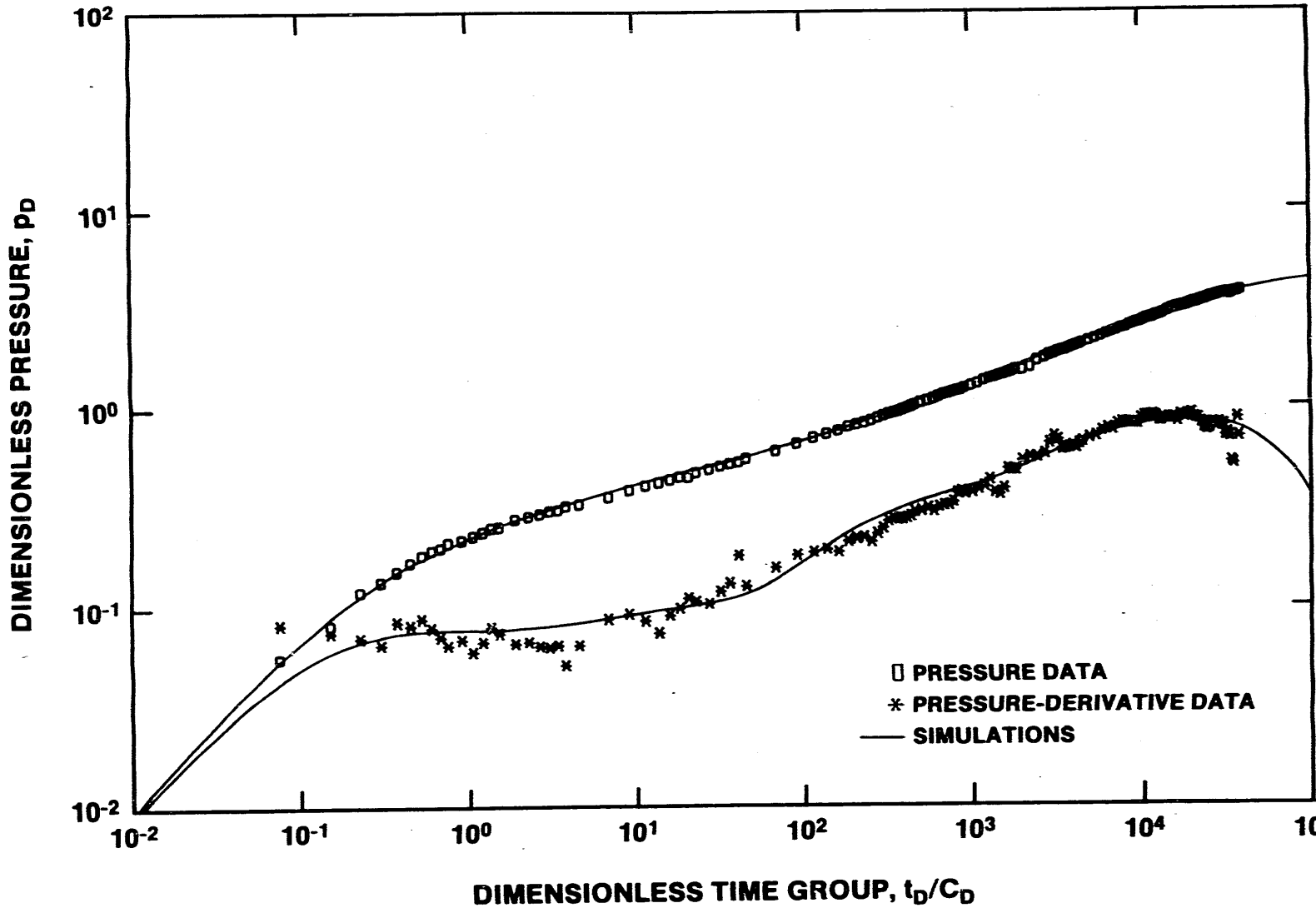


Figure 4.1.18: Measured and simulated hydrologic response of WIPP-13 during the pumping phase of the WIPP-13 multipad interference test. Slightly simplified from Figure 6-1 of Beauheim (1987c).

Table 4.7: Summary of analytical interpretation of results of the WIPP-13 multipad interference test. Slightly modified from data conatined in Tables 3-1, 5-1, and 6-1 of Beauheim (1987c).

Well	Distance(m)[1]	Direction	First [2] Drawdown (hrs)	Delay in Max. Drawdown (hr)	Maximum Drawdown (Psi)	T(m^2/s)[3]	S	Water-Level Modification (m/day)
WIPP-13	0	-	0	0		7.4×10^{-5}	-	-
DOE-2	1475	N45E	1	1	17.3	6.1×10^{-5}	5.1×10^{-6}	-
H-6a	2192	N20W	8	5	7.7	7.6×10^{-5}	8.2×10^{-6}	-
H-6b	2189	N20W	8	5	7.9	7.4×10^{-5}	7.9×10^{-6}	-
WIPP-30	5587	N12E	61	136	4.9	3.0×10^{-5}	5.6×10^{-6}	5.3×10^{-3}
WIPP-12	1283	S55E	74	186	11.9	8.5×10^{-6}	3.6×10^{-5}	4.5×10^{-3}
WIPP-18	1521	S45E	74	86	9.3	2.5×10^{-5}	4.0×10^{-5}	3.6×10^{-3}
WIPP-19	1823	S37E	102	186	7.2	2.6×10^{-5}	4.0×10^{-5}	7.6×10^{-3}
WIPP-21	2216	S29E	133	396	3.6	2.4×10^{-5}	5.3×10^{-5}	1.7×10^{-2}
WIPP-22	1933	S34E	102	286	5.7	2.0×10^{-5}	4.7×10^{-5}	8.2×10^{-3}
H-1	2676	S16E	600	2086(?)	1.1	2.2×10^{-5}	1.3×10^{-4}	1.4×10^{-2}
H-2b2	2597	S0W	445	986	1.4	1.7×10^{-5}	7.3×10^{-5}	6.0×10^{-3}
ERDA-9	2518	S24E	550	396	2.0	2.4×10^{-5}	5.4×10^{-5}	1.6×10^{-2}
Exhaust shaft	2414	S26E	400	336	3	3.0×10^{-5}	5.5×10^{-5}	2.9×10^{-2}
P-14	4228	S58W	71	56	0.8	2.8×10^{-4}	5.2×10^{-5}	-
WIPP-25	6264	S88W	76	26	0.3	7.0×10^{-4}	6.4×10^{-5}	-

(1) Distance and direction from WIPP-13.
(2) Time relative to beginning and ending of pumping phase.
(3) Apparent and effective transmissivity (T) and storativity (S) assume homogenous properties between WIPP-13 and given well, as well as radial flow into WIPP-13.

apparent average transmissivities between WIPP-13 and holes DOE-2 and H-6b are 6.1 x 10^{-5} m^2/s and 7.4 x 10^{-5} m^2/s, respectively. The rapid responses at DOE-2 and H-6b and the low apparent storativities between these holes and WIPP-13, 5.1 x 10^{-6} and 7.9 x 10^{-6}, respectively, suggest that the hydraulic response in this region is strongly affected by fracturing (Beauheim, 1987c).

The boundaries of the zone containing WIPP-13, DOE-2, and H-6 are complex. To the north, the zone appears to extend nearly to hole WIPP-30 (Beauheim, 1987c). This interpretation is based largely on the fact that WIPP-30, with a reported transmissivity of only 3.2 x 10^{-7} m^2/s (Beauheim, 1987b; Mercer, 1983) and at a distance of 5587 m from WIPP-13, responded within 61 hours to the beginning of pumping. In addition, the apparent average storativity between WIPP-13 and WIPP-30, 5.6 x 10^{-6}, is similar to that calculated between WIPP-13 and both DOE-2 and H-6b. Analytical interpretation of the response of DOE-2 to pumping of WIPP-13 requires addition of a low-permeability boundary; i.e., the response at DOE-2 shows the effects of a low-permeability region nearby. A change from high to low Culebra transmissivities must occur somewhere between DOE-2 and WIPP-12, as well as between DOE-2 and H-5.

Results contained in Beauheim (1987b) indicate a Culebra transmissivity of approximately 1.0 x 10^{-7} m^2/s in WIPP-12 (Table 4.2). The apparent average transmissivity between WIPP-13 and WIPP-12 is 8.5 x 10^{-6} m^2/s (Beauheim, 1987c). WIPP-12, only 1283 m from WIPP-13, did not respond to pumping of WIPP-13 until 74 hours into the test. Thus, by analogy with arguments concerning the response of WIPP-30, the boundary between the high-transmissivity zone containing WIPP-13 and the low-transmissivity zone containing WIPP-12 must lie relatively close to WIPP-13.

South of WIPP-12, the boundary between high-transmissivity and low-transmissivity domains probably lies further away from WIPP-13. Holes WIPP-18, 19, 21, 22; H-1, 2; and ERDA-9 all have estimated Culebra transmissivities of 1.0 x 10^{-6} m^2/s or less (Table 4.1). The apparent effective average transmissivities between WIPP-13 and these holes range from 1.7 x 10^{-5} to 2.6 x 10^{-5} m^2/s (Table 4.7), while that between WIPP-13 and the WIPP exhaust shaft is 3.0 x 10^{-5} m^2/s. Times required for the first response to pumping of WIPP-13 range from 74 to 600 hours, including the exhaust shaft. The high-transmissivity zone containing WIPP-13 is consistently represented as a high-permeability boundary in interpretation of the response of these observation holes (Beauheim, 1987c). The apparent behavior between WIPP-13 and the WIPP exhaust shaft is consistent with that between WIPP-13 and nearby observation holes. Beauheim (1987c) notes that the responses in both ERDA-9 and the exhaust shaft appear to be complicated by activities within the shaft.

The relatively homogeneous zone containing WIPP-13, DOE-2, and H-6 appears to be bounded on the west by a zone of higher transmissivity extending into the main portion of Nash Draw (Beauheim, 1987c). Apparent transmissivities between WIPP-13 and holes P-14 and WIPP-25 are 2.8 x 10^{-4} and 7.0 x 10^{-4} m^2/s, respectively. Hole WIPP-25, at a distance of 6264 m from WIPP-13, was the most distant monitoring hole used in the test (Figure 4.1.17).

The presence of both higher-transmissivity and lower-transmissivity domains outside the WIPP-13 - DOE-2 - H-6 region is consistent with the fact the analytical interpretation of the hydrologic behavior at WIPP-13 required the addition of both low-permeability and high-permeability boundaries (Beauheim, 1987c). In addition, a linear-flow interpretation of the flow near WIPP-13 analogous to that completed for the H-3 multipad test by Tomasko and Jensen (1987) was not successful.

The numerical simulation of Culebra hydrology over a large area, including the region stressed in the WIPP-13 test, is discussed and summarized in LaVenue et al. (1988). The emphasis in LaVenue et al. (1988) is on simulation of the Culebra hydrology as it existed before construction of the WIPP shafts, i.e., prior to 1981. Detailed numerical interpretation of the transient hydrologic stresses imposed by the WIPP-13 multipad test, sinking of the WIPP air-intake shaft, and a combined multipad interference test and conservative-tracer test at the H-11 pad will be conducted in 1988.

As noted in Section 4.1.1, there has been a significant increase in the Culebra transmissivity, head, and fluid-density data base since April 1986. In addition, as evident in Figure 4.1.19, the area included in modeling described in LaVenue et al. (1988), 24 x 25 km, is significantly larger than that included in Haug et al. (1987) (see Figure 4.1.6). As a result, the total data base considered in LaVenue et al. (1988) is much larger than that considered only 1.5 years earlier. Culebra transmissivity data from 38 individual wells or hydropads are considered in the 1988 report, as opposed to 24 locations in the 1987 report (Table 4.1). Compilation of the data base used by LaVenue et al. (1988) was significantly more complex for the data base used by Haug et al. (1987), both because of the increased number of holes and because of the increased awareness and concern about transient phenomena in Rustler hydrology. For example, development of the baseline water-level data required consideration of long-term transients, even in holes not directly affected by hydraulic testing at and near the WIPP site. In addition, some well locations were resurveyed (LaVenue et al., 1988); most Culebra fluid densities were revised as a result of recent sampling (Uhland et al., 1987), and were evaluated by detailed pressure-density surveys (Crawley, 1987).

The initial kriged Culebra transmissivities of LaVenue et al. (1988) are shown in Figure 4.1.19, based on data available as of November 1987. The general pattern is different from that indicated in Haug et al. (1987) (Figure 4.1.9). The increase in the available data base results in the initial kriged distribution in Figure 4.1.19 varying smoothly across much of the site area. The kriged transmissivities tend to be higher towards the west and lower towards the east, with an isolated zone of higher transmissivities at H-11 and DOE-1. In Figure 4.1.9, with the exception of the hole pairs H-1 - H-2 and H-11 - DOE-1, each data point tends to define a separate transmissivity zone.

The effects of the increased number of measurements on the Culebra transmissivity data base are demonstrated more clearly by comparison of Figure 4.1.10 with Figures 4.1.20 and 4.1.21. Kriging of the transmissivity data base available as of April 1986 (Figure 4.1.10) indicated that regions of

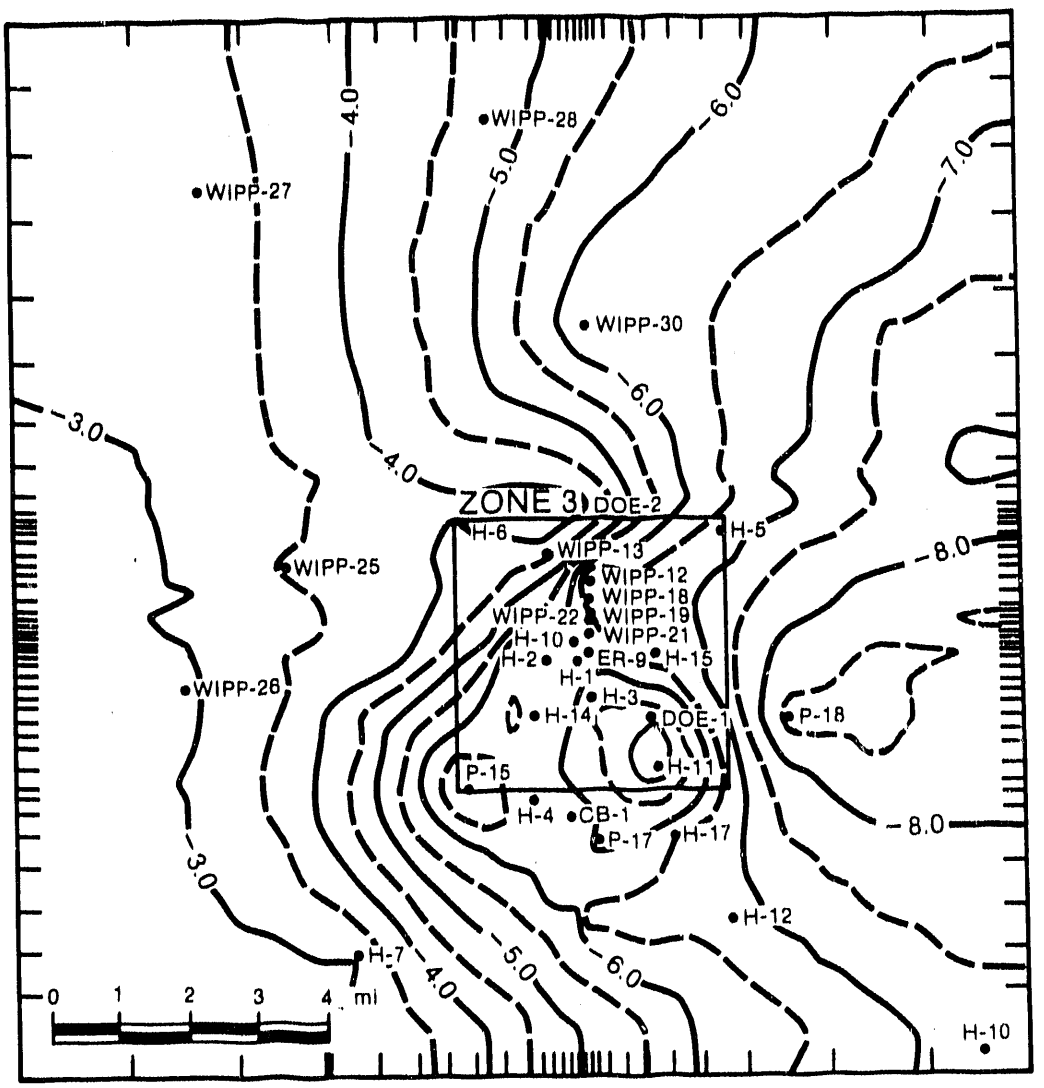


Figure 4.1.19: Initial kriged Culebra transmissivities, based on data available as of November, 1987. Values kriged with code AKRIP. Figure 3.12A of LaVenue et al. (1988).

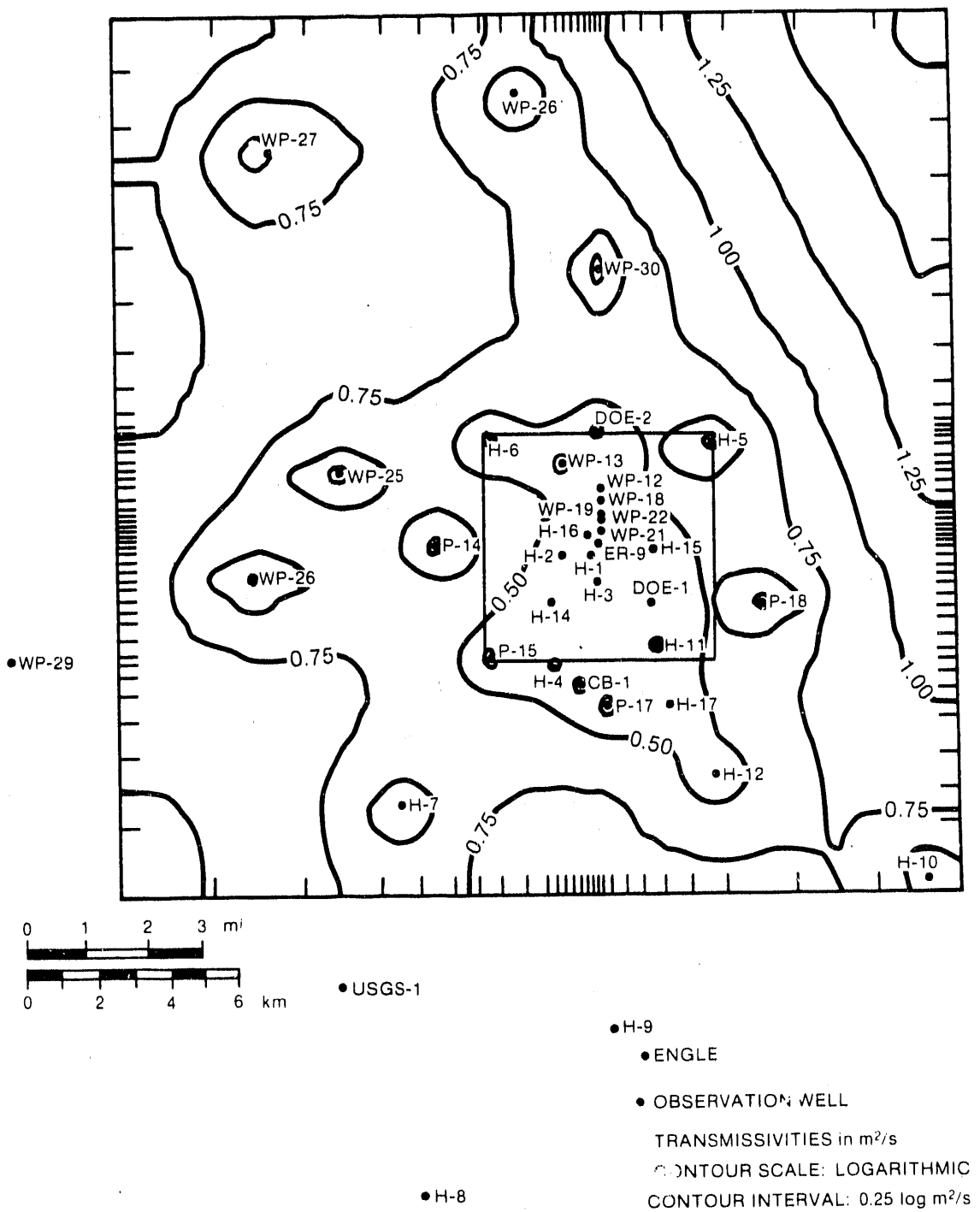


Figure 4.1.20: Estimation error in initial kriged Culebra transmissivities (one standard deviation), based on data available as of November 1987, assuming no uncertainty in individual measurements. Values kriged using code AKRIP. Figure 3.12B of LaVenue et al. (1988).

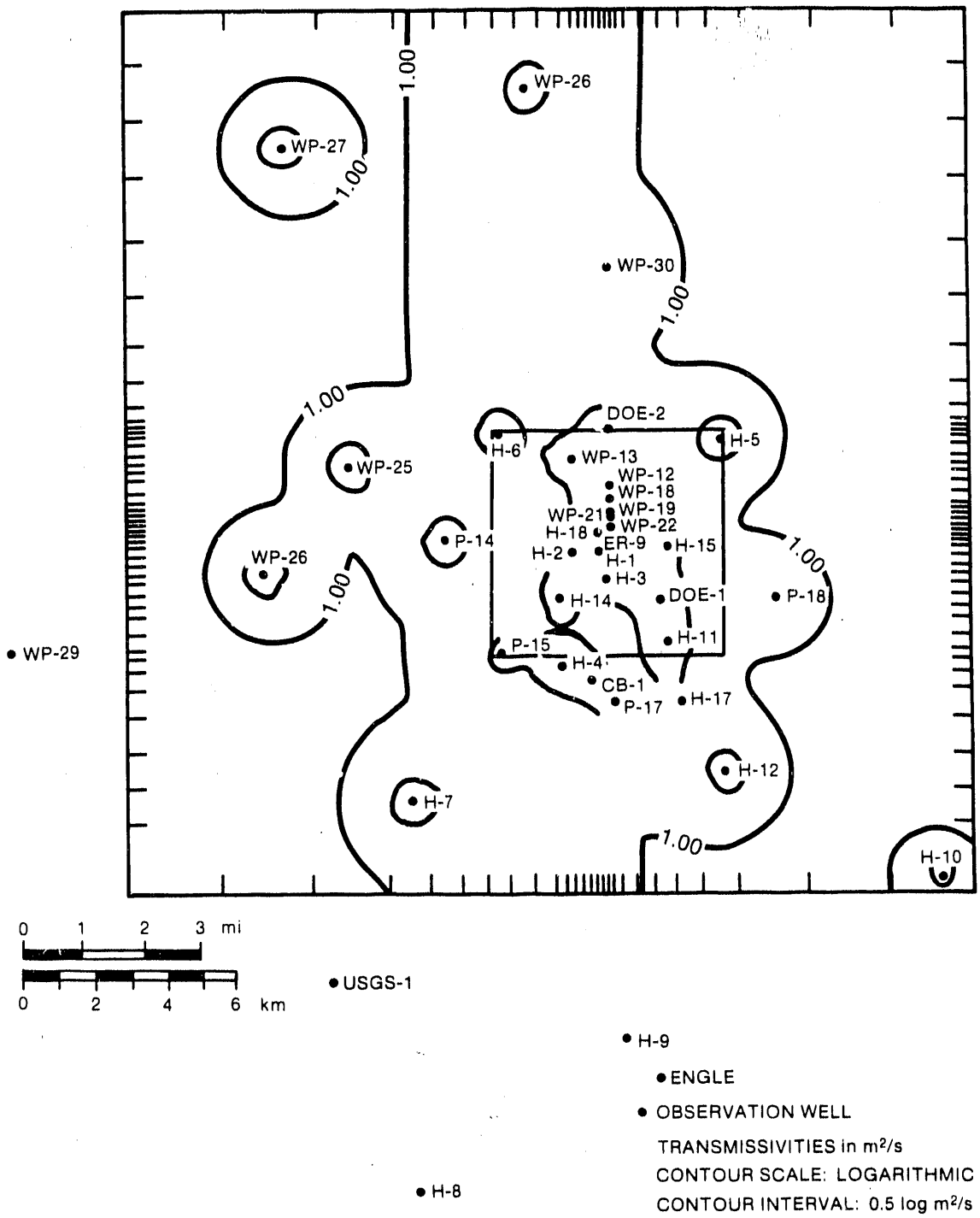


Figure 4.1.21: Estimation error in initial kriged Culebra transmissivities (one standard deviation), including estimated uncertainty in individual measurements. Values kriged using code K603. Figure 3.11B of LaVenue et al. (1988).

one order of magnitude uncertainty (defined at one standard deviation) did not overlap, except in very limited areas. Because of the limited data base available at that time, it was not possible for Haug et al. (1987) to consider either an underlying regional trend in the data or uncertainty in the measured data.

LaVenue et al. (1988) apply two kriging techniques to the Culebra transmissivity data in order to consider both the regional west-to-east decrease in transmissivities (Figure 4.1.19) and uncertainties in the measured data. Kriging of the enlarged data base using the AKRIP code, which fits a polynomial surface to the regional trend, but does not consider uncertainty in the measured data (LaVenue et al., 1988), indicates that the uncertainty in Culebra transmissivities over a large area, including most of Zone 3, should be less than 0.5 log unit at one standard deviation and less than one order of magnitude (1.0 log unit) at two standard deviations (Figure 4.1.20). Within the smaller area including both the center of the WIPP site and the locations the WIPP shafts, the uncertainty at two standard deviations is 0.5 log units or less; i.e., Culebra transmissivities should be estimated to within a factor of approximately three in this region, if it is assumed that field measurements are precise.

Results analogous to those in Figure 4.1.20, calculated by LaVenue et al. (1988) using the K603 code, which applies a linear trend surface to regional data, but allows consideration of uncertainty in measured data, are shown in Figure 4.1.21. LaVenue et al. (1988) estimate the uncertainty in measurements of Culebra transmissivities to be 0.25 log unit when transmissivity is estimated from pumping tests and 0.5 log units when estimated from other tests. Inclusion of these estimated uncertainties in individual measurements, combined with a simplified regional trend surface, suggests (Figure 4.1.21) an estimation error (one standard deviation) of 0.5 log unit or less within most of Zone 3. These results indicate that the uncertainty in Culebra transmissivities at two standard deviations within much of Zone 3, i.e., in a region extending from DOE-2 in the north to beyond H-11 in the south, is less than an order of magnitude, even including the estimated uncertainties in field measurements.

Such statistical approaches must not be overinterpreted, because they include no direct consideration of geologic processes. However, comparison of Figures 4.1.20 and 4.1.21 with Figure 4.1.10 provides a direct impression of the qualitative increase in both the size and reliability of the Culebra data base since April 1986.

The present distribution of measured Culebra fluid densities (LaVenue et al., 1988) is shown in Figure 4.1.22. Although the overall pattern is similar to that estimated on the basis of data available in April 1986 (Figure 4.1.13), with a general west-to-east increase in density, there are two significant differences. The density distribution in the west half of Zone 3 in Figure 4.1.13 is strongly non-linear, due to relatively high densities at H-6 and/or DOE-2. The variation in fluid densities in the region H-1 - DOE-2 - H-6 - P-14, based on data available as of November 1987 (Figure 4.1.22), is less irregular, and the regional trend is more consistent with the general west-to-east increase in density. Fluid

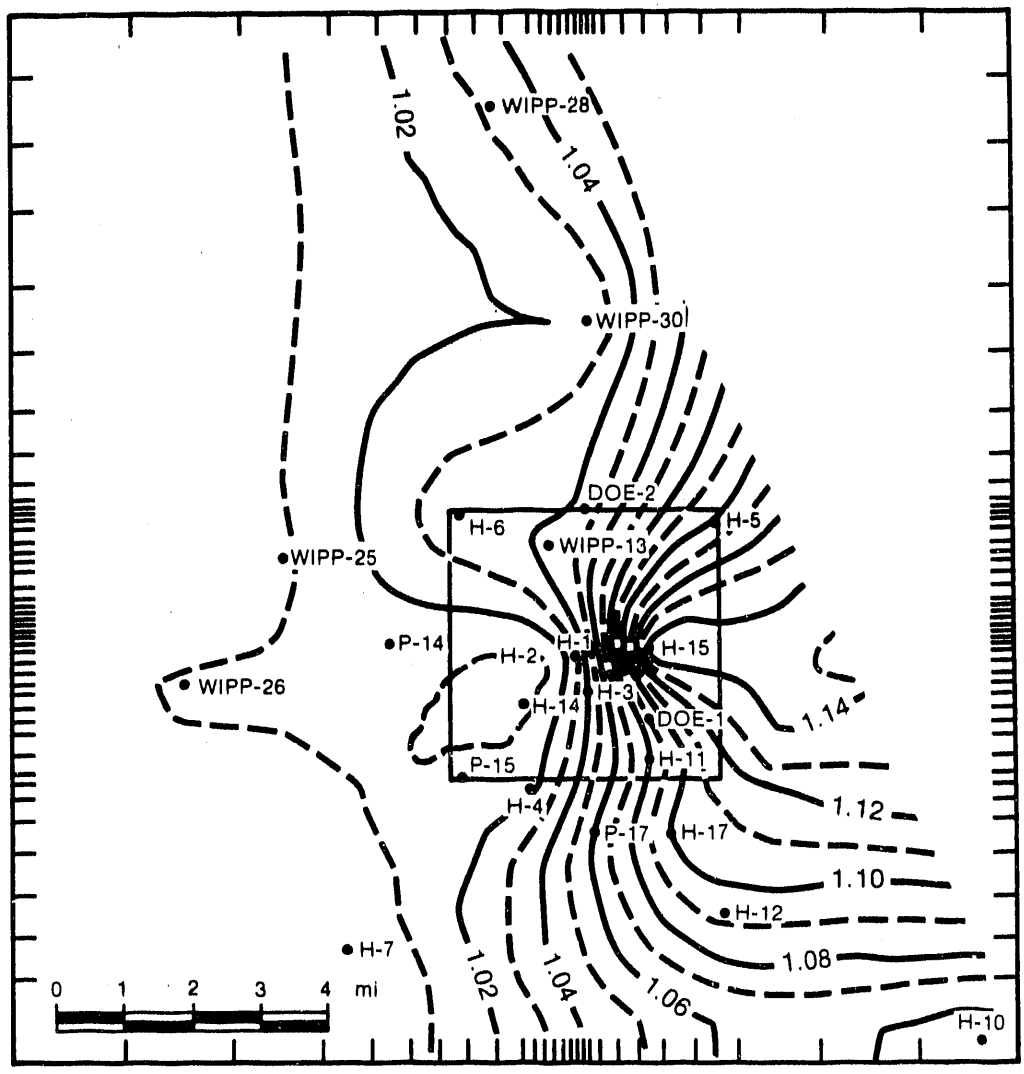


Figure 4.1.22: Measured density distribution of Culebra fluids, based on information available as of November 1987. Figure 3.15 of LaVenue et al. (1988).

densities in the region H-14 - H-2 - P-14 still appear to be anomalously low. The brine density distribution in the eastern part of Zone 3 (Figure 4.1.22) is also somewhat different than in Figure 4.1.13. In Figure 4.1.13, a general north-south trend of constant-density lines extends largely across the WIPP site west of holes DOE-1 and H-11. The distribution is more complex east of these holes. In Figure 4.1.22, the estimated brine density of approximately 1.14 g/cm^3 at hole H-15 causes significant curvature in the density distribution in the eastern portion of Zone 3. Nonetheless, the overall pattern of the distribution of Culebra brine densities based on data available as of November 1987 is simpler than previously estimated.

The present understanding of the distribution of pre-shaft freshwater-equivalent heads within the Culebra dolomite is shown in Figure 4.1.23. The general pattern is similar to that estimated by Haug et al. (1987), with a north-south head gradient of approximately 10^{-3} m/m across the area of the WIPP site. Gradients within the Culebra both south and north of the site are lower, approximately 10^{-4} m/m.

There is, however, one significant difference between the head distributions shown in Figures 4.1.23 and 4.1.11. Head contours form a sharp embayment in the southeastern portion of Zone 3 in Figure 4.1.11, extending at least as far north as the east-center of the site. Interpretation of water-level and fluid-density data available to November 1987 indicates (Figure 4.1.23) that there is little evidence of an embayment in Culebra freshwater-equivalent heads within WIPP Zone 3, except for the 913-m contour in the extreme southern part of the zone. Within the modeled area, head contours up to 919 m elevation do define a broad embayment south and east of the WIPP site. Expansion and improvement of the data base for calculation of Culebra freshwater-equivalent heads during 1986 and 1987 has resulted in significant smoothing of the estimated head distribution, especially within Zone 3.

In calibration efforts by Haug et al. (1987), it was assumed that Culebra fluid pressures and fluid densities were at steady state before construction of the WIPP shafts. As discussed in Section 4.1.3.1, assumption of steady state is adequate for simulation of pre-shaft Culebra heads or fluid pressures. The results in Haug et al. (1987), however, indicated problems with the assumption of steady-state confined flow in simulation of Culebra brine densities. The calibration approach taken by LaVenue et al. (1988) differed from that taken earlier. LaVenue et al. (1988) assumed that the fluid-density distribution remains fixed on the time scale required for pressure equilibration, and no calibration against the brine-density distribution was attempted. The calculations do take account of the variable fluid density at each point within the Culebra; they assume that effects of variable brine density on the modern flow directions can be estimated reliably fixing the modern fluid-density distribution in place. The results of calibration of Culebra transmissivities against the freshwater-equivalent head distribution shown in Figure 4.1.23, assuming that the fluid-density distribution shown in Figure 4.1.22 remains fixed (LaVenue et al., 1988), are shown in Figure 4.1.24.

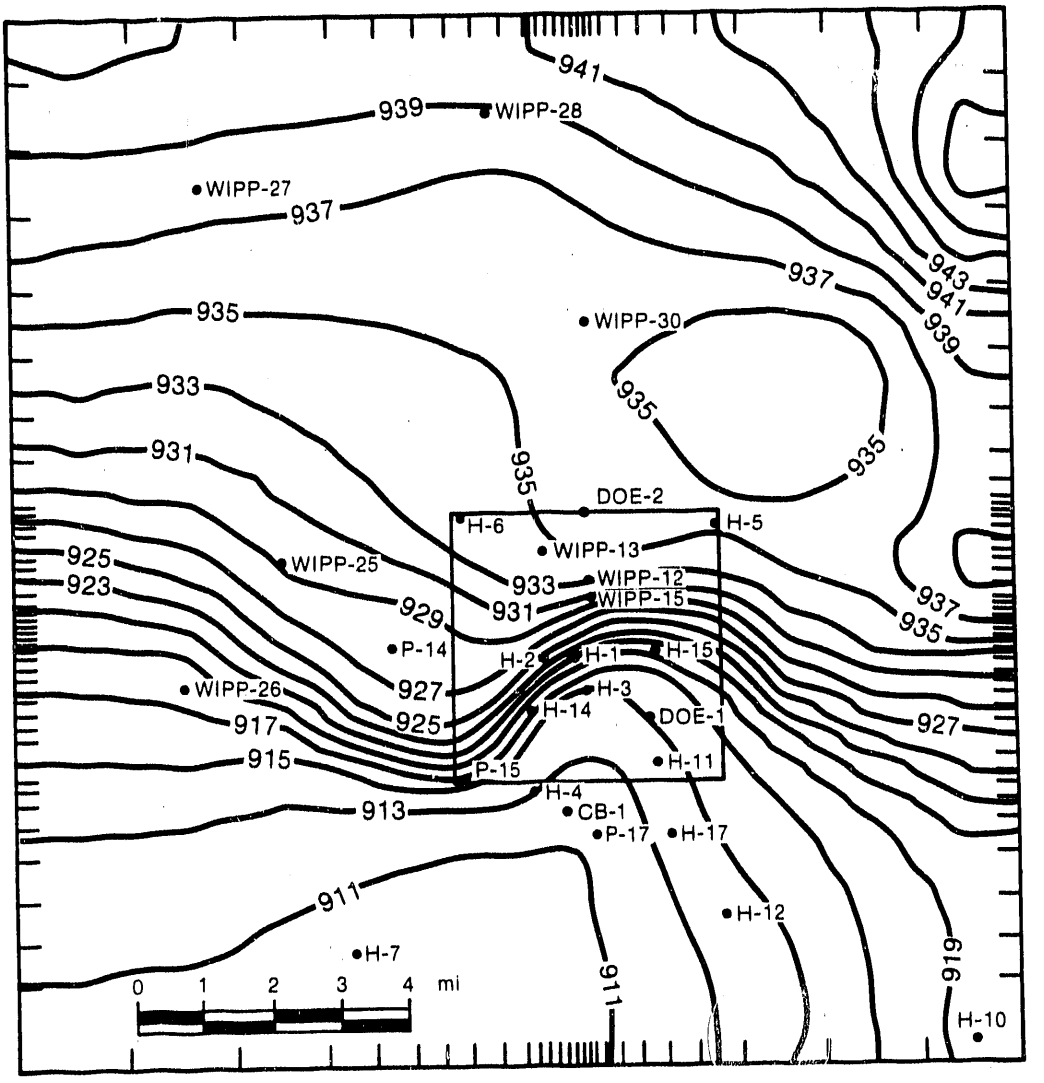


Figure 4.1.23: Estimate of pre-shaft, freshwater-equivalent heads in the Culebra dolomite, based on data available as of November 1987. Figure 3.14 of LaVenue et al. (1988).

The overall distribution of calibrated transmissivities (Figure 4.1.24) is not greatly different from the initial kriged distribution (Figure 4.1.19). The general trend of decreasing transmissivities from west to east is preserved. During calibration, transmissivities west of WIPP-30 and WIPP-28 were increased. Transmissivities in the area containing H-6, P-14, and WIPP-25 were generally decreased slightly, while those in the southern part of Nash Draw were increased. The low-transmissivity domain in WIPP Zone 3 ($T < 10^{-6}$ m^2/s) is expanded in the more recent interpretation (Figure 4.1.24). This region, including the center of the WIPP site, is now expected to be continuous from H-5 in the northeast to P-15, H-4, and Cabin Baby-1 to the southwest.

Calibration in the region between holes H-17, H-11, P-17, and extending to the south, required significant adjustment to the kriged distribution. Transmissivities in this region were increased from kriged values, similar to changes required during calibration by Haug et al. (1987). In order to simulate the low heads at H-11 and DOE-1 and the sharp head embayment in the southern part of Zone 3 expected on the basis of April 1986 data (Figure 4.1.11), Haug et al. (1987) included a narrow high-transmissivity zone east of P-17 (Figure 4.1.16). During calibration by Haug et al., a maximum transmissivity of approximately 3×10^{-4} m^2/s was assigned in this zone. The calibrated transmissivity distribution of LaVenue et al. (1988) in this region does not include as marked a high-transmissivity structure (Figure 4.1.24). Relatively high transmissivities are still required in the area, because of both the relatively low heads at H-11 and DOE-1 and the low gradients south of the WIPP site. However, the maximum transmissivity assigned at the pilot points shown in Figure 4.1.24 is approximately 5×10^{-5} m^2/s, only a factor of two greater than the effective transmissivity of 2.8×10^{-5} m^2/s calculated at the H-11 pad (Table 4.1).

LaVenue et al. (1988) investigate the need for the high-transmissivity zone by making calibration runs in which the increase in transmissivities south of H-11 was not incorporated, as well as runs in which the assigned heads along the southwestern part of the model were increased slightly. In all cases, the fit between calculated and estimated heads was worse than when increased transmissivities south of H-11 were included. Thus, a region of relatively high transmissivities is still expected to be present south of H-11. Transmissivities within this zone may be approximately twice as great as those measured at H-11. Both the lateral extent of the zone and the contrast between the high-transmissivity zone and surrounding regions are expected to be smaller than estimated in Haug et al. (1987). The zone is still expected to connect with the high-transmissivity region further to the south.

The changes in estimated transmissivities within and near the WIPP site are a direct result of the increase in the Culebra data base since April 1986 (Table 4.1). For example, hole H-14 was drilled and tested in 1986, specifically to examine transmissivities southwest of the site center (Section 4.1.1). Holes P-15, H-4, H-15, H-16, P-17, Cabin Baby-1, ERDA-9, and WIPP-12 have all been tested or retested since April 1986 (Table 4.2). Hole H-17 was drilled and tested specifically to evaluate the high-transmissivity zone east of P-17. Transmissivities at both DOE-1 and H-11 have been interpreted in detail since 1986, as discussed in Section 4.1.1.

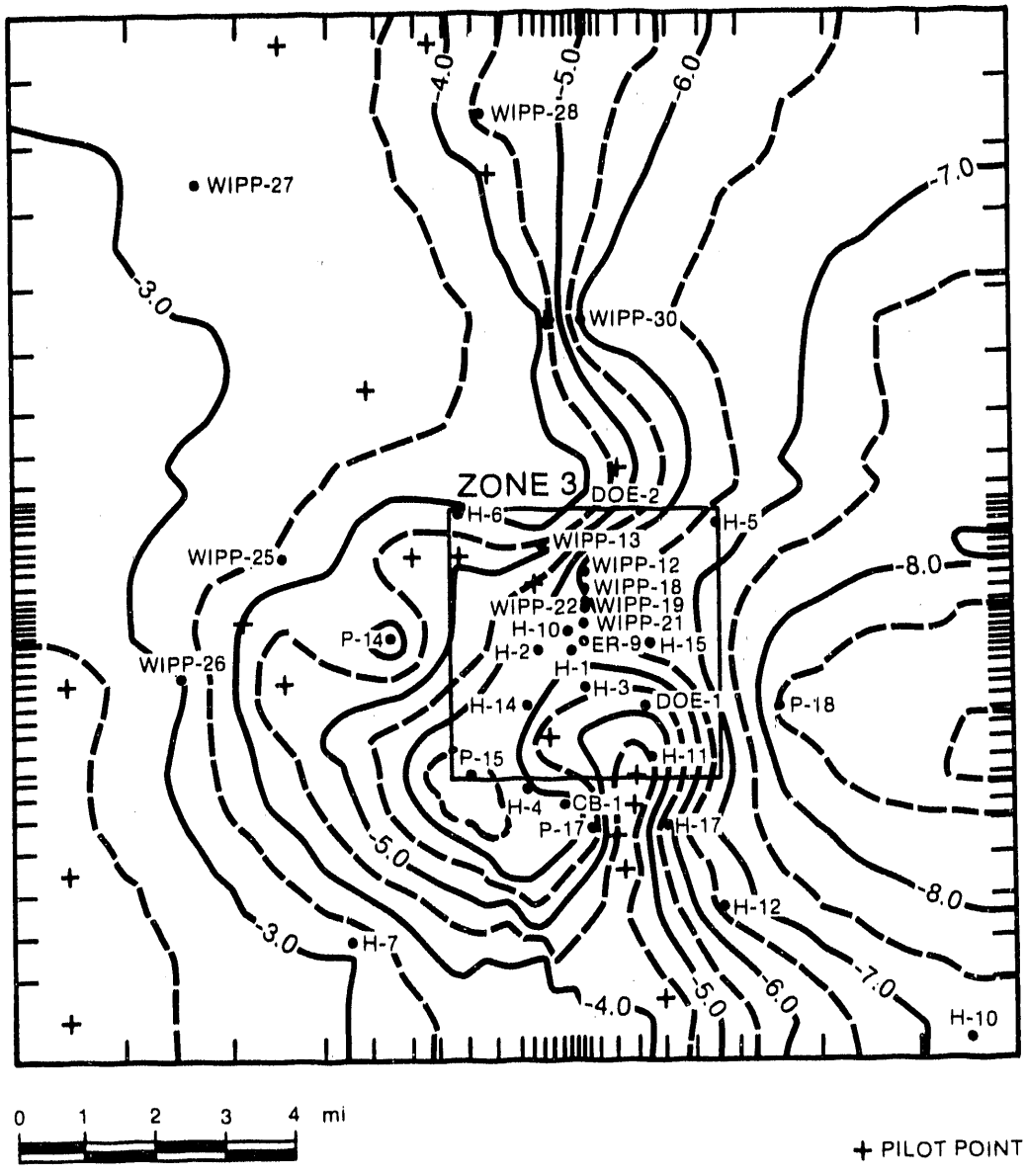


Figure 4.1.24: Calculated Culebra transmissivities at and near the WIPP site, based on steady-state calibration against freshwater-equivalent head distribution shown in Figure 4.1.23, fixing in place the fluid-density distribution shown in Figure 4.1.22. Figure 4.3 of LaVenue et al. (1988).

The distribution of Culebra pre-shaft head potentials calculated using the calibrated transmissivity distribution shown in Figure 4.1.24, is shown in Figure 4.1.25. Differences between calculated heads and those estimated on the basis of field data (Figure 4.1.23) are shown in Figure 4.1.26. The agreement is excellent, generally to within 1 m. This is less than the estimated uncertainty in freshwater-equivalent heads at individual wells, approximately 2 meters (LaVenue et al., 1988).

The modern flow directions and Darcy velocities within the Culebra dolomite at and near the WIPP site calculated by LaVenue et al. (1988) are shown in Figure 4.1.27. Darcy velocities do not include consideration of effective porosity; therefore, they do not represent actual groundwater particle velocities. Flow within the Culebra at and near the WIPP site is largely north-south, except in relatively low-transmissivity areas directly affected by either the high-transmissivity zone south of H-11 or by Nash Draw. Calculated Darcy velocities vary by six orders of magnitude, from 10^{-12} m/s (m^3/m^2s) east of the WIPP site to as high as 10^{-6} m/s along the axis of Nash Draw. In the region between WIPP-12 and the WIPP shafts, calculated Darcy velocities range from 2.5 to 7.5 x 10^{-10} m/s, and flow is north-south. LaVenue et al. (1988) note that calculated flow directions in the vicinity of DOE-2 appear unreliable due to local irregularities in the structure of the Culebra. As a result of the high-transmissivity zone south of H-11, flow in the vicinity of H-14 is towards the southeast, with a Darcy velocity of less than 10^{-9} m/s. Flow within the zone south of H-11 is to the south, with a Darcy velocity of approximately 2.5 x 10^{-9} m/s. The Darcy velocities shown in Figure 4.1.27 assume completely confined flow within the Culebra, and also assume steady-state heads and fixed brine-density distribution (LaVenue et al., 1988). They provide a realistic indication of modern flow directions.

Particle flowpaths and flowtimes calculated within the modelled area, assuming that the effective porosity of the Culebra is uniform at 16% are shown in Figure 4.1.28. As noted in Section 4.2, measured porosities within the Culebra range from 0.07 to 0.30. The effective in situ porosity is not known, but must be variable. It is not clear that assumption of confined flow within Nash Draw is valid. In addition, as discussed in Sections 4.3 and 4.4, Culebra hydrology is not at steady state, and there has probably been at least some change in flow directions within the Culebra within the last 10,000 years; the magnitude of the change remains uncertain. The travel times shown in Figure 4.1.28 must be taken only as an indication of the effects of relative variability in estimated particle flow rates.

Calculated particle velocities within Nash Draw are quite high, and calculated flow times across the entire modeled area are quite short in this region. Calculated travel times along paths A, B, and C (Figure 4.1.28) increase from west to east, from a low of 450 years to a high of 2800 years. Changes in Rustler water levels within Nash Draw since the beginning of potash mining approximately 50 years ago, described by Hunter (1985), indicate that the steady-state assumption is not realistic in this region, even on this relatively short time scale. At the other extreme, flow of a groundwater particle from H-5 to the southern boundary of the modeled area of LaVenue et al. (1988) is calculated to take more than one

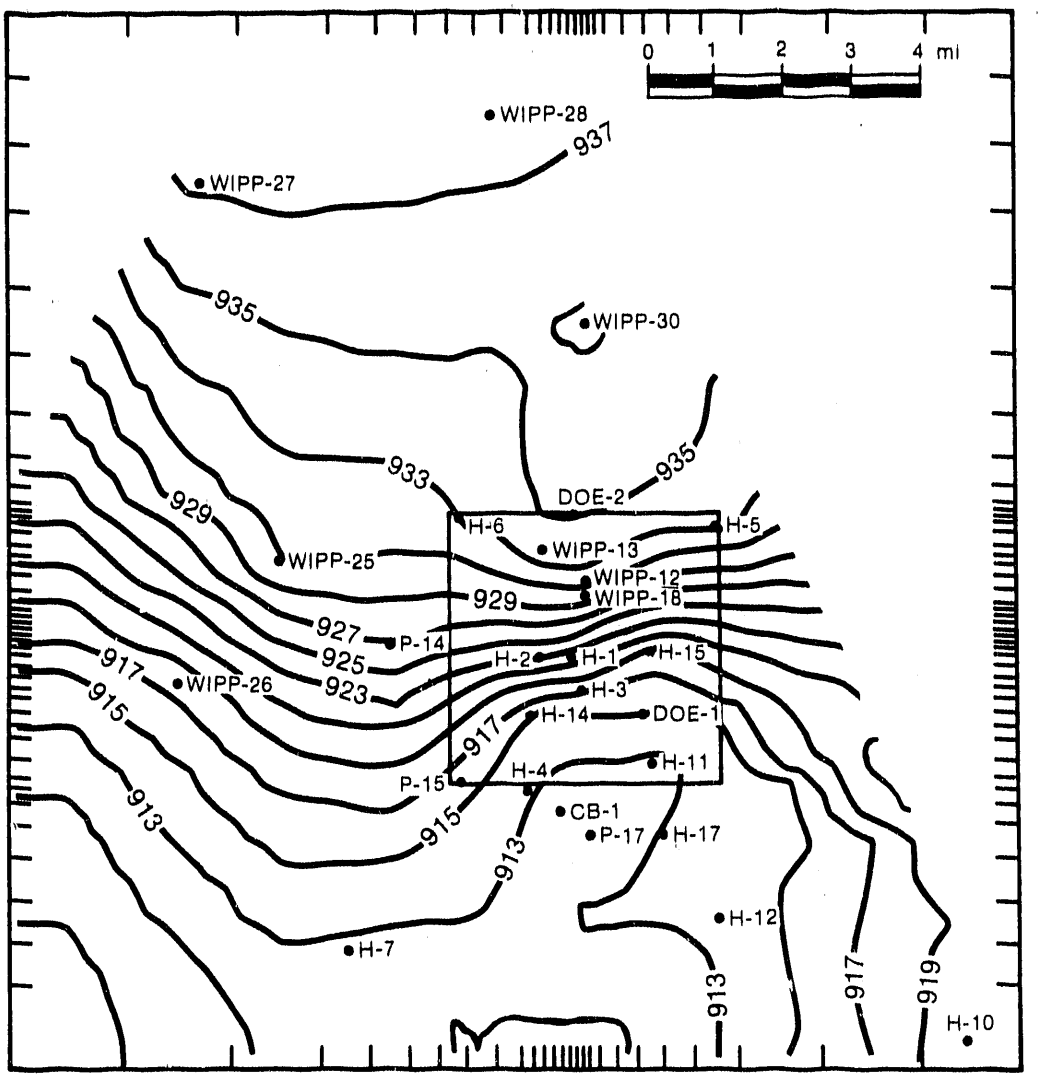


Figure 4.1.25: Calculated pre-shaft, freshwater-equivalent head distribution in the Culebra dolomite, based on calibrated transmissivity distribution shown in Figure 4.1.24. Figure 4.5A of LaVenue et al. (1988).

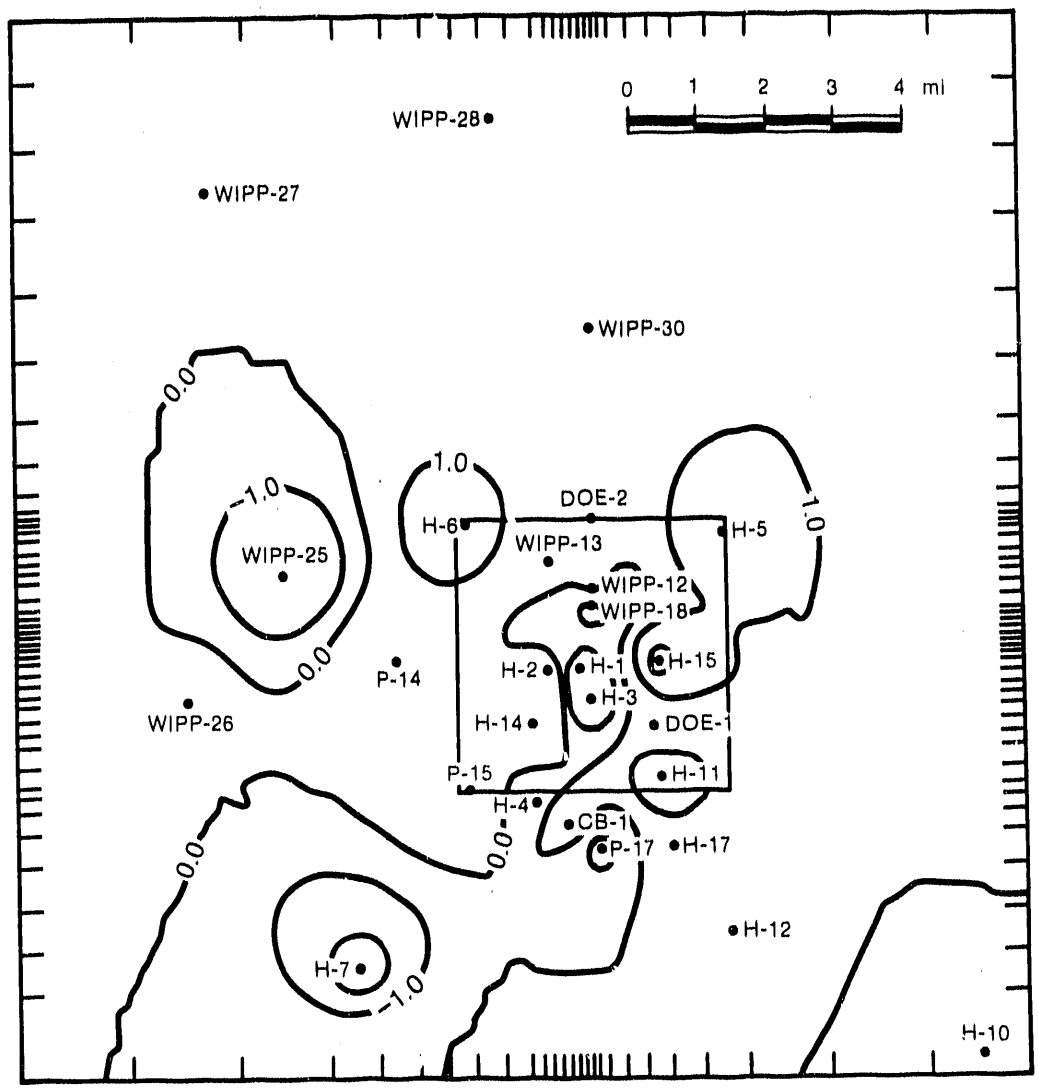


Figure 4.1.26: Difference between calculated Culebra head distribution (Figure 4.1.25) and measured pre-shaft head distribution (Figure 4.1.23). Figure 4.6 of LaVenue et al. (1988).

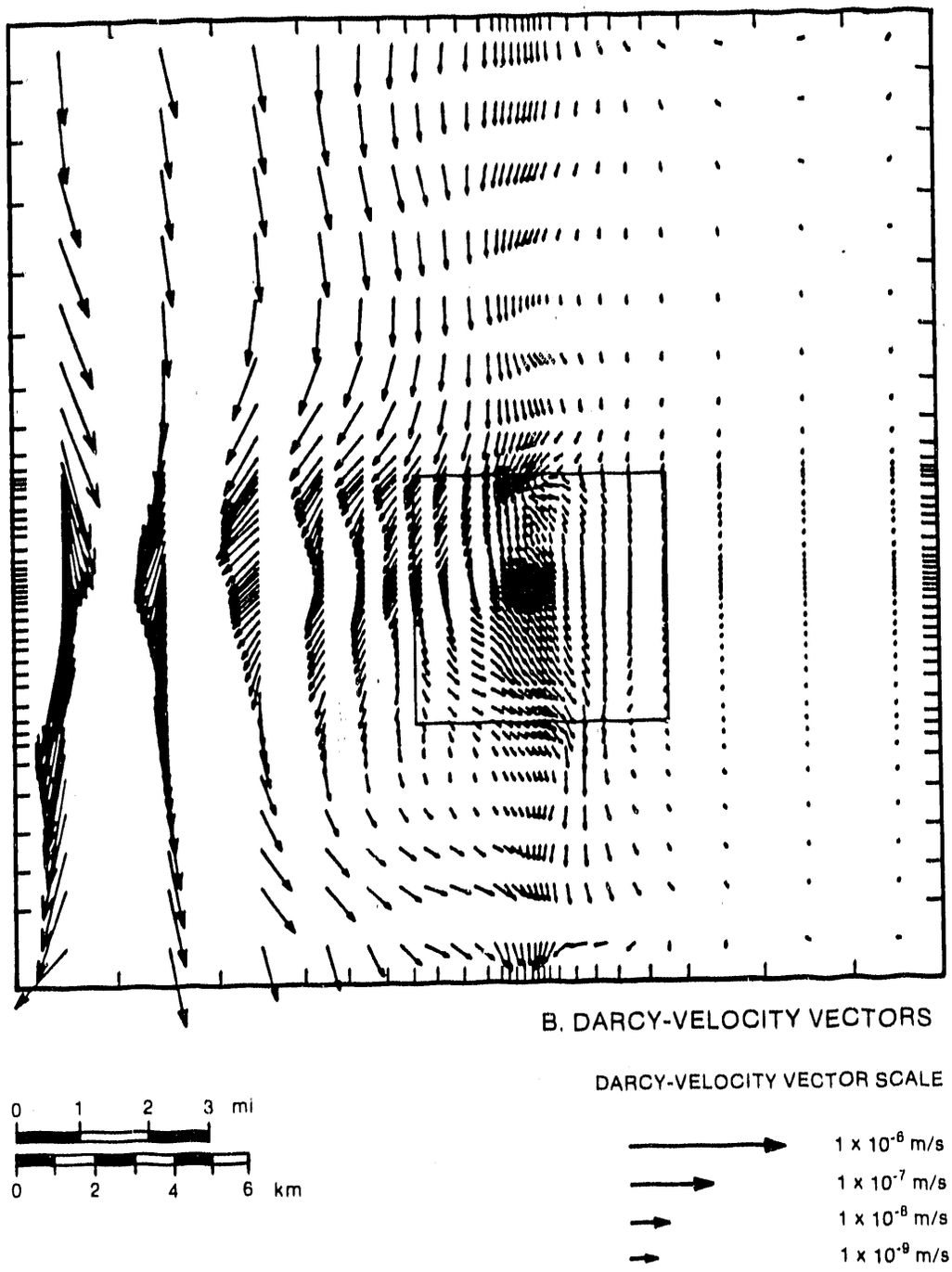


Figure 4.1.27: Calculated Darcy-velocity vectors in the Culebra dolomite, assuming the transmissivity distribution shown in Figure 4.1.24 and head distribution shown in Figure 4.1.25. Figure 4.5B of LaVenue et al. (1988).

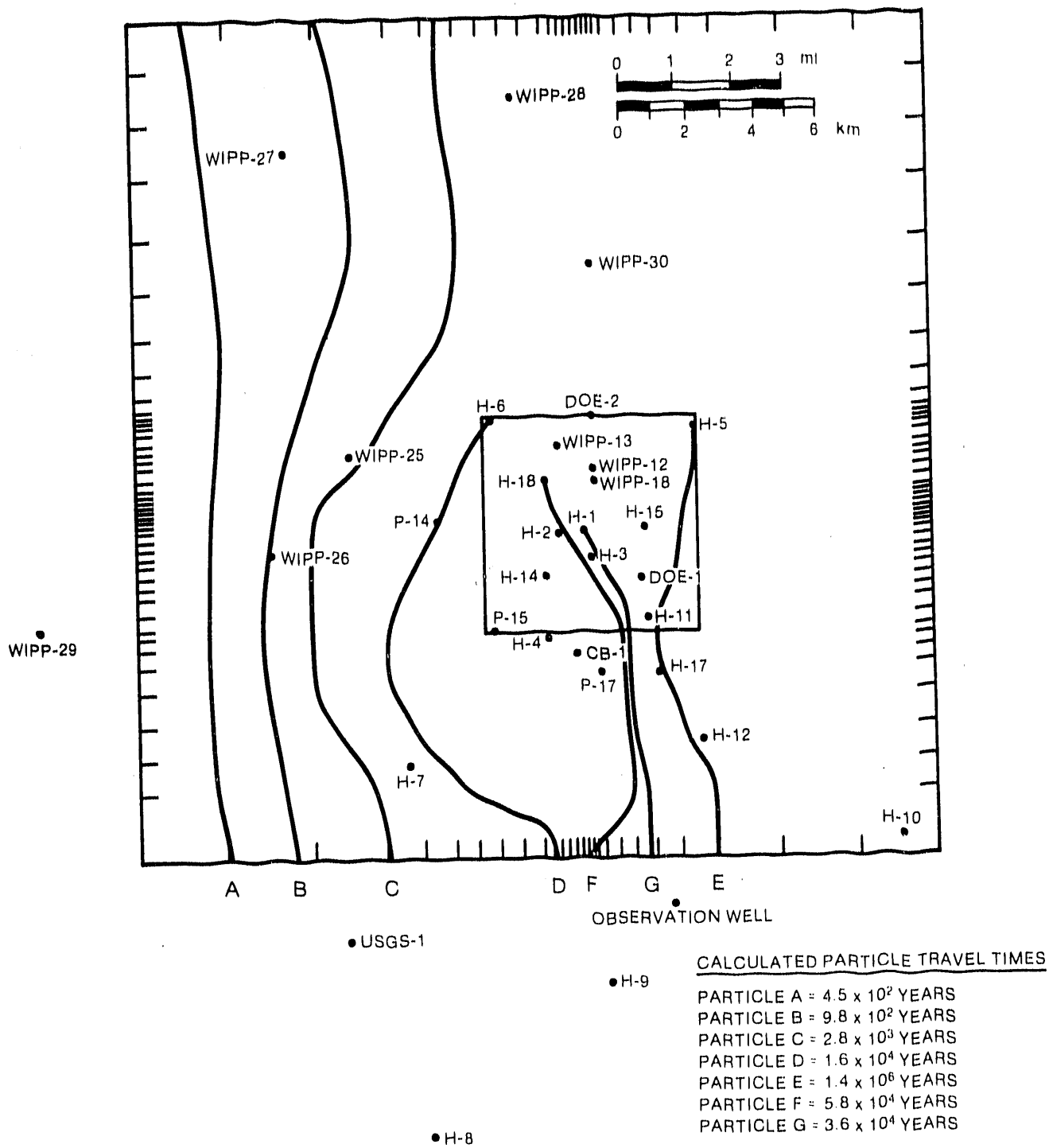


Figure 4.1.28: Calculated particle flowpaths and flow times within the Culebra dolomite, assuming steady-state and the transmissivity and head distributions shown in Figures 4.1.24 and 4.1.25. Figure 4.17 of LaVenue at al. (1988).

million years. Given that Culebra hydrology is in transient response to the end of the last pluvial period, it is not realistic to expect steady-state flow within the unit on a time scale of 106 years (LaVenue et al., 1988). The result indicates, however, that groundwater flow within the Culebra on the eastern part of the WIPP site is extremely slow.

Figure 4.1.28 also demonstrates an important consequence of the recent changes in the understanding of the distribution of Culebra transmissivities. Path G represents assumed steady-state flow from a position above the center of the WIPP waste-emplacement panels, analogous to the flowpath used in the detailed generic transport calculations contained in Reeves et al. (1987) (Section 4.2). Reeves et al. (1987) used the Culebra transmissivity distribution calculated by Haug et al. (1987), which included higher transmissivities south of H-11 than estimated by LaVenue et al. (1988) (Figure 4.1.24). The groundwater travel time calculated by LaVenue et al. (1988) for flow from directly above the center of the waste-emplacement panels to the southern boundary of the model shown in Figure 4.1.24 is 36,000 years. The calculated flow time from the release point of path G to the southern boundary of the WIPP site (Zone 3) is approximately 13,000 years, roughly 2.5 times that estimated by Reeves et al. (1987) along an analogous flowpath, but assuming the transmissivity distribution shown in Figure 4.1.16. The changes in interpreted Culebra transmissivities and head potentials since April 1986 have significantly increased expected groundwater flow times across the WIPP site within the Culebra dolomite. However, given the uncertainties in effective porosities, flowpaths, and transmissivities within the Culebra dolomite, the recent results must be considered approximate.

4.2 Pad-Scale and Regional-Scale Studies of Contaminant Transport within the Culebra Dolomite

For purposes of WIPP performance assessment, contaminant (radionuclide) transport within the Culebra dolomite is of concern in two general types of breach scenario. Section 4.2 discusses contaminant-transport results at both the hydropad and regional scale, under "low-pressure," relatively undisturbed conditions. Low-pressure conditions correspond to a release of fluids from the WIPP facility that does not disturb the pre-existing head distribution in the Culebra. "High-pressure" conditions, for which studies have not yet been completed, represent a breach involving effective connection of the Culebra dolomite with a pressurized brine in the Castile Formation beneath the WIPP facility (see Section 3.2) for a long enough period of time to significantly change the head gradients within the Culebra.

Detailed field testing of transport properties in the Culebra dolomite has been carried out only at the hydropad scale and is discussed in Section 4.2.1. Recent interpretation of conservative-tracer testing at the H-3 hydropad indicates that fracturing plays a major role in pad-scale contaminant transport in the transmissive (fractured) portions of the Culebra. In low-transmissivity areas, such as at the H-4 pad, pad-scale transport within the Culebra is best modelled using the equivalent-porous-medium assumption.

For purposes of performance assessment, however, the critical scale for transport within the Culebra dolomite is not the hydropad, but rather the distance between the point of breach into the Culebra and the boundary to the accessible environment. For purposes of consistency within this report, the boundary of WIPP Zone 3 is assumed to represent the boundary to the accessible environment. Contaminant transport over the 3.2 km from the center of the WIPP site to the boundary of Zone 3 is not amenable to field testing on a reasonable time scale. It is thus necessary to estimate the "regional-scale" transport behavior within the Culebra by numerical modeling. Section 4.2.2 discusses the regional-scale transport behavior of the Culebra dolomite at and near the WIPP site. The results in Section 4.2.2 indicate that, at least as long as the Culebra heads are not significantly disturbed and the assumed flow paths and material properties within the Culebra are reasonably representative, numerical simulation of regional-scale transport within the Culebra at and near the WIPP site need not include effects due to fracturing.

4.2.1 Hydropad-Scale Transport of Conservative Tracers at the H-3 and H-4 Hydropads

Convergent-flow tracer tests operated at the H-3 hydropad in May and June 1984 and at the H-4 hydropad between October 1982 and October 1984 are interpreted by Kelley and Pickens (1986). The interpretations are summarized here, with the objectives of examining the relative importance of dual-porosity or fracture-flow effects on the hydropad scale at two separate locations and discussing the ranges of transport parameters at the two locations.

The first stage of a convergent-flow tracer test is to establish approximate steady-state gradients between the observation holes and the pumped well. Tracers are then injected into the observation wells and their transport to the pumped well monitored. The fluorinated organic tracers meta-trifluoromethylbenzoate (m-TFMB) and pentafluorobenzoate (PFB) were used in testing at the H-3 pad. These same tracers were used at the H-4 pad, in addition to para-fluorobenzoate (p-FB) and thiocyanate (SCN). It is generally assumed that the tracers are chemically stable throughout a test, and that they do not interact with the surrounding rock mass except by diffusion (Kelley and Pickens, 1986).

The interpretation of the H-3 and H-4 tracer tests was done using the code SWIFT II (Reeves et al., 1986a; 1986b). SWIFT II handles the hydraulic and transport behavior of fractured media by means of a "dual-porosity" formalism, in which the composite medium is assumed to consist of an array of porous matrix blocks (primary porosity) and regularly spaced fractures (secondary porosity). The fractures and matrix are allowed to interact. The matrix-block geometry is idealized as either uniform slabs (parallel non-intersecting fractures) or cubes (three orthogonal fracture sets). In interpretation, radial flow towards the pumped hole was assumed.

Interpretation assuming the presence of three orthogonal sets of fractures and the assumption of radial flow are both equivalent to the assumption of isotropy. As mentioned in Section 4.1.2, however, interpretation of

hydraulic interference testing at the H-4, H-5, H-6, and H-11 hydropads indicates some directional dependence of Culebra hydraulic properties. In contrast, interpretation of the hydraulic behavior on the H-3 pad (Beauheim, 1987a) indicates effectively isotropic behavior. The results contained in Kelley and Pickens (1986) must be considered approximate.

4.2.1.1 Conservative-Tracer Tests at the H-3 Hydropad--The observed tracer behavior during convergent-flow testing at H-3 is shown in Figure 4.2.1, and is summarized in Table 4.8. Hole H-3b3 was the pumped hole in this test. Meta-trifluoromethylbenzoate (m-TFMB) injected in hole H-3b1 was first detected in hole H-3b3 ("breakthrough") approximately 0.92 days (22 hrs) after injection, and reached a well-defined peak concentration approximately 2.6 days (62.4 hrs) after injection. After this time, tracer concentration decreased rapidly towards a relatively steady-state value. In contrast, the pentafluorobenzoate (PFB) injected into hole H-3b2 travelled to the sampling hole much more slowly, was first detected approximately 3.76 days (90.2 hrs) after injection, reaching a very broadly defined peak concentration (if any) after approximately 23 days (552 hrs).

Thus, there is a marked difference between the apparent directional dependence of hydraulic behavior and transport behavior at the H-3 pad. Hydraulic anisotropy at the H-3 pad is negligible. However, m-TFMB breakthrough along the H-3b1 - H-3b3 path was four times more rapid than PFB breakthrough along the H-3b2 - H-3b3 path. The preliminary interpretation of a convergent-flow conservative-tracer test at the H-6 pad (Gonzalez, 1983b) also indicates a discrepancy between the directional dependence of hydraulic and transport behavior within the Culebra. In testing at H-6, PFB injected into H-6b arrived at H-6c 16 times more rapidly than did m-TFMB injected into H-6a (Gonzalez, 1983b). These results suggest that the apparent difference between the behaviors of m-TFMB and PFB at the H-3 pad reflects differences in transport behavior along the two flow paths, rather than inherent differences in the behavior of the two tracers.

Parameters resulting from calibration to the observed behavior of the H-3 test are shown in Table 4.9. In calibration, varying input parameters are used to simulate the observed tracer behavior until satisfactory agreement is reached. Because these same parameters were used in regional-scale transport calculations (Section 4.2.2), it is important to understand the character of the parameters listed in Table 4.9.

Three parameters, solute free-water diffusion coefficient, matrix tortuosity, and longitudinal dispersivity, were taken by Kelley and Pickens (1986) from ranges of published values, not based on WIPP-specific information. Specifically, values of 0.15 and 0.45 for matrix tortuosity were used as variable input to calculations. The matrix porosity value shown in Table 4.9 (0.20) is the approximate average of a series of six helium-pycnometer measurements made on Culebra core from holes H-3b2 and H-3b3.

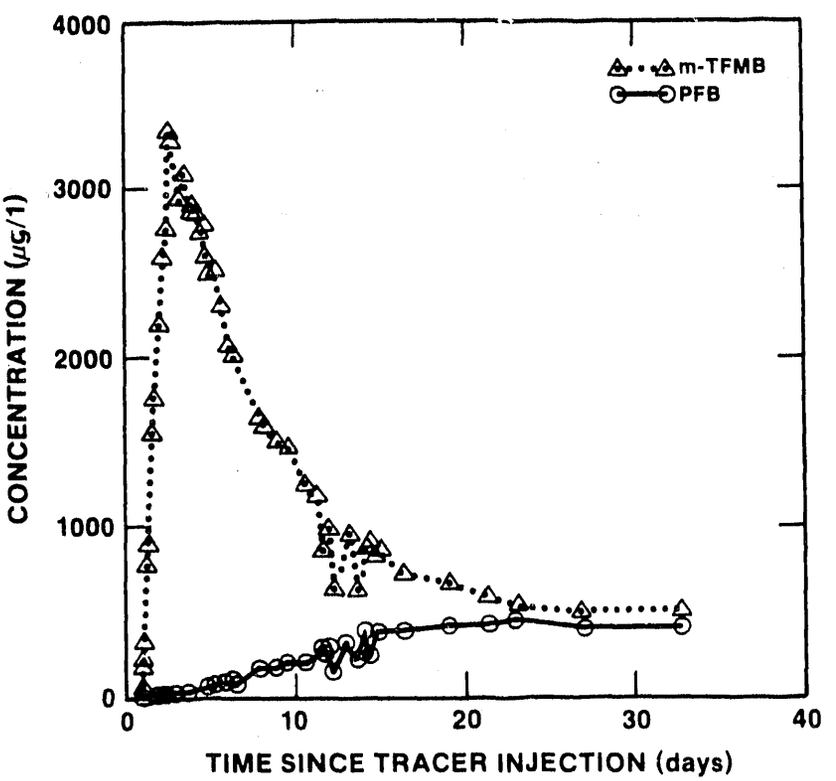


Figure 4.2.1: Observed tracer behavior during the convergent-flow test at the H-3 hydropad. Figure 4.5 of Kelley and Pickens (1986).

Table 4.8: Summary of observed tracer behavior during the convergent-flow test at the H-3 hydropad. Slightly modified from Table 4.2 of Kelley and Pickens (1986).

Parameter	Tracer	
	m-TFMB	PFB
1. Flow path	H-3b1 to H-3b3	H3b2 to H-3b3
2. First detection (days)	0.92	3.76
3. First reported concentration (mg/ℓ)	56	20
4. Time of peak concentration (days)	2.59	23.04
5. Peak concentration (mg/ℓ)	3379	444
6. Relative Peak Concentration (m/m_o)	3.3×10^{-6}	4.3×10^{-7}
7. Total tracer mass recovered (m/m_o)	0.53	0.15
8. Apparent fracture porosity	0.0019	0.019

Fracture porosity and matrix block length are specific outputs of the calculations, for the specific input values of other variables. Thus, in extrapolation of H-3 transport properties to other locations, only matrix block lengths and fracture porosities are based on the results of the H-3 tracer test; other values were input to interpretation of the H-3 testing based on either literature review or laboratory measurements.

The calculated fracture porosity of 0.19% along the H-3b1 - H-3b3 flow path (Table 4.9) was estimated directly from the relationship among pumping rate, H-3b1 - H-3b3 path length assuming direct radial flow, Culebra thickness, and time required for m-TFMB to reach peak concentration (22 hrs). Similar analysis along the H-3b2 - H-3b3 path yields an estimated fracture porosity of 1.9%. A fracture porosity of .19% was used in sensitivity studies, and was assumed to be applicable along both flowpaths on the H-3 pad (Kelley and Pickens, 1986).

Figures 4.2.2 and 4.2.3 show the best-fit simulations of transport behavior along the H-3b1 - H-3b3 flow path as a function of the specified input parameters. There is excellent agreement between measured and simulated results, with two different effective block sizes (1.2 and 2.1 m) being

Table 4.9: Input and best-fit calibration parameters from interpretation of the conservative-tracer test at the H-3 hydropad. Slightly modified from Table 4.3 of Kelley and Pickens (1986).

	Tracer	
	m-TFMB	PFB
Flow path	H-3b1 to H-3b3	H-3b2 to H-3b3
Input Parameters		
1. Diffusion coefficient for solute-free water (m^2/s)	7.4×10^{-10}	7.4×10^{-10}
2. Matrix tortuosity	0.15, 0.45	0.15, 0.45
3. Longitudinal disporsivity (m)	3.0	1.5
4. Matrix porosity	0.20	0.20
5. Fracture porosity	-	1.9×10^{-3}
Output Parameters		
1. Fracture porosity	1.9×10^{-3}	(1.9×10^{-2})
2. Matrix-block length (m)	1.2, 2.1	0.25, 0.44

calculated as a function of two different input matrix tortuosities (0.15 and 0.45, respectively). Figure 4.2.4 shows the analogous best-fit simulation for the H-3b2 - H-3b3 flowpath, assuming a matrix tortuosity of 0.15. The calculated effective block size along the H-3b2 - H-3b3 flowpath, 0.25 to 0.44 m, is smaller than along the path H-3b1 - H-3b3. As mentioned earlier, the calculated block sizes are only qualitative although, as noted by Kelley and Pickens (1986) they are consistent with observation of both Culebra core and exposures within the WIPP shafts. Thus, conservative-tracer testing at the H-3 pad indicates both the strong role of fracturing in transport at this scale (at least in some directions) and the strong directional dependence of estimated transport parameters such as effective block size.

The role of both matrix and fractures in pad-scale contaminant transport of conservative (non-sorbing) trace contaminants in the Culebra dolomite at the H-3 pad is emphasized in Figures 4.2.5 and 4.2.6. If dual-porosity and single-porosity simulations are both adjusted to match the time of peak

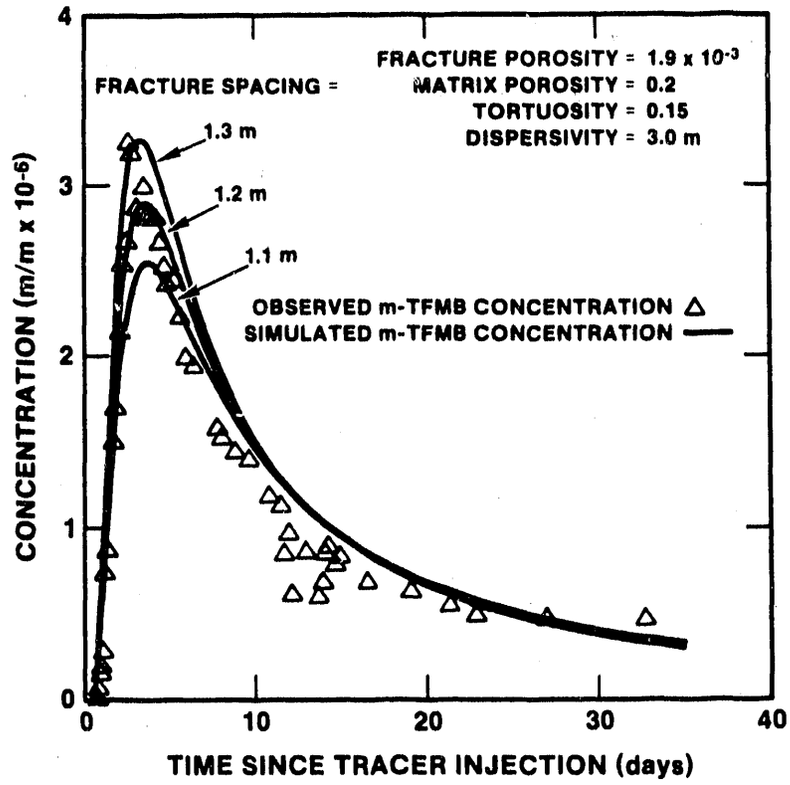


Figure 4.2.2: Best-fit simulation of measured transport behavior along the H-3b1 - H-3b3 flow path, assuming matrix tortuosity of 0.15. It is assumed that 1 kg of m-TFMB was successfully injected, and remained stable throughout the test. Figure 4.10a of Kelley and Pickens (1986).

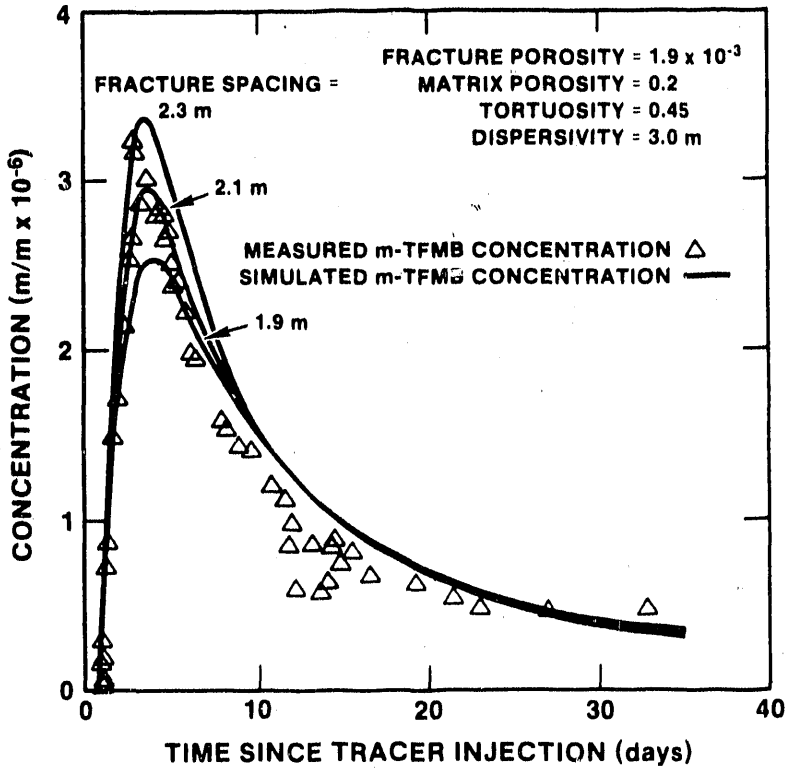


Figure 4.2.3: Best-fit simulation of measured transport behavior along the H-3b1 - H-3b3 flow path, assuming matrix tortuosity of 0.45. Figure 4.10b of Kelley and Pickens (1986).

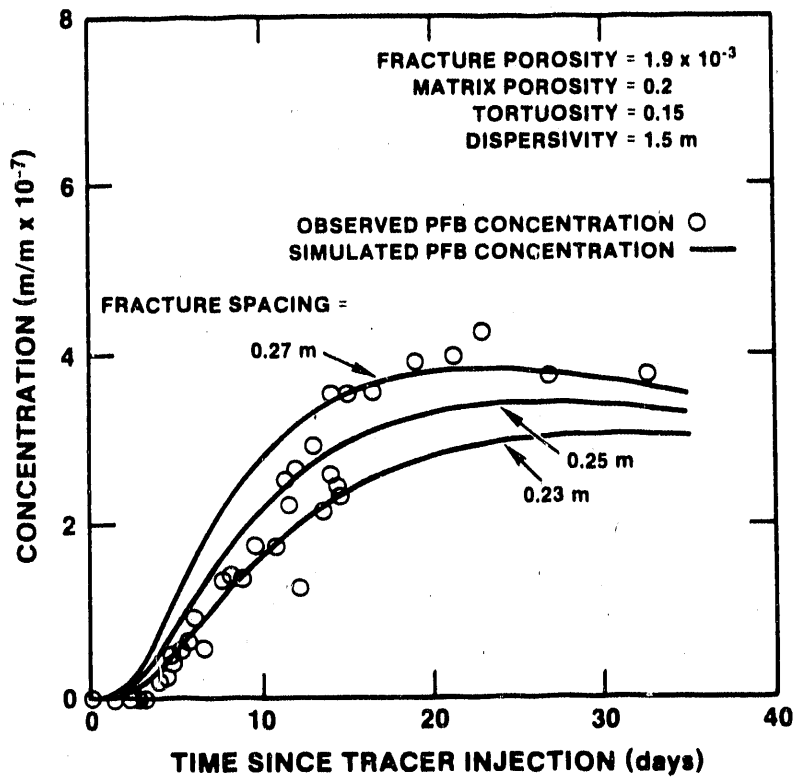


Figure 4.2.4: Best-fit simulation of measured transport behavior along the H-3b2 - H-3b3 flow path, assuming matrix tortuosity of 0.15. Fracture porosity is assumed to be the same as calculated for the flow path H-3b1 to H-3b3. Figure 4.11a of Kelley and Pickens (1986).

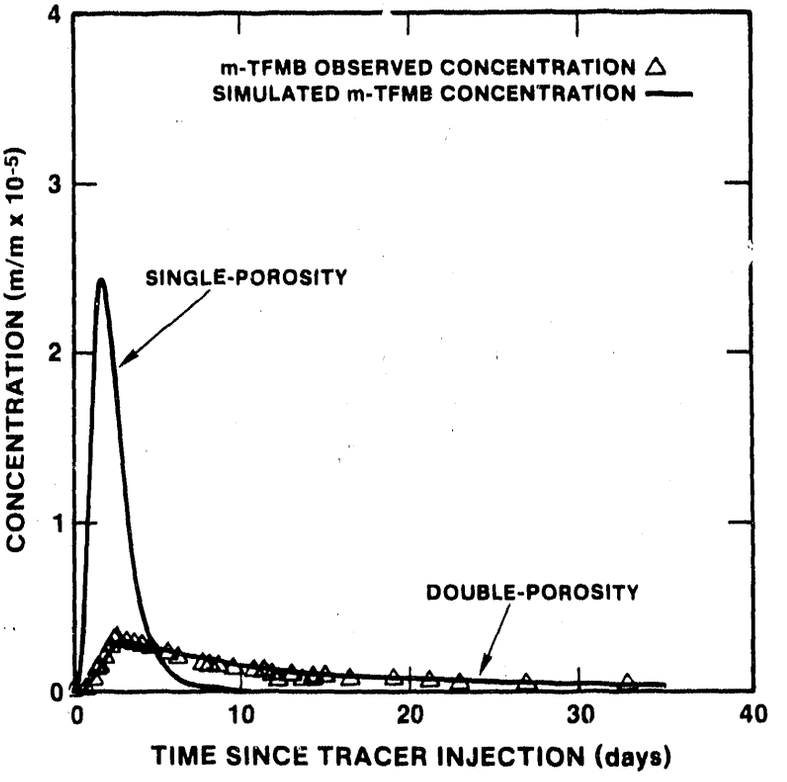


Figure 4.2.5: Best-fit single-porosity and dual-porosity simulations of tracer behavior along the H-3b1 - H-3b3 flow path when both simulations are forced to match the time of peak concentration. Figure 4.12 of Kelley and Pickens (1986).

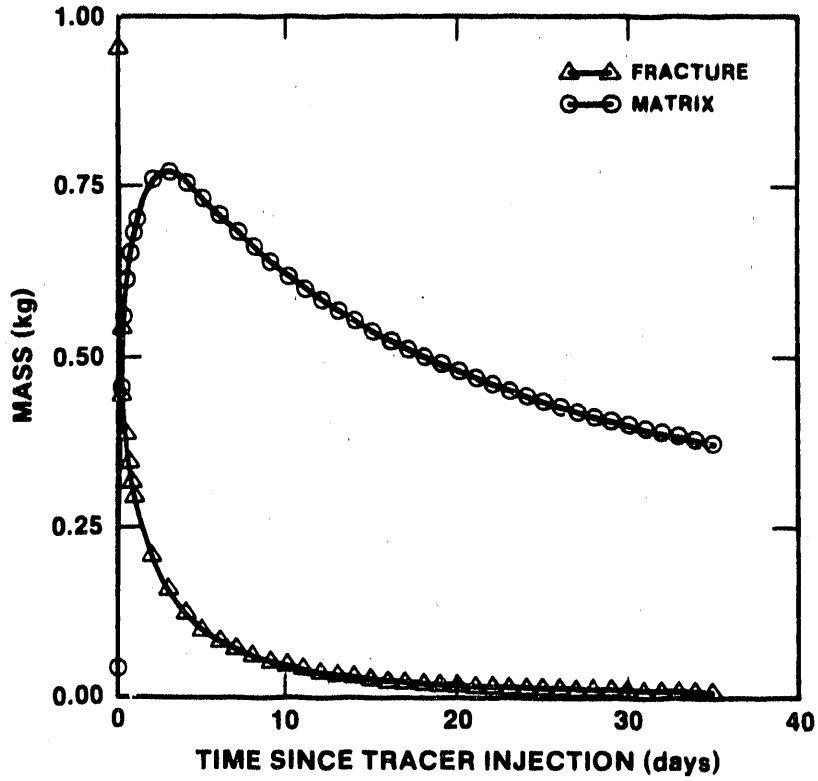


Figure 4.2.6: Calculated total masses of tracer m-TFMB in matrix and fractures as a function of time after injection. The fact that the total mass is less than 1 kg after approximately 2.5 days into the test reflects removal of tracer at the sampling hole, H-3b3. Figure 4.13 of Kelley and Pickens (1986).

concentration for m-TFMB transport along the path H-3b1 - H-3b3 (Figure 4.2.5), the post-peak behavior of the two simulations is qualitatively different. In the single-porosity simulation, the effective rock-mass porosity required to match the time of peak concentration is 0.0019, equivalent to the estimated fracture porosity in the dual-porosity simulation. The single-porosity simulation is thus equivalent to assuming no interaction between fractures and matrix, i.e., it is a "discrete-fracture" simulation, in which interaction between fractures and matrix is negligible. The peak concentration in the single-porosity simulation, which is overestimated by a factor of approximately eight, drops off very quickly, approaching zero, eight days after tracer injection. In contrast, the best-fit dual-porosity simulation matches both the time and magnitude of the tracer peak concentration well. In addition, both the observed tracer concentrations and those calculated with the best-fit dual-porosity parameters are above the detection limit more than 30 days after injection.

The conclusion by Kelley and Pickens (1986) that both the short-term and long-term transport behavior at the H-3 pad are affected by interaction of fractures and matrix is also supported by Figure 4.1.26. This figure indicates the total masses of m-TFMB calculated to be present in the matrix and fractures as a function of time since tracer injection. Initially, all of the injected tracer is contained in the fractures, and the total tracer mass in the matrix is zero. After approximately 0.5 days, however, tracer storage within the matrix blocks dominates as a result of diffusion from the fractures. At early times, storage within the matrix decreases both the concentration and the total mass of tracer in the fractures, consistent with the lower peak concentration calculated using the dual-porosity formalism (Figure 4.2.5). At longer times, the concentration of material within the matrix is greater than that within the fractures. Therefore, material diffuses from the matrix into the fractures, effectively keeping the concentration within the fractures from rapidly decreasing to zero as it does in the single-porosity simulation.

Interpretation of the H-3 conservative-tracer experiment provided the first estimates of Culebra transport parameters (fracture porosity and effective matrix block size) in fractured portions of the Culebra dolomite. There are unavoidable uncertainties in these estimates, however, due to both the need to assume radial flow in the interpretation and uncertainties in parameters such as effective matrix porosity. Regardless of these limitations, the conservative-tracer test at the H-3 pad provides direct evidence of the role of matrix diffusion in contaminant transport in fractured portions of the Culebra dolomite. This evidence is critical in supporting assumptions made in calculation of regional-scale transport within the Culebra (Section 4.2.2).

4.2.1.2 Conservative-Tracer Tests at the H-4 Hydropad--Conservative-tracer testing at H-3 investigated pad-scale contaminant transport where the Culebra is known to be effectively fractured (transmissivity approximately 2×10^{-6} m^2/s). At the H-4 pad, however, the transmissivity is lower (10^{-6} m^2/s or less; Tables 4.1 and 4.2), and there is no evidence of dual-porosity behavior in hydraulic testing.

The physical layout of the H-4 hydropad is shown in Figure 4.2.7. During steady-state, convergent-flow tracer testing at the pad between October 27, 1982, and October 15, 1984, H-4c was the pumped hole (at nominal rates of 1.66×10^{-2} and 3.33×10^{-2} l/s), and tracers were injected into holes H-4a and H-4b. Due to the very long test time at the H-4 pad, detailed interpretation of tracer behavior is hampered by pumping-rate fluctuations and pump breakdowns, as well as by questionable tracer stability (Kelley and Pickens, 1986).

The observed tracer behavior during testing at H-4 is summarized in Table 4.10. The first tracer detected in H-4c was m-TFMB travelling along the path H-4b to H-4c. However, the tracer was not detected until 262 days after injection. Tracer recovery was very limited during the test, the greatest being 37% of the total mass of m-TFMB injected. Because of the limited tracer recovery, the emphasis here is on m-TFMB behavior.

The calculated effective matrix or fracture porosities controlling first arrival of m-TFMB and PFB (Table 4.9), analyzed in the same method as in testing at the H-3 pad, are 0.033 and 0.053, respectively. Lab-measured total porosity for samples from the H-2, H-3, H-4, and H-6 pads range from 0.07 to 0.30, with an average value of 0.16 (Reeves et al., 1987). The two Culebra samples from hole H-4b have reported total porosities of 0.20 and 0.30. Therefore, the apparent porosities calculated from peak-concentration behavior in the H-4 tracer test may indicate that the hydraulically effective porosity of the Culebra at H-4 is significantly less than total porosity, that the tracers used did not remain stable and non-reactive for the two-year duration of the test, and/or that the Culebra core samples from H-4 are not representative.

Kelley and Pickens (1986) applied three different interpretative models to the behavior of m-TFMB at the H-4 pad: 1) a single-porosity model; 2) a dual-porosity model; and 3) a layered porous-medium model. The first two models are analogous to those used in interpretation of conservative-tracer testing at the H-3 pad. The third model is different in that it assumes that the Culebra consists of a specified number of parallel high-permeability and low-permeability porous layers. In this approach, unlike the dual-porosity approach, the total surface area available for diffusive transport between high-permeability and low-permeability zones is fixed by the specified number of high-permeability zones.

The simulation of m-TFMB behavior shown in Figure 4.2.8 assumes specified numbers of high-permeability zones and stability of 1 kg of tracer for the duration of the test. The time of peak concentration (388 days) is matched with an effective porosity of 0.04. However, the peak concentration is overestimated by a factor of approximately two if the Culebra is assumed to be uniform (one high-permeability zone). Kelley and Pickens (1986) note that improved agreement between observed and calculated behavior resulted if it was assumed that only 0.5 kg of tracer was effectively injected, rather than the nominal 1.0 kg.

A dual-permeability formalism was also used by Kelley and Pickens (1986), assuming that both low-permeability and high-permeability zones had an

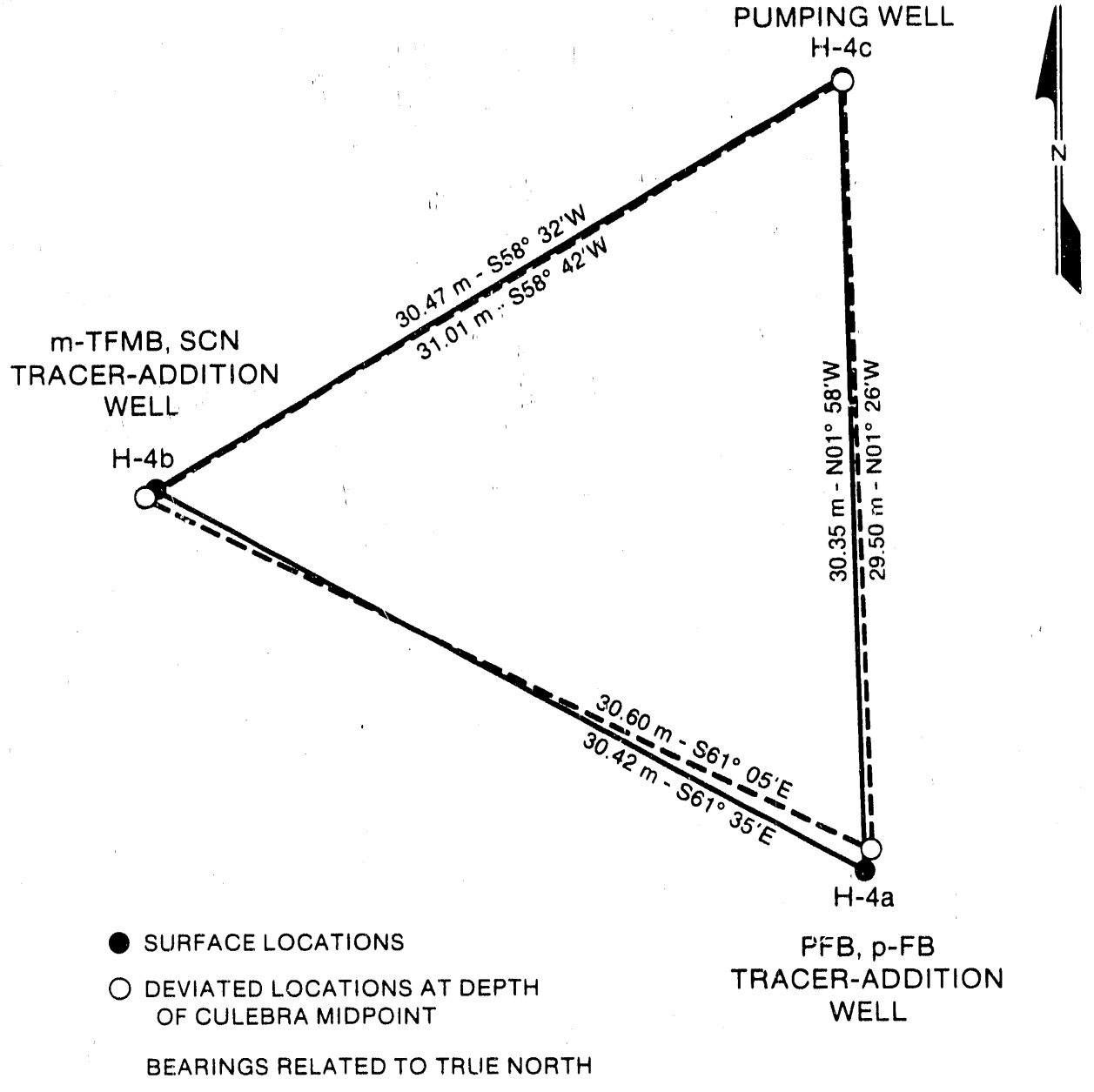


Figure 4.2.7: Physical layout of the H-4 hydropad. The figure includes orientations and spacings between holes, both at the surface and at the depth of the Culebra dolomite. Figure 6.1 of Kelley and Pickens (1986).

Table 4.10: Summary of observed tracer behavior during the convergent-flow, conservative-tracer test at the H-4 hydropad. Slightly modified from Table 6.2 of Kelley and Reeves (1986).

Parameter	Tracer	
	m-TFMB	PFB
1. Flow path	H-4b to H-4c	H-4a to H-4c
2. First detection (days)	262.2	501.1
3. First reported concentration (mg/ℓ)	78	48
4. Time of peak concentration (days)	388.2	507
5. Peak concentration (mg/ℓ)	723	54
6. Relative peak concentration (m/m_o)	7.1×10^{-7}	5.3×10^{-8}
7. Tracer Mass recovered (m/m_o)	0.37	0.022
8. Apparent fracture porosity from peak concentration	0.033	0.053(1)

(1) Apparent porosities for SCN = 0.024; p-FB = 0.064.

effective porosity of 0.20. The number of high-permeability zones was allowed to vary. It was assumed that 1.0 kg of m-TFMB remained stable throughout the test. The presence of increasing numbers of interfaces between high-permeability zones and "matrix" zones, in which only diffusive transport is allowed, effectively decreases the simulated peak concentration (Figure 4.2.8). The best fit was obtained for five or six high-permeability zones, although none of the fits were satisfactory (Kelley and Pickens, 1986), in part because they overestimate tracer concentrations at longer times. In order to improve the long-term fit, it would have to be assumed that there was some tracer degradation at longer times.

In summary, interpretation of the conservative-tracer test at the H-4 pad, while not successful in developing detailed estimates of transport parameters in unfractured portions of the Culebra, does indicate important considerations in both tracer testing at the pad scale and interpretation of regional-scale modeling of transport behavior. Both tracer and hydraulic behavior during the test are consistent with porous-medium behavior, indicating that fracturing need not be considered in evaluation of pad-scale or regional-scale transport in areas of relatively low Culebra

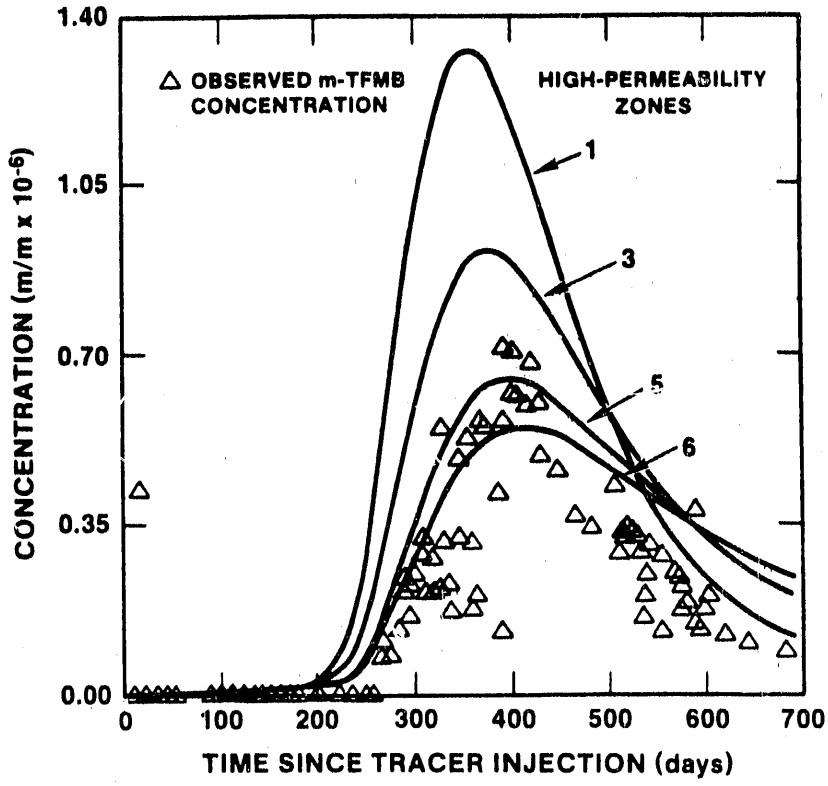


Figure 4.2.8: Best-fit simulation of m-TFMB behavior during testing at the H-4 hydropad, assuming effective injection and stability of 1 kg of tracer and control of behavior by the specified numbers of multiple high-permeability zones. Figure 6.11 of Kelley and Pickens (1986).

transmissivity ($T \leq$ approximately 10^{-6} m^2/s). If it is assumed that the Culebra at H-4 is vertically homogeneous and that the tracers used were stable and non-reactive for the duration of the test, then the hydraulically effective matrix porosity of the Culebra may be significantly less than the total porosity. Given the long duration of the H-4 test, however, it is probable that the tracers degraded during the test.

4.2.2 Regional-Scale Contaminant Transport in the Culebra Dolomite under Low-Pressure Conditions

Regional-scale contaminant transport within the Culebra dolomite under the low-pressure type of breach scenario, i.e., under conditions which do not disturb the head distribution within the Culebra, has been examined by Reeves et al. (1987). Significant transport under these conditions might be expected in the event of failure of the WIPP shaft seals in the absence of human intrusion, or in the event of an imperfectly plugged human-intrusion breach involving a high-pressure brine source within the Castile Formation. Calculations are ongoing to investigate behavior following a second type of breach, in which fluids are assumed to be injected at high pressures into the Culebra for long enough to dominate the local head potentials and flow rates.

The calculations in Reeves et al. (1987) investigate: 1) the significance of the interactions between matrix and fractures seen in tracer and hydraulic testing at the H-3 pad in regional-scale transport within fractured portions of the Culebra dolomite; and 2) the relative importance of several transport and material parameters of the Culebra in regional transport within fractured portions of the Culebra. The calculations in Reeves et al. (1987) were made using the following approach and/or assumptions:

1. Contaminants were assumed to be continuously injected into the Culebra dolomite at points directly above the WIPP waste-emplacement panels at a constant rate after time zero. The injection was slow enough not to disturb the "natural" (pre-WIPP-shaft) gradient or transmissivity distribution.

2. The boundary of WIPP Zone 3 was assumed to represent the boundary of the accessible environment.

3. Effects of radioactive decay and lateral dispersion were assumed negligible, and were not included. If lateral dispersion were included in the calculations, it would effectively slow down transport. The effects of lateral dispersivity on total integrated release to the accessible environment have not been quantified.

4. Material properties and flow velocity were assumed homogeneous between the point of entry into the Culebra and the accessible environment. The analysis was done in terms of an average Darcy velocity yielding groundwater travel times equivalent to those calculated from the flow model described in Haug et al. (1987). Fluid

flow and contaminant transport were controlled by the transmissivity and head distributions estimated by Haug et al. (1987), and were calculated along the flow paths shown in Figure 4.2.9.

5. As a result of the strong interactions between fractures and matrix observed in the conservative-tracer test conducted at the H-3 hydropad (Section 4.2.1), the double-porosity formalism was initially assumed to be appropriate for modeling of transport within fractured portions of the Culebra. However, a major objective of the report was to examine the consequences of both the "discrete-fracture" and "equivalent-porous-medium" end-member behaviors in regional transport.

6. The base-case values and ranges of properties shown in Table 4.11 were assumed to be representative for fractured portions of the Culebra dolomite. The Culebra transport properties estimated in conservative-tracer testing at the H-3 pad were taken as the base-case properties.

7. "Breakthrough," defined by Reeves et al. (1987) as the time at which the calculated contaminant concentration at the boundary to WIPP Zone 3 equaled 10% of the injected concentration, was assumed to provide a meaningful measure of transport behavior. Conclusions in the report are specifically evaluated on the basis of this assumption.

8. It was assumed that retardation effects within the Culebra dolomite can be realistically modeled as a linear process, i.e., that chemical reactions are "fast" relative to flow times within fractures, are reversible, and reflect local equilibrium within the matrix. Thus, it was assumed that chemical retardation within the matrix of the Culebra dolomite can be represented realistically by using an appropriate "matrix distribution coefficient," k_d.

9. The possible presence of mineralogical "skins" on matrix blocks was ignored, as were advective transport within the matrix and sorption on fracture surfaces. These assumptions appear to be generally "conservative," i.e., they should bias the calculations towards greater fracture flow, except for the case of mineralogical skins inhibiting diffusion into the matrix.

Figure 4.2.10 compares the average calculated travel times for a conservative contaminant from positions above the WIPP facility to the southern boundary of WIPP Zone 3, along the flow paths shown in Figure 4.2.9, according to three different assumptions. Using the dual-porosity formalism and assuming uniform distribution of the base-case material properties estimated at the H-3 pad, the time predicted for "breakthrough" of a conservative (non-sorbing) contaminant at the boundary of WIPP Zone 3 is 3490 years after the beginning of continuous injection. This is approximately 90% of the 3730 years predicted by single-porosity calculations in which the porosity is set equal to the sum of the base-case matrix and fracture porosities, 16.2%. In the absence of chemical retardation of the contaminant, the role of the matrix in transport is largely one of storage due to diffusion from fractures into/out of matrix blocks (Section 4.2.1).

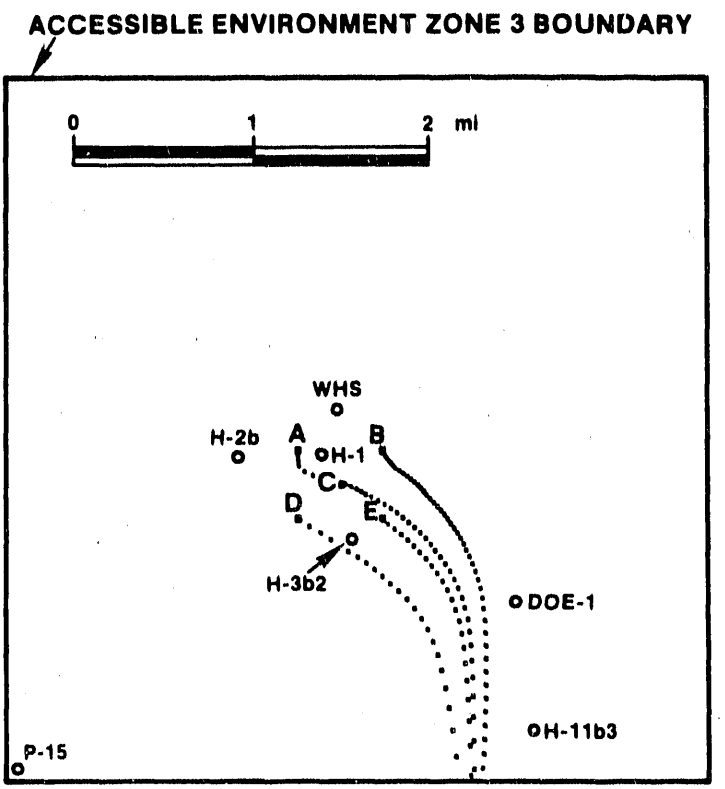


Figure 4.2.9: Release points into the Culebra dolomite and flow paths to the accessible environment considered by Reeves et al. (1987). Points A-E are vertical projections of the corners and center of the WIPP waste-emplacement panels upwards onto the Culebra dolomite. The small crosses extending from points A-E to the southern boundary of Zone 3 are equal-time marks along the flow paths. Slightly modified from Figure 1.7 of Reeves et al. (1987).

Table 4.11: Base-case Culebra transport properties and ranges of properties considered in regional-scale transport within Culebra dolomite. Slightly modified from Table 2.2 of Reeves et al. (1987).

Parameter	Units	Symbol	Base-Case	Range in Values	Relative Range (2)
1. Free-water diffusivity	cm^2/s	D'	2×10^{-5}	4×10^{-6} to 9×10^{-5}	4.30
2. Matrix tortuosity	-	θ'	0.15	0.05 to 0.50	3.00
3. Matrix-block length	$2L'$	m	2.4	0.25 to 7.0	2.81
4. Matrix porosity	-	ϕ'	0.16	0.07 to 0.30	1.44
5. Fracture porosity	-	ϕ	2×10^{-3}	2×10^{-4} to 2×10^{-2}	9.90
6. Longitudinal dispersivity	m	α	100	50 to 300	2.50
7. Specific matrix flux	m^3/m^2s	u	3.2×10^{-9}	2.2×10^{-9} to 4.7×10^{-9}	0.78
8. Matrix distribution coefficient	$m\ell/g$	k_d	(1)	(1)	-
9. Fraction distribution coefficient	$m\ell/g$	k_d	0	0	-

(1) Calculations done with fixed values of k_d = 0.0, 10, 10^2, 10^4 $m\ell/g$.
(2) Range divided by base-case value.

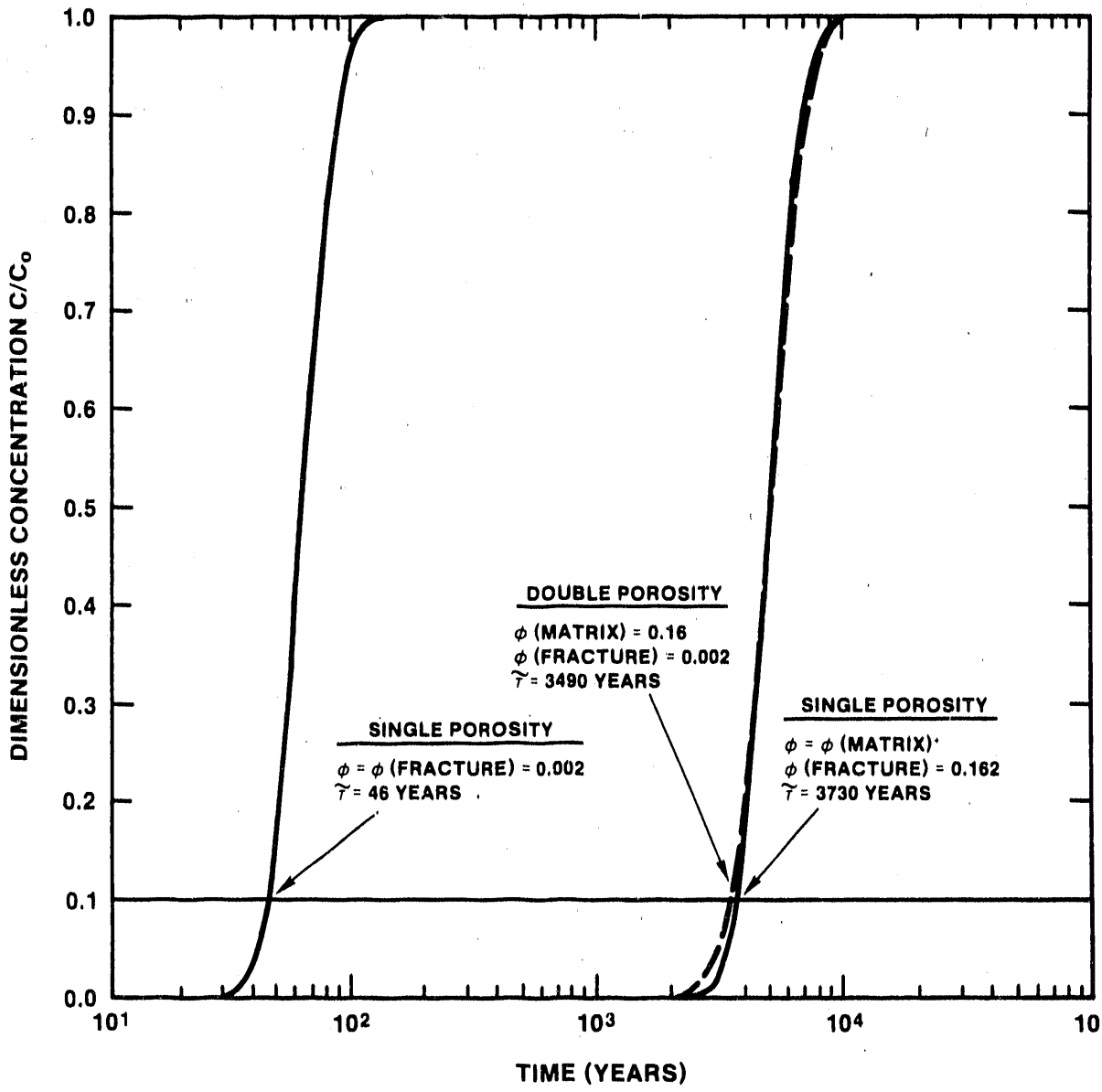


Figure 4.2.10: Comparison of base-case, regional-scale transport behavior of a conservative contaminant in the Culebra dolomite under discrete-fracture, dual-porosity, and porous-medium assumptions. Breakthrough is defined here as the time at which the concentration at the boundary of WIPP Zone 3 equals 10% of the injected concentration. Figure 5.1 of Reeves et al. (1987).

In effect, the single-porosity curve on the right-hand side of Figure 4.2.10 assumes instantaneous diffusion into and equilibration with the matrix.

At the other extreme, diffusion time into the matrix is infinite in fracture flow if it is assumed that fractures and matrix do not interact. The breakthrough time calculated (Figure 4.2.10) assuming that transport occurs only within fractures, assuming a fracture porosity of 0.2%, is 46 years (Reeves et al., 1987).

The experimental results at the H-3 hydropad (Section 4.2.1.1) and the calculated variations in breakthrough time at the boundary of WIPP Zone 3 shown in Figure 4.2.11 indicate the importance of matrix diffusion in both pad-scale and regional-scale transport in the Culebra dolomite. As described by Reeves et al. (1987), a diffusion time means that 1000 years is required for contaminant concentration in the center of matrix blocks to reach approximately 68% of the concentration at fracture surfaces. The base-case diffusion time (Figure 4.2.11) is 152 years. Even for diffusion times significantly greater than the base case value, a large benefit is gained from diffusion of non-sorbing contaminants into matrix blocks (Figure 4.2.11). Base-case transport properties were assumed in the calculations summarized in Figure 4.2.11, except for diffusion into matrix blocks.

Thus, the effective transport behavior within the Culebra dolomite for transport between any breach point directly above the WIPP emplacement panels and the boundary of Zone 3, assuming the breach does not disturb the head distribution within the Culebra, appears to be nearly that of an equivalent porous medium having a porosity equal to the sum of matrix plus fracture porosities. Inclusion of the dual-porosity formalism at this scale, given the assumed properties and flow paths, does not change calculated travel times by more than approximately 10%.

The conclusions supported by results shown in Figures 4.2.10 and 4.2.11 only apply directly to calculations assuming the base-case transport and material properties for the Culebra, which are based largely on interpretation of the conservative-tracer test at the H-3 pad (Section 4.2.1.1). Therefore, Reeves et al. (1987) examined the sensitivity of the results to variations in parameters. The relative importance of several transport parameters in regional-scale transport in the Culebra estimated by Reeves et al. (1987) is summarized in Table 4.12. Reeves et al. (1987) define importance in terms of both the sensitivity of calculated behavior to uncertainty in a given parameter and the estimated range of uncertainty of that parameter in the Culebra dolomite at and near the WIPP site. Thus, a highly sensitive parameter that was known with perfect precision would have zero importance. In contrast, a relatively insensitive parameter could be very important if its range of uncertainty was large.

Reeves at al. (1987) conclude that five parameters are most important in controlling "breakthrough" time to the southern boundary of WIPP Zone 3 in the Culebra dolomite. These are: 1) the matrix retardation (K'), where K' is proportional to $(1 + k_d')$ and k_d' is the matrix distribution

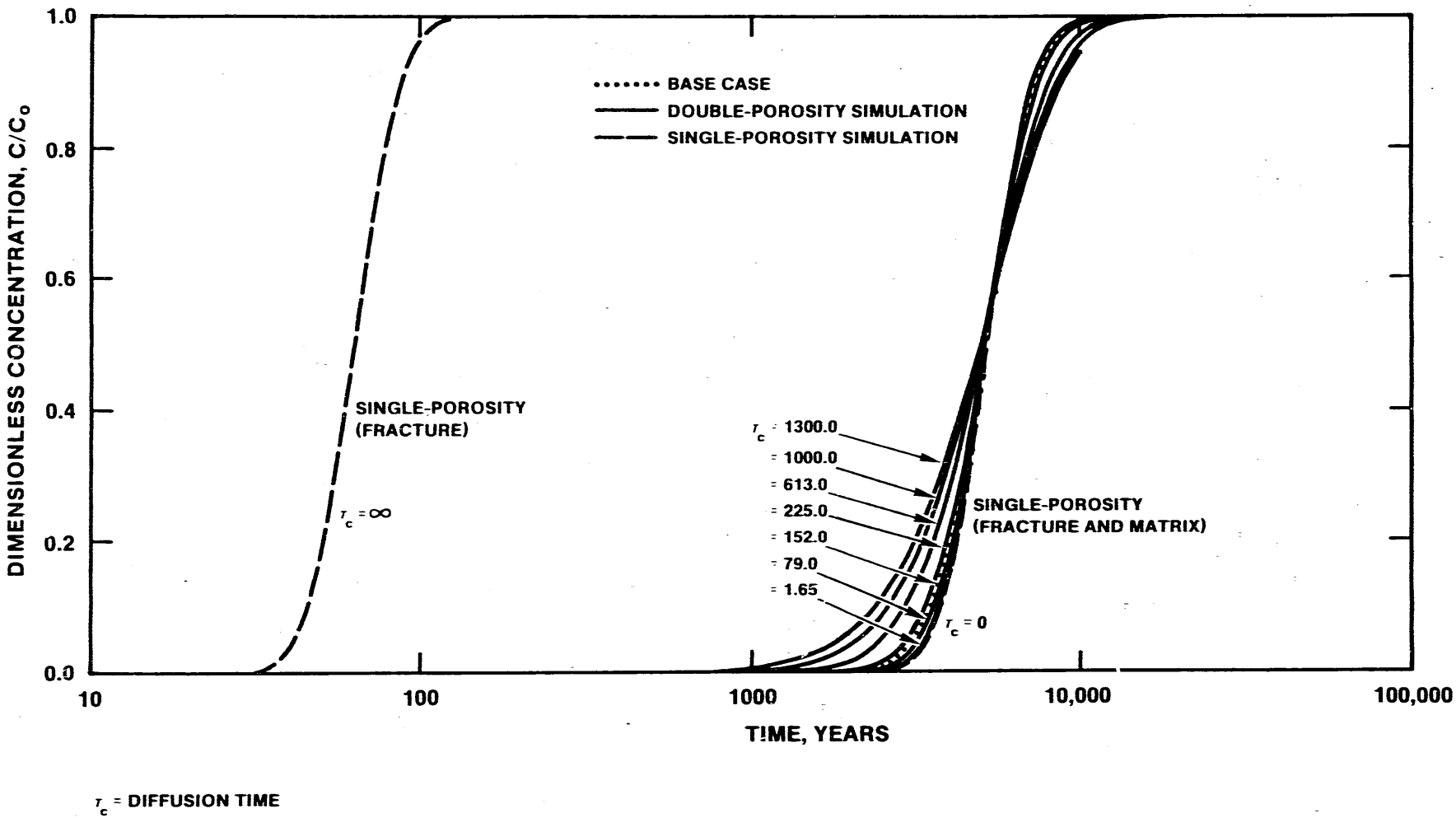


Figure 4.2.11: Estimated effect of variations in diffusion time on breakthrough, otherwise assuming base-case Culebra properties. The diffusion time is the time required for contaminant concentration at the center of matrix blocks to equal approximately 63% of the concentration in fractures. Modified from Figure 4.3 of Reeves et al. (1987).

Table 4.12: Estimated importance of different parameters in regional-scale contaminant transport within the Culebra dolomite. Table 4.5 of Reeves et al. (1987).

Parameter	Symbol	Sensitivity[a]	Importance Coefficient[a]	Importance Ranking
Free water diffusivity	D'	0.064	0.28	5
Matrix tortuosity	θ'	0.064	0.19	6
Matrix-block length	$2L'$	-0.13	0.36	4
Matrix porosity	ϕ'	1.1	1.58	1
Fracture porosity	ϕ	0.013[b]	0.13	7
Fracture dispersivity	α	-0.17	0.43	3
Fracture flux	u	-1.1	0.86	2

(a) Results are valid for retardations $K' = 1$, 1.50×10^2, 1.49×10^3, and 1.49×10^5.
(b) Upper-bound estimate.

coefficient; 2) the effective matrix porosity; 3) the Darcy flux within the fractures (defined as a specific flux m^3/m^2s); 4) the dispersivity in the fractures; and 5) the effective matrix-block size. Reeves et al. (1987) conclude that four parameters are relatively unimportant in controlling regional transport within the Culebra. These include: 1) free-water diffusivity; 2) matrix tortuosity; 3) fracture porosity; and 4) retardation in the fractures (not shown in Table 4.12).

The linear dependence of calculated breakthrough time on matrix retardation (K') is indicated in Figure 4.2.12. This behavior also indicates the effective porous-medium behavior on the regional scale, since for an ideal porous medium the dependence of breakthrough time on retardation is strictly linear. Breakthrough to the southern boundary of Zone 3 should not occur within 10,000 years after release for any matrix distribution coefficient (k_d) greater than approximately 0.2 mL/g for the assumed base-case Culebra material properties.

Valid use or extrapolation of the results contained in Reeves at al. (1987) depends on the assumptions listed at the beginning of this section, especially the representative character of the base-case transport properties and range of properties used in the calculations. The validity of the results is also dependent on the validity of the transmissivity and head distribution within the Culebra dolomite between the calculated

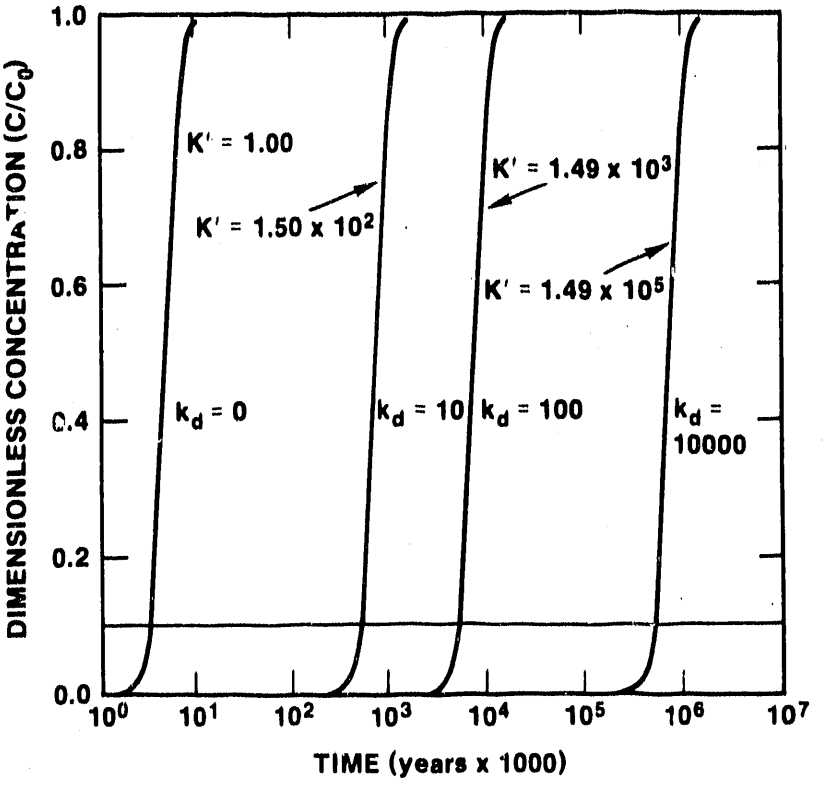


Figure 4.2.12: Variations in calculated breakthrough times to the boundary of WIPP zone 3 as a function of assumed matrix retardation, otherwise assuming base-case material properties. Matrix retardation (K') is proportional to $1 + k_d'$. Therefore, for a matrix distribution coefficient (k_d') of 0, K'=1.0. Slightly modified from Figure 4.1 of Reeves et al. (1987).

release points and the southern boundary of Zone 3. The results of LaVenue et al. (1988) discussed in Section 4.1.3.2 indicate that groundwater and contaminant travel times in the southern part of WIPP Zone 3 may be even slower than calculated by Reeves et al. (1988), so long as flow directions and rates within the Culebra are not affected too greatly by the continuing transient response of the Culebra to the end of the last pluvial period.

Effective matrix diffusion within fractured portions of the Culebra may be possible only because of the relatively slow flow velocities calculated assuming an undisturbed Culebra head distribution. In the event of a brine-reservoir breach of the WIPP facility, the volumes of brine injected from the Castile Formation into the Culebra dolomite might be sufficient to redefine the head distribution within the Culebra, greatly increase hydraulic gradients, and decrease flow times to the accessible environment. Calculations are underway to determine if the dual-porosity formalism is required to evaluate transport within the Culebra under these conditions.

4.3 Geochemical Studies in the Rustler Formation and Shallower Units

The hydrologic studies discussed in Section 4.1 and transport studies discussed in Section 4.2 largely ignore both geochemical behavior within the Rustler Formation and the overall geologic behavior of the WIPP site, except for interaction between the Culebra dolomite and trace contaminants. The status and present conclusions of geochemical studies within the Rustler Formation and shallower units are discussed in this section. The results of these studies, summarized by Siegel et al. (1988a), help place constraints on the relationship between the modern geochemistry and flow directions within both the Culebra dolomite and the Rustler Formation as a whole.

Section 4.3.1 describes the status of geochemical studies of major and minor solutes, in which Culebra groundwaters have been divided into four hydrochemical facies that may be diagnostic of natural interactions between Culebra waters and the matrix of the Culebra dolomite. The results, when compared with modern flow directions within the Culebra, indicate that the geochemistry of Culebra fluids is inconsistent with steady-state confined flow.

Section 4.3.2 discusses the expansion of the stable-isotope results and interpretations contained in Lambert (1983) to interpretations contained in Lambert (1987b) and Lambert and Harvey (1987). Stable-isotope studies themselves do not provide any information concerning the absolute ages of groundwaters. The studies can, in some cases, indicate whether different bodies of water were recharged under similar or different climatic conditions. The results of the recent stable-isotope studies indicate that the isotopic composition of Rustler groundwaters at and near the WIPP site is distinct from that of modern meteoric precipitation at similar elevations in the northern Delaware Basin.

Section 4.3.3 summarizes studies examining the lengths of time groundwaters in the Rustler/Salado contact zone, Rustler Formation, and Dewey Lake Red

Beds in the region of the WIPP site may have been isolated from contact with atmospherically derived components such as radiocarbon, tritium, and chlorine-36 (Lambert, 1987a). At the WIPP site, the applicability of such "environmental isotopes," which occur in ultratrace amounts, is unavoidably limited by the variability of the rock types present, as well as by the ages of both rocks and groundwaters. Specifically, no detectable ^{36}Cl above background has been detected in Rustler fluids, because of the large chlorine background inherent in fluids which have been involved in dissolution of halite from within the Rustler Formation. Nor have tritium levels significantly above background been identified in Rustler fluids, except in hole WIPP-29, interpreted on other grounds to be contaminated by potash mining. Radiocarbon studies met with only limited success, because the normal techniques used in drilling hydrocarbon-exploration and hydrologic test holes at and near the WIPP have resulted, in many cases, in some contamination with organic materials. The limited number of minimally contaminated radiocarbon results, however, indicate that the Culebra dolomite and part of the Dewey Lake Red Beds at the WIPP site have been isolated from atmospheric carbon sources for at least 12,000 years.

Section 4.3.4 discusses fluid-flow directions and rates within the Culebra dolomite, as interpreted from uranium-disequilibrium studies (Lambert and Carter, 1987). The results provide an effectively independent check of conceptual models derived from other studies. Although the present uranium-disequilibrium data base is limited, allowing considerable uncertainty in flow directions, the results indicate that there must have been a significant change in flow directions within the Culebra dolomite, on a time scale generally consistent with the end of local recharge indicated by radiocarbon studies.

4.3.1 Solute Geochemistry and Delineation of Hydrochemical Facies within the Culebra Dolomite

This section summarizes the currently available data and hypotheses (Siegel et al., 1988a) concerning the origin and compositions of waters in the Culebra dolomite. These authors delineate Culebra fluids into various hydrochemical facies, consider the compatibility of these facies with modern flow patterns derived from stratigraphic and hydrologic studies, and examine the interactions of Culebra solutes and host-rock mineralogies. Although Siegel et al. (1988a) emphasize the Culebra, relevant preliminary results of work on fluids from the Magenta dolomite, Rustler/Salado contact zone, and Dewey Lake Red Beds are included. One section of Siegel et al. (1988a), Bodine et al. (1988), was prepared as a summary interpretation of a separate study (Bodine and Jones, 1988), based on an independent data base. Data used in estimation of oxidation potentials (Eh) (Myers et al., 1988) were collected as part of the WIPP Water-Quality Sampling Program.

4.3.1.1 Hydrochemical Facies--The analytical ranges of compositions of Culebra waters and compositions used in calculations contained in Siegel et al. (1988a) are included in Table 4.13; major solutes are listed in Table 4.13a, minor and trace solutes in Table 4.13b. Individual data sets

Table 4.13a: Major solutes and other parameters in analyzed groundwaters from the Culebra, Magenta, Dewey Lake, and Bell Canyon. From Siegel et al. (1988b).

Well(s)	Collection Date[1]	Lab[2]	Total Dissolved Solids (mg/L)[7]	Ionic Strength (molal)[8]	Bromide (mg/L as Br)	Fluoride (mg/L as F)	Iodide (mg/L as I)	Boron (mg/L as B)	Lithium (mg/L as Li)	Strontium (mg/L as Sr)	Silica (mg/L as SiO_2)	Iron (mg/L as Fe)	Manganese (mg/L as Mn)
Culebra													
DOE-1	4/85	UNC	131200	2.53	56	-	-	37	0.64	26	8.4	0.28	-
DOE-1	(2)	avg			60	1.2	-	36	0.64	21	-	-	-
DOE-1	(2)	rng			56-64	1.0-1.7	-	35-37	(1)	16-26	8-24	-	-
DOE-2	3/85	UNC	60400	1.19	34	1.7	0.22	16	0.47	38	17	0.036	0.30
DOE-2	(2)	avg			35	1.6	0.22	18	0.47	29	-	-	-
DOE-2	(2)	rng			34-36	1.2-2.2	(1)	14-24	(1)	22-38	17-24	-	-
H-2A	4/86	UNC	12900	0.27	5.6	2.2	0.081	10	0.22	9.5	13	1.1	0.055
H-3B3	6/84	UNC	55000	1.08	29	2.1	0.13	30	0.53	23	9.8	0.57	0.13
H-3B3	2/85	UNC	55800	1.08	26	1.9	0.14	26	0.40	30	11	0.20	0.12
H-3B2, H3B3	(4)	avg			31	1.8	0.14	28	0.41	25	-	-	-
H-3B2, H3B3	(4)	rng			26-39	1.5-2.1	0.13-0.14	21-34	0.30-0.53	23-30	9-20	-	-
H-4B	5/81	UNC	21700	0.46	42	-	-	18	0.39	14	11	-	-
H-4C	8/84	UNC	21200	0.45	48	2.1	0.23	20	0.49	18	13	2.2	0.20
H-4B	7/85	UNC	20200	0.42	43	2.7	-	14	0.40	14	14	0.32	0.11
H-4B, H-4C	(4)	avg			44	2.2	0.23	18	0.42	15	-	-	-
H-4B, H-4C	(4)	rng			43-48	1.7-2.7	(1)	14-23	0.39-0.49	13-18	11-30	-	-
H-5B	6/81	UNC	154400	2.99	62	-	-	33	0.77	32	6.2	-	-
H-5C	10/81	UNC	154500	3.00	64	-	-	35	0.77	31	5.8	-	-
H-5B	8/85	UNC	152600	2.97	49	2.0	0.19	34	0.81	29	7.1	2.9	0.29
H-5B, H-5C	(4)	avg			58	1.3	0.19	33	0.78	31	-	-	-
H-5B, H-5C	(4)	rng			49-64	0.8-2.0	(1)	29-35	0.77-0.81	29-32	5-36	-	-
H-6B	5/81	UNC	59300	1.18	34	-	-	11	0.44	32	20	-	-
H-6B	9/85	UNC	57400	1.13	34	1.9	0.096	10	0.45	30	18	0.094	0.13
H-6B	(3)	avg			34	1.6	0.096	9.5	0.44	28	-	-	-
H-6B	(3)	rng			34-35	1.3-1.9	(1)	7-11	0.44-0.45	24-32	18-43	-	-

Table 4.13a: Major solutes and other parameters in analyzed groundwaters from the Culebra, Magenta, Dewey Lake, and Bell Canyon. From Siegel et al. (1988b). (Continued)

Well(s)	Collection Date[1]	Lab[2]	Total Dissolved Solids (mg/L)[7]	Ionic Strength (molal)[8]	Bromide (mg/L as Br)	Fluoride (mg/L as F)	Iodide (mg/L as I)	Boron (mg/L as B)	Lithium (mg/L as Li)	Strontium (mg/L as Sr)	Silica (mg/L as SiO_2)	Iron (mg/L as Fe)	Manganese (mg/L as Mn)
H-7B1	3/86	UNC	3220	0.089	0.57	1.5	0.052	0.76	0.10	8.5	47	0.056	0.050
H-7B1	(3)	avg			0.57	1.4	0.052	0.77	0.11	7.7	-	-	-
H-7B1	(3)	rng			(1)	1.2-1.5	(1)	0.34-0.80	0.10-0.12	5.8-8.7	47-92	-	-
H-8B	1/86	UNC	2830	0.083	0.085	2.5	0.14	0.48	0.12	6.9	29	0.036	0.021
H-8B	(2)	avg			0.085	2.4	0.14	0.49	0.12	6.7	-	-	-
H-8B	(2)	rng			(1)	2.1-2.5	(1)	0.48-0.50	0.12	5.9-7.4	29-56	-	-
H-9B	11/85	UNC	3080	0.087	0.24	3.3	0.11	0.63	0.18	7.5	27	0.032	0.015
H-9B	(2)	avg			0.24	3.0	0.11	0.66	0.18	7.2	-	-	-
H-9B	(2)	rng			(1)	2.6-3.3	(1)	0.63-0.70	0.17-0.18	7.0-7.5	27-39	-	-
H-10B	3/80	GS	65700	1?	-	1.3	-	13	-	-	1.5	-	-
H-11B3	6/85	UNC	117400	2.23	47	-	-	32	0.62	25	-	0.14	0.22
H-11B3	(2)	avg			48	1.3	-	31	0.50	20	-	-	-
H-11B3	(2)	rng			47-48	1.0-1.6	-	30-32	0.38-0.62	18-25	25-32	-	-
H-12	8/85	UNC	140500	2.72	76	-	-	39	1.2	31	7.2	0.22	0.087
H-12	(2)	avg			76	1.5	-	38	0.85	29	-	-	-
H-12	(2)	rng			76-77	1.1-2.3	-	35-39	0.61-1.2	18-38	7-96	-	-
P-14	2/86	UNC	24900	0.58	72	1.7	0.42	0.72	0.28	51	30	2.0	0.18
P-14	(2)	avg			72	1.5	0.42	0.72	0.28	50	-	-	-
P-14	(2)	rng			(1)	1.2-1.7	(1)	(1)	(1)	48-51	30-69	-	-
P-17	3/86	UNC	86500	1.67	72	1.9	0.18	38	0.87	29	8.5	4.0	0.87
P-17	(2)	avg			70	1.6	0.18	35	0.87	32	-	-	-
P-17	(2)	rng			69-72	1.2-1.9	(1)	32-38	(1)	28-36	0-8.5	-	-
P-18	10/77	GS	118300	2.5?	-	1.2	-	100	-	-	1.0	-	-

Table 4.13a: Major solutes and other parameters in analyzed groundwaters from the Culebra, Magenta, Dewey Lake, and Bell Canyon. From Siegel et al. (1988b). (Continued)

Well(s)	Collection Date[1]	Lab[2]	Total Dissolved Solids (mg/L)[7]	Ionic Strength (molal)[8]	Bromide (mg/L as Br)	Fluoride (mg/L as F)	Iodide (mg/L as I)	Boron (mg/L as B)	Lithium (mg/L as Li)	Strontium (mg/L as Sr)	Silica (mg/L as SiO_2)	Iron (mg/L as Fe)	Manganese (mg/L as Mn)
WIPP-13	2/87	avg	-	-	39	1.4	-	11	0.35	25	-	-	-
WIPP-25	8/80	UNC	12100	0.26	2.6	-	-	1.5	0.20	12	34	-	-
WIPP-25	8/80	avg			2.6	-	-	1.5	0.20	12	-	-	-
WIPP-25	8/80	rng			(2)	-	-	(1)	(1)	(1)	(1)	-	-
WIPP-25	2/86	UNC	13600	-	3.4	1.7	0.042	1.7	0.22	17	33	0.50	0.11
WIPP-25	2/86	avg			3.8	1.6	0.042	1.7	0.22	17	-	-	-
WIPP-25	2/86	rng			3.4-4.2	1.6-1.7	(1)	1.7	(1)	(1)	33-67	-	-
WIPP-26	8/80	UNC	15100	0.33	3.2	-	-	1.4	0.24	17	33	-	-
WIPP-26	8/80	avg			3.2	-	-	1.4	0.24	17	-	-	-
WIPP-26	8/80	rng			(1)	-	-	(1)	(1)	(1)	(1)	-	-
WIPP-26	11/85	UNC	17600	0.37	3.9	1.7	0.070	1.6	0.23	20	35	0.026	<0.01
WIPP-26	11/85	avg			3.9	1.5	0.070	1.6	0.23	18	-	-	-
WIPP-26	11/85	rng			(1)	1.3-1.7	(1)	(1)	(1)	17-20	35-65	-	-
WIPP-27	9/80	UNC	134700	2.57	28	-	-	2.3	0.33	51	23	-	-
WIPP-27	(2)	avg			28	-	-	2.1	0.33	51	-	-	-
WIPP-27	(2)	rng			(1)	-	-	1.9-2.3	(1)	(1)	13-23	-	-
WIPP-28	9/80	UNC	46600	0.90	7.2	-	-	5.8	0.30	16	36	-	-
WIPP-28	9/80	avg			7.2	-	-	5.8	0.30	16	-	-	-
WIPP-28		rng			(1)	-	-	(1)	(1)	(1)	(1)	-	-
WIPP-29	8/80	UNC	245400	4.91	45	-	-	4.4	0.78	29	22	-	-
WIPP-29	8/80	avg			45	-	-	4.4	0.78	29	-	-	-
WIPP-29	8/80	rng			(1)			(1)	(1)	(1)	(1)	-	-
WIPP-29	12/85	UNC	324100	6.57	61	4.6	0.38	5.2	0.70	13	15	1.1	1.7
WIPP-29	12/85	avg			61	-	0.38	5.5	0.70	11	-	-	-
WIPP-29	12/85	rng			(1)	0.9-4.6	(1)	5.2-5.8	(1)	9-13	15-110	-	-
WIPP-30	9/80	UNC	29100	0.58	10	-	-	6.1	0.27	18	6.5	-	-
WIPP-30	9/80	avg			10	-	-	6.1	0.27	18	-	-	-
WIPP-30	9/80	rng			(1)			(1)	(1)	(1)	(1)	-	-

Table 4.13a: Major solutes and other parameters in analyzed groundwaters from the Culebra, Magenta, Dewey Lake, and Bell Canyon. From Siegel et al. (1988b). (Concluded)

Well(s)	Collection Date[1]	Lab[2]	Total Dissolved Solids (mg/L)[7]	Ionic Strength (molal)[8]	Bromide (mg/L as Br)	Fluoride (mg/L as F)	Iodide (mg/L as I)	Boron (mg/L as B)	Lithium (mg/L as Li)	Strontium (mg/L as Sr)	Silica (mg/L as SiO_2)	Iron (mg/L as Fe)	Manganese (mg/L as Mn)
Engle	3/85	UNC	3270	0.09	0.27	2.8	0.12	0.97	0.17	8.4	29	0.59	0.060
Engle	3/85	avg			0.27	2.8	0.12	0.87	0.17	7.7	-	-	-
Engle	3/85	rng			(1)	2.8-2.9	(1)	0.77-0.97	(1)	7.0-8.4	29-54	-	-
Magenta													
H-3B1	7/85	UNC	8560	-	5.8	2.4	1.2	2.0	0.32	17	10	0.11	0.028
H-3B1	(3)	rng			5.8-6.0	1.8-2.6	1.2-2.0	2.0-4.5	0.32	13-18	10-26	-	-
H-4C	11/86	UNC	23900	-	5.9	2.4	0.31	12	0.46	12	9.1	0.71	0.29
H-4C	(2)	rng			5.9-7.5	2.2-2.6	(1)	11-12	0.41-0.46	12-14	9-26	-	-
H-5C	10/86	UNC	6980	-	0.93	2.5	0.31	11	0.20	10	11	1.5	0.020
H-5C	10/86	rng			(1)	2.5	(1)	10-11	0.20	8-10	11-26	-	-
H-6C	10/86	UNC	4540	-	2.3	1.5	0.086	2.2	0.21	9.8	11	0.26	0.010
H-6C	10/86	rng			1.0-2.3	1.5-1.7	(1)	2.2-2.4	0.19-0.21	7.1-9.8	11-28	-	-
Dewey Lake Red Beds													
Ranch	6/86	UNC	2520	-	2.3	0.82	0.13	0.10	0.12	5.9	52	0.024	<0.01
Ranch	6/86	rng			2.3	0.8-1.0	(1)	0.10-0.19	(1)	3.2-5.9	52-86	-	-
Twin-Pasture	1/86	UNC	401	-	0.17	0.58	<0.01	0.13	<0.05	1.1	47	<0.01	<0.01
Twin-Pasture	1/86	rng			(1)	0.5-1.4	(1)	0.13-0.16	(1)	0.6-1.1	47-90	-	-
Bell Canyon Frm.													
DOE-2	7/85	UNC	149500	-	250	1.1	6.4	54	5.8	150	2.5	11	28
DOE-2	7/85	rng			(1)	0.4-1.4	6.4-7.9	54-61	2.8-5.8	150-300	2-30	-	-

Table 4.13b: Minor and trace solutes and other parameters in analyzed groundwaters from the Culebra, Magenta, Dewey Lake, and Bell Canyon. From Siegel et al. (1988b).

Well(s)	Collection Date[1]	Lab[2]	Zone[3]	Sodium (mg/L as Na)	Potassium (mg/L as K)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Chloride (mg/L as Cl)	Sulfate (mg/L as SO_4)	Bicarbonate (mg/L as HCO_3)[4]	pCO_2[5]	pH[4]
Culebra												
DOE-1	4/85	UNC	A	45800	1100	1730	1610	73600	7350	45	-2.60	7.1
DOE-1	(2)	avg	A	46000	1100	1700	1600	75000	7400	-		-
DOE-1	(2)	rng	A	45000-46000	(1)	(1)	(1)	73000-77000	(1)	45-46		7.1
DOE-2	3/85	UNC	C	18400	410	1960	1060	34600	3950	67	-2.33	7.0
DOE-2	(2)	avg	C	18000	420	1900	1000	33000	3700	-		-
DOE-2	(2)	rng	C	17000-19000	410-420	1900-2000	900-1100	32000-35000	3400-4000	(1)		(1)
H-2A	4/86	UNC	C	3570	93.5	743	167	5310	2980	57	-3.38	8.0
H-3B3	6/84	UNC	C	17400	495	1550	829	29500	5130	-	-2.83	7.4
H-3B3	2/85	UNC	C	18000	425	1470	783	30300	4820	52	-2.86	7.4
H-3B2, H-3B3	(4)	avg	C	18000	440	1400	760	29000	4800	-		-
H-3B2, H-3B3	(4)	rng	C	17000-19000	360-500	1200-1600	690-830	27000-31000	4600-5200	50-52		7.4
H-4B	5/81	UNC	C	6080	215	700	455	7980	6230	71	-3.35	8.0
H-4C	8/84	UNC	C	6150	222	698	505	7950	5700	75	-3.11	7.8
H-4B	7/85	UNC	C	5850	210	691	427	7480	5520	69	-3.04	7.7
H-4B, H-4C	(4)	avg	C	6000	220	690	450	7700	5700	-		-
H-4B, H-4C	(4)	rng	C	5800-6200	180-260	690-700	400-510	7400-8000	5500-6300	68-75		7.6-8.0
H-5B	6/81	UNC	A	52400	1290	1710	2140	89500	7360	80	-3.21	7.9
H-5C	10/81	UNC	A	52300	1300	1720	2150	89500	7570	86	-3.17	7.9
H-5B	8/85	UNC	A	54100	1350	1700	2170	85400	7840	50	-2.86	7.4
H-5B, H-5C	(4)	avg	A	53000	1300	1700	2200	87000	7600	-		-
H-5B, H-5C	(4)	rng	A	52000-55000	1200-1400	1700-1800	2100-2200	84000-90000	7300-7900	-		-
H-6B	5/81	UNC	C	18600	450	2150	1080	33000	3980	96	-2.16	7.0
H-6B	9/85	UNC	C	18000	375	2040	1040	32300	3570	94	-2.07	6.9
H-6B	(3)	avg	C	18000	420	2000	1100	33000	3600	-		-
H-6B	(3)	rng	C	17000-19000	370-450	1900-2200	1000-1200	32000-34000	3300-4000	90-96		6.9-7.2

Table 4.13b: Minor and trace solutes and other parameters in analyzed groundwaters from the Culebra, Magenta, Dewey Lake, and Bell Canyon. From Siegel et al. (1988b). (Continued)

Well(s)	Collection Date[1]	Lab[2]	Zone[3]	Sodium (mg/L as Na)	Potassium (mg/L as K)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Chloride (mg/L as Cl)	Sulfate (mg/L as SO_4)	Bicarbonate (mg/L as HCO_3)[4]	pCO_2[5]	pH[4]
H-7B1	3/86	UNC	B	207	7.0	587	130	320	1850	120	-2.20	7.
H-7B1	(3)	avg	B	210	7.0	570	130	320	1800	-		-
H-7B1	(3)	rng	B	200-210	7.0	540-590	130	300-350	1700-1900	120		7.3-7.4
H-8B	1/86	UNC	B	55.1	3.83	548	157	30.5	1950	96	-2.70	7.3
H-8B	(2)	avg	B	54	3.9	540	170	32	1800	-		-
H-8B	(2)	rng	B	51-56	3.7-4.1	520-550	150-180	30-33	1600-2000	93-96		7.2-7.3
H-9B	11/85	UNC	B	146	6.85	590	137	194	1900	110	-2.43	7.4
H-9B	(2)	avg	B	150	7.2	580	150	190	1800	-		-
H-9B	(2)	rng	B	140-150	6.8-7.6	560-620	130-170	170-200	1700-1900	110		7.3-7.4
H-10B	3/80	GS	C	21000	520	1600	1000	36000	5600	45	-	8.3
H-11B3	6/85	UNC	A	40400	943	1700	1320	65900	7180	54	-2.63	7.2
H-11B3	(2)	avg	A	39000	940	1600	1300	66000	7200	-		-
H-11B3	(2)	rng	A	37000-41000	(1)	1500-1700	1300-1400	65000-67000	(1)	54-55		7.2-7.3
H-12	8/85	UNC	A	49200	1270	1760	1980	79000	7210	53	-2.61	7.2
H-12	(2)	avg	A	50000	1300	1800	2000	80000	7200	-		-
H-12	(2)	rng	A	49000-51000	(1)	1700-1900	1900-2000	78000-80000	(1)	53-62		7.2
P-14	2/86	UNC	C	4360	37.9	3520	840	14500	1590	110	-1.81	6.8
P-14	(2)	avg	C	4100	41	3700	800	14000	1600	-		-
P-14	(2)	rng	C	3700-4400	37-45	3500-3900	760-840	13000-15000	1500-1700	100-110		6.8-6.9
P-17	3/86	UNC	C	28300	782	1620	1460	48200	6020	64	-2.90	7.5
P-17	(2)	avg	C	28000	820	1600	1500	49000	6000	-		-
P-17	(2)	rng	C	28000-29000	780-880	1500-1700	1400-1600	48000-51000	5900-6100	61-64		7.5
P-18	10/77	GS	A	9200	6200	5600	16000	80000	980	310	-	7.2

Table 4.13b: Minor and trace solutes and other parameters in analyzed groundwaters from the Culebra, Magenta, Dewey Lake, and Bell Canyon. From Siegel et al. (1988b). (Continued)

Well(s)	Collection Date[1]	Lab[2]	Zone[3]	Sodium (mg/L as Na)	Potassium (mg/L as K)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Chloride (mg/L as Cl)	Sulfate (mg/L as So_4)	Bicarbonate (mg/L as HCO^3)[4]	pCO_2[5]	pH[4]
WIPP-13	2/87	avg	C	19000	340	-	-	36000	4500	-120	-	-6.6
WIPP-25	8/80	UNC	C	3160	73.5	905	260	5250	2500	210	-1.69	6.9
WIPP-25	8/80	avg	C	3200	74	900	260	5200	2500	-		-
WIPP-25	8/80	rng	C	(1)	(1)	(1)	(1)	5200-5300	(1)	(1)		(1)
WIPP-25	2/86	UNC	C	3180	102	1140	315	6320	2380	130	-	7.2
WIPP-25	2/86	avg	C	3300	100	1100	330	6200	2400	-		-
WIPP-25	2/86	rng	C	3100-3400	100-110	1100-1200	310-340	6200-6400	2300-2400	(1)		(1)
WIPP-26	8/80	UNC	C	3620	170	1240	355	7200	2480	140	-1.86	6.9
WIPP-26	8/80	avg	C	3600	170	1200	360	7000	2500	-		-
WIPP-26	8/80	rng	C	(1)	(1)	(1)	(1)	6900-	(1)	(1)		6.9
WIPP-26	11/85	UNC	C	4220	343	1340	380	8770	2420	120	-2.14	7.1
WIPP-26	11/85	avg	C	4100	350	1300	390	8600	2400	-		-
WIPP-26	11/85	rng	C	3800-4300	340-360	1200-1400	370-430	8400-8800	2300-2500	(1)		(1)
WIPP-27	9/80	UNC	D	39200	8060	3210	1900	78500	3830	120	-1.33	6.4
WIPP-27	(2)	avg	D	39000	8100	3200	2000	78000	3900	-		-
WIPP-27	(2)	rng	D	39000-40000	(1)	3100-3300	1900-2000	77000-79000	3800-3900	(1)		6.4
WIPP-28	9/80	UNC	C	15200	485	1180	555	24800	4380	-	-0.76	6.5
WIPP-28	9/80	avg	C	15000	480	1200	560	24000	4400	-		-
WIPP-28	9/80	rng	C	(1)	(1)	(1)	(1)	24000-25000	(1)	-		-
WIPP-29	8/80	UNC	D	71400	15600	950	5480	138000	14000	210	-0.87	6.1
WIPP-29	8/80	avg	D	71000	16000	880	5600	140000	14000	-		-
WIPP-29	8/80	rng	D	(1)	(1)	810-950	5400-5700	130000-140000	13000-14000	(1)		6.1
WIPP-29	12/85	UNC	D	94900	23300	413	6500	179000	20000	160	-0.75	5.9
WIPP-29	12/85	avg	D	92000	22000	410	6400	180000	18000	-		-
WIPP-29	12/85	rng	D	90000-95000	20000-24000	(1)	6300-6500	179000-180000	17000-20000	(1)		(1)

Table 4.13b: Minor and trace solutes and other parameters in analyzed groundwaters from the Culebra, Magenta, Dewey Lake, and Bell Canyon. From Siegel et al. (1988b). (Concluded)

Well(s)	Collection Date[1]	Lab[2]	Zone[3]	Sodium (mg/L as Na)	Potassium (mg/L as K)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Chloride (mg/L as Cl)	Sulfate (mg/L as SO_4)	Bicarbonate (mg/L as HCO_3)[4]	pCO_2[5]	pH[4]
WIPP-30	9/80	UNC	C	8570	255	1140	460	14600	4120	40 HCO_3	-4.41	8.8
WIPP-30	9/80	avg	C	8600	260	1100	460	15000	4100	17 CO_3		-
WIPP-30	9/80	rng	C	(1)	(1)	(1)	(1)	14000-15000	(1)	(1)		(1)
Engle	3/85	UNC	B	200	5.60	588	152	231	1990	110	-2.44	7.4
Engle	3/85	avg	B	190	5.5	580	140	230	1900	-		-
Engle	3/85	rng	B	180-200	5.4-5.6	570-590	130-160	220-240	1800-2000	(1)		(1)
Magenta												
H-3B1	7/85	UNC	Mag	1520	34.5	1000	292	3360	2310	47	-	8.0
H-3B1	(3)	rng	Mag	1500-1600	34-36	1000	270-300	3300-3400	2200-2400	45-47		7.7-8.0
H-4C	11/86	UNC	Mag	7110	85.1	651	411	8460	7100	70	-	8.4
H-4C	(2)	rng	Mag	7100-7300	85-99	610-660	390-420	8400-8500	(1)	70-85		8.1-8.4
H-5C	10/86	UNC	Mag	1480	33.6	550	173	1070	3620	56	-	8.0
H-5C	10/86	rng	Mag	1400-1500	(1)	(1)	170-190	1000-1100	(1)	(1)		(1)
H-6C	10/86	UNC	Mag	642	16.6	546	160	428	2700	51	-	7.7
H-6C	10/86	rng	Mag	(1)	(1)	(1)	160-170	420-430	2400-2700	(1)		(1)
Ranch	6/86	UNC	DL	200	4.0	420	202	418	1100	220	-	7.0
Ranch	6/86	rng	DL	180-200	3.6-4.0	(1)	190-210	390-420	920-1100	(1)		(1)
Dewey Lake Red Beds												
Twin-Pasture	1/86	UNC	DL	25.4	3.85	80.4	22.5	44.1	75.1	230	-	7.8
Twin-Pasture	1/86	rng	DL	24-26	3.7-4.3	80-81	22-25	44-47	70-76	(1)		(1)
Bell Canyon												
DOE-2	7/85	UNC	BC	49600	885	5910	1330	89700	2020	48	-	6.8
DOE-2	7/85	rng	BC	(1)	(1)	(1)	(1)	89000-90000	(1)	(lab)		(1)

Footnotes for Tables 4.13a and 4.13b

*Solute values from various labs have been rounded as follows:

-Na, K, Ca, Mg, CL, SO_4 from UNC	: 3 significant figures
-all others from UNC	: 2 sig. figs
-all solutes from GS	: 2 sig. figs
-all "avg" values	: 2 sig. figs
-all minimum 'rng' values	: down to 2 sig. figs
-all maximum 'rng' values	: up to 2 sig. figs
-all total dissolved solids (TDS)	: to nearest 100 mg/L or to 3 sig. figs (for TDS<10000)
-all bicarbonate values	: to 2 sig. figs
-all pH values	: to 0.1 pH unit
-all pCO_2 values	: to 0.01 unit
-all ionic strength values	: to 0.01 molal

(1) Collection date: a number in parentheses indicates that values in that row are averages or ranges of data for up to that number of samples

(2) avg - average of one or more values from one or more laboratories; used to calculate element ratios and generate contour plots (Siegel and others, 1988)
rng - range of values from one or more laboratories; gives a crude estimate of the uncertainties associated with the data. A single value in the range row means that all values were indentical. A "(1)" in the range row means that only one reliable value was available
GS - USGS Central labs
UNC - UNC Geotech (before Oct. 1, 1986, Bendix Field Engineering Corp.), Grand Junction, Co.

(3) zone - hydrochemical facies zone described by Siegel and others (1988). Applies only to Culebra.

(4) Bicarbonate and pH values were measured in the field when the samples were collected. (Exception: HCO_3 in the DOE-2 Bell Canyon sample was measured in the lab)

(5) pCO_2 - calculated using PHRQPITZ (Siegel and others, 1988)

(6) Stratigraphic horizon: BC - Bell Canyon Formation
DL - Dewey Lake Red Beds
Mag - Magenta Dolomite

(7) Total dissolved solids - calculated by summing the major solutes

(8) Ionic strength - calculated using PHRQPITZ (Siegel and others, 1988)

evaluated in compiling the table and methods for evaluating the data are discussed in Robinson (1988), Lambert and Harvey (1987), and Siegel et al. (1988b). The data in Tables 4.13a and 4.13b were used by Siegel et al. (1988a) in facies assignments of Culebra fluids, saturation-index calculations, and factor analyses, as well as in plotting of element-ratio contours.

On the basis of the available major-solute analyses (Table 4.13a), Culebra waters can be combined into four hydrochemical facies (Figure 4.3.1). These include:

1. Zone A (H-5, H-11, H-12; DOE-1, P-17, P-18(?)), containing saline NaCl brines (about 2 to 3 molal) with a Ca/Mg weight ratio near unity. These waters are found in the eastern third of the WIPP site and further east, in a region roughly coincident with the region of lowest Culebra transmissivity. In the western part of Zone A, halite is present only in the unnamed lower member (Figure 1.5); in the eastern part of the zone, halite is present throughout the Rustler.

2. Zone B (H-7, H-8, H-9, Engle), containing relatively fresh waters (<0.1 molal) in which Ca^{++} and $SO_4^{=}$ are the dominant solutes. These waters are found only south of the WIPP site. No Rustler halite is present in this zone. Data from the South and Indian wells (Bodine and Jones, 1988) suggest that these wells should also be classified as part of Zone B.

3. Zone C, containing waters of variable compositions, low to moderate ionic strength (about 0.3 to 1.1 molal), and Ca/Mg weight ratios greater than 1.5:1. These waters extend from the central part of the WIPP site to the eastern part of Nash Draw, in regions of low to high Culebra transmissivity. In the eastern part of the zone, halite is present in the unnamed lower member; on the western side of the zone, Rustler halite is absent. In general, the most saline brines in Zone C are found in the eastern part of the zone.

4. Zone D, containing waters of anomalously high salinities (about 3 to 7 molal) and K/Na mole ratios (about 0.2) relative to other sampled fluids (3 molal or less; K/Na mole ratios of 0.01 to 0.09) This zone is apparently confined to western Nash Draw, and contains only holes WIPP-27 and WIPP-29. Fluid compositions at WIPP-29 have have changed over the course of seven years of monitoring, probably in response to nearby potash refining operations.

The chemical characteristics of the defined Culebra fluid facies can be summarized graphically in a Piper (trilinear) diagram (Figure 4.3.2). This plot generalizes the relationships between several major solutes, i.e., those in the Na-K-Mg-Ca-Cl-SO_4-CO_3 system. Relative proportions of cations and anions are shown in the triangular plots in the bottom half of the figure, relative ratios of divalent to monovalent cations and chloride to (sulfate plus carbonate) in the parallelogram portion of the figure.

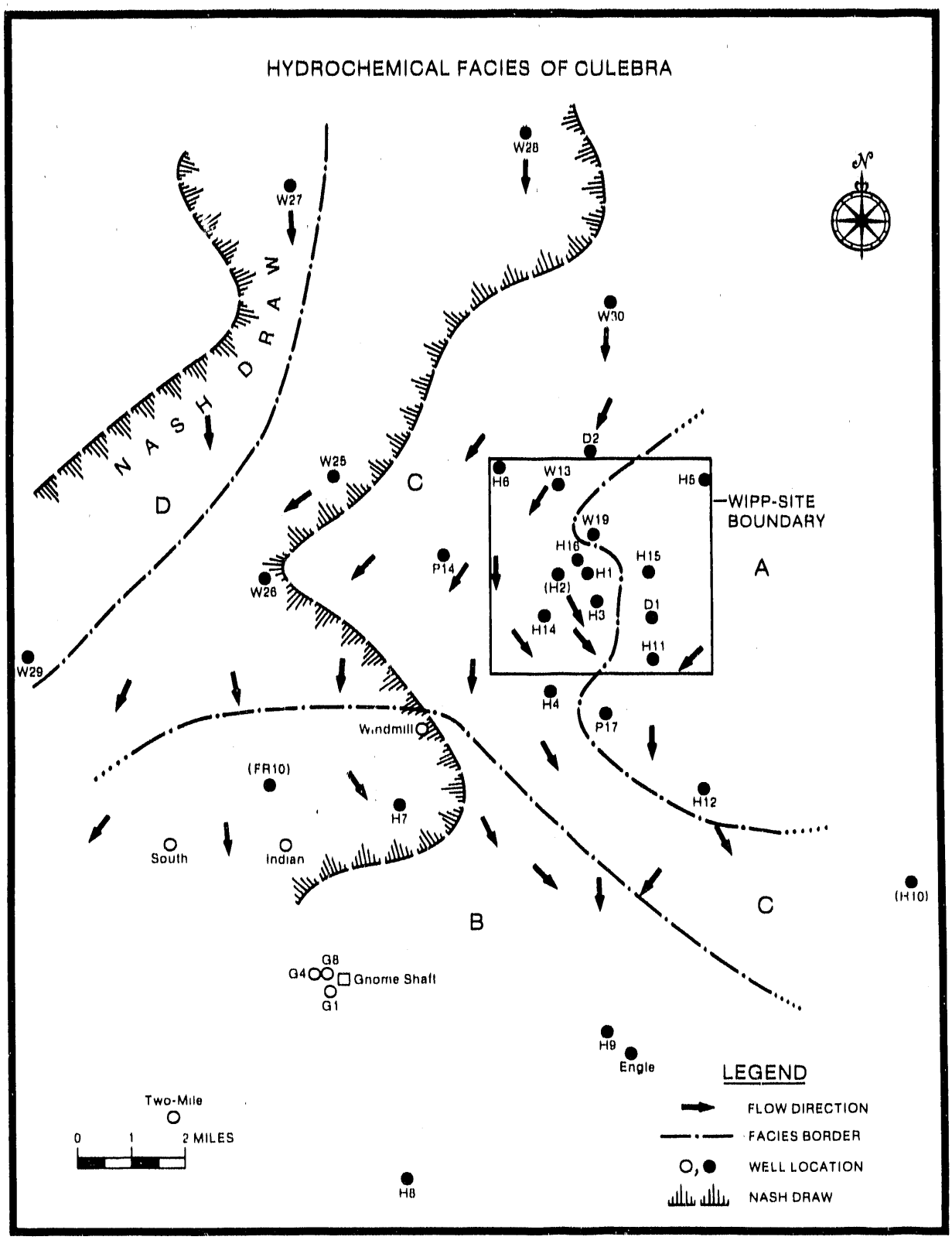


Figure 4.3.1: Summary of hydrochemical facies and local flow directions in the Culebra dolomite. Facies boundaries from Siegel et al. (1988a); modern flow directions from Figure 4.5B of LaVenue et al. (1988).

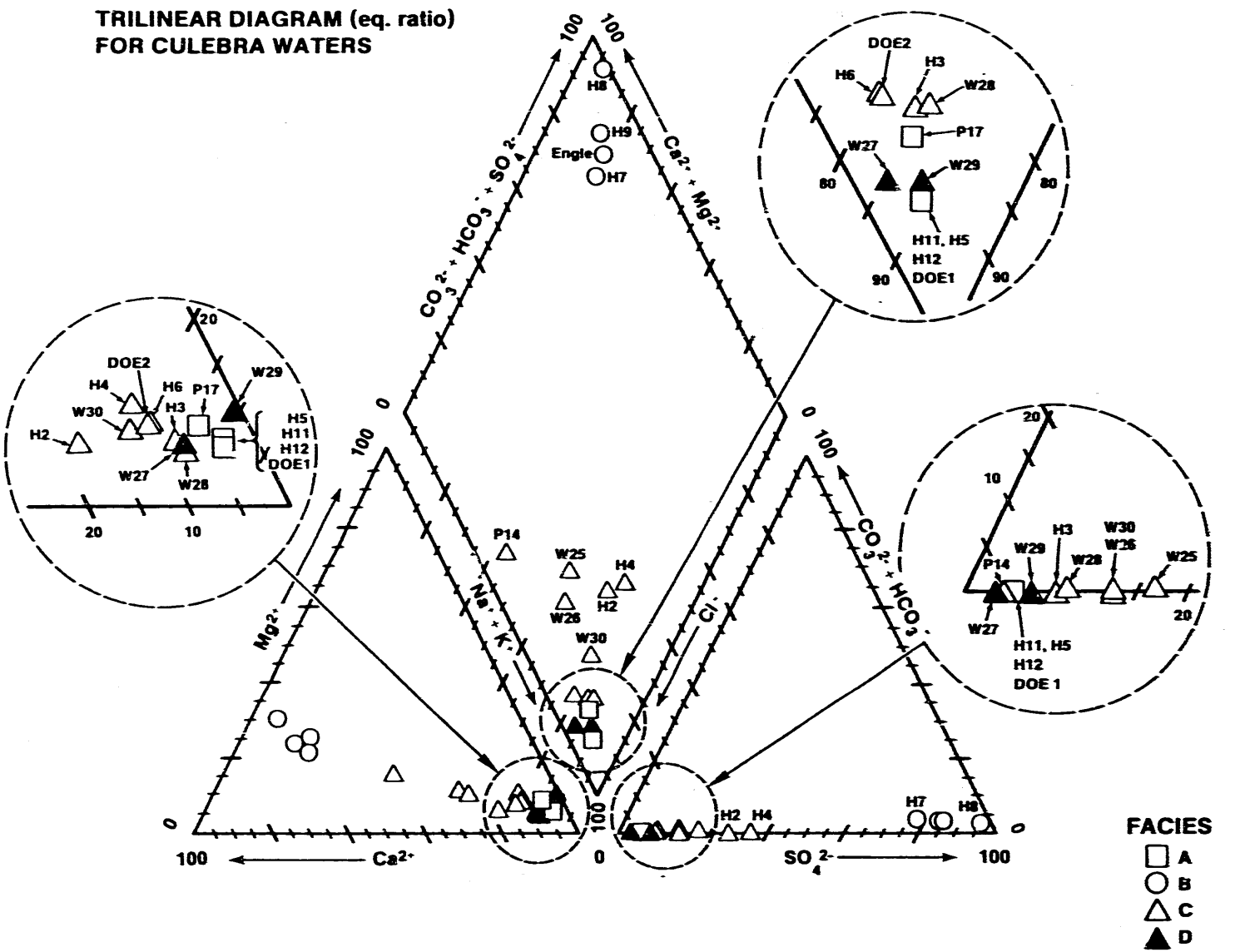


Figure 4.3.2: Piper (trilinear) diagram for analyzed Culebra fluids. Analyses are represented in terms of equivalents per liter. From Siegel et al. (1988b).

The analyses from Zone A have nearly identical ionic proportions (Figure 4.3.2), and plot very near the Na-Cl corner in both parts of the figure. In contrast, the analyses of the dilute fluids from Zone B all plot near the Ca-Mg-SO_4 corner in the upper part of the figure. Analyses from Zone C are variable, and those groundwaters closer to the Na-Cl corner of the plot are similar to waters from Zone A. Zones A and C are distinguished primarily on the basis of Ca/Mg ratio and ionic strength. Waters from Zone D have similar ionic ratios as fluids from Zone A except for K/Na; Zone D is distinguished primarily on the basis of its high K/Na ratios.

The overall interpretation of the facies distribution (Siegel et al., 1988a), assuming that the Culebra is relatively confined, is that flow directions within the Culebra must be transient. The inconsistency of Culebra fluid densities and steady-state confined flow was noted in Section 4.1, based on numerical modeling studies of Haug et al. (1987) and LaVenue et al. (1988). Ramey (1985) noted that modern flow directions within the Culebra do not appear consistent with the modern salinity distribution. This inconsistency is also evident in Figure 4.3.1, which is based on a larger and more reliable data base than considered by Ramey (1985). The most striking evidence is that fluids in Zone B, a facies with low salinity, lie down-gradient from more saline waters in Zone C. It is difficult to explain the origin of fluids presently in Zone B by steady-state confined flow through Zone C (Figure 4.3.1). One alternative to steady-state flow, based on isotopic studies (Sections 4.3.2, 4.3.3, and 4.3.4), is that there has been a significant change in flow directions within the Culebra dolomite in the last (approximately) 12,000 years. This is consistent with geologic evidence indicating the transient geologic and hydrologic setting of the WIPP site (Section 4.4).

4.3.1.2 Normative Salt Assemblages of Rustler Waters--The chemical variability of Culebra fluids has also been evaluated on the basis of normative salt assemblages, as summarized by Bodine et al. (1988). The normative salt assemblage (salt norm) of a given water is the equilibrium assemblage of salts that would precipitate from the water if it were evaporated to dryness under standard conditions (25 degrees C, 1 atmosphere pressure). In this interpretation, the SNORM code (Bodine and Jones, 1986) was applied by Bodine et al. (1988) to a different data base than that shown in Table 4.13.

The interpretations of the derivation of Culebra fluids based on hydrochemical facies, isotopic data, and physical hydrology are not in all cases consistent with those based on interpretation of salt norms. Siegel and Lambert (1988) conclude that the overall hydrologic setting of the Culebra is transient. Bodine et al. (1988) conclude that the present distribution of salt norms within the Rustler Formation is, when considered alone, generally consistent with the modern Culebra flow field. These authors relax the vertical confinement of the Rustler. On the basis of solutes alone, their interpretation cannot exclude dilution of primitive-diagenetic brines at P-14 and in the low-permeability, halite-rich zones of the Culebra east of WIPP Zone 3 (for example at P-18) by water that has infiltrated from the surface and dissolved both halite and anhydrite or gypsum. With increasing distances from P-18 and P-14, increasing amounts

of solutes from recharge are interpreted to have mixed with primitive-connate Culebra solutes.

Based on salt-norm calculations, Bodine et al. (1988) suggest four end-member fluid compositions from evaporitic rocks at the WIPP site. These are:

1. Brines containing alkaline earth (Ca, Mg, Ba, Sr, etc) chloride salts in their normative assemblages, combined with relatively low Cl/Br weight ratios (<300). These brines could arise as primitive-diagenetic fluids, for example when connate waters are involved in dolomitization. The data base supporting this end member is limited.

2. Dilute alkali-bearing carbonate waters, produced during recharge by carbonic-acid dissolution of detrital silicates in the zone of infiltration.

3. Dilute sulfate-rich waters, produced when meteoric waters dissolve anhydrite and/or gypsum, but little else.

4. Variably saline halite-rich fluids or brines, produced when meteoric waters dissolve both anhydrite/gypsum and halite in the Rustler and upper Salado Formations.

Bodine et al. (1988) conclude that the solutes in most waters in the Rustler Formation can be produced by mixing of these four end members. Water produced by dewatering of gypsum is not precluded by the solute assemblages. However, the stable-isotope compositions of confined Culebra and Magenta waters (Section 4.3.2) are characteristically meteoric, indicating that gypsum dewatering has not played an identifiable role in their derivation. Bodine et al. (1988) conclude that, if analyzed solutes from the Culebra at P-18 are representative, the Culebra water from P-18 has the highest proportion of apparent primitive-diagenetic brine. They also suggest that some components of the water from P-14 may be primitive, if it is assumed that there has been no mixing or contamination. Waters from the Rustler-Salado contact zone at H-5 and H-6 contain the highest proportion of the primitive-connate solutes. According to Bodine et al (1988), the relative proportion of recharge-type solutes to primitive-diagenetic solutes within the Culebra increases from the WIPP site towards the north, west, and south.

The interpretative model of Bodine et al. (1988) relies heavily on the compositions of Culebra fluids at P-18 and P-14. As noted by Siegel et al. (1988b), the representative character of samples of Culebra fluids from P-18 is suspect, i.e., the analyses appear reliable, but may not represent actual Culebra fluids at this location. Hydrologic considerations also weigh against the reliability of these data. The Culebra transmissivity at P-18 (7.5×10^{-11} to 4.3×10^{-9} m^2/s, Table 4.2) is the lowest yet measured at or near the WIPP site. Therefore, while the Culebra at P-18 intuitively seems likely to contain connate brine, consistent with the norm-based interpretation of Bodine et al. (1988), the very fact that the Culebra is

so low in transmissivity at P-18 permeability makes it extremely difficult if not impossible to collect a meaningful fluid sample from the hole. In P-14, the situation is reversed. The Culebra in P-14 is extremely transmissive (2.3×10^{-4} m^2/s, Table 4.1). The preservation of original connate or diagenetic fluids in such a permeable region does not seem possible or consistent with expected rates of fluid flow in the vicinity (Figure 4.1.28). In addition (Section 4.3.2), the stable-isotope composition of Culebra waters from P-14 is meteoric, suggesting that P-14 fluids have not been involved in extensive diagenetic reactions. However, the analyses of Culebra waters from P-14 do appear reliable. The cause of the apparent primitive-diagenetic component in these fluids is not known.

The salt-norm interpretation also relies heavily on vertical recharge from the surface to provide fluids for dilution of the interpreted primitive-diagenetic signature of Culebra fluids, especially south of the WIPP site. However, the isotopic evidence, discussed in later parts of Section 4.3 and in Section 4.4, as well as the measured head and transmissivity distributions within the Rustler, discussed in Section 4.1, suggest that vertical recharge to the Culebra from the surface is not currently active at and near the WIPP site. The Culebra dolomite is confined at and south of the site, while the Dewey Lake Red Beds, where tested, are effectively impermeable. Finally, as discussed in Section 4.4, the preservation of large amounts of anhydrite in the Tamarisk Member overlying the Culebra, suggests that vertical infiltration of dilute solutions through the Tamarisk has been minimal. These relationships do not indicate that there has been no vertical fluid movement within the Rustler Formation or between the Dewey Lake and the Rustler, but that such movement is limited, and does not currently extend from the surface down to the Culebra.

4.3.1.3 Saturation Indices and Factor Analysis of Culebra Waters--Saturation indices of several evaporite minerals in analyzed Culebra waters have been calculated using the code PHRQPITZ (Plummer et al., 1988), and are summarized in Siegel et al. (1988a). The variation in halite saturation index as a function of ionic strength is shown in Figure 4.3.3. All fluids are undersaturated with respect to halite and Na and Cl concentrations vary widely. There is a consistent increase in halite saturation index with increasing ionic strength.

The variations in calculated gypsum and anhydrite saturation indices with ionic strength are shown in Figure 4.3.4. The data are internally consistent and indicate both a general saturation with respect to gypsum and an increase in anhydrite saturation with increasing ionic strength. However, with the exception of WIPP-29 (Zone D) all samples are undersaturated with respect to anhydrite. As a result, almost all Culebra waters are capable of converting into gypsum any anhydrite with which they might come into contact.

Most calculated dolomite saturation indices for Culebra fluids indicate saturation or apparent supersaturation (Figure 4.3.5). The relationships between saturation indices, pH, and calculated pCO_2 suggest, as discussed in Siegel et al. (1988b), that loss of CO_2 during sample collection may be

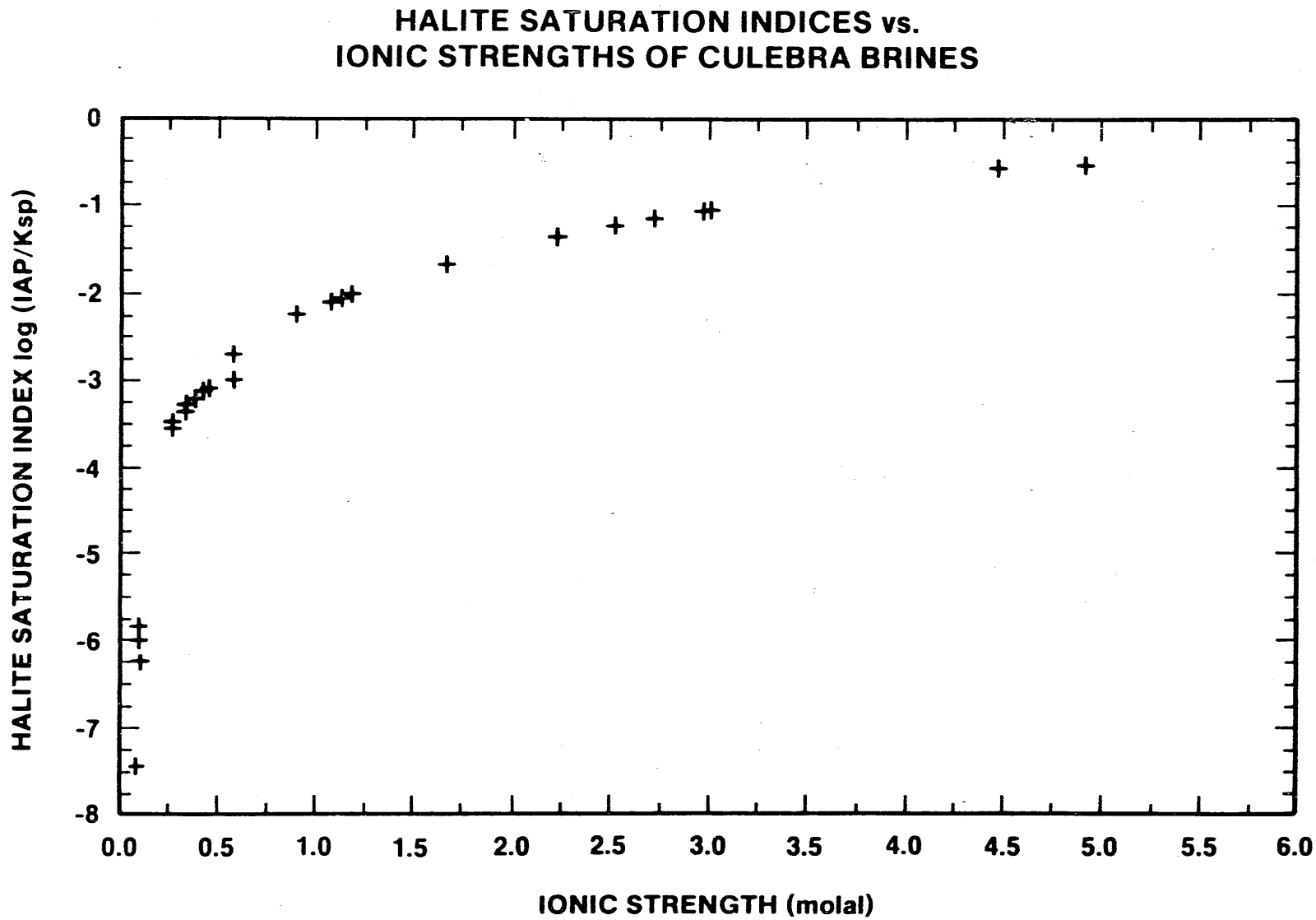


Figure 4.3.3: Variation in calculated halite saturation indices of Culebra waters as a function of ionic strength. From Siegel et al. (1988b).

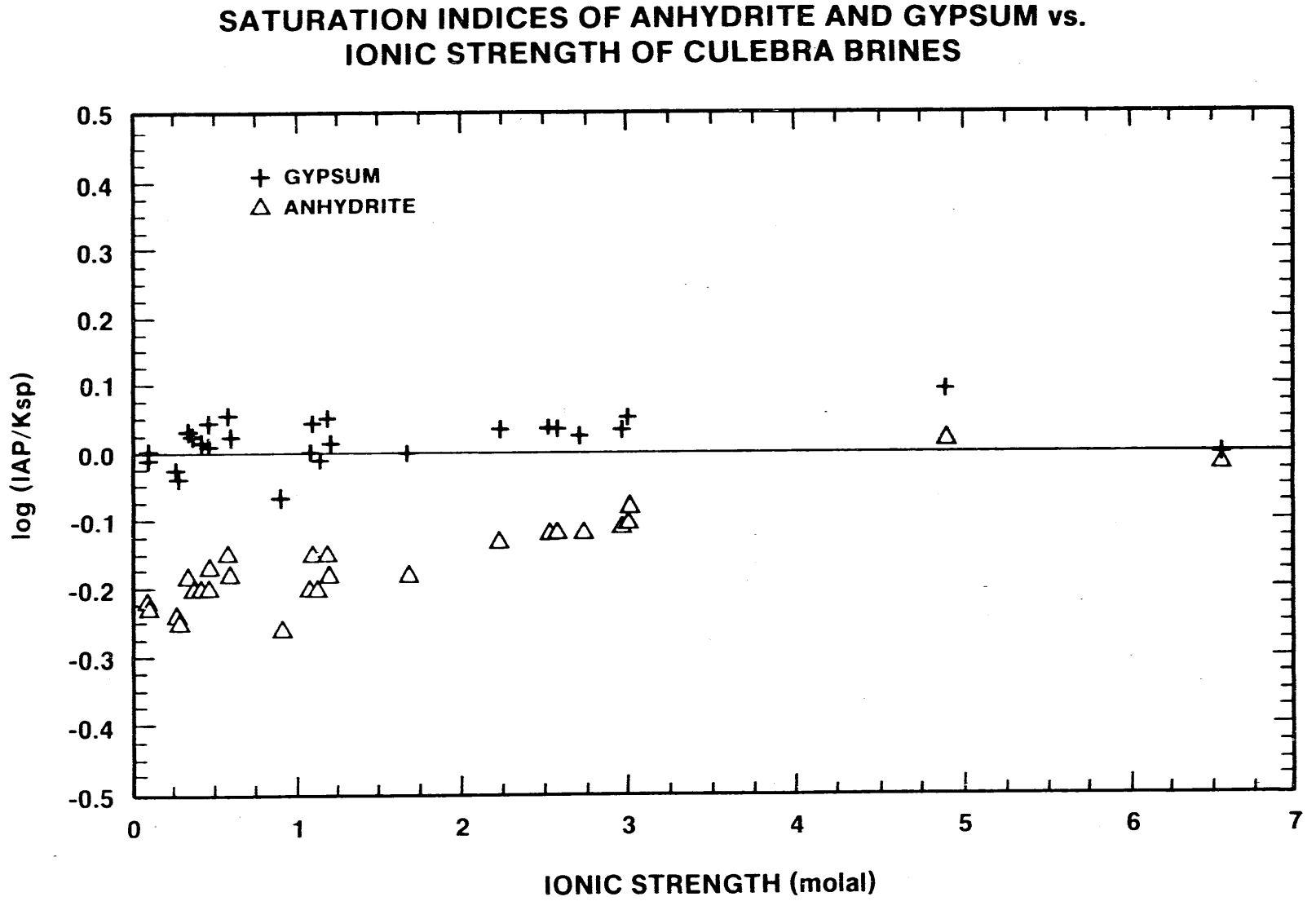


Figure 4.3.4: Variation in calculated gypsum and anhydrite saturation indices of Culebra waters as a function of ionic strength. From Siegel et al. (1988b).

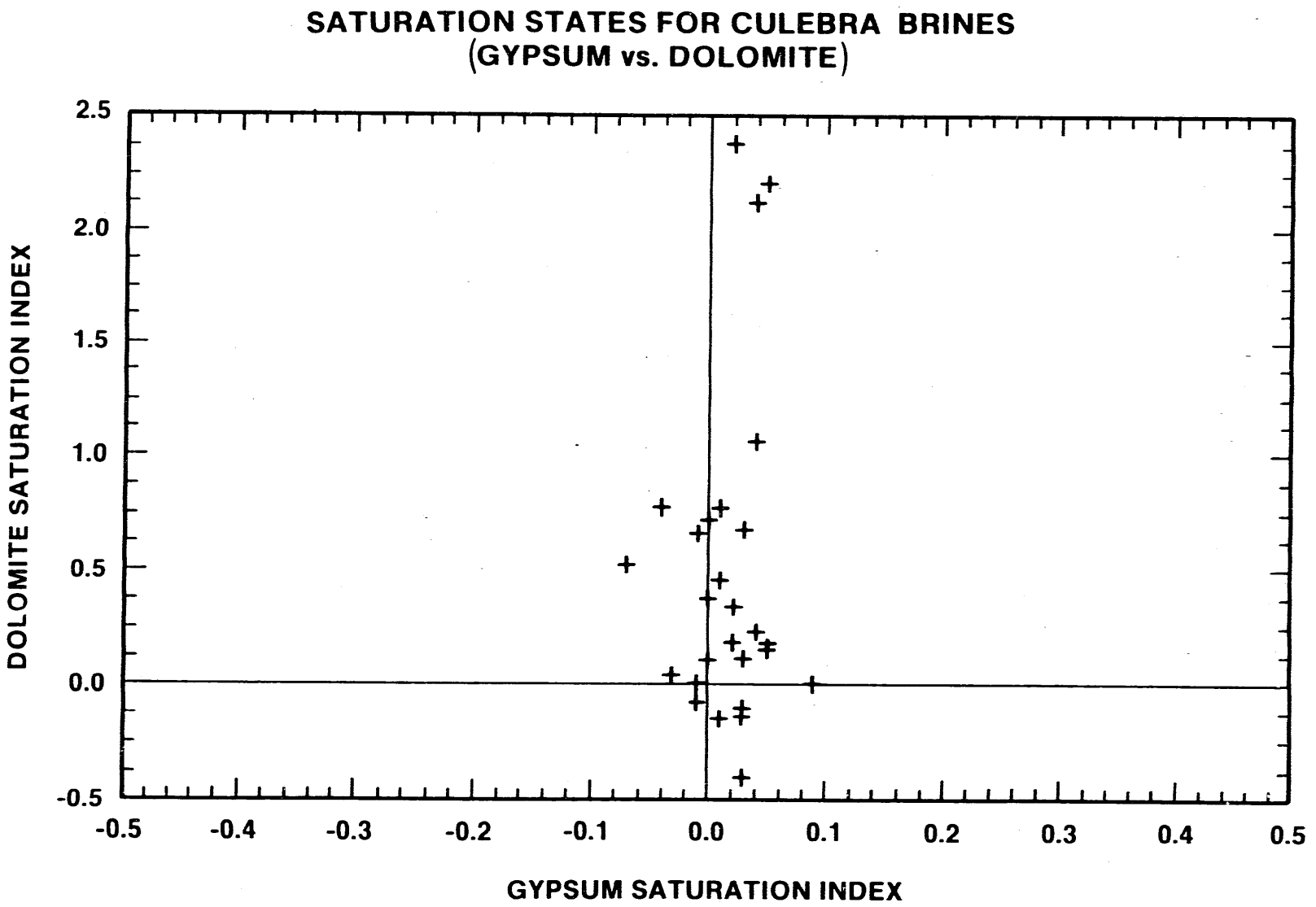


Figure 4.3.5: Variations in calculated dolomite saturation indices of Culebra waters as a function of calculated gypsum indices (Figure 4.3.4). From Siegel et al. (1988b).

responsible for the apparent supersaturation; other potential sources of error include use of an inappropriate free energy for dolomite and analytical error. The wide scatter in dolomite saturation indices gives some indication of the apparent effect of degassing on calculations involving dolomite. The origins of the high original pCO_2 in Culebra waters is not known, but may include carbonate dissolution and/or microbial action (see Section 4.3.3).

In addition to the major solutes used in defining hydrochemical facies and in calculating saturation indices considered thus far, there are consistent trends in both major-element (Ca, Mg, Na, K, Cl, and SO_4) and minor-element (Br, I, Sr) ratios in Culebra fluids. These trends, which are discussed in more detail in Siegel et al. (1988b) include the following:

1. The Na/Cl ratios of fluids south of the WIPP site are higher than would be produced by simple dissolution of halite, suggesting the importance of dissolution of Na-silicates at some time in the derivation of fluids in this area. This is consistent with the norm-based end member of dilute meteoric alkali-bearing carbonate waters discussed in Section 4.3.1.1.

2. At WIPP-27 and WIPP-29, the K/Na ratios and Na, K, Mg, Cl, and SO_4 concentrations are significantly higher than at other wells in Nash Draw or west of the site, suggesting that potash refining operations have significantly contaminated these locations. This is consistent with the definition of hydrochemical facies "D" in Section 4.3.1.1.

3. Both ratios and concentrations of several elements are anomalous in samples collected from P-14, compared to surrounding wells. For example, concentrations of Ca, Sr, and I are anomalously high at P-14, and K and SO_4, low. The Na/Cl, K/Na, and Mg/Ca ratios are somewhat low, and the Cl/Br ratio distinctly low at this well. The "primitive-diagenetic" salt norm at P-14 is anomalous (Section 4.3.1.1).

4. Regionally, the Cl/Br weight ratios are highest in Nash Draw, intermediate through the center of the WIPP site and to the south, and lowest at P-14 and H-4.

Examination of the relations between element ratios discussed above indicate that correlations between elements are not simply linear. For this reason, the data in Table 4.13 were also examined using Principal Component Analysis (PCA). The technique is described in detail in Siegel et al. (1988b). The purposes of PCA are to determine if the fluids come from a single or continuously variable population, and to delineate the different independent ways (factors) by which major and minor elements are correlated.

The preliminary results of factor analysis of Culebra fluids indicate that, on a regional scale, the samples are all drawn from a single chemical population; i.e., their chemistry is controlled by a consistent set of components. The most important component shown by R-mode PCA is dominated

by Na, K, Mg, Br, and Cl. All solutes except SiO_2, alkalinity, and pH exhibit positive correlation with this factor. The second major factor also includes Na and Cl, but is dominated by Ca, HCO_3, and Sr. Overall, the data are interpreted to suggest that the two fluid-compositional factors describing the variability of Culebra waters represent addition of solutes by dissolution of halite, gypsum/anhydrite, and carbonates (Siegel et al., 1988b).

However, because the amount of solute added by halite dissolution is so large relative to that added by other reactions, i.e., because halite solubility is much greater than that of other minerals considered, other chemical correlations may be masked. For this reason, a second set of PCA was carried out by Siegel et al. (1988b), using a method designed to be independent of total dissolved solids and hence halite dissolution. The primary component determined in this analysis contains two groups of elements that are inversely correlated. One group contains Mg, bicarbonate alkalinity, and SiO_2; the other group contains Na, pH, B, and Li. This pattern of element association is tentatively interpreted by Siegel et al. (1988b) to reflect clay diagenesis or silicate hydrolysis. The apparent uniformity of the compositional factors describing the variability of Culebra waters does not identify a discrete mechanistic or mineralogical delineation between the hydrochemical facies defined in Section 4.3.1.1.

4.3.1.4 Estimated Oxidation-Reduction Potentials of Culebra Waters--Many of the transuranic elements to be emplaced in the WIPP facility have multiple valence states. Therefore, given the possible role of the Culebra dolomite in transport to the accessible environment, it is important to estimate oxidation potentials (redox potentials, Eh) within the unit. Available measurements of redox potentials in Culebra waters are described in detail by Myers et al. (1988), and are summarized in Figure 4.3.6. Myers et al. (1988) conclude that the calculated potentials summarized in Figure 4.3.6, based on the data from Pt electrodes and redox pairs involving N, I, As, and Se, are fairly insensitive to assumptions concerning activity-concentration relationships, reasonable uncertainties in analytical data, and errors introduced by uncertainty in field pH. Absolute potential measurements made with Pt electrodes are not generally considered highly reliable; they are included here only for purposes of inter-well comparison. Nonetheless, many of the data are internally inconsistent.

The internally consistent values, indicated in Figure 4.3.6 by the vertical shaded bars, are interpreted by Myers et al. (1988) to bracket the redox potentials for the wells in Zone B (H-7, H-8, H-9, and Engle) between +330 and +630 mv (or higher). A similar range is indicated for WIPP-26 (Zone C) in the eastern part of Nash Draw. Data for the nitrogen couple in hydrochemical facies A and C (Figure 4.3.1), except for WIPP-26, indicate less oxidizing conditions, with an estimated Eh of less than approximately +330 mv.

Quantitative data are not available from within most of Nash Draw. The internally consistent data from WIPP-26 indicate a similar range of redox potential to that at H-7, H-8, and H-9. The platinum-electrode

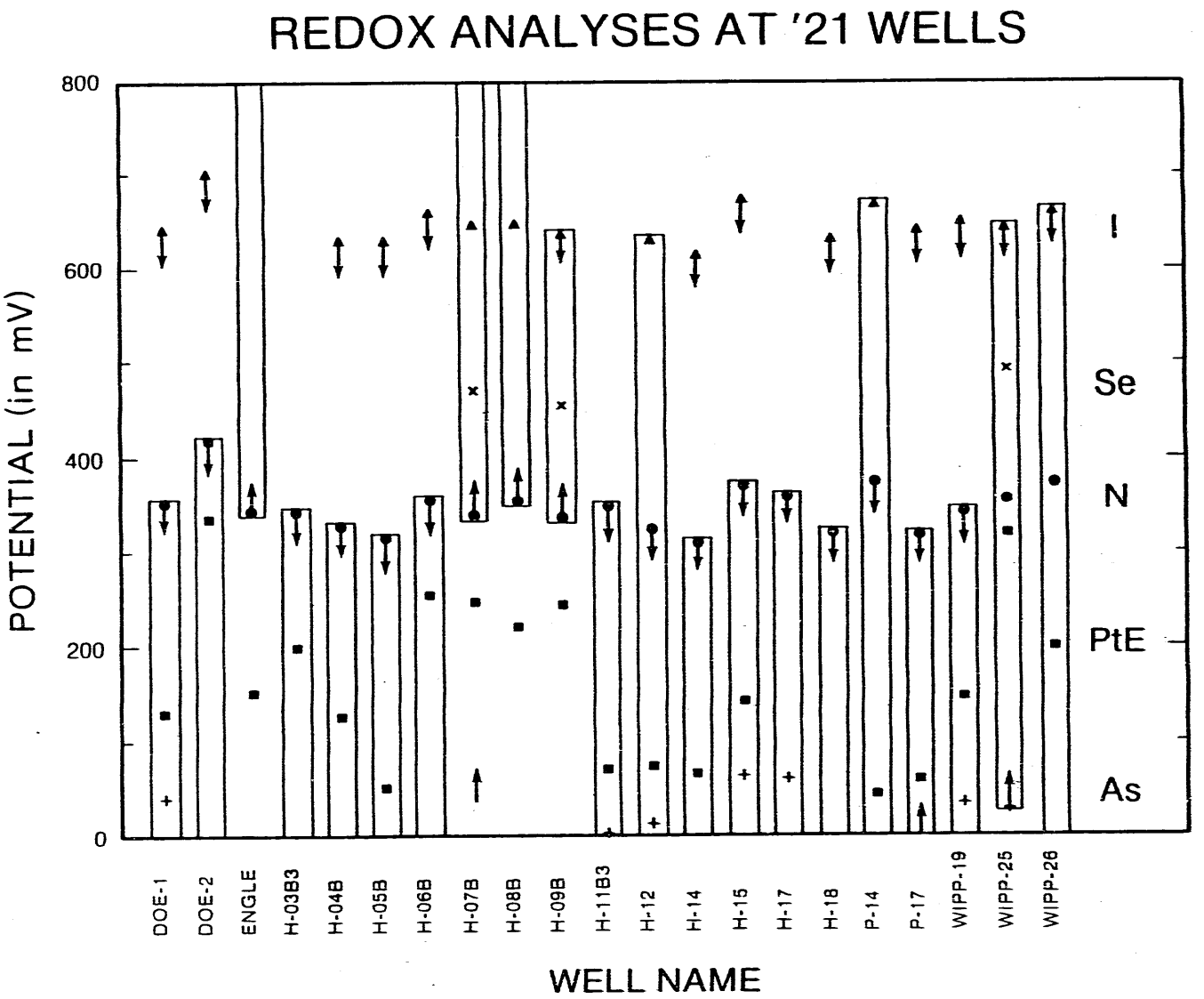


Figure 4.3.6: Variability in approximate redox potential of waters from several Culebra wells. Symbols: + = AsIII/AsV; □ = platinum electrode; o = NH_3/NO_3^-; x = SeIV/SeVI; ▲ = I^-/IO_3^-. Arrows indicate upper or lower limits resulting from one member of pair being present at levels below the detection limit. From Siegel et al. (1988b).

measurements in H-7, H-8, H-9 and WIPP-26 (Figure 4.3.6) are higher than those at most other locations. The apparent range of consistent potentials in WIPP-25 is large. Lambert and Robinson (1984) note, however, that WIPP-25 evolved H_2S during fluid sampling, suggesting that these results are suspect. Relative measurements with Pt electrodes (Lambert and Robinson, 1984), also indicate that redox potentials in the Culebra in Nash Draw are higher than those in the underlying Rustler/Salado contact zone.

Thus, there appear to be consistent variations in redox potential within the Culebra dolomite, with more reducing conditions to the northeast and more oxidizing conditions toward the southwest. This regional variation in the modern oxidation potential plays a significant role in interpretation of uranium-disequilibrium studies discussed in Section 4.3.4.

4.3.1.5 Mineralogy of the Culebra Dolomite--It has already been noted that both the composition and density of Culebra fluids vary considerably at and near the WIPP site. One objective of studies summarized in Siegel et al. (1988a) was to determine whether or not variations in Culebra mineralogy correlate with variations in Culebra fluid compositions. Accordingly, detailed mineralogical studies of Culebra samples from ten different locations along three east-west traverses have been conducted, and are described by Sewards et al. (1988).

Figure 4.3.7 shows a mineralogical cross section of the Culebra dolomite from Nash Draw towards the east, south of the WIPP site proper, as interpreted from sampled core (Sewards et al., 1988). As in any core study, especially in a locally fractured unit such as the Culebra, it cannot be demonstrated that the sampled core has been in contact with flowing groundwater. Mineralogical contents estimated by Lambert (1988) during preparation of rubbled material selected for isotopic analysis of Culebra matrix and veins (Section 4.4.2) differ somewhat from analyses summarized in Figure 4.3.7. The mineralogy at H-7 and H-10 (Figure 4.3.7) is probably representative of intact core samples at the WIPP. The dominant mineral in the selected cores is fairly pure dolomite, comprising about 85% of the bulk rock (by weight). Minor amounts of gypsum, calcite, and clay are observed throughout the sampled cores, but their distribution is heterogeneous both vertically and laterally. Fractures, which are present in most cores, are most commonly lined with clay and gypsum. Gypsum ($CaSO_4 \cdot 2H_2O$) occurs as both fracture and vug fillings. Available analyses indicate that it is nearly pure. Both the composition and textural features suggest that it is secondary in origin. Calcite from the upper portion of the Culebra in WIPP-29 is also interpreted to be secondary. Minor amounts of pyrite, magnesite, quartz, and authigenic feldspar have been observed in some cores. Finally, a dark optically-amorphous and X-ray-amorphous material is present in some abundance in Culebra samples examined, and has been tentatively identified as organic matter. It is generally associated with clays, and often occurs in algal structures or haloes surrounding vugs, the origin of which is attributed to biological activity.

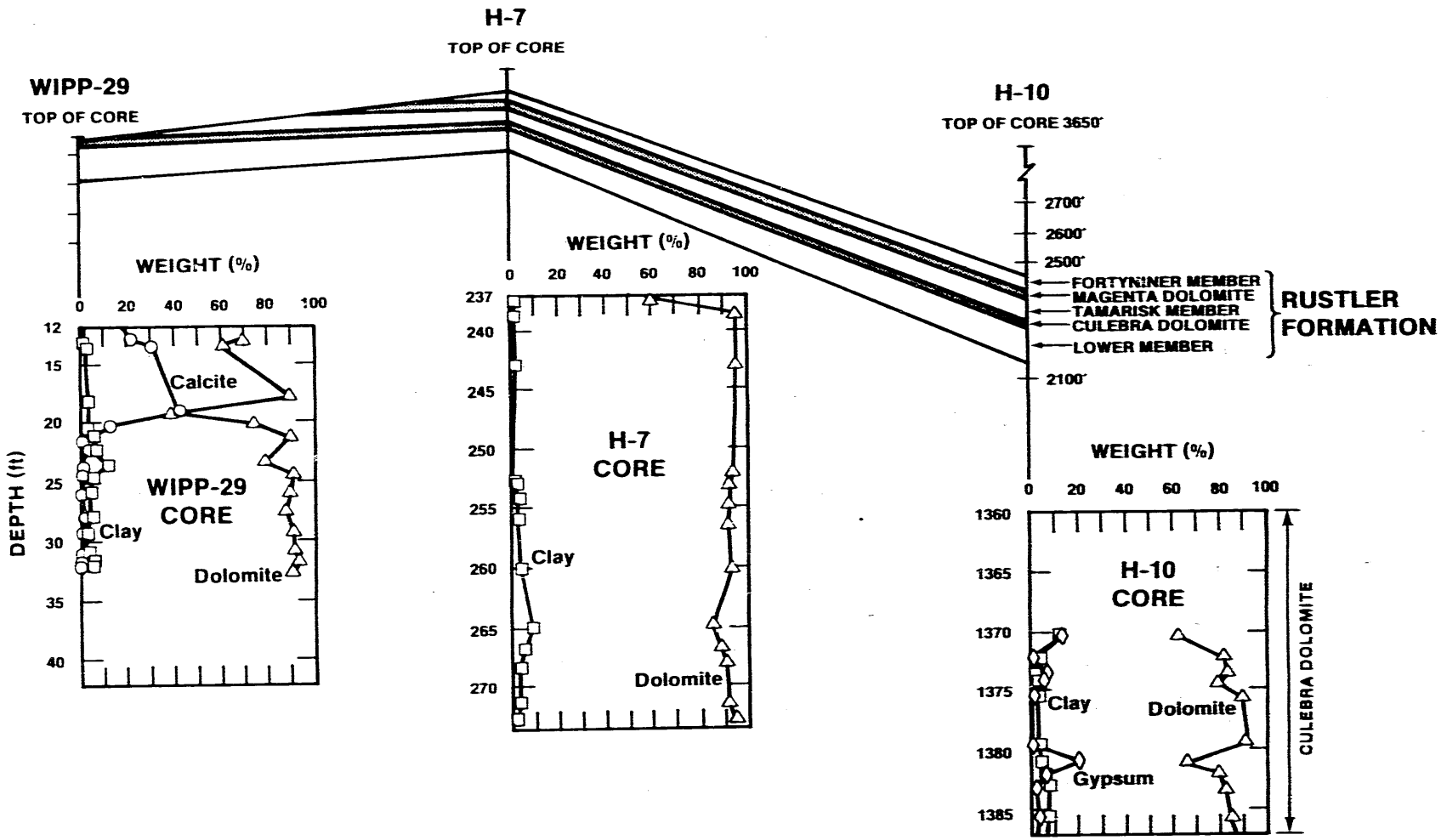


Figure 4.3.7: Fence diagram of variations in bulk mineralogy of core samples of the Culebra dolomite along the east-west section including holes WIPP-29, H-7, and H-10. From Siegel et al. (1988a).

In the intact cores examined by Sewards et al. (1988), corrensite, an ordered mixed-layer illite-smectite clay, is the second most abundant mineral within the Culebra after dolomite. In addition to occurring along fractures, clays are also present in the matrix of all Culebra samples, and commonly make up 3 to 5 weight percent of the bulk sample. The dominant clay minerals are corrensite, illite, chlorite, and a serpentine-like mineral, tentatively identified as amesite.

The recent mineralogical studies in the Culebra indicate that the unit is vertically and laterally heterogeneous. The dominant variation in Culebra fluids, variation in Na and Cl (Section 4.3.1.1), is not reflected in the presence or absence of halite in Culebra core. Dolomite, clays, and gypsum are ubiquitous, and calcite local in occurrence. Table 4.14 summarizes potential rock/water reactions that may influence the chemistry of Culebra waters. With the exception of halite, all of the minerals involved in reactions listed in Table 4.14 occur in the Culebra throughout the area at and near the WIPP site. Halite that has definitely not been introduced during drilling has not been reliably identified in any Culebra core. With the exception of halite dissolution, any of the reactions indicated in Table 4.14 can occur in any of the Culebra hydrochemical facies zones defined. Examination of potential rock/water reactions affecting fluids within the Culebra has not yet identified unique or discontinuous relationships between matrix mineralogy and fluid composition that can be used to place additional constraints on either present or past directions of fluid flow.

In summary, the highly variable fluids within the Culebra dolomite can be divided into four facies. The distribution of these facies is not consistent with modern regional flow directions estimated from hydrologic measurements, if steady-state confined flow is assumed. Zone B, containing lower-salinity fluids lies down-gradient from Zone C, which contains more saline waters. An internally consistent interpretation of the variability of Rustler fluids is possible on the basis of salt norms if large-scale vertical recharge is assumed in some areas. However, some of the analyses used in this interpretation do not appear to be representative, and both isotopic and hydrologic evidence suggest that such vertical fluid movement is not now operative at and near the WIPP site. The mineralogy of core samples from the Culebra dolomite is consistent only in its variability. It cannot be demonstrated that sampled fluids at a given well have been in contact with a given piece of core; therefore it cannot be directly demonstrated that rock/water interactions identified on the basis of a given core sample control or affect the local fluid composition. The available data cannot identify any unique relations between Culebra matrix mineralogy and major-solute or minor-solute compositions of Culebra waters that can themselves be used to place constraints on either past or present flow directions within either the Culebra or the Rustler Formation as a whole. As discussed in Section 4.4.2, however, the isotopic compositions of some minerals within the Rustler, especially gypsums, can be used to place constraints on vertical fluid flow.

Table 4.14: Summary of possible rock-water reactions affecting compositions of Culebra fluids. From Siegel et al. (1988a).

Chemical Process	Potential Effect on Culebra Water
Halite Dissolution	increase Na, Cl, Br, Li; decrease Cl/Br; increase solubility of carbonates and sulfates up to 3 molal NaCl and then decrease solubility causing changes in Ca, Mg, SO_4, CO_3
Precipitation/dissolution of gypsum	decrease/increase Ca, SO_4
Precipitation/dissolution of calcite and dolomite	decrease/increase Ca, Mg, CO_3
Dolomitization: calcite + Mg -> dolomite + Ca	decrease Mg/Ca
Dedolomitization: dissolution of gypsum and dolomite with concurrent precipitation of calcite.	decrease pH, alkalinity/SO_4; maintain Mg/Ca molar ration < 1
Ion exchange involving Mg, K-rich clays in NaCl brines	loss of Na, gain of Mg, K by solution
Mixing of connate hypersaline formation water with recharge water that has dissolved gypsum,	increase Mg, Ca, K, Na, Cl; decrease SO_4, Cl/Br
Incongruent dissolution of polyhalite	increase Mg, K, SO_4; decrease Ca, Cl/Br

4.3.2 Recent Stable-Isotope Studies of Groundwaters from the Rustler Formation and Younger Units

4.3.2.1 The Character of Modern Recharge in the Northern Delaware Basin--As mentioned above, stable-isotope studies do not provide direct information concerning the age of groundwater. Rather, they may indicate whether or not two or more bodies of water were recharged under similar climatic conditions and whether or not one of the bodies of water is modern. At the WIPP site, the approach requires both determination of the isotopic character of modern recharge in the region and determination of

whether or not the isotopic character of groundwaters in the Rustler Formation and younger units is consistent with that of modern precipitation. Recent stable-isotope studies of groundwaters in the northern Delaware Basin conducted as part of WIPP site-characterization activities are summarized by Lambert and Harvey (1987).

The present stable-isotope data base for waters from Carlsbad Caverns (Lambert and Harvey, 1987), is summarized in Figure 4.3.8. Samples were collected from active drips or pools in portions of the cavern system well above the modern water table. Depending on assumptions concerning seasonal averaging of fluid compositions during infiltration and possible evaporation within the caverns, these waters may or may not be representative of modern meteoric recharge in the northern Delaware Basin at elevations similar to that of the surface of the WIPP site.

Lambert and Harvey (1987) conclude that, with one possible exception (sample "GS"), evaporation and rock-water interaction do not play a significant role in derivation of the waters shown in Figure 4.3.8. This is because the waters fall in or near the "meteoric field," defined by the compositional space between the statistical world-wide precipitation trends calculated by Craig (1961) and by Epstein et al. (1965, 1970). Therefore, the isotopic character of the waters (Figure 4.3.8) is interpreted as consistent with that of modern meteoric recharge in the northern Delaware Basin.

The character of modern precipitation in the northern Delaware Basin also rests on other analyses. In 1983, waters from Carlsbad Caverns were essentially the only waters interpreted to represent this recharge. As shown in Figure 4.3.9, most of the more recent measurements on surficial waters and some on shallow groundwaters in the vicinity of the WIPP site and at similar elevations are consistent with measurements on unconfined waters from the Capitan limestone. Samples from a local storm (August 26, 1980) fall within the Carlsbad Caverns field, as do samples from the Dewey Lake Red Beds at the James Ranch and Quaternary alluvium at WIPP-15. The character of the water from the Dewey Lake Red Beds in the James Ranch well is consistent with the interpretation that the Dewey Lake is experiencing modern recharge at this location. The well at the James Ranch (identified as "ranch well" in Figure 1.2) is close to a locally active dune field south of the WIPP site; WIPP-15 was drilled specifically to investigate San Simon Sink (Figure 1.1), an active collapse feature over the Capitan limestone. The measured deuterium/hydrogen ratios of nine water-table samples from the Ogallala Formation in southeastern New Mexico are consistent with the lighter end of the Carlsbad Caverns field in Figure 4.3.9. Heavier Ogallala samples also high in tritium, discussed by Lambert (1988), are consistent with this field. Thus, Lambert and Harvey (1987) base the isotopic composition range of their field of "demonstrably modern precipitation" used in discussions below and in later figures in this section on measurements at several localities, and in several different geologic units. Additional information, especially concerning both the deuterium and tritium characteristics of groundwaters in the High Plains of Texas and the northern Delaware Basin of New Mexico is contained in Lambert (1988).

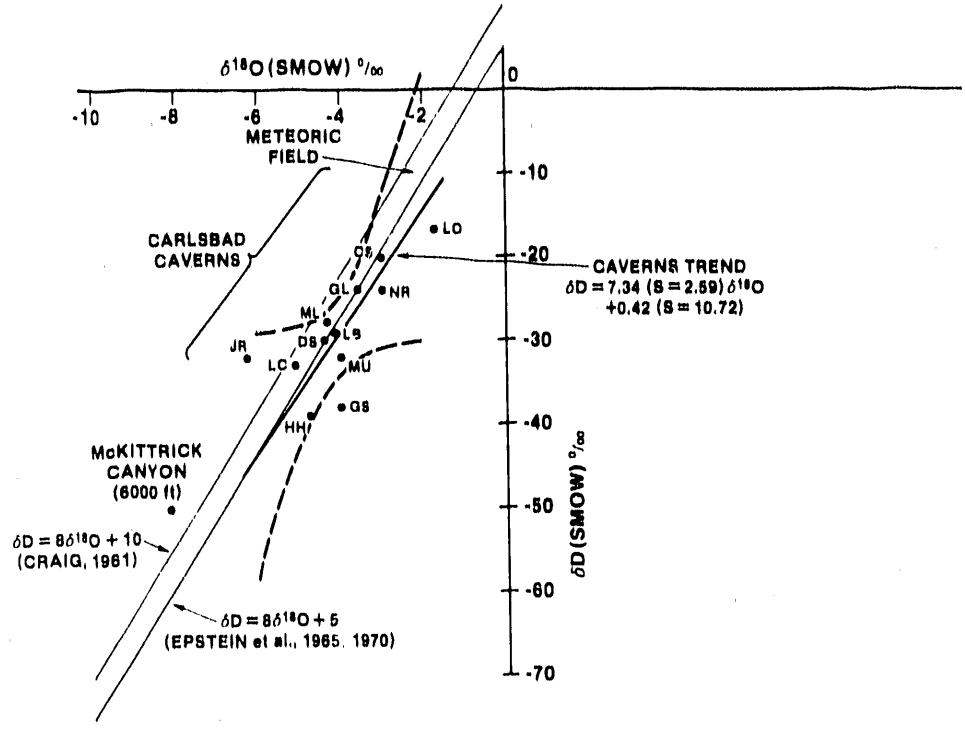


Figure 4.3.8: Available stable-isotope analyses of waters from the unconfined portion of the Capitan limestone in Carlsbad Caverns, New Mexico. The two-letter identification of individual samples is fully explained in Table 3 of Lambert and Harvey (1987). The meteoric field is defined as the area between the statistical correlation lines of Craig (1961) and Epstein et al. (1965, 1970). Slightly modified from Figure 6 of Lambert and Harvey (1987).

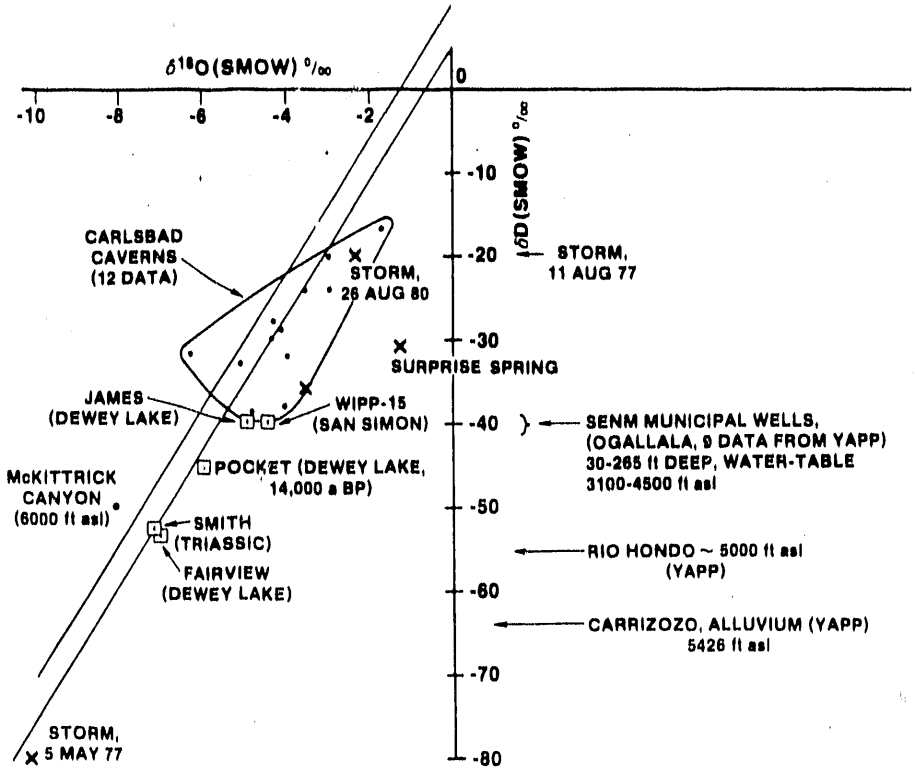


Figure 4.3.9: Recent stable-isotope analyses of surficial and near-surface waters in the northern Delaware Basin. Slightly modified from Figure 9 of Lambert and Harvey (1987).

Stable-isotope data from both the travertine deposit in McKittrick Canyon and a local storm (May 5, 1977) are much lighter than the Carlsbad Caverns field shown in Figure 4.3.9. The isotopic character of these samples is interpreted by Lambert and Harvey (1987) to be due to local elevation effects and point-data variability of individual storms. A similar elevation-dependent argument is made concerning the deuterium data available for Rio Hondo and at Carrizozo (see Lambert and Harvey, 1987 for discussion and detailed sample locations).

Not all data from stratigraphic units above the Rustler fall in the Carlsbad Caverns field in Figure 4.3.9. Water from the Dewey Lake Red Beds at the Pocket well is relatively light. This water has a calculated minimum radiocarbon age of 14,000 years (Section 4.3.3). The ages or isolation times of the relatively light waters from the Smith and Fairview wells are not known. The available stable-isotope results indicate complexity within the Dewey Lake Red Beds. The James Ranch well appears to contain "modern" water, and is located near an active dune field. The Pocket and Fairview wells, which both contain water isotopically distinct from the Carlsbad Caverns field in Figure 4.3.9, are both located near the southwestern lobe of Nash Draw.

4.3.2.2 The Hydrology of the WIPP Site and Vicinity Relative to Modern Recharge--Figure 4.3.10 summarizes the available stable-isotope data for groundwaters from the Magenta and Culebra dolomites at and near the WIPP site. In this figure, the isotopic character of these waters is contrasted with the Lambert and Harvey (1987) estimate of "demonstrably modern Delaware Basin recharge at 3,000 - 4,500 feet elevation," discussed above. The compositionally distinct waters from WIPP-29 and Surprise Spring, both of which are distinct from the meteoric field (Figure 4.3.8) are discussed separately below.

There is no overlap between the Culebra/Magenta data near the meteoric field and the interpreted compositional field representing modern recharge (Figure 4.3.10). On the basis of the consistent compositional distinctions shown in Figure 4.3.10, Lambert and Harvey (1987) conclude that: 1) the stable-isotope compositions of Culebra and Magenta groundwaters do not reflect modern meteoric recharge of the Rustler Formation; 2) there is no significant modern recharge to the Magenta and Culebra dolomites at and near the WIPP site; and 3) the waters presently contained within the Magenta and Culebra at and near the WIPP site were recharged under different climatic conditions than those at present. Therefore, at least some aspects of the hydrology of the Rustler Formation must be transient on some time scale.

The Rustler Formation is not the only unit in the northern Delaware Basin that contains older water. There is also significant variability in the isotopic character of fluids within the Capitan limestone (Figure 4.3.11). The heavier samples defining the "Carlsbad Caverns" compositional field in this figure, which is almost identical to the modern recharge field in Figure 4.3.10, are from the unconfined and partially saturated hydrologic system within Carlsbad Caverns. The lighter samples are from wells drilled

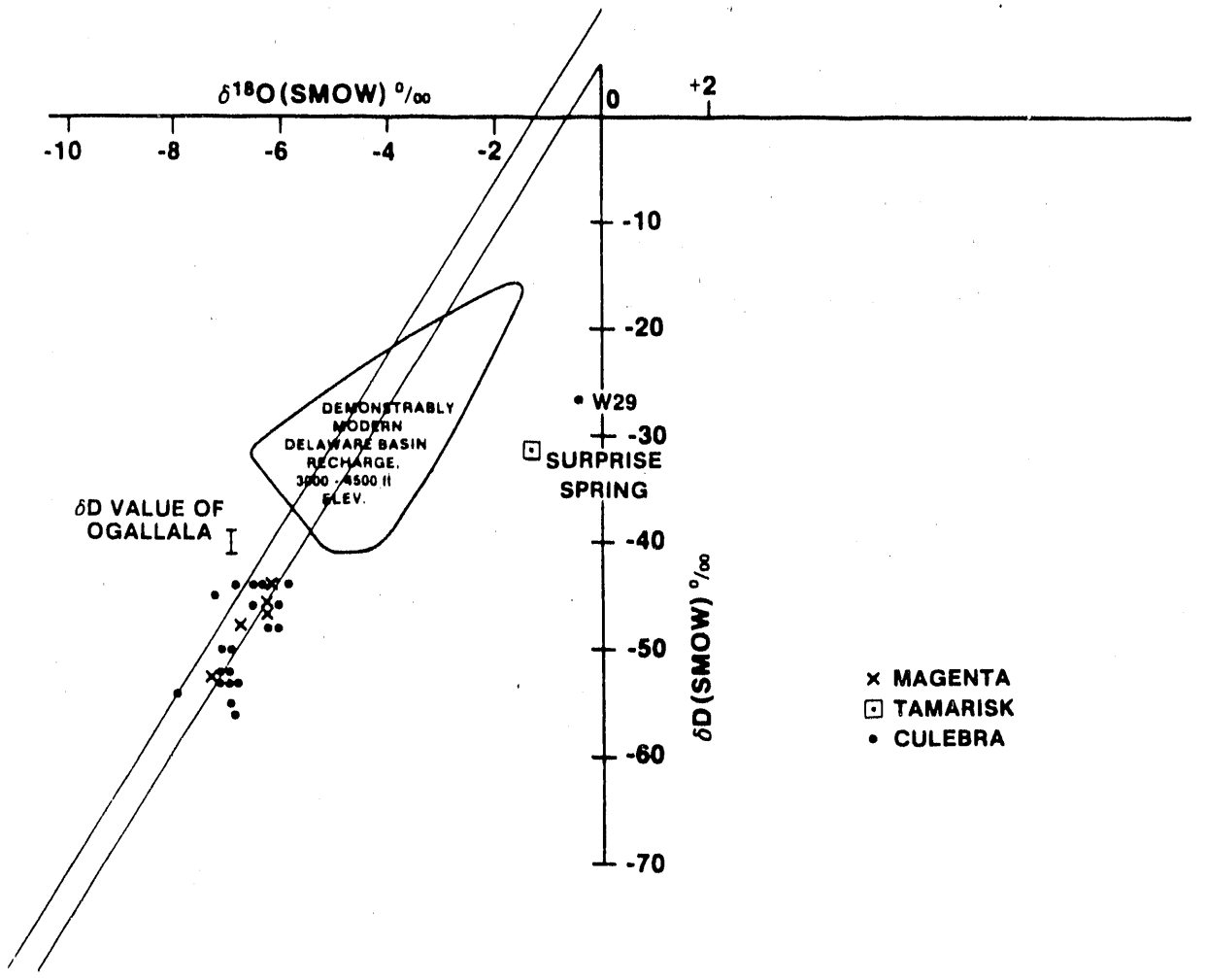


Figure 4.3.10: Stable-isotope compositions of waters from the Culebra and Magenta dolomites at and near the WIPP site. The "modern recharge" field is defined by the Carlsbad Caverns field and other consistent data contained in Figures 4.3.8 and 4.3.9. Note the anomalous character of samples from WIPP-29 and Surprise Spring. Slightly modified from Figure 14 of Lambert and Harvey (1987).

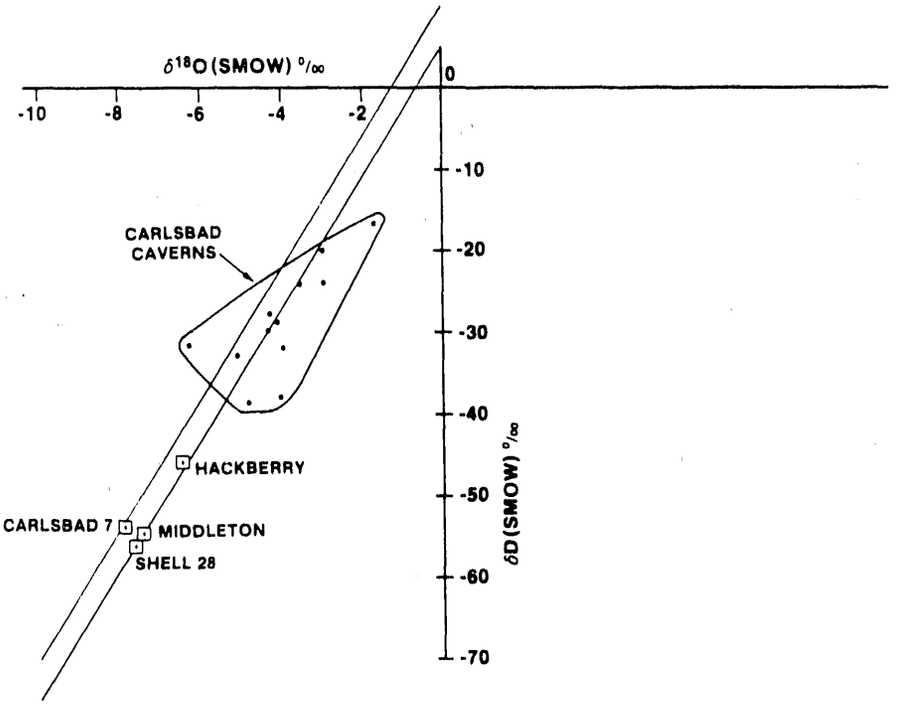


Figure 4.3.11: Comparison of stable-isotope character of waters from unconfined and confined portions of the Capitan limestone. Slightly modified from Figure 10 of Lambert and Harvey (1987).

into confined regions of the Capitan. The signatures of samples from confined portions of the Capitan limestone fall within the same compositional field as most Rustler fluids. Based on uranium-disequilibrium studies, Barr et al. (1983) estimate the isolation times for the Capitan waters from the Middleton and Hackberry wells (Figure 1.1) as 5.8×10^5 and 1.05×10^6 years, respectively.

Thus, stable-isotope measurements in the Rustler Formation, Dewey Lake Red Beds, and Capitan limestone are consistent with the conclusion that the hydrology of the northern Delaware Basin is transient. The fundamental conclusions of Lambert and Harvey (1987) and Lambert (1988) concerning the hydrologic setting of the northern Delaware Basin are:

1. The isotopic compositions of waters from unconfined portions of the Capitan limestone, the Ogallala Formation, and several other unconfined sampling locations at elevations similar to that of the WIPP site are representative of modern meteoric recharge within the northern Delaware Basin.

2. The general isotopic composition of samples from the Culebra and Magenta dolomites of the Rustler Formation at and near the WIPP site, as well as of samples from confined portions of the Capitan limestone, is distinct from that of modern meteoric precipitation within the northern Delaware Basin.

3. The Culebra and Magenta dolomites at and near the WIPP site, in addition to part of the Dewey Lake Red Beds and confined portions of the Capitan limestone, were recharged under climatic conditions different from those effective at the present time.

4. Therefore, the hydrology of the northern Delaware Basin is transient on some time scale. The stable-isotope technique itself provides no information concerning the possible times or time gaps between two interpreted recharge intervals or events, nor does it necessarily provide information concerning where recharge might have taken or be taking place. In the specific case of the Rustler Formation, however, the stable-isotope technique does indicate that significant modern meteoric recharge to the Culebra or Magenta is not taking place at any of the sampled localities.

One site-specific focus of Lambert and Harvey (1987) is the determination of whether or not southeastern Nash Draw, specifically the area including hole WIPP-29 and Surprise Spring (Figure 1.1), is a major point of discharge for Rustler fluids flowing across the WIPP site. Lambert and Harvey (1987) evaluate the question by comparison of the solute and isotopic characteristics of fluids from hole WIPP-29 and Surprise Spring with those of other Rustler fluids. As shown in Figure 4.3.10, the isotopic signatures of fluids from both WIPP-29 and Surprise Spring are quite distinct from the meteoric field. Lambert and Harvey (1987) conclude that the solute characters of WIPP-29 and Surprise Spring waters are also distinct.

In general, the modern flow directions within the Culebra in Nash Draw are roughly parallel to the axis of Nash Draw (Section 4.1). This suggests that, if Surprise Spring is to be a major point of Culebra discharge, fluids must first flow through the region of hole WIPP-29. Rustler groundwaters have been sampled at both Surprise Spring and WIPP-29. It is essentially impossible to derive Surprise Spring waters from evaporation of WIPP-29 Culebra waters, since the lower chloride content at Surprise Spring (Figure 4.3.1) indicates major dilution relative to WIPP-29. The same argument applies to derivation of Surprise Spring waters from Culebra waters at both H-5 and H-6 at the WIPP site, and at many holes within Nash Draw itself. Further, as noted by Lambert and Harvey (1987), Surprise Spring appears to discharge from the Tamarisk Member of the Rustler, rather than from either the Culebra or Magenta.

In addition, the Cl/K (weight) ratios for fluids from holes WIPP-27 and WIPP-29 are distinctly lower than those of other Rustler fluids both in and outside Nash Draw, including Surprise Spring (Section 4.3.1.1). Culebra groundwaters from WIPP-27 and WIPP-29 have Cl/K ratios of ten and nine, respectively, compared to ratios generally from 38 to 73 in holes outside Nash Draw, and a value of 52 at Surprise Spring. Hole WIPP-27 is downslope from the tailings ponds of Mississippi Chemical Corporation's potash refinery in Nash Draw, while WIPP-29 is downslope from the tailings ponds of the International Minerals and Chemicals refinery (Lambert and Harvey, 1987).

Lambert and Harvey (1987) interpret these relationships and the fact that the isotopic compositions of waters from WIPP-29 and Surprise Spring are both distinct from the meteoric field to indicate that:

1. The hydrology of Surprise Spring is essentially isolated and independent from that of the Culebra at WIPP-29, and is not dominated by confined Rustler groundwaters from elsewhere. Surprise Spring discharges from the Tamarisk Member of the Rustler. Nearby exposures of the Tamarisk serve as a likely recharge area for Tamarisk discharge at Surprise Spring, and may or may not be contaminated by local potash-refining operations. The isotopic compositions of groundwaters at both WIPP-29 and Surprise Spring appear to have been derived from surface-type water by partial evaporation.

2. Surprise Spring is not at present a significant point of discharge for Culebra and/or Magenta fluids flowing across the WIPP site.

3. As indicated by the relatively low Cl/K weight ratios in fluids from WIPP-27 and WIPP-29, local potash refining has a major impact on Rustler geochemistry and hydrology within Nash Draw (Section 4.3.1.1).

Lambert and Harvey (1987) conclude that the isotopic character of fluids collected from the Rustler/Salado contact zone (Figure 4.3.13) is strongly affected by rock-water interaction (isotope shift). The extent of this effect generally increases with increasing distance from Nash Draw, paralleling a general decrease in permeability (Section 4.1) and increase in rock-water ratios.

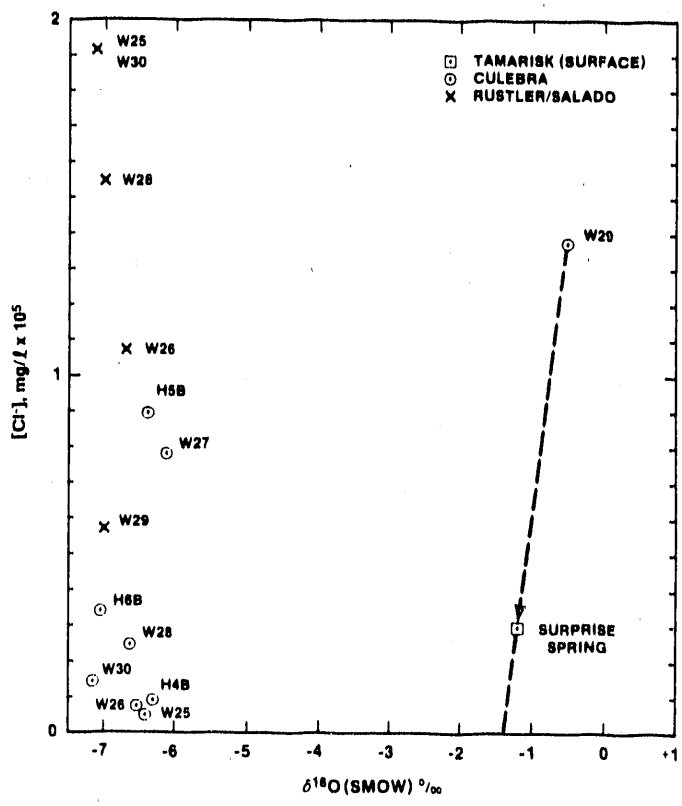


Figure 4.3.12: Relationship between oxygen fractionation and chloride content for analyzed fluids from the Culebra, Magenta, and Rustler/Salado contact. Figure 21 of Lambert and Harvey (1987).

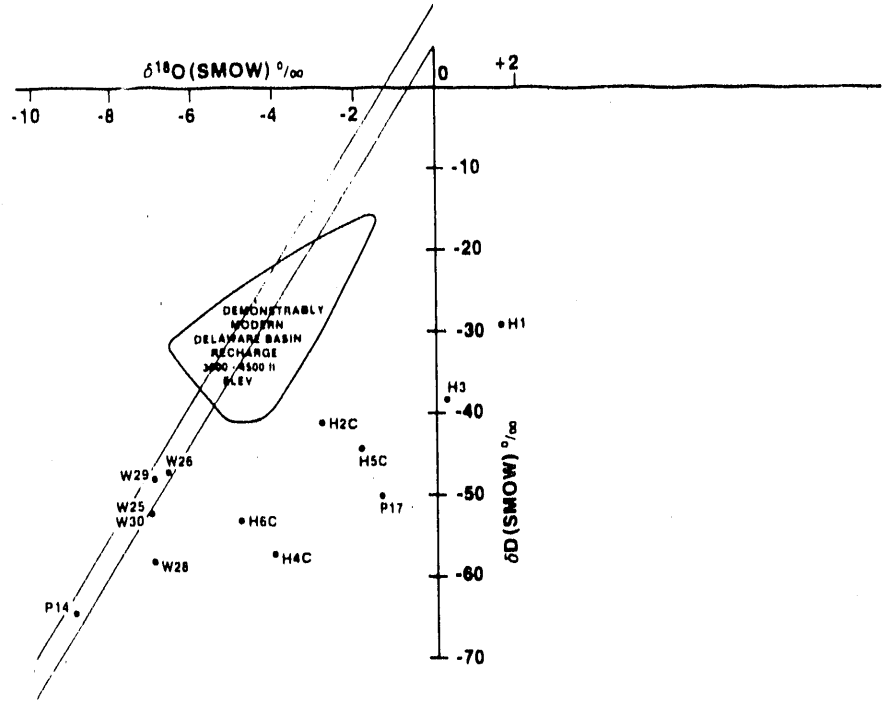
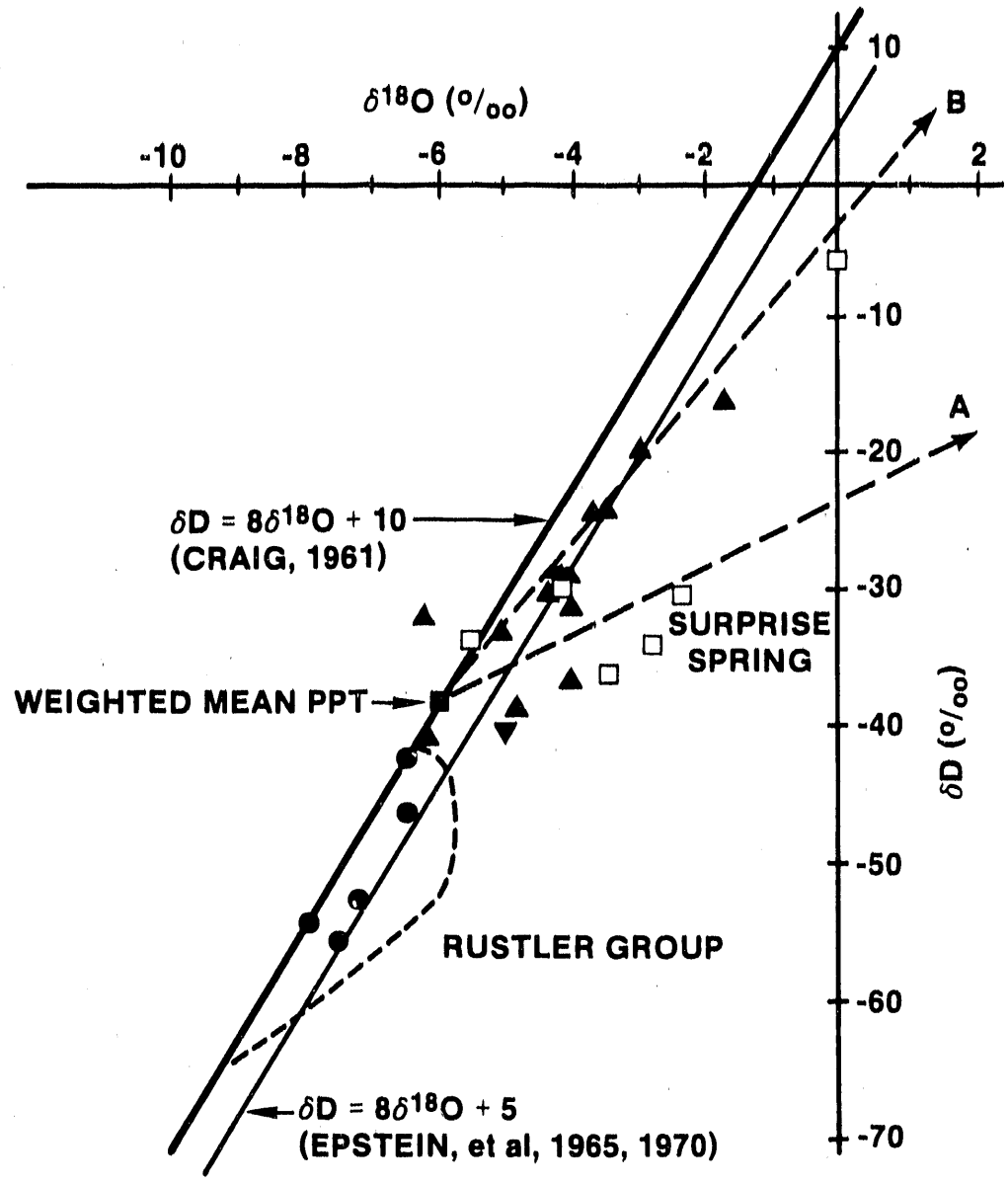


Figure 4.3.13: Stable-isotope character of waters from the Rustler/Salado contact, compared with modern precipitation in the northern Delaware Basin. The "modern recharge" field is defined as in Figure 4.3.10. Figure 15 of Lambert and Harvey (1987).

The interpretations of Lambert and Harvey (1987) and Lambert (1987b) are not consistent with some conclusions contained in Chapman (1986), which is based on review of much of the data contained in the two later reports. The fundamental disagreement lies in interpretation of the distinctions between waters from unconfined portions of the Capitan limestone, modern precipitation, and Rustler waters from at and near the WIPP site. The logic behind a portion of the disagreement is shown in Figure 4.3.14. Chapman (1986) concludes that the isotopic character of modern meteoric recharge in both the northern Delaware Basin and the Roswell Basin is represented by the weighted mean precipitation for the town of Roswell, calculated by Hoy and Gross (1982) (Figure 4.3.14), and that meteoric variability in both areas is closely represented by the trend line of Craig (1961). If these assumptions are valid, then it is possible to derive most of the isotopic compositions of unconfined waters collected within Carlsbad Caverns by "high-humidity" evaporation (line B in Figure 4.3.14) of water representing the calculated Roswell-weighted mean precipitation. Under this interpretation, the unconfined waters from Carlsbad Caverns would be secondary, and would not represent modern meteoric precipitation. As shown, the weighted mean precipitation used by Chapman to derive unconfined Capitan waters is also distinct from the compositional field defined by most Rustler, Dewey Lake, and confined Capitan waters. Chapman (1986) attributes this difference to a "seasonal or amount effect."

Chapman (1986) also notes that, if only stable-isotope relationships are considered, the isotopic character of waters from Surprise Spring can be derived by partial near-surface evaporation of Rustler groundwaters (Line A in Figure 4.3.14); i.e., that Surprise Spring could be a major point of discharge for Rustler waters at and near the WIPP site. While this appears to be theoretically possible on the basis of stable-isotope relationships alone, the solute-composition relationships described in Lambert and Harvey (1987) and summarized above preclude this possibility.

The disagreement between the interpretations contained in Lambert and Harvey (1987) and Chapman (1986) concerning the overall nature of the hydrology in southeastern New Mexico is fundamental, and cannot be resolved by stable-isotope studies alone. However, these studies do clarify the differences in opinion. Chapman (1986), in effect assumes that the hydrology of southeastern New Mexico is at steady state (or, alternatively, that its response to changing climatic conditions is effectively instantaneous). She assumes that the weighted mean precipitation for Roswell and the statistical correlation of Craig (1961) are significant by themselves, and demonstrates that it is possible, based on these assumptions, to generate unconfined waters from Carlsbad Caverns by evaporation. By Chapman's interpretation, the unconfined Capitan waters do not represent modern recharge. However, the field of demonstrably modern Delaware Basin recharge defined by Lambert and Harvey (1987) includes or is consistent with analyses from several other locations in addition to Carlsbad Caverns. The weighted mean precipitation used by Chapman to derive unconfined Capitan waters by evaporation is also distinct from the compositional field defined by most Rustler, Dewey Lake, and confined Capitan waters. Chapman (1986) attributes this difference to a "seasonal or amount effect." The



A: TREND FOR "LOW-HUMIDITY" EVAPORATION
B: TREND FOR "HIGH-HUMIDITY" EVAPORATION

- ● CAPITAN AQUIFER
- ▼ SHALLOW AQUIFERS: SANTA ROSA, DEWEY LAKE
- □ SURFACE WATER
- ▲ CARLSBAD CAVERNS
- ■ WEIGHTED MEAN PPT

Figure 4.3.14: Possible derivation of Carlsbad Caverns waters from modern precipitation. Modified from Figures 13 and 14 of Chapman (1986), by addition of the statistical correlation line for meteoric precipitation of Epstein et al. (1965, 1970) and deletion of waters from the Roswell Basin.

operation of this effect on Rustler, Dewey Lake, and confined Capitan waters, as well as Ogallala water from the High Plains is not explained.

Lambert and Harvey (1987) do not assume that the hydrology of southeastern New Mexico is at steady state. They do assume that significant departure in isotopic signature from the meteoric field defined by the compositional space between the statistical correlations of Craig (1961) and Epstein et al. (1965, 1970) is required before any recourse to evaporation is justified. Unconfined Capitan waters (and others, such as Ogallala fluids and samples from alluvium at WIPP-15) are interpreted by Lambert and Harvey (1987) to represent modern meteoric recharge in the northern Delaware Basin. The demonstrably different isotopic character of most Rustler, Dewey Lake, and confined Capitan waters from the field they interpret to represent modern recharge in the northern Delaware Basin is taken to reflect recharge under conditions distinctly different from those controlling modern recharge. Since steady state is not assumed, no single weighted mean precipitation is either defined or deemed relevant. The conclusions of isotopic studies discussed in Sections 4.3.3, 4.3.4, and 4.4.2 are consistent with the interpretation of a transient hydrologic setting of the Rustler Formation and shallower units at and near the WIPP site.

4.3.3 Recent Isotopic Studies with Emphasis on Radiocarbon

Studies investigating the applicability of several environmental isotopes (isotopes generated primarily within the atmosphere), especially radiocarbon, to the shallow stratigraphic units at the WIPP are summarized by Lambert (1987a, 1988). Although the emphasis in these studies was on radiocarbon, tritium, and chlorine-36 were briefly evaluated. No ^{36}Cl above background could be identified, nor could tritium values significantly above background be identified except in hole WIPP-27. The high chlorine background is to be expected in fluids in a halite-bearing evaporite section. The tritium at WIPP-27, consistent with the major-solute composition of Culebra groundwaters from WIPP-27 (Section 4.3.1.1), is interpreted to be due to contamination by potash-refining operations. Radiocarbon studies indicate that many of the sampled wells have been contaminated by organic materials during drilling, casing, and/or hydrologic testing. The successful radiocarbon measurements indicate isolation times of at least 12,000 to 16,000 years for three Culebra waters and one Dewey Lake water. Two of the four measurement points lie on nearly opposite sides of the WIPP site.

The relationship between calculated "percent modern carbon" (PMC) and the bicarbonate content of most of the fluids analyzed to date, including three samples from the Rustler/Salado contact zone, is summarized in Figure 4.3.15. PMC is carbon counts relative to 1950 wood. As shown in Figure 4.3.15, there is a strongly linear relationship between PMC and bicarbonate. The apparent end members are: a) a 0-PMC fluid with a bicarbonate content of approximately 60 mg/l, i.e., groundwater in equilibrium with carbonate, assuming bicarbonate is equal to total carbonate; and b) a 100-PMC fluid with a bicarbonate content of approximately 300 mg/l.

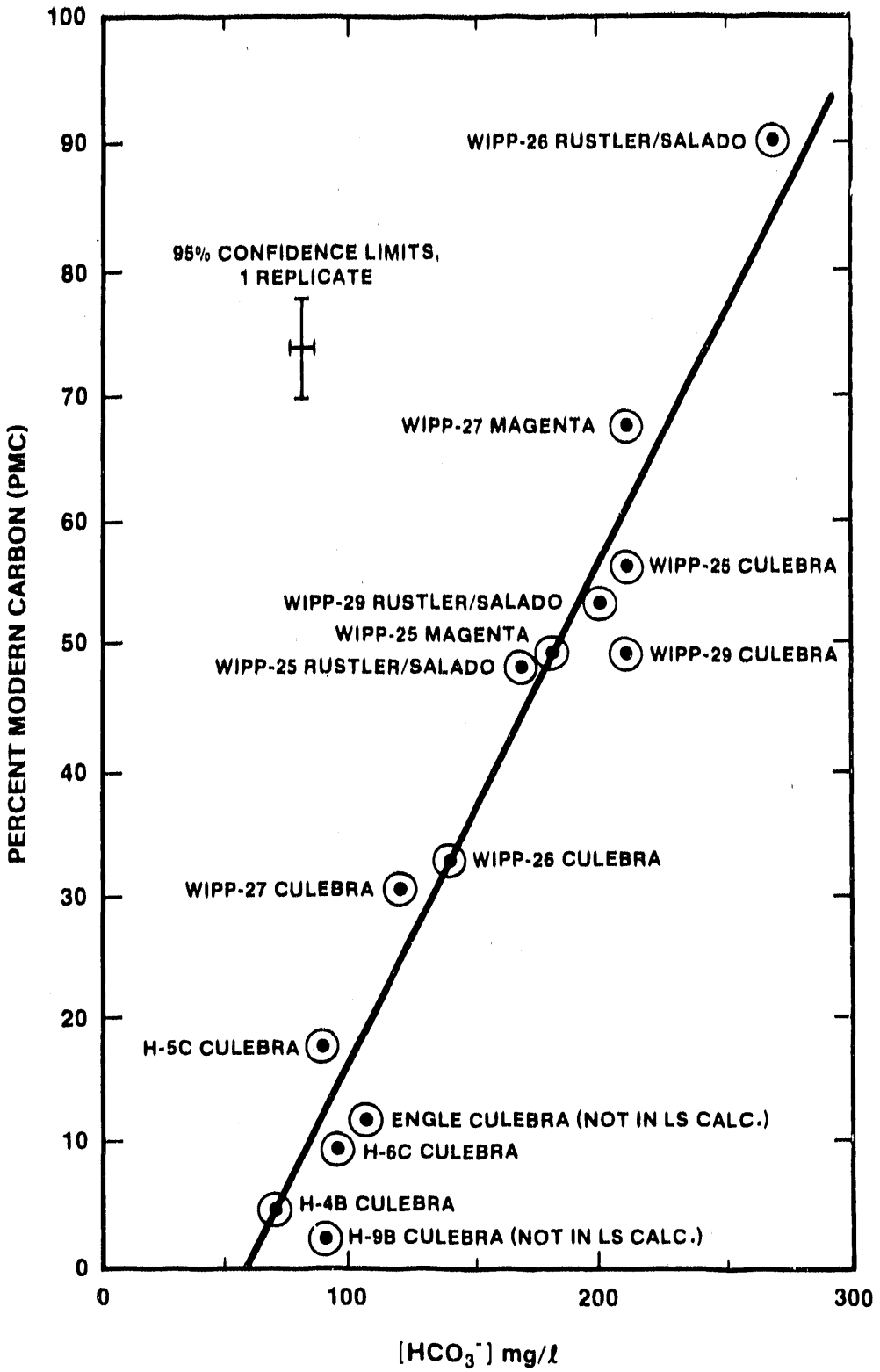


Figure 4.3.15: Relationship between calculated percent modern carbon (PMC) and bicarbonate in analyzed fluids. Figure 3 of Lambert (1987a).

If, as is commonly the case in radiocarbon studies, it is assumed that recharge groundwaters initially containing small amounts of atmospherically derived CO_2 (PMC near 100) equilibrate fairly quickly with carbonate minerals underground, it is difficult to explain waters in Figure 4.3.15 having greater than approximately 60 mg/l bicarbonate. In other words, one would expect the slope in Figure 4.3.15 to be negative rather than positive if this slope reflected increasing equilibration with underground carbonates with increasing time (decreasing PMC) (Lambert, 1987a). By this logic, the high-PMC samples in Figure 4.3.15 do not represent modern infiltration.

Regardless of the origin of high-PMC contents, a linear relationship should result from evaluation of any two compositional variables for the same fluids, if the data distribution in Figure 4.3.15 is a result of linear mixing of two fluid components. This is not the case for the analyzed fluids since the relationship between ^{13}C fractionation and bicarbonate (Figure 4.3.16) is statistically random. This result suggests that at least three fluid components may be involved in mixing to develop the indicated ^{13}C distribution. In such mixing, unique delineation of the mixing relationships and the ages or isolation times of the specific groundwater components involved is most likely impossible (Lambert, 1987a).

The relation between percent modern carbon (PMC) and ^{13}C fractionation for the samples on which adequate data are presently available is shown in Figure 4.3.17. The sampled fluids fall into two relatively distinct groups: a) a small group containing samples with less than approximately 10 PMC; and b) a larger group with from 10 to greater than 90 PMC. Data from H-5c and Engle could be included with the low-PMC group shown in Figure 4.53, though, as noted by Lambert (1987a), the statistical correlations within both data groupings are stronger if the four low-PMC samples (H-4b, H-6c, H-9b, and Pocket) are considered as a separate group. Of the four low-PMC samples, all but that from the Pocket well are for fluids from the Culebra dolomite; the Pocket sample is from the Dewey Lake Red Beds.

The definition of two distinct data groupings (Figure 4.3.17) leads to identification of three carbon-isotopic compositional components apparently involved in mixing within Rustler, Dewey Lake, and Rustler/Salado fluids. These are:

1. Dissolved carbon from Permian marine carbonates. Because the Permian carbonates are more than 200 million years old, this carbon is no longer measureably radioactive.

2. CO_2 derived from modern organic materials injected in variable amounts into the sampled holes during drilling and/or casing activities. Lambert (1987a) found it pointless to attempt dating of almost all of these contaminated samples, as discussed below.

3. CO_2 derived from Pleistocene and older organics during recharge. The location of this recharge cannot be specified on the basis of these studies. Because of the possible contamination of all these samples by small amounts of CO_2 from the modern reservoir, calculated PMC values

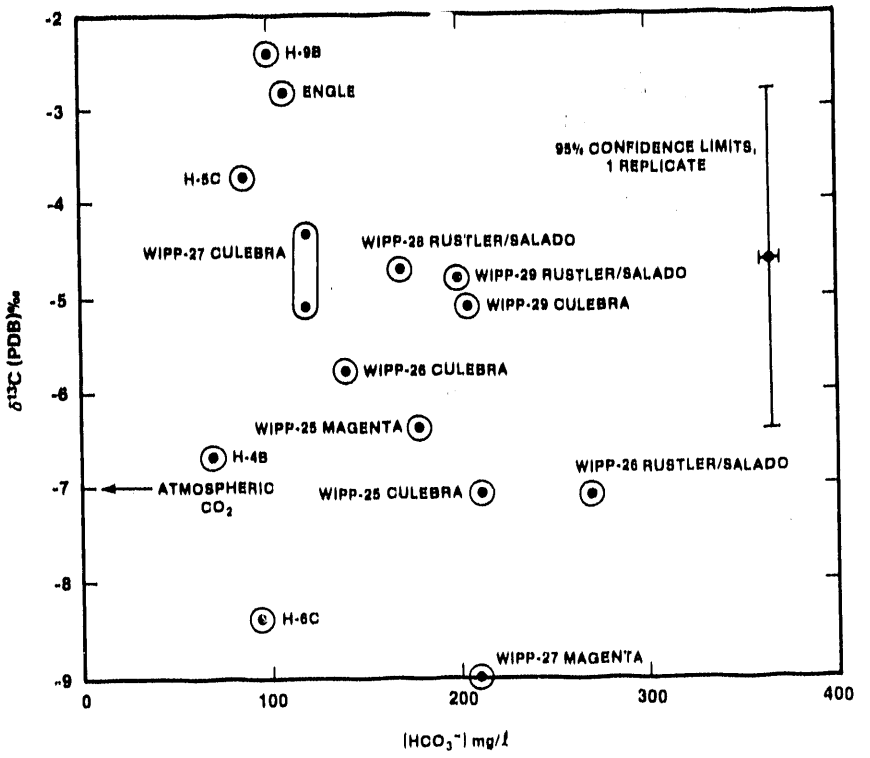


Figure 4.3.16: Relationship between ^{13}C fractionation and bicarbonate for analyzed fluids. Figure 4 of Lambert (1987a).

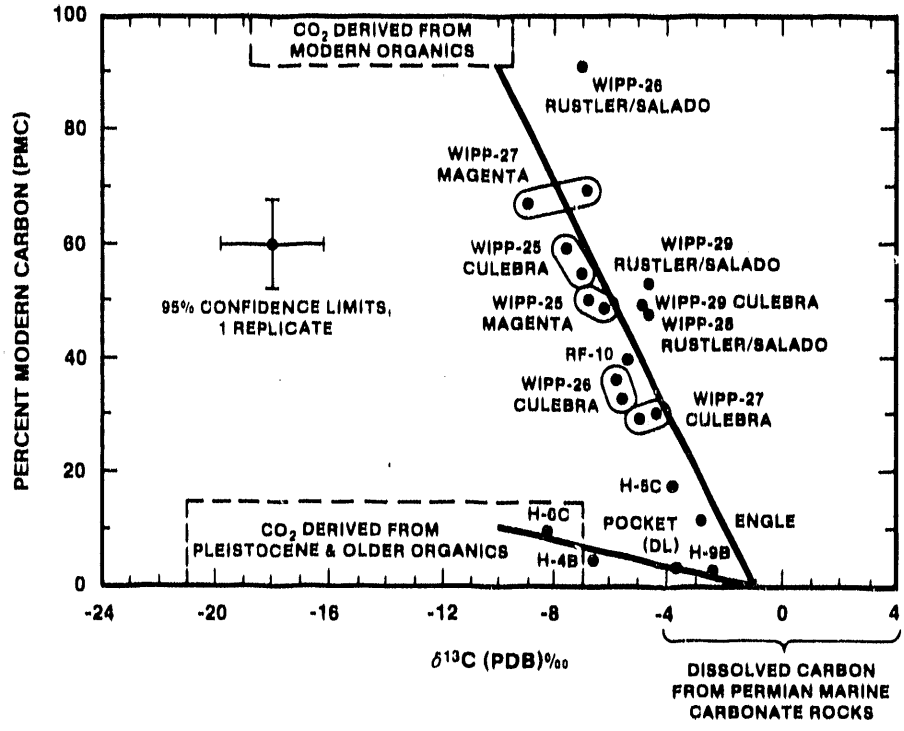


Figure 4.3.17: Relationship between percent modern carbon and ^{13}C fractionation for analyzed fluids. Three-component mixing is a plausible explanation for carbon-isotope characteristics of sampled Rustler and Dewey Lake fluids. In addition to "dead" carbon resulting from interaction with Permian carbonates, all samples may contain both CO_2 derived from Pleistocene and older organics and an unresolved component of CO_2 derived from modern organics. Figure 9 of Lambert (1987a).

in the four low-PMC samples shown in Figure 4.3.17 must be upper limits. Conversely, calculated ages or residence times for the fluids must be lower limits.

Lambert (1987a) applied several different numerical models to the analyzed groundwaters. The results, summarized in Table 4.15, indicate calculated isolation times of the sampled waters from any significant component of atmospherically derived carbon. The ages do not indicate that the fluids have been in their present location for the indicated time, simply that they have been isolated from a near-surface environment for approximately the time indicated. For the samples on which application of the models of Tamers (1975), Pearson and Swarzenki (1974), Mook (1976), and Evans et al. (1979) were generally successful, i.e., the four low-PMC samples (H-4 Culebra, H-6 Culebra, H-9 Culebra, and Pocket Dewey Lake), the results indicate isolation times of between 10,600 and 25,700 years, depending on both sample and model used. The different models used vary in the correction mechanisms assumed to effect fluid interaction with the rock. Lambert (1988) notes that it is not possible to reliably separate the effects of natural isotope evolution from effects of contamination for any data lying off the two-component mixing lines in Figure 4.3.17, i.e., within the three-component mixing triangle.

Because of the method it uses in correcting for equilibration between groundwater and carbonates, and because it involves only a limited number of empirically-derived inputs, Lambert (1987a) concludes that the model of Evans et al. (1979) is the available model most applicable in the WIPP environment. One conclusion arising from the presence of Permian marine carbonates in the Rustler and use of the model of Evans et al. (1979) is that any groundwater sample with greater then 50 PMC must either be contaminated, or must be assumed to have had very limited exposure to the carbonates present. Application of the model of Evans et al. (1979) to the entire data set results in: a) calculated isolation times of 12,100 to 16,100 years for the four low-PMC samples identified in Figure 4.3.17; and b) physically impossible negative model ages for all samples on and near the trend including modern organics in Figure 4.3.17, with the exception of samples from H-5c (Culebra) and Engle (Culebra). These two samples yield model ages of 714 and 2,410 years, respectively, but lie within the three-component mixing triangle shown in Figure 4.3.17.

Based on radiocarbon studies, Lambert (1987a) concludes that:

1. The four interpretable radiocarbon ages on Rustler and Dewey Lake fluids, i.e., those calculated on minimally contaminated samples using the model of Evans et al. (1979), indicate that some Culebra and Dewey Lake fluids present in the vicinity of the WIPP site were isolated from atmospheric radiocarbon at least 12,000 to 16,000 years ago. The relatively tight cluster of ages may suggest some type of recharge episode, rather than a gradient resulting from continuous recharge.

2. Because of there being no consistent directional age gradient in calculated ages in such old groundwaters, the radiocarbon technique provides no information concerning directions or rates of fluid flow within either the Rustler Formation or the Dewey Lake Red Beds in applications to date on WIPP groundwaters.

Table 4.15: Results of application of different interpretative models to available radiocarbon analyses, including corrections involving dolomite. Part of Table 4 of Lambert (1987a).

Locality	PMC	$\delta^{13}C$	Tamers (1975)	Pearson and Swarzenki (1974)	Mook (1976)	Evans et al. (1979)
H-4	4.82	-6.7	19300	17300	12000	16100
H-6	9.7	-8.4	13600	12600	10600	12100
H-9	2.22	-2.4	25700	20200	indet.	14900
Pocket	3.67	-3.8	21600	17400	indet.	14000

3. To date, most radiocarbon measurements on Rustler fluids collected in hydrologic drillholes are invalidated by unknown amounts and types of organic contamination occurring during and after drilling. Most fluids have a carbon-isotopic signature apparently reflecting nonresolvable three-component mixing among inorganic carbon, organic carbon from a past period of surficial recharge, and modern organic contamination introduced during drilling. All samples collected may be contaminated at some level; therefore, most calculated groundwater ages are lower limits.

4. Application of several models to calculate radiocarbon ages indicates that the best useable model is that of Evans et al. (1979), which accounts for both congruent dissolution of carbonates and possible continuing exhange of radiocarbon between the diluted groundwater solution and the surrounding country rock.

While the radiocarbon studies described by Lambert (1987a; 1988) were partially successful and indicate lower-limit isolation times for sampled fluids at four specific locations, extrapolation of the results must be done carefully. The results do not: a) mean that the sampled fluids have been in residence at the sampling sites for the indicated lengths of time; b) provide any information about where major recharge occurred when it did take place; or c) rule out small but indeterminate amounts of modern vertical recharge to the Rustler and Dewey Lake at the WIPP site. The available radiocarbon data can be interpreted consistently to mean that "steady-state" recharge of the Rustler and Dewey Lake is an actively ongoing process only at locations removed from the WIPP site, and that flow times from the point(s) of recharge to the sample localities are at least 12,000 to 16,000 years. However, the results mean that surficial recharge at the WIPP site, if significant at some time in the past, effectively stopped at the sampled localities at least 12,000 to 16,000 years ago. Two of the sampling localities, H-4 and H-6 lie close to and on nearly opposite sides of WIPP Zone 3.

Lambert (1987a) also concludes that measured ^{36}Cl and tritium contents on minimally contaminated Rustler fluids at and near the WIPP site cannot be discriminated from background values. Because of the high chlorine background in fluids that have been in contact with halite present in the Rustler and/or in surficial deposits in southeast New Mexico, no measurable ^{36}Cl was detected. No tritium content greater than 0.2 tritium units (TU) was found in any fluid that was demonstrably minimally contaminated, in contrast to a reasonable "background" level of 3 - 7 TU. The highest measured tritium content in Culebra water is 6.9 TU from WIPP-27 (Lambert, 1987a). However (Section 4.3.1.1) the Culebra at WIPP-27 is interpreted to be contaminated by potash-refining operations, on the ground of major-solute chemistry. Therefore, Lambert (1987a) concludes that there is no advantage in pursuing either technique further in the Rustler Formation at the WIPP site.

4.3.4 Uranium-Disequilibrium Studies in the Culebra Dolomite

The radiocarbon studies summarized in Section 4.3.3 indicate that the recharge age of groundwaters presently in the Culebra dolomite and part of the Dewey Lake Red Beds at and near the WIPP site is at least 12,000 to 16,000 years. While these results indicate that, independent of flow path, travel times from recharge to their present location are long, they indicate nothing about the flow directions or distances involved. The uranium-disequilibrium technique discussed in this section addresses some questions which cannot be addressed by radiocarbon or stable-isotope techniques, such as apparent directions of fluid flow. The basic principles of the uranium-disequilibrium method are discussed in both Lambert and Carter (1984) and Lambert and Carter (1987).

Interpretations of uranium-disequilibrium data can only be as reliable as the number and quality of the samples from which the data are derived, and are also limited by the applicability of the principles involved in the interpretations. There are two specific constraints to interpretation of uranium-disequilibrium data at and near the WIPP site. First, data east of Nash Draw are extremely limited in number, since values are known at only four locations, H-4, H-5, H-6, and WIPP-30. As a result, there is considerable uncertainty in both contouring of results and inferred flow directions east of Nash Draw. Second, as noted by Lambert and Carter (1987), there is no known trace component of Rustler fluids which reliably indicates whether or not any sampled groundwater is representative with respect to either total uranium content or uranium-disequilibrium "activity ratio" (A.R.). The activity ratio considered here is in terms of relative decay rates of the ^{234}U and ^{238}U isotopes, not the ratio of chemical activities. Two measurement trends have been noted which help evaluate the extent of approach to steady-state fluid composition during serial sampling and/or indicate the direction from which the sampled fluid may approach or bound a representative state for groundwater at the sampling locality. Uranium is a trace contaminant, at concentrations greater than normal for evaporitic rocks, in drilling and sampling apparatus, especially casing. Therefore, total uranium in the sampled fluid generally decreases with increasing pumping rate and/or total pumping time (Lambert and Carter, 1984), as the amount of contamination is reduced. Measured total uranium

contents in Culebra waters should represent upper bounds. The measured $^{234}U/^{238}U$ activity ratio in sampled fluids generally increases with total pumping volume and rate; i.e., with decreasing contamination from the casing and/or sampling apparatus (Lambert and Carter, 1984). This is presumably because the contamination present in sampling apparatus and casing has an Activity Ratio (A.R.) very near 1.0. Any measured A.R. in a sampled fluid should thus represent lower bounds.

As noted in Lambert and Carter (1987), interpretation of uranium-disequilibrium studies involves additional assumptions. During recharge, an initial A.R. equal to or not much greater than 1.0 (generally 1 - 3) is assumed to be fixed at the edge of the oxidation zone. There are several generalized sequences of behavior that can follow infiltration. The conceptual and numerical model used is essentially that of Osmond and Cowart (1976). The variability can be simplified by considering the relationship between A.R. and total uranium in the analyzed fluid. Under reducing conditions, the total uranium content of the fluids remains low, and the A.R. normally increases along the direction of fluid flow. This increase is a result of the preferential leachability of the ^{234}Th resulting from the alpha decay of ^{238}U within the country rock, relative to the leachability of ^{238}U (Lambert and Carter, 1984; 1987). Thus, the combination of low total uranium content and elevated A.R. is interpreted to reflect flow along a flow path under relatively reducing conditions or locally "stagnant" flow conditions, both occurring on a time scale for which the technique is applicable, approximately 2,000,000 years (Lambert and Carter, 1984). In contrast, a measured groundwater A.R. near 1.0 is taken to indicate one of three things: 1) approach to secular equilibrium after a lengthy period of radioactive decay; 2) sampling of fluids soon after recharge; and/or 3) possible "swamping" of a higher A.R. by dissolution of rock uranium having an A.R. very near 1.0. A strong correlation of increasing total uranium content of sampled fluids with decreasing fluid A.R. along an inferred flow path favors the third interpretation. This can only occur under relatively oxidizing conditions under which the congruent solubility of uranium is enhanced.

The available data for the $^{234}U/^{238}U$ A.R.s in Culebra fluids at and near the WIPP site are summarized in Figure 4.3.18. The figure shows a general eastward or southeastward increase in A.R.s east of Nash Draw. Contour lines shown in Figure 4.3.18 are based on the assumption that variations in A.R. are approximately linear between data points. From the resulting contours, it was inferred by Lambert and Carter (1987) that the most likely region of recharge for Culebra groundwaters is in or near the upturned edge of the Rustler units within Nash Draw. This interpretation reflects a major easterly or southeasterly component of flow from a recharge region within Nash Draw, assuming that high A.R.s such as measured in the WIPP site area at H-4, WIPP-30, and H-5 are generated by downgradient flow under relatively reducing conditions.

The flow directions implied by the contouring in Figure 4.3.18 are not unique, because of both the limited data east of Nash Draw and uncertain relationships between flow directions and directions in which A.R.s increase. All that is certain is that, unless no reaction is taking place, fluid flow must be at some angle to the lines of constant A.R., but need

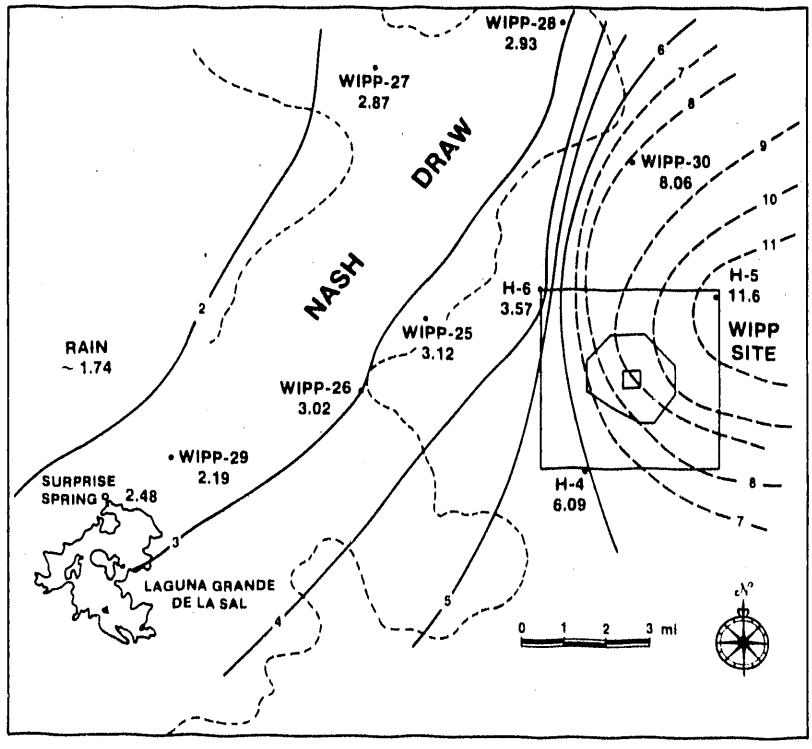


Figure 4.3.18: $^{234}U/^{238}U$ activity ratios in analyzed Culebra fluids. Figure 3 of Lambert and Carter (1987).

not be perpendicular to these lines. By analogy, groundwater flow in a fractured or anisotropic medium need not be perpendicular to potentiometric contours. If fluid flow is assumed to be perpendicular to the A.R. contours in Figure 4.3.18, flow is required to have taken place from regions of (present) high permeability in Nash Draw towards regions of (present) low permeability east of Nash Draw, such as the vicinity of H-5.

In addition, there is considerable freedom in the contouring of A.R. values themselves. An indication of this is shown in Figure 4.3.19. In the interpretation shown in Figure 4.3.19, the assumption of roughly linear variation in A.R. between data points is relaxed, and contours are rotated into a more north-south position. Under this interpretation, since the flow direction must be inclined to A.R. contours, the present A.R. distribution would be consistent with flow towards the south or southeast following recharge, i.e., at a lower angle to both the axis of Nash Draw and the very loose regional zonation of permeability within the Culebra (Section 4.1) than implied in Figure 4.3.18. However, flow towards the axis of Nash Draw is not consistent with the data.

While the uranium-disequilibrium method is not always capable of identifying the recharge area, it is capable, unlike radiocarbon applied to Rustler groundwaters, of estimating flow directions following recharge. The higher-permeability areas within the Rustler Formation in Nash Draw seem a more likely paleorecharge area than either the surface of the WIPP site area or the low-permeability areas east of WIPP-30. Therefore, flow within the Culebra following recharge probably had at least some easterly component.

Regardless of the estimated fluid-flow directions following recharge, the flow times estimated for the buildup to measured A.R.s east of Nash Draw depend on both the measured or assumed original uranium content of the host rock and the measured or assumed total uranium content of the groundwater fluid immediately after recharge. This buildup is a result of a combination of differential leachability of ^{234}Th and ^{238}U under reducing conditions and radioactive decay. In general, estimated flow times towards a measured high A.R. are inversely proportional to the initial uranium content of the groundwater and proportional to the estimated uranium content of the country rock. For example, Lambert and Carter (1987) found it impossible to generate calculated A.R.s greater than 3.4 using the mean present-day U concentration in Culebra core (0.9×10^{-6} g/g) and the lowest measured U concentration in Culebra fluid (0.134×10^{-9} g/g) as input. They interpret this inability to indicate that: (a) the present uranium concentration of the available Culebra core samples is probably not representative of the rock controlling A.R. buildup; and (b) the lowest measured uranium concentration in the fluid phase has been increased by at least some congruent dissolution.

Lambert and Carter (1987) estimated flow times to H-5, assuming that the original U content of Culebra fluids was the same as the lower value measured in fluid from the Rustler/Salado contact in hole WIPP-30 (0.024×10^{-9} g/g). Calculated travel times are approximately 550,000 and 30,000 years, for an assumed low-uranium and high-uranium Culebra matrix, respectively. The low-uranium matrix was taken as the average value

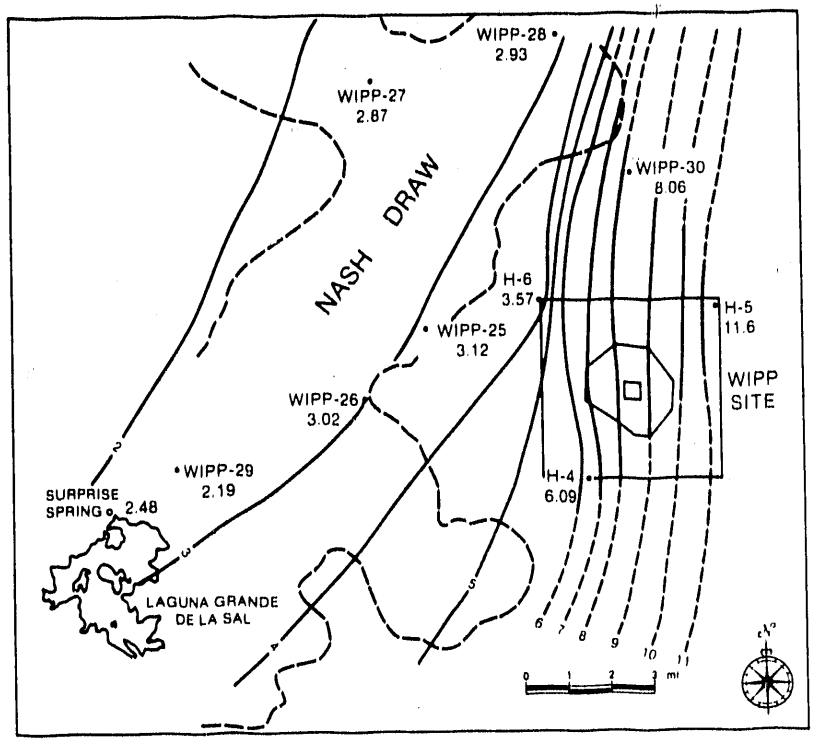


Figure 4.3.19: Contours of $^{234}U/^{238}U$ activity ratios in analyzed fluids, relaxing constraint of linear variation between data points. Modified from Figure 3 of Lambert and Carter (1987).

measured on core (0.9×10^{-6} g/g), and the high-uranium matrix (9.0×10^{-6} g/g) was assumed. The assumed value is similar to that measured in a silty zone found within a Permian limestone in Carlsbad Caverns. In the WIPP site area, local high U contents within Culebra are supported by a known (but uncored) occurrence of a silty zone in hole P-15, indicated by geophysical logging to be rich in (uranium + thorium + potassium). A final A.R.-evolution path, assuming the initial uranium content in the fluid was the same as that measured in Carlsbad rain, 0.01×10^{-9} g/g, yields estimated flow times to H-5 of 140,000 and 12,000 years, respectively for the low-uranium and high-uranium Culebra matrices.

Thus, the minimum estimated times required for ingrowth of ^{234}U to give the measured high A.R.s at H-5, assuming a uranium-rich Culebra matrix, are qualitatively consistent with the estimated minimum recharge ages based on radiocarbon studies reported in Lambert (1987a). Analyzed Culebra core has a lower uranium content than assumed in these calculations. Therefore, flow times from the position of recharge to H-5 were almost certainly much greater. The measured A.R. of greater than 11.0 at H-5 is inconsistent with any significant modern recharge in this area. A minimum flow time of at least several thousand years is required under reducing conditions to generate such an A.R., regardless of assumptions concerning initial fluid and rock-matrix properties, location of recharge, and directions of fluid flow.

The ingrowth of A.R.s cannot be considered independently of the total dissolved uranium in the fluid phase. Figure 4.3.20 indicates a westerly or northwesterly increase in the amount of uranium in Culebra waters, from the WIPP site towards Nash Draw. Although there is uncertainty in the contouring of total uranium contents, the general direction of increase correlates with a general decrease in A.R. in a similar direction (Figure 4.3.18 or 4.3.19).

It is difficult to explain how any easterly flow of oxidized fluids involved in significant evaporite dissolution could maintain both high A.R.s and low total uranium contents measured east of Nash Draw, as would be required by any interpretation involving steady-state flow directions consistent with A.R. contouring in either Figure 4.3.18 or 4.3.19. During such flow, uranium would have to be precipitated within the Culebra dolomite. No evidence for elevated uranium concentrations has been found within the Culebra, except in hole P-15; the P-15 occurrence may in fact be a detrital accumulation. Measured uranium contents of bulk Culebra core are too low to account for the measured A.R.s.

A logical explanation of the combination of measured A.R.s and total uranium contents of Culebra groundwaters at and near the WIPP site involves a change of flow directions, after development or ingrowth of the elevated A.R.s measured east of Nash Draw (Lambert and Carter, 1987). In this interpretation, an early flow system with at least some component of easterly flow under reducing conditions, would later be changed, resulting in some component of westerly flow. The magnitude of the required change in flow directions within the Culebra is not well defined at present. Combination of the contours in Figure 4.3.19 and 4.3.20 requires something like a 60-degree change, assuming recharge occurred in the northern part of

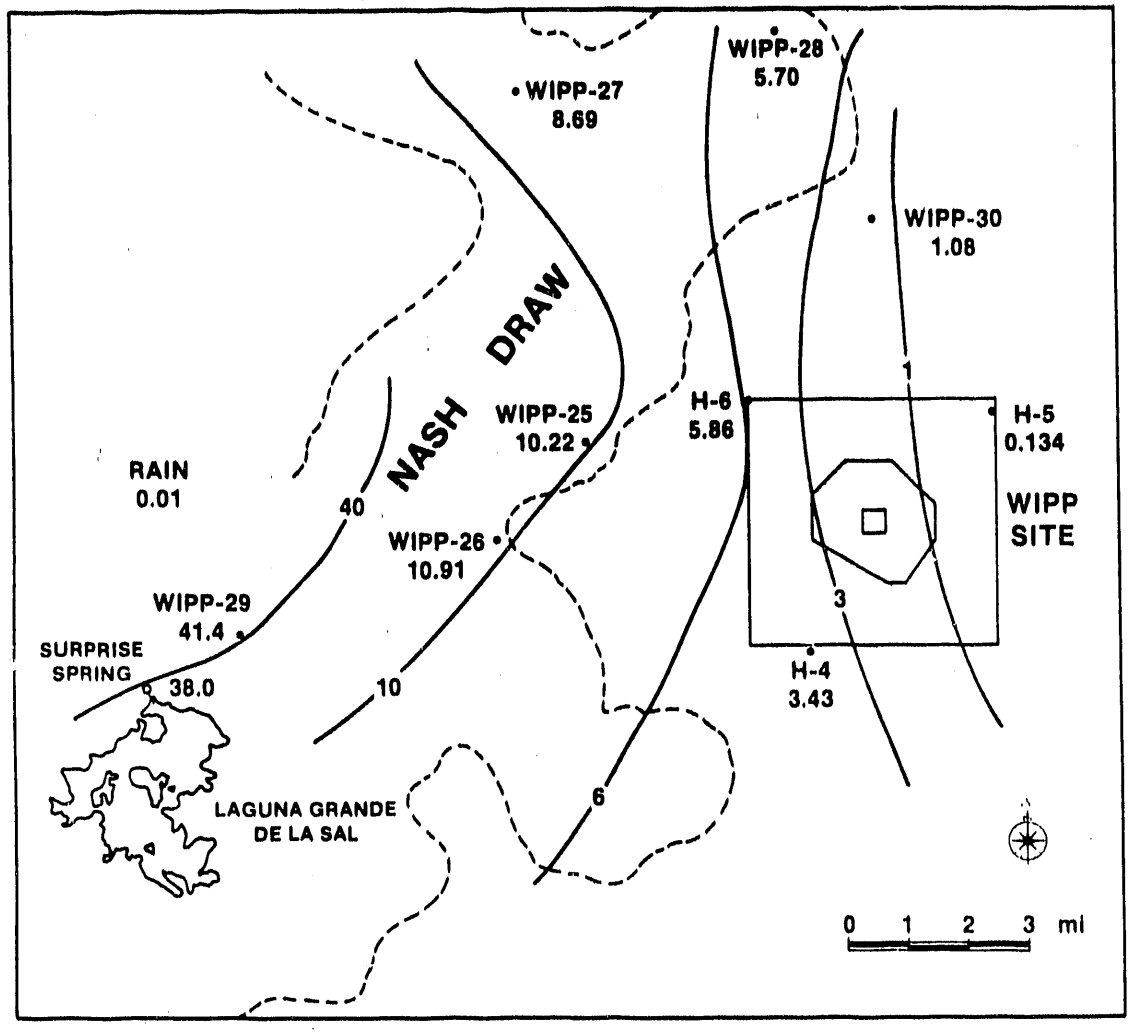


Figure 4.3.20: Total dissolved uranium content of analyzed fluids. Figure 2 of Lambert and Carter (1987).

Nash Draw. Combination of the contours in Figure 4.3.18 and Figure 4.3.20, assuming recharge within the main part of Nash Draw, implies a more marked "reversal" of flow directions.

Because of the general westward increase in total uranium in the Culebra groundwaters, the process resulting in a change in flow directions within the Culebra must include a general westward increase in oxidation potential, with resulting increase in uranium solubility. The mechanism for such an increase in oxidation potential, while not well defined at present, would presumably be related to the continuing exhumation of the Rustler Formation within Nash Draw (Lambert and Carter, 1987). Consistent with this interpretation, the redox measurements discussed in Section 4.3.1.4 generally indicate more oxidizing conditions within the Culebra south of the WIPP site and within at least part of Nash Draw than at the WIPP site.

Regardless of the detailed interpretation of transient flow directions within the Culebra, the uranium-disequilibrium studies of Lambert and Carter (1987) place strong constraints on some aspects of Culebra hydrology at and near the WIPP. These include the three constraints that:

1. Culebra fluid residence times at or flow times to sampling localities east of Nash Draw (H-4, H-5, H-6, and WIPP-30) are at least several thousand years. The shortest calculated residence or flow times are consistent with minimum groundwater isolation times estimated in radiocarbon studies (Section 4.3.3).

2. Regardless of the high Culebra head potentials in the area (Figure 4.1.23), no significant recharge is occurring in the vicinity of H-5. This conclusion is indicated by the high A.R. and low total fluid uranium in this area.

3. A significant amount of evaporite dissolution, under relatively oxidizing conditions appears to have taken place in and near Nash Draw, as indicated by the relatively high dissolved uranium contents in this area.

4.4 Recent Studies Addressing Near-Surface Geology and Hydrology at and near the WIPP Site

Considerable emphasis since 1983 has been given to evaluation of near-surface processes at the WIPP site. The primary objective of this effort has been evaluation of the potential for evaporite dissolution within the Rustler Formation. Regardless of conclusions concerning evaporite dissolution within the Rustler, studies of near-surface processes and stratigraphy at the WIPP demonstrate the transient nature of the climate and near-surface hydrologic setting in southeastern New Mexico. Section 4.4.1 summarizes recent studies of the near-surface stratigraphy and general geologic and hydrologic setting of southeastern New Mexico. Section 4.4.2 briefly summarizes recent studies concerning the extent of rock/water interactions and evaporite dissolution within the Rustler Formation.

4.4.1 Recent Studies of Near-Surface Stratigraphy at and near the WIPP Site

Recent studies of the near-surface stratigraphy at and near the WIPP site summarized in Bachman (1985) were conducted as part of the evaluation of possible near-surface evaporite dissolution. The present distribution of the Gatuna Formation at and near the WIPP site is shown in Figure 4.4.1. An ash bed relatively high in the Gatuna is between 500,000 and 600,000 years in age (Bachman, 1980). Since the Gatuna is overlain by the Mescalero caliche, which began to form approximately 500,000 years ago (Bachman, 1980), Bachman (1985) concludes that the Gatuna is ". . . at least as old as Middle Pleistocene and may contain some much older deposits." While preparing the isopachs shown in Figure 4.4.1, Bachman determined that the Gatuna along Livingston Ridge, on the east side of Nash Draw (Figure 1.1), contains cross-bedded channel deposits and conglomerates deposited by westward-flowing streams. The Bachman (1985) interpretation of the probable courses of streams at and near the WIPP site during Gatuna time is shown in Figure 4.4.2. Areas near the WIPP site presently overlain by Gatuna gravels were occupied approximately 600,000 years ago by moderate-energy stream channels. Based on comparison of the isopach maps for the Gatuna (Figure 4.4.1), Triassic rocks (Figure 4.4.3), and the Dewey Lake Red Beds (Figure 4.4.4), Bachman (1985) concludes that the Gatuna streams flowed across and eroded both Triassic and Dewey Lake Red Beds strata. In contrast, the present climate and surface-hydrologic setting at the WIPP site does not support any moderate-energy streams.

The Mescalero caliche, which overlies the Gatuna, is interpreted by Bachman (1985) as reflecting a slow process of soil formation on a stable geomorphic surface. The caliche is well-developed, and, in locations where the ". . . laminar horizon and the dense plugged horizons within the caliche are at the surface," contributes to ". . . rapid runoff and even to flooding during periods of heavy rainfall" (Bachman, 1985). Radiometric measurements indicate that the basal and upper portions of the Mescalero caliche began to form approximately 510,000 and 410,000 years ago, respectively (Bachman, 1980). The Mescalero surface on which the Mescalero caliche formed, encompasses the Livingston Ridge surface at and near the WIPP site (Figure 1.1). The widespread occurrence of the Mescalero caliche indicates relative structural stability of the Livingston Ridge surface over at least the last 400,000 years.

The Berino soil, a locally distributed paleosol up to approximately 1 m thick, is interpreted by Bachman (1985) as a remnant soil sequence that originally included the older Mescalero caliche. Local survival of the Berino, which began to form approximately 350,000 years ago, is interpreted to require ". . . a long period of tectonic and geomorphic stability within a limited climatic regime" (Bachman, 1985).

There is widespread evidence that the hydrologic setting of the vicinity of the WIPP site has changed at least once over the last 600,000 years. The Gatuna Formation, including moderate-energy stream gravels and conglomerates, was deposited at least 600,000 years ago in a setting which included actively eroding streams. Since approximately 350,000 years ago, the Livingston Ridge surface developed on the Mescalero caliche has remained

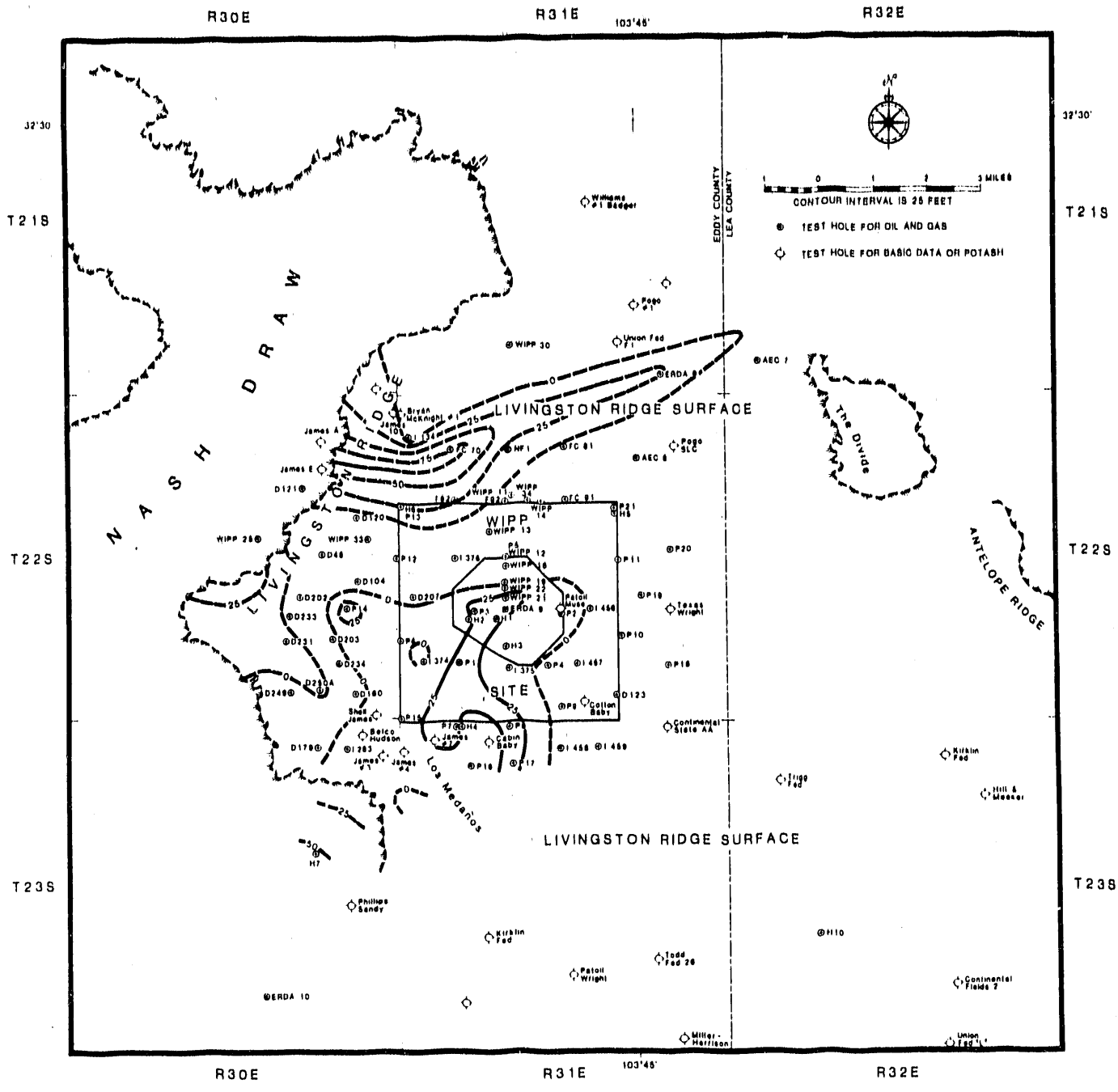


Figure 4.4.1: Distribution and thickness of the Gatuna Formation at and near the WIPP site. Figure 4 of Bachman (1985).

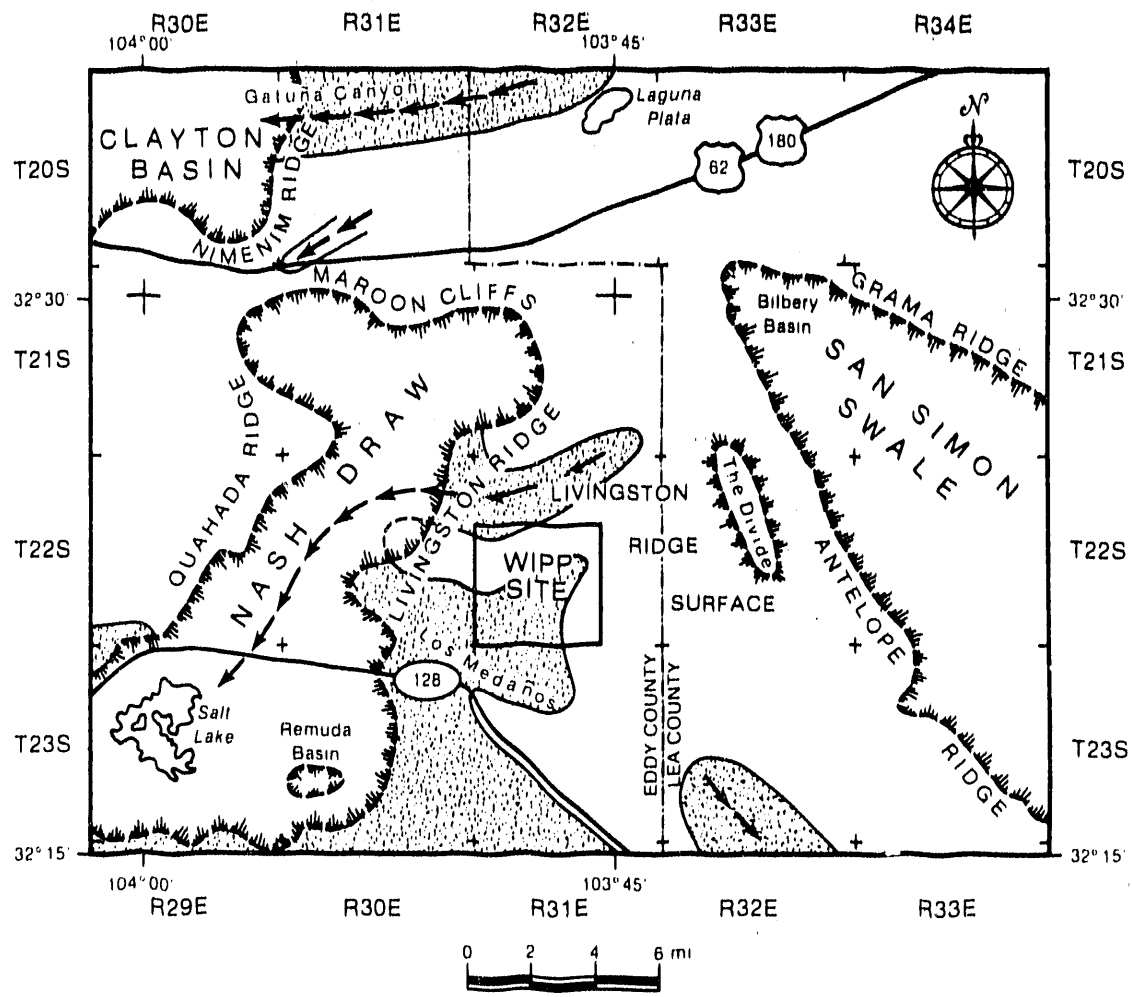


Figure 4.4.2: Probable distribution of stream channels and flow directions at and near the WIPP site during Gatuna time. Figure 11 of Bachman (1985). The present distribution of the Gatuna Formation is indicated by the stippled pattern.

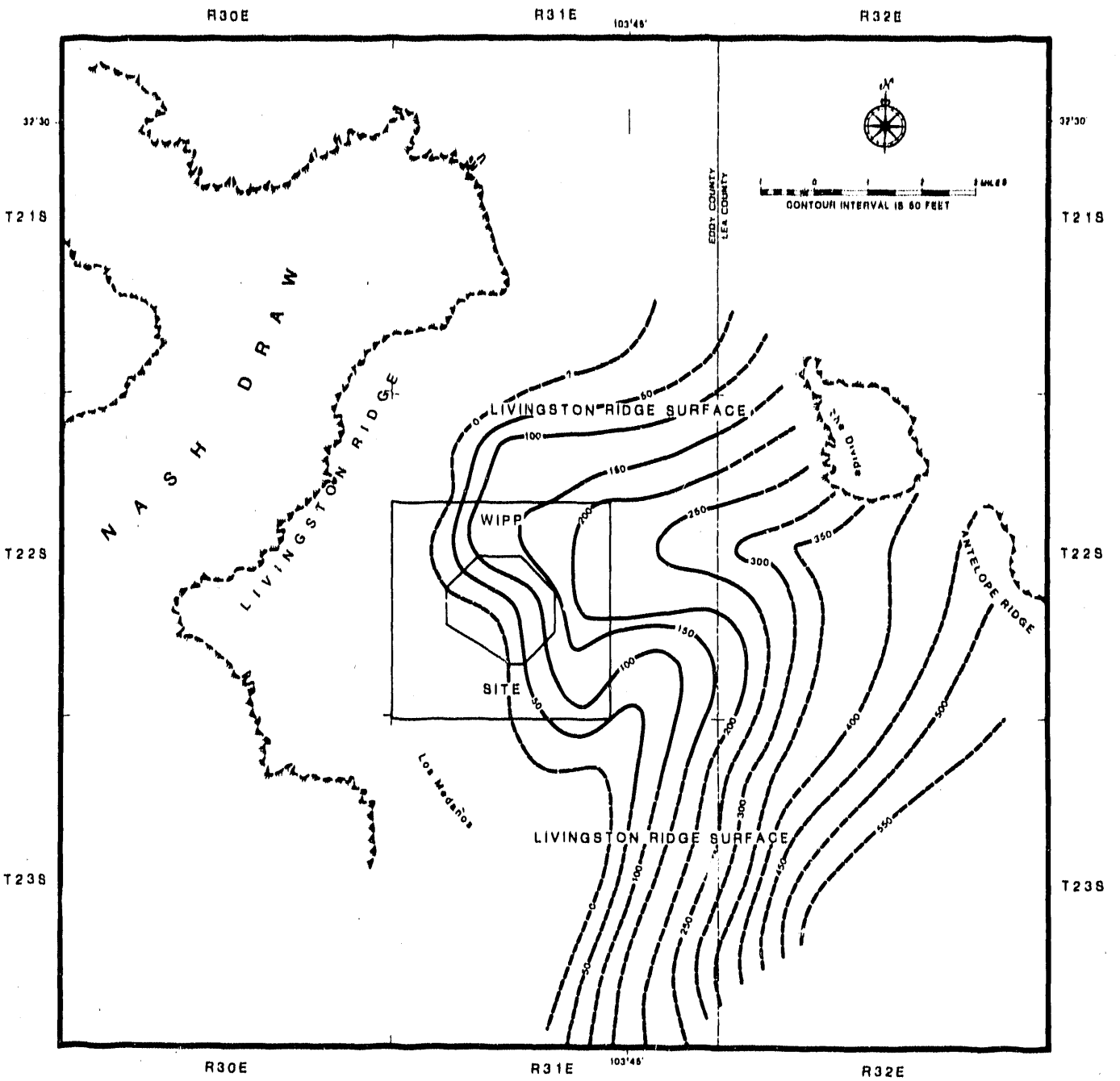


Figure 4.4.3: Distribution and thickness of Triassic rocks at and near the WIPP site. Figure 5 of Bachman (1985).

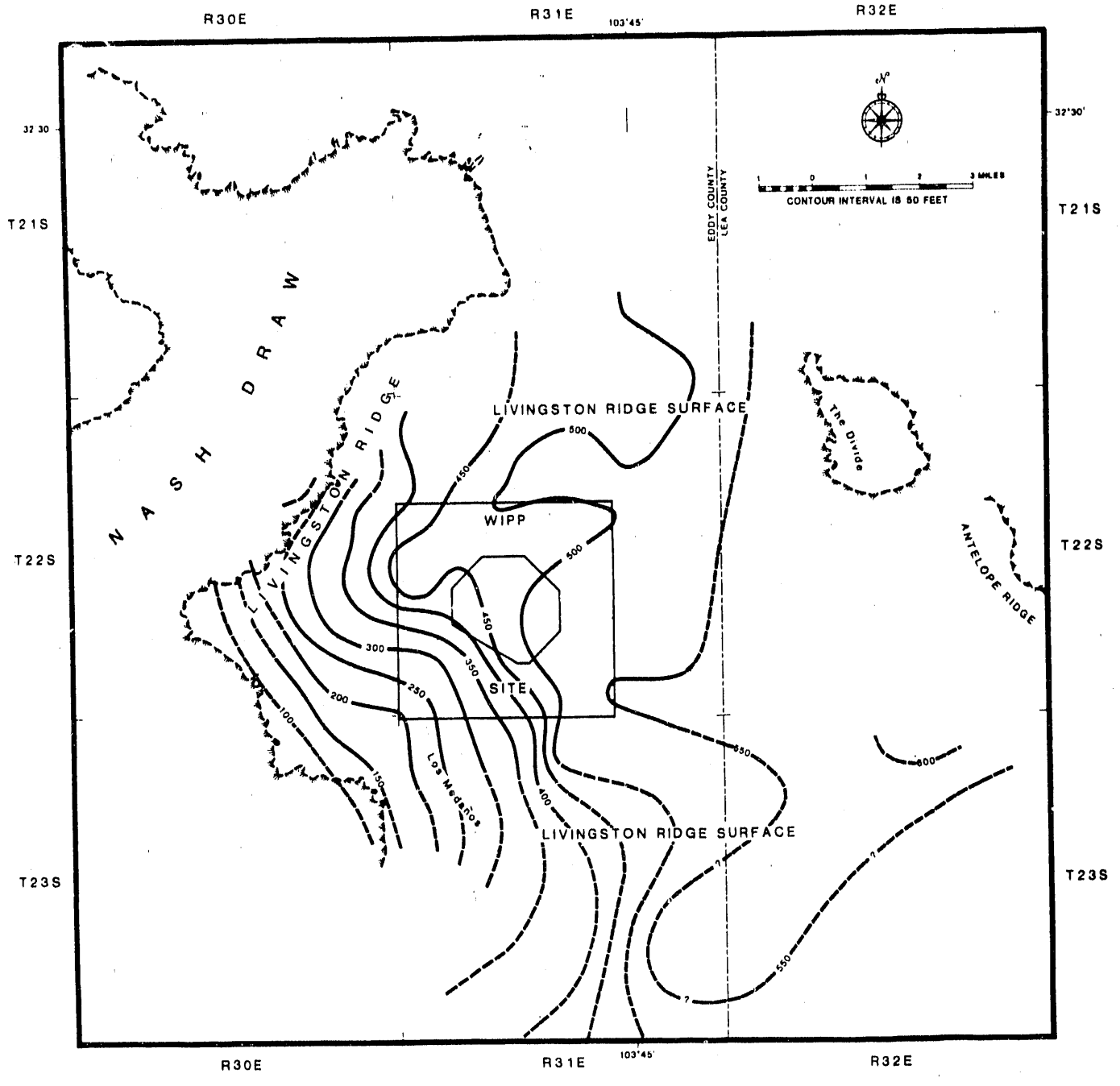


Figure 4.4.4: Distribution and thickness of the Dewey Lake Red Beds at and near the WIPP site. Figure 6 of Bachman (1985).

relatively stable; i.e., stable enough for local survival of the thin, 350,000-year-old Berino soil. The time scale of the climatic change between the Gatuna and Mescalero, however, is more than an order of magnitude greater than most groundwater residence, flow, and/or recharge times discussed in Section 4.3.

There is, however, evidence of local surface-water activity near the WIPP site, ending some 25,000 years ago (Bachman, 1980; 1985). This evidence consists of gypsite (calcium sulfate) spring deposits along the east side of Nash Draw. The fact that these springs are no longer active is interpreted by Bachman (1985) to indicate that ". . . the groundwater regime originally responsible for dissolving underground beds of gypsum and depositing spring deposits is no longer active." Bachman (1985) interprets the spring activity as ". . . part of a paleokarst system resulting from a much different [wetter] climatic regime" than the present regime in southeastern New Mexico.

There is limited evidence of regional climatic variability in southeastern New Mexico on approximately the same time scale as the gypsite springs in Nash Draw. As noted by Lambert (1987a), ". . . additional evidence for [a] wetter local climate is given by VanDevender (1980). From studying packrat middens in Rocky Arroyo, northwest of Carlsbad, New Mexico (about 35 miles northwest of the [present] study area . . . he determined that a juniper-oak community was present in the early Holocene (10,500 to 10,000 radiocarbon years ago), where now desert scrub communities exist." The presence of these middens is taken by Lambert and Harvey (1987) to indicate that ". . . in the immediate vicinity of the Delaware Basin, a wetter climate prevailed more than 10,000 years ago; the present desert scrub-plant communities have been stable in the last 4,000 years." Unfortunately, the data presented by VanDevender (1980) provide no information concerning variations in the climate in the area between approximately 10,000 and 4,000 years ago.

There is strong evidence for both climatic and hydrologic changes having occurred since at least 600,000 years ago in the vicinity of the WIPP site, and limited evidence for a "wetter" climate than present approximately 10,000 years ago. Unfortunately, there are broad time gaps in the regional information that is available. For example, no deposits are known at or near the WIPP site that are intermediate in age between the Berino soil and the gypsite springs in Nash Draw (Lambert, 1988).

The stratigraphic and paleoclimatic studies discussed in this section are not alone in indicating a transient hydrologic setting for the WIPP site and vicinity. Fluid-density and flow-time relations discussed in Sections 4.1.3.1 and 4.1.3.2, as well as hydrochemical facies discussed in Section 4.3.1 are all inconsistent with steady-state confined flow. The isotopic studies discussed in Sections 4.3.2, 4.3.3, and 4.3.4 indicate a transient hydrologic setting for the Rustler. The time scale of transience is generally consistent to within less than an order of magnitude with the time scale of the climatic change indicated by the gypsite springs in Nash Draw (Bachman, 1980; 1985) and the packrat-midden studies of Van Devender (1980).

4.4.2 Recent Studies of Evaporite Dissolution and/or Vertical Fluid Movement within the Rustler and Younger Formations

4.4.2.1 General Geologic Studies--As mentioned above, the Mescalero caliche is relatively continuous at and near the WIPP site. Where continuous, it plays a major role in limiting modern infiltration of precipitation. As noted by Bachman (1973), however, the unit is not completely continuous, since it is locally pierced by conical structures, roughly 1 m or less in diameter, resulting from localized caliche dissolution by humic acid released by plant roots. The structures generally do not completely penetrate the caliche (Bachman, 1973). Where these structures do completely penetrate, local infiltration through the Mescalero caliche may occur, at least to the depth of plant roots. The widespread presence of the Mescalero caliche on the Livingston Ridge surface must be taken to indicate structural stability of the surface, not to indicate the impossibility of localized infiltration. The widespread preservation of the caliche does indicate that not enough infiltration on a regional scale has taken place since its formation to result in its wholesale dissolution.

As discussed in Section 4.1.1 and 4.1.3, the measured head relations and relative transmissivities of members of the Rustler indicate only limited vertical fluid flow within the Rustler Formation. While there is limited vertical movement, stratabound or confined flow within the Culebra dolomite dominates the hydrology of the Rustler Formation at and near the WIPP site. If, however, vertical flow were to extend from the surface to the Rustler, through both the Mescalero caliche and the Dewey Lake Red Beds, the hydrologic setting of the Rustler Formation at and near the WIPP site might be "karstic." In such a system, vertical fluid movement both from the surface to the Rustler and within the Rustler might result in formation of solution channels or cavities. If karstic hydrology dominated within the Rustler at and near the WIPP site, transport rates to the accessible environment would be significantly increased (e.g., Chaturvedi and Channell, 1985). The presence of karstic cavities within the Rustler at the WIPP site has been proposed by Barrows et al. (1983) to explain apparent gravity patterns in the vicinity of holes WIPP-14 and WIPP-34 (Figure 4.4.1). Two additional structures have been interpreted by some to indicate the extension of the evaporite-karst behavior within Nash Draw over the WIPP site itself (see Neill et al., 1983). The first, a depression and related breach of the Mescalero caliche at hole WIPP-33, is interpreted (e.g., Bachman, 1985) as having originated by downward infiltration from the surface to sulfatic portions of the Forty-niner and Tamarisk Members of the Rustler immediately above and below the Magenta dolomite. The second is a relatively large but shallow depression in the SW1/4, SW1/4, Sec.29, T22S, R31E (see Figure 3.2 for general location), examined directly by Bachman. Bachman (1985) concludes that this structure is a result of wind erosion.

One approach used in arguing in favor of karstic hydrology in the Rustler at and near the WIPP (e.g., Barrows, 1982) is based on the assumption of an idealized water budget or water balance, independent of the presence or absence of specific structures indicating infiltration of surface recharge to the required depths. In such an approach, values of variables such as

infiltration, precipitation, and evapotranspiration are assumed to be known with high precision and accuracy. Any excess of estimated precipitation over estimated evapotranspiration is then attributed to vertical recharge from the surface to the Rustler, i.e., to karstic hydrology. As shown by Hunter (1985), however, the uncertainties in precipitation, infiltration, evapotranspiration and Rustler-discharge data at and near the WIPP site are so large that water-budget techniques cannot be used either to determine the amount of recharge or to determine that recharge is occurring. The detailed water budget described by Hunter (1985) is, in fact, not inconsistent with the conclusion (Sections 4.3.2, 4.3.3, 4.3.4) that no recharge is now occurring at and near the WIPP site. The evaluation of the potential for karst hydrology within the Rustler at and near the WIPP site must be by means of hydrologic and geochemical studies (see Sections 4.1, 4.3, and 4.4.2), rather than by an idealized water budget. The recent hydrologic and isotopic studies discussed in Sections 4.1, 4.3, and 4.4.2 place serious constraints on the plausibility of karstic recharge presently being active at the WIPP site.

If surface waters are to infiltrate to the level of the Rustler Formation, they must penetrate the Dewey Lake, after having penetrated both surficial sands and the Mescalero caliche. The presence of local structures penetrating the Mescalero indicates that localized infiltration is possible, although these structures generally do not completely penetrate the caliche and contain secondary laminar deposits resulting from infilling. Extensive studies of local surface depressions at and near the WIPP site led Bachman (1985) to conclude that:

1. Breaches of the Mescalero significantly larger than those represented by the structures resulting from dissolution by humic acid are required for more than extremely localized infiltration, i.e., for development of karstic structures or hydrology in underlying units. The Mescalero caliche continues underneath the depression in the SW1/4, SW1/4, Sec.29, T22S, R31E examined at the specific request of the New Mexico Environmental Evaluation Group (Neill et al., 1983). Therefore, Bachman (1985) concludes that the depression is a surface structure resulting from wind erosion.

2. The relatively large breach of the Mescalero beneath the surficial depression examined by drilling of hole WIPP-33 (Figure 4.4.1) in 1979 (Snyder and McIntyre, 1981) is a result of infiltration, but is unique at and near the WIPP site. The vicinity of WIPP-33 is the only region near the WIPP site in which vertical infiltration from the surface to the Rustler and resulting development of karstic hydrology and structures in the Rustler is reasonable.

Bachman (1985) does suggest that the gypsite springs along the east side of Nash Draw are the result of removal of anhydrite/gypsum from within the Rustler and development of a local flow system connecting WIPP-33 with the eastern side of Nash Draw. Either cavernous porosity or very soft clay-rich debris was encountered in Forty-niner and Tamarisk anhydrites directly above and below the Magenta dolomite in WIPP-33, but not in either the Magenta or Culebra dolomites. The depth of burial of the Forty-niner anhydrite in WIPP-33 is approximately 120 m.

The apparent WIPP-33 structure within the Rustler is consistent with interpretations that:

1. Rustler dolomites are nearly the last rock type to be significantly affected by evaporite dissolution (Snyder, 1985).

2. Because of the relative mechanical weakness of gypsum, the maintenance of open karstic structures within gypsum is possible only at relatively shallow depths. Bachman (1987) examines the regional distribution and impact of the dissolution of anhydrite and gypsum at relatively shallow depths. Certainly, sulfate dissolution has taken and is taking place within the Rustler Formation in Nash Draw, as evidenced by the continuing formation of small caves and sinkholes in the gypsums/anhydrites of the Tamarisk and Forty-niner Members.

3. The only Rustler carbonate from a water-bearing zone in the region to have recrystallized in response to input of meteoric water is at WIPP-33 (Lambert, 1988).

There is no consensus concerning the amount of evaporite dissolution within the Rustler east of Nash Draw. Two schools of thought exist. One approach, most recently summarized by Snyder (1985) and Lowenstein (1987), basically assumes an original laterally homogeneous halite distribution within the Rustler. By this assumption, lateral variability within the Rustler, especially the presence or absence of halite within the claystone portions of the unnamed lower member, Tamarisk, and Forty-niner Members, is due to halite dissolution. A simplified representation of halite distribution within the Rustler is shown in Figure 1.5. A representative cross section showing the variations in thicknesses and lithologies of individual members of the Rustler is shown in Figure 4.4.5.

As shown in Figure 4.4.5, the progressive east-to-west decrease in halite in successively lower members of the Rustler is reflected largely in decreasing thickness of the affected member. The thickness of the Culebra and Magenta dolomites varies only slightly across the area of the WIPP site. In fact, as shown by changes in Rustler thickness between holes WIPP-25 and BLM-1 (Figure 4.4.6), advanced stages of evaporite dissolution within the Rustler involve alteration/dissolution of anhydrite and gypsum rather than dolomites. The interpretations contained in Snyder (1985) and Lowenstein (1987) maximize both the total amount of halite originally present within the Rustler Formation and the amount of later dissolution. The conclusion in the WIPP FEIS (1980) that evaporite dissolution within the Rustler Formation was not of concern to the WIPP Project was based largely on extrapolation of vertical dissolution rates required to generate the depth of Nash Draw in the approximately 600,000 years since deposition of the Gatuna Formation (Bachman, 1974).

In contrast, Holt and Powers (1984; 1987) conclude on the basis of sedimentological arguments and structures that many structures within the Rustler Formation interpreted by authors such as Snyder (1985) and Lowenstein (1987) as resulting from halite dissolution are a result of primary depositional variability. By this interpretation, the amount of

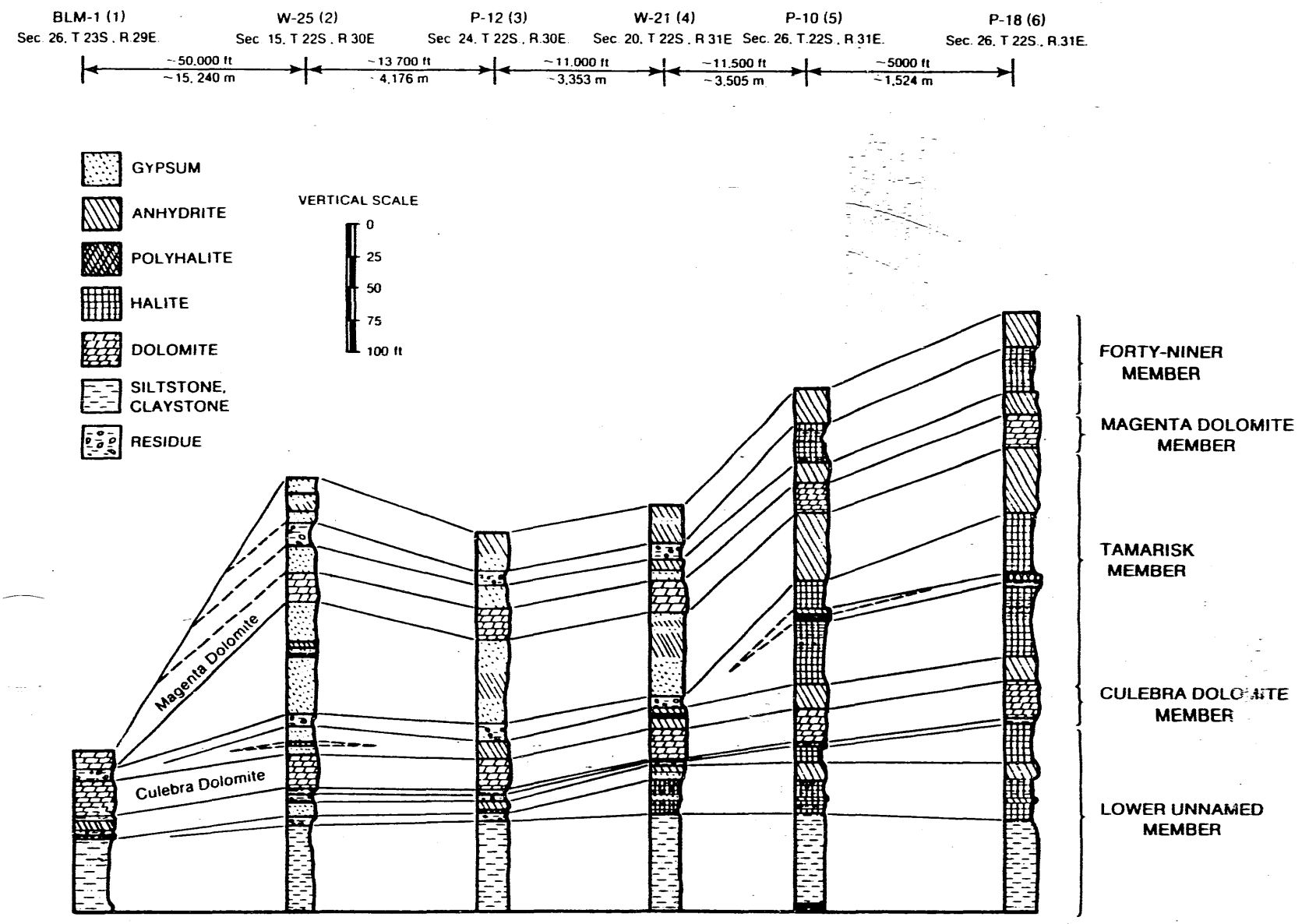


Figure 4.4.5: Columnar cross section across the WIPP site, showing lithologic correlations and variability of units in the Rustler Formation. Figure 2 of Snyder (1985).

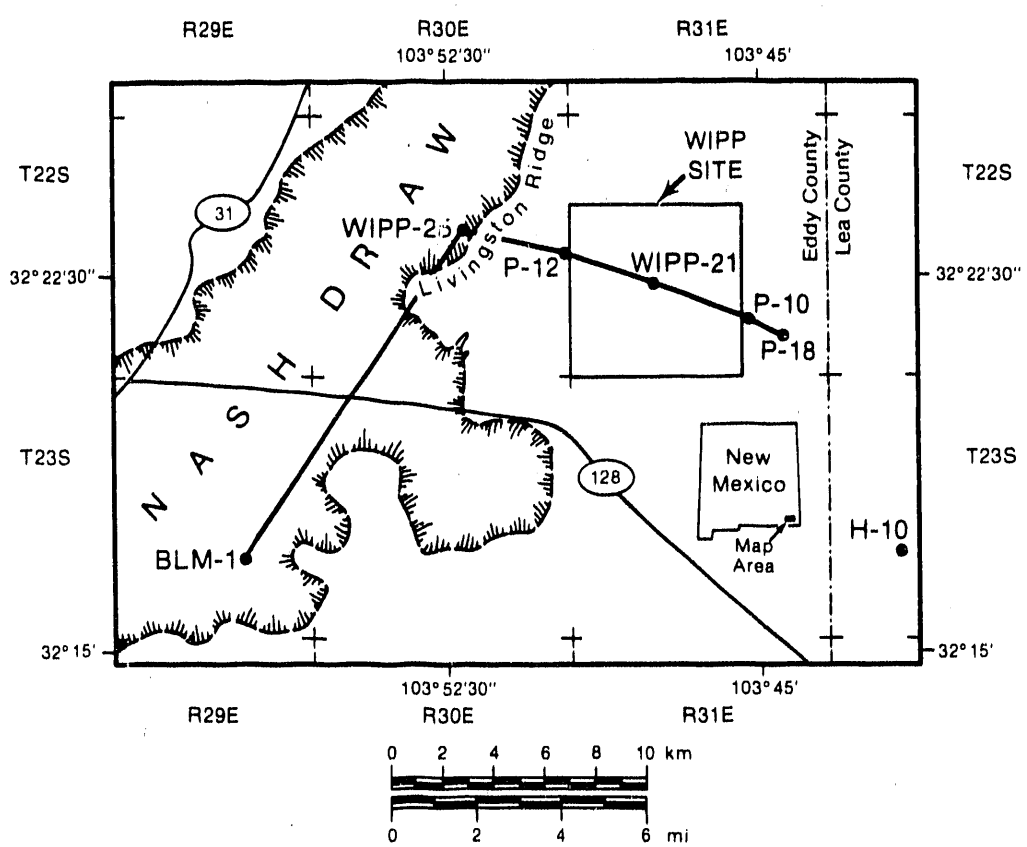


Figure 4.4.6: Hole locations used in Figure 4.4.5. Figure 1 of Snyder (1985).

halite later removed from the Rustler by evaporite dissolution is reduced. Since extrapolation of the estimated rates of dissolution within Nash Draw (Bachman, 1974) indicate that there is no need for concern at the WIPP site over the next 10,000 years, the differing interpretations do not directly affect the expected reliability of the WIPP facility. However, as discussed in Beauheim (1987b), primary depositional variability within the Rustler weakens the present understanding of the correlation between halite distribution within the Rustler, fracturing, and the transmissivity of the Culebra dolomite.

The conclusion that some of the gypsum observed within the Rustler is primary, rather than being due to alteration of preexisting anhydrite, is part of the interpretation by Holt and Powers (1984; 1987). Thus, little movement of water outside the Culebra or Magenta members might be required to account for gypsum observed in the Forty-niner or Tamarisk Members. At the other extreme, the assumption that infiltration from the surface to the Rustler is presently operative at the WIPP site, i.e., that karstic hydrology is important in the Rustler Formation east of Nash Draw or WIPP-33, requires that alteration within the Rustler and overlying formations involves surficial waters. At least localized flow through the anhydritic portions of the Forty-niner and Tamarisk Members is required by this assumption. Recent isotopic studies summarized by Lambert (1988) place constraints on the extent to which waters and hydrated minerals within the Rustler and Dewey Lake Red Beds reflect connate fluids, fluids resulting from stratabound movement, and fluids involved in vertical infiltration.

4.4.2.2 Isotopic Studies--Figure 4.4.7 summarizes $^{87}Sr/^{86}Sr$ measurements (Brookins and Lambert, 1988) on sulfates (anhydrites and gypsum) and carbonates from several evaporitic zones at the WIPP, as well as the Dewey Lake Red Beds. The isotopic signatures of samples from both the Nash Draw gypsite springs and the Mescalero caliche (see Section 4.4.1) are interpreted to represent surficial components; i.e., high $^{87}Sr/^{86}Sr$ ratios resulting from surficial weathering. At the other extreme, the markedly different and internally homogeneous isotopic signature of the anhydrites from throughout the Castile and Salado Formations is interpreted to imply that there has been no distinguishable input of surficial components to these rocks. Anhydrites and gypsums from the unnamed lower member, Tamarisk, and Forty-niner indicate only a very limited input of surficial material, presumably by solute transport by either vertical or stratabound flow.

The Magenta dolomite, which is significantly less permeable than the Culebra in most areas (see Section 4.1.1) is also more similar in $^{87}Sr/^{86}Sr$ character to the surrounding anhydrites and gypsums than is the Culebra. This implies, consistent with conclusions reached in Sections 4.1 and 4.3, dominantly stratabound fluid flow within the Rustler, with the Culebra dolomite being predominant. If the apparent surficial component of the Culebra were a result of vertical infiltration, rather than stratabound flow of originally surficial waters, the infiltration would be expected to alter the overlying portions of the Rustler. Instead, there is much less overlap between $^{87}Sr/^{87}Sr$ ratios measured in the Magenta, Tamarisk, and

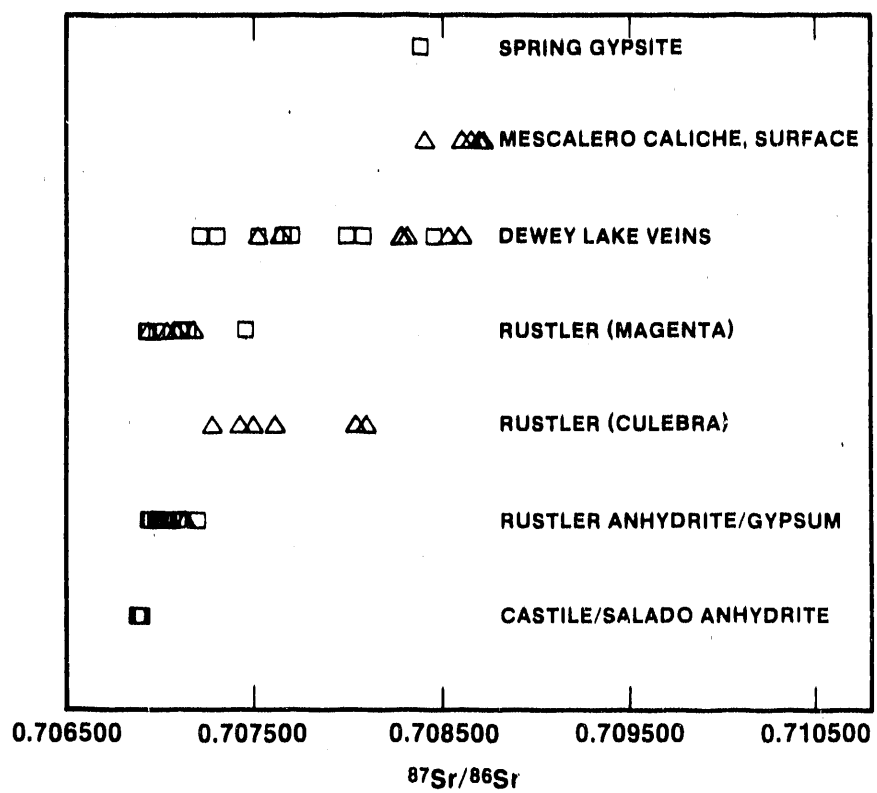


Figure 4.4.7: $^{87}Sr/^{86}Sr$ in Ochoan and related rocks at and near the WIPP site. Squares are anhydrites or gypsums; triangles are carbonates. All samples from the Dewey Lake are from veins. Samples from other units include both matrix and veins. Figure 17 of Lambert (1988).

Forty-niner Members with those measured in the Dewey Lake Red Beds than between the ratios measured in the Culebra and in the Dewey Lake.

Results contained in Figure 4.4.8 indicate further that the hydrologic system in the Dewey Lake Red Beds is significantly distinct from that of underlying units. With the exception of the Dewey Lake Red Beds, this figure summarizes the $^{87}Sr/^{86}Sr$ relationships between coexisting mineral pairs in evaporitic host rocks and in gypsum and/or calcite veins in the same unit. The question is whether these veins are locally derived or result from fluid movement over relatively long-distances. The matrix of the Dewey Lake Red Beds, however, is made up of silicic siltstones and sandstones. Therefore, carbonates and sulfates are rare in the matrix and analyses of Dewey Lake matrix materials are not included in Figure 4.4.8. The gypsum veins within the Dewey Lake probably cannot be locally derived. The strontium-isotopic character of the Dewey Lake gypsum veins (Figure 4.4.8) spans the range from surficial values represented by caliche and spring deposits in Figure 4.4.7 to isotopic values from underlying units. Since effectively none of the Dewey Lake veins can be locally derived, the range in their isotopic character indicates varying degrees of mixing of surficial waters and waters driven upward from the underlying evaporitic zones, consistent with modern head relationships discussed in Section 4.1.1.

Without exception, the strontium-isotope characters of coexisting mineral pairs from veins and host rock in units beneath the Dewey Lake are statistically identical to each other (Figure 4.4.8), indicating that the isotopic character of the vein material is controlled by that of the accompanying host rock, and not by a pervasive hydrologic system interconnected with veins in the Dewey Lake. This is even true for the one sample pair from the Culebra. These results indicate that there is little or no input of surficial material transported by groundwater below the Dewey Lake Red Beds, even into veins. All units below the Dewey Lake Red Beds considered here are evaporitic, i.e., they contain significant carbonates and/or sulfates in their matrix. Therefore, the local derivation of vein carbonates or sulfates is internally consistent.

Figures 4.4.9 and 4.4.10 indicate some constraints in rock-water ratios during gypsum crystallization or recrystallization in the Rustler and Dewey Lake. The dashed lines in Figures 4.4.9 and 4.4.10 represent the ranges in deuterium/hydrogen characteristics of Rustler water and modern surface-meteoric waters identified by Lambert and Harvey (1987) and Lambert (1988). At a sufficiently high rock/water ratio, i.e., when all of the available water is consumed in gypsum formation, for example during alteration of preexisting anhydrite, the deuterium characteristics of the resulting gypsum water of crystallization are constrained to be the same as that of the water added to the system. Therefore, the dashed fields in Figures 4.4.9 and 4.4.10 also represent the expected isotopic character of secondary gypsums formed under conditions involving very high rock/water ratios (Lambert, 1988). At equilibrium with a large excess of water, the deuterium/hydrogen ratio in gypsum is approximately 20 parts per thousand less than that of the coexisting water (Lambert, 1988). Therefore, the fields outlined by solid lines in Figures 4.4.9 and 4.4.10 are decreased from the fields outlined by dashed lines by 20 per mil and represent the

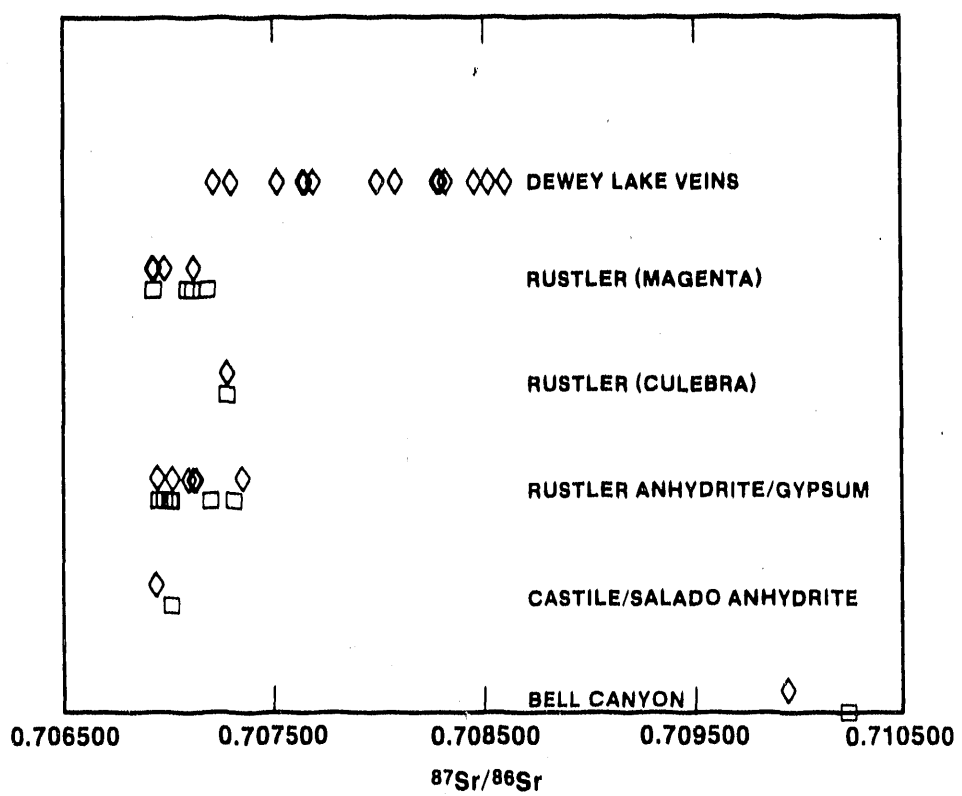


Figure 4.4.8: $^{87}Sr/^{86}Sr$ in coexisting mineral pairs from veins and Ochoan host rocks at and near the WIPP site. Squares are host rocks; diamonds are veins. Figure 18 of Lambert (1988).

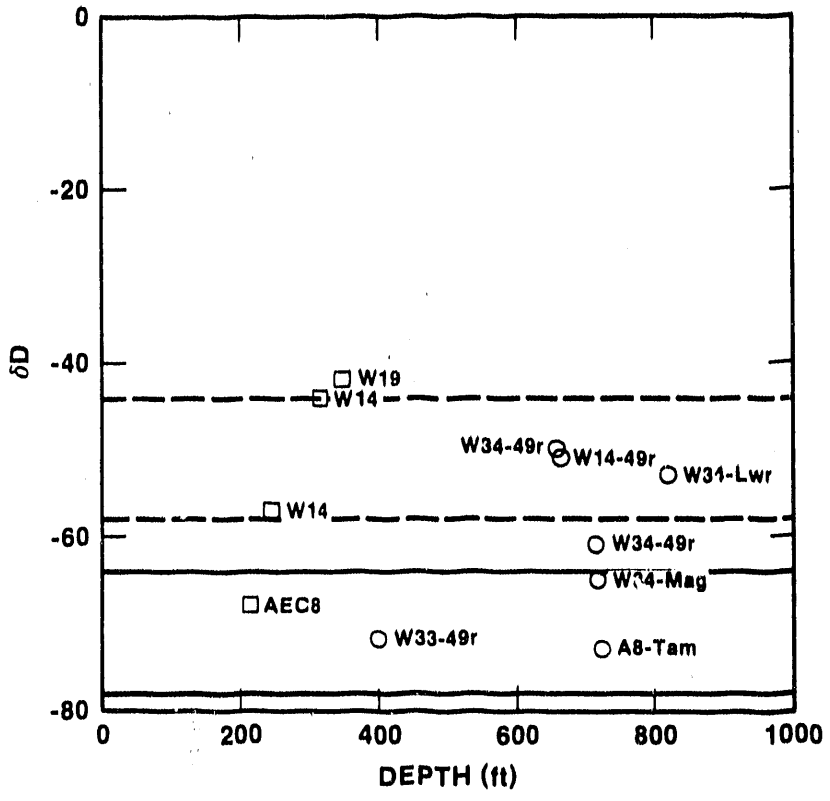


Figure 4.4.9: Deuterium distribution of the waters of crystallization of gypsums from the Dewey Lake Red Beds (squares) and Rustler Formation (circles) at and near the WIPP site, as a function of variations in rock/water ratio involving only Rustler-type water, the range in deuterium content of which is taken from Figure 4.3.10. Solid lines are for crystallization in the presence of a large amount of water, dashed lines for crystallization under conditions involving a very high rock/water ratio, in which all of the water is consumed in gypsum formation. Figure 19A of Lambert (1988).

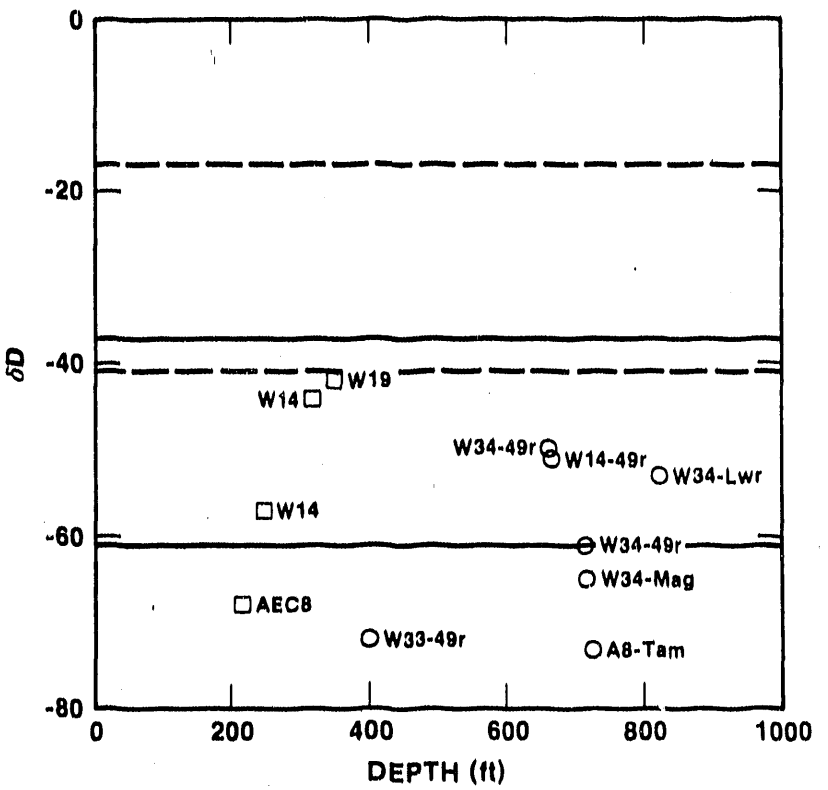


Figure 4.4.10: Deuterium distribution of the waters of crystallization of gypsums from the Dewey Lake Red Beds (squares) and Rustler Formation (circles) at and near the WIPP site, as a function of variations in rock/water ratio involving only surface-type water, the range in deuterium content of which is taken from consistent data in Figures 4.3.8 and 4.3.9. Solid lines are for crystallization in the presence of a large amount of water, dashed lines for crystallization under conditions involving a very high rock/water ratio, in which all of the water is consumed in gypsum formation. Figure 19B of Lambert (1988).

expected hydrogen-isotopic character of gypsums crystallized in the presence of excess amounts of Rustler-type and modern surface-meteoric waters, respectively.

The relationships shown in Figure 4.4.9 are consistent with crystallization of all of the analyzed gypsums with varying amounts of Rustler-type water, with the possible exception of vein material from the Dewey Lake in WIPP-19. Formation of the Dewey Lake gypsum veins in WIPP-19 apparently required infiltration of waters with the same isotopic character as those interpreted by Lambert and Harvey (1987) to represent modern meteoric precipitation. The character of the gypsum from WIPP-33 indicates crystallization in the presence of a large excess of Rustler-type water, but is not consistent with crystallization in the presence of any amount of modern-type water (Figure 4.4.10). [If it is assumed that the Magenta dolomite is more porous (permeable) than surrounding zones within the Rustler at this location, the isotopic variations in the vein gypsums from hole WIPP-34 are consistent with gypsum crystallization under varying ratios of rock to Rustler-type water.] The isotopic relationships (Figure 4.4.9) are consistent with crystallization of gypsums within the unnamed lower and Forty-niner members in response to vertical fluid flow upwards and downwards from the Magenta, assuming increasing effective rock/water ratio with increasing distance from the Magenta. This interpretation is also consistent with modern Rustler head relationships shown in Figure 4.1.3.

While results shown in Figure 4.4.9 are generally consistent with gypsum crystallization in equilibrium with varying amounts of Rustler-type waters, the results in Figure 4.4.10 indicate that this need not be the case for all samples. In Figure 4.4.10, the dashed field represents expected gypsum compositions for crystallization using modern surface-meteoric water, at a very high rock/water ratio, the solid field crystallization in the presence of greatly excess water. The hydrogen-isotopic relations indicate that it is impossible to form the gypsum from the Forty-niner Member at WIPP-33 with modern surface-meteoric water. This conclusion is consistent with the interpretations of Bachman (1980) that the gypsite springs in Nash Draw, which he believes to be the discharge for the WIPP-33 structure, are not presently active. The relations shown in Figure 4.4.10 also indicate that it is not possible to form the gypsum from the Magenta dolomite in WIPP-34 with surface-meteoric waters. The internally consistent interpretation of vertical variations in rock/water ratios within the Rustler Formation in WIPP-34, evident in Figure 4.4.9, breaks down if surface-meteoric waters are assumed to be involved.

The isotopic results summarized by Lambert (1988) indicate that there has been significant involvement of surficial waters in formation of gypsum veins within the Dewey Lake Red Beds. These same results indicate that the hydrologic behavior of the Dewey Lake is largely distinct from that of the underlying units and that there has been some upward movement of fluids into the Dewey Lake from the underlying Rustler Formation, consistent with the modern head relationships discussed in Section 4.1. Isotopic relations within secondary gypsums in the Rustler and Dewey Lake are somewhat ambiguous. In many cases, a given gypsum may have crystallized in equilibrium with either Rustler-type or modern surficial-meteoric waters,

depending on the rock/water ratio that is assumed to have been effective at the time of crystallization. The isotopic variability of gypsums from hole WIPP-34 is, however, best explained by local vertical movement of Rustler-type waters out of the Magenta dolomite, without the vertical karst channel system proposed for this locality by Barrows et al. (1983). It appears impossible to have crystallized secondary gypsum veins from the Dewey Lake at hole WIPP-19 without input of modern surface-meteoric waters. At WIPP-33, where the best physical evidence exists for vertical fluid movement from the surface downwards to the Rustler at depth, the isotopic character of analyzed vein gypsum from the Forty-niner indicates that this movement and related gypsum crystallization does not involve modern surface-meteoric water, i.e., that the WIPP-33 structure is essentially no longer active.

5.0 SUMMARY OF WIPP SITE-CHARACTERIZATION ACTIVITIES, 1983 THROUGH 1987

This section summarizes the present understanding of major aspects of WIPP site characterization, including some effort to place the WIPP facility in a regional hydrologic, structural, and geochemical prespective. A general conceptual model for the geologic behavior of the WIPP site and facility vicinity is presented in Section 5.1. Later sections describe more specific inclusions and briefly discuss remaining uncertainties or limitations. It must not be assumed **either** that any uncertainty discussed is significant to performance of the WIPP facility, **or** that any given uncertainty could be significantly reduced by further work. It is ultimately the role of the WIPP performance-assessment activity to determine which uncertainties are expected to be significant in evaluation of the short-term and long-term performance of the WIPP facility. The effort here is to provide as complete a conceptual model as possible for these decisions.

5.1 General Conceptual Model for the Geologic Behavior of the WIPP Site and Facility

The overall geologic and hydrologic setting of the WIPP site area has been transient (not steady-state) since before the beginning of deposition of the Bell Canyon Formation, approximately 250 million years ago, and will continue to be transient long after effective closure of the WIPP facility. Some events, such as crystallization of secondary minerals within the Salado Formation approximately 200 million years ago and formation of the Mescalero caliche 400,000 to 500,000 years ago, have taken place on a very long time scale relative to WIPP performance assessment, which must consider only a 10,000-year time frame. Two types of transient response have occurred or are occurring at and near the WIPP site within the 10,000-year time frame of regulatory interest. These are: a) the continuing natural response of the geologic and hydrologic systems to the end of the last pluvial period (period of decreased temperatures and increased precipitation) in southeast New Mexico; and b) the continuing responses to hydrologic, geochemical, and structural transients resulting from WIPP site characterization and facility construction. The transient responses induced by the presence of the WIPP underground workings will continue until reequilibration following effective structural and hydrologic closure of the facility.

The Bell Canyon Formation, consisting largely of shales, siltstones, and sandstones, contains the first relatively continuous water-bearing zone beneath the WIPP facility. In some parts of the northern Delaware Basin, the unit contains permeable channel sandstones that are targets for hydrocarbon exploration. Recent studies suggest that the upper Bell Canyon at the WIPP site does not contain any major channel sandstone. This decreases the probability of the Bell Canyon serving as a source of fluids for dissolution of overlying evaporites at the WIPP. These same studies indicate that the final direction of fluid flow following interconnection of the Bell Canyon, Salado, and Rustler Formations within a drillhole would be downward into the Bell Canyon, after accounting for density increases in the fluids due to dissolution of halite within the Salado. It is assumed

here that the measured hydrologic characteristics of the Bell Canyon Formation are more significant to WIPP performance assessment than those of underlying units. The head distribution within the upper Bell Canyon near the WIPP site indicates flow towards the northeast.

Both regional studies and studies within the WIPP facility indicate that the Castile and Salado Formations, both of which are made up predominantly of layered anhydrites and halites, should be considered as low-permeability units that deform regionally in response to gravity. In general, permeabilities and fluid-flow rates in both units are very low and insensitive to stratigraphy. Formation permeabilities in the Castile and Salado Formations remote from the WIPP excavations are generally 0.1 microdarcy or less, and the regional water content of Salado halites is up to 2 weight percent. Exceptions include local brine occurrences in Castile anhydrites and gas occurrences in the Salado Formation, both of which are fracture-controlled, can be large in volume, and can be under pressures high enough to cause fluid flow to the surface. No major gas occurrence within the Salado Formation has been encountered at the WIPP site. In fact, where it has been possible to measure far-field brine pressures within the Salado, the pressures, permeabilities, and available brine volumes combine to indicate the potential for only very limited fluid flow upwards into the overlying Rustler Formation. It is not certain that the Castile and Salado Formations are hydrologically saturated regionally.

Pressurized Castile brines have been encountered in Castile anhydrite in hole WIPP-12, approximately 1.5 km north of the center of the WIPP site. Geophysical studies indicate that Castile brines probably are present beneath a portion of the WIPP waste-emplacement panels, consistent with earlier assumptions. These brines are stratigraphically 200 m or more below the WIPP facility horizon and are not of concern except in the case of human-intrusion breach of the facility.

In the western part of the Delaware Basin, extensive halite dissolution has apparently taken place in both the Castile and Salado Formations. However, much of the variability in structure and internal stratigraphic thicknesses within the Castile and Salado Formations results from deformation and original depositional variability, rather than from evaporite dissolution. Regional or far-field deformation of the Castile and Salado Formations involves pressure solution as a major mechanism, due to the presence of intergranular fluids, but occurs too slowly to be of future concern to the WIPP Project. Structures within hole DOE-2 result from deformation rather than dissolution.

The hydrologic and structural characteristics of the Salado Formation in the disturbed zone generated by the presence of the WIPP facility are different than those in the far field. Formation permeability within a couple of meters of the underground workings at the facility horizon increases significantly. Near-field deformation of the Salado Formation involves both the opening of preexisting fractures in anhydrite beneath the facility horizon (Marker Bed 139) and generation of new fractures in halite. Fluid contents in the disturbed zone at the facility horizon decrease in response to facility ventilation and/or deformation. Within a few meters of the underground workings, both hydrologic and structural

behavior of the Salado Formation become essentially those of the far field. Brine seepage into the WIPP facility includes a significant transient phase, which will probably last until effective facility closure. The results of preliminary hydrologic testing in the Salado Formation adjacent to the WIPP air-intake shaft indicate extremely low permeabilities, with no apparent stratigraphic variability. The results also indicate that development of a disturbed zone around the WIPP shafts is less extensive than at the facility horizon. The extent, characteristics, and importance of the disturbed-rock zones around the WIPP shafts and at the facility horizon remain to be determined in detail.

Where not extensively altered, the Rustler Formation should be considered as a layered unit of anhydrites, siltstones, and halites, containing an important and variably fractured carbonate unit, the Culebra dolomite. The Culebra dolomite is the first continuous water-bearing unit above the WIPP facility and, at the WIPP site, is at least an order of magnitude more permeable than other members of the Rustler Formation, including the Magenta dolomite. The transmissivities of Rustler anhydrites at the WIPP site are too low to measure. As a result, the Culebra dominates fluid flow within the Rustler Formation at the WIPP site and is the most significant pathway to the accessible environment from the WIPP facility, except for direct breach to the surface by human intrusion. The transmissivity of the Culebra varies by approximately six orders of magnitude in the region containing the WIPP site. The Culebra transmissivity in the central portion of the site, including the locations of all four WIPP shafts, is low. Higher Culebra transmissivities are found in areas southeast and northwest of the central part of the site. Fluid flow rates within the Culebra are very low at the site center and in regions to the east, but relatively high within Nash Draw. Modern flow in the Culebra is confined and largely north-south in the area of the WIPP site.

Fluid flow and geochemistry within the Culebra dolomite and shallower units are in continuing transient response to the marked decrease or cessation of local recharge at approximately the end of the last pluvial period. Both bulk chemistry and isotopic relations within Culebra fluids are inconsistent with modern flow directions if steady-state confined flow is assumed. Because of the relative head potentials within the Rustler Formation at and near the WIPP site, there must be a small amount of vertical fluid flow between its members, even though the permeabilities of Rustler members other than the Culebra dolomite are quite low. Where measured successfully, the modern head potentials within the Rustler prevent fluid flow from the surface downward into the Rustler carbonates. These results do not prohibit either the modern movement of fluids from the underlying Salado Formation upwards into the Rustler Formation or the downward movement of Dewey Lake waters into the Rustler Formation during or even after the cessation of local recharge at the end of the last pluvial period. They do, however, suggest that recharge from the surface to the Rustler Formation is not now occurring at the WIPP site. The results of stable-isotope, radiocarbon, and uranium-disequilibrium studies are also consistent with the interpretation that there is no measurable modern recharge to the Culebra dolomite from the surface at and near the WIPP site. The transient hydrologic response of the Rustler Formation to the end of the last pluvial period has involved at least some change in flow

directions in the Culebra dolomite. Although the modern flow is largely north-south, the results of uranium-disequilibrium studies suggest that flow was more easterly during previous recharge.

Within and near Nash Draw, evaporite karst is operative within the Rustler, as evidenced by the continuing development of small caves and sinkholes in near-surface anhydrites and gypsums of the Forty-niner and Tamarisk Members. There is no evidence of karstic hydrology in the Rustler at and near the WIPP site. However fracturing of some portions of the Culebra dolomite is sufficient at the site to strongly affect both hydraulic and transport behavior on the hydropad scale, i.e., over distances of approximately 30 m. Interpretation of multipad interference tests conducted both north and south of the center of the WIPP site indicates that this fracturing need not be incorporated into numerical modeling of the regional-scale hydraulic behavior of the Culebra east of Nash Draw. Similarly, detailed transport calculations indicate that effects due to fracturing are not significant in regional-scale transport within the Culebra dolomite at and near the WIPP site, at least as long as the modern head distribution is not significantly disturbed and the calculated flow directions and transport properties are representative.

The Dewey Lake Red Beds overlying the Rustler Formation consist largely of siltstones and claystones, with subordinate sandstones. In tested locations, the Dewey Lake may be hydrologically unsaturated, but is too low in permeability for successful hydrologic testing. South of the WIPP site, near an area where the unit may be receiving modern recharge, sandstones within the Dewey Lake locally produce potable water. In general, water levels within the Dewey Lake Red Beds, like those in the underlying Rustler Formation, must be in transient response to the end of the last pluvial period. Isotopic relations suggest that surficial waters have been involved in the formation of secondary gypsum veins within the Dewey Lake, but that the Dewey Lake and Rustler hydrologic systems are largely separate.

The major near-surface units at the WIPP site are the Gatuna Formation and Mescalero caliche. The sandstones and stream-channel conglomerates within the Gatuna indicate that major changes in local climate have occurred over (at least) the last 600,000 years. The widespread preservation of the Mescalero caliche indicates not only the relative structural stability of the Livingston Ridge surface (on which the WIPP surface facilities are sited) over the last 400,000 years, but also that infiltration over this same time period has not been sufficient to dissolve a layer of carbonate 1 to 2 m thick.

5.2 Individual Conclusions and Discussions

This Section contains descriptions and discussions of more specific conclusions concerning geologic chracterization of the WIPP site and vicinity. In each case, the description of the conclusion is followed by a brief discussion.

5.2.1 Conclusions Concerning the Overall Geologic and Hydrologic Setting of the WIPP Site and Vicinity

1. Conclusion: The overall geologic behavior at the WIPP site has been transient since before the beginning of deposition of the Bell Canyon Formation approximately 250 million years ago. Radiometric age dating indicates that secondary polyhalites in the Salado Formation near the WIPP facility horizon crystallized approximately 200 million years ago, some 40 million years after deposition of the Salado. Fractures within MB139, which are now partially healed, probably formed in response to rapid unloading at the end of the Cretaceous or in the Tertiary, i.e., more than approximately 2 million years ago. The hydrologic setting of the WIPP site appears to be in transient response to the end of the last pluvial period.

Discussion: Not all of the secondary minerals in the Salado have been dated. The age of magnesite, which appears to play a large role in controlling the composition of fluid inclusions, has not been determined. The age of fracturing in MB139 has not been determined directly. However, given that estimated ages of secondary mineralization and fracturing within MB139 appear large relative to the regulatory time frame of 10,000 years, the present estimates are adequate. Understanding of the hydrology of the WIPP site, especially the Rustler Formation, has been a major focus of site-characterization activities (see below).

2. Conclusion: There is abundant evidence for climatic and hydrologic transients at the WIPP site over the time interval of approximately 600,000 to 300,000 years before the present, as well as for long-term structural stability of the Livingston Ridge surface, on which the WIPP surface facilities are sited. The Gatuna Formation indicates a much wetter climate approximately 600,000 years ago, resulting in the presence of relatively high-energy streams on what is now the Livingston Ridge surface. The formation of the Mescalero caliche and Berino soil indicate a relatively drier climate approximately 500,000 and 300,000 years ago. The widespread preservation of the Mescalero indicates structural stability of the Livingston Ridge surface for approximately 300,000 years. In addition to structural stability, the preservation of the Mescalero caliche indicates that the regional infiltration over approximately the last 500,000 years has been insufficient to dissolve the existing caliche.

Discussion: The available geologic data do not provide a continuous time-stratigraphic record over the last 600,000 years. For example, only the upper portion of the Gatuna Formation has been dated; the age of lower portions of the unit is unknown. No dated deposits younger than the Berino soil are present at the WIPP site. Regional preservation of the Mescalero caliche does not mean that there is no local infiltration of surficial waters, since local dissolution of caliche due to the action of plant roots is known; in some places, the resulting structures completely pierce the Mescalero.

3. Conclusion: There is localized evidence for climatic and hydrologic changes near the WIPP site on the time scale of 25,000 to 10,500 years ago. Gypsite springs along the east side of Nash Draw appear to have been inactive for approximately 25,000 years. Packrat middens northwest of Carlsbad indicate a climate approximately 10,000 years ago significantly cooler and wetter than that approximately 4,000 years ago.

Discussion: Neither gypsite springs nor packrat middens have been found at the WIPP site proper. The radiometric age-dating of the gypsite spring deposits is not internally consistent, although the faunal assemblage in the deposits is definitely Late Pleistocene in age. The gypsite springs and packrat middens provide only a qualitative indication of change in climate and precipitation. Therefore, they cannot be used as direct input for transient boundary conditions in numerical modeling of hydrology at the WIPP site. Little information is available concerning the climate and hydrology of the northern Delaware Basin between approximately 10,000 and 4,000 years ago.

4. Conclusion: There is abundant evidence that the natural fluid flow and geochemistry of the Rustler are dominated by confined flow within the Culebra dolomite at and near the WIPP site, and that flow within the Culebra is transient on a time scale of approximately 10,000 years or longer.

   The hydrology and geochemistry of the Rustler, and therefore those of all other units as well, are recovering from the most recent pluvial interval in southeastern New Mexico. Factors indicating the overall transient setting of Rustler hydrology at and near the WIPP site include: a) the inconsistency between modern flow directions and present brine-density distribution within the Culebra dolomite if steady-state confined flow is assumed; b) the inconsistency between present hydrochemical facies within Culebra fluids and modern flow directions if steady-state confined flow is assumed; c) the inconsistency between the isotopic characteristics of Rustler fluids and both modern flow directions and surficial recharge to the Rustler at and near the WIPP site; and d) geologic, isotopic, and hydrologic studies indicating that vertical fluid movement into and out of the Rustler Formation is limited.

   Because the transmissivities of non-carbonate units within the Rustler are not zero and different hydraulic heads are known in different Rustler members, there must be limited vertical fluid flow within the Rustler Formation. However, the transmissivities of Rustler anhydrites and the Tamarisk claystone at and near the WIPP site are too low to measure; therefore vertical fluid flow must be extremely limited.

Discussion: The present isotopic data bases are limited in size. Therefore, the presence of small structures inconsistent with regional interpretations is possible. In addition, because of the limited data base, directions of flow interpreted from uranium-disequilibrium studies include considerable uncertainty. The available results indicate that,

although stratabound flow within the Culebra dolomite dominates at and near the WIPP site, this is not necessarily true within Nash Draw. Because of the existence of small caves and sinkholes within Tamarisk and Forty-niner anhydrites in Nash Draw, there must be a qualitative increase in the transmissivity of these members somewhere between the WIPP site and Nash Draw. Avaliable evidence suggests that this change does not take place east of WIPP-33.

5. Conclusion: At least three types of man-induced transients at the WIPP site are known or can be expected. The transients include hydrologic, geochemical, and structural effects, independent of the emplacement of waste.

   The hydrology of the Rustler Formation at and near the WIPP has been and will continue to be affected by both hydrologic testing in the area and the construction and sealing of the WIPP shafts. The hydrologic behavior of the Salado Formation, both in the WIPP facility itself and adjacent to the access shafts, has been altered by construction of the WIPP facility and shafts. This alteration includes development of a local altered or disturbed rock zone, within which permeability is significantly increased and a zone of partial saturation has probably developed. The altered zone, however, is probably less extensive around lined shafts than at the facility horizon.

   In the Rustler Formation, the use of lost-circulation materials during the drilling of hydrocarbon-exploration holes and hydrologic test holes not drilled with air has resulted in development of at least local geochemical transients of unknown magnitude, lateral extent, and duration. Any far-field radionuclide migration outside the WIPP facility in the Rustler may be superimposed on these transients. Possible geochemical alteration within the Salado Formation due to the presence of the WIPP facility remains to be examined in detail, with the exception of effects due to emplacement of TRU wastes. For example, the long-term geochemical stability of grouting materials used in both the Rustler and Salado is not yet known.

   The construction of the WIPP facility imposes a transient near-field structural effect on at least nearby portions of the Salado Formation. At the facility horizon, this effect includes both local opening of preexisting fractures in MB139 and formation of fractures in halite. Transient structural behavior around the WIPP shafts will include the Rustler Formation and extend to the land surface. However, the limited information available to date suggests that structural effects around the WIPP shafts will be less than those at the facility horizon.

Discussion: The effective time scales of the man-induced transients in and near the WIPP facility are not well known. Transients directly resulting from the construction of the WIPP facility will last until reequilibration following the effective hydrologic and structural closure of the facility. The time scale of hydrologic transients within the Rustler induced by hydrologic testing is short, maybe decades. The time scale of induced geochemical transients within the Rustler is not known. Only those

transients which might affect the performance of the WIPP facility need be determined in any more detail than indicated here. Determination of which transients need be considered is part of the WIPP Performance Assessment activity.

5.2.2 Conclusions Concerning the Bell Canyon Formation

1. Conclusion: Calculations completed as part of the WIPP SPDV effort indicate that the Bell Canyon does not have sufficient brine-carrying capacity to dissolve halite rapidly enough for halite dissolution within the Castile and/or Salado Formations as a result of brine-density flow. Therefore, in regions of the Castile and Salado reasonably removed from concern regarding stratabound dissolution, such as the WIPP site, only halite dissolution as a result of diffusional processes need be considered. Such diffusion proceeds at a rate too slow to be of concern to the WIPP Project.

Discussion: The conclusions are dependent upon the assumed gradients within the Bell Canyon and range of Bell Canyon hydraulic properties, both of which are somewhat uncertain. The SPDV calculations did not result in total agreement that point-source dissolution was not a feasible mechanism at the WIPP site. However, the structure specifically proposed as a result of point-source dissolution was directly examined by drilling and testing of hole DOE-2, and was found to result from deformation within the Castile and Salado Formations, rather than from halite dissolution.

2. Conclusion: Investigations in holes Cabin Baby-1 and DOE-2 suggest indicate that the upper Bell Canyon Formation beneath the WIPP site is not significantly permeable. Therefore, regardless of the relative heads, the volumes of fluid flow between the Culebra dolomite and the upper Bell Canyon would be minor if the two units were interconnected as a result of drilling. These same studies indicate that the final direction of fluid flow would be downward into the Bell Canyon.

Discussion: Although Cabin Baby-1 and DOE-2 lie directly south and north of the WIPP site center, they provide only two data points. Given the regional trends of the Ramsey channel sands in the upper Bell Canyon, it is possible that a narrow sand crosses the center of the site from northeast to southwest, without having been intersected by either drill hole. The conclusion concerning directions of fluid flow pertains only to the final direction of flow, assuming halite saturation of both Bell Canyon and Culebra fluids as a result of dissolution of Salado halite. The conclusion does not describe either directions or rates of fluid flow prior to such saturation. In addition, the conclusion assumes that the fluid-carrying capacity of the Bell Canyon is sufficient to completely overwhelm any potential heads within the Salado Formation. This assumption appears reasonable, given the extremely small volumes of Salado flow intersected in hydrologic test holes at the WIPP site.

5.2.3 Conclusions Concerning the Castile and Salado Formations

1. Conclusion: Regional-scale deformation of the Castile and Salado Formations may well be ongoing at and near the WIPP site in response to gravity. However, estimation of the time required for formation of the WIPP-12 anticline indicates that such deformation probably occurs at a rate too slow to be of concern to the behavior of the WIPP facility. Fluids play a major role in regional-scale deformation of the Castile and Salado Formations, especially in deformation of halites and anhydrite stringers or laminae. Both estimated deformation rates and mechanistic considerations are consistent with pressure solution being a major deformation mechanism on the regional scale. This conclusion is consistent with greater deformation rates at lower differential stresses than would be the case for strictly anhydrous deformation. Inclusion of pressure solution as a deformation mechanism results in predicted strain rates at the WIPP site which are consistent with estimated rates elsewhere.

Discussion: Regional-scale deformation in response to gravity is not constrained to occur at a constant rate. Therefore, deformation rates averaged over long periods of time may be exceeded during shorter intervals. For pressure solution to be active, there must be a relatively continuous fluid film along grain boundaries. While textural evidence of pressure solution has been noted in core from the WIPP site, the presence of the required grain-boundary film has not been demonstrated directly. Although the role of pressure solution in regional-scale deformation is probable, it is not clear if or when the same mechanism will become dominant in near-field deformation around the WIPP facility. If it did become active, it would help accelerate mechanical closure of the facility by increasing deformation at relatively low differential stresses.

2. Conclusion: Much of the variability in both total and interval stratigraphic thicknesses of the Castile and Salado Formations at and near the WIPP site is due to syndepositional and postdepositional deformation, rather than to evaporite dissolution. Therefore, any interpretation of the thicknesses of these units must be done on a vertical scale involving as much of the Salado and Castile as possible, rather than on the scale of a single stratigraphic interval. Similarly, the interpretation must be done on as large a geographic scale as possible, since horizontal movement, especially of halites, is involved. Apparent one-hole anomalies are especially suspect.

Discussion: On the regional scale, especially in the western portion of the Delaware Basin, regional dissolution has apparently removed the halite from both the Castile and Salado Formations, and the original thickness of halite is unknown. At the local scale, as demonstrated in hole DOE-2, dissolution cannot be ruled out without interpretation on a broad stratigraphic and geographic scale.

3. Conclusion: The basinal structure in hole DOE-2, near the northern boundary of WIPP Zone 3, extends downwards from MB124 in the Salado to the top of Castile Anhydrite I. However, the DOE-2 structure resulted

from syndepositional and postdepositional deformation, rather than from halite dissolution. Deformation involved in formation of the DOE-2 structure resulted in displacement of all but 2 m of halite from the Castile Formation. However, both the Castile anhydrites and the entire Salado Formation (especially halites) are unusually thick in this hole. No evidence of dissolution was identified in DOE-2 core.

Discussion: The present understanding of the hydrology and structural behavior of the Castile and Salado Formations indicates that point-source dissolution of evaporites requires connection with a major source of unsaturated water, such as the Capitan limestone. This is not known to have occurrd within the body of the Delaware Basin, with the possible exception of the emplacement of Castile brines. While the present hydrologic and structural understanding does not allow prediction of where either point-source dissolution or a gravitational structure such as that at DOE-2 might form in the future, the drilling, coring, and hydrologic testing of DOE-2 demonstrates that no such structure presently exists within WIPP Zone 3. Calculations indicate that rates of gravitationally driven deformation are too slow to be of concern to the WIPP facility on the regulatory time scale.

4. Conclusion: The average far-field permeability of the Salado Formation, based on testing both from the surface and near the WIPP facility horizon, is 0.1 microdarcy or less, except where fractures locally contain small or large volumes of gas at elevated pressures. The stratigraphic variability of far-field permeability within the Salado is presently unknown, but appears negligible.

Discussion: It is not known for sure that the Salado is hydraulically saturated in the far-field. Known gas occurrences in drilling from the surface and within the WIPP facility indicate that partial saturation may be present in both the near-field and far-field, at relatively high confining pressures. The distribution of fracture systems, range of possible initial gas pressures, and effective fracture permeabilities in the far-field Salado remain unknown.

5. Conclusion: Where it has been possible to measure Salado fluid pressures, calculated heads indicate the potential for limited fluid flow upwards into the overlying Rustler Formation. Measurements to date indicate, however, that the amount of fluid available from the Salado is extremely limited. At least in the case of WIPP-12, the Salado fluid pressures and calculated heads exceed those in the underlying Castile brine reservoir. It has not been possible to determine any discrete source of fluid flow within the Salado Formation in testing from the surface.

Discussion: The measured Salado fluid pressures indicate only the possible directions of modern fluid flow. The measured pressures may be relict, developed under different geologic conditions than those at present, e.g., they may have been developed during the last pluvial period. The time scale on which such pressures or heads might change as part of the transient overall response of the WIPP hydrologic setting to the end of the

last pluvial period is not known, but must be long, given the low regional permeability of the Salado.

6. Conclusion: Water contents of Salado halites in the far-field appear to be as much as 2 weight percent, based on geophysical logging, greater than previously estimated. This does not have any direct impact on expected fluid flow into the WIPP facility, other than indicating that fluid volumes available to support long-term fluid flow may be greater than previously expected.

Discussion: To date, the interpretation of far-field water contents is based only on geophysical studies. Measurements on core are ongoing.

7. Conclusion: Consistent with assumptions maintained since brine was encountered in Castile Anhydrite III in WIPP-12, recent geophysical studies indicate that Castile brine may be present beneath a portion of the WIPP waste-emplacement panels. Brine is most likely present beneath the northern and northeastern portion of the waste-emplacement panels, and probably comes close to the southwestern and southeastern corners of the panels. However, the brines, if present, are 200 m or more below the WIPP facility horizon, and are not of concern except in the event of drilling-induced breach connecting a brine occurrence with the WIPP facility.

Discussion: Because of the dominant effect of the underlying Bell Canyon Formation, it is possible that the interpreted brine occurrences within the Castile are not real. Three-dimensional modeling of the results does not appear promising in defining the lateral distribution of Castile brines more accurately. Because of the vertical uncertainty inherent in the measurements, it is not possible to distinguish between brine occurrence within Anhydrite III and within Anhydrite II. However, where Castile brines have been encountered, it has always been present in the uppermost anhydrite.

8. Conclusion: Both uranium-disequilibrium studies and structural calculations appear consistent with emplacement of brines into fractured Castile anhydrites as a result of an episodic process. The process may involve either local brine movement during deformation and fracturing of anhydrite in low-pressure locations such as anticlinal crests, or long-distance fluid movement into preexisting fractures as a result of episodic hydrologic connection of the Capitan limestone and Castile Formation.

Discussion: It is not agreed that deformation or hydrologic connection of the Capitan limestone and Castile is the relevant episodic process involved in generation and/or emplacement of Castile brines. Structural studies indicate that deformation of the Castile Formation is episodic, with resultant episodic generation and emplacement of brines. Under these assumptions, generation of fractures and migration of brines into anhydrites may occur during the next 10,000 years, but probably at too low

a rate to be of concern to the WIPP Project. Isotopic studies are interpreted to indicate a residence time for Castile brines sampled at ERDA-6 and WIPP-12 of more than 100,000 years. While this interpretation indicates prior hydraulic connection of the Castile anhydrites and the Capitan limestone, it also indicates that this connection has not been operative for more than 100,000 years.

9. Conclusion: Both fluid-inclusion and grain-boundary fluids are present within the Salado Formation, in addition to loosely-held waters of hydration in hydrated minerals. The composition of Salado fluid inclusions is apparently controlled by the crystallization of polyhalite and magnesite. Radiometric age dating of polyhalites indicates that they are approximately 200 million years old. Therefore, the Salado fluid inclusions appear to be approximately 200 million years old. Fluids encountered within macroscopic flows into the WIPP facility appear to be dominantly grain-boundary fluids rather than fluids from fluid inclusions. The composition of grain boundary fluids within the Salado is apparently controlled by diagenetic reactions involving crystallization of Mg-rich layer silicates. Because the kinetics of these reactions are slow, it is concluded that the residence time of grain-boundary fluids within the Salado is at least several million years. The marked vertical variability of fluids near the WIPP facility horizon indicates very limited vertical fluid flow within the Salado.

Discussion: Crystallization of magnesite appears to have a major affect on fluid-inclusion compositions. However, magnesite from samples at the WIPP has not been dated. It has not been possible to estimate the residence time of Salado grain-boundary fluids directly. Radiometric measurements indicating ages for clay minerals greater than the Permian indicate that diagenetic or secondary reactions involving Mg have not involved complete recrystallization.

10. Conclusion: In the Salado Formation near the WIPP facility, there is strong coupling of deformation and hydraulic behavior. Within approximately 2 m of the underground rooms and entryways, fracturing and probable matrix dilation have led to a marked increase in permeability, and quite possibly to development of a zone of partial saturation. The increase in permeability appears to be both time-dependent and geometry-dependent. Within a few meters of the underground workings, however, the hydrologic properties of the Salado essentially become the same as regional properties.

    The time scale on which the WIPP facility will affect the local hydrology of the Salado Formation, while undetermined at present, is likely to be extensive, continuing until reequilibration after effective mechanical closure of the facility. Within the facility, there is a three-stage generalized flow behavior. Holes are normally dry when first drilled. Fluid flow then normally rises rapidly to a maximum flow rate, after which it more slowly decreases to something approximating steady-state flow, though probably still decreasing. Porous-medium calculations based on the estimated far-field permeability indicate that steady-state fluid flow might not be

reached for more than 5000 years, because of the extremely low permeabilities; these calculations do not yet include consideration of facility closure. The observed "steady-state" flow is qualitatively consistent with measured far-field permeabilities. Both measurement and calculations to date indicate that effective pore pressures within the Salado have been affected by the presence of the WIPP facility only within a few meters of the facility.

Discussion: Within the altered zone around the WIPP facility, the porous-medium approximation may not be adequate for either flow or transport modeling. The distances from the underground workings at which this simplifying assumption becomes valid remain to be determined. At present, there is not an adequate characterization of the fracturing adjacent to the WIPP facility to allow realistic modeling of flow and transport behavior within the altered zone, nor do adequate models exist. The long-term extent of the altered (fractured) zone around both underground workings and shafts remains unknown. However, the zone should be larger around underground workings than around lined shafts. Both the total long-term brine seepage to be expected from the Salado and the total volume of the Salado affected by fluid flow depend on the available porosity as a function of time within the WIPP facility and any altered zone that may be present. The effects of stress relief around the WIPP facility on both near-field and far-field hydrology will be examined in detail during the WIPP operational-demonstration period.

11. Conclusion: Preliminary hydrologic testing adjacent to the WIPP waste-handling shaft indicates that all of the tested intervals, which include claystone and siltstone in the unnamed lower member of the Rustler and both halites and anhydrites within the Salado, are extremely low in permeability. While there was evidence of a hydraulic cone of depression around the shaft, there was no evidence of fracturing or alteration, except at the 850-ft level. At this level, pressurized fluids were encountered at the liner/rock interface and flowed into the test hole. Testing extended from approximately 2 m outside the shaft liner to a depth of some 10 m. The results are consistent with the interpretation that damage effects due to either blasting of the shaft or deformation around the shaft do not presently extend more than two meters into the surrounding rock mass.

Discussion: Due to scheduling constraints, only one or two holes was/were tested at each level. Therefore, these results do not indicate a complete absence of fracturing, merely that fractures were not intersected by the one or two holes at each level, except the 850-foot level. To better determine the presence or absence of fracturing by direct measurement, arrays of three or more holes would be needed at each level. The results do not indicate a potential altered zone within 2 m of the liner. Finally, the waste-handling shaft has been at its present diameter for approximately four years. The operational phase of the WIPP is expected to extend approximately 25 years, after which shaft seals must be emplaced successfully. The extrapolation of the present results to 25 years may not be reliable.

12. Conclusion: Anhydrite Marker Bed 139, approximately 1 to 2 m beneath the WIPP facility horizon, contains partially healed and filled fractures which predate construction of the WIPP facility and play a significant role in both mechanical deformation near the WIPP facility and the near-field enhancement in permeability. The estimated age of the fractures is at least two million years. However, the far-field permeability of MB139 is not significantly greater than that of the surrounding halites.

Discussion: Development of any altered zone around the WIPP facility will be time dependent. Therefore, the boundary between the hydrologic near-field and far-field regimes will also be time dependent. The rate and extent to which the fracture porosity and permeability of MB139 in the altered zone near the WIPP facility horizon will be reduced during closure of the WIPP facility has not yet been demonstrated.

5.2.4 Conclusions Concerning the Rustler Formation and Younger Units

1. Conclusion: The available transmissivity data base at and near the WIPP site suggests that: a) the Culebra dolomite is at least one order of magnitude more transmissive than other members of the Rustler at most locations; and b) except where it is fractured in or near Nash Draw, the transmissivity of the Magenta dolomite is the same order of magnitude as that of other members of the Rustler. Consequently, confined flow within the Culebra dominates the hydrology of the Rustler at and near the WIPP site, and Rustler karst is not present.

Discussion: The Magenta data base is significantly smaller than that of the Culebra. Transmissivities of Rustler claystone/siltstones are very low but measurable at the Site, except for the Tamarisk claystone, which has not been successfully tested due to its low transmissivity. The transmissivity of Rustler anhydrites at the Site are too low to measure successfully. Somewhere between the WIPP ite and Nash Draw (including WIPP-33), there must be a marked increase in the local permeability of Rustler anhydrites/gypsums. Where they are exposed or relatively near the surface, i.e., in Nash Draw and at WIPP-33, Rustler anhydrites are capable of supporting open cavernous porosity. The character and location of this transition in behavior of the Rustler anhydrites are not known in detail, but apparently involve decreasing overburden pressure (allowing the gypsums to maintain open porosity) and specific structures at the locations of both recharge and discharge.

The WIPP-33 structure is unique at and near the WIPP site, since it includes the three components necessary but not sufficient for karstic geology within the Rustler: 1) a sufficiently large breach in the Mescalero caliche and relatively thin Dewey Lake Red Beds; 2) shallow enough depth to gypsums within the Forty-niner and Tamarisk Members to allow maintenance of open porosity in gypsums above and below the Magenta; and 3) a probable local base level at the time the structure was mainly active, namely the gypsite springs on the east side of Nash Draw. Both the deuterium/hydrogen ratios of secondary gypsum from WIPP-33 and approximate dating of the gypsite springs within Nash Draw suggest that the WIPP-33 structure is largely inactive at present.

2. Conclusion: Measurements of relative heads within the Rustler Formation at the WIPP site are not consistent with modern infiltration from the surface to the Magenta, let alone from the surface to the Culebra. Therefore, at least at the measured locations, there is no modern infiltration of surficial waters to Rustler carbonates.

Discussion: The holes on which this conclusion is based provide only limited geographic coverage, and do not include any locations at which the Dewey Lake Red Beds are known to be hydraulically saturated. Where tested, the Dewey Lake was too tight for hydraulic testing, and may be either completely or partially saturated. No head or transmissivity information is available from the Tamarisk Member of the Rustler, due to its exceedingly low transmissivity. These results do not rule out vertical movement of water from either the surface or the Dewey Lake into the Rustler in areas in which the Dewey Lake is saturated directly above the Rustler, or in any area in the past if heads in the Dewey Lake were higher at that time.

3. Conclusion: Culebra transmissivity varies by approximately six orders of magnitude in the region of the WIPP site and Nash Draw. Transmissivities generally decrease from west to east across the site area. For purposes of generalization, the distribution can be divided into broad areas of relatively low Culebra transmissivity ($\leq 10^{-6}$ m^2/s), in which the porous-medium assumption appears adequate to describe local hydraulic and transport behavior, and areas of relatively high transmissivity ($\geq 10^{-5}$ m^2/s), in which a dual-porosity formalism appears adequate to describe local hydraulic and transport behavior. Both of these zones are represented by several wells. Two wells (H-3 and H-18) penetrate an apparently thin transition zone, in which transmissivity varies between 10^{-6} and 10^{-5} m^2/s.

The central portion of the WIPP site, including all four WIPP shafts, lies within an apparently continuous area of low transmissivity. This area extends well east of the site, and includes the holes H-1, 2, 4, 5, 10, 12, 14, 15, 16, and 17; WIPP-12, 18, 19, 21, and 22; ERDA-9; Cabin Baby-1; P-15, 17, and 18, in addition to the WIPP shafts. North of the WIPP site, measurements at WIPP-30 indicate the presence of a northern zone of low transmissivity, which may or may not be continuous with the zone near the site center.

There is a zone of relatively high Culebra transmissivity southeast of the center of the Site, which is indicated both by point measurements at H-11 and DOE-1 and by the presence of very low hydraulic gradients south of WIPP Zone 3. Northwest of the site center, there is a relatively uniform high-transmissivity zone containing holes WIPP-13, DOE-2, and H-6. This zone is bounded by low-transmissivity domains to the north, east, and southeast, and by an even higher-transmissivity domain to the southwest and west. Within both Nash Draw and the valley south of the WIPP site containing H-7 and H-9, Culebra transmissivity is both high and variable.

Discussion: There are some exceptions to the generalizations listed above. WIPP-21, which has a low transmissivity, responds quite rapidly to activities in the WIPP shafts, indicating that the region containing WIPP-21 is connected to the shafts by a low-storativity structure, which may involve fractures. Tests at individual low-transmissivity wells examine only a very small area. Neither analytical nor numerical modeling is capable of identifying a small, discrete high-transmissivity structure embedded in a low-transmissivity domain, unless it is close to measured data points. No evidence for such a discrete structure is known at the WIPP site. On the other hand, the hydraulic behavior of the Engle well, which has a high transmissivity, shows no dual-porosity effects. Test results from the Culebra in Nash Draw have not been examined for dual-porosity behavior; fracturing may be extensive enough in Nash Draw to make a dual-porosity formalism unnecessary.

The boundaries of the low-transmissivity zone including WIPP-30 remain unknown. The interpretation based on the rapid and large response of this hole to the WIPP-13 pumping test suggests that the high-transmissivity domain including WIPP-13, DOE-2 and H-6 extends close to WIPP-30.

The boundaries of the high-transmissivity zone south of H-11 and DOE-1 and the connection of this zone with the larger high-transmissivity region containing H-7, H-8, and H-9 have not been determined directly, nor has the maximum transmissivity within the zone. The presence of the zone south of H-11 and DOE-1 is indicated by both analytical and numerical modeling of the H-3 multipad interference test, as well as by more recent calibration of Culebra transmissivities against calculated pre-shaft heads. This zone will be investigated during 1988 by a multipad interference test to be conducted at the H-11 pad. The reason for the relatively high transmissivities at H-11 and DOE-1 remains unknown.

4. Conclusion: The estimation error for Culebra transmissivities over most of the WIPP site (in terms of m^2/s) is less than one log unit at two standard deviations, including estimated uncertainties in field measurements. The estimation error is generally larger outside Zone 3.

Discussion: The statistical treatment of Culebra transmissivities should not be overinterpreted, since it does not include specific consideration of geologic processes. In addition, this treatment assumes vertical homogeneity within the Culebra. Testing at H-14 indicates that transmissivity may vary by a factor of about 2 across the Culebra at a given locality.

5. Conclusion: Groundwater flow rates within the Culebra vary greatly. Flow within Nash Draw is relatively rapid; flow in the central portion of the WIPP site and in regions further east is extremely slow. The estimated flow time from a position above the center of the WIPP waste-emplacement panels to the southern boundary of Zone 3, assuming steady-state distribution of the present heads and transmissivities within the Culebra, is approximately 13,000 years.

Discussion: Calculated particle-flow rates and integrated travel times are approximate. The head distribution and flow directions within the Culebra are not at steady state. The similar Culebra and Magenta heads within Nash Draw suggest that assumption of confined flow within the Culebra may not be realistic in this region. In addition, the calculations assume a uniform effective porosity of 16%. The effective Culebra porosity probably varies laterally, suggesting that both flow rates times and flow paths are more variable than calculated.

6. Conclusion: Single-pad interference testing at the H-3 and H-11 hydropads indicates a complex role of fracturing within the Culebra. At H-3, the system transmissivity is approximately 2×10^{-6} m^2/s, and no significant directional dependence of hydraulic response has been measured. However, the data from observation holes on the H-3 pad had to be interpreted as if the radius of the pumped well extended beyond the observation holes; i.e., the response of the observation holes to the beginning and end of pumping was practically instantaneous. At the H-11 pad, the transmissivity is 1.2 to 3.0×10^{-5} m^2/s. However, the observation holes on the H-11 pad responded more slowly during testing thar those on the H-3 pad. The extent or effectiveness of fracturing is not a simple function of transmissivity

Discussion: The available data are only sufficient for detailed interpretation of interference testing using a dual-porosity formalism, i.e., assuming uniform fracture spacing. This limitation is irreduceable, however, given the limited core recovery within the Culebra. Detailed interpretation of interference testing has been completed only for testing at the H-3 and H-11 hydropads. Interpretation of interference testing at the H-2, H-4, H-5, H-6, H-7, and H-9 hydropads will be completed in the next year.

7. Conclusion: Regional-scale simulations indicate that it is not necessary to incorporate a dual-porosity formalism into regional-scale modeling of Culebra head distributions. This is because the time scale for pressure equilibration between fracture and matrix for matrix-block sizes up to the thickness of the Culebra is very short relative to the time scale required for regional groundwater flow.

Discussion: The pressure effects of a discrete or narrow high-transmissivity structure embedded within a low-transmissivity domain remain to be determined in detail. It cannot be claimed that any reasonable amount of drilling or hydrologic testing will completely eliminate the possibility of a small high-transmissivity structure being present within the Culebra dolomite. However, no such structure is known to exist at or near the WIPP site.

8. Conclusion: Both fractures and matrix play a major role in pad-scale transport of contaminants within fractured portions of the Culebra dolomite. At the H-3 pad, the first detected arrival of conservative (non-reacting) tracers in a convergent-flow test was strongly

controlled by fracturing, while tracer behavior both at and after the time of peak concentration showed evidence of strong interaction between fractures and matrix. Storage within the matrix served to decrease peak concentrations, but also resulted in greater concentrations at longer times than expected for fracture transport alone. The results indicate that matrix storage should play a major role in regional-scale transport of even conservative contaminants, so long as these contaminants have a reasonable diffusion coefficient into the matrix.

In addition, the results of the conservative-tracer test at the H-3 pad indicate that the relationship between hydraulic properties and transport properties can be complex. At H-3, no directional dependence of hydraulic behavior has been measured. In contrast, the time interval before first detected arrivals of tracers along the two flow paths investigated differed by a factor of about four.

Discussion: Detailed interpretation of dual-porosity effects in contaminant transport within the Culebra is presently completed only for testing at the H-3 pad. An additional conservative-tracer test will be conducted during 1988 at the H-11 hydropad, along the apparent regional flow path from the center of the WIPP site to the southern boundary of Zone 3. Any significant role of the matrix in contaminant transport within fractured portions of the Culebra requires that conservative contaminants be able to diffuse into matrix blocks. Interpretation to date of the H-3 test involves superposition of two radial-flow solutions; calculations are ongoing to investigate the possible effects of matrix anisotropy on transport behavior.

9. Conclusion: Calculations indicate that regional-scale contaminant transport within the Culebra Dolomite can be modeled realistically using the porous-medium assumption, so long as the Culebra transport properties and flowpaths used in these calculations are representative, and at least so long as the existing distribution of head potentials within the Culebra is not significantly disturbed. Calculated times required for contaminants to break through to the southern boundary of WIPP Zone 3 following release at any point directly above the WIPP waste-emplacement panels are only approximately 10% lower if a dual-porosity formalism is used than if the same release is modeled using the porous-medium assumption. The completed regional-scale calculations assume a transmissivity distribution which probably assigns too high a transmissivity to the region including holes H-11 and DOE-1.

Discussion: Calculations are presently ongoing to investigate the utility validity of the porous-medium approximation in modeling transport within the Culebra in the event of a breach involving a Castile brine occurrence. The assumption that there is effective diffusion from fractures into the adjacent Culebra matrix is explicit in conclusions based on calculations completed to date. Results of interference testing support the conclusion that fluid flow is unrestricted between matrix blocks and fractures, i.e., that there are no significant or continuous low-permeability skins on

matrix blocks. This has been demonstrated in the conservative-tracer experiment at the H-3 pad. Effective matrix retardation within the Culebra has not yet been demonstrated for some radionuclides making up the WIPP inventory, but will be demonstrated experimentally in the laboratory during the WIPP operational-demonstration phase.

10. Conclusion: The variability in compositions of Culebra groundwaters allows their subdivision into four hydrochemical facies. Zone A, east of the WIPP site, contains saline Na-Cl brines. Zone B, south of the site, contains relatively fresh waters in which Ca and SO_4 are the main solutes. Zone C, which includes the WIPP site and the eastern part of Nash Draw, contains quite variable fluids. Zone D, within Nash Draw, shows evidence of contamination from potash refining operations. The modern distribution of hydrochemical facies within the Culebra is not consistent with steady-state confined flow within the Culebra. Therefore, the solute geochemistry of Culebra fluids is not at steady-state, nor is the overall hydrology of the Culebra.

Discussion: This conclusion assumes the dominance of confined flow within the Rustler in the vicinity of the WIPP site, consistent with both isotopic studies and measurements of the modern relative head potentials and transmissivities of the several members of the Rustler.

Interpretation of normative salts within Rustler fluids is partially consistent with steady-state flow, if extensive vertical mixing is allowed. The measured head relationships within the Rustler are inconsistent with infiltration from the surface. The composition of Culebra waters at P-18 and P-14 play a major role in normative interpretation Culebra waters. The representative character of groundwater samples from the Culebra from P-14 and P-18 is suspect.

11. Conclusion: Analyzed Culebra fluids are all undersaturated with respect to halite, but approximately saturated with respect to gypsum and carbonate (dolomite). All fluids except that from hole WIPP-29 are undersaturated with respect to anhydrite. Therefore, almost all Culebra waters are capable of converting into gypsum any anhydrite they may contact. Carbonates, sulfates, and clay minerals are ubiquitous in Culebra core. Halite not introduced during coring has not been identified reliably. With the exception of halite, all analyzed Culebra fluids appear to be in approximate equilibrium with the host rock. Studies to date have not identified any discrete variations in Culebra mineralogy that can be used to bound hydrochemical facies.

Discussion: The dominant reactions controlling the variability of Culebra fluids appear to be the dissolution of halite and reactions between fluids and a ubiquitous but variable clay-mineral phase. Both the compositions of clays and the detailed reactions between clays and Culebra remain to be determined in detail. It cannot be demonstrated that the mineralogy of intact core specimens is representative of portions of the Culebra that have been in significant contact with groundwater.

12. Conclusion: There appear to be significant lateral variations in the oxidation state of Culebra waters. Fluids from hydrochemical facies Zone B, south of the site, appear to be more oxidized than those within Zones A and C, which include the WIPP site. The available information from within Nash Draw indicates that the redox potential at WIPP-26 is similar to that within Zone B. Results at WIPP-25 appear to be problematical, due to evolution of H_2S during sampling. The results indicate generally more oxidizing conditions south and southwest of the WIPP site than at the site itself.

Discussion: Oxidation states of Culebra fluids are not known in detail, and are generally bracketed by the occurrence of one member of a redox couple at too low a concentration for analysis. The possible effects of contamination have been evaluated only in hole WIPP-25.

13. Conclusion: Recent stable-isotope studies indicate that the bulk of the Rustler Formation and part of the Dewey Lake Red Beds at and near the WIPP site were last recharged under climatic conditions significantly different than those of today. This is consistent with the interpretations that the overall hydrology of the Rustler Formation is in transient response to the end of the last pluvial period in southeastern New Mexico, and that there is no modern meteoric recharge to the Rustler Formation at and near the WIPP.

Discussion: The data base on which the interpreted isotopic range of modern meteoric recharge is based includes measurements from several different rock types and locations, including the Capitan limestone in Carlsbad Caverns, alluvium at WIPP-15, the Ogallala Formation in both southeastern New Mexico and on the High Plains of Texas, and the Dewey Lake Red Beds near an active dune field. The Dewey Lake, however, appears to include both modern and older waters. The stable-isotopic signature of all analyzed waters from confined portions of the Culebra and Magenta dolomites are distinct from the defined meteoric field.

The stable-isotope results do not provide any direct information about the timing of recharge, only about different conditions of recharge. In addition, the results do not rule out modern recharge to the Rustler at some location removed from the WIPP site itself. However, the results do indicate that measurable amounts of recharge are not now occurring at the WIPP site.

14. Conclusion: Both stable-isotope and compositional characteristics of Rustler waters at Surprise Spring, in the southwestern portion of Nash Draw, are dominated by near-surface recharge and discharge, including partial evaporation. Major dilution would be required to derive the solute chemistry at Surprise Spring from Culebra waters at WIPP-29, which is nearby. In addition, Surprise Spring apparently discharges from the Tamarisk Member of the Rustler, rather than the Culebra. Therefore, Surprise Spring, does not appear to be a discharge point for Culebra or Magenta waters crossing the WIPP site.

Discussion: It is possible that some Rustler waters from the area of the WIPP site discharge in southern Nash Draw, including Surprise Spring. The results summarized here, however, suggest that the hydrology and solute chemistry at Surprise Spring are dominated by local processes and groundwaters, and that any input of waters from the area of the WIPP site would not be identifiable, even if present.

15. Conclusion: Use of lost-circulation materials in hydrocarbon-exploration hole and hydrologic test holes (except those drilled with air) and metabolism of these materials by introduced and/or natural organisms within the Rustler makes meaningful radiocarbon measurements on Rustler fluids difficult. All Rustler and Dewey Lake holes may be contaminated to some degree. Therefore, estimated periods for which Rustler or Dewey Lake waters have been isolated from atmospheric carbon should represent lower bounds.

16. Conclusion: Available radiocarbon measurements indicate isolation times of three Culebra and one Dewey Lake water from input of atmospherically generated nuclides for at least 12,000 years. This is consistent with paleoclimatic studies indicating a wetter climate in the northern Delaware basin approximately 10,000 years ago. The results are taken to imply that there has not been significant (i.e., detectable) vertical recharge to the Culebra and at least part of the Dewey Lake near the WIPP site in at least 12,000 years. The results also indicate, because of the relatively tight clustering of ages, that recharge may have been a pulse event rather than continuous. At any rate, the available radiocarbon results do not indicate any consistent age gradient for waters within the Culebra, and cannot be used to indicate paleoflow directions.

Discussion: The data base of successful radiocarbon measurements is extremely limited in size. Extrapolation of these results to the confined Culebra over the entire Site area may be tenuous, but is consistent with both the fact that the Culebra is regionally confined and the results of both stable-isotope uranium-disequilibrium studies. Additional radiocarbon measurements will be made over the next (approximately) two years.

17. Conclusion: Available uranium-disequilibrium results for Culebra rocks and groundwaters indicate that there must have been a significant distinct change in flow directions within the Culebra on the time scale of approximately 10,000 years. The paleoflow direction involved at least some component of easterly flow, in contrast to the modern flow directions within the Culebra, which are essentially north-south in the Site area. The change in flow directions has apparently occurred as a result of the end of Culebra recharge at or near the end of the last pluvial period. The estimated flow time to the vicinity of H-5 is at least several thousand years, and flow has occurred under reducing conditions, regardless of where recharge is interpreted to have taken place. Therefore, modern recharge is not occurring at H-5, regardless of the relatively high Culebra heads in the region. The

current distribution of total dissolved uranium in analyzed Culebra groundwaters is qualitatively consistent with regional variations in the oxidation potential within the unit, with more reducing conditions in the area at the WIPP site than south of the site and in at least part of Nash Draw. The interpretation based on uranium-disequilibrium studies is consistent with the distribution of Culebra hydrochemical facies, stable-isotope studies, and radiocarbon studies in indicating that the overall hydrologic and geochemical setting of the Rustler is transient on a time scale of approximately 10,000 years, and is recovering from the last pluvial period in southeastern New Mexico.

Discussion: The present uranium-disequilibrium data base is extremely limited in size, especially south of the WIPP site. Therefore, significant uncertainty remains concerning the constraints imposed by these studies on both paleo and modern flow directions. However, some change in flow directions within the Culebra is required by the data.

18. Conclusion: $^{87}Sr/^{86}Sr$ studies on both matrix minerals and coexisting mineral pairs from matrix and veins in the evaporitic units below the Dewey Lake Red Beds, and on veins and/or matrix materials from the Dewey Lake, Mescalero caliche, and gypsite springs in Nash Draw indicate distinct variations in the amounts of high-$^{87}Sr/^{86}Sr$ material derived from surficial weathering that are involved in the different units. The measured strontium-isotopic character of the gypsite springs and the Mescalero caliche indicate derivation from surficial components. The character of both matrix minerals and coexisting mineral pairs from matrix and veins in the Castile and Salado Formations, as well as in Rustler anhydrites and the Magenta dolomite indicate little or no input of surficial components. The isotopic compositions of coexisting mineral pairs from veins and matrices are statistically identical, indicating that the components of the veins were locally derived in all units but the Dewey Lake.

There is a broad range of strontium-isotopic character of vein minerals from the Dewey Lake, from surficial values to values similar to those from underlying anhydrites and the Magenta dolomite. Since sulfates and carbonates are very rare in the matrix of the Dewey Lake, the broad range in strontium-isotopic character of Dewey Lake vein gypsums is taken to indicate a mix of surface-type components and components from the underlying Rustler. Upward flow from the Rustler Formation is consistent with measured head relationship. The strontium-isotopic character of analyzed carbonate minerals from the Culebra shows more overlap with that of vein material from the Dewey Lake than does the character of either the intervening Rustler anhydrites or the Magenta dolomite. This is taken to imply that surficial components in the Culebra probably result from confined flow following recharge at some location removed from the WIPP site. If the Culebra near the WIPP site were presently receiving surficial components by vertical recharge, this recharge would be expected to have altered the isotopic character of Rustler zones above the Culebra.

Discussion: The isotopic data base for veins and host-rock minerals in the Rustler and Dewey Lake is limited in size. It has not yet been possible to date any of the secondary minerals directly. Therefore the strontium-isotopic results, while indicating the types of waters involved, do not provide any direct information concerning the ages of these waters.

19. Conclusion: The study of deuterium/hydrogen ratios in vein gypsums in the Dewey Lake and Rustler indicate that all of the gypsums, with the possible exception of vein gypsum from the Dewey Lake in WIPP-19, may have crystallized in the presence of varying amounts of Rustler-type water, rather than in the presence of water representing modern meteoric recharge in the region. The hydrogen-isotope character of secondary Rustler gypsums in hole WIPP-34 is consistently explained by Rustler-type fluids moving both upwards and downwards from the Magenta dolomite into surrounding members, with increasing rock/water ratios corresponding to increasing distance from the Magenta. This internal consistency is lost if crystallization of gypsums from WIPP-34 is assumed to have taken place in the presence of modern meteoric waters.

In fact, it does not appear possible to have crystallized vein gypsums from either the Magenta and Tamarisk in WIPP-34 or from the Forty-niner in WIPP-33 in the presence of any amount of water representing modern meteoric recharge. Both WIPP-33 and WIPP-34 were drilled to investigate either geophysical anomalies or structures that might be the result of Rustler karst. There is no indication of anomalous structure at WIPP-34. The WIPP-33 structure is interpreted to be the result of karst hydrology, but is apparently unique at and near the WIPP site. The isotopic results suggest, consistent with geologic interpretations, that the WIPP-33 structure is no longer significantly active.

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GEOLOGICAL CHARACTERIZATION REPORT, WASTE ISOLATION PILOT PLANT (WIPP) SITE, SOUTHEASTERN NEW MEXICO

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Volume I

August 1978

Dennis W. Powers, Steven J. Lambert, Sue-Ellen Shaffer,
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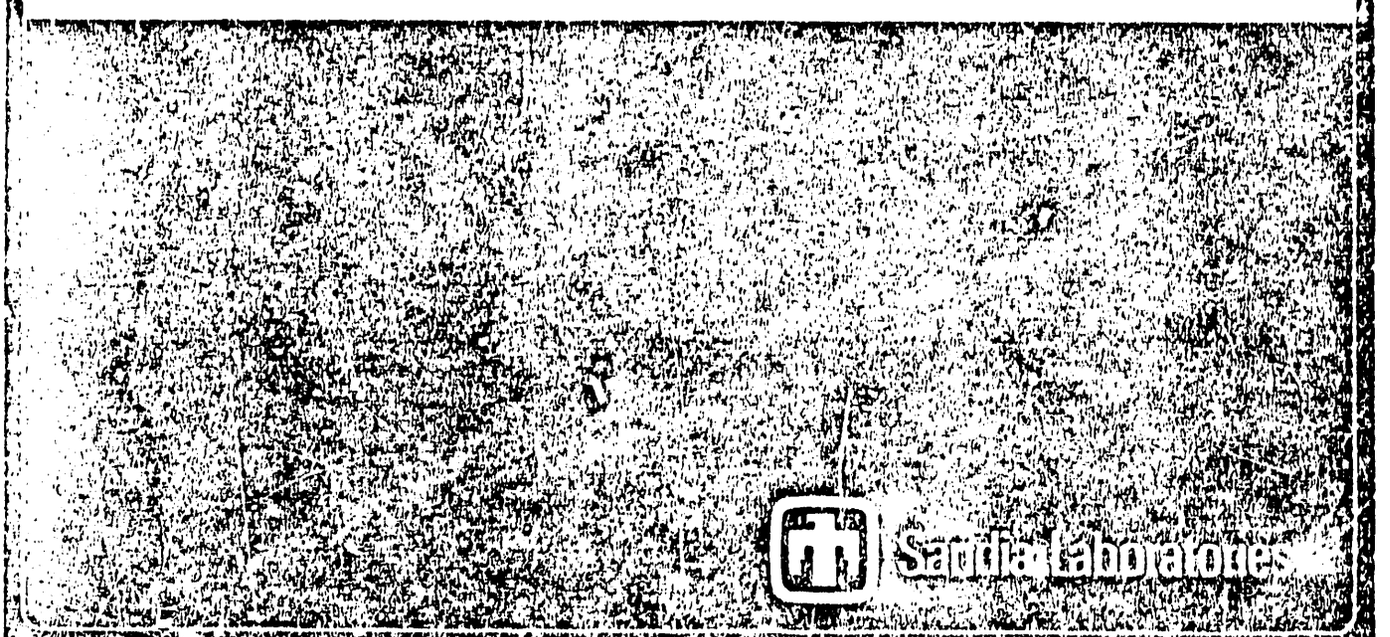

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GEOLOGICAL CHARACTERIZATION REPORT
WASTE ISOLATION PILOT PLANT (WIPP) SITE, SOUTHEASTERN NEW MEXICO

SAND78-1596

VOLUME I

Dennis W. Powers, Steven J. Lambert, Sue-Ellen Shaffer,
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PREFACE

The Geological Characterization Report (GCR) for the WIPP site presents, in one document, a compilation of geologic information available to August, 1978, which is judged to be relevant to studies for the WIPP. As such, commonly available documents are summarized as appropriate while other documents may be presented more fully. In some instances, the information presented may be preliminary or may reflect continuing studies not yet complete. The Geological Characterization Report certainly should not be construed as the final word on the WIPP geology. Furthermore, specific judgements of how the geologic information affects the WIPP are restricted since the document is intended as a source of information. However, recommendations may be made on the basis of the document. The Geological Characterization Report for the WIPP site is neither a Preliminary Safety Analysis Report nor an Environmental Impact Statement; these documents, when prepared, should be consulted for appropriate discussion of safety analysis and environmental impact. The Geological Characterization Report of the WIPP site is a unique document and at this time is not required by regulatory process.

The Geological Characterization Report (GCR) for the WIPP has been created through the efforts of many individuals who are to be acknowledged for their contributions; little of the material presented, however, is original material created solely for the Geological Characterization Report. At Sandia Laboratories, principal contributors to the writing of the GCR are, in alphabetical order: G.E. Barr, B.M. Butcher, R.G. Dosch, L.R. Hill, S.J. Lambert, D.W. Powers, S.E. Shaffer, W. Wawersik, and W.D. Weart. Bechtel Corporation provided basic summaries for many chapters; the principal participants were: D. Dale, C. Farrell, V. Howes, J. Litehiser, D. Roberts, R. Sayer. In particular, J. Litehiser provided the analysis of seismic risk in Chapter 5. G.B. Griswold of Tecolote Corporation summarized resources in Chapter 8. F.H. Dove of NUS summarized hydrology in Chapter 6.

Editorial and review comments were solicited on a working copy and received from independent agencies with personnel familiar with the geology of southeastern New Mexico, particularly the New Mexico Bureau of Mines and Mineral Resources. An internal review at Sandia Laboratories of a working copy of the entire document also resulted in detailed comments. Those review comments were incorporated as appropriate into this draft copy. As usual, some of the suggestions were not followed for various reasons. The draft copy received review and comment by the WIPP Panel (Committee on Radioactive Waste Management, National Research Council) of the National Academy of Science, the Office of Nuclear Waste Isolation (ONWI) and various subcontractors, and by Westinghouse as a contractor to DOE. Major parts of the draft were reviewed by members of the Special Projects Branch, USGS. These comments have resulted in some revision of the final copy, as seemed appropriate. The editors assume responsibility for the contents of this report.

The editors and writers acknowledge the enormous volume of accumulated data and interpretations which provide the background for the Geological Characterization Report; referencing of authors is intended to reflect this background and to properly attribute material.

The Report is primarily intended for use by those with a technical background in earth sciences. However, the text should also be generally readable without all of this background by referral to the American Geological Institute Glossary of Geology (1974).

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GCR CHAPTER 1
EXECUTIVE SUMMARY

This Executive Summary presents, in condensed form, geotechnical information relevant to the Waste Isolation Pilot Plant (WIPP) in southeastern New Mexico. The presentation of material follows the Geological Characterization Report (GCR) chapter organization, beginning with Chapter 2, INTRODUCTION. Figures and a reference list are not included in the Executive Summary; where desired the reader must examine the figure and reference list following each Chapter.

INTRODUCTION (Chapter 2)

The Introduction provides an overview of the purpose of the WIPP, the purpose of the Geological Characterization Report, the site selection criteria, the events leading to studies in New Mexico, status of studies, and the techniques employed during geological characterization.

The purpose of the Waste Isolation Pilot Plant (WIPP) is to demonstrate the technology for the disposal of the transuranic (TRU) waste resulting from this nation's past and current defense programs. It is anticipated that the WIPP will be converted to a repository after successful demonstration of this technology and assessment of safety of a repository for southeastern New Mexico. In addition, the WIPP is to provide a research facility to examine, on a large scale, the interactions between bedded salt and high-level radioactive waste. A Department of Energy (DOE) Task Force (DOE/ER-0004/D, 1978) has recommended that WIPP also be used to demonstrate surface and subsurface methods of handling, storing and disposing of up to 1,000 canisters of spent reactor fuel. A decision on implementing this recommendation has not been made at this time.

If this site is accepted by the DOE, the schedule calls for the initiation of facility construction in early 1981; completion is to be late 1985, and the first waste to be accepted in 1986. The TRU waste would be readily retrievable for a five to ten year period of initial

operation. All HLW for experiments would be retrieved upon completion of the experiments. The conceptual design of WIPP facilities is complete. DOE has expressed an intent to request licensing of the WIPP by the Nuclear Regulatory Commission (NRC), but this issue is not yet resolved.

Interest in disposal of radioactive waste in geologic media may be traced back to a 1957 committee report by the National Academy of Sciences - National Research Council, that recommended guidelines for permanent disposal of radioactive waste in geological media. Recommendations fell into two categories: burial in bedded salt deposits or in deep sedimentary basins (perhaps 4000 - 5000 m deep).

Salt became the leading candidate as a disposal medium, and from 1957 until the 1970's most disposal studies in the U.S. concentrated on bedded salt. In the mid-1960's, Oak Ridge National Laboratories (ORNL) conducted a successful in situ experimental program called "Project Salt Vault" in a salt mine near Lyons, Kansas. A subsequent plan to establish a federal repository near Lyons was withdrawn due to both technical and political objections.

Subsequent evaluation of salt basins in the United States by ORNL and the USGS led in 1974 to field investigations of Permian salt deposits of the Delaware Basin in southeastern New Mexico to determine if the geologic setting was adequate for a radioactive waste repository. Permian evaporite deposits consist of the Castile Formation which is interbedded halite and anhydrite, the Salado Formation which consists principally of halite and the Rustler Formation which is mostly anhydrite but contains halite, dolomite, and siltstone.

In 1975, the AEC (later Energy Research and Development Administration (ERDA) and now Department of Energy (DOE)) assigned responsibility for site evaluation and conceptual design for this project in New Mexico to Sandia Laboratories of Albuquerque, New Mexico. The project in New Mexico is now known as the Waste Isolation Pilot Plant (WIPP).

Preliminary site selection criteria were general in nature. (Most areas are not well enough known to allow application of precise criteria.) After Sandia Laboratories determined in 1975 that the first preliminary study area originally selected by ORNL was geologically unsuitable, site selection factors were refined specifically for and applied to the Delaware Basin in New Mexico to define the present study area. The major siting factors employed in southeastern New Mexico are that the repository salt beds should be: (a) relatively pure; (b) several hundred feet thick; (c) between depths of 1000 and 3000 feet; (d) located where groundwater dissolutioning is relatively limited; (e) at least one mile from boreholes that completely penetrate the evaporite section, (f) generally located to avoid private land; (g) located where strata are relatively flat; and (h) located to minimize conflicts with mineral resources. Data from hundreds of borehole geophysical logs and more than fifteen hundred miles of existing seismic reflection lines from petroleum companies were analyzed and considered along with hydrologic data and available information on natural resources to narrow the area of search. A relatively restrictive criterion was the requirement the repository be one mile or more to the nearest borehole penetrating the complete evaporite section. Existing studies of borehole dissolution indicated one mile is sufficient, though perhaps not necessary, to ensure repository integrity.

Geologic studies for the WIPP fall into three different phases: preliminary site selection activities, geological characterization, and studies of long-range geologic processes affecting a repository. Preliminary site selection activities are complete now, and geological characterization is nearing completion with this report. Studies of long-range processes are becoming the focus of geotechnical programs; some of these latter studies are already underway. These studies, which will be oriented toward geologic processes and rates, will mostly be completed before conversion of the WIPP to a permanent repository for defense waste; these studies plus operation should provide further refinement to criteria for conversion of the WIPP.

Many standard petroleum and mineral industry techniques have been used to characterize the WIPP site. Considerable reliance has been placed on the combination of geophysical techniques corroborated by borehole information. The geophysical techniques most widely used to characterize the WIPP site include seismic reflection and resistivity. By summer, 1978, about 75 line miles of new seismic reflection data were obtained and over 9000 resistivity measurements had been made and analyzed. Twenty-one boreholes were drilled to evaluate potash, 14 hydrologic test holes were drilled and four potash holes were converted for hydrologic studies of the aquifers above the Salado Formation. Ten stratigraphic test boreholes have been drilled on or around the WIPP site as of early August, 1978, and two other holes have been drilled well away from the WIPP site to study dissolution processes. Two of these holes were drilled through the salt to test deep aquifers and to acquire geologic data.

Most of the WIPP geologic studies to date advanced geological characterization. Geologic studies will continue in order to permit a better quantification of the rates of geologic processes in and near the WIPP site and to develop a more thorough understanding of the geologic phenomena of interest (see Chapter 10).

REGIONAL GEOLOGY (Chapter 3)

Regional Geology provides a broad assessment of the surface and subsurface environment of the area within a radius of about 200 miles of the proposed WIPP Site. The discussion comprises a synthesis of the available data pertaining to the physiography and geomorphology, stratigraphy and lithology, structure, tectonic development and geologic history of this region. Such information is necessary to understand the geological processes that need to be understood for assessment of long-term safety of a repository in the Delaware Basin of southeastern New Mexico. The paragraphs below present a brief summary of this information.

The WIPP site is located within the Pecos Valley section of the southern Great Plains physiographic province, a broad highland belt which slopes gently eastward from the Rocky Mountains and Basin and Range province to the Central Lowlands province. The Pecos Valley section itself is dominated by the Pecos River valley, a long north-south trough from 5 to 30 miles wide and as much as 1,000 feet deep, which exhibits an uneven rock and alluvium-covered floor marked by widespread solution subsidence features resulting from dissolution within the underlying Upper Permian Ochoan rocks. The section is bordered on the east by the Llano Estacado, the virtually uneroded fluviatile plain of the High Plains section, and on the west by the Sacramento and Guadalupe Mountains area of the Sacramento section.

The principal geomorphic features with bearing on the site area include the Pecos River drainage system, the Mescalero Plain, karst topography and wind erosion "blow-outs." The Pecos River system has evolved from the south, cutting headward through the Ogallala sediments to capture what is now the upper Pecos and becoming entrenched sometime after the Middle Pleistocene. The system at present receives almost all the surface and subsurface drainage of the region; most of its tributaries are intermittent, due to the contemporary semi-arid climate. Most of the ground surface east of the Pecos River valley comprises the Mescalero Plain, a poorly drained surface covered by gravels, eolian sand and caliche, which has developed since Early to Middle Pleistocene time. The surface of the region exhibits karst topography containing superficial sinkholes, dolines, solution-subsidence troughs, and related features, formed as a result of both surface erosion and subsurface solutioning activity.

The WIPP site lies on a caliche and sand covered drainage divide separating two major and perhaps still developing solution-erosional features, Nash Draw on the west and San Simon Swale to the east. This prevailing erosional pattern is expected to continue in the future, with most local erosion occurring in the draw and swale areas. The site is located west of the local drainage divide.

The stratigraphic section present in the site region includes Precambrian through Triassic rocks, overlain by outliers of possible Cretaceous age, and widespread Late Tertiary through Holocene sediments.

Metasediments and granitic-volcanic igneous materials constitute the majority of the regional basement, cropping out in isolated areas to the west and north. The granitic rocks range in age from about 1,400 million years in the north to about 1,000 million years in the south and are overlain in places by younger Precanibrain volcanic terrains. The surface of the Precambrian reflects the Late Paleozoic platform and basin structural configuration of the area.

The Paleozoic section comprises up to 20,000 feet of Upper Cambrian sandstones through Upper Permian evaporites and redbeds. The Ordovician, Silurian and Devonian rocks are primarily carbonates with lesser sands, shales and cherts which were deposited in shallow, rather calm shelf areas of broadly subsiding areas of the Tobosa Basin, with some minor influence from uplifted areas such as the ancestral Central Basin Platform. The Mississippian sequence consists of locally cherty limestones overlain by silty and sandy shales, truncated against adjacent emerging uplands. Post-Mississippian orogeny caused uplift, tilting and erosion, producing a massive section of Lower Pennsylvanian continental sediments, interbedded with dark limestones, particularly toward the top of the section. Late in the Pennsylvanian, a basin, basin margin, and shelf configuration, which endured through the Permian, developed, resulting in deposition of dark shales, clastics and some limestones and bioclastics forming a series of reefs along the basin margins, and shallow-water limestones and clastics on the adjacent shelves. Upon filling of the basins in the Late Permian, a sequence of evaporites totalling 4000-5000 feet in thickness was deposited during recurrent retreats of shallow seas restricted by the encircling Guadalupian reefs. The Castile Formation consists of anyhdrite interlaminated with calcite and halite overlain by the Salado Formation, which is primarily halite with lesser clastics, anhydrite and a suite of salts. The Rustler Formation overlying the Salado is composed of anhydrite, gypsum and

lesser salt with carbonates and clastics. The top of the Paleozoic is marked by the thin Dewey Lake Redbeds.

The Mesozoic sequence is represented by only the Upper Triassic Dockum Group of terrigenous redbeds, which in many places are truncated or removed by erosion, and by scattered patches of Cretaceous limestone and sandstones.

The lower Cenozoic section is missing from the region due to erosion and/or non-deposition, and the widespread Late Miocene-Pliocene Ogallala clastics represent the earliest deposition of the section. The Ogallala is capped by a dense, resistant layer of caliche, which probably started to form during the Late Pliocene. Quaternary deposits occur only locally and consist of the Middle Pleistocene to Holocene terrace, channel and playa deposits as well as windblown sands.

The major structural framework of the region is provided by the large-scale basins and platforms of late Paleozoic age and by Cenozoic features primarily associated with Basin and Range tectonics.

The principal late Paleozoic features of the area consisted of the western extent of the Tobosa and later the Permian Basin and its border lands. These elements include the Delaware Basin, Central Basin Platform, Midland Basin, the Northwestern Shelf, Pedernal Uplift, Matador Arch, Val Verde Basin and Diablo Platform.

The site is located in the northern portion of the Delaware Basin, a broad, oval-shaped asymmetrical trough with a northerly trend and southward plunge and a structural relief of more than 20,000 feet on top of the Precambrian. Deformation of the basin rocks is minor, those formations older than Late Permian are only gently downwarped. Deep-seated faults, some reflecting Precambrian faults, occur in the basin, as do folds, joint sets, and a number of smaller, probably solution-related structures originating in the Upper Permian evaporites. The basin was defined by early Pennsylvanian time, and major structural

adjustment occurred from Late Pennsylvanian to Early Permian time. By the Late Permian, this episode of tectonic activity ended in the basin; regional eastward tilting occurred later, in the Cenozoic.

The Central Basin Platform, a northward-trending feature, separated from the Delaware Basin to its west by a zone of major normal faulting, represents a broad uplift of Precambrian to Pennsylvanian rocks, within which movement took place periodically, probably from the Precambrian until the late Paleozoic when the basin became structurally stable.

North and northwest of the Delaware Basin lies the Northwestern Shelf, which was well-developed before Permian time and may have originated in the Early Paleozoic, when it formed the margin of the Tobosa Basin. A number of flexures, arches, and faults which have been identified on the shelf had probably ceased tectonic activity in Tertiary time.

The Diablo Platform, forming the southwestern border of the Delaware Basin, experienced primary deformation in the late Paleozoic in the form of uplift, folding and faulting. Deformation also occurred here during late Tertiary time through block faulting and buckling. Recent uplift along its eastern side suggests continuing tectonic development in the area. The remainder of the previously listed late Paleozoic structural elements of the area are only remotely related to the site area.

Late Tertiary Basin and Range tectonics produced the Sacramento, Guadalupe and Delaware Mountains bordering the region on the west. These uplifts are generally eastward-tilted fault blocks bordered on the west by complex normal fault systems forming short, steep westward slopes and backslopes dipping gently eastward. Tectonic activity began in this area during Mississippian to Early Permian time in the form of fault systems, followed by the major Basin and Range tectonics. Small fault scarps in recent alluvium along the western edge of these ranges, as well as some seismic activity, suggest that structural development here may still be taking place.

Post-Precambrian igneous activity in the region consists of Tertiary intrusives and Tertiary to Quaternary volcanic terrains located on the north, west and south of the site area. Only minor igneous activity, in the form of dikes and possibly sills, is known to have occurred within the Delaware Basin.

The closest such igneous feature to the site is a near-vertical trachyte or lamprophyre dike or series of en echelon dikes trending about N50°E for perhaps 75 miles into New Mexico from near the Texas-New Mexico border southwest of Carlsbad Caverns, passing about 9 miles northwest of the site. Evidence for the dike's existence consists of exposures in two mines, cuttings from several drill holes, aeromagnetic indications and surface exposures some 42 miles southwest of the site in the Yeso Hills. This dike has been dated as mid-Tertiary and intrudes only the Late Permian Salado and underlying formations.

The principal Tertiary igneous features of the area beyond the Delaware Basin include several intrusive bodies within the Delaware Mountains, widespread occurrences further south in the Trans-Pecos region and several areas well to the north of the basin, in the form of the eastward-trending El Camino del Diablo and Railroad Mountain dikes (near Roswell) and the stocks of the Capitan and Sierra Blanca Mountains. Quaternary volcanic and related extrusive terrains are present west of the site region, well within the Basin and Range province.

The geologic history of the region is recorded in igneous and metasedimentary rocks as old as about 1,400 million years which indicate a complex Precambrian history of mountain-building, igneous events, metamorphism and erosional cycles. Probably before Paleozoic time, erosion had reduced the area to a nearly level plain.

The early to middle Paleozoic Era was characterized by generally mild epeirogenic movements and carbonate deposition interrupted by only minor clastic sedimentation. The oldest sediments in the region are the Late Cambrian and perhaps Early Ordovician Bliss sandstones. Following Early

Ordovician time, a broad sag, the Tobosa Basin, formed and began deepening. Shelf depositions of clastics continued, derived partly from the ancestral Central Basin Platform, and carbonates deposited in shallow waters. By Late Ordovician time, the Marathon Ouachita geosyncline to the south of the area began subsiding, but until the Middle Mississippian, only mild tectonic activity continued, with several periods of minor folding and perhaps some faulting, the basin subsiding, the Pedernal landmass to the north emergent and some regional erosion occurring.

From late in Mississippian time through the Pennsylvanian, regional tectonic activity accelerated, folding up the Central Basin Platform, Matador Arch and the Ancestral Rockies, producing massive deposition of clastics. The Tobosa Basin was definitively split into the rapidly subsiding Delaware, Midland and Val Verde Basins. Throughout the Permian, sedimentation was continous in the basins, climaxing in the development of massive reefs, and, following stabilization in the Late Permian, in the deposition of a thick sequence of evaporites. By the end of the period, the area was slightly emergent, and a thin sheet of redbeds covered the evaporites.

Since the close of the Permian, the basin area has been relatively stable tectonically, and the Mesozoic through Cenozoic eras have been characterized by erosion, with only relatively minor deposition of terrestrial materials. During the Triassic, a broad flood plain sediment surface developed, followed late in the period by fluvial clastic deposition and formation of a rolling topography. Sometime during the Cretaceous, submergence occurred, and thin limestone and clastics collected in intermittent, shallow seas. During the Jurassic and perhaps as early as the Triassic, subsurface dissolution of the Upper Permian evaporites began. The close of the Mesozoic was marked by the Laramide orogeny and uplift of the Rocky Mountains, with mild tectonic and igneous activity to the west and north of the site area. Throughout most of the Tertiary, erosion dominated, until deposition of the Ogallala late in the era. Mid to late Tertiary Basin and Range uplift of the Sacramento and

Guadalupe-Delaware Mountains was accompanied by regional uplift and east-southeastward tilting. Upon this gently sloping surface the Miocene-Pliocene Ogallala fan deposits accumulated, and a resistant caliche caprock began to form. During Quaternary time, the present landscape has developed through processes of surface erosion and dissolution of the Upper Permian evaporites, accompanied by terrace and stream valley deposition and eolian activity.

The regional geology shows that the northern Delaware Basin has been a part of large structures reacting slowly to tectonic and climatic processes. About 300 million years of Paleozoic geologic history indicate a downwarping basin on a grand scale. The last 200 million years are characterized by slow uplift relative to surroundings resulting in some erosion and dissolution of rocks in the Delaware Basin. Dramatic geologic events such as faults and volcanic activity have not occurred in the northern Delaware Basin where the WIPP site is located. The nearest events of this type are occurring west of the Guadalupe Mountains about 70 miles southwest of the WIPP site. The regional geology does not indicate that any dramatic changes in geologic processes or rates have recently occurred at the WIPP site.

SITE GEOLOGY (Chapter 4)

Much investigative effort has been expended to define subsurface geologic conditions at the WIPP site. These studies not only provide detailed information regarding mining conditions at the repository levels, but also furnish a basis for an assessment of the level of protection or safeguard against possible modes of containment failure at the site, in the context of the long-term isolation requirements of radioactive waste. Information for geologic investigations conducted by the U.S. Geological Survey and reported in several open-file reports by that agency, as well as details of salt deformation investigated by other consultants, have done much to define the general geologic conditions in the vicinity of the WIPP site and have been freely utilized in assembling Chapter 4 of the GCR. Detailed site-specific exploration techniques include seismic

reflection, resistivity, gravity and magnetic surveys, borehole exploration including coring, geophysical logging and hydrologic testing, and reconnaissance geologic mapping. From data thus obtained a series of structure contour and isopach maps were constructed which are presented and discussed in section 4.3 and 4.4 A continuously cored stratigraphic test hole, ERDA-9, has been drilled to a depth of 2,875 feet below ground surface near the center of the WIPP site and provides much detail on geologic properties at and above the WIPP repository levels.

The surface of the WIPP site is a slightly hummocky plain sloping gently southwest at about 50 feet per mile; elevations range at the site from about 3300 to 3600 feet above sea level. There are no permanent drainage courses in the site area. Any intermittent runoff drains west into Nash Draw, a broad swale of about 150 feet of relief leading southwest toward the Pecos River. A declivity marking the east edge of Nash Draw in the site area, known as Livingston Ridge, is located about 4 miles west of the center of the site. Nash Draw, now partly filled with Pleistocene sediments, has evolved both by surface erosion and by subsurface dissolution of salt, presumably during wetter intervals in the geologic past.

Recent windblown sand and partly stabilized sand dunes blanket most of the site area. A hard, resistant duricrust or caliche (Mescalero caliche) is typically present beneath the sand blanket and has developed upon the surface of the underlying Pleistocene fluvial (Gatuna) deposits. The fluvial deposits are tentatively assigned a Kansan age and the caliche formed upon them a Yarmouth (interglacial) age; that is, the caliche formed starting approximately 500,000 years ago. At some places, the caliche is fractured and drapes into Nash Draw along Livingston Ridge, indicating that some erosion and dissolution has taken place in Nash Draw since the caliche was formed, presumably during wetter climatic intervals associated with Illinoian and Wisconsin glaciations. Increased erosion from runoff, should the climate of the region become more humid in the future, would be expected to occur in the existing drainage courses, leaving the drainage patterns relatively unaltered.

The proposed WIPP underground storage facilities are to be placed near the middle of a 3,600-foot-thick sequence of relatively pure evaporite strata containing primarily rock salt and anhydrite, lying between depths of about 500 and 4,100 feet beneath ground surface. The formation richest in rock salt, the Salado Formation, is nearly 2,000 feet thick and contains the relatively pure salt layers in which the two proposed underground storage levels are to be constructed, at a depth near 2,120 feet for the upper level and near 2,670 feet for the lower. The storage horizons are well isolated from the hydrologic environment by adjacent evaporite strata. A thickness of at least 1,300 feet of undisturbed evaporite rock, primarily rock salt, overlies the upper storage horizon and about an equivalent thickness of anhydrite and rock salt intervenes between the lower storage horizon and the next adjacent underlying non-evaporite formation. The salt deposits of the Castile and Salado Formations at the WIPP site were formed about 225 million years ago and have remained isolated from dissolution since about that time.

The total thickness of the sedimentary pile resting on top of Precambrian basement beneath the WIPP site is about 18,000 feet of Ordovician to Recent strata. Following is a brief summary of the stratigraphy, proceeding from the surface down to the basement. Beneath a thin but persistent veneer of windblown sand at the site are sediments representing Pleistocene, Upper Triassic, and uppermost Permian strata, all of which occur above the evaporite sequence. Sandstone of the Pleistocene Gatuna Formation, capped by Mescalero caliche also developed in Pleistocene time, is only a few tens of feet thick at the site and is of interest primarily for the geochronologic and paleoclimatic implications of its presence. Between the Pleistocene deposits and the evaporite sequence is a 500-foot-thick succession of nonmarine redbeds of Late Triassic Age (Santa Rosa sandstone) and marine redbeds of latest Permian age (Dewey Lake Redbeds). This redbed sequence thins westward and thickens eastward, having been beveled westward by several post-Late Triassic erosional episodes; the thickness of redbed deposits remaining above the evaporite sequence is crudely proportional to the degree to which the underlying salt horizons have been protected from surficial processes leading to erosion and dissolution.

At the center of the site all but the uppermost 50 feet of the 18,000 feet of strata are of Paleozoic age, the marine Dewey Lake Redbeds being the topmost Paleozoic rocks. The Permian section alone, about 12,000 feet thick, constitutes over two-thirds of the sedimentary pile. The Permian section is divided into four series, the three lowest of which (Wolfcampian, Leonardian and Guadalupian) contain thick clastic sequences, and the uppermost of which (Ochoan) is represented by the Castile, Salado, Rustler, and Dewey Lake (in ascending order).

The Rustler, which lies over the Salado, contains the largest percentage of clastic material of the three evaporite formations, yet where its original thickness of around 450 feet has been protected from salt dissolution, about 70 percent of the formation is composed of evaporite minerals, more than half of which is halides. Beneath the Los Medanos site the Rustler has been leached of most of its rock salt, with the result that 310 feet of the formation was encountered at ERDA-9 at the center of the site. This implies that up to 140 feet of rock salt have been removed and that the overlying strata have subsided accordingly; it does not, however, imply that dissolution and subsidence is presently active or even that it has recently occurred. The uppermost occurrence of halite in the Rustler Formation was encountered at a depth of about 760 feet (about 100 feet above the base of the formation). Between this level and the upper level storage zone of the proposed WIPP facility over 1,300 feet of undisturbed evaporite rock, primarily Salado rock salt, intervene.

The 2,000-foot thickness of the salt-rich Salado Formation is divided into three members by the recognition of a middle member referred to as the McNutt potash zone, which is the interval within the Salado that contains all of the potential reserves of potash, or potassium minerals commercially mined in the Carlsbad district west of the site. The lowest member of the Salado, beneath the McNutt potash member, is the member that contains the nearly pure halite chosen for the proposed facility. The Castile Formation beneath the Salado contains highly pure beds of halite but, unlike the Salado, also contains much massive anhydrite.

The rest of the Permian section beneath the evaporite sequence, together with the subjacent Pennsylvanian and possibly Late Mississippian sections, contain dominantly clastic rocks that represent deposition during the time in which the Delaware Basin existed as a distinct structural entity. Much of these pre-evaporite, basinal sediments, which total about 11,000 feet in thickness beneath the site, have been targeted for petroleum exploration at one point or another in the Delaware Basin and contain nearly all of the region's known potential reserve of hydrocarbons.

The remainder of the Paleozoic section (Mississippian down through the Ordovician) consists of about 3,000 feet of mainly carbonate strata deposited in shallow-water or shelf conditions over a period of long-sustained crustal stability.

The underlying crystalline basement is believed to be a granitic terrane, formed about 1,300 million years ago. The only other igneous rocks that are known in the site area are known only in the subsurface and occur as lamprophyre (basaltic) dike rock intruded into evaporite beds along a single northeast dike trend that approaches no closer than about 9 miles northwest of the center of the proposed WIPP site.

With regard to subsurface geologic structure at the site, all of the Permian and older strata exhibit a gentle, regional homoclinal dip to the east or southeast, reflecting the presence of the Delaware Basin tectonic structure. No surface faulting is known. A general summary and assessment of structure in the site area was provided by C.L. Jones in an open-file report issued by the U.S. Geological Survey in 1973. Jones stated,

> "The structure of the Los Medanos area is basically simple and the rocks are, for the most part, only slightly deformed. Nevertheless, the rocks have been tilted, warped, eroded, and subroded, (ed. note: subjected to subsurface removal by dissolution), and discrete structural features can be recognized. These include: (1) structural features of regional extent related to Permian sedimentation, (2) intraformational folds of limited extent related

> to "down-the-dip" movement of salt under the influence of gravity and weight of overburden and (3) subsidence folds related to warping and settling of rocks to conform with the general shape and topography of the surface of salt in areas of subrosion...
>
> "On the basis of available geological information, the salt deposits of Los Medanos area seem in many ways to constitute a suitable receptacle for use in a pilot-plant repository for radioactive wastes. The deposits have thick seams of rock salt at moderate depths, they have a substantial cover of well-consolidated rocks, and they have escaped almost completely undamaged long periods of erosion. The deposits are only slightly structurally deformed, and they are located in an area that has had a long history of tectonic stability."

Information developed in the succeeding five years of investigations do not significantly alter that assessment relative to the structural and tectonic conditions present at the Los Medanos site. Based on exploration accomplished to date, a series of structure contour and isopach maps are presented for rocks ranging in age from Devonian to Pleistocene. This and other information indicate that active tectonic faulting and warping of rocks in the site vicinity seems to have predated Permian evaporite deposition; certain minor faulting within the thick Permian section appears to have occurred contemporaneously with sedimentation and may be ascribed to compaction. Deformation related to salt flowage has occurred primarily in the Castile Formation beneath the Salado, and has locally modified the regional easterly gradient to 80 to 100 feet per mile at the level of the storage horizons near the base of the Salado. Areas in the vicinity of the site in which artesian brine reservoirs have been encountered are associated with thickened salt sections and salt-flow anticlines in the Castile, but no such major structural features are recognizable within the limits of the WIPP storage facility on any of the Salado horizons contoured. The site appears to be in a slight structural saddle, a condition considered to be favorable for site selection. Dissolution of bedded salt at the site has been restricted to horizons within the Rustler Formation; there is no evidence that the resulting settlement produced any significant

structural irregularities or collapse features in the overlying strata within the area of the Los Medanos site. Investigations are continuing to further define the extent to which salt deformation in the Castile may have affected the structural configuration within the lower part of the Salado where excavation of the remote handling (RH) and contact handling (CH) levels is presently planned. These investigations will permit a more detailed assessment of the optimum layout, design and construction method of the storage facility.

The geologic history of the Los Medanos site may be organized into three main phases occurring subsequent to the original establishment of a granitic basement intrusive complex between about one billion and 1.4 billion years ago, forming the cratonic crust beneath the site. The first phase, of at least 500 million years duration, was a time of uplift and erosion of all pre-existing Precambrian sedimentary and metamorphic rocks which may have once been deposited or formed in the site area, eventually exposing the deep-seated igneous rocks.

The second phase, which corresponds to the Paleozoic Era, was characterized by an almost continuous marine submergence lasting about 225 million years, wherein shelf and shallow basin sediments slowly accumulated. It culminated in a comparatively rapid accumulation of over 13,000 feet of Permian sediment within a relatively brief period lasting 50 to 55 million years, toward the end of which time thick evaporite beds, mainly rock salt, were deposited. This rapid Permian deposition was presaged in Late Mississippian time by tectonic activity that differentially upwarped elements of the craton, such as the Central Basin Platform, thereby defining the Delaware Basin as a tectonic feature for the first time. During Pennsylvanian time, repeated marginal faulting caused periodic uplift of bordering platforms and some warping within the basin. By early Permian time, this tectonic activity apparently died out as basin subsidence and sedimentation accelerated. Eventually the Permian sea became shallow and briny, at first characterized by extensive reef development, but eventually in Ochoan time by a vast brine flat in

which thick evaporite deposits formed, burying the earlier reef masses. The final event of the long, nearly continuous accumulation of marine sediment of the second phase was deposition of a blanket of marine or brackish tidal flat redbeds over the evaporite strata.

Uplift and subaerial conditions next occurred at the site in the third and final phase, and persisted some 225 million years to the present, with the exception of a brief marine inundation in about the middle of that span of time. Periods of terrestrial deposition alternated with erosional episodes, so that a series of nonmarine deposits separated by angular unconformities blanket the evaporite beds at the site. These angular unconformities represent intervals during which the salt beds at the WIPP site were tilted and subjected to potential dissolution. At least four erosional episodes separated by depositional intervals are recognized: (1) Early Triassic time in which the Dewey Lake Redbeds were tilted and eroded to a slight angular unconformity before deposition of the Upper Triassic Dockum Group; (2) Jurassic-Early Cretaceous time in which the Dockum Group was tilted and eroded to a wedge before marine inundation in Washitan time (latest Early Cretaceous); (3) a Late Cretaceous through mid-Tertiary erosional interval when the region was again tilted and the Triassic Dockum Group of sediments was bevelled for a second time; and (4) a post-Ogallala (post-Pliocene) uplift and erosion in early Pleistocene time, prior to deposition of the (Kansan?) Gatuna Formation took place. Subsequent to deposition of the Gatuna, there probably were intervals corresponding to the later Illinoisian and Wisconsin glaciations during which accelerated erosion in these wetter times occurred in the area of the WIPP site.

Each period of tilting, which accompanied renewed erosion as outlined above, afforded an opportunity for salt flow by plastic deformation along the imposed gradient and salt deformation as the salt impinged against reef abutments or responded to uneven, differential sediment loading or erosional unloading; therefore there may have been several episodes of salt deformation of this type. To the extent that some "deep dissolution" features are recognized today in salt at depths of several

thousand feet below the surface, it seems likely that subsurface dissolution of salt could have been initiated at comparable depths beneath the surface as soon as Early Triassic time. It is reasonable to assume that episodes of active dissolution occurred during the Jurassic and Late Cretaceous-mid Tertiary erosional intervals, as well as during the several pluvial periods corresponding to Pleistocene glacial stages. Any attempt at reconstructing past history of salt dissolution in the Los Medanos area as an approach to predicting the future course of salt erosion must contend with the likelihood of the existence of times of greatly accelerated dissolution of salt in the geologic past interspersed with intervals of much lesser activity. The evidence available today indicates little if any change in erosion rates at the WIPP site in the recent geologic past. Detailed mapping studies are underway which will contribute to information on dissolution rates at various times in the geologic history of the site.

The discussion of the site geology defines the present conditions of the site which must be known to establish the WIPP. These conditions relate mostly to physical characteristics such as thickness, depth, extent, purity, and structure of the evaporites (as well as some of the surrounding beds). In addition, baseline conditions regarding the processes of dissolution and erosion as they affect the immediate site have been determined. Thus the baseline geological conditions at the site are presented so that judgement of the site relative to the present criteria may be undertaken and so that continuing studies will focus on geologic processes important to assessment of repository safety.

The site geomorphology indicates tectonic stability at the site for the last 500,000 years or more. The local stratigraphy is continuous with the regional stratigraphy. Local minor structures exist within the evaporite beds, but no severe displacements or brine or gas have been encountered. Potential repository zones at depths of 2730-2620 feet and 2176-2074 feet have been chosen on the combined basis of purity, depth, thickness, mutual separation, and depth below the potash zone.

SEISMOLOGY (Chapter 5)

Regional seismicity of the Los Medanos site is discussed in two separate time intervals suggested by the type and quality of information available for each interval. These intervals are before 1962 (non-instrumental) and from 1962 to the present (instrumental).

Before 1962 almost all data on earthquakes within 300 kilometers of the site are based on collection, cataloging, and consideration of non-instrumental reports. These data indicate that twenty earthquakes with maximum reported intensities between III and VIII on the Modified Mercalli Scale have occurred within a 300 kilometer radius of the site region from 1923 to 1960. There have been no earthquakes of epicentral intensity V or greater within about 200 kilometers of the site in this period. The closest reported shocks are two intensity IV events at Carlsbad in 1923 and 1949. The strongest reported earthquake to occur within 300 kilometers is the intensity VIII Valentine, Texas event of August 16, 1931 at a distance of approximately 210 kilometers.

Between 1962 and 1972 inclusive, a general instrumental survey of the site region shows 38 earthquakes with magnitudes ranging from 1.2 to 4.6 (Richter scale). The seismicity pattern of these instrumentally located events is very similar to pre-instrumental data except that a number of earthquakes occur on the Central Basin Platform in the latter data set. The closest reported shock between 1962 and 1972 was a magnitude 2.8 event on July 26, 1972 about 40 kilometers northwest of the site. The largest event in this period is the magnitude 4.6 earthquake almost 300 kilometers to the southwest.

Three investigations of a more local and temporally restricted nature have impact on the Los Medanos site. These involve earthquakes recorded at a seismographic station installed near the site itself, events recorded at an array of seismographic stations installed on the Central Basin Platform near Kermit, Texas, and three earthquakes recorded regionally and found to have occurred near the site.

At the beginning of April, 1974 a vertical, single-component, continuously recording seismograph station (with letter designation CLN) was installed very near the site. During the latest available reporting period, April, 1974 to October, 1977, 291 events identifiable as local and regional earthquakes have been recorded and locations for 75 of the 291 events have been obtained. The seismicity pattern suggested is very similar to that of the general 1962-1972 instrumental survey. Approximately one-half of all located events in the CLN data set occur on the Central Basin Platform while most of the rest occur to the west and southwest of the site in the Rio Grande Rift Zone. There is also a scattering of earthquakes in the High Plains physiographic province of the site. Included is a magnitude 3.6 event on November 28, 1974 at about 40 kilometers to the northwest, which was close to the July 26, 1972 earthquake mentioned above.

Instrumental studies show earthquake activity in the Central Basin Platform at a higher level than expected. Primarily for this reason, the Kermit, Texas seismographic station array was established in late 1975 to more closely monitor this activity. During the latest available reporting period for this array (November, 1975 to July, 1977), 407 local events have been detected and 135 located with array data. Of the located events 56 were in the interior of the array while the rest have been peripheral to it. Earthquakes with magnitudes calculated both using Kermit array data and regional seismographic station and CLN data show that Kermit magnitudes are almost one unit higher. This inconsistency remains unresolved at this time.

As a result of general survey and specialized seismic instrumental studies in the Los Medanos site region there is little doubt that the Central Basin Platform has been seismically active since at least mid-1964, and that during this time it has been the most active seismic area within 300 kilometers of the site in terms of number of events. The basic conclusion from all instrumental data is that seismic activity is equally likely to occur anywhere along the Central Basin Platform structure without particular regard to small scale structural details

such as pre-Permian buried faults. Attempts have been made to relate this seismicity to secondary oil recovery operations in the area. Although both spatial and temporal coincidences of Central Basin Platform seismicity with secondary recovery projects are highly suggestive of a close relationship, this has not been satisfactorily established at this time.

Questions of the tectonism and seismic activity very near or at the site are of great interest. For this reason the most important seismic events instrumentally recorded are those closest to the site: July 26, 1972, and November 28, 1974, magnitudes 2.8 and 3.6, respectively; and a later shock on January 28, 1978, with only preliminary data yet available. If these events are an indication of normal background seismicity in the immediate site area, they might cause a re-evaluation of previous estimates of seismic risk at the Los Medanos site (Sanford and Toppozada, 1974). At the time of the first two events rockfalls and surface ground cracking were reported at the National Potash Company Eddy Co. Mine. To see if mine collapse at this mine was responsible for both events, an analysis was run to see if both epicenters could be made coincident with each other. Such a coincidence would be a strong indication of a rock fall origin for both events. At this time the best available analysis indicates that these small events did not both occur at the Eddy Co. Mine and thus they cannot both have been caused by a very localized non-tectonic source there. The third shock is located, in a very preliminary fashion, north of the station an estimated 17 km.

Using all the information developed above on regional seismicity and some additional simple assumptions about regional tectonism a preliminary analysis of risk from vibratory ground motion at the surface is derived in a way useful to seismic design characterization at the site during its active phase of development and use. The results of this analysis are that the 1000 year acceleration is less than or equal to 0.06 g and the 10,000-year acceleration is less than or equal to 0.1 g for all models tried. Probabilities at which higher acceleration levels occur depend almost exclusively on the assumptions made about the seismic potential of the immediate site area.

In addition to its use to determine risk as a function of vibratory ground motion level, regional seismicity is also considered as an indicator of longer-term tectonic processes. Natural regional seismicity should be consistent with the geologic indicators of tectonic processes unless the tectonic setting is changing. Regional stress patterns, as implied by focal mechanism solutions for regional earthquakes and in site measurements, and regional tectonism, as implied by earthquake recurrence statistics, are both considered. Although other explanations cannot be precluded, it seems that the most reasonable interpretation of the seismic implications to tectonism at this time are: (1) Observed geologic and seismic data are in general agreement in the Rio Grande rift zone to the west and southwest of the site where the largest historic earthquakes within 300 kilometers of the site have occurred. Future significant earthquakes can be expected there. (2) The current level of seismic activity on the Central Basin Platform is probably related to fluid injection for secondary recovery of oil. (3) The lack of geologic indications of natural recent tectonic activity for the High Plains province of the site can probably be reconciled with the seismic data by assuming a maximum magnitude limit of the earthquakes that have occurred here.

The importance of seismicity information over the immediate future is to provide a data base for design of facilities for the operational time of the WIPP. Seismicity information also serves as an indicator of the tectonic situation in assessing the WIPP site for a repository.

HYDROLOGY (Chapter 6)

Chapter 6 contains an assessment of surface and groundwater resources in and surrounding the proposed WIPP site and a status report of current hydrogeologic investigations in the local site area. The water resource assessment incorporates the published results of regional and local hydrologic studies supported by universities and state and federal agencies since the late 1930's. Present studies of the proposed site and

adjacent area are directed toward a more quantitative evaluation of the salt dissolution process, the hydrogeologic parameters affecting groundwater movement, and the major elements of surface and groundwater quality as related to water resource use and local ecology. The collection of hydrologic data is projected to continue for several years to provide site-specific information for a detailed safety analysis of the WIPP. Because of the relationship to hydrologic processes, dissolution activity is also summarized within this chapter.

The only major stream near the site is the Pecos River which flows southeasterly through Carlsbad. At its closest point, the river is approximately 14 miles southwest of the WIPP site. Several reservoirs, located on the Pecos upstream of the site, regulate river flow. The maximum recorded flood on the Pecos River occurred on August 23, 1966, with a discharge of 120,000 cfs and a maximum water surface elevation near Malaga of approximately 2936 feet. The minimum surface elevation of the site is more than 310 feet above this historic flood level.

Climatological records show that mean annual precipitation at the site is approximately 12 inches per year. The maximum daily precipitation recorded at Carlsbad was 5.12 inches in August 1916, and the maximum daily snowfall was 10 inches in December 1923. Winter storms in the area occur as a result of fronts moving from the west while summer storms, generally the most severe, occur as thunderstorms from moist air moving northwest from the Gulf of Mexico.

Surface drainage patterns at the site are undeveloped. Infiltration rates are high because of the sandy, gravelly soils that cover the region. However, the nearest groundwater is more than 50 feet below the land surface. Aided by the low relative humidity (typically 36% during daylight hours) and high mean annual temperature (61°F), most infiltration escapes the soil through evaporation and transpiration.

Important aquifers of the region include the San Andres Formation, a major source for irrigation waters in the Roswell Basin and other areas

to the north and northwest of the site region. Potable water is present in the Capitan aquifer southwest of the community of Carlsbad and is the primary source of municipal water in the local area. Other important aquifers of the region include the Ogallala Formation to the east of the proposed site, and unconsolidated alluvium along the Pecos River.

Groundwater within the Delaware Basin is predominantly of poor quality with total dissolved solids concentrations typically in excess of 3,000 ppm. The only large quantities of potable groundwater are found in aquifers west of and along the Pecos River. To the west, the formations of the basin crop out, and the soluble salts have been leached from the Ochoan evaporites. From recharge areas west of the Pecos River, groundwater in the Delaware Basin moves eastward. From the site area, water in hydrologic units above the salt moves generally southwest to the Pecos. These shallow units, or those cut by the Pecos River, discharge to the river, either directly or to alluvium of the river channel. Although a local hydraulic connection between the river and the Capitan aquifer may occur near Carlsbad, groundwater flow in the reef formation is severely restricted near the Eddy-Lea county line. Groundwater in formations older than the Capitan is not directly affected by the river, is present under confined conditions, and flows eastward. The aquifer of most significance to the proposed site in these older formations is the Bell Canyon Formation.

Water-bearing strata in the local site area at elevations above the proposed repository include the Santa Rosa Sandstone and the Culebra and Magenta members of the Rustler Formation. Hydrologic units below the repository elevation include the Bell Canyon Formation of the Delaware Mountain Group. Hydrologic test results to date show the average head elevations of the potentiometric surfaces from these aquifers are 3200 feet for the Santa Rosa Sandstone, 3150 feet for the composite Rustler Formation, and 3350 feet for the Delaware Mountain Group (equivalent "fresh-water" elevation). The thick halite beds of the Salado Formation are isolated from circulating groundwaters by confining layers of low hydraulic conductivity, directly above and below the salt formation.

In the vicinity of the proposed site, potable groundwater is not present, except in small, isolated, near-surface perched pockets. Thus, it would appear that the proposed repository is favorably situated in relation to groundwater circulation and occurrence. Detailed investigations of groundwater hydrology at the proposed site have been conducted and are continuing. The data will provide a basis for more quantitative determinations regarding the continued isolation of the proposed repository from groundwater circulation.

A shallow salt dissolution zone occurs in Nash Draw at the contact between the Salado and Rustler Formations. The dissolution area ranges in width from 2 to 10 miles and has a length of approximately 30 miles. The brine solution flows southwesterly and discharges into the Pecos River at Malaga Bend. The average rate of vertical dissolution has been estimated to be between 0.33 and 0.5 feet per 1,000 years, and the average rate for lateral dissolution has been estimated to be between 6 and 8 miles per million years. Dissolution of salt at the top of the Salado occurs about 2 miles west of the center of the site. Eastward across the site salt is present in the Rustler at progressively higher levels, indicating that the salt has not been dissolved out of the Rustler and that the Salado has not been attacked by dissolution.

Future measurements obtained from the hydrologic test programs and analyses of the test data will be used to refine bounding calculations, such as estimates of groundwater travel times, and to provide a more detailed description of the physical system and system dynamics. The use of computer models as predictive tools is expected to be closely coordinated with timely observations from an established monitoring network. The predictive results and the real time measurements will aid in the continued assessment of repository isolation from dissolution and groundwater circulation. The retardation of radioisotopes within the hydrologic system (Chapter 9.3), when coupled with the hydrologic model,

will allow realistic calculations of radioisotope transport for postulated failure scenarios.

GEOCHEMISTRY (Chapter 7)

Chapter 7 of this WIPP Geological Characterization Report discusses geochemical properties of geologic materials from Southeastern New Mexico. Geochemistry includes accounts of mineralogy and petrology of evaporites and the associated non-evaporites, volatile constituents of the Salado Formation, fluid inclusions in evaporite minerals, ground water chemistry, and age-dating of evaporites and ground waters.

Megascopic, microscopic and x-ray diffraction examination of the Permian (Ochoan) evaporite section showed the three most common minerals of the Salado Formation to be halite, anhydrite and polyhalite. In addition, there are the potassic and magnesic minerals sylvite, kainite, kieserite, langbeinite, loeweite and bloedite in the McNutt Potash Zone of the Salado Formation. Marker beds throughout the Salado Formation (mostly anhydrite and polyhalite) occur at intervals of a few tens of meters, are on the order of 10 to 100 cm thick, and are laterally traceable in core holes adjacent to the center of this investigation. The McNutt Potash Zone varies laterally in mineralogy, and contains "clay partings" typically at the top of each individual ore zone. Silicate minerals in the Salado Formation are quartz, illite, feldspar, chlorite, talc, serpentine, and several varieties of expandable clay, including saponite, illite-saponite and chlorite-saponite. In rock salt, the contribution of silicates is 0.004 to 2.5 weight percent in the lower part of the Salado (>2400 ft. depth in ERDA No. 9), 0.009 to 5 weight percent in the middle Salado (2000 - 2400 ft. depth), and 0.003 to 21% in the McNutt Potash Zone (above 1,650 ft. depth).

Petrographic textures reveal that significant portions of the evaporites have preserved their original depositional textures, indicating no

post-depositional recrystallization or other sorts of alteration. Other portions have undergone extensive recrystallization to non-primary evaporite minerals such as sylvite and polyhalite, which do not precipitate from sea water in normal evaporation. Textures of bedded anhydrite in the Castile Formation below the Salado Formation show a finely laminated arrangement of evaporite and detrital materials in alternating laminae, implying an original depositional form. Petrographic relationships of minerals in the McNutt Potash Zone show that at no time were these minerals in equilibrium with a solution only of sodium chloride, also precluding the possibility of large incursions of surface-derived water in the geologic past.

Amounts and compositions of volatile constituents in the evaporite minerals were determined by heating rock samples to 600°C, recording mass loss, and in some cases analyzing the effluent in a gas chromatograph/mass spectrometer. Except for samples rich in hydrous minerals (polyhalites, clay partings, potash zones), the vast majority of rock salt contains less than 0.5 weight percent total volatiles.

The most abundant volatile constituent in that 0.5% or less is water. Next most abundant is nitrogen, followed by CO_2. Traces of hydrocarbons and fluorides from drilling operations were detected as contaminants in the core.

In addition to fluid inclusions in halite, (see below), the minerals thought to be sources of volatiles in the Salado Formation include clays and polyhalite, and traces of gypsum, magnesite, carnallite, celestite, glauconite, and kainite. The typical volatile content in Salado salt is 3 to 30 times less than that in the Hutchinson (Kansas) rock salt. An additional contributor to the less than 0.5 total weight percent may be traces of hydrated iron oxides, which account for the red-orange to red-violet colors in some accumulations of polyhalite, sylvite, carnallite and halite in the evaporite section.

Fluid inclusions have been studied in core samples from nineteen horizons above and below the levels of the proposed repository in Salado salt beds. The techniques used include mainly petrography, freezing stage, heating stage, crushing stage and decrepitation tests. The purpose was to determine those inclusion parameters that might be pertinent to an understanding of the origin and geological history of these salt beds.

Four general types of inclusions were found in these samples: type A - extremely abundant but minute primary liquid inclusions, with or without a tiny vacuum bubble, outlining primary growth features; type B - much larger liquid inclusions, trapped during several stages of recrystallization of the primary salt, some with a small vacuum bubble and/or unidentified daughter crystals; type C - scarce large liquid inclusions with large and variable gas bubbles under pressure, presumably from fracturing and refilling of type B inclusions; and type D - empty (i.e., gas) inclusions, found principally along grain boundaries, that have leaked and hence have lost their liquid contents.

The total weight percent of liquid as fluid inclusions in these 19 samples, as measured, ranged from 0.1 to 1.7%, mostly as type B inclusions; the amount of liquid in these same samples <u>in situ</u> was larger, since many of the largest inclusions, that are the major contributors to the total percentage and the intergranular fluids, have been drained during the boring and sample preparation. The temperatures at which these inclusions were trapped were generally in the range of 25-45°C. The brines in them are never simple saturated NaCl solutions, or even NaCl-KCl solutions; freezing temperatures indicate that they must contain considerable amounts of other ions such as Mg and Ca.

When the host crystal is uniaxially stressed, the geometries of the inclusion walls show visible changes within several minutes, possibly due to solution and redeposition, as well as deformation. Internal fracturing of the inclusion walls, but generally without leakage, occurs on freezing.

The distribution of primary type A inclusions provides evidence that they have not moved visibly (i.e., less than a few micrometers at most) in that fraction of the 225 million years between original deposition and the present that these samples have been in the small but finite normal-geothermal gradient.

Subsurface samples of water from various rock types in the Delaware Basin of Southeastern New Mexico and West Texas have been analyzed for their solute contents and $^{18}O/^{16}O$ and D/H ratios. Saturated brines (total dissolved solids greater than 300,000 mg/l) were found in one well in the Bell Canyon Formation, two wells in the Castile and in potash mine seeps in the Salado. According to Cl/Br ratios (between 430 and 900), all the waters have derived their dominant solute (NaCl) from nearby rocks. Potash mine seeps and saline Capitan waters contain solutes corresponding to common primary evaporite mineral assemblages, (halite-anhydrite-kainite-carnallite-bischofite) indicative of simple uptake of dissolved solids. Bell Canyon and Morrow brines contain less magnesium but more calcium than primary evaporite assemblages, and have participated in ion exchange reactions. Stable isotope measurements indicate that Santa Rosa, Rustler and Capitan waters are meteoric, while Salado, Bell Canyon, Morrow and one of the Castile waters (ERDA No. 6) have undergone episodes of low-temperature isotopic exchange with oxygen- and hydrogen-bearing minerals. Isotopically the Carlsbad Caverns hydrologic system is unique to the Guadalupe Mountains, unrelated to the Delaware Basin as a whole.

The ERDA No. 6 occurrence of saturated NaCl-Na_2SO_4 brine and H_2S-rich gas (55% CO_2, 28% H_2S, 15% CH_4, 1.5% N_2 and 0.5% C_2H_5 by weight) in the Castile represents a biogenically-produced sulfide-sulfate disequilibrium. The brine's Na_2SO_4 content may have arisen by rock/fluid ion exchange involving a replacement of magnesium by sodium in the solution. None of the saline groundwaters were found to be original evaporite mother-liquors or products of partial evaporation.

Rb-Sr geochronologic study of the bedded salt deposits from the Salado Formation has been undertaken to age date the last episode of evaporite

crystallization or recrystallization, and to test their feasibility for alkali and alkaline earth retention.

Whole rock samples (i.e., water soluble plus insoluble material) are typically unsuited for Rb-Sr isochron work due to the low Rb/Sr ratio; however, several of these samples do indicate the R_o (i.e., $^{87}Sr/^{86}Sr$ at T=0) value to be about 0.708, thus indicating that large amounts of brine, typically enriched in ^{87}Sr, have not been generated in the sample area since evaporite formation some 235 $\pm$ 10 m.y. ago.

The water soluble fraction of evaporite samples yields an apparent isochron date of 206 m.y. with R_o = 0.7084 while clay minerals (less than two micron size) yield 325 m.y. with R_o = 0.7123. A composite of the water soluble fractions and clay minerals yields a date of 204 m.y. with R_o = 0.7137. This 204 m.y. date is interpreted as a minimum date due to the high R_o value; but it does suffice to indicate that the evaporite-clay mineral assemblages apparently have remained closed to widespread alkali-alkaline earth migration since about the time the evaporites were formed.

Regional exploration of bedded salt for a radioactive waste repository in the Delaware Basin included boreholes into the evaporites and associated rocks. One such hole, ERDA No. 6, encountered an accumulation of saturated $NaCl-Na_2SO_4$ brine accompanied by H_2S-rich gas. This fluid and fluids from other boreholes elsewhere in the area have been characterized geochemically according to solute content, $^{18}O/^{16}O$ and D/H ratios and natural actinide content. Deviations from the equilibrium $^{234}U/^{238}U$ activity ratio (α) of 1.0 were found in all water samples. These deviations are used to affirm the isolation of ERDA No. 6 and to establish bounds on the age of the ERDA No. 6 fluid.

A mathematical model for the age of ERDA No. 6 water intrusion was formulated in terms of the following variables: initial α-value (α_0) of the brine precursor waters, zero order kinetic rate constants of leaching of ^{234}Th and ^{238}U from the rocks, and degree of leaching of

^{234}Th from the rocks. The model allows calculation of α-values of brines as a function of time, leach rate and α_0. Various combinations of α_0's, leach fractions and leach rates indicate that the leach rate must be low. If no leaching is assumed and the α_0 is the highest known α from the nearby Capitan Reef (α_0 = 5.2 at present), the fluid is older than 880,000 years. ERDA No. 6 brine has undergone more profound rock/fluid interactions, reflected in its solutes and stable isotopes, compared with younger meteoric Capitan waters.

The geochemistry of the proposed WIPP site shows that the mineralogy of most of the rock salt is relatively simple. The evaporites have been recrystallized, resulting in some mineral assemblages different from those precipitated from original sea-water-like solutions at one time present in the Delaware Basin. The last episode of such recrystallization took place more than 204 million years ago. The recrystallization resulted in evaporite mineral assemblages which apparently have reached thermodynamic equilibrium. The nature, distribution, geochronology and composition of fluid inclusions, clay minerals, and isolated accumulations of aqueous solutions in the evaporites show no evidence of movement of surface-derived water through the WIPP evaporites (at depths greater than 1000 feet) since their deposition in the Permian Period.

RESOURCES (Chapter 8)

Potash salts and natural gas are the two resources of economic significance under the WIPP site. Other minerals present are halite (salt), gypsum, and caliche, but deposits of similar (if not better) quality exist in the surrounding areas. Other economic minerals and elements, including lithium, uranium, sulfur and metalliferous deposits, could exist in a geologic setting like that of the WIPP, but none appears to be present.

Potassium salts occur in a variety of mineral types, but only sylvite (KCl) and langbeinite ($K_2Mg_2(SO_4)_3$) are mined in the Carlsbad

Potash Mining District, which is the largest domestic source of potash, accounting for approximately 80% of U.S. production. The U.S. is a net importer of potassic fertilizers. The U.S. Bureau of Mines has judged that a langbeinite deposit located in the northeast quadrant of the WIPP site could be profitably mined using today's technology at the current market price for the refined product. The deposit extends beyond the bounds of the WIPP site, but about 49 million tons of langbeinite averaging on the order of 9% K_2O, lie inside the WIPP withdrawal area. Several deposits of sylvite are present, but none meet today's economic conditions; to meet them would require the market price for refined sylvite to increase from $43 to $52 or more per ton.

Natural gas accompanied with some distillate and oil with associated gas are being produced from various beds in the Delaware Basin. One particular formation, the Morrow of Pennsylvanian age, is a consistent producer in this region, and the exploration risk ("wildcatting") is justifiable in much of the western half of the site. About 37 billion cubic feet of natural gas accompanied by about 0.5 million barrels of distillate are estimated to be economically recoverable from beneath the WIPP site.

The studies also included estimation of total resources under the site, not just the resources that could be considered economic today. The U.S. Geological Survey estimates that there are 353.3 million tons of sylvite and langbeinite mineralization under the WIPP site of sufficient quality to require competitive bidding for mineral rights. The WIPP site accounts for about 7% of the potash resources that the USGS believes to be present in the Carlsbad area. Langbeinite is probably the most significant mineral resource under the WIPP site. It is a specialized agricultural fertilizer that finds its use on crops that need potassium but cannot tolerate additional chlorine. Langbeinite adds potassium but is a sulfate. Southeast New Mexico is the only economic source for this particular mineral in the free world. Langbeinite equivalent is produced from potassium and magnesium sulfates from brine lakes. A report is in preparation for DOE which will estimate the fraction of the Carlsbad district's langbeinite resources within the WIPP site.

The New Mexico Bureau of Mines and Mineral Resources studied a large area surrounding the site area, and in its judgement the total hydrocarbon resource in that area is 37.5 million barrels of crude oil, 490 billion cubic feet of natural gas, and 7.33 million barrels of distillate. While these are large quantities, they represent only about 1% of the hydrocarbon resources for southeast New Mexico.

SPECIAL STUDIES OF REPOSITORY ROCKS (Chapter 9)

Special studies are being conducted to address issues of particular interest because the site is being evaluated for the isolation of radioactive wastes. Rocks from the WIPP site were tested in four broad areas: (1) petrography (2) physical properties (density, moisture content, resistivity), (3) thermo-mechanical properties (quasi-static and creep parameters), and 4) radionuclide sorption. Because of a scarcity of core, only those tests deemed necessary for early design were conducted. Testing at specified temperature and creep rates is continuing.

Physical properties representative of rock salt found in the WIPP horizons are summarized in the following table:

Property	Average Value* (Range)
Density	2.18 grams/cm^3
Porosity	0.5 percent (0.1-0.8)
Moisture Loss to 300°C	0.4 weight per cent (0-1.0)
Resistivity	58,100 ohm-meters (4,900-230,000)
Gas Permeability	$< 0.05 \times 10^{-6}$ darcy
Compressional Wave Velocity	4.5 km/sec (4.42-4.62)
Thermal Conductivity	5.75 w/m°K

*Except for moisture loss, values are given at 25°C

Rock salt properties are both time and temperature dependent; as a result, mechanical properties must be generated at a specific loading rate and temperature. Parameters defining the mechanical behavior at different load conditions must be inferred with considerable caution and with proper regard for the time dependent nature of the material. Quasi-static experiments were carried out at particular loading rates, e.g. 30 psi/min.

Quasi-static Properties of WIPP Rock Salt at 23 $^{o}_{C}$

Unconfined Strength	2,450 to 3,700 psi
Secant Modulus	2 X 10^5 psi
Principal Strain Ratio	0.25-0.35
Strain at failure:	
confining pressure	strain at failure
0 psi	2.5-6.0%
500 psi	17-20%
3,000 psi	> 20%
Tensile Strength	220 psi
Initial Yield Stress	$(\sigma_1 - \sigma_3) \approx$ 100 psi

Preliminary Creep Properties

Steady State Creep Rate ($\dot{\varepsilon}$)

At 23°C:	$(\sigma_1 - \sigma_3)$=1000psi	$\dot{\varepsilon} = 10^{-10}$ sec^{-1}
At 130°C:	$(\sigma_1 - \sigma_3)$=2000psi	$\dot{\varepsilon} = 10^{-7}$ sec^{-1}

Results analyzed to date indicate that WIPP salt may undergo both transient and steady-state creep. However the latter is a tentative observation as occurrence of steady-state creep is uncommon. Indeed, if steady state creep occurs under loading conditions expected in the WIPP,

design calculations should consider creep in detail. This most likely will be of concern if elevated temperatures are involved. Although present considerations of steady-state creep are incomplete, it appears that steady-state creep rates range from 10^{-10} to 10^{-7} /sec. The transient creep results indicate that pressure, principal stress difference and temperatures are strongly coupled. Furthermore, of these three, temperature appears to have the most dramatic effect on the creep rate.

Data from the petrographic and physical properties studies show the WIPP horizon rock salt has low moisture content (less than 0.5%), is essentially impermeable (less than 5×10^{-8} darcy) and has a high thermal conductivity (about 5.75 watts/m^{o}K). These properties, along with the studies of fabric and fracture, indicate that this rock salt is ideally suited from a physical standpoint for the storage of heat producing radioactive wastes.

It has been shown that rock salt can experience large creep strains (greater than 25%) prior to loss of load bearing capacity. Gradual creep is an acceptable feature in the design of underground openings in rock salt as it allows the structure to close without a reduction in bearing strength. As long as allowances for creep are incorporated into design and the shape of the opening does not create large shear stresses, the WIPP rock salt can be expected to sustain stable openings.

A survey of the potential of geological media from the vicinity of the WIPP site in southeastern New Mexico for retardation of radionuclide migration in an aqueous carrier was conducted. The survey included the measurement of sorption coefficients (Kd) for twelve radionuclides between three natural water simulants and ten samples from various geological strata.

The nuclides included ^{137}Cs, ^{85}Sr, ^{131}I, ^{99}Tc, ^{125}Sb, ^{144}Ce, ^{152}Eu, ^{153}Gd, ^{106}Ru, ^{243}Am, ^{244}Cm, and ^{238}Pu. The compositions of the simulant solutions were those expected of water in contact with halite

deposits in the area and in a typical groundwater found in the Delaware Basin. The geological samples were obtained from potential aquifers above and below the proposed repository horizons and from bedded salt deposits in the repository horizons.

In brine solutions, Tc and I were not significantly adsorbed by any of the minerals and Cs and Sr showed minimal adsorption (Kd's < 1). The lanthanide and actinide Kd's were typically > 10^3 and Ru and Sb Kd's varied in the range of 25 to > 10^3. In the groundwater simulant, Tc and I showed the same behavior, but the Kd's of the other nuclides were generally higher.

Some initial parametric studies involving pH, trace organic constituents in the simulant solutions, and radionuclide concentrations were carried out. Differences in the observed Kd's can result from varying one or more of these solution parameters.

The WIPP site rocks, including rock salt, show an affinity for radionuclide sorption ($K_d > 0$). Even small values of K_d ($0<K_d<1$) are effective in retarding the movement of radionuclides in groundwaters.

It is not anticipated that results of these special studies will be pivotal in site selection; rather, they are being performed to provide additional confidence in geologic isolation in bedded salt.

CONTINUING STUDIES (Chapter 10)

Although much detailed information has been reported here as a result of site selection and characterization, there remain a number of programs which have not come to completion, or in some cases, have not begun. These pending programs are aimed at refining and supplementing information gathered to increase the confidence to be placed in factors relating to site selection. Furthermore, some kinds of information remain to be gathered to support laboratory and in-situ experiments and long-term safety assessment.

In regional geology, paleoclimatic studies based on detailed geologic mapping, geomorphology studies, microfossils, and age-dating are planned to provide a history of past climatic changes and to help assess the possible effects of future changes. Tectonic studies, involving examination of LANDSAT photos and accompanying field evaluation, first-order levelling surveys, and seismic monitoring of structural features adjacent to the Delaware Basin will continue to provide an account of the dynamic forces which might affect the Basin.

Continuing studies in site geology are aimed at expanding the details of site characterization for the purpose of refining site-specific safety assessment modeling scenarios for the repository. Geologic mapping is being undertaken to establish the local geomorphologic stability. High resolution aeromagnetic surveys will be implemented to provide greater confidence that possible geologic anomalies such as breccia pipes and igneous dikes have been identified and may be examined and sampled in detail.

Seismological studies will continue to document and evaluate the seismicity of the region due to various sources (mining, secondary hydrocarbon recovery, tectonic activity). The data will assure the appropriate seismic risk has been assumed in facility design and will further the safety assessment in general.

Hydrological studies will continue to expand the area around the site for which the groundwater behavior is characterized. In addition to hydrologic monitoring points near site center and periphery, a system of points will be established in nearby Nash Draw to evaluate the relationships among groundwater movement, evaporite dissolution and resulting subsidence. Also, investigations of "breccia pipes" will be undertaken to improve our understanding of why, how and when these features developed. The hydrologic monitoring system will provide the basis for development of a regional groundwater model to be used in safety assessment, and will be evaluated as a monitoring tool for repository-induced changes in the groundwater system.

Continuing studies in geochemistry are designed to support other investigations (such as the examination of dissolution products), provide detailed characterization of geologic materials to be used in in-situ and laboratory experimental programs (such as waste-rock interactions) and to contribute towards our understanding of the nature of Ochoan evaporites in general. These studies include mineralogy, petrology, volatile and fluid inclusion analyses, major, minor and trace element analyses in rocks and fluids, age-dating, stable isotopes, and examination of dike-evaporite interactions as a partial analogue of waste-evaporite interactions.

There are no continuing studies of resources planned at the WIPP site.

Continuing special studies of rock properties include long-term creep analyses in various temperature regimes, micromechanics of rock deformation, migration of volatiles, and mechanistic studies of radionuclide sorption on rocks. Some of these special studies are designed to provide an understanding about differences in mineralogy, grain size, volatile content and rock fabric which are to be found at different in-situ test horizons. The physical properties of the various horizons will be examined with these variations in mind. Non-salt horizons, which may be significant in the development of refined models for calculation of repository effects, will also be tested.

Continuing studies of radionuclide sorption include measurements of dynamic sorption from fluids flowing through columns of WIPP rocks in laboratory environments. In addition, parametric studies will continue to determine changes in sorption which accompany changes in mineralogy, pH, oxidation state, radionuclide concentration, and concentrations of organic contaminants. The rates at which sorption takes place and the differences between the processes of sorption and desorption will be investigated.

GCR CHAPTER 2
INTRODUCTION

The purpose of this chapter is to provide introductory information concerning the function of the WIPP and to discuss the site selection criteria and factors affecting the criteria; the criteria and factors are specific to the WIPP and to the Delaware Basin of southeastern New Mexico. In addition, some of the site exploration techniques are briefly mentioned here as background to further discussion of geological characterization.

2.1 THE PURPOSE OF WIPP

The purpose of the WIPP should be understood clearly as it is distinct from that of several other projects for the disposal of radioactive waste. The WIPP will demonstrate disposal technology for the transuranic (TRU) waste resulting from this nation's defense programs of over 30 years. After a period (5-10 years) of limited (pilot) operation it is anticipated that the WIPP will be converted to a full-scale repository for permanent disposal of defense TRU waste. Secondly, the WIPP is to provide a research facility to examine, on a large scale, the interactions between bedded salt and high-level radioactive waste. These interactions will involve physical and chemical phenomena resulting from thermal and radiation fluxes. A DOE Task Force (DOE/ER-0004/D, 1978) has recommended that WIPP also be used to demonstrate surface and subsurface methods of handling, storing and disposing of up to 1,000 canisters of spent reactor fuel; however, a decision on this recommendation has not been made at this time.

If the site is accepted by the DOE, the schedule calls for the initiation of facility construction in 1981; completion is to be about 1985, and the first waste to be accepted in 1986. The conceptual design of facilities is complete. The Draft Environmental Impact Statement and this Geological Characterization Report for DOE are presently scheduled for completion in late 1979. DOE has expressed an intent to request

licensing of the WIPP by the Nuclear Regulatory Commission (NRC), but this policy is presently under discussion between the DOE and Congress.

2.2 PURPOSE OF GEOLOGICAL CHARACTERIZATION REPORT (GCR)

The purpose of the GCR is to provide an account of the known geotechnical information considered relevant to site selection (see Section 2.3) for the proposed WIPP site. The GCR presents background information as well as information regarding factors related to selection criteria; for the most part, specific judgements regarding the suitability of the site are not made. Those judgements and recommendations are the function of other processes and documents. The GCR is neither a Preliminary Safety Analysis Report nor an Environmental Impact Statement; these documents, when prepared, should be consulted for appropriate discussion of safety analysis and environmental impact. The GCR is intended as a source document on the geology of the WIPP site for individuals, groups, or agencies seeking basic information. Therefore, rather extensive reference lists of reports and documents are provided at the end of chapters for the reader who may desire extended detail concerning particular geotechnical subjects discussed in this report. The GCR is not intended to present primary source material, and the instances of reporting original data or information in this document have been limited.

2.3 SITE SELECTION

Within this document, "site selection" primarily refers to the activities whereby the Los Medanos (or other) area is evaluated, on geotechnical grounds, as to whether it is an acceptable location for the WIPP. "Preliminary site selection" may be used here or elsewhere as a description of the activities which result in selecting a site for characterization; the characterization of such a site establishes technical grounds for the more specific site location of the WIPP. "Site selection" has also been described as that action which results when all technical aspects of establishing a repository site have been satisfied. For the WIPP studies, this latter action is termed "site confirmation";

the criteria for "site confirmation," which means conversion to a repository, will in part be developed through operation of the WIPP as a demonstration facility. Because of unforeseen geological occurrences or enhanced understanding of geological processes, final satisfaction regarding the geological suitability of the site for a repository may not develop until significant portions of the underground workings are explored and studies of geological processes finished. Site selection here refers to the position that most, if not all, of the extant geological characteristics are favorable to the WIPP; the rates of some geological processes may require further examination to reduce that uncertainty with regard to specific detailed effects on a repository. Site selection for the WIPP is not to be interpreted as a guarantee that a repository will be established.

2.3.1 History of WIPP Site Selection Effort

The sequence of events which has culminated in the WIPP site selection activities in the Delaware Basin of southeast New Mexico began in 1955 when the Atomic Energy Commission (AEC) requested the National Academy of Science (NAS) to examine the issue of permanent disposal of radioactive wastes. The Academy's Committee on Waste Management issued a report (NAS/NRC Report) in 1957 in which they stated, "The most promising method of disposal of high level waste at the present time seems to be in salt deposits." This recommendation initiated several years of research, directed by Oak Ridge National Laboratory (ORNL), on the phenomena associated with disposal of radioactive waste in salt. In 1961 (NAS/NRC Meeting Minutes, December, 1961), the NAS waste management committee reaffirmed its position on the use of salt beds for disposal commenting that "Experience both in the field and in the laboratory on the disposal of wastes in salt have been very productive and well conceived; plans for the future are very promising." Pierce and Rich (1962) reported on salt deposits in the United States that might be suitable for disposal of radioactive wastes. The Delaware Basin was one of these areas discussed. The ORNL research was expanded to include a large-scale field program in which simulated waste (irradiated fuel elements), supplemented

by electric heaters, was placed in salt beds for observation of the resulting phenomena. This experiment, called Project Salt Vault (Bradshaw and McClain, 1971), was conducted in an existing salt mine at Lyons, Kansas, from 1963 to 1967. Results from this program were favorable, and no unacceptable phenomena occurred which would rule out salt as a repository medium. The NAS committee again reviewed and endorsed the NAS position regarding disposal in salt (NAS/NRC Report, 1966). In June, 1970, the Lyons site was tentatively selected by the AEC as the location for a radioactive waste repository. The concept and location were conditionally endorsed by the NAS committee in November, 1970 (NAS/NRC, 1970). Conceptual design for a facility accommodating both transuranic (TRU) and high-level waste (HLW) was completed in 1971. During 1971, as plans for the repository proceeded, two technical problems arose. The first involved the presence of [redacted] existing boreholes in the vicinity of the repository that penetrated through the salt beds into underlying aquifers. There was concern that not all these holes could be adequately plugged and that not all such drill holes were on record and identified. This prospect meant that borehole dissolutioning and eventual breaching of the repository could not be ruled out. The second concern related to the [redacted] being carried on by the American Salt Mining Company [redacted] for the proposed repository but only [redacted] an extension of the [redacted] was to contain the repository. The revelation that large volumes of water were unaccountably "lost" in the hydraulic fracturing and solution mining was regarded as illustrating a mechanism threatening to the repository site. This site was opposed by the Director of the Kansas Geologic Survey and political opposition within the state increased. By early 1972, the proposal for a repository at Lyons was abandoned and a much expanded search for a suitable repository site was commenced. Other potential sites in the state were identified by the Kansas Geological Survey, and the United States Geological Survey (USGS) examined potential salt sites in other areas of the United States.

After a nationwide search for a suitable repository site (Pierce and Rich, 1962; Anderson et al., 1973; Bachman and Johnson, 1973; Hite and

Lohman, 1970; Jones et al., 1973; Mytton, 1973; Ekren et al., 1974), the USGS and ORNL selected the Permian Basin in New Mexico as best satisfying their site selection guidelines. Four locations within this area were examined in more detail (Brokaw et al, 1972; Jones et al, 1973; Jones, 1974a; Jones, 1974b), and a location in the Los Medanos area, about 30 miles east of Carlsbad, New Mexico, was chosen for exploratory work. One of the most restrictive site selection criteria, primarily because of the Lyons experience, was avoidance of drill holes penetrating through the salt within two miles of the repository border. This criterion caused the potential site to be shifted twice within the Los Medanos area as oil/gas wells were drilled in the vicinity. The eventual site selected by ORNL was located on the Eddy-Lea county line, 30 miles due east of Carlsbad, New Mexico.

Field investigations began at this site in March, 1974, with the drilling of core holes AEC 7 (3,918 feet deep) and AEC 8 (3,028 feet deep) at the northeast and southwest corners of the 1 1/2 by 2 mile rectangular site. The data from these holes was considered satisfactory by ORNL, but further work at the site was suspended in May, 1974. This suspension was due in part to a shift in AEC waste management emphasis to retrievable surface storage facilities (RSSF) and in part to a reluctance at the commission level to ask for land withdrawal to set aside the necessary area for the repository and its protective "buffer" zones.

Sandia received program funding to continue field investigations in southeastern New Mexico on March 31, 1975. Geologic investigations resumed at the ORNL site in May, 1975. Extensive review sessions with ORNL and the USGS covered past efforts in site selection. Studies conducted by the USGS and ORNL consultants on regional geology, seismicity, hydrology and solutioning of salt were re-evaluated. Sandia concurred that the northern Delaware Basin seemed appropriate for siting a waste repository.

In the opinions of both ORNL and USGS, the two core holes, AEC 7 and 8, indicated acceptable subsurface geology at the ORNL site. The first

Sandia task, therefore, was to confirm this by additional drilling and geophysical investigations. Core hole ERDA 6 was initiated in May, 1975, at the northwest corner of the ORNL site. ERDA 6 encountered unexpected subsurface geology. Formation contacts were much higher than anticipated, and salt and anhydrite beds exhibited severe distortion with dips up to 75 degrees. Sections of the upper Castile Formation were missing, and the fractured anhydrite encountered at a depth of 2710 feet contained a pocket of pressurized brine. The unpredictability of the detailed geology at this site was not compatible with Sandia requirements for the pilot plant; therefore, site selection activities were expanded. Reconsideration of site selection guidelines in light of the results of continuing studies and exploration in southeast New Mexico led to the adoption of additional guidelines and some modification of the original guidelines. Evaluation of oil company seismic and drilling data and the resultant structural contours on the Castile Formation confirmed deformation of Castile salt beds in a band about five miles wide paralleling the Capitan Reef front. Since this deformation and the distortion of the geologic units encountered in ERDA 6 was believed due to gravity-induced buckling of salt beds abutting against the Capitan Reef, an additional site selection factor was established requiring a site area to be at least six miles from the reef front.

The proximity of boreholes penetrating the salt formations, another site selection criterion, was re-evaluated during this period. Analytical studies and field research conducted for ORNL after the Lyons, Kansas, borehole problems allowed a more quantitative judgment (Snow and Chang, 1975; Walters, 1975). In the Los Medanos area, a requirement to separate the repository from boreholes penetrating through the salt by one mile seemed quite conservative and was adopted. This buffer would assure more than a quarter million years of isolation using very conservative flow assumptions. While improved borehole plugging and study of the consequences of an unplugged hole may make such holes acceptable even closer to the repository, neither has yet been demonstrated.

The New Mexico portion of the Dolaware Basin was re-examined by both the USGS and Sandia in late 1975. On November 14, 1975, the USGS recommended an area about seven miles southwest of the ORNL site for further examination. Sandia had independently selected the same area as showing the most promise for a repository site. Considerable geologic data were available in this region from oil/gas wells and from shallow drill holes used to explore for potash. In a regional study, the USGS found that initial dissolution of Salado salt, the formation of interest, was sufficiently distant from the proposed site that dissolution would pose little, if any, threat to the WIPP. The three-square mile repository could be located to avoid the known potash areas (PAA) and to be at least one mile from all boreholes penetrating through the salt. No private (fee) land and less than three sections of state land were present in the potential withdrawal area. A stratigraphic core hole, ERDA 9, was started in parallel with geophysical studies of the area. ERDA 9, drilled in the center of the area under study, revealed the expected geology and indicated the desired flat bedding (dips are about 75 feet/mile). Physical properties of the salt beds were found to be satisfactory; beds at depths of about 2100 and 2600 feet were selected as appropriate for TRU and heat-generating wastes respectively. Consequently, an extensive program of site evaluation and laboratory investigation was begun and is continuing as of the date of this report (August, 1978). Sufficient information has now been developed to allow the site to be adequately characterized for site selection purposes.

2.3.2 General Location and Land Requirements of WIPP Facility

Figure 2-1 shows the general location of the Los Medanos site within the regional geographic setting. The nearest town is Loving, New Mexico, (population about 1100) 18 miles west-southwest of the site. Carlsbad, New Mexico, (population about 25,000) is 26 miles west of the site, and Carlsbad Caverns National Park is about 40 miles to the southwest.

Figure 2-2 is a diagram of the WIPP site showing proposed land use controls around the limits of the underground facilities (Zone II).

Engineering studies had indicated that approximately 3 square miles were desired for ultimate development of underground facilities at the WIPP site, necessitating the restriction of land use within an equivalent area of land at ground surface. Administrative control of additional land (Table 2-1) will also be required beyond the boundary of the excavated area to protect the repository: a mile-wide restricted zone around the repository in which, for the present, no underground mining, excavation, or through-going boreholes will be considered (Zone III); and an additional mile-wide buffer zone in which limited (i.e. subject to control and regulation by DOE) underground mining and deep drilling will be allowed (Zone IV). "Hydrofracing" and other injection methods of hydrocarbon recovery, and any kind of solution mining, would be prohibited. This zonation is shown in Figure 2-2, (which also indicates the corresponding total acreage of restricted land needed for the WIPP site). On the surface, only the plant site itself (Zone I) will exclude land access.

The irregular pattern of the outer boundary of the WIPP site (Figure 2-2) originated from a desire to conform to the Bureau of Land Management's (BLM) land subdivision system and to exclude private land and producing wells. The WIPP program plan calls for the entire area within this boundary to be brought under control of the DOE. [redacted]

2.3.3 General Considerations and Requirements of Underground Storage Facilities for Radioactive Waste

Neglecting consideration of surface restrictions and land use conflicts for the purposes of this report, geotechnical siting requirements for an underground radioactive waste repository are ultimately determined by: 1) the physical (including thermal), chemical and radioactive interactions between the waste and the surrounding media, 2) the type of rock chosen in which to place the repository, and 3) the level of

assurance desired against failure of the containment. While WIPP is anticipated to be a repository for defense transuranic waste, Sandia was also requested to consider possible future options for high-level waste in its site selection studies of bedded salt in the Delaware Basin. For WIPP, the desired goal is complete isolation of waste with negligible consequence in the event of containment failure for the total duration of time in which the radioactivity of the waste could constitute a potential hazard to the biosphere or humans in general.

These unprecedented long storage requirements, which embrace a small but significant interval of geologic time, call for a careful characterization of long-term hydrologic, geologic and climatic processes, potentially affecting stability and survival of the underground facility, in order that appropriate siting criteria may be specified. These and other considerations in the long-term management of radioactive wastes have been defined and discussed in ORNL reports by Gera and Jacobs (1972) where they identify geologic processes relevant to waste disposal and discuss the suitability of various geologic media for radioactive waste storage. Claiborne and Gera (1974) describe and evaluate potential mechanisms of containment failure and of hydrologic release of contaminants from the bedded salt deposits in the southeastern New Mexico area. The conclusions and recommendation of these studies, which are not repeated here, have been utilized as guidelines in formulating siting criteria employed in the selection of candidate site locations in the Delaware Basin area of southeastern New Mexico. Regarding the overall danger of contamination from properly sited underground waste storage facilities, however, it is appropriate for proper perspective to repeat the observation of Claiborne and Gera (1974, p.4) that

> "the conditions required for a serious release of activity to the biosphere from a repository in bedded salt tend to approach the bizarre and have considerably less credibility than the 'maximum credible accident' assumed for nuclear power plant safety analyses."

2.3.4 Initial Screening Criteria and Selection of the Original (ORNL) Site in the Delaware Basin

Preliminary site screening studies for an underground waste isolation storage facility in the Delaware Basin were initiated jointly in 1972 by ORNL and the USGS for the AEC. Guidelines developed at that time were mostly contained in the ORNL report by Gera and Jacobs (1972) and in ORNL-TM-4219, which, however, did not address conditions in the southeastern New Mexico area specifically. Geologic information was assembled by the USGS for use in evaluating the suitability of various areas in the Delaware Basin for disposal of radioactive wastes; this information appeared in open-file form in the report by Brokaw, et al. (1972). Additional data by Bachman, et al. (1972) appeared as an ORNL report.

Large-scale (Stage I) site screening criteria (ORNL-TM-4219) were developed and were employed in an initial selection of a site at the Lea-Eddy County boundary, about 7 miles northeast of the present WIPP site. In addition to the usual geologic standards some technical criteria which were applied by ORNL were as follows (Griswold, 1977, p.12):

[redacted] into the Delaware, or deeper formations.

[redacted]

The maximum depth indicated was solely a mine engineering criterion dictated by the viscous flow potential of salt at pressures exerted by the lithostatic loading and at temperatures imposed by the expected geothermal gradient coupled with the maximum thermal flux of the stored waste; the minimum depth was that considered adequate to insure against disinterment by erosion.

Figure 2-3 shows the results of this initial screening process. A two-mile radius from deep wells proved to be the most restrictive criterion; on the figure the shaded areas indicate land, more than two miles from deep wells, also satisfying the depth and mineral resource exclusion criteria. The site initially selected by this method is also indicated.

Cores from AEC Nos. 7 and 8 intercepted leasable grades of potash; ERDA No. 6 cores did not. However, at ERDA No. 6, evidence of complex evaporite structure and the encounter of an artesian flow of brine were sufficient evidence that this original site was unsuitable and that more information would be needed to define additional criteria to be used in selection of acceptable alternate sites.

2.3.5 Site Selection and Evaluation Criteria for the Los Medanos Site

When the initial Delaware Basin repository study area was shown to be unacceptable, Sandia undertook the task of locating a satisfactory site in the New Mexico portion of the Delaware Basin. By late 1975 a more complete understanding of the geology of the basin and of potential repository failure mechanisms permitted a reformulation of siting criteria and site selection factors. These criteria and factors were developed rather specifically for the Delaware Basin in southeastern New Mexico, and are neither generic criteria for bedded salt nor generic criteria for all rock types.

Some of the specific studies contributing to this effort include the following: Claiborne and Gera (1974) considered potential failure modes of bedded salt containment in the Delaware Basin; Bachman and Johnson (1973); Jones (1973); Bachman (1974) and Piper (1973) reported on geologic and hydrologic conditions in the Permian Basin region and in the Delaware Basin in particular; Jones (1975) discussed potash deposits; and Foster (1974) and Netherland, Sewell and Associates (1975) investigated hydrocarbon resources. Reports on dissolutioning associated with unplugged boreholes (Snow and Chang, 1975; Walters, 1975; Fader, 1973)

were also available. The selection of additional alternate sites made in November, 1975, utilized this information. Two factors which received careful attention because of the experience gained in locating and evaluating the original site were the [redacted] and the [redacted] through the evaporites.

Siting factors were formulated to eliminate from further consideration areas of possible severe structural deformation or complexity of the salt beds. Geologic evidence (Jones, 1973) indicated the tendency for [redacted] structural complexity to occur in salt beds adjacent to the Capitan reef front. Substantial salt deformation resulting in displacement and fracturing of anyhdrite beds was encountered in ERDA-6. Structural contouring of the Castile Formation, based on petroleum drilling and seismic reflection data, indicates this [redacted] in part, about five miles wide, parallel to the reef front. Accordingly, a belt with a width of six miles basinward from the Capitan reef was eliminated from eligible areas. This also served to avoid any possible dissolution hazards which might be associated with the reef. [redacted] features in the subsurface, inferred by the avoidance of pronounced anticlinal structures [redacted].

The extent of deep drilling, resulting from hydrocarbon exploration in the Delaware Basin, indicated that a careful evaluation of the required separation from boreholes be performed. Desirable regions could be excluded from consideration if this factor was unduly restrictive. The two mile separation distance established after the Lyons, Kansas, experiences, was modified to one mile based on studies by Snow and Chang (1975), Walters (1975), and Fadec (1973). These studies improved prospects for assuring plugging of boreholes, and the hydrologic conditions expected in the acceptable portions of the Delaware Basin all indicate that a one-mile buffer zone is amply conservative against potential borehole dissolution (Griswold, 1977, p. 12). Figure 2-4 shows

areas that are more than one mile from boreholes penetrating into the Delaware Mountain Group. Avoiding these boreholes would also result in avoiding existing oil or gas fields.

In addition to the salt anticline and borehole restrictions already mentioned as assuming a primary role in narrowing the choice of acceptable sites, several other aspects proved to be significant for the northern portion of the Delaware Basin. Proximity to the dissolution front at the top of the Salado Formation and the existence of local solution features were prime considerations.

Although open joints, fractures or faults are not expected to occur in salt, intrusions in the form of igneous dikes which pass through the salt beds are known to exist locally in the Delaware Basin. The proximity of such a feature might be cause for rejection of a site for geologic, hydrologic and engineering reasons. Shown in Figure 2-5 are areas where undesirable structure, such as salt deformation, brine-flow anticlines, or dike trends, are known or presumed to occur; the dike trend is magnetically expressed and is defined by magnetic survey methods.

Candidate sites should be located in areas affording adequate long-term protection against encroachment of salt dissolution. Surface dissolution was assumed to be related to downward percolation of meteoric water and removal through Nash Draw and the Pecos drainage system. In addition, evidence of possible dissolution in salt over the Capitan reef aquifer is known in such places as San Simon Sink. Dissolution fronts, or boundaries at which salt has been or is being dissolved from the enclosing rock material, had been recognized at various horizons in the evaporite sequence of the Delaware Basin. Rates of dissolution were estimated by Bachman (1974), and longevity of Salado salt was diagrammed by Jones (1973, Figure 7). These observations were translated into appropriate avoidance criteria. Dissolution of salt in the Rustler Formation was not considered to be a significant hazard to a repository located in the lower part of the Salado; however, areas that exhibit extensive salt dissolution at the top of the Salado would be rejected.

For conservatism, sites that would be in, or within a mile of, areas of known dissolution at the top of the Salado were considered less desirable. Figure 2-6 displays areas where dissolution at the top of Salado was indicated to occur, based on studies current at that time.

The interception of commercial grades of potash by holes AEC-7 and AEC-8 and the known occurrences of potash nearby highlighted the necessity of evaluating the potential of this resource to assess possible resource conflict. Areas of potash mineralization meeting minimum grade and thickness criteria, termed the "potash enclave" by Aguilar et al. (1976), would be avoided to the extent possible by the three square mile core of the site. Regarding possible conflict with hydrocarbon reserves, the avoidance of deep drill holes automatically insures that a potential site would not be located over an existing oil or gas field. To minimize the possibility of siting over areas having favorable potential for discovery of additional hydrocarbon reserves, oil and gas trends in the subsurface beneath a possible site location would be considered in siting the repository. The locations of such trends are shown in Figure 2-7.

Finally, with regard to land ownership, the [redacted] to the extent possible to expedite site exploration and land withdrawal. [redacted] would be avoided by Zones I and II to the extent feasible.

2.3.6 Site Selection: Criteria and Factors

Two principal stages are involved in establishing a nuclear waste repository. The first stage, outlined mainly in the previous section (2.3.5), involves preliminary site selection of the most desirable site from among the potentially acceptable study areas. This selection is based on application of criteria and selection factors to the existing knowledge and general reconnaissance information available for the areas. Specific and detailed studies are not conducted at this stage. The second stage is to determine the characteristics and processes affecting a site or sites sufficiently well to allow confirmation of a

site for a repository. It is possible that this detailed study will reveal that some factors are less than ideal. It is unlikely (and unnecessary) that a site will be ideal with respect to all selection factors. Similarly, it is unnecessary and, indeed, impossible to prove that the "best" site has been selected. The extent of investigation in stage two is such that all prospective sites cannot be examined in this detail. Rather it is sufficient to establish that an adequate, safe, and acceptable site has been identified. This knowledge requires that potential failure modes and hazards be recognized and that siting factors take them into consideration.

For the WIPP, the facility demonstration and additional studies of processes and underground geology will lead to further development of criteria for a repository and subsequent assessment of the safety of the WIPP site as a repository. Thus, at least for WIPP, it is necessary to refine criteria, through operation and continued study, sufficient for confirmation as a repository.

For site selection of the Los Medanos site the following criteria and the factors which address those criteria are listed. In most cases, the nature of the factor desired can be indicated but not quantitatively specified a priori since the acceptable combinations of factors under the multiple barrier concept is so large. Many of the desired factors are just that - desired. They are sufficient but may not be necessary for long-term repository safety. The general relationship of factors to WIPP studies is indicated by referring to principal chapters containing information about particular factors.

Geology Criterion: The [redacted] while the waste poses a significant hazard to man. The geology must also permit safe operation of the WIPP.

Factors: Topography - Must permit access for transportation. Effect on inducing salt flow during excavation must be considered. Surface water flow and future inundation must be evaluated. (See 3.2, 4.2)

Depth - Repository horizons should be deeper than 1000 feet to assure erosion and consequences of surficial phenomena are not a major concern. Depth of suitable horizons will not exceed 3000 feet to limit rate of salt deformation around the excavations. (See 3.3, 4.3, 9.2)

Thickness - Total thickness of the salt deposits should be several hundred feet to buffer thermal and mechanical effects. The desired thickness for the repository bed is 70 feet or more to mitigate the thermal and mechanical effects at non-halite units. (See 4.3.2, 9.2)

Lateral Extent - The distance to structural or dissolution boundaries must be adequate to provide for future site integrity. For the Los Medanos area a distance of five miles to the Capitan reef and one mile to regional Salado dissolution have been established. (See 3.3, 4.3, 6.3)

Lithology - Purity of the salt beds is desirable to reduce the brine content of the salt. Pending further investigations, three percent brine is established as a desirable upper limit for the heat-producing waste horizon. Additional geochemical interactions must be considered if significant chemical or mineralogical impurities are present. (See 4.3, 7.2, 7.3, 7.4, 7.5, 7.6)

Stratigraphy - Continuity of beds, character of inter-bedding and nature of beds over- and underlying the salt are important considerations in construction of the facility and in assessment of possible failure scenarios. (See 3.3, 3.4, 4.3, 4.4)

Structure - Relatively flat bedding ($< 3^{o}$) is desirable for operational purposes. Steep anticlines and major faults are to be avoided. (See 3.4, 4.4)

Erosion - While the depth factor reduces concern for erosion it is desirable to avoid features which would tend to localize and/or accelerate erosion. (See 3.2.3, 3.6, 4.2, 4.5, 6.2)

Hydrology Criterion: The geology of the site must provide high confidence that natural dissolution will not breach the site while the waste poses a significant hazard to man. Accidental penetrations should not result in undue hazards to mankind.

Factors: Surface Water - Present and future run-off patterns, flooding potential, etc., should not endanger the penetrations into the repository while these openings are unplugged. (See 6.2)

Aquifers - For WIPP, the over- and underlying aquifers represent a secondary barrier if the salt is breached. Consequently low permeability and transmissivity are desirable but not mandatory. Accurate knowledge of aquifer parameters is important to construction, decommissioning and realistic calculation of the consequences of failure scenarios. (See 6.3)

Dissolution - Regional and/or local dissolution must not breach the repository while the wastes represent a significant hazard to man. While there are various suggestions for the time a repository should remain isolated from the biosphere, 250,000 years (ten half-lives of ^{239}Pu) is one period which may be sufficient for evaluating the WIPP site. (See 6.3.6)

Subsidence - Subsidence due to dissolution of salt will be avoided when the subsidence adversely affects the repository beds or unduly accelerates the rate of

dissolution to the jeopardy of long-term integrity of the repository. (See 6.3.6, 10.6)

Hydrologic Transport - For the WIPP, this is a secondary factor which must be evaluated to allow quantitative calculations of the consequences of various failure scenarios. Slow transport of isotopes is acceptable if more critical factors have been satisfied. (See 6.3, 9.3. 10.6)

Climatic Fluctuations - Possible pluvial cycles must be considered when estimating the effects of the above factors. (See 3.6, 4.5, Chapter 6, 10.3)

Man-made Penetrations - The effect of drill-holes and mining operations on the site selection must be evaluated in considerations of dissolution.

Tectonic Stability Criterion: [redacted] while the wastes represent a significant hazard to man and should not require extreme precautions during the operational period of the repository.

Factors: Seismic Activity - The frequency and magnitude of seismic activity impacts facility design and safety of operation. Low levels of seismicity are desirable but facility design can accommodate higher levels as well. (See Chapter 5, 10.5)

Faulting/Fracturing - While open faults, fractures or joints are not expected in salt, the more brittle units within and surrounding the salt may support such features which can enhance dissolution and hydrologic transport. Major faults and pronounced linear structural trends should be avoided. (See 3.4, 4.4)

Salt Flow/Anticlines - Major deformation of salt beds by flow can fracture brittle rock and create porosity for brine accumulations. Major anticlines resulting from salt flow should be avoided or evaluated to check on brine presence and anhydrite fracturing. (See 4.4)

Diapirism - An extreme result of salt flow, this feature will be avoided for WIPP siting. (See 4.4)

Regional Stability - Areas of pronounced regional uplift or subsidence should be avoided since such behavior makes anticipation of future dissolution, erosion and salt flow more uncertain. (See 3.4, 4.4, 10.3.2)

Igneous Activity - Areas of active or recent volcanism or igneous intrusion should be avoided to minimize these hazards to the repository. (See 3.5)

Geothermal Gradient - Abnormally high geothermal gradients should be avoided to allow construction in salt at 3000 feet. High gradients may also be indicative of recent igneous or tectonic activity. (Sec 4.4.1)

Physico-chemical Compatibility: The repository medium must not interact with the waste in ways which create unacceptable operational or long term hazards.

Factors: Fluid Content - The repository bed containing high level waste should not contain more than three percent brine. The limit for TRU waste has not been established, but the same value used for HLW is acceptable. (See 7.5, 10.7.8)

Thermal Properties - No major natural thermal barriers should exist closer than 20 feet to avoid undesirable temperature rises. (See 4.3, 9.2.3)

Mechanical Properties - The medium must safely support excavation of openings even while thermally loaded. Clay seams and zones of unusual structural weakness should be avoided in selection of the repository horizon. (See 9.2.4)

Chemical Properties/Mineralogy - Beds of unusual composition and/or containing minerals with bound water should not occur within 20 feet of the waste horizon. This will lessen the uncertainties with regard to thermally driven geochemical interactions. (See 4.3, 7.2, 7.3, 7.4, 7.5)

Radiation Effects - While no unacceptably deleterious effects are postulated, these phenomena are best quantified in halite and thus the purer rock salt beds are desired for high- level waste. (See 9.3)

Permeability - Salt has very low permeability and only the inter-beds and surrounding media are considered for siting with respect to this factor. Low permeability is desirable, but quantitative limits need not be specified for site selection. (Salt permeability to gases may be important in establishing waste acceptance criteria.) (See 9.2.3)

Nuclide Mobility - This is a secondary factor in siting since confinement by the salt and isolation from water is the basic isolation premise. Ion sorption must be determined to allow quantification of safety analyses and to indicate whether engineered barriers (clay) would be beneficial. (See 9.3)

Economic/Social Compatibility Criterion - [redacted]

Factors: Natural Resources - Unavoidable conflict of the repository with actual or potential resources will be minimized to the extent possible. (See Chapter 8)

Man-made Penetrations - Boreholes or shafts which penetrate through the salt into underlying aquifers shall be avoided within one mile of the repository. Existing mining activity, unrelated to the repository, should not be present within two miles of the repository. Future, controlled mining, will be allowable up to one mile from the repository. Future studies may permit still closer mining and drilling if properly controlled. (See 2.3, Chapter 4)

Transportation - Transportation should be capable of ready development. Avoidance of population centers by transportation routes is not a factor in WIPP siting. (Not addressed in GCR)

Accessibility - The site should be readily accessible for transportation and utilities. (Not specifically addressed in GCR; see Chapter 2 figures)

Land Jurisdiction - [redacted] will be on federally controlled land to the extent possible. (Not specifically addressed in GCR; see Chapter 2 and 8 figures)

Population Density - Proximity to population centers and rural habitats will be considered in siting. Low population density in the immediate site area is desirable. (Not addressed in GCR)

Ecological Effects - Major impacts on ecology due to construction and operation should not occur. Archaeological and historical features of significance should be preserved. (Not addressed in GCR)

Sociological Impacts - Demographic and economic effects should not result in unacceptable sociological impacts. (Not addressed in GCR)

One may [redacted] having the greatest impact as follows:

Avoidance of land within one mile of any boring through the Ochoan evaporites and into the Delaware or deeper formations.

Salt of high purity at a depth between 1000 and 3,000 ft.

Avoidance of areas where dissolution had advanced to the top of Salado or deeper levels, by establishing a distance of one mile or more from dissolution fronts at the top of Salado.

Avoidance of possible salt deformation in a belt 6 miles wide basinward from the Capitan reef.

Avoidance of pronounced known anticlinal structures.

Avoidance of known oil and gas trends.

Avoidance of the known potash enclave above the repository and minimizing conflict with the known enclave in the buffer zone.

Minimize existing potash lease rights in Zones I and II.

Minimize state and private land in Zones I through IV.

These criteria were applied to all areas within the Delaware Basin in New Mexico. Figure 2-8 illustrates result of application of the expanded set of criteria. Two alternate sites survived the constraints imposed by the site selection criteria.

2.3.7 Preferred Preliminary Site Selection

Since only two alternate sites in the New Mexico part of the Delaware Basin withstood the set of revised Stage II siting criteria, the preliminary selection of a preferred site was fairly straightforward. Alternate I, now known as the Los Medanos site, appeared to be the preferred site. Alternate II was considered less desirable because it was restricted in size, the acceptable salt zones were deeper, and the high-purity salt lying between the Cowden anhydrite (in the lower Salado Formation) and the Castile was thought to be absent. The top of the Salado was about 800 feet deep at Los Medanos versus 1500 feet at Alternate II. Other factors that favored the selection were:

Structural interpretation of what seismic data was then available to Sandia indicated the Los Medanos site would be in a synclinal area unfavorable for oil and gas acccumulation.

Similarly, if the site were in a syncline, geopressured brine reservoirs would be less likely.

The Alternate II area lay adjacent to the Double X and Triple X shallow oil fields where water flooding for secondary recovery could occur.

No seismic exploration data whatsoever was available to Sandia on the Alternate II area, and only partial coverage at Los Medanos.

Sandia Laboratories selected the Los Medanos alternate as the best candidate area in early December, 1975. Figure 2-9 illustrates how the siting criteria apply to the Los Medanos site.

Geological characterization activities were then expanded to focus on obtaining subsurface data at the Los Medanos site. A descriptive summary of these programs is given in Section 2.5.

2.4 STATUS OF STUDIES

In review, geologic studies for the WIPP fall naturally into three different phases: preliminary site selection activities, geological characterization, and studies of long-range geologic processes affecting a repository. Preliminary site selection activities are complete now; these consisted primarily of national and regional studies over the past fifteen years, and resulted in selection of the WIPP study area for geological characterization. The work of geological characterization should be considered to have begun with the drilling of ERDA 9 and the initiation of seismic reflection work on the site. That geological characterization, which is primarily oriented to provide specific data concerning the present geology of the site, will be virtually complete in 1978 when this Geological Characterization Report is submitted to DOE; much basic information has been gathered indicating no major technical problems with the site as it is now understood. Studies of long-term

processes which might affect a repository or have an effect on safety analyses will be the major geotechnical activity for the WIPP project after 1978, although some of these activities are already underway. These studies will concern the age of significant features and the rates and processes which produce those features. The information so gained will be useful in increasing the confidence in evaluation of the safety of a repository when a decision is necessary regarding conversion of the WIPP to a repository.

2.5 EXPLORATION TECHNIQUES

Much of the geological characterization of the WIPP study area is done using exploration geophysics and boreholes. About 75 line miles of new seismic reflection data and 9000 resistivity measurements were collected and 47 drillholes completed to support WIPP geological characterization to date (August, 1978). For convenience, the boreholes are listed in Table 2-2 according to primary objective. Twelve geologic exploratory holes (two by ORNL and ten by Sandia Labs) have been drilled to date in support of this program (Table 2-2A); three holes were drilled at the old study area, two are located off the WIPP site, and seven were drilled on the WIPP site. ERDA 9 is located at the center of the present study area (Figure 2-10). These boreholes were extensively logged, cored, and drill-stem tested in the evaporite section. The cores form the basis for several continuing laboratory studies that are important to an understanding of the physical and chemical phenomena associated with the WIPP and contribute to general knowledge about the formation of evaporites. Two of the exploratory boreholes have been drilled well outside the immediate site to obtain dissolution and paleoclimate data. Twenty-one holes (Table 2-2B) were drilled in conformance with industry standards to obtain core from the potash zones to supplement more than 30 existing industry holes for evaluation of potash resources within the WIPP study area by the USGS and the U.S. Bureau of Mines (Figure 2-11). When that evaluation is complete, others may use the core for studies of potash ore formation. Fourteen hydrologic holes (Table 2-2C) have been drilled and four potash holes converted to hydrologic monitoring to

provide a total of eighteen holes now dedicated to hydrologic studies. Hydrologic tests of the Bell Canyon Formation underlying the evaporites have also been conducted in two of the exploratory boreholes, one northeast and one south of the site. Except for ERDA 9, none of the boreholes within Zones I, II, or III penetrate as deep as the repository horizons. Future holes will sample repository horizons within these zones.

Seismic reflection data available from petroleum companies and 26 line miles initially obtained strictly for the study area (Figure 2-12), were collected using standard techniques for the petroleum industry. The data are excellent for interpreting deeper structure, but are not as useful for showing reflectors in the upper 3000 feet. In 1977, about 48 line miles of new data (Figure 2-13) were collected using shorter spacings for geophones, higher frequencies from vibroseis units, and higher rates of data sampling. These data show much improved reflections from, and better resolution in, the shallow section of interest. Resistivity has also been extensively used as a characterization tool. Field tests indicated that resistivity could detect certain types of solution features; more than 9,000 measurements have been taken in the study area to search for such features (Figure 2-14). Additional measurements of resistivity using expander arrays have been made to study resistivity changes with depth and to help interpret the detailed measurements (Figure 2-15). Analysis of geophysical data for the geological characterization was nearly complete by Summer, 1978. One resistivity anomaly was drilled to determine the cause of the anomaly and consequences, if any, for the WIPP. This anomaly did not result from dissolution phenomena. Further detailed geophysical investigation of the site, using techniques previously described for better resolution of shallow horizons, is now underway (Summer, 1978) for the primary purpose of providing detailed engineering information.

A variety of studies to continue geological characterization and contribute to long-range assessments are under way. Studies directed primarily toward geochemistry include water chemistry and stable isotope

studies of surface and subsurface water of the Delaware Basin; fluid inclusion studies of the evaporite beds; chemical and mineralogic effects of an igneous intrusion into the evaporite section; Rb/Sr dating of potash ores; and sorptive capacities of evaporites and associated rocks for various radionuclides. The dissolution history for the area and the local paleoclimate are being investigated through analysis of a core taken from a sink in nearby San Simon Swale. Field investigations of the climatic history and stability of the Pecos River drainage are beginning, and caliche studies will form a significant part of this effort. Studies of LANDSAT images will conclude in 1979. In addition, the first 200 km of the first-order level line from Carlsbad to El Paso, Texas, has been resurveyed to examine regional tectonic movements associated with the West Texas salt flats graben and trans-Pecos volcanic area. A first-order level line has also been established from Carlsbad east to the WIPP site through Nash Draw for future assessment of tectonic, erosion, solutioning, and subsidence phenomena. Further assessment of basin tectonics may be derived through measurements of <u>in situ</u> stress. These long-range studies will continue until sufficient data are available to permit reasonable and confident assessment of the risks involved in having a repository in bedded salt in southeastern New Mexico. These studies, plus the successful operation of the WIPP as a demonstration facility, are essential for the development of criteria for the conversion of the WIPP to a repository.

2.6 SUMMARY

Bedded salt has been a leading candidate as a rock type for the storage of radioactive waste; a combination of technical factors has led to the examination of the Delaware Basin in southeastern New Mexico as a location for the WIPP. Through preliminary site selection and partial site characterization of an early site near the WIPP, site selection criteria and factors which are rather specific to southeastern New Mexico were refined, and a new preliminary site was selected. Chapter 2 contains the description of the criteria and factors used in this process as an introduction to the geological characterization of the WIPP site

which is presented in the following chapters. The geological techniques used in the characterization of the WIPP site are a combination of well-tested conventional techniques supported by state of the art tools. Multiple, supporting techniques are used where appropriate. Continuing geological studies will increase the data base for assessment of the WIPP as a repository and allow refinement of criteria for conversion to a repository.

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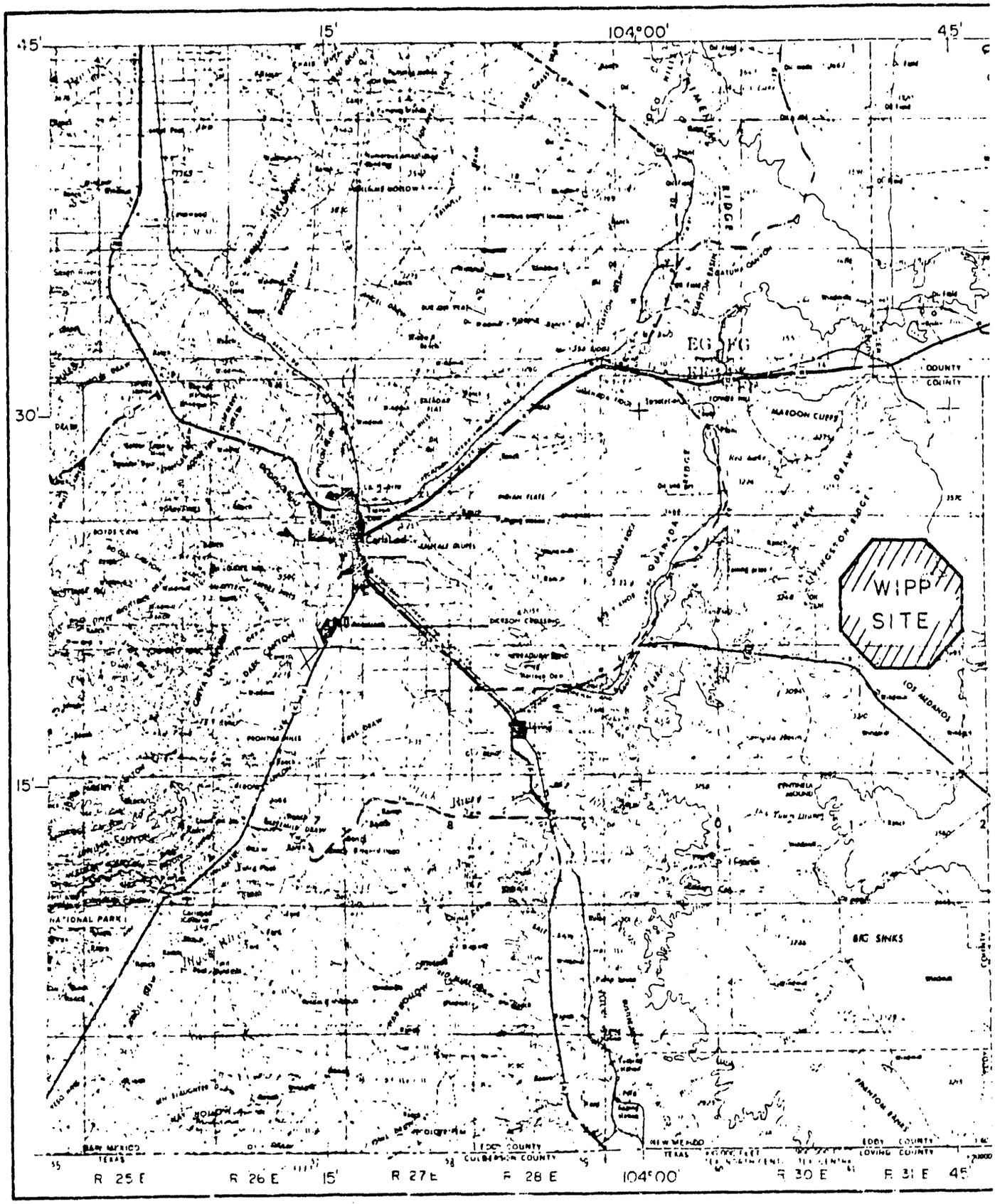
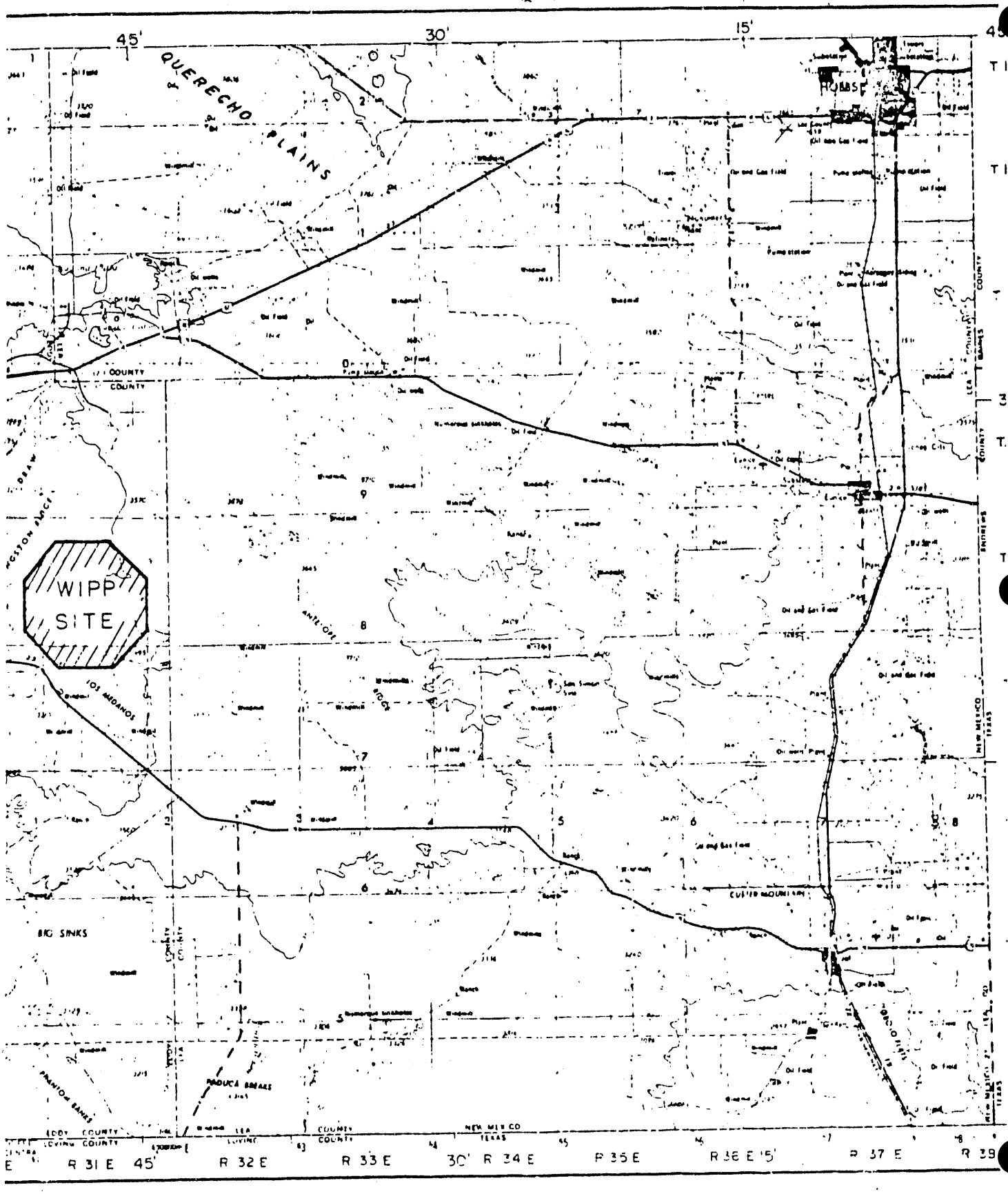

15'
104°00'
45'
30'
15'
WIPP
SITE
EG FG
BIG SINKS
NATIONAL PARK
R 25 E
R 26 E
15'
R 27 E
R 28 E
104°00'
R 30 E
R 31 E
45'


45'
30'
15'
QUERECHO PLAINS
HOBBS
WIPP SITE
LOS MEDANOS
ANTELOPE RIDGE
BIG SINKS
PADUCA BREAKS
CULP BREAKS
CUTTER MOUNTAIN
LEA COUNTY
EDDY COUNTY
LOVING COUNTY
NEW MEXICO
TEXAS
R 31 E
45'
R 32 E
R 33 E
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R 36 E
15'
R 37 E
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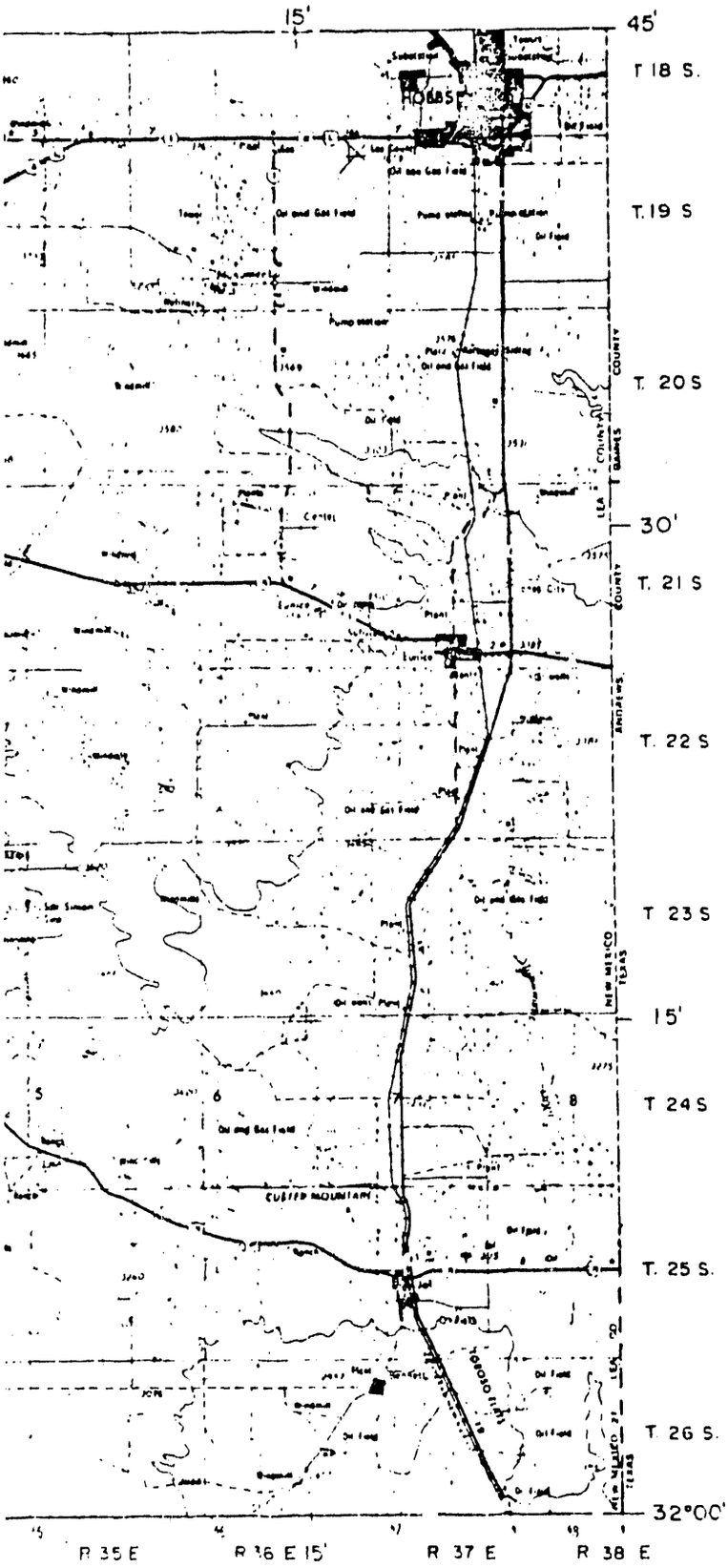
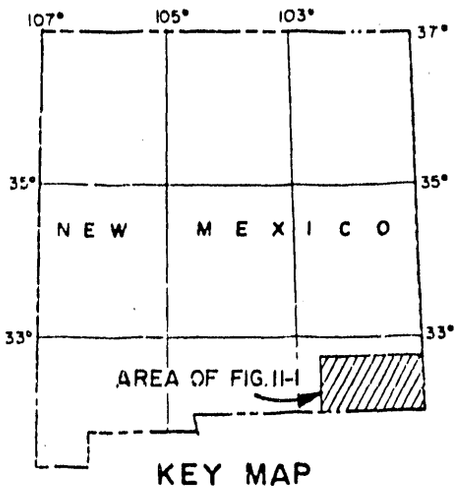




KEY MAP

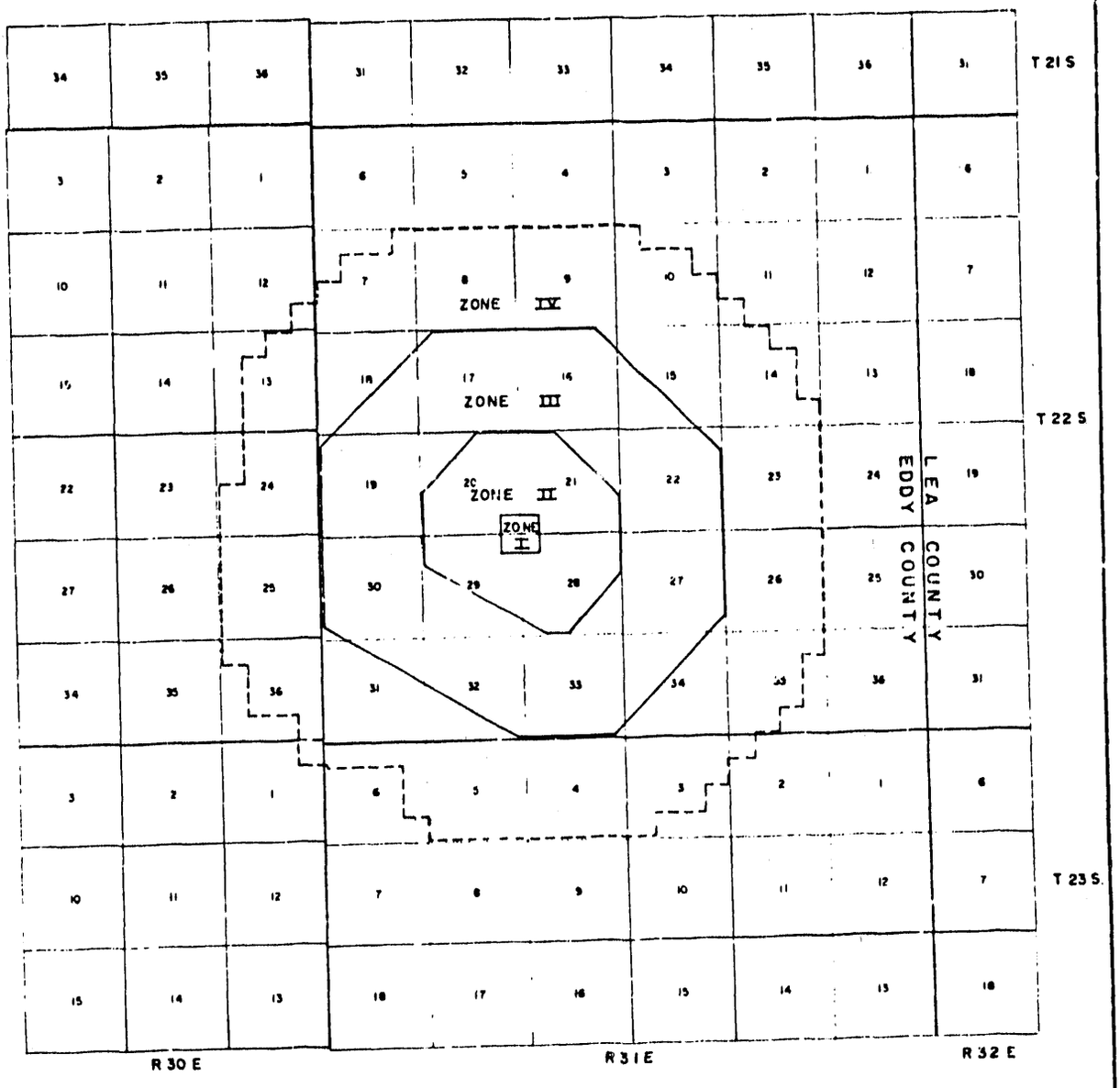
0 100 200 300KM
0 50 100 150 200MI
SCALE

Base map from U.S.G.S. 1:250,000 series Carlsbad and Hobbs sheets.

0 5 10 15 20KM
0 5 10 15 MI
S C A L E

GEOGRAPHIC LOCATION MAP

FIGURE 2-1



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ZONE ACREAGE

ZONE I - 60-100 (surface facilities)

ZONE II - 1860 (underground repository)

ZONE III - 6230 (no mining or drilling)

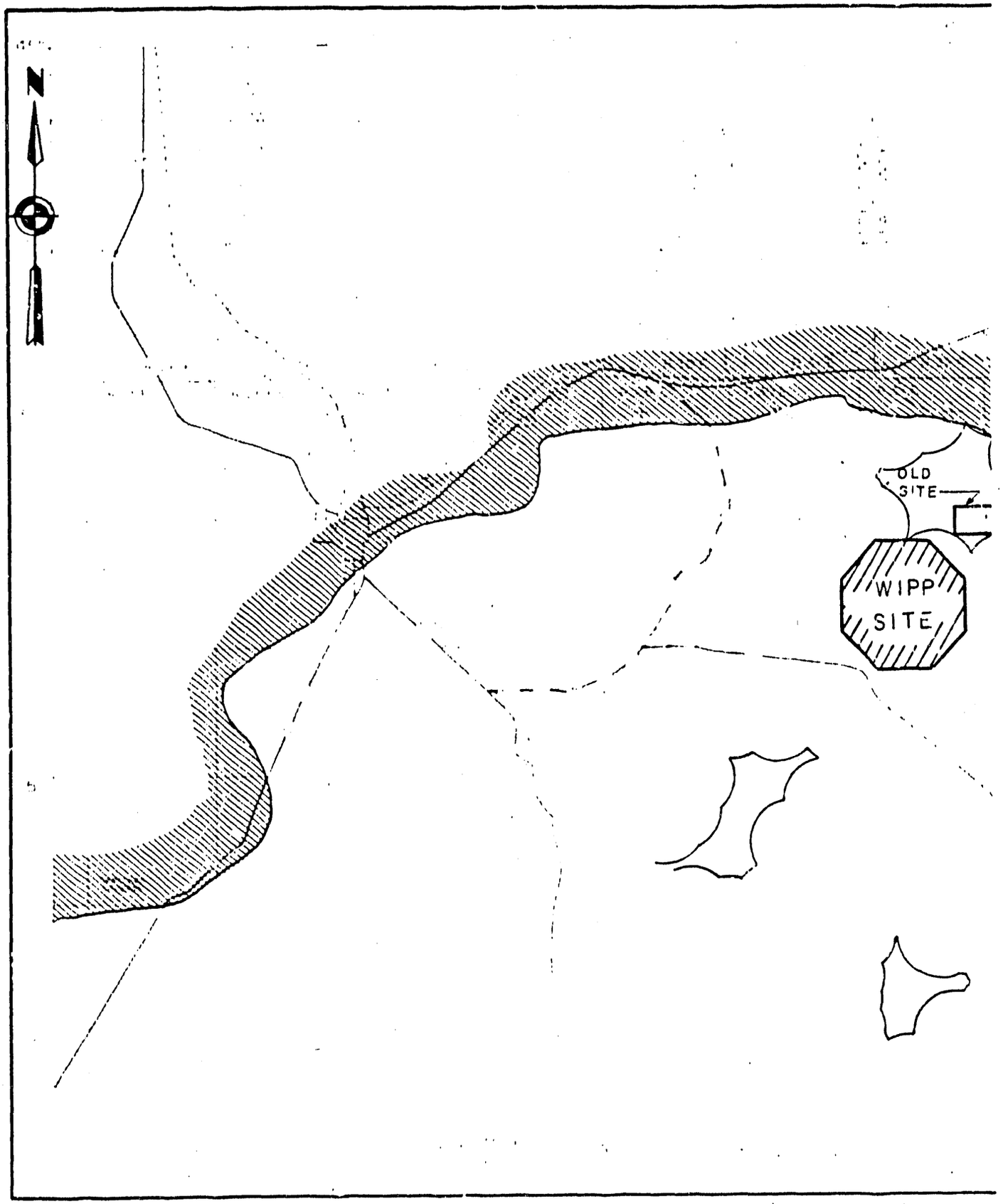
ZONE IV - 10,810 (DOE-controlled mining and drilling)

1 0 1 2 3

SCALE IN MILES

WIPP SITE ZONATION

FIGURE 2-2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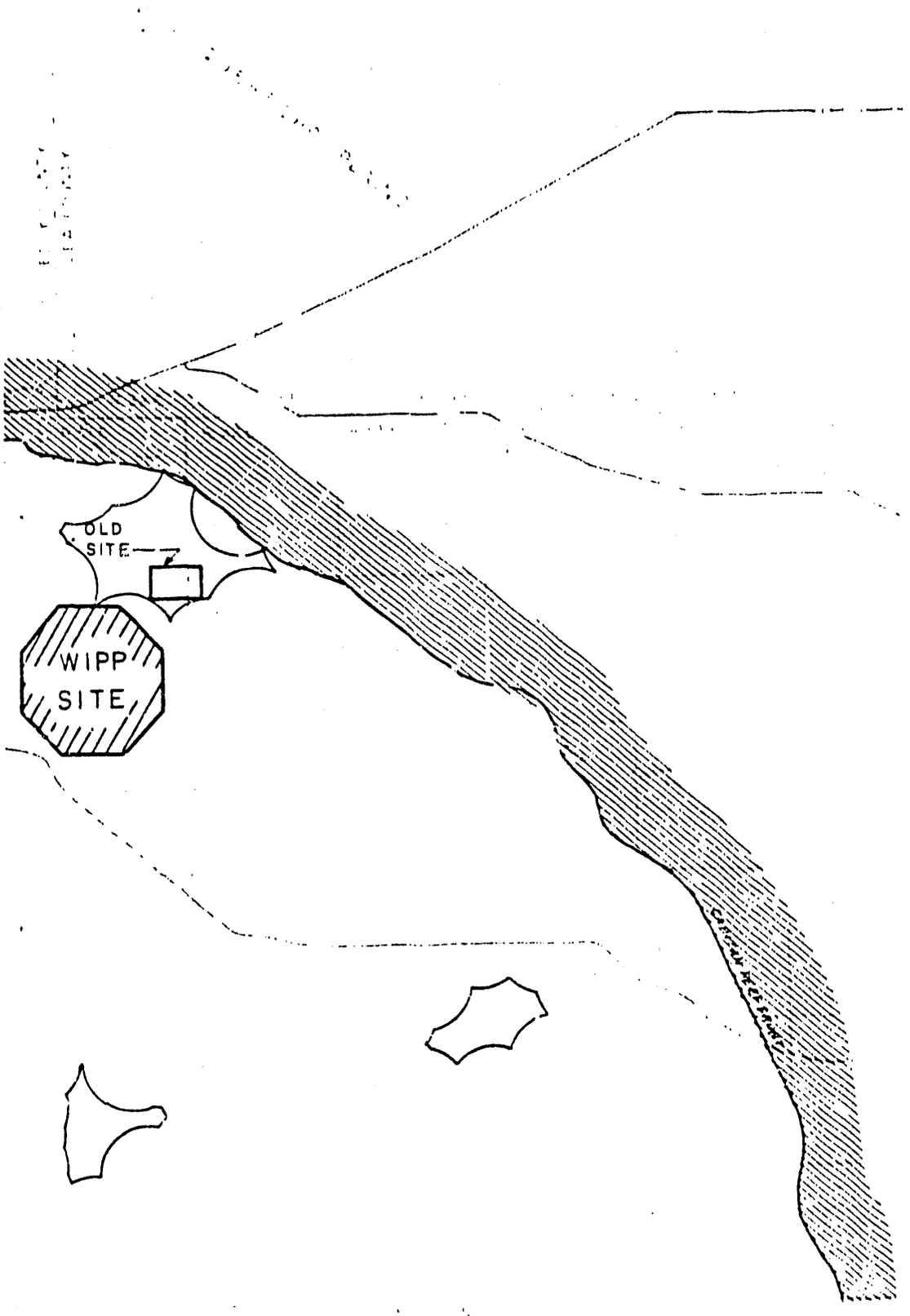
WIPP
SITE


OLD
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WIPP
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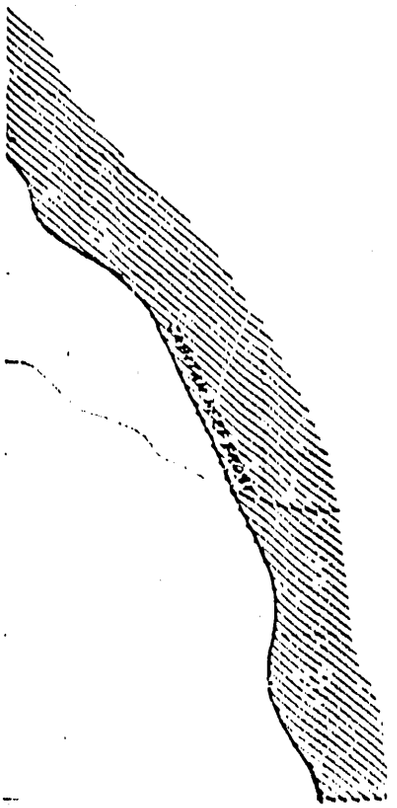


EXPLANATION

CAPITAN REEF FRONT

AREAS MORE THAN TWO MILES FROM DEEP DRILL HOLES

REFERENCE:

GRISWOLD, 1977, FIGURE 1

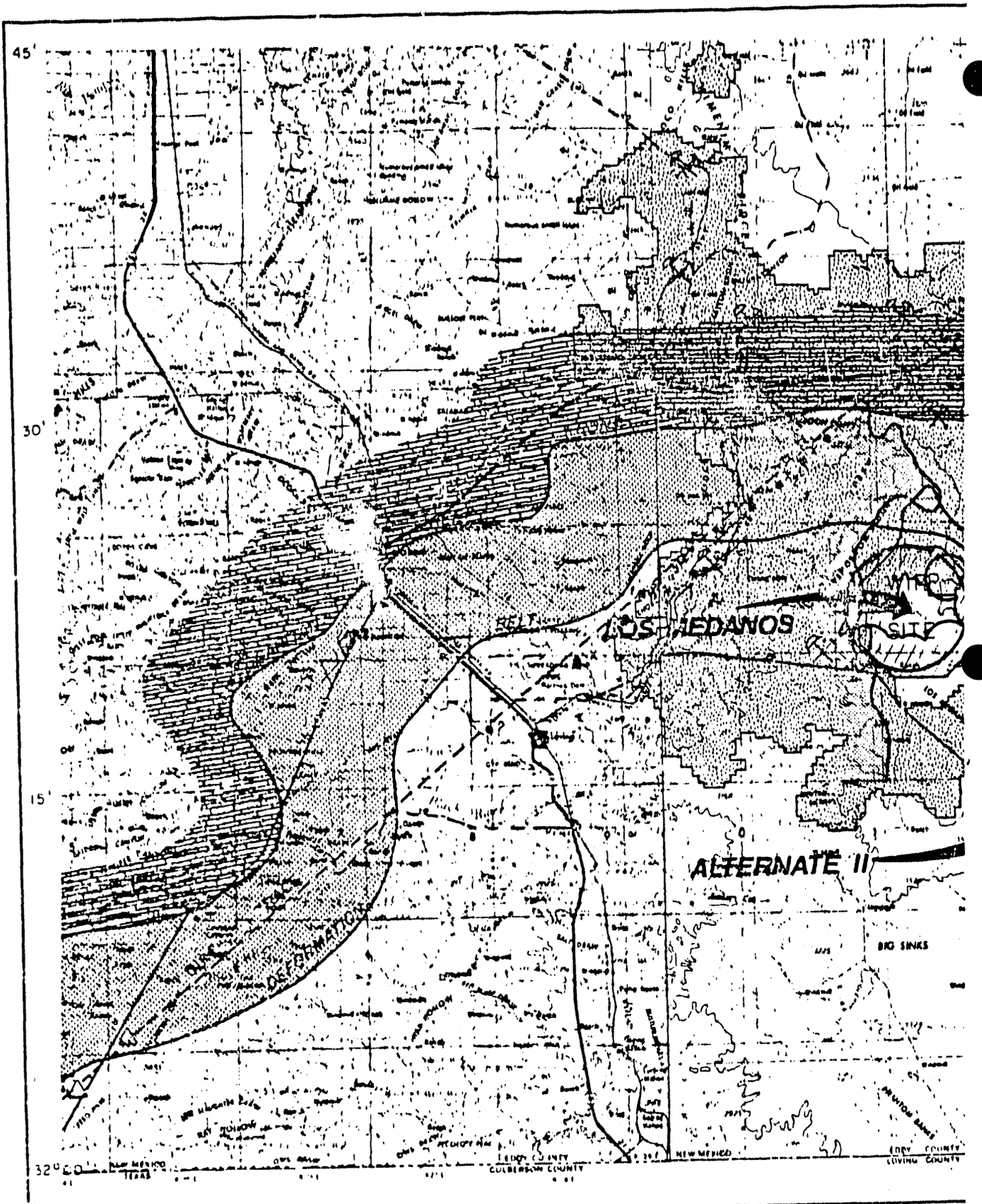
0 5 10 15 20 KM

0 5 10 15 MI

SCALE

APPLICATION OF
PRELIMINARY SITE
SCREENING CRITERIA BY ORNL

FIGURE 2-3



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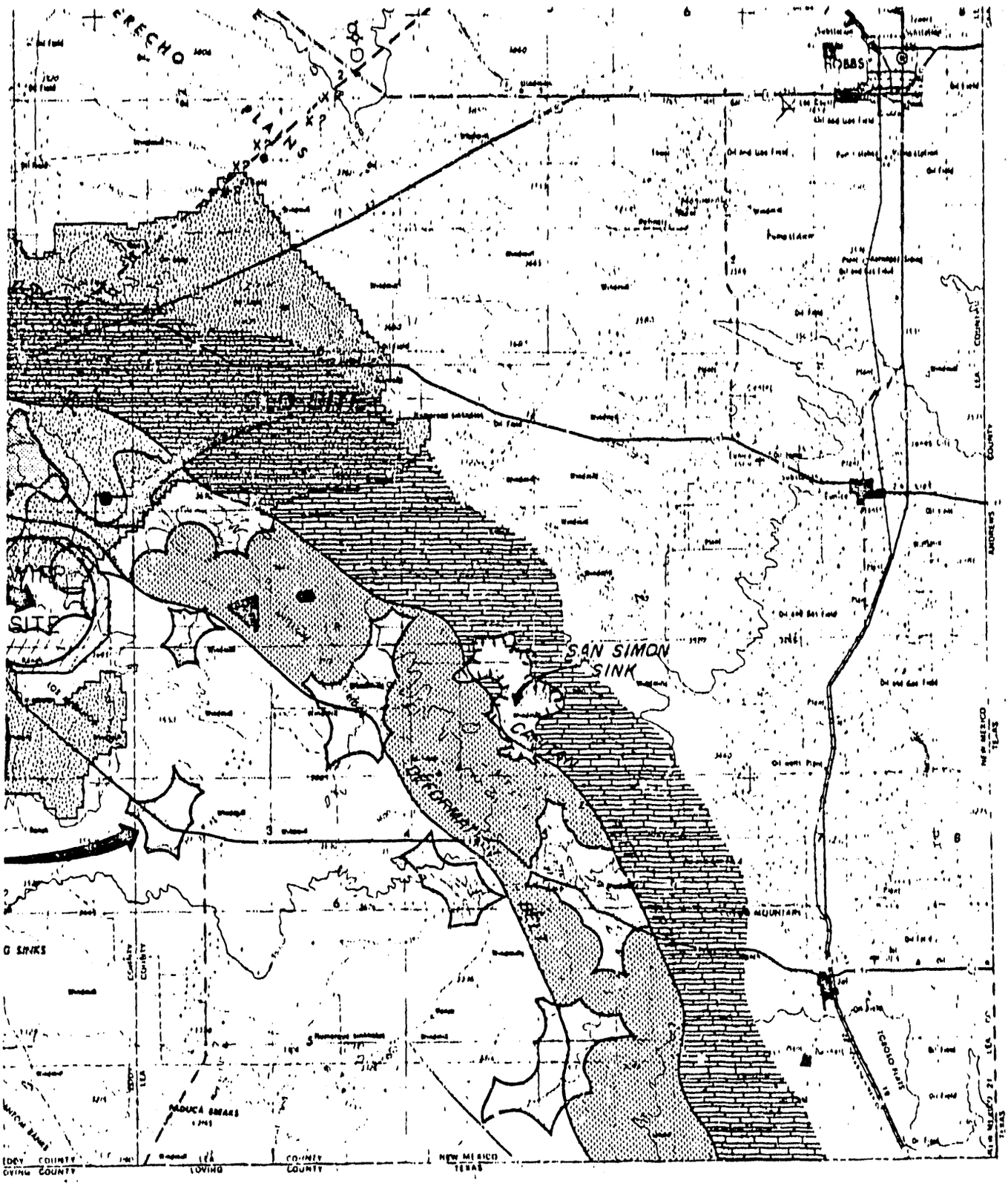
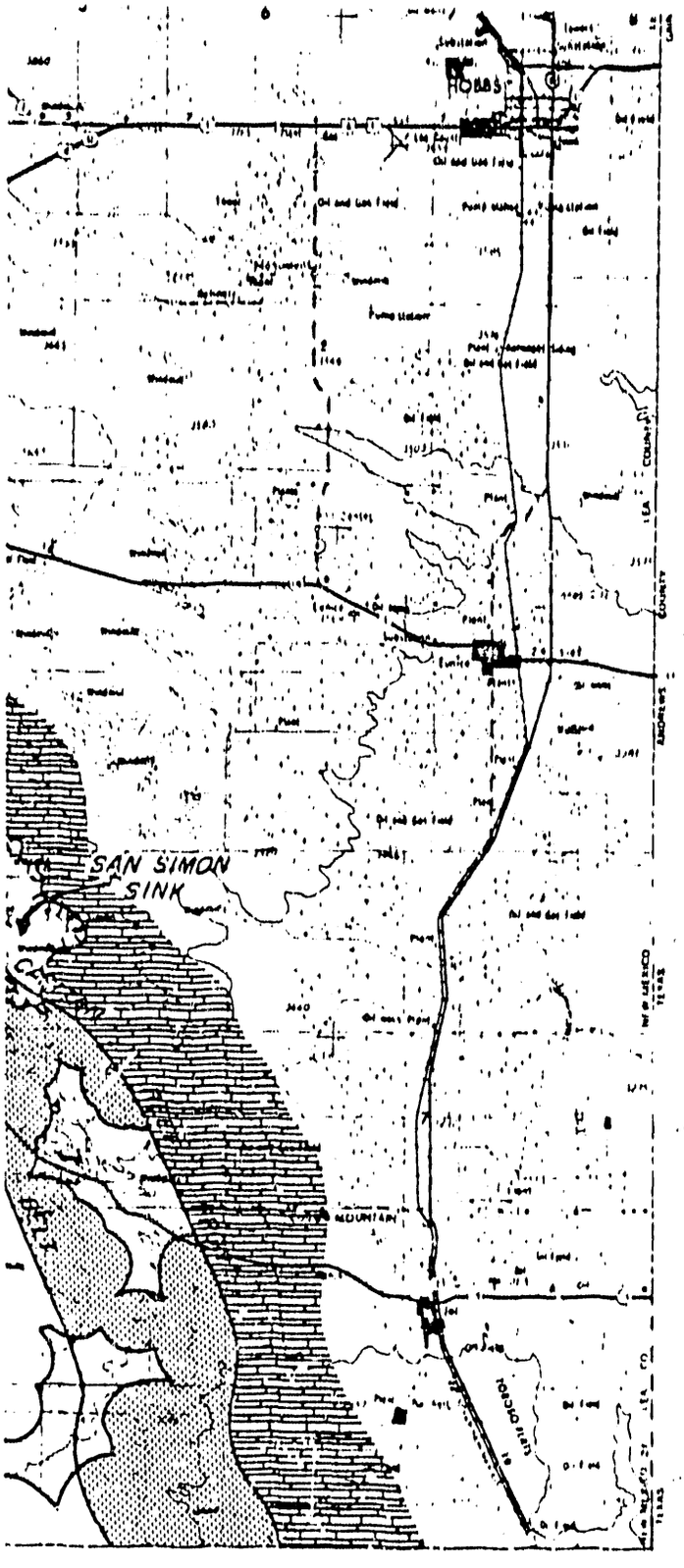

ERECHO PLAINS
HOBBS
SAN SIMON SINK
MOUNTAIN
LEA COUNTY
NEW MEXICO
TEXAS



EXPLANATION

AREAS MORE THAN ONE MILE FROM DEEP DRILL HOLES

CAPITAN REEF FRONT

DEFORMATION BELT

DISSOLUTION FRONT AT TOP OF SALADO

KNOWN POTASH ENCLAVE

ARTESIAN BRINE FLOW (1, 2 OR 3 WELLS)

DIKE TREND SYMBOLS

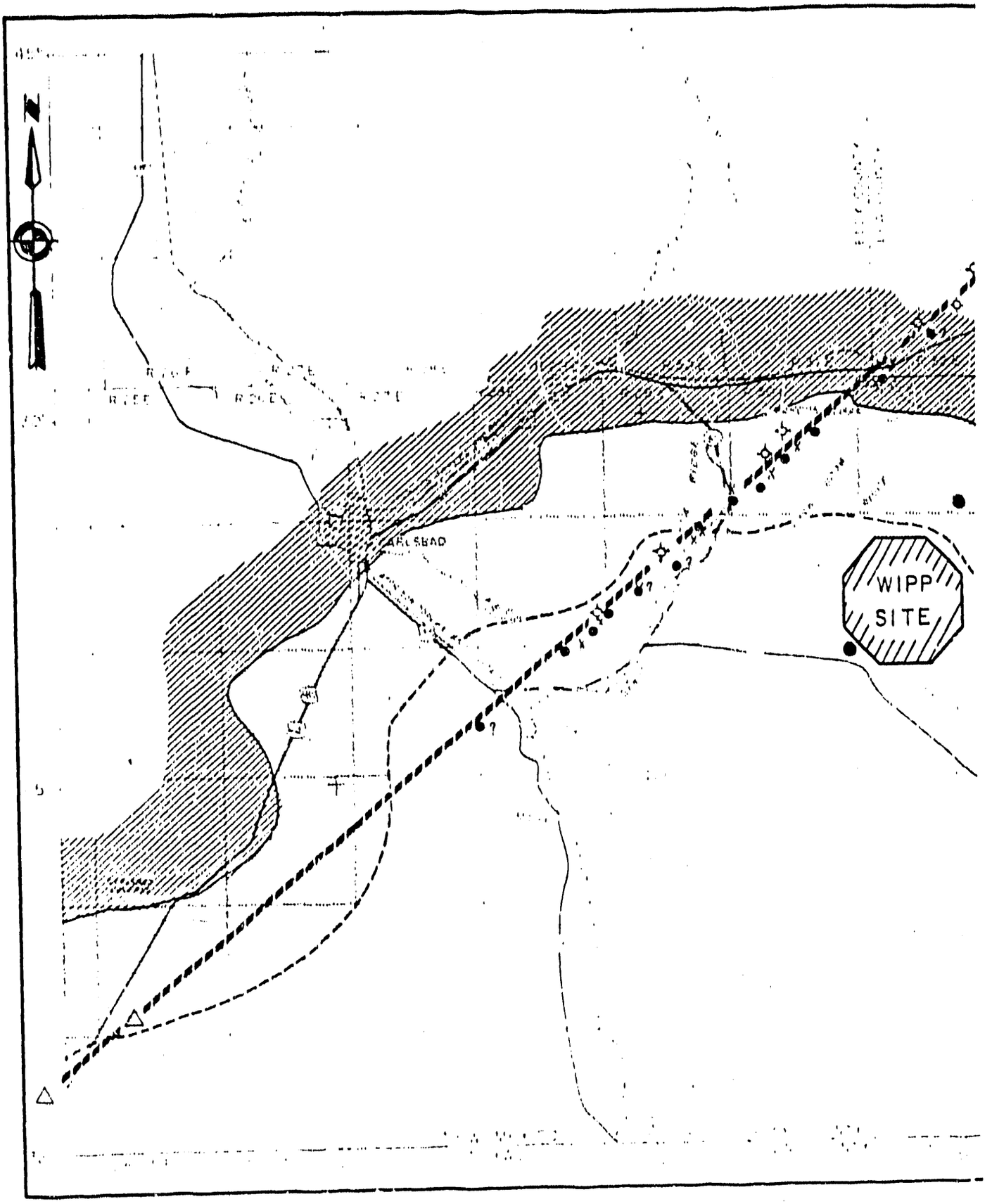
- Outcrop of Dike
- Well Intercept of Dike
- Airborne Magnetic Response - 1980
- Airborne Magnetic Response - 1983-84

0 5 10 15 20 KM.
0 5 10 15 MI
SCALE

REFERENCE:
GRISWOLD, 197?

SUMMARY OF APPLICATION OF SITE SELECTION CRITERIA BY SANDIA

FIGURE 2-4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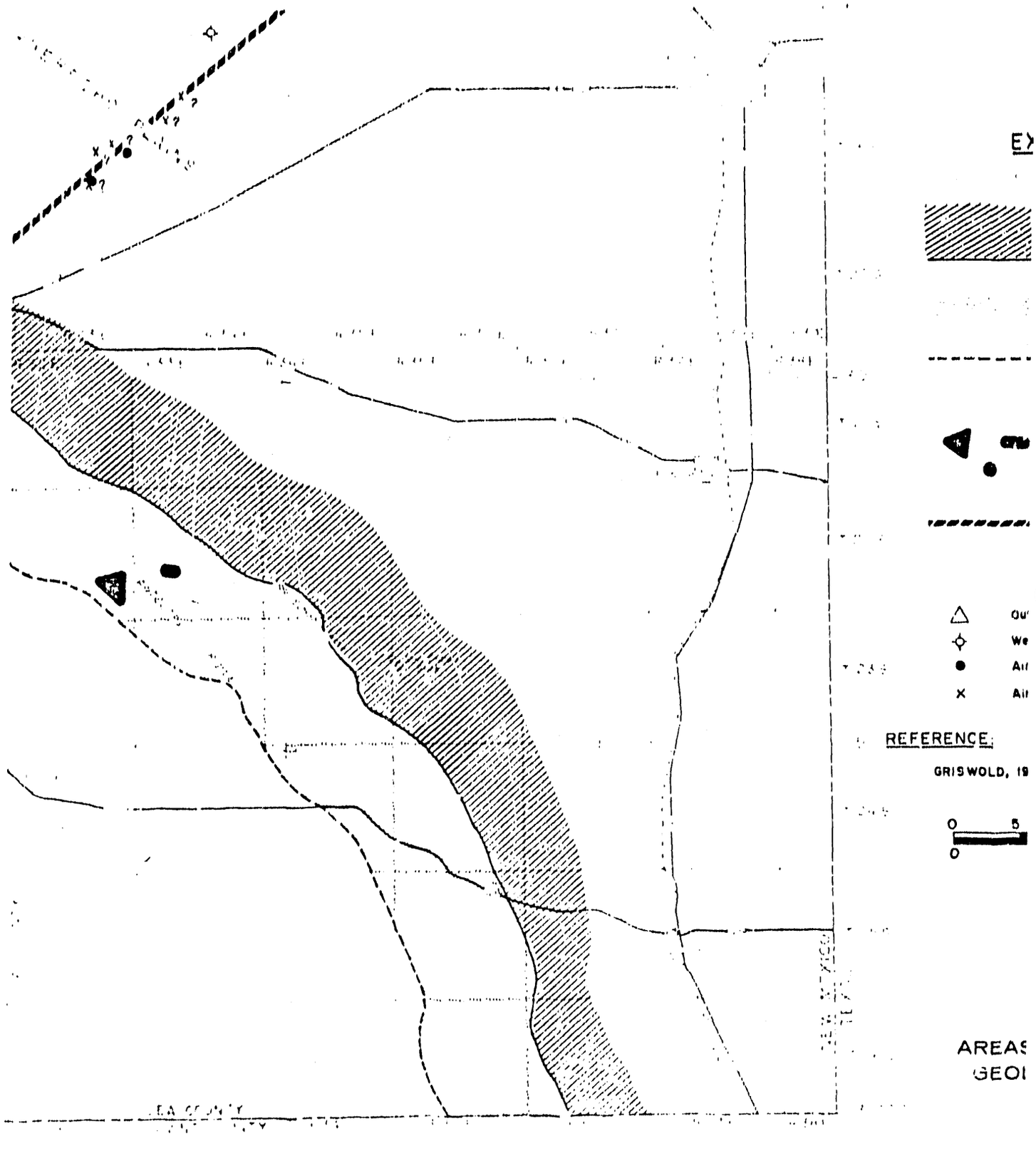
CARLSBAD
WIPP
SITE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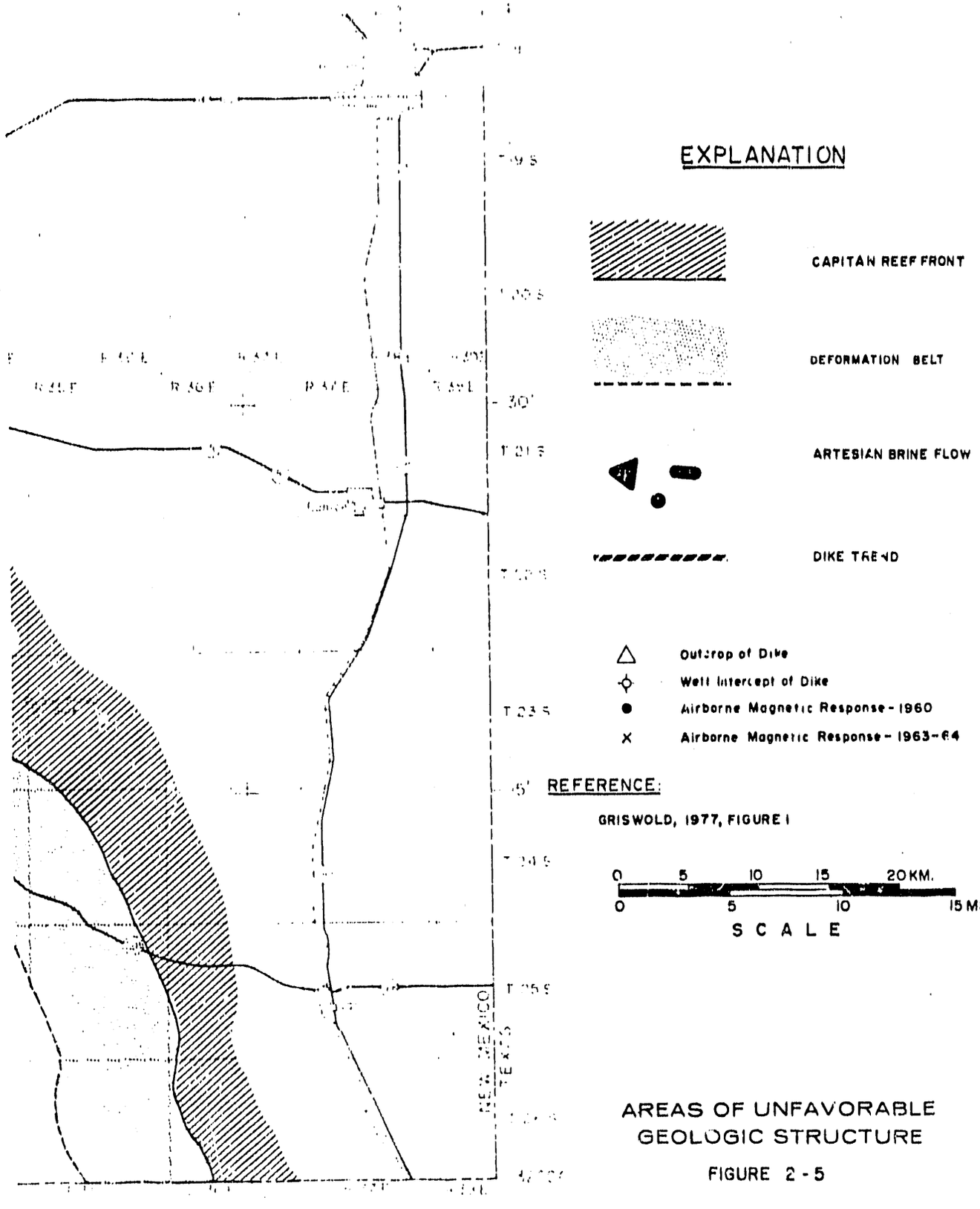
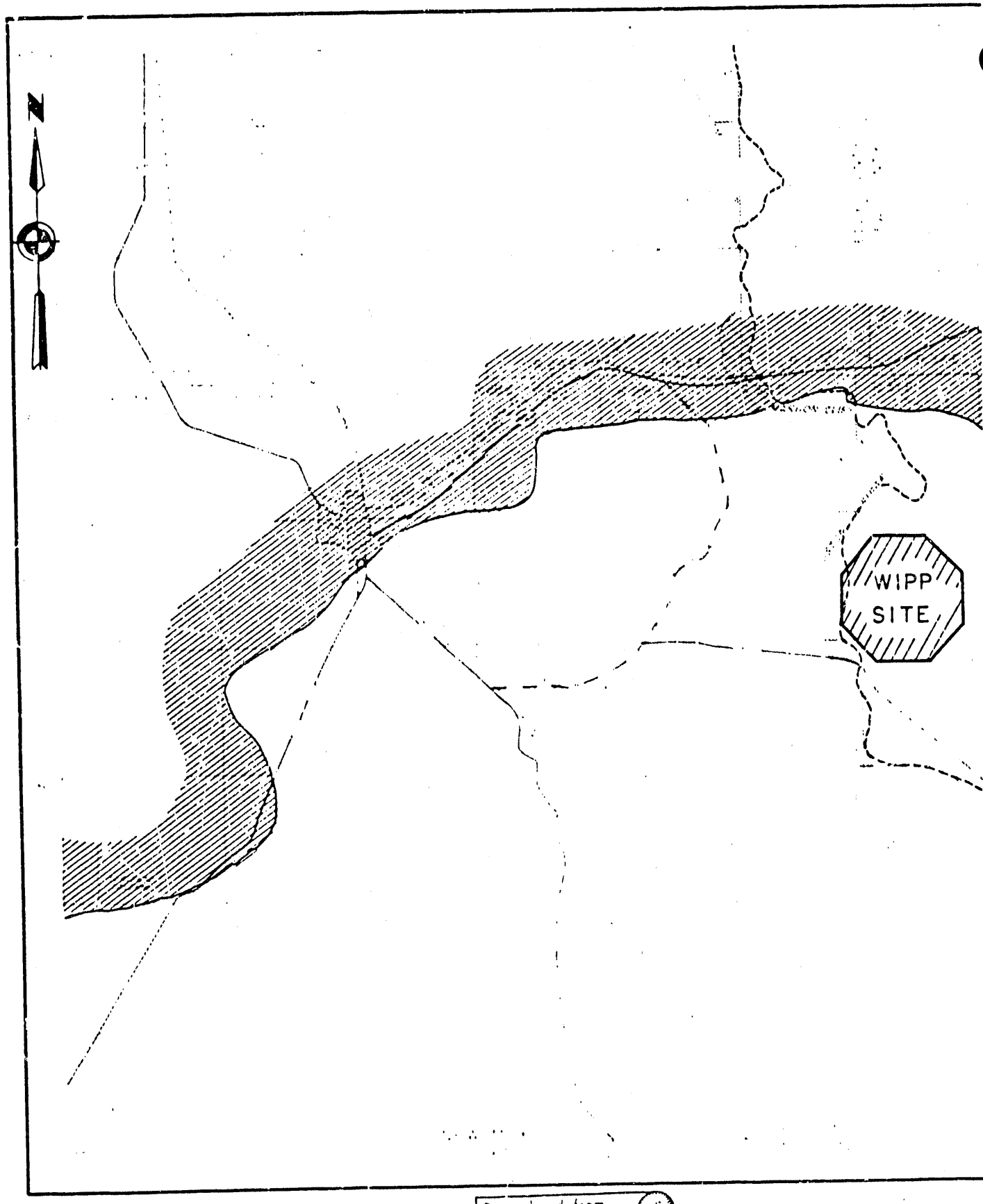


AREAS OF UNFAVORABLE GEOLOGIC STRUCTURE

FIGURE 2 - 5



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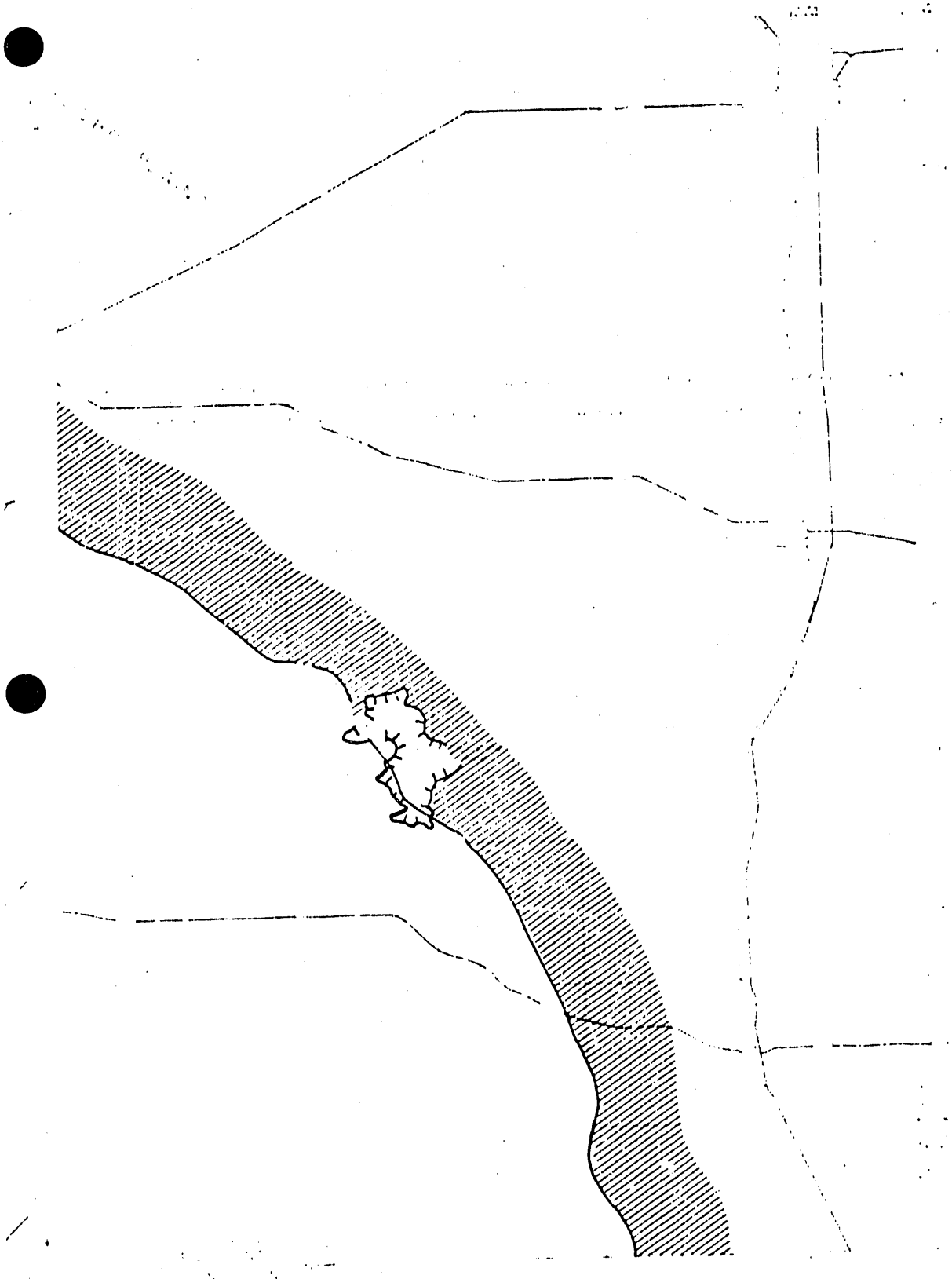

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REFERENCES:

GRISWOLD, 1977, F
BROKAW, ET AL, 1
JONES, 1973, FIG

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SUBSURFA
EXCLU

FIGUI

EXPLANATION

CAPITAN REEF FRONT

DISSOLUTION FRONT AT TOP OF SALADO (MOVING WEST TO EAST)

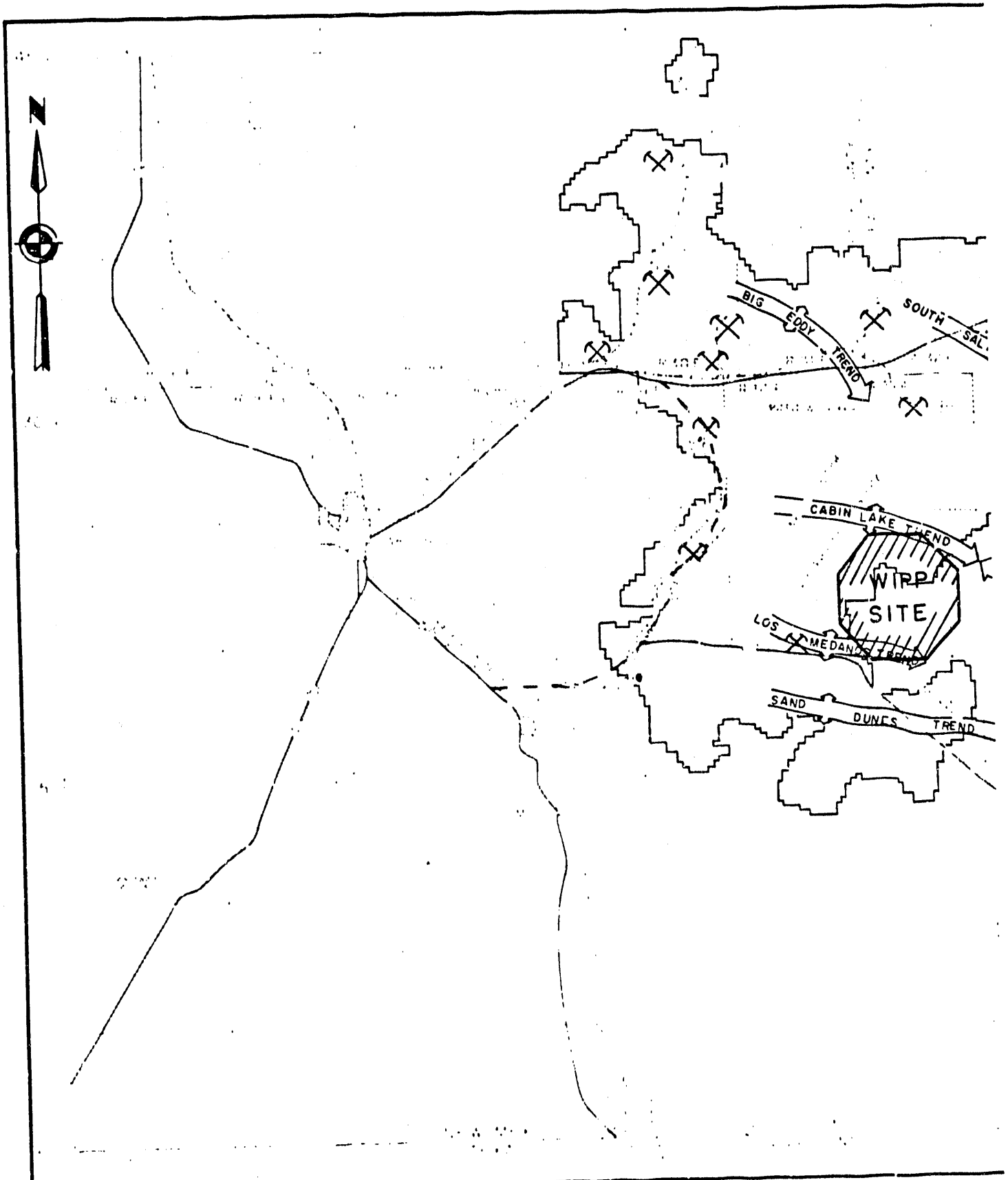
REFERENCES:

GRISWOLD, 1977, FIGURE 1
BROKAW, ET AL, 1972, FIGURE 8
JONES, 1973, FIGURE 7

0 5 10 15 20 KM.
0 5 10 15 MI
SCALE

SUBSURFACE HYDROLOGIC EXCLUSION AREAS

FIGURE 2-6



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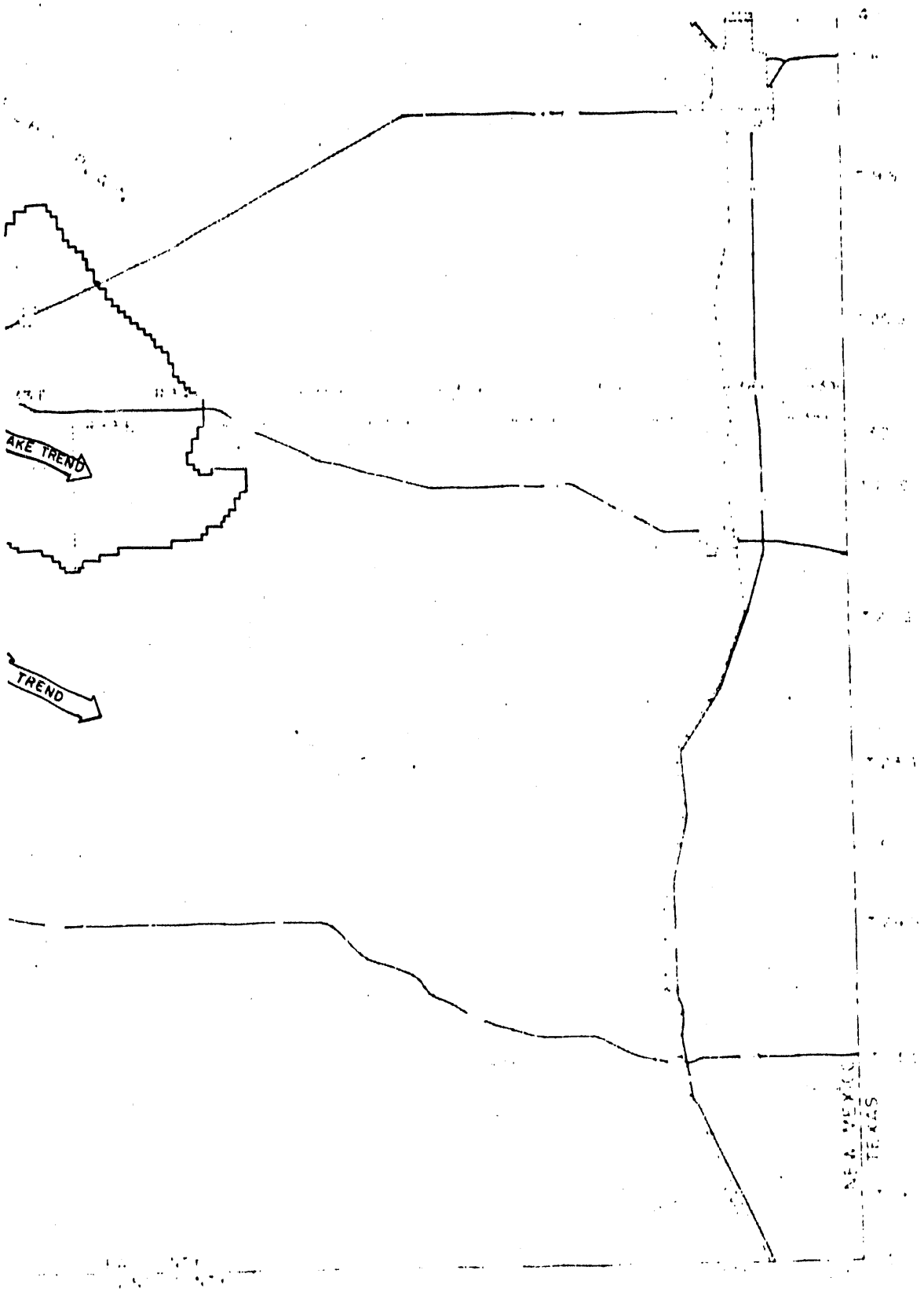

EXPLAI

REFERENCES:

1. Griswold,
2. Netherlan

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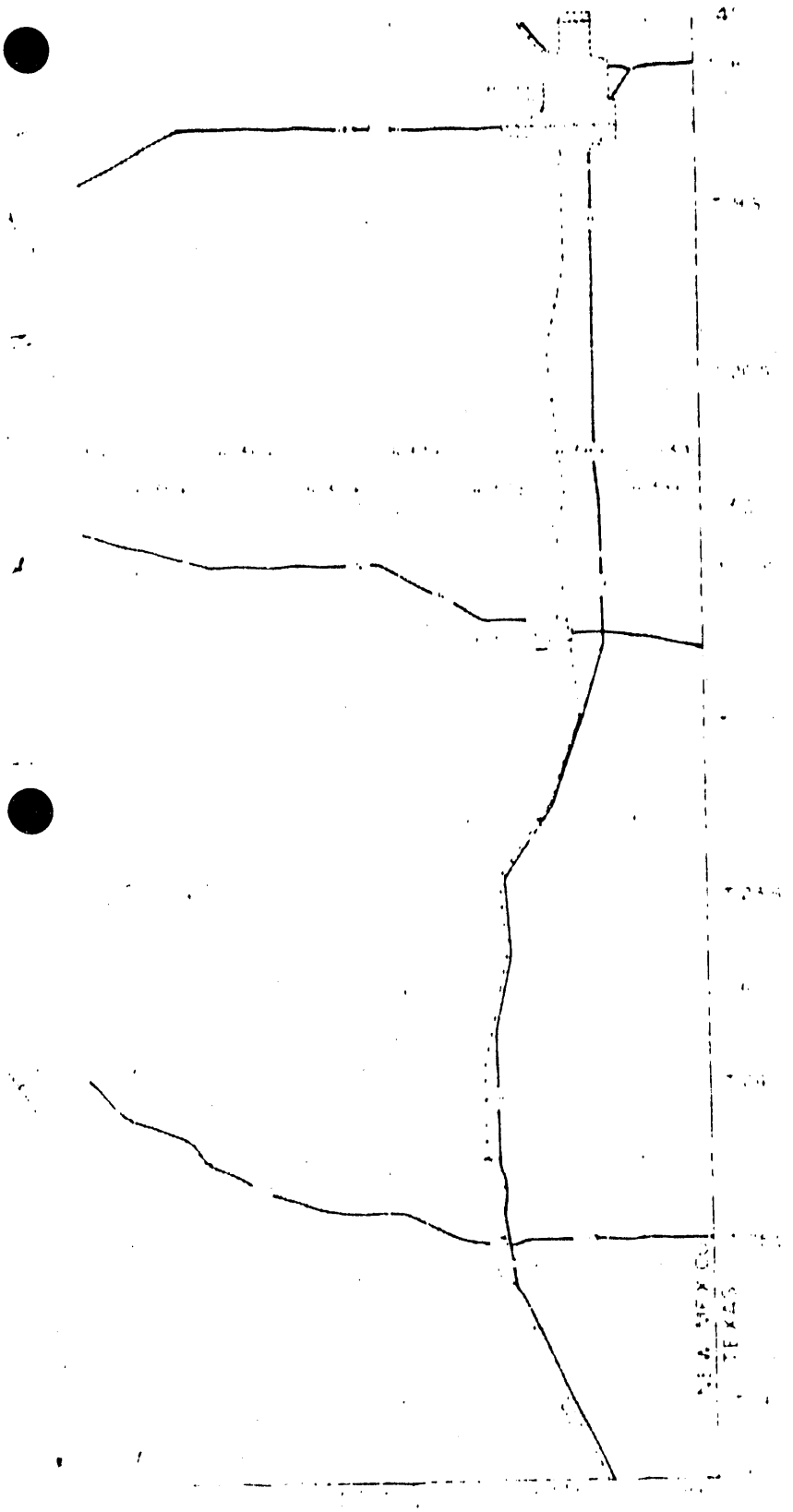
MINERAL F
EXCLUS

FIGURE



EXPLANATION

OIL OR GAS TREND

POTASH ENCLAVE

POTASH MINES

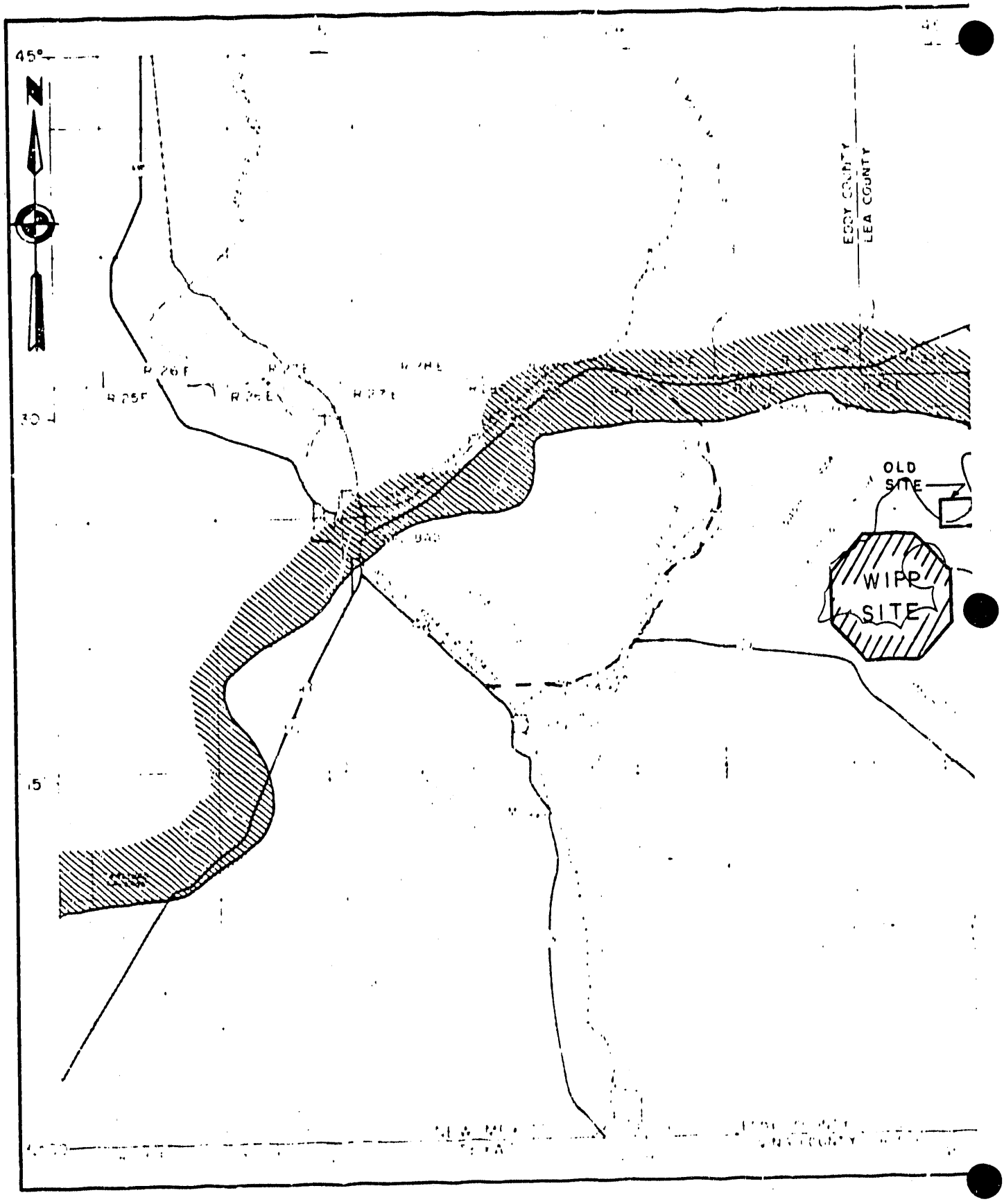
REFERENCES

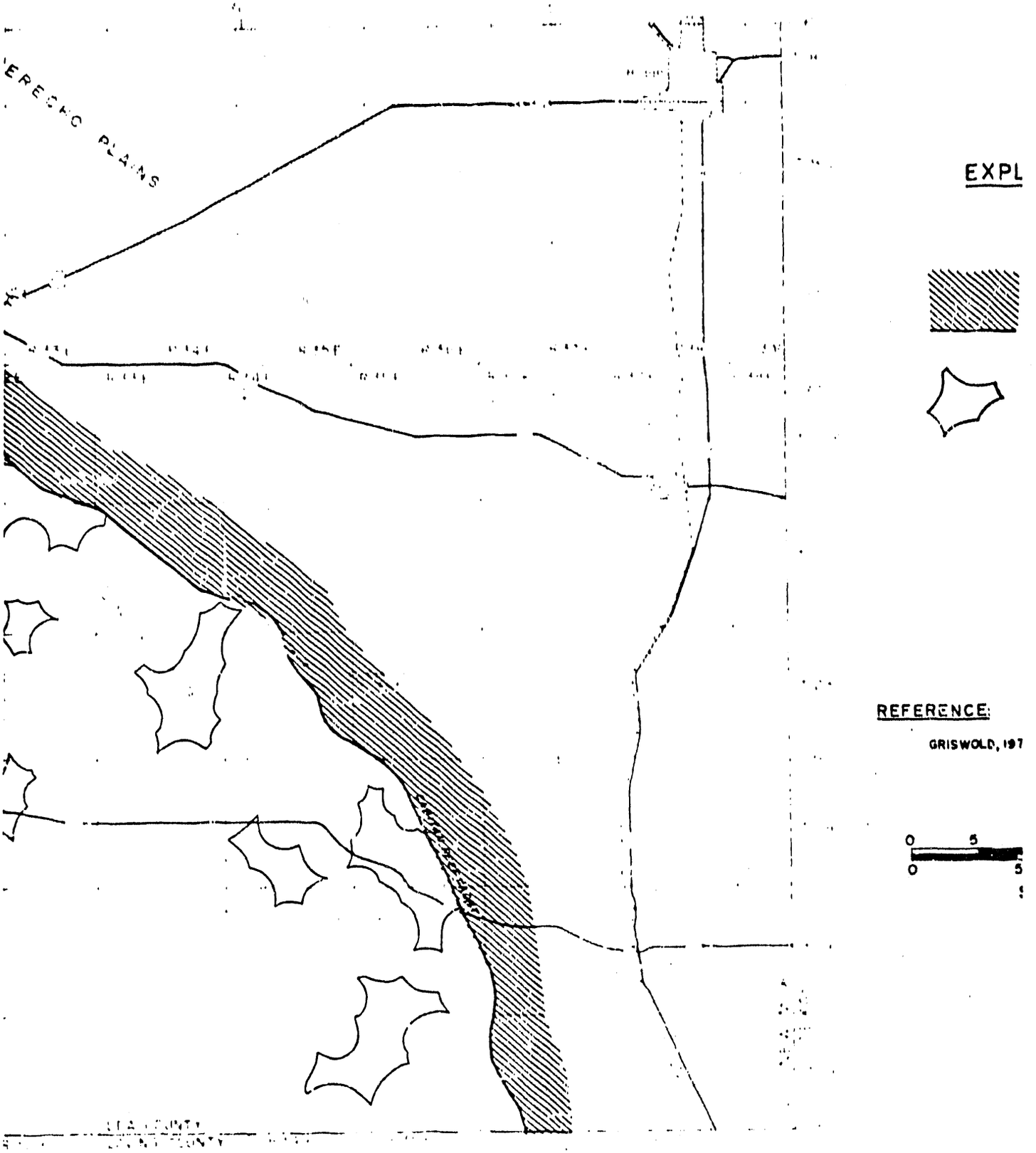
1. Griswold, 1977, Figure 1
2. Netherland, Sewell & Assoc., 1974, Exbt G-19

0 5 10 15 20 KM.
0 5 10 15 MI
SCALE

MINERAL RESOURCES
EXCLUSION AREAS

FIGURE 2-7


45°
N
30
15
EDDY COUNTY
LEA COUNTY
OLD SITE
WIPP SITE


EXPL
REFERENCE:
GRISWOLD, 197
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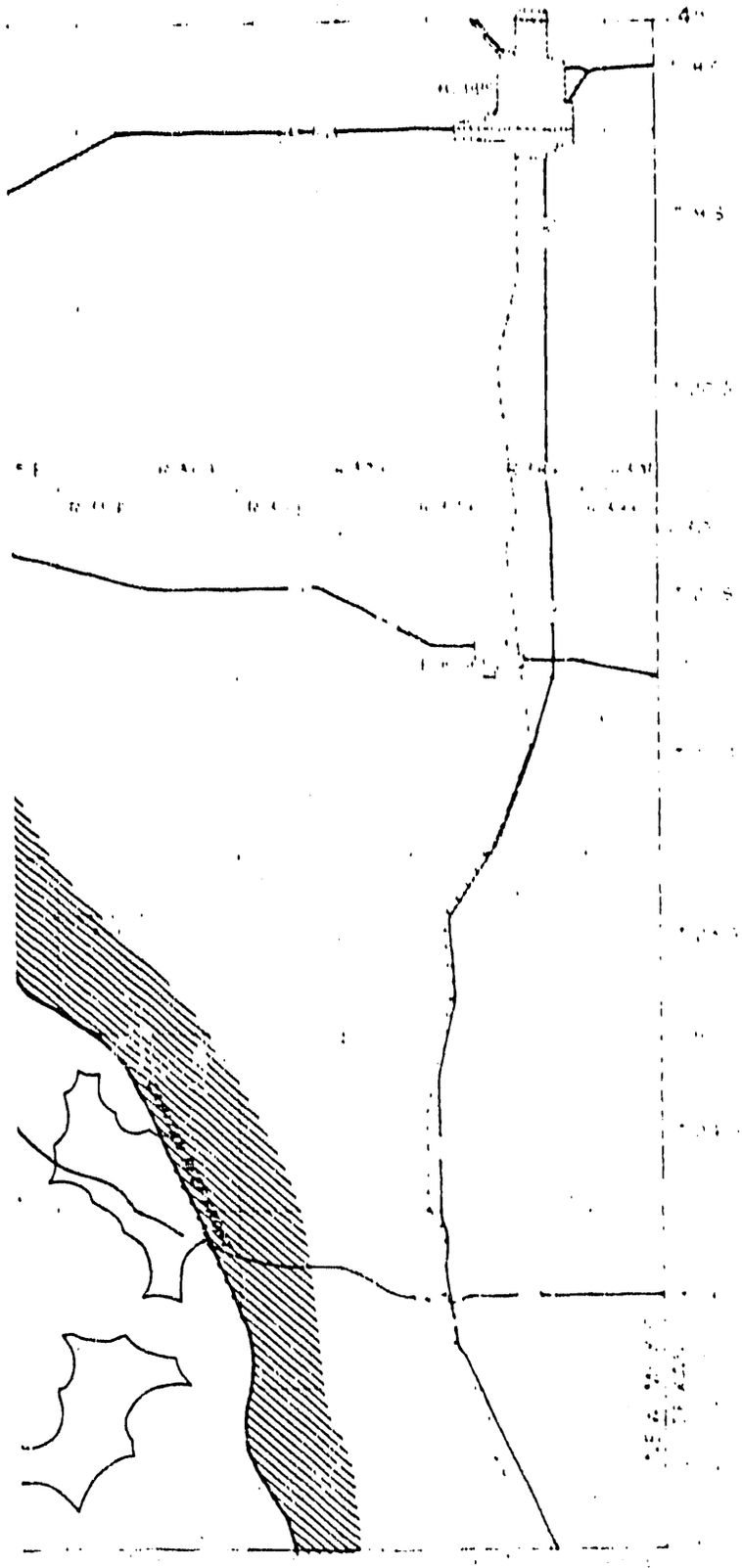


EXPLANATION

CAPITAN REEF FRONT

AREAS MORE THAN ONE MILE FROM DEEP DRILL HOLES

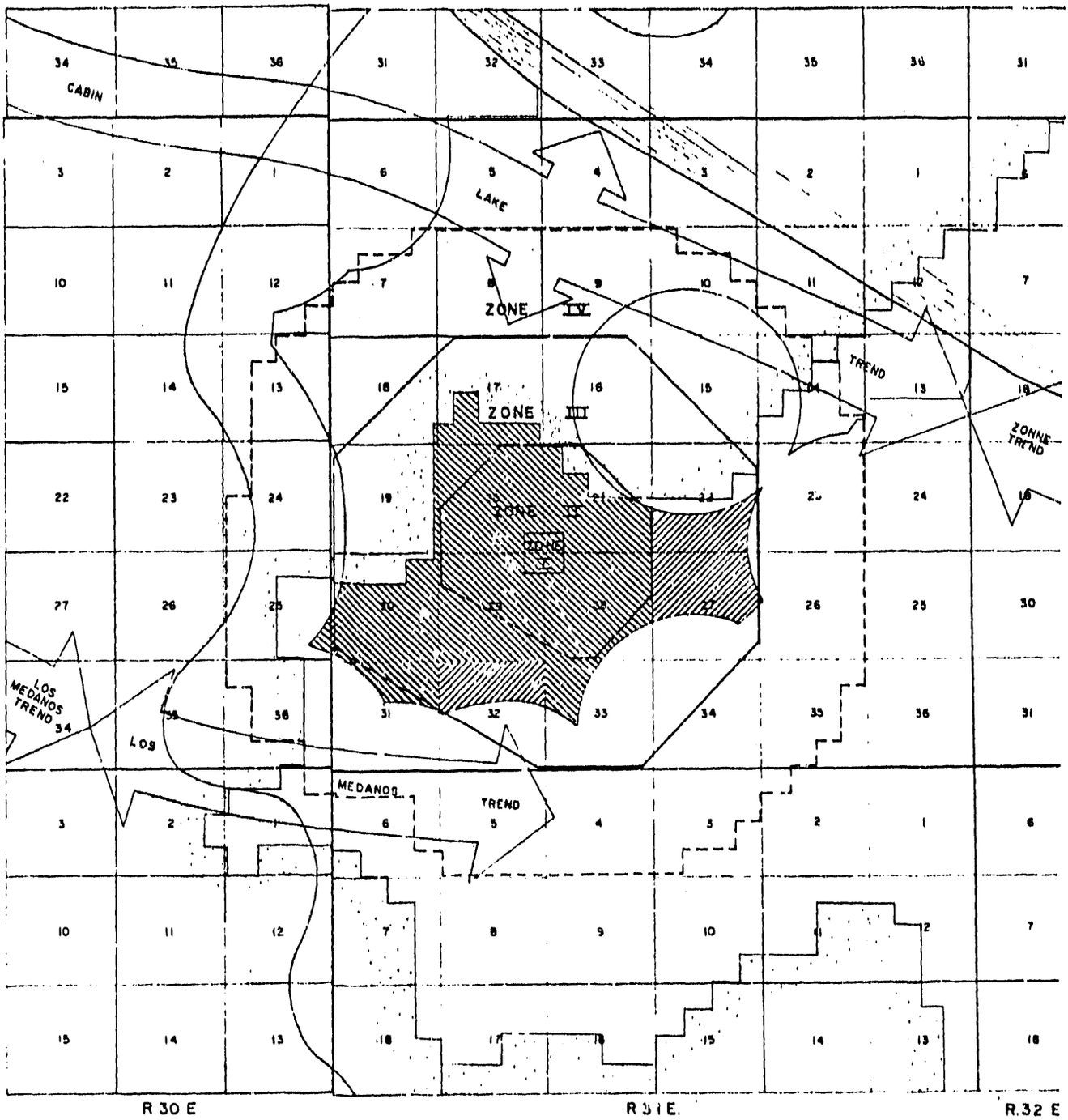
REFERENCE:

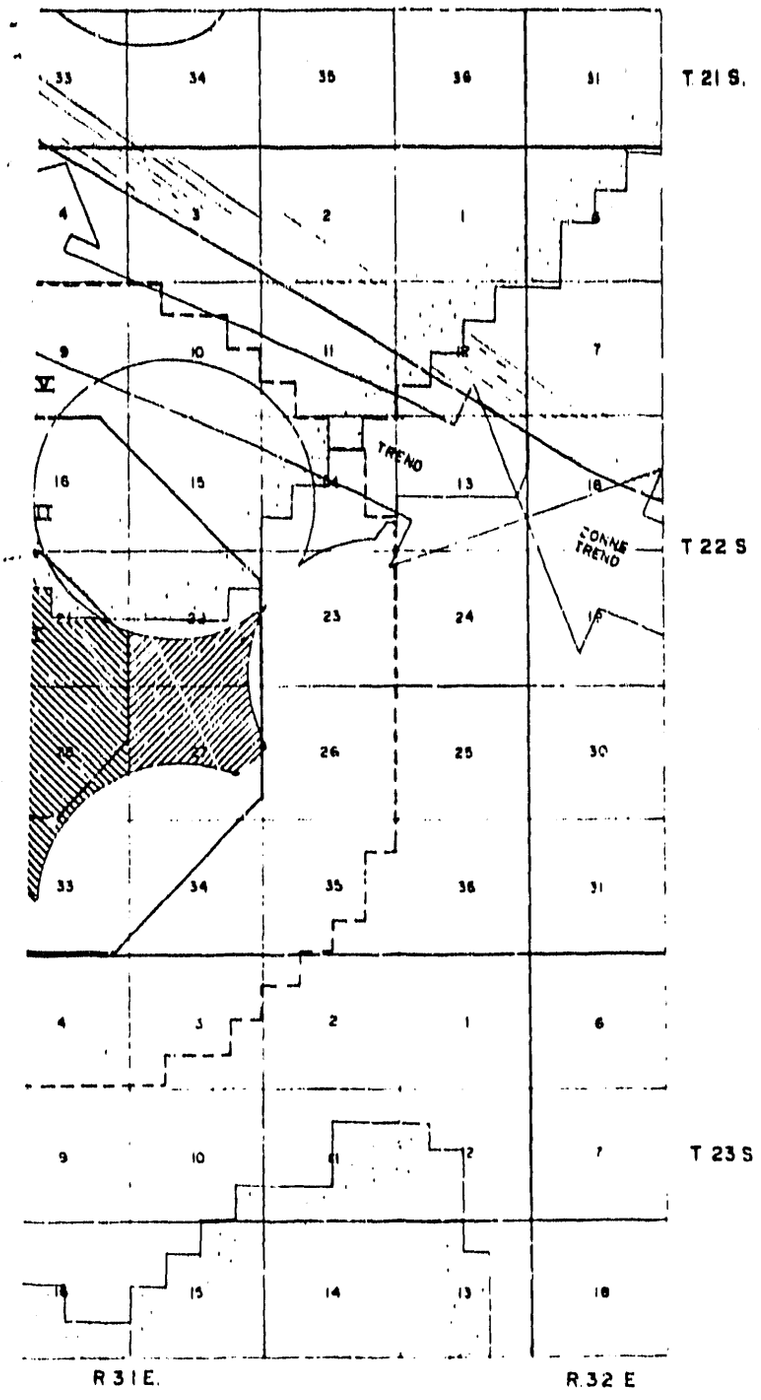
GRISWOLD, 1977

0 5 10 15 20 KM.
0 5 10 15 MI
SCALE

DEEP DRILL-HOLE EXCLUSION AREAS

FIGURE 2-8


CABIN
LAKE
ZONE IV
ZONE III
ZONE II
ZONE I
TREND
ZONNE TREND
LOS MEDANOS TREND
LOS
MEDANOS
TREND
R 30 E
R 31 E.
R.32 E



EXPLANATION

- OIL OR GAS TREND
- DISSOLUTION FRONT
- BUFFER FROM DEEP HOLE
- KNOWN POTASH ENCLAVE
- DEFORMATION BELT
- STATE LAND
- ACCEPTABLE FOR WIPP

REFERENCE

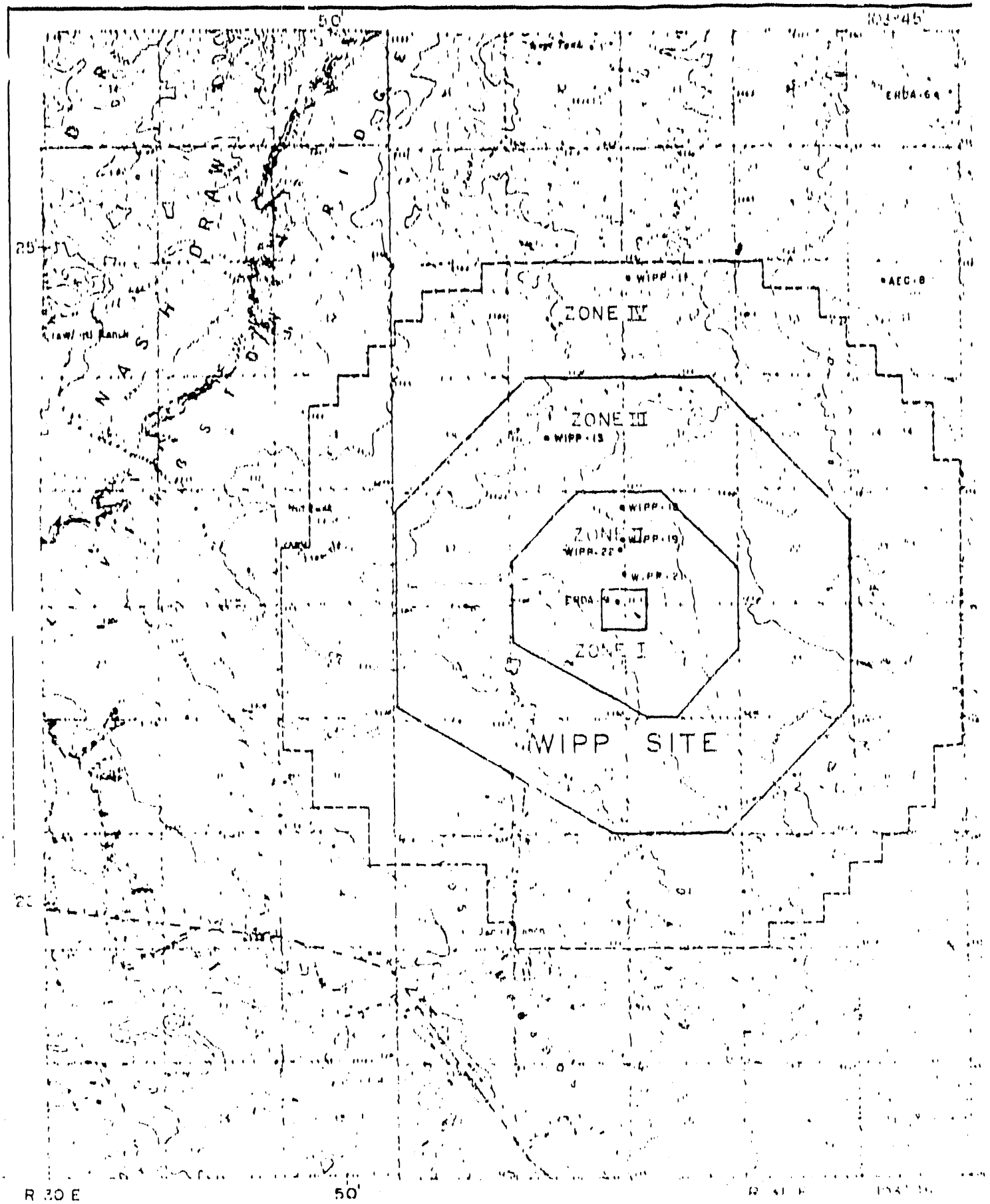
GRISWOLD, 1977, FIGURE 2

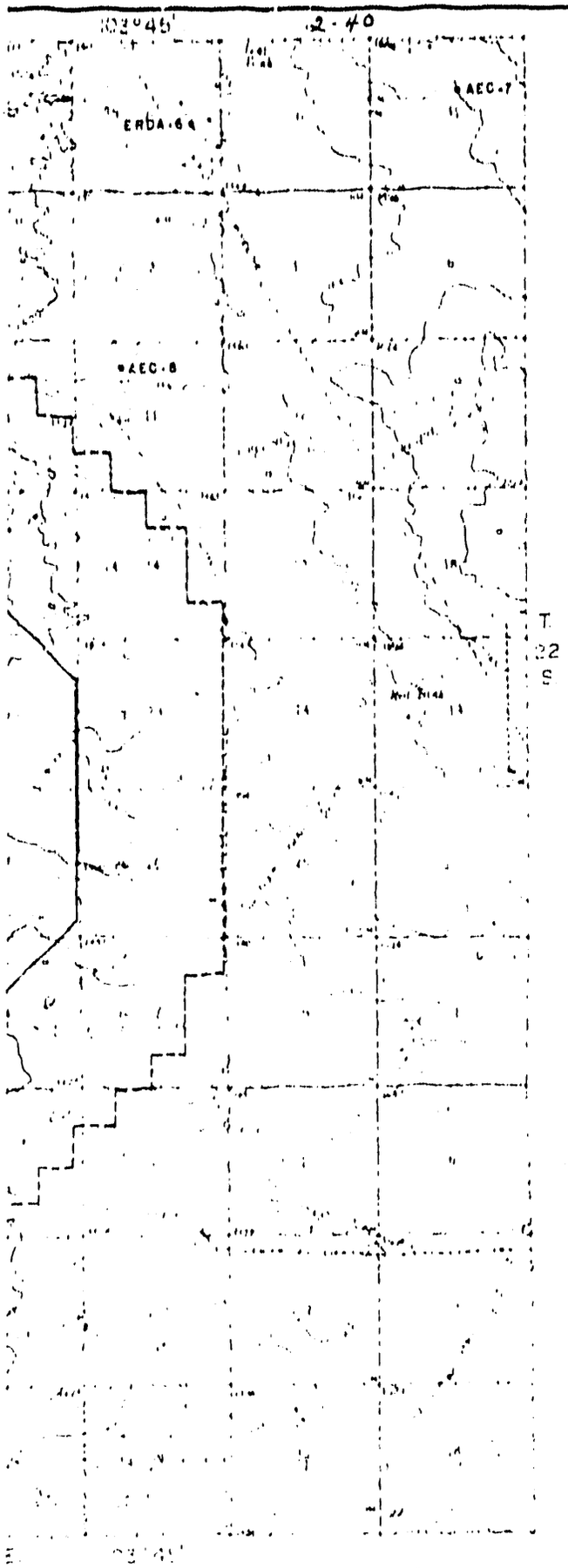
SCALE IN MILES

N

SELECTION OF PREFERRED SITE

FIGURE 2.9


ZONE IV
ZONE III
ZONE II
ZONE I
WIPP SITE
WIPP-11
WIPP-13
WIPP-19
WIPP-22
EHDA-6
AEC-8
NASH DRAW
R 30 E
50'



REFERENCE:

U.S.G.S. 15 minute quadrangles: Nash Draw, N. Mex., 1965 and Hat Mesa, N. Mex., 1972.

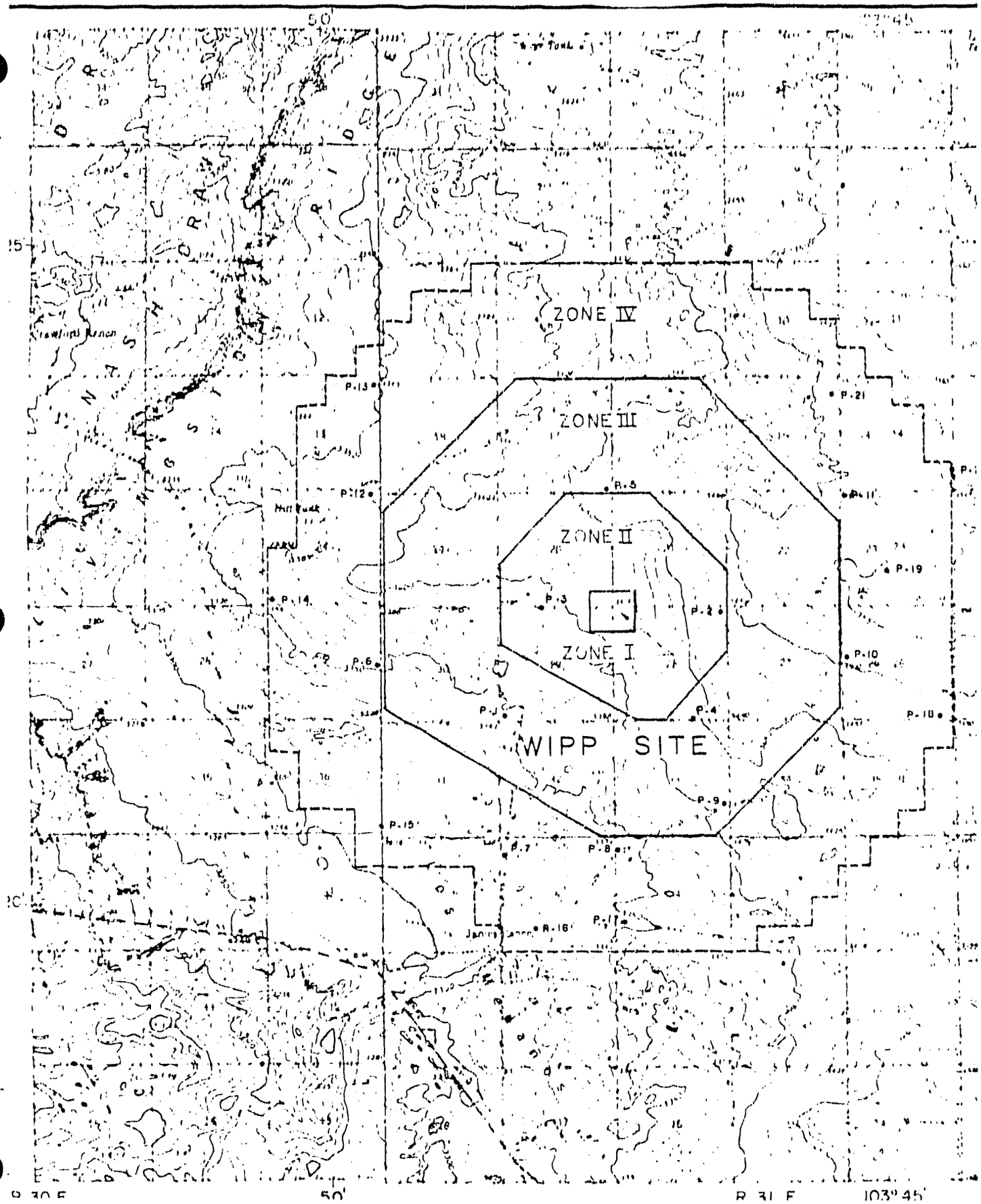
0 1 2 3 MILES

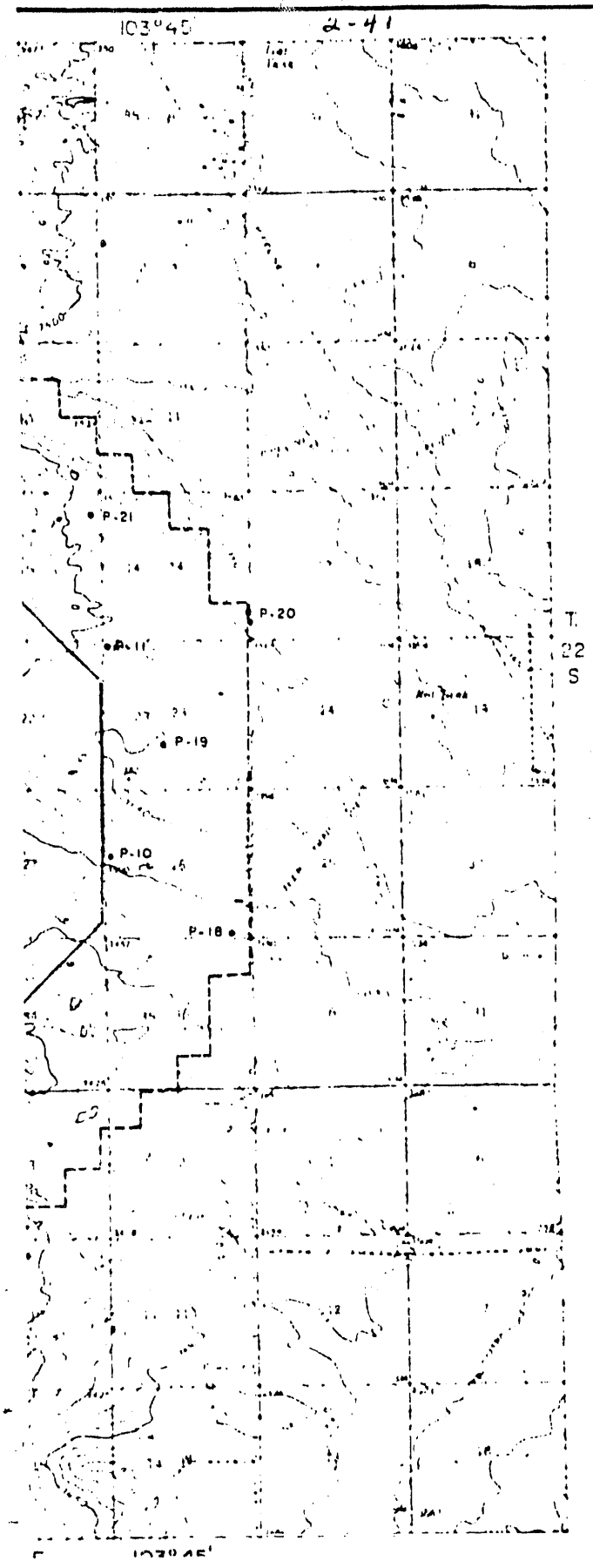
0 1 2 3 KM.

SCALE

WIPP SITE STRATIGRAPHIC HOLES

FIGURE 2-10


ZONE IV
ZONE III
ZONE II
ZONE I
WIPP SITE
P-1
P-2
P-3
P-4
P-5
P-6
P-7
P-8
P-9
P-10
P-11
P-12
P-13
P-14
P-15
P-16
P-17
P-18
P-19
P-21
R-5
R-16
50'
15
20
R 30 E
R 31 E
103° 45'



REFERENCE:

U.S.G.S. 15 minute quadrangles: Nash Draw, N.Mex., 1965 and Hat Mesa, N.Mex., 1972.

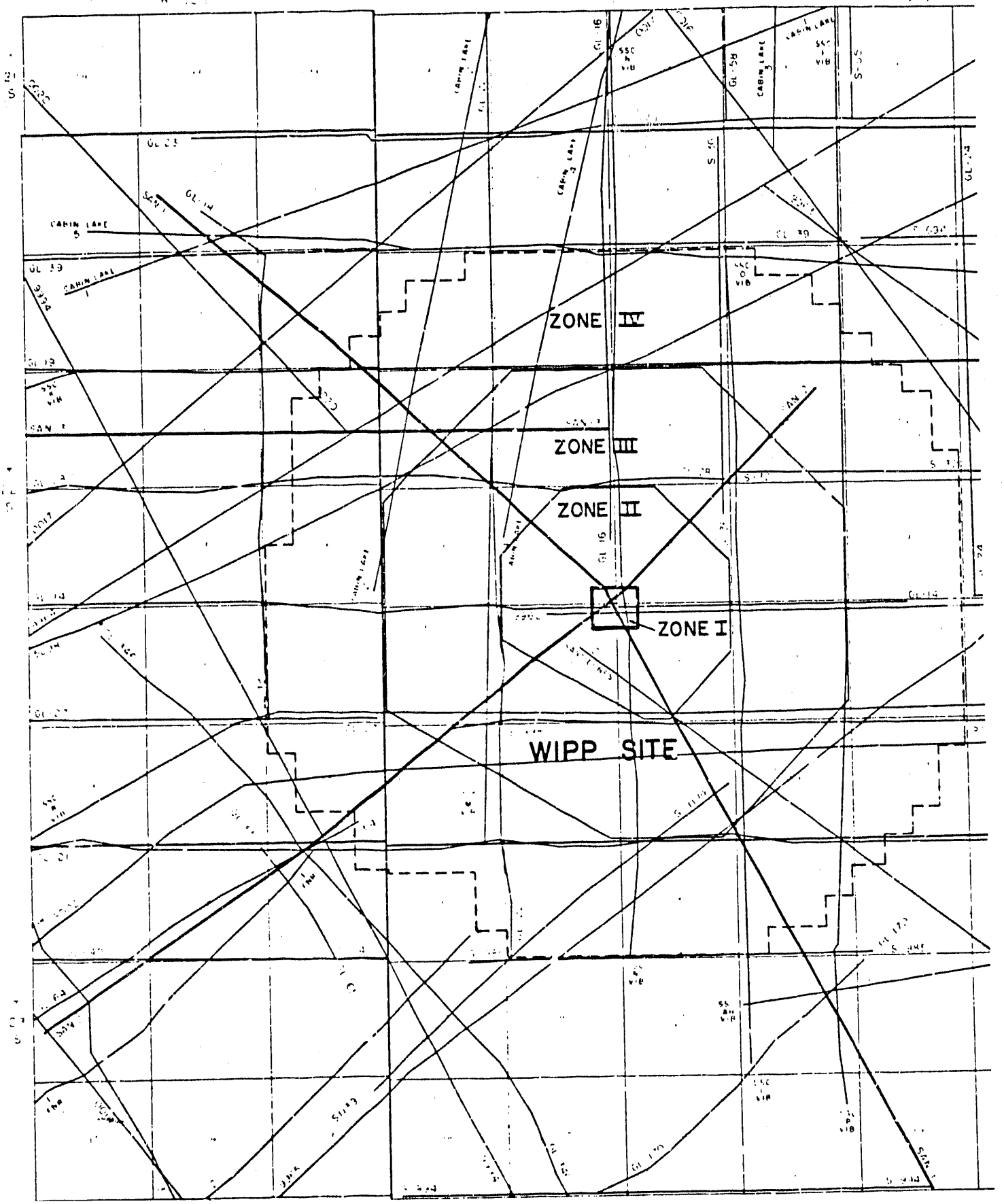
0 1 2 3 MILES

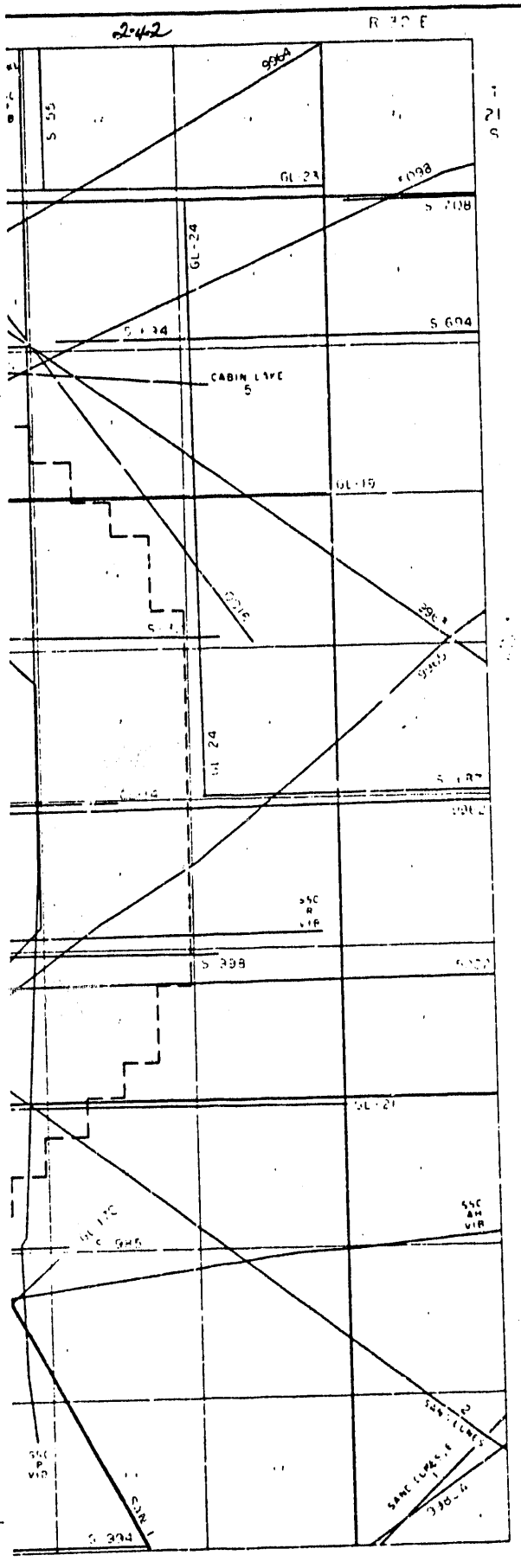
0 1 2 3 KM.

SCALE

WIPP SITE POTASH DRILLING BY ERDA, 1976

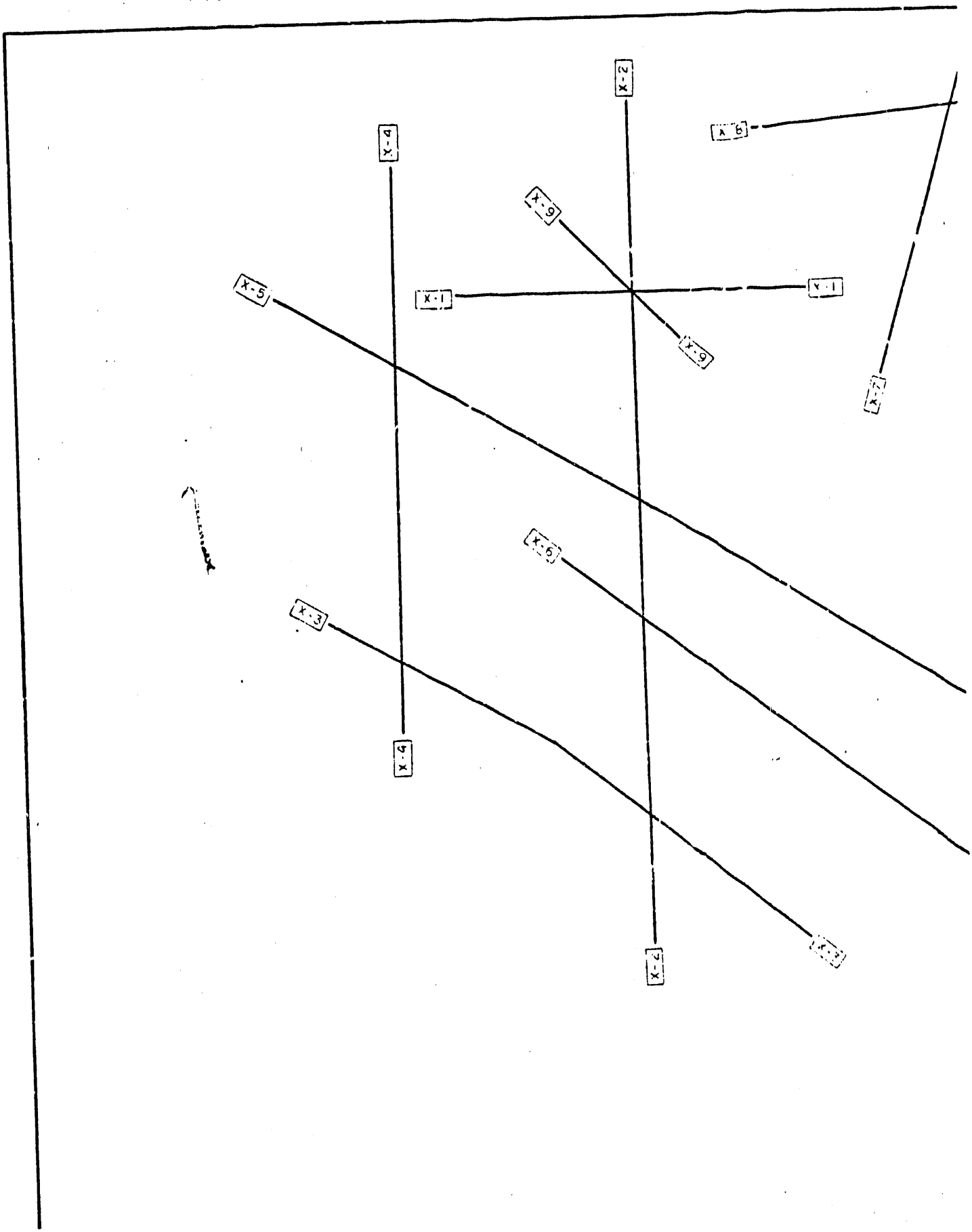
FIGURE 2-11

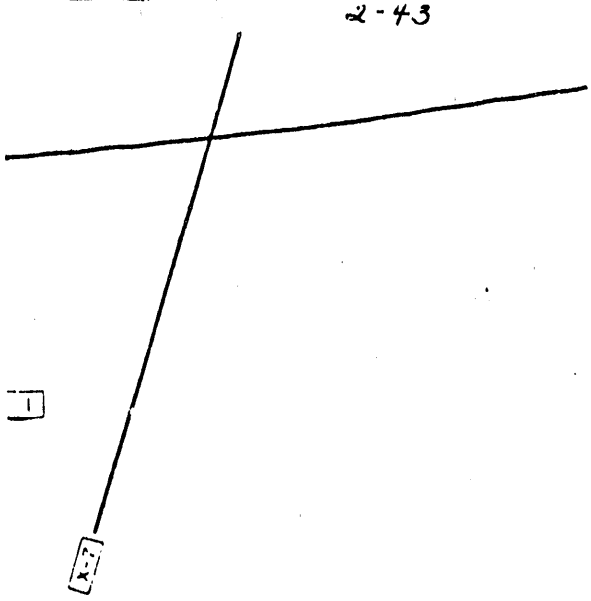

ZONE IV
ZONE III
ZONE II
ZONE I
WIPP SITE
CABIN LAKE 5
CABIN LAKE 1
CABIN LAKE 3

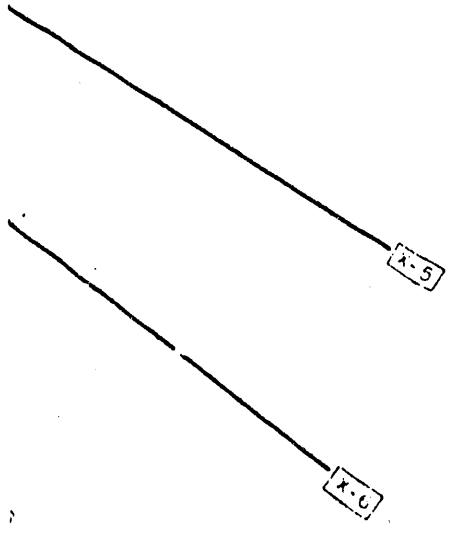


INDUSTRY SEISMIC REFLECTION LINES
PLUS SANDIA REFLECTION LINES
(SAN. – 1, 2, 3) FROM 1976

FIGURE 2-12

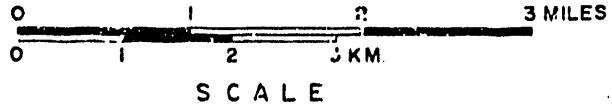

X-2
X-4
X-6
X-9
X-1
X-1
X-5
X-9
X-7
X-6
X-3
X-4
X-4
X-7





REFERENCE:

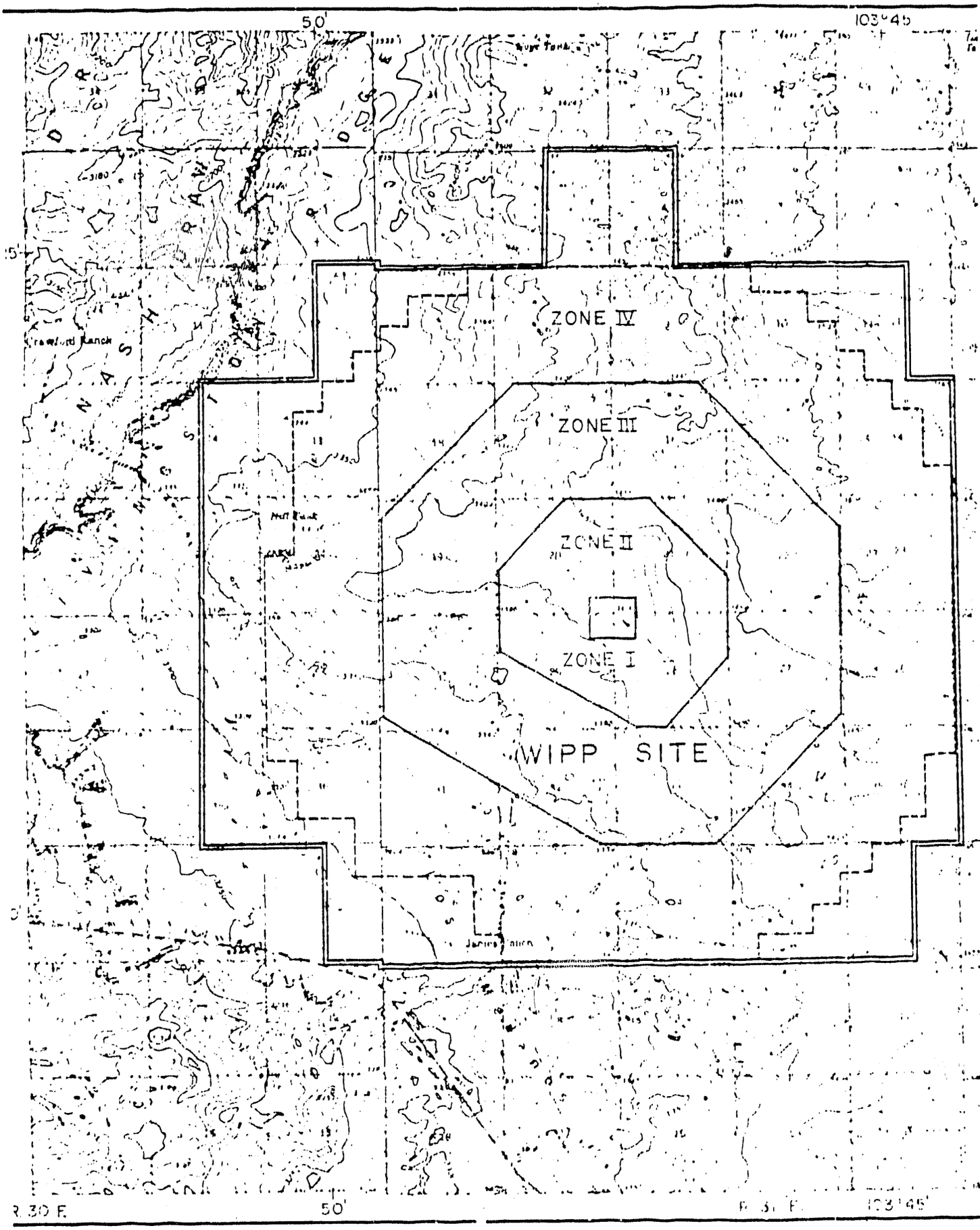
U.S.G.S. 15 minute quadrangles: Nash Draw, N.Mex., 1965 and Hat Mesa, N.Mex., 1972.

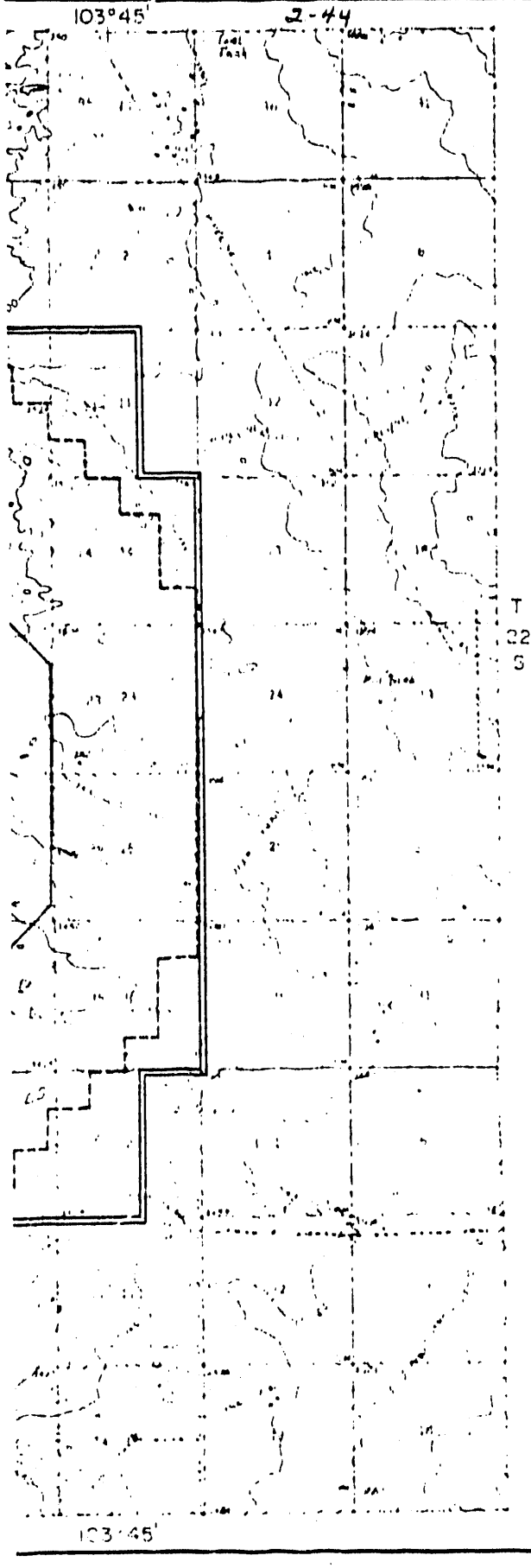


SEISMIC REFECTION LINES FOR

SEISMIC PROGRAM, 1977

FIGURE 2-13


50'
103°45'
ZONE IV
ZONE III
ZONE II
ZONE I
WIPP SITE
Crawford Ranch
Mott Ranch
Jarnigan
R. 30 E.
50'
103°45'



EXPLANATION:

Outer Boundary of Resistivity Measurement Area

REFERENCE:

U.S.G.S. 15 minute quadrangles: Nash Draw, N.Mex., 1965 and Hat Mesa, N.Mex., 1972.

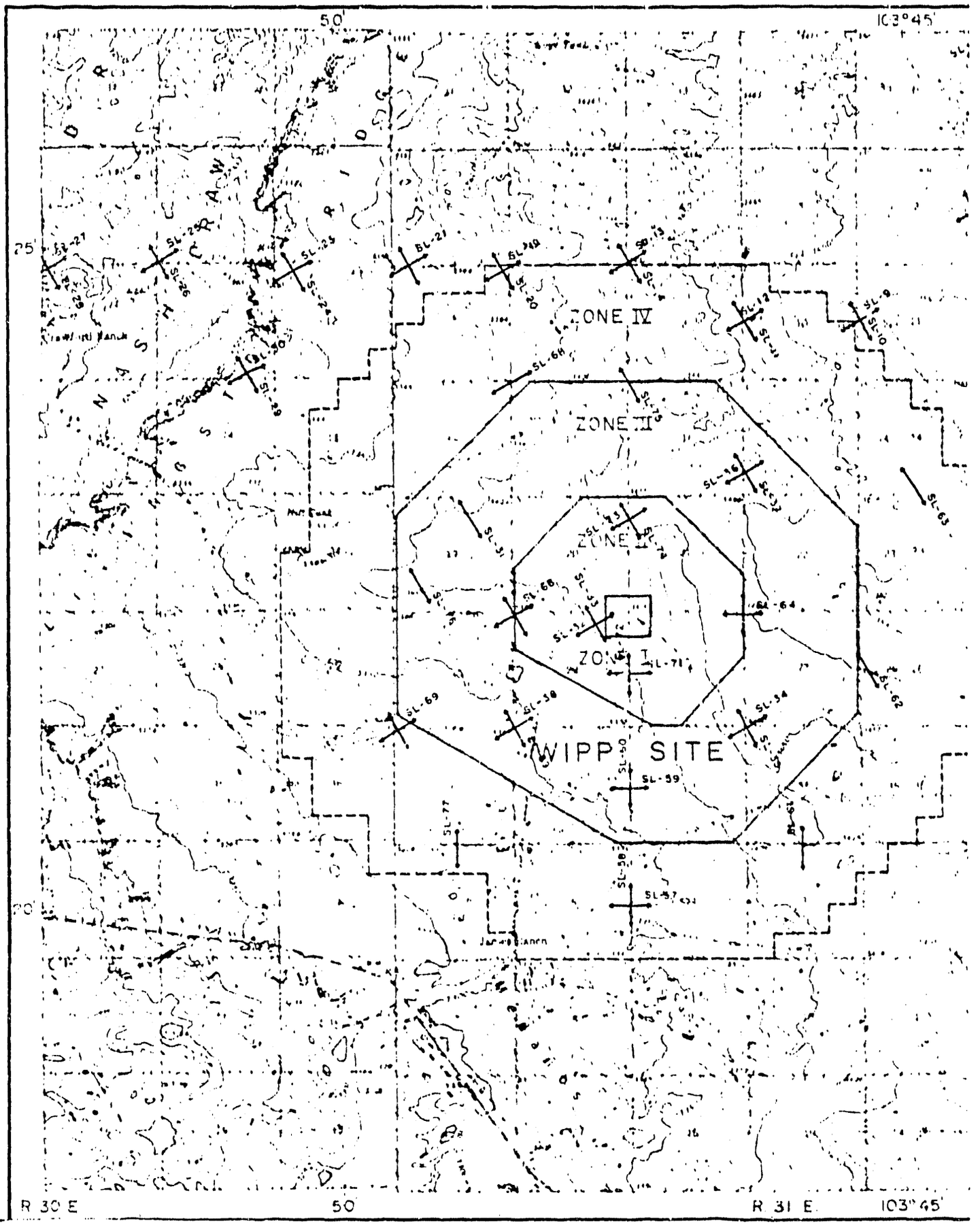
0 1 2 3 MILES

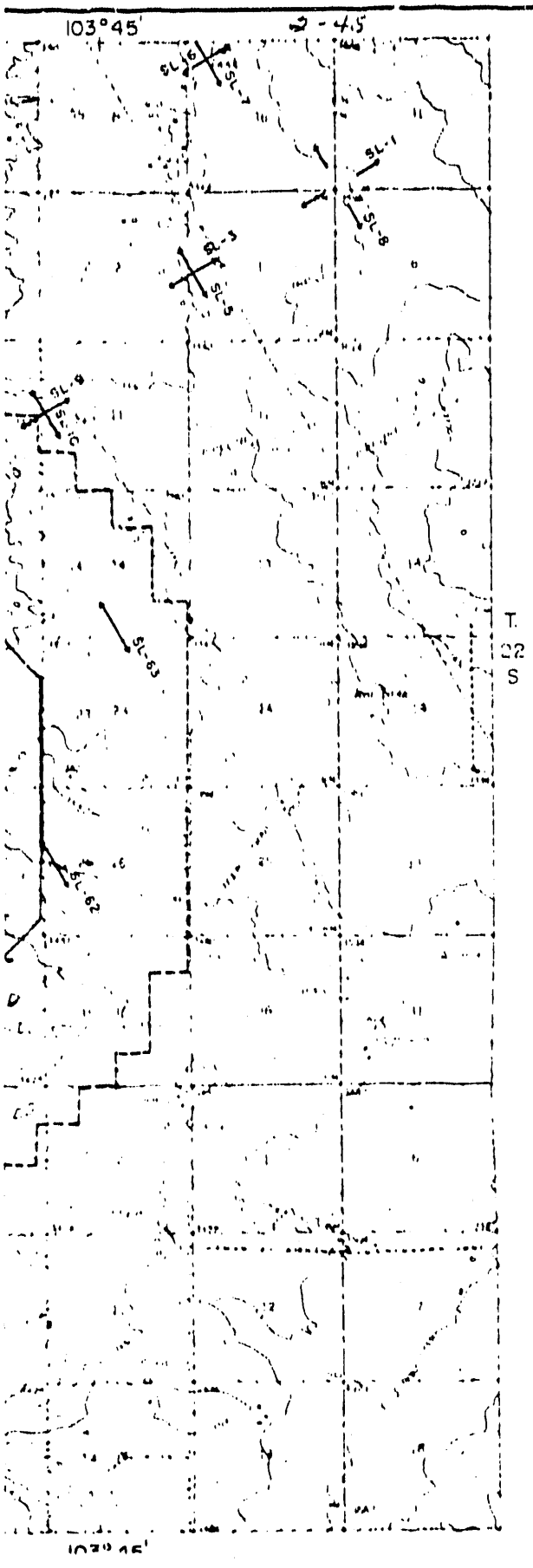
0 1 2 3 KM.

SCALE

PROFILE LOCATION MAP
OF
GRADIENT ARRAY RESISTIVITY

FIGURE 2-14


50'
103°45'
25'
20'
ZONE IV
ZONE III
ZONE II
ZONE I
WIPP SITE
R 30 E
50
R 31 E
103°45'



Schlumberger Array Soundings with Line No. and Direction

REFERENCE:

U.S.G.S. 15 minute quadrangles: Nash Draw, N.Mex., 1965 and Hat Mesa, N.Mex., 1972.

0 1 2 3 MILES

0 1 2 3 KM.

SCALE

LOCATION MAP
FOR
RESISTIVITY SOUNDINGS

FIGURE 2-15

TABLE 2-1

WIPP SITE CONTROL ZONES

Zone	Area Description	Surface Use and Activity Control	Approximate Acreage
I	Surface Exclusion Area	All non-WIPP activities excluded (security fenced area).	60(to 100)
II	Underground Storage Limits	Restricted; land use same as Zone III. Must be free of prior lease rights.	1,860
III	Restricted Buffer Zone	Drilling & mining operations prohibited. Current livestock grazing activities permitted. Other future activities subject to approval and regulation under ERDA authority.	6,230
IV	Controlled Use Buffer Zone	Drilling and mining operations permitted but restricted in conformance with ERDA specifications. Solution mining, well injection recovery methods prohibited. Other activities as specified for Zone III.	10,810
		TOTALS	18,960

TABLE 2-2

A. GEOLOGIC EXPLORATORY HOLES
(Figure 2-10)

Designation	Location	Date	Purpose
AEC 7	21/32/31	3/74	ORNL Stratigraphic--Old Site
AEC 8	22/31/11	4/74, 6/76	ORNL Stratigraphic--Old Site Sandia--Deep Hydrology--Old Site
ERDA 6	21/31/35	6/75	Stratigraphic--Old Site
ERDA 9	22/31/20	4/76	Stratigraphic--WIPP Site
ERDA 10*	23/30/34	8/77	Deep Dissolution--Off Site
WIPP 11	22/31/9	2/78	Stratigraphic--WIPP Site
WIPP 13	22/31/17	7/78	Stratigraphic--WIPP Site
WIPP 15*	23/35/18	3/78	Paleoclimate--Off Site
WIPP 18	22/31/20	3/78	Stratigraphic--WIPP Site
WIPP 19	22/31/20	4/78	Stratigraphic--WIPP Site
WIPP 21	22/31/20	5/78	Stratigraphic--WIPP Site
WIPP 22	22/31/20	5/78	Stratigraphic--WIPP Site

* not shown on Figure 2-10

B. ERDA POTASH HOLES
(Figure 2-11)

Designation	Location	Date
P1	22/31/29	8/76
P2	22/31/21	8/76
P3	22/31/20	8/76
P4	22/31/28	8/76
P5	22/31/17	9/76
P6	22/31/30	9/76
P7	23/31/5	9/76
P8	23/31/4	9/76
P10	22/31/26	9/76
P11	22/31/23	9/76
P12	22/30/24	9/76
P13	22/31/18	9/76
P14	22/30/24	9/76
P15	22/31/21	8/76
P16	23/31/5	9/76
P17	23/31/4	10/76
P18	22/31/26	10/76
P19	22/31/23	10/76
P20	22/31/14	10/76
P21	22/31/15	10/76

TABLE 2-2 (Continued)

C. HYDROLOGIC TEST HOLES
(See Figure 6.3-5)

Designation	Location	Date	Purpose
H1	22/31/29	5/76	Rustler, Top Salado Hydro
H2a	22/31/29	2/77	Magenta
H2b	22/31/29	2/77	Culebra
H2c	22/31/29	2/77	Top Salado
H3	22/31/29	7/76	Rustler, Top Salado Hydro
H4a*	22/31/5	5/78	Magenta
H4b*	22/31/5	5/78	Culebra
H4c*	22/31/5	4/78	Top Salado
H5a*	22/31/15	6/78	Magenta
H5b*	22/31/15	6/78	Culebra
H5c*	22/31/15	5/78	Top Salado
H6a*	22/31/18	7/78	Magenta
H6b*	22/31/18	6/78	Culebra
H6c*	22/31/18	6/78	Top Salado

* Holes being drilled at time of report

GCR CHAPTER 3
REGIONAL GEOLOGY

3.1 INTRODUCTION

This chapter considers the physiography and geomorphology, stratigraphy and lithology, structure and tectonics, igneous activity, and geologic history of the southeast New Mexico-west Texas area within a radius of about 200 miles of the proposed WIPP site. The information presented in the discussion below has been derived from previously available published and unpublished sources, including well-known reference texts, U.S. Geological Survey publications and open-file reports, Roswell Geological Society and New Mexico State Bureau of Mines and Mineral Resources materials, journal articles, and reports prepared under contract to Sandia Labs. A study of LANDSAT imagery was also conducted to examine lineaments as well as physiographic and structural features.

Section 3.2 presents a general description of the physiographic divisions, illustrated in Figure 3.2-1, which lie within approximately 200 miles of the site, followed by a more detailed study of the origin and development of those geomorphic features having significance to the site and by a consideration of relative erosion rates estimated for the future in the area surrounding the site.

Section 3.3 summarizes the major rock types and stratigraphic nomenclature by which the Precambrian basement and overlying sedimentary section are characterized within an area roughly bounded by the Sacramento Mountains on the northwest, and by Texas' Midland and Val Verde basins on the south and southeast. Generalized cross sections, depicting the entire stratigraphic section present in the area (Figure 3.3-2) and a study of Permian reef relationships (Figure 3.3-4) as well as correlations of the Precambrian rocks, (Figure 3.3-1) and Permian section (Figure 3.3-3) supplement the discussion.

Section 3.4 describes the major structural elements comprising the southeast New Mexico-west Texas region and summarizes the history of their tectonic development. The features discussed include the major subsurface basins and platforms of Late Paleozoic origin, which together have produced the essential structural framework of the area, and large-scale Cenozoic features, which generally possess surficial structural expression, as well as the more important smaller structures occurring within the boundaries of these elements. The structures considered in this section are displayed in Figure 3.4-1, and a basement contour structure map (Figure 3.4-2) demonstrates the basic structural configuration of the region.

The major occurrences of igneous activity within the site region are described in Section 3.5. As demonstrated in Figure 3.5-1, this igneous activity has been generally limited to the area west and south of the proposed WIPP site, in the form of Tertiary intrusive bodies and volcanic terrains. The igneous feature nearest to the site, a northeast-trending dike located about nine miles northwest of the site, is discussed separately in this section and is illustrated in Figure 3.5-2.

Section 3.6 presents a synthesis of the major events which have affected the site region, as these have been determined from lithologic and structural data available in the area. A schematic visualization of the regional geologic history, as correlated with the geologic time scale, is provided in Figure 3.6-1.

3.2 REGIONAL PHYSIOGRAPHY AND GEOMORPHOLOGY

Figure 3.2-1 presents the major physiographic units which encompass the southeast New Mexico-west Texas region. The discussion below includes a general description of the physiographic sections, as defined by Fenneman (1931), which lie within a radius of about 200 miles of the proposed WIPP site. This is followed by a more detailed description of the development of the major nearer site landforms.

3.2.1 Physiographic Setting

The proposed WIPP site is located within the eastern part of the Pecos Valley section of the southern Great Plains physiographic province. The Great Plains physiographic province comprises a broad highland belt sloping gradually eastward from the Rocky Mountains and Basin and Range province to the Central Lowlands province. The Great Plains province in turn represents the western extent of the Interior Plains major physiographic division (Fenneman, 1931).

Pecos Valley Physiographic Section The Pecos Valley section consists of the Pecos and upper Canadian valleys, which together form a long north-south trough carved from what was once part of the High Plains section on the east, but whose axis now lies 500 to 1,000 feet below the High Plains surface -- the Llano Estacado. The Guadalupe and Sacramento mountains of the Basin and Range physiographic province flank the Pecos Valley section to the west.

The topography of the Pecos Valley section varies from flat plains and lowlands to rugged canyon lands. Except where covered by alluvium, much of the land surface has an uneven rock floor, which results from the erosion of the moderately resistant limestones, sandstones, shales and gypsum to form scarps, cuestas, terraces, side canyons and some mesas of limited extent. The valleys of the Pecos River in the vicinity of the Delaware Basin exhibit a characteristic lowland topography marked by widespread solution-subsidence features, which have resulted from dissolution within the Upper Permian Ochoan rocks (see the karst topography discussion below).

The land surface generally slopes gently eastward, reflecting the attitude of the underlying rock strata. The average elevations within the section range from over 6,000 feet above sea level in the northwest and about 5,000 feet in the north to 4,000 feet on the east and 2,000 feet to the south (Fenneman, 1931).

The Pecos Valley section is drained primarily by the Pecos River which lies slightly to the west of the center of the Pecos trough and flows in a southeast to southward direction through most of the length of the section. The extreme northeastern portion of the section is also drained by a short segment of the generally eastward-flowing Canadian River. Owing to the desert character of the area, most of the tributaries of these major streams flow only intermittently, and some creeks drain into local depressions, where the water evaporates or percolates into the underlying sediments.

The Canadian River has cut much more deeply into the surrounding land than has the Pecos River, thereby producing a much greater relief in the far nothern portion of the section than is present to the south.

The northern portion of the Pecos River, north of Roswell, has cut a valley in places as deep as 1,000 feet below the surrounding land surface and from 5 to 30 miles wide. The central portion of the river, from about 50 miles north of Roswell to near the New Mexico-Texas border, flows through an alluvial valley of comparable width but much reduced relief and is underlain by as much as 250 feet of alluvium near Carlsbad. The southern part of the Pecos, just north of the Edwards Plateau, flows across an alluvial plain, called the Toyah Basin, which is similar to that further north and comprises most of the west Texas portion of the Pecos Valley section (Fenneman, 1931). The genesis and development of the Pecos River system are discussed in Section 3.2.2, below.

The immediate valley of the Pecos River is bordered on the east by almost continuous bluffs, beyond which the eastward-dipping rock strata lie at or near the surface for a distance of several miles. A sloping alluvium-mantled plain extends eastward from this rocky belt to the westward face of the Llano Estacado (Fenneman, 1931).

<u>High Plains Physiographic Section</u> East of the Pecos Valley section lies the High Plains section of the Great Plains physiographic province,

extending from South Dakota on the north to near the Rio Grande (river) in Texas. The High Plains are remnants of a former great fluviatile plain, which stretched from the mountains on the west to the Central Lowlands on the east. The portion of the High Plains east of the Pecos valley is known as the Llano Estacado and comprises approximately 20,000 mi^2 of almost completely flat plain, which has undergone very little dissection. Northward, the land is more dissected, and the original flat surface is still preserved only along stream divides.

The High Plains originated through deposition of the Late Tertiary Ogallala Formation, resulting in more than 500 feet of silts with lesser gravels and sand. The deposits were laid down in alluvial fans by overloaded streams flowing eastward from the Rocky Mountain area over an irregular erosional surface. By the end of the time of formation of the Ogallala, the High Plains surface was probably continous across the area of the present Pecos River drainage to the back slope of the Sacramento Mountains (Bachman, 1976) (also see Section 3.6.5). In many areas, the nearly flat surface which resulted was later cemented by a hard caliche layer. The almost perfect preservation of the orginal topography in the Llano Estacado area is due to a combination of the porous nature of the sediments, the protection afforded by the caliche, and the relatively arid climate of the region (Fenneman, 1931).

The few, generally insignificant topographic features present in the High Plains section consist mainly of depressions derived from a variety of origins, such as dissolution with subsidence, blowout activity, buffalo wallowing or differential compaction of the Tertiary sediments. Ponding of water occurs in these depressions following rain storms, and a few maintain permanent pools (Thornbury, 1965). Sand dunes also occur in scattered locations throughout the section, generally fringing the leeward sides of streams (Fenneman, 1931).

Edwards Plateau Physiographic Section The Llano Estacado merges southward into the Edwards Plateau section of the Great Plains province by the gradual thinning and disappearance of the Ogallala Formation. It

comprises a wedge-shaped portion of west Texas, and then extends across the Rio Grande into Mexico. The Edwards Plateau is bounded on all sides by an escarpment, except for two small areas, where it merges with the Llano Estacado on the northwest and where it terminates against the mountains of the Mexican Highlands on the west. The northern edge of the plateau, bounding the Central Texas Section, is formed by an eroded and deeply notched southward-retreating escarpment, and the southern boundary is marked by a line of faulting and local folds, which produces an escarpment up to 1,000 feet high (Fenneman, 1931).

The Edwards Plateau ranges in elevation from 3,000 feet on the north at its border with the Llano Estacado and 4,000 feet at the foot of the mountains on the west to 2,200 feet along its southern margin and 1,000 feet at the southeast corner.

The surface of the Edwards Plateau is underlain by a single resistant layer of limestone dipping gently to the south and east, which has encouraged the development of rather flat-lying terrain and bold escarpments. In the eastern part of the plateau, where rainfall is greatest, the plateau is narrow and highly cut by the dissection moving inward from the margins. West of the 100th meridian, the plateau becomes a drier, broad area covered by a plain much like the Llano Estacado. The wide, shallow valleys that have formed in this part of the section generally carry runoff only during rain storms. However, the Pecos River and Rio Grande have cut canyons across the section as deep as 1,000 feet. And on all sides where escarpments exist, the dissected edges carry outflowing streams.

Other surface features on the plateau are limited and generally restricted to erosion or dissolution-type structures. Some shallow sinkholes exist in areas where dissolution of the underlying limestone has caused a collapse of the land surface (Fenneman, 1931).

Sacramento Physiographic Section West of the Pecos section lies the Sacramento section of the Basin and Range physiographic province,

comprising a narrow, north-south strip approximately 300 miles long and less than 70 miles wide (Fenneman, 1931). The section is bordered on the west and south by the Rio Grande depression (Thornbury, 1965) and Mexican Highlands and on the east by the Great Plains province. The northeastern boundary of the Sacramento section is formed by the eastward escarpment of the Glorieta mesa, an intricately carved divide of horizontal strata. Farther south, the Capitan escarpment marks the boundary of the two provinces along the southeast side of the Guadalupe Mountains and is exposed for a distance of some 45 miles between Carlsbad and El Capitan Peak (Thornbury, 1965).

Topographically, the section is characterized by two major basinal areas, called bolsons, located at the north and south ends of the section, and by a series of intervening mountain ranges (Thornbury, 1965).

The Estancia Valley, or Sandoval Bolson, forms the central feature of the north part of the section, and is bordered on the east by the Glorieta Mesa and Pedernal Hills, on the west by the Sandia and Manzano Mountains, and on the south by the elevated Chupadera Mesa. The Estancia Valley, primarily composed of a group of salt basins and dunes or low hills, was the site of an extensive lake during Pleistocene time (Thornbury, 1965), which is now reduced to several small salt lakes.

Southeastward from the Estancia Valley and Pedernal Hills lie a series of mountain ranges, many of which are bordered on the west by bold scarps and on the east by gently dipping slopes extending toward the Pecos Valley. Sierra Blanca, the highest of the mountain ranges, reaches an elevation of approximately 12,000 feet above sea level. The other ranges attain maximum elevations of from 8,000 to 10,000 feet (Fenneman, 1931).

At the south end of the Sacramento section is a second large bolson known as the Salt Basin, situated west of the Guadalupe and Delaware Mountains and east of the Sierra Diablo or Diablo Plateau. The Salt Basin is a large down-faulted block with an average floor elevation of about 3,600 feet above sea level. The floor lies some 800 feet below the basin rim

(Thornbury, 1965). The basin covers an area approximately 150 miles long and from 8 to 20 miles wide, rising on both north and south ends to merge into rocky plateaus (Fenneman, 1931). The floor of the basin is covered almost entirely by unconsolidated Cenozoic sediments, with rocky outcrops limited primarily to the margins of the basin (Thornbury, 1965). The LANDSAT color composite of this vicinity shows that the surface sediments are sandy, with a series of salt lakes present in the center of the Salt Basin. Evidence of two Pleistocene lake phases in the basin have been described by King (1948), but their time of formation during the Pleistocene is uncertain.

Mexican Highland Physiographic Section West and south of the Sacramento section lies the vast Mexican Highland section of the Basin and Range physiographic province. This section extends southeastward from Nevada and the Colorado Plateau far into Mexico, where it has its maximum development. The eastern boundary in New Mexio is unclear but is defined as extending east of the Rio Grande to about longitude 106°W, where alternating basins and ranges give way to the faulted and sloping plateaus of the Sacramento section (Fenneman, 1931).

The Mexican Highland section consists of almost equal areas of mountains and plains or basins. In the eastern portion of the section, the mountains generally trend north-south, while in the west they trend northwestward. Of the intermountain area, about half is bolson, and the rest drains or slopes toward the major rivers, such as the Rio Grande. The following discussion considers further only the large-scale features within the eastern part of the section.

The Mexico Highlands mountain ranges of Texas and New Mexico can be grouped into three or more north-south lines from 10 to 50 miles apart and are dominantly Great Basin type, in common with those of the western half of the section. Faulting and related deformation as well as volcanic activity have formed these ranges since Late Tertiary times.

Between the eastern mountain ranges lie generally continuous, flat-floored troughs separated by divides into bolsons or drainage basins (Fenneman, 1931). The two major basins here are the Hueco and Tularosa, on the north, which together mark the eastern border of the section in New Mexico and Texas. They form a trough about 30 to 40 miles wide and 125 miles long, interrupted at the Texas border by a low divide separating the two basins. These basins are grabens in general configuration, bordered on both east and west by fault-bounded mountain ranges. The floors of the basins are relatively flat and slope southward from an elevation of about 4,500 feet at the north end of the Tularosa Basin to 3,500 feet at the south end of the Hueco Basin. The Tularosa Basin exhibits centripetal drainage marked by arroyos and a great salt marsh flanked by the gypsum dunes of White Sands monument.

The northern end of the Tularosa Basin is bordered by Chupadera Mesa averaging 7,000 feet elevation and underlain by gently eastward-dipping Permian strata, which have been dissected almost to maturity (Fenneman, 1931).

3.2.2 Major Geomorphic Features in the Site Vicinity The geomorphic development of the major land forms which constitute the near-site setting are discussed in this section. These features include the Pecos River drainage system, the Mescalero Plain and associated deposits, karst topography and blowouts. In general, these geomorphic features as considered below are located within the Pecos Valley physiographic section.

Pecos River Drainage System The Pecos River, 20 miles west of the site is the only major, perennial stream in the Eddy and Lea Counties area of southeastern New Mexico. It receives almost all of the surface drainage in this region and a large part of the subsurface drainage. The Pecos originates in the southern Rocky Mountains of north-central New Mexico and flows south and southeastward to join the Rio Grande in west Texas (Kottlowski, et al., 1965). The dimensions of the contemporary river valley are stated above in Section 3.2.1 under the Pecos Valley section.

According to King (1948), the Pecos River apparently had its origin to the south, in the Edwards Plateau, as a short tributary of the Rio Grande River. As the Pecos worked its way northward, eroding the Ogallala sediments in the process, it captured the westward-flowing streams of the present upper Pecos valley, thereby reversing their drainage direction. This stream piracy was facilitated by the underlying poorly resistant Permian rocks (Thornbury, 1965).

Bachman (1973, 1974) has expressed the opinion, in accordance with Lee (1925) and Morgan (1942), that the present course of the Pecos was formed, at least in part, through the coalesence of trains of solution sinks (see Karst Topography below, for discussion of solution-sink development). Bachman cites as evidence for this theory many places along the course of the river in southeast New Mexico where the river follows broad meanders, although the floodplain as a whole is unusually narrow or nonexistent, as well as locations adjacent to the Pecos where intermittant tributaries follow semicircular collapse valleys. Bachman concludes that the river became entrenched in its present position by a combination of this solution-subsidence, headward cutting, and piracy.

The age of entrenchment of the Pecos River is somewhat uncertain. Thornbury (1965) has stated that the age of the piracy which constituted part of the entrenchment process is rather definitely dated as post-Pliocene and is assumed to have taken place in the early Pleistocene. Bachman (1974) has stated that it is not possible to precisely date the entrenchment of the ancestral Pecos River in southern New Mexico. But Bachman has observed (1976) that the Pecos entrenched itself near its present channel along the toes of pediments east of the Sacramento Mountains sometime after middle Pleistocene, which would place the establishment of the present course at a later date.

Since entrenchment, the river has carved a valley in which a variety of subsidence features have developed through dissolution processes which are probably still active in the valley today.

Mescalero Plain East of the Pecos River to about longitude 104°W lies an extensive, gently sloping pediment surface known as the Mescalero Plain (Thornbury, 1965), which extends from the vicinity of Fort Sumner in northern New Mexico to south of the Mexico-Texas border (Bachman, 1974). The surface of the plain rises eastward from about 150 feet above the Pecos River to as much as 400 feet above the river at the base of the Llano Estacado (Bachman, 1973; Kelley, 1971). The average elevations range from about 3,800 to 4,100 feet above sea level in northwestern Lea County near Mescalero Ridge to about 3,100 feet in southeastern Eddy County, south of Big Sinks (Bachman, 1973).

Although termed a "plain", the area includes many low mesas, bluffs and wide draws. Locally the surface has been dissected by intermittent streams, but in general the area is poorly drained and contains numerous playa pans and smaller sinks (Brokaw, et al., 1972; Kelley, 1971). The surface of the plain is covered widely with gravels and sands, often cemented with caliche. As much as 5 to 10 feet, and locally more, of these materials are exposed along the edges of the long irregular mesas of the area (Kelley, 1971).

The Mescalero Plain is very obvious on LANDSAT imagery. The surface materials of the plain are generally darker in color and exhibit more vegetation and higher moisture content than sandy areas.

The Mescalero Plain probably formed during a period of tectonic stability after deposition of the Gatuna Formation in the Early to Middle Pleistocene and has been modified both during and after its formation by solution-subsidence features, discussed below (Bachman, 1976). The widely distributed gravel deposits have probably been derived from erosion of the Ogallala Formation in the Llano Estacado, to the east (Kelley, 1971). The development and distribution of caliche and sand dune deposits, both of which overlie extensive portions of the pre-caliche Mescalero surface in southeast New Mexico, are discussed separately in the following paragraphs.

1) Mescalero Caliche

The deposits of the Mescalero Plain are generally covered by the calcareous, cemented remnant of an extensive soil profile known as the Mescalero caliche (see Section 3.3.4). The caliche forms a resistant caprock which averages 3 to 5 feet thick and is generally less than 10 feet thick. It consists of a basal earthy to firm, nodular calcareous deposit and an upper well-cemented laminar caprock (Bachman, 1976). In places, the caliche has weathered to a ledge that overhangs less resistant deposits. The caliche is generally thin; it is locally absent over the solution depressions of the plain, and in areas of collapse may be nearly vertical. Caliche may also be locally absent due to erosion on nondeposition. Because of the generally uniform covering by the erosion-resistant caliche, it is probable that these irregular surfaces result from subsurface solutioning and subsidence of the underlying sediments, primarily after the caliche caprock formed.

Although the genesis of the Mescalero caliche is uncertain, it is thought to be a process dependent upon climatic conditions involving certain ranges of both temperature and rainfall, in which carbonate movement is produced within the soil profile, resulting in the reworking and cementing of the soil constituents into a cohesive, calcareous mass. This caliche formed during a period of stable, semiarid climatic conditions which have been tentatively correlated with the Yarmouthian interglacial stage of the middle Pleistocene (Bachman, 1974, 1976).

2) Eolian Sand

Eolian sand covers much of the Mescalero Plain in southeastern New Mexico and is known locally as the Mescalero sand (Vine, 1963). This sand generally forms two distinct types of deposits - sheetlike stretches of surficial sand, which vary in thickness from about 5 to 15 feet (Bachman, 1973; Vine, 1963), and dunes, having a maximum thickness of about 60 feet (Hendrickson & Jones, 1952).

The eolian sand deposits of the Mescalero Plain have probably been derived from a widespread source of fine-grained sediments. Bachman (1974) suggests that most of this sand originated from the Ogallala Formation, although local sources, such as blowouts, have also been a source of some dune materials. There is little evidence to indicate that much sand has been derived from the Pecos River (Bachman, 1973, 1974, 1976).

Except where the sand is stabilized by vegetation, it is continually blown about to form transverse dune ridges and barchan dune areas separated by broad flats. The orientation of the dune ridges is not uniform throughout the area, with the long dimension of the ridges apparently reflecting the direction of the strongest prevailing winds at the time of their formation (Vine, 1963) (also see Section 3.6.5).

At least two periods of eolian sand emplacement have occurred since the formation of the Mescalero Plain in Pleistocene time and are evidenced in some places by two distinct layers of sand. The lower deposit consists of a semiconsolidated somewhat clayey sand, as much as 1.5 feet thick, overlain by as much as 20 to 25 feet of loose surficial sand forming the contemporary sheet and dune formations (Bachman, 1976).

Karst Topography The land surface in southeastern New Mexico locally exhibits a karst topography, characterized by geomorphic features such as sinkholes, linear depressions (called solution-subsidence troughs by Olive, 1957), domes (including one known "breccia pipe"), "castiles" and collapsed outliers (Anderson, 1978). Many of these features show up on LANDSAT imagery as ponds and other water-filled depressions concentrated particularly near Roswell and also between the Pecos River and Mescalero Ridge. These features have resulted from the dissolution of salts and other soluble materials within the upper Permian Ochoan Series (see Section 3.3.2), particularly in the Rustler and the Upper Salado. The water required for the dissolution process has come into contact with the soluble materials either by surface exposure, following erosional removal of the protective mantle of younger sediments such as the Ogallala and

caliche, or at depth, by means of the downward percolation of local surface water or by contact by means of fracture systems between the Ochoan rocks and underlying regional aquifers, which have been exposed along basin margins by the Cenozoic regional uplift, tilting and erosion. These solution processes have been followed by collapse of the insoluble strata into the voids left behind by the dissolution (Bachman, 1974).

Development of karst features may have occurred in southeastern New Mexico as early as Triassic or Jurassic time, when the area was above sea level and probably undergoing extensive erosion which exposed the soluble materials. Bachman (1976) surmised that some dissolution of Permian salts and gypsum probably took place in the western part of the Delaware Basin during Jurassic time, before resubmergence in the Cretaceous. Extensive regional erosion also took place during the early Tertiary, presumably with accompanying renewed dissolution activity, although no sedimentary records of that period are preserved today. The earliest and most widespread basis for relative dating of solution-collapse features in the area is the Mescalero caliche, of Middle Pleistocene time. If, as is generally believed the caliche was derived from a soil profile, it could not have formed on the irregular and, in places, very steep slopes of today. Additionally, the fracturing and slumping of the Mescalero caliche along the widely occurring depressions of the area indicates collapse after Mescalero time. Some of the major collapse features here, such as Nash Draw, Clayton Basin and Crow Flats, exhibit evidence of several intervals of dissolution and subsidence activity. For example, Crow Flats, a large feature 15 miles east of Artesia, contains evidence for at least 3 such episodes, ranging in time from after Triassic and before Pleistocene Gatuna deposition, during or after Gatuna time and after Mescalero time (Bachman, 1976). Notwithstanding this evidence of long term dissolution history, Anderson (1978) believes that many of the deep-seated dissolution features formed during the most recent and most extensive period of salt removal following the Cenozoic erosion and exposure of the evaporites. Much of this activity is suggested to have occurred during the past few million years; dissolution has apparently progressed from west to east and from south to north across the Delaware Basin.

1) Principal Types of Solution - Subsidence Features

a) Sinkholes

Sinkholes form a category of features represented by thin or missing sections of halite in the Castile or by surficial depressions. Thin or missing halite in the Castile may be determined on the basis of borehole geophysical logs (see Anderson, 1978); the data may not assuredly represent dissolution at depth. Sinkholes designated on the basis of one borehole should also be viewed with caution. Similar data might be obtained in an area with some salt deformation. For the purposes of building a working hypothesis of deep dissolution, Anderson (1978) took these data as possible indications of deep dissolution.

Many of the sinkholes present in the northern Delaware Basin area developed as deep-seated features originating in the Castile Formation. These sinks are often expressed as thin or missing sections of the "Halite I" and "Halite II" salt of the Castile, and to a lesser extent of smaller salt beds above these units, and resulting structural depression of the overlying stratigraphic units. At least 100 deep-seated sinks are estimated to exist presently in the New Mexico portion of the basin. Around the margin of the basin, a number of these deep-seated sinks appear to be associated with anticlinal structures in the salt; in the mid-basin area, these sinks occur as both isolated features and in association with salt anticlines (Anderson, 1978). In addition to these deep-seated features, there are many sinks present in the area which are associated with active near-surface dissolution, such as those along the Pecos River and in Nash Draw (Anderson, 1978).

Compound sinkholes, resulting from coalescing collapse sinks, are common along the Pecos River valley south of Roswell. Many of these sinks have collapsed within historic time (Bachman, 1974). As discussed above, Bachman (1974) has suggested that the course of the Pecos River southward from Carlsbad to near the New Mexico-Texas border lies within a major belt of such collapse sinks. Bachman has also described similar

developments along the east side of the Pecos River southeast of Carlsbad, where a linear scarp is believed to have formed as the result of a collapse structure which is now occupied by the river.

b) Dolines

Dolines are very common features in southeastern New Mexico, forming on limestone bedrock and caliche surfaces. Dolines are defined as relatively shallow solution sinks that develop on the surface beneath the soil mantle without physically disturbing the underlying rocks or being underlain by subsurface solution cavities (Bachman, 1974).

c) Solution-Subsidence Troughs

Narrow, linear, generally northeast-trending depressions that vary in width from a few hundred feet to a mile and in length from one-half mile to 10 miles in southeastern New Mexico have been termed solution-subsidence troughs by Olive (1957), who proposes that these troughs result from the subsidence of near-surface material which fills voids dissolved by water flowing in underground channels. According to Thornbury (1965), these troughs are particularly common west of the Pecos in areas underlain by the Castile Formation and extend eastward, parallel to the regional dip as a result of dissolution along eastward-trending joint systems that parallel the regional dip.

Bachman and Johnson (1973) also describe linear features occurring in areas generally underlain by the Ogallala, to the north and northeast of the site, and suggest that at least some of these depressions may be the result of alternate leaching and wind deflation (Judson, 1950; Price, 1958). These features appear on LANDSAT imagery as alternating linear strips of vegetation and white to gray soil, trending NW-SE. They are most prominent north of Hobbs, north of San Simon Sink, and at scattered locations on the Mescalero Plain. The leaching may have been produced by the chemical action of plant growth on the caliche surface between longitudinal sand dunes where small amounts of ground water were able to

collect during periods of eolian quiescence; later periods of eolian activity removed these leached sediments from between the dunes. The swales left behind by this leaching activity mark the location of former longitudinal dune fields which have been displaced or removed by continued eolian activity. The effect of these linear features has been to provide depressions in which surface runoff collects and serves as sources of ground water recharge. Solutioning and erosion along these lineaments may have also opened conduits to the subsurface and contributed to a more rapid dissolution of the underlying soluble rocks (Bachman and Johnson, 1973).

d) Breccia Pipes and Domes

Various domal structures, having diameters of from several hundred to several thousand feet, occur in southeastern New Mexico, particularly along and east of the Pecos River, and are associated with areas of relatively recent surface salt dissolution (Anderson, 1978). Although they have been termed "breccia pipes," these features have no relationship whatsoever to volcanic activity. Many of the domes have been breached by erosion to reveal brecciated cores of stratigraphically displaced Gatuna, Rustler, and Triassic beds. These features are also characterized by doming-related deformation of rocks as young as the Mescalero caliche (Vine, 1960). The depth to which these breccia pipes extend is not known; one pipe is known to reach as deep as the McNutt member of the Salado Formation, as evidenced by underground exposures in the Mississippi Chemical Company potash mine (Griswold, 1977).

Anderson (1978) hypothesized that breccia pipes originate from the dissolution of salt at depth by waters circulating along intersecting joint sets in adjacent brittle rocks. Subsequent collapse of insolubles into the cavity forms a rubble breccia chimney, which sometimes penetrates to the ground surface. The only known breccia pipe (located in the Mississippi Chemical Corporation mine in Nash Draw) is observed to be well-cemented by fine-grained material with no perceptible open space. There is no evidence of removal of soluble material from the

evaporites adjacent to the feature in the mine. This particular feature is expressed at the surface by a dome with a collapsed center. The doming of this brecciated core takes place at a later time. Vine (1960) has suggested three possible mechanisms for this later deformation: the erosion of the rock surrounding the core of the sink; the upward flow of salt into the sink; an increase in volume of rock as anhydrite is altered to gypsum in the brecciated core. Anderson (1978) expressed the opinion that the doming has been produced by regional near-surface dissolution removing the salt from around the pipes and producing a sagging of the beds around the pipes. As a result of the doming process, the rock strata surrounding the dome at the surface generally dip away from the breccia pipe core (Vine, 1960). Underground, in the Mississippi Chemical mine, beds adjacent to the breccia pipe dip down toward the breccia pipe at about 10-20°.

The age of the breccia pipe formation in this area has not been determined. Mescalero caliche, of Middle Pleistocene age, is present on the flanks of breccia pipes and lying at steeper angles than those at which the caliche probably originally formed. This may indicate that the breccia pipes are younger than the Mid-Pleistocene. It is also possible, however, that the breccia pipes predate the caliche and that later subsurface removal of salt by dissolution produced greater amounts of downdrop away from the more resistant breccia pipes, resulting in the slopes present today. (Continuing studies of these features are addressed in Chapter 10.)

Despite the fact that the breccia pipes which have been recognized are generally expressed topographically as domes, it has been surmised that others may have no surficial expression and have therefore gone undetected to the present time. Geophysical exploration has been used to explore for pipes without surficial expression. Electrical resistivity surveys have shown that the breccia core of the known pipe has a much lower resistivity than does the surrounding undisturbed strata (Elliot, 1976). Continuity of seismic reflections are lost when similar geomorphic features are crossed by survey lines (Griswold, 1977).

e) Collapsed Outliers and "Castiles"

Outliers of the Rustler Formation, separated from the main outcrop area through erosional processes, as described by Anderson (1978), are circular to elongate or irregular collapse features consisting mostly of the Culebra dolomite. They occur where the salt has been completely dissolved from the evaporites.

Limestone buttes, called Castiles, occur west and south of the collapsed outliers, primarily in Texas, in the lower part of the Castile Formation outcrop area. These features consist of biogenic calcite which has replaced the gypsum or anhydrite of the Castile Formation, and some exhibit collapse structures with brecciated cores. These buttes are similar in size and distribution to the collapsed outliers (Anderson, 1978).

2) Major Near-Site Features

Major geomorphic features which have formed in the area of the proposed WIPP site as a result of sinkhole formation and related solution-subsidence mechanisms include Nash Draw and San Simon Swale (see Figure 2-1 for their location and topographic configurations). These features and their specific development are discussed separately, below.

a) Nash Draw

Approximately 5 miles northwest of the proposed WIPP site is a prominent geomorphic feature, known as Nash Draw, which Vine (1960) described as "a sinuous depression about 4 miles wide and 18 miles long." Its surface structural expression is similar to that of a breached anticline plunging gently northward, with the older Rustler Formation exposed in its center and the younger Dewey Lake redbeds and Santa Rosa Sandstone exposed along its flanks. However, well records in the area indicate that the bedrock underlying the draw exhibits a gentle homoclinal configuration. Accordingly, Nash Draw has been identified as an undrained physiographic

depression, which has probably developed as a result of regional and differential dissolution of the anhydrite, gypsum and halite beds of the Rustler and upper Salado Formations (Vine, 1963).

According to Vine (1963), dissolution on top of the massive salt in the Salado has produced a rather uniform lowering of the land surface in Nash Draw, but its surficial structural features have been produced and greatly modified by differential solution of the more soluble portions of the Rustler Formation. While the bedrock in the northern part of Nash Draw is generally covered by eolian sand, caliche and alluvium, the central and southern portions of the draw contain exposures of Rustler that has been highly deformed primarily as a result of large-scale collapse following solution of the Rustler and Salado. This dissolution activity has also produced numerous individual sinkholes in Nash Draw, which vary in configuration from circular features a few tens or hundreds of feet across to irregular or arcuate features up to more than a mile across. Many of the larger depressions in the area of Nash Draw, including the basin at its southwestern extent which contains Salt Lake, have probably formed through the coalescing of several smaller solution depressions or sinks. Some such places, where several depressions tend to line up may also indicate the location of subterranean cavernous water courses (Vine, 1963).

The age of the earliest solution activity that produced Nash Draw is uncertain. It is thought that some of the deep-seated solution in the Delaware Basin area had occurred by the middle part of the Mesozic, but that a substantial amount of this process has taken place since the Late Tertiary regional tilting of this area. Within Nash Draw, the formation of a large number of the individual solution features has resulted in the deformation of rock units as young as the Pleistocene Mescalero caliche, which indicates that Quaternary dissolution of the Salado and Rustler Formations is of primary importance in the geomorphic history of Nash Draw. Assuming that this disturbed caliche originally lay at an elevation corresponding to that of the adjacent Mescalero Plain, then at least 100 to 150 feet of local warping and depression has occurred in

Nash Draw within relatively recent time (Vine, 1963). Bachman (1974) estimated that at one place in Nash Draw a surface lowering of approximately 180 feet, almost wholly the result of solutioning and subsidence, has occurred in the past 600,000 years.

b) San Simon Swale

San Simon Swale is one of a series of large deep-dissolution depressions filled with Cenozoic sediments, lying above the inner margin of the Capitan reef along the eastern side of the Delaware Basin (Anderson, 1978). Situated approximately 20 miles east of the proposed WIPP site, San Simon Swale forms a southeasterly-trending depression approximately 25 miles long and from 2 to 6 miles in width. Much of the surface of the swale is at present covered by eolian sand, which masks the relief. Of particular interest within San Simon Swale is a compound collapse feature called San Simon Sink, which occupies an area about 2 miles long and 1 mile wide at the southeastern end of the swale (Bachman and Johnson, 1973).

San Simon Swale originated from a combination of surface stream erosion and solution-subsidence (Bachman & Johnson, 1973). During the Pleistocene, a major tributary of the Pecos River is thought to have flowed southeastward through what is now San Simon Swale to join the Pecos in western Texas. The initial course of this tributary was determined as it eroded its way through the caliche caprock of the Ogallala Formation (Bachman and Johnson, 1973). The dissolution and subsequent removal of these beds resulted in the formation of numerous sinkholes, some of which coalesced to form, at least in part, the depression now known as San Simon Swale (Bachman and Johnson, 1973). The swale has been lowered at least 180 to 200 feet below its original surface, in view of lake deposits in the sink encountered during preliminary WIPP studies. Current drilling operations reveal a thickness of over 600 feet of post-Ogallala sediments underlying the present floor of the swale.

Within San Simon Swale, the San Simon Sink formed as a secondary collapse structure, probably during the Pleistocene. Numerous ring fractures around the sink indicate that it has had a long history of successive collapse events since its initial formation (Bachman and Johnson, 1973). The most recent of these events is reported to have occurred in the 1930's (Nicholson and Clebsch, 1961). It is therefore assumed that salt dissolution in the underlying formation is continuing here and it is thought by some that the resulting brine is being carried in a southeasterly direction toward Texas (Bachman and Johnson, 1973).

On the basis of written communication from C.L. Jones of the U.S. Geological Survey, Bachman (1973) reported that over 500 feet of Cenozoic sediments have thus far been deposited in San Simon Sink. Nicholson and Clebsch (1961) have estimated that alluvium is presently being deposited in the sink at a rate of about 1 foot in 5 years. Recently acquired core (WIPP 15) from San Simon Sink has been analyzed in a preliminary way (Anderson, 1978) showing about 545 feet of fill on top of Triassic sediments. Dates on the fill have not yet been obtained.

Blowouts Some of the basins which are present in southeastern New Mexico have been formed by processes other than the previously described mechanisms of dissolution and collapse. The most conspicuous of these basins in the area of the proposed WIPP site are named Williams Sink, Laguna Gatuna and Laguna Plata, all of which are situated approximately 15 miles to the north of the site.

These features, termed blowouts, have formed through the removal of loose sand deposits by wind erosion. During the rainy season, many of the depressions which have resulted are partially filled with water. The floors of the blowouts are mantled with clay and saline deposits, and many blowouts are surrounded by eolian sand. Dune fields commonly develop along the northeastern and eastern leeward margins of these depressions (Bachman, 1974).

3.2.3 Erosion Rate- Significance of Geomorphic Developments to Site

This section provides a short review of the degree to which the major surface and subsurface processes discussed in the previous section have affected the land surface in the vicinity of the site and discusses to what extent these activities may be predictive of future geomorphic modifications in this area.

The resistant Mescalero caliche covers most of the land surface in the vicinity of the site and underlies the site itself. Where present, the caliche provides an indication that no significant erosion of the surface in these areas has occurred since the formation of the caliche in Mid-Pleistocene time.

The major areas of relief which have developed since this time have probably been produced to a large extent from subsurface dissolution and subsidence. The two major features of significance to the site, originating from these processes, are Nash Draw and San Simon Swale. In Nash Draw the surface has been lowered at least 100 feet by dissolution, and locally as much as 180 feet, within approximately the past half million years. Bachman (1974) also cited one location within the draw where the lowering of the ground surface appears to have exceeeded the rate of salt removal, indicating a surface erosion of about 40 feet in addition to solution activities. San Simon Swale, a product of surface erosion as well as solution-subsidence, lies at its lowest point some 180 to 200 feet below the surrounding land surface (Claiborne and Gera, 1974), and may have undergone a total subsidence of about 750 feet. No age has yet been obtained from the sediments obtained during recent drilling. (See Chapter 10, Continuing Studies.)

Wind erosion has produced other depressions in the area, with a resultant buildup of material in the same vicinity. However, these features are generally of only minor dimensions and are local in extent (Claiborne and Gera, 1974).

These observations should not be considered as constants for rates of erosion which would hold true for the future. But in providing a general indication of the surface modification in the vicinity of the WIPP site, they do indicate the pattern of continuing geomorphic development of the area. Variations in climatic conditions give rise to variations in rates of denudation and also in rates of subsurface dissolution. The nature of the ground surface is also of major importance in terms of its vulnerability to erosional processes.

The site is located west of and near a drainage divide between Nash Draw and San Simon Swale, where it appears that very little dissolution or surface erosion has occurred since Early Pleistocene time, as evidenced by the relatively undisturbed nature of the Mescalero caliche there, which has also served as a protective layer for the underlying soluble rock units. Contouring studies, too, indicate that this area has been a drainage divide between San Simon Swale and Nash Draw at least since Mid-Pleistocene time (Bachman, 1976). Although erosion here has been minimal under the present semiarid climatic conditions, if more humid conditions should develop in the future, an accelerated erosion of the caliche is reasonable to expect. However, with increased rainfall, it is also expected that Nash Draw and San Simon Swale will be exposed to more erosive stress, since most of the runoff will probably flow out of the immediate area along these depressions.

3.3 REGIONAL STRATIGRAPHY AND LITHOLOGY

3.3.1 Precambrian Rocks

Metasediments and granitic igneous materials consititute the majority of the basement rock of the southeast New Mexico - west Texas region. These Precambrian rocks crop out in only a few localities, in the western part of the region, such as the Nigger Ed Canyon area of the Sacramento Mountains (Pray, 1954), in the core of the Pajarito Mountain dome (Kelley, 1971) and in the Bent Dome, east of Tularosa (Bachman, 1960). Data on the Precambrian underlying the Delaware Basin and further east

and south across the Central Basin Platform into southwest Texas have been obtained principally through oil company records; hundreds of wells have been drilled in this area, particularly on the Central Basin Platform. Little data are available from the basin areas, where most wells penetrate only to the Upper and Middle Paleozoic sections.

The configuration of the Precambrian basement surface reflects the late Paleozoic structural framework of the region (see Figure 3.4-2). The surface is deepest along the northern axial portion of the Delaware Basin, where it reaches a depth of about 20,000 feet below sea level. The basement surface rises to the east, north and west of the Delaware Basin. On the northeast, into Otero and Chaves Counties, the basement rises fairly uniformly to more than 4,000 feet above sea level; on the east, the surface rises rapidly on the Central Basin Platform to elevations of between -5,000 and -4,000 feet (Cohee, et al., 1962; Foster and Stipp, 1961). Well data suggest that a number of post-Precambrian faults break the profile of the basement surface throughout the region. A notable example of this occurs along the west margin of the uplifted Central Basin Platform, where a vertical offset of perhaps more than 5,000 feet is present along the south portion of a large normal fault system.

The Precambrian sections which have been examined display a complex association of metasedimentary, sedimentary, metavolcanic, volcanic and plutonic rock types, suggesting a history of repeated orogenic activity interspersed with erosional episodes. Muehlberger, et al. (1967) have classified the Precambrian rocks of the region into a number of terranes of various age and lithology. A modified version of their geological map, Figure 3.3-1, presents the distribution of the major Precambrian rock types of the area.

Outcrops of probably Late Precambrian age slightly metamorphosed siltstones, shales and fine-grained quartz sandstone with associated intrusive sills are found in the vicinity of Nigger Ed Canyon in the Sacramento Mountains. The majority of the sills are diabase, and some are markedly porphyritic (Pray, 1954, 1961).

In the subsurface, similar Precambrian diabase and incipiently metamorphased clastics, including quartzite, siltstone and impure limestone, comprise a broad band which extends from southern Otero County northward for over 200 miles to southeastern Guadalupe Country. Muehlberger, et al. (1967) have termed these rocks the DeBaca terrane. In the Franklin Mountains at the extreme western tip of Texas, these metasediments attain a known thickness of almost 4,000 feet (Harbour, 1960). The rocks are underlain, at least in part, by rhyolites of the Panhandle volcanic terrane, discussed below, and are overlain in the Franklin Mountains by up to 1,000 feet of rhyolite (Harbour, 1960) dated at 900 million years.

To the east of the Sacramento Mountains on the Northwestern Shelf, an approximately 2-square-mile outcrop of Precambrian rock is exposed in the core of Pajarito Mountain dome. These rocks, radiometrically dated as 1,270 million years old, consist of hornblende, syenite, hornblende syenite gneiss, and some diabase, locally intruded by leucocratic syenite and hornblende syenite pegmatite (Kelley, 1971). Granitics apparently underlie most of the south-central parts of New Mexico and large areas in Eddy and Lea Counties (Foster & Stipp, 1961), extending at least as far west as the Guadalupe Mountains as well as south and southeastward into Texas (Flawn 1954; Muehlberger et al. 1967). These rocks, named the Chaves granitic terrane, are largely granite, granodiorite, compositionally equivalent gneiss and lesser amounts of metasedimentary and metaigneous rocks. Granite comprises about 80 percent of the samples studied. Foliation in these rocks is generally faint, but is enhanced by some shearing (Muehlberger et al., 1967). Wasserberg et al. (1962) dated the granitics in this area as between 1,250 and 1,400 million years in the north and as young as 1,090 million years to the south. These granitics appear to predate the sedimentary Precambrian rocks to the west (Foster & Stipp, 1961).

Younger volcanics, which appear to have been extruded and deposited as a relatively thin layer above the granitics, are present in at least parts of Chaves, Lea, Roosevelt, Curry and Quay counties as well as near the

south border of New Mexico west of the Brokeoff Mountains and eastward in the Texas Panhandle (Foster & Stipp, 1961; Muehlberger, 1967). These rocks, known as the Panhandle volcanics, are primarily rhyolitic flows and tuffs and pyroclastics with subordinate trachytic and andesitic types. The volcanics are mostly undeformed and unmetamorphosed. Rb-Sr dating of these rocks yields an average age of 1,140 ± 50 million years (Muehlberger et al., 1967).

Gabbro and diabase or basalt, commonly showing intergranular ophitic to subophitic textures, underlies parts of Roosevelt and southern Curry Counties and extends eastward into Texas. These rocks, termed the Swisher diabasic terrane, intrude the volcanics, and, although their age is uncertain, are considered Precambrian (Muehlberger et al., 1967; Flawn, 1954). According to Flawn (1954, 1956), these rocks appear to be a great stratiform body occupying a major basement syncline, although no large positive gravity or magnetic anomaly is present over this region.

Clastics of Late Precambrian age crop out near Van Horn, Texas. These deposits are part of an alluvial fan which is overlain by the Bliss sandstone (McGowan and Groat, 1971). Elsewhere, including the Guadalupe Mountains, these rocks have been studied through well cuttings.

3.3.2 Paleozoic Rocks

Cambrian Rocks

Very little is known about the existence or nature of any Cambrian sediments underlying the Delaware and Val Verde Basins area of southeast New Mexico-west Texas, partly because the great thickness of the overlying section in this region and partly because the belief that the Ordovician Ellenburger is the deepest potential reservoir formation has discouraged deeper drilling (Vertrees et al., 1959).

Basal Paleozoic clastics were named the Bliss Sandstone by Richardson (1904) for exposures in the Franklin Mountains. They range in thickness from 0 feet to the north to about 375 feet toward the south. The Bliss unconformably overlies the Precambrian and in most places is conformably overlain by the El Paso Group (Hayes, 1964). According to Harbour (1960), the Bliss is probably a beach or near-shore deposit of the sea in which the overlying El Paso Limestone accumulated.

In its type locality and in most areas east of longitude 107°W, the Bliss generally consists of over 90% sandstone that is thin-bedded and jointed. Subordinate, thin interbeds of siltstone or shale and rare thin beds of sandy limestone or dolomite are present. Dark siltstone grains, cemented by glauconite and hematite, combine to produce a dark color (Hayes, 1975; Harbour, 1972).

In the Sacramento Mountains of southeastern New Mexico, the Bliss Sandstone is exposed in the vicinity of Nigger Ed Canyon. A 10° angular unconformity separates it from the underlying Precambrian. The Bliss in this area contains 110 feet of quartz sandstone, minor dolomitic sandstone, sandy dolomite, brown-weathering sandstone interbeds in the upper third of the section. Abundant glauconite is present in some of the strata. In general, this section is similar to that at the type locality near El Paso (Pray 1954, 1961). Farther southeast in the subsurface at the Guadalupe Mountains area, the Bliss consists of less than 30 feet of light gray to white, poorly sorted, coarse-grained quartz sandstone at the base and top, separated by gray, fine-to-medium grained, sandy dolomite (Hayes, 1964).

Most investigators consider the Bliss Sandstone to be diachronous, ranging in age from Late Camorian through Early Ordovician, becoming younger from west to east, as determined from faunal evidence and lithologic correlations (Hayes, 1975). The Bliss of the Sacramento Mountain area has been dated as Cambrian by the Residue Research Laboratory of Midland (Roswell Geological Society, 1953). However, Flower (1953) has indicated that the formation is time-transgressive and

contains both Late Cambrian and Early Ordovician fauna in New Mexico (Harbour, 1972). The evidence indicates that in its easternmost localities, the entire Bliss is of Early Ordovician age (Hayes, 1975). Hayes reported in 1964 that it is very likely that the Bliss in the subsurface of the Guadalupe Mountains area is entirely Ordovician. Foster (1974) also considers that the Bliss sediments of the southeastern New Mexico Delaware Basin area probably correlates only with the Ordovician part of the unit as defined in Texas.

Ordovician Rocks The Lower Ordovician section is composed mainly of carbonates deposited in a shallow sea with a relatively calm shelf environment (see Figure 3.3-2). In 1904 Richardson named exposures in the Franklin Mountains the El Paso Limestone (Hayes, 1975). Cloud and Barnes (1948) named exposures in western and central Texas the Ellenburger Group, and this name is commonly applied to subsurface rocks in the Permian Basin. Some workers have subdivided these rocks into formational groupings that are recognizable over much of the region. For discussion of nomenclature and detailed stratigraphy, refer to Hayes (1975).

Where the El Paso crops out in the Sacramento Mountains escarpment, it is composed of up to about 420 feet of light-to-olive-gray, very fine-to medium-grained dolomite. Thin to medium beds predominate, chert nodules occur sporadically, and interbeds of dolomitic quartz sandstone are common toward the base, derived from erosion of rocks to the east. In the Sacramento Mountain area, at least, the El Paso appears to be either time-transitional with the Bliss Sandstone or separated from it by a minor disconformity (Pray, 1961). To the southeast, in the subsurface of the Guadalupe Mountains, the El Paso comprises from 520 to 550 feet of gray, fine-to medium-grained, crystalline, siliceous dolomite with some sand near the base and top and some light-colored aphanitic chert. Eastward in the Delaware Basin over 700 feet of El Paso or Ellenburger has been encountered. In the New Mexico portion of the basin, the formation is almost entirely a light-gray to gray crystalline dolomite with small amounts of sandstone; much chert is present in some localities

near the top of the section (Haigler, 1962). South and southeastward in the west Texas Delaware-Val Verde Basin area, the Ellenburger reaches a maximum thickness of at least 1,600 feet and is composed almost entirely of limestone and dolomite (Vertrees et al., 1959). Its limestones are light-gray and dominantly sublithographic, becoming purer upward; the dolomites range from coarse-grained pale rocks, generally near the bottom to finer-grained, more brightly colored ones above (Cloud and Barnes, 1946).

Middle Ordovician sediments comprising the Simpson Group are recognized in the subsurface from the Guadalupe Mountains area through the Delaware Basin and east into Texas. The Simpson thins rapidly to the west at an average rate of about 10 feet per mile (Hayes, 1964), wedging out near Artesia, New Mexico. To the north, it extends to the latitude of Roswell and elsewhere is truncated by erosional unconformities. Where the Simpson, or equivalent, is encountered within the New Mexico portion of the Delaware Basin, it ranges in thickness from less than 200 feet to 1,850 feet in southern Lea County (Nicholson & Clebsch, 1961). In the basin, the Simpson consists of 3 main layers of limestone, alternating with thinner green, brown and black shale, black shale with rounded quartz grain inclusions, and sandstone (Haigler, 1962). Towards the south and southeast, the formation thickens considerably, reaching a maximum of at least 2,250 feet before wedging out in the Marathon Mountains region. Shaly facies predominate towards the south. In the Delaware-Val Verde region, the sandstones and some of the carbonate members are potential oil and gas reservoirs (Vertrees et al., 1959).

In the subsurface of the Permian Basin, the Simpson is overlain conformably by carbonates of the Montoya Group, assigned to the Middle and Late Ordovician by Hayes (1975). At the type locality in the Franklin Mountains, the Montoya ranges in thickness from about 140 to 250 feet, averaging about 200 to 225 feet, and consists of a lower olive gray to dark gray cliff-forming dolomite with a thin, very coarse-grained quartz sandstone at the base and an upper, lighter colored cherty and finer-grained, slope-forming dolomite. The top of the group is marked by

a zone of bedded chert (Bachman and Myers, 1969). Eastward in the north part of the Delaware Basin, the Montoya ranges from about 280 to 440 feet in thickness and consists of medium-to dark-gray dolomite with minor amounts of dark gray limestone and chert (Haigler, 1962). Where it occurs on the Central Basin Platform, the Montoya is a cherty limestone about 150 feet thick. To the south, the Montoya is composed of primarily chert and dolomite, reaching a maximum thickness of 600 feet (Vertrees et al., 1959).

The uppermost rocks of Ordovician age in the area consist of a generally light-gray, thin-bedded dolomite with some marl. It had been included by Darton (1917, 1928) as the lower part of the Fusselman, but having been recognized by Kelley and Silver (1952) as Ordovician, it was removed from the Fusselman and renamed the Cutter Formation. Pray (1954) called it the Valmont, where he encountered it in the Sacramento Mountains. Now, however, these beds have been established as the Cutter Member of the Montoya Dolomite (Harbour, 1972; Bachman and Myers, 1969).

Silurian Rocks The Silurian of the southeast New Mexico - west Texas areas consists of the Fusselman limestone and the carbonates and shales of an "Upper Silurian" unit, both of which were deposited in a broad subsiding area named the Tobosa Basin

The Fusselman rests unconformably on the Late Ordovician Montoya and ranges in thickness from 0 to 1,000 feet in part of southern New Mexico and west Texas, and thins westward and northward into an erosional wedge (Hayes, 1975). It is composed of a massively-bedded, clean, light-colored dolomite and locally limestone. The limestone facies is dominant to the southeast; a thicker dolomite facies is dominant to the north and west. The Fusselman has been dated as Middle Silurian and possibly also Early Silurian in age (McGlasson, 1968; Hayes, 1975; Pray 1958).

In the Sacramento Mountain area, the sequence overlying the Montoya has been divided by Pray (1953, 1954, 1961) into two units. The lower member, which he termed the Valmont, is composed mostly of light gray, very finely textured dolomite ranging in thickness from 150 to 225 feet. The upper part of the sequence in the Sacramento area, recognized by Pray (1954) as Silurian, comprises a medium to finely crystalline, light to medium gray, cherty dolomite not exceeding 100 feet. As identified in the subsurface of the Guadalupe Mountains, the Fusselman ranges from 580 feet to about 710 feet of white to light gray, coarse to medium crystalline dolomite, which contrasts sharply with the darker, fine-grained underlying Montoya (Hayes, 1964). In the Delaware Basin, the Fusselman is a light-colored dolomite containing abundant chert and two thick limestone intervals. It reaches its maximum thickness in southern Lea Country. Eastward across the Central Basin Platform, the Fusselman is represented by a coarse-grained crystalline glauconitic limestone and dolomite 180 to 200 feet thick (Nicholson & Clebsch, 1961).

The subsurface unit informally called the "Upper Silurian" consists of a shaly facies to the southeast and much thicker carbonate facies to the north and west. The unit is more restricted areally than is the underlying Fusselman, pinching out northward and westward across north-central Eddy and Lea Counties. The carbonate facies predominates in the New Mexico portion of the Delaware Basin and includes both limestones and dolomites, reaching over 1,500 feet in thickness (McGlasson, 1969). On the Central Basin Platform, it consists of 180 feet of green, gray, and black shales interbedded with dense limestones (Nicholson & Clebsch, 1961). Southward into Texas, the shaly facies is composed of bright green to dark brown shales and white to brown calcilutites with a maximum thickness of 300 feet (McGlasson, 1968).

Devonian Rocks Lower to Middle Devonian rocks are known only from subsurface exploration, and only in the southeastern corner of Lea County, New Mexico. Called the "Devonian" rock unit by McGlasson (1965), these rocks are more restricted in area than the "Upper Silurian" and range in thickness from zero to 1,000 feet in the vicinity of Crane

County, Texas. The unit is composed primarily of chert in the southwest, grading northeastward into dark siliceous micrite and light-colored calcarenite. After deposition, the unit underwent considerable diagenetic alteration.

In the western part of the region, along the Sacramento Mountain escarpment, a unit dated as upper Middle Devonian, the Onate, has been recognized (Pray, 1954, 1961). It consists largely of dark gray to olive gray, very fine-grained dolomite mixed with coarse silt to very fine quartz sand, with minor shale, increasing to the south. Small, irregular chert or silicified dolomite nodules several inches long are distinctive lithologic features of the upper part of the formation in the central and northern parts of the escarpment. To the west the Onate forms beds generally less than 1 foot thick and rarely thicker than 2 feet but is as much as 60 feet thick in the central escarpment area, thinning northward and southward.

Upper Devonian rocks in the subsurface of the southeast New Mexico area constitute the Woodford shale, portions of which are also variously known as the Percha shale and Canutillo Formation. These rocks are described by McGlasson (1968) as extending from eastern Chaves and southern Roosevelt Counties in New Mexico, southward and eastward through western Texas and ranging in thickness from zero to approximately 700 feet near the southeast corner of Lea County, with an average of 200 feet elsewhere (Vertrees et al., 1959). The Woodford is a dark brown to black, fissile, bituminous, spore-bearing shale which becomes arenaceous northward and contains black chert to the south and west (McGlasson, 1968).

Across the Central Basin Platform, the rocks correlative to the Woodford in age consist of interbedded, calcareous chert and siliceous limestone, reaching a maximum thickness of 980 feet (Nicholson & Clebsch, 1961). Westward in the northern Delaware Basin, the unit decreases to less than about 200 feet thick and is an organic pyritic shale. In the Guadalupe Mountain area, the unit comprises less than 100 feet of dark gray, locally silty shale, with a few feet of dark or medium gray chert at its

base (Hayes, 1964). At the northwestern limit of the unit in the Sacramento Mountains, the lower Upper Devonian section has been called the Sly Gap Formation and consists of up to 50 feet of calcareous, yellow-gray to dark gray shale with irregular nodular limestone becoming predominant upward. This unit is absent in the south half of the escarpment, where the Upper Devonian is represented by a dark gray noncalcareous shale, considered equivalent of the Percha shale and recognized southward as the Woodford (Pray, 1954).

The Woodford and equivalent units are transgressive and lie unconformably on an erosional surface formed on the rocks of the older Devonian section through the Ordovician Montoya Group. According to McGlasson (1968), the upper portion of the Woodford deposition probably was deposited in Early Mississippian time. At its upper limit, the Woodford is conformably overlain by limestones and sandstones of the Early Mississippian.

Mississippian Rocks Mississippian rocks throughout most of the southeast New Mexico-west Texas area consist of limestones overlain by shales, which together attain a maximum thickness of some 2,400 feet, truncated by erosional unconformities (Vertrees et al., 1959). Rocks of definite Mississippian age appear to be absent across the Central Basin Platform (Nicholson & Chelbsch, 1961).

The Lower Mississippian Kinderhookian-Osagian series is represented in southeast New Mexico and west Texas by a limestone unit (Roswell Geol. Soc. 1958). It is 365 feet thick in the Guadalupe Mountains and 220 to 320 feet in the northern Delaware Basin, thickening to the southeast and thinning to the west (Haigler, 1961). The limestone is light gray to brown, finely crystalline and commonly cherty, with a basal dark gray organic-rich shale unit. The limestone partially grades to shale southeastward from the northern margin of the Delaware Basin (Brokaw et al., 1972; Haigler, 1962). The northwestern face of the Sacramento Mountains contains exposed units of equivalent age, but detailed correlation with the foregoing surface data from the rest of the area is unreliable (Haigler, 1962). The Kinderhookian here is represented by up

to 60 feet of Caballero limestone and calcareous shales. The overlying Osagian series Lake Valley Formation, which attains a thickness of about 400 feet in the northern and central Sacramento Mountains, is composed of 6 members whose dominant lithology is limestone containing various amounts of chert and argillaceous and biohermal materials (Pray, 1954).

The Upper Mississippian rocks in the subsurface of southeast New Mexico, apart from the Sacramento area, consist of black, brown and gray shale much of which is silty, variously named the Barnett, Chester or Meramec (Brokaw et al., 1972; Haigler, 1962). Near the north and west edges of the Delaware Basin, and in the Guadalupe Mountains, gray limestone beds occur at the top of the Mississippian shale, with some interspersed thin sandstone beds. To the east and south, in the central portion of the Delaware Basin, the unit consists of between 250 and 320 feet of primarily a black argillaceous shale with a dark gray to black calcareous shale of shaly limestone comprising approximately the lower 100 feet of section (Haigler, 1962). Equivalent age rocks in the western part of the region have been defined as the Rancheria and Helms Formations of Meramacian and Chesterian age, respectively. The Rancheria, whose type locality is north of El Paso, Texas, closely resembles the Lower Mississippian limestones of the southeast New Mexico area. (For detailed description, refer to Harbour, 1972). The Rancheria is up to 400 feet thick in the Franklin Mountains and 300 feet at the south end of the Sacramento Mountains, thinning northward, and is composed of gray argillaceous and silty thin-bedded limestone with minor shales and massive crinoidal limestone strata. Its basal contact is an angular unconformity with the underlying Lake Valley and Caballero. The Helms, of latest Mississippian age, which reaches a maximum of 230 feet in the Franklin Mountains and only 60 feet northward in the Sacramento Mountains, consists of thin-bedded, argillaceous limestone and yellow to gray calcareous interbedded shales with lesser limestones (Harbour, 1972; Pray, 1954).

Pennsylvanian Rocks Post-Mississippian orogeny uplifted and tilted much of the southeast New Mexico-west Texas basinal areas, eroding the exposed rocks and, upon subsequent Pennsylvanian deposition, producing a major angular unconformity called the Springer hiatus (McGlasson, 1968). Relatively rapid, almost continual deposition in most of the region resulted in a thick Pennsylvanian carbonate section, with large volumes of terrigenous clastics in some places. The Pennsylvanian in places is thicker than the entire underlying Paleozoic section (Pray, 1954). Total thickness of the Pennsylvanian section varies from about 3,000 feet in the Sacramento Mountains, near 2,500 feet in the northern Delaware Basin, and between 1,650 and 2,700 feet in southern Lea County along the Central Basin Platform.

The rocks of Pennsylvanian age were derived from a variety of different sources and deposited in increasingly active structural settings. As a result, the lithology of the section is highly variable, both horizontally and vertically, and correlations on the basis of mappable rock units are difficult to make (Pray, 1961; Oriel et al., 1967). Although a variety of schemes have thus been utilized to subdivide the Pennsylvanian section of the area, the following discussion employs the common usage of Morrowan through Virgilian stages as a framework for consideration of the dominant lithologies and several formations identified in this region.

1) Morrowan Series Of the stages present in New Mexico, the basal Pennsylvanian Morrowan rocks occupy the smallest area and contain, in the central and northern portions of the Delaware Basin, the largest proportion of clastic material. These rocks, which mark the initiation of a major transgression climaxing in the Virgilian, attain a thickness of about 1,250 feet in the Permian Basin area and wedge out northward in southeast New Mexico (Meyer, 1968). The Morrowan rocks in New Mexico consist largely of limestone and shaly limestone; fine-grained sediments predominate (Bachman, 1975).

In the Sacramento Mountains, at the northwest extent of the area, the basal Pennsylvanian strata were deposited on a surface of at least 100 feet of local relief, the lowest parts of which were filled with coarse sandstone or cobble conglomerates derived from Mississippian cherts. The percentage of shales and dark limestones increase upwards into the Atokan. These rocks have been called the basal part of the Gobbler formation by Pray (1954). Southward across the Guadalupe Mountains area of the Northwest Shelf, the Morrowan consists of from 230 to over 400 feet of fine to coarse-grained, poorly sorted, locally conglomeratic quartz sandstone, mottled medium gray oolitic limestone and medium to dark gray shale, which resemble the lower Gobbler as well as the rocks of central to northern New Mexico, called the Sandia Formation (Hayes, 1964). Fine-grained detrital sediments trend southeasterly from the Pedernal Uplift into the western Delaware Basin. Within the Delaware Basin, the Morrowan is composed primarily of brown to gray argillaceous limestones and gray quartzose sandstones with dark gray to black shale. Across the Central Basin Platform into Texas, the basal Pennsylvanian unit is a black shale (Nicholson & Clebsch, 1961; Bachman, 1975).

2) Atokan Series The Early-Middle Pennsylvanian rocks, assigned to the Atokan or Derryan Stage, consist of dark-colored sandstones, shales and limestones, which attain a maximum thickness of about 1,000 feet. These rocks were deposited over the entire area, with the exception of the Pedernal Uplift to the north (Meyer, 1968).

Interbedded shales and dark limestone constitute the top of the 200 to 500 foot section of the lower Pennsylvanian Atokan deposition to the northwest in the Sacramento Mountains (Pray, 1954). Southward into the northern Delaware Basin, the unit consists of gray to brown and black, fine-grained to dense limestone and chert and dark gray to black shale with minor sandstone. In the southern Delaware and Val Verde Basins region, the Atokan rocks consist mainly of sandstones and shales in the lower part and carbonate rocks in the upper part, reaching about 1,000 feet in thickness (Vertrees et al., 1959). The top of the Atokan section is transitional, and is placed at the change from dominantly terrigenous, detrital rocks below to predominantly carbonates above (Bachman, 1975)

3) Desmoinesian Series Upper-Middle Pennsylvanian Desmoinesian rocks are predominantly carbonates, and attain a maximum thickness of about 1,000 feet in the Delaware and Lucero Basins and in northwestern New Mexico (Bachman, 1975). Sedimentation during this time was primarily influenced by reef and adjacent shelf and basinal deposition within the areas of the Permian Basin and Orogrande Basin to the west. Also known as the Strawn, the unit is the only readily identifiable Pennsylvanian rock found widespread over the southeast New Mexico-west Texas area (Vertrees et al., 1959).

The Desmoinesian rocks of the Sacramento Mountain area constitute up to 1,000 feet of contrasting facies: a shelf limestone or reef, consisting almost entirely of cherty calcilutites, and a deltaic facies of equal thickness but smaller lateral extent, composed of quartz sandstones, subgraywackes, shales and minor limestones (Gray, 1954). Southward and eastward, in the Permian Basin area, the Desmoinesian strata were deposited in a variety of environments from back-reef lagoon, to reef, to deep marine basin - a spectrum which lasted from this time through most of the Permian (Meyer, 1968). Within the Delaware Basin, these rocks are typically dark brown, fine-grained cherty limestones, the lower part of which may contain interbeds of gray shale and gray to white, medium-grained angular quartz sandstone (Meyer, 1966). Reef facies of the Desmoinesian also extend south and eastward into the Val Verde Basin. The limestones of the Desmoinesian within both the Delaware and Val Verde Basins are known for their numerous stratigraphic traps, and have been attractive for oil and gas exploration (Vertrees et al., 1959). Desmoinesian limestones also occur across the Central Basin Platform into Texas.

4) Missourian Series The Missourian rocks of the late Lower Pennsylvanian age constitute up to 1,000 feet of mostly clastic sediments, such as interbedded arkose and arkosic sandstone, as well as mudstone and limestone, deposited in environments similar to those of Desmoinesian time (Meyer, 1968; Bachman, 1975).

On the northwest, as much as 500 feet of thin-bedded, argillaceous limestone and shale of the Missourian overlie the shelf limestone and deltaic deposits of the Desmoinesian. Most of these rocks reflect basinal deposition, but locally there was cyclic deposition in turbulent shallow waters (Pray, 1954). To the south, Missourian rocks are identified generally only in the deeper parts of the Permian Basin area. Within the New Mexico portion of the Delaware Basin, the Missourian rocks consist of dark gray shales and limestones, quartz sandstone, and some chert, ranging in thickness from zero to 1,250 feet (Meyer, 1966). Toward the Val Verde Basin near the Texas-New Mexico border and across the Central Basin Platform, the unit grades into a dark gray, non-fossiliferous shale (Vertrees et al., 1959). The absence of datable materials in this unit has made its correlation as Upper Pennsylvanian difficult to verify.

5) Virgilian Series The uppermost Pennsylvania section is similar to that of the Missourian but contains, in addition to carbonates, some continental shales, coarser clastics and evaporites.

Over most of the area to the northwest, algal reefs up to 100 feet thick formed. The Virgilian deposition grades upwards into more uniformly bedded, light-colored limestone with interbedded shale and minor sandstones. At the top of the section, red shales and limestone conglomerates repeat cyclically with nonred shales and massive nodular limestone, indicating fluctuations in depth and gradual transition to final emergence of the northwestern area. The Upper Pennsylvanian units of this area were named the Holder Formation by Pray (1959). Within the Permian Basin proper, over 1,000 feet of Virgilian limestones and shales were concurrently deposited. Southward over the Northwestern Shelf and eastern side of the Central Basin Platform and northeastward of the Horseshoe Atoll, the series is represented by limestone. Toward the Eastern shelf, the unit consists of both mudstone and limestone with some interbedded sand (Oriel et al., 1967). Reefs formed along the northern margin of the Delaware Basin (Meyer, 1968), while within the basin up to 1,000 feet of brown to tan, fine-grained limestone, black to brown shale and white, fine-to coarse-grained subangular quartz sandstone were

deposited (Meyer, 1966). Southward in the deeper part of the basin, dark nonfossiliferous shale, similar to the underlying Missourian, continued to be deposited.

Permian Rocks. In many parts of the southeast New Mexico area, the lower boundary of the Permian is difficult to determine except on the basis of fusilinids, because the Permian rocks are underlain by lithologically similar Pennsylvanian rocks. In the Delaware and Val Verde Basins, the boundary is located below several hundred feet of dark gray mudstone unit. No lithologic basis of recognizing the boundary is apparent on the Northwestern Shelf, along the east margin of the Central Basin Platform, or in the area of the Horseshoe Atoll (in the northern Midland Basin). Only in the structurally positive areas where Pennsylvanian rocks are missing, as in many locations on the Central Basin Platform, is the base of the Permian clear. In other places, such as the Sierra Diablo, an angular unconformity separates the Permian from underlying units. Ages of basin rocks to the base of the Permian are usually assigned through fusilinids interpretation but it is sometimes difficult because of the scarcity of fossils (Oriel et al., 1967). The thickness of the Permian sediments equals or exceeds the total thickness of the underlying Paleozoic systems. Details are presented in the discussions of each series below. Figure 3.3-2 provides a schematic illustration of the subsurface distribution and relative thicknesses of the Permian.

Most of the major structural elements that influenced Permian sedimentation in the area were well developed late in Pennsylvanian to very early in the Permian; thus, marked differences in lithology occur from the Northwestern shelf region, through the Delaware Basin and across the Central Basin Platform into the Midland Basin, and the stratigraphic nomenclature differs from place to place. In general, the units of the basins contain a much higher proportion of clastics than do the adjacent shelf areas, and the basin carbonates are much less dolomitized than are the shelf carbonates. The rock units along the basin margins are partially dolomitized, and contain less clastics than equivalent shelf units. In common practice, the different facies of the region have been

related to each other by time-stratigraphic units. The provincial series names used in New Mexico and Texas are, from oldest to youngest, the Wolfcampian, Leonardian, Guadalupian and Ochoan (Oriel et al., 1967). Figure 3.3-3 presents a summary and correlation of the major Permian formations of the region which are discussed below.

1) Wolfcampian Series The Wolfcampian series consists primarily of limestones and dolomites. A few reefs are present on the shelves; dark gray shales, sandstones, and conglomerates are present in the basins. The basinal sediments of the Delaware, Midland and Val Verde were probably deposited under stagnant, reducing, deep-water conditions, while the limestone on the Northwestern and Eastern shelf and Central Basin Platform were deposited in relatively shallow and well-aerated water. The series thickens southward from generally less than 1,000 feet over the shelf areas and 1,500 feet in the subsurface of the Guadalupe Mountains area of the Northwestern Shelf, to somewhat less than 5,000 feet in the Midland Basin, 7,500 feet in the central Delaware Basin, and over 15,000 feet southward in the eastern half of the Val Verde Basin (Oriel et al., 1967). The name Hueco limestone has been applied to the rocks of the basal Permian in the region; however, some workers prefer to restrict this term to the Northwestern shelf and northernmost Delaware Basin (Hayes, 1964).

On the Northwestern Shelf, the Wolfcampian is subdivided into two cherty limestone units separated by interbedded limestones and red, green and gray mudstones, which thicken northward and become sandy. Along the shelf margins, medium to dark-gray mudstone layers intertongue with the limestone (Oriel et al., 1967).

Within the northern Delaware Basin, the Wolfcamp consists of about equal parts of gray, black or brown shale and fine, crystalline, rarely cherty, brown limestone with a few thin beds of micaceous and calcareous sandstone (Hayes, 1964). Southward, in the deeper parts of the basin, it consists primarily of dark shale with brown sand and some coarser clastics. Here the absence of index fossils precludes satisfactory lower

time boundary detection. Within the Delaware Basin, both the sandstone and carbonate facies have been recognized as potential oil and gas reservoirs. Southward, in the Val Verde Basin, sandstones interbedded within the shales of the Wolfcampian are established as a commercial gas reservoir (Vertrees et al., 1959).

Eastward, over the Central Basin Platform, the Wolfcampian consists chiefly of limestone with a basal unit of as much as 440 feet of red and green shale and conglomerate (Nicholson & Clebsch, 1961). The Wolfcampian within the Midland Basin is similar to that of the Delaware Basin, except for the presence of an upper zone of dark argillaceous, locally cherty limestone and interbedded dark mudstone. The lower part of the section consists of dark mudstone with thin units of fine-grained, argillaceous sandstone and fossiliferous limestone, which increase in thickness north and west along the basin periphery (Oriel et al., 1967).

2) Leonardian Series The Leonardian series of the Lower Permian is represented by a highly variable group of facies consisting of limestone and dolomite, with mudstones, sandstones and some chert. Clastics are dominant in the lower parts of the basins, while calcareous deposits dominate the margin and shelf areas. The series was deposited under mostly marine conditions, but some strata formed in restricted or marginal environments. The Leonardian rocks are over 4,000 feet thick in two north-trending belts along the east and west margins of the Delaware Basin and in the south-central part of the Midland Basin. In the Val Verde Basin, thicknesses average 2,000 to 3,000 feet. On the shelf north and west of the Delaware Basin along the oil-producing Abo reef trend, thicknesses are over 3,500 feet. On the Eastern Shelf, the Leonardian is less than 2,000 feet. Minimum thicknesses in the area are about 900 feet (Vertrees et al., 1959; Oriel et al., 1967).

The Bone Spring Limestone represents the basin facies of the Leonardian in the Delaware Basin and northwest end of the Val Verde Basin, and consists of a dominantly dark-gray, thin-bedded, argillaceous limestone, a gray to buff, very fine-grained sandstone in three separate zones, and

a black shale with some chert nodules and beds. The base is a sandstone member which may be Wolfcampian, and the top is placed above a black shale with dark gray limestone. Deep water conditions with poor circulation probably characterized these basin settings (Oriel et al., 1967).

Eastward, in the Midland Basin, the Leonardian rocks have been assigned to formations different from those in the Delaware, but the rock types, dominantly black shales and limestones, are similar. The section--known as the upper Wichita Group, the Clear Fork Group and the lower part of the Pease River Group at the top--consists of mudstone with lesser sandstone and limestone at the base, two fine-grained sandstone members divided by dark calcareous mudstone and a muddy limestone, that may be time-correlative with two of the three sandstone layers of the Bone Spring. Above this zone, limestone and dolomite predominate, with lenses of mudstone and sandstone; the top of the unit is primarily carbonate.

At the margins of the basins, these basin units grade laterally into limestones. Around the perimeter of the Delaware Basin, the lower part of the Bone Spring Limestone grades into thick-bedded gray limestone overlapping unconformably on the Hueco Limestone (King, 1965). The middle and upper part of the Bone Spring grades into the shelf-margin dolomite of the Victorio Peak, which is correlative with the Yeso of the shelf. The Victorio Peak is a light-gray, thick-bedded fossiliferous limestone containing some chert and sandstone and made up of small, discontinuous or patch reefs and a limestone bank. Unconformably overlying the Victorio Peak of Leonardian to Guadalupian age, is the Cutoff shale consisting of as much as 150 feet of a thin-bedded, platy gray to black limestone, black siliceous or sandy mudstone, and thin-bedded, fine-grained sandstone (Hayes, 1964). In the Midland Basin, the unit grades laterally north and westward into almost pure limestone and dolomite along the peripheries of the Central Basin Platform and Northern Shelf (Oriel et al., 1967).

Away from the Delaware Basin onto the shelves and Central Basin Platform areas, the Leonardian series grades laterally from the Bone Spring and Victorio Peak a into light-colored dolomite, almost 3,000 feet thick, with a few sandstone units. The lower portion of the dolomite has been called the Wichita Group on the Central Basin Platform and the Abo Formation in central eastern New Mexico, which grades northward into red mudstone, sandstone and anhydrite. The Yeso overlies the Abo in central eastern New Mexico, and consists of medium to light gray, fine-crystalline dolomite with lesser sandstones and siltstones (Hayes, 1964). Somewhat below the middle of the Leonardian shelf dolomite on the Central Basin Platform, is a thin but extensive sandstone bed called the Tubb, Fullerton or Drinkard, which serves as a regional marker. The name "Clear Fork Group" is sometimes applied to the section of dolomite encompassing this bed on the Central Basin Platform, and is roughly age-equivalent with the Yeso. The upper limit of the Leonardian on the shelves is formed by a unit consisting of two sandstone layers separated by dolomite. On the northwest shelf, this unit is called the Glorieta; on the Central Basin Platform, it is called the San Angelo (Oriel et al., 1967; King, 1948; Hayes, 1964).

3) Guadalupian Series

The Guadalupian Series in the southeastern New Mexico region encompasses three distinct depositional settings, closely related to structural elements: clastic sedimentation in the Delaware Basin and on the Eastern Shelf, carbonate reefs along the margins, and mixed carbonate and evaporite deposition on platforms and shelves other than the Eastern Shelf. The series is over 5,500 feet thick in the Delaware Basin, and gradually thins northward on the Northwestern Shelf to less than 3,000 feet. It thins southeastward from less than 2,000 feet to 1,400 feet at the south end of the Central Basin Platform. Maximum thicknesses in the Midland and Val Verde Basins are about 3,500 feet (Oriel et al., 1967).

a) Basin Facies

The basin facies of the Guadalupian, known as the Delaware Mountain Group, is composed mainly of light gray, very fine-grained sandstone and

siltstone separated by gray shale and a few thin light gray to gray limestone and dolomite members with minor evaporites, indicating frequent relative sea level changes. The Delaware Mountain sandstones produce oil and gas and are important exploration objectives (Vertrees et al., 1959). The Group has been subdivided into three formations from oldest to youngest--the Brushy Canyon, the Cherry Canyon, and Bell Canyon--each of which are up to 1,000 feet in thickness. The Brushy Canyon differs from the upper two formations in that its sandstones are coarser grained with minimal amounts of sediments other than sandstone, and its structural features are indicative of deposition in agitated water. Harms (1974) discusses the Brushy Canyon and proposes density currents as the origin of the formation rather than turbidity currents. This formation terminates northward against the Bone Spring flexure at the basin margin. The Cherry Canyon and Bell Canyon are fine-grained sandstone to siltstone and very finely laminated. The sandstone tongue of the Cherry Canyon disconformably overlies the Cutoff Shale as a shelfward extension of the lower fourth of the Cherry Canyon Formation. Along the reef facies area, the tongue averages 200 to 300 feet thick and, where described in Last Chance Canyon of the Guadalupe Mountains, consists of moderately resistant, indistinctively bedded, grayish-orange, very fine-grained, well-sorted quartz sandstone with scattered chert nodules and silicified megafossils. The upper 25 to 30 feet of the unit is transitional shelfward into an overlying dolomite tongue of the San Andres Limestone (Hayes, 1964) (Also see Figure 3.3-3). The upper Cherry Canyon and the Bell Canyon grade into reef facies at the margin of the basin.

b) Reef Facies

The Guadalupian reef facies consists of the Goat Seep Dolomite and the overlying Capitan Limestone. A generalized cross-section through the reef facies, Figure 3.3-4, demonstrates the relationships between the various Guadalupian units along the reef margins.

Gradationally overlying the sandstone tongue of the Cherry Canyon Formation is the Goat Seep Dolomite. The Goat Seep was a reef, which grew primarily upward and formed a barrier around a considerable portion of the western side of the Delaware Basin. King (1948) originally extended the name Goat Seep to include the shelfward-lying thin-bedded limestones and interbedded sandstones, but Newell et al., (1953) restricted the formation to the massive "reef and forereef talus facies" of the basin margin, a designation maintained by Hayes (1964). The lowerportion of the Goat Seep is thick-bedded, and the upper portion is a massive light gray, fine-crystalline to saccharoidal, in places very porous, dolomite.

The overlying Capitan Limestone is a light colored, fossiliferous and vuggy limestone and breccia which reaches a maximum vertical thickness of about 2,000 feet in McKittrick Canyon of the Guadalupe Mountains, and is at least 6 times as broad as thick, reaching a width of from 10 to 14 miles along the Northwestern Shelf. It apparently formed primarily by oblique or horizontal basinward growth (Newell, et al., 1972; Hayes, 1964; Hiss, 1975). The Capitan virtually encircles the Delaware Basin. It extends from the west side of the Guadalupe Mountains northward and eastward as a bold escarpment which gradually descends to the hills in the vicinity of Carlsbad, where it is overlain by younger rocks (Dunham, 1972). The buried reef front trends northeastward to eastward from there across the Eddy-Lea County line, turns southward to parallel the length of the Central Basin Platform, and then turns west and crops out in the Glass Mountains (Hiss, 1976; Kelley, 1971). The Capitan grades laterally basinward into the Bell Canyon Formation and possibly into the lowermost beds of the Castile; onto the Northwestern Shelf the Capitan grades laterally into the Seven Rivers, Yates, and Tansill Formations of the Artesia Group (Hayes, 1964) (Also see Figure 3.3-3).

The limits of the Capitan described by Crandall (1929) and Lang (1937) have been used by most of the more recent workers, including King (1948), Adams and Frenzell (1950), Newell, et al., (1957), Hayes (1964), and Kelley (1971) and are followed in this report. For a different interpretation, see Dunham (1972).

Hayes (1964) recognizes two units as comprising the Capitan Limestone, a massive member and a breccia member, which grade into each other both laterally and vertically. The massive member forms nearly vertical, smooth-weathering cliffs and ranges in thickness from about 250 to 270 feet averaging 400 feet along its Guadalupe Mountains portion. This member is composed primarily of light to yellowish gray, fine-textured, fossiliferous limestone with virtually no discernible bedding planes. Isolated aggregates of coarsely crystalline calcite are common, and some dolomite, sandstone dikes, and isolated sandstone pockets occur. Solution and recrystallization, weathering, and the very small size of the fossils have made the organic content difficult to recognize in the field. Newell, et al., (1953), however, have identified 115 species of fossils within the formation, including fusulinids, sponges, corals, crinoids, bryozoans, brachiopods, and mollusks; in total volume, stromatolites are probably most important in the construction of this rock unit (Hayes, 1964).

The breccia member, which generally forms more easily eroded uneven slopes, consists of thick beds dipping basinward at 20 to 30 degrees or more on the west side of the Delaware Basin. Most of this member is composed of microbreccia derived from the massive member and from the Artesia Group and also contains coarse, angular cobbles and boulders of limestone and dolomite from these sources. The breccia attains a maximum vertical thickness of about 1,750 feet and averages 1,250 feet and as such comprises about two-thirds of the bulk of the Capitan (Hayes, 1964).

Although it has been generally agreed that the Capitan Formation represents a "geologic reef," (a thick, laterally restricted mass of pure or largely pure carbonate, according to Dunham, 1972), investigators of the Capitan have over the years proposed different interpretations as to its genesis and environment of formation.

Crandall et al. (1929) published the barrier reef hypothesis, according to which reef-building, sediment-binding organisms grew practically at sea level on a reef which developed rapidly enough, despite erosion, to

maintain a nearly vertical front, overriding its own debris. Newell, et al., (1953) concurred with Crandall, based on their detailed petrological work on the reef constituents, and a number of recent investigators, such as Hayes (1964), Boyd (1955), Adams (1944), and Adams and Rhodes (1960) have generally followed this interpretation.

A second alternative was advocated by King (1948) and named by Dunham (1972) the "uninterrupted slope hypothesis." King used it to explain his findings in the southern Guadalupe Mountains which seemed to indicate facies change due to change in slope as the shelf descended to the Delaware Basin. Dunham (1972) pointed out, however, that King studied only portions of the structure. Had he gone farther northwestward, his findings would have corroborated Lang (1937), who proposed a third hypothesis, that of the marginal mound.

According to the marginal mound alternative, supported elaborately by Dunham (1972), organisms produced carbonate particulate sediment upon a broad topographic high which was at different times a sandy shoal or an island bordered by sand and mud flats. The sediment was cemented during the island stages of development. Achauer (1969) has advocated a somewhat similar view that the Capitan represents an ancestral organic bank, rather than a classical barrier reef.

c) Back-Reef or Shelf Facies

The thick massively-bedded limestones along the margins of the basins grade shelfward into thin-bedded dolomites. On the Northwestern and Eastern Shelves and southward along the Central Basin Platform, the Guadalupian includes the San Andres Limestone and overlying Artesia Group (also identified eastward on the Central Basin Platform as the Whitehorse Group by Nicholson and Clebsch, 1961). This group includes from base to top the Grayburg, Queen, Seven Rivers, Yates and Tansill Formations (Hayes, 1964). These shelf units are also recognized in the Midland Basin area. There is some disagreement as to whether the Lower Guadalupian there is missing or greatly resembles the upper Leonardian (Hendrickson & Jones, 1952; Oriel et al., 1967).

In the western part of the Delaware Basin, parallel to the reef front, facies encountered in a shelfward direction are: 1) dolomitized coquin and calcarenite, 2) pisolites, 3) fine-grained dolomite, 4) evaporites, and 5) terrigenous red detritus (Newell et al., 1953). This general succession of facies is also described by Dunham (1972) in the vicinity of the Capitan Escarpment. Hayes (1964) presents a comprehensive discussion of the Guadalupian shelf rocks.

The San Andres is partly time-correlative with the basinal Brushy Canyon; at its base it may be upper Leonardian, and at its top it interfingers with the base of the Cherry Canyon. The San Andres is mainly dolomite with minor limestone near its base and some chert, sandstone and reddish mudstone (Oriel et al., 1967; Kelley, 1971). It extends shelfward much farther than the Artesia Group before grading into evaporites and detrital materials. The San Andres thins eastward across the Midland Basin, and detrital and evaporite contents increase progressively to the east.

The Artesia Group ranges in thickness from about 880 feet to over 1,500 feet. In the shelf and Central Basin Platform areas, it is separated from the underlying San Andres by an unconformity, according to Nicholson and Clebsch (1961). The basal Grayburg and Queen Formations are time-correlative with the marginal Goat Seep Reef and basinal Cherry Canyon Formation. To the south, they consist of dolomites and sandstone; they grade northward into gypsum, mudstones and dolomite (Kelley, 1971). The Queen Formation is distinguished from the underlying Grayburg by its much greater abundance of clastics and red mudstones. The Seven Rivers, Yates and Tansill Formations are all correlative with the Capitan Limestone at the margin, and with the Bell Canyon in the Delaware Basin. To the south, they all resemble the lower two formations of the Group, except for the presence of gypsum and limestone in the Yates. Toward the north, gypsum and anhydrite increase in the Tansill, and siltstone and dolomite increase in both the Yates and Tansill.

Ochoan Series

The Late Permian Ochoan series consists primarily of evaporites that were deposited during recurrent retreats of a shallow sea restricted by the Guadalupian reefs. The lower three formations in the series, the Castile, Salado and Rustler, comprise what is perhaps the thickest and most extensive evaporite rock sequence in North America (Oriel et al. 1967). They are overlain by the Dewey Lake Redbeds, which may be either Permian or Triassic in age. Within the Ochoan, halite is dominant on the shelf north of the Delaware Basin, where the Salado Formation makes up the bulk of the unit; total thickness of salt is greatest, however, in the Delaware Basin, but the presence of the Castile Formation in the basin reduces the proportion of halite there. The proportion of carbonates to other rock types increases southwestward and southward, and the proportion of detrital rocks increases eastward and northeastward (Oriel et al., 1967). The total thickness of the Ochoan ranges from slightly more than 5,000 feet in the center of the Delaware Basin and 4,000 feet in a north trending belt through the basin, to about 1,500 feet in the Midland Basin and 1,000 feet on the shelves. Irregular thinning occurs near the basin margins as a result of erosion and leaching of the more soluble beds (Oriel et al., 1967; Nicholson & Clebsch, 1961).

The Castile Formation is confined to the Delaware Basin and was deposited upon the Bell Canyon, in "apparent conformity," according to Kelley (1971), but unconformably, according to Nicholson and Clebsch (1961), and is laterally bounded by the Capitan limestone reef. The Castile is generally of uniform thickness, up to about 2,000 feet, throughout the basin. The formation consists primarily of massive anhydrite, limestone interlaminated with anhydrite, and halite in beds as thick as several hundred feet (Vine, 1963). In the lower to middle portion of the sequence, banded light gray anhydrite is interlaminated with brown bituminous limestone on a scale of millimeters. Two very extensive layers of fairly pure halite averaging 200 to 350 feet thick persist throughout the northern Delaware Basin. Several smaller tongues of halite are also present through the unit. Towards the basin margins, the

Castile thins abruptly. The basal part of the banded portion grades reefward into laminated limestone and the upper part into massive anhydrite. The top of the Castile is light-gray massive anhydrite, grading into the basal part of the overlying Salado by wedging of thin anhydrite tongues northeastward into salt (Jones, 1954; Brokaw et al., 1972).

The Salado Formation extends from the Delaware Basin area beyond the limits of the Castile and across most of the Permian basin, including the Midland Basin, the Northwestern Shelf and the Central Basin Platform. The complete Salado is present only in the subsurface of this area, and is represented at the surface only by a solution residue. Its thickness varies because of leaching, but it is generally up to 2,000 feet near the northern Delaware Basin, thinning northward over the Capitan reef to 700 to 1,200 feet and thinner farther north and east. In the shelf and platform areas, it rests unconformably on the Artesia, or Whitehorse, Group (Brokaw et al., 1972; Nicholson & Clebsch, 1961).

The Salado is mainly halite, some of which is argillaceous, red mudstones, sandstone, siltstone, abundant anhydrite and a suite of salts including polyhalite, kieserite, glauberite, sylvite, carnallite, langbeinite, kainite and leonite. Beds locally rich in sylvite, KCl, and other soluble potassium minerals constitute valuable potash ores (Vine, 1963). The principle lithologic materials occur in cyclic sequences 2 to 30 feet thick consisting of a detrital layer, a relatively thin sulfate layer chiefly composed of anhydrite and polyhalite, and a thicker halite zone, overlain by a mixed halite-detrital layer, all with gradational contacts. The potash ores occur near the middle of the formation in irregularly lenticular to tabular bodies (Brokaw et al., 1972; Oriel et al., 1967). The upper part of the Salado is locally characterized by a leached zone from which the halite has been removed, and is largely unconsolidated reddish-gray to brown silt and clay with varying amounts of brecciated gray or red gypsum (Vine, 1963).

The Rustler Formation ranges in thickness from 90 to about 400 feet, and overlies the Salado in the Permian Basin area. In the central part of the Permian Basin, the Rustler conformably overlies the Salado, but in other places, as along the west and north margins of the Delaware Basin, it truncates the Salado by a marked unconformity (J. A. Adams, 1944; Nicholson and Clebsch, 1961). In outcrop, the Rustler appears as calcareous sandstone, fine grained dolomites and gypsum. The subsurface Rustler consists primarily of anhydrite or gypsum and subordinate salt, with lesser amounts of dolomite, limestone, siltstone and sandstone. Within the Delaware Basin, the limestone and dolomite increase to the south and southeast.

Vine (1963) has described the Rustler in the northern part of the Delaware Basin. Here, the lower part of the Rustler consists of over 100 feet of siltstone and very fine-grained sandstone with interbeds of gypsum or anhydrite. Next above is the Culebra dolomite, about 30 feet of uniformly microcystalline gray dolomite or dolomitic limestone with numerous small, generally unconnected, nearly spherical cavities. Overlying the Culebra is the Tamarisk member, about 115 feet of anhydrite with local gypsum and a 5 foot thick siltstone bed some 20 feet from its base. The Magenta member, above the Tamarisk, consists of about 20 feet of thin, wavy, lenticular laminae of dolomite and anhydrite (or gypsum). The uppermost member of the formation is the Forty-niner, consisting of up to 65 feet of anhydrite (or broken gypsum in outcrops) with a bed of massive siltstone near the base. According to Jones et al., (1960), the siltstone represents insoluble residue from a bed of halite present in the subsurface to the east.

The top of the Rustler has been placed at the top of the first persistent anhydrite bed penetrated by oil and gas tests and provides a clear marker for structural correlations (Oriel et al., 1967).

Overlying the Rustler in apparent conformable relationship is a sequence of redbeds, up to about 600 feet thick, which represents deposition of terrigenous materials in shallow water remaining in the basin areas over

the older evaporate sequence (Mercer & Orr, 1977; Oriel et al., 1967). On the basis of physical stratigraphy, the unit has been traditionally assigned a Permian age (Oriel et al., 1967). No fossils have been found. Although several names (e.g. the Pierce Canyon) have been proposed for this unit, the term Dewey Lake Redbeds, as defined in west Texas (Page and Adams, 1940), is generally used throughout the area (Nicholson & Clebsch, 1961).

The Dewey Lake consists of a series of micaceous, orange to red sandy siltstones, sandstones and some mudstone. Gypsum commonly forms cement, secondary crystals and veins. The lower 10 feet of the sequence contains a widely distributed zone of coarse, frosted quartz grains.

The top of the redbed unit is marked by an erosion surface, upon which younger units were deposited with a slight angular discordance. In some places, the Dewey Lake has been removed by later erosion, and rocks of Cretaceous or Cenozoic age rest on the Rustler or Salado (Oriel et al., 1967).

3.3.3 Mesozoic Rocks

Triassic Rocks Unconformably overlying the rocks of Late Permian age is the Upper Triassic Dockum Group of red beds, composed of up to 1,500 feet of moderate-reddish-brown to yellow-brown conglomeratic sandstones, siltstones and shales (Brokaw et al., 1972). The sediments of this group display characteristics of rapid deposition from a local source, in their poorly rounded sand grains and micaceous minor constituents. This group has been subdivided into two formations, the Santa Rosa Sandstone and overlying Chinle Formation; however, because of poor exposures and lithologic similarities between the sandstones of the two units, the distinction cannot be made throughout the entire southeast New Mexico area (Nicholson & Clebsch, 1961).

The Santa Rosa is a fine-to-coarse-grained sandstone, generally red but containing white, gray, and greenish to lavender sands and some minor reddish-brown mudstones and conglomerate. The unit is commonly cross-stratified and ranges in thickness from about 140 to over 300 feet (Kelley, 1971; Nicholson & Clebsch, 1961).

The upper portion of the Dockum Group, the Chinle Formation, ranges in thickness from zero to almost 1,300 feet, thickest to the east, near the Texas-New Mexico border, and entirely absent in the west, where it has been removed by post-Mesozoic erosion. The Chinle is a reddish-brown to greenish-gray shaly mudstone with interbedded lenses of conglomerate and thin, gray to reddish-brown sandstone and siltstone (Mercer & Orr, 1977; Nicholson & Clebsch, 1961).

Jurassic Rocks No record of Jurassic deposition has been shown to exist in the southeast New Mexico region.

Cretaceous Rocks Kelley (1971) described three formations, identified as Cretaceous, which crop out to the north and northwest, in the Sierra Blanca and Capitan area, named the Dakota Sandstone, Mancos Shale and Mesaverde formation. The Dakota is comprised of up to 150 feet of sandstone, conglomerate, and beach shale. The overlying Mancos is up to 700 feet of dark shales, siltstone and local thin sandstone and limestone. The Mesaverde Formation comprises from 500 to 1,500 feet of light-colored to maroon coarse clastics and mudstones, and coal. These deposits reflect subsidence of the area during the Cretaceous to a shallow marine and floodplain environment. An outlier of Cretaceous rocks is also present on the crest of the Sacramento Mountains. Here, a pebble-bearing quartz sandstone 150 feet thick is overlain by a shale containing fossils of late Early to early Late Cretaceous age (Pray & Allen, 1956).

Further south on the Northwestern Shelf, there are no definite Cretaceous age outcrops, but solution cavities on the surface of the Castile southeast of the Guadalupe Mountains contain pebbles of limestone and

sandstone with fossils of early Washita age. At several places along the top of the Reef Escarpment, low areas on the ridge and joints in the Permian Tansill formation contain conglomeratic quartz sandstone which closely resembles the Cretaceous deposits in the Sacamento Mountains (Hayes, 1964).

To the southeast, in the Lea County area, only several exposures of Cretaceous rocks are known. A gravel pit east of Eunice contains large slump blocks, up to 5 feet thick and 20 feet long, of massive, highly fossiliferous, white to buff sandstone containing some sand and shaly partings along the bedding planes (Nicholson and Clebsch, 1961; Ash and Clebsch, 1961). This rock and the Comanche limestone of Early Cretaceous age are strikingly similar, so are believed by Ash and Clebsch (1961) to be equivalent. Another outcrop of Cretaceous rocks at North Lake consists of dark gray siltstone and thin interbedded stringers of light brown crystalline to light gray, fine-grained limestone. According to fossil and lithologic similarities, the rocks at North Lake are correlated with the Early Cretaceous Tucumcari shale (Ash & Clebsch, 1961). In the subsurface of Lea County, 5 feet or more of yellow, blue, or gray clay or shale encountered by drilling and consistent with the description of the rock at North Lake constitute the major evidence for the subsurface presence of Cretaceous outliers in the area. Based on some 8,000 water-well logs and seismic shotholes, Ash and Clebsch (1961) have determined that in the subsurface Cretaceous rocks are generally continuous in the northeastern portion of Lea County, but further west and south, only scattered, discontinuous occurrences have been encountered.

Rocks of Cretaceous age were deposited over the southeast New Mexico area but have been almost entirely removed by erosion. Now only scattered patches or reworked pockets of limestone and sandstones of probable Early and Mid-Cretaceous age are present in the area; Cretaceous rocks have also been identified here in the subsurface through drilling (Bachman, 1975; Hayes, 1964; Nicholson and Clebsch, 1961).

3.3.4 Cenozoic Rocks

Tertiary Rocks. Following Cretaceous deposition, widespread uplift and erosion occurred throughout the region, and the earliest Cenozoic deposits for which there is record, the Ogallala, were depositied in Late Tertiary Miocene to Pliocene time.

The Ogallala Formation underlies the High Plains of eastern New Mexico and west Texas. Although there are no confirmed remnants of the Ogallala west of easternmost Eddy County, isolated gravels to the west in the Pecos Valley and Guadalupe Mountains have been interpreted as belonging to this formation (Mercer and Orr, 1977). The Ogallala was deposited on an irregular, broadly sloping pediment or complex alluvial fan surface by southeastward flowing streams under rapidly changing conditions (Bachman, 1976).

The Ogallala in the region is up to 400 feet thick (Bachman, 1976) and consists of a yellowish-gray semi-consolidated, fine-to medium-grained, calcarous sand containing some silt, clay, and gravel. In many places, a basal gravel deposited within stream beds is also encountered. Some beds of well consolidated silica-cemented conglomeratic sandstone from one to three feet thick also occur within the formation. As a result of intertonguing, lensing and pinching out of the beds caused by the varying depositional conditions there are no consistent marker beds within the Ogalalla (Nicholson and Clebsch, 1961; Bachman, 1973).

The Ogallala is capped by a dense layer of brecciated and pisolitic caliche ranging in thickness from a few feet to as much as 60 feet. At the surface it is a well indurated calcium carbonate, but below the surface, it becomes softer and more porous and grades into the underlying sands. This capping was formed in post-Ogallala time and before the extensive Pleistocene erosion of the area, probably during the Late Pliocene. The caliche accumulated within the zone of illuviation of a pedocal "climax soil," which developed on the depositional surface of the

Ogallala (Nicholson and Cletsch, 1961; Bachman, 1976). (Pedogenic caliche formation in southern New Mexico is described in detail by Gile, et al., (1966).)

Quaternary Rocks Following Pliocene time, erosion removed much of the Ogallala as well as some of the older materials, and stream systems became entrenched. Periodic deposition also occurred in the southeastern New Mexico area during the Pleistocene and Holocene, leaving behind the Gatuna Formation, caliche, terrace, channel and playa deposits and windblown sand.

The Gatuna, of Pleistocene age, unconformably overlies rocks as old as Permian and Triassic and consists of up to several hundred feet of reddish-brown friable sandstone, siltstone and cherty and siliceous conglomerate, but locally also includes gypsum, gray shale and claystone. Remnants of the formation are discontinuous and may have been deposited in local depressions such as stream channels and solution subsidence areas (Bachman, 1973; Vine, 1963).

Unconformably above the Gatuna and older deposits throughout southeastern New Mexico, there formed a fairly continuous mantle of caliche called the Mescalero. It is a sandy light gray to white deposit composed of a lower nodular calcareous zone and upper dense laminar caprock and ranges in thickness from 3 to 10 feet. According to Bachman (1973), the caliche is the remnant of an extensive soil profile.

Late Pleistocene to Holocene terrace and channel deposits are preserved in the western part of the area, particularly along the Pecos River and the Guadalupe Mountains area. Channel deposits consist of silt and sand to boulders. Within the Guadalupe Mountains area, deposits are generally limestone cobbles and boulders. Three terraces are commonly recognized in the area: the Blackdom, Orchard Park and Lakewood. The Blackdom and Orchard Park have been dated as Pleistocene while the Lakewood may be of Holocene age. The deposits of the Blackdom terrace are generally coarser than those of the younger terraces, but the two Pleistocene terraces are

similar in composition, consisting of limestone-porphyry conglomerates capped by caliche. The younger Lakewood terrace contains river conglomerates and pond, marsh, and lake silts (Bachman, 1973; Hendrickson and Jones, 1952).

Playa and shallow lake deposits are present in the area in many small shallow depressions, particularly east of the Pecos River. In most of these depressions, lakes formed after heavy runoff and evaporated rapidly, but some contain generally perennial lakes, the largest of which is Laguna Grande de la Sal, in Nash Draw. The playa deposits consist of alluvium, reworked eolian sands, silt and clay. Around some of the standing lakes, gypsum, carbonate minerals, and some halite have been deposited. These deposits date from the Late Pleistocene to Holocene time (Hendrickson and Jones, 1952, Vine, 1963).

Windblown sands mantle much of the surface east of the Pecos River for 20 to 30 miles eastward to the Mescalero ridge and south to the Texas border. The sand is very erratic in both thickness and distribution, and appears to be fairly uniform, fine-grained light brown to pale reddish-brown quartz. Many of the grains are rounded and frosted. Some of the sand rests in coppice dune fields where the sand is as thick as 25 feet. Most of the sand has been stablized by mesquite, bunchgrass and other vegetation.

3.4 REGIONAL STRUCTURE AND TECTONICS

The major tectonic structures of the region are displayed in Figure 3.4-1. Most of the large-scale elements that provide the structural framework of the area were developed in the Late Paleozoic, principally from Late Pennsylvanian to Early Permian time. These include the Delaware Basin, the Central Basin Platform, the Midland Basin, and the Northwestern Shelf of the western extent of the Permian Basin, the Pedernal Uplift, the Matador Arch, the Val Verde Basin, and the Diablo Platform, as well as secondary features such as the Huapache Monocline and Artesia-Vacuum Arch and the northeast-trending buckles and smaller

fold systems believed to be expressions of basement faulting. Middle to Late Tertiary Basin and Range-related doming and faulting produced the remainder of the major tectonic features in the area, including the Guadalupe, Delaware, and Sacramento Mountains, and associated west-bounding faults, as well as a gentle regional east to southeastward tilt which affected the entire region under consideration.

The WIPP site lies near the western margin of the region of the Western Interior known as the Permian Basin, which comprises a series of sedimentary basins in which halite and associated salts accumulated during Permian time and where Permian rocks have reached their maximum development. The region extends about 520 miles from the Amarillo uplift on the north to the Marathon thrust belt on the south and some 300 miles westward, from west-central Texas to the Diablo Platform and the present Sacramento and Guadalupe Mountains (Hills, 1963).

The formation of a depositional basin in the west Texas-southeast New Mexico area began following Lower Ordovician Canadian time, when a broad sag, named the Tobosa Basin by Galley (1958), developed. Several periods of minor folding and perhaps some faulting occurred in the Tobosa Basin area prior to Pennsylvanian time. There was some erosion, but a general tectonic stability prevailed until the Late Mississippian to Late Pennsylvanian-Early Permian time. Tectonic activity accelerated in the area coincident with the Marathon disturbance, and the sag was split into two rapidly subsiding basins--Midland to the east, and Delaware on the west--by the final uplift of the median ridge, the Central Basin Platform (Foster, 1974). Continuing basin and platform development occurred throughout the Permian Basin through Permian time. Stabilization of the basins followed, during which time evaporites were deposited. Since Permian time, the Permian Salt Basin has been relatively stable tectonically (Bachman & Johnson, 1973); thus, the large structural features of the Permian Basin are reflected only indirectly in the Mesozoic and Cenozoic rocks (Nicholson & Clebsch, 1961).

The structure of each of the major tectonic units of the Permian Basin in the site region is described below, followed by discussion of the larger secondary features and younger Tertiary Basin and Range-related structures.

3.4.1. Delaware Basin

The site is located within the northern portion of the Delaware Basin, which, during most of Permian time, was a deep-water embayment extending into what is now southeastern New Mexico and western Texas. The Delaware Basin is a broad, oval-shaped asymmetrical trough with a northerly trend and southward plunge, as reflected on the top of the Precambrian (Figure 3.4-2). Its axis lies in central Lea County, New Mexico, roughly paralleling the Central Basin Platform. The eastern slope of the trough rises rapidly to the platform, while the western slope is much gentler (Figure 3.3-2). The basin comprises an area of about 12,000 mi^2 and measures roughly 75 to 100 miles east to west and 135 to 160 miles north to south. The Delaware Basin is nearly surrounded by the large horseshoe-shaped Capitan limestone that extends from Carlsbad on the northwest and opens to the south in Texas, between the Davis and Glass Mountains. However, the structural boundaries of the basin encompass a larger area to the north, beyond the Capitan reef front, into which the older and deeper lying basin sediments (e.g. the Delaware Mountain Group and Bone Spring) extend. The Delaware Basin represents the area of maximum subsidence of the Permian Basin, with more than 20,000 feet of structural relief, on the Precambrian (See Figure 3.4-2), and it is also here that the Permian section is thickest, with some 13,000 feet of Permian strata present in southeast New Mexico (Oriel, et al., 1967)

Regional structural deformation of the Delaware Basin rocks is relatively minor. The sediments older than Late Permian are gently downwarped as a result of concurrent basinal development. The Late Permian Ochoan rocks and Triassic rocks do not reflect this basinwide warping; their major structural feature is the regional eastward slope (Brokaw, et al., 1972).

There are no known active faults within the northern Delaware Basin study area of the WIPP site. Deep-seated faults, which may be partly of tectonic origin, do occur within the older sediments of the Delaware Basin. Some of these faults probably originated from the rapid Pennsylvanian-Early Permian subsidence of the basin, during which widespread block faulting occurred within the basin (Adams, 1965). Others are pre-Permian and basement structures which are reflected in the overlying beds. An example of this type of intrabasin feature is the Bell Lake fault, recognized by Haigler (1962, 1972), which has a displacement of about 500 feet in the Precambrian. The structure is reflected upwards through the Pennsylvanian Section and Foster's (1974) map. It shows as a north-south high with closure on the south. Closure is also indicated on the Bone Springs map. Whether this structural representation results from continued movement of the Bell Lake fault system up to that time or is only an effect of compaction is not known (Foster, 1974). A complex series of faults with several thousand feet of offset marks the boundary between the Delaware Basin and Central Basin Platform. These faults were involved in the development of the basin and are considered to have been inactive after Permian time. They are discussed in more detail in the following section.

Two sets of joints, with strikes to the northwest and northeast, have been recognized within the basin. The northeasterly set appears to be better developed and penetrates the lower anhydrite of the Castile Formation along the western margin of the basin, where the formation is exposed. This set also controlled the emplacement of replacement limestone within the evaporites (Anderson, 1978).

Other structures within the Delaware Basin include flexures, some of which formed during Early to Mid-Permian basinal downwarping and deposition of the Bone Spring and Delaware Mountain Groups (Pray, 1954), and minor scattered folding of the younger beds (U.S. Bureau of Mines, 1977). Evidence of anticlinal structures as well as an unusual type of fracturing and microfolding within the Castile anhydrite has been cited by Anderson and Powers (1978) and Anderson, et al., (1972), as evidence

of salt movement. C. L. Jones (unpub.) has described a deformation zone encircling the inner margin of the basin and extending inward about 5 miles, as well as a number of similar structures in the interior of the basin, which, according to Anderson and Powers (1978), may be salt anticlines. These features may have formed as a result of differential stress from unloading related to salt dissolution (Anderson, 1978). Scattered small domes, various collapse structures due to salt and/or gypsum dissolution (including domal structures with collapsed centers, known colloquially as breccia pipes), limestone buttes (Castiles), collapsed outliers, and deep-seated sinks can be found in the evaporite sections (Vine, 1960; Anderson, 1978). Stipp (1954) also identified brecciation in the beds of the Wolfcampian and Leonardian rocks, which he attributed to adjustment in the basin in response to sedimentation and structural forces.

The tectonic development of the Delaware Basin, as reflected in the structures discussed in this section, may be summarized as follows. The Delaware Basin was defined by early Pennsylvanian time and major structural adjustment took place in Late Pennsylvanian to Early Permian time. Regional subsidence in conjunction with broad arching, folding, and faulting occurred until Late Permian time, when the basin's history as an active structural feature ended (Brokaw, et al., 1972). Regional uplift and deposition of continental red beds in Triassic time was followed by continued emergent conditions, resulting in erosion or nondeposition. Mid-Cenozoic to Late Cenozoic regional eastward tilting of the basin much later shifted the deepest part of the Basin to its present position close to and paralleling the Central Basin Platform (Stipp, 1954). Since then, the only structural developments in the basin have been related to hydration and solutioning of the Late Paleozoic sediments.

3.4.2 Central Basin Platform

The Central Basin Platform is a subsurface feature (see Figure 3.3-2) which represents an ancient broad uplift of Precambrian and Cambrian to

Pennsylvanian rocks separating the Delaware and Midland Basins at the southern extreme of the Permian Basin in southeastern New Mexico and southwest Texas. The platform extends in a north-northwest trend for about 200 miles to the south flank of the Matador Arch (Bachman and Johnson, 1973). The Central Basin Platform may represent a zone of structural weakness along which movements took place periodically at least into Late Paleozoic time. Displacement within and along the margins of the platform appears to have been along large, high-angle normal or reverse faults, which trend north to northwest and break Early Permian and older rocks; all faults predate the salt deposits of the adjacent basins (Bachman and Johnson, 1973). According to Hills (1970), these faults may have been involved in considerable lateral as well as vertical movement.

The platform itself is a horst. In the structurally higher parts of the platform identified by Foster (1974) as the Hobbs and Eunice blocks, the Precambrian surface is from 4,000 to 7,000 feet below sea level, while the adjacent Monument-Jal block stands at 6,500 to 11,500 feet below sea level. The fault system separating the Hobbs and Eunice blocks from the Monument-Jal block has a displacement of about 1,000 feet in the north to possibly 4,000 feet west of Eunice. The fault bounding the Monument-Jal block extends about 50 miles southward, into Texas, with an inferred displacement of 1,500 feet at the north to over 6,000 feet west of Jal. The aeromagnetic map of the Carlsbad area (U.S.G.S., 1973) provides fairly good definition of the trend of the major features of the Central Basin Platform (Foster, 1974).

The maximum structural relief east-west between the Central Basin Platform and the Delaware Basin is remarkably uniform, at about 9,000 feet (Foster, 1974). Complex fault systems form the boundary between these two structural units. Hills (1970) indicated a fault in approximately this location and termed it the West Platform fault. According to Haigler (1962), this fault system has a relief about equivalent to that of the Huapache monocline bordering the west side of the Delaware Basin.

The Central Basin Platform has been more intensely deformed than han the Delaware Basin or shelf areas (Brokaw, et al., 1972). The tectonic development of the Central Basin Platform may have begun in Precambrian time, and it appears to have been a high during Early Ordovician time. The platform was unstable during late Devonian time but was generally an area of stability thoughout early to Mid-Paleozoic time. In latest Mississippian or early Pennsylvanian time, the area was deformed to an elevated emergent fold belt, trending north-northwest. After submergence and deposition in Middle and part of Late Pennsylvanian time, renewed orogeny further elevated the area and sharpened, compressed, and faulted the folds (Hills, 1963). The complex fault system bordering the platform on the west formed either in Late Pennsylvanian or Early Permian time, according to Haigler (1962), and contributed as well to the structural development of the Delaware Basin. Claiborne and Gera (1974) also identify the subsurface faults outlying the Central Basin Platform as no younger than Permian age, since the Permian and younger beds in the area are unfaulted. Over the faulted platforms, the sedimentary formations were broadly arched, and concurrently eroded, in places to the Precambrian basement. Subsidence followed, and upper Wolfcampian-through Guadalupian-age carbonates were deposited on the roots of the earlier mountain ranges. Since filling of the Midland and Delaware Basins in Late Permian time, the platform has been structurally stable (Brokaw, et al., 1972). Recent seismic activity there is being studied to determine its relationship to secondary oil recovery operations (see Section 5.). The Central Basin Platform is probably not naturally active at the present time, in view of the lack of fault scarps to match the seismic activity (Sanford, 1978).

3.4.3 Midland Basin

The Midland Basin, situated to the east of the Central Basin Platform, is similar in most respects to the Delaware Basin but shallower, having experienced less structural development. The Midland Basin extends some 200 miles along a north to northwest trend to the Matador Arch vicinity. Its shape is much more symmetric than is the Delaware Basin, and its

relief is only 4,000 to 5,000 feet. Extensive major faulting occurred before the deposition of Late Permian salt in the southern part of the basin and on its west flank in proximity to the Central Basin Platform (Bachman & Johnson, 1973). As is the case with the Delaware Basin, general tectonic stability has prevailed in the Midland Basin since Permian time.

3.4.4 Matador Arch

The Matador Arch is a narrow east-west trending Paleozoic highland of irregular relief and outline underlain by Precambrian granitic rocks. The uplift extends for some 300 miles across the Permian Basin, from west of Wichita Falls, continuing westward, north of Lubbock and entering New Mexico in southern Roosevelt County. Its western limits are uncertain, but some have supposed a connection with the Capitan Mountains to the west, by way of the intrusive igneous Railroad Mountain and Camino del Diablo dikes that parallel the trend of the Matador arch in eastern New Mexico (Stipp, 1960). The Matador Arch provides structural division between the Delaware and Midland Basins to the south and the Hardeman, Palo Duro, and Tucumcari Basins in the northern part of the Permian Basin.

The Precambrian structural framework of the Matador Arch itself is probably not a continuous ridge, but a series of prominences which may be the roots of a chain of islands or hills existent during Precambrian and Early Paleozoic times. The only large tectonic structures on the Matador Arch consist of strong faults and folds that trend obliquely across the uplift in a northwest direction (Eardley, 1962). These faults are present only on the southern flank of the arch, near its western extremity and break only the Precambrian basement rocks (Bachman and Johnson, 1973). The history of the major tectonic development and activity of the Matador can thus be considered to have ended by early Paleozoic time.

3.4.5 Pedernal Uplift

The Pedernal Uplift represents a southward extension of the Rocky Mountains in south-central New Mexico about midway between the Rio Grande and Pecos Rivers. The boundaries of the uplift are not very well defined but in general trend north-south from the eastern side of the Sacramento Mountains in Otero County, apparently continuously to northern Torrance County (Eardley, 1962). The uplift is named for Pedernal Mountain in Torrance County, which is considered to be a remnant and the southernmost exposure of the Ancestral Rockies.

Together with the Permian Basin, the Pedernal landmass strongly influenced the depositional and structural patterns of the region. The Pedernal Uplift appears to have been a wide and not particularly emergent area connecting southward with the Diablo Uplift, and existed, according to Thompson (1942), and Pray (1961), from Early Pennsylvanian time until well after the beginning of Permian time. Within the confines of the Uplift, red shales, sandstones, variegated shales, and limestones of Permian age rest directly on igneous and metamorphic rocks of Precambrian age (Eardley, 1962). In structure, the uplift may have been a broad upwarp in some places and fault-bounded blocks in others. The uplift was probably sharpest on the west with the possible exception of the southeastern edge along the buried Huapache zone (Kelley, 1971).

There is some disagreement as to the time of initial uplift of the Pedernal. According to Stipp (1960), the uplift apparently rose in Late Mississippian or Early Pennsylvanian concurrently with the Central Basin Platform, and was subsequently eroded down to its Precambrian core. Kelley (1971) states that the Pedernal began its rise in Late Pennsylvanian time. According to Bachman (1975), the earliest indication of Ancestral Rocky Mountain building in New Mexico occurred during the Middle Pennsylvanian Desmoinesian time but the Ancestral Rocky Mountain-Pedernal Uplift activity accelerated and was extended southward into New Mexico during Late Pennsylvanian Missourian time, and the uplift reached its maximum in New Mexico during the Virgilian, with accompanying

major faulting occurring along the west side of the Pedernal Uplift. Acceleration of uplift continued through Wolfcampian time, denuding the rocks well into the Precambrian core. Some broad arching and erosion had taken place before the basal Artesia was deposited, followed by renewed rise during and following Salado deposition. Post-Triassic to pre-Dakota time saw renewed rise of the Pedernal Uplift. Structural development ended with a slight uplift and tilting of the Pedernal towards the north during Late Jurassic to Early Cretaceous time (Kelley, 1971).

3.4.6 Diablo Platform

The Diablo Platform is a northwest-trending, structurally positive area southwest of the Delaware Basin, extending southeastward from the Cornudas Mountains at the New Mexico-Texas border and terminating with the Marathon Uplift area and Ouachita tectonic belt to the southeast. The platform is a horst with an average elevation of 1,200 meters above sea level and is bounded on the east, south, and west by grabens. At its northern extent and closest approach to the site, the platform is bordered on the east by the Salt Flat graben (Barker, et al., 1977). (See Figure 3.4-1).

The Diablo Platform experienced primary deformation in Late Pennsylvanian or Early Permian time, but topographic relief and the presence of coarse detritus favor Early Permian for the major portion of the activity. Deformation consisted of uplift, folding, and faulting. The uplift was greater on the south than the north, in the Carrizo Mountain-Van Horn area, where subsequent erosion exposed Precambrian rocks. Faulting is also known to have occurred in post-Permian rocks along the northeast margin of the platform. The Late Cenozoic Basin and Range activity affected the Diablo platform through prominent block faulting and buckling. Major movement in this area was on northwest-trending faults along the northeast margin of the Diablo Platform. Late Cenozoic regional uplift concurrently affected the platform (Oriel, et al., 1967). Oliver (1977) reports several centimeters of relative uplift of the eastern Diablo Plateau and western Salt Basin between 1934 and 1958.

Releveling of this first-order line by the National Geodetic Survey in 1977 for the WIPP indicates only millimeters of relative uplift during the period 1934-1958 and about 5 centimeters of downwarping from 1958-1977 relative to the 1958 line. Further studies of this area are indicated in Chapter 10.

3.4.7 Val Verde Basin

The Val Verde Basin was a deep Early Permian depositional basin at the southwestern extent of the Permian Basin area. The Val Verde Basin trends east-southeast towards the Delaware Basin, adjacent to the north rim of the Ouachita tectonic belt.

The Val Verde Basin attained its major structural definition in Late Paleozoic time. The southeastern part of the south margin of the trough may have been established early in Pennsylvanian time. During Upper-Middle Pennsylvanian Desmoinesian time, the Val Verde area was a fairly stable foreland. But near the beginning of Permian time, the Val Verde trough was abruptly deepened and its north side irregularly steepened opposite the Marathon salient of the south rimming structural belt. Large-scale faulting believed to be of Pennsylvanian age has been recognized, through drilling, along the north flank of the trough; sagging along these zones of weakness during the Early Permian deepening of the trough is probable, according to Vinson (1959), Hester and Holland (1959) and Oriel et al., (1967). The large-scale rapid downwarping that occurred in earliest Permian time caused Permian rocks to accumulate here to a thickness exceeding 17,000 feet, the greatest accumulation of Permian rocks to be found in the Permian Basin. By the Mid-Permian there was a marked decrease in deformation, and a shelf formed across part of the area. Permian rocks here were later warped, possibly in Early Triassic time and eroded (Oriel et al., 1967).

3.4.8 Huapache Flexure

The Huapache Flexure is a long, narrow, northwest-trending monoclinal structure along the eastern slope of the Guadalupe Mountains on the west border of the Delaware Basin. The monocline extends from parallel to the Guadalupe Ridge anticline on the south, northward across the Capitan Reef escarpment, where it is offset to the west. Similar offset occurs farther north as it crosses the folds along the shelf margin. The monocline terminates at the north end of the Guadalupe uplift.

The Huapache flexure is marked by tonal and textured differences on LANDSAT imagery. On the southwest side of the mapped flexure line, the terrain is more dissected, has more vegetation, and from the visible shadows appears to be topographically much higher than the area to the northeast.

The width of the flexure ranges from 0.5 to 2.5 miles. The Precambrian structural relief ranges from 300 to 400 feet in the north to as much as 1,000 feet in the south, just north of Guadalupe Ridge. In the Delaware Basin, the structural relief on the Precambrian along the monocline is from 300 to 600 feet. The maximum dip along the flexure is about 15 degrees to the east, and above and below the structure, dips are from 3 to 5 degrees (Kelley, 1971).

Although the Huapache structure has the configuration of a monocline at the surface, there is evidence that it overlies a thrust fault or series of faults in the Precambrian basement and Paleozoic sedimentary section, and so represents the draping of sediments over a fault or fault zone (Stipp, 1960; Hayes, 1964). Haigler (1962) interpreted the results of drilling as indicating a displacement of as much as 5,400 feet along an underlying fault.

According to Claiborne and Gera (1974), the age of inception of the Huapache was Pennsylvanian; according to Haigler (1962), it was late Pennsylvanian to Permian, contributing to the final structural

development of the Delaware Basin. Hayes (1964) has indicated that the Huapache thrust faulting must have been post-Mississippian in age, since Mississippian rocks show no lithologic change across the zone but are vertically displaced as much as 4,000 to 6,000 feet, with a much higher Pennsylvanian section east of the zone (also see Meyer, 1966). According to Hayes, the zone was apparently intermittently active through all or most of Pennsylvanian time, into Early Permian. The Guadalupian San Andres Limestone, however, is not ruptured; thus, the faulting must have been pre-Guadalupian. According to Kelley (1971), too, movement ceased in Leonardian time. Since then, deposition of sediments above the fault trace has produced the low eastward-dipping flexure configuration exposed today. Although no major activity has occurred here since the Mid-Permian, Hayes (1964) believes that inasmuch as the monocline affects rocks of Late Guadalupian age, it appears that minor post-Guadalupian, probably Tertiary, movement has taken place along the old zone of weakness.

3.4.9 The Northwestern Shelf

North and northwestward of the Delaware Basin is a large platform area. Some investigators have taken the southward front of the platform to be delineated by the Capitan Reef Escarpment. Here the dips of the beds average about 20° to the southeast (Hendrickson & Jones, 1952).

The Northwestern Shelf was well developed before the onset of Permian time, as shown by the abundance of shelf limestones, including numerous reefs of Virgilian age, along its present trend. This tectonic element may have originated in early Paleozoic time, when it formed the margin of the early Tobosa Basin (Galley, 1958, Oriel, et al., 1967).

A number of flexures, arches, and buried fault systems have been identified in this area, several of the largest and best known of which are discussed below. The consensus is that tectonic activity along the individual structures had ceased in Tertiary time, and since then, only broad regional monoclinal flexing has occurred. Other than minor

surficial effects du to solution and hydration of evaporates, the entire southern part of the shelf appears to have been stable in Quaternary time (Brokaw, et al., 1972).

Folds A belt from 6 to 9 miles wide of sharply flexured folds lies just back of the Capitan Reef front, extending in long arcs convex to the west and parallel to the shelf margin for a distance of about 65 miles eastward to the Central Basin Platform. These symmetrical and parallel folds termed the Carlsbad folds by Kelley (1971), average about 1.5 miles apart from crest to crest and have an average fold amplitude of about 100 feet (Motts, 1972). Kelley (1971) describes their shape as "domical uplifts," circular to elliptical, with average dimensions of 1.5 by 3 miles. These folds are partly expressed in the present topography. Shelf domes, consisting of biohermal cores covered by shelf beds, are superimposed on the folds, which suggests to Motts (1972) that the folds may have been topographically positive features during the time of Capitan Reef. Brokaw, et al., (1972) dates these folds as of early Tertiary or perhaps older age. According to Hayes (1964), they are presumed to be Laramide in age, since they post date the Permian rocks and antedate the development of Carlsbad Cavern in early and middle Tertiary.

Another arcuate fold belt, called the Waterhole Anticlinorium, is present about 12 miles west of Carlsbad and extends for about 20 miles with a width of 1 to 2 miles. The feature consists of a narrow, closely spaced set of 3 synclines alternating with 3 anticlines. Structural relief on the folds is from 200 to 400 feet. The axes of the anticlines are sharper than those of the synclines, and locally, their axial planes appear to be faults (Kelley, 1971). Like the Carlsbad folds, this system has been dated as early Tertiary or older (Brokaw et al., 1972).

The Cenozoic folds that parallel the reef escarpment on its northwest may be indirectly related to the older Bone Spring Monocline, which formed a broad southeast-dipping fold along the basinward edge of the Victorio Peak Limestone in the Late Leonardian-Early Guadalupian time. The

monocline is exposed only in the south end of the Guadalupe Mountains in Texas but is presumed to continue northeastward into New Mexico, forming the southeast flank of the 15 to 20 mile-wide Bone Springs Arch. The arch was virtually buried in Brushy Canyon time, but near the end of San Andres time the flexure was rejuvenated and produced an accentuated northwest margin for the Delaware Basin. This had a great effect on later Permian deposition and may have controlled the position of the Capitan limestone (Hayes, 1964).

Numerous other local fold structures have been identified on the shelf area, a good number of which are described by Kelley (1971), by Motts (1972), and by Hayes (1964). Many of these folds have north to northwesterly curving axes and structural closure of up to 100 feet or more. According to Motts (1972), the size of some of these features, such as the McKittrick anticline and adjacent Dark Canyon syncline, as well as their possible influence upon the orientation of the Capitan reef, suggests that they may reflect deeper flexures or faults in the basement. Some of these features have been dated: Motts (1972) has found evidence that the McKittrick anticline and Dark Canyon syncline were a topographic high and low, respectively, during Guadalupian time.

Faults The most prominent area of fault-like structures on the shelf north of the Delaware Basin is the zone of straight northeast-trending shears extending from several miles north of Artesia northwestward toward the Sacramento Uplift and Capitan Mountains. The major structures of this group, such as the Y-O, Six-Mile Hill, and Border Hills Buckles, are exposed for from 35 to 80 miles along strike and spaced at distances of 8 to 20 miles. Movement along these features has involved folding, faulting along strike, and overthrusting, and along the strike of these buckles the nature of deformation may change markedly over a short distance. These features are visible on LANDSAT imagery to varying degrees. The Border Hills Buckle appears as a very obvious scarp and adjacent depression which is visible along its entire length, whereas there are no obvious scarps or depressions along the mapped trace of the Six-Mile Hill Buckle, although some stream offsets are aligned along its

trend, and the Y-O fault is marked only by portions of 3 streams which follow the fault line a short distance. Evidence exists that movement on these zones was initiated in Carboniferous or earlier times and may have been basically right lateral (Brokaw et al., 1972 and Kelley, 1971).

Kelley (1971) has described two faults, named the Barrera and Carlsbad, fronting the reef escarpment 32 kilometers and 16 kilometers southwest of Carlsbad and having "late Tertiary with possible Quarternary movement." However, many other geologists who have investigated the area are not convinced that the linear features seen on aerial photos are actually faults. (Claiborne and Gera, 1974).

Artesia-Vacuum Trend The Artesia-Vacuum trend is a long, low, east-trending arch in Permian rocks, which extends eastward from a little south of the town of Artesia, in Eddy County, New Mexico, for a distance of about 75 miles, roughly paralleling the Carlsbad folds. The trend represents slightly warped Permian strata in an eastward-plunging anticline (Stipp, 1960). The arch is almost completely covered by post-Permian beds, except for a short stretch near Chalk Bluff Draw where the plunging south limb is seen dipping southeastward at about 4 degrees. This feature has been dated as either Early Permian or pre-Permian, and, according to Brokaw et al. (1972), is largely or wholly the product of differential compaction over the Abo reef of Early Permian age.

3.4.10 Sacramento Mountains

The Sacramento Mountains constitute an uplift area to the west of the Northwestern Shelf and form the local eastern border of the Basin and Range province. The uplift extends for a distance of over 45 miles in a north to slightly northeast direction, and most of the structures within the range also exhibit a northerly trend. The overall structure of the Sacramento Mountains is a tilted fault block, with a regional dip to the east of about 1 degree. The eastern flank of the mountains is characterized by its simple, undeformed eastward dip of 100 to 140 ft/mi. Greater

uplift along the central crestal zone has produced dips of several degrees in the strata on the north and south ends of the range. The Sacramento uplift is separated from the Tularosa Basin on the west by one or more normal faults involving several thousand feet of displacement (Stipp, 1960).

The Sacramento Mountains have developed through several periods of tectonic activity, probably beginning in Late Pennsylvanian and early Wolfcampian time. Pre-Permian strata of the range are deformed by folding and faulting during this time, and many of the internal structures of the Sacramento Mountains formed then. Some further deformation occurred during Mesozoic or early Cenozoic time (Pray, 1959). Cretaceous strata, strongly folded and faulted and intruded by dikes and sills, occur extensively in the northern Sacramento Mountains, especially between the towns of Capitan and Carrizozo. Here the structure suggests a depressed synclinal block greatly affected by igneous activity (Stipp, 1960).

Late Cenozoic Basin and Range faulting, which produced uplift and tilting, gave the Sacramento Mountains their present configuration. The dominant location of this activity has been the large fault zone at the western base of the uplift in the Tularosa Basin, and the uplift appears to be still in progress (Pray, 1959).

3.4.11 Guadalupe-Delaware Mountains Uplift

The Guadalupe-Delaware Uplift is a gently northeastward-tilting fault block extending northwestward for some 110 miles, from the Diablo Platform area near Van Horn, Texas, to east of Pinon, New Mexico. In New Mexico, the western boundary of the uplift is a great fault scarp produced by a system of nearly en echelon, normal faults of Late Cenozoic age, along which the displacement ranges from 2,000 to 4,000 feet (Kelley, 1971; Hayes, 1964). The eastern margin is formed largely by erosional conformance to the Late Paleozic to Tertiary Huapache Monocline, and the southeast margin of the range coincides with the Reef

Escarpment, which, according to Hayes (1964) may have resulted partly from Cenozoic rejuvenation of the Late Paleozoic Bone Spring Monocline. Using the Huapache Monocline as the east boundary, the uplift is about 11 miles wide in its southern part, tapering northward to about 3 miles (Kelley, 1971). The Guadalupe Mountains lie within the Sacramento section of the Basin and Range province and are structurally part of the Northwestern Shelf (Brokaw, et al., 1972).

In cross section, the mountains have a cuesta-like or asymmetric profile, with the fault scarp forming a short, steep western slope and a backslope dipping gently eastward at generally less than 3° or about 200 ft/mi. The beds usually dip more steeply than the land surface, thus exposing progressively younger rocks to the east and southeast (Hendrickson & Jones, 1952).

The principal structural elements within the Guadalupe Mountains area have been described in detail by Hayes (1964), Boyd (1958), and King (1948). These include the Huapache and Bone Springs Flexures and the folds which parallel the Reef Escarpment (refer to Section 3.4.8). The only faults along the eastern periphery of the uplift, paralleling the reef, are short normal faults of very small displacement, which probably originated as tension joints (Hayes, 1964). The major faulting in the area is located to the west of the Guadalupe Mountains Uplift, where many closely spaced faults trend north to northwest. Hayes (1964) describes those in the New Mexico portion of the area in three groups: those along the Guadalupe Mountains scarp north of Stone Canyon, those parallel to the Shattuck Valley scarp south of Stone Canyon, and those in and north of the Brokeoff Mountains. Along the Guadalupe Escarpment are numerous, closely spaced, high-angle normal faults paralleling the scarp and generally downthrown on the west. From high on the scarp westward into Big Dog Canyon, the faults decrease in dip to as low as 60 degrees and increase in displacement from rarely over 100 feet on the east to about 800 feet in the canyon, low on the scarp. The faults south of Stone Canyon are separated from those to the north by an unfaulted monocline some 1 1/2 miles wide. Most of the displacement on the scarp here is

along a large fault high on the scarp having a displacement of as much as 800 feet, and an arcuarte trace convex to the east, adjacent to its trace are a number of small strike faults (Hayes, 1964; see also King, 1948; Boyd, 1958). West of the Guadalupe Mountains is a graben area occupied by a complex north-northwestward trending zone of Late Cenozoic faults in and adjacent to the Brokeoff Mountains. Most of the faults are high angle and normal and are downthrown to the east, except for several in the north that form grabens and horsts. Stratigraphic displacements here range from a few feet to about 600 feet (Hayes, 1964).

Evidence has been presented by King (1948) that tectonic deformation was occurring in the southern Guadalupe area before Middle Permian time and produced the Bone Spring Flexure, which possibly governed the location of the Delaware Basin. Hayes (1964) describes a fault zone in the Guadalupe Mountains that may have trended southeastward into the western edge of the Delaware Basin and may have been active during Mississippian to Early Permian time. Like the Sacramento Uplift, though, the Guadalupe-Delaware Mountains are primarily a Late Cenozoic structural feature, uplifted and tilted eastward by the Basin and Range tectonic activity.

King (1948) dated most of the major normal faulting of the Guadalupe Mountains area as Late Pliocene to Early Pleistocene. He did note, however, that some renewed movement along pre-existent faults probably took place in the Early Pleistocene, as evidenced by dissection of probable early Pleistocene deposits due to change in base level. But he found no evidence for younger movements in the Delaware or Guadalupe Mountains.

There is evidence, though, that development of the uplift may still be continuing at a reduced rate today. Kelley (1971) reports that during his work a small scarp in the alluvial fans along the northeastern end of the Guadalupe Fault Scarp, in T20S, R17E was found, indicating some slight Holocene uplift. More recent field investigations in the Salt Basin graben region adjacent to the Guadalupe Mountains in Texas have identified over 100 Quaternary-age normal, en echelan, and discontinuous

fault scarps and photolineaments with displacments of as much as 18 feet, which appear to be controlled by preexisting structural zones of weakness. The orientation of the scarps, the proximity of recurring seismic activity, and the youthfulness of offset surfaces suggest that these scarps have a tectonic origin and are maintained by intermittent activity which is in some places younger than 1,000 years old and probably continuing (Goetz, 1977). Such data would thus indicate some ongoing Holocene structural development of the eastern extent of the Basin and Range elements in the Southeast New Mexico west-Texas region.

3.5 REGIONAL IGNEOUS ACTIVITY

Large-scale post-Precambrian igneous activity in the southeast New Mexico-west Texas area consists of Early to mid-Tertiary intrusive bodies and Tertiary to Quaternary volcanic terrains located well to the north, west, and south of the site area. Figure 3.5-1 presents the regional distribution of known igneous features. Within the northern Delaware Basin, only minor igneous activity, in the form of one or more Tertiary dikes and possibly associated sills, is known to have occurred. This section discusses the igneous features known to exist within about 100 miles of the WIPP site and considers in particular detail the near-site intrusives within the northern Delaware Basin.

3.5.1 Near-site Activity

The outcrops of igneous dike-related material nearest to the WIPP site are located about 42 miles southwest of the site, in the Yeso Hills. Subsurface samples of intrusive igneous rock within about 9 miles of the site have also been obtained from drill holes and from two underground potash mining operations, located some 10 miles apart in the Salado Formation. Aeromagnetic investigations have also indicated the presence of magnetically responsive, perhaps igneous, materials in this area. Whether all these occurrences represent parts of one dike or en echelon dikes, they together produce a very linear trend striking approximately N50° E for a distance in excess of 75 miles. This trend extends from a

point near the Texas-New Mexico border southeast of Carlsbad Caverns at least to the northeasterly most well intercept, some 30 miles northeast of the site (Elliot, 1976b; Claiborne and Gera, 1974). The location of the intercepts and magnetic indications and the dike trace they suggest are plotted on Figure 3.5-2.

The outcrops in the Yeso Hills consist of rectilinear patches of rust-colored, earthy material studded with occasional sharp, small fragments of a dark, fine-grained igneous rock that represent the surface expression of three parallel, en enchelon dikes within the outcropping Castile gypsum. The dikes trend east northeast and vary in width up to about 20 feet and in length up to about one-half mile (Pratt, 1954). These outcrops are separated by a distance of about 27 miles from the nearest subsurface dike intercepts or definite magnetic response along strike to the northeast.

Intercepts of intrusive igneous material have been reported from at least 9 drill holes within the northern Delaware Basin along the trend indicated above (See Table 3.5-I). These intercepts have generally been multiple in each well or drill hole. For instance, the Stanolind U.S. Duncan #1 is reported to have 8 intercepts which range in depth of location from 470 to 13,300 feet. Several petroleum exploration geologists have interpreted the occurrences to represent a series of sill-like intrusions (Elliot, 1976b), a theory which may be supported by magnetic data discussed below.

Dike exposures have also been observed in the underground workings of the International Minerals and Chemical Corporation mine, located approximately 9-1/2 miles northwest of the proposed WIPP site, and in the Hobbs Plant mine of the Kerr-McGee Chemical Corporation, some 10-1/2 miles north of the site (See Table 3.5-1). The dike exposures in these mines are intruded into the Upper Permian Salado Formation. These intrusives are nearly vertical and usually only a few inches to a foot thick, but thicken to approximately 15 feet wide at their widest observed point, in the Kerr McGee mine. No displacement exists between the salt

beds on the two sides of the dike and, in one of the mines, the end of the dike can be observed (Claiborne & Gera, 1974), indicating a discontinuous, segmented character.

Airborne magnetic surveys of the region, performed by the U.S. Geological Survey, have been utilized to help determine the position of the dike material and its genetic relationship to the surrounding rock strata. These surveys show magnetic indications of a dike-like structure extending southwestward from a point approximately 30 miles northeast of the WIPP site to near the Pecos River. The width of the magnetic anomaly so indicated varies from several miles at its base, at a depth of about 12,000 to 13,000 feet, near the Precambrian basement to a very thin trace at its upper extremity near the ground surface. Elliot (1976b) noted that an aeromagnetic response indicating such an apparent single, broad anomaly may be produced by a series of dikes which have a broad base and pinch out vertically. The feature under consideration may thus represent "a multiplicity of en echelon dikes forming a swarm, which rise generally vertically from the basement and pinch out in an upward direction (Elliot, 1976b)". According to this interpretation, one of these dikes extends upward above the other dikes, penetrating units as young as the Salado Formation, and is encountered in the outcrops and subsurface intercepts. The multiple showings from one drill hole are, according to this interpretation, thought to represent small sill-like projections which extend outward horizontally from the main vertical dike source.

The dike or series of dike-related features indicated by the above lines of evidence has a similar appearance, composition, and structure wherever it has been encountered in the subsurface. The dike rock is a medium-gray to grayish-black, fine-grained porphyritic material identified as lamprophyre by Jones (1973). The groundmass of the rock consists of orthoclase with accessory biotite, which is partially altered to vermiculite, and minor amounts of ilmenite, apatite, anatase and pyrite. The rock also contains corroded andesine phenocrysts and pseudomorphs of siderite and antigorite after pyroxene. Amygdules as large as 2 mm in diameter, filled with halite, siderite, calcite, and natrolite are dispersed through the dike rock.

Nearly vertical and subhorizontal fissures are present throughout the dike and are usually filled with halite, with local polyhalite, anhydrite and minor amounts of pyrite, dolomite, quartz and crystalline hydrocarbons. The dike has a rather poorly-developed flow structure and a chilled border. The halite of the adjacent intruded beds has been recrystallized as much as 3/4 inch along the dike contact, and, in places, contains methane and other gases under pressure. Where the termination of the intrusive mass is observed, a vein of polyhalite, also containing minor amounts of pyrite, dolomite, and crystalline hydrocarbons, extends upward into the adjacent salt, indicating that some migration of fluids along the dike must have taken place following intrusion. Later recrystallization and plastic flowage have, however, healed any permeable zones which may have formed at the time of the intrusion and flowing water is not now present where the dike is observable (Claiborne & Gera, 1974).

Specimens of the dike material from the Yeso Hills were classified by Peter H. Masson (reported in Pratt, 1954) as an alkali trachyte and as a soda trachyte of porphyritic texture with principal minerals of anorthoclase, albite, chlorite, ilmenite, and magnetite. The rocks are severely altered, and the walls of the dikes are not clearly defined. Both specimens examined were vesicular, indicating a surface environment of cooling and crystallization. Calcite and gypsum often line the vesicles as secondary deposits (Pratt, 1954).

The emplacement of the lamprophyre dikes probably occurred during mid-Tertiary time, approximately 30 million years ago. Urry (1936) dated the intrusives at 30 +1.5 m.y., from drill hole cuttings of the Texas Co. No. 1 Moore well, located about 12 miles north of the WIPP site. More recent K/Ar whole-rock dating by the U.S. Geological Survey, Denver, has determined an age for a sample (#J-1-71(M75)) of this dike of about 34.8±0.8 million years (recalculated for recent change in measured decay constant) (C. L. Jones, personal communication).

The span of time thus indicated since intrusion has been ample to provide for complete cooling of even the largest of these intrusive bodies, and at the present time there is no evidence of magnetic masses unusually close to the surface in the area.

These dike indications may represent part of an en echelon dike arrays extending northeastward for almost 80 miles from the Gypsum Hills in southern Eddy County, near the New Mexico-Texas state line, to the Vacuum oil field south of Buckeye in central Lea County, New Mexico.

The northeast trend of all these dikes generally coincides with the orientation of several tectonic lineaments in the area and also parallels the trend of crevasses and joints in the carbonate rock of the Capitan and Tansill Formation near Carlsbad Caverns. These fractures are filled with Early Cretaceous sandstones and conglomerates. Thus, the emplacement of the magmatic material may have been facilitated by earlier patterns of structural weakness, which developed in response to regional stresses operative previous to Cenozoic time. The date of the dikes, however, suggests that their development may have been related events which were precursors to the later Basin and Range tectonism of Mid-to-late Tertiary time.

3.5.2 Guadalupe-Delaware Mountains Area Activity

King (1948) described several occurrences of igneous material in the Guadalupe-Delaware Mountain area. He identified one small intrusive plug, about 15 miles southwest of the Yeso Hills dikes, located within the Delaware Mountains in a ravine one-half mile north of Lamar Canyon, 1-1/2 miles east of its junction with Cherry Canyon. This plug forms a low ridge several hundred feet long and cuts sandstones within the Guadalupian-age Bell Canyon Formation. These sandstones have been tilted, baked, and silicified, according to King, for about 10 feet from the edge of the plug. The intrusive rock itself he described as "light gray and aphanitic, probably a trachyte." Pratt (1954) later examined this reported plug and similar outcrops in the area. He found no igneous

rock or any tilted or baked sandstones, only evidence of intense silicification of the sandstones within low parallel ridges oriented north northwest. Pratt, however, interpreted these features to be evidence of underlying intrusive dikes, as did King. Pratt futher stated that the dikes formed part of the siliceous mantle of an underlying igneous intrusion.

Seven miles to the east southeast of these chalcedony-like ridges, within the Magnolia Petroleum Company's Homer Cowden No. 1 well, a body of igneous rock has been intercepted at depths from 8,730 feet to 9,140 feet (Pratt, 1954). The feature is oriented parallel to the trend of the hypothesized dikes of Lamar Canyon and is interpreted as a sill. Pratt (1954) suggests that "the source of this intrusion may also be the source of the solutions which so intensely silicified the conspicuous outcrops" in the Delaware Mountains, described above. The "sill" is composed of extremely porous, light gray and holocrystalline rock with prominent black needles of a ferromagnesian mineral, which has been analyzed by Peter T. Flawn as a "lenco syendiorite," otherwise possibly termed a monzonite (Pratt, 1954).

King (1948) has postulated the existence of a third buried intrusive, located in the Guadalupe Mountains of Texas, approximately 1-1/2 miles south of the Otero-Eddy county line, on the northeast slope of Lost Peak. His hypothesis is based on the observation that the Carlsbad limestone here, at the Calumet and Texas mine, "has been replaced by copper, lead, zinc, and iron minerals, which probably emanated from an igneous source beneath (King, 1948)."

The age of the igneous intrusive activity in the Guadalupe-Delaware Mountains region has been conjectured by King (1948) as Early Tertiary or somewhat younger, representing the northern extension of a vast number of intrusives related to the intense Trans-Pecos Davis Mountain activity. Unlike the region further south, however, little remains of these records in the Guadalupe Mountains area, and only minor igneous activity occurred here (King, 1948). Pratt (1954), in agreement with King's dating work,

has stated that the Delaware Mountain materials he investigated "may reasonably be presumed to be of Tertiary age." He based this judgement on the assumption that these rocks are similar in composition to the generally alkalic igneous rocks identified by Flawn (1952) as comprising the Tertiary intrusives of the west Texas-eastern New Mexico area.

3.5.3 Trans-Pecos Magmatic Province

The Trans-Pecos "magmatic province" comprises a vast area of both intrusive and extrusive igneous outcrop terrains of Tertiary age situated east of the Rio Grande River and west and south of the Guadalupe-Delaware Mountains, approaching within about 90 miles of the WIPP site at the northern extent of the province. The magmatic province extends a distance of about 225 miles from the Diablo Plateau-Cornudas Mountains outcrops near the New Mexico-Texas border, southeastward through the Davis Mountains volcanic area and associated intrusives to the southern tip of Texas (see Figure 3.5-I). The entire province contains in excess of 200 intrusive bodies having outcrops exceeding about 1/2 square mile each in surface area (Barker, 1977) in addition to the approximately 6,000 square-mile region of volcanic outcrop terrain of the Davis Mountains area (from Cohee, et al., 1962). According to King (1948), this magmatic province was developed during Early Tertiary time, when great sheets of lava spread over the Davis Mountains and adjacent areas, across a surface of Cretaceous and older rocks. Both the lavas and sedimentary rocks were then intruded by a host of small to large intrusive masses, some of which were far removed from the Davis Mountains region. Barker (1977) has determined that the magmatic activity in the Trans-Pecos province occurred during the interval from 43 to 16 million years before present. Those intrusives which lie closest to the site are discussed further, below.

Within the northern portion of the Diablo plateau, some 22 intrusive igneous bodies are exposed along a north northwest trending belt. The northernmost of these igneous outcrops occurs within the Cornudas Mountains, which are centered approximately 105 miles west-southwest of the proposed WIPP site, on the Texas-New Mexico border.

These intrusions, known collectively as the Cornudas Group, generally consist of a central group of plugs, surrounded by sills and laccoliths. The materials composing these intrusions have been classified as nepheline syenites, phonolites, or quartz-bearing syenites. The older rocks are generally fine to coarse-grained, equigranular to porphyritic, with only weakly and locally developed flow structure. The younger rocks of the group are fine-grained, microporphyritic and vesicular, with strongly developed flow structure. Abundant autoliths of alkalic igneous material are contained within several of the intrusions of the Cornudas Mountains (Barker, et al., 1977).

K-Ar dating of biotite in igneous rock samples from the Cornudas Group yields an age of approximately 31 to 37 m.y. for the time of intrusion. The intrusives were emplaced in sedimentary rocks which range in age from Early Permian to Cretaceous (Barker, et al., 1977).

3.5.4 El Camino del Diablo and Railroad Mountain Dikes

The east-west trending El Camino del Diablo and Railroad Mountain dikes are the igneous features nearest to the WIPP site on the north, beyond the limits of the Delaware Basin. The outcrop areas of both dikes are covered by a thin veneer of gravel, caliche, and alluvium (Kelley, 1971), and neither have much expression on LANDSAT imagery.

The southernmost of the two dikes, El Camino del Diablo, is located approximately 67 miles north of the WIPP site. The dike can be traced on the surface for about 25 miles (Kelley, 1971) from the caliche-capped plains east of the Pecos River eastward until it disappears under the Mescalero sands. The dike varies in width from some 32 feet on the west to about 47 feet at its easternmost outcrop. Although it exhibits very little topographic expression, in places along its trace the dike is marked by a slight depression produced by a greater erosion of the dike than of the surrounding country rock. The intrusive material is an excensively altered, fine-grained, slightly porphyritic, bluish-gray rock displaying typical diabasic texture and is composed of augite and

magnetite in a matrix of lath-shaped feldspar crystals. Since the composition is intermediate between an andesite and basalt, the rock has been classified as an "augite-andesite" (Semmes, 1920). Bordering the dike are contact zones from one to 12 feet wide, which consist primarily of a mere baking of the country rock with no appreciable mineralization.

The Railroad Mountain Dike parallels the Camino del Diablo Dike 13 miles to the north and extends a distance of about 30 miles from the eastern side of the Pecos River eastward into the Mescalero sands. The width of the dike is remarkably constant, measuring at most about 100 feet, which suggested to Semmes (1920) that the exposed portion represents only a fraction of the entire intrusion (Kelley, 1971; Semmes, 1920). In contrast with the Camino del Diablo Dike, this dike forms a ridge, which in places reaches as high as 60 to 80 feet. On LANDSAT imagery, it has its most pronounced expression as it approaches the Matador uplift region to the east. The dike material is a massive, dense, dark-blue, medium-grained granitoid rock composed of pyroxene and olivine with considerable magnetite in a felt-like mass of interlocking lath-shaped plagioclase crystals. The rock may thus be classified as an olivine gabbro, of more basic nature than most of the other intrusives of the region. Almost no secondary alteration has occurred, which accounts for the dike's prominent ridge-like expression (Semmes, 1920). The contact zone between the dike and host rock displays a slight baking but little mineralization and is, at most, several feet wide.

Both the Railroad Mountain and El Camino del Diablo Dikes have been classified as Tertiary in age by Cohee (1962) and have intruded rocks as young as the Triassic Santa Rosa Sandstone (Kelley, 1971). Semmes (1920) considered the dikes to have been Eocene or younger in age and possibly as young as Middle to Late Tertiary, representing later stages in Tertiary igneous activity, when the basaltic intrusives and extrusives of the area originated. The generic relationship of the dikes to other features in the region is unclear, but airborne magnetic surveys indicate that both of the dikes "nose out" to both east and west (Elliot, 1976b).

This would seem to preclude the dikes being direct extensions of either the Capitan stock activity, to the west (see section 3.5.5, below), or of the Matador Arch (section 3.4.4) to the east.

3.5.5 Capitan and Sierra Blanca Mountains Region

The Capitan intrusive is located within the Capitan Mountains region approximately 117 miles northwest of the WIPP site. The feature is about 21 miles long and from 3.5 to 5 miles wide, with an above ground volume of about 20 cubic miles (Kelley, 1971; Semmes, 1920). There is some controversy regarding the nature of the intrusion, due to the fact that it has characteristics of both a laccolith and a stock. Typical of a laccolith, there is evidence of a concordant roof along most of the summit, but the structural and stratigraphic discordances, including observed uplift and structural nosing, favor its designation as a stock. In any case, the intrusion has penetrated units as young as the Rio Bonito member of the San Andres Formation and the Yeso Formation, of Middle Permian Leonardian age. Along the eastern end of the mountain, the Yeso beds stand almost vertically near the contact (Kelley, 1971). "Mesaverde beds" of Cretaceous age show thermal alteration as well according to Kelley (1971).

The Capitan intrusive is remarkably uniform for its size in both composition and texture. It is a medium- to fine-grained, slightly porphyritic rock, classified by Kelley (1971) as a leucoratic quartz syenite. The Capitan intrusive has been designated as Tertiary in age by Cohee (1962); Semmes (1920) suggested that it may be of Early Tertiary age, in concurrence with Lindgren, et al. (1910), who considered all of the quartz-bearing monzonitic and dioritic intrusives of this area to be Early Tertiary. Semmes (1920) considered these acidic intrusives to represent an early stage in igneous activity, preceeding the more basic, less extrusive diorities and gabbros of later Tertiary time.

Immediately west and southwest of the Capitan intrusive, underlying and cropping out in the Sierra Blanca Mountains, are the Sierra Blanca volcanics, dikes, and stocks.

The Sierra Blanca volcanics crop out in an area of some 200 square miles; Thompson (1966) believes that the field was once as large as 750 square miles prior to intrusion by the stocks and Late Tertiary erosion. The volcanics consist of massive, purplish-brown, andesitic breccias, flow, and tuffs overlain by trachtye breccia and have a recorded thickness of as much as 3,340 feet. These volcanics are thought to be of Early to Mid-Tertiary age (Kelley, 1971; Thompson, 1966).

Some 200 dikes occur in swarms oriented generally radially with respect to the Sierra Blanca stocks and in a great swarm 7 miles wide and 22 miles long, trending north northeastward from Ruidoso to east of Patos Mountain. The dikes are generally traceable for less than one mile and range in thickness from one foot to 60 or 70 feet. They vary in composition from a few occurrences of syenite porpnyry to diabasic, although 60 to 70 percent of the dikes are basic (Kelley, 1971). Since the dikes intrude the Sierra Blanca volcanics, they post-date them, and may be Mid-Tertiary in age.

3.5.6 Conclusions

The data presented above indicate that, within some 100 miles of the WIPP site, no igneous activity has taken place since the early part of Basin and Range tectonism, which began in the mid-Tertiary. In the near-site vicinity, the closest igneous feature to the site is a lamprophyre dike or series of en echelon dikes, which approaches no nearer than about nine miles from the site; no associated igneous bodies have been found to approach or underlie the site itself. The dike has been dated as approximately 35 m.y. old and has long since completely solidified and cooled. Younger intrusive and extrusive features are situated far to the west of the site, beyond the area of discussion, and are associated with the regions of more recent Basin and Range tectonism. Thus, judging from the pattern of the structural development of the northern Delaware Basin area, further igneous activity is not expected in the near-site region.

3.6 REGIONAL GEOLOGIC HISTORY

Figure 3.6-1 presents a summary of the major geologic events which have affected the southeast New Mexico-west Texas area as have been determined from the rock types and structural relationships for which evidence remains and has been uncovered.

3.6.1 Precambrian

Very little is known about the Precambrian history of the southeast New Mexico-west Texas area. The Precambrian rocks penetrated in the Guadalupe Mountain and Sacramento uplift regions in southern Lea County and in west Texas, consist of plutonic granitics and metamorphics, which suggest that the region has a complex Precambrian history of mountain building, metamorphism, and erosional cycles (Nicholson & Clebsch, 1961; Hayes, 1964; Kelley, 1971). According to Flawn (1956), the Precambrian granitics encountered in the southern part of this area comprise a generally stable mass, called the Texas Craton, which extended northward from Texas into southeastern New Mexico. Muehlberger, et al. (1967), however, have demonstrated that these materials comprise part of a much more complicated basement surface representing a variety of environments involving intrusive and extrusive igneous activity as well as metamorphism of sediments.

The ages suggested for the Precambrian rocks encountered in this region are all fairly ancient. In the core of the Pajarito Mountain dome, southeast of the Sacramento uplift, the metamorphics have a radiometric date of 1,270 million years (Kelley, 1971). The granitics and metamorphics of the Guadalupe Mountain area are probably somewhat less than one billion years old (Hayes, 1964), while slightly greater ages have been indicated for the Precambrian rocks of the Texas Craton. Wasserberg, et al. (1962) determined ages of 1,250 to 1,400 million years in the northern part of the area and a younger 1,090 million years terrain to the south, suggesting progressively younger metamorphic events from north to south in this region during the Precambrian.

There is no record of the latest Precambrian or of most of the Cambrian time in this region; however, about one billion years before present the area was reduced to a nearly level plain upon which the Paleozoic rocks were later deposited (Hayes, 1964).

3.6.2 Early and Middle Paleozoic

During most of the Paleozoic Era, from at least Late Cambrian until near the close of the Mississippian Period, the eastern New Mexico-western Texas area was part of a broad, low-lying, generally stable region named the Tobosa Basin by Galley (1958). The shallow basins of the area formed northern arms of the Ouachita trough, which shoaled on the north in south-central New Mexico and merged southward with the Ouachita-Marathon geosyncline, connecting with the open sea in the vicinity of the present Gulf Coast or coast of southern California (Brokaw, et al., 1972; Hills, 1972). During the early Paleozoic there seem to have been no well-marked platforms within the basin. However, lines of weakness along strike-slip faults in the basement probably were present (Hills, 1970). Along these faults later vertical movement took place (Hills, 1972).

For a span of about 180 million years, until Late Mississippian time, almost continuous deposition occurred in this area under conditions of general tectonic stability in shallow seas periodically transgressing from the south. Shelf-type carbonate deposition predominated but was interrupted by shale sedimentation during Middle Ordovician, Late Devonian, and Early Mississippian. The total section of these sediments is about 2,500 feet, from the base of the Bliss Sandstone to the top of the Helms Shale, in the Guadalupe Uplift-southeastern New Mexico area (Hayes, 1964).

The chief events which characterized each period of the Early through Middle Paleozoic are summarized below.

Cambrian-Ordovician. No rock record older than Late Cambrian age has been uncovered in the southeastern New Mexico area (Hayes, 1964). The Bliss

Sandstone near El Paso, Texas, provides evidence of clastic sedimentation in that area during part of the Late Cambrian. After the Precambrian rocks had been uplifted and deeply eroded, a sea advanced over the region from the west or southwest and the Bliss sandstone was deposited; the abundant quartz grains in the Bliss were probably derived from reworking of sedimentary debris on the eroded Precambrian surface (Harbour, 1972; Bachman and Meyers, 1969).

During Early Ordovician time, the sea in which the Bliss was deposited continued to transgress eastward and extended at least as far north as Roswell. During this time, the carbonates and clastics known as the El Paso Formation in New Mexico and the Ellenburger in west Texas were deposited in shallow seas containing abundant marine life (Bachman, 1969). These sediments thickened southeastward from a thin layer lapping onto a positive area of Precambrian basement then present in northern New Mexico and Colorado to a massive deposit over 2,000 feet thick in Texas, at the edge of what may have been the continental shelf (Eardley, 1962). At this time, the ancestral Central Basin Platform was a granitic upland or island chain which provided clastics to the early Ordovician shelf and adjacent shallow basin deposits.

During the Ordovician, the Marathon-Ouachita geosyncline bounding the Tobosa Basin area on the south began subsiding (McGlasson, 1968). In Mid-Ordovician time, a broad and gently emergent peninsula, extending southeastward through Texas, rose, and the region was also tilted southward. To the north, the shales, sandstones, and sandy limestones of the Simpson Group were deposited above the El Paso--Ellenburger, wedging out north at the latitude of Roswell, west around Artesia and east around the Central Basin Platform. Southward, toward the deepening basin regions, the deposits thickened and became predominantly shaly. In Middle to Late Ordovician time, fewer clastics were provided to the area, and the carbonates, and fine-grained calcareous muds of the Montoya Group were deposited in shallower, calmer seas than earlier, that moved northward over the tilted surface of the El Paso Formation. At the close of Montoya time, a gentle southward tilting occurred (Bachman, 1969).

Silurian-Devonian. During Silurian and Devonian time, the Pedernal Landmass, to the northwest, and the Texas Peninsula, to the south, were land areas of low relief. The Tobosa Basin between these two areas, joined southward with the Marathon-Ouachita geosyncline. There is no evidence of major tectonic activity during this time in west Texas or southeast New Mexico. However, mild epeirogenic movements did occur, and the Tobosa Basin was gently subsiding throughout the period, becoming also more restricted areally. To the south, the Ouachita-Marathon geosyncline reached its maximum depth.

During Early Silurian time, most of the Tobosa Basin was emergent but low-lying. By the Middle Silurian, the sea returned, perhaps transgressing from the south and southeast, and broad, shallow areas developed around the northern, eastern, and western margins of the Tobosa Basin, upon which the thick Fusselman dolomites and limestones were deposited conformably in a marine environment atop the Montoya Group in clear, well-circulating water (McGlasson, 1968; Harbour, 1972; Bachman, 1969). At this time, the basin waters reached their furthest extent into New Mexico. Minor fluctuations of sea level within this shallow area of deposition produced a karst topography on the surface of the periodically exposed carbonates. During Late Silurian time, southward tilting occurred once more, and the sea regressed. Within the deeper areas to the south into Texas, a sediment-starved condition developed, resulting in deposition of micrites and green shales. Around the Tobosa Basin rim, carbonates continued to form (McGlasson, 1968).

The shallow sea continued to retreat from the New Mexico area through Early and Middle Devonian time. In Early Devonian, the shoreline had retreated, producing a carbonate plain of low relief. The depositional basin had an asymmetrical shape with the deepest water to the west, in which cherts and silicious limestones were deposited. By the late Middle Devonian, mild uplift and southward tilting had occurred, and most of the Tobosa Basin was exposed to erosional processes; the only deep water lay to the south, where the basin plunged into the Marathon-Ouachita geosyncline. In Late Devonian time, the area was again submerged as

shallow seas spread across southern New Mexico, and the dark heavily clastic Woodford shales were deposited in a nearshore environment (Bachman 1969), overlapping all of the previous Devonian and Silurian deposits (McGlasson, 1968). Woodford deposition continued into Mississippian time.

Mississippian. Subsidence of the Tobosa Basin continued into Mississippian time. The Texas peninsula to the south and the Pedernal landmass to the northwest were mildly positive features and remained so until the Middle Mississippian (McGlasson, 1968).

In Early Mississippian time, a new paleogeographic regime began to develop in this region. The ancient Tobosa Basin began deepening on either side of a medial zone, later to become the Central Basin Platform, that was bounded by Precambrian basement faults. Shelf deposition continued along the margins of the basinal areas.

Toward Late Mississippian time, regional tectonic activity accelerated in the Tobosa Basin area, folding up the medial zone along its ancient lines of weakness. By the end of the period, erosion had probably exposed Precambrian rocks in the cores of the larger anticlines (Hills, 1963). Meanwhile, deep, broad basins, the forerunners of the Delaware and Midland Basins, formed to the east and west of the median upland area. Broad carbonate shelves developed around the margins of these basins, while black shale sedimentation occurred in their deep central portions. The black shale deposition was probably slow, much of it taking place during times of slight sea level sinking (Hills, 1972). Toward the south end of the basins, deposition of the shale and sandstone of the Tesnus Formation continued from Late Mississippian into the beginning of Pennsylvanian time, the clastics apparently being derived from highlands on the southeast which were rising in the earliest activity of the Ouachita orogeny (Flawn, 1961).

To the north of the basins, the Matador Arch was upfolded in the latest Mississippian and rapidly eroded to expose its Precambrian core. At the same time, orogenic forces raised the Ancestral Rocky Mountains to the

west, in a general north-south trend through central New Mexico (Stipp, 1960), producing a regional southward tilt which resulted in widespread erosion, exposing progressively older rocks toward the north.

By the close of the Mississippian Period, most of northeast New Mexico formed a low hilly area of Precambrian rocks, rimmed on the north and east by outcrops of Lower Ordovician dolomites and on the south by the uplifted former site of the Tobosa basin.

3.6.3 Late Paleozoic

Pennsylvanian. Following Mississippian time, the entire region was invaded by the sea from the south and east, and, particularly near the uplifted areas, tremendous thicknesses of Pennsylvanian rocks were deposited unconformably over the tilted bedrock strata, which ranged in age from Mississippian in the south to Precambrian northward in central New Mexico (Hills, 1963; Meyer, 1968). The tectonic processes initiated near the close of the Mississippian, including uplift and erosion of mountains in the Ouachita-Marathon area, of the mountain range separating the early Delaware and Midland Basin areas, and of the Matador Arch and Ancestral Rockies, continued into early Pennsylvanian, providing clastic materials to the adjacent basins. This tectonic activity also involved vertical movement along the ancient strike slip faults, with some new faulting taking place in the recently deposited early Pennsylvanian rocks (Hills, 1972; Stipp, 1960).

The basal Pennsylvanian rocks, the Morrowan, occupied the smallest area, wedging out northward, and contained the greatest proportion of coarse clastic material of the Pennsylvanian section. Along the edges of the platforms, especially in the eastern basin, strong reef and bank growth also occurred during the beginning of the Pennsylvanian. At the same time, submarine tectonism began in the Guadalupe Mountains area, continuing intermittently through the period, elevating the southeastern part of the area relative to the northeast along the northwest-trending Huapache thrust zone (Hayes, 1964).

Lower Middle Pennsylvanian Atokan strata were deposited over most of the southeastern New Mexico area except for the then-positive Pedernal uplift. During this time, anticlinal folds developed north of the Delaware Basin area on the Northwestern Shelf, and the Central Basin Platform range was uplifted as a fault block and eroded. By Desmoinesian time in upper Middle Pennsylvanian, deposition in the Permian basin region consisted primarily of limestones. The environmental setting consisted of a back-reef (lagoon), reef, and basin or open sea, a situation which persisted from this time through Late Pennsylvanian and much of Permian time (Meyer, 1968).

During most of the Late Pennsylvanian, depositional conditions in the Permian Basin were similar to those of Desmoinesian time. The sea encroached farther than before onto the rising Pedernal landmass, followed by a regression beginning in the northwest. To the northeast, the land was intermittently emergent. And southward, in Texas, the Ouachita-Marathon disturbance folding and uplift was being followed by strong northward thrusting, which continued into early Permian time (Hills, 1963). Ensuing erosion from these areas provided an abundance of clastics to the Late Pennsylvanian deposits. The Central Basin Platform, emergent throughout most of the Pennsylvanian, began to subside and received a sequence of Late Pennsylvanian sediments (Nicholson & Clebsch, 1961). Meanwhile, reef banks continued to form, especially along the northwestern edge of the Delaware Basin.

Toward the close of Pennsylvanian time, tectonic activity had virtually ceased, and mixed continental and marine sediments were deposited in the lower areas, nearly obscuring the irregular sea bottom caused by the earlier tectonism (Hayes, 1964).

At the end of Pennsylvanian time the entire region subsided, and the major features of the Permian Basin became firmly established. The rapidly eroding range of the Central Basin Platform separated the Delaware and Midland Basins which were rimmed to the north by a broad shelf area. By this time, the Delaware and Midland Basins were probably both

topographically and structurally deep; only the northern part of the Midland Basin remained a relatively shallow platform, upon which the Horseshoe Atoll grew (Oriel et al., 1967). The Central Basin Platform and shelf areas were subsiding more slowly than was the Delaware Basin and consequently received a lesser thickness of sediments, which were lithologically distinct from the deeper water deposits of the basin (Nicholson & Clebsch, 1961).

Permian. Through Early Permian Wolfcampian time, sedimentation was continuous in most of the basin areas of southeast New Mexico and west Texas, with shales deposited in the low areas and limestone on the shelves (Hills, 1972). The regression in the northwest which had commenced in the Late Pennsylvanian became pronounced, and the acceleration of the rise of the Pedernal uplift through Early Permian resulted in its denudation well into the Precambrian basement rocks. Southward, the Delaware and Midland Basins and the Val Verde Trough were rapidly sinking, at a rate exceeding that of deposition, a situation which favored shales and other stagnant-water deposits to form there (Oriel et al., 1967). The deepening of these basins, as well as uplift elsewhere, was encouraged by the development of major normal fault zones towards late Wolfcampian time (Meyer, 1968), along the north and west sides of the Diablo Platform, on the southeast side of the Pedernal Uplift, and along the periodically emergent Central Basin Platform, where strong submarine relief was produced. Around the perimeter of the Delaware Basin, the Abo reef developed, along with back-reef lagoons into which muds and carbonates accumulated. Along the south border of the Permian Basin region, the final northward thrusting of the Ouchita-Marathon structural belt occurred, causing Late Pennsylvanian and Early Permian strata to be overridden and a large volume of detritus to pour into the Val Verde trough (Hills, 1963; Oriel, et al, 1967). Following the close of this activity, the rest of Permian time was marked by regional tectonic stability in which depositional basins separated by platform areas passed through maturity.

Through Middle Permian time, restriction of marine circulation, coupled with eustatic withdrawal of the sea in a southwest direction, resulted in the development of high reefs and carbonate banks, behind which evaporites, ranging from dolomites, sulfates, and chlorides to potash minerals, were deposited in highly saline, shallow lagoons (Hills, 1972).

Early in lower Middle Permian Leonardian time, movement on a line along the Delaware Basin margin, the later Bone Spring monoclinal structure, accompanied by continued subsidence of the basin, produced a more definite northwest margin of the basin, the development of which resulted in deposition of a great submarine bank that formed a barrier to free circulation of the sea water. The gray carbonates of the Victorio Peak formation represent patch reefs which built upward and southwards across earlier deposits as the basin margin regressed. Similar carbonate reefs and banks formed along the margins of the Midland Basin as well as on the Central Basin Platform, overlying the old medial mountain range (Hills, 1972). Within the deep basin areas the black limestones and shales of the Bone Spring were deposited, and on the broad back-reef lagoonal shelf north and northeast of the basin, the Yeso gypsum and limestone or dolomite and clastics were laid down. Northwestward, the entire area including the Pedernal was gradually overlapped by sediments, and, by latest Leonardian time, all but a few of the highest Precambrian peaks were buried (Kelley, 1971).

At the end of Leonardian time and into the Guadalupian, pronounced differential movement occurred along the Delaware Basin margin, and a broad, southeastward-dipping fold, the Bone Spring Arch, was elevated, forming a barrier 15 to 20 miles wide between the basin and the Northwestern Shelf area (Hayes, 1964). In a marked regression, the seas withdrew, and were nearly restricted to the Delaware Basin (King, 1942).

As Guadalupian time opened, the arching and limited evaporitic conditions resulted in deposition of clastics in the basins and limestone on the shelf areas (Kelley, 1971; Hayes, 1964).

By the mid-Guadalupian, slight rejuvenation of the Bone Spring arch led to growth of lime-bank deposits upon the arch, which provided the foundation for a barrier reef, the Goat Seep. As the Delaware Basin continued to deepen, the reef grew primarily upwards, in consequence, restricting circulation, thus producing sediment-starved conditions within the basin and leading to the precipitation of calcium sulfate shelfward for a distance of 15 to 25 miles. (Oriel et al., 1967; Hayes, 1964). Eastward, the Midland Basin gradually filled and became favorable for evaporite deposition, in common with the adjacent shelves and Central Basin Platform.

Late Guadalupian time brought gradual subsidence of the shelf and even greater downwarping of the Delaware Basin, while renewed reef growth occurred at great pace around the periphery of the Delaware Basin. The Capitan Limestone began to grow upward and basinward in oblique fashion from the top of the Goat Seep dolomite, resulting in a wide barrier which even at its narrowest point was six times as wide as it was high (Hayes, 1964; Newell et al., 1972). Most investigators consider the Capitan to have been a true barrier reef. Achauer (1969), however, believes that it originated as a linear organic belt, instead, since he finds no coincidence between the topographic and lithologic break produced by it, and Dunham (1972) hypothesizes that the structure represents a marginal mound. In any case, as the structure grew, deposition in the basin proceeded more slowly than on the shelf and did not keep pace with the sinking of the basin, so that by the close of the period, the sea bottom in the Delaware Basin was about 1,500 feet below the adjacent reef and lagoon floor to the northwest. The reefs and banks eventually grew almost continually around the periphery of the Delaware Basin, and by the close of Guadalupian time, access of water to and from the open ocean was sharply restricted. the seas of the shelf area evaporated, and the water of the Delaware Basin itself became highly saline, thus halting the reef growth.

The Delaware Basin was essentially an evaporating pan by the beginning of Late Permian Ochoan time. Many hundreds of feet of Castile evaporites, containing anhydrite and limestone laminae at the bottom and a few beds of

halite, were deposited in the basin, with apparently little in the reef and back-reef areas. By the latest Castile time, the basin had filled such that a thin tongue of anhydrite extended northward across the reef to the shelf. Saline waters then spread from the Delaware Basin over the shelf, the Central Basin Platform and Midland Basin areas, and extensive salt deposition occurred, resulting in the predominantly halite Salado Formation. From this time on, the old Permian Basin structures, notably the Central Basin Platform, became progressively more deeply buried by Late Permian sediments and no longer constituted depositional barriers. Periodically, clastics swept into the area from the north and northwest, increasing towards the end of Salado time, as the Pedernal Landmass underwent renewed uplift. At the same time, the sea freshened somewhat, probably from the south, judging from the presence of more soluble salts northward, in New Mexico. Halite deposition decreased while anhydrite became dominant, along with an increase in carbonate muds during Rustler Formation deposition (Hayes, 1964; Brokaw et al., 1972). Broad epeirogenic uplift at the close of Permian time caused the seas to withdraw, and the continental fine sands and silts of the Dewey Lake Redbeds were deposited in a thin layer on broad mudflats over the former seabed (Brokaw et al., 1972; Kelley, 1971). As terrestrial conditions developed across the New Mexico-west Texas area, erosion became the dominant geologic process.

3.6.4 Mesozoic Rocks

Triassic. During most of Triassic time, the southeast New Mexico area was emergent and subject to erosion, and by late Triassic the entire area, including the Pedernal, must have been reduced to a great peneplain (Kelley, 1971). In Late Triassic time, a broad floodplain basin formed on the site of the Permian Basin over a large area and beyond the borders of the Delaware Basin. This was an interior basin draining toward the northwest into other interior basins (Hills, 1963, Brokaw, et al., 1972). Source areas to the north provided fluvial sands, muds, and gravels to the basin, forming the Dockum Group red beds that included the Santa Rosa Sandstone and finer-grained Chinle Formation.

The nearly conformable relationship which exists between these Upper Triassic strata and the Permian Dewey Lake Redbeds indicates continued regional tectonic stability through Triassic time (Oriel, et al., 1967). It is possible that some dissolution of soluble Permian rocks occurred during the general emergence of Triassic time. Bachman and Johnson (1973) state that during this period, sinkholes may have formed in parts of the Pecos Valley due to removal of salts (Gorman & Robeck, 1946). And Bachman (1974) describes a Late Triassic karst topography in the vicinity of Santa Rosa, New Mexico. However, direct evidence for this Triassic dissolution and collapse has not been found in southeastern New Mexico (Bachman, 1974).

Jurassic. During Jurassic time, the southeast New Mexico area was uplifted above sea level so that the Triassic and perhaps Permian rocks in the western part of the Delaware Basin and westward were eroded away. Some dissolution of Permian salt deposits probably occurred here at this time. The period of exposure, which generally affected the entire Permian Basin, may have been 50 million years; however, the surface relief was probably low, and erosion was not deep. This is the first of three erosional cycles which have incised the Triassic rocks of the area (Nicholson & Clebsch, 1961; Bachman, 1974).

During Jurassic time, continental rocks were laid down to the north, in central and northern New Mexico, derived from the sediments being stripped from the eroding basin area in southeastern New Mexico. South of the basins, in western Texas and northern Mexico, marine conditions prevailed during at least part of the time (Bachman, 1974). By Late Jurassic Entrada and Morrison time, seas again encroached on the north, covering southeast Colorado and northeastern New Mexico. And from the Late Jurassic into the Early Cretaceous, a slight tilt involving uplift took place in the northern part of the former basins region, accompanied by widespread erosional stripping across the area (Hills, 1963; Kelley, 1971).

Cretaceous. By the early part of Cretaceous time, the west Texas-southeast New Mexico area comprised a rolling topography of Triassic rocks with beds from Precambrian to Permian exposed on the uplifts and on

the Diablo Platform. The geography evolved from that of interior basins with highlands in the north and east to a general gulfward slope with highlands in the west and evidence of only slight tectonic activity (Hills, 1963; Kelley, 1971).

During Cretaceous time, a large part of the western interior of North America became submerged beneath epicontinental seas. By late in the Early Cretaceous, the southeast New Mexico area had subsided slightly, and shallow shelf seas advanced over the area from the south and remained until early in Late Cretaceous time, when the seas probably withdrew for the last time, leaving behind a thin deposit of fossiliferous limestone and coarse sandstone and conglomerate (Hayes, 1964; Nicholson & Clebsch, 1961). Isolated slump blocks of limestone and shale in Lea County east of Eunice, in the Pecos River drainage, in the Sacramento and Guadalupe Mountains and perhaps on the crest of the reef escarpment are the only remaining evidence of the sea's advance in the southeast New Mexico area (Hayes, 1964; Bachman, 1973).

There is no record of most of the Late Cretaceous in the area. The land surface was probably slightly above sea level, and the region was dry land by the close of Cretaceous time (Bachman & Johnson, 1973).

3.6.5 Cenozoic

Early Tertiary. The Mesozoic Era came to a close with the Laramide revolution and uplift of the Rocky Mountains. Late in the Cretaceous or very early in the Tertiary Period, the entire region from north of the Guadalupe Mountains through southeast New Mexico was elevated by broad epeirogenic uplift and tilted slightly to the northeast. Mild tectonism affected the Guadalupe area of the Northwestern Shelf, producing small igneous dikes, fold systems, and setting the stage for the ancestral northeast flowing drainage system (Hayes, 1964). Igneous activity also occurred to the northwest in the Sierra Blanca and Capitan Mountains (Bachman, 1974). In general, however, most of the area southwest of the Pedernal Uplift and Matador Arch was not subject to such tectonic forces.

According to Hills (1963), these ancient positive elements formed buttresses which transmitted and distributed the orogenic forces on the east, and this protected the basins on the southeast from folding.

The dominant process in southeast New Mexico from Late Cretaceous until Late Tertiary, notwithstanding the minor tectonism, was erosion. No Early or Middle Tertiary rocks are represented in the Permian Basin. The Cretaceous and Triassic rocks of the area underwent intense erosion to form a surface of low relief, sloping gently east and southeast (Bachman, 1974; Brokaw, et al., 1972). In the Lea County area of southeast New Mexico, the entire sequence of Cretaceous rocks, particularly to the west, was stripped off, except for small remnants, and the Triassic rocks were subjected to a second cycle of erosion (Nicholson & Clebsch, 1961). By Late Tertiary Miocene time, erosion had again exposed the Permian rocks to dissolution, notably in the vicinity of San Simon Swale (Bachman, 1974).

Late Tertiary (Miocene-Pliocene). In Late Tertiary time, regional uplift and east-to-southeastward tilting occurred throughout southeastern New Mexico into Texas, as Basin and Range tectonic activity commenced to the west, producing the western escarpments of the Delaware, Guadalupe, and Sacramento Mountains. The western section of the Permian evaporites was elevated, and exposed to dissolution and subsidence, particularly in the vicinity of the Pecos River divide, which created new patterns of groundwater movement (Bachman, 1973; Mercer & Orr, 1977). Erosional forces carved a pediment-like surface, down which streams flowing eastward from the Rocky Mountains deposited an extensive blanket of gravel, sand, and related deposits in coalescing fans, which comprise the Ogallala Formation. Deposition of the Ogallala began about 12 million years ago, in Miocene time. The Ogallala represents the first preserved sedimentary record in the vicinity of the Delaware Basin since Cretaceous deposition (Bachman, 1974). The Ogallala formed a thick mantle throughout the Permian Basin, producing the even surface of the High Plains, called the Llano Estacado in western Texas and eastern New Mexico. Locally, eolian activity played a part in deposition, and periodically, widespread soils formed (Frye, 1970).

Ogallala deposition ended about 4 million years ago, in Pliocene time, with regional warping and uplift. Eolian activity reworked the sediments, producing a widespread soil profile across the Great Plains. A caliche zone formed within the soil complex and constitutes the carbonate "caprock" of today (Mercer & Orr, 1977; Bachman & Johnson, 1973). The caliche caprock has since undergone a complex history of brecciation, solution, and recementation (Bachman, 1973).

Pleistocene-Holocene. During the Late Pliocene and Early Pleistocene, the major part of the faulting and uplift of the Guadalupe Mountains occurred (Hayes, 1964). Concurrently to the east, fields of great longitudinal dunes formed atop the Ogallala surface of the southern Great Plains as a result of desert conditions with westerly to northwesterly prevailing winds. Since this time, erosion has exceeded deposition in the Permian salt basin area. Etching and thinning of the caliche caprock between the dunes created series of parallel swales. Erosion and coalescence of subsided areas removed Ogallala sediments, and in places also eroded the Triassic rocks a third time and entrenched the Pecos and San Simon drainages (Nicholson Clebsch, 1961; Mercer & Orr, 1977). Also during early to Middle Pleistocene time, Nash Draw, Clayton Basin, and probably San Simon Swale underwent extensive subsidence and partial filling (Bachman, 1973). Local sink holes and other solution features began to form at this time.

The most humid climate and the greatest erosion occurred during the Middle Pleistocene. The western escarpment of the High Plains underwent severe erosion, followed by a period of aggradation in the valley areas, during which the mostly locally-derived pebbles and other coarse debris of the Gatuna Formation filled the depressions and mantled the slopes (Brokaw, et al., 1972). During this time of heavy precipitation and stream flow, major salt dissolution is assumed to have occurred within the Delaware basin (Bachman, 1974). After Gatuna time, but still during the Middle Pleistocene, the region became more stable and semi-arid, and the Mescalero caliche formed on the ground surface.

During the Late Pleistocene, there were intermittent episodes of caliche formation and renewed periods of high rainfall accompanied by erosion and salt dissolution, which produced local subsidence and deposition of fluvial and lacustrine sediments.

From Late Pleistocene through Holocene time, the climate has remained variable although becoming more arid. The detrital materials have been reworked by winds from the west and southwest, giving rise to the vast deposits of dune sand that now cover large parts of southeast New Mexico east of the Pecos River (Nicholson & Clebsch, 1961; Bachman, 1973). Some slight uplift is also probably still occurring along the western escarpments of the Basin and Range structures, such as the Guadalupe Mountains. Renewed periodic downcutting by streams and subsurface solution with resultant subsidence, have continued to the present, accompanied by intermittant local accumulations of pediment and terrace alluvium and playa deposits. Most of the recent erosion has been confined to the Pecos Valley, and solution and subsidence have occurred at a slower rate than during the earlier Pleistocene time (Bachman, 1973).

3.7 SUMMARY

The regional geology of SENM is the source of much information germane to long-term safety; knowledge of the regional geology also permits preliminary site selection and general evaluation of the consistency of site geology with regional geology.

The regional geology and geological history may first be divided into three major intervals of about .5 billion years each. This period from about 1.5 to 1.0 billion years ago is represented by metamorphosed rocks of various sedimentary to igneous origins. The time from about 1.0 to .5 billion years ago is not known to be represented by rocks through most of the region; erosion is assumed to be the dominant geological process during this time. The last interval, from about .5 billion years ago to the present, shows more complexity in the rock record. From about 500 to

100 million years ago, SENM shows a rock record of mostly marine sediments deposited in a basin that became shallower as time passed. About 225 million years ago the marine environment became quite restricted, resulting in deposition of about 4000 feet of evaporites in which it is proposed to dispose of radioactive waste. The lack of rock record in much of the region from about 100 million years to about 4 million years ago imply that erosion has been dominant. Fluvial sediments and caliche developed within the last 4 million years suggest some change in base level but considerable stability.

The list of important structural events in the region include metamonolusm and relative uplift during the Precambrian, downwarping through much of the Paleozoic, some downwarping and uplift during the Mesozoic, and some uplift during the Cenozoic. Specific structural features include basin and range type faulting more than 70 miles west of the site and about 10 eastward tilting of the Delaware Basin; both of these features are believed to be about mid-Cenozoic in age. The Central Basin Platform to the east of the site has probably not been active since the Permian (see also Chapter 5).

Thus the regional geology furnishes evidence of tectonic and geologic stability that will be used for assessing the safety of a repository at the WIPP site.

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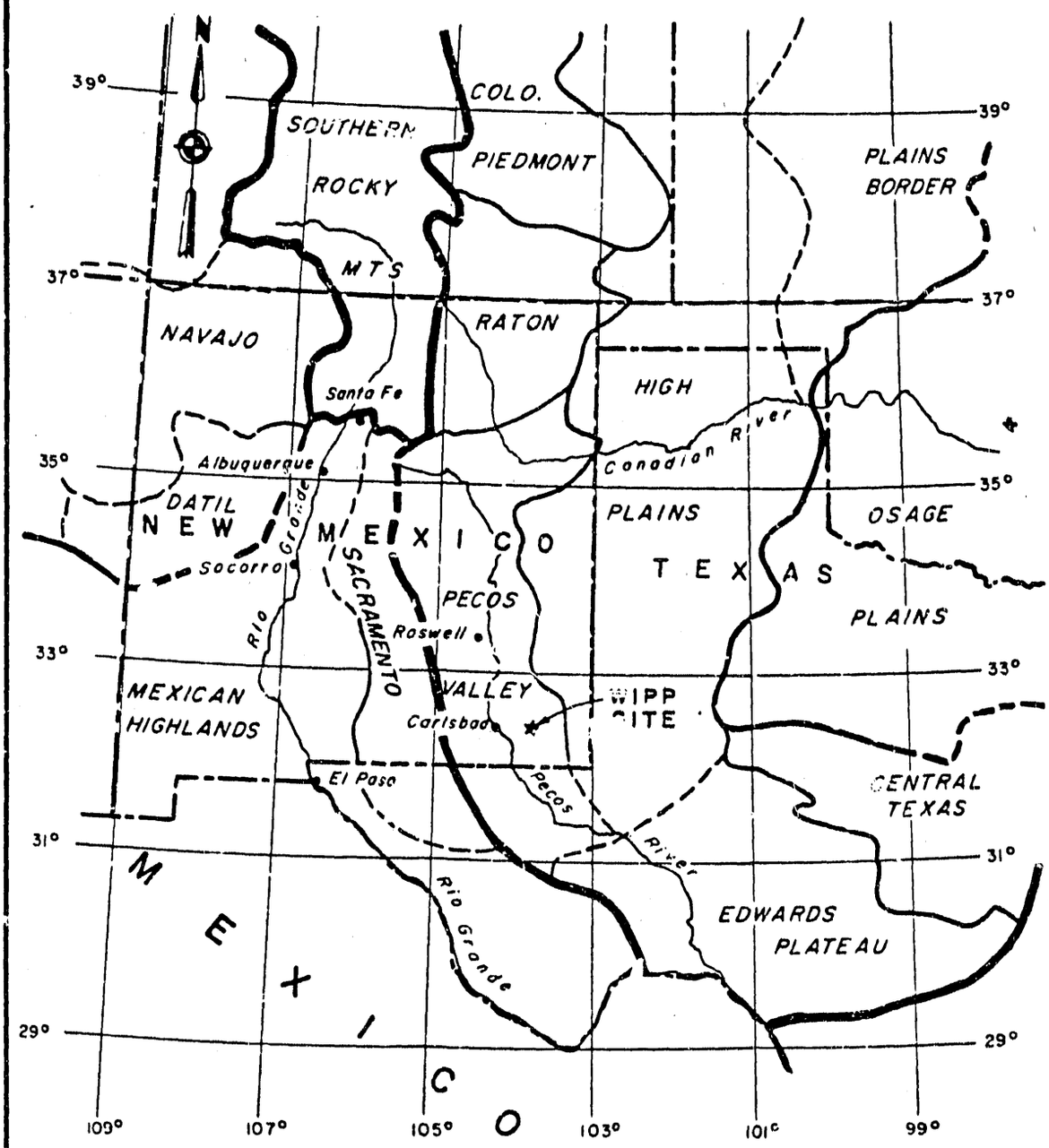


EXPLANATION

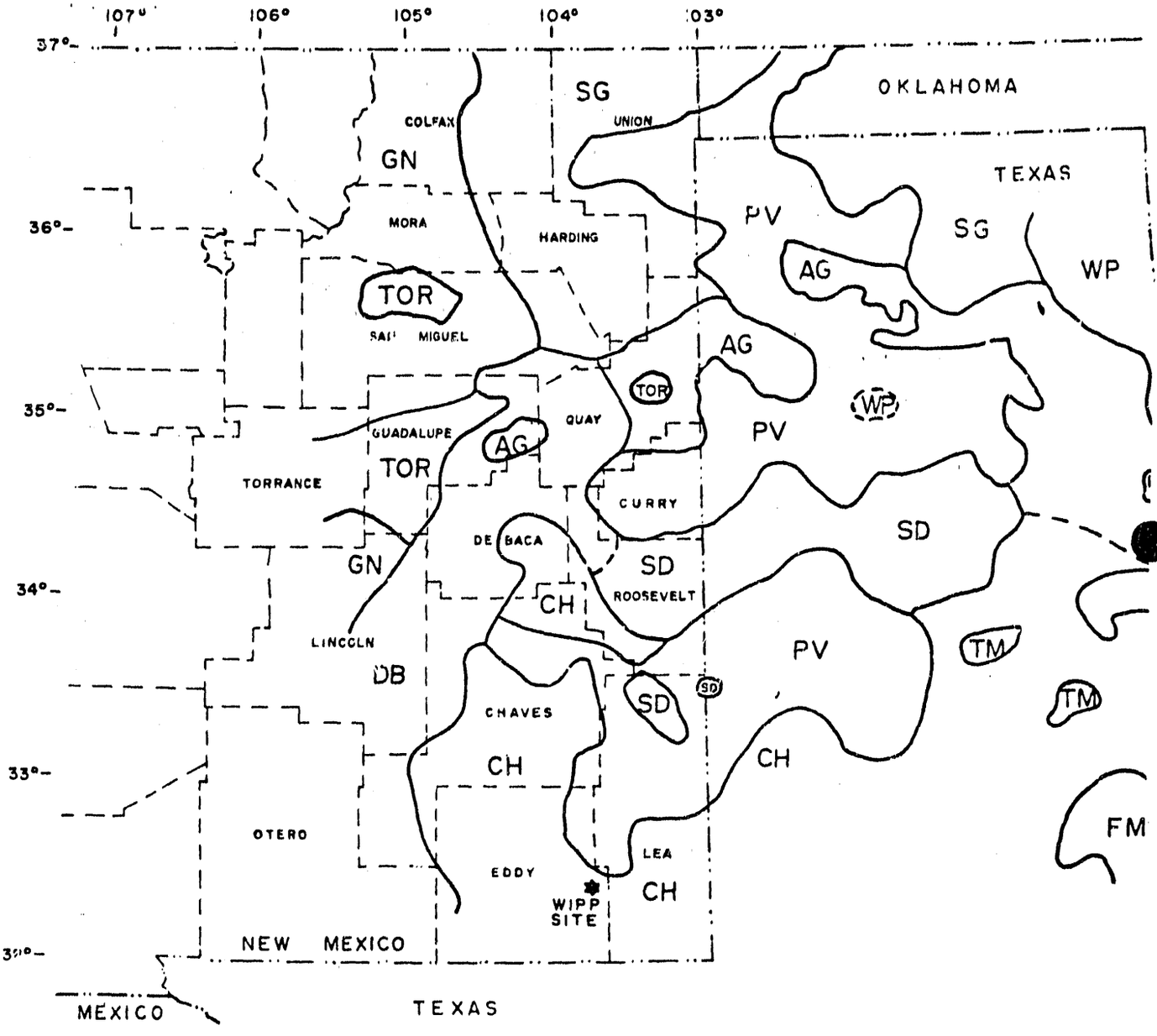
- Boundary of major physiographic division
- Boundary of physiographic province
- Boundary of physiographic section

PHYSIOGRAPHIC SECTIONS

REFERENCE:

Fenneman, N.M., and D.W. Johnson, 1946.

FIGURE 3.2 1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COLFAX
UNION
OKLAHOMA
TEXAS
GN
SG
MORA
HARDING
PV
SG
AG
WP
TOR
SAN MIGUEL
AG
TOR
WP
QUAY
GUADALUPE
AG
PV
TOR
TORRANCE
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ROOSEVELT
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LINCOLN
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NEW MEXICO
MEXICO
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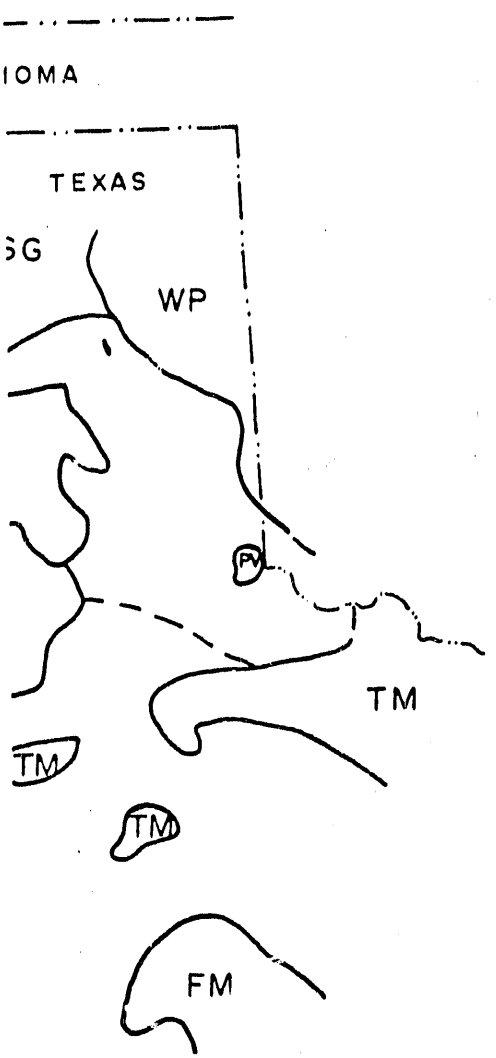


EXPLANATION

CH: Chaves granitic terrane

PV: Panhandle volcanic terrane

SD: Swisher diabasic terrane

DB: De Baca terrane

TM: Tillman metasedimentary group

GN: Older gneiss and granite

AG: Amarillo granite terrane

TOR: Older metasedimentary and meta-igneous rocks

SG: Sierra Grande granite terrane

WP: Cambrian igneous rocks: Wichita Province

FM: Fisher metasedimentary terrane

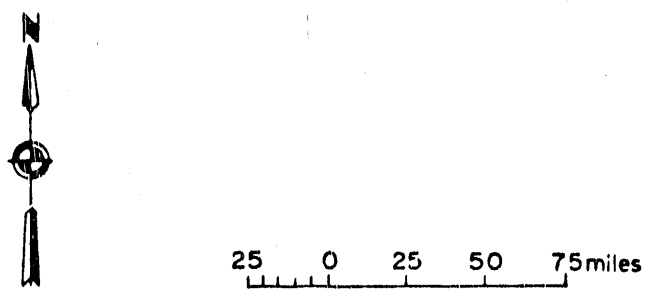
_ _ _ _ County boundary

—·—·— State boundary

—··—··— International boundary

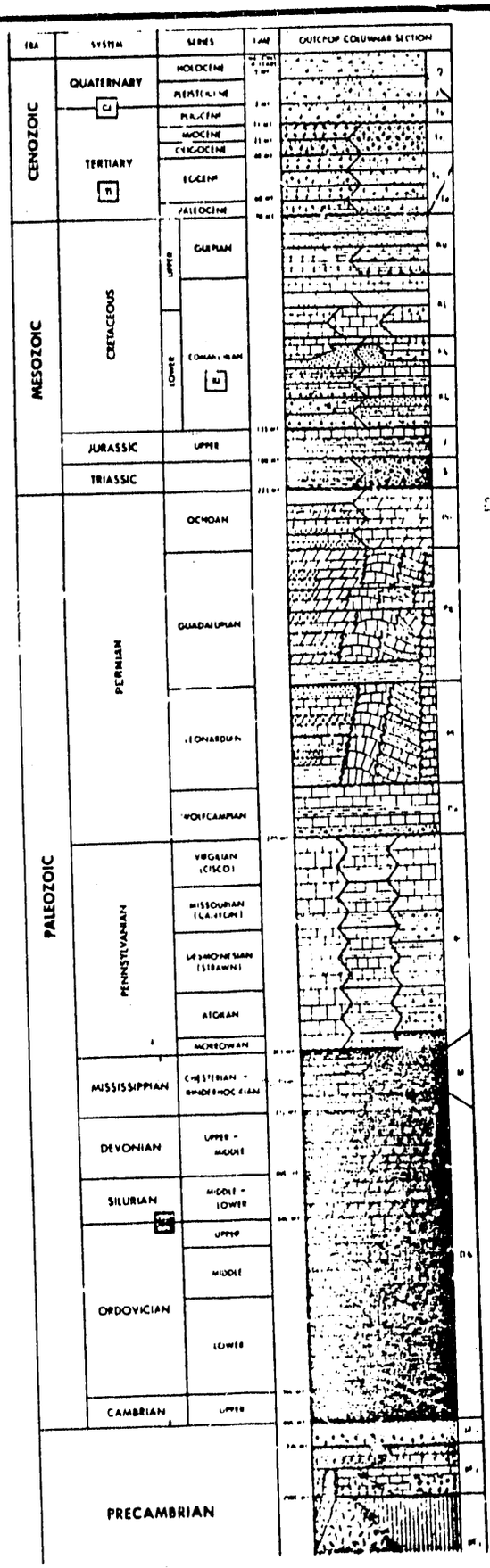
REFERENCE:

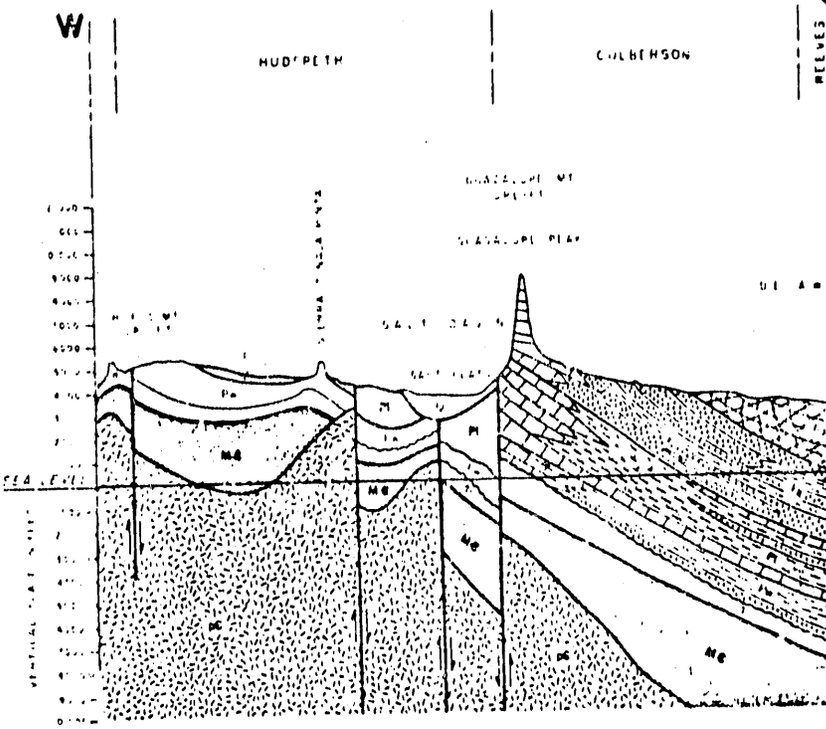
Muehlberger, et al. (1967)

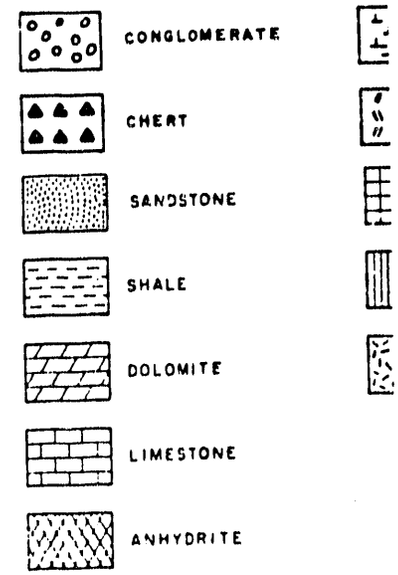


PRECAMBRIAN ROCKS OF TEXAS PANHANDLE AND EASTERN NEW MEXICO

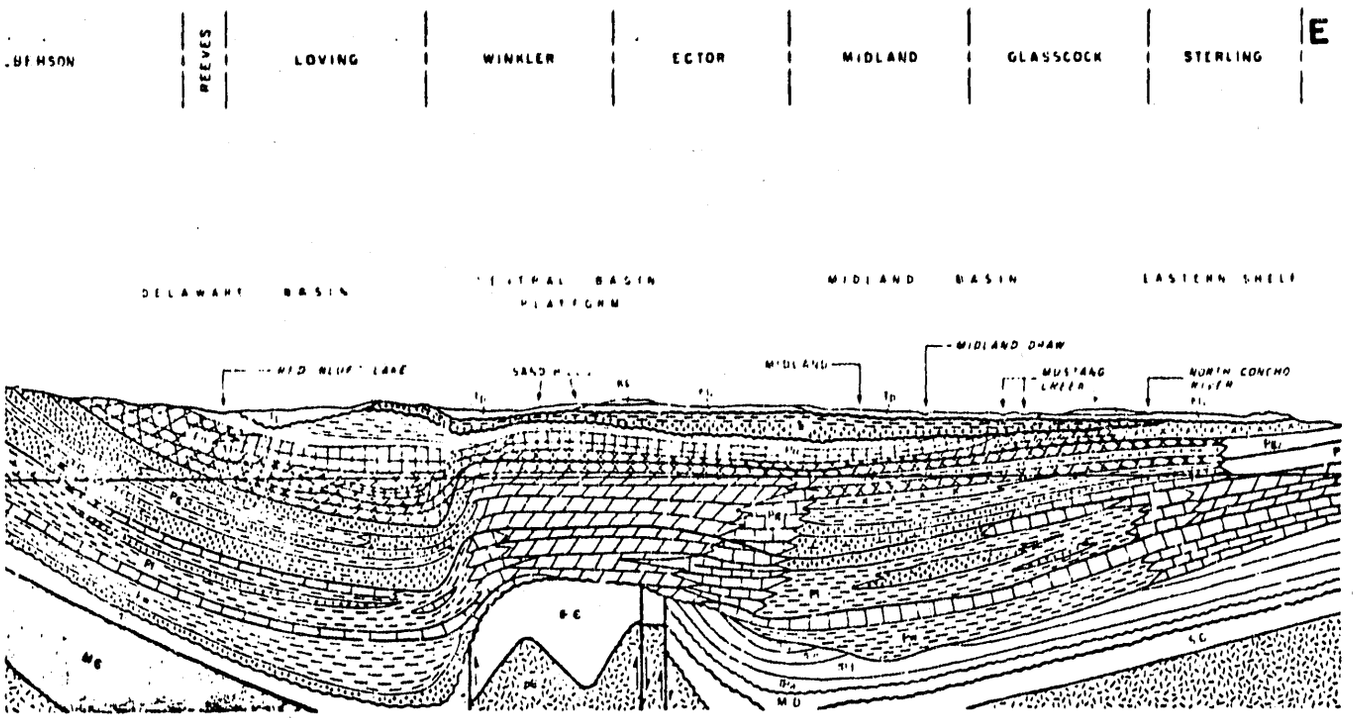
FIGURE 3.3-1

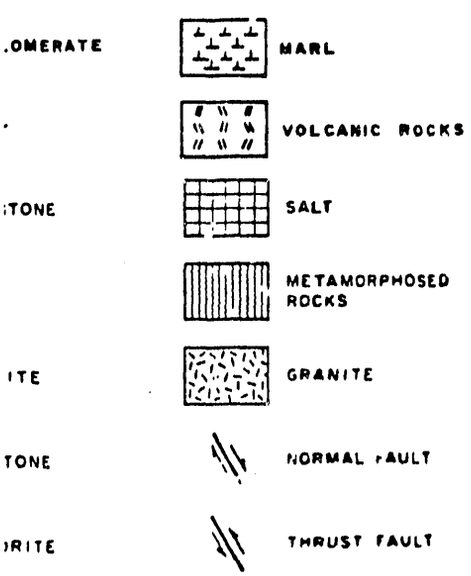






REFERENCE: From Geological Highway

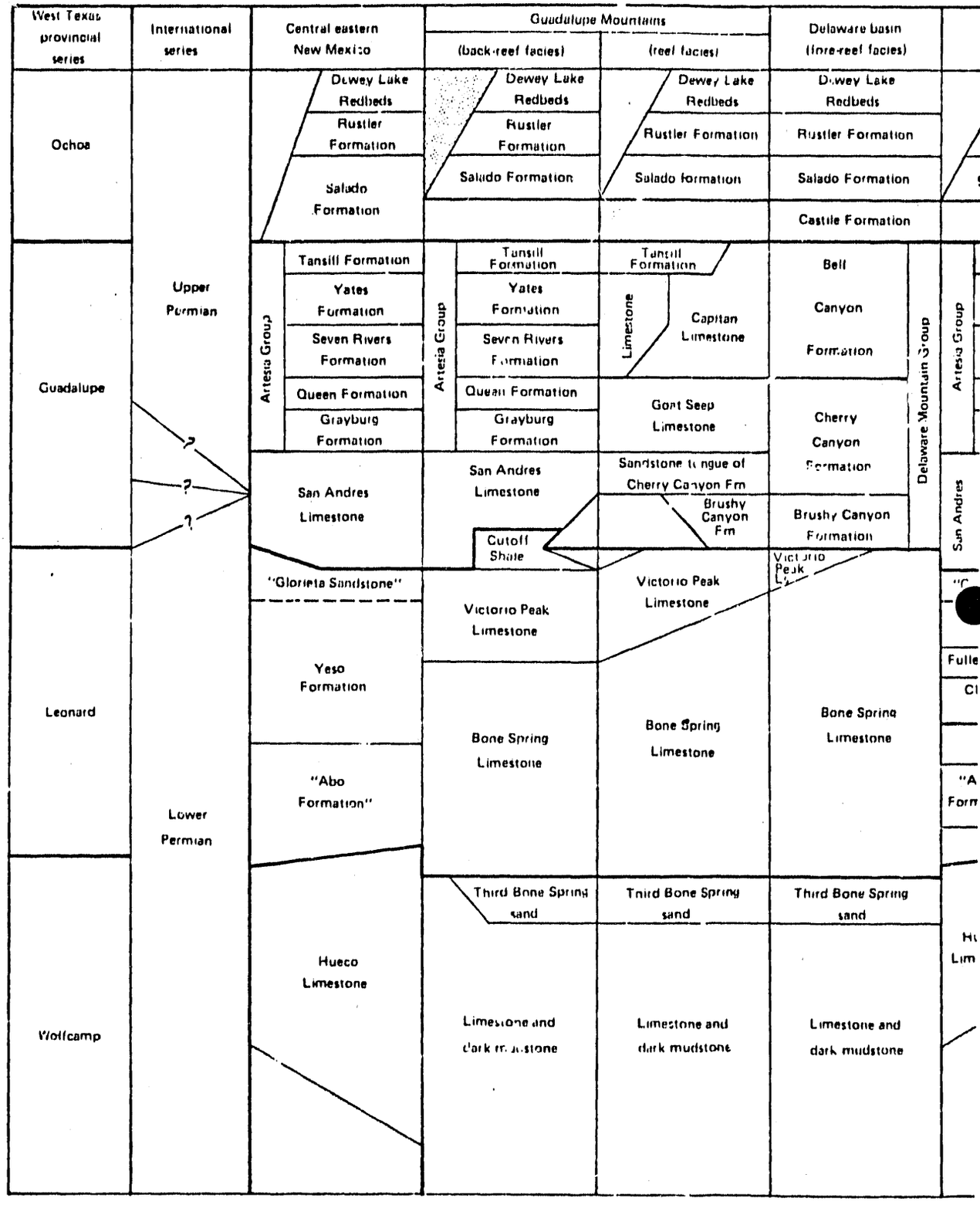


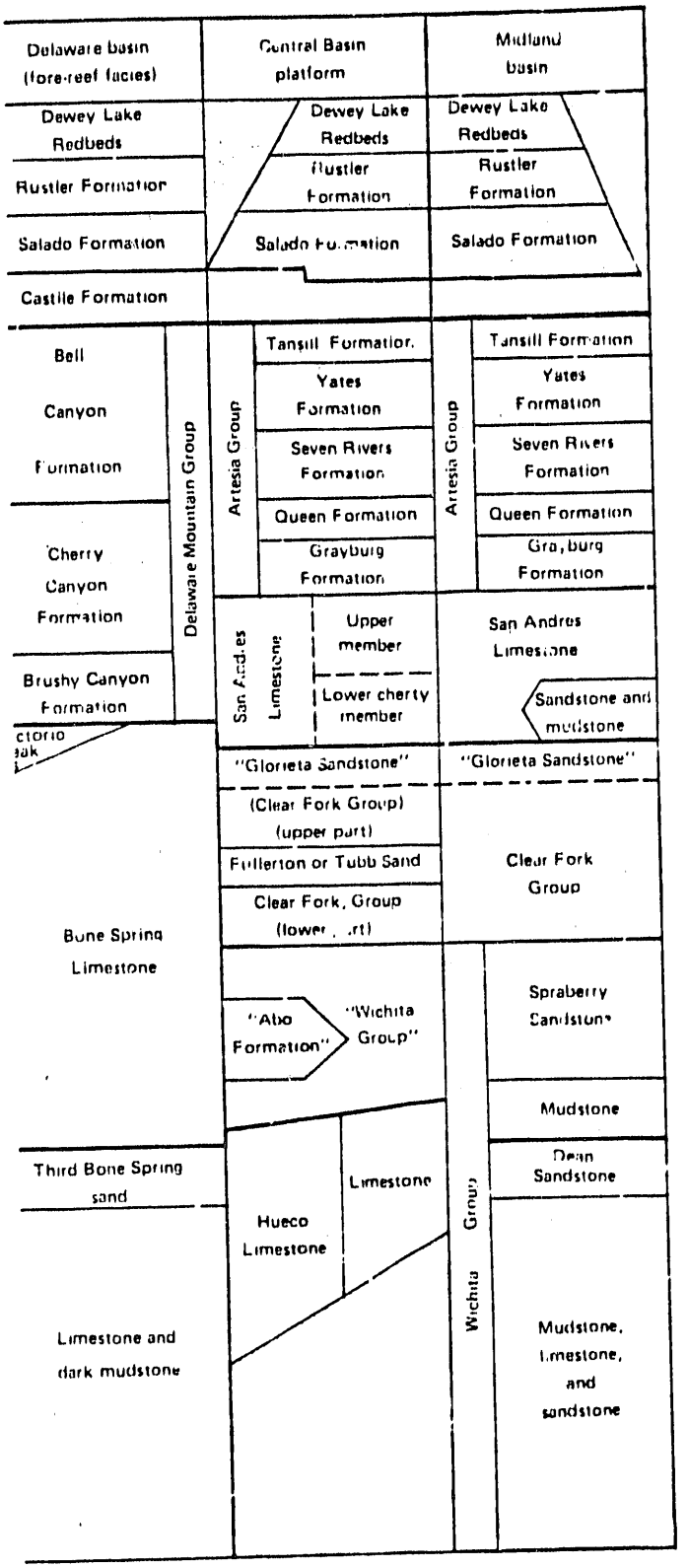


WEST–EAST CROSS SECTION
NEW MEXICO – TEXAS BORDER

FIGURE 3.3-2

Highway Map of Texas, 1973


West Texas provincial series
International series
Central eastern New Mexico
Guadalupe Mountains
(back-reef facies)
(reef facies)
Delaware basin (fore-reef facies)
Ochoa
Guadalupe
Leonard
Wolfcamp
Upper Permian
Lower Permian
Dewey Lake Redbeds
Rustler Formation
Salado Formation
Castile Formation
Tansill Formation
Yates Formation
Seven Rivers Formation
Queen Formation
Grayburg Formation
Artesia Group
San Andres Limestone
Cutoff Shale
Capitan Limestone
Goat Seep Limestone
Sandstone tongue of Cherry Canyon Fm
Brushy Canyon Fm
Bell Canyon Formation
Cherry Canyon Formation
Brushy Canyon Formation
Delaware Mountain Group
"Glorieta Sandstone"
Yeso Formation
"Abo Formation"
Victorio Peak Limestone
Bone Spring Limestone
Third Bone Spring sand
Hueco Limestone
Limestone and dark mudstone



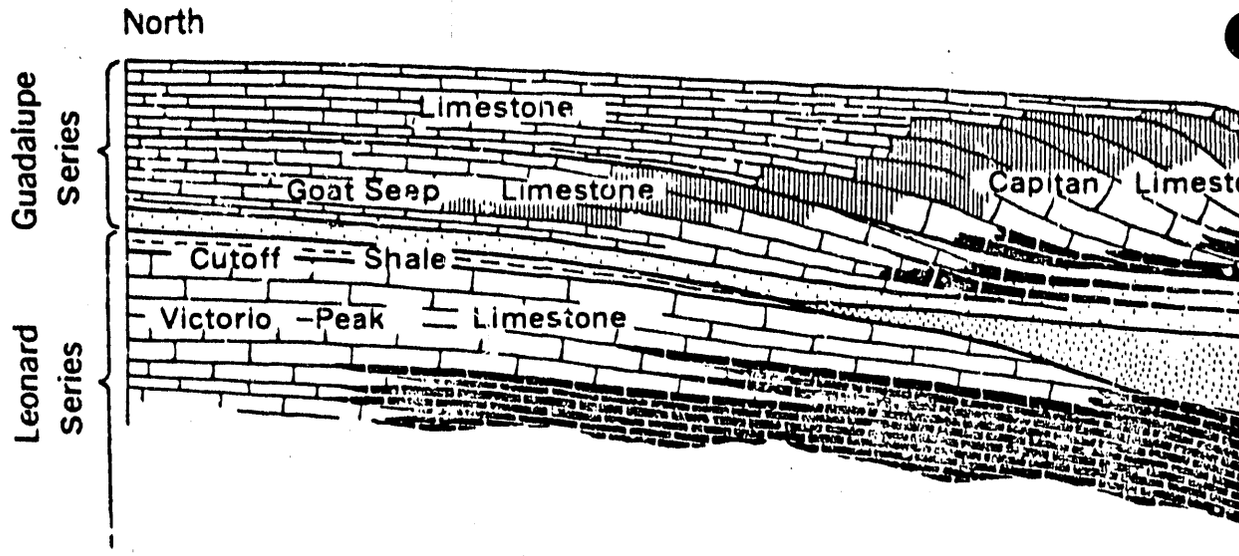
REFERENCE:

U.S.G.S. Prof. Paper 515, Table 1, 1967.

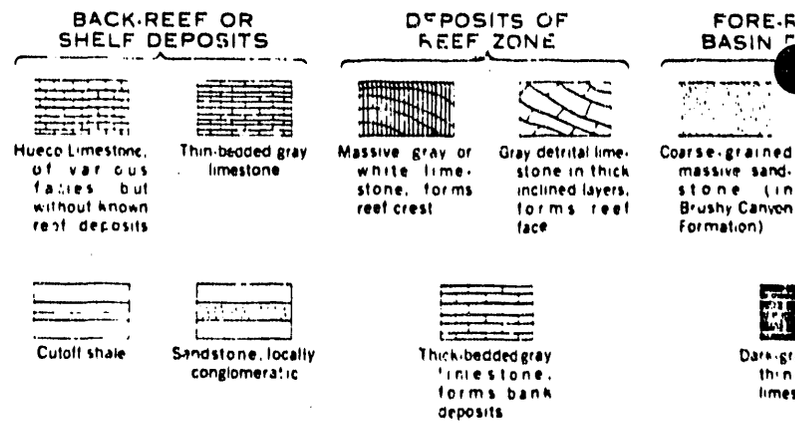
MISSING SECTION

STRATIGRAPHIC CORRELATIONS
PERMIAN SYSTEM
SOUTHEAST NEW MEXICO

FIGURE 3.3-3



EXPLANATION

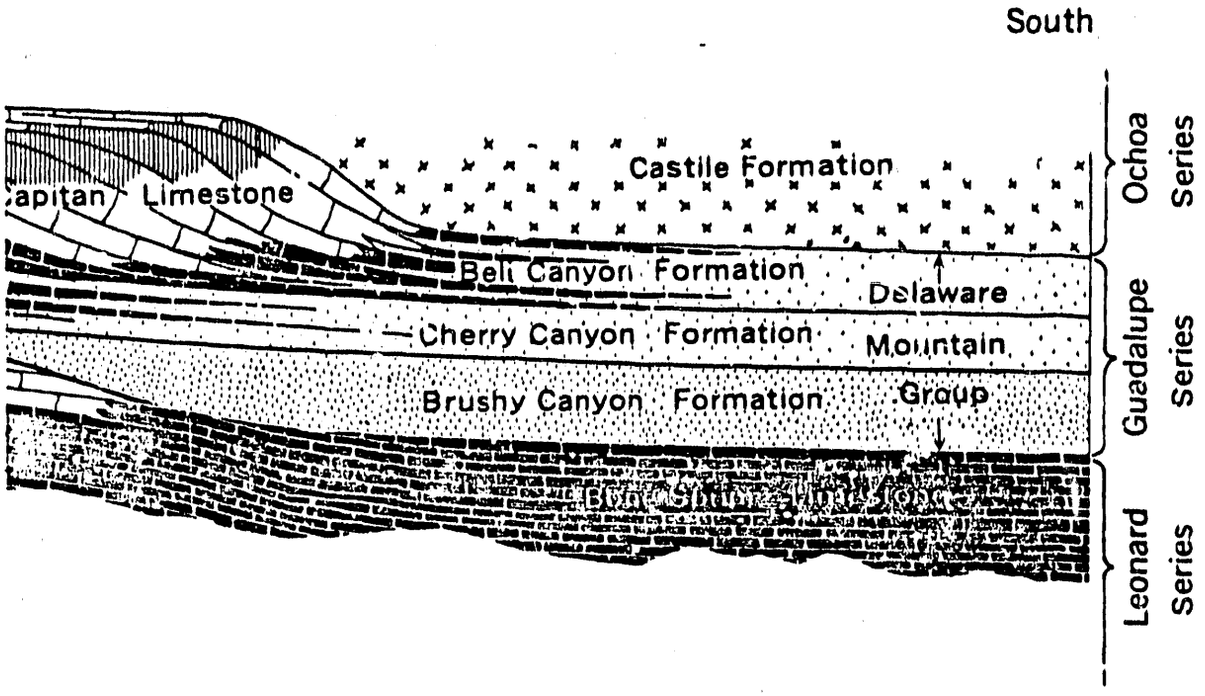


Stratigraphic sumniary of the Guadalupe, L series of the Permian System in the Southern Delaware basin area is to the right and the s to the left. Rock facies are greatly generalize

REFERENCE:

Adapted from E.D. McKee, et al. (1967). (Originally compiled from P.B. King (1942, 1948;

3-117



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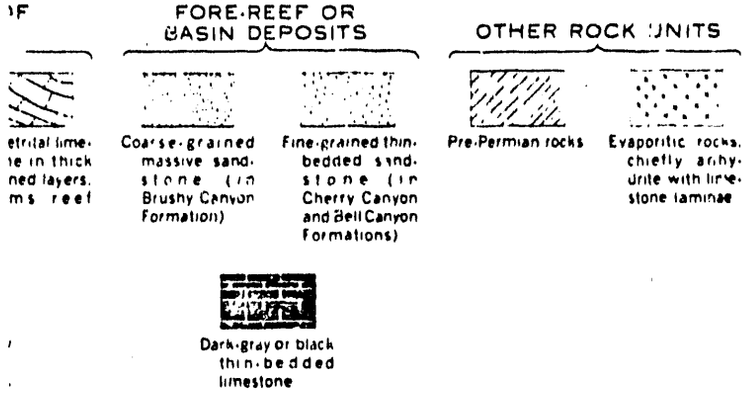

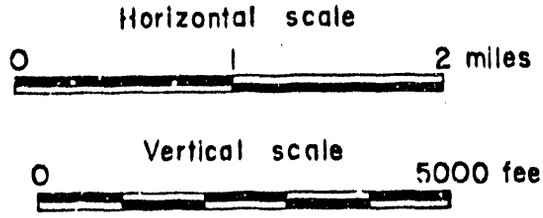

Guadalupe, Leonard, and adjacent
n the Southern Guadalupe Mountains. The
right and the shelf or platform area is to
eatly generalized.

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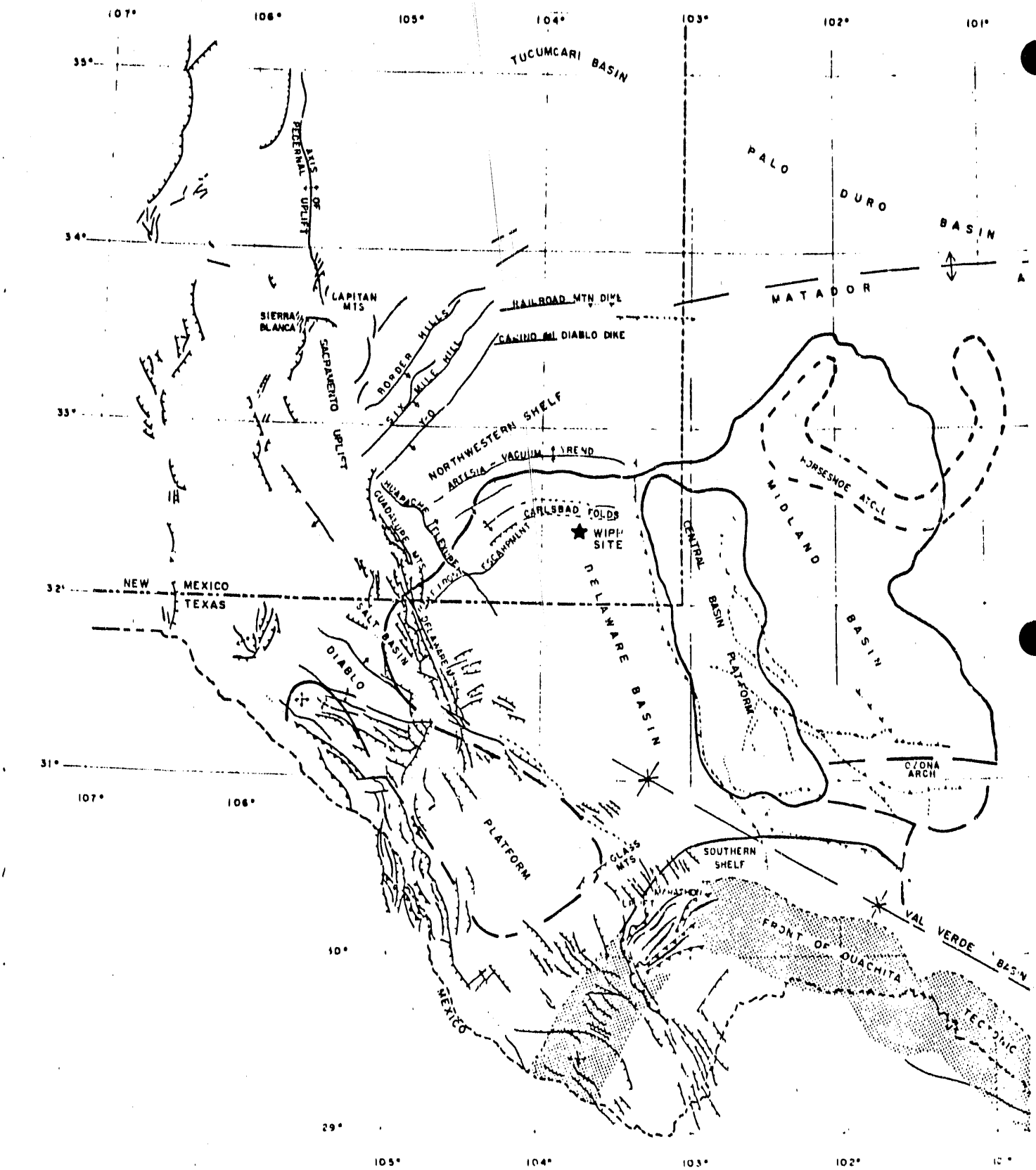
ıg (1942, 1948)).

CROSS SECTION OF
CAPITAN REEF AREA

FIGURE 3.3-4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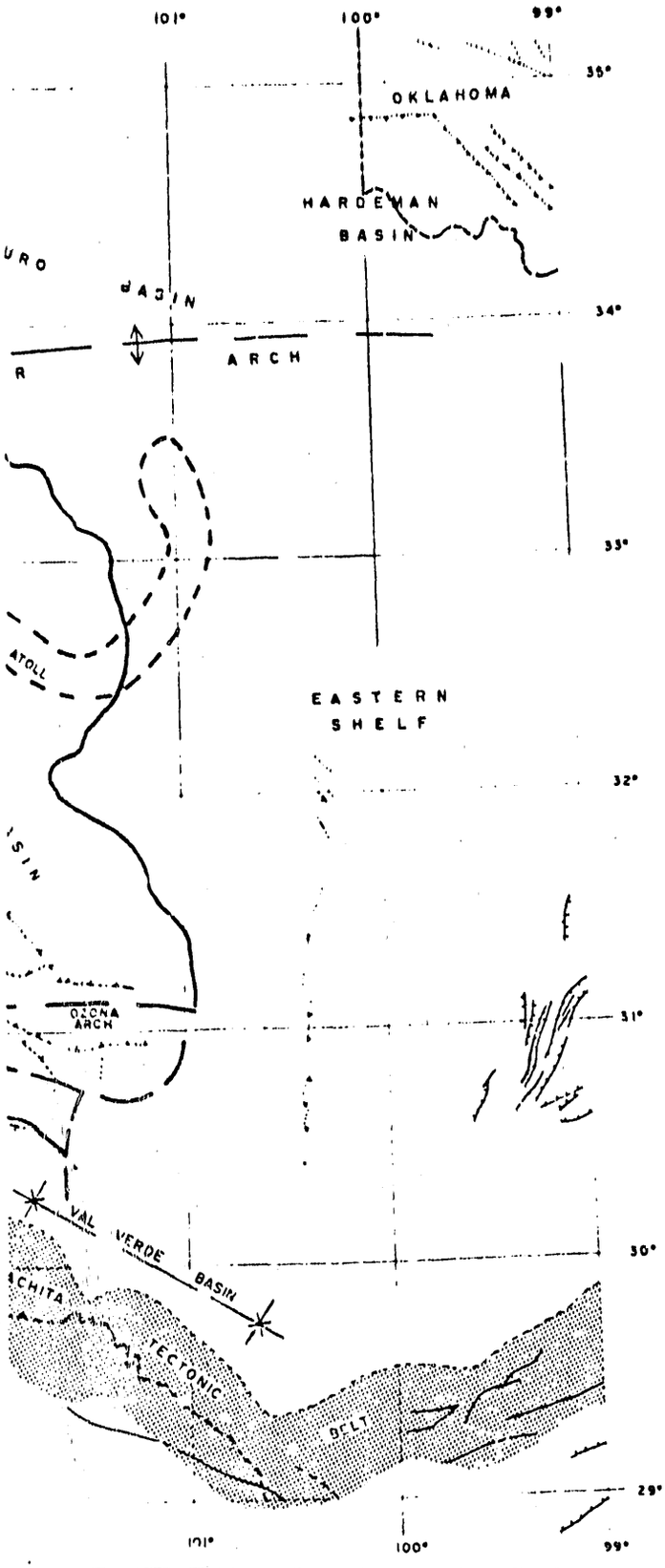
TUCUMCARI BASIN
PALO DURO BASIN
MATADOR
AXIS OF PEDERNAL UPLIFT
LAPITAN MTS
SIERRA BLANCA
SACRAMENTO UPLIFT
RORDER HILLS
SIX MILE HILL
RAILROAD MTN DIKE
CANINO del DIABLO DIKE
NORTHWESTERN SHELF
ARTESIA – VACUUM TREND
HUAPACHE
GUADALUPE MTS
CARLSBAD FOLDS
ESCAMPHLINT
WIPP SITE
NEW MEXICO
TEXAS
SALT BASIN
DIABLO
DELAWARE MTS
DELAWARE BASIN
CENTRAL BASIN PLATFORM
MIDLAND BASIN
HORSESHOE ATOLL
OZONA ARCH
PLATFORM
GLASS MTS
SOUTHERN SHELF
MARATHON
VAL VERDE BASIN
FRONT OF OUACHITA TECTONIC
MEXICO

3-118



EXPLANATION

Fault, type unspecified; dashed where inferred, dotted where concealed.

Thrust fault, saw teeth on upthrown side, dashed where inferred, dotted where concealed.

Normal fault; hachures on downthrown side, dashed where inferred, dotted where concealed.

Elongate, closely compressed anticline; width suggests height, steepness or size of fold.

Axis of major anticline.

Axis of major syncline.

Dome.

Boundaries of major structural elements. (From Steven S. Oriel, et al., 1967)

Ouachita Tectonic Belt.

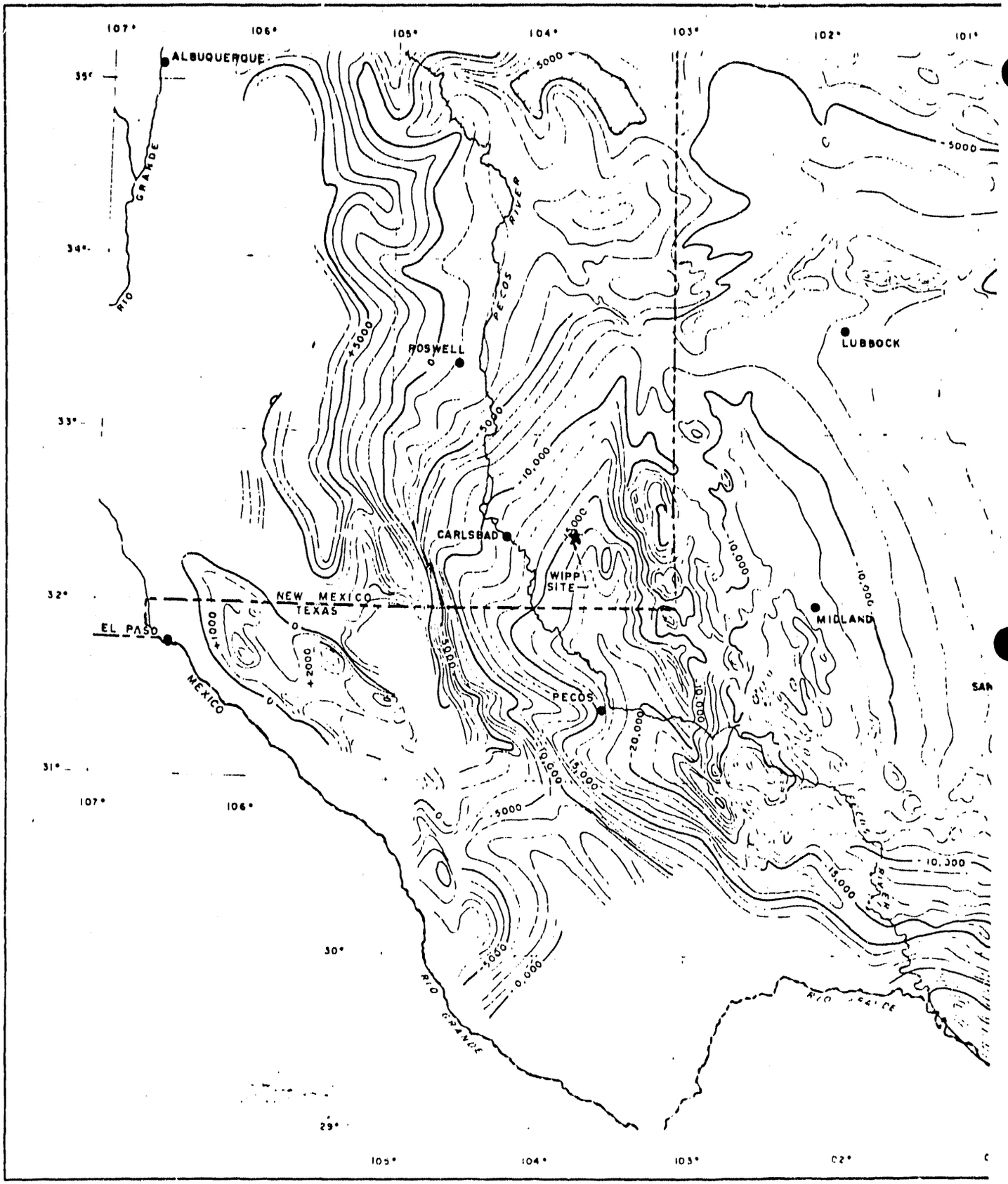
REFERENCES:

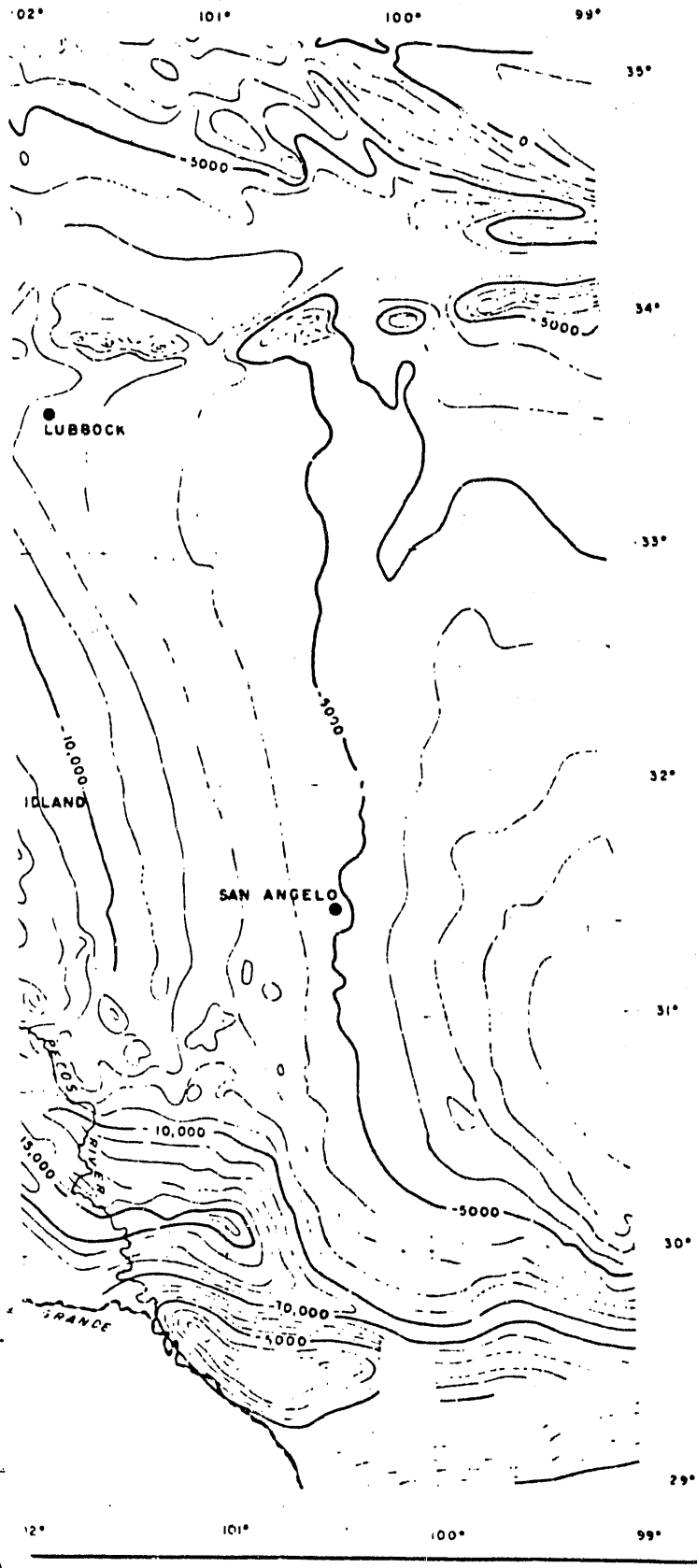
1. Cohee, G.V., et al, 1962
2. Kelley, V. C., 1971.
3. Claiborne, H.C., and F. Gera, 1974.
4. Oriel, S. S., et al., 1967.

0 50 100 150 KM
0 25 50 75 100 MI
SCALE

MAJOR REGIONAL STRUCTURES

FIGURE 3.4-1


ALBUQUERQUE
ROSWELL
CARLSBAD
WIPP SITE
LUBBOCK
MIDLAND
EL PASO
PECOS
NEW MEXICO
TEXAS
MEXICO
RIO GRANDE
PECOS RIVER
107°
106°
105°
104°
103°
102°
101°
35°
34°
33°
32°
31°
30°
29°
5000
10,000
15,000
20,000

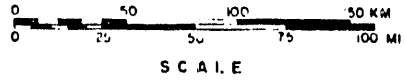


EXPLANATION

-1300- Structure contours, in feet, at top of Precambrian section. Contour interval is 1000 feet, datum is sea level.

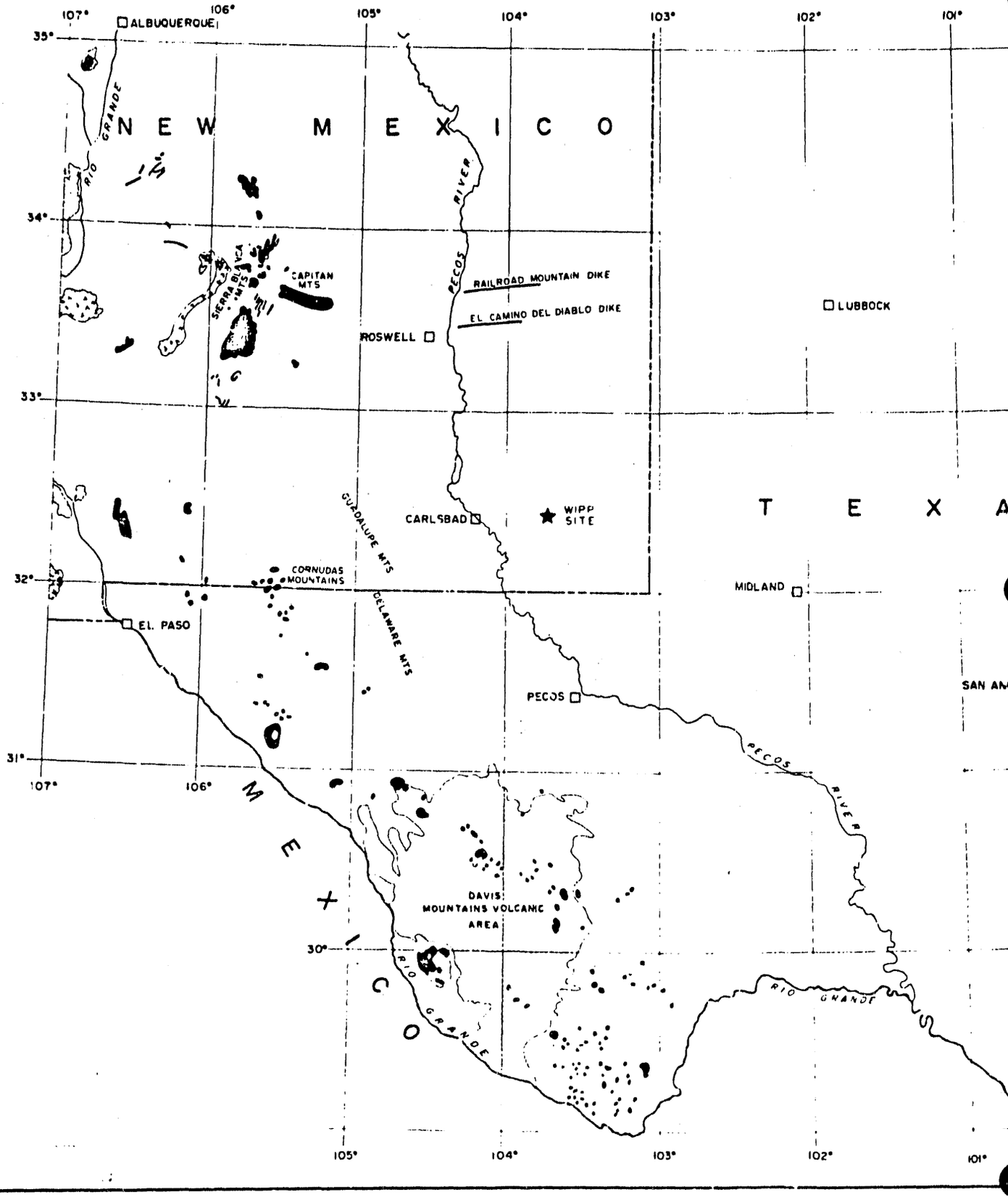
REFERENCE:

Cohee, G. V, et al, 1962

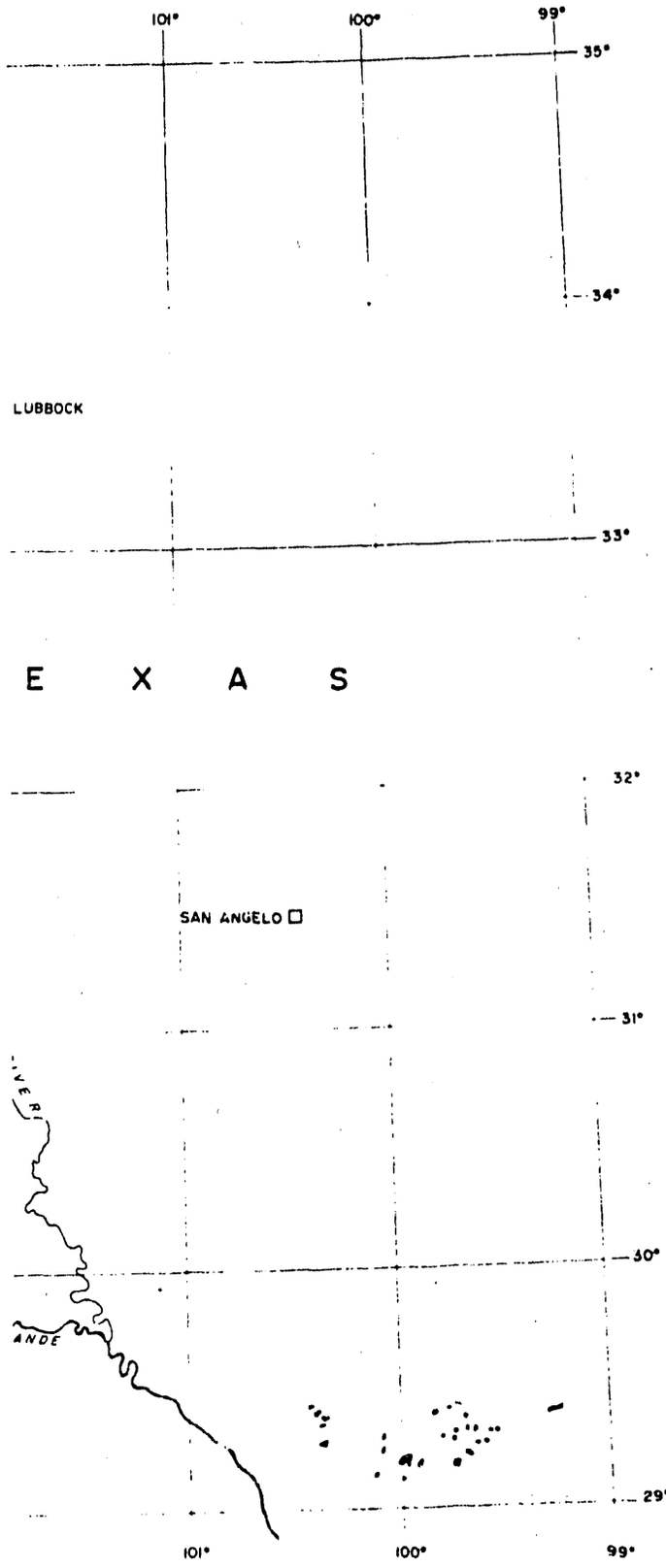


STRUCTURE CONTOURS
ON TOP OF PRECAMBRIAN ROCKS

FIGURE 3.4-2


107°
106°
105°
104°
103°
102°
101°
35°
34°
33°
32°
31°
ALBUQUERQUE
NEW MEXICO
RIO GRANDE
PECOS RIVER
CAPITAN MTS
SIERRA BLANCA MTS
RAILROAD MOUNTAIN DIKE
EL CAMINO DEL DIABLO DIKE
ROSWELL
LUBBOCK
CARLSBAD
WIPP SITE
GUADALUPE MTS
DELAWARE MTS
CORNUDAS MOUNTAINS
EL PASO
MIDLAND
PECOS
TEXAS
SAN ANG
MEXICO
DAVIS MOUNTAINS VOLCANIC AREA
RIO GRANDE

3-120



EXPLANATION

INTRUSIVE IGNEOUS ROCKS

Tertiary intrusive bodies; dikes, plugs, stocks, laccoliths

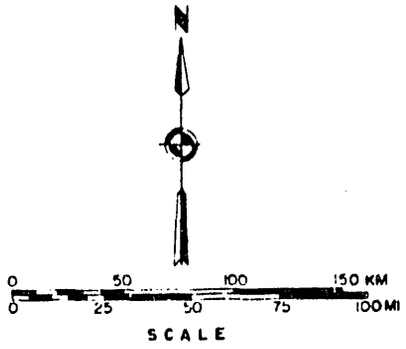
VOLCANIC ROCKS AND FEATURES

Volcanoes and volcanic cones of Quaternary and Late Tertiary age

Tertiary and Quaternary volcanic rocks Only larger areas or areas of tectonic significance are shown Mainly of various Tertiary ages Volcanic rocks of Quaternary distinguished in places by v pattern

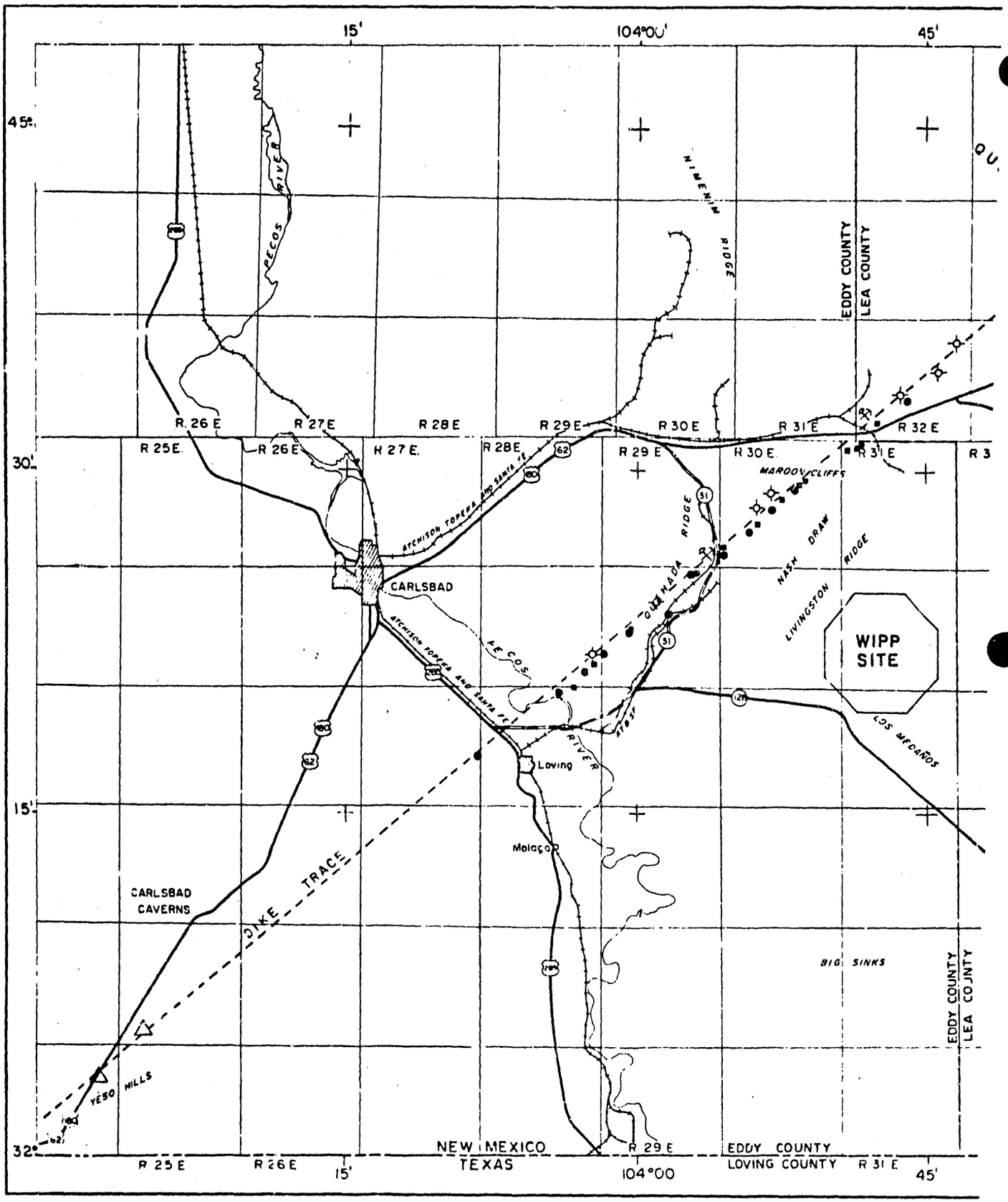
REFERENCE

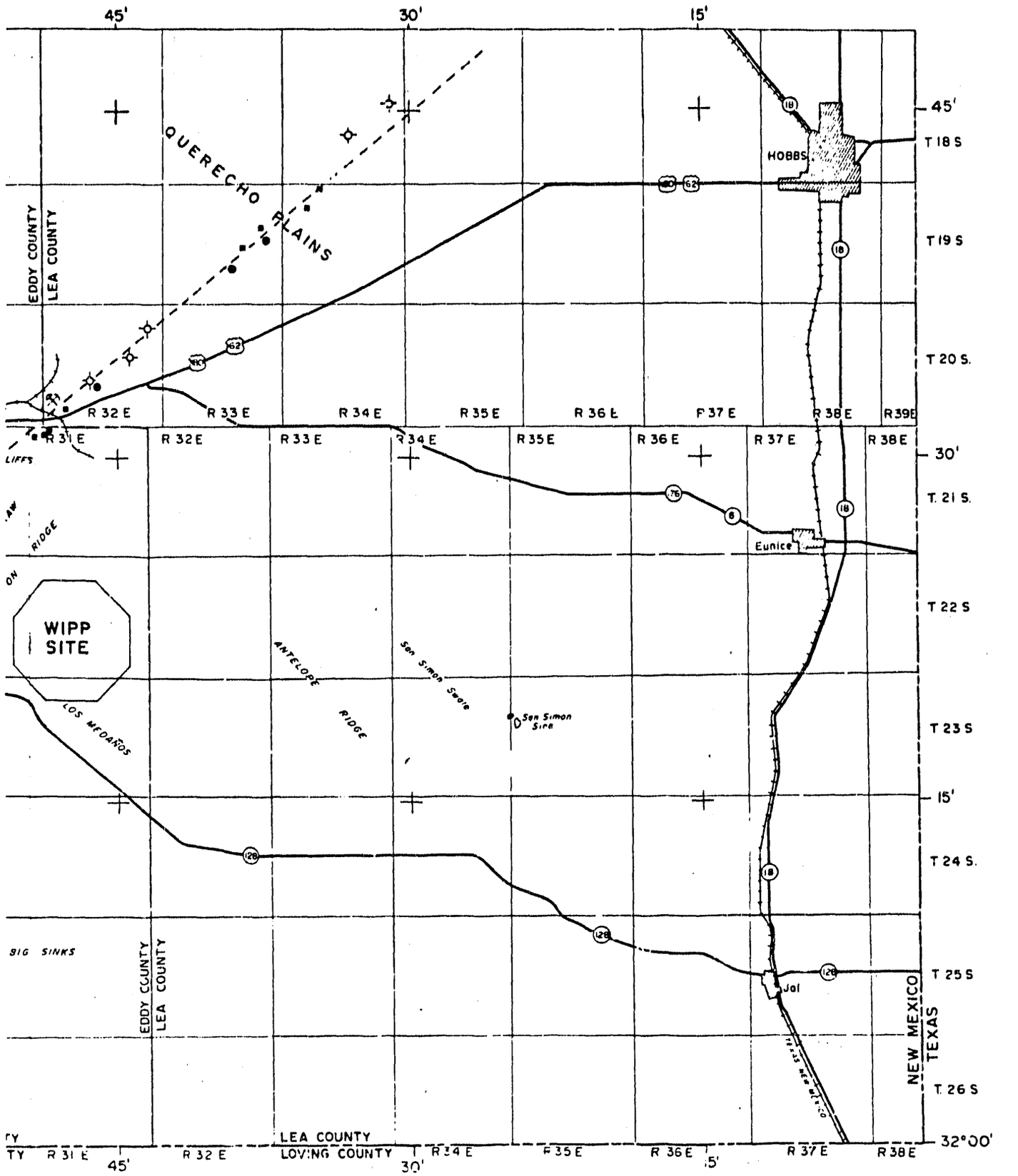
Cohee, G V, et al., 1962

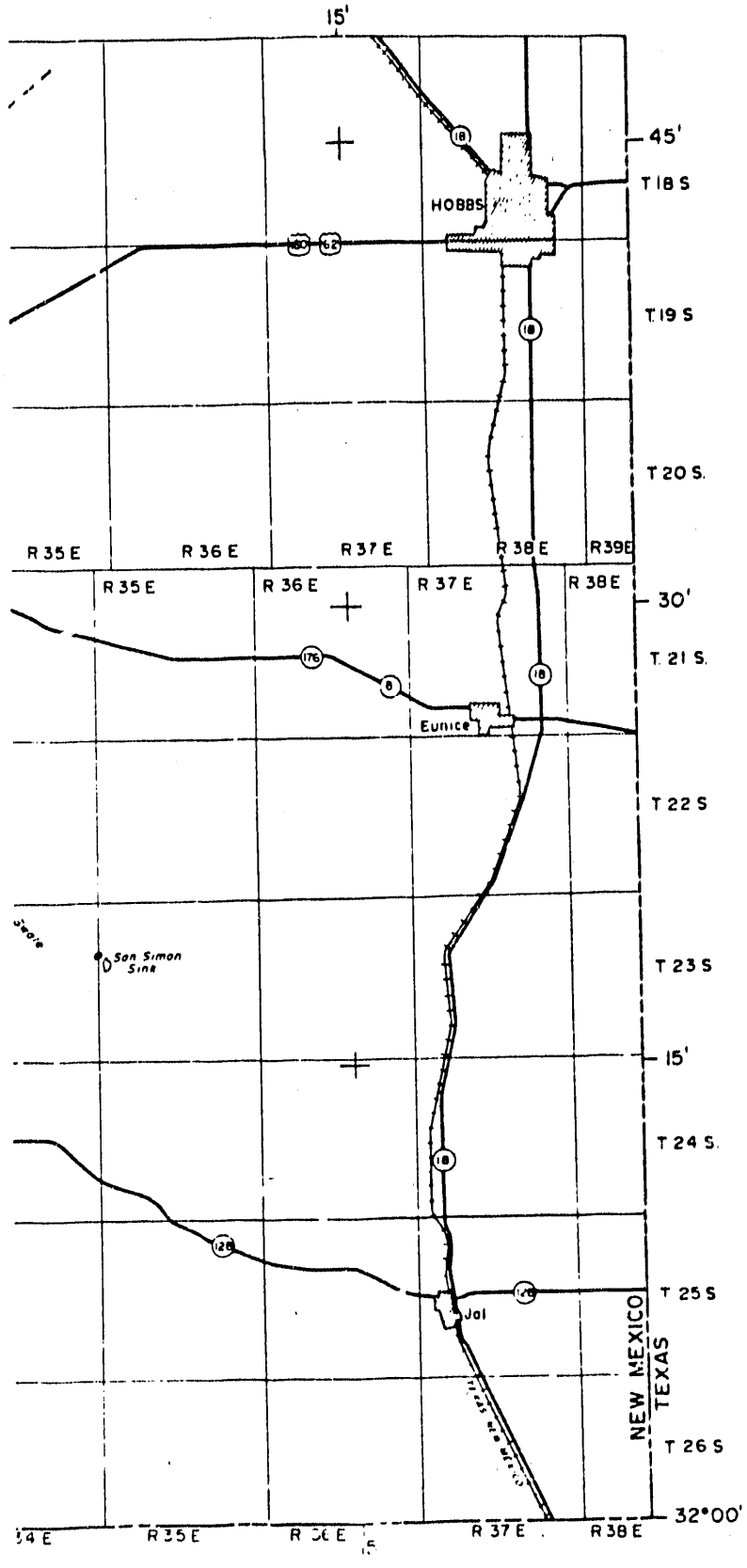


REGIONAL DISTRIBUTION OF EXPOSED IGNEOUS FEATURES

FIGURE 3.5-1


15'
104°00'
45'
45°
30'
15'
32°
PECOS RIVER
MESCALERO RIDGE
EDDY COUNTY
LEA COUNTY
R 26 E
R 27E
R 28E
R 29E
R 30E
R 31E
R 32E
R 25E.
R 26E
R 27E.
R 28E
R 29 E
R 30 E.
R 31 E
R 3
MAROON CLIFFS
ATCHISON TOPEKA AND SANTA FE
CARLSBAD
PECOS
MESA
RIDGE
NASH DRAW
LIVINGSTON RIDGE
WIPP SITE
LOS MEDAÑOS
Loving
RIVER
Malaga
CARLSBAD CAVERNS
DIKE TRACE
YESO HILLS
BIG SINKS
EDDY COUNTY
LEA COUNTY
NEW MEXICO
TEXAS
EDDY COUNTY
LOVING COUNTY
R 25 E
R 26 E
R 29 E
R 31 E
15'
104°00
45'


45'
30'
15'
QUERECHO PLAINS
EDDY COUNTY
LEA COUNTY
HOBBS
Eunice
Jal
WIPP SITE
ANTELOPE RIDGE
San Simon Swale
San Simon Sink
LOS MEDAÑOS
BIG SINKS
RIDGE
LIFFS
NEW MEXICO
TEXAS
LEA COUNTY
LOVING COUNTY
R 31 E
R 32 E
R 33 E
R 34 E
R 35 E
R 36 E
R 37 E
R 38 E
R39E
T 18 S
T 19 S
T 20 S.
T. 21 S.
T 22 S
T 23 S
T 24 S.
T 25 S
T. 26 S
32°00'

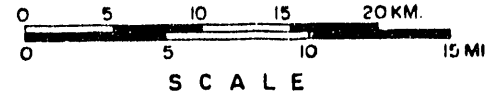


EXPLANATION

- △ Outcrop of dike
- ⊹ Well intercept of dike
- ● Airborne Magnetic Response – 1960
- ▪ Airborne Magnetic Response – 1963-64
- ⚒ Dike exposed in mine

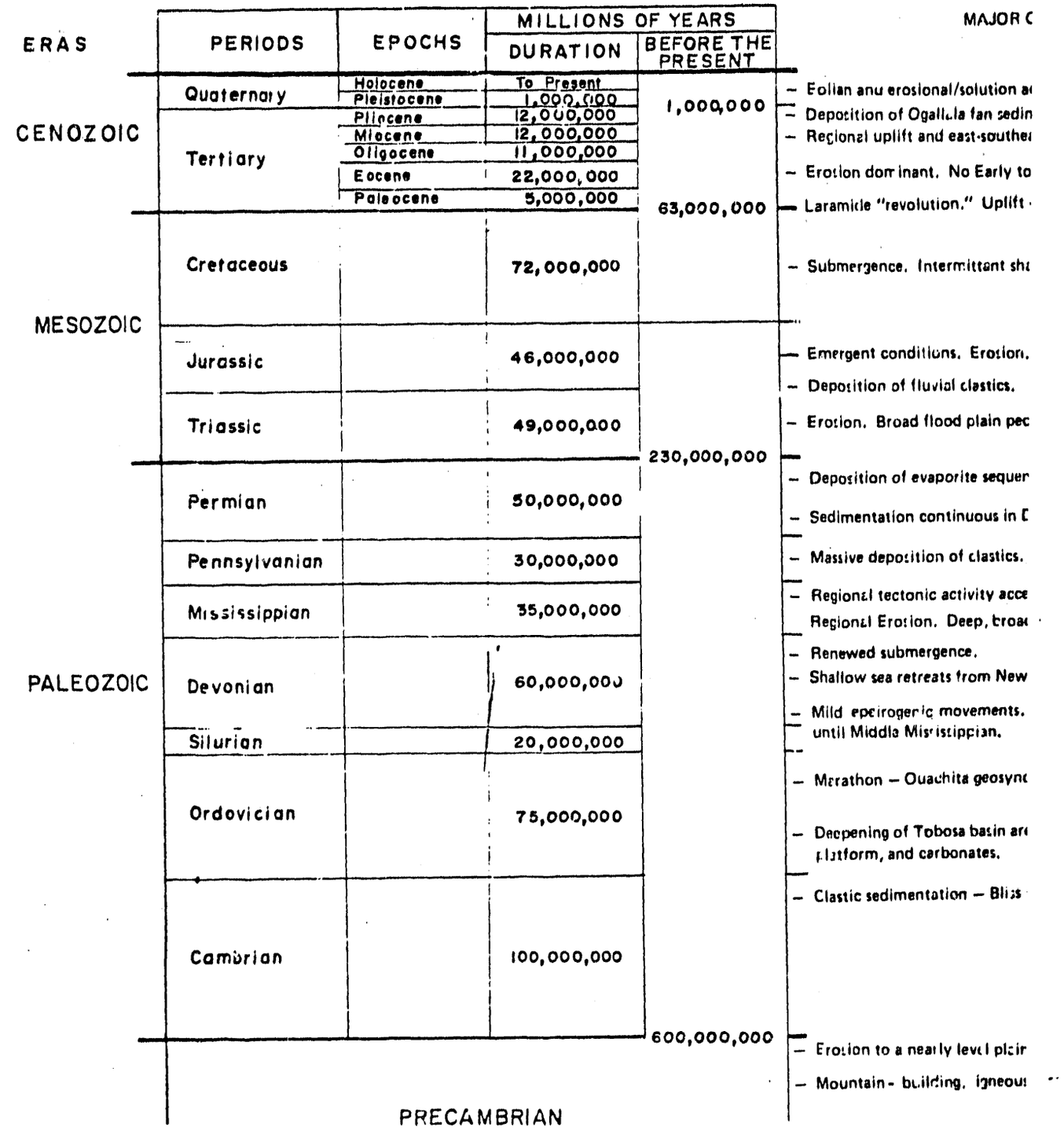
REFERENCE:

Adapted from: Griswold, G. B., 1977, Figure 1.



EVIDENCE OF NEAR-SITE DIKE

FIGURE 3.5-2



ERAS	PERIODS	EPOCHS	MILLIONS OF YEARS DURATION	MILLIONS OF YEARS BEFORE THE PRESENT	MAJOR C
CENOZOIC	Quaternary	Holocene	To Present	1,000,000	– Eolian and erosional/solution a
		Pleistocene	1,000,000		– Deposition of Ogallala fan sedin
	Tertiary	Pliocene	12,000,000		– Regional uplift and east-southe
		Miocene	12,000,000		
		Oligocene	11,000,000		– Erosion dominant. No Early to
		Eocene	22,000,000		
		Paleocene	5,000,000	63,000,000	– Laramide "revolution." Uplift
MESOZOIC	Cretaceous		72,000,000		– Submergence. Intermittant sh
	Jurassic		46,000,000		– Emergent conditions. Erosion.
					– Deposition of fluvial clastics.
	Triassic		49,000,000		– Erosion. Broad flood plain pec
				230,000,000	
PALEOZOIC	Permian		50,000,000		– Deposition of evaporite sequer
					– Sedimentation continuous in D
	Pennsylvanian		30,000,000		– Massive deposition of clastics.
	Mississippian		35,000,000		– Regional tectonic activity acce
					Regional Erosion. Deep, broa
	Devonian		60,000,000		– Renewed submergence.
					– Shallow sea retreats from New
					– Mild epirogenic movements.
	Silurian		20,000,000		until Middle Mississippian.
	Ordovician		75,000,000		– Marathon – Ouachita geosync
					– Deepening of Tobosa basin ar
					platform, and carbonates.
	Cambrian		100,000,000		– Clastic sedimentation – Bliss
				600,000,000	
PRECAMBRIAN					– Erosion to a nearly level plair
					– Mountain-building, igneous

MAJOR GEOLOGIC EVENTS – SOUTHEAST NEW MEXICO REGION

olian and erosional/solution activity. Development of present landscape.

lepostion of Ogallala fan sediments. Formation of caliche caprock.

legional uplift and east-southeastward tilting; Basin-Range uplift of Sacramento and Guadalupe - Delaware Mountains.

rosion dominant. No Early to Mid-Tertiary rocks present.

aramide "revolution." Uplift of Rocky Mountains. Mild tectonism and igneous activity to west and north.

ubmergence. Intermittant shallow seas. Thin limestone and clastics deposited.

mergent conditions. Erosion. Formation of rolling topography.

lepostion of fluvial clastics.

rosion. Broad flood plain pediment surface develops.

leposition of evaporite sequence followed by continental redbeds.

ledimentation continuous in Delaware, Midland, Val Verde basins and shelf areas.

lassive deposition of clastics. Shelf, margin, basin pattern of deposition develops.

legional tectonic activity accelerates, folding up Central Basin platform, Matador arch, Ancestral Rockies.

legional Erosion. Deep, broad basins to east and west of platform develop.

lenewed submergence.

hallow sea retreats from New Mexico. Erosion.

lild epeirogenic movements. Tobosa basin subsiding. Pedernal landmass and Texas peninsula emergent, ntil Middle Mississippian.

Arrathon – Ouachita geosyncline, to south, begins subsiding.

Deepening of Tobosa basin area; shelf deposition of clastics, derived partly from ancestral Central Basin latform, and carbonates.

Clastic sedimentation – Bliss sandstone.

MAJOR GEOLOGIC EVENTS –
SOUTHEAST NEW MEXICO

rosion to a nearly level plain.

Mountain - building, igneous activity, metamorphism, erosional cycles.

FIGURE 3.6-1

TABLE 3.5-I

REPORTED DIKE INTERCEPTS OR SURFACE EXPOSURES

WELL OR DRILL HOLE NAME	LOCATION	INTERCEPT DEPTHS IN FEET
Humble Oil & Refining; State "BO"#3	SE 1/4 Sec. 12, T18S-R34E	8745
Continental; Forest #1	Sec. 22, T18S-R34E	7210-8640
International Minerals Corp.; ConcDale #95	NW 1/4 Sec. 12, T20S-R32E	2239
Noranda; MB-10	SW 1/4 Sec. 14, T20S-R32E	1700
Texaco; Moore #1	SW 1/4 Sec. 21, T20S-R32E	2115
Kerr-McGee; Mine	Sec. 31, T20S-R32E	1530
Perry R. Bass; Big Eddy #44	SE 1/4 Sec. 25, T22S-R28E	12120-13330
Stanolind; U.S. Duncan #1	SW 1/4 Sec. 30, T21S-R30E	470-2710(8 Intercepts)
International Minerals Corp.; Mine	Sec. 36, T21S-R29E	790
H & W Drilling: Danford #1	SE 1/4 Sec. 9, T22S-R29E	2210
Perry R. Bass; Big Eddy #43	SE 1/4 Sec. 25, T22S-R28E	940-2050
Outcrop	Sec. 31, T25S-R25E	Surface
Outcrop	Sec. 11, T26S-R24E	Surface
Amoco; Teledyne Gas #1	Sec. 13, T23S-R28E	Rumor?
Unknown	Sec. 25, T22S-R28E	1880-1900 (γ Ray Response)

Reference: C. L. Elliot (1976 b), Table I.

3-12.3

GCR CHAPTER 4
SITE GEOLOGY

4.1 INTRODUCTION

This chapter is a detailed review of the geologic characteristics of the Waste Isolation Pilot Plant (WIPP) repository site and its environs, including discussions of geomorphology, stratigraphy, structure, and tectonics. In keeping with the concept of underground placement of the radioactive wastes, subsurface geologic conditions are emphasized. Structure contour and isopach maps are presented and discussed. Particular effort has been made throughout the text to relate site-specific aspects to regional geologic conditions. A final section on geologic history reviews the geologic origin and development of the WIPP site.

The available literature, including maps and reports on file with federal and state agencies, has been consulted. Results of field and research investigations carried out specifically to define site geologic conditions have been integrated into the discussion and the investigative reports referenced. Detailed descriptions of the various exploration programs and investigations may be found in Chapter 2.

4.1.1 Area of Study

The area to be considered in detail in this chapter on site geology is shown in Figure 4.1-1. It represents a 10-by-10-mile square area centered on the site, including all of Township 22 South, Range 31 East and parts of the adjacent townships in eastern Eddy and western Lea Counties in the southeastern corner of New Mexico. In many instances, however, the topics under discussion were judged to require consideration of areas more distantly removed or to benefit from a somewhat broader focus, so that Figure 4.1-1 should not be construed as a limitation of the area considered or discussed.

Also shown in Figure 4.1-1 is the outline of the WIPP site itself, locating land-use restriction zones. Zone I is the area of the surface facilities. The roughly octagonal Zone II represents the underground area which would be mined if a fully developed (3 square miles) repository were developed here. No drill hole extending through the salt beds to deeper strata occurs within one mile of the Zone II boundary. Other zones represent levels of land-use restriction and are discussed elsewhere in this report (for example, see Table 2-1). The outer boundary of Zone IV defines the area of the WIPP site. The term "Los Medanos" is also frequently used to refer to the WIPP site area, as for instance in the site selection process to distinguish the WIPP site from other alternate sites in the same region (see Chapter 2). Griswold (1977) defined the 10-by-10-mile square of Figure 4.1-1 as the "Los Medanos site"; however, for the purpose of this report, it seems more appropriate to use the term "Los Medanos" to refer to the general vicinity of the WIPP site, roughly corresponding to the sand- and dune-mantled area bearing that name and within which the site occurs.

4.2.1 Sources of Data

Much of the information specific to the Los Medanos area and to the WIPP site is available from various agencies commissioned to carry out special technical studies. In assembling these descriptions, free recourse has been made to what is available in the open literature, particularly to the numerous open-file reports released by the U.S. Geological Survey. Much useful information on surficial stratigraphy of the Los Medanos area is provided by Vine (1963) and by Bachman (1974; also in Jones, 1973); both have provided surficial geologic maps of parts of the area. Valuable compilations of stratigraphy and structure of the Ochoan evaporite sequence have been assembled by Jones (1972, 1973, 1975), by Brokaw et al. (1972), by Anderson et al. (1972), and by Anderson (1978). Permian Basin geology in general is extensively discussed in King (1948) and in McKee et al. (1967a, 1967b). Pennsylvanian studies are presented for the Los Medanos area by Foster (1974) and regionally by Meyer (1966). Much of the available information regarding pre-Pennsylvanian

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stratigraphy is reviewed in Foster (1974), who presents numerous reference sections and isopach and structure contour maps for these deeply buried strata.

A series of subsurface structure contour and isopach maps has been prepared specifically for the WIPP site by Griswold (1977) and most are incorporated into this chapter. The data base for these maps is furnished by available well and borehole information supplemented by specially contracted seismic reflection surveys. The location of all boreholes and seismic reflection profiles used in the subsurface studies reported herein are shown in Figure 4.1-2 and listed in Table 4.1-1.

A glance at the depths of holes listed in Table 4.1-1 shows the paucity of data available for horizons deeper than about two thousand feet. With the possible exception of oil or gas fields where deep holes are clustered, well spacing is typically such that minor faulting probably would not be delineated; only the smoothed trend of local depressions and arches is outlined. The detection of minor faulting and other local structural detail is generally possible only through the use of deep seismic reflection techniques, supplemented by deep well control where available. Horizons which most efficiently reflect seismic wave energy are the most logical targets for detailed study of deep structures. Beneath the site, horizons which are found to be good reflectors include top of the Silurian carbonate sequence, top of Morrow limestone (lower part of Pennsylvanian rocks), and top of Delaware sand (below base of Castile). Although many hundreds of miles of seismic reflection profiling have been carried out in the Delaware Basin, nearly all of it is privately owned by industry sources and the record profiles are not subject to disclosure. Accordingly, Sandia Laboratories engaged the services of G.J. Long and Associates, Inc., of Houston, Texas and Permian Exploration Company of Roswell, New Mexico, to carry out a program of seismic reflection profiling across the WIPP site, supplemented by any oil industry data which was made accessible for examination. Over 1,500 miles of private seismic data were examined and about 70 miles of new

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seismic data have been obtained by Sandia. (For further information on seismic reflection profiling and well data control used in the exploration for deep structure at the site, refer to Section 2.5).

Data regarding structural detail of bedded salt in the Delaware Basin, in contrast to deeper horizons, are not generally available in the form of seismic reflection surveys of the type normally used in subsurface exploration, nor do petroleum exploration companies generally pick stratigraphic markers above the Delaware, as there is no commercial hydrocarbon interest in these relatively shallow strata. Perhaps the lack of early recognition of the character of deformation within the bedded salt sequence is accounted for by the petroleum industry's disinterest in non-petroliferous strata. The intensive exploration drilling for potash deposits by commercial mining interests, however, has provided a means of obtaining at least some general outline of deformation features within the evaporite sequence down through the McNutt potash zone of the Salado that would not otherwise have been available. In addition, mine workings have provided supplementary detail in localized areas. Within the site exclusion area, additional potash exploratory holes have been drilled under contract to Sandia Laboratories. Because commercial potash exploration is targeted to the McNutt member of the Salado Formation, shallower strata have generally not been extensively logged and sampled, with the result that details of structure in the Rustler Formation and Dewey Lake Redbeds were not well recorded. The holes drilled under contract to Sandia Laboratories to determine the extent of potash reserves in the site area were logged through these upper formations by wireline geophysical methods and are the source of much of the shallow subsurface data near the WIPP site. Figures 4.4-11 through 4.4-15 are constructed from these data.

Nothwithstanding the apparent wealth of drill hole data in the area, it should be emphasized that well data necessarily represent an incomplete sampling and extrapolation from such data will be imprecise to an extent dependent on the well spacing, the complexity of the subsurface structure, and the level of detail desired. Well picks probably will not

record absolute maxima or minima of sharper crests and troughs, and certain smaller features could remain undetected. Other techniques such as seismic reflection aid in finding smaller structures.

4.2 SITE PHYSIOGRAPHY AND SURFICIAL GEOLOGY

4.2.1 Site Physiography

The proposed WIPP site is located on the eastern edge of the Pecos Valley section of the southern Great Plains physiographic province (Figure 3.2-1). The land surface within the area of the site is a monotonous, semi-arid, eolian plain sloping gently to the west and southwest (Figure 4.2-1a), its surface made somewhat hummocky by an abundance of sand ridges and dunes. Figure 4.2-2 is a topographic map of the area in the vicinity of the site (from Nash Draw and Hat Mesa 15-minute topographic quadrangle maps). Also shown on this figure are the boundary zones of the WIPP site as discussed in Section 4.1, extending a maximum distance of about 3 miles from the geographic center of the site. Within these boundaries, elevations range from 3,570 feet in the east to 3,250 feet in the western part of the site. The average slope from east to west is 50 feet per mile (Griswold, 1977).

In the vicinity of the site, Livingston Ridge is perhaps the most prominent physiographic feature. Located about a mile beyond the northwestern border of the WIPP site, it is a northeast-southwest trending, west facing escarpment about 75 feet high marking the east edge of Nash Draw. Nash Draw, the nearest drainage course of any significance in the vicinity of the site, is a shallow, 5-mile-wide valley open to the southwest. Elevations within Nash Draw, which descend from about 3,300 feet at its northeast head to 2,945 feet at Salt Lake, near the Pecos River, are generally 200 to 300 feet lower than the surrounding terrain and may reflect substantial subsurface dissolution of salt from the Rustler and Salado Formations and accompanying subsidence of overlying materials. Livingston Ridge marks the approximate boundary, therefore, between terrain that has undergone erosion and/or solution collapse and

terrain that has not been so affected, and may be considered to indicate the approximate position east of which significant dissolution of the underlying Salado Formation has not occurred (refer to Chapter 6 and Section 3.2 for further discussion).

East of the site, the nearest major drainage course is the southeast-trending San Simon Swale, some 15 miles or more distant (a more regional topographic map is shown in Figure 2-1). It, too, most likely owes part of its decreased elevation to subsurface dissolution. Between Sam Simon Swale and the WIPP site, a broad, low mesa named "The Divide" occurs about 6 miles east of the site, rising about 100 feet above the surrounding terrain and attaining an elevation of about 3,800 feet, and, as such, marks a local boundary between general southwest drainage toward Nash Draw and general southeast drainage toward San Simon Swale. The Divide is capped by the Ogallala formation, and overlying caprock caliche upon which have formed small, elongate depressions similar to those found developed on the Ogallala of the High Plains, proper, farther east (refer to Regional Geomorphology, Section 3.2, for additional discussion of these features).

Surface drainage in the site area is intermittent; the nearest perennial stream is the Pecos River, more than 15 miles south-west of the center of the site. Surface runoff in the site area finds its way to the Pecos River via Nash Draw; discharge of shallow groundwater is likewise believed to be controlled by the Pecos River (refer to hydrology sections 6.2.5 and 6.3). Although basins like Nash Draw may have evolved partly through active subsurface dissolution of thick, buried salt deposits, there is no evidence available at present to evaluate differences in rates of dissolution which may have prevailed under different climatic conditions. That the site is in a natural divide between drainage basins indicates that it is protected from serious flooding and erosion from heavy runoff. Should the climate of the region become more humid in the future, any perennial streams which might then arise would be expected to follow the present basins, and Nash Draw and San Simon Swale would undergo the greatest amount of erosion from this increased humidity, leaving the divide area relatively intact (Bachman, 1974).

Because of the presence in Nash Draw and elsewhere in the Delaware Basin of extensive subsidence which appears to be caused by subsurface dissolution of salt, much attention has been focused on the search for geomorphic indications of possible subsidence features in the vicinity of the site. One feature that has attracted some attention is described by Griswold (1977) as a shallow sink about 8 miles north of the site in the southeast part of Section 9, T. 21 S., R. 31 E. (pictured in Figure 4.2-1b). The feature is very subdued, about 1,000 feet in diameter and 30 feet deep. Resistivity studies conducted by Elliot (1976) indicate very shallow surficial fill within the feature and no disturbance of underlying beds, indicating a probable surface rather than subsurface origin. This type of feature is common in southeastern New Mexico and is not necessarily indicative of an origin tied to subsurface subsidence. On the other hand, recent resistivity surveys conducted over the surficial sand cover within the WIPP site area (Elliot, 1977e) have disclosed a resistivity anomaly in section 17, T. 22 S., R. 31 E., within the limits of the Zone II exclusion area. The anomaly bears some resemblance in character to the pattern observed over a known sink, a so-called salt "breccia pipe" (Elliot 1977a). Recent drilling (WIPP 13) has shown this resistivity anomaly is not caused by dissolutioning but by lower than average resistivity in the Dewey Lake Redbeds.

4.2.2 Site Surficial Geology

Most of the site area is covered by blanket eolian sand or, especially on the north, east, and southeast, by partially stabilized sand dunes. Active sand dunes are located in the southern portion of the site (Figure 4.2-3). The sand, of Holocene age ("Mescalero sand"), forms a thin, persistent veneer no more than a few meters thick (except where dunes occur) that is believed to have been swept westward from the High Plains, where the inferred source material, the sandy Ogallala Formation, is abundant. The widespread sand cover is readily apparent on the surficial geologic map of the site area, Figure 4.2-4, which is compiled from maps prepared by Vine (1963) and Bachman (1974).

Not at all apparent from the map, however, is the general occurrence of a hard, caliche layer up to 10 feet thick immediately beneath the eolian sand blanket. The relatively high resistance of the caliche to erosion has protected the more erodable underlying strata from dissection and exposure. It is recognized over a regionally broad area and has been termed the "Mescalero caliche". Caliche may form pedogenically over geologic time at or near the surface through capillary rise of carbonate-laden water in the vadose zone followed by precipitation of solute upon evaporation of pore water (Brown, 1956). The youngest formation on which the Mescalero caliche has formed is the Pleistocene Gatuna Formation, of presumed Kansan age (Bachman, 1974). Bachman (1974) indicates that the formation of the Mescalero caliche probably dates back to the Yarmouth interglacial stage, or approximately 500,000 years ago. That such a thick, areally extensive, and continuous caliche had accreted implies past stable climatic and geomorphic conditions over the considerable time period required for its formation. The relevance of this type of paleoenvironmental indicator to the stability of present climatic conditions and to possible future climatic variability, and the implications regarding the long-term integrity of the WIPP repository, are presently being pursued by Bachman (see Chapter 10).

On the surficial geologic map (Figure 4.2-4) exposures of the Mescalero caliche are indicated. These occur where the eolian cover is very thin or removed entirely, mostly near the edge of Nash Draw, into which much of the nearby loose sand may have been swept. Along Livingston Ridge, the Mescalero caliche is draped inward into Nash Draw and is present over much of the north half of the valley, indicating that at least some subsidence or lateral backwasting along Nash Draw has occurred subsequent to the formation of the caliche, presumably during the more humid glacial stages (Illinoian or Wisconsin) of Pleistocene time.

Within Nash Draw, and the WIPP site area, the Triassic Santa Rosa Sandstone, the Ochoan Dewey Lake Redbeds, and more than half of the Rustler Formation are sporadically exposed. Field descriptions of these formations are included in Section 4.3.

The overall geology and structure of the WIPP site is quite simple. It is characterized by a persistent, gentle homoclinal dip toward the east of 50 to 200 feet per mile (2 degrees or less), depending upon depth. Successively older rocks are seen to occur toward the west, the result of erosional bevelling of the gently eastward-dipping strata. Additional information regarding erosional history of the WIPP site is presented in section 4.5; details of the site structure and stratigraphy are discussed in the following sections.

4.3 SITE STRATIGRAPHY AND LITHOLOGY

The following paragraphs briefly summarize the stratigraphic sequence at the WIPP site; systematic description of the various lithologic units commences in Section 4.3.1.

The proposed WIPP underground storage facilities are to be placed near the middle of a 3,600-foot-thick sequence of relatively pure evaporite strata containing primarily rock salt and anhydrite, lying between depths of about 500 and 4,100 feet beneath ground surface. The formation richest in rock salt, the Salado Formation, is nearly 2,000 feet thick. The Salado contains the relatively pure salt layers in which the two proposed underground storage levels are to be constructed, at a depth near 2,120 feet for the upper level and near 2,670 feet for the lower. The storage horizons are well isolated from the enviroment by adjacent evaporite strata. A thickness of at least 1,300 feet of undisturbed evaporite, primarily rock salt, overlies the upper storage horizon, and about an equivalent thickness of anhydrite and rock salt intervenes between the lower storage horizon and the next adjacent underlying non-evaporite formation. The salt deposits were formed at least 225 million years ago and have apparently remained isolated since that time.

The total thickness of the sediments resting on Precambrian basement beneath the surface of the proposed WIPP facility is about 18,000 feet of Ordovician to Recent strata. Depicted in Figure 4.3-1 is a generalized stratigraphic section of the site, showing the vertical sequence of major

units and their relative thicknesses. More detail, but still of a generalized nature, is provided in Figure 4.3-2, Site Geologic Column, which shows simplified graphic and descriptive lithologies of the major units known or inferred to occur beneath the site and gives the geologic classification of rock units used in this report. Following is a brief summary of the stratigraphy, proceeding from the surface down to basement.

Beneath a thin but persistent veneer of windblown sand at the site are sediments representing Pleistocene, Upper Triassic, and uppermost Permian strata, all of which occur above the evaporite sequence. Sandstone of the Pleistocene Gatuna Formation, capped by Mescalero caliche, also developed in Pleistocene time, is only a few tens of feet thick at the site and is of interest primarily for the geochronologic and paleoclimatic implications of its presence; it was deposited, and much of the caliche on its surface believed to have developed, half a million years ago (Kansan-Yarmouth time) (Bachman, 1974). Between the Pleistocene sandstone and the evaporite sequence is a 500-foot-thick succession of nonmarine redbeds of Late Triassic age (Santa Rosa Sandstone) and marine redbeds of latest Permian age (Dewey Lake Redbeds). This redbed sequence thins westward and thickens eastward, having been beveled to the west by one or more post-Late Triassic erosional episodes; the thickness of redbed deposits remaining above the evaporite sequence is crudely proportional to the degree to which the underlying salt horizons have been protected from surficial processes leading to erosion and dissolution.

At the center of the site, all but the uppermost 50 feet of the 18,000 feet of strata are of Paleozoic age, the marine Dewey Lake Redbeds being the topmost of the Paleozoic rocks. The Permian section alone, about 12,800 feet thick, constitutes over two-thirds of the sedimentary column. The Permian section is divided into four series, the three lowest of which (Wolfcampian, Leonardian, and Guadalupian) contain thick clastic sequences, and the uppermost of which, the Ochoan Series, contains the evaporite formations, which are in descending order the

Rustler, Salado, and Castile Formations. (The topmost Ochoan formation, the Dewey Lake Redbeds, is not part of the evaporite sequence but represents a return of clastic, normal marine deposition.)

The Rustler, which overlies the Salado, contains the largest percentage of clastic material of the three evaporite formations. However, where its original thickness of around 450 feet has been protected from salt dissolution, about 70 percent of the formation is composed of evaporite beds, including about 40 percent rock salt. Beneath the WIPP site, the Rustler has been leached of most of its rock salt in the geologic past. At ERDA-9, 310 feet of the formation was encountered, which implies that up to 150 feet of rock salt has been removed and that the overlying strata have subsided accordingly. It does not, however, imply that dissolution and subsidence is necessarily presently active or even that it has recently occurred. At ERDA 9 halite was logged in the lower 100 feet of the Rustler. Over 1,300 feet of undisturbed evaporite rock, primarily Salado rock salt, occur above the upper level storage zone of the proposed WIPP facility.

The 2,000-foot thickness of the salt-rich Salado Formation is divided into three members by the recognition of a middle member referred to as the McNutt potash zone, which is the interval within the Salado that contains the potential reserves of potash minerals mined in the Carlsbad District west of the site. The lowest member of the Salado, beneath the McNutt potash member, is the member that contains the nearly pure halite which is proposed for the WIPP facility. The Castile Formation beneath the Salado also contains nearly pure beds of halite but, unlike the Salado, also contains massive anhydrite beds.

The rest of the Permian section beneath the evaporite sequence, together with the subjacent Pennsylvanian and possibly Late Mississippian sections, contain dominantly clastic rocks that represent deposition during the time in which the Delaware Basin existed as a distinct structural entity. These pre-evaporite, basinal sediments, which total about 11,000 feet in thickness beneath the site, have been targeted for

petroleum exploration at one point or another throughout the Delaware Basin. They contain nearly all of the region's known potential reserve of hydrocarbons.

The remainder of the Paleozoic section (Mississippian down through the Ordovician) consists of about 3,000 feet of mainly carbonate strata deposited in shallow-water or shelf conditions over a period of long-sustained crustal stability.

The underlying crystalline basement is believed to be a granitic terrane, formed about 1,300 million years ago. The only other igneous rocks known in the area occur as a lamprophyre dike rock intruded into the evaporite beds along a single northeast dike trend that approaches no closer than about 8 miles northwest of the center of the proposed WIPP site.

Brief descriptions of the various stratigraphic units are provided in the following sections, in order of deposition from oldest to youngest, with emphasis on the evaporite beds, particularly the Salado Formation.

4.3.1 Precambrian Eonothem

Few holes in the near vicinity of the WIPP site have penetrated entirely through the Paleozoic section. The nearest such holes are the Richardson and Bass No. 1 Cobb-Federal, approximately 13 miles north-northwest of the center of the site, and the Texas No. 1 Richards, 12-1/2 miles to the north-northeast. Inferences about the nature of basement rock lying beneath the site have been gleaned from these wells and others more distantly removed.

Crystalline basement rocks beneath the Mesozoic and Paleozic sedimentary pile near the proposed site are believed to be either granitic igneous rock or metamorphosed granites and rhyolites. The basement surface here is at a depth of approximately 17,900 feet (Foster and Stipp, 1961); a slightly greater depth (approximately 18,200 feet) has been inferred by independent consultants (Sipes et al., 1976). The basement rocks occur

within what has been considered by Flawn (1954, 1956) to be part of a regional Precambrian granitic terrane constituting the Texas craton. A later investigation (Muehlberger et al., 1967), which reclassified the rocks within the Texas foreland or craton, among other areas, suggests that the basement rocks in the area near the site belong to the Chaves granitic terrane, composed largely of granite, granodiorite, and equivalent gneisses, with a minor amount of other metamorphic rocks included. Measured radiometric dates for basement rocks in the area range between 1,140 to 1,350 million years (Foster, 1974; Muehlberger et al., 1967); the Chaves terrane is defined to include the 1,350 m.y.-old granitic basement rocks.

4.3.2 Paleozoic Erathem

Cambrian System. No Cambrian strata are recognized in the subsurface in the vicinity of the WIPP site. Basal conglomerate and sandstone resting on the Precambrian of southeastern New Mexico are sometimes called Bliss sandstone, which is partly Late Cambrian and partly Early Ordovician in age, but such rocks in this area probably correlate only with the Ordovician part of the Bliss (Foster, 1974) and are here considered a member of the Ellenburger Group.

Ordovician System. In the Los Medanos area, the Paleozoic section begins with an estimated 1,290 feet of Ordovician rocks beneath the center of the site (Foster, 1974), assuming an even gradient between widely spaced well control points. In ascending order the sequence includes the Ellenburger, Simpson, and Montoya Groups, representing Lower, Middle, and Upper Ordovician strata, respectively.

Detail of the local stratigraphy of the Ordovician is based on samples and a radioactivity log from the Texas No. 1 Richards well, 12-1/2 miles north-northeast of the site. The Ellenburger Group there consists of at least 300 feet of dolomite with some chert; included is a basal member of sandstone and conglomerate about 75 feet thick. The top of the Ellenburger may be at a depth of as much as 17,800 feet beneath the

center of the site (Netherland, Sowell, 1974). Overlying the Ellenburger dolomite is a sequence of alternating limestone and green or gray shale members, with several sandstone units occurring in the upper half of the sequence. The Upper Ordovician Montoya Group is almost entirely carbonate rock. At the Texas 1 Richards well, the lower half of the Montoya is limestone and the upper half dolomite, chert being fairly common, particularly in the middle of the section; whereas 14 miles south of the site the Montoya has been logged as mostly limestone and sandy limestone. Some intermediate lithology is therefore to be expected beneath the WIPP site.

In the Texas 1 Richards reference section the Ordovician rocks total 975 feet in thickness; however, the section thickens in a south to southeast direction at a rate estimated to be 25 to 40 feet per mile (Foster, 1974), most of which is due to the thickening of the Ellenburger and Simpson groups in that direction. It is likely that the Ellenburger and Simpson are each between 400 and 500 feet thick in the site area.

Silurian System. Lying above the dolomite of the Ordovician Montoya Group is additional carbonate rock of Silurian, or perhaps Siluro-Devonian age. Near the site it consists entirely of light-colored dolomite with appreciable chert, except for two prominent intervals of limestone, one about 100 feet thick near the middle of the section and one about 200 feet thick near the top (Foster, 1974). The basal contact is apparently disconformable in this area.

The relatively homogenous lithology of the Silurian carbonate sequence in the subsurface of southeastern New Mexico has thus far precluded its formal separation into formational units. McGlasson (1968), however, has suggested that the lower part is correlative with the Fusselman Formation of Early and Middle Silurian age, and that the upper part, generally referred to as "Upper Silurian" strata, may be correlative with the Henryhouse Formation of partly late Middle and partly Late Silurian age. McGlasson (1968) also shows that no Devonian carbonate rocks were deposited in New Mexico, except in the extreme southwest corner of Lea

County. Nevertheless, common oil-field usage refers to these carbonates as "Siluro-Devonian" carbonates (Foster, 1974). Probably most if not all of the post-Montoya, pre-Woodford carbonate strata beneath the WIPP site is Silurian in age, according to McGlasson's studies. Isopach maps (Foster, 1974) indicate the total thickness of the Silurian or "Siluro-Devonian" carbonates at the site to be about 1,140 feet. The sequence thins westward relatively uniformly at a rate of about 25-50 feet per mile toward a landmass emergent during Silurian time.

The marked contrast in lithology between the Silurian carbonate and the overlying Devonian shale is believed to provide a good seismic reflecting horizon. Structure contour maps on top of "Siluro-Devonian lime" indicate that the top of Silurian, equivalent to base of Devonian, is at a depth of about 15,850 feet beneath the center of the WIPP site (elev. minus 12,450 feet) (Netherland, Sewell, 1974).

Devonian System. The Devonian system is represented by a distinctive unit of organic, pyritic black shale which unconformably overlies the Silurian carbonate sequence. McGlasson (1968) correlates it with the Upper Devonian Woodford Shale of Oklahoma and describes it as a "dark brown to black, fissile, bituminous, spore-bearing shale". He shows that it is a transgressive unit which overlaps successively older units to the northwest (McGlasson, 1968). Beneath the center of the site it is indicated to be about 175 feet thick, thickening gradually southeastward (Foster, 1974). Haigler and Cunningham (1972) show the top of undifferentiated Silurian and Devonian rocks at an elevation of slightly above minus 12,300 feet MSL at the center of the WIPP site. The uppermost portion of the Woodford Shale in the Delaware Basin is reported to be actually of earliest Mississippian age (McGlasson, 1968).

Mississippian System. Rocks of the Mississippian System at the site include a series of limestones referred to simply as "Mississippian limestone," and an overlying shale interval called the Barnett shale. At the Texas 1 Richards locality, the limestone is light-yellowish brown, locally cherty, with some minor gray shale, contrasting with brown,

locally silty shale of the Barnett. Like the top of Silurian carbonate, the top of Mississippian carbonate most likely affords a good reflecting horizon; structure contour maps indicate that it is about 15,150 feet below Zone I at the site (elev. minus 11,750 feet) (Netherland, Sewell, 1974). Total thickness of the carbonate appears to be about 480 feet at the site, gradually thickening northward. The overlying black shale is about 175 feet thick.

Stratigraphic relations between subsurface Mississippian strata in southeastern New Mexico and formational units defined in other areas are unclear. On the basis of the local fauna, the carbonate sequence in the Delaware Basin is assigned to the Lower Mississippian (Foster, 1974). Lithologically it is similar to the Rancheria Formation in the Franklin Mountains. At or near the site, deposition of the Barnett Shale corresponds for the most part to Late Mississippian time.

Pennsylvanian System. Approximately 2,200 feet of Pennsylvanian strata occur in the subsurface at the WIPP site (Foster, 1974). The section consists of alternating members of sandstone, shale, and limestone, and rests unconformably on the underlying Barnett Shale.

Unlike most of the earlier Paleozoic strata, the Pennsylvanian strata in the Delaware Basin, and some of the Lower Permian strata as well, are characterized by relatively numerous changes in lithology vertically in the section and by an abundance of lateral facies changes along time-equivalent horizons. Lithologic units traceable over broad areas in the subsurface generally cannot be assumed to represent time-stratigraphic units under these conditions. Attempts to construct a basin-wide geologic history for Pennsylvanian time and to develop regional correlations based on time equivalence are greatly complicated by these lithologic changes. These complexities have spawned efforts such as those of Meyer (1966) to develop a method for placing surface outcrop and subsurface strata into a formal Pennsylvanian time-stratigraphic framework. As defined by this approach, the Lower Pennsylvanian Series includes rocks assigned to the Morrowan Stage, the

Middle Pennsylvanian Series to rocks assigned to the Atokan (or Derryan) and Desmoinesian Stages, and the Upper Pennsylvanian Series to rocks assigned to the Missourian and Virgilian Stages.

In the Delaware Basin, local subsurface stratigraphic units have sometimes been informally defined, or extended on the basis of lithology and are therefore, strictly speaking, lithostratigraphic and not time-stratigraphic units. Thus, rocks considered part of, for example, the "Morrow" or the Morrow Series on the basis of subsurface lithologies may not necessarily all be encompassed within or represent all of the time of the Morrowan Stage as formally defined. Although the Pennsylvanian section is herein described by reference to lithologies recorded in nearby wells, for the reasons stated the section at the site cannot from the nature of data available be positively correlated with formal stage names or with Lower, Middle, or Upper Pennsylvanian Series. Nevertheless, the designations of Morrowan, Atokan, Desmoinesian, and Missourian-Virgilian rocks for the respective Bend, Strawn, and Canyon-Cisco rock units have frequently been used with modifications for some time (Thompson, 1942; Haigler, 1962, p. 7-8, Netherland-Sewell, 1974, exbt. G-2; see also Meyer, 1966, p. 11). The bipartite classification of Lower Pennsylvanian for Morrowan and Atoka and Upper Pennsylvanian for Strawn has also been employed (e.g., Sipes et al., 1976).

Foster (1974), in his description of Pennsylvanian subsurface lithologies in the vicinity of the site, adopted the usage of Morrow, Atoka and Strawn, which denote from deepest to shallowest the respective principal oil and gas producing zones in Pennsylvanian rocks of the Delaware Basin. He noted that the "overlying rocks of Missourian and Virgilian ages are present... but following the common oil-field usage (they) are included in the Wolfcamp sequence". Hence, "... it appears that the top of (Meyer's) Desmoinesian Stage is the same as the top of the Strawn..." (Foster, 1974). This usage is followed in this chapter in the interest of its adaptability to existing commercial exploratory data. Reference sections are provided by Foster for Pennsylvanian strata some distance

north and south of the site (his Figures 12 and 36, respectively). Sipes, et al. (1976) show "picks" on Pennsylvanian units in the Clayton W. Williams Jr., Badger Unit Federal well about 2 miles northeast of the center of the site, and they present down-hole logs on this and other exploration holes in the vicinity of the site as well.

Morrowan rocks near the site consist mostly of fine- to coarse-grained sandstone with varying amounts of dark gray shale. Some limestone, generally as a series of relatively thin beds with shale and sandstone, typically occurs in the upper part of the sequence and is often separately identified. The Morrow sand is a known hydrocarbon producer of oil and gas in this part of the Delaware Basin, particularly from fields in the area north of the site (refer to Section 8.3.2). Foster (1974) shows areal distribution of sand lithologies in this zone.

The Atoka rocks are principally limestone, becoming cherty toward the middle of the section, and alternating with varying amounts of medium- to dark-gray shale. Sandstones are subordinate. The Atoka is considered to have locally significant hydrocarbon potential in this part of the Delaware Basin, as in the Los Medanos field which is southwest of and nearest to the WIPP site.

The lower part of the Strawn (regionally the Desmoinesian) is dominated by light gray to white, medium- to coarse-grained sandstone, locally conglomeratic in the site area. In its upper part, the Strawn is dominantly limestone, apparently with a minor amount of chert but becoming more abundant northeastward in the immediate vicinity of the site (Foster, 1974). Thin beds of dark gray and brown shale are present throughout the section.

Records of the apparent thickness of the Morrow, Atoka and Strawn vary considerably from area to area simply because there is no completely agreed-upon way of selecting "picks" on down-hole logs and seismic reflection data. In some oil fields, "picks" above the Morrow include

Atoka (or Bend), Strawn, Missourian and Virgilian. According to Foster (1974), "in well completion reports the top of the Strawn is picked fairly consistently," but selections for the top of Morrow and Atoka may differ significantly, and generally the Canyon and Cisco are not distinguished in this part of basin. Sipes et al. (1976) show the top of Strawn at elevation minus 9,400 feet msl beneath the center of the WIPP site. The "picks" they show in the C.W. Williams Jr., Badger Unit Federal well two miles northeast of ERDA 9 yield thicknesses of 1,224, 607, and 257 feet for the Morrow, Atoka, and Strawn rocks, respectively, for a total thickness of 2,088 feet for the Pennsylvanian. Presumably, one or more units thicken southwestward slightly to attain the 2,200-foot value that Foster shows at the center of the site, a value which specifically excludes at least some Missourian-Virgilian strata. Probably the value of approximately 2,500 feet shown by Meyer (1966, Figure 48) is more truly representative of the total accumulation of strata beneath the site during Pennsylvanian time.

Permian Rocks. As much as 13,000 feet of Permian strata were deposited within the area of the Delaware Basin, which constitutes the most complete succession of the Permian in North America (Brokaw et al., 1972). The entire Permian section beneath the WIPP site averages about 12,800 feet in thickness, over two-thirds that of the entire sedimentary column, or over twice as thick as all of the earlier Paleozoic formations combined (about 5,200 feet). Of this total, about 3,600 to 3,800 feet of thick, relatively pure evaporite beds (primarily salt and anhydrite) occur in the upper part of the sequence, in which the proposed waste isolation facility is to be constructed.

Because the Permian in the Delaware Basin and surrounding region has long been the subject of intensive exploration and study by both commercial and non-commercial interests, its subsurface and surface stratigraphy have become a relatively well understood aspect of a classic study area (e.g., King, 1942, 1948; Adams, 1944, Newell et al., 1953; McKee et al., 1967a, 1967b; Anderson et al., 1972; Brokaw et al., 1972; Jones, 1973).

Even so, problems in stratigraphic nomenclature still abound, particularly with regard to the more deeply buried basin sediments of the Lower Permian within the Delaware Basin.

Permian rocks are divided into four series (Adams et al., 1939), two of which (Wolfcampian and Leonardian) are equated with Lower Permian time and two (Guadalupian and Ochoan) with Upper Permian. The well-known massive reef deposits bordering the Delaware Basin were built up mainly during Guadalupian time; massive evaporite deposits were formed only during Ochoan time, between 225 and 250 million years b.p. (before present). Regional correlations of the Permian are shown in Figure 3.3-3.

1) Wolfcampian Series

"Apparently sedimentation in the Permian Basin was continuous from Pennsylvanian time throughout Wolfcampian" (Meyer, 1966, p. 1); "major tectonic elements of Early Permian time in west Texas and southeastern New Mexico were inherited from the Pennsylvanian and continued to grow" (Oriel et al., 1967, p. 37). These regional generalities suggest the difficulty that has been experienced, at least basinward from shelves, in identifying the base of the Wolfcamp strata. An arbitrary convention in exploration practice in the Delaware Basin is to use the top of the Strawn to mark the top of the Pennsylvanian. If any Pennsylvanian strata are present above the Strawn, they are very similar to the overlying Wolfcampian Series and attempts have not normally been made to distinguish the two in the subsurface.

In the site area, the Strawn is overlain by a thick sequence of interbedded, dark-colored limestone and shale, including considerable dolomite. Sandstone is insignificant. No formational status has yet been designated for this interval; informally the sequence is sometimes called "Wolfcamp formation". It is known to markedly thicken southward with increasing shale and sand content toward the Val Verde trough, where extremely thick Wolfcampian strata are known. Toward the north, it thins and gains limestone content, suggesting a shelf margin facies. Foster (1974) indicates that at the WIPP site the shale content probably nearly

equals that of the carbonate. Isopachs presented in Foster (1974) indicate slightly less than 1,400 feet of Wolfcampian strata beneath the site, whereas Meyer (1966) shows between 1,000 and 1,100 feet; the latter value excludes some rocks above the Strawn. A regional map by McKee et al., (1967a) appears to indicate nearly 2,000 feet. The nearest "pick", in the Badger Unit Federal Well, indicates 1,495 feet of Wolfcampian strata, 2 miles northeast of the center of site (Sipes et al., 1976). These differing values reflect the uncertainties in identifying lower and upper limits of subsurface Wolfcampian strata in the Delaware Basin.

2) Leonardian Series.

The Leonardian series of the Lower Permian Series is represented by basinal sandy equivalents of the Bone Springs Limestone, which was originally defined for a shelf and bank facies of the unit at the margin of the Delaware Basin. Both the name "Bone Spring" and "Bone Springs" have been used in the past, and both usages are found in the current literature. Originally defined as Bone Springs by Blanchard and Davis (1929), King (1948, p. 13) changed it to Bone Spring "to agree with the geographic term" of the type locality, which "is in the lower course of Bone Canyon below Bone Spring..." The U.S.G.S. Lexicon (Keroher et al., 1966) also gives Bone Spring Limestone, but states that it is "named for Bone Springs Canyon...," citing Blanchard and Davis (1929).

Conditions favoring significant buildup of reef and bank limestone at the edge of the Delaware Basin existed in Leonardian time (Victorio Peak Limestone), but development of by far the most extensive of these limestones occurred subsequently in Guadalupian time. Within the basin in the vicinity of the WIPP site, the Bone Springs interval thickens markedly and consists of alternating units of sandstone and dark-colored limestone, with a thick, slightly cherty limestone at the top. Three laterally persistent, very fine to fine-grained sandstone units are recognized as the first, second, and third Bone Springs sands. Shale is a minor constituent of the Bone Springs strata, but the limestone beds are commonly argillaceous.

Foster (1974) shows the WIPP site to be near a local center of maximum thickness of Bone Springs strata, about 3,500 feet. The unit becomes thinner to the east and northeast. The Badger Unit Federal well is indicated to have penetrated 3,427 feet of Bone Springs rocks.

3) Guadalupian Series.

The Delaware Mountain Group includes all basin facies rocks of Guadalupian age in the Delaware Basin, which at the site are composed mostly of sandstones interbedded with some dark shales and a few thin-bedded limestones. A dramatic facies change takes place about 10 miles north of the site, where the basin facies terminates abruptly against massive reef limestones. Because these reef limestones almost completely encircle the Delaware Basin, they seem to conveniently demark the structural limits of the basin, although earlier basin sediments of the Delaware Group extend some distance beneath, or behind, the latest and most massive of the reefs, represented by the Capitan Limestone. North of the site, these reefs are buried by later sediments but become progressively less deeply buried toward the west; west of Carlsbad they surface and form a bold escarpment that defines the eastern boundary of the Guadalupe Mountains, for which the Guadalupian Series was named.

During their earlier development, the reefs at first built upward at the margin of the basin, but during later development progressed outward into the basin as well. Thus, successively older formations of the basin facies of the Delaware Mountain Group have greater areal extent beyond the Delaware Basin as defined by the uppermost part of the Capitan reef. Like modern reefs, the lateral development of these Guadalupian reefs was accompanied by an appreciable vertical buildup of material, in some cases exceeding 1,000 feet, such that sediments being contemporaneously deposited in the basin now appear structurally to be correspondingly lower in the section, where in actuality they are time-stratigraphic equivalents. By the same token, the evaporitic materials (Ochoan evaporites) that later filled the basin now appear to some extent to be laterally equivalent to the reef masses. These stratigraphic relationships are especially well portrayed by Haigler (1962) and King (1948).

A thickness of 3,944 feet of Delaware Mountain Group strata is recorded 2 miles northeast of the center of the WIPP site. Surface mapping at the margins of the basin led to the recognition there of three formations; namely, in ascending order, the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations. Generally, petroleum exploration practice in the Delaware Basin has been not to attempt to define these formations in the subsurface. However, Foster (1974) provides a reference section showing stratigraphic positions of the formations of the Delaware Mountain Group in the Shell No. 1 James Ranch well about 3 miles southwest of the site, and Sipes et al. (1976) give similar "picks" in the Clayton W. Williams, Jr., well to the northeast of the area. Foster shows 3,970 feet of Delaware Mountain strata.

The Shell No. 1 James Ranch well lithologies indicate that the Brushy Canyon Formation is 1,540 feet thick and consists of mostly fine-grained, gray to brown sandstone with minor brown shale and dolomite. The Cherry Canyon Formation consists of 1,070 feet of sandstone similar to that in the Brushy Canyon Formation, interbedded with shale, dolomite, and some limestone. The Bell Canyon Formation, 1,180 feet thick, also consists mostly of fine-grained sandstone, but has a greater percentage of limestone, the result of closer proximity to the shelf-margin carbonates. A limestone member at the top of the Bell Canyon Formation, known as the Lamar limestone, is recognizable over a considerable part of the Delaware Basin. Basinwide the sands of all three formations are targets for hydrocarbon exploration. The top of the Delaware beneath the center of the site is contoured by Sipes et al. (1976) at minus 650 feet (depth 4,065 feet). It is overlain by evaporites of the Castile Formation.

4) Ochoan Series.

The Ochoan Series "includes perhaps the thickest and most extensive evaporite rock sequence in North America" (Oriel et al., 1967). It also contains, within the Salado Formation east of Carlsbad, extensive potash evaporite deposits which contain 65 percent of presently exploitable potash resources available within the United States (Jones, 1975).

All of the salt deposits and other evaporites of the Los Medanos area are restricted to the Ochoan rocks, of Late Permian age. The Ochoan rocks are entirely of marine origin, but have two unlike parts--a thick lower section of evaporite and a thin upper section of red beds (Jones, 1973). The lower section includes, in ascending order, the Castile, Salado, and Rustler Formations; the upper section is made up of the Dewey Lake Redbeds. Together the four formations have a maximum thickness of 3,600 feet, slightly more than 3,000 feet of which are evaporite beds of the lower three formations, which are composed dominantly of anhydrite and rock salt with minor amounts of gypsum, potassium evaporite minerals, carbonate rock, and fine-grained clastic material.

At the WIPP site, the Ochoan rocks are about 3,900 to 4,000 feet thick, of which 3,600 to 3,800 feet, or about 90 percent, are the evaporite sequence. Of the three evaporite formations, roughly one-half the total thickness belongs to the Salado. Both the underlying Castile and overlying Rustler are richer in anhydrite and poorer in rock salt than the Salado, and they provide this salt-rich formation with considerable protection from fluids which might be present in adjacent rocks (Jones, 1973). Jones (1972) provides lithologic percentages of the complete Ochoan evaporite sequence (Castile-Rustler), obtained from exploratory potash drilling, as follows: 59 percent halite and associated potash deposits; 33 percent anhydrite and gypsum, with glauberite and polyhalite; 6 percent carbonate rock (limestone, dolomite, magnesite) and 2 percent clastic rock (clays and silts).

Considered broadly, the evaporites represent a transitional zone between underlying reef and normal marine limestones (Guadalupian beds) and the overlying Dewey Lake which was deposited under brackish or restricted marine conditions (Jones, 1968). The floor of the Delaware Basin in early Ochoan time is generally estimated to have been at least 1,200 feet below the top of the Capitan reef, which almost completely encircled it, restricting southern access to the open sea and setting the stage for deposition of evaporites within the basin (Brokaw, et al., 1972).

Castile Formation

The Castile Formation is almost completely confined within the limits of the Delaware Basin (Oriel et al., 1967), the only evaporite formation so restricted. It gradationally overlies the Bell Canyon Formation (Brokaw et al., 1972).

Lithologically, the Castile is the least complex of the evaporite formations, being composed chiefly of anhydrite with a few interbeds of rock salt. Limestone is present in secondary amounts; clastic materials (siltstone, shale, sandstone) are notably absent. A lithologic summary by Jones (1972) lists 59 percent anhydrite and other sulfates, 30 percent halite and other chlorides, 11 percent limestone, dolomite, and magnesite, and no clastic rock for the Castile Formation, based on data from exploratory drilling. The rock is sparingly bituminous and yields a fetid odor. It has a faint to conspicuous lamination or banded structure involving a color change, a difference in texture, or a rhythmic alternation of bituminous calcite and anhydrite, bitumen and anhydrite, or anhydrite and halite in layers a fraction of a millimeter to a few centimeters thick. The color of the rock ranges from white to dark gray, becoming darker with increasing depth below the top of the formation (Jones, 1975).

In the subsurface, the Castile Formation, to use Jones' description, is readily divisible into three informal members by a salt-rich zone 200-400 feet above the base: a lower member composed chiefly of anhydrite, a middle member composed chiefly of rock salt, and an upper member composed chiefly of anhydrite. The three members are discrete, readily distinguished lithologic units that are laterally persistent over wide sections of the Delaware Basin. Near the margin of the basin, however, they merge into a single wedge-like mass of anhydrite that rapidly thins to a narrow tongue and extends across the basin margin for a few miles before thinning out in the southern part of the Northwestern Shelf.

As described by Jones (1973), the lower member of the Castile Formation is a well-stratified evaporite consisting of laminae of gray anhydrite and brownish-gray limestone in regular, rhythmic alternation. Some beds of laminated dark-gray and brownish-gray limestones, a few inches to several feet thick, are present at wide intervals in the lower and middle parts of the member, and there are a few thicker beds of massive gray anhydrite at long intervals. The member is 200-240 feet thick south of the site, but it thickens northward and reaches a thickness of at least 400 feet before merging with other members of the Castile to form a single unbroken mass of anhydrite adjacent to the Capitan reef mass.

The middle member of the Castile Formation, a salt-rich, tabular zone that forms a widespread, lithologically distinct stratigraphic marker, is 500-700 feet thick in the southern part of the Carlsbad potash area, but thickens northward and attains thicknesses of 800-1000 feet along a broad 2 to 3-mile-wide belt of deformation within the evaporite sequence paralleling the margin of the Delaware Basin (refer to Section 4.3.2.7). The member is predominantly rock salt, but it contains thin to thick layers of interlaminated anhydrite-limestone rock. The thickest of these layers averages about 100 feet, and it divides the member into two almost equally thick salt beds. The upper bed includes several interlaminated anhydrite-limestone layers, some of which are 2-5 feet thick, whereas the lower bed has none. This member terminates northward by grading laterally into, and intertonguing with, anhydrite.

The upper member of the Castile Formation exhibits greater lithologic complexity and is composed chiefly of anhydrite interlaminated and interbedded with calcitic limestone and, to a lesser extent, with massive anhydrite, rock salt, and carbonate rock, including both magnesite and dolomite. It contains a northward-thinning tongue of magnesitic anhydrite that overlaps the Capitan Limestone along the margin of the Delaware Basin and extends a few miles into the northwest shelf. Though 600-700 feet thick some distance south of the site, the upper member thins rapidly northward to as little as 170 feet near the margin of the basin. The nature of this northward reduction in thickness is, as

subsurface studies in the Carlsbad potash area and elsewhere in the Delaware Basin have shown, due both to a lateral gradation and to an intertonguing, or pinching out, of individual anhydrite beds at the top of the Castile into the rock-salt beds of the overlying Salado Formation, resulting in a northward stratigraphic descent of identifiable Castile anhydrite. These relationships demonstrate that the contact between the Castile Formation and the overlying Salado Formation is conformable and gradational; nevertheless, the contact at any particular location is generally rather sharply definable as the horizon at which dominant anhydrite below gives way to rock salt above.

A somewhat different classification scheme of the Castile Formation has been established by R.Y. Anderson and his co-workers. Working in the central and southern part of the basin with thin sections of cores obtained through special drilling arrangements made with industry operators, Anderson et al. (1972) divided the Castile into three separate halite members and four anhydrite members across the width of the Delaware Basin. Furthermore, they traced individual laminae in the anhydrite members over distances as great as 113 km. Each anhydrite-calcite couplet is believed to represent an annual varve, the nature of the evaporite precipitation being controlled by changes in the partial pressure of carbon dioxide in the Castile brine sea as the growth of brine algae waxed and waned with the seasons. Some 250,000 varve couplets are inferred, by representative counts, beginning below the Lamar limestone in the Bell Canyon and ending in the lower part of the Salado (Anderson et al., 1972).

Toward the northern part of the Delaware Basin, the upper halite and anhydrite units appear to converge and cannot be traced basinwide as major units. In the site area two lower anhydrite members (AI, AII) and two halite members (HI, HII) are recognized as basinwide equivalents of units identified elsewhere; a more heterogeneous upper unit, principally anhydrite, corresponds to the position of Anhydrite IV but may not be stratigraphically equivalent to it (Anderson et al., 1972; Anderson and Powers, 1978; Anderson, 1978). These anhydrite and halite members are

identified on Figure 4.3-2. Thicknesses are taken from isopach maps which appear in Anderson et al. (1972) and Anderson, (1978). Thus, the lower anhydrite (Anhydrite-I) member is indicated to be nearly 250 feet thick in the vicinity of the WIPP site; Halite-I, about 330 feet thick; Anhydrite-II, 100 feet thick; and Halite-II, 210 feet thick. The remainder of the total thickness of the formation is occupied by the upper anhydrite described by Jones (1973), as quoted above. Jones' middle halite unit is equivalent to Anderson's Halite-I plus Anhydrite-II plus Halite-II sequence; Anderson has simply subdivided the sequence based on the presence of a middle anhydrite member (Anhydrite-II) that Jones also recognized (see above). Both Jones and Anderson recognize that here the upper anhydrite unit does not display the varved interlaminations comparable to those observed in the lower anhydrite units.

The only major disagreement between Anderson and Jones appears to center around the nature of the Castile-Salado contact. Jones asserts that the contact is conformable and laterally intertongues (see discussion above), whereas Anderson believes an unconformity exists. Anderson (1978) cites as evidence for this the presence of some dissolution breccia near the top of the Castile, suggesting a period of non-deposition or even subaerial erosion. Furthermore, Halite-III is missing over the northern part of the basin, which could be explained by a local erosional episode there. Anderson also notes that the basal infra-Cowden salt of the Salado Formation (see below) does not occur to the south and is thickest wherever the Halite-III member is absent. This controversy has not been resolved to date; whether or not significant dissolution took place during deposition of the Castile and Salado evaporite sequence could have important implications regarding models invoked to estimate past and present rates of salt dissolution in the Delaware Basin.

Because no drill hole within Zones I-III of the WIPP site has made a complete penetration of the Castile, the thickness of the Castile beneath the repository must be estimated. Beneath the site, the base of the Castile is indicated by structure contours in Figure 10 of Jones (1972)

to be at an elevation of about minus 680 feet MSL at the center of the site; Sipes, et al. (1976) show it at minus 650 feet MSL. Since ERDA-9 intersected the top of Castile at elevation 579 feet above sea level, the Castile is indicated to be about 1,230-1,260 feet thick at the site, or approximately 1,250 feet thick. Drill hole AEC-8 encountered 1,333 feet of Castile in section 11, about 4 miles northeast of ERDA-9 (Griswold, 1977, Table III).

b) Salado Formation. The Salado Formation contains the thick salt beds in which the contemplated WIPP repository would be constructed. It is one of the principal deposits of halite on the North American continent (Brokaw, et al., 1972, p. 21), and it contains the Carlsbad potash enclave, the principal producer of potash in the United States.

As of the date of this report, one core hole, ERDA No. 9, has been drilled through the Salado at the location of the proposed repository. A schematic section of that hole, including general lithology, location of marker beds, position of halite zones in which the repository will be located, and well construction data, is given in Figure 4.3-3a. The detailed lithologic log is included as Figure 4.3-3b of this report. Details of the numerous down-hole logs performed, mineralogical and geochemical determinations made, and rock mechanics tests conducted are not discussed here but are given in Chapters 7 and 9 of this report, to which the reader is referred.

At the ERDA-9 location at the center of the site, the base of the Salado is 2824 feet and the top 848 feet below ground surface (elevations 590 and 2,566 feet above sea level, respectively), for a total thickness of 1,976 feet. The proposed contact handling (CH) zone halite interval, containing halite of relatively high purity, is between elevations 1,250 and 1,352 feet, and the remote handling (RH) zone, high-purity halite interval between elevations 696 and 806 feet. (Ground surface elevation at the ERDA-9 hole location is given as 3414.70 feet MSL).

Variations in the thickness of the Salado in the vicinity of the WIPP site are on the order of 300 feet (1,700 to 2,000 feet), based on results of the AEC and ERDA test holes (Griswold, 1977, Table III). Thicker sections of the Salado (over 2,300 feet) are known where it may have been affected by deformation due to salt flow. West of the site in the Nash Draw area the thickness of the formation locally and erratically decreases owing to local solution and removal of rock salt in the upper part of the formation (Vine, 1963; Jones, 1973). These variations are illustrated by a subregional isopach map of the Salado Formation presented by Brokaw et al. (1972).

As discussed by Brokaw et al. (1972),

> "In exposures of the Salado Formation along the west side of the Carlsbad potash area (10 or more miles west of the site), all the salt has been removed by solution and the anhydrite and polyhalite have been altered to gypsum. The alternation of the evaporite rocks extends to depths ranging from 260 feet to almost 1,600 feet below the surface and is responsible for a fourfold to sixfold reduction in the thickness of that part of the Salado and for a change in composition from dominantly rock salt in the subsurface to dominantly gypsum in the outcrop. The contact between the two highly dissimilar parts of the formation, known locally as the 'base of leached zone' and also as the 'top of salt', is highly irregular, with many closed depressions and isolated pinnacles. The contact dips generally eastward but rises in stratigraphic position from the base of the Salado near the west side of the potash area to the top of the formation near the Eddy-Lea County line at the east side of the area."

Figure 8 of Brokaw, et al. (1972) shows the location of the contact at the top of the Salado, or in other words the easternmost extent of dissolution in the Salado, to be located about 1 mile from the east edge of Range 30 E.; that is, about 2 miles west of the center of the WIPP. Additional discussion of solutioning is discussed in Section 6.3.7 of this report.

Broadly considered, the Salado is characterized by a predominance of rock salt compared to a predominance of anhydrite in the Castile and by typically thinner bedding or interbedding of lithologic units. Unlike the Castile, the Salado as well as the overlying Rustler extends over and beyond the confining Capitan reef masses to the north and east, in effect

overfilling the ancient basin formed by the reefs. The Salado sea was, in general, even more saline than the sea of Castile time. Lacking a shield of carbonate reefs, it received, however, considerable fine clastic sediment. Consequently, its halite deposits are generally less pure than those of the Castile (Brokaw et al., 1972), although thick intervals of highly pure halite are known in the lower half of the Salado Formation.

A detailed description of the overall lithology and member units has been provided by Jones (1973), who studied data from the numerous potash exploratory holes drilled in the Los Medanos area. The remainder of this section incorporates Jones' description, modified where appropriate by discussion of more recent data from ERDA-9.

The Salado Formation is composed of rock salt, anhydrite, and potassium rocks with varying amounts of other evaporites and fine-grained rocks. Rock salt constitutes about 85-90 percent of the formation except in the western part of the area where percolating ground water has dissolved and removed some of it. The next most abundant rock in the formation is anhydrite. The remainder of the formation is chiefly polyhalite and other potassium and magnesium-bearing minerals with minor amounts of sandstone, and claystone.

The rock salt in the Salado is composed of halite and clayey halite in discrete layers ranging from an inch to several feet in thickness. The two rock types differ primarily in that the halite is free of detrital debris and the clayey halite characteristically contains this debris in significant but typically small amounts. The detritus is chiefly quartz and clay, including illite, chlorite, and a corrensite-type of swelling, regular mixed-layered clay mineral (Grim et al., 1960). In general, the detritus-bearing clayey halite is mostly brown and tan; it is moderately crystalline but somewhat porous with a scattering of small cavities or vugs filled with clay and other detritus, and it either lies between seams of claystone or has a layer of halite below and a seam of claystone

above. The halite is typically reddish orange but its color grades to amber, gray, and white. It is generally somewhat more coarsely crystalline than the clayey halite.

Common to both the halite and the clayey halite in the rock salt of the Salado are traces to very minor amounts of polyhalite and anhydrite. Locally, glauberite is present in small amounts, and there are several potassium and magnesium minerals, including sylvite, carnallite, kieserite, and several other exotic evaporite minerals that occur in small to large amounts in seams of rock salt in the middle and upper parts of the formation. Other constituents of the halite and clayey halite include traces to very minor amounts of brine and gas that fill microscopic to very small cubic and rectangular cavities in grains of halite and other evaporite minerals. Less common, but more notable in other respects, are much larger cavities or pockets that contain halite-saturated brine and nitrogenous gas confined under presure sufficient to produce "blow-outs" when encountered during drilling operations.

The seams of anhydrite and polyhalite, which alternate with rock salt in all sections of the Salado, are very persistent but highly variable in composition (Jones, 1954; Jones, 1972). Lateral replacement of anhydrite by polyhalite is common, and nearly all seams show one or more stages of replacement between an initial slight development of polyhalite in the lower and upper parts of the seam to complete replacement of anhydrite by polyhalite. Locally, anhydrite and polyhalite give way laterally to glauberite, and polyhalite in the middle and upper parts of the Salado is replaced by hartsalz consisting of a coarsely crystalline mixture of anhydrite, kieserite, and carnallite.

Close examination of the Salado in drill cores and geophysical logs of boreholes in the Los Medanos area and vicinity reveals that rock sequences show a regular order of succession. A typical sequence, repeated many times between the base and top of the formation, involves a change from claystone upward through anhydrite or polyhalite and halite

to clayey halite capped by claystone. In other sequences the change is from halite to clayey halite capped by claystone. Boundaries between individual members of a rock sequence are gradational, but those along the lower and upper sides of the individual sequences are corrosion surfaces that form sharp, clear-cut breaks in the evaporite section but, nevertheless, are laterally persistent and convergent northward. The rock sequences represent a fundamental sedimentation unit or evaporite cycle, and they are believed to record discrete periods of influx and subsequent precipitation of calcium sulfate and soldium chloride during evaporation of sea water or an initially dilute brine. The ubiquitous claystone is thought to be a residue concentrated during dissolution of clayey halite by inflowing sea water or dilute brine.

The Salado Formation is divided into three members (Figure 4.3-3), but more subtle divisions can be made, for the beds are very persistent. In fact, the persistence of individual beds is the prime basis for the system of numbering individual seams of anhydrite and polyhalite which was introduced by geologists of the United States Geological Survey (USGS), such as Jones (1960) and is widely used by mining companies in the Carlsbad potash field. The numbers used in the USGS system to designate some seams of anhydrite and polyhalite in selected parts of the three members of the Salado are shown on Figure 4.3-3, and on Figures 4 and 6 of Jones (1973).

The threefold division of the Salado used herein includes: an unnamed lower member, a middle member known locally as the McNutt potash zone, and an unnamed upper member. The three members are about equally rich in rock salt, anhydrite, polyhalite, and fine-grained clastic rocks, and they are generally similar in all but one major respect. The lower and upper members are generally lacking or poor in sylvite, carnallite, and other potassium- and magnesium-bearing minerals, while the McNutt potash zone is generally rich in these minerals and accounts for the large and extensive deposits in the potash field.

Lower Member. Located below Marker Bed 126, the lower member of the Salado is the rock unit in which it is proposed to place both levels of the repository. As shown in Figure 4.3-3, the CH-zone is defined as the interval between Marker Beds 137 and 139 near the middle of the lower member, 560 feet above the base of the Salado. The RH-zone is in a zone devoid of nearby polyhalite marker beds, beneath a prominent anhydrite bed known as the "Cowden anhydrite." The top of the RH-zone is 344 feet below the base of the CH-zone; its base is 106 feet above the base of the Salado. The choice of zone intervals was made on the basis of combined purity, depth, thickness, mutual separation, and depth below the potash zone (Griswold, 1977).

The Cowden anhydrite identified above forms a distinctive, areally extensive bed of anhydrite about 20 feet thick below which is a salt bed of exceptional purity. This thick salt bed lying below the Cowden and above the Castile-Salado contact is sometimes referred to as the "Infra-Cowden", a sub-member located at the base of the Salado as shown in Figure 4.3-3. It is 296 feet thick at ERDA-9.

Lithologic details of each of the three members in the site area are provided by Jones (1973). The lower member of the Salado Formation is almost entirely made up of alternating thick seams of rock salt and thinner seams of anhydrite and polyhalite. Magnesite in thin bands, laminae, and ragged knots form a carbonate-rich zone in the lower part of most anhydrite and polyhalite seams. Seams and partings of claystone underlie the anhydrite and polyhalite seams, and claystone caps layers of clayey halite in the rock salt. There are also a few beds of very-fine-grained halitic sandstone, a few inches to a foot or so thick, near the base and top of the member. Insofar as has been determined by drilling, the member is completely free of carnallite and other hydrous potassium and magnesium evaporite minerals in all parts of the Los Medanos area, but the upper part contains traces to small amounts of these minerals several miles to the north of the area.

The lower member is 1,195 feet thick as recorded in ERDA-9. The member thins to 430 feet near the northeast corner of the area; in this instance the decrease of thickness seems to be due to beds missing at the corrosion surfaces that truncate individual rock sequences, as well as to thinning of all beds northeastward. Southward, the lower 240-300 feet of the member (that is, the Infra-Cowden) grades, according to Jones (1973), by intertonguing into the upper part of the Castile Formation, and the thickness of the member decreases to between 785 and 950. Anderson (1978) diragrees with the concept of an intertonguing lithofacies relationship between the Infra-Cowden salt and Castile anhydrite. He asserts that the Infra-Cowden wedges out southward and that the top of the Castile is unconformable with the Salado because of dissolution at or near the top of Castile prior to Salado deposition (refer to discussion above). Anderson (1978) presents an isopach map showing distribution of Infra-Cowden salt across the northern part of the Delaware Basin.

McNutt Potash Zone. The McNutt potash zone, located between the Vaca Triste halitic sandstone and the 126-marker bed, is another salt-rich member of the Salado Formation. However, unlike other members of the Salado, the McNutt may contain potassic rocks rich in sylvite, langbeinite, and hydrous evaporite minerals. The potassic rocks occur at short to long intervals in seams of rock salt scattered through nearly all parts of the McNutt zone. They are the obvious lithologic feature by which the NcNutt is distinguished, yet they are absent locally and, at best, probably comprise only 3 to 5 percent of the member in the most potassium-rich sections of the Los Medanos area.

Apart from the potassic rocks, the McNutt presents virtually the same aspect as other members of the Salado. Thick seams of rock salt alternate with thinner seams of anhydrite and polyhalite. There are partings of claystone beneath most anhydrite and

polyhalite seams and above layers of clayey halite. A bed of very-fine-grained halitic sandstone, the Vaca Triste, a foot or so thick, occurs in clayey halite at the top of the member.

The McNutt potash zone is 369 feet thick at ERDA-9, decreasing in thickness to the northeast. This decrease is similar in nature to that observed for the lower member. As a rule, where the member is thinnest it seems to be more thinly bedded and to have fewer beds.

Upper member. The upper member of the Salado, located above the Vaca Triste marker, consists of rock salt, minor anhydrite and polyhalite, and two persistent beds of very-fine-grained halitic sandstone, which are, respectively, 30-40 feet and 110-115 feet below the top of the unit. Claystone underlies seams of anhydrite and polyhalite, and coats the upper surfaces of clayey halite layers in the rock salt. Most parts of the upper member are generally free of hydrous evaporite minerals, but, nevertheless, some intervals of rock salt and other rocks in the upper 130 to 180 feet of the unit commonly contain traces to very small amounts of carnallite and kieserite.

Of particular interest is the occurrence of carnallite at the top of the upper member. The carnallite forms a major deposit of potassic rock that extends over a wide section in the northern part of the Los Medanos area and much of the region immediately to the north. The deposit is the only one known to occur in the upper member of the Salado, but is not restricted to the unit. It extends irregularly upward into sandstone of the overlying Rustler Formation.

At the WIPP site, the upper member of the Salado Formation is 512 feet thick (ERDA-9), becoming thinner (between 430 to 480 feet) farther north. This thinning northward seems to be partly depositional and partly erosional, for the member is more thinly bedded in the north and contains fewer beds. Many seams of anhydrite, polyhalite, and other evaporites are only about

three-fourths as thick as at the south end of the area. Beds of halite and clayey halite are missing beneath many of the corrosion surfaces that separate rock sequences in the unit.

Several miles west of the site in the Nash Draw area, variations in thickness of the upper member are fairly complex and large. The complexity and thickness of the member are believed to reflect a combination of geologic factors involving mostly (1) gradual thinning northward in response to changes in deposition patterns during the Ochoan Epoch, and (2) rapid thinning westward in response to change in dissolution patterns during the Pleistocene and earlier parts of the Cenozoic Era. In contrast to the modest northward thinning, the westward thinning of the member toward Nash Draw involves as much as a fourfold reduction in thickness in a distance of 4 to 6 miles, and the member is as thin as 150 to 170 feet at places along the west side of the area. This small thickness is considered to include the residue or remnants of at least a 450- to 500-foot-thick section of rock from which soluble salts have been leached by percolating ground water. The section of rock from which salts have been leached decreases in thickness eastward and feathers out in the area immediately east of Nash Draw. Insofar as can be determined from drilling records, the feather-edge of the residual materials marks the easternmost extent of dissolution of the upper member of the Salado Formation at any time. Apparently the regime here is highly stabilized and of long duration, with very little or practically no dissolution since the Pleistocene, or perhaps earlier. Estimates prepared by Bachman and Johnson (1973) indicate that the rate of salt removal during dissolution may amount to as much as 0.5 foot per 1,000 years. This rate suggests that roughly 1 million years would be required to reduce 450 to 500 feet of the upper member to an insoluble residual debris, and that dissolution in the western part of Los Medanos area has a long history extending back at least as far as mid-Pleistocene time. Other considerations, however, suggest that its history is even longer and may have begun by the mid-Tertiary (Bachman, 1976).

In all parts of the Los Medanos area, where the upper member of the Salado is thinned by dissolution, the section of rock between the upper surface of salt and the upper surface of the formation is composed of clay with crudely interlayered seams of broken and shattered gypsum and fine-grained sandstone. The clay is considered to be a subsurface residue concentrated through dissolution of clayey halite and other clay-bearing evaporites by percolating ground water. The gypsum is clearly the hydrated remnant of anhydrite and polyhalite seams, for it commonly contains ragged and embayed masses of anhydrite and polyhalite, and also grades laterally into anhydrite and polyhalite. The clay, gypsum, and sandstone comprise a fairly distinct residual unit that thins out eastward by grading into, and intertonguing with, rock salt and the other precursory rocks from which it originated. The residual unit thickens westward and crops out locally along the Pecos River west of the Los Medanos area. The unit is generally assigned by geologists mapping areas along the Pecos River to the lower member of the Rustler Formation, but this practice should be discontinued, for the clayey residue is clearly part of the Salado Formation.

Isopach maps of intervals in the upper member and in the McNutt potash zone are shown in Figures 4.3-4 through 4.3-7 referenced to the marker beds indicated. The same gradual northward decrease in thickness at the rate of about 10 to 15 feet per mile is exhibited by all four intervals contoured. It is significant that pronounced westward thinning of the Salado, which would be related to dissolution of salt from the Salado toward the Nash Draw area, is evidenced only in the uppermost interval (figure 4.3-7), and then only in Range 31 E., a mile or more west of the proposed WIPP repository boundary. The onset of westward thinning of the Salado Formation as defined by these isopach countours delimits a "suberosion" front at the top of the Salado (Griswold, 1977; Brokaw, et al., 1972; Jones, 1973) or the leading edge of a wedge of dissolution in the Salado progressing from west to east. This indicates that, insofar as can be detected by isopach patterns,

leaching of salt at the top of the Salado Formation by dissolution activity centered in the Nash Draw area has not occurred closer than approximately 1 mile west of the proposed WIPP repository.

In the Los Medanos area, the Salado Formation is overlain conformably by the Rustler Formation. The contact between the two formations is rather sharply defined as the horizon at which dominant rock salt below gives way to a 35- to 55-foot-thick unit of fine-grained sandstone that is generally dolomitic in the basal few feet.

Rustler Formation. The Rustler Formation, the uppermost or last of the three Ochoan evaporite formations, contains the least quantity of rock salt and the largest proportion of clastic material in this evaporite sequence. It was deposited in the last stages of the saline Permian sea that inundated the Delaware Basin, and is very largely coextensive with the Salado in this area (Brokaw et al., 1972). Jones (1972) lists lithologic percentages in the Rustler, presumably from areas in the Delaware Basin where Rustler salt has not been leached, as follows: 43 percent rock salt and other halides, 30 percent anhydrite, polyhalite, gypsum, and other sulfates, 17 percent clastic rocks, and 10 percent dolomite, limestone, and magnesite.

Shallowest of the evaporites to be exposed in the site area, the Rustler Formation crops out locally about 5 miles west of the center of the site, beyond the Livingston Ridge escarpment which forms the east edge of Nash Draw (refer to Figure 4.2-4, Surficial Geologic Map) Generally it is covered by alluvial material, sand dunes, or collapse debris.

The following descriptions of the Rustler are given by Jones (1973). As typically exposed in outcrop, the Rustler is a broken and somewhat jumbled mass of gypsum with minor dolomite and a few crude seams of virtually unconsolidated sands and clays. The outcrops in Nash Draw are decidedly poor for any study that requires precise information on the lithology, thickness, or specific chemical or physical properties of the

formation, and, as previously noted by Vine (1963), it is impossible to piece together a meaningful stratigraphic section from study or mapping of outcrops. Exposed rocks are porous, friable, and loose-textured, and all are strongly jointed, cavernous, and locally brecciated. Stratification is obscured or completely obliterated, and the attitude of bedding can rarely be determined with any degreee of confidence. The considerable deformation attests to the removal of much soluble material by percolating ground water and to the altered nature of the debris exposed in outcrop.

Two areally persistent beds of dolomite in the Rustler serve as important marker beds. The lowermost of the two dolomite beds, normally 100-150 feet above the base of the formation, is known as the Culebra Dolomite member. The upper bed, 200-250 feet above the base, is the Magenta Dolomite member. They were named and described by Adams (1944) Clastic rocks, consisting of thin to thick beds of sandstone and claystone, make up the remainder of the less soluble part of the formation.

In the subsurface, proceeding eastward across the WIPP site and into Lea County, all the gypsum in the Rustler gives way to anhydrite and minor polyhalite, and the sands and clays grade into sandy and clayey rock salt. In western Lea County at depths of 900-1,000 feet, the Rustler is largely an alternation of thick seams of rock salt and anydrite. A persistent seam of polyhalite occurs near the middle of the formation, and, insofar as has been determined, it is the only hydrous evaporite rock of any great extent or major importance in the stratigraphy of the formation.

With the eastward, down-dip change in composition from gypsum to anhydrite and rock salt, the thickness of the Rustler also changes rather significantly. The thickness ranges between 280 and 300 feet near the Nash Draw outcrop , but increases eastward to 490 feet about 10 miles southeast of the site and to 385 feet about 10 miles to the northeast. The increase ranges in amount between 105 and 160 feet and provides a crude measure of the minimum thickness of rock salt that is missing in

the area of outcrop. The difference in formation thickness between the southeast and northeast corners of the area is probably depositional in origin, for the formation is more thickly bedded in the southeast where it is thickest (Jones, 1973). These relationships are shown on a Rustler isopach map in Brokaw, et al. (1972).

In the immediate site area, the Rustler is lithologically divisible into a sandy lower part and an anhydritic upper part (Jones, 1975). The sandy lower part, 92 to 125 feet thick, is dominantly very fine-grained, silty sandstone, with less abundant anhydrite and rock salt; the sandstone is halitic and light to dark gray in its lower section and reddish brown and salt-free in its upper section. The anhydritic upper part of the formation, 200 to 227 feet thick, is largely gray anhydrite, with a few interbeds of reddish-brown clay and gray dolomite. The anhydrite is in fairly massive beds which have gypsiferous rinds along their lower and upper sides.

At the proposed WIPP site, ERDA-9 encountered 310 feet of Rustler commencing at a depth of 550 feet (refer to Figure 4.3-3). The Culebra and Magenta members were both encountered and measured at 26 and 24 feet thick, respectively. The thickness of the formation as a whole would indicate that much of the halite originally contained in the formation has been leached away, particularly in the upper part of the formation. The detailed well record of ERDA-9 (Griswold, 1977) shows that clayey halite was encountered in the Rustler below the Culebra dolomite, about 100 feet above the base of the formation. Between this position downward to the proposed upper level CH-storage zone, over 1300 feet of undisturbed evaporite rock, primarily Salado rock salt, intervene.

An isopach map of the Rustler Formation is shown in Figure 4.3-8. The closely spaced contours at the east edge of the site are a measure of the increasing amount of salt remaining in the Rustler in the eastward direction. The formation increases in thickness eastward and southeastward by about 180 feet over a distance of about 2.7 miles, or over 65 feet per mile. As with the Salado Formation, these contours can be used to postulate a dissolution front in the Rustler.

The Rustler Formation is separated from the overlying Dewey Lake Redbeds by a sharp lithologic break, an abrupt change from gray anhydrite to reddish-brown mudstone. The anhydrite below the break is free of sand and clay, and it ranges erratically in thickness from 18 to 32 feet. There is no indication of northward thinning, such as that common to most, if not all, rock units in the Rustler and underlying Salado Formations, and it would appear that the contact between the Rustler and Dewey Lake is an unconformity. The discordance and hiatus is probably not very great.

Dewey Lake Redbeds. The Dewey Lake Redbeds are the uppermost of the Late Permian Ochoan Series of formations and represent as well the top of the Paleozoic in the Delaware Basin. The term "Dewey Lake" is synonymous with the term "Pierce Canyon" originally proposed by Lang (1935) and applied to the redbeds in the Nash Draw area by Vine (1963). Actually the assignment of the Dewey Lake to the Permian Ochoan sequence is somewhat arbitrary, being based on certain lithologic details and stratigraphic aspects, rather than any definitely demonstrable affinity. Like the underlying Ochoan evaporites, the Dewey Lake appears to lack fossils despite its marine origin. Bachman (in Jones, 1973), while acknowledging the customary age assignment of the formation, nevertheless feels "that the Dewey Lake of southeastern New Mexico may actually be Triassic in age." He does not state, however, whether he believes it might be of Early or Late Triassic age.

The Dewey Lake crops out in places along the west edge of Nash Draw where partial thicknesses are exposed (refer to Surficial Geologic Map, Figure 4.2-4), but generally the formation is mantled by dune sand and caliche. Beneath the surficial cover, however, the Dewey Lake occupies a broad band between the center of the WIPP site and Nash Draw. It is bounded on the west by gypsiferous residue of the uppermost anhydrite seam in the Rustler Formation and on the east by coarse-grained clastic rocks of the Santa Rosa Sandstone of Late Triassic age. The latter contact occurs approximately across the center of the WIPP site.

The Dewey Lake is differentiated from other formations by its lithology, distinctive reddish-orange to reddish-brown color, and sedimentary structures. The formation consists almost entirely of an alternation of siltstone and very-fine-grained sandstone beds a few inches to several feet thick, but there are a few beds of claystone in its lower and upper parts. Individual beds are persistent, and the formation is readily separable on well log records into several sequences alternately richer or poorer in sandstone. Surficially, most rock is evenly and thinly bedded, liberally sprinkled with greenish-gray spots, and irregularly intruded by horizontal and criss-crossing veins of fibrous selenite. Some beds are structureless, whereas others are either horizontally laminated or cross-laminated. Many bedding surfaces carry shallow current or oscillation ripple marks. Silt-filled mud cracks occur at the top of many mudstone layers, and there are small chips and flattened pellets of mudstone in the basal part of many siltstone and sandstone layers (Jones, 1975).

According to Vine (1963), the Dewey Lake Redbeds represent the beginning of continuous deposition of detrital sediment following the long period of predominantly evaporite deposition in the Delaware Basin and adjacent shelf areas of southeastern New Mexico. However, the abrupt change in lithology does not necessarily signify a sudden tectonic or eustatic movement, but only a gradual decrease in the salinity or depth of the water plus a new source for the detrital sediments which were deposited.

Certain general features of the Dewey Lake are especially noteworthy. The lithology and color appear to be remarkably uniform. Viewed from the distance of a few feet, the stratification nearly always appears to be parallel, even though small-scale cross-lamination may be seen on close inspection. The small grain size, together with the minute scale of primary sedimentary structures, such as cross-lamination in sets less than 1 cm thick and oscillation ripple marks less than 1 inch from crest to crest, suggests that the silt was deposited in extremely shallow water extending over a broad flat. Lenses of medium-scale, cross-laminated, fine-grained sandstone or siltstone in the upper part of the Dewey Lake

probably indicate a gradual change toward fluvial deposition near the end of Dewey Lake time. The deposit undoubtedly blanketed the Delaware Basin and part of the shelf area to the north, but the source of the sediment is unknown.

The ERDA-9 well records a thickness of 487 feet of Dewey Lake strata. The thickness varies greatly across the area, however, from about 550 feet a few miles southeast of the site to 100 feet a few miles to the southwest (refer to isopach map, Figure 4.3-9). Normally in this area, the Dewey Lake ranges betwen 500 and 560 feet in thickness, thinning to the northwest. This northwestward thinning is attributed to pre-Late Triassic erosion after the redbeds had been tilted southeastward (Jones, 1973, p. 25). Locally, however, where the Dewey Lake forms the surface of either pre-late Tertiary terrain or Quaternary terrain, erosion later than Triassic has cut through the Dewey Lake, producing the steepened isopach gradients. In Figure 4.3-9 the gradients of 20 to 40 feet per mile observable in the eastern half of the map reflect pre-Late Triassic erosional thinning, while the steeper dips of up to 150 feet per mile to the west represent later dissection, apparently related to the origin and development of Nash Draw. A geologic section given by Jones (1973, Figure 3) illustrates the effect of this later dissection on the Dewey Lake surface.

4.3.3 Mesozoic Erathem

Triassic System. Triassic rocks in the northern part of the Delaware Basin are all Late Triassic in age and are included in the Dockum Group. The Dockum is entirely of continental origin and consists of the dominantly fine sediments of broad flood plains and coarse alluvial debris deposited over a very broad area extended beyond the borders of the Delaware Basin. It surfaces the pre-Tertiary terrane at and east of the WIPP site. Local subdivisions of the Dockum Group are the Santa Rosa Sandstone (Darton, 1922) and the Chinle Formation.

J) Santa Rosa Sandstone

The Santa Rosa Sandstone rests unconformably with sharp lithologic contact on the underlying Dewey Lake Redbeds. Vine (1963), based on outcrop observation, called this contact a disconformity (that is, parallel beds on either side of the contact representing a time-rock gap), but Jones (1973) considers it "an angular unconformity of low angle." Corresponding to an interval between the end of Permian time and the start of Late Triassic time, this unconformity represents a break in deposition perhaps longer than had previously occurred in the region since Mississippian time or even earlier, assuming the assignment of the Dewey Lake Redbeds to the Permian is valid.

At the site, the Santa Rosa occurs as an erosional wedge pinching out westward just beyond the center of the site; a thickness of only 9 feet of Santa Rosa Sandstone was recorded at ERDA-9. Eastward the formation forms the pre-Gatuna surface (See Figure 2 in Jones, 1973) but is blanketed by such an extensive veneer of Upper Tertiary alluvial deposits and caliche, and Recent dune sand, that the nearest extensive outcrops occur about 7 miles to the north (Vine, 1963).

The wedge of Santa Rosa thickens relatively rapidly eastward at the rate of up to 150 feet per mile, attaining a maximum thickness of 250 feet over a distance of only two or three miles, thereafter maintaining a more uniform profile (refer to isopach map of the Santa Rosa, Figure 4.3-10). Sections compiled by Jones (1973) indicate a relatively uniform thickness of the Santa Rosa on the order of 250 feet at least as far as several miles east of the Lea County boundary. The steepened wedge effect of the Santa Rosa across the site area is undoubtedly due to the post-Late Triassic, pre-Gatuna erosion that cut downward into the Dewey Lake surface, which is discussed above (compare Figure 4.3-9).

The Santa Rosa Sandstone consists, for the most part, of cross-stratified, medium- to coarse-grained, gray to yellow-brown sandstone, but includes both conglomerate and reddish-brown mudstone. In

outcrop it has been observed by Vine (1963) to consist of large-scale, trough-type, cross-bedded, pale-red sandstone and conglomerate lenses, 3 to 15 feet thick, separated by thin partings of moderate reddish-brown siltstone and silty claystone. The conglomerate lenses contain both silty dolomite pebbles and chert or quartz pebbles. The sandstone is characteristically poorly sorted. The formation differs from the underlying Dewey Lake Redbeds by being coarser grained, less well sorted, and by having beds that are thicker and more lenticular. Fossil plant impressions, carbonaceous plant fragments, and fossil reptile bones and teeth thought to be from phytosaurs characterize some of the beds. Clay is a relatively minor constitutent in most of the Santa Rosa Sandstone. Secondary dolomite is the most abundant cement, and it probably constitutes at least 10 percent of the rock.

The Santa Rosa Sandstone represents a change in the environment of deposition as compared with the Dewey Lake Redbeds. The large-scale trough-type crossbedding probably indicates a fluvial environment. The lack of sorting, arkosic composition, and angularity of the grains suggests rapid deposition by streams descending from a predominantly crystalline terrain (Vine, 1963).

2) Chinle Formation

The Chinle Formation, though not present at the WIPP site itself, occurs at about the Lea County line 5 miles to the east, where it forms the subcrop surface of pre-Tertiary rock, as shown by Jones (1973). Like the Santa Rosa Sandstone at the site, in profile the Chinle is seen to wedge out from the east at the Lea County line, beveled by pre-Gatuna erosion. Farther east, the Chinle appears not to attain a thickness in excess of 100 feet as shown by Jones (1973). Northward, however, it achieves a thickness of about 800 feet near the Hat Mesa gas field, about 11 miles northeast of the site, where the Chinle is blanketed by Late Tertiary Ogallala Formation (Jones, 1973). These relationships plus the areal distribution of Ogallala remnants indicate that post-Chinle, pre-Ogallala erosion occurred subsequent to an eastward to northward tilting of at

least the northern part of the Delaware Basin, resulting in a greater amount of Chinle sediments removed progressively southward and eastward. Later, one or more erosional episodes beveled a westward-sloping surface on post-Ogallala terrain.

In lithology, the Chinle is dominantly reddish-brown shaly mudstone interspersed with some greenish-gray mudstone and minor lenses of sandstone and conglomerate, deposited in a floodplain or alluvial environment basically similar to that of the Santa Rosa. Its contact with the underlying Santa Rosa Sandstone is conformable and is at the change from sandstone of the Santa Rosa to shaly mudstone of the Chinle. It is overlain unconformably by the Ogallala Formation of Late Tertiary age.

Post-Triassic Rocks of Mesozoic Age. No Mesozoic rocks later than the Chinle strata are known to exist in the WIPP site area. According to Jones (1973), there are good reasons to infer from paleogeology and other considerations that the Jurassic Period was a time of erosion and removal of the Dockum. Some rocks of Cretaceous age, though absent from the site area, almost certainly were deposited by Early Cretaceous seas which advanced northward across southeastern New Mexico. Small outliers, crevasse deposits, and other remnants of Lower Cretaceous rocks are found lying unconformably on the Capitan, Tansill, and Castile Formations near Carlsbad Caverns (Hayes, 1964; Lang, 1937), on the Salado Formation near Black River Village, on the Rustler Formation a few miles northeast of Carlsbad, New Mexico, and on the Chinle Formation at many places to the north and east of the WIPP site area (Asn and Clebsch, 1961).

4.3.4 Cenozoic Erathem

Tertiary System. No Early or Middle Tertiary sedimentary rocks are known to be present in the region. A lamprophyre dike, the only igneous rock later than Precambrian age known in the region, is observed to intrude the Salado Formation at the Kerr-McGee potash mine, about ten miles north of the center of the WIPP site (refer to Figure 3.5-2). Part of a

northeast-southwest dike trend of regional extent, the closest approach of which is at least eight miles northwest of the center of the site, the dike is not exposed at the surface east of the Pecos River. A radiometric date of 30 million years for the lamprophyre has been in the record for some time (Urry, 1936); an Oligocene or mid-Tertiary age for emplacement is therefore indicated. Further discussion of this dike trend, including an account of more recent investigations conducted, is included in Regional Geology, Section 3.5.1.

In Late Tertiary time extensive alluvial fans carried sandy and gravelly material eastward over a broad erosional plain that had developed in the region by Late Miocene time. The sediments accumulated during this alluviation, which lasted until Late Pliocene time, constitute the Ogallala Formation. The youngest fauna present in the Ogallala Formation is of Kimball age. This fauna may be as old as 4.6 million years (Bachman, 1974).

Only one area occupied by the Ogallala is present within 10 miles of the site, namely, a relatively thin erosional remnant capping The Divide located between 6 and 9 miles east-northeast of the center of the site (refer to Figure 4.2-4, Surficial Geologic Map). A geologic map by Bachman (in Jones, 1973) indicates that the Ogallala at the Divide is restricted to elevations above 3750 feet, where it is about 25 feet thick and includes about 10 feet of conglomeratic sandstone at the base overlain by about 15 feet of caliche. Pebbles of rounded quartzite and chert as much as 1-1/2 inches in diameter are present in lenticular beds (Bachman, 1974).

Special attention has been given to the caliche developed on the Ogallala by Bachman (in Jones, 1973), who suggests that it may be distinct in origin from caliche observed elsewhere in the area. Based on field examination, he finds that

> "Caliche of the Ogallala Formation is a distinctive travertine-like calcium carbonate. It is dense, light gray to white, and composed of concentrically laminated fragments that range from less than one-half inch to more than 2 inches in diameter. Space between

> these fragments is filled with structureless or, in places, laminated limestone. The weathered surface appears algal or pisolitic in places. However, these concentric laminae probably are not the result of organic activity but indicate repeated generations of inorganic solution and reprecipitation. The caliche is sandy and has been precipitated in porous spaces between sand grains; therefore, individual sand grains appear to float in the caliche. The Ogallala caliche probably formed as a part of a soil profile that developed on the High Plains surface either during or after deposition of the Ogallala Formation."

In the High Plains to the east of The Divide, longitudinal depressions in the Ogallala caliche are interpreted to be interdunal swales caused by solution etching of Ogallala caliche where it was not protected by Pleistocene sand dunes (Bachman, 1976).

Quaternary System

1) Pleistocene Series

a) Gatuna Formation

The only Pleistocene deposit at the proposed WIPP site which has been assigned a formal stratigraphic name is the Gatuna Formation. In the immediate area, the Gatuna forms a thin blanket, locally absent, ranging in thickness from zero to slightly more than 30 feet (refer to Figure 4.3-11, Gatuna Isopach Map); at ERDA-9, 27 feet of Gatuna were recognized. In spite of its shallow depth below the surface, however, the Gatuna crops out only rarely, being for the most part obscured by a thin but persistent veneer of caliche and surficial sand. The nearest mapped outcrops occur along the west-facing slope of Livingston Ridge at the edge of Nash Draw (about four miles northwest of the center of the site; see Figure 4.2-4, Surficial Geologic Map) where they were mapped by Vine (1963), and to the southeast of the site as mapped by Bachman (1974). In Nash Draw itself the Gatuna locally exceeds 100 feet in thickness and fills sinkholes previously formed by dissolution of salt and other evaporites. It has alluviated most drainage valleys of an ancient Pecos system, of which Nash Draw was a part. Though the Gatuna is predominantly a fine-grained, reddish or brownish friable sandstone,

conglomerate lenses and blankets are common regionally. It is the pebbles in the conglomerate which have proved most useful in providing evidence relating to geologic history, age, and provenance of the formation.

Bachman (1974) discusses age, lithology, and paleoclimatic implications of the Gatuna at some length. Generally, the Gatuna was stream-laid under pluvial conditions. In some areas having fine-grained materials in the lower part of thicker sections, the Gatuna first filled collapsed basins and extensive sinks; in other areas, such as in the southern part of Nash Draw, gypsum-rich clays and silts in the section suggest deposition in areas then undergoing sinking and collapse. Based on examination of pebble clasts in Gatuna gravels of the Pecos River northwest of the site in Chaves and northern Eddy Counties (refer to Regional Geology and Regional Geomorphology sections for additional discussion of these gravels), Bachman concludes that the Gatuna was deposited in a much wetter climate than present. There is no indication that modern drainage is carrying clasts of the size and quantity preserved in Gatuna stream deposits. The discovery of Ogallala pisolitic debris (i.e., pebbles of Ogallala caprock caliche) in the Gatuna demonstrates that the Gatuna is Pleistocene rather than Pliocene in age. Futhermore, on the basis of the many stream and pond deposits in the Gatuna and the evidence for widespread solution and collapse, Gatuna time represents the most humid Pleistocene stage in southeastern New Mexico. Regional considerations lead Bachman to assign a tentative Kansan age to the Gatuna, or approximately an age of 600,000 years (Bachman, 1974).

b) Mescalero Caliche

Beneath an obscuring cover of wind-blown sand, much if not all of the site area, excluding some depressions and drainages such as Nash Draw, are covered by a hard, resistant caliche crust. It is very extensive to the north in Chaves County on the Mescalero plain between the Pecos River and the Llano Estacado and is informally called the Mescalero caliche. Though generally less than 10 feet thick in the site area, its resistance to weathering in the dry climate has effectively prevented natural

exposure of older strata and has allowed it to form extensive surfaces that can themselves be mapped in definite stratigraphic sequence with other deposits.

Vine (1963) provides a detailed account of caliche as he observed its occurrence in the Nash Draw quadrangle. He states,

> "Caliche is a near-surface accumulation of calcareous and clastic material that forms a resistant mantle. It is characterized by an excess of calcareous material over that required to cement the clastic grains, with the result that the grains appear to float in the matrix. In many areas the caliche is characteristically brecciated and recemented. In addition to sand and calcareous material, pebbles are locally abundant, and silica in the form of chalcedony or opal also forms part of the cementing matrix. Other soluble minerals, including gypsum, are probably locally present. Where the top surface of caliche has long been exposed to weathering, it almost invariably has a very hard dense limestone surface that could easily be misinterpreted as an outcrop of massive limestone similar to those in some older formations Close inspection, however, generally reveals sand grains, chalcedony, and brecciation. Commonly the dense layer at the top is only 1 or 2 feet thick, and the rock becomes more friable and shows a greater proportion of sand grains to matrix within a few feet of the surface. The less calcareous zone in turn grades downward within 5 or 10 feet into the underlying bedrock, which generally is broken into angular fragments recemented with calcareous material. (Note: five feet of caliche were encountered at ERDA-9.) In many areas caliche has concentric lamination or colloform structure resembling calcareous algal structures. The widespread mantle of caliche has much the same composition throughout the area regardless of whether the underlying bedrock is red sandstone and siltstone from the Gatuna Formation, Santa Rosa Sandstone, and Pierce Canyon (=Dewey Lake) Redbeds, or gypsum from the Rustler Formation."

Bachman (1974) shows a regional structure contour map of the Mescalero caliche. He confirms Vine's recognition of an upper dense zone over an earthy-to-firm nodular calcareous deposit, and notes that it is the upper dense caprock that is prominently laminated. The character of the laminae indicates that the Mescalero caliche arose through successive cycles of dissolution and reprecipitation of the matrix, and that this occurred during an interval of tectonic stability that followed deposition of the Gatuna Formation--that is, in the semiarid environment that followed the moist conditions of Gatuna time. Based on regional geomorphic considerations, Bachman correlates the formation of the

Mescalero caliche with the Yarmouthian interglacial stage, or mid-Pleistocene time, about 500,000 years ago. Brown (1956) reached generally similar conclusions on the origin of caliche he studied on the Llano Estacado of the Texas panhandle, where he found that "the caliche, with interruptions, apparently has been forming continuously since its inception in the Pliocene, and its multiple occurrence is a reflection of climatic variations in the Pliocene and Pleistocene". Noting that the Mescalero caliche dips abruptly into Nash Draw along Livingston Ridge, Bachman (1974; also in Jones, 1973) concludes that Nash Draw was subjected to subsidence after the formation of the caliche, presumably during the more pluvial conditions of the subsequent Illinoian or Wisconsin glaciations.

2) Recent Deposits

Deposits of Recent age in the vicinity of the WIPP site include windblown sand, alluvium, and playa lake deposits.

The most prevalent deposit by far is the windblown sand which covers nearly all of the area of the WIPP site itself. The sand, locally known as the Mescalero sand (Vine, 1963), occurs either as a sheet deposit resting on caliche or as tracts of conspicuous dune fields (Los Medanos). In the former case, the sand is probably no more than 10 to 15 feet thick on the average; in the latter, the sand may attain 100 feet in thickness locally. At many places the sand consists of two parts: a compacted, slightly clayey moderate-brown eolian sand up to 1-1/2 feet thick, overlain by loose, windblown light-brown to light yellowish-gray sand. The sand dunes appear to be relatively inactive at present, partly stabilized by sparse plant cover. The widespread deposits of windblown sand are indicative of a large source of fine sand as well as of the extreme fluctuations of climate that have occurred during Pleistocene time. There is very little evidence that much sand has been derived from the Pecos River. Bachman (1974) suggests that most sand has been derived from deposits of the Ogallala Formation. During humid intervals in Pleistocene time the sand has been eroded from the Ogallala, and during arid intervals the wind has moved this sand across the Mescalero plain.

Deposits of alluvium are mapped by Vine (1963) generally in belts 1/4 to 3/4 of a mile wide along the base of declivities into Nash Draw, as along the base of Livingston Ridge, and locally in smaller depressions (refer to Figure 4.2-4, Surficial Geologic Map). These deposits are similar to sheet wash or small alluvial fans, and Vine considers them analogous to pediment or bolson deposits.

Playa deposits occur in mudflats, and consist of eolian sand and alluvium reworked by shallow-lake waters. Vine (1963) shows these areas clustered mostly within Nash Draw, where the occasional runoff accumulates. The nearest playas are mostly small, circular areas about 5 miles west of the center of the site filling in the bottoms of sinkhole depressions adjacent to Nash Draw.

4.4 SITE STRUCTURE AND TECTONICS

4.4.1 Tectonic and Structural Setting of Los Medaños Site

Relation of Site Structure to Regional Tectonics. The single dominating tectonic feature in the region around the proposed WIPP site is the Delaware Basin, the locus of unusually thick and rapid sedimentation in Permian time. Beneath the site, for example, about 15,000 feet of Pennsylvanian and Permian clastics, limy clastics, and evaporites accumulated. The basin was marginal to an orogenic belt located farther southwest (the Diablo Platform) which was tectonically active in Late Pennsylvanian and Permian time. The basin evolved by downwarp of Precambrian basement terrane of the Texas foreland, a granitic craton. South of the New Mexico border in Texas, the Delaware Basin in Late Pennsylvanian time was trough-like and received much of its sediment from a bordering mobile orogenic belt (Marathon system), in the manner of a molasse trough or exogeosyncline; in New Mexico, however, the northern part of the Delaware Basin received sediment from intracratonic highs located both to the west (Huapache flexure) and to the east (Central Basin Platform) and assumed more the character of an intracratonic basin in which subsidence was accomplished mainly by downwarping of the craton

without major marginal faulting and without subsequent folding or compressive tectonic deformation, although buried normal faults of fairly large displacement are known at the margins of the Central Basin Platform. The Central Basin Platform, located approximately along the New Mexico-Texas border east of the site, may be viewed as a medial, arched horst, now deeply buried by later sedimentary deposits, which separated and partly isolated the Delaware Basin from its eastern counterpart, the Midland Basin, during Late Pennsylvanian and Early Permian time; later in Permian time these basins constituted part of the broad Permian Basin (refer to Sections 3.4 and 3.6; see Figure 1 of Bachman and Johnson (1973) for the extent of the Permian salt basin).

In the Delaware Basin toward the close of Permian time, as much as 4,000 feet of evaporite beds, dominantly rock salt, accumulated, during which time differential subsidence ceased and stable cratonic conditions returned to the area. Later, Triassic redbeds mantled the region. In mid to late Tertiary time, rifting and tensional faulting occurred in the Basin and Range region of New Mexico as far east as the Sacramento and Delaware Mountain anticlinal structures west of the Delaware Basin, and southeast along the Diablo Platform to the Big Bend area of Texas, but did not occur within the Delaware Basin itself. The basin was, however, tilted gently one or more times between Late Triassic and Pliocene time, producing a general net eastward tilt of about 2 degrees. The Late Permian Ochoan rocks and the Triassic rocks exposed in the basin today do not reflect basinwide warping; the major structual feature of these deposits is merely the regional eastward slope produced after Triassic time (Bachman and Johnson, 1973).

Tectonic and Nontectonic Mechanisms at the Site. At the site, stresses associated with the origin and development of the Permian Delaware Basin have deformed the pre-existing rocks or contemporaneous sediments in different ways. Specifically, these stresses included the nontectonic downward pressure imposed by the weight of rapidly deposited sediment and the tectonic stress arising from within the earth's crust and transmitted through the basement rocks to the sedimentary pile. The tectonic stress

would have been most effectively imposed upon those rocks of the sedimentary pile that had already undergone lithification and were therefore mechanically coupled with the basement rocks. Stress imposed by sedimentary loading would have been most effectively absorbed by subjacent materials that were the least lithified and therefore the most compressible and capable of adjusting to differential sediment loads. Each mechanism would have produced different kinds of structures and caused different types of faulting in the rocks beneath the basin. The temperatures measured and heat flow calculated for AEC 8 (Mansure and Reiter, 1977) show evidence of normal geothermal gradients.

The presence of thick salt beds profoundly affects the type of deformation which occurs in the salt itself and which is imposed upon rocks and sediment lying above the salt, inasmuch as thick salt is known to deform plastically and to behave as a viscous medium over extended periods of time. This behavior is promoted by high overburden pressures and increased temperatures. Under favorable conditions, even slight tilting of the beds or lateral differences in lithostatic pressure are sufficient to initiate long-term viscous flow of salt. Salt deformation is therefore quite different in mechanism and manifestation than the deformation of the enclosing rock materials. As a result, deformational features exhibited by rocks and sediments lying above thick salt would normally be expected to have little or no mechanical relationship to structures in rocks occurring beneath the salt, because the intervening salt effectively decouples the two rock masses. Rocks overlying salt would be expected to display local structures that are generated by mass flow of salt. In addition, because shallow salt is susceptible to dissolution by unsaturated ground water, sediments above shallow salt where active solutioning had occurred could be expected to exhibit karst and collapse features, or to have internal irregularity and chaotic structure brought about by uneven subsidence or upward stoping following removal of significant thicknesses of salt in the subsurface. It should be emphasized, however, that at the WIPP site, evaporite dissolution has been restricted to salt beds of the Rustler Formation. No evidence has been obtained to date to indicate that this relatively small amount of dissolution of Rustler salt has resulted in significant differential

subsidence in the site area. In contrast, the potential for subsidence structures to occur has been realized in areas such as Nash Draw, where partial dissolution of Salado evaporite beds has taken place.

It is concluded on the basis of the preceding discussion that the nature of the origin and development of possible structural features in the rocks which occur in the Los Medanos area is spatially related to the position of these rocks in the geologic column relative to the position of thick bedded salt. Accordingly, the following description of geologic structure at the WIPP site is organized into separate discussions of deep structure (i.e., structure in rocks underlying Ochoan salt), salt deformation, and shallow structure.

4.4.2 Deep Structures

Subregional Structure of Pre-Evaporite Rocks. A variety of structure contour maps covering an area within about a 25-mile radius of the WIPP site has been prepared, generally from well data. Foster (1974) provides seven such subregional maps from top of Precambrian to top of Bell Canyon (base of Castile); Sipes et al. (1976) show somewhat more structural detail on top of Devonian, Morrow, Atokan, Strawn, and Delaware strata (their exhibits 11,10, 9, and 8, respectively, the first two of which incorporate seismic reflection profile interpretations). Netherland, Sewell and Associates (1974) present generalized structure contour maps of a slightly different area on eleven horizons, from Ellenburger to top of Bell Canyon (their Figures G-6 through G-16).

Structure contour maps express a homoclinal regional dip toward the southeast to east on all pre-Ochoan Paleozoic strata, reflecting the presence of the Delaware Basin downwarp. Gradients on all pre-Permian horizons are similar in magnitude and direction, decreasing from about 150 feet per mile southeasterly in the lower Paleozoic to about 100 feet per mile at the top of the Pennsylvanian. The nearest fault large enough to be indicated by subsurface well control is a north-trending fault shown by Foster (1974) about 15-20 miles east and southeast of the WIPP

site, and referred to as the "Bell Lake fault." It has a length of about 15 miles and a displacement of about 500 feet. Located west of the central axis of the Delaware Basin, it nevertheless appears to be structurally related by orientation and displacement (upthrown to the east) to the west-bounding fault of the Central Basin Platform farther east, as is shown on the regional structure contour map of Haigler and Cunningham (1972). The fault is not indicated to offset Permian strata (Foster, 1974), but contours of Wolfcamp and Bone Springs strata in the lower part of the Permian section are deflected in the area of the fault. Permian structure contour maps indicate a difference in gradient and direction of horizons compared to earlier strata. This indicates significant tectonic activity in the basin in Late Pennsylvanian and Early Permian time, which was the major period of structural adjustment in the Delaware Basin (Foster, 1974). Permian strata beneath the Ochoan Series slope east-southeast at about 50 feet per mile (Foster, 1974), markedly less than pre-Permian strata.

Site-Specific Interpretations. In the immediate site area seismic reflection data can be utilized as an adjunct to well control in preparing more detailed structure contour interpretations. Figures 4.4-1 thru 4.4-3 contour horizons at, respectively, the top of the Silurian (Siluro-Devonian carbonate, refer to Section 4.3.2), top of Morrow, and near the top of the Delaware. Seismic profile lines are indicated and well control points are shown. Structural interpretation of seismic reflection profiles has been furnished by G.J. Long and Associates, Inc. (1977). (Additional seismic profiling has been performed (G.J. Long, 1977b) or is presently being undertaken as part of a continuing program by Sandia Laboratories to delineate subsurface structures at the WIPP site. These additional data will be presented and discussed when the analyses are completed.)

In general, Figures 4.4-1 through 4.4-3 reveal the existence of minor faulting and secondary warping (swells and saddles) in Paleozoic strata below the evaporite beds. Comparing Figure 4.4-1 with 4.4-2, a pattern of generally north-northeast-trending faults has been interpreted,

oriented roughly parallel to regional strike and typically upthrown to the east. Small, subdued dome-like features and complementary saddles spaced several miles apart and with crest-to-trough amplitude of several hundred feet are superimposed on the regional gradient and appear to persist in position through both horizons. In the Silurian, for example, several small arches of up to 300 feet of relief are aligned in an east-southeast or west-northwest anticlinal trend passing just north of the Zone II exclusion area (Figure 4.4-1). In the Morrow a similar east-west trend in about the same location is defined by more subdued structural gradients and highs of lower amplitude (Figure 4.4-2). This trend is identified as the "Cabin Lake" trend by Netherland, Sewell and Assoc. (1974); see also Figure 2-7 of this report. On both horizons a domal feature is evident beyond the southwest edge of the site. This feature, which Netherland, Sewell (1974) indicate is at the east edge of the "Los Medanos" trend, is presumably responsible for the gas production of the Los Medanos field, the nearest hydrocarbon field to the site. Between these two anticlinal trends, a northwest-trending saddle is defined, located beneath the southwestern edge of the site.

The north-northeast-trending faults inferred in Figures 4.4-1 and 4.4-2 are, as interpreted from seismic reflection records, of greater intensity in the Devonian, being traceable over distances exceeding ten miles and having displacements of up to 400 feet (Figure 4.4-1). Faulting of the Morrow (Figure 4.4-2), some 2,500 feet higher stratigraphically, is roughly correlative with the deeper displacements, but seems to dissipate into discontinuous segments of generally smaller displacement.

Small-scale structures interpreted on the Delaware Mountain Group, roughly 9,500 feet above the Morrow horizon, show little or no correlation with deeper features (refer to Figure 4.4-3). The north-northeast-trending faulting is no longer apparent; instead, seismic reflection studies (G.J. Long, 1977a) indicate short (less than 5 miles in length), discontinuous northwest-trending offsets of small displacement (less than 50 feet) passing beneath the northeast half of the site; refer to Figure 4.4-3. The fact that the faults are not

detected at greater depths suggests a shallow-seated origin. Warping in the Delaware Mountain Group appears to be much more subdued than in the Morrow; structure contours lack closure around irregularities, and trends in the Delaware Mountain Group appear to be unrelated to Morrow and deeper trends. One feature of note shown (Figure 4.4-3) is a shallow, northwest-trending saddle of not more than 100 feet of structural relief, located beneath the center of the site; the presence of such structural lows is considered to be a favorable site selection criterion (refer to Section 2).

The contrasting structural characteristics between the Delaware and pre-Permian horizons suggest different origins. All strata from the Pennsylvanian on down have been deformed in continuity, with intensity of deformation increasing with depth. Tectonic deformation apparently occurred in Late Pennsylvanian or Early Permian time and established the local structural elements of all pre-Permian rocks. The "rootless" character of at least some of the normal faulting in the Permian suggests that these are shallow-seated features. Considering the unusually rapid rate of accumulation of material in Permian time (about 13,000 feet), it seems reasonable to presume a predisposition for the occurrence of contemporaneous sedimentary deformation brought about by such factors as gravity creep, compaction during diagenesis, differential sedimentary loading and rates of dewatering, and differential subsidence. Such deformation has been documented along "growth faults" in the Gulf Coast basin (Murray, 1961, p. 137; Fisher and McGowen, 1967, Figure 3; Bishop, 1973; Bruce, 1973). Contemporaneous faults of this type may have been initiated during deposition of thick pre-Ochoan clastic sequences. Conceivably, further movement might have been promoted by mass movement of salt subsequent to evaporite deposition, which shifted overburden loads over possibly still compressible sedimentary material.

Figures 4.4-4 and 4.4-5 show southwest-northeast and northwest-southeast sections, respectively, across the proposed WIPP site area, adapted from Griswold (1977). The overwhelming thickness of Permian pre-evaporite strata relative to earlier deposition is graphically displayed. Faults

arising in the basement offset Pennsylvanian strata but do not propagate through the lowest Permian series, the Wolfcampian. The regional dip of the Delaware Basin is most evident in Figure 4.4-5.

4.4.3 Salt Deformation

For the purpose of this discussion, detailed description of deformational features within the salt beneath the site and in the northern part of the Delaware Basin is restricted to consideration of structure displayed by the Castile and Salado Formations even though the Rustler is normally considered part of the evaporite sequence. At the site and in the vicinity of the site, the Rustler has been leached of much of its salt with the result that most of its structure is surficial in origin and is included in the discussion of site surficial structure, Section 4.4.4.

Of previous studies available in the literature on the northern part of the Delaware Basin, the papers by Brokaw et al. (1972), Anderson et al. (1972), Jones (1973) and Anderson (1978) are most relevant to salt deformation in the area of the proposed WIPP site.

Subregional Structure of Evaporite Beds. Throughout the northern Delaware Basin, the general uniformity in direction and amount of the gentle southeastward homoclinal dip is practically the only structural feature that is common to all levels of the evaporite section (Jones, 1973). Superimposed on this homocline is a rather complex system of flow features variably developed relative to both areal location and stratigraphic position, features attributable to mass migration of salt.

Features that are of subregional significance, and that appear to have a fundamental role in the development of salt deformation, include the Capitan reef front. It formed a steep, submarine prominence or wall 1,000 to 1,500 feet high isolating the deep water of the early Castile brine sea from the rest of the Permian inland sea (refer to Sections 4.3.2 and 3.6). Figure 10 of Jones (1973), a structure contour map on the base of the Castile Formation, graphically depicts the structural

relationship of reef and basin in the site area. Immediately basinward of these buried reef masses, which are located 8 miles north of the WIPP site, is a northwest-southeast-trending structural trough paralleling the base of the reef and descending in elevation, or plunging, southeastward. The most intense deformation in the evaporite sequence seems to be spatially related to this trough; not only is the trough expressed within the salt layers, but the top of the clastic Delaware Mountain Group (Bell Canyon Formation) is also depressed. Subregional geologic sections constructed by Jones across Nash Draw and Livingston Ridge (Brokaw, et al., 1972, Jones, 1973,) illustrate the general configuration of reef, trough, and deformation within the evaporite sequence in the site area. Jones' (1973) assessment of these particular features is pertinent:

> "At intermediate and other levels in the (evaporite) section, the structure is generally more uneven than at the base of the Castile Formation, and minor folds are somewhat more prominent. Salt and anhydrite in the middle member of the Castile are crumpled in sharp intraformational folds that appear to die out northwestward up the dip and to become more pronounced southeastward down the dip. Spatially the intraformational folding of the salt and anhydrite appears to be confined to a single long northwestwardly-trending belt, about 3-4 miles wide, that more or less coincides in trend and extent with the prominent southeastwardly plunging trough at the base of the Castile. The folding has resulted in some buckling and downwarping of rocks in the Salado Formation, and it has uplifted the Salado and other rocks as young as the Chinle Formation in a fairly broad arch that trends northwestward across the area. The exact age of the deformation is unknown; it can be dated only very broadly as post-Late Triassic to pre-Pliocene. Specific considerations concerning minimum thickness of overburden required to initiate salt movement suggest that the deformation may have occurred during or shortly after the period of regional tilting that followed the deposition of Cretaceous rocks. The deformation almost certainly had to occur before any great thickness of Cretaceous rocks was removed by erosion."

Subsequent studies by Anderson (1978) and Anderson and Powers (1978) have supplied some detail on the character of the salt deformation recognized by Jones. Apparently the only part of the Castile that has not been

involved in significant plastic flow deformation is the lower or basal anhydrite, Anhydrite I (refer to site stratigraphy, section 4.3.2 for discussion of Castile stratigraphy). On the other hand, the lowest thick Castile salt member, Halite I, has undergone severalfold increases in thickness in some areas. Anderson (1978) presents a basinwide isopach map of the lower Castile Halite-I unit which shows an increase of thickness from a normal value of about 300-350 feet, as occurs in the area of the proposed WIPP site, to a value of 1,200 feet at the ERDA-6 location 5 miles north-northeast of the site. The isopach lines at this location define an elongate, sharply thickened bulge of the Halite-I unit, the long axis of which is about 12 miles long and is oriented parallel to, and on the basin side of, the buried Capitan reef front. Anderson's isopach map also shows numerous similar, slightly smaller elongate bulges, their long axes all about 3-1/2 times the length of their shorter ones, contained within a belt about 5 miles wide paralleling the basin side of the reef front. Since the anhydrite unit (Anhydrite I) underlying this deformed salt is not significantly deformed and does not itself rest on deformed rocks (Jones, 1973), the tops of these large salt mounds or bulges define what may be termed salt anticlines. These are not anticlines in the usual sense of the term because the top and base of the unit have totally dissimilar profiles; piercement associated with the term salt anticline is not generally present. This belt of salt anticlines, then, is the northwestward-trending belt of intraformational salt deformation recognized by Jones as occurring within the Castile and affecting strata above the Castile.

Structural detail within the large salt anticline located about 5 miles northeast of the center of the proposed WIPP site has been provided by cores recovered from the ERDA-6 hole drilled near the center of the anticline (Anderson and Powers, 1978). Stratigraphic interpretation made by Anderson and Powers from study of the core indicates that the middle anhydrite bed which overlies the salt has indeed been pushed up by the rising salt but has apparently acted as a semirigid confining blanket that was stretched upward like a flexible sheath; whether the anhydrite bed everywhere remained intact or was in places fully ruptured and

detached by extension is not known. What is displayed in the core is that most of the anhydrite, which actually consists of finely interlaminated calcite and anhydrite, was stretched by extensional microfracturing of the calcite laminae and in-filling of the fractures by mobilized calcium sulfate, which presumably was derived by diffusion or creep from adjacent anhydrite laminate. The process seems closely analogous to boudinage in metamorphic rocks, and could be viewed as a microboudinage structure brought about by the properties of finely laminated calcite and anhydrite when subjected to high shear stress under sufficient confining pressure.

Anderson and Powers (1978) find that Halite-I salt, together with streched Anhydrite II or middle anhydrite, have in their upward migration pushed aside both the overlying upper salt (Halite II) and upper anhydrite (Anhydrite III) beds in the manner of an intrusion, since the stratigraphy in the ERDA-6 hole passes directly from Infra-Cowden salt to Anhydrite II. The authors show that the overlying Salado beds, though not breached by the intrusion, are arched over it. It is therefore evident that the arching effect in beds of the Salado and even younger rocks referred to by Jones (1973) along the belt of deformation is in at least some cases due to the presence beneath these anticlines of a salt core which arose from the lower part of the Castile and partly intruded the overlying rocks.

In addition to revealing the cores of many of the salt anticlines in the northwest-southeast belt of deformation described above, the subregional Halite-I isopach map (Anderson, 1978) shows numerous, sharply defined localized depressions at locations where the Halite-I salt is entirely missing from the section. In the central part of the basin, these "deep-seated sinks", as Anderson calls them, do not have obvious surface expression, and are not clearly related to shallower dissolution features--such as collapsed and uncollapsed domes, dissolution fronts, castiles, and collapsed outliers--which have been described and

documented elsewhere in the Delaware Basin region. Many of these isopachous depressions, some of which are defined by a single data point, may possibly be attributed to "deep dissolution" processes (Anderson, 1978), presumably acting from near, or perhaps below, the base of the salt section. A few appear, however, to originate within the Castile in salt zones above the lower halite. Anderson (1978) has proposed that some of them may have propagated vertically upward in the evaporite section to form known cylinders or chimneys of dissolved and collapsed debris. Alternatively, halite flow from adjacent regions into anticlines may account for these paired features as illustrated in Anderson and Powers (1978). (For description of these features in the Delaware Basin subregion and a discussion of their origin and development, refer to regional geomorphology, regional structure, and subsurface hydrology, Sections 3.2, 3.4, and 6.3).

Unlike the belt of salt anticlines having cores of Halite-I salt, the distribution of the localized pockets of missing, or greatly reduced thickness of, Halite I and higher Castile or Infra-Cowden halite that Anderson classifies as "deep sinks" is not confined to a belt above or adjacent to the Capitan reef but includes mid-basin areas as well, as illustrated by Figure 16 of Anderson (1978). The nearest of these deep mid-basin features to the proposed WIPP site as disclosed by the various halite isopach maps of Anderson (1978) occurs about 5 miles southeast of the site at the Eddy-Lea County line. This particular feature is not indicated to originate within the Halite-I zone of the Castile; rather, it appears to be a feature in the infra-Cowden salt (Anderson, 1978, Figure 7); compare this report, Figure 4.4-7, and refer to the section immediately following for additonal detail on the near-site structure.

It is not yet clear whether all or even some of these deeply buried mid-basin "sinks" identified by Anderson have a hydrologic origin subsequent to diagenesis and salt deformation. If they do, they may well be related to other collapse features in the Delaware Basin region as simply one manifestation of the same general process being seen at different levels of exhumation by erosion (Anderson, 1978, p. 58-59).

The concept that these diverse solution structures are being exhumed by present-day erosion suggests that the conditions of their formation in the geologic past may not be present today in kind or to the same degree.

The nature of the deformation in the middle and upper part of the salt sequence above the Halite-I zone is recorded by the subregional halite isopach and structure contour maps of Anderson (1978) and Brokaw et al. (1972). The salt isopachs of Anderson (1978, Figures 4 through 10) clearly show that no other salt member of the evaporite sequence has experienced local flow deformation as severe as the Halite-I zone, nor are the "deep sinks" apparently as prevalent in the middle and upper part as they are near the base of the Castile. The Halite-II member of the Castile mirrors the same thickness trends exhibited by the Halite-I bed, but in a much muted manner. The infra-Cowden salt is the highest salt of the Castile-Salado sequence to exhibit marked thickening along the trend of the buried Capitan reef; it is also the lowest, or first, major salt bed to overtop and extend beyond the confines of the reef margin in this part of the basin. Even though no appreciable thickening of Salado salt above the infra-Cowden is apparent over the Capitan reef margin (Anderson, 1978), structure contours at the base of the Salado Formation (= top of Castile) (Jones, 1973) and on the 124-marker bed within the McNutt potash zone (Anderson, 1978) document that the Salado is indeed arched along the basinward edge of the reef and confirm that the salt deformation which occurs at depth around this margin had imposed an anticlinal structure on overlying strata, much as Jones (1973) described (also compare Brokaw et al., 1972 with Jones, 1973).

The evidence presented in this section regarding the subsurface structure of Castile and Salado halite beds and the spatial relationship of deformation structures with the bounding Capitan reef margin suggests that viscous flow of salt was initiated by post-depositional regional tilting and that the Capitan reef acted as a dam or abutment obstructing the eastward subsurface viscous flow of the lower part of the salt section which impinged against it. The salt piled up slightly, as a rug might when gently pushed against a wall, until lithostatic equilibrium

was attained with the superjacent rock mass. That larger, more dramatic salt plumes were not formed in the Delaware Basin, as they are known to occur in the Gulf Coast basin, for example, may be attributed to several factors. Two of these factors are the gentleness of the regional tilt and perhaps a relatively shallow depth of burial of salt. This would have resulted in lower lithostatic pressures and relatively higher viscosity of salt and hence greater resistance to migration. Evidence from structures nearer the site (e.g., WIPP 11, as discussed in the next section) indicates that the redbeds overlying the Salado are not always involved in the structure. This implies that some of the structures may be Permian in age.

No conclusive evidence establishing the exact time of regional tilting of the Delaware Basin has yet been found, except that it occurred after Chinle deposition (Late Triassic time) and before Ogallala time (uppermost Miocene). King (1948) has proposed that regional tilting took place in early to mid-Tertiary, concomitant with known Basin and Range faulting that occurred in the region west of the Delaware Basin, with relative upthrow of the Guadalupe and Delaware Mountains. Certain relations of Cretaceous strata, as described and discussed in section 4.5 on geologic history, and the long time span between Triassic and Late Cenozoic, suggest that there may have been earlier episodes of moderate regional tilting, of which the present eastward tilt is merely the resultant vector summation.

Geologic Structure of Salt at the Site. Within the context of the subregional relationships of deformation in the Castile-Salado evaporite sequence described and discussed in the previous sub-section, geologic structural features in the salt lying beneath the WIPP site may now be reviewed. Figures 4.4-6 through 4.4-10 show, respectively, structure contours on top of Castile, on the 124-marker bed of the Salado (within the McNutt potash zone in the middle part of the Salado), on top of the Vaca Triste member (top of McNutt), on the 103-marker bed, and on top of the Salado. Geological sections across the site area are shown on Figures 4.4-4 and 4.4-5. Gross structure of all evaporite horizons

reflects the regional easterly homoclinal dip of 50 to 100 feet per mile. Salt deformation has modified this homocline to a variable extent, generally more so in the Castile than in the Salado, inasmuch as the lower halite beds of the Castile appear to have been the most mobile (refer to subsection 4.3.3).

Seismic reflection surveys performed at the site (G.J. Long, 1977a 1977b) were designed in part to record the relatively shallow Castile horizons (for description of the seismic survey programs refer to Section 2.4); survey lines are shown on Figure 4.4-6 along with the well control points. A reflecting horizon tentatively identified on the seismic records as the top of Castile (located about 100 feet below the base of the RH-zone) is contoured on Figure 4.4-6, which also shows preliminary structural interpretations made from the seismic records. The contours of Figure 4.4-6 indicate that the easterly regional dip of the Castile is modified by a broad, northwesterly-trending ridge and saddle configuration, with crest-to-trough separation of 2 to 3 miles and total structural relief of up to 400 feet. According to this interpretation, the normal gradient of bedding in this part of the Delaware Basin (about 100 feet per mile or 1 to 2 degrees to the east/southeast) may be significantly greater and different in direction locally at the top of Castile, directly beneath the proposed WIPP underground Facility. Specifically, Figure 4.4-6, G.J. Long's preliminary interpretation of structure on the presumed top of Castile about 100 feet beneath the proposed RH-Zone level, indicates as drawn that local gradients may be as great as 400 feet per mile (about 4 1/2 degrees) to the south and southwest.

Northeast of the site, G.J. Long (December, 1977) shows a domal feature in section 36, T. 31 S., R. 22 E of about 500 feet of structural relief (Figure 4.4-6). ERDA-6, which was drilled in section 35 just west of the crest of this feature, encountered a geopressured (artesian) brine reservoir in the Castile. Studies of the ERDA-6 core establish that the doming in this area is due to a salt anticline with a core of mobilized Halite-I salt (Anderson and Powers, 1978); refer to Figure 4.4-4. This

dome is located within the belt of salt deformation flanking the Capitan reef (refer to Section 4.4.3.1 and Chapter 2, Figure 2-4) where such occurrences are to be expected. Artesian brine flow was also encountered by Belco No. 1 Hudson-Federal over a similar domal feature southwest of the site in the Los Medanos gas field area (Section 1, T. 23 S., R. 30 E)., although no salt-cored anticline of the type encountered at ERDA-6 is known to occur there.

The origin of the inferred northwest-trending structural ridge at the top of the Castile at the northeast edge of the Zone-II exclusion area has not yet been determined; it may be a depositional structure, or it may reflect possible past deformation by salt in underlying halite units. The steepness of the southward gradient suggests possible offset of one or more anhydrite beds as G.J. Long (1977b) has proposed. By contrast, a deep seismic reflection profile running southwest-northeast across the center of the site (Sandia Line 2, G.J. Long, 1977a; compare Figure 4.4-4) detected no anomalies at and below the lower part of the Castile across the trend of the ridge, whereas a significant anomaly is apparent in the same profile at the lower Castile-upper Delaware levels across the Los Medanos gas field southwest of the site (refer to Figure 4.4-4).

The more recent seismic investigation (G.J. Long, 1977b) also defined an area of poor data quality to the north of the site. From the ERDA-6 anomaly westward into Range 30 E. and southward into section 17 at the north edge of the the site, the quality and continuity of data as viewed on the seismic records deteriorate. This suggests the possibility of increased structural disturbance in this area, presumably caused, if real, by some form of previous salt deformation. Deterioration of the seismic record can also be brought about by anomalous or irregular transmission characteristics of the overlying medium. For example, near-surface structural disturbance, such as might be caused by dissolution in the Rustler, or the presence of an anomalously rigid near-surface layer such as caliche could change the quality of the seismic record (Dobrin, et al., 1954). A salt anticline at the northwest corner of Section 9, T22S, R31E, was suspected on the basis of seismic reflection data; drilling (WIPP 11) confirmed the structure was present

in the Castile. WIPP 11 did not show any brine or gas though drilled to the lower anhydrite of the Castile Formation. This confirms that anticlinal structures within the evaporites are not always associated with brine and gas. The apparent non-involvement of the redbeds in the structure may be interpreted, as noted in the previous section, as indicating a Permian age for this structure.

At the present time, while these seismic reflection records are undergoing further study and review, additional seismic reflection surveys are being undertaken in conjunction with exploratory drilling at critical locations. The results of these further investigations are to be reported at a later date.

Figure 4.4-7 presents 10-foot structural contours on the base of the 124-marker bed of the Salado, which is the deepest and most consistently reported horizon in the potash exploration grid. Figure 4.3-3 provides a stratigraphic orientation for the 124 bed, which is in the lower part of the McNutt, or middle Salado; at ERDA-9, the 124 marker is 470 and 1,020 feet, respectively, above the CH- and RH-level mining horizons selected for waste disposal. A uniform, gentle eastward regional gradient of 80 to 100 feet per mile across the repository is evident; there is no suggestion of a northwest-southeast ridge for the Castile (Figure 4.4-6). Two anticlines, or domal structures, are present, one centered near the ERDA-6 locality and the other at the Los Medanos gas field. At both structures, and only at these structures in the map area, exploratory drilling encountered artesian brine reservoirs in the Castile. No such structures are indicated by the 124-marker bed contours to be present within the site exclusion area.

The comparison of Figures 4.4-6 through 4.4-8 to each other indicates that structural disturbance is present within the Castile that is not reflected upward to any great extent. Structural relief on the upper beds is a fraction of that of the Castile. The inferred faulting at depth has not been confirmed by drilling, seismic data and drilling in the area indicates salt remains in the Castile rather than disappearing as any consequence of the faulting.

Two depressions in the 124-marker bed are indicated to occur near the site (Figure 4.4-7). In Lea County in section 31 at the east edge of the map there is a depression with probably less than 100 feet of closure; this is the same feature identified by Anderson (1978) as a possible "deep sink", and apparently is related to a greatly reduced or missing section of the Infra-Cowden (Anderson, 1978, Figure 7). It is nearly 4 miles from the edge of the Zone-II exclusion area. A second depression of the 124-marker bed horizon is centered about a mile north of Zone-II exclusion area, at the southwest corner of section 9. A single-hole anomaly with 50 feet structural closure, it is not reflected by any isopach anomalies in the Salado (Figures 4.3-4 through 4.3-7), nor does it correspond to any evident structural feature higher in the Salado (compare figures 4.4-8 thru 4-4-10). Salt isopach maps of Anderson (1978) indicate no anomaly at this location, nor does the recent seismic reflection work by Long (1977b) show subsurface disturbance of horizons near this point. These negative indications suggest the feature might have developed contemporaneously with depostion and is not significant to the WIPP site. Nevertheless, results obtained from exploratory drilling will be noted and applied if relevant. Higher levels within the Salado are contoured in Figures 4.4-8 and 4.4-9 (refer to Figure 4.3-3 for location in section). Within the area contoured on these Figures, which is somewhat less than the area covered by Figures 4.4-7 and 4.4-10, the two maps are virtually identical in configuration and gradient and exhibit no significant structural features other than the regional gradient.

Structure contours on top of the Salado, or at the contact between the Salado and the Rustler, are displayed in Figure 4.4-10. It should be recalled (Section 4.1) that there is less data control for the top of the Salado than for deeper horizons in the Salado, because potash industry exploration practice normally includes coring and geophysical wireline logging only for horizons below the top of the Salado. Reliable control for top of the Salado is therefore provided mainly by those potash exploratory holes commissioned by DOE. Outlined by contours on Figur 4.4-10, the same domal feature associated with the salt-cored anticline

and brine reservoir encountered by ERDA-6 is still in evidence. The change from regular contours in Range 31 E. to a more irregular configuration in Range 30 E. is due to dissolution at the top of Salado, and is also reflected in the upper Salado isopach map (Figure 4.3-7). (Refer to Section 6.3 for a discussion of dissolution processes in the site area.). A 70-foot depression is apparently recorded by an industrial potash hole (Hole F-91) a mile northeast of the Zone-II exclusion boundary; two similar but smaller features occur a couple of miles farther northwest. Since there is no geophysical or core record available for hole F-91 at the top of the Salado, it may well be that the first encounter of Salado salt is simply not recognizable in the record for this particular hole.

Assuming the record is accurate, however, it is not known at this time whether the apparent depression is a feature of sedimentary origin, although the horizon is a contact zone between two formations, or whether the feature is related to post-depositional solution processes. It should be noted that this apparent depression is about a mile east of, and structurally about 700 feet higher than, a similar depression contoured on the 124-marker bed (Figure 4.4-7, discussed above). However, no such anomalies have been detected on intervening horizons in the Salado (Figures 4.4-8 and 4.4-9). Furthermore, a line connecting the two apparent depressions would have a maximum slope of less than 8 degrees. The available evidence therefore indicates that it is unlikely that there is a physical continuation of this assumed depression at the top of the Salado to horizons lower in the evaporite sequence. On the other hand, there is an approximate spatial coincidence of this depression with a shallow (less than 30 feet of relief) topographic depression at ground surface containing mapped playa deposits (Figure 4.2-4). Resistivity profiles (Elliot, 1977) indicate only minor surficial disturbance attributable to shallow basin fill with no indication of probable subsurface collapse structure.

Preliminary interpretation of seismic reflection data (Long, 1977b) near the top of the Salado indicated the possibility of faulting, with a possible displacement of 100-250 feet, less than one mile north of ERDA 9. Consequently four holes (WIPP 18, 19, 21, 22) were drilled bracketing the possible location of the faulting (see Figure 2-10) to validate the interpretation. The resulting borehole data shows no apparent faulting in this region. The data collected by seismic reflection for that particular seismic program are not apparently useful for primary interpretation of the stratigraphy at the top of the Salado. Revision of field parameters in future surveys may permit more secure interpretation of data for such shallow reflectors.

A preliminary assessment of the proposed WIPP site relative to structural features presently indicated in the Salado and Castile salt formation enclosing the selected CH- and RH-storage levels can now be stated. Structure contour maps of various horizons in the Salado Formation indicate a uniform easterly regional structural gradient of about 80 to 100 feet per mile across the limits of the proposed storage facility, with little indication of the presence of any significant structural anomalies. Plastic deformation and buckling associated with salt migration or flowage has apparently not occurred in the Salado in the geologic past to the extent that it has in the lower levels of the underlying Castile Formation. Areas in the region in which artesian brine reservoirs have been encountered are associated with thickened salt sections and salt-cored anticlines in the Castile. However, a thickened salt section and salt cored anticline was drilled in WIPP 11 (Sec. 9, T. 22 S. R. 31 E.) without encountering fluids. Further, the occurrence of these reservoirs appears to be correlative with consistent structural highs, delimited by structure contours of successive horizons in the overlying Salado Formation. No such structural features are recognizable within the limits of the WIPP storage facility on any of the Salado horizons contoured; in fact, the site, if anything, appears to be in a slight structural saddle.

Among aspects needing further investigation, perhaps the most significant is a determination of the extent to which the upper levels of the Castile closest to the repository levels have been deformed by any salt deformation that may have taken place in the lower halite units of the Castile. There is no suggestion here of deformation of the type associated with artesian brine reservoirs. Seismic reflection techniques suggest, however, that a certain amount of flexure occurs in the upper levels of the Castile beneath the proposed limits of the repository, which could possibly affect local structural gradients in the lower part of the Salado. Faulting on the Castile reflector has also been inferred. Investigations are in progress to further define and delimit structural configurations near the top of the Castile and the extent to which these structures may be reflected within the lower part of the Salado where excavation of the RH- and CH-levels is presently planned. This knowledge will permit a more detailed assessment relative to the location, design and construction of the storage facility but is not believed necessary for a general qualification of the site area.

4.4.4 Shallow Structure

As discussed in Section 4.4.1, in the Los Medanos area a distinction may conveniently be made between structural features exhibited by rocks occurring above unleached salt beds and structural features of all other strata. The distinction may be made because rocks above the Salado at the site have at one time or another in the geologic past been subject to weathering processes and hence might display secondary structures related to surficial dissolution and subsidence that would not have been imposed upon deeper strata. Accordingly, shallow structures at the WIPP site have a potential for greater irregularity and complexity than those which occur at depth. "Shallow structure" is here defined to include the Rustler Formation which extends to a depth of about 850 feet beneath the center of the site (refer to Figure 4.3-3). Figures 4.4-11 through 4.4-15 are structure contour maps on Rustler and higher strata, constructed from the data obtained from wireline geophysical logging of holes drilled at the WIPP site to assess potash reserve potential.

Shallow Subsurface Structure. Structure contours on top of the Culebra Dolomite member of the Rustler Formation are shown on Figure 4.4-11 (refer to Figure 4.3-3 for location in site geologic column). The Culebra is the most productive aquifer in the Rustler Formation. The closely spaced contours in the southwestern quadrant of the map define a slope of about 80 feet per mile eastward (compare Figure 4.4-9). The wider spacing of contours in the eastern half of the map is anomalous with respect to regional structure and marks the increasing amount of halite preserved progressively eastward in the Rustler below the Culebra member. A similar configuration is evident on top of the Rustler, Figure 4.4-12: again the regional gradient appears in the southwestern quadrant, while an anomalously gentle eastward gradient, in some places even reversed, signifies thickening due to an increasing content of salt preserved from dissolution (see Figure 6.3-7). Virtually the same pattern is observed with respect to the structure contours of the Magenta Dolomite member (Griswold, 1977). Isopachs of the Rustler (Figure 4.3-8) show the gradient and amount of eastward thickening. A broad, shallow depression with 30 to 40 feet of closure near hole P-11 appears near the northeast corner of the site on both the Magenta and the top of Rustler levels, but not on the Culebra. Possibly it represents an area of greater dissolution in the upper part of the Rustler, since Rustler isopachs show the Rustler is not thickening eastward at this particular location (Figure 4.3-8)

The area in Figures 4.4-11 and 4.4.-12 wherein the regional gradient is reflected by the Rustler structure contours identifies the area where the Rustler has been leached of most of its salt, and hence presumably where maximum settlement of overlying rocks has occurred, assuming, of course, that no dissolution took place prior to deposition of overlying Dewey Lake strata. Jones (1973) supplies a subregional structure contour map of the Dewey Lake-Rustler contact and recognizes that the unevenness it shows is due to the added complexities of subsidence (Jones, 1973). A low resolution seismic reflection survey conducted at the site (C.B. Reynolds, 1976) suggests the presence in the Rustler of more localized and higher amplitude irregularities than would necessarily be defined by

data points in Figure 4.4-12. However, the known top-of-Rustler data points from potash exploration shown on Figure 4.4-12 are in nearly complete disagreement with elevations of this horizon interpreted from the shallow seismic data (Reynolds, 1976). It would appear that the reflections of horizons in the Rustler obtained by this shallow survey method are not of sufficient quality to provide a basis for making structural interpretations. The subsurface data collected to date indicate that the dissolution of salt in the Rustler has not been accompanied by the development of highly irregular subsidence structures in the overlying strata at the WIPP site.

Proceeding higher in the section, the top of Dewey Lake Redbeds (Figure 4.4-13) is the first horizon that does not reveal the eastward gradient of the Delaware Basin that all lower horizons show. The Dewey Lake surface across the site area is undulatory, possibly reflecting to some extent original undulations in the uncomformable Dewey Lake-Santa Rosa contact mentioned by Jones (1973). A broad depression near hole P-11 with about 50 feet of closure is in the same location as a similar depression on the underlying Rustler surface (Figure 4.4-12). Subregional structure contours of Jones (1973) indicate considerable irregularity of the Dewey Lake surface as is also suggested by Figure 4.4-13, but overall the surface slopes northeastward. Isopachs of the Dewey Lake Redbeds (Figure 4.3-9) disclose that the west-trending slope of the Dewey Lake surface at the west edge of Figure 4.4-13 is the result of the Late Tertiary erosion which is associated with the development of Nash Draw and which completely truncates the Dewey Lake in Nash Draw itself (Brokaw, et al., 1972). Continuation of this erosion surface to the east across higher strata is quite obvious in Figure 4.4-14, contoured on the surface of the Santa Rosa Sandstone. Structure contours of the Gatuna surface (below Mescalero caliche) (refer to Figure 4.4-15) show virtually the same configuration as does the Santa Rosa surface on the east and the Dewey Lake surface on the west, indicating that the thin Gatuna veneer was deposited over these surfaces after erosion occurred.

Surficial Structures. Extensive surficial deposits of dense sand all but preclude the observation of surface geologic structure at the WIPP site (Figure 4.2-4; refer to maps by Bachman in Jones, 1973, and by Vine, 1963). The nearest measurements of bedding orientation appearing on Bachman's map are at the edge of The Divide, some 6 miles northeast of the center of the proposed WIPP site. The Nash Draw geologic quadrangle map by Vine (1963) shows no such measurements, for Vine recognized that dissolution of salt in rocks beneath Nash Draw had caused widespread slumping of the surface rocks. Thus, they are not indicative of original structures. He documents places where not only salt but considerable gypsum has been dissolved. In Nash Draw the Magenta and Culebra dolomite members of the Rustler are observed in contact, whereas normally, when leached of salt only, they are separated by 120 feet of gypsum (Vine, 1963). In mapping the overlying Dewey Lake Redbeds, he noted that,

> "exposures of the redbeds are commonly tilted or draped into simple structures as a result of the collapse and swelling that accompanies solution and hydration of the underlying evaporite rocks. Some exposures...along the margin of Nash Draw show a downwarping into the topographic depression that is presumably the result of removal of soluble rocks. For this reason, strike and dip readings, even on the very apparent parallel stratification of the redbeds, do not necessarily reflect the structure of older rocks" (Vine, 1963).

Jones (1973) affirms that "it is impossible to piece together a meaningful stratigraphic section from study or mapping of outcrops" in Nash Draw. "The (exposed) rocks are porous, friable, and loose-textured, and all are strongly jointed, cavernous, and locally brecciated. Stratification is obscured or completely obliterated, and the attitude of bedding can rarely be determined with any degree of confidence" (Jones, 1973, refer also to discussion of Rustler stratigraphy, Section 4.3.2). It should be emphasized that this surface evidence of jumbled structure is restricted to Nash Draw and has not been described for the area between Livingston Ridge and the WIPP site.

No surface faults have been mapped within 5 miles of the center of the WIPP site; faults that are mapped at the surface are distant and are plainly related to collapse features. Bachman's (1976) mapping east of the WIPP site shows no surface faults. The nearest faults mapped by Vine (1963) involve Rustler offsets in Nash Draw about 9 miles southwest of the site in section 18, T. 23 S., R. 30 E. Although he recognized these faults as being produced by karst processes, involving areas of circular or semicircular rock deformation up to a few thousand feet in diameter, he was unsure of how to account for the fact that some were positive

topographic features or domes (Vine, 1960; Vine, 1963). Anderson (1978) believes that they may be the eroded remnants of former caverns in salt whose roofs had collapsed; the collapsed debris then remained as the upper part of the surrounding salt was partially dissolved and carried away (refer to regional geomorphology, Section 3.2).

Livingston Ridge, 4 miles northwest of the site, marks the edge of Nash Draw, a broad swale developed by a combination of erosional and dissolution processes. Bachman (1974) mapped occurrences of caliche in the region around the WIPP site, and noted the structural relationship of the caliche to depressions such as Nash Draw (refer to structure contour map of the Mescalero caliche in Bachman, 1976). He concludes that,

> "major solution and collapse preceded and followed the accumulation of the Mescalero caliche in Nash Draw..." (Bachman,1976). "The Mescalero caliche probably formed on an undulatory stable surface. ...Along Livingston, Quehada, and Nimenim Ridges...the caliche dips abruptly into the adjacent depressions. The crowding of contours, the presence of fractures, and the uniform thickness of the caliche along these ridges indicate that Nash Draw Draw and Clayton Basin were subjected to collapse after the formation of the Mescalero caliche. On the other hand... the uniform spacing of the contours in the area of the Divide between Livingston and Antelope Ridges suggest that this surface...approaches its original slope" (Bachman, 1974).

Thus, surface mapping and structural interpretations have found no evidence of any anomalous structure in the vicinity of the WIPP site east of Nash Draw that might be indicative of significant differential subsidence of underlying strata. Such surface features and structural relationships that are exposed in the area reveal no indication of any surface faulting at the WIPP site.

In summary, surface and shallow subsurface structure in the vicinity of the WIPP site has presumably been modified to some extent by loss from dissolution of 100-200 feet of salt originally present in the Rustler Formation. The resulting subsidence and settlement would not be expected to have progressed in a perfectly constant and uniform manner over an area of several square miles. On the other hand, there is no indication of the presence of the types of chaotic structure encountered in the Rustler in Nash Draw, as described by Jones (1973) and by Vine (1963).

In the Nash Draw area, the widespread collapse structures observed are due to extensive dissolution in the Salado rather than in the Rustler alone. Further, the successive erosional stripping of Santa Rosa, Dewey, and Rustler strata westward into Nash Draw, coupled with the general eastward regional dip of the evaporite strata, indicates that the amount of overburden above the level of dissolution actually was much less in Nash Draw than it presently is east of Livingston Ridge. Thus the potential for significant differential subsidence to have occurred beneath the Los Medanos site seems to have been minimized by the restriction of salt dissolution to beds within the Rustler and by the relatively high overburden pressure which would have tended to provide more uniform settlement as salt was being removed. Stratigraphic data from potash holes drilled in the site area indicate no major irregularities in horizons above the Salado (Figures 4.4-10 through 4.4-15).

4.4.5 Summary and Conclusions

Jones (1973) concludes that:

> "The structure of the Los Medanos area is basically simple and the rocks are, for the most part, only slightly deformed. Nevertheless, the rocks have been tilted, warped, eroded, and subroded (i.e., subjected to subsurface solution), and discrete structural features can be recognized. These include: (1) structural features of regional extent related to Permian sedimentation, (2) intra-formational folds of limited extent related to "down-the-dip" movement of salt under the influence of gravity and weight of overburden, and (3) subsidence folds related to warping and settling of rocks to comform with the general shape and topography of the surface of salt in areas of subrosion...
>
> "On the basis of available geological information, the salt deposits of (the) Los Medanos area seem in many ways to constitute a suitable receptacle for use in a pilot-plant repository for radioactive wastes. The deposits have thick seams of rock salt at moderate depths, they have escaped almost completely undamaged from long periods of erosion. The deposits are only slightly structurally deformed, and they are located in an area that has had a long history of tectonic stability."

Information that has been developed in the succeeding five years of investigations has little altered that assessment relative to the

structural and tectonic conditions present at the WIPP site. Based on exploration accomplished to date, a series of structure contour and isopach maps is presented for rocks ranging in age from Devonian to Pleistocene. This and other information indicates that tectonic faulting and warping of rocks in the site vicinity seems to be restricted to Pennsylvanian and older rocks and to have predated Permian evaporite deposition; certain minor faulting within the thick Permian section appears to have occurred contemporaneously with sedimentation. Deformation related to salt flowage has occurred primarily in the Castile Formation beneath the Salado, and has perhaps modified the regional easterly gradient to 80 to 100 feet per mile to some extent at the level of the storage horizons near the base of the Salado. Areas in the vicinity of the site in which artesian brine reservoirs have been encountered are associated with thickened salt sections and salt-cored anticlines in the Castile, but no such structural features are recognizable within the limits of the WIPP storage facility on any of the Salado horizons contoured. The site, if anything, appears to be in a slight structural saddle, a condition considered to be a favorable criterion for site selection. Dissolution of bedded salt beneath the site has been resticted to horizons within the Rustler Formation; there is no evidence that the resulting settlement produced any significant structural irregularities or collapse features in the overlying strata within the area of the WIPP site. Investigations are continuing to further define the extent to which salt deformation in the Castile may have affected the structural configuration within the lower part of the Salado where excavation of the RH- and CH- levels is presently planned. These investigations will permit a more detailed assessment of the optimum location, design, and construction method of the storage facility.

4.5 Site Geologic History

Three main phases characterize the geologic history of the WIPP site subsequent to the original establishment of a granitic basement intrusive complex between a billion and a half-billion years ago, forming the cratonic crust beneath the site. The first phase, of at least 500

million years' duration, was a time of uplift and erosion of all pre-existing Precambrian sedimentary and metamorphic rocks which may have once been deposited or formed in the site area, eventually exposing the deep-seated igneous rocks. The second phase was characterized by an almost continuous marine submergence lasting about 225 million years, wherein shelf and shallow basin sediments slowly accumulated. This depositional phase culminated in a comparatively rapid accumulation of over 13,000 feet of sediment within a relatively brief period lasting 50 to 75 million years, toward the end of which time thick evaporite beds, mainly rock salt, were deposited. Uplift and subaerial conditions next returned to the site in the third and final phase, and have persisted some 225 million years to the present, with the exception of a brief marine inundation in the middle of that span of time. Periods of terrestrial deposition alternated with erosional episodes, so that a series of nonmarine deposits separated by unconformities blanket the evaporite beds at the site.

Since the first phase mentioned above really reflects the absence of any evidence in the geologic record at the site for specific events which may have occurred during the latter part of Precambrian time, the following review of site geologic history considers only post-Precambrian events. Additional discussion of geologic history in a regional context is contained in Section 3.6. The reader is referred to Figure 4.3-2 for stratigraphic orientation.

The Precambrian basement terrane, exhumed during the vast erosional regime of late Precambrian time, was first submerged at the start of Ordovician time, with deposition of the basal Bliss Sandstone. From Ordovician time through Pennsylvanian time in the southeastern part of New Mexico where the site is located, marine sediments accumulated slowly but continuously. Shelf and shallow basin deposition progressed marginally to or within broad, nearly flat subsiding basin areas of the Tobosa Basin that formed northern arms of the Ouachita trough (Brokaw et al., 1972).

The dominantly carbonate section (dolomite and limestone) from Ordovician through Mississippian time (a span of roughly 180 million years) indicates stable shelf and gently subsiding shallow basin environments. A sandy clastic sequence in mid-Ordovician time (Simpson Group) may perhaps signify mild uplift of a landmass ancestral to the Central Basin Platform. Although an Ordovician-Silurian unconformity has been recognized elsewhere in the region (refer to Section 3.5), none is evident in the site area. The first significant post-Cambrian emergence or marine regression occurred during the Early and Middle Devonian, but the area apparently was a broad plain never elevated much above sea level. Marine waters reinvaded the area in Late Devonian time, accompanied by unconformable deposition of distinctive black shale (Woodford Shale), followed by a return to carbonate accumulation in Early Mississippian time. Continued subsidence of the area was accompanied by deep-water deposition of dark, silty shale (Barnett).

The end of Mississipian time heralded significant regional warping and tectonic activity. Major faulting accompanied upwarp of positive tectonic elements in the region, including the Central Basin Platform area (refer to Section 3.6). These positive land masses provided a more abundant supply of clastic detritus which was carried into adjacent marine basins and deposited on moderately warped, tilted surfaces. At about this time, the tectonic framework of the Delaware Basin began development. The site area received sandy Lower Pennsylvanian Morrowan sediment and more or less continuously accumulated sediment over the remainder of the period as repeated basin margin faulting caused periodic, strong uplift of the bordering platforms and some warping within the basin. By the end of Pennsylvanian time, differential tectonic upwarp had ceased (refer to Section 3.6).

At the WIPP site, sedimentation was continuous from Pennsylvanian into Early Permian time. In contrast to Pennsylvanian deposition, however, the Delaware Basin subsided at a greatly accelerated pac during Permian time, partly by downwarp and partly by downfaulting along pre-existing basin margin faults. Perhaps the previous Pennsylvanian tectonic

activity had predisposed the Delaware Basin to more rapid downwarping; at any rate, a thickness of about 9,000 feet of Wolfcampian, Leonardian, and Guadalupian sediment was deposited over little more time than had been required for about 2,500 feet of Pennsylvanian strata to accumulate. The sequence tended to progress from shale to basin limestone to sand, possibly related to encroachment of the basin margin reef deposits, as the central part of the basin continued to subside more rapidly than the shelf areas. Although basin margin reef buildup was active in both Leonardian (Bone Springs) and Guadalupian (Delaware Mountain) time, it was not until the latter part of Guadalupian time that continuous, massive reefs, accreting rapidly to keep pace with continued basin subsidence, virtually encircled the basin. This process culminated with the formation of the massive Capitan reef limestone, which approaches to within 9 miles of the site and delimited the Delaware Basin at that time. Although for many millions of years previous to this time, various lesser reef deposits had been encroaching inward upon the basin, the Capitan reef defined a more restricted area of the Delaware Basin than was ever the case previously. At the WIPP site, the basin facies equivalent to the Capitan reef is the Bell Canyon Formation, mostly siliceous sandstone in lithology. When the Capitan reef eventually encircled the basin at the close of Guadalupian time, the top of Bell Canyon was 1,000 to 1,500 feet lower in elevation than its facies equivalent high on top of the reef only a few miles away. At this time the reef had closed off free access of the open sea to the Delaware Basin, setting the stage for the ensuing precipitation of the Ochoan evaporites.

As the seawater in the salt basin of Castile time evaporated to brine, precipitation of anhydrite and limestone, followed by anhydrite and finally salt (halite) occurred. Several major incursions of seawater must have refilled the basin, for there are a number of thick, laminated anhydrite-calcite beds separated by thick salt members. Because this salt basin was shielded from clastic sediment deposition by high bounding reefs, the Castile evaporites tend to be the most chemically pure of the Ochoan evaporites. Eventually the Castile evaporites filled the basin

enclave to the level of the top of the sheltering reef masses. The Salado salt then extended over the top of the still subsiding reefs, burying them and extending outward into the Permian Basin. Although the region continued to subside, reef organisms could not survive in the briny environment, and burial of the reefs by the Salado resulted in the final disappearance of the Delaware Basin as a paleogeomorphic entity.

The Salado, inasmuch as it formed in a broad, regionally extensive brine basin not bounded by protective reefs, was more susceptible to clastic influx, and therefore its halite deposits are generally somewhat less pure than those of the Castile. Nearly 2,000 feet of mostly rock salt accumulated before an increase of clastic influx accompanied by a decrease in salinity caused deposition of Rustler lithologies to occur (anhydrite more dominant with significant thicknesses of clastic rocks). Finally in a shallowing sea or on marginal mudflats, the Dewey Lake Redbeds were deposited as subsidence gradually ended, covering the salt beds with a thick clastic blanket. This was the final episode, about 225 million years ago, of a remarkable accumulation of marine deposits which had been first laid down in Ordovician time.

No Lower Triassic strata occur at the WIPP site, nor are they known in the region (refer to Section 3.6.4). It was a time of general regional epeirogenic uplift and erosion; only a slight angular unconformity is present between Dewey Lake strata and overlying strata (Jones, 1973). According to Bachman (1974), "it is possible that some dissolution of Permian soluble rocks occurred in the periods of uplift during Triassic time", but direct evidence of this has not been found in southeastern New Mexico. Isopachs of the Dewey Lake where it is covered by Upper Triassic rocks indicate a thickness of about 500 feet. Furthermore, Jones (1973) indicates the pre-Upper Triassic Dewey Lake thickness decreases northwestward. Although the actual original protective thickness of the Dewey Lake westward across Nash Draw and over to the Pecos is now indeterminate due to later removal by erosion, it is interesting to speculate whether some dissolution features and processes presently observed there may not have had their beginning in Early Triassic time, over 200 million years ago.

In Late Triassic time inland basin streams laid down floodplain deposits of the Santa Rosa and Chinle Formations, the first record of non-marine deposition in the area. The total original thickness of Late Triassic deposition is not known, because of an erosional surface on the Triassic of the region. The first erosion to have acted upon the Triassic rocks lasted from the close of Triassic time to Late Early Cretaceous, a period which may have lasted as long as 90 million years. In latest Early Cretaceous time (Washita, about 100 m.y.b.p), a shallow sea transgressed across the site area and deposited an unknown thickness of marine sediments. Later erosion removed all but slumped or sunken residual fragments of a presumably once extensive Cretaceous cover.

These Late Triassic-Early Cretaceous relationships hold important implications for the history of both salt dissolution and salt deformation in the Delaware Basin. As Bachman (1974), has stated,

> "In central and southeastern New Mexico where Triassic rocks are preserved they are overstepped by rocks of Cretaceous age. In general, these Cretaceous rocks rest on progressively older rocks toward the south and southwest. After cutting across the wedge edge of Triassic rocks, the Cretaceous rocks rest on Permian or older strata at many places in southern New Mexico."

By plotting locations of these small Cretaceous outliers and noting the age of rocks on which they occur, Bachman (1976) reconstructed an approximation of the Jurassic erosion surface, showing where Permian rocks were unprotected by Triassic cover and exposed to erosion sometime during the Jurassic-Early Cretaceous erosional interval. The sketch shows that Permian rocks along the western edge of the Delaware Basin were exposed to the atmosphere and presumably eroded during Jurassic time. "Probably some dissolution of Permian salt and gypsum occurred in the western part of the Delaware Basin at this time" (Bachman, 1976). To the extent that "deep dissolution" features are recognized today in salt at depths of several thousand feet below the surface (Anderson, 1978), it seems quite likely that similar features would have been present and developing at comparable depths during the Jurassic erosion 100-190 million years ago. Further, considerable dissolution effects could have been initiated or accelerated during the Cretaceous at times preceding or

subsequent to Washitan submergence, particularly in view of the humid or even tropical conditions known to have characterized the Cretaceous in North America.

A second aspect of the above-described Triassic-Early Cretaceous relationships relates to the history of salt deformation at the WIPP site. Prior to Cretaceous submergence, Jurassic erosion had bevelled the blanket of Upper Triassic Dockum sediments to a wedge that pinched out westward across the Delaware Basin. Evidently, eastward regional tilting had occurred, at least by the end of Jurassic erosion. Since this tilt would have involved the underlying salt beds, some salt flow and deformation may have occurred at this time. Deformation may even have continued during the time in which the region was submerged by the Cretaceous marine incursion and was later covered by an unknown thickness of marine strata.

Although the duration of the Cretaceous epicontinental marine transgression is not precisely known for this area, probably early in late Cretaceous time the sea withdrew; during the remainder of Late Cretaceous time the area was probably of low relief and only slightly above sea level (Hayes, 1964). No early or middle Tertiary deposits are known in the site area, so that geologic events near the site over the 60 million years after the end of Cretaceous time and the beginning of Pliocene time are poorly known. Major uplift probably took place concurrent with the Laramide orogeny that occurred farther north and west. "Probably late in the Cretaceous Period or very early in the Tertiary Period the entire region was elevated by broad epirogenic uplift and was tilted slightly to the northeast" (Hayes, 1964). The Cretaceous rocks were eroded to expose Triassic rocks in the eastern half of the Delaware Basin and Permian rocks in the western half of the basin. This erosion again subjected Permian salt to further dissolution (Bachman, 1974), and produced a second erosional truncation of Late Triassic Dockum sediments (Jones, 1973). In Oligocene time (35 m.y.b.p.), lamprophyr-

(basaltic) dikes were intruded in the subsurface along a northeast-southwest dike trend which occurs about 8 miles northwest of the site; this is the only post-Precambrian igneous rock known in the New Mexico part of the Delaware basin.

By Late Miocene time conditions became less arid and eastward-flowing alluvial distributories began to deposit sandy and gravelly sediment over an irregular erosion surface. Deposition of these sediments, referred to as the Ogallala Formation, began as early as 12 million years ago and ended before the close of Pliocene time, perhaps as early as 4 million years ago (Bachman and Johnson, 1973). The nearest Ogallala occurrence is at The Divide, 6 or more miles northeast of the site, where its maximum thickness is only 27 feet, which is considered to represent an original, or depositional, thickness (Bachman, 1974).

It is not known whether any Ogallala sediments were ever deposited at or west of the site, or to what extent dissolution subsidence features were geomorphically expressed in Nash Draw and southwestward within the Delaware Basin by the time the erosional plain associated with Ogallala deposition had developed. Bachman (1976) states that, "by the end of Ogallala time the High Plains surface was probably continuous westward across the present Pecos River drainage to the backslope of the Sacramento Mountains" in the region north of the Delaware Basin but that "the Ogallala Formation may not have been deposited in the Pecos depression southward from Carlsbad.... Although some form of major drainage may have been present in the vicinity of the modern Pecos River during pre-Ogallala time, (Bachman's) work does not support an interpretation of thick Ogallala fill southwest of The Divide" (Bachman, 1974). Nevertheless, Bachman (1976) believes "much of the lowering of the Pecos River Valley has occurred as a result of dissolution of evaporites in the underlying Permian rocks since Ogallala time."

When Ogallala deposition ceased in Late Pliocene time, the region around the site was tectonically stable and the climate was arid to semiarid; during this time a caliche caprock developed on the Ogallala surface.

Renewed erosion took place during early Pleistocene time following Basin-and-Range tectonic activity and rejuvenation of the Rocky Mountains. At the site the effect of this uplift and increased rainfall was to cause a renewal of erosional and dissolutional activity. Active stream erosion in the site area caused a third erosional surface to be incised into the Late Triassic sediments; in Nash Draw, this erosion cut deep into the Dewey Lake Redbeds at the same time that Nash Draw was actively collapsing due to subsurface dissolution. Eventually these channels and sinks were filled with the Gatuna Formation, which was derived from reworked Ogallala and older sediments, and a veneer of Gatuna material was deposited across the Los Medanos Mid-Pleistocene surface. Bachman considers that this erosion and deposition occurred "during the most humid climatic conditions that have existed in the area since Ogallala time" (Bachman, 1974), and tentatively correlates the Gatuna deposition with Kansan time, which ended approximately 600,000 years ago.

After deposition of the Gatuna Formation, a caliche (Mescalero caliche) caprock formed on the Gatuna surface in a semiarid environment during an interval of climatic and tectonic stability (Bachman, 1974). Regional climatic considerations lead Bachman to assign a mid-Pleistocene age for the Mescalero caliche, which he tentatively correlates with the Yarmouth interglacial stage, or about 600,000 years before the present (refer to Section 4.3.2).

Since the formation of the Mescalero caliche some half a million years ago, little geological activity has occurred at the WIPP site. In the Pecos Valley a number of Pleistocene surfaces can be identified which provide some clue to the evolution of the regional drainage system (refer to Regional Geomorphology, section 3.2.2.1). At the edge of Nash Draw along Livingston Ridge, the Mescalero caliche is fractured and draped into the draw, indicating that Nash Draw was subjected to some dissolution and subsidence in the half million years subsequent to formation of the caliche, presumably during the more pluvial periods of Illinoian or Wisconsinan glaciations. Similar evidence exists along

other slopes and in sinks within and adjacent to Nash Draw, but is not observed away from Nash Draw in the direction of the site. Perhaps the most obvious activity at the site has been the formation of a nearly continuous cover of windblown sand and sand dunes in Late Pleistocene and Recent time, believed to have been supplied from the east rather than from the Pecos area to the west. The sand apparently was eroded from the Ogallala in wet climatic intervals and was blown westward across the area during dry intervals.

4.6 SUMMARY

Investigations of the site geology for the WIPP define the geology as it is presently known for determination of the general suitability of the site. Many of the factors in Chapter 2 are addressed here in Chapter 4. The ultimate acceptability of the site for a repository may only come after the detailed geology of the site is known from underground workings.

The site physiography and geomorphology shows the site to have been relatively stable through the last 500,000 years or more. The development of the Mescalero caliche, and the lack of developed drainage are indicative. Localized sinks or basins are surficial.

Site stratigraphy and lithology including the evaporites shows continuity from the regional setting. The evaporites at the site are about 3500' thick, and include the Castile Formation, Salado Formation and Rustler Formation from bottom to top. The subsurface structure at the WIPP site within the evaporites is salt deformation three miles north of the site center and possibly also one mile north. The structure three miles north involves deformation of the Castile and lower Salado; drilling (WIPP 11) showed the deformation to be upward bulging of salt, but no severe displacements and no brine or gas were encountered. The structure one mile north appears to be smaller, and is of concern mainly for design of underground workings. It is being investigated further for this purpose. Within the site structure contours on evaporite horizons show areas with slight closure; the range of precision of data from industry

sources and natural variability can probably account for these features though slight deformation or dissolution could also be invoked. No surficial faults are known at the WIPP site.

The potential repository zones are located in the Salado Formation at depths from 2730' to 2620' (remote handling) and 2176' to 2074' (contact handling). These beds are chosen on the combined basis of purity, depth, thickness, mutual separation, and depth below the potash zone.

The geological history of the site is encompassed in the geological history of the region.

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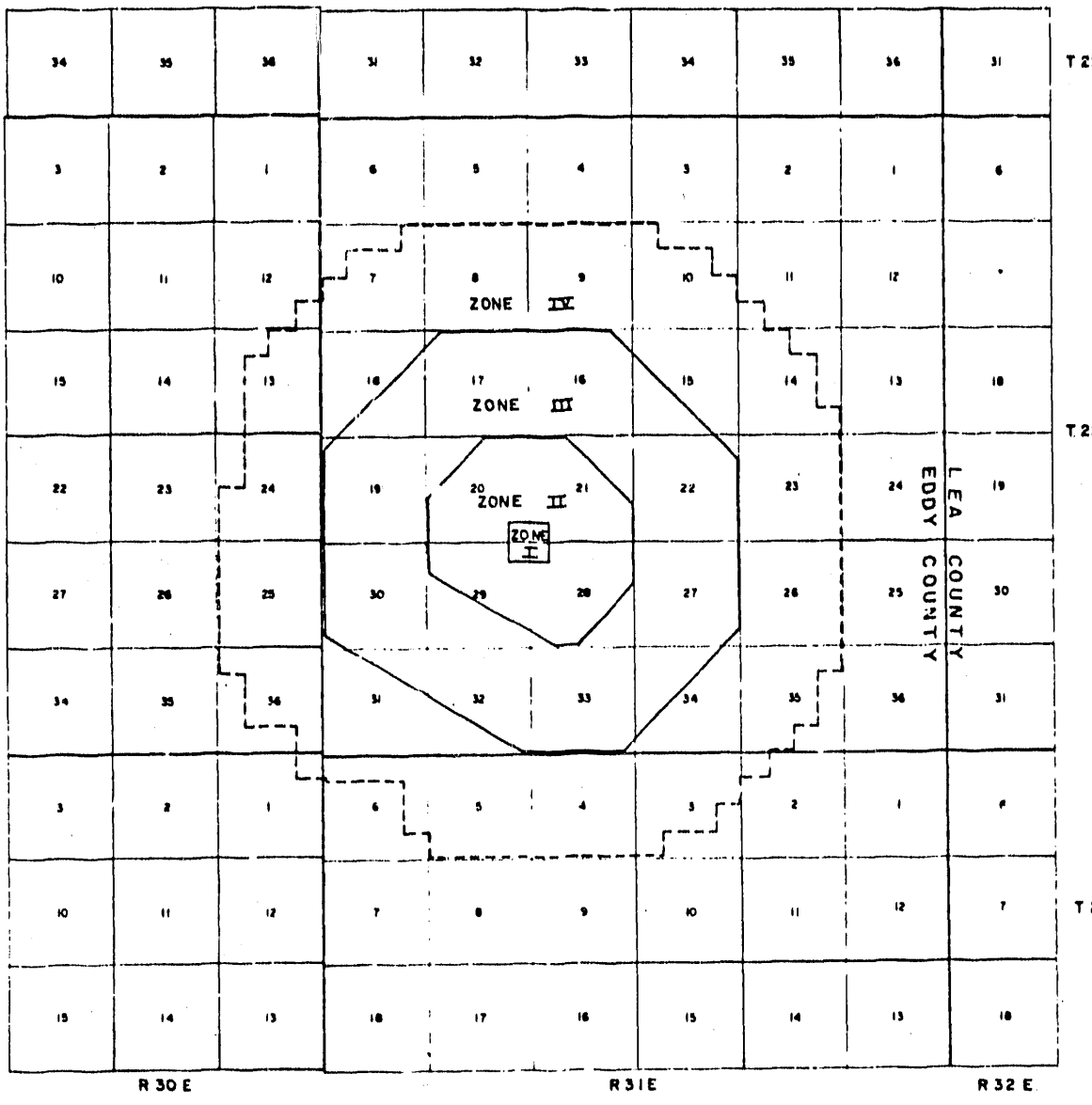


ZONE ACREAGE

ZONE I - 60-100 (surface facilities)

ZONE II - 1860 (underground repository)

ZONE III - 6230 (no mining or drilling)

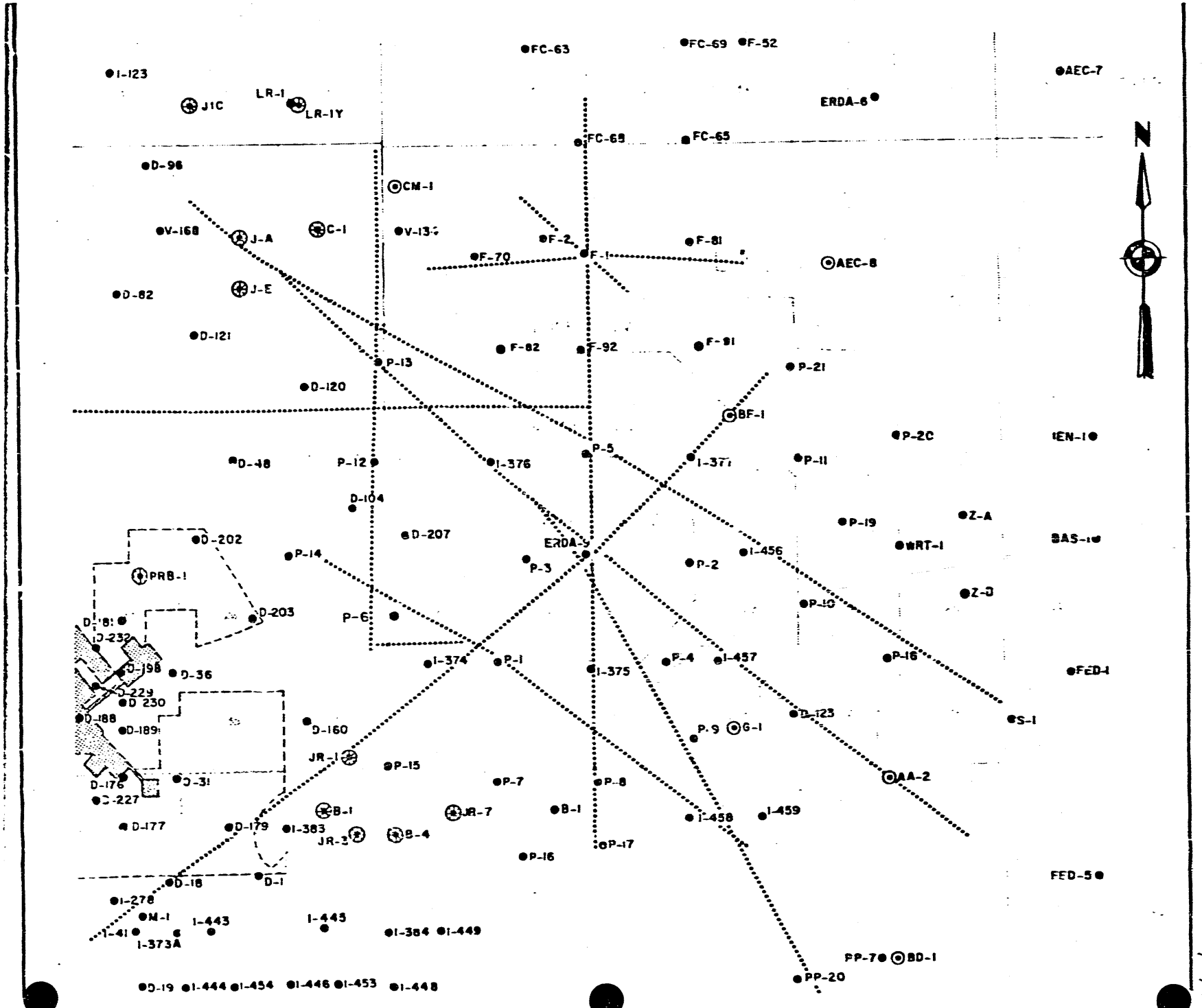
ZONE IV - 10,810 (DOE-controlled mining and drilling)

SCALE IN MILES

0 1 2 3

WIPP SITE ZONATION

FIGURE 4.1-1


FC-63
FC-69
F-52
I-123
AEC-7
J1C
LR-1
LR-1Y
ERDA-6
FC-68
FC-65
D-96
CM-1
V-168
J-A
C-1
V-13
F-2
F-81
F-70
F-1
AEC-8
D-82
J-E
D-121
F-82
F-92
F-91
P-13
P-21
D-120
BF-1
P-2C
IEN-1
P-5
D-48
P-12
I-376
I-377
P-11
D-104
P-19
Z-A
D-202
D-207
ERDA-5
WRT-1
SAS-1
P-14
P-3
I-456
P-2
PRB-1
Z-B
D-203
P-6
P-10
D-232
I-374
P-1
I-375
P-4
I-457
P-16
FED-1
D-198
D-36
D-229
D 230
D-123
S-1
D-188
D-189
D-160
P-9
G-1
JR-1
P-15
AA-2
D-176
D-31
P-7
P-8
D-227
B-1
JR-7
B-1
I-458
I-459
D-177
D-179
I-383
JR-3
B-4
P-17
P-16
D-18
D-1
FED-5
I-278
M-1
I-443
I-445
I-41
I-373A
I-384
I-449
PP-7
BD-1
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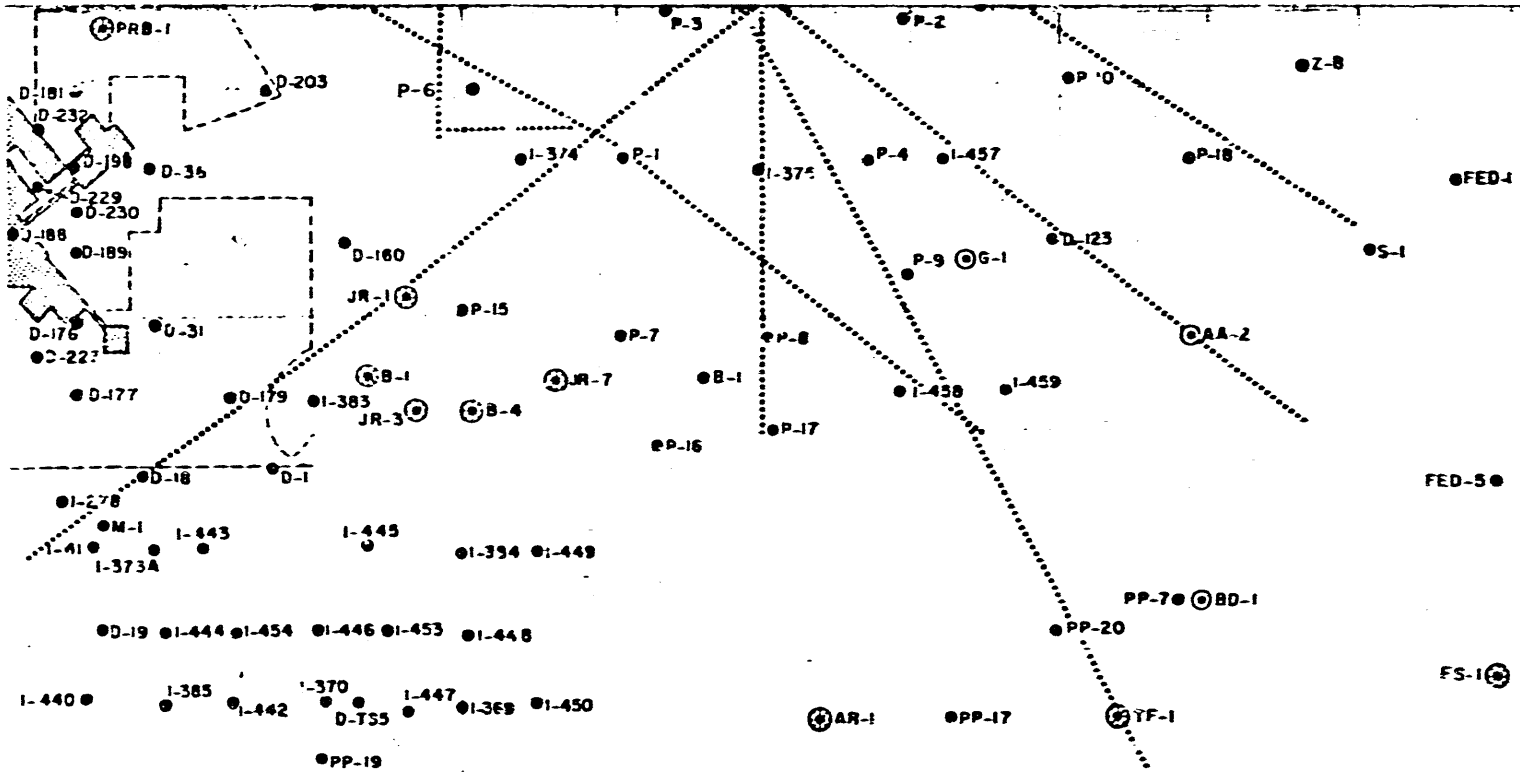
D-19
I-444
I-454
I-446
I-453
I-448

16-4



EXPLANATION

- Shallow drill holes (bottoming above the Delaware)
- Drill holes penetrating Delaware and deeper horizons
- Hydrocarbon producer (past or present)
- Seismic reflection survey lines
- Location of underground potash mines
- Area of planned underground potash mining

NOTE

1 Additional drill hole data are listed in Table 4.1-1

2 All seismic profiling shown was performed under

0 1 2 3

SCALE IN MILES

REFERENCES

Griswold, 1977, figure 4.

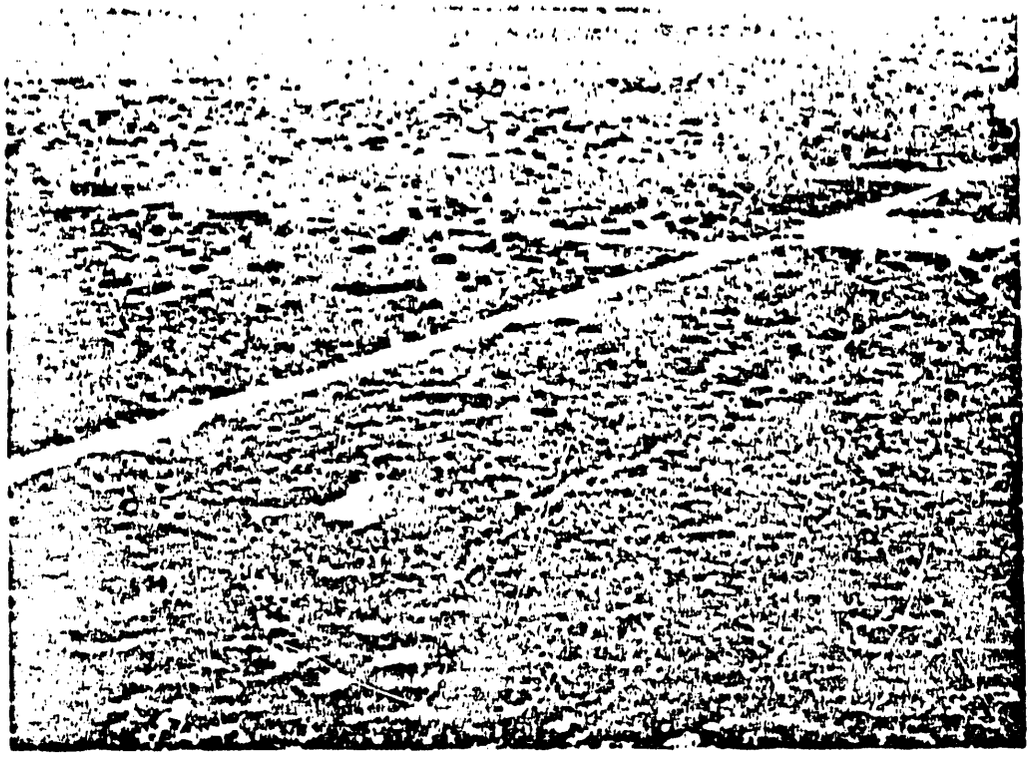
G. J. Long & Associates, May 1977

G. J. Long & Associates, Dec., 1977

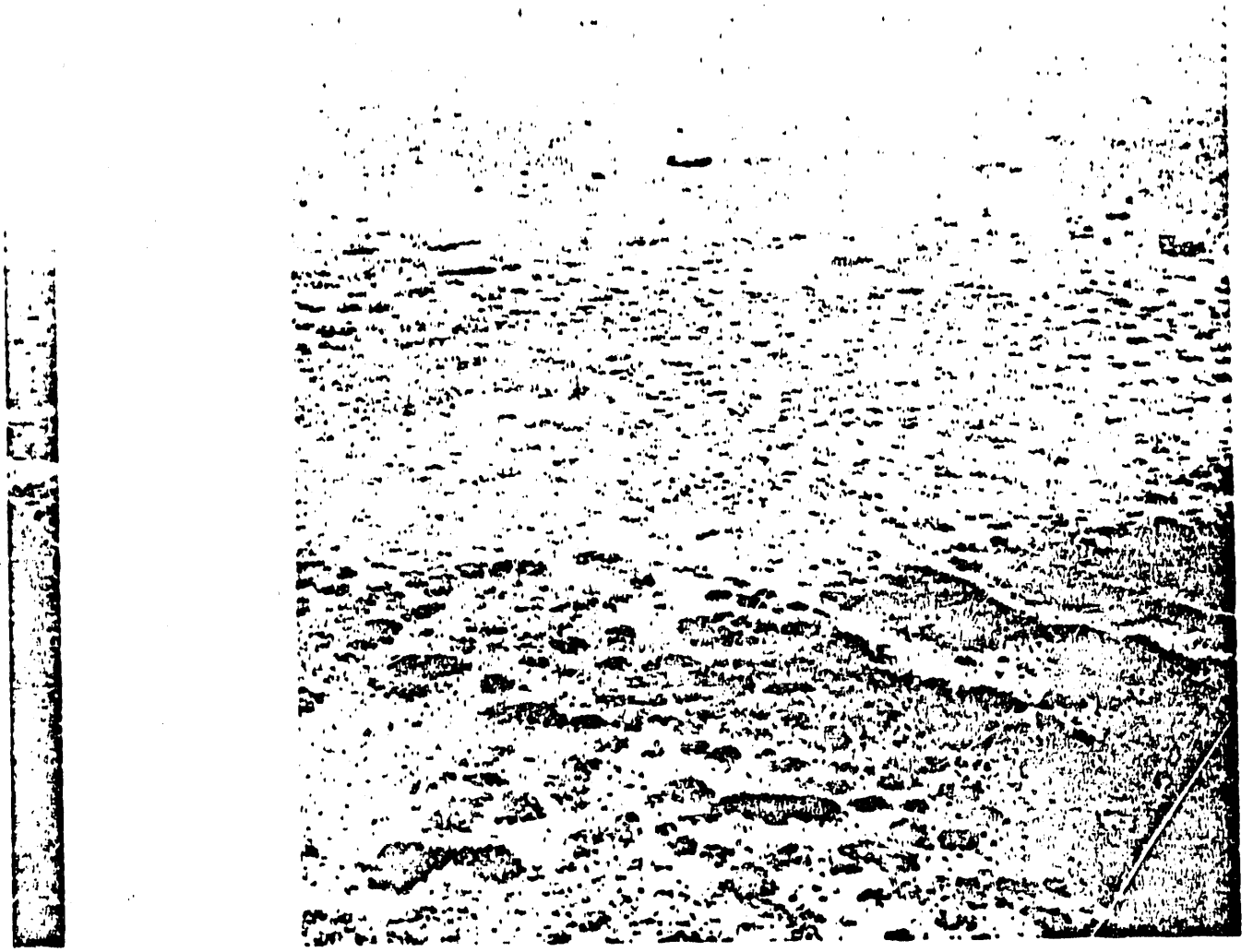
SITE EXPLORATION

DRILL HOLES AND SEISMIC REFLECTION LINES

4.4-6



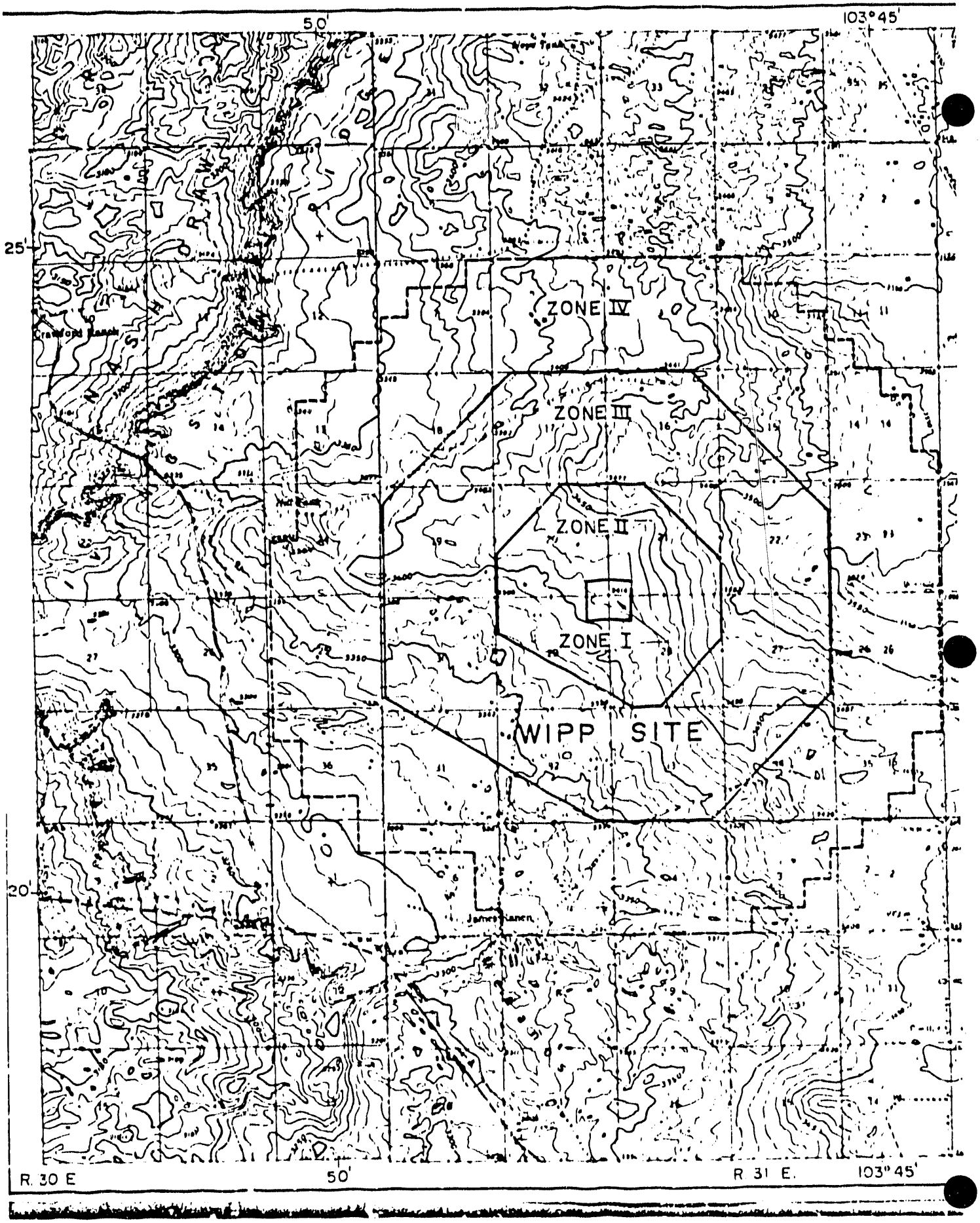
A) Air view northwest across WIPP Site, showing general terrain. Drill rig at right is near center of site, working on ERDA-9. Rig at left is set up on hole H-1.

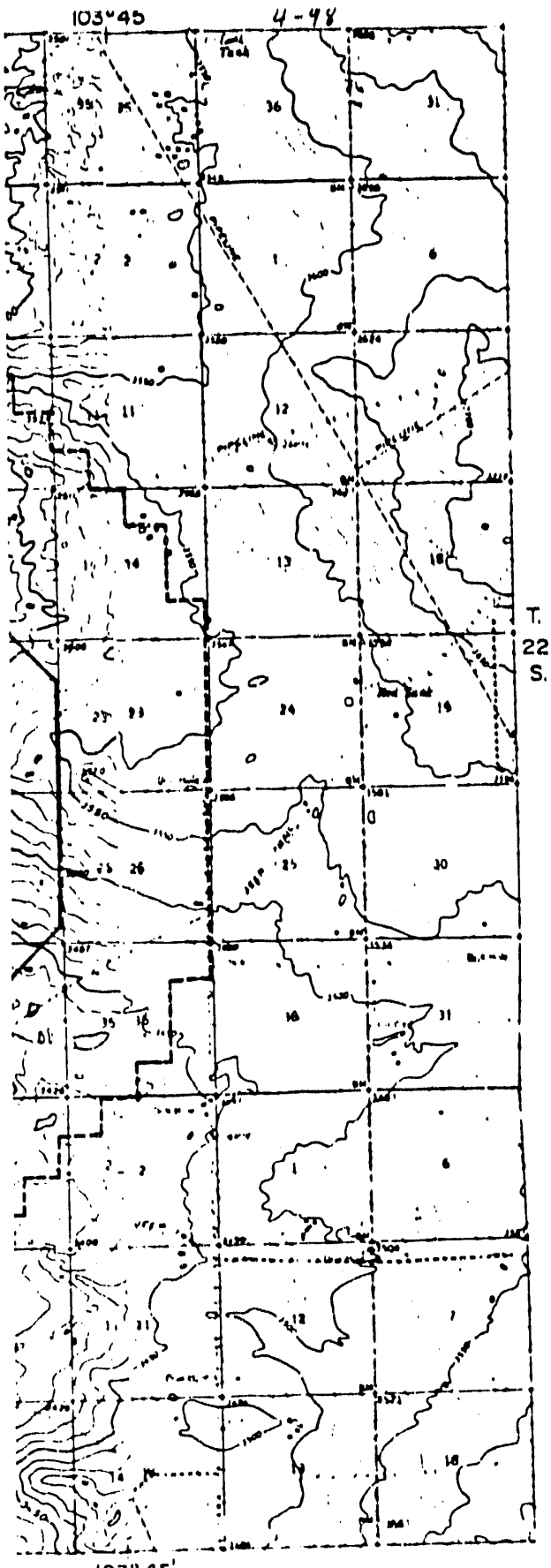


B) Shallow depression eight miles north of site. Diameter about 1000 feet and relief about 30 feet. Investigation of this feature has found no indication of subsurface subsidence or collapse.

SITE PHYSIOGRAPHIC FEATURES

FIGURE 4.2-1


50'
103°45'
25'
ZONE IV
ZONE III
ZONE II
ZONE I
WIPP SITE
20'
R. 30 E
50'
R 31 E.
103°45'



REFERENCE:

U S G S. 15 minute quadrangles Nash Draw, N.Mex., 1965 and Hat Mesa, N.Mex., 1972.

0 1 2 3 MILES

0 1 2 3 KM

SCALE

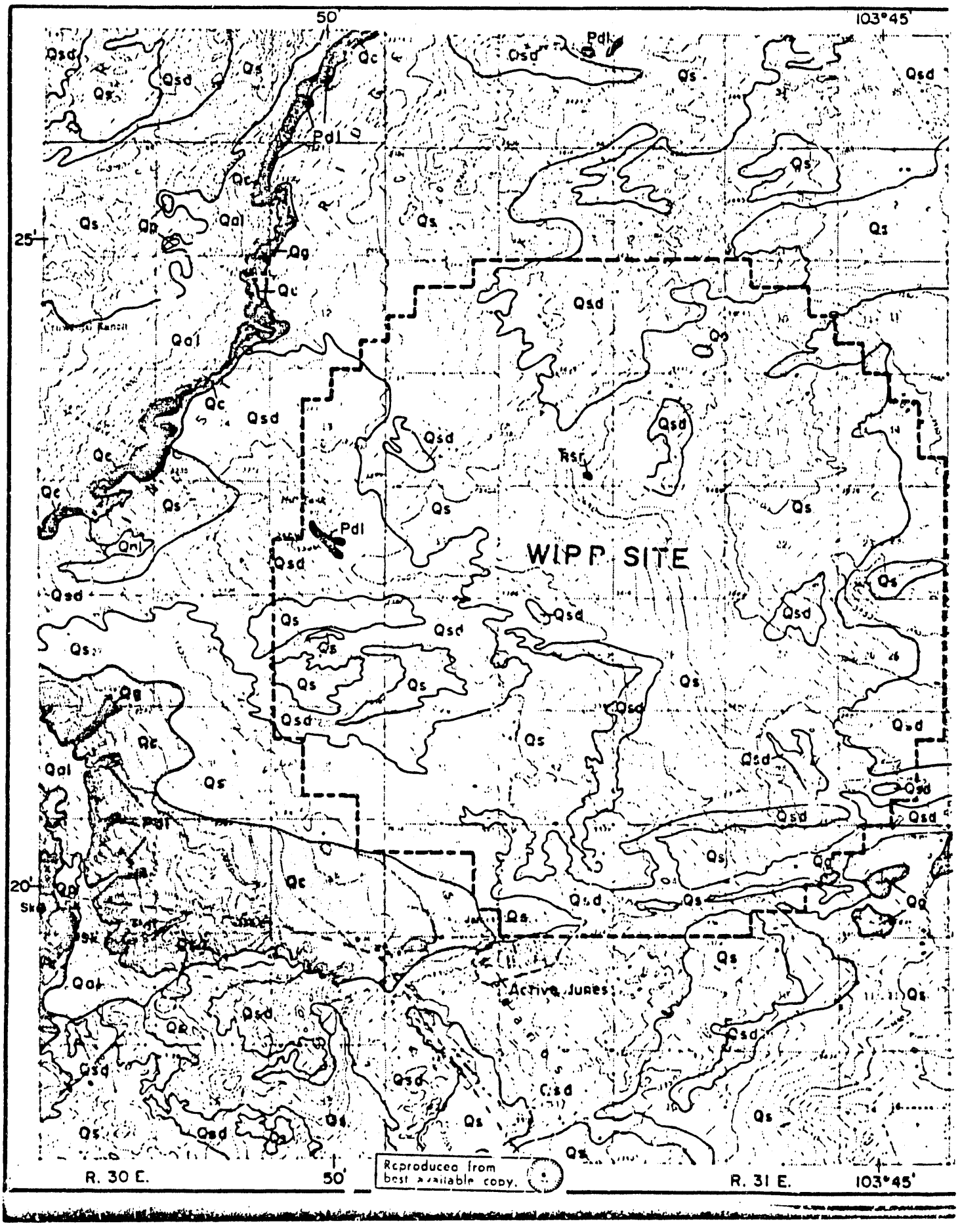
SITE TOPOGRAPHIC MAP

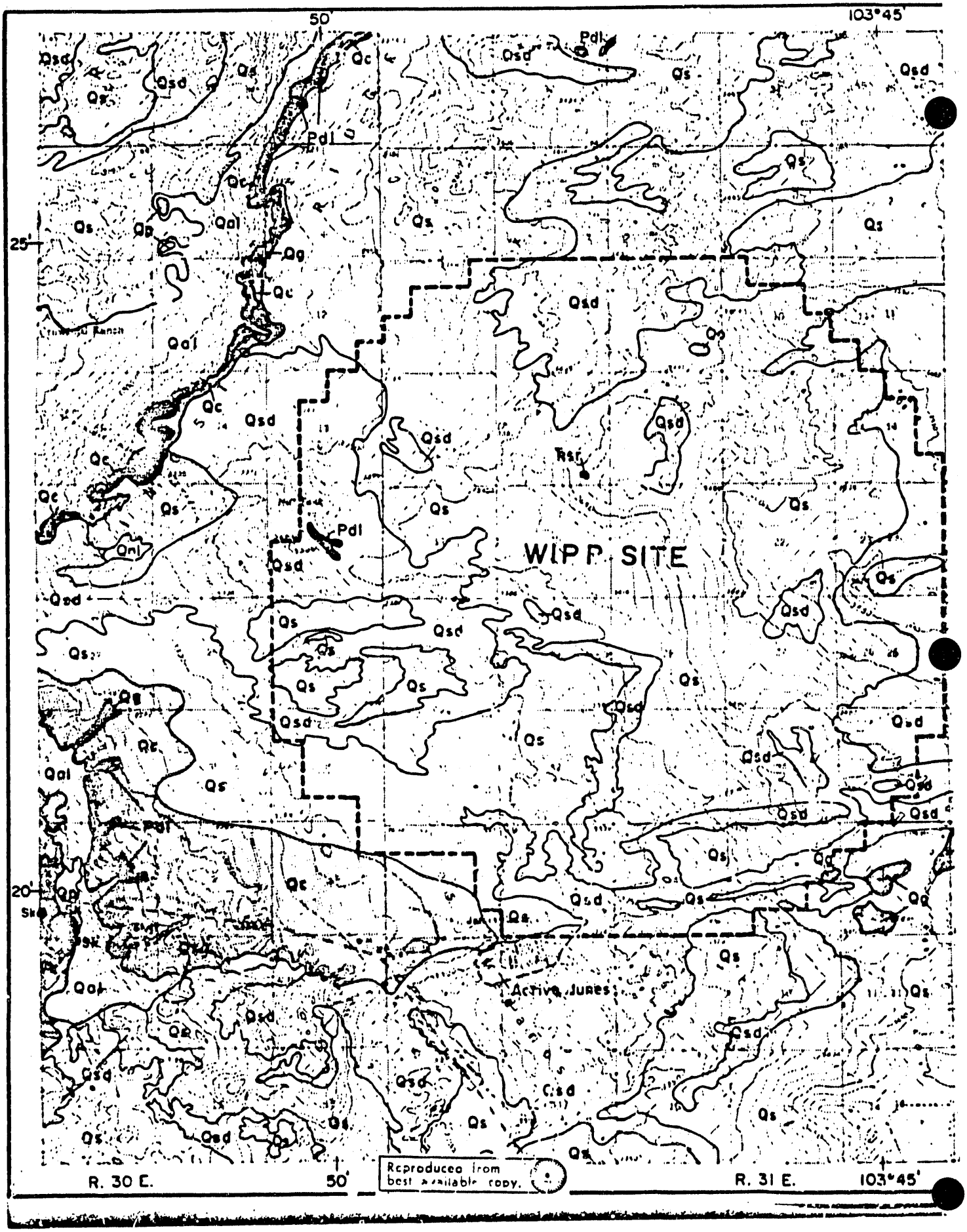
FIGURE 4.2-2

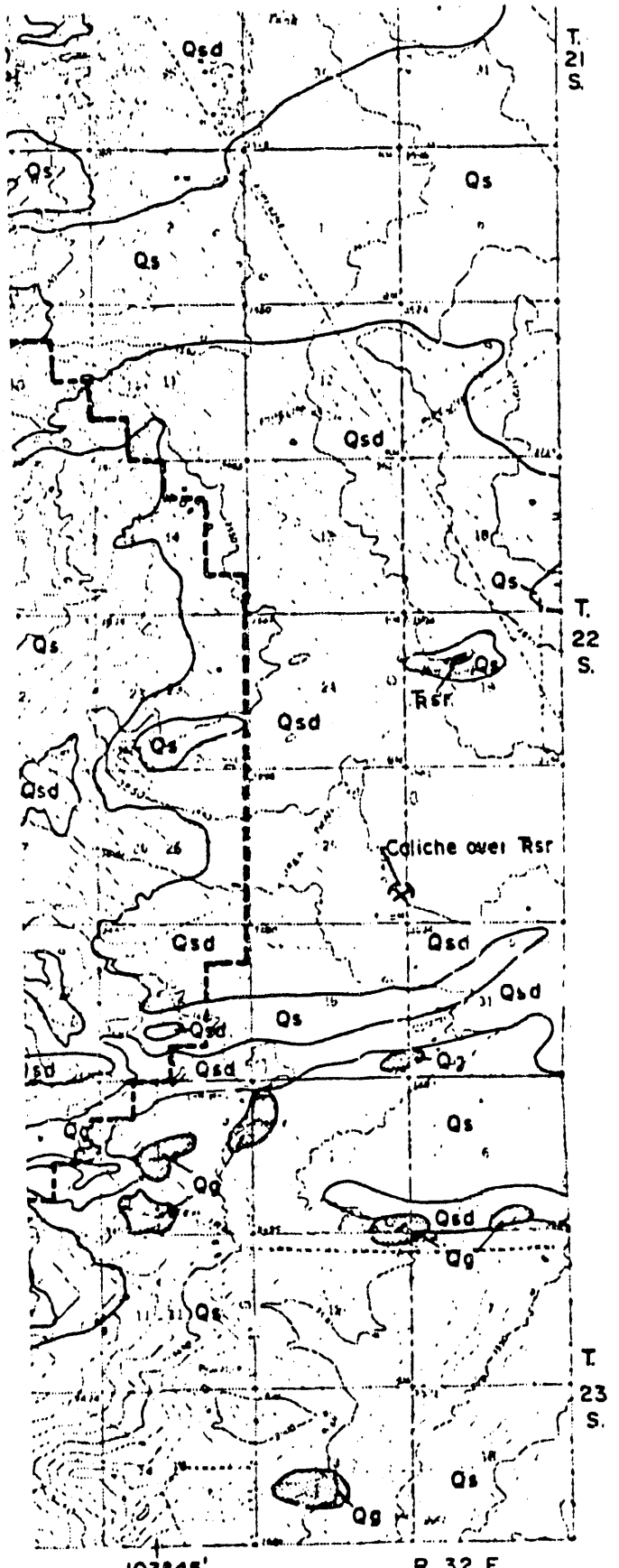
Active sand dunes at James Ranch. Location is 3 miles south of center of site. Viewed southeast.

ACTIVE DUNES NEAR SITE

FIGURE 4.2-3


50'
103°45'
25'
20'
WIPP SITE
Active Dunes
Qsd
Qs
Qc
Qdl
Qal
Qg
Qr
Pdl
Qnl
Tsr
Ske
R. 30 E.
50'
R. 31 E.
103°45'
Reproduced from best available copy.


50'
103°45'
25'
20'
WIPP SITE
Pdl
Qsd
Qs
Qc
Qal
Qg
Qr
Qnl
Rsr
Active Dunes
R. 30 E.
50'
Reproduced from best available copy.
R. 31 E.
103°45'



EXPLANATION

QUATERNARY — RECENT

Qs (Qsd) — SAND – Eolian sand plains (Mescalero sand); Qsd, conspicuous dunes, generally stabilized or partly stabilized.

Qa (Qp) — ALLUVIUM – Sand and silt, locally conglomeratic, deposited on gentle slopes and depressions. Qp, playa deposits of sand and silt in shallow intermittent ponds or lakes.

QUATERNARY — PLEISTOCENE

Qc — CALICHE – Limestone (Mescalero caliche), dense to travertine-like, with included sand grains and rock fragments. Has been assigned to Yarmouth interglacial stage.

Qg — GATUNA FORMATION – Gravel, sand silt and clay deposited as alluvium; dominantly reddish-orange, grading to pink, gray or yellow. Has been assigned to Kansan glacial stage.

TRIASSIC — UPPER TRIASSIC

Rsr — SANTA ROSA SANDSTONE – Conglomeratic sandstone, moderate reddish-brown to light brown, poorly sorted, cross-bedded; interbedded locally with moderate reddish-brown claystone and siltstone.

PERMIAN — OCHOAN

Pdl — DEWEY LAKE REDBEDS – Fine sandstone and siltstone, moderate reddish-orange to reddish-brown, conspicuous thin laminae generally less than 1/4 inch thick, locally clayey and with light greenish-gray partings.

Pr — RUSTLER FORMATION – White, massive gypsum

SK — Sinkhole

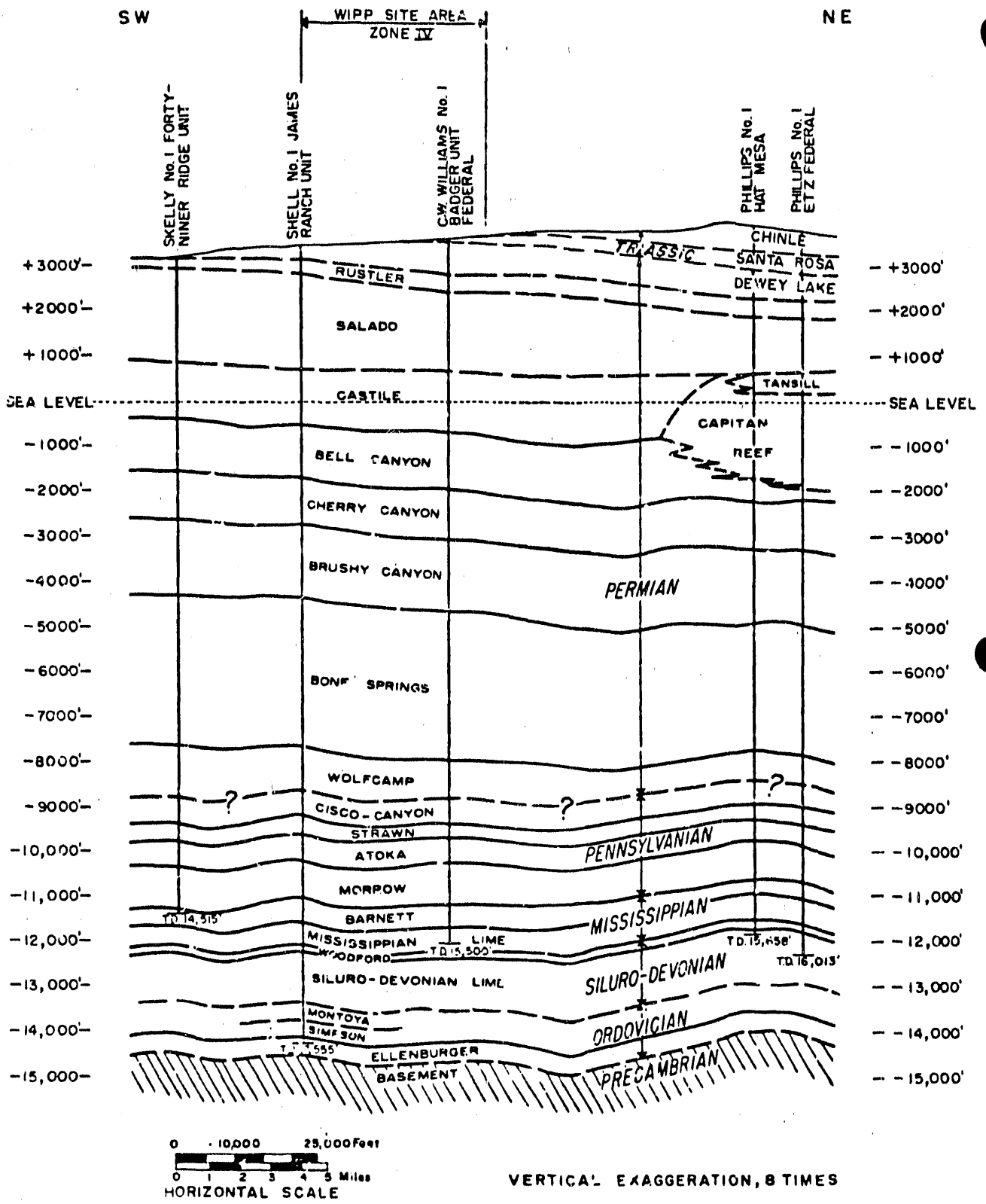
Quarry

REFERENCES: Compiled from geologic maps by Vine (1963) and Bachman (1974).

0 1 2 3 MILES
0 1 2 3 KM.
SCALE

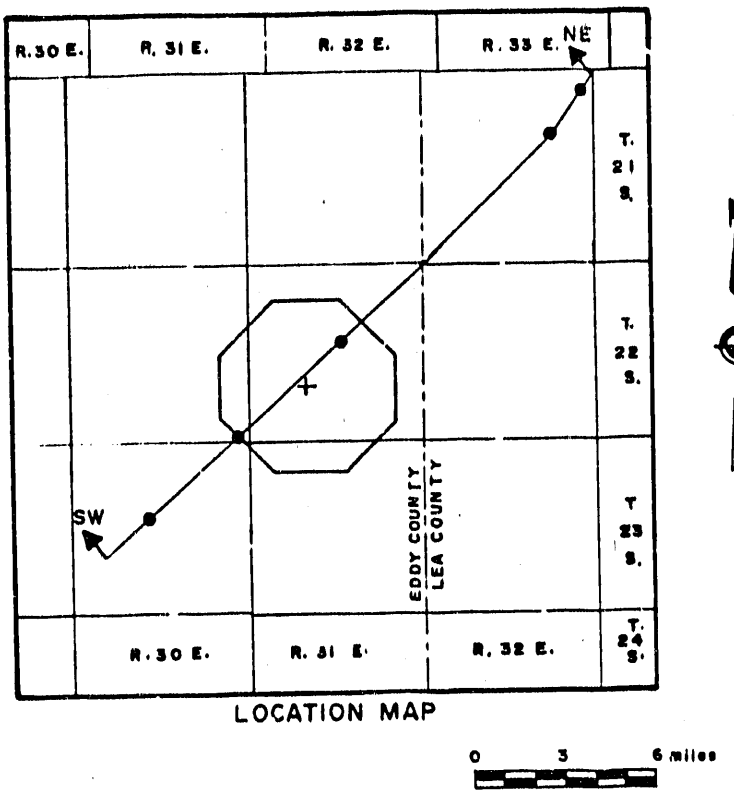
SURFICIAL GEOLOGIC MAP

FIGURE 4.2-4


SW
NE
WIPP SITE AREA
ZONE IV
SKELLY No. 1 FORTY-NINER RIDGE UNIT
SHELL No. 1 JAMES RANCH UNIT
C.W. WILLIAMS No. 1 BADGER UNIT FEDERAL
PHILLIPS No. 1 HAT MESA
PHILLIPS No. 1 ETZ FEDERAL
+3000'
+2000'
+1000'
SEA LEVEL
-1000'
-2000'
-3000'
-4000'
-5000'
-6000'
-7000'
-8000'
-9000'
-10,000'
-11,000'
-12,000'
-13,000'
-14,000'
-15,000'
TRIASSIC
CHINLE
SANTA ROSA
DEWEY LAKE
RUSTLER
SALADO
CASTILE
TANSILL
CAPITAN REEF
BELL CANYON
CHERRY CANYON
BRUSHY CANYON
PERMIAN
BONE SPRINGS
WOLFCAMP
CISCO-CANYON
STRAWN
ATOKA
MORROW
PENNSYLVANIAN
BARNETT
MISSISSIPPIAN
LIME
WOODFORD
T.D. 14,515'
T.D. 15,500'
T.D. 15,458'
T.D. 16,013'
SILURO-DEVONIAN LIME
SILURO-DEVONIAN
MONTOYA
SIMPSON
ORDOVICIAN
ELLENBURGER
BASEMENT
PRECAMBRIAN
0 10,000 25,000 Feet
0 1 2 3 4 5 Miles
HORIZONTAL SCALE
VERTICAL EXAGGERATION, 8 TIMES

E

- +3000'
- +2000'
- +1000'
- SEA LEVEL
- -1000'
- -2000'
- -3000'
- -4000'
- -5000'
- -6000'
- -7000'
- -8000'
- -9000'
- -10,000'
- -11,000'
- -12,000'
- -13,000'
- -14,000'
- -15,000'



LOCATION MAP

REFERENCE:
Netherland, Sewell & Associates, 1974, Exbt. G-18

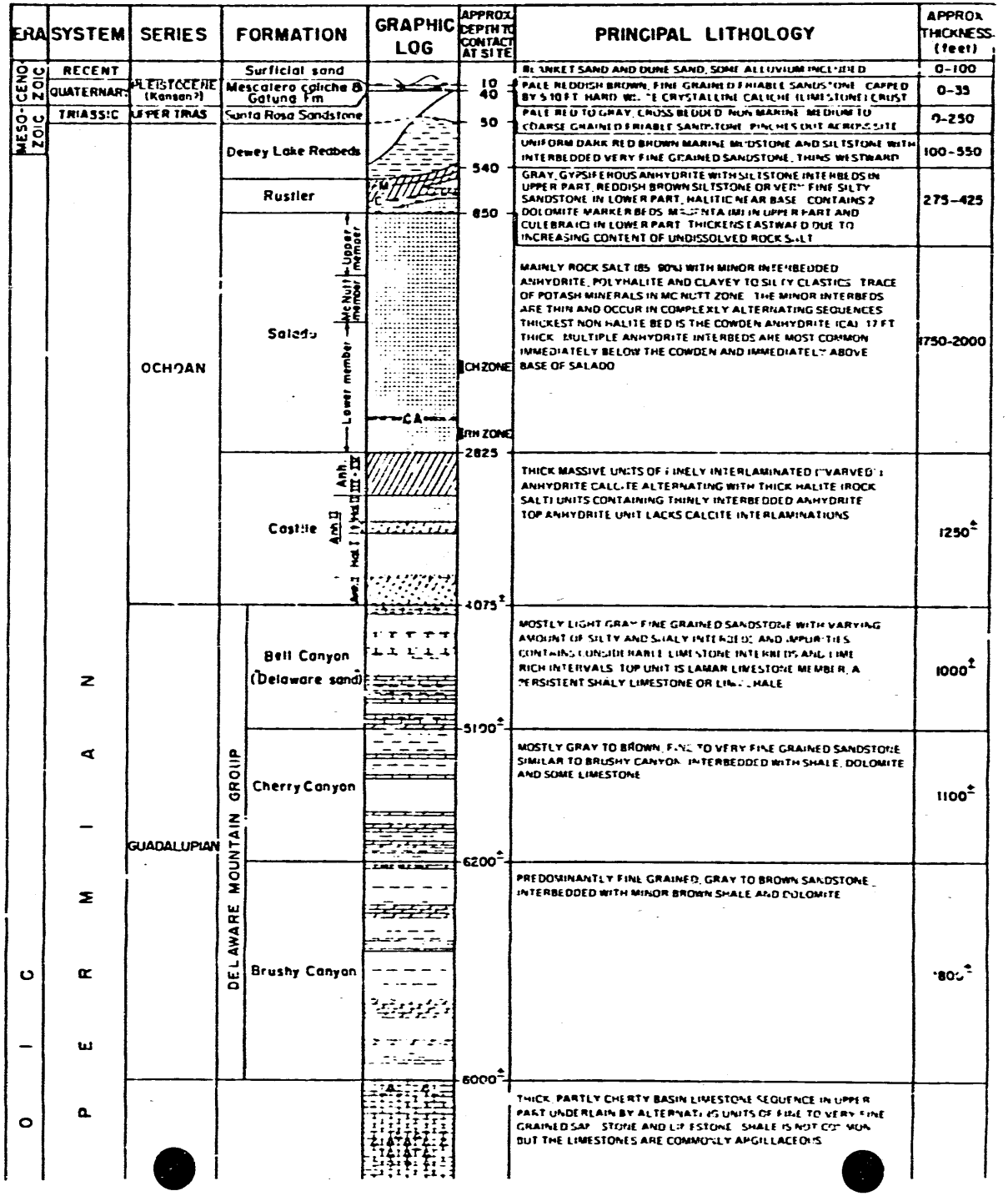
GENERALIZED SITE STRATIGRAPHIC SECTION

FIGURE 4.3-1

EXPLANATION

LITHOLOGIC SYMBOLS

- Sandstone
- Mudstone; siltstone; silty and sandy shale.
- Shale
- Limestone
- Dolomite
- Cherty limestone and dolomite
- Shaly limestone
- Anhydrite (or gypsum)
- Interlaminated anhydrite-calcite
- Halite (rock salt)
- Granitic rocks



REFERENCES:

1. Anderson, 1978
2. Anderson, et al, 1972
3. Brokaw, et al, 1972
4. Foster, 1974
5. Griswold, 1977
6. Meyer, 1966
7. Sipes, Williamson and Aycock, 1976

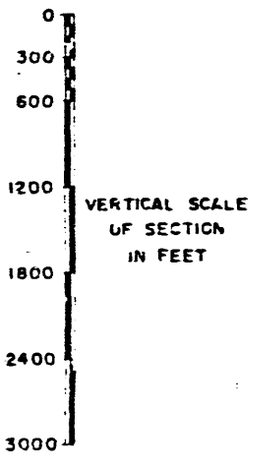
NOTE:

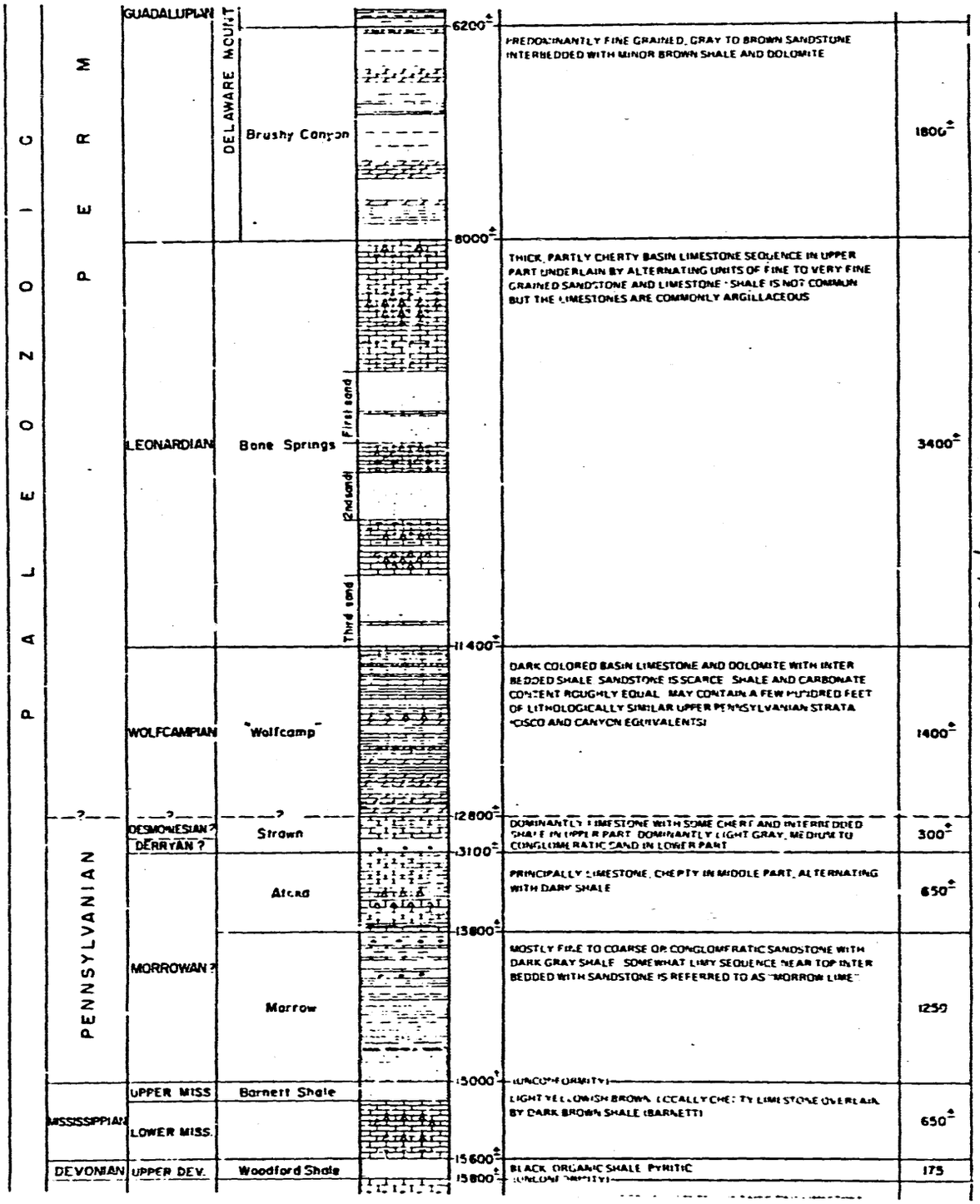
REFERENCES:

1. Anderson, 1978
2. Anderson, et al, 1972
3. Brokaw, et al, 1972
4. Foster, 1974
5. Griswold, 1977
6. Meyer, 1966
7. Sipes, Williamson and Aycock, 1976

NOTE:

For complete citations, refer to reference list for chapter 4.





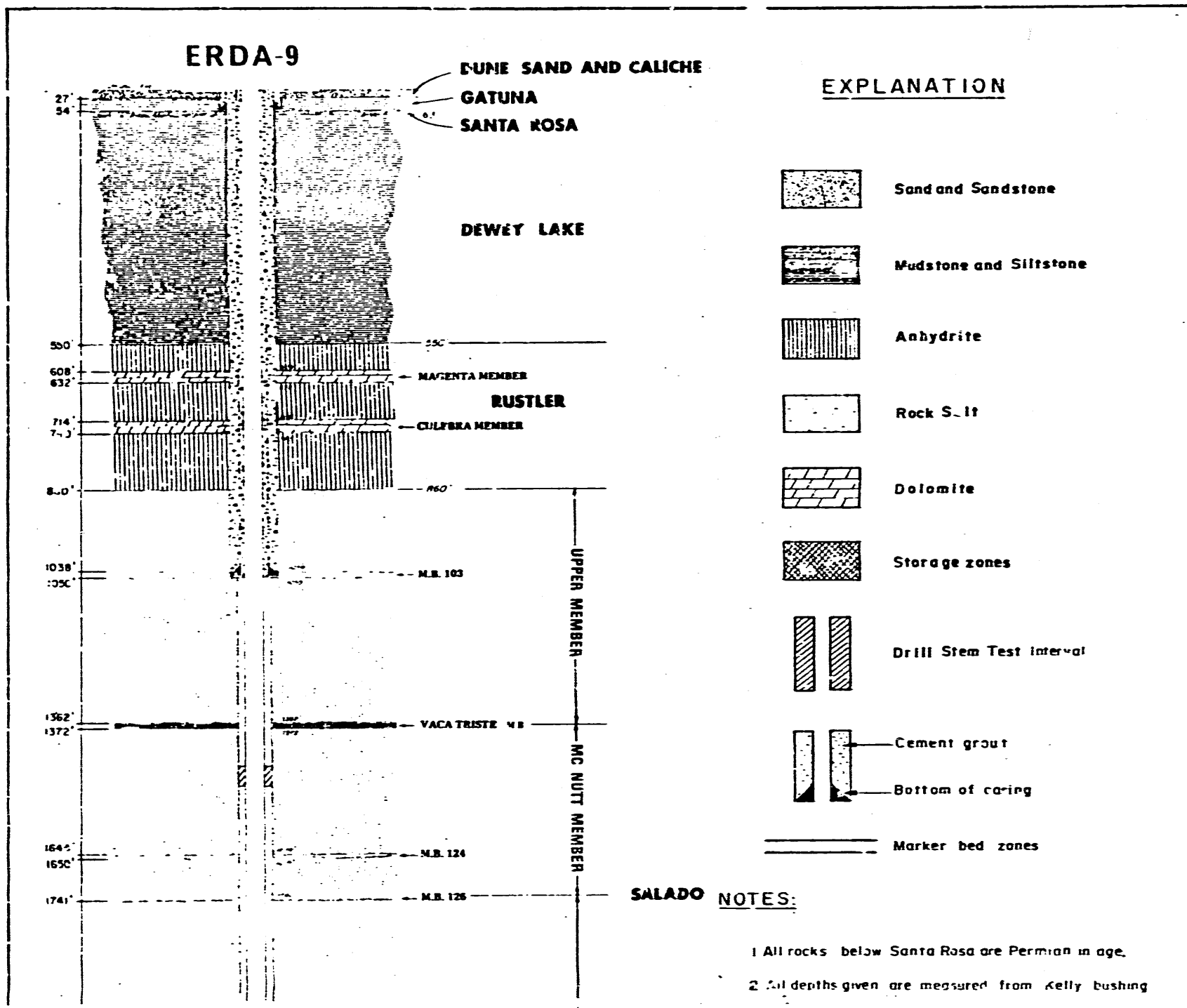
4-102

SITE

4-102

SITE GEOLOGIC COLUMN

FIGURE 4.3-2


ERDA-9
DUNE SAND AND CALICHE
GATUNA
SANTA ROSA
DEWEY LAKE
RUSTLER
MAGENTA MEMBER
CULEBRA MEMBER
UPPER MEMBER
MC NUTT MEMBER
VACA TRISTE M.B.
M.B. 103
M.B. 124
M.B. 126
SALADO
27'
54'
550'
608'
632'
714'
840'
1038'
1362'
1372'
1644'
1650'
1741'
EXPLANATION
Sand and Sandstone
Mudstone and Siltstone
Anhydrite
Rock Salt
Dolomite
Storage zones
Drill Stem Test interval
Cement grout
Bottom of coring
Marker bed zones
NOTES:
1 All rocks below Santa Rosa are Permian in age.
2 All depths given are measured from Kelly bushing

2 All depths given are measured from Kelly bushing reference point (See note 4).

3 Ground surface elevation is 3414.70 feet, MSL

4 Kelly bushing elevation is 3426.25 feet, MSL

5 MB = Marker Bed

REFERENCE

Griswold, 1977, fig 19

KEY PLAN

GENERALIZED ERDA-9 STRATIGRAPHY

FIGURE 4.3-3 A

U.S. GEOLOGICAL SURVEY

WELL RECORD

Company: Sandia Laboratories

Well: #9 ERDA

Sec. 20 Twp. 22S Rge. 31E

Location: 280 FSL and 184 FEL

County: Eddy State: New Mexico

Area: James Ranch

R 31 E

T 22 S

20

0

	Feet above or below datum	Elevation (ft)
Log Measured From: Kelly Bushing (KB)	+11.55	KB 3426.25
Drilling Measured From: KB	+11.55	DF 3424.00
Permanent Datum: Ground Level (GL)		GL 3414.70

Contractor: Sonora Drilling Co.

Spud: 4/28/76 Comp.: 6/ /76

TD: 2889 feet

Geologist(s): C. L. Jones, B. M. Madsen, D. F. Fuqua

16 inches conductor @ 52 feet

10-3/4 inches surface @ 1045 feet

Formation	Thickness	Subsea datum
Gatuna Formation	27	3399
Santa Rosa Sandstone	54	3372
Dewey Lake Red Beds	63	3363
Rustler Formation	550	2876
Salado Formation	860	2566
Castile Formation	2836	591

SANDSTONE

SILTSTONE

ANHYDRITE

DOLOMITE

HALITE (Polyhalitic and(or) Anhydritic)

POLYHALITE

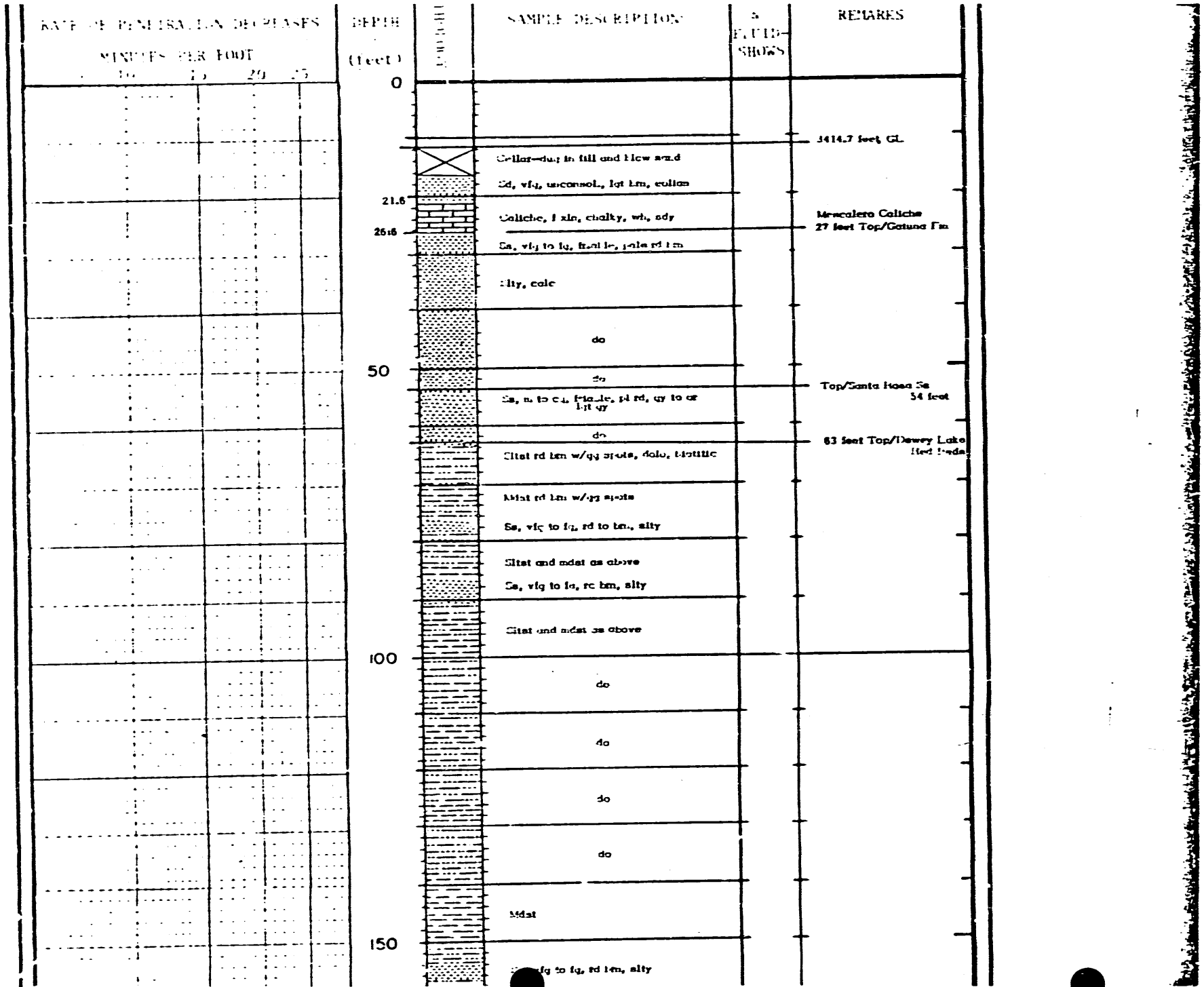
MUDSTONE

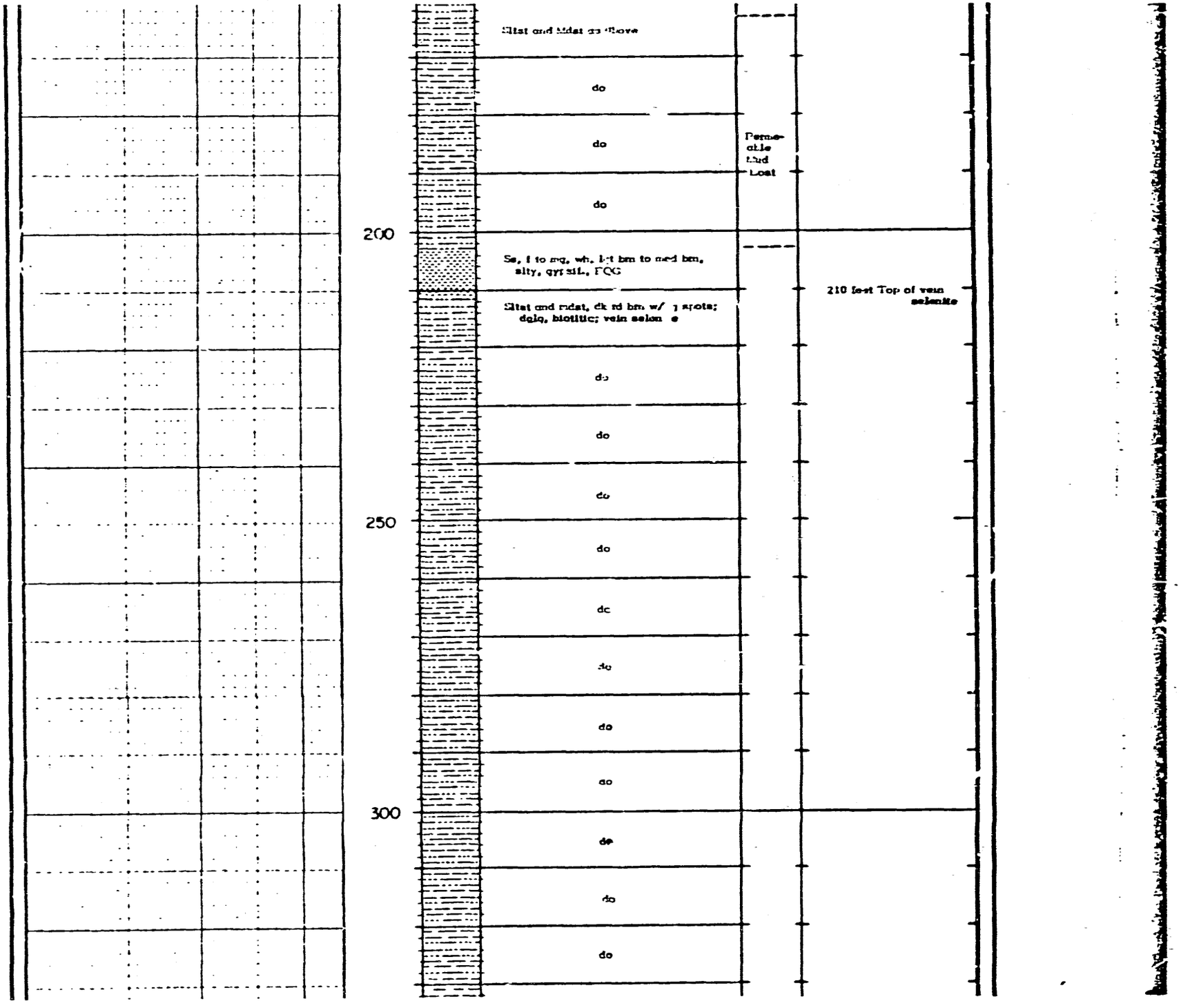
LIMESTONE

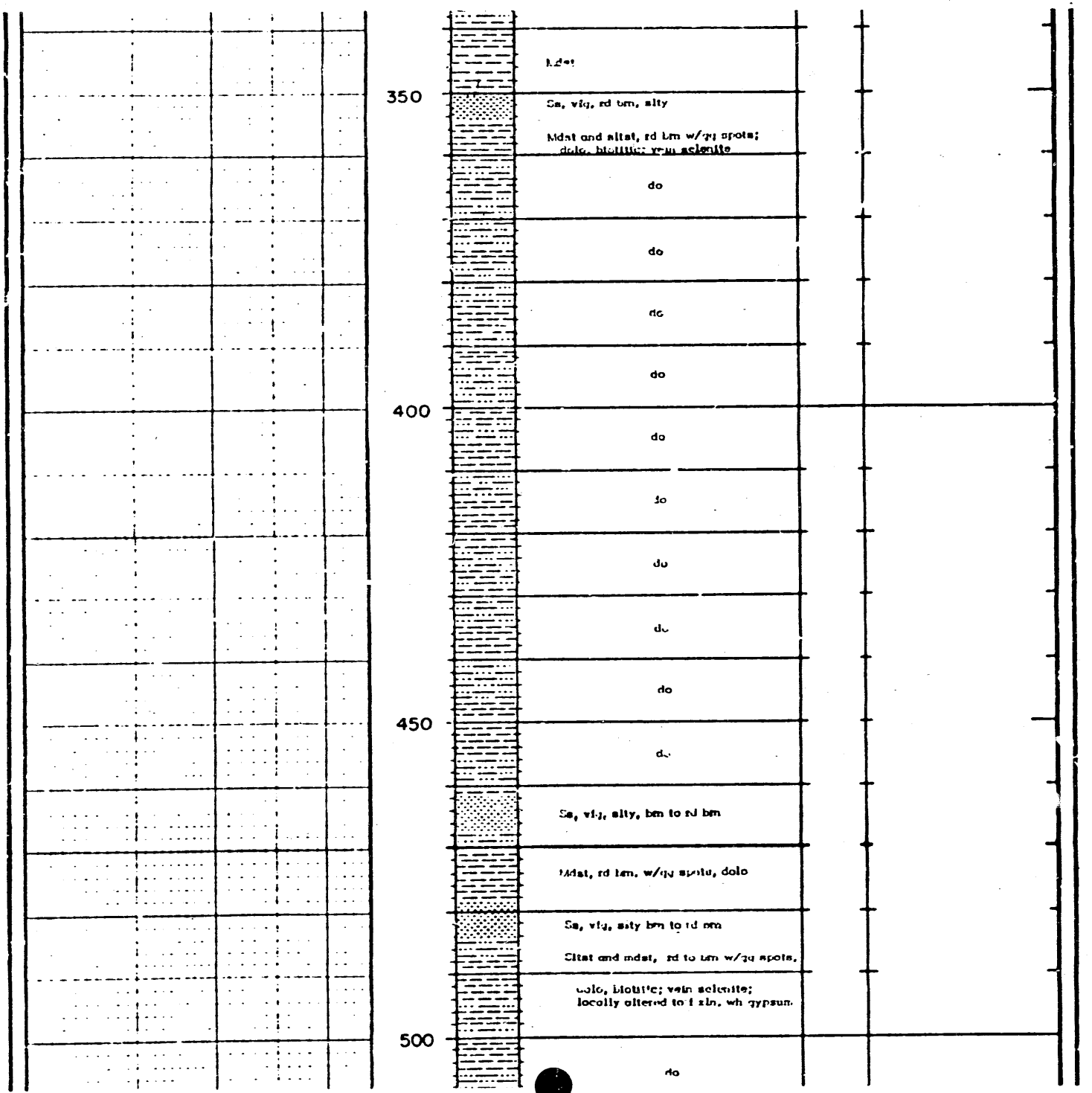
DEPOSIT OF POTASSIUM AND(OR) MAGNESIUM MINERALS

GYPSUM

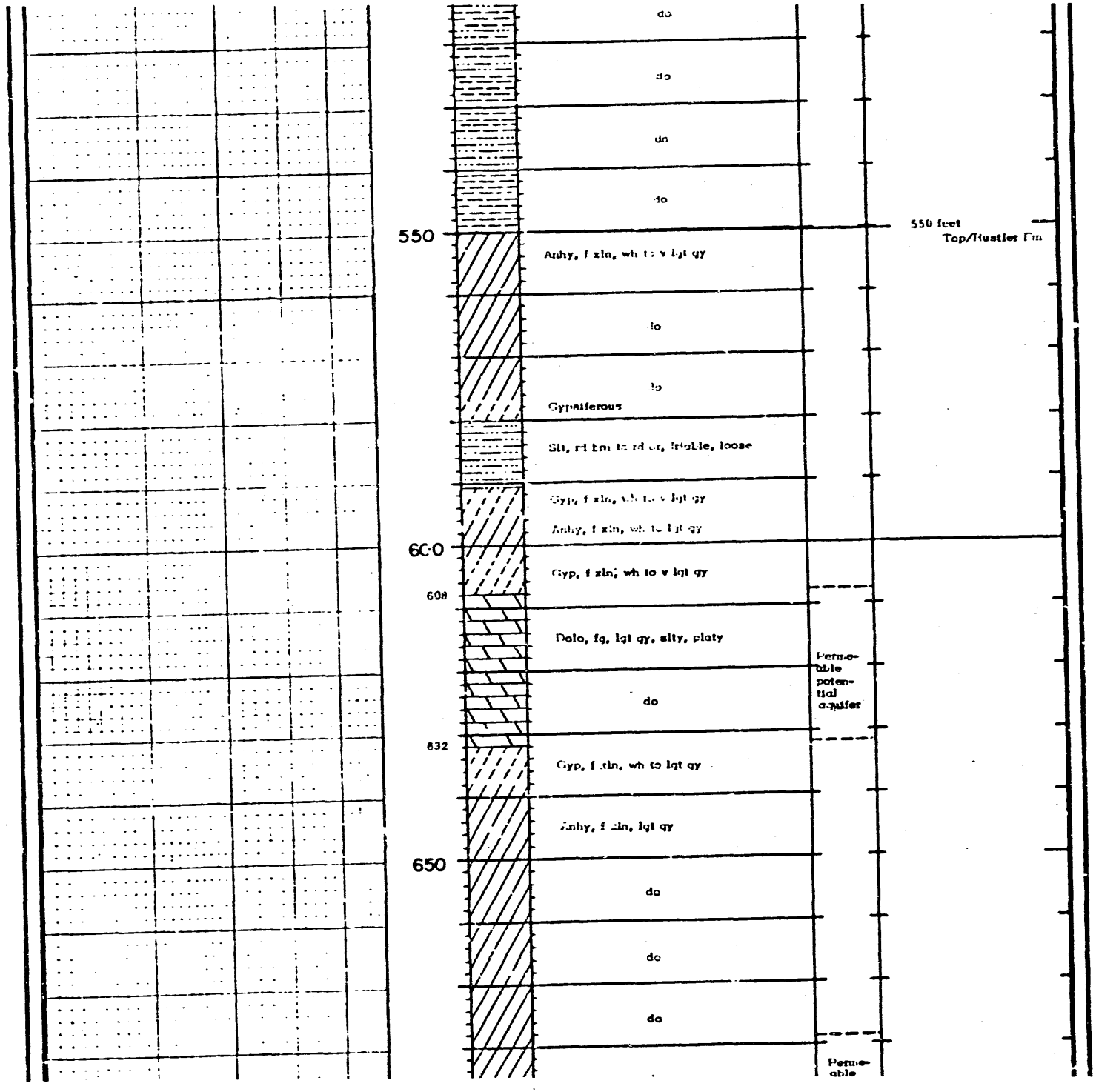
HALITE (Argillic)

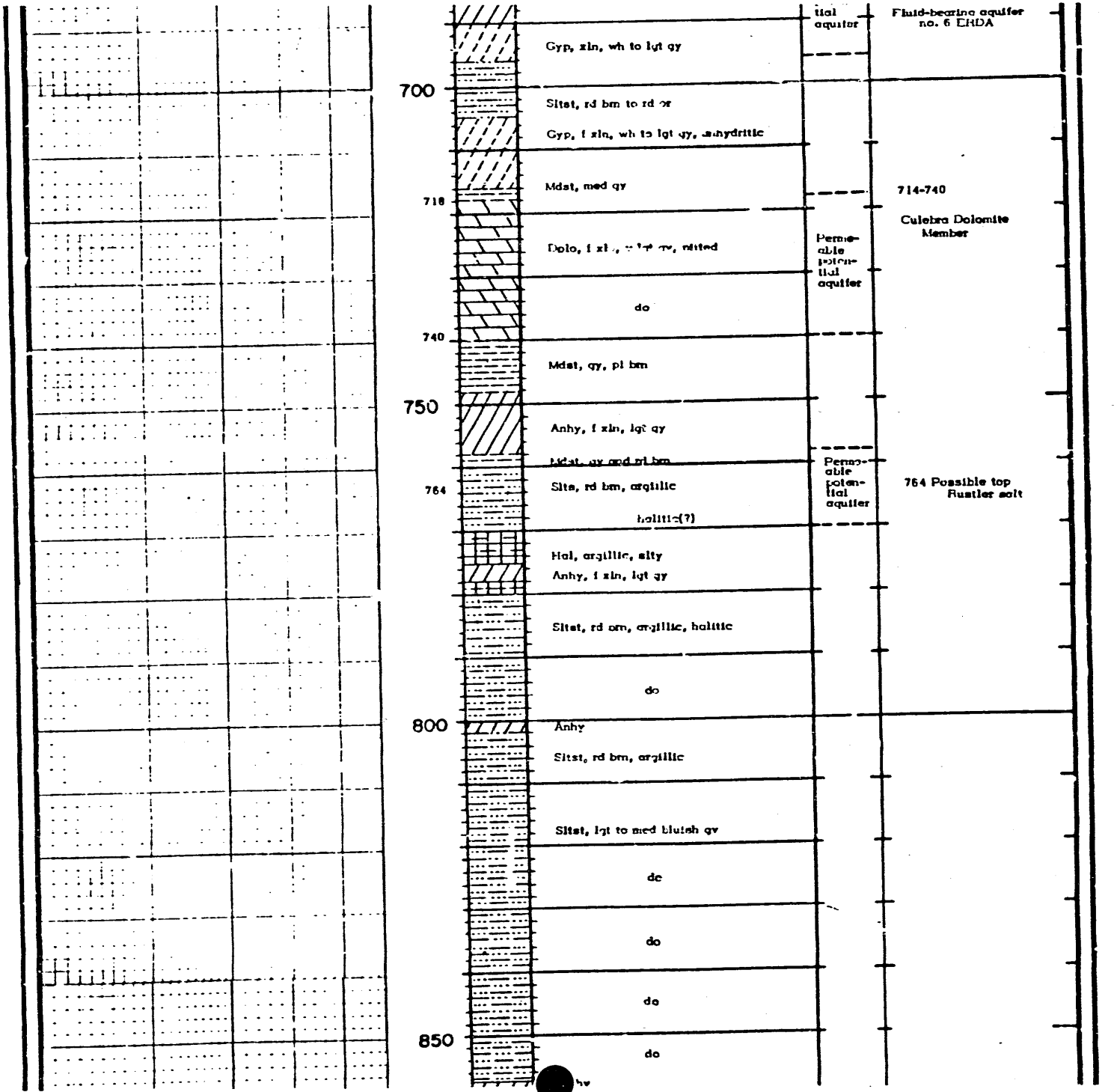

RATE OF PENETRATION IN MINUTES PER FOOT
DEPTH (feet)
SAMPLE DESCRIPTION
REMARKS
0
3414.7 feet GL
Cellar—dug in fill and blow sand
Sd, vfg, unconsol., lgt brn, eolian
21.6
Caliche, l xln, chalky, wh, sdy
Mescalero Caliche
25.6
27 feet Top/Gatuna Fm
Sa, vfg to fg, frost lc, pale rd brn
Silty, calc
do
50
do
Top/Santa Rosa Ss
54 feet
Sa, m to c-g, frosted, pl rd, qy to clr lgt qy
do
83 feet Top/Dewey Lake
Red Beds
Silst rd brn w/qq grns, dolo, blotitic
Mdst rd brn w/qq grns
Sa, vfg to fg, rd to brn., silty
Silst and mdst as above
Sa, vfg to fg, rc brn, silty
Silst and mdst as above
100
do
do
do
do
Mdst
150
Sa, vfg to fg, rd brn, silty


Silst and sdst as above
do
do
do
Perme-
able
Mud
Lost
200
Ss, f to mg, wh, lt bm to med bm,
silty, qtz sil., FCG
Silst and sdst, dk rd bm w/] spots;
dolo, biotitic; vein selen e
210 feet Top of vein
selenite
do
do
do
250
do
dc
do
do
do
300
do
do
do


350
400
450
500
Sa, vfg, rd brn, silty
Mdst and siltst, rd brn w/gy spots;
dolo, biotitic; vein selenite
do
do
do
do
do
do
do
do
do
do
Sa, vfg, silty, brn to rd brn
Mdst, rd brn, w/gy spots, dolo
Sa, vfg, silty brn to rd brn
Siltst and mdst, rd to brn w/gy spots,
dolo, biotitic; vein selenite;
locally altered to f zln, wh gypsum
do

4-104


do
do
do
do
550
Anhy, f xln, wh to v lgt gy
550 feet
Top/Hustler Fm
do
do
Gypsiferous
Slt, rd brn to rd br, friable, loose
Gyp, f xln, wh to v lgt gy
Anhy, f xln, wh to lgt gy
600
Gyp, f xln, wh to v lgt gy
608
Dolo, fg, lgt gy, silty, platy
Perme-
able
poten-
tial
aquifer
do
632
Gyp, f xln, wh to lgt gy
Anhy, f xln, lgt gy
650
do
do
do
Perme-
able


700
718
740
750
764
800
850
Gyp, xln, wh to lgt gy
Sltst, rd brn to rd or
Gyp, f xln, wh to lgt gy, anhydritic
Mdst, med gy
Dolo, f xl
do
Mdst, gy, pl brn
Anhy, f xln, lgt gy
Mdst, gy and pl brn
Slts, rd brn, argillic
halitic(?)
Hal, argillic, silty
Anhy, f xln, lgt gy
Sltst, rd brn, argillic, halitic
do
Anhy
Sltst, rd brn, argillic
Sltst, lgt to med bluish gy
do
do
do
do
itial aquifer
Permeable potential aquifer
Permeable potential aquifer
Fluid-bearing aquifer no. 6 ERDA
714-740
Culebra Dolomite Member
764 Possible top Rustler salt

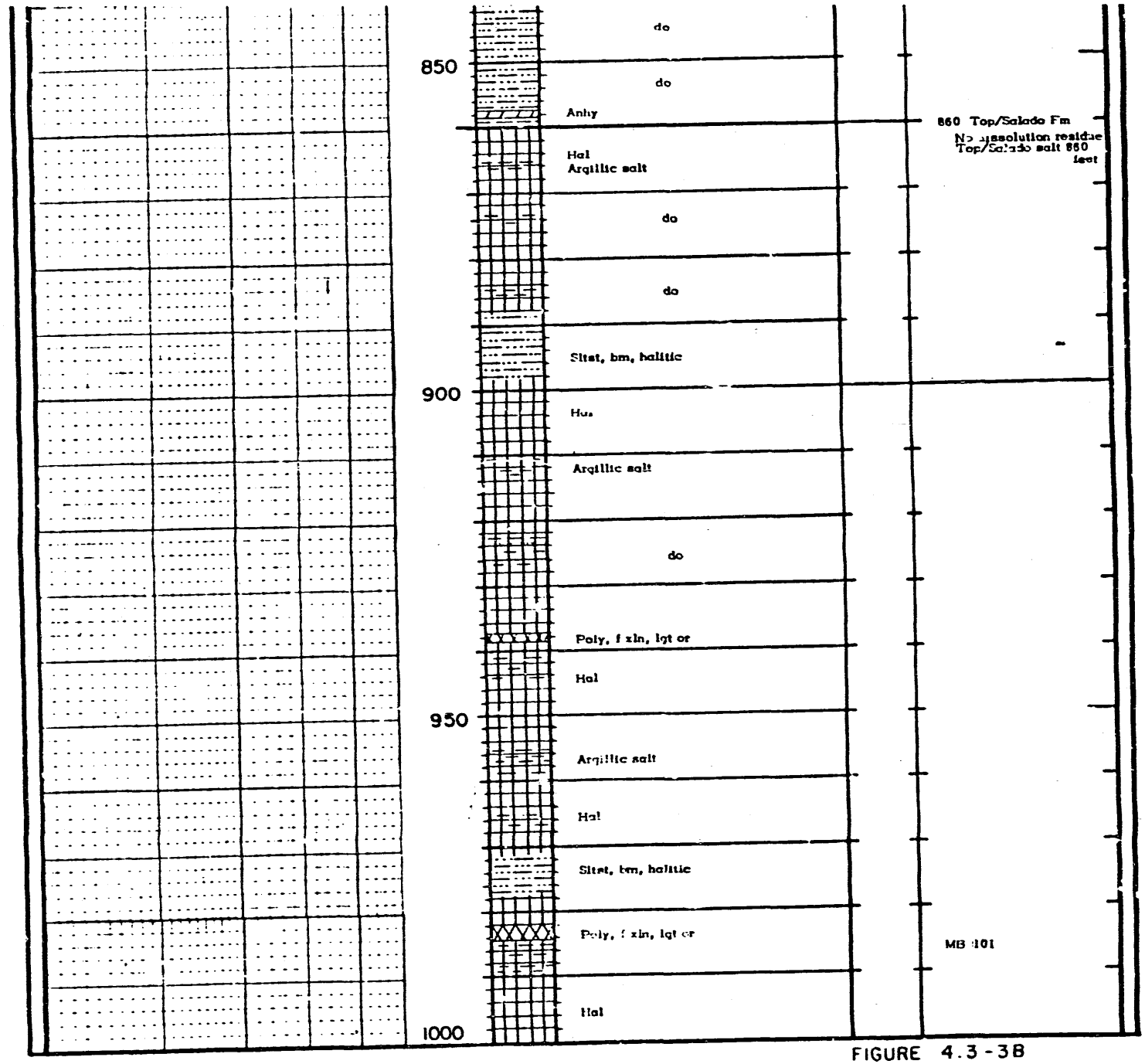
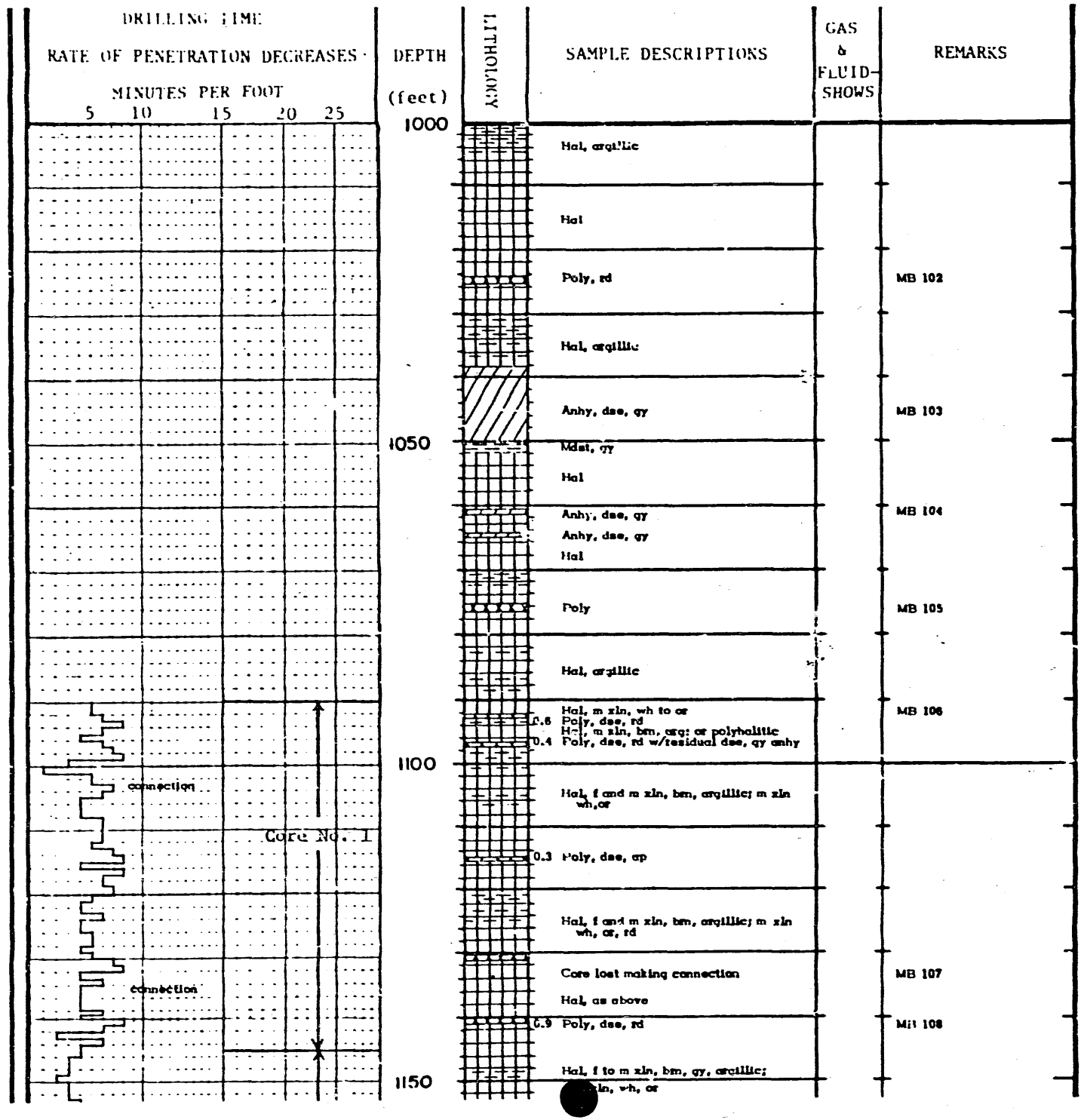
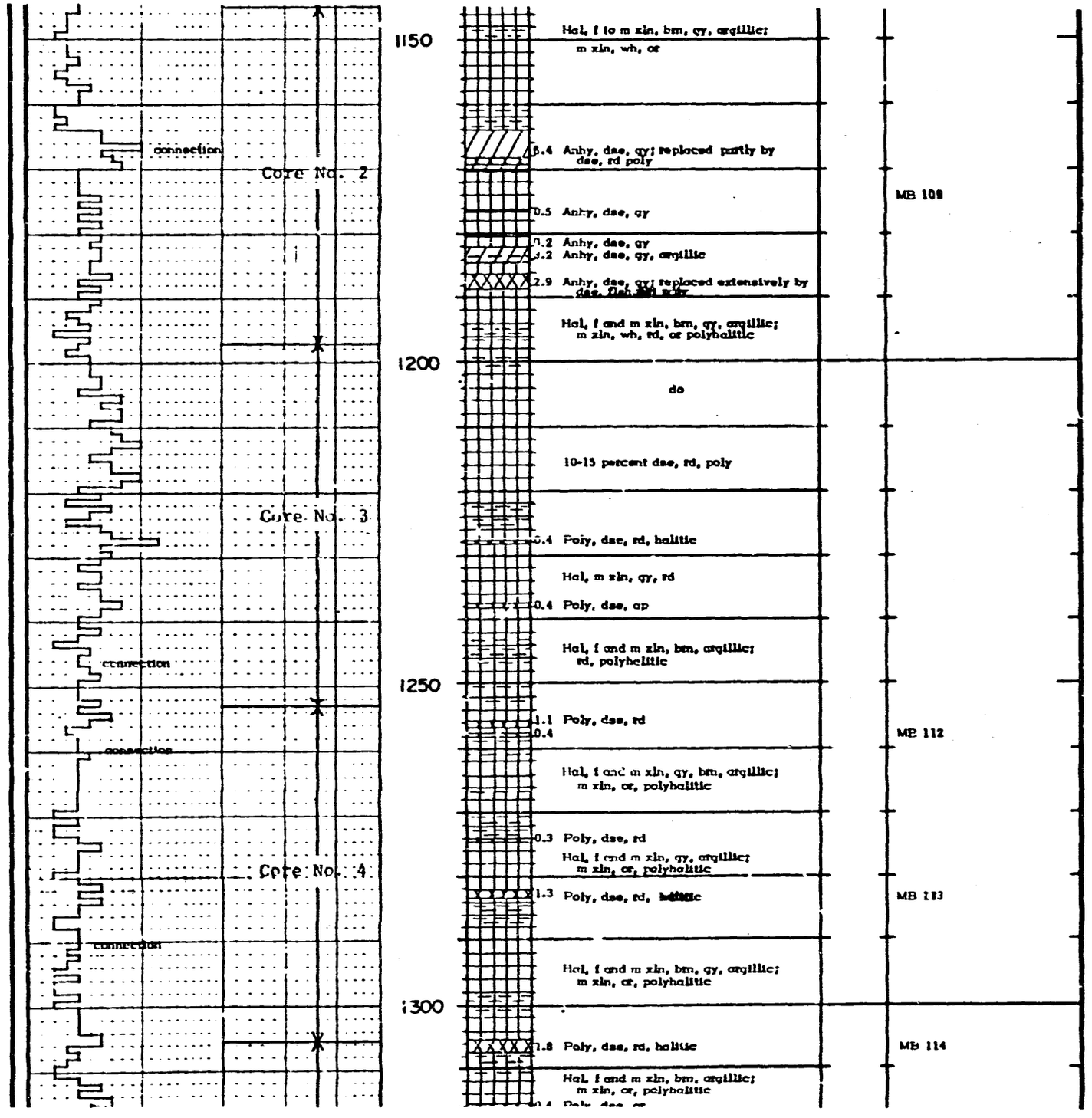
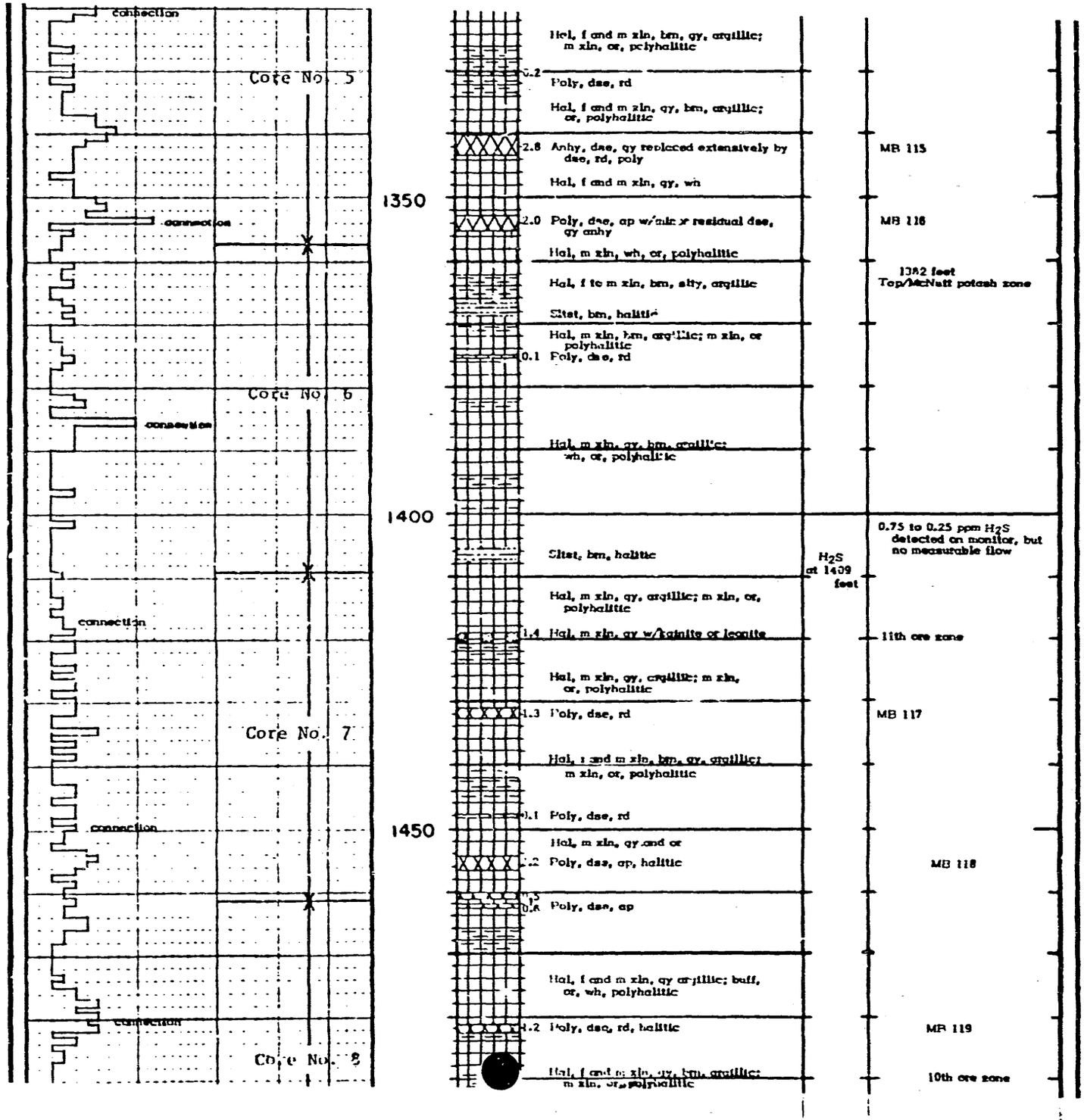
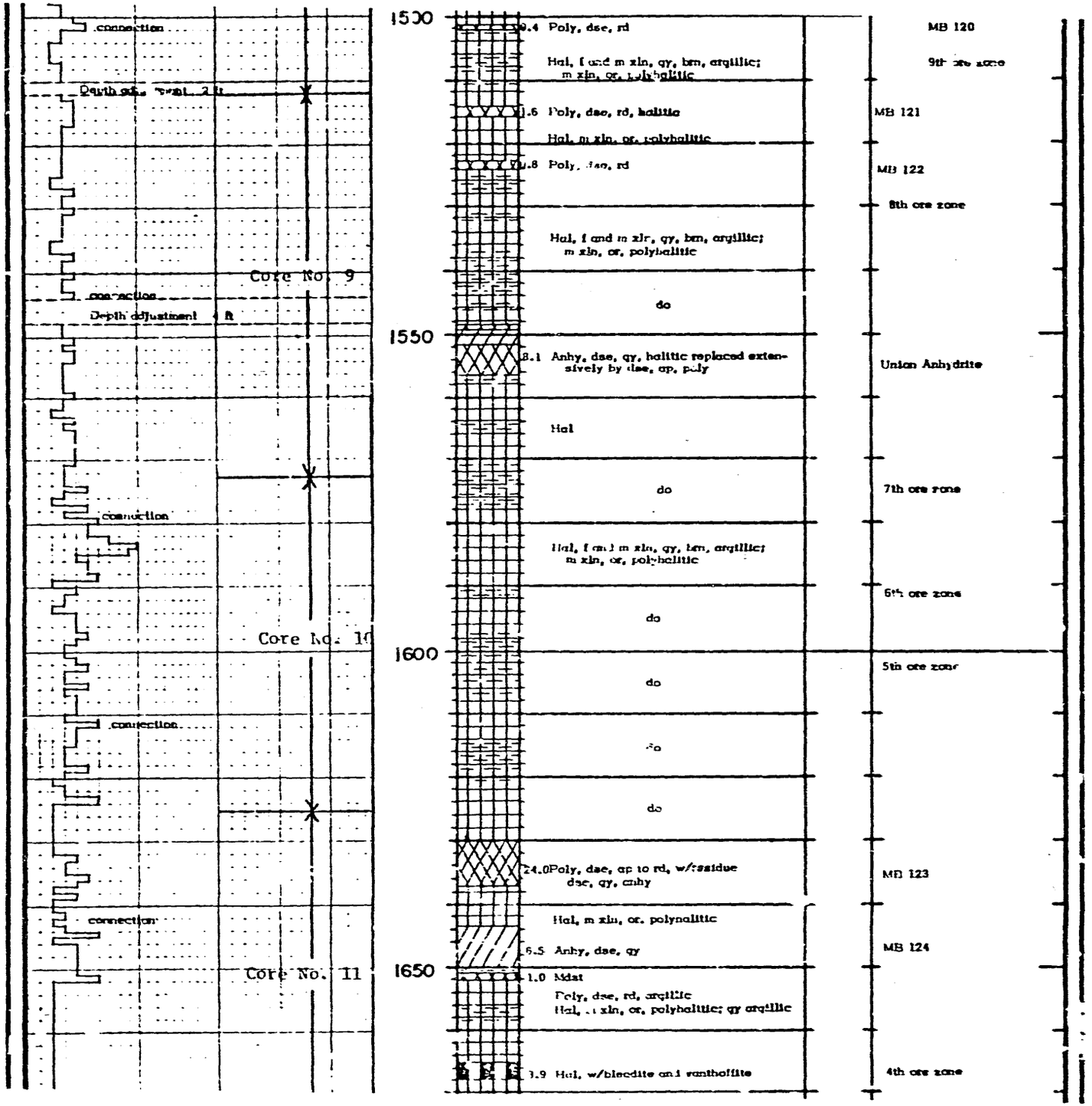

850
900
950
1000
do
do
Anhy
Hal
Argillic salt
do
do
Sltst, bm, halitic
Hal
Argillic salt
do
Poly, f xln, lgt or
Hal
Argillic salt
Hal
Sltst, bm, halitic
Poly, f xln, lgt or
Hal
860 Top/Salado Fm
MB 101

FIGURE 4.3-3B

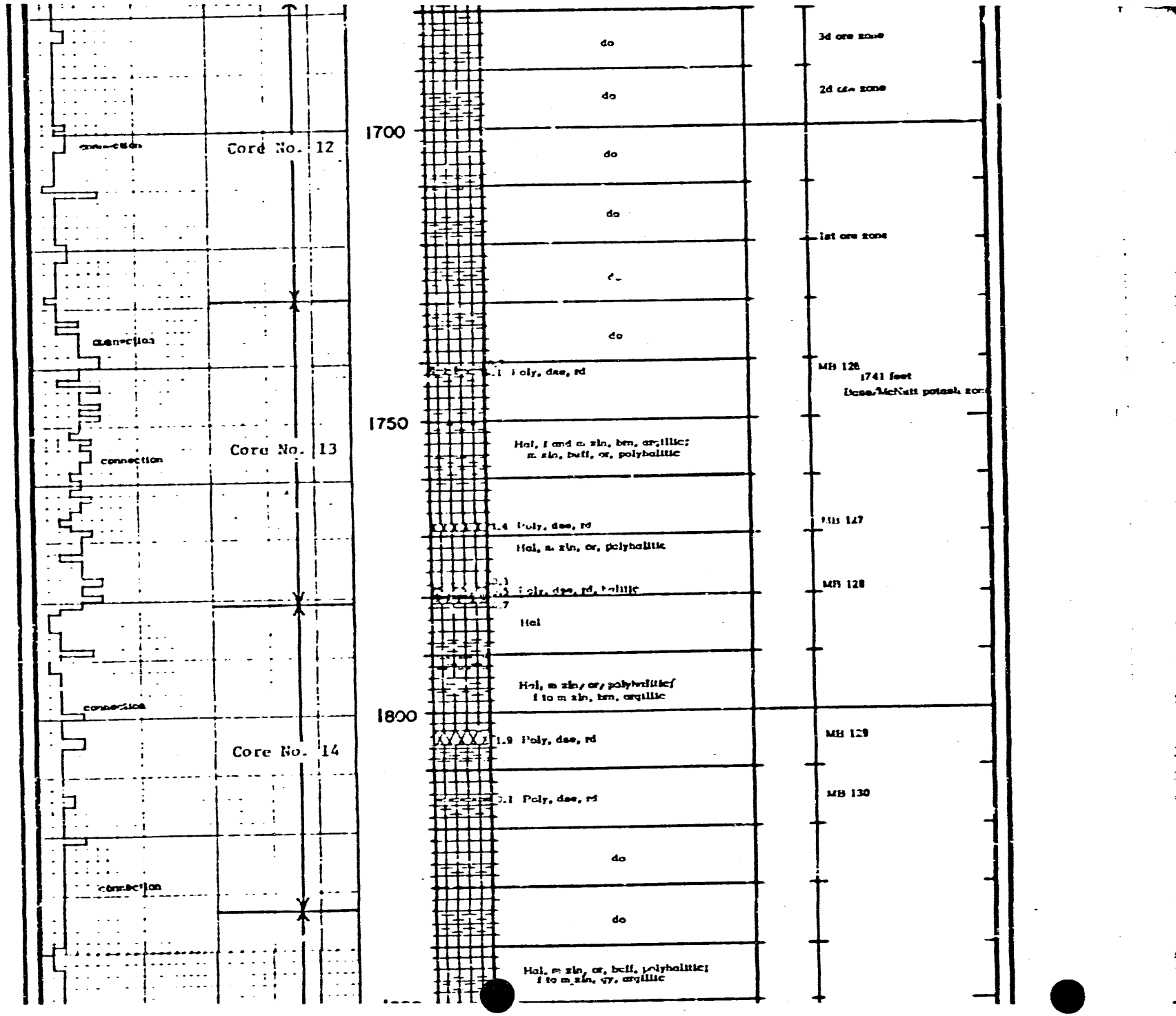

DRILLING TIME
RATE OF PENETRATION DECREASES
MINUTES PER FOOT
5
10
15
20
25
DEPTH
(feet)
1000
1050
1100
1150
LITHOLOGY
SAMPLE DESCRIPTIONS
GAS & FLUID SHOWS
REMARKS
Hal, argillic
Hal
Poly, rd
MB 102
Hal, argillic
Anhy, dse, gy
MB 103
Mdst, gy
Hal
Anhy, dse, gy
MB 104
Anhy, dse, gy
Hal
Poly
MB 105
Hal, argillic
Hal, m xln, wh to or
MB 106
0.6 Poly, dse, rd
Hal, m xln, bm, arg; or polyhalitic
0.4 Poly, dse, rd w/residual dse, gy anhy
connection
Hal, f and m xln, bm, argillic; m xln wh, or
Core No. 1
0.3 Poly, dse, gp
Hal, f and m xln, bm, argillic; m xln wh, or, rd
connection
Core lost making connection
MB 107
Hal, as above
0.9 Poly, dse, rd
MB 108
Hal, f to m xln, bm, gy, argillic;
xln, wh, or

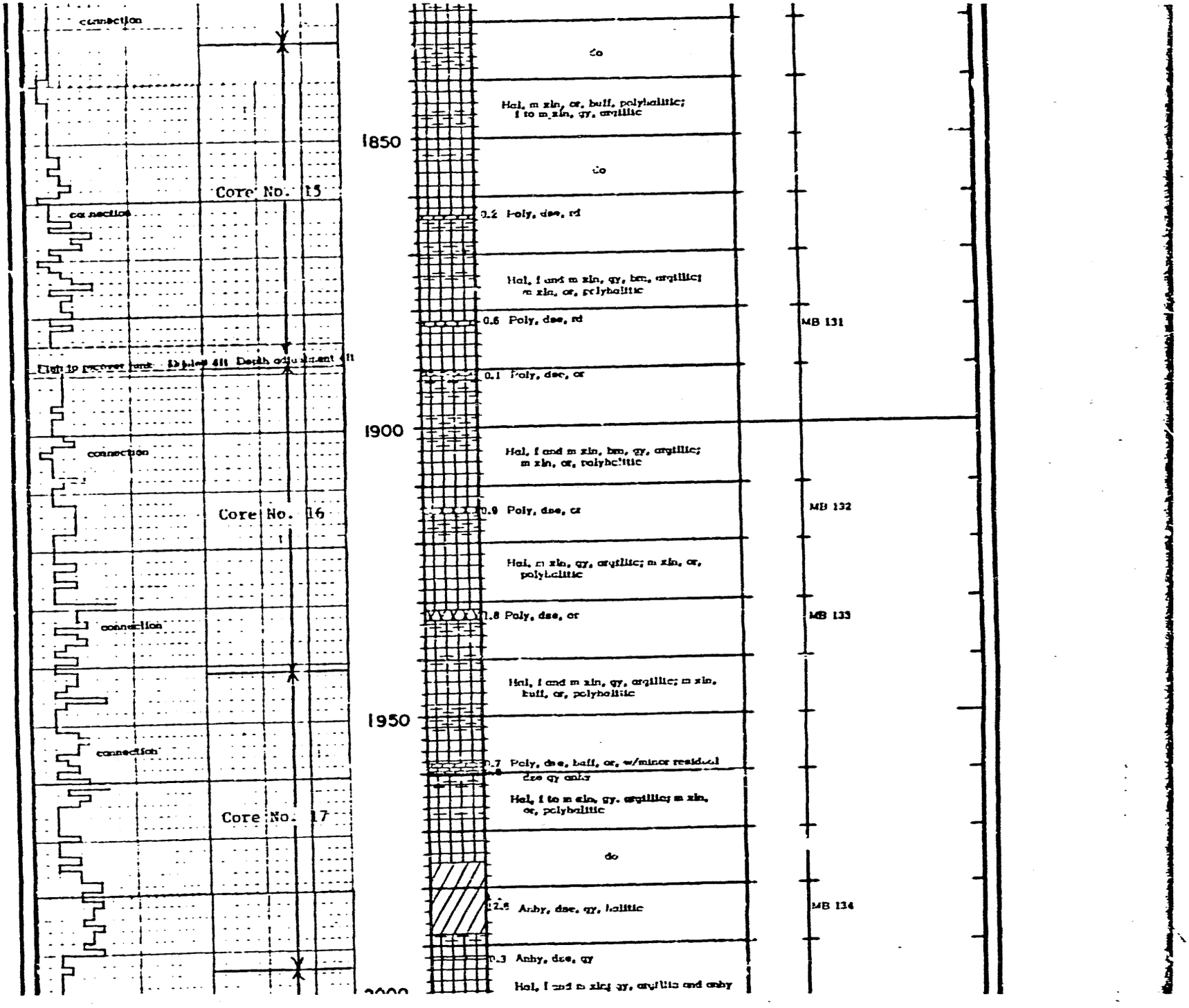

connection
Core No. 2
Core No. 3
connection
connection
Core No. 4
connection
1150
1200
1250
1300
Hal, f to m xln, bm, gy, argillic; m xln, wh, or
8.4 Anhy, dse, gy; replaced partly by dse, rd poly
MB 109
0.5 Anhy, dse, gy
0.2 Anhy, dse, gy
1.2 Anhy, dse, gy, argillic
2.9 Anhy, dse, gy; replaced extensively by dse, flesh red poly
Hal, f and m xln, bm, gy, argillic; m xln, wh, rd, or polyhalitic
do
10-15 percent dse, rd, poly
0.4 Poly, dse, rd, halitic
Hal, m xln, gy, rd
0.4 Poly, dse, op
Hal, f and m xln, bm, argillic; rd, polyhalitic
1.1 Poly, dse, rd
0.4
MB 112
Hal, f and m xln, gy, bm, argillic; m xln, or, polyhalitic
0.3 Poly, dse, rd
Hal, f and m xln, gy, argillic; m xln, or, polyhalitic
1.3 Poly, dse, rd, halitic
MB 113
Hal, f and m xln, bm, gy, argillic; m xln, or, polyhalitic
1.8 Poly, dse, rd, halitic
MB 114
Hal, f and m xln, bm, argillic; m xln, or, polyhalitic

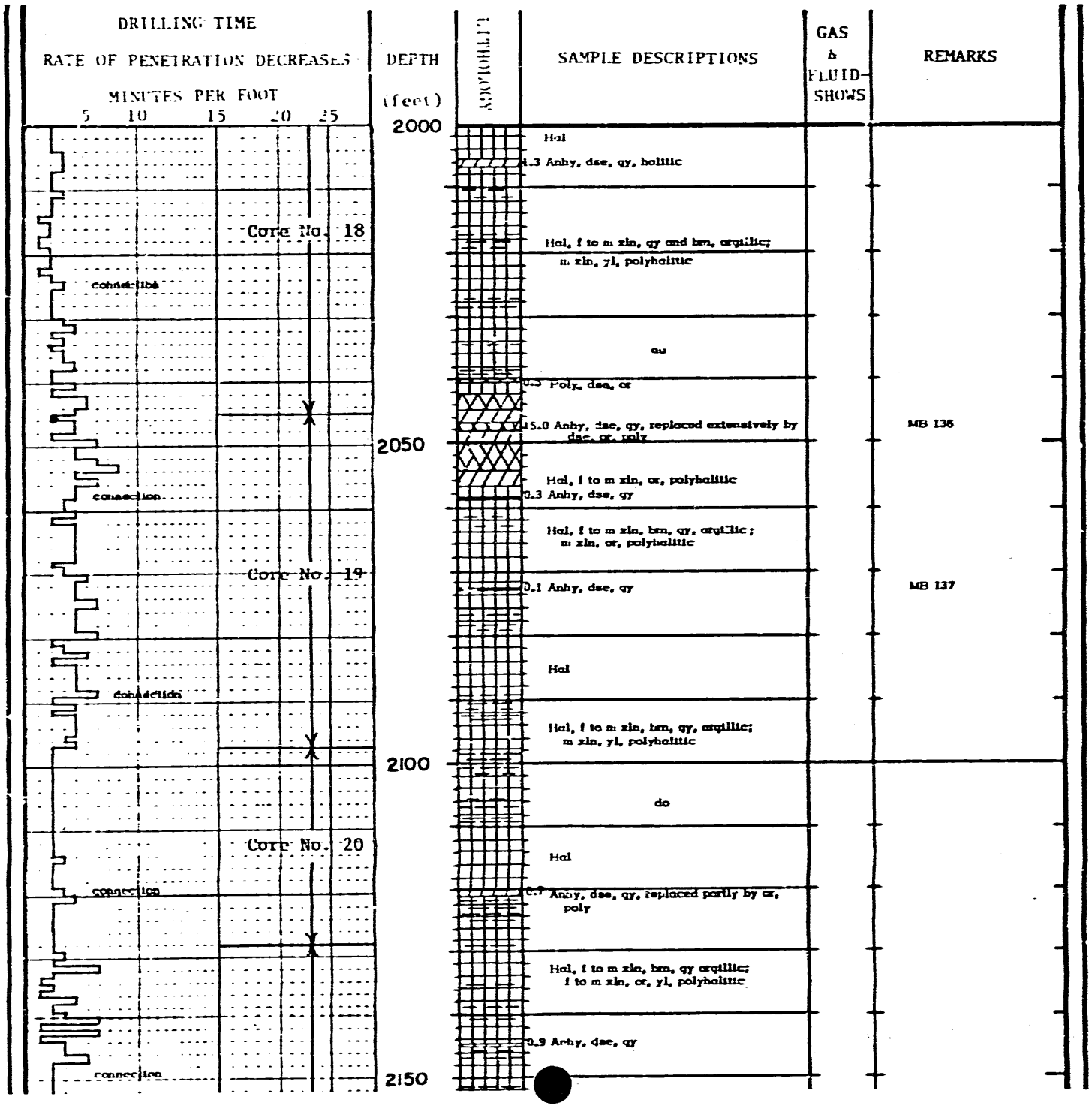

connection
Core No. 5
connection
1350
Core No. 6
connection
connection
1400
Core No. 7
connection
1450
connection
Core No. 8
Hal, f and m xln, bm, gy, argillic; m xln, or, polyhalitic
Poly, dse, rd
Hal, f and m xln, gy, bm, argillic; or, polyhalitic
2.8 Anhy, dse, gy replaced extensively by dse, rd, poly
Hal, f and m xln, gy, wh
2.0 Poly, dse, gp w/anhydrite residual dse, gy anhy
Hal, m xln, wh, or, polyhalitic
Hal, f to m xln, bm, silty, argillic
Siltst, bm, halitic
Hal, m xln, bm, argillic; m xln, or polyhalitic
0.1 Poly, dse, rd
Hal, m xln, gy, bm, argillic; wh, or, polyhalitic
Siltst, bm, halitic
Hal, m xln, gy, argillic; m xln, or, polyhalitic
1.4 Hal, m xln, gy w/kainite or leonite
Hal, m xln, gy, argillic; m xln, or, polyhalitic
1.3 Poly, dse, rd
Hal, f and m xln, bm, gy, argillic; m xln, or, polyhalitic
0.1 Poly, dse, rd
Hal, m xln, gy and or
1.2 Poly, dse, gp, halitic
0.6 Poly, dse, gp
Hal, f and m xln, gy argillic; buff, or, wh, polyhalitic
1.2 Poly, dse, rd, halitic
Hal, f and m xln, gy, bm, argillic; m xln, or, polyhalitic
H2S at 1409 feet
MB 115
MB 116
1382 feet
Top McNutt potash zone
0.75 to 0.25 ppm H2S detected on monitor, but no measurable flow
11th ore zone
MB 117
MB 118
MB 119
10th ore zone

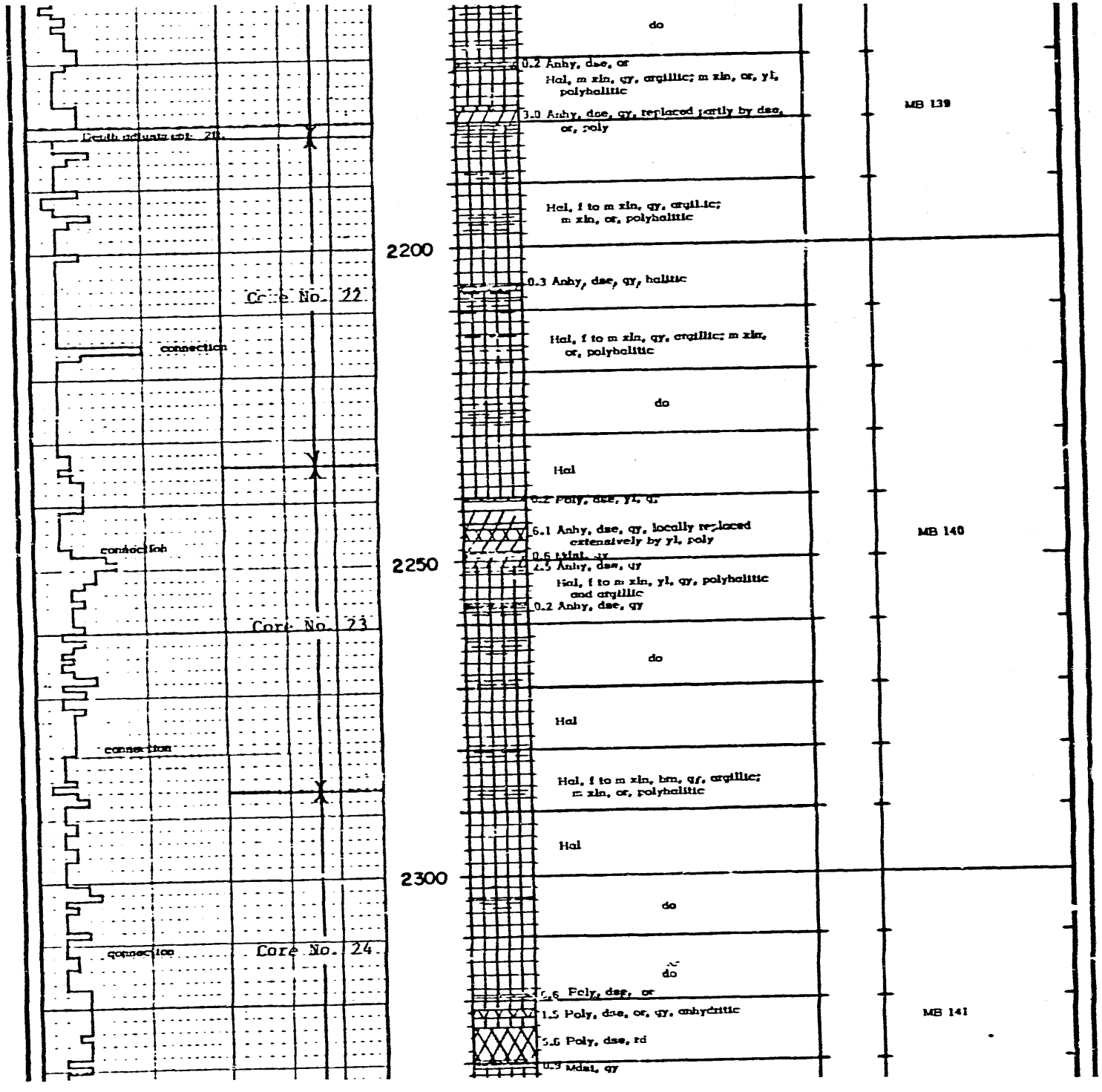

connection
Depth adjustment 2 ft
Core No. 9
connection
Depth adjustment + ft
Core No. 10
connection
connection
Core No. 11
1500
1550
1600
1650
0.4 Poly, dse, rd
Hal, f and m xln, qy, bm, argillic; m xln, or, polyhalitic
1.6 Poly, dse, rd, halitic
Hal, m xln, or, polyhalitic
0.8 Poly, dse, rd
Hal, f and m xln, qy, bm, argillic; m xln, or, polyhalitic
do
8.1 Anhy, dse, qy, halitic replaced extensively by dse, qp, poly
Hal
do
Hal, f and m xln, qy, bm, argillic; m xln, or, polyhalitic
do
do
do
do
24.0Poly, dse, qp to rd, w/ residue dse, qy, anhy
Hal, m xln, or, polyhalitic
6.5 Anhy, dse, qy
1.0 Mdst
Poly, dse, rd, argillic
Hal, m xln, or, polyhalitic; qy argillic
3.9 Hal, w/bleedite and xanthoffite
MB 120
9th ore zone
MB 121
MB 122
8th ore zone
Union Anhydrite
7th ore zone
6th ore zone
5th ore zone
MB 123
MB 124
4th ore zone

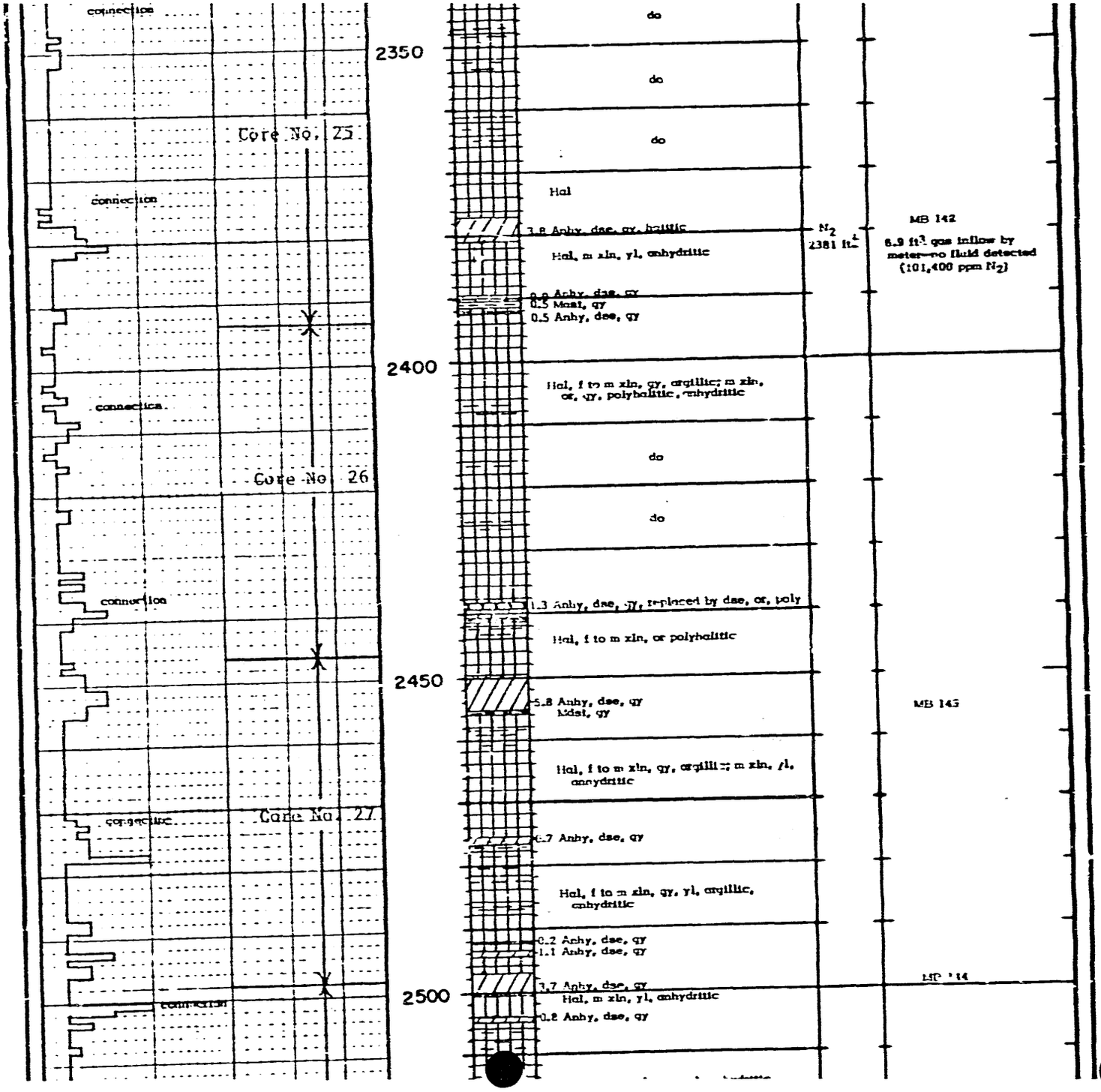
S-01-4

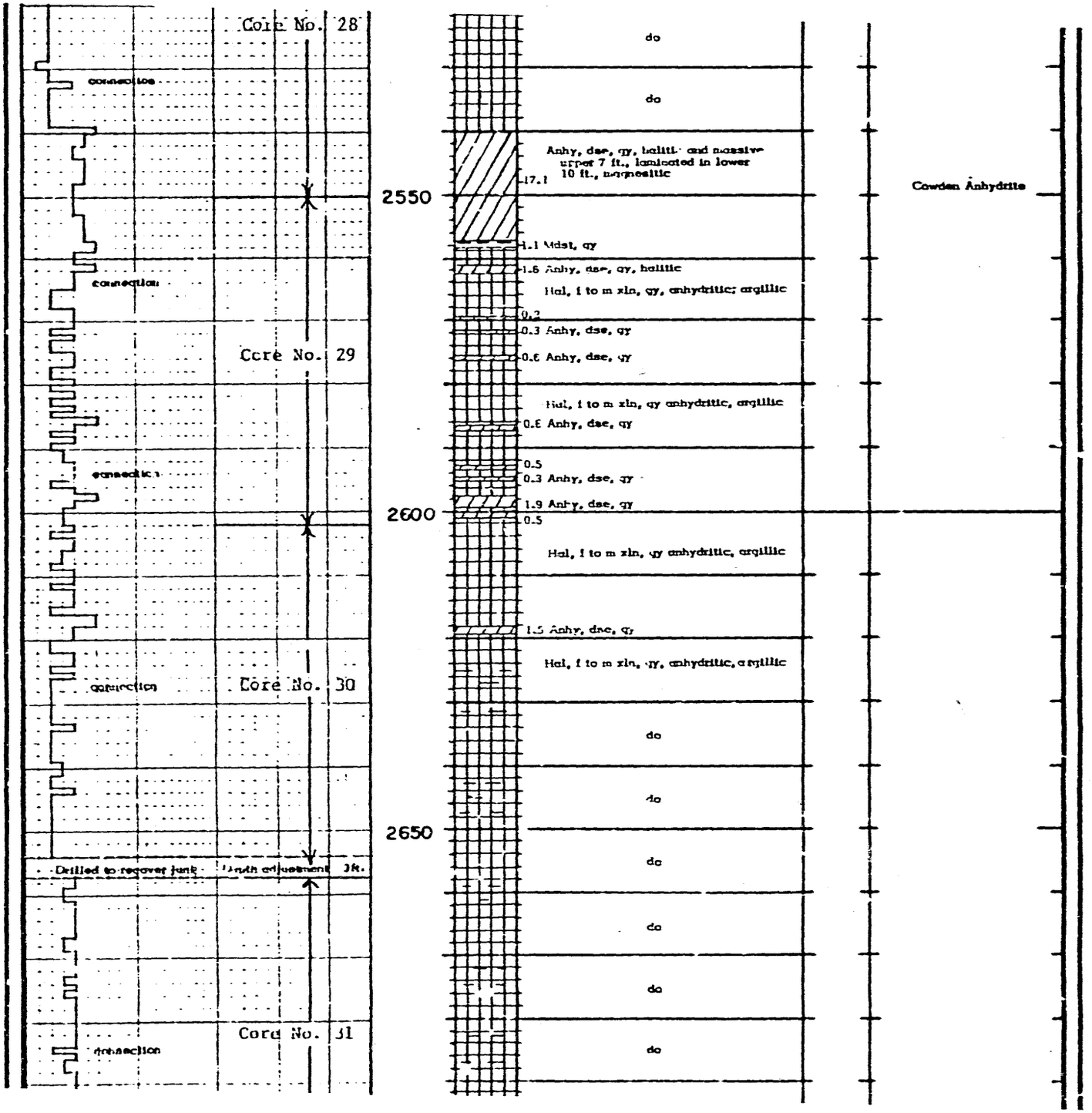

Core No. 12
connection
connection
Core No. 13
connection
connection
Core No. 14
connection
1700
1750
1800
do
do
do
do
do
do
1 Poly, dse, rd
Hal, f and c. sln, brn, argillic;
c. sln, buff, or, polyhalitic
1.4 Poly, dse, rd
Hal, c. sln, or, polyhalitic
Poly, dse, rd, halitic
Hal
Hal, c sln, or, polyhalitic;
f to m sln, brn, argillic
1.9 Poly, dse, rd
0.1 Poly, dse, rd
do
do
Hal, c sln, or, buff, polyhalitic;
f to m sln, gy, argillic
3d ore zone
2d ore zone
1st ore zone
MB 126
1741 feet
MB 147
MB 128
MB 129
MB 130

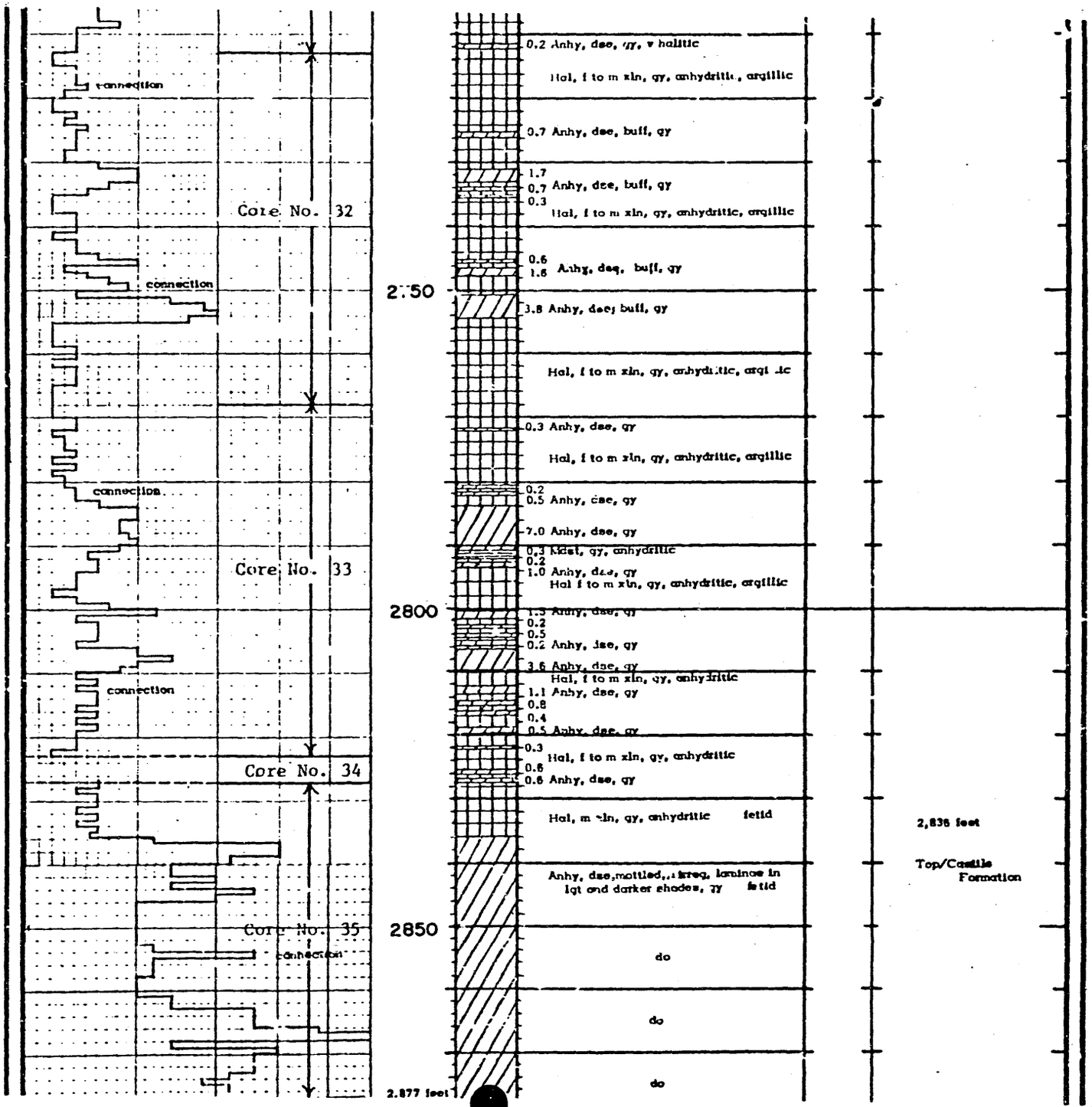

connection
Core No. 15
connection
Core No. 16
connection
connection
Core No. 17
1850
1900
1950
do
Hal, m xln, or, buff, polyhalitic; f to m xln, gy, argillic
do
0.2 Poly, dse, rd
Hal, f and m xln, gy, brn, argillic; m xln, or, polyhalitic
0.6 Poly, dse, rd
0.1 Poly, dse, or
Hal, f and m xln, brn, gy, argillic; m xln, or, polyhalitic
0.9 Poly, dse, or
Hal, m xln, gy, argillic; m xln, or, polyhalitic
1.8 Poly, dse, or
Hal, f and m xln, gy, argillic; m xln, buff, or, polyhalitic
0.7 Poly, dse, buff, or, w/minor residual dse gy anhy
Hal, f to m xln, gy, argillic; m xln, or, polyhalitic
do
2.8 Anhy, dse, gy, halitic
0.3 Anhy, dse, gy
Hal, f and m xln, gy, argillic and anhy
MB 131
MB 132
MB 133
MB 134

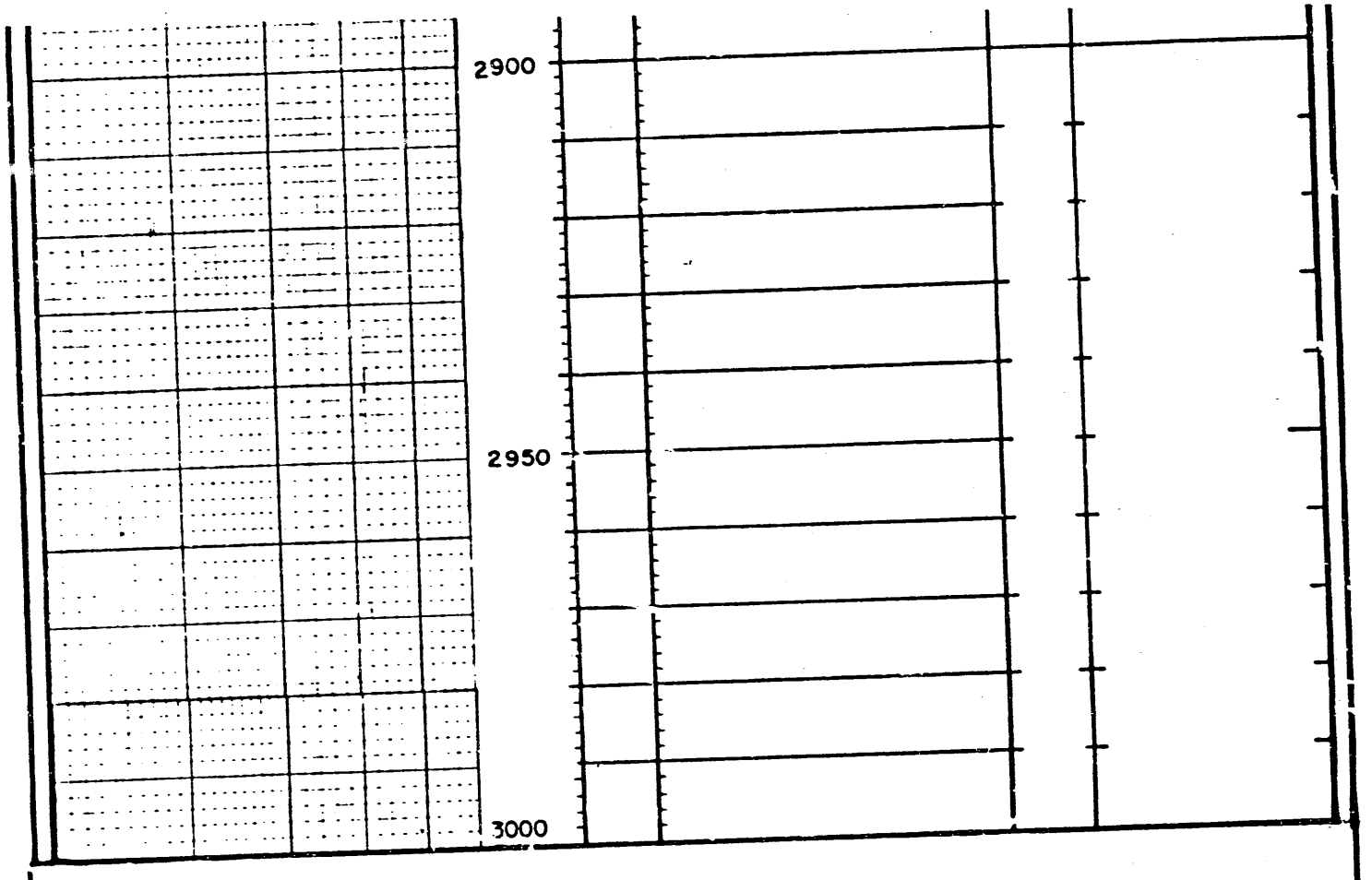

DRILLING TIME
RATE OF PENETRATION DECREASES
MINUTES PER FOOT
5
10
15
20
25
DEPTH
(feet)
2000
2050
2100
2150
Core No. 18
Core No. 19
Core No. 20
connection
connection
connection
connection
LITHOLOGY
SAMPLE DESCRIPTIONS
Hal
4.3 Anhy, dse, qy, hollitic
Hal, f to m xln, qy and brn, argilic;
m xln, yl, polyhalitic
au
0.3 Poly, dse, or
15.0 Anhy, dse, qy, replaced extensively by dse, or, poly
Hal, f to m xln, or, polyhalitic
0.3 Anhy, dse, qy
Hal, f to m xln, brn, qy, argilic;
m xln, or, polyhalitic
0.1 Anhy, dse, qy
Hal
Hal, f to m xln, brn, qy, argilic;
m xln, yl, polyhalitic
do
Hal
0.7 Anhy, dse, qy, replaced partly by or, poly
Hal, f to m xln, brn, qy argilic;
f to m xln, or, yl, polyhalitic
0.9 Anhy, dse, qy
GAS & FLUID SHOWS
REMARKS
MB 136
MB 137


Depth adjustment: 2ft.
Core No. 22
connection
Core No. 23
connection
connection
Core No. 24
2200
2250
2300
do
0.2 Anhy, dse, or
Hal, m xln, qy, argillic; m xln, or, yl, polyhalitic
3.0 Anhy, dse, qy, replaced partly by dse, or, poly
Hal, f to m xln, qy, argillic; m xln, or, polyhalitic
0.3 Anhy, dse, qy, halitic
Hal, f to m xln, qy, argillic; m xln, or, polyhalitic
do
Hal
0.2 Poly, dse, yl, q
6.1 Anhy, dse, qy, locally replaced extensively by yl, poly
0.6 Hal, qy
2.5 Anhy, dse, qy
Hal, f to m xln, yl, qy, polyhalitic and argillic
0.2 Anhy, dse, qy
do
Hal
Hal, f to m xln, bm, qy, argillic; m xln, or, polyhalitic
Hal
do
do
0.6 Poly, dse, or
1.5 Poly, dse, or, qy, anhydritic
5.6 Poly, dse, rd
0.9 Mdst, qy
MB 139
MB 140
MB 141


connection
2350
Core No. 25
connection
connection
2400
Core No. 26
connection
connection
2450
Core No. 27
connection
connection
2500
do
do
do
Hal
3.8 Anhy, dse, qy, halitic
Hal, m xln, yl, anhydritic
0.9 Anhy, dse, qy
0.5 Mdst, qy
0.5 Anhy, dse, qy
Hal, f to m xln, qy, argillic; m xln, or, qy, polyhalitic, anhydritic
do
do
1.3 Anhy, dse, qy, replaced by dse, or, poly
Hal, f to m xln, or polyhalitic
5.8 Anhy, dse, qy
Mdst, qy
Hal, f to m xln, qy, argillic; m xln, yl, anhydritic
6.7 Anhy, dse, qy
Hal, f to m xln, qy, yl, argillic, anhydritic
0.2 Anhy, dse, qy
1.1 Anhy, dse, qy
3.7 Anhy, dse, qy
Hal, m xln, yl, anhydritic
0.8 Anhy, dse, qy
N2
2381 ft
MB 142
6.9 ft3 gas inflow by meter—no fluid detected (101,400 ppm N2)
MB 143
MP 114


Core No. 28
connection
connection
Core No. 29
connection
connection
Core No. 30
Drilled to recover junk
Core No. 31
connection
2550
2600
2650
do
do
Anhy, dse, qy, halitic and massive upper 7 ft., laminated in lower 10 ft., magnesitic
17.1
1.1 Mdst, qy
1.6 Anhy, dse, qy, halitic
Hal, f to m xln, qy, anhydritic; argillic
0.2
0.3 Anhy, dse, qy
0.6 Anhy, dse, qy
Hal, f to m xln, qy anhydritic, argillic
0.6 Anhy, dse, qy
0.5
0.3 Anhy, dse, qy
1.9 Anhy, dse, qy
0.5
Hal, f to m xln, qy anhydritic, argillic
1.5 Anhy, dse, qy
Hal, f to m xln, qy, anhydritic, argillic
do
do
do
do
do
do
Cowden Anhydrite


connection
Core No. 32
connection
2750
connection
Core No. 33
connection
Core No. 34
2850
Core No. 35
connection
2,877 feet
0.2 Anhy, dse, gy, v halitic
Hal, f to m xln, gy, anhydritic, argillic
0.7 Anhy, dse, buff, gy
1.7
0.7 Anhy, dse, buff, gy
0.3
Hal, f to m xln, gy, anhydritic, argillic
0.6
1.8 Anhy, dsg, buff, gy
3.8 Anhy, dse; buff, gy
Hal, f to m xln, gy, anhydritic, argillic
0.3 Anhy, dse, gy
Hal, f to m xln, gy, anhydritic, argillic
0.2
0.5 Anhy, dse, gy
7.0 Anhy, dse, gy
0.3 Mdst, gy, anhydritic
0.2
1.0 Anhy, dse, gy
Hal f to m xln, gy, anhydritic, argillic
2800
1.3 Anhy, dse, gy
0.2
0.5
0.2 Anhy, dse, gy
3.6 Anhy, dse, gy
Hal, f to m xln, gy, anhydritic
1.1 Anhy, dse, gy
0.8
0.4
0.5 Anhy, dse, gy
0.3
Hal, f to m xln, gy, anhydritic
0.6
0.6 Anhy, dse, gy
Hal, m xln, gy, anhydritic fetid
Anhy, dse,mottled,,irreg, laminae in lgt and darker shades, gy fetid
do
do
do
2,836 feet
Top/Castile Formation



90,

ABBREVIATIONS

Anhy, anhydrite

ap, apricot

arg, argillic

brn, brown

calc, calcareous

cg, coarse grained

dk, dark

dolo, dolomitic

lgt, light

m, moderate

mdst, mudstone

med, medium

or, orange

pl, pale

Poly, polyhalitic

rd, red, reddish

Anhy, anhydrite

ap, apricot

arg, argillic

brn, brown

calc, calcareous

cg, coarse grained

dk, dark

dolo, dolomitic

dse, dense

f, fine

FEL, from east line

fg, fine grained

FQG, frosted quartz grains

FSL, from south line

gg, greenish gray

GL, ground level

gy, gray

gyp, gypsum

gypsif, gypsiferous

Hal, halite

irreg, irregular

KB, Kelly bushing

lgt, light

m, moderate

mdst, mudstone

med, medium

or, orange

pl, pale

Poly, polyhalitic

rd, red, reddish

Sd, sand

Sdy, sandy

slt, silt

Sltst, siltstone

Slty, silty

Ss, sandstone

unconsol, unconsolidated

v, very

vfg, very fine grained

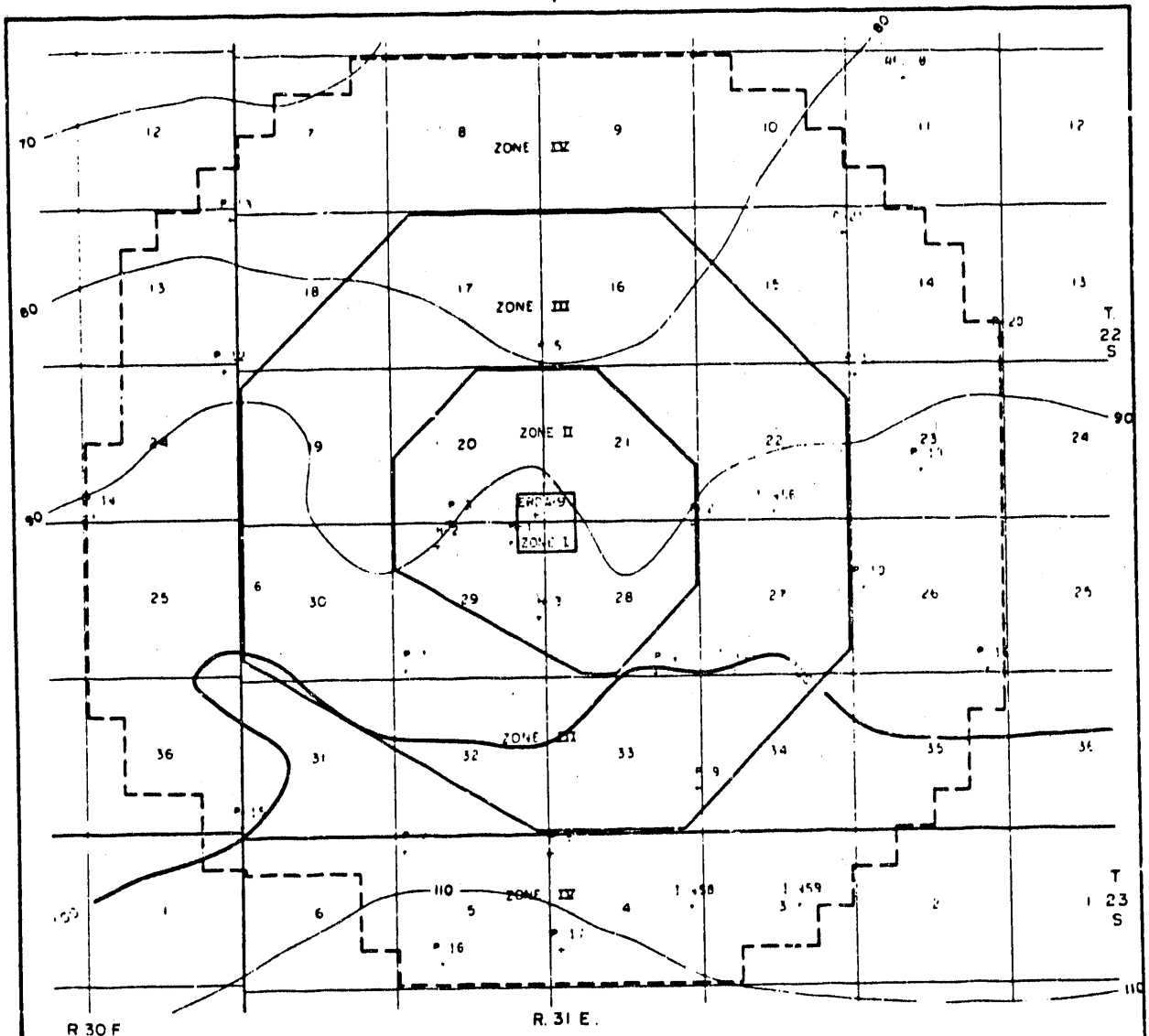
w/, with

wh, white

xln, crystalline

yl, yellow

FIGURE 4.3-3B



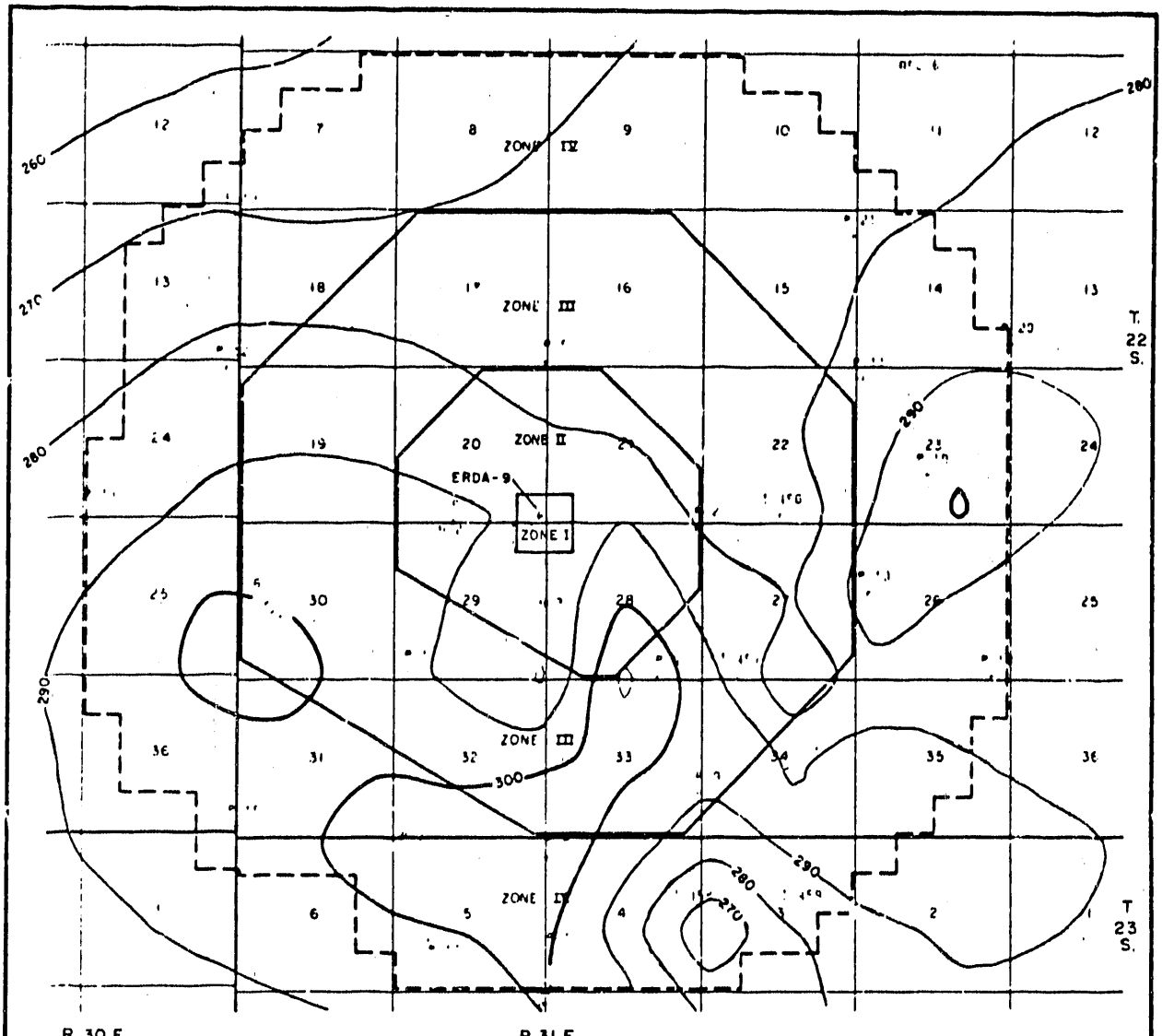
REFERENCE:

Griswold, 1977, figure 11

ISOPACH MAP

124 TO 126 MARKER BEDS

FIGURE 4.3-4

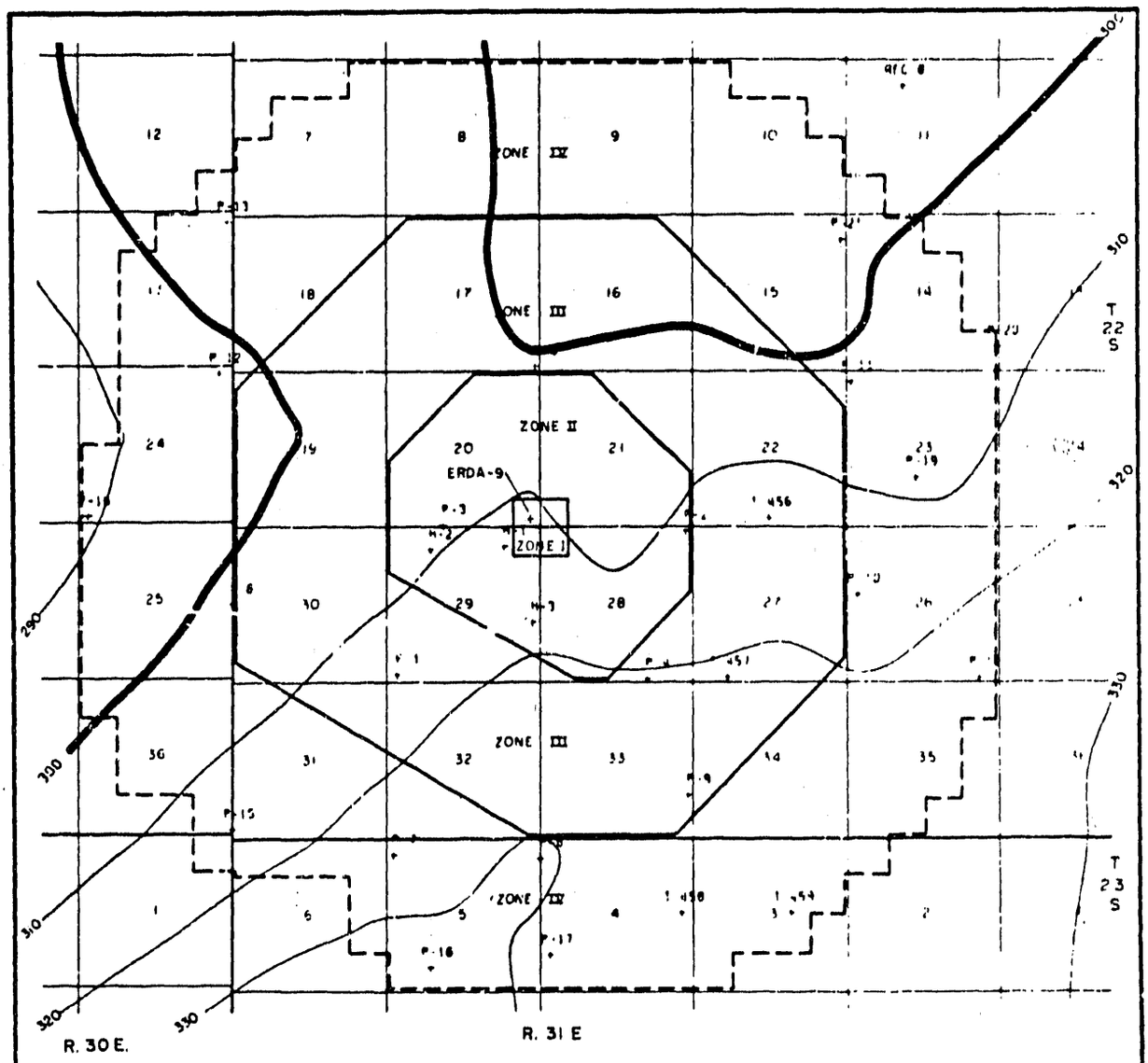


REFERENCE.

Griswold, 1977, figure 11

ISOPACH MAP VACA TRISTE TO 124-MARKER BEDS

FIGURE 4.3-5

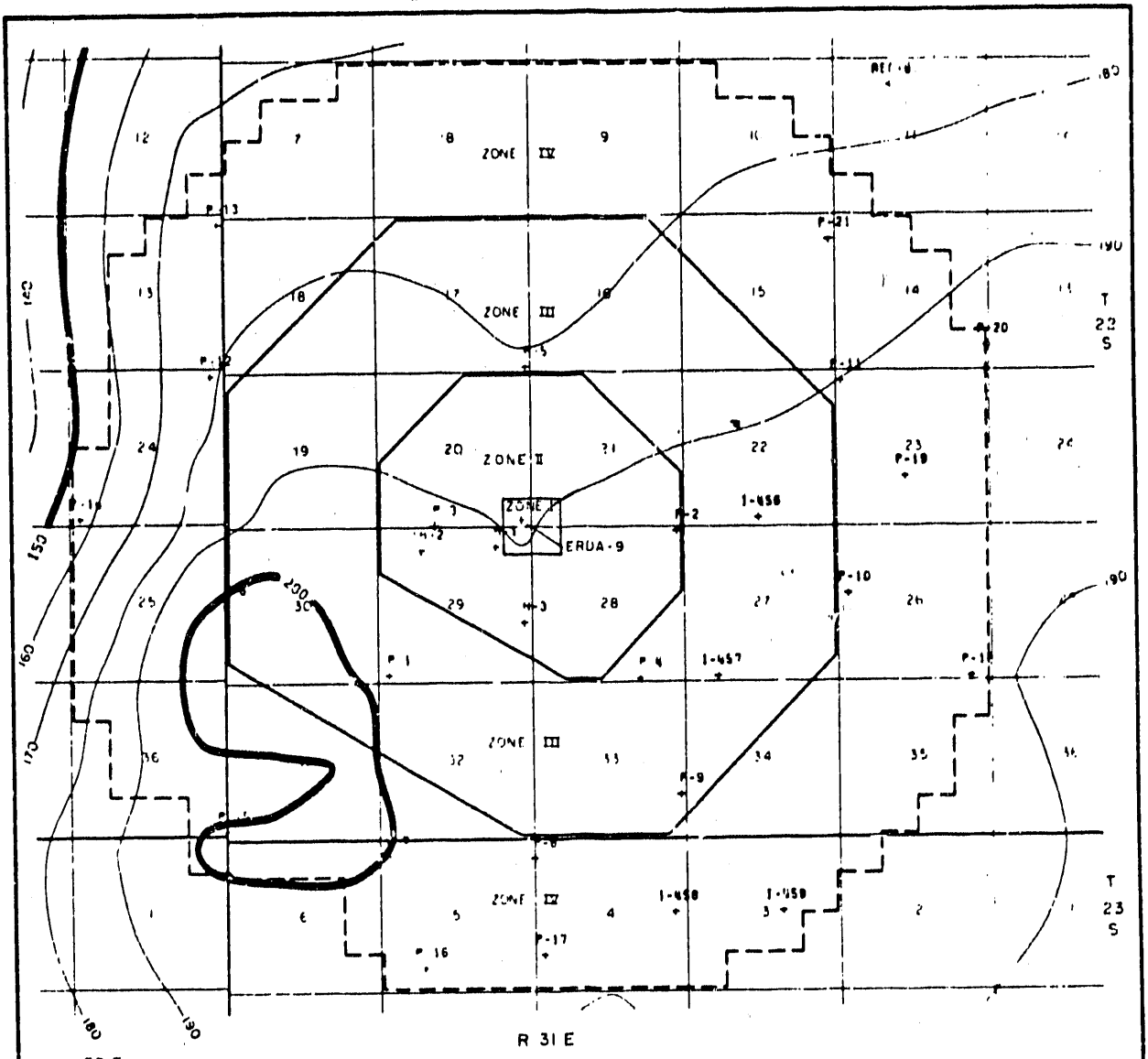


ISOPACH MAP 103 TO
VACA TRISTE MARKER BEDS

FIGURE 4.3-6

REFERENCE

Griswold, 1977, figure II

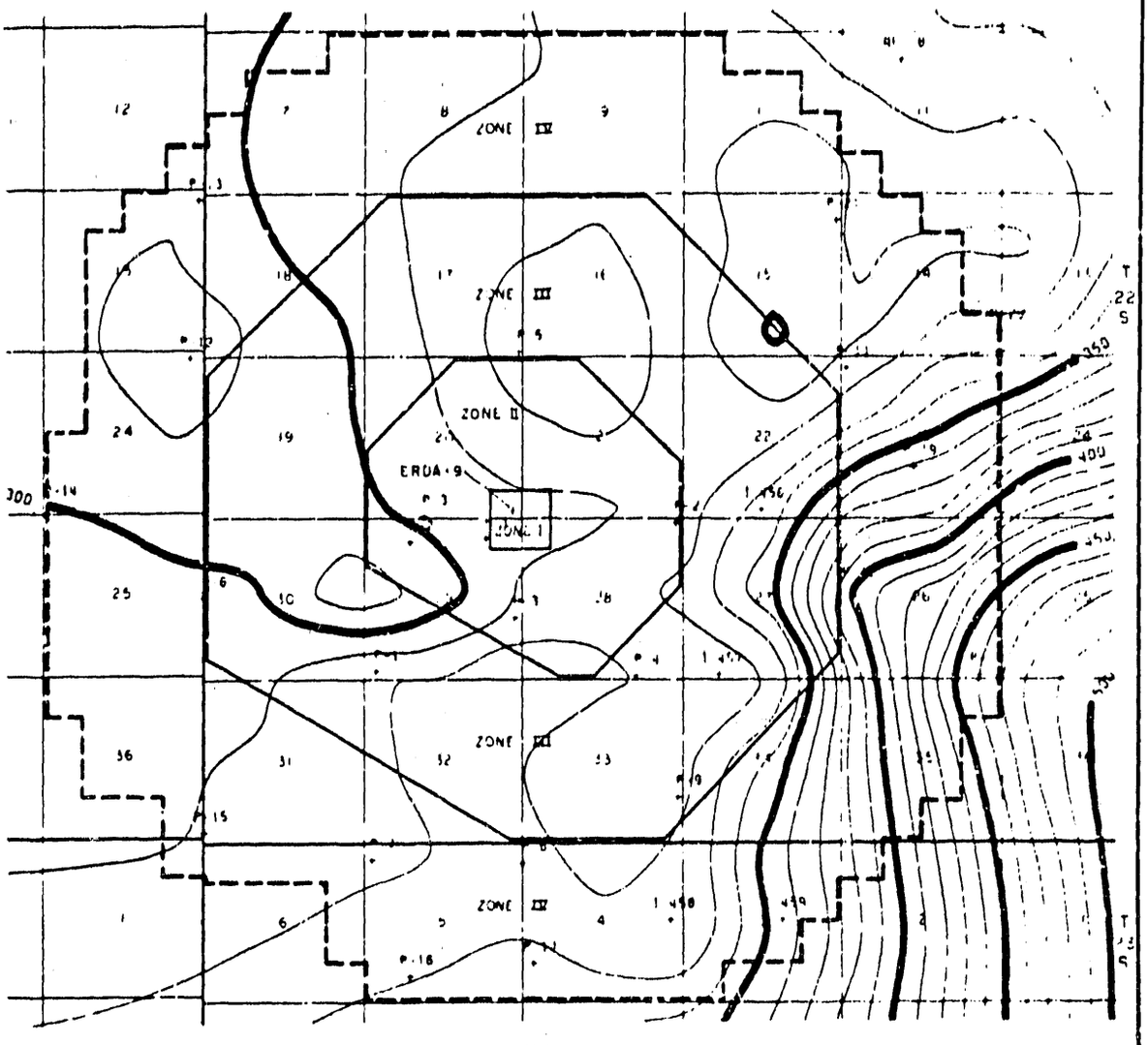


ISOPACH MAP TOP OF SALADO TO :03-MARKER BED

REFERENCE

Griswold, 1977, figure II

FIGURE 4.3-7

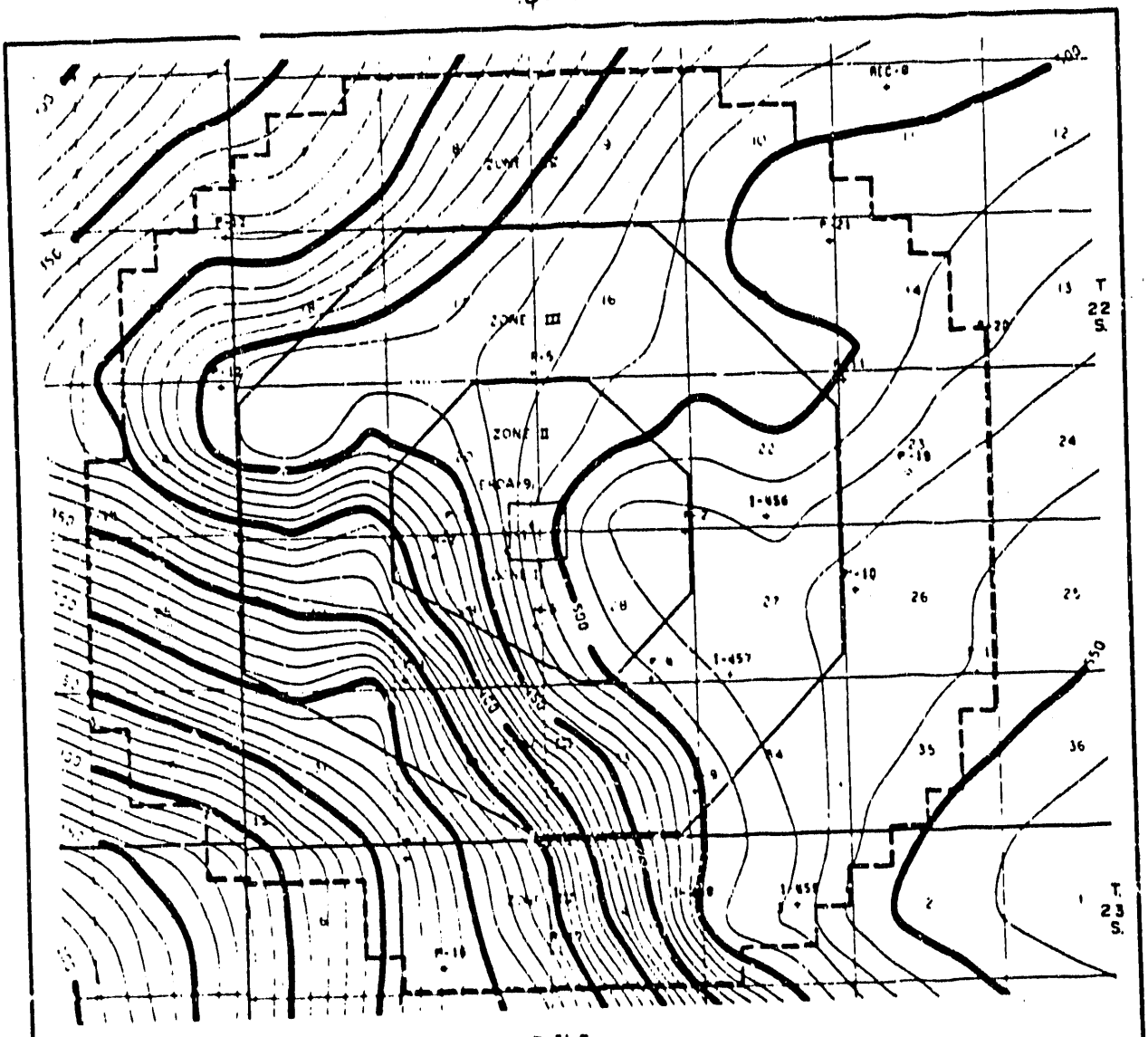


REFERENCE.

Griswold, 1977, figure 10

ISOPACH MAP
RUSTLER FORMATION

FIGURE 4.3-8



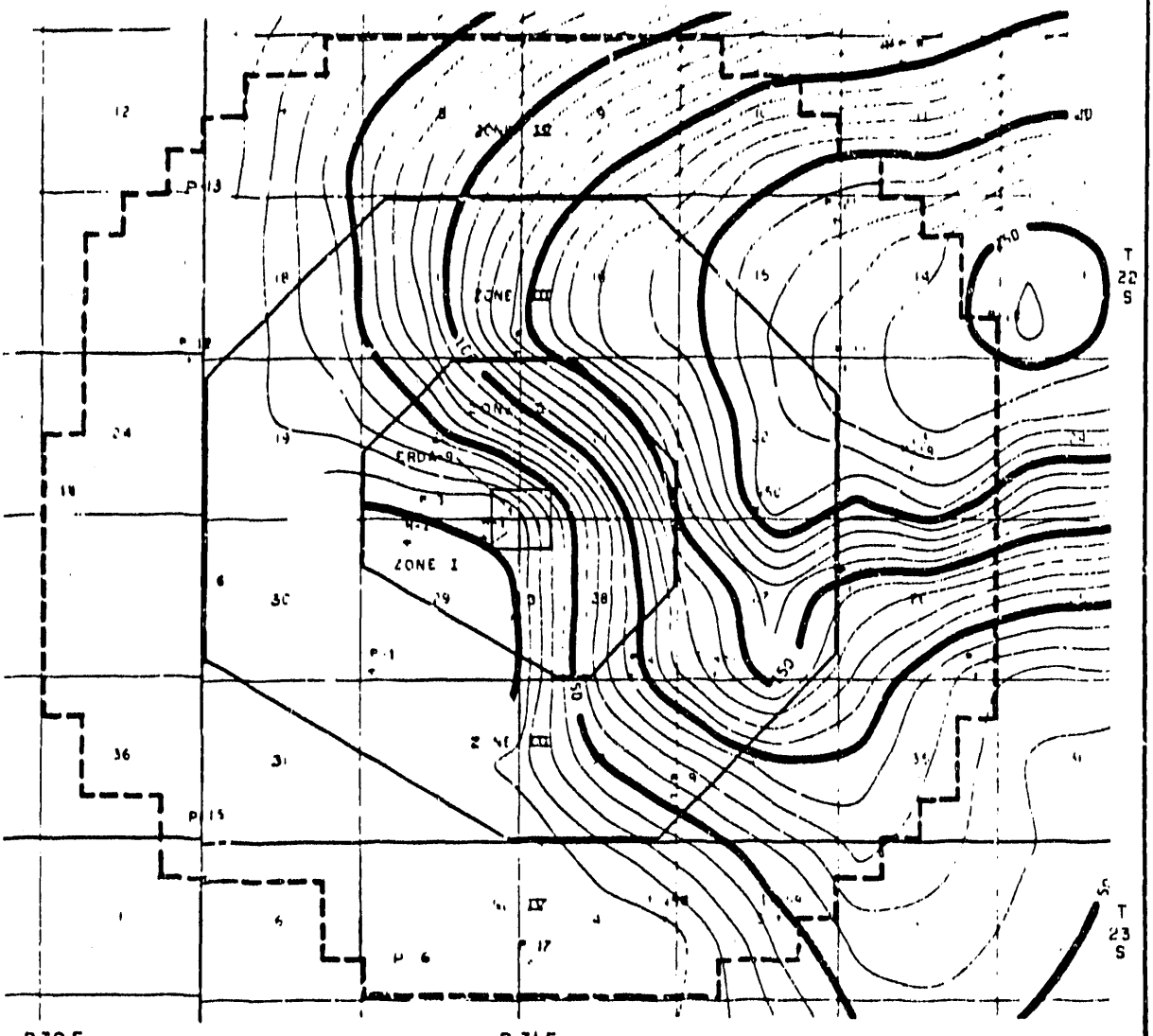
CONTOUR INTERVAL - 10 FEET

REFERENCE.

Griswold, 1977, figure 10

ISOPACH MAP
DEWEY LAKE REDBEDS

FIGURE 4.3-9

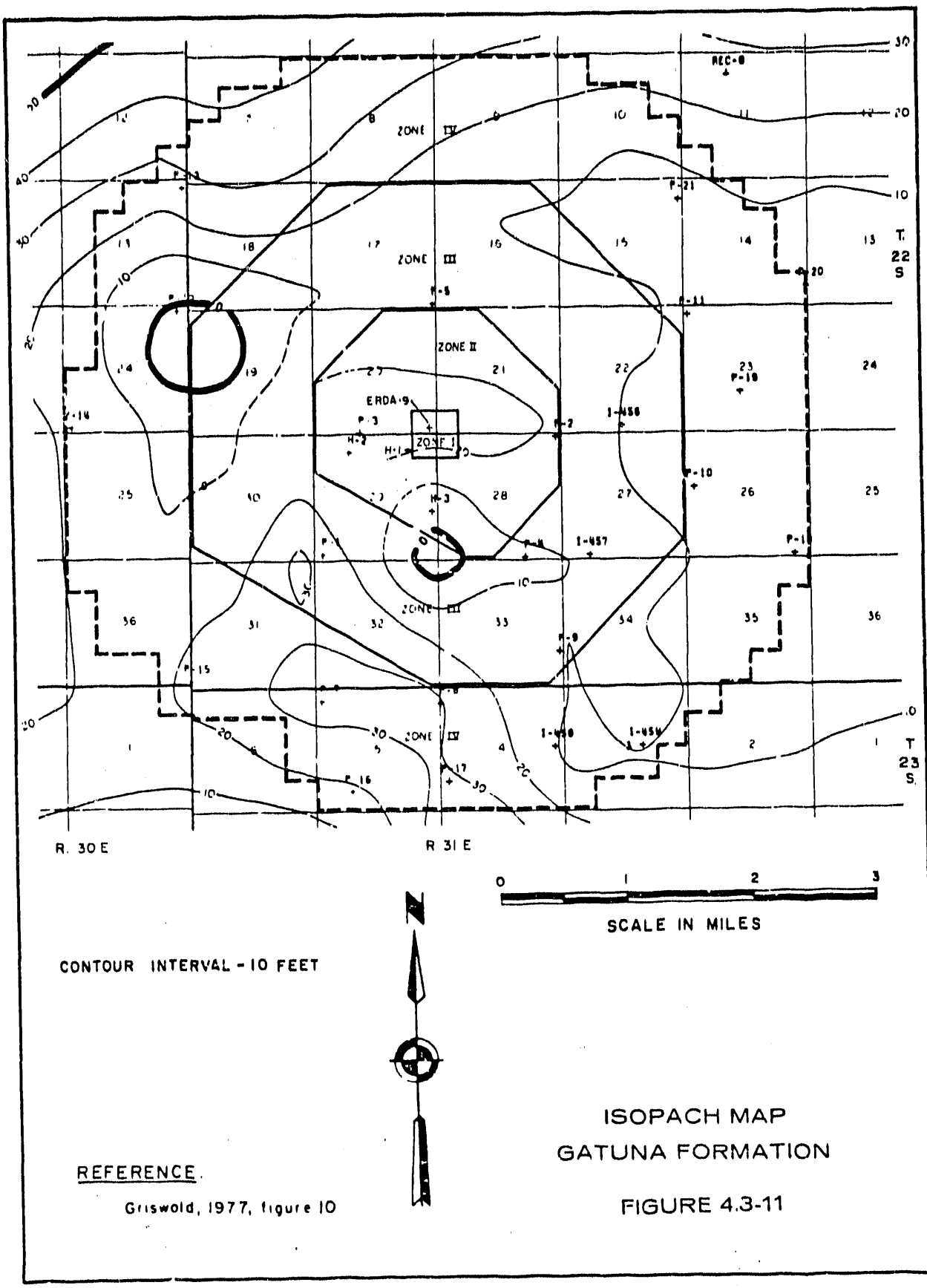


REFERENCE:

Griswold, 1977, figure 10

ISOPACH MAP
SANTA ROSA SANDSTONE

FIGURE 4.3-10

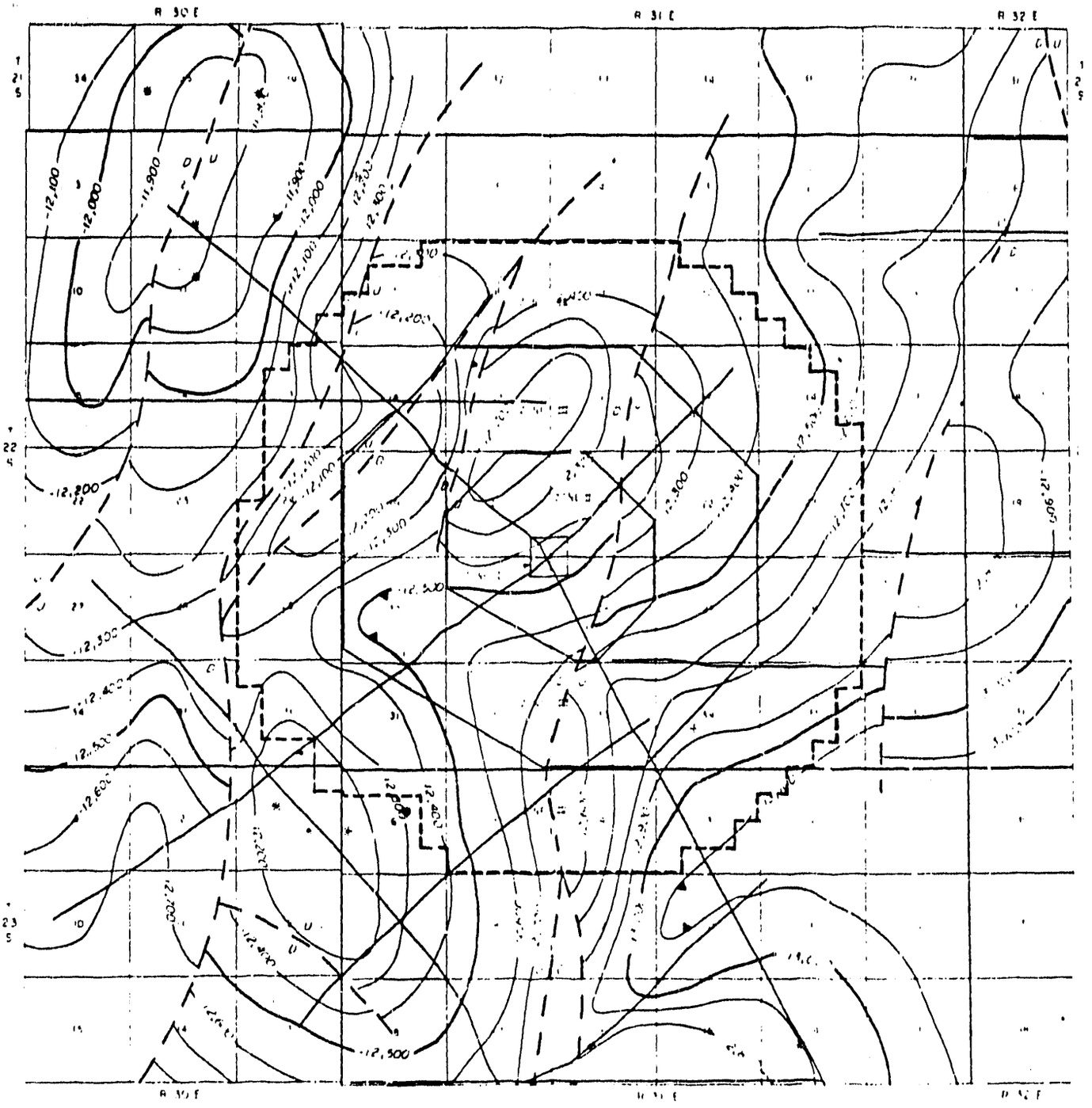


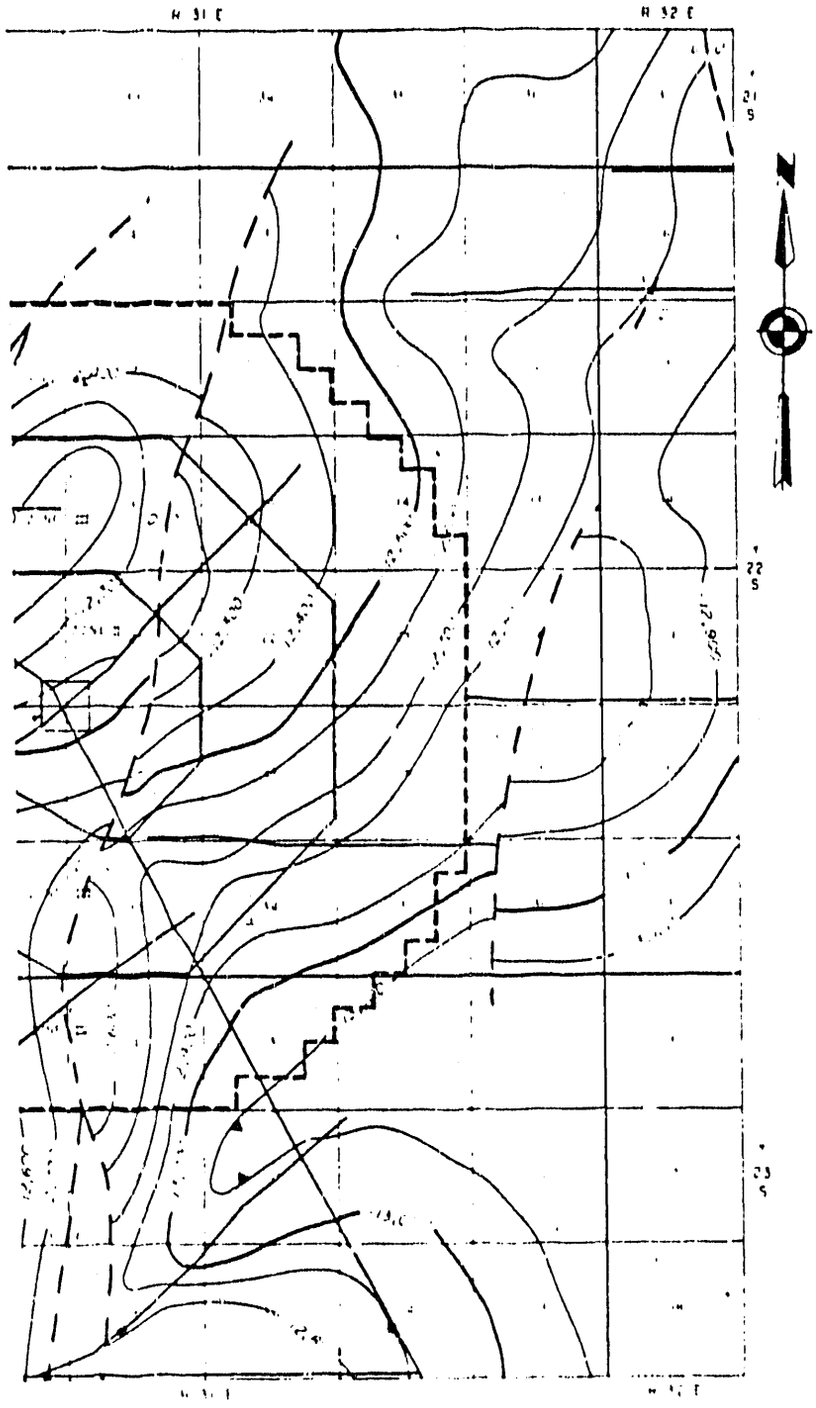
ISOPACH MAP
GATUNA FORMATION

FIGURE 4.3-11

REFERENCE

Griswold, 1977, figure 10


R 30 E
R 31 E
R 32 E
T 21 S
T 22 S
T 23 S
-12,100
-12,000
-11,900
-12,200
-12,300
-12,400
-12,500
-12,600



EXPLANATION

Seismic reflection profile lines

U
D

Inferred faults
U - Upthrown side
D - Downthrown side

- Well - Dry and Abandoned
- Completed Well - Producing Gas
- Completed Well - Producing Oil

Contour interval - 100 feet
Datum is mean sea level

REFERENCE

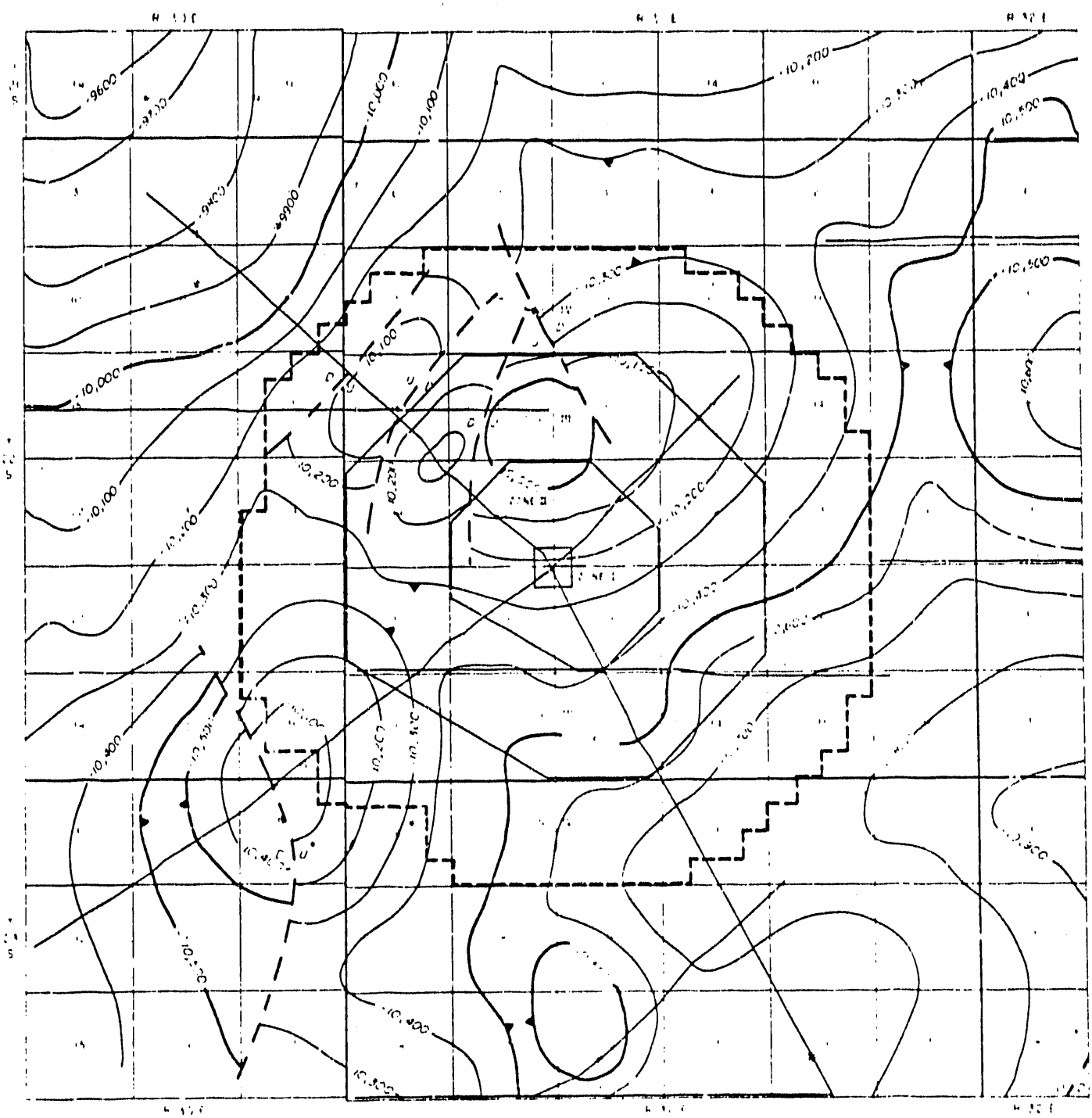
Griswold, 1977, Figure 17

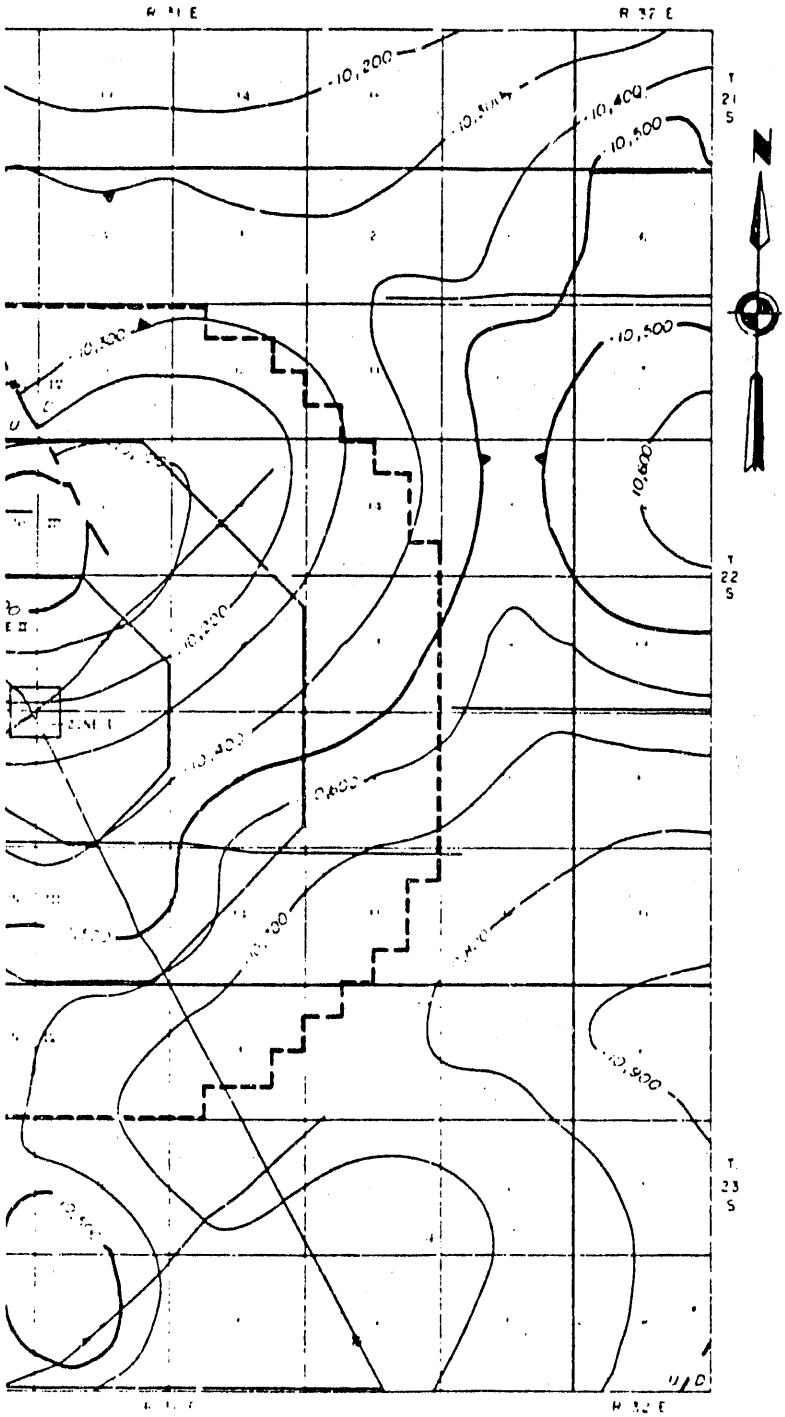
0 2 3

SCALE IN MILES

STRUCTURE CONTOURS
ON TOP OF SILURIAN

FIGURE 4.4-1


-9600
-9800
-9900
-10,000
-10,100
-10,200
-10,300
-10,400
-10,500



EXPLANATION

Seismic reflection profile lines.

Inferred faults.
U-Upthrown side
D-Downthrown side

- Well - Dry and Abandoned
- Completed Well - Producing Gas
- Completed Well - Producing Oil

Contour interval - 100 feet
Datum is mean sea level

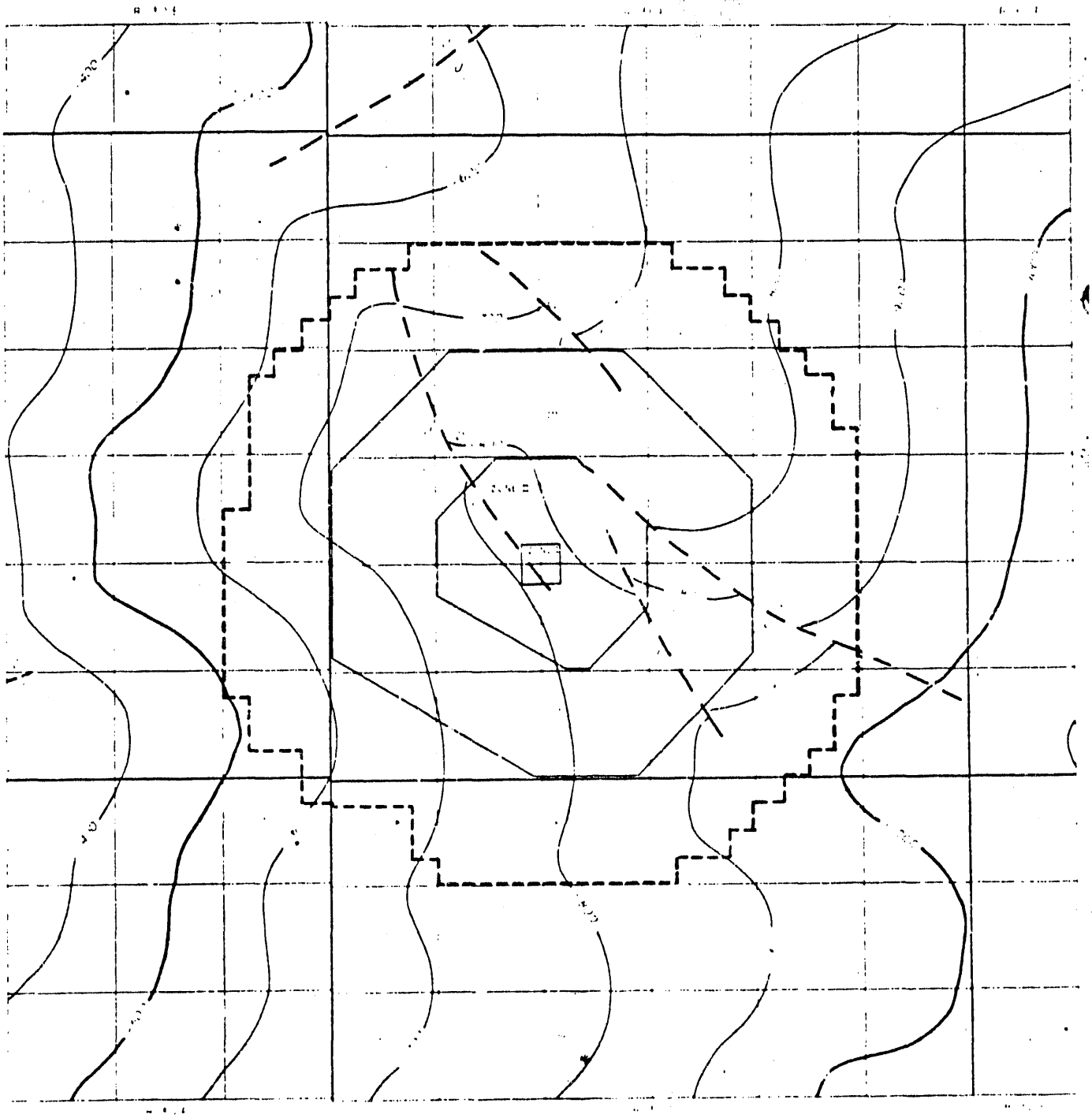
REFERENCE:

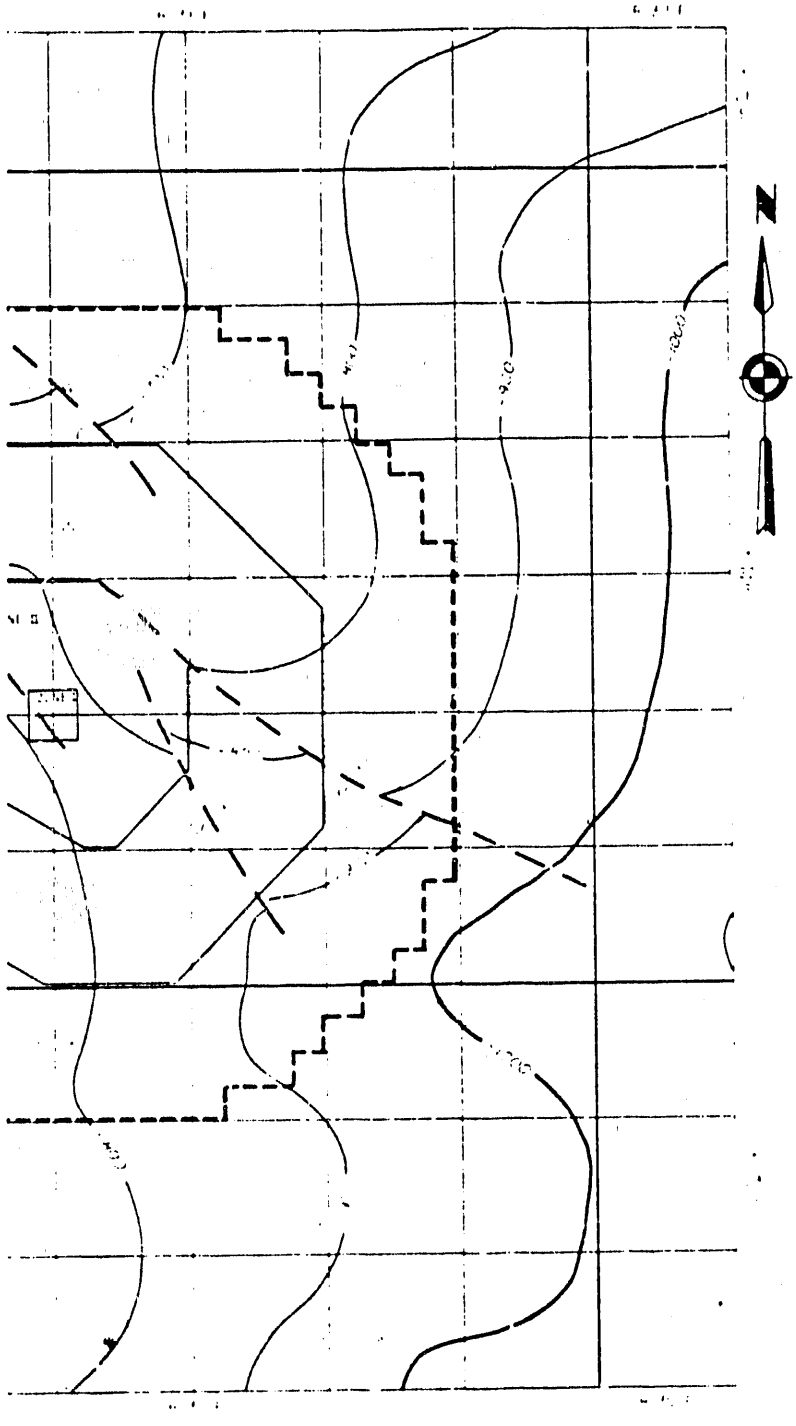
Griswold, 1977, figure 16

0 1 2 3
SCALE IN MILES

STRUCTURE CONTOURS
ON TOP OF
MORROW LIMESTONE

FIGURE 4.4-2





EXPLANATION

D
U

Possible faults
U – Upthrown side
D – Downthrown side

- Well - Dry and Abandoned
- Completed Well - Producing Gas
- Completed Well - Producing Oil

Contour interval - 100 feet
Datum is mean sea level

REFERENCE

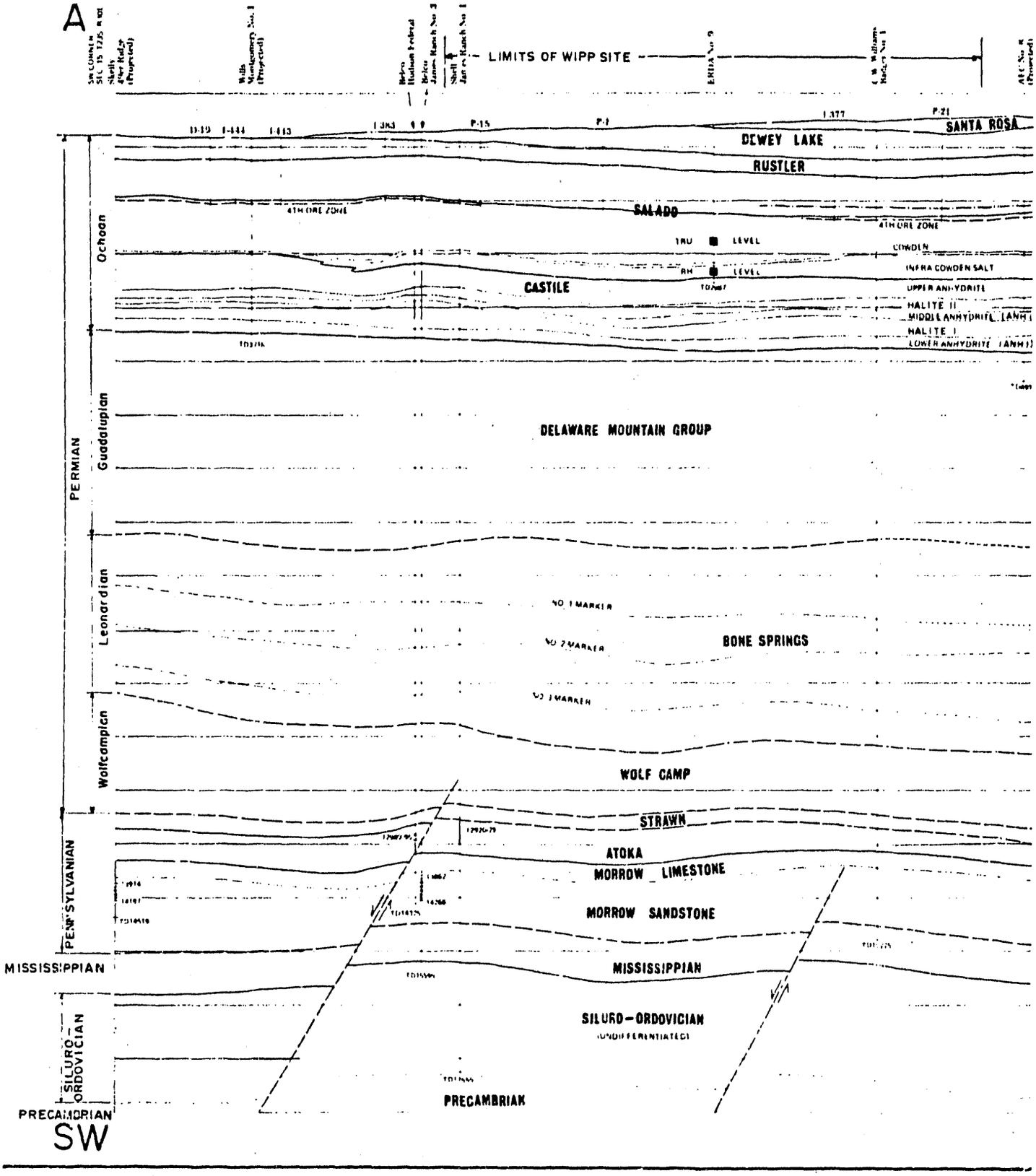
Griswold, 1977, figure 15

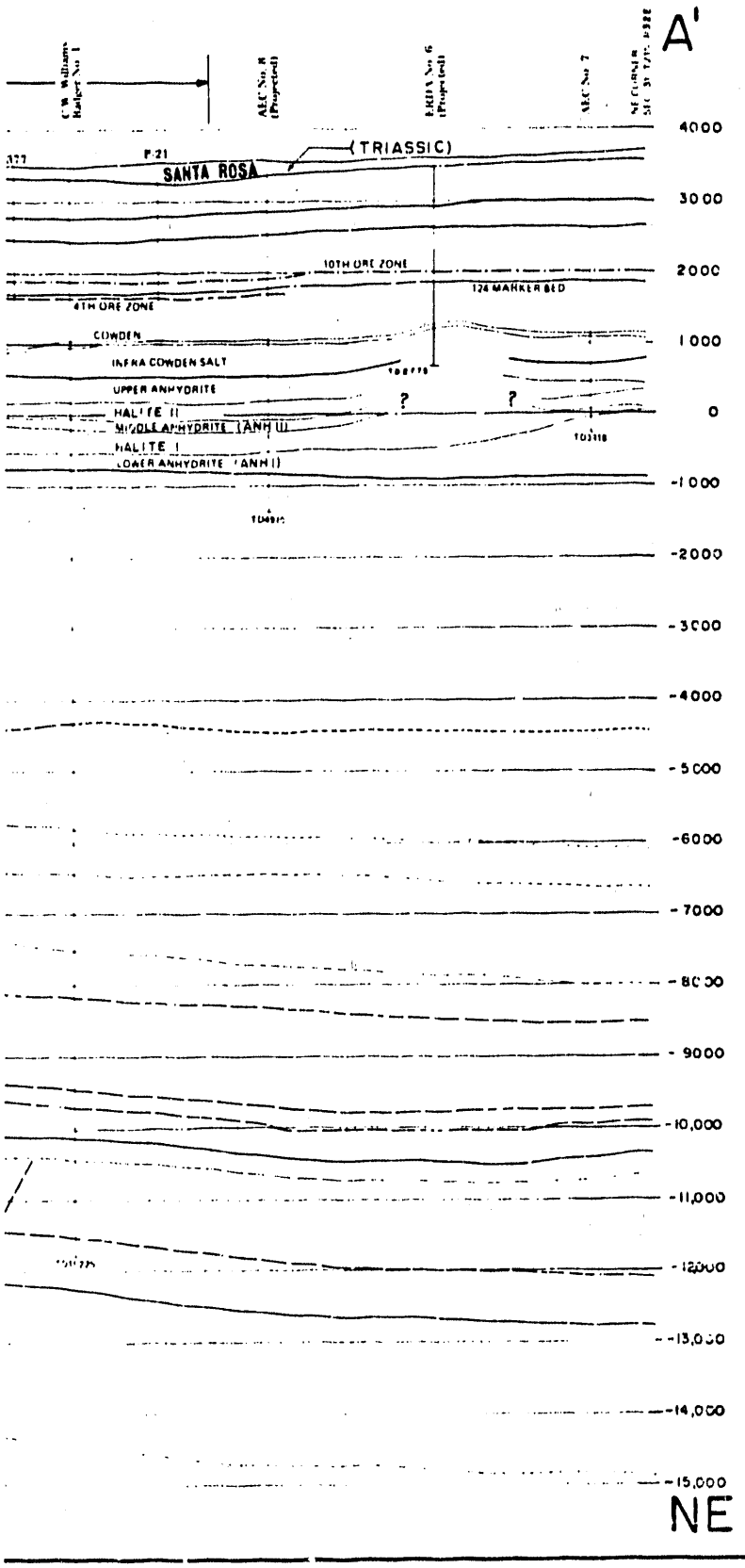
0 1 2 3

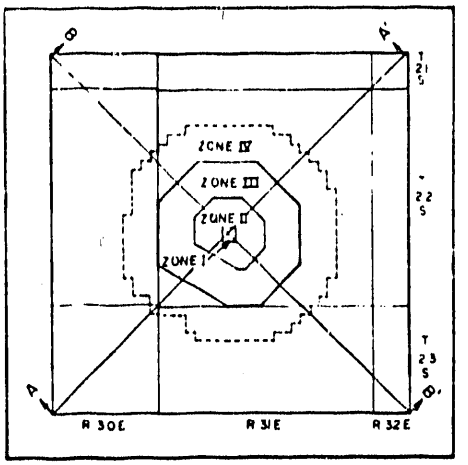
SCALE IN MILES

STRUCTURE CONTOURS
ON TOP OF
DELAWARE SANDSTONE

FIGURE 4.4-3


A
LIMITS OF WIPP SITE
SANTA ROSA
DEWEY LAKE
RUSTLER
SALADO
4TH ORE ZONE
TRU LEVEL
COWDEN
INFRA COWDEN SALT
RH LEVEL
CASTILE
UPPER ANHYDRITE
HALITE II
MIDDLE ANHYDRITE (ANH)
HALITE I
LOWER ANHYDRITE (ANH)
DELAWARE MOUNTAIN GROUP
NO. 1 MARKER
NO. 2 MARKER
NO. 3 MARKER
BONE SPRINGS
WOLF CAMP
STRAWN
ATOKA
MORROW LIMESTONE
MORROW SANDSTONE
MISSISSIPPIAN
SILURO-ORDOVICIAN
(UNDIFFERENTIATED)
PRECAMBRIAN
PERMIAN
Ochoan
Guadalupian
Leonardian
Wolfcampian
PENNSYLVANIAN
MISSISSIPPIAN
SILURO-ORDOVICIAN
PRECAMBRIAN
SW





LOCATION MAP

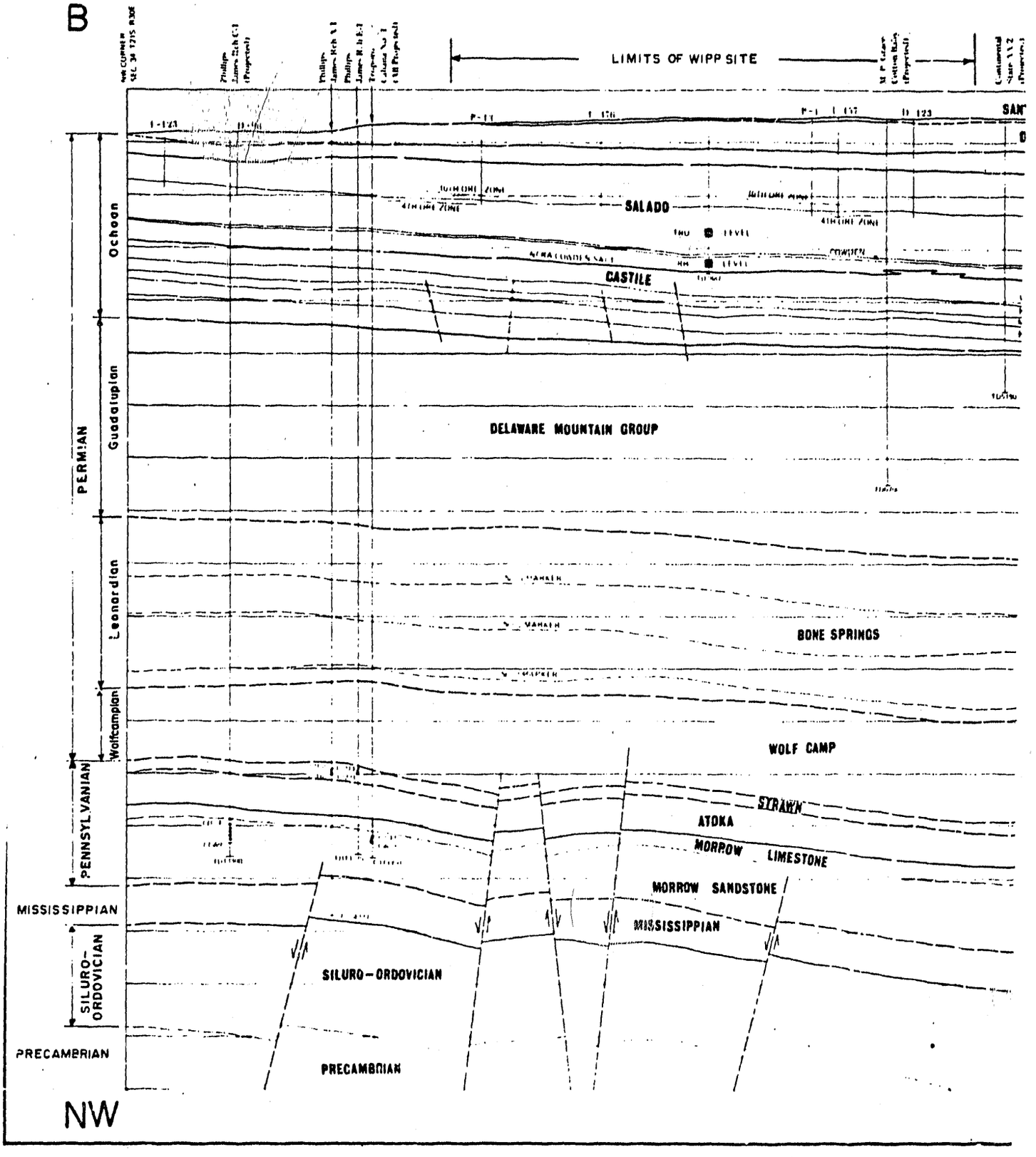
0 1 2 3 4
SCALE IN MILES

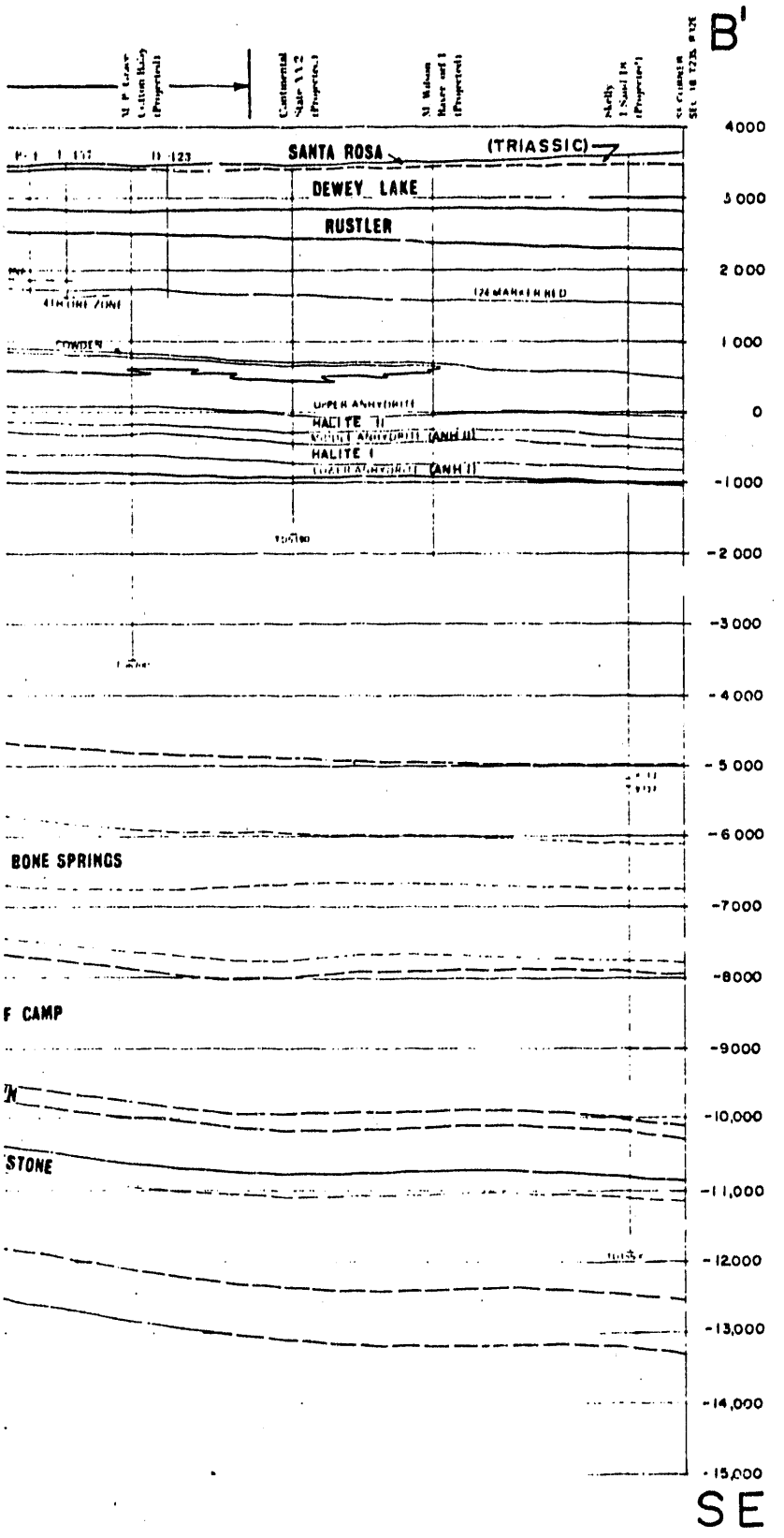
REFERENCE
Griswold, 1977, figure 6

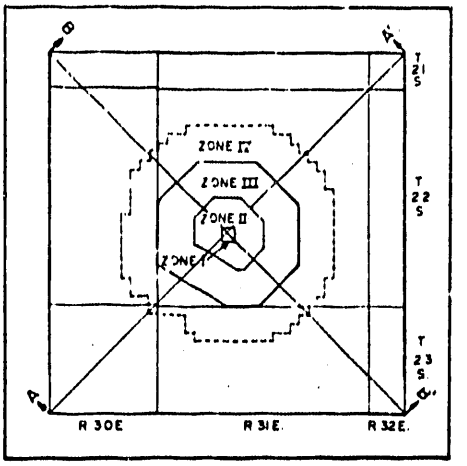
0 1 2 3
HORIZONTAL SCALE IN MILES
VERTICAL EXAGGERATION, APPROX. 3 1/2 TIMES
DATUM IS MEAN SEA LEVEL

SITE GEOLOGIC SECTION A-A'

FIGURE 4.4-4


B
LIMITS OF WIPP SITE
SALADO
CASTILE
DELAWARE MOUNTAIN GROUP
BONE SPRINGS
WOLF CAMP
STRAWN
ATOKA
MORROW
LIMESTONE
MORROW SANDSTONE
MISSISSIPPIAN
SILURO-ORDOVICIAN
PRECAMBRIAN
PERMIAN
Ochoan
Guadalupian
Leonardian
Wolfcampian
PENNSYLVANIAN
MISSISSIPPIAN
SILURO-ORDOVICIAN
PRECAMBRIAN
NW





LOCATION MAP

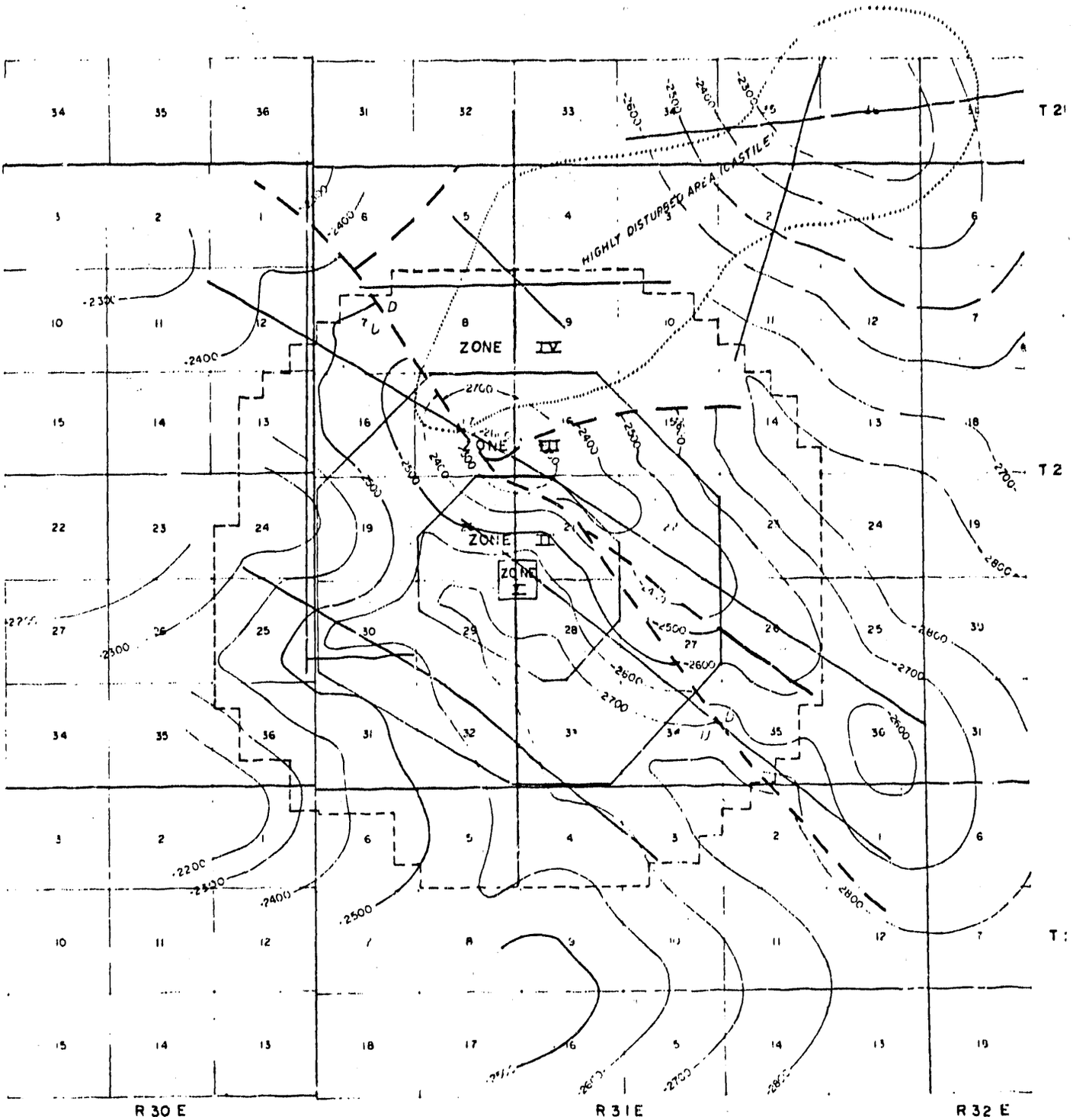
SCALE IN MILES

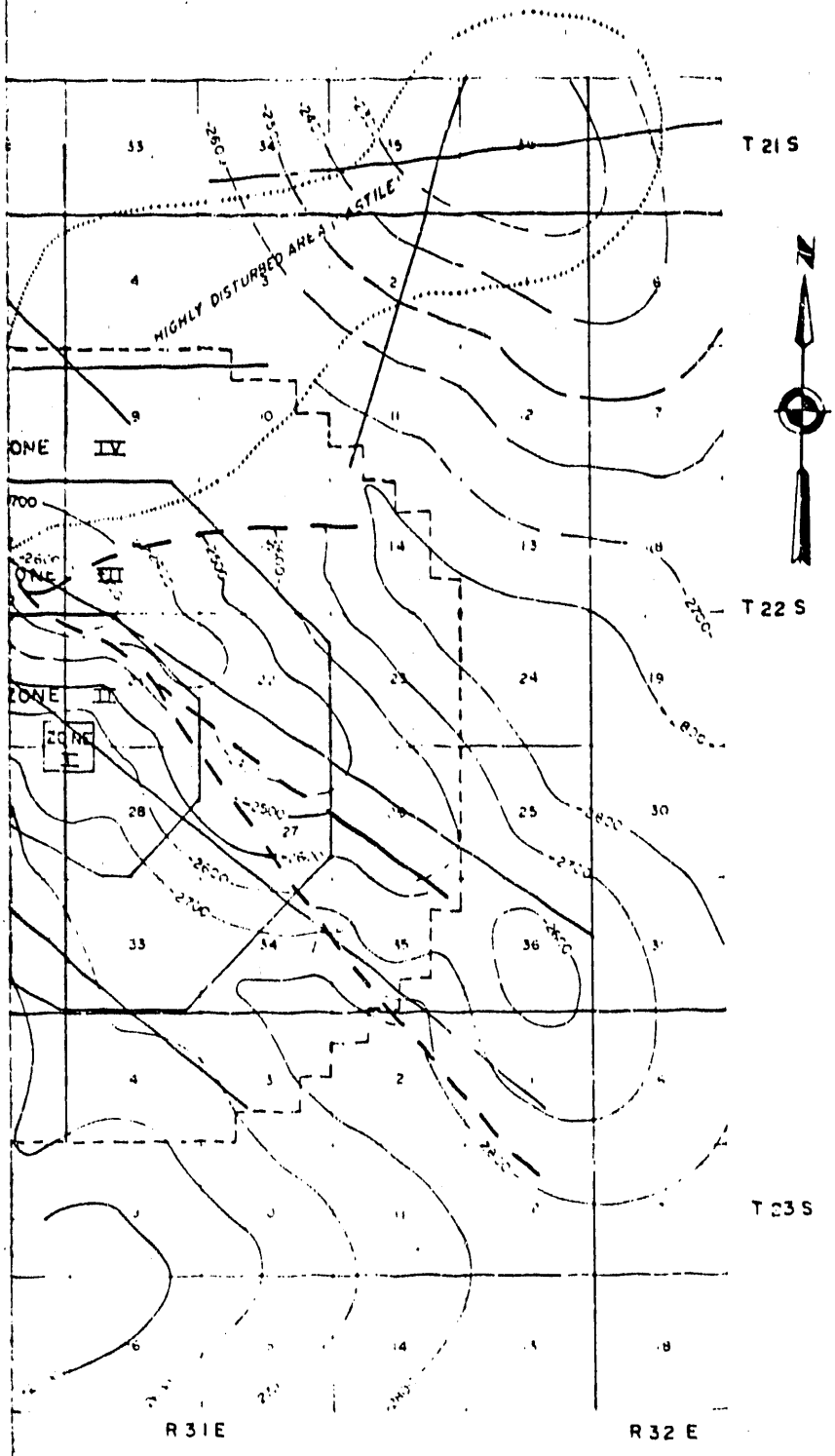
REFERENCE
Griswold, 1977, figure 7

HORIZONTAL SCALE IN MILES
VERTICAL EXAGGERATION, APPROX. 3 1/2 TIMES
DATUM IS MEAN SEA LEVEL

SITE GEOLOGIC SECTION B-B'

FIGURE 4.4-5


HIGHLY DISTURBED AREA (CASTILE)
ZONE IV
ZONE III
ZONE II
ZONE I
T 21
T 2
T
R 30 E
R 31 E
R 32 E



EXPLANATION

Seismic reflection profile lines

Inferred faults
U - Upthrown side
D - Downthrown side

Contour interval, 100 ft

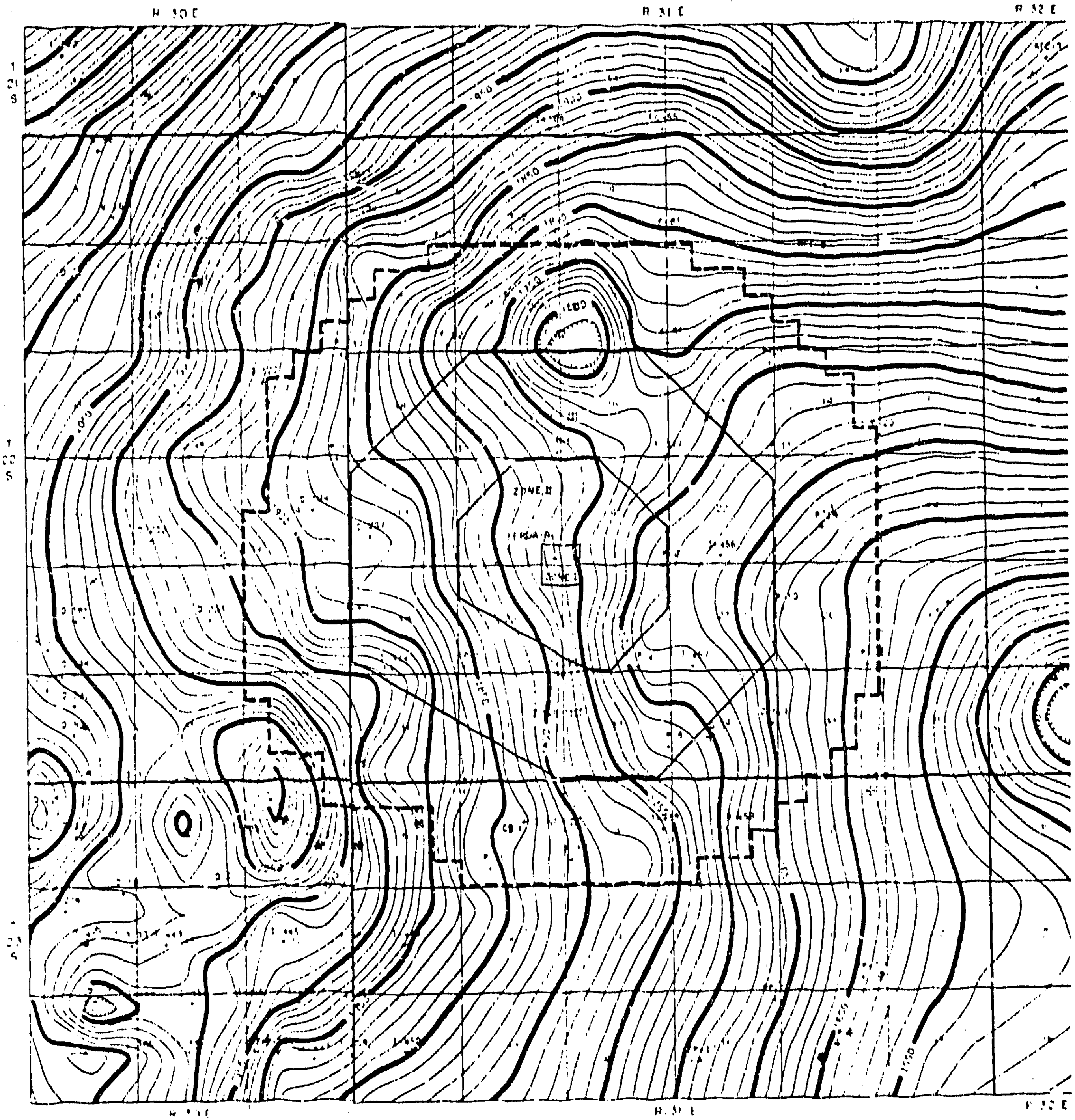
REFERENCE:
G.J. LONG & ASSOC., DEC 1977

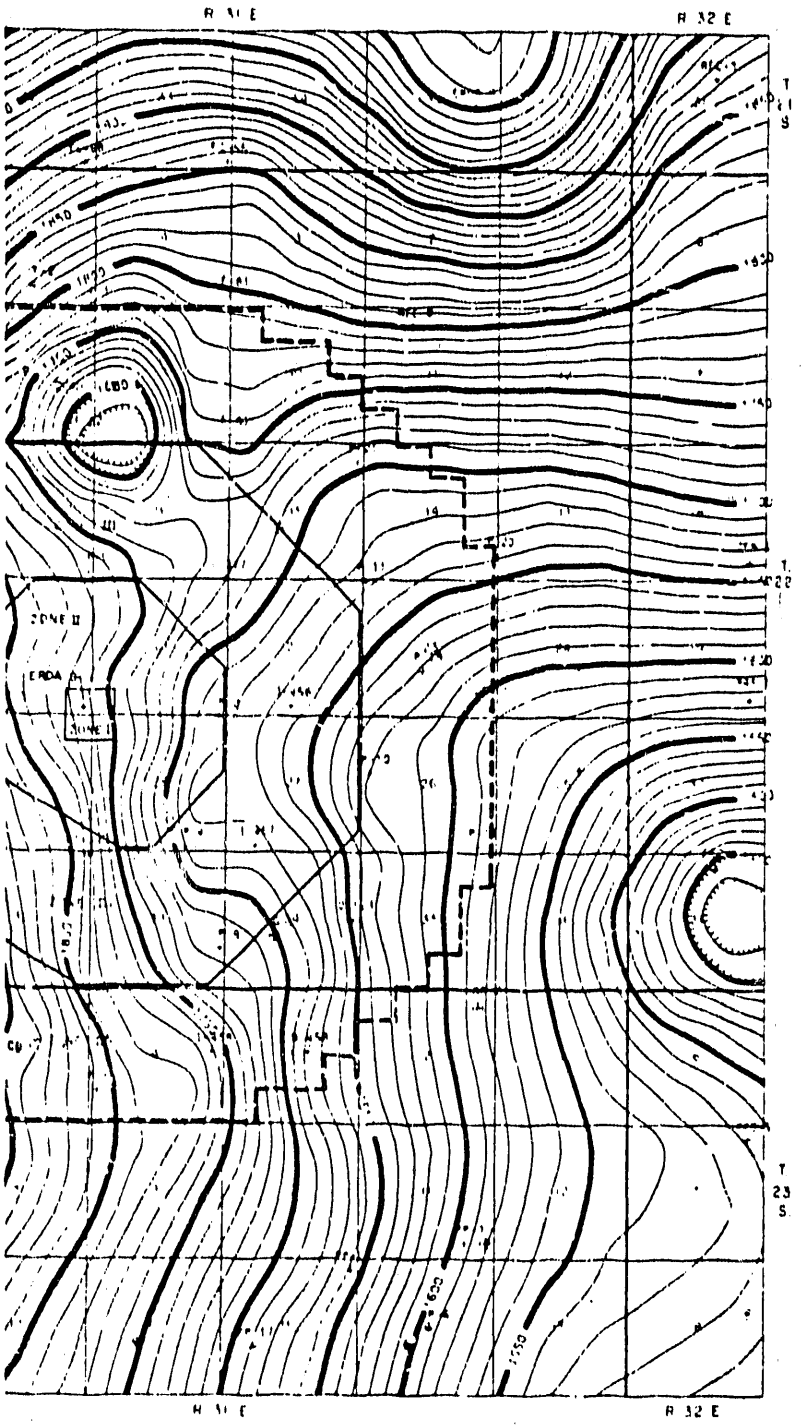
0 1 2 3
SCALE IN MILES

DATUM IS 3400' ABOVE MEAN SEA LEVEL

STRUCTURE CONTOURS ON TOP OF CASTILE

FIGURE 4.4-6


R 30 E
R 31 E
R 32 E
ZONE II



Note:
Borehole sources of data are shown.

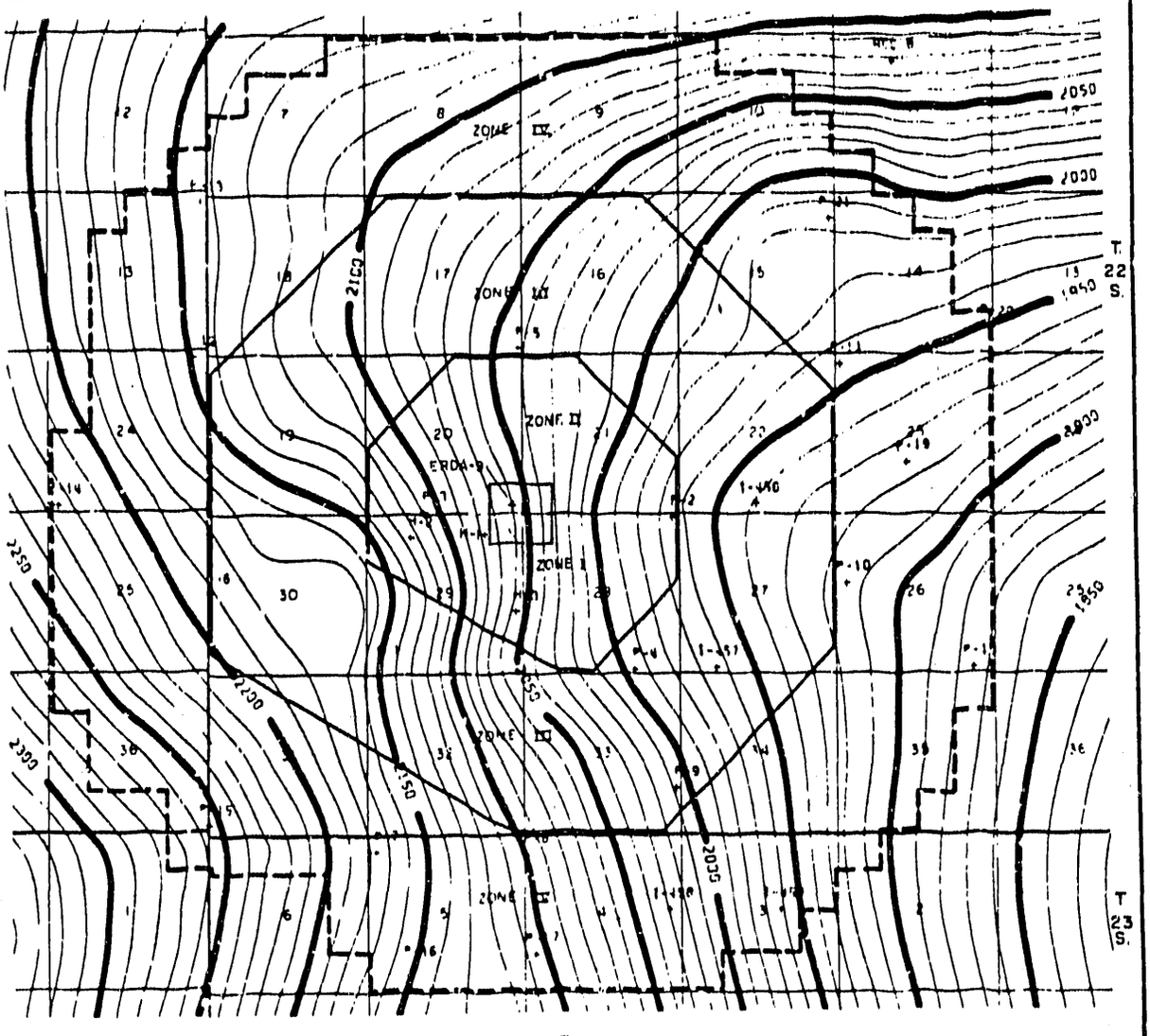
REFERENCE
Griswold, 1977, figure 13

Contour interval, 10 feet

0 1 2 3
SCALE IN MILES

STRUCTURE CONTOURS
ON 124-MARKER BED

FIGURE 4.4-7



Contour interval, 10 feet

Note:
Borehole sources of data are shown.

0 1 2 3

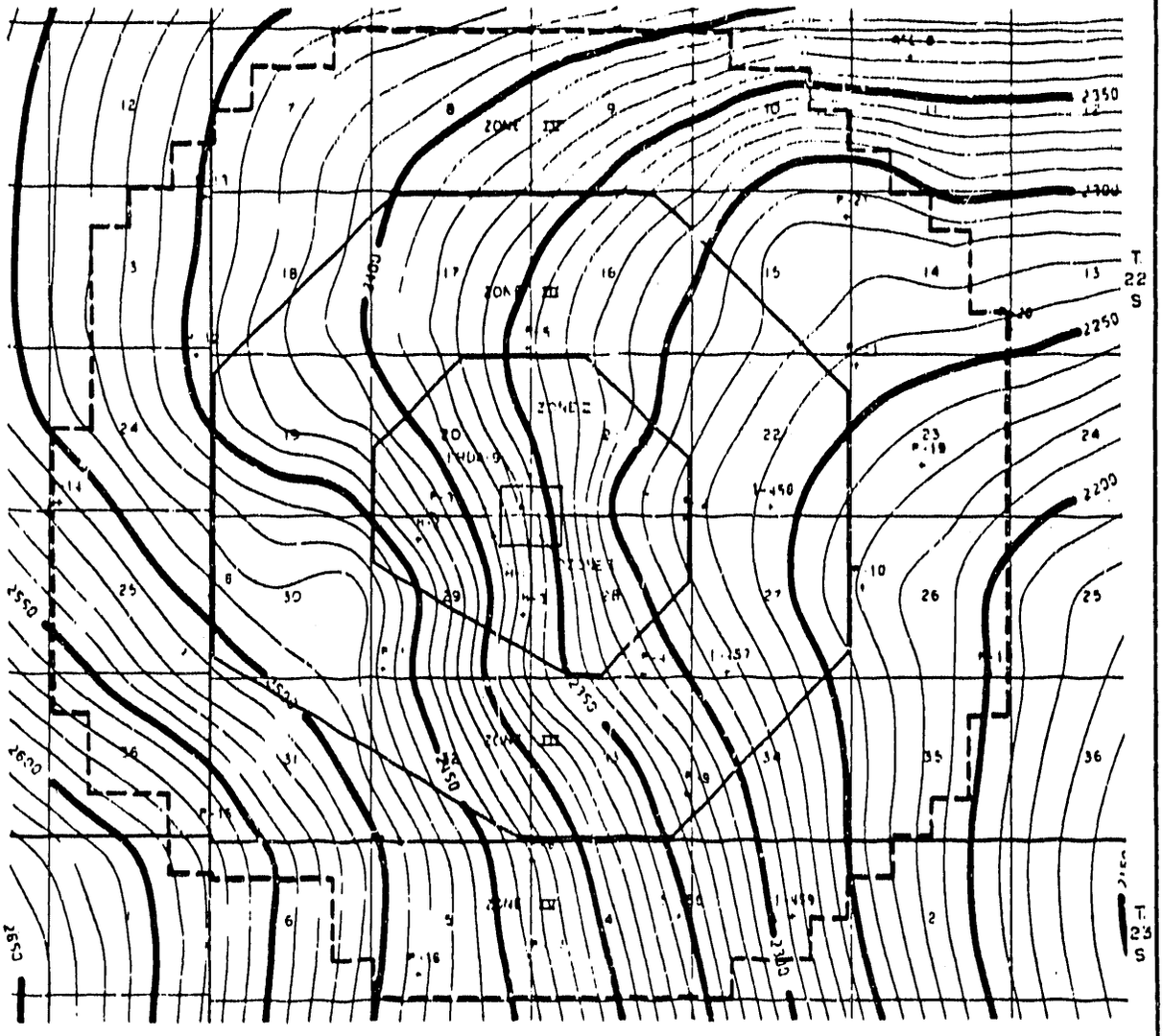
SCALE IN MILES

REFERENCE

Griswold, 1977, figure 9

STRUCTURE CONTOURS
ON TOP OF
VACA TRISTE MARKER BED

FIGURE 4.4-8



Contour interval, 10 feet

Note:
Borehole sources of data are shown.

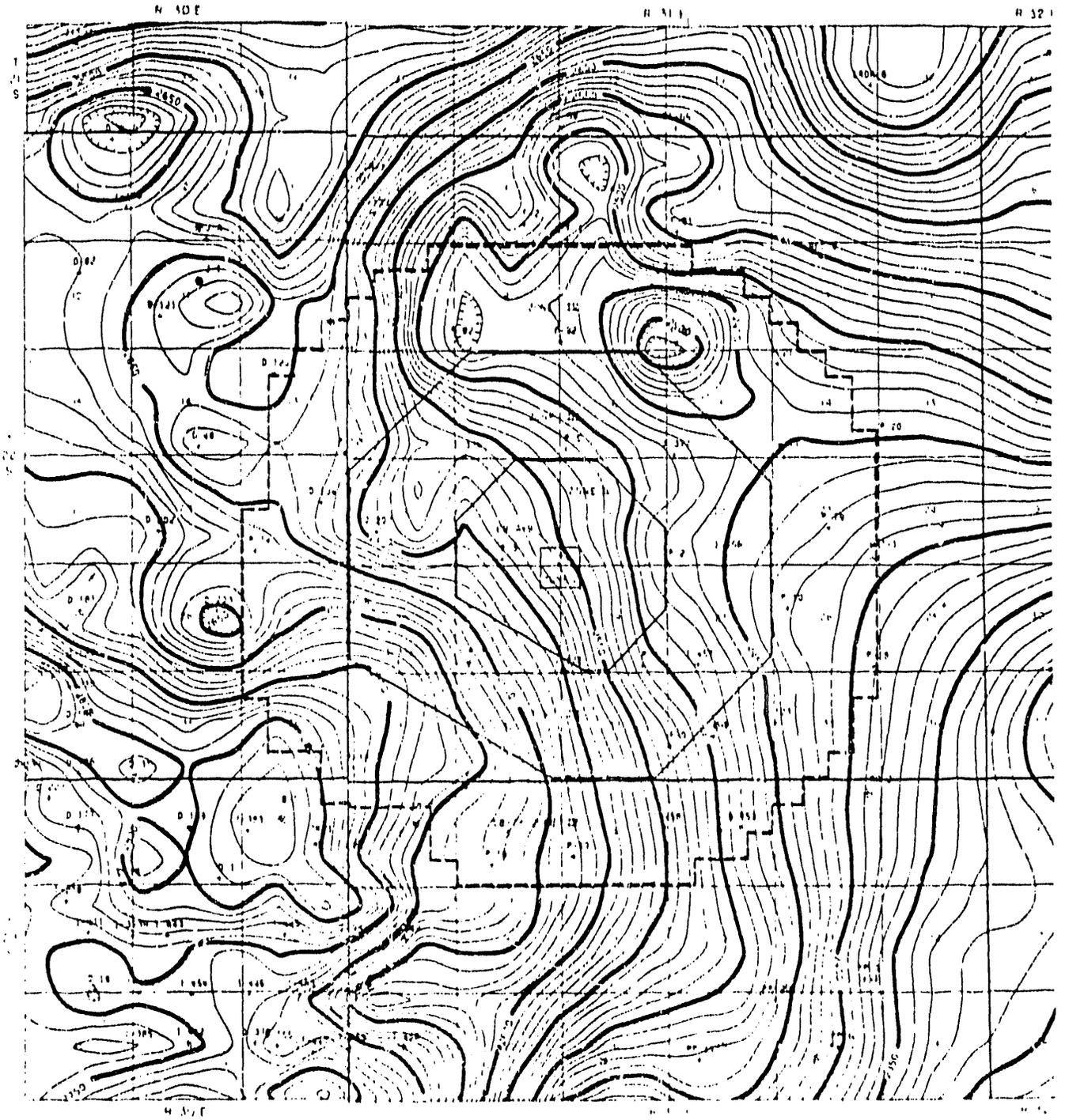
REFERENCE

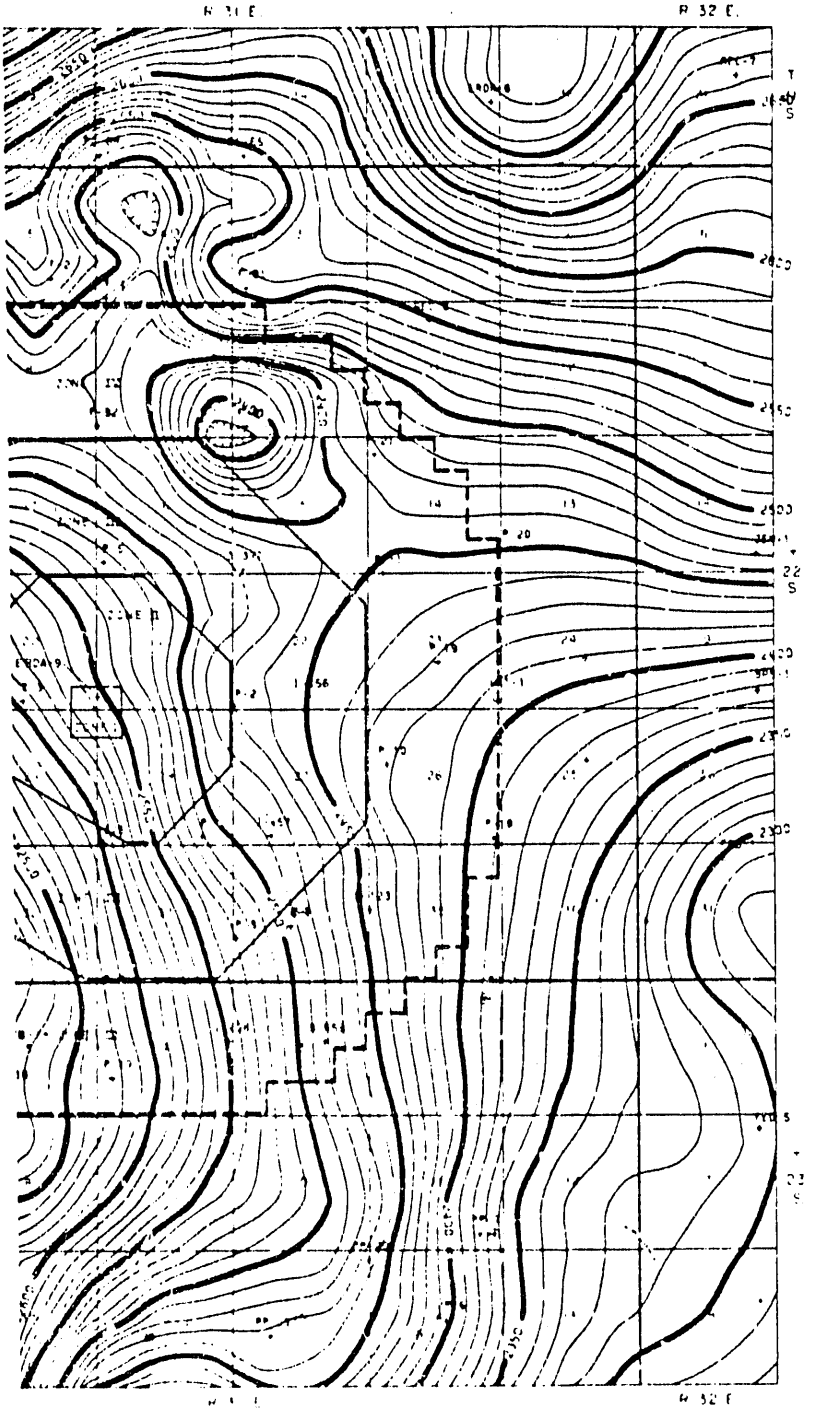
Griswold, 1977 figure 9

STRUCTURE CONTOURS

ON 103 MARKER BED

FIGURE 4.4-9





EXPLANATION

Contours based on geologic logs of ERDA and industry potash exploration logs. In the site area i.e., within Zones I-IV, the contours are considered accurate within 10 feet in elevation. Outside Zone IV they are approximate, and the error may exceed 50 feet in some areas. The Top of Salado may be higher in the west because drill records report only "top of salt". Datum is sea level.

Note:
Borehole sources of data are shown.

REFERENCE:
Griswold, 1977, figure 12

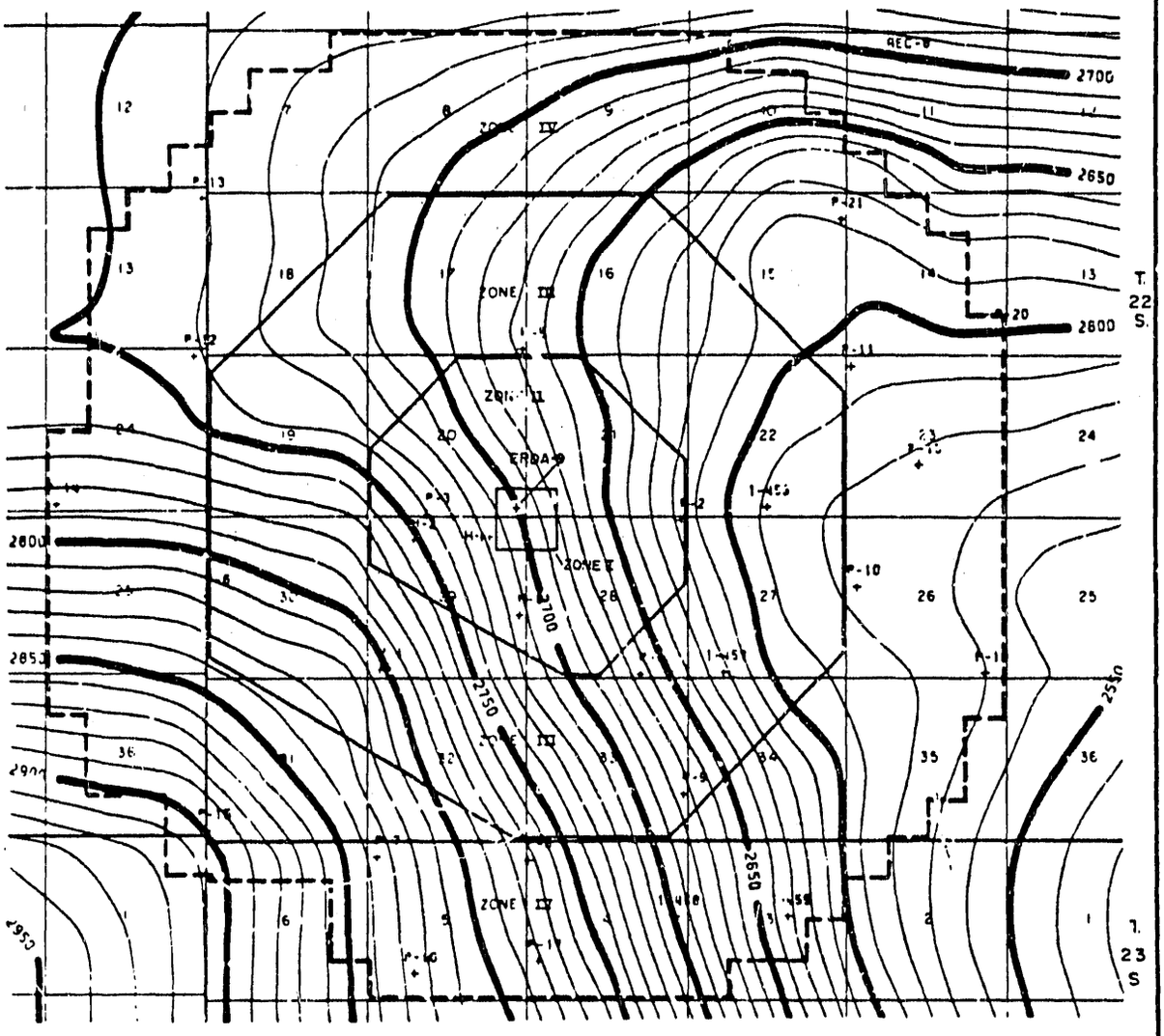
Contour interval, 10 feet

0 1 2 3

SCALE IN MILES

STRUCTURE CONTOURS
ON TOP OF
SALADO FORMATION

FIGURE 4.4-10



Contour interval, 10 feet

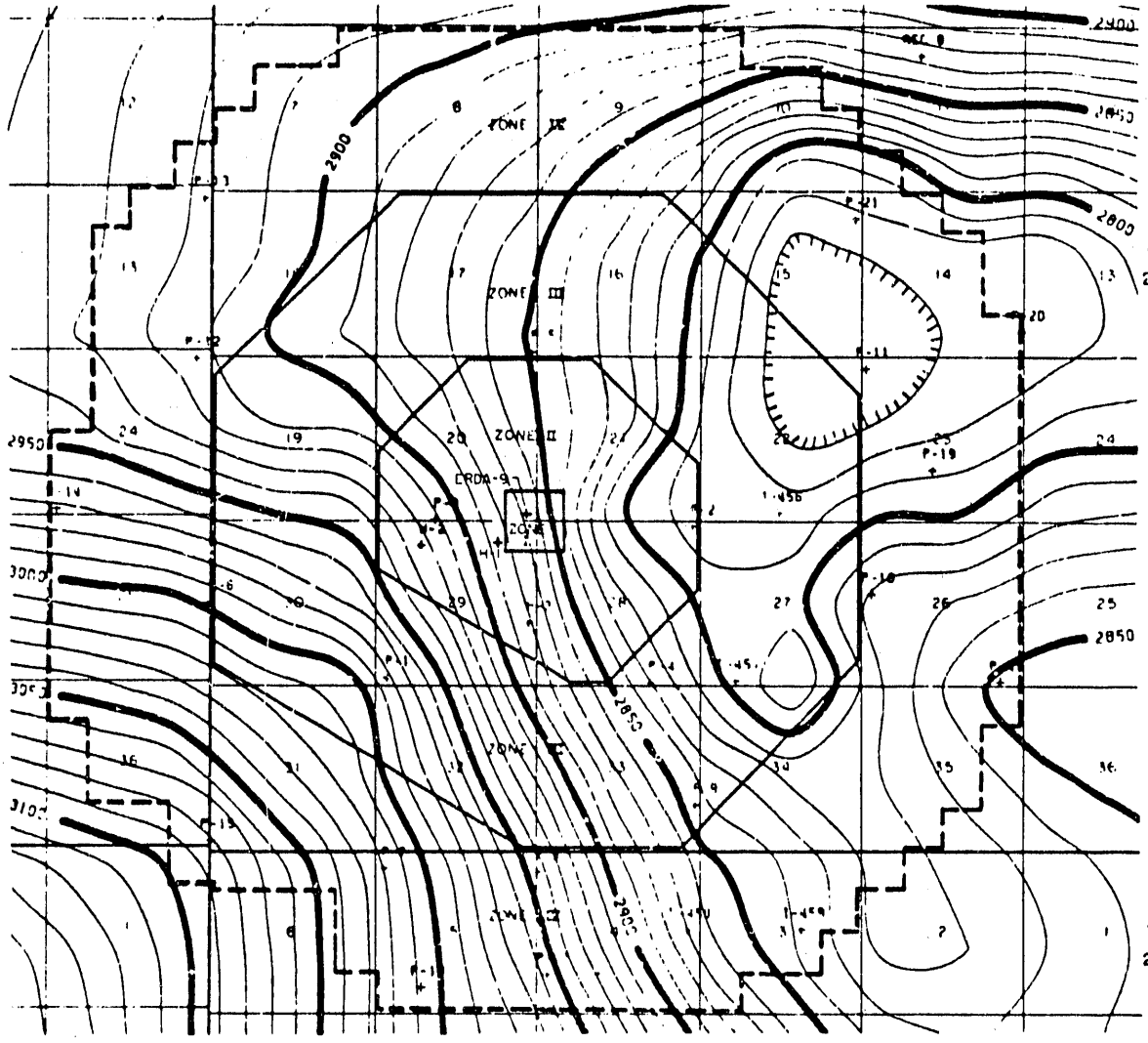
Note:
Borehole sources of data are shown.

REFERENCE:

Griswold, 1977, figure 9

STRUCTURE CONTOURS
ON TOP OF
CULEBRA DOLOMITE MEMBER

FIGURE 4.4-11



Contour interval, 10 feet

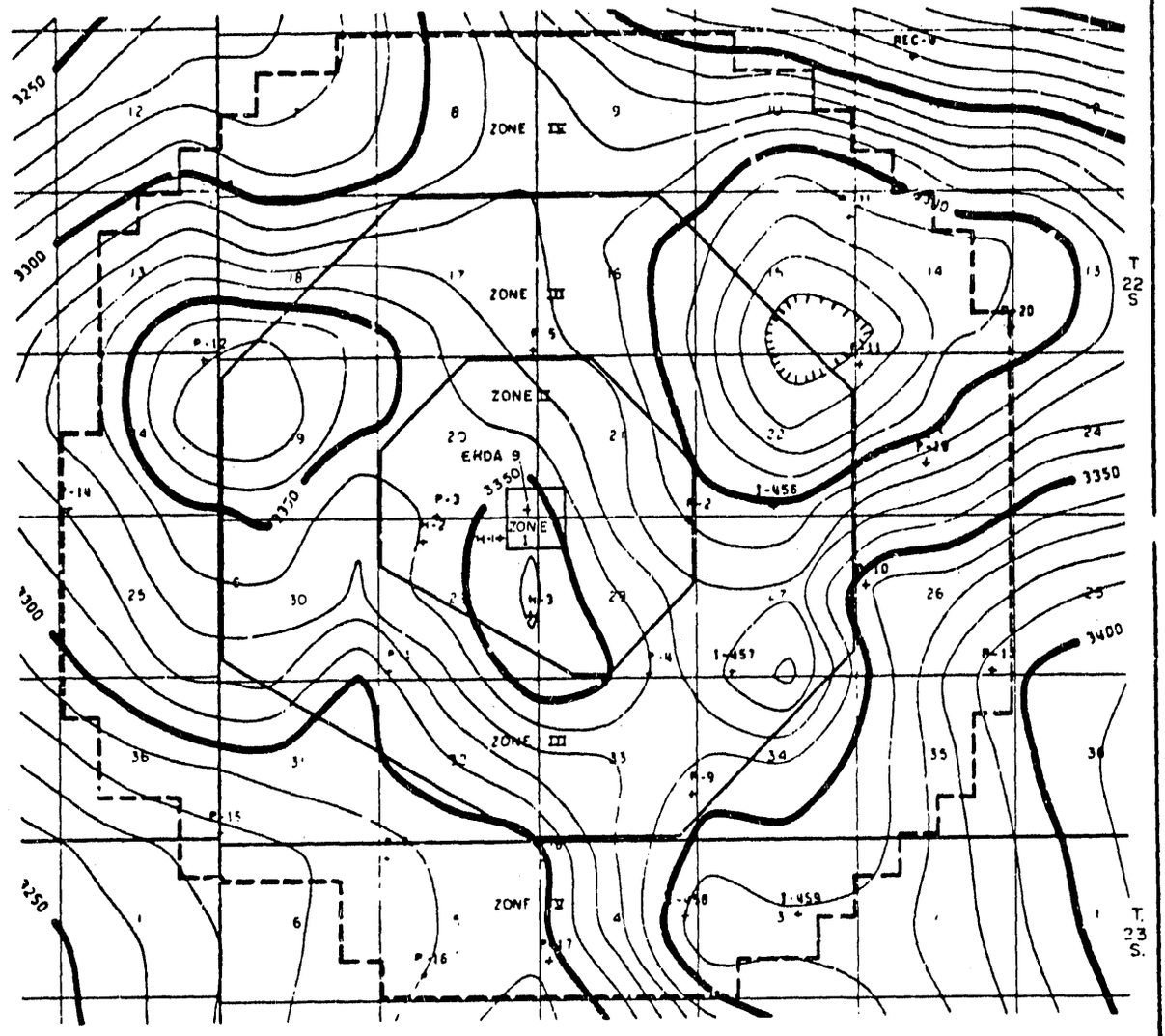
Note:
Borehole sources of data are shown.

REFERENCE

Griswold, 977, figure 8

STRUCTURE CONTOURS
ON TOP OF
RUSTLER FORMATION

FIGURE 4.4-12



Contour interval, 10 feet

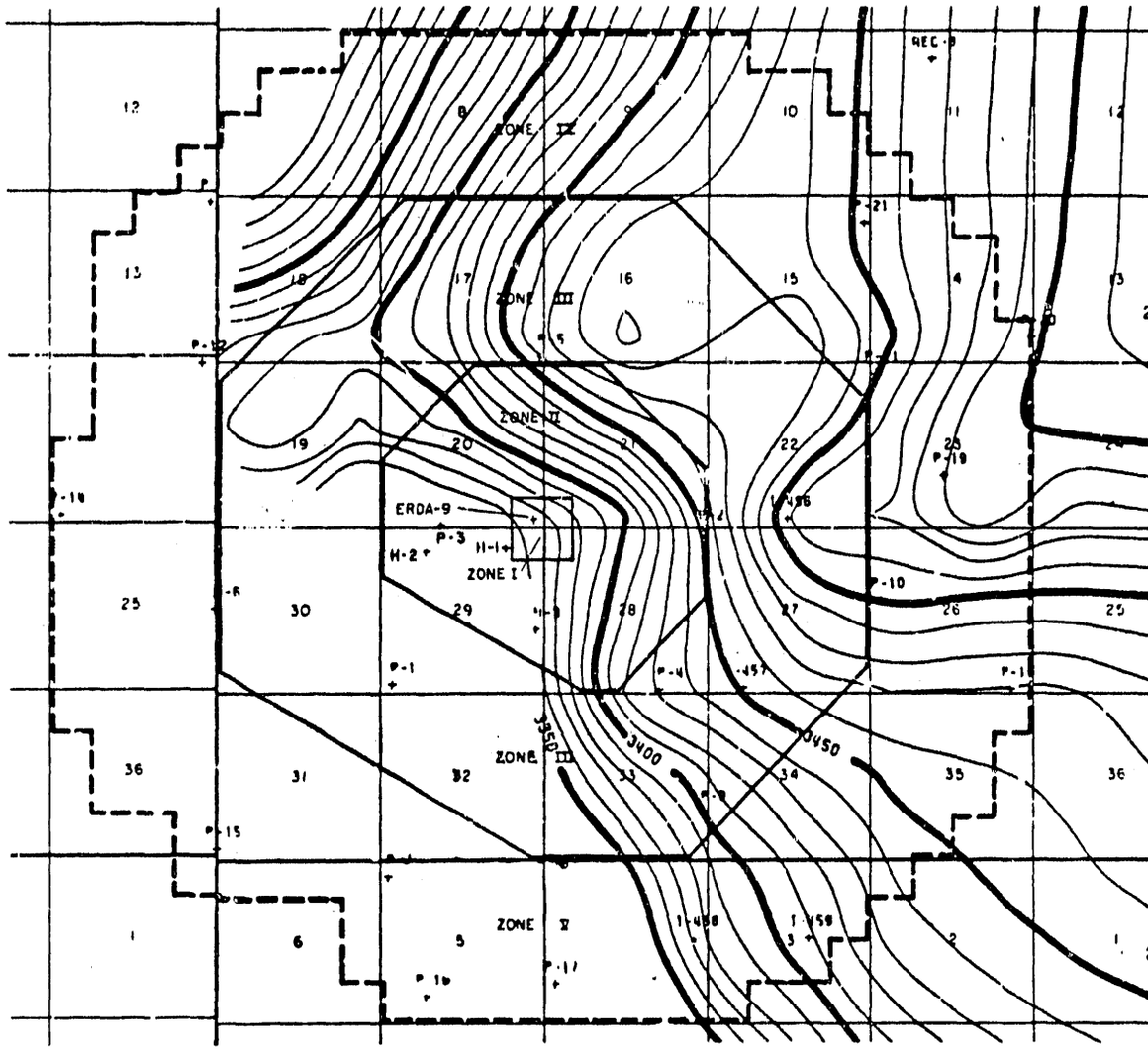
Note:
Borehole sources of data are shown.

REFERENCE:

Griswold, 1977, figure 8

STRUCTURE CONTOURS
ON TOP OF
DEWEY LAKE REDBEDS

FIGURE 4.4-13



Contour interval, 10 feet

Note:
Borehole sources of data are shown.

0 1 2 3

SCALE IN MILES

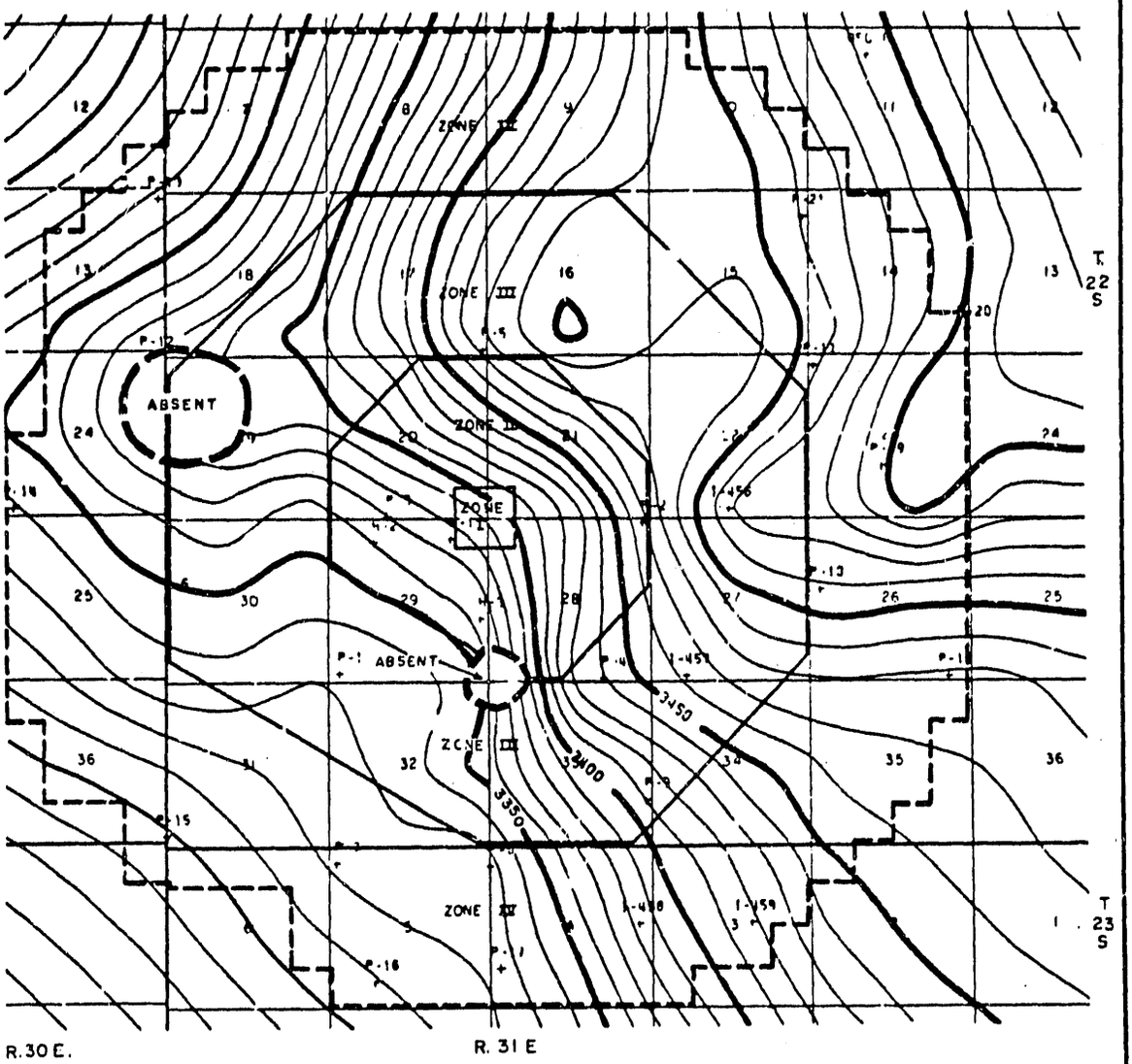
N

REFERENCE:

Griswold, 1977, figure 8

STRUCTURE CONTOURS
ON TOP OF
SANTA ROSA SANDSTONE

FIGURE 4.4-14



Contour interval, 10 feet

Note:
Borehole sources of data are shown.

REFERENCE:

Griswold, 1977, figure 8

STRUCTURE CONTOURS
ON TOP OF
GATUNA FORMATION

FIGURE 4.4-15

BOREHOLE INFORMATION FOR THE VICINITY OF THE WI

TABLE 4.1-1

HOLE NO.	T/R/S	COLLAR ELEVATION	SALADO ELEVATION	BASE 124 ELEVATION	TOTAL DEPTH
I 123	21/30/34	3170	2182	1382	1880
W-7	21/31/31	3313	2743	2046	N/A
FC-63	21/31/32	3419	2719	1997	1483
FC-68	21/31/32	3430	2610	1881	1644
F-52	21/31/34	3485	2626	1970	1623
FC-65	21/31/34	3465	2645	1854	1669
FC-69	21/31/34	3461	2632	1987	1562
ERDA-6	21/31/35	3536	2721	1999	2776
AEC-7	21/32/31	3662	2664	1874	3918
C-1	22/30/1	3357	2727	1954	13950
D 96	22/30/3	3189	2609	2133	1210
V 166	22/30/3	3170	2660	2108	1173
D-82	22/30/10	3149	2669	2102	1135
D 121	22/30/11	3202	2642	2045	1266
J-A	22/30/11	3191	2673	2014	14923
J E	22/30/11	3220	2626	1991	13950
D-120	22/30/13	3338	2654	1930	1500
D-48	22/30/14	3337	2627	1937	1524
D-202	22/30/23	3323	2703	1981	1443
D-104	22/30/24	3388	2679	1883	1596
P-12	22/30/24	3376	2627	1867	1598
P-14	22/30/24	3358	2671	1939	1545
D-203	22/30/26	3317	2647	1965	1443
D 181	22/30/27	3298	2748	2039	1345
D 198	22/30/27	3258	2748	2069	1302
D-229	22/30/27	3218	2825	2068	1268
D-232	22/30/27	3258	N/A	2063	1221
D 36	22/30/34	N/A	N/A	N/A	N/A
D-180	22/30/34	3210	2790	2083	1230
D 188	22/30/34	N/A	N/A	N/A	N/A
D-230	22/30/34	3231	2821	2067	1195
JR-1	22/30/36	3308	2802	2037	17655
D-160	22/30/36	N/A	N/A	N/A	N/A
F-81	22/31/3	3471	2851	1797	1735
F-2	22/31/5	3404	2629	1818	1690
CM-1	22/31/6	3376	2668	1961	14050
V 134	22/31/6	3363	2622	1898	1563
F-70	22/31/7	3388	2490	1867	1603
F-82	22/31/8	3382	2472	1781	1684
F 92	22/31/8	3420	2470	1688	1818
F-1	22/31/9	3422	2482	1781	1747
F-91	22/31/10	3460	2390	1755	1788
AEC-8	22/31/11	3542	2548	1801	4910
P 20	22/31/14	3553	2450	1662	1995
P-21	22/31/15	3510	2467	1705	1915
P-5	22/31/17	3472	2525	1767	1830
P-13	22/31/18	3345	2624	1874	1576
D-207	22/31/19	3406	2595	1886	1613
ERDA-9	22/31/20	3415	2555	1765	2890
I-378	22/31/20	3410	2570	1819	1702
P-3	22/31/20	3382	2596	1803	1676
I 377	22/31/22	3490	2478	1720	1878
I-456	22/31/22	3520	2451	1667	1975
P-11	22/31/23	3506	2448	1673	1940
P 19	22/31/23	3546	2429	1679	2000
WRT-1	22/31/23	3595	2406	1596	4766
P-10	22/31/26	3508	2422	1670	2009
P 18	22/31/26	3479	2391	1590	1993
I-457	22/31/27	3460	2480	1683	1885
P-2	22/31/28	3478	2470	1683	1895
P-4	22/31/29				
P-1	22/31/29				
P-6	22/31/30				
I-374	22/31/30				
P-15	22/31/31				
P-9	22/31/33				
I 375	22/31/33				
D-123	22/31/34				
G-1	22/31/34				
JEN-1	22/32/18				
BAS-1	22/32/19				
FED-1	22/32/31				
B-1	23/30/1				
I 383	23/30/1				
JR-3	23/30/1				
D-1	23/30/2				
D-31	23/30/2				
D-179	23/30/2				
D-176	23/30/3				
D 177	23/30/3				
D 197	23/30/3				
D-227	23/30/3				
D-18	23/30/10				
I 278	23/30/10				
I-373A	23/30/10				
I-411	23/30/10				
I-443	23/30/11				
I-445	23/30/12				
D-TS5	23/30/13				
PP-19	23/30/13				
I-370	23/30/13				
I-446	23/30/				
I-447	23/				
I-453	23/				
I-385	23/30/				
I-442	23/30/14				
I-444	23/30/14				
I-454	23/30/14				
O 19	23/30/15				
I-440	23/30/15				
AA 2	23/31/2				
I-459	23/31/3				
I-458	23/31/4				
P-8	23/31/4				
P 17	23/31/4				
P-7	23/31/5				
P 16	23/31/5				
CB-1	23/31/5				
JR-7	23/31/6				
I 384	23/31/7				
I-449	23/31/7				
PP-7	23/31/11				
PP-8	23/31/14				
PP-17	23/31/15				
PP 20	23/31/15				
I-369	23/31/18				
I-448	23/31/10				
I-450	23/31/18				
FED-5	23/32/7				

P—ERDA POTASH HOLE
V—U.S. POTASH CO. (MISSISSIPPI POTASH)
D DTS DUVAL CORP.
I-INTERNATIONAL MINERALS
PP-PERMIAN POTASH
F—FC -KERR McGEE
N/A—NOT AVAILABLE

: INFORMATION FOR THE VICINITY OF THE WIPP SITE

TABLE 4.1-1

4 ON	TOTAL DEPTH	HOLE NO.	T/R/S	COLLAR ELEVATION	SALADO ELEVATION	BASE 124 ELEVATION	TOTAL DEPTH
	1680	P-4	22/31/28	3441	2511	1688	1857
	N/A	P-1	22/31/29	3446	2668	1859	1531
	1483	P-6	22/31/30	3554	2695	1892	1573
	1644	H-374	22/31/30	3340	2735	1931	1538
	1623	P-15	22/31/31	3310	2768	1957	1466
	1669	P-9	22/31/33	3408	2528	1714	1796
	1562	H 375	22/31/33	3390	2600	1788	1746
	2775	D 123	22/31/34	3432	2444	1644	1880
	3918	G 1	22/31/34	3450	2495	1708	4475
	13950	JEN-1	22/32/18	3896	2471	1664	4896
	1210	B-S-1	22/32/19	3820	2378	1578	4802
	1173	FED-1	22/32/31	3827	2294	1447	4777
	1135	B-1	23/30/1	3280	2625	2115	14312
	1266	H-383	23/30/1	3272	2832	2061	1307
	14923	JR-3	23/30/1	3288	2806	2047	15692
	13950	D 1	23/30/2	3241	2809	2032	1310
	1500	D-31	23/30/2	3244	2812	2038	1314
	1524	D-179	23/30/2	3244	2784	1987	1350
	1443	D 178	23/30/3	3197	2782	2078	1223
	1596	D 177	23/30/3	3161	2741	2088	1188
	1598	D 197	23/30/3	3161	2731	2110	1136
	1545	D 227	23/30/3	3246	2818	N/A	1573
	1443	D 18	23/30/10	3190	2808	2040	1265
	1345	H 278	23/30/10	3120	2780	2035	1217
	1302	H 373A	23/30/10	3140	2765	2036	1242
	1286	H-411	23/30/10	3128	2753	2041	1208
	1221	H-443	23/30/11	3185	2770	2028	1270
	N/A	H-445	23/30/12	3235	2785	1988	1387
	1230	D-TSS	23/30/13	3210	2685	1848	1496
	N/A	PP-19	23/30/13	N/A	N/A	N/A	N/A
	1196	H 370	23/30/13	3220	2740	1988	1341
	17555	H-446	23/30/13	3210	2730	1978	1345
	N/A	H-447	23/30/13	3250	2741	1991	1480
	1735	H-453	23/30/13	3240	2730	1963	1405
	1690	H-385	23/30/14	3185	2770	2045	1236
	14050	H-442	23/30/14	3170	2755	2007	1275
	1583	H-444	23/30/14	3130	2745	2003	1240
	1603	H-454	23/30/14	3170	2735	2000	1300
	1684	D 19	23/30/15	3149	2727	1957	1369
	1818	H-440	23/30/15	N/A	N/A	N/A	N/A
	1747	AA 2	23/31/2	3453	2383	1583	5190
	1788	H-459	23/31/3	3418	2482	1679	1855
	4910	H-458	23/31/4	3385	2549	1762	1750
	1995	P-8	23/31/4	3336	2621	1791	1660
	1915	P-17	23/31/4	3340	2625	1805	1660
	1630	P-7	23/31/5	3332	2702	1873	1575
	1576	P-16	23/31/5	3323	2677	1853	1795
	1813	CB 1	23/31/5	3320	2672	1845	4150
	2890	JR-7	23/31/6	3319	2713	1920	14590
	1702	H 384	23/31/7	3290	2790	1964	1438
	1676	H-449	23/31/7	3310	2680	1906	1515
	1876	PP 7	23/31/11	3485	2375	1593	2033
	1975	PP 8	23/31/14	3486	2405	1594	2079
	1940	PP 17	23/31/15	3418	2488	1689	1920
	2000	PP 20	23/31/15	3429	2469	1660	1910
	4766	H 369	23/31/18	3280	2715	1871	1938
	2009	H-448	23/31/18	3280	2625	1900	1510
	1993	H-450	23/31/18	3300	2690	1854	1570
	1885	FED-5	23/32/7	3439	N/A	N/A	4712
	1895						

REFERENCE

Adopted from Griswold, 1977

GCR CHAPTER 5
SEISMOLOGY

5.1 INTRODUCTION

The study of the Los Medanos site region's seismicity is of interest for two reasons. First, it forms the primary basis for the analysis and selection of reasonably expected vibratory ground motion for use in aseismic design; second, when considered along with the geology and tectonic history of the region, it provides some indication of current and long-term tectonic stability. In this chapter both aspects of the regional seismicity are discussed.

In Section 5.2 the temporal and geographic distribution of observed earthquakes in the site region are discussed. The regional seismicity is considered in two separate time intervals suggested by the type and quality of information available during each interval. These intervals are: before 1962, and from 1962 to the present. In the post-1962 period, several specialized instrumental studies are considered in addition to a more general regional instrumental survey.

Using the information developed on regional seismicity, and some additional simple assumptions about regional tectonism, a preliminary analysis of probabilistic vibratory ground motion at the ground surface is derived in Section 5.3 in a way that is useful for seismic design characterization at the site during its active phase of development and use. This analysis shows that short-term accelerations during the operational phase are likely to be very modest. Probabilities at which higher acceleration levels occur depend almost exclusively on the assumptions made about the seismic capabilities of the immediate site area.

Finally, in Section 5.4, regional seismicity is considered as an indicator of long-term tectonic processes. Regional stress patterns, as implied by focal mechanism solutions for regional earthquakes and in-situ stress measurements, and regional tectonism, as implied by earthqua

recurrence statistics, are both considered. Several tentative conclusions are reached as a result of this study and are outlined at the conclusion of this chapter.

5.2 SEISMICITY

In this section the temporal and geographic distribution characteristics of observed earthquakes in the site region are discussed. Detailed discussion is restricted to earthquakes within 300 kilometers (about 186 miles) of the Los Medanos site in view of historical analysis by Sanford and Toppozada (1974).

As always, in studying any single earthquake or group of earthquakes, it is important to note the date of occurrence in relation to the state of the art of seismology at the time. The certainty with which fundamental properties of earthquakes, such as size and location, can be determined largely depends on the availability and quality of instrumental data. Prior to 1960, nearly all information on the strengths and distribution of earthquakes in New Mexico was determined without the aid of instruments (Sanford, 1965). Therefore, inferences which may be drawn from pre-1960 seismicity studies are fundamentally different and more speculative than instrumentally derived parameters.

Instrumental studies of earthquakes in New Mexico began in June 1960 when high magnification seismographs were placed in operation by the New Mexico Institute of Mines and Technology at Socorro, and by the Atomic Energy Commission at Sandia Base near Albuquerque (Sanford et al., 1972). Those two stations provided some information on locations and strengths of earthquakes in central New Mexico, but accurate information about locations throughout the state was not available until the beginning of 1962, when additional high-gain stations went into operation in New Mexico and bordering states (Las Cruces, N.M.; Payson, Arizona; Ft. Sill, Oklahoma). Also at this time the United States Coast and Geodetic Survey (U.S.C.G.S.) established a regular reporting station at Albuquerque. Instrumental seismology for the state of New Mexico as a whole dates from this time.

In this discussion the format of a previous study by Sanford and Toppozada (1974) is followed. Regional seismicity of the Los Medanos site area is considered in two distinct time frames in accordance with the types of data available. Preinstrumental data, roughly that before 1962 in the site area, is treated first; a separate study of the later period for which seismograph records exist follows in several separate subsections.

Two very recent investigations of seismicity on a much more local scale affect the Los Medanos site. One involves recordings made on a continuously operating, vertical component, high frequency system installed and operated at the site itself by personnel from the New Mexico Institute of Mining and Technology at Socorro. The principal objective of this station, which has gathered data for most of the interval April 5, 1974, to October 29, 1977, and which continues to function, has been to determine if seismic activity is occurring at or near the proposed nuclear waste repository at such a low level that it might not be adequately detected by more standard instrumental data surveys (Sanford et al., 1976a). The other recent study is one designed to investigate in detail local small magnitude seismicity in and near the Central Basin Platform of west Texas. To this end, a seismic array centered near Kermit, Texas, has been installed. Initial operation of this array began in early November 1975, and some preliminary conclusions have been reached at this time (Hays, 1977; Rogers and Malkiel, 1978). Both of these recent study efforts will be discussed in separate subsections of this report.

In a final subsection, two small earthquakes important to the question of background seismicity level in the immediate site area are discussed.

5.2.1 Preinstrumental Data - Regional

Most historic earthquakes in New Mexico cataloged before seismic instrumentation occur in the Rio Grande Valley area between Albuquerque and Socorro. About half the earthquakes of Modified Mercalli Intensity V

or greater in New Mexico between 1868 and 1973 are in this region. In conformity with previous studies (Sanford and Toppozada, 1974; Sanford et al., 1978) these events are not considered to be of immediate concern for this study and will not be discussed further. As will be seen, the area within roughly 200 kilometers of the site has experienced only low intensity earthquakes prior to the first availability of seismographic data in 1961; there have been a few modestly damaging earthquakes during the same interval between 200 and 300 kilometers from the site. The area up to 300 kilometers from the site is defined as the site region in the following discussions.

Figure 5.2-1 shows locations of earthquakes occurring before 1961 that have been assigned epicenters within 300 kilometers of the site. Table 5.2-1 lists the events shown on Figure 5.2-1. Intensities appearing in this table, and anywhere in this section, are Modified Mercalli intensities (Wood and Neumann, 1931).

The primary source used was Sanford and Toppozada (1974), although some supplemental descriptive material was obtained from Neumann and Bodle (1932), Neumann (1932, 1938, and 1940), Murphy and Ulrich (1951), Murphy and Cloud (1954 and 1957), Northrop and Sanford (1972), and Coffman and Von Hake (1973). An abridged version of the Modified Mercalli Intensity Scale of 1931 may be found in Table 5.2-2. In the descriptions below, intensities in parentheses were assigned by Sanford and Toppozada (1974) based only on their personal evaluation of the data.

1923, Mar. 7 El Paso, Texas V Felt in Sierra Blanca (166 kilometers to SE), Columbus (130 kilometers to W), Alamogordo (135 kilometers to N). Newspaper accounts suggest epicenter in northern Chihuahua. (Sanford and Toppozada, 1974).

1926, July 17 Hope and Lake Arthur, N.M. III Earth sounds heard in NE direction at Hope; windows rattled at Lake Arthur. (Sanford and Toppozada, 1974).

1930, Oct. 4 Duran, N.M. IV A moderate shock felt by many. Rolling motion, rumbling sound, rattled windows. No damage. (Neumann and Bodle, 1932).

1931, Aug. 16 Valentine, Texas VIII At Valentine, the point of maximum destruction, all types of buildings, especially adobe, were heavily damaged; many chimneys fell. There were some cracks in the ground, and tombstones rotated both clockwise and counterclockwise. While people were panic-stricken, there were no fatalities and only a few minor casualties. There were cracked walls and damaged chimneys in several towns in Brewster, Jeff Davis, Culberson, and Presidio Counties. Some rockslides occurred in the mountains. There were rumbling and roaring sounds. This earthquake would have been severe in a densely populated region. (Coffman and Von Hake, 1973).

1931, Aug. 16 Valentine, Texas (V) Strong aftershock of intensity VIII event.

1931 Aug. 18 West Texas V at Alpine, Pecos, Lobo, and Valentine; IV at Carlsbad, N. Mex. This was preceded by a lighter shock on the same day. Recorded at Tucson. (Neumann, 1932).

1931, Aug. 19 Valentine, Texas (V) Strong aftershock of intensity VIII event.

1931, Oct. 2 El Paso, Texas III "To-day", El Paso, Texas. Feeble. (Neumann, 1932).

1931, Nov. 3 Valentine, Texas (V) West Texas. Felt at Valentine. Aftershock of August 16 earthquake. Recorded at Tucson.

1935, Dec. 20 Clovis, New Mexico III-V Two Shocks. A tile wall in a creamery was cracked. Another report of wall paper being split (AP news item). (Northrop and Sanford, 1972).

1936, Jan. 8 Carlsbad, N.M.? (IV) Felt by few; press reports some property damage (Neumann, 1938). Newspaper account indicates this earthquake was probably centered near Ruidoso, N.M. (Sanford and Toppozada, 1974).

1936, Aug. 8 El Paso, Texas (III) Weak shock not felt elsewhere (Neumann, 1938).

1936, Oct. 15 El Paso, Texas (III) "Earth tremor" shortly before noon. No details. (Neumann, 1938).

1937, Mar. 31 El Paso, Texas (V) Slight. Felt by many. (Neumann, 1940).

1937, Sept. 30 Ft. Stanton, N.M. V Slight. Awakened many. (Neumann, 1940).

1943, Dec. 27 Tularosa, N.M. IV Rattled windows. (Sanford and Toppozada, 1974).

1949, Feb. 2 Carlsbad, N.M. IV Press reported two distinct shocks which were felt by several. A few people were frightened. Windows, doors, and dishes rattled; houses seemed to shudder momentarily. (Murphy and Ulrich, 1951).

1949, May 23 East Vaughn, N.M. VI Felt over an area of only about 1300 square miles. "Results of a questionnaire coverage indicated the felt area to be a 20-mile strip connecting Pastura with Vaughn and East Vaughn. Maximum intensity VI at the last named place where a few things fell from shelves, loose objects rattled and buildings creaked. Deep rumbling and grinding sounds were heard before and during shock" (Murphy and Ulrich, 1951). Many people were awakened and many were frightened. One person felt the shock while driving a car 20 miles southeast of Vaughn on the highway to Roswell. (Northrup and Sanford, 1972).

1952, May 22 Dog Canyon, New Mexico (about 70 miles northwest of Carlsbad). IV Felt by two in ranch house. Windows, doors, and dishes rattled; house creaked. (Murphy and Cloud, 1954).

1955, Jan 27 Valentine, Texas IV Felt by many. Houses shook (Murphy and Cloud, 1957).

As can be seen from the above data, there have been no earthquakes of epicentral intensity V or greater recorded as occurring within about 200 kilometers of the Los Medanos site when noninstrumental data alone is considered. The strongest earthquake reported to occur within 300 kilometers of the site was the Valentine, Texas event of August 16, 1931. The reported maximum intensity for this shock was VIII on the Modified Mercalli scale (Table 5.2-2). Reports of earthquake intensity for a wide area have been compiled into several isoseismal maps (Neumann, 1932; Sellards, 1933). Intensities in these maps are based on the Rossi-Forel scale which was subsequently abandoned for the Modified Mercalli Scale of 1931. Sanford and Toppozada (1974) have assigned Modified Mercalli intensities on the basis of descriptions of the earthquake effects for this event and plotted the isoseismal map shown in Figure 5.2-2. According to this map the intensity at the site was probably no greater than V. This is the largest known historical site intensity.

Close to the source, the isoseismals are elongated northwest-southeast conforming to the structural grain of the region. Further from the epicenter, the earthquake had higher intensities to the east than west due to lower topographic relief to the east (Sanford and Toppozada, 1974), differences in attenuation, or some other reason. The data to the southwest, in Mexico, are particularly sparse.

Two instrumental locations have been published for this earthquake. The U.S.C.G.S. (Neumann, 1932) places the epicenter at 29.9°N and 104.2°W with an origin time of 11:40:15 GMT. Byerly (1934), who made a detailed instrumental investigation of this earthquake, found the epicenter to be

at 30.9°N and 104.2°W with an origin time of 11:40:21 GMT. Byerly's epicenter, 110 kilometers north of the U.S.C.G.S. epicenter is closer to the region of highest reported intensities and may for this reason be considered the more accurate of the two. Although neither is particularly close to Valentine, Texas, the USCGS and Byerly epicenters bracket this area of max reported intensity fairly well. For the purposes of Figure 5.2-1 and Table 5.2-1, Valentine, Texas, has been adopted for the location of the main earthquake and its aftershocks in agreement with the work of Sanford and Toppozada (1974).

The area over which an earthquake is perceptible can be used to estimate its magnitude (Slemmons et al., 1965; Wiegel, 1970), although this relationship is an empirical one different for different regions of the United States. If a felt area of 4.5×10^5 mi^2 is accepted (1.15×10^6 km^2) as reported by the U.S.C.G.S. (Neumann, 1932) and a magnitude-felt area formula for the central United States and Rocky Mountain region is used (Wiegel, 1970), a magnitude of about 6.4 is calculated for the Valentine, Texas, earthquake. This result appears reasonable and is compatible with the maximum intensity reported for the shock (Sanford and Toppozada, 1974). It is also in good agreement with the estimate of magnitude for this event calculated at Pasadena (Gutenberg and Richter, 1954).

Other earthquakes within 300 kilometers of the site were probably not perceptible or resulted in low intensities in the site area.

5.2.2 Instrumental Data--Regional

As mentioned above instrumental studies of earthquakes in New Mexico began in June 1960 when high-magnification seismographs were placed in operation on the campus of the New Mexico Institute of Mining and Technology at Socorro and by the Atomic Energy Commission at Sandia Base near Albuquerque (Sanford et al., 1972). Most of the early seismic research at Socorro was concentrated on near shocks (Sanford and Holmes, 1961, 1962; Sanford, 1963) because of this initial station distribution

and because information from other stations located in New Mexico and adjacent states was not available in sufficient quantity for a study of the seismicity of the entire state. This situation changed about the beginning of 1962 when stations at Albuquerque and Las Cruces, New Mexico; Payson, Arizona; and Ft. Sill, Oklahoma; began continuous operation.

Detailed reports on the instrumental seismicity of New Mexico as a whole have appeared in a number of publications, principally Sanford (1965), Sanford and Cash (1969), and Toppozada and Sanford (1972). Collectively, these papers cover the interval January 1, 1962, through June 30, 1971. The study of instrumental seismicity in this area, as in any other, evolved over this 11 year period. Not only did more data become available as more seismograph stations began operation, but these data were processed in increasingly sophisticated ways. The ways regional earthquakes have been located and analyzed during this period are summarized below. For a more complete discussion, the reader is referred to the original reports; both those mentioned above and Sanford et al. (1972), Sanford and Toppozada (1974), Sanford (1976a), Sanford (1976b), and Sanford et al. (1976b).

The method used to initially locate the earthquakes during the period January 1, 1962, through June 30, 1964 (Sanford, 1965) was based on the procedure described by Richter (1958). This is an arc intersection procedure where: 1) a trial origin time is estimated from measured S-P intervals, 2) a depth is selected, either 5 kilometers or 10 kilometers, 3) station-epicenter distance is calculated from the P-O (origin time) intervals and a T-D curve (in this instance a graph relating travel time to distance for each of the two depths of focus) and 4) the epicenter is determined from the intersection of the arcs whose radii have just been calculated in step 3) above. If no satisfactory intersection occurs, the process is repeated after adjustment of the origin time estimate. The time-distance curves used by Sanford (1965) in this process were based on a simple crustal model close to the average of those found for the region in previous studies (Tatel and Tuve, 1955; Stewart and Pakiser, 1962;

Romney et al., 1962). The crustal model adopted consisted of a single 39 kilometers thick layer with a P-wave velocity of 6.0 km/sec overlying a half-space with a P-wave velocity of 8.0 km/sec. The two T-D curves, one for a depth of focus of 5 kilometers and one for a 10 kilometers focal depth, were calculated using this model.

For earthquakes occurring between July 1, 1964, and December 31, 1967, a slightly different format was used to present the data (Sanford and Cash, 1969'. Whenever available, origin times and epicentral coordinates were taken directly from U.S.C.G.S. reports. Two types of data distributed by the U.S.C.G.S. were consulted; the Monthly Summary series, or where these were not yet published, as for the period October 1966 through December 1967, the Preliminary Determination of Epicenters reports. A majority of the New Mexico earthquakes listed in this period were not located by the U.S.C.G.S., however. When this was the case, events were located precisely as outlined above for the earthquakes of January 1962 through June 1964.

Finally, for initial location of those shocks occurring from January 1968 to June 1971, inclusive, the procedure adopted was identical to that of the previous reporting period except that for those earthquakes located by the New Mexico Institute of Mining and Technology a focal depth of 8 kilometers was used to construct the T-D curves (Toppozada and Sanford, 1972).

The method of assigning magnitudes to the earthquakes of New Mexico has also undergone some evolution. From the start the idea has been to calculate a close analog to the Richter local magnitude (M_L). Magnitude can be expressed by the equation $M_L = \log A - \log A_o$, where A is the maximum trace amplitude (almost always the crustal shear wave, Sg, for local and regional New Mexico earthquakes, Sanford, personal communication, 1978) in millimeters on the seismogram and A_o is the corresponding trace amplitude for a calibration earthquake selected as the standard. The numbers obtained for M_L are dependent on the magnification and frequency response of the seismograph used, and on the

selection of the standard shock. The original Richter scale is based on the Wood-Anderson seismograph, an instrument which records horizontal motion, whose natural period is 0.8 second, and whose static magnification and damping are 2800 and 0.8 critical, respectively. Furthermore, the standard or zero magnitude event is defined such that it would produce a trace deflection of one thousandth of a millimeter when recorded by a Wood-Anderson seismograph at a distance of 100 kilometers.

The direct application of the Richter scale to New Mexico earthquakes was impossible, because none of the available data came from Wood-Anderson seismographs. As an initial best estimate, Sanford (1965) decided to rate the shocks on the basis of the amplitude a Wood-Anderson instrument would produce had it recorded these shocks; that is, maximum trace deflections were first converted to ground displacements, which in turn, were converted to equivalent Wood-Anderson trace amplitudes using the known response characteristics of this instrument. An attempt was made to consider response differences between the actual recording seismograph and the Wood-Anderson seismograph as a function of frequency. The Richter values for A_o were adopted with no attempt to consider possible source or wave transmission differences between those earthquakes occurring in California, where the Richter Scale was developed, and those occurring in New Mexico. Most of the magnitudes were calculated from the maximum SH (or horizontally polarized shear wave) ground motions reported by the station at Las Cruces. When no SH amplitude information was available from the Las Cruces station, magnitude was assigned on the basis of the maximum SV ground motion at Albuquerque. The relation between SV (or vertically polarized shear wave) motion at Albuquerque and magnitude was established from data on shocks detected by both the Las Cruces and Albuquerque stations (Sanford, 1965). This initial attempt to assign magnitudes to New Mexico earthquakes was never intended to be completely accurate but rather to serve as rough indications of the relative strengths of shocks.

Slightly different procedures were followed for magnitudes calculated for the two later reporting periods of July 1964 to December 1967 and January 1968 to June 1971. In these periods three magnitudes are listed: 1) U.S.C.G.S., 2) Albuquerque, and 3) Socorro. Magnitudes assigned by the U.S.C.G.S. (or its later administrative equivalents, such as the National Oceanic and Atmospheric Administration) are body wave magnitudes (m_b) based on the maximum amplitude of the initial P phase. Magnitudes calculated from Albuquerque and Socorro seismograms are based on the amplitudes of the S phases as noted above. For Albuquerque, the maximum SH ground motion was converted to an equivalent Wood-Anderson trace amplitude and the previous procedure was used to obtain an estimate of the equivalent Richter magnitude. A similar procedure was used for Socorro magnitudes, except that for these computations it was necessary to substitute maximum SV motion for maximum SH motion. Checks at the Socorro station indicate SH averages about 1.5 times as large as SV. This correction factor was included in the Socorro magnitudes computations.

Since the initial publication of the 1962-1972 instrumental data (Sanford, 1965; Sanford and Cash, 1969; Toppozada and Sanford, 1972) several additional studies have been undertaken to partially rework this data. Two of these, Sanford and Toppozada (1974) and Sanford et al. (1978), are of particular interest since they deal almost exclusively with earthquakes within 300 kilometers of the Los Medanos site. Sanford and Toppozada (1974) list a total of 34 earthquakes in this area. Of these, 12 appeared in the previously discussed studies, 13 represented new locations by the New Mexico Institute of Mining and Technology not previously published, and the remaining events were taken directly from U.S. Department of Commerce reports, either the Seismological Bulletin or Earthquake Data Reports. An updated version of this listing is presented in Sanford et al (1978). In this update four shocks have been added to the Sanford and Toppozada (1974) tabulation: February 11, 1964; March 3, 1964; October 20, 1964; July 26, 1972. The last of these is most noteworthy because of its proximity to the site. This event will be considered in greater detail in a later subsection. The October 20, 1964

earthquake is included here in conformity with Sanford et al (1978) even though this event apparently falls slightly beyond the 300 kilometers circle specified as the region of interest.

The most significant difference between the 1978 and all previous tabulations is in the magnitudes assigned to the individual earthquakes. The shocks listed in Sanford et al. (1978) have local magnitudes (M_L) substantially lower than those published earlier by the New Mexico Institute of Mining and Technology or the U.S.C.G.S. These revised magnitudes came about because in calculating local magnitudes for single earthquakes, it was noticed that a systematic increase in calculated magnitude occurred with increasing distance from the earthquake. This strongly suggested that more efficient transmission of the phase producing maximum trace amplitude was occurring in New Mexico than would be indicated by an uncritical use of the A_o standard earthquake amplitude attenuation factor of Richter (1958). Therefore, a correction factor for attenuation differences, as well as another correction factor for individual station effects, has been incorporated in the latest magnitude calculations.

Listed in Table 5.2-3 and shown in Figure 5.2-1 are the 38 earthquakes as they appear in Sanford et al. (1978). These data represent the latest and best estimate of all significant parameters associated with those earthquakes occurring within 300 kilometers of the Los Medanos site for the interval January 1, 1961, through December 31, 1972.

5.2.3 Specialized Instrumental Studies--Station CLN

With the publication of Sanford and Toppozada (1974), the first phase of the investigation of southeastern New Mexico seismicity ended. This early phase was concerned with the estimation of seismicity in the Los Medanos area based on careful evaluation of available geologic and seismic data. In early 1974 the emphasis changed. Since at that time no data were available from a station very near the site area itself, it was decided that acquisition of new instrumental data from such a station

would be of immediate value. With the installation of a high-gain seismograph in the site area, the question of the occurrence of low level seismic activity at or near the proposed waste repository could be more meaningfully addressed. Therefore, at the beginning of April, 1974, a single component (vertical) high-gain, continuously recording seismograph station (given the letter designation CLN by the U.S. Geological Survey) was installed in a shack located in a caliche pit very near the proposed nuclear waste disposal site. Analysis and interpretation of the data collected by this station may be found in Sanford et al (1976a), Caravella and Sanford (1977) and Sanford et al (1978). In this section the findings presented in these publications will be briefly discussed.

The essential elements of station CLN are a short-period, vertical seismometer (Earth Sciences Ranger SD 211), an amplifier (Astrodata 120), a film recorder (Earth Sciences RF 220), and a WWVB radio receiver (Specific Products--T60). The recording rate is 1 mm/sec, a speed that can produce high-resolution seismograms of small local and regional earthquakes. At this recording rate, the seismograph requires a film change every three weeks. Otherwise, the station is self-sufficient. Five minutes of the WWVB coded time signal is placed on the record every two hours to assure excellent time control. The ground displacement response of the seismograph has varied slightly over its operating lifetime as the free period and percent critical damping of the seismometer changed. These changes are summarized in Sanford et al. (1978). However, the magnification response of the system has remained essentially constant within the frequency range 4 to 30 Hz. The peak magnification is near 455 thousand times when a factor of 12 for record enlargement during photographic processing is included. This peak occurs near 22 Hz.

For most of the time since the station went into operation on April 5, 1974, the seismograph has performed as expected, except for the changes in response characteristics already mentioned. However, there were times when no records were obtained and when the station was without time signals. Table 5.2-4 lists these periods and the reasons for the breaks

in service. From April 5, 1974, to October 29, 1977, the total reporting period considered in this subsection, the station was in operation 83 percent of the time.

During the April 1974 to October 1977 period, 291 events identifiable as local and regional earthquakes (Sg - Pg $\leq$ 81 seconds, where Sg and Pg are the crustal shear-wave and compressional-wave arrival times) were recorded at station CLN. For a complete list of these events see Sanford et al. (1978, Table 3). For each earthquake the date, arrival time (GMT), and character, whether impulsive or of several phases, are given. The Sg phase amplitudes (from which magnitudes are determined) are also listed. With the aid of additional arrival times from other regional seismograph stations, epicenters for 75 of these 291 events were obtained. This group of 75 events may be further subdivided into those which are fairly well located (49) and those for which only tentative epicentral locations may be given (26). Table 5.2-5 lists the origin times, locations, and magnitudes (and seismograph stations used) for the seismic events whose epicenters are reasonably well known. A map of these epicenters is shown in Figure 5.2-3. Table 5.2-6 lists the remaining events for which there are insufficient data to allow exact locations. For many earthquakes in Table 5.2-6 two epicenters are possible because readings are presently available from only two stations. In this case, the epicenter is listed that is most compatible with the locations of the well-determined events.

Figure 5.2-4 shows histograms of the number of recorded earthquakes versus the Sg-Pg interval in seconds. The upper histogram represents the complete data set at station CLN for all those events whose Sg-Pg interval is less than or equal to 40 seconds. Major peaks in the histogram occur at Sg-Pg intervals of 8 to 13 seconds, 22 to 24 seconds, and 31 to 36 seconds. The middle histogram shows those events in the CLN data set which occurred during local day-time hours (12:00-02:00 GMT), and the bottom histogram those during the local nighttime hours (02:00-12:00 GMT). The similarity in shape of the middle and bottom histograms suggest that explosions from any small number of specific

sources have been largely eliminated from the data set. However, the disproportionate number of events during the day-time hours (7.62 X 10^{-3}/hour) compared to the nighttime hours (5.14 X 10^{-3}/hour) does not rule out the possibility that some cultural sources still exist in the data set.

Because a substantial fraction of the shocks within each of the prominent peaks of the histogram in Figure 5.2-4 are located, speculation on the epicenters for the other shocks is possible. All of the located shocks within the Sg-Pg distance range of 8 to 13 seconds have epicenters within the area from 31.7° to 32.3°N and from 102.8° to 103.2°W. These coordinates bracket a section of the Central Basin Platform centered roughly on the southeastern corner of New Mexico. All of the evidence suggests that all shocks with Sg-Pg times from 8 to 13 seconds are generated within this section of the Center Basin Platform.

Nearly all of the located shocks with Sg-Pg intervals between 22 and 24 seconds have epicenters within the area from 31.5° to 31.85°N and from 102.2° to 102.8°W. The region defined by these coordinates is centered on a section of the Central Basin Platform located about 50 kilometers southeast of the southeastern corner of New Mexico. Most unlocated shocks with Sg-Pg intervals from 22 to 24 seconds are believed to originate from this section of the Central Basin Platform.

The known epicenters for shocks with Sg-Pg intervals from 31 to 36 seconds indicate a number of tectonically active regions are contributing to this peak in the histogram. Notable among these is a region centered on Valentine, Texas, the site of a strong earthquake in 1931 (Sanford and Toppozada, 1974), and much of the Tularosa Basin.

5.2.4 Specialized Instrumental Studies--Central Basin Platform

The first earthquake to be located in the Central Basin Platform from instrumental data occurred on February 3, 1965. This event attracted little attention at first although it was recorded at a number of

regional stations (Socorro, New Mexico; Lubbock, Texas; Ft. Sill, Oklahoma; Vernal, Utah; Las Cruces, New Mexico; El Paso, Texas; and Albuquerque, New Mexico) and was located by the New Mexico Institute of Mining and Technology (Sanford and Cash, 1969). It was not, for example, listed in the Preliminary Determination of Epicenters reports of the U.S.C.G.S.

To learn more about the seismicity of the Central Basin Platform in conjunction with their study of southeastern New Mexico earthquake risk, Sanford and Toppozada (1974) examined the total available record from station FOTX, a Long Range Seismic Measurements (LRSM) station near Ft. Stockton, Texas, in operation from June 21, 1964 to April 12, 1965. Apparently, this is the only high-magnification station (350-400 thousand times at 1 Hz) to have operated for any substantial period within 120 kilometers of the Central Basin Platform before installation of station CLN in 1974. FOTX was in operation at the time of the February 3, 1965 earthquake on the Central Basin Platform. Based on this examination a number of earthquakes believed to have originated in the Central Basin Platform were found including two occurring before the February 3, 1965 event. Prior to examination of the FOTX records these two events on November 8 and 21, 1964 were unknown. All events located by Sanford and Toppozada in the Central Basin Platform during the operation of FOTX - and based primarily on readings from this station - are listed in Table 5.2-7.

The studies by Sanford and Toppozada (1974) suggested earthquake activity on the Central Basin Platform at a level higher than expected, but were not conclusive because of the very small amount of instrumental data available close to this area. About all that could be said at that time was that eight significant earthquakes (see Table 5.2-8) had occurred near the Central Basin Platform between November 1964 and September 1971 ranging in magnitude (new revised estimates as discussed in Section 5.2.2) from 2.5 M_L to 3.2 M_L; that one of these events, August 14, 1966, had an associated maximum intensity of VI on the Modified Mercalli scale; and that a number of smaller earthquakes had apparently occurred

at about the same location during the operating lifetime of station FOTX. The basis for this latter supposition was that all of the measured Sg-Pg intervals on the FOTX seismograms yielded an epicentral distance corresponding to the distance between the FOTX station and the area of activity on the Central Basin Platform. In addition, for some of the stronger shocks, arrival times were available from the Las Cruces station (LCN). The difference between P arrival times at LCN and FOTX was the same (34.7 plus or minus 0.5 sec) for the unlocated shocks as for the located events in November 1964 and February 1965. Thus, it is reasonably certain that the Central Basin Platform has been seismically active since mid-1964. Since the activity rate was roughly the same at the end as at the beginning of the 10-month period for which FOTX records were available, it can be supposed that earthquakes also occurred before mid-1964. If such activity had occurred, it probably would not have been detected on the regional seismograph stations then in existence.

The instrumental coverage of this part of the country has improved markedly in the past several years. The first important improvement took place in the spring of 1974 when station CLN was installed by personnel of the New Mexico Institute of Mining and Technology. Data recorded by this station between April 1974 and the end of October 1977 has already been discussed in detail in subsection 5.2.3. However, it should be mentioned that of the 49 earthquakes recorded during this period by CLN and enough other regional stations to allow accurate location (Sanford et al., 1978), 24 of them occurred within the active parts of the Central Basin Platform. Of the 26 less well located earthquakes of Table 5.2-6 and Figure 5.2-3, 13 of them are thought to belong to the Central Basin Platform area. Thus, for the period of operation of station CLN through October 1977 (which represents the last records so far analyzed from this station) nearly half of the events located within 300 kilometers of the Los Medanos site have occurred within the Central Basin Platform

The most recent advancement in the instrumental coverage of the Central Basin Platform area took place with the initiation of operation of the

Kermit, Texas, seismic array in November 1975. The remainder of this subsection is concerned with discussions of the operation and preliminary findings of this array.

Based on the seismicity information developed by Sanford and Toppozada (1974) the Central Basin Platform was instrumented with an array of seismograph stations encompassing the largest historical events discussed above. The purpose of this array is to study, in some detail, the seismicity of this region which is of interest both because it is important to the evaluation of seismic risk at the Los Medanos site and because secondary petroleum recovery projects have been active in this area for a period roughly coincident with its known seismic activity. It is hoped that ultimately such a study will answer questions fundamental to an evaluation of the implications of Central Basin Platform earthquakes to the tectonism, not only of the platform, but of surrounding regions. Evaluation of the Kermit, Texas, array data has not yet progressed to this point, but some preliminary discussion is possible at this time. The treatment below is largely abstracted from Hays (1977) and Rogers and Malkiel (1978).

The Kermit seismic network currently consists of 10 self-contained radio telemetry systems placed in a grid pattern covering 2200 square kilometers. Each field station is equipped with a single component vertical seismometer and accompanying amplifier-transmitter equipment. The seismometers are Mark Products L-4C's with a natural period of one second and 67 percent critical damping. Typical magnifications range from 25 to 50K near 1 Hz increasing 6dB/octave to 10 Hz. A receiver station is centrally located at the Winkler County Airport at distances from individual stations ranging from 12 to 40 kilometers. The current locations of the 10 array stations are shown in Figure 5.2-5 taken from Rogers and Malkiel (1978). Those stations designated by a three symbol code followed by an "A" represent second locations for these instruments. The moves were usually made to diminish background noise levels or improve foundation conditions. The initial location of these stations may be found in Hays (1977). In general, the effect of unfavorable surface

geology and high cultural noise in this area has posed problems that have resulted in less than optimum station gain for a micro-earthquake study (Rogers and Malkiel, 1978).

Once the signals are placed on the phone lines, recording and timing take place at the National Earthquake Information Center (NEIC) in Golden, Colorado. Signals from the individual stations are put on film (in a 20 channel Develocorder microfilm recorder) and the highest quality station (KT?, see Figure 5.2-5) is simultaneously recorded on a Helicorder visible recorder to provide rapid identification of events of interest. Film recording speed is 3 cm/min and optical enlargement of 20 times permits resolution of plus or minus 0.01 seconds for impulsive arrivals. Direct recording of station WWV also insures correct absolute timing.

The average level of detection within the array is given as magnitude M_{LD}=2.0, where M_{LD} is a magnitude determined from the coda length as discussed in Lee and Lahr (1972). This represents a relatively low array sensitivity due to the surface geology and unfavorable operating environment as previously mentioned. Detection threshold for individual stations varies from a high of M_{LD} = 2.5 in oil fields with sandy surface conditions to a low of M_{LD} = 0.5 along the west edge of the array where low levels of pumping, and caliche "bedrock", allow higher gains to be used. In the discussion below, M_L will be used for M_{LD} wherever the Rogers and Malkiel (1978) data are referenced.

During the current reporting period (November 1975 through July 1977) 407 events have been detected of which 135 have been well enough recorded to be located. These earthquake locations were determined using the hypocenter location program HYPO71 (Lee and Lahr, 1972) and a four layer over a half-space crustal model developed by Stewart and Pakiser (1962) for eastern New Mexico.

Of the 135 located events, 56 occurred within the area of the array. these earthquakes are shown in Figure 5.2-6 and listed in Table 5.2-9. Of these 56 earthquakes, 22 have been located using the readings from only

three stations. This is inadequate to allow hypocentral depth to behave as an unknown in the normal location algorithm so that for all these events an assigned depth of 5 kilometers is used (denoted 5.00* in Table 5.2-9). For an additional 14 events, locations have been accomplished using only four stations. In this case the hypocenter may be fixed deterministically but no redundancy in possible locations exists to allow some estimate of the uncertainty in the formal location. Thus, of the 56 internal, and presumably best located, earthquakes of Table 5.2-9 only 20 are available with an estimate of both depth and hypocentral uncertainty, at least in a formal sense.

An interesting independent estimate of the accuracy with which events have been recently characterized in the Central Basin Platform is provided by a comparison of earthquakes common to both Tables 5.2-9 and 5.2-5. There are only four such events. The majority of those earthquakes appearing in both the Sanford et al. (1978) and Rogers and Malkiel (1978) "well located" data sets are somewhat peripheral to the Kermit array as will be seen below. The location and origin time agreement is very good; differences averaging 0.04 degree and 0.6 seconds respectively. Such modest differences can probably be easily explained by minor model differences and, in the case of the Sanford et al. (1978) data set, focal depth assumptions. However, estimates of local magnitude, M_L, differ significantly. The four events under consideration average over 0.9 magnitude units higher in the Rogers and Malkiel data set than that of Sanford et al. This point is worth keeping in mind.

Table 5.2-10 lists those earthquakes occurring on the periphery of the Kermit array with locations that use readings from at least five array stations. This does not necessarily imply that these events are well located. In fact, many are given a low location quality factor by Rogers and Malkiel (1978). Indeed, these authors do not plot the formal hypocentral positions for earthquakes occurring outside the boundaries of the array but instead outline zones in which these events apparently lie. These zones are meant only to be indicative of the general area where earthquakes appear to be occurring. Both the zone boundaries and formal locations are shown in Figure 5.2-6.

The events listed in Table 5.2-10 may be compared with those in Table 5.2-5 in a manner similar to that discussed above in connection with Table 5.2-9. Of the 51 earthquakes around the periphery of the Kermit, Texas, array as determined by array station readings, 15 also appear in Table 5.2-5. The average origin time difference is greater in this case, being 1.9 sec., and a larger epicenter location difference of 0.1 degree is also present. Again, the most interesting differences are in local magnitude, M_L. As before, the Kermit array data set shows magnitudes consistently higher (in this case 0.84 units higher) than the New Mexico Institute of Mining and Technology values as they appear in Sanford et al. (1978).

Solely to present consistent-looking plots, events listed in Tables 5.2-9 and 5.2-10 and shown in Figure 5.2-6 have been scaled to circumvent this magnitude disparity. That is, the symbol used for a particular earthquake epicenter of magnitude M_L in Figure 5.2-6 is the same as would have been used for a magnitude M_L-0.85 in previous epicenter plots.

All available data through mid-1977 for the Central Basin Platform have now been considered. It is clear that continuing effort in this area will improve the understanding of this seismicity. Before outlining the speculations that have been made based on information to date, it seems appropriate here to briefly summarize this seismicity in very general terms.

There is little doubt that the Central Basin Platform has been seismically active since at least mid-1964. Its activity before this time will likely remain speculative. There is no evidence of historical felt reports for events felt in this area similar to the epicentral intensity = VI earthquake of August 14, 1966, even though local histories and newspapers have now been searched specifically for any such reference (Sanford and Toppozada, 1974). Conclusions as to the lack of previous seismic activity on this basis, however, must be tempered somewhat by the knowledge that this part of western Texas has never had a large population.

Since the first instrumental detection of events in the Central Basin Platform region, the number of recorded earthquakes has been largely a function of the number and sophistication of the seismograph stations available to record them. With the startups of station CLN in 1974, and, more important, with the Kermit array, large numbers of small earthquakes are now being noted that previously would have completely escaped notice. It is now clear that, at least for the last several years and probably for the last decade, the Central Basin Platform has been the most seismically active area within 300 kilometers of the Los Medanos site in terms of number of events.

It is worthwhile here to put the Central Basin Platform activity into perspective. Even though some events near magnitude 0 are recorded (Rogers and Malkiel, 1978), fewer than ten detected events are reported for many months during the operation of the Kermit array. This rate is relatively low compared with the activity rates of some of the more active areas in the eastern U.S. such as Blue Mt. Lake, New York (Sbar et al., 1972), or southeastern Missouri (Stauder et al., 1976). The largest known earthquake to occur in the Central Basin Platform had, by the most recent estimate, a magnitude of less than 3-1/4. It is very difficult to believe that any event very much larger than this (say $M_L \geq 5$) could have escaped instrumental notice during the past 50 years or so. The Valentine, Texas, earthquake of 1931, to the south, for example, had an epicentral intensity of VIII on the Modified Mercalli Scale and was recorded worldwide (Byerly, 1934). The magnitude of this event has been estimated to be 6.4 based on the felt area (Sanford and Toppozada, 1974). The I_o=VI event of August 1966, where I_o is epicentral intensity, has recently been assigned a magnitude somewhat less than 3. In short, the Central Basin Platform has exhibited some activity since mid-1964, but this activity has been of small magnitude. There is no evidence to suggest that moderate or large magnitude events occurred before mid-1964. Within limits imposed by general regional and worldwide seismographic capabilities, there is no evidence to allow a determination of the small magnitude earthquake activity in this area before 1964.

In the remaining discussion, the causes and implications of the Central Basin Platform seismicity, as best these have been determined, are considered. This discussion is speculative since the definitive evidence critical to a unique view of either the causes or implications of these earthquakes does not yet exist. Figure 5.2-6 shows the 107 earthquakes of Tables 5.2-9 and 5.2-10, as well as the approximate boundaries of the Central Basin Platform and a series of pre-Permian faults inferred from drilling. These faults, which are all deeply buried, are taken from 1:9600 scale maps provided by Geomap Corporation to Rogers and Malkiel (1978). From a comparison of fault and epicenter locations it is clearly not possible to associate the earthquakes with known faulting although an alignment of epicenters in the southwest corner of the array appears to occur on a short fault segment. Other events or groups of events appear equally likely to occur in the vicinity of faults as not. In a very general sense, however, it appears that both the eastern and western boundaries are active (Rogers and Malkiel, 1978). The basic conclusion from all instrumental data is that seismic activity is equally likely to occur anywhere along the Central Basin Platform structure as asserted by Sanford et al. (1978) without particular regard to small scale structural details such as individual pre-Permian faults.

Attempts have also been made to relate Central Basin Platform seismicity to secondary oil recovery operations in the area. Both the spatial and temporal association of Central Basin Platform seismicity with secondary recovery projects at oilfields in the area are very suggestive of some cause and effect relationship.

Shurbet (1969) was the first to suggest that seismic activity on the Central Basin Platform is related to water injection for secondary recovery of oil. His suggestion was based on the clearly established association between earthquakes and waste injection into crystalline bedrock at the Rocky Mountain Arsenal near Denver (Healy et al., 1968). Subsequently, a direct association between earthquakes and fluid injection for secondary recovery of oil was established at the Rangely field in northwestern Colorado (Healy et al., 1972). As the fluid pressure builds

up during injection, the effective stress acrons pre-existing fractures diminishes with an associated decrease in frictional resistance to sliding.

There appears to be a correlation between the number of active waterflood projects and the first known occurrence of earthquakes in 1964. Although waterflood projects began in this area as early as 1944, the number of projects began to increase considerably in the mid-1960's and, on the average, injection pressures have also increased with time (Rogers and Malkiel, 1978). A study of the number of active secondary recovery projects versus time in this area shows a rapid increase in the early 1960's, a peak in 1968, and relative constancy since that time. The increase in secondary recovery activity occurs prior to, but in rough conjunction with, the first occurrence of earthquakes in the area. During the period of operation of the Kermit array, the largest earthquakes recorded have occurred in the vicinity of the Keystone unitized oil field. The Dollarhide unitized field, although outside the boundaries of the array, appears to be one of the most seismically active areas. Other areas of seismic activity occur, however, that are not within the major oil field boundaries, and major secondary recovery fields exist that apparently are not seismically active. Although the evidence is not conclusive, based on this seismicity pattern and the absence of recent geologic faulting within the Central Basin Platform it is believed that the best working hypothesis at this time is that earthquakes are associated with the release of low level residual stress by secondary recovery operations. It is neither proved nor precluded by a consideration of current best estimates of regional stress regime (Hays, 1977) as discussed in a later subsection.

5.2.5 The Events of July 26, 1972 and November 28, 1974

Questions on the tectonism and seismic activity very near or at the site are of great interest. For this reason tne single most important seismic event to occur since installation of station CLN at the Los Medanos site has been the earthquake at 03:35:20 GMT on November 28, 1974 (see Table 5.2-5 and Figure 5.2-3). This earthquake, whose most recently estimated

magnitude is 3.6 (Sanford et al., 1978), had an epicenter about 40 kilometers northwest of station CLN. If it is an indication of normal background seismicity in the immediate site area, this event might cause a reevaluation of previous estimates of seismic risk at the Los Medanos site by Sanford and Toppozada (1974) who considered the likely principal sources of site vibratory ground motion to be a major earthquake to the west, no closer than approximately 115 kilometers, and a moderate earthquake in the Central Basin Platform. Because of its potential importance, this event has attracted considerable notice. It was prominently mentioned in two studies (Sanford et al., 1976a; Sanford et al., 1978) and was the main topic of another (Caravella and Sanford, 1977).

As may be seen from Table 5.2-5 the event of November 28, 1974 has been located by the New Mexico Institute of Mining and Technology at about $32.6^{\circ}N$, $104.1^{\circ}W$ by using phase readings from six stations. An independent location by the U.S. Geological Survey places this earthquake at $32.3^{\circ}N$, $104.1^{\circ}W$. Both solutions give a virtually identical origin time. At the time of this earthquake, a rockfall and considerable ground cracking were reported at the National Potash Co. Eddy County Mine. The location of this rockfall was $32.55^{\circ}N$, $104.04^{\circ}W$ and it occurred within about one minute of the calculated earthquake origin time. In view of this rather remarkable coincidence the question naturally arose as to the cause and effect relationship of the rockfall to the recorded seismic event. The issue was whether the source of this event could be related to a non-tectonic cause such as mine collapse at the Eddy County Mine or if it should be considered a more normal release of accumulated strain energy. Clearly the epicentral uncertainty grossly implied by the two different formal solutions found by the New Mexico Insitute of Mining and Technology and the U.S. Geological Survey allowed actual spatial coincidence of rockfall and seismic disturbance. Therefore it was decided that a more careful location effort would be worthwhile.

As information was being collected for this redetermination effort, it was discovered that a previous rockfall had occurred at the National Potash Co. Eddy County Mine on July 26, 1972. A check of past seismograph

records revealed that a seismic event had been recorded at a number of regional seismograph stations, too. A subsequent location using these readings put this event at 32.6°N, 104.1°W and assigned a magnitude of M_L=2.8 (see Table 5.2-3). Thus this event, although weaker, was found to be located very near the November 28, 1974 event, and study of the individual station records indicated that its coda was of nearly identical character to the later event. Since more records were available for the earlier event, it was decided that a detailed relocation effort would be attempted for it first. The question of the nature of its source was still of primary concern.

The relocation method is described thoroughly in Caravella and Sanford (1977) and will only be outlined here. The origin time was picked by extrapolation to the S-P interval equal zero intercept of a straight line fit of S-P versus P data. Such a procedure, using data from all six stations recording the July 26, 1972 event (LUB, SNM, ALQ, JCT, TUC, and GOL) yielded an origin time of 04:35:40.4; ± about 3.3 seconds at the 95 percent confidence level. A similar linear regression using only the first five S-P intervals yielded an origin time of 04:35:43.9 ± about 2.8 seconds at the same confidence level. Ultimately, the five interval origin time was selected because a better location was obtained with it.

To develop a velocity model to use in the relocation effort the following procedure was adopted: seismic wave arrival times from the underground nuclear explosion GNOME were noted. This explosion, which was detonated at 19:00:00 GMT on December 10, 1961, at 32.264°N, 103.866°W (located about 35 km south of the National Potash Co. Eddy County Mine) was recorded by many of the stations noted above (see Romney et al., 1962). From these arrival times, crustal and subcrustal velocities were developed over the ray paths from GNOME to each individual station. In essence, each station was modeled as being underlain by two layers over a half space. The velocity and thickness of the upper layer were assumed known from independent sources (Reddy, 1966; Romney et al., 1962; Wilson et al., 1969; Major, 1975; Shurbet, 1975; Toppozada and Sanford, 1976) and the velocity (and implied critical incidence angles) of the lower (and main)

crustal layer was then found by an iterative technique for each station independently. Subcrustal velocities could then be similarly found. Corrected crustal velocities (layer two) determined in this way ranged from 6.31 km/sec to 6.02 km/sec. Thus lateral inhomogeneity is built into the model.

Using the station-dependent model and the preferred origin time, 95 percent confidence interval arcs were drawn from each station. The results are shown in Figure 5.2-7. As can be seen, the intersecting arcs so constructed define a rather large area of approximately 1900 km^2. Although the Eddy County Mine lies very near this area, other locations within the same area have the same formal likelihood of being the epicentral location.

The November 28, 1974, seismic event was not relocated in the same way. Instead, another fundamental question was asked. That is, could the two events, July 1972 and November 1974, have occurred at the same focus based on existing seismographic evidence. The test applied is that if the events had the same hypocenter, the differences in arrival times of specific phases at common stations should be the same for all stations. As may be seen from Table 5.2-11 this is not the case for the limited data set available.

The difference between the smallest and largest time difference is 1.4 sec. Caravella and Sanford (1977) believe this is too large to be explained by reading errors. The time differences indicate, under this conclusion, that the two events did not have the same hypocenter, even though location uncertainties are such that either of them might, by itself, have occurred at the rockfall site. The time differences can be explained by locating the hypocenter of the November 28, 1974 event about 10 kilometers northwest or southwest of the July 26, 1972 shock (Caravella and Sanford, 1977). At this time, then, best available analysis indicates that both of these small events did not occur at the Eddy County Mine and cannot both be caused by some nontectonic source at that location. In the seismic risk analysis of the next section, therefore, some background earthquake activity in the immediate site area is considered.

5.3 SEISMIC RISK ANALYSIS

In this section, a broad characterization of the site region's seismicity is developed in a way useful for making conservative earthquake-resistant design decisions. This risk analysis is intended to be applicable only to vibratory ground motion resistant design of surface facilities on good foundations. Generalization of the results of this analysis to less idealized conditions, such as design of subsurface facilities for shaking during an earthquake or allowance for poor surface foundation conditions (should they be encountered), may be accomplished at a later time without altering the import of the original analysis. However, it must be emphasized that in this section the risk formally presented is intended to be a meaningful and conservative estimate of proper design values for short-term features of the facility. "Short-term" as used here means time periods on the order of decades. Specifically, it is not believed that any results presented here can be simply extrapolated to periods of tens or hundreds of thousands of years even though formal extrapolations of this kind are possible. This is not a severe handicap in this case. Although the lifetime of the repository will be longer than the limits of applicability of this risk analysis, the length of time for which vibratory ground motion will be of concern is much shorter (during surface facilities use) and, in fact, falls well within the intent of this analysis.

There are a number of ways to characterize site seismicity in a way useful for rational design against the effects of earthquake associated ground shaking. One measure of the proper design value is the maximum historical site intensity which can be estimated from the historical earthquake record and some intensity attenuation law, whether this law is explicitly or only implicitly considered. As noted in the previous section, the maximum historical intensity at the Los Medanos site is estimated to be less than or equal to V on the Modified Mercalli Intensity Scale (Wood and Neumann, 1931). This characterization of earthquake design motion has the great advantage of being simple and straightforward. It is not, however, generally used for important structures or facilities because it does not

provide a basis for estimating whether future events will result in site intensities exceeding the maximum historical site intensity. This is a serious drawback for areas with a relatively short historic record such as the United States, and especially its western half.

To construct seismic design values for a particular site that go beyond a simple interpretation of a maximum historical measure of ground motion, something more than historical seismicity must be considered. Therefore, the geology of a region is often used in several ways to supplement historic earthquake data. There are several studies that attempt to present a seismic zonation of the United States using both seismic and geologic arguments. The stated intent of one of these (Richter, 1959) is to present a seismic regionalization showing the maximum reasonably expectable intensity during future earthquakes on ground of prevailing character. The Los Medanos site is in a region of intensity VIII according to this study. Algermissen 1969) has developed a Seismic Risk Map that has been closely associated with editions of the Uniform Building Code since 1970 (Uniform Building Code, 1970, 1973, and 1976) and by this association is most directly applicable to an estimate of proper design of structures with lifetimes measured in decades. The Los Medanos site intensity is shown to be V and/or VI in this zonation. Both these seismic risk maps, which were considered for the site region by Sanford and Toppozada (1974), are based on essentially the same data. The differences are due to varying interpretations and intent. That the interpretations are not really very far apart is indicated by a statement by Richter (1959) that an individual structure intended for a lifetime of the order of 30 years might within that life be exposed to shaking of no more than one scale degree below that mapped. Thus, over several decades, the Los Medanos site might reasonably be subjected to shaking at around the V to VII intensity level according to both Richter and Algermissen.

Although based on both historical seismicity and large scale geologic features, the seismic regionalization maps of Richter and Algermissen do not explicitly consider frequency of occurrence of damaging earthquakes. More fundamentally, the subjective decisions implicit in any

characterization of future earthquake ground motion are largely concealed and not subject to scrutiny. Any shifts of emphasis or new geologic or seismic information are, therefore, very difficult to incorporate into such zonations. In recent years, several procedures have been developed that allow formal determination of earthquake design parameters to be made (Cornell, 1968; Cornell and Vanmarke, 1969), and a number of studies incorporating these procedures have been performed (e.g., Cornell and Merz, 1975; Shah et al., 1975; Algermissen and Perkins, 1976). In typical seismic hazard analyses of this kind, the definition of seismicity is made by using geologic and tectonic data as well as observed earthquake locations. The region of study is divided into seismic sources within which future events are considered equally likely to occur at any location. For each seismic source area the rate of occurrence of events above a chosen threshold level is estimated, using the observed frequency of historical events. The sizes of successive events in each source are assumed to be independent and exponentially distributed; the slope of the log-number versus frequency relationship is estimated from the relative frequency of different sizes of events observed in the historical data. This slope, often termed the b value (Richter, 1958), is determined either for each seismic source individually or for all sources in the region jointly. Finally, the maximum possible size of events for each source is determined, using judgment and the historical record (McGuire, 1977).

It is clear from this description that all assumptions, no matter what the level of subjectivity employed in making them, must be made explicit. In addition, this method of determining site-specific earthquake risk may be used for a wide range of geologic and seismic assumptions. In this section, the method of Cornell (1968) will be applied to the question of risk as a function of ground shaking at some prescribed level at the Los Medanos site. Input parameters at each stage of the development will be taken from current best information available in the literature. These input parameters are discussed below in some detail following a general discussion of the mechanics of the Cornell method itself. Finally, several curves showing probability of maximum ground surface acceleration versus acceleration level, will be presented and discussed for several

different assumptions about the individual source area capabilities. The conclusions that may be drawn from these curves will be considered. It is believed that the data, treated in this way, may be used to arrive at a general preliminary statement of risk from vibratory ground motion that is applicable at the site during its active phase of development and use.

5.3.1 The Method of Cornell

Cornell (1968) developed a method to produce relationships between ground motion parameters, such as peak ground displacement or maximum ground acceleration, and their average return period. The data used include best estimates of average activity levels for various potential sources of earthquakes. Arbitrary geographical relationships are allowed between these potential sources and the site. Cornell provides a technique for integrating the individual influences of these sources into the probability distribution of the ground motion parameter and the average return period then follows directly. The potential sources are modeled geometrically in such a way as to permit a solution of closed analytical form.

In this Section, a calculation is made of the probability that a random peak ground acceleration "A" will exceed a given value "a" once an event of magnitude greater than some threshold level has occurred. Before the method can be used, a geometric model or characterization of the potential earthquake sources must be made. Cornell develops the necessary formulation for point, line, and annular area sources. The geological structure and seismic history of the Los Medanos site do not imply that linear or point source models are appropriate, so use of the technique begins with an approximation of the source regions (Algermissen and Perkins, 1976) by annular segments (see Fig. 5.3-5). As discussed in the next subsection, the annular segments are in all cases believed conservative approximations of the source regions.

Let acceleration be related to Richter magnitude M and hypocentral distance R (in kilometers) by the equation:

$$a = b_1 \exp(b_2 M) R^{-b_3}$$

where a is in units of cm/sec^2 and the values of the constants (b_1, b_2, b_3) are discussed in a later subsection. Then if M and R are assumed to be probabilistically independent within the source areas, the probability of an acceleration A exceeding a given value a can be expressed as:

$$P\left[A \geq a\right] = 1 - F_M(m) = P\left[M \leq (\ln a + b_3 \ln R - \ln b_1)/b_2\right]$$

where F(m) is a distribution function of earthquake magnitudes, which can be calculated using a recurrence relation of the form (Gutenberg and Richter, 1942):

$$\log N = \underline{a} - \underline{b}M$$

where $\underline{a}$ and $\underline{b}$ are constants.

To find the proportion of events having magnitudes in the range $m_o < M < m$ the number of such events ($N_{m_o} - N_m$) is divided by the total total number of events with magnitude greater than m_o

$$F_M(m) = (N_{m_o} - N_m)/N_{m_o} = 1 - \exp\left[-B(m - m_o)\right]$$

where $m_o < m < \infty$ and B is used to denote the constant $b \ln 10$. However, it is desirable to impose an upper limit on the magnitude of an event that may occur in a given source area, i.e., to specify that $m_o \leq m \leq m_1$. Our cumulative distribution function must now satisfy the boundary condition $F_M(m \geq m_1) = 1$ so:

$$F_M(m) = C\left[1 - \exp\left[-B(m - m_o)\right]\right]$$

where C is a constant such that

$$C = 1/\left[1 - \exp\left[-B(m_1 - m_o)\right]\right] \equiv 1/(1 - k_{m_1})$$

In this case, the probability expression may be rewritten as

$$P\left[A \geq a\right] = 1 - F_M(m) = \left[-k_{m_1} = \exp\left[-B(m - m_o)\right]\right]/(1 - k_{m_1})$$

where $k_{m_1} = \exp\left[-B(m_1 - m_o)\right]$. For values of m less than m_o, $\left[P\ A \geq a\right] = 1$ while for values of $m > m_1$, $P\left[A \geq a\right] = 0$.

Aside from the limits on the range of r due to the inner and outer radii of the annular segment, it is important to note that the condition $m_o \leq m \leq m_1$ also places limits on the range over which the above probability is valid. Specifically, the condition on m implies, for a given acceleration value a, that:

$$\left[\exp(b_2 m_o/b_3)\right](b_1/a)^{1/b_3} \leq r \leq \left[\exp(b_2 m_1/b_3)\right](b_1/a)^{1/b_3}$$

The lower boundary value of r may be thought of as the distance from the site within which any event of magnitude m or greater will result in an acceleration of a or greater. In other words, the probability is unity that for values of r less than the cutoff value a random acceleration A will exceed the chosen a. The upper boundary is the maximum radius from the site at which an event of magnitude m could have a nonzero probability of causing an acceleration a, given an attenuation law of the proper form. A schematic representation of these limits on r, for a given a, over which the above probability is valid is shown in Figure 5.3-1 (top).

In order to find the cumulative distribution $F_M(m)$ for all possible values of the focal distance and their relative likelihoods, integration over the annular area under consideration is performed:

$$P[A \geq a]_{\text{annular area}} = \frac{1}{2\pi}\int_0^{2\pi}\int_d^{r_o} P[A \geq a] \cdot f_{R,\Theta}(r,\theta)\, dr d\theta$$

where $f_{R,\Theta}(r,\Theta)$ is the probability density function of R, Θ the coordinates of a random focal position within the annulus (see Fig. 5.3-1bottom). Assuming that $f_{R,\Theta}(r,\Theta)$ is independent of Θ, the probability of the source falling within the annular area bounded by X (Fig. 5.1-1bottom) is just the ratio of this area to the total area or

$$F_{R,\Theta}(r,\theta) = \pi(X^2 - \Delta^2)/\pi(\ell^2 - \Delta^2) = (r^2 - h^2 - \Delta^2)/(\ell^2 - \Delta^2)$$

so then

$$f_{R,\Theta}(r,\theta) = \frac{d}{dr} F_{R,\Theta} = 2r/(\ell^2 - \Delta^2)$$

Substituting the expression for $f_{R,\Theta}(r,\Theta)$ into the probability equation and integrating, an expression is found of the form:

$$P[A \geq a]_{ann.} = \frac{2}{\ell^2 - \Delta^2}(1 - k_{m_1})^{-1}[Da^{-B/b_2}\left(\frac{1}{(\gamma-1)d^{\gamma-1}}\left[1 - \left(\frac{r_0}{d}\right)^{-(\gamma-1)}\right]\right) - \frac{k_{m_1}}{2}(r_0^2 - d^2)]$$

where

$$D = b_1^{B/b_2}\exp(Bm_o) \quad ; \gamma = Bb_3/b_2) - 1$$

The question of the random number of occurrences in any time period is next considered. It is assumed that for the magnitudes of interest the occurrence of any event is Poissonian, that earthquakes have equal likelihood of occurring anywhere within the source area considered, and that the average occurrence rate, ν per year, is constant in time. The above three assumptions, particularly that of Poissonian distribution of events, are fundamental.

It may then be shown that the probability that $A_{max}(t)$, the maximum value attained by A over a time of t years, will be less than or equal to a is:

$$P\left[A_{max}(t) \leq a\right] = \exp(-p\nu t)$$

where p is the annular area probability, $\left[P\ A \geq a\right]_{ann.}$, calculated above and is the average occurrence rate..

The risk or annual probability that A_{max} will exceed a is

$$1 - P\left[A_{max}(t=1) \leq a\right] = 1 - \exp(-p\nu)$$

Sources near the Los Medanos site will be modelled by angular segments of an annulus. In this case, a simple modification of p in the above exponential is required but the method is otherwise the same.

The average return period, T, of an acceleration equal to or greater than a is defined as the reciprocal of $P\left[A_{max} \geq a\right]$, that is:

$$T(\text{years}) = 1/P\left[A_{max} \geq a\right]$$

Tables of values of annual risk (and average return period) versus values of a can be constructed for each source area near and surrounding the site. The risk at the site arising from all such sources may then be found by combining the results above in the following way: Consider source areas A, B, and C to be independent in a statistical sense. Then, where $P^{ABC}\left[A_{max} \leq a\right]$ is the familiar probability that the maximum value of A, the peak ground acceleration arising from composite source area ABC, is less than a at the site, is

$$P^{ABC}\left[A_{max} \leq a\right] = P^{A}\left[A_{max} \leq a\right] \cdot P^{B}\left[A_{max} \leq a\right] \cdot P^{C}\left[A_{max} \leq a\right]$$

If it is assumed that all the sources are modeled by annular segments (i.e., not a combination of annular and line sources), then the composite probability of exceeding a in terms of the probability results for the individual areas can be written as

$$P^{ABC}\left[A_{max} \geq a\right] = 1 - P^{ABC}\left[A_{max} \leq a\right]$$

or:

$$P^{ABC}[A_{max} \geq a] = 1 - [(1 - P^{A}[A_{max} \geq a]) \cdot (1 - P^{B}[A_{max} \geq a]) \cdot (1 - P[A_{max} \geq a])]$$

This equation is the desired formula for combining the previous probability results into a composite curve for "risk" which takes into account influences of all the various source areas near the site.

Thus, given certain input parameters, and estimates of average activity rates for potential sources of earthquakes, Cornell's method offers the means by which to make a quantitative estimate of the seismic risk at a site. Subject to certain fundamental assumptions stated above, the results can be expressed in a form that is easily applied and interpreted.

In the next subsection, the values used for input parameters such as constants of attenuation, and average seismic activity rates for individual source areas, will be discussed. The choice of annular segments approximating the source areas surrounding the site will also be discussed in some detail.

5.3.2 Input Parameters

The first input parameters that must be considered are those having to do with acceleration attenuation as a function of earthquake magnitude and epicentral distance. An unmodified use of Cornell's (1968) hazard analysis method requires, as seen above, a law of the form

$$a = b_1 \exp(b_2 M) R^{-b_3}$$

where a is acceleration in cm/sec^2, M is earthquake magnitude, and R is distance in kilometers. A number of relationships of the above form exist in the literature (Esteva and Rosenblueth, 1964; Seed, et al., 1968; Orphal and Lahoud, 1974). In all these studies, however, the constants b_1, b_2, and b_3 are found for data collected exclusively, or almost exclusively in the western part of the United States and are

therefore applicable there. Recently, several reasons have emerged, both theoretical and empirical, that indicate fundamental differences in acceleration attenuation in the central part of the U.S. For example, it has been demonstrated that the attenuation of body waves (Evernden, 1967) and surface waves (Mitchell, 1973; Nuttli, 1973a) is appreciably lower east of the Rocky Mountains than west. This serves to explain the much larger areas of perceptibility and of damage for central United States earthquakes than for west coast earthquakes of the same magnitude. It is also the source of the reluctance here to use previously published attenuation constants uncritically for this study. With particular reference to attenuation of acceleration, Nuttli (1973b) found that in the central United States the acceleration values of greatest engineering significance may be related to the vector resultants of the vertical and horizontal components of the sustained maximum surface-wave motion rather than to isolated peaks. This is true for ground motion at some distance from the source and for a wide range of magnitudes. The amplitude and shape of the attenuation curve for surface waves (Lg) in the frequency range of interest is known (Nuttli, 1973b) so that the accelerations associated with the Sg/Lg part of the earthquake ground motion coda may be plotted as a function of frequency and epicentral distance (see Nuttli, 1973c, Figure 8) for an event of a given magnitude.

The site area is very close to the western margin of the region of interest in Nuttli's studies so that it is not immediately clear that central United States attenuation laws are more pertinent than their western counterparts. It is believed, however, that there are several reasons for adopting a central United States formula. First, the site geology seems appropriate. The site is near the western boundary of the High Plains physiographic province (Sanford et al., 1976b) which extends eastward well into that part of the continental United States considered the "central U.S." by Nuttli (1973c). Second, there are features of the time histories recorded in the site region that are suggestive of kinship with central United States records. For example, the maximum record motions are almost always in the Sg part of the coda (Sanford, personal communication, 1978) in analogy to central United States Sg/Lg motion.

This feature has the interesting implication that magnitude scales are most naturally developed for this wave in the site region. Third, as mentioned in subsection 5.2.2, recent revision in the method of magnitude determination of events in the source region by stations in this region has been made necessary by the realization that peak record amplitudes have not attenuated with distance as quickly as implied by the uncritical use of Richter's (1958) standard earthquake ground amplitude values. Finally, the observation made by Sanford and Toppozada (1974) that the Valentine, Texas isoseismals apparently encompass more area to the east than to the west of the source is an indication on a very graphic level that attenuation is less in that direction. All these observations, although not rigorously indicative, are at least suggestive of acceleration attenuation in the site region similar to that found appropriate for the central region of the country. For these reasons, it was decided to use such a law for this seismic hazard analysis.

Algermissen and Perkins (1976) found that east of 105°W longitude the Schnabel and Seed (1973) curve developed from western United States data was consistent at about the magnitude 7.6 level with the similarly defined acceleration attenuation curve suggested by Nuttli (1973c) for the central United States out to distances of about 50 kilometers. Beyond this distance, the Nuttli curve attenuates at a slower rate (see Algermissen and Perkins, 1976, Figure 3). Curves applicable to other magnitudes are drawn by Algermissen and Perkins (1976) tangent to the Schnabel and Seed curves, but taking the same general shape as the Nuttli curve. These curves are shown in Figure 5.3-2 for magnitudes of 4.2, 5.2, 5.6, 6.6, 7.6, and 8.5. It is clear that these curves will not fit a single attenuation law of the form desired for simple application of Cornell's (1968) method as discussed in the previous subsection. Such a form requires not only a constant slope for all distances but a constant line spacing for equal magnitude intervals. Neither of these requirements is met by the acceleration attenuation curves taken from Algermissen and Perkins. The task then is to find proper coefficients for a Cornell type attenuation law such that the predicted acceleration so derived for a given magnitude and distance will be conservative

relative to the plotted values taken from Algermissen and Perkins. After some experimentation, the coefficients b_1=17, b_2=0.92, b_3=1.0 were selected (Bickers, 1978). Curves using these values are also shown in Figure 5.3-2 for the same suite of magnitudes. As can be seen from this figure, the model equation with the above constants yields higher accelerations for all values of magnitude and distance than the corresponding Algermissen and Perkins curves and is most closely matched to these curves in the region 10 kilometers $< R <$ 300 kilometers and $5 < M < 6$. This adopted attenuation law, therefore, represents a conservative compromise between the estimated curves of previous authors and the required form of Cornell.

The next feature needed for hazard curve development for the site is some idealization of the regional seismic source areas. Whatever configuration is ultimately chosen for the geometry and location of the source regions affecting the site, the fundamental data are basically regional seismicity and geology. These features of the southeastern New Mexico region have already been evaluated in the literature (Algermissen and Perkins, 1976) with precisely the intent of developing an estimate of maximum acceleration in rock in a probabilistic format. Therefore, it was decided to investigate the feasibility of using these same source zones in the slightly different context of the current hazard evaluation.

As originally defined, the probabilistic estimate of maximum acceleration determined by Algermissen and Perkins (1976) was based primarily on the seismic record; geologic data, primarily distribution of faults, was employed only to a minor extent. In particular, the general principle used by those authors in the construction of seismic source zones was that future earthquake occurrences are assumed to have the same general time rate characteristics as the earthquakes in the past in the same overall region, but that future earthquakes in a particular area might occur over somewhat more extended areas than indicated by historical data. In practice, the seismic source zones were drawn using the following guidelines:

1) Areas of seismicity where shocks of maximum Modified Mercalli intensity V or greater have occurred were considered source zones. (Note that intensity and magnitude are deterministically related by the formula (Gutenberg and Richter, 1942) $M_c = 1.3 + 0.6I_o$ where "M_c is the magnitude corresponding to I_o" (Algermissen and Perkins, 1976). Thus $I_o = V$ is equivalent to $M_c = 4.3$). For any given zone the average distance from the epicenters to the boundary was chosen to be approximately the average separation distance for earthquakes of the maximum intensity found there, when these were sufficiently numerous to establish such a distance. If the maximum intensity earthquake in a source area only occurred once or twice (as in the case of source areas in and near southeastern New Mexico), the distance between earthquakes of the second largest intensity was used.

2) Some zones such as described above were extended to include adjacent areas where evidence of Holocene faulting is present. This type of extension was used in the Great Plains and Southern Rocky Mountains where epicentral clusters could be associated with faults appearing on the tectonic maps of the United States.

3) From 2) above, areas of known Quaternary faulting are generally within source zones, if the faulting is associated with at least low-level historical seismicity. Except as noted above, Quaternary or older faulting not associated with historical earthquakes of Modified Mercalli intensities greater than V or magnitudes greater than 4.0 was not included within source areas.

Using these principles, the seismic source zones of interest to the calculation of hazard at the site as drawn by Algermissen and Perkins are shown in Figure 5.3-3. As seen below, independent studies of regional Quaternary faulting and the more detailed seismicity studies of the last several years do not seriously imply the modification of these source area boundaries with one conceptual exception involving small earthquakes within the immediate site area. This observation is most directly supported by considering the historical seismicity through 1972 as shown

in Figure 5.2-1 in conjunction with the three earthquake source zones of Algermissen and Perkins as shown in Figure 5.3-3. To aid this comparison, the epicenters of the former figure have been drafted on to Figure 5.3-3. It is clear from this superposition that the large majority of significant historical seismicity conforms well with the zonation presented. The location of the Valentine, Texas, earthquake and its aftershocks (if these are formally constrained to share the location of the main event in this sequence), apparently lie slightly to the east of the boundary of the southernmost seismic source zone if the Byerly (1934) location is used. It should be noted, however, that the instrumental location is not well constrained by the data available at the time of Byerly's study and, in particular, the epicentral uncertainty is such that a more southerly or westerly location is equally likely. For example, as may be seen from Figure 5.3-2 both the U.S.C.G.S. instrumental location for this event and the town of Valentine, Texas itself are within the source zone as drawn by Algermissen and Perkins. For the purposes of this risk analysis, the Valentine earthquake and its aftershocks are assumed to have occurred within the southernmost seismic source zone of Algermissen and Perkins.

Of more immediate concern is the scattered residual small magnitude seismicity occurring throughout the site area which cannot be associated with any of the source zones as drawn in Figure 5.3-3. This problem was recognized by Algermissen and Perkins (1976). These authors treated these isolated earthquakes which could not be associated with known faults or tectonic features as seismic background and the same shall be done here. On a nationwide basis these events could have an intensity of VII or less on the Modified Mercalli Scale and were assumed capable of happening over broad areas of the midwest; however they produced acceleration levels below the lowest acceleration contour on their map, because this contour represented the 0.04g level with a 90-percent probability of not being exceeded in a 50-year period (Algermissen and Perkins, 1976). Since acceleration levels for much longer time intervals are of interest in this study, some more explicit treatment of these random events will be necessary, and some explicit source zone including

the site must be considered. This is the conceptual modification of the Algermissen and Perkins study mentioned above.

A simple calculation is adequate to show that it is not necessary to consider any source zone other than the four already mentioned--the three of Figure 5.3-3 and an additional one including the site. The next closest source zone of Algermissen and Perkins is approximately 300 kilometers away from the site and all others are even farther away. Using this distance, the attenuation law considered above and (for the moment) an arbitrary maximum magnitude 7.5 earthquake, the maximum acceleration at the site is slightly less than 0.06g. Thus, such a source zone cannot contribute anything to site accelerations higher than this at any probability level. Furtnermore, as will be more forcibly indicated in the next subsection where some actual hazard curves will be discussed, the contributions to probabilities of occurrence from distance source zones even at lower acceleration levels are insignificant when compared to the contributions from the closer zones.

An independent estimate of the appropriateness of the source zones as drawn in Figure 5.3-3 can be obtained from a consideration of faults offsetting Quaternary geomorphic surfaces. This is an independent estimate in the sense that no episode of surface faulting associated with historic seismicity is known in the site region. Nevertheless, Quaternary faulting has often been used as an indicator of the seismic activity of an area over a longer time span than is furnished by the historical seismicity record (e.g. Allen et al., 1965). Sanford and Toppozada (1974) have made an investigation of fault scarps within 300 kilometers of the disposal site, exclusive of the Permian Basin in which the site lies. This investigation consisted primarily of a literature search supplemented by limited reconnaissance of aerial photographs. The study was restricted to fault scarps offsetting Quaternary alluvial surfaces because these are the only fault displacements whose age can be estimated with any certainty. The authors note that tectonic movements in the area may have occurred during the Quaternary along faults cutting older rocks, but detection of recent offsets along such faults are nearly

impossible. Bachman and Johnson (1973) have completed a detailed investigation of the surface features in the Permian Basin which indicates recent fault scarps of a tectonic nature do not exist in this area. Since completion of the Sanford and Toppozada (1974) study, further studies on the existence or nature of fault scarps in the general site region have been actively pursued by Dr. Muehlberger and his students of the University of Texas, Austin (Sanford et al., 1978). To date, the most recent data are consistent with the picture derived from the earlier studies. That is, the Rio Grande Rift and southern Basin and Range provinces have abundant geologic evidence - primarily recent fault scarps - of recent crustal movements (Sanford et al., 1972; Muehlberger et al, 1978) whereas the High Plains, which is the physiographic province of the Permian Salt Basin in the site area, does not. The closest known Quaternary offset is about 125Km from the site.

Shown in Figure 5.3-4 are the faults noted by Sanford and Toppozada (1974) and Muehlberger et al. (1978) superimposed on the Algermissen and Perkins source zones. The references used in construction of these fault traces are Talmage (1934), Reiche (1938), Kelley (1971), Dake and Nelson (1933), King (1948, 1965), Kottlowski (1960), Kottlowski and Foster (1960), and Pray (1961). Also shown is the eastern boundary of the area of investigation of Sanford and Toppozada, that is, the western boundary of the Permian Basin.

It is clear that the Quaternary faults are completely contained within the two western seismic source zones of Algermissen and Perkins. These two zones may be combined under the name "southern Basin and Range--Rio Grande Rift" source zone since they include the parts of those provinces significant to the evaluation of probabilistic acceleration at the site. The reason for combining the two original zones is implied by a comparison of Figures 5.3-3 and 5.3-4. Although the historical seismicity has been of a higher level in the more southerly of the two zones (Algermissen and Perkins assign a maximum intensity of VIII to this southerly zone to correspond to the Valentine, Texas, earthquake and one of only V to the northern zone), the Quaternary fault offset strongly

suggests that to insure conservatism this pattern should be considered a happenstance of the short historical earthquake record. Thus for the purposes of this analysis, the seismic capabilities of the southern zone will be shared by the region to its north. Although only epicenters of earthquakes occurring prior to 1973 are shown in Figure 5.3-3, the implications of more recent activity as they affect the southern Basin and Range--Rio Grande Rift source zone (which will be referred to only as the Rio Grande Rift source zone in the following discussion for brevity) are similar. For example, Figures 5.2-3 and 5.2-4 show that the known epicenters for shocks between April 1974 and November 1977 with Sg-Pg intervals at station CLN from 31 to 36 seconds occur in apparently historically active regions, notably centered around Valentine, Texas and much of the Tularosa Basin. That is, they occur precisely in the Rio Grande Rift source zone as defined above.

One important implication of these studies is that the easternmost of the three Algermissen and Perkins source zones, that corresponding to the post-1964 seismic activity around Wink, Texas, on the Central Basin Platform, is based on seismic evidence alone. This activity was discussed in detail in subsection 5.2.4. For the purposes of specifying a conservative source zone geometry, the only geometrical issue with regard to the Central Basin Platform source zone, then, is the closest approach of the Central Basin Platform relative to the source zone used to model it. Shown in Figure 5.3-4 is an outline of the buried Central Basin Platform as it appears in Rogers and Malkiel (1978). It may be easily seen that the closest approach to the site of the Algermissen and Perkins Central Basin Platform seismic source zone implies its use is adequate. Therefore, this zone, as drawn, will be used for the model to be developed. The general model will consist of three source zones:

1) The Rio Grande Rift zone drawn by combining the western source zones as discussed above.

2) The Central Basin Platform zone as shown in Figure 5.3-4.

3) A site source zone centered at the site and with a radius to be specified below.

There are two purely geometrical issues to be resolved. The first involves specifying a focal depth for th events in each of the source zones. The second is really an exercise in adapting the irregular zones, as shown, to Cornell's method much as it was necessary to adapt the form of the attenuation law.

There is little doubt that the focal depths of earthquakes in the site region should be considered shallow. As we saw in subsection 5.2.2, early instrumental locations were achieved using an arc intersection method employing travel-time-distance curves calculated from a given crustal model and the assumption that focal depths were either 5 kilometers, 10 kilometers, or for later calculations, 8 kilometers. Good epicentral locations could generally be obtained under these assumptions. Confidence in calculated or assumed focal depths is greatly increased, of course, if at least one recording station is situated not much farther away from the epicenter than the focal depth. This situation is not generally realized for New Mexico region earthquakes but several specialized studies for which this criterion has been satisfied are suggestive. For an approximately two-year period beginning in June 1960, several hundred natural microearthquakes having S-P intervals of less than 2.3 seconds were recorded by high-magnification seismographs west of Socorro, New Mexico (Sanford and Holmes, 1962). Rather detailed studies of the depths of these events indicated hypocenters ranging from 2.7 to 6.3 kilometers. More recently, and nearer to the site, preliminary data from the Kermit, Texas, array indicate focal depths ranging from very near the surface down to about 10 kilometers although only about 20 percent of the events are located at depths greater than about 3.7 kilometers (Rogers and Malkiel, 1978). For the formal instrumental location procedure with array data, an initial trial hypocenter at 5 kilometers depth is used by these authors.

Within the range discussed - that is, focal depths of from 0 to 10 kilometers - the issue of selecting a proper depth for the probabilistic acceleration analysis at this site is clearly important only in the site source zone itself. For example, the difference in hypocentral distance - the distance to be used in the acceleration attenuation formula - for a closest approach event in the Central Basin Platform is only 1.93 kilometers in this depth range assuming that the closest approach of this source zone is 25 kilometers as is indicated by Figures 5.3-3 or 5.3-4. This is clearly the greatest difference of this kind outside the site source zone. Within the site source zone the selection of focal depth can be, formally, very important simply because the form of the attenuation law used asymptotically approaches infinite acceleration at very small distances. This is certainly not mechanically realistic and is not the intent of the empirical fitting process to an attenuation law of this form. There is some empirical evidence that the rate of increase of peak acceleration with decreasing hypocentral distance becomes less as the zone of energy release is approached. This is the case for example, for the Parkfield and San Fernando, California earthquakes of 1966 and 1971, respectively (see Page et al., 1972, Figures 4 and 6). Some empirical acceleration attenuation curves make use of this property in extrapolating to the vicinity of energy release. Most importantly for our purposes here, the attenuation curves of Schnabel and Seed (1973) are constructed in this manner and it is these curves that form the basis for near-source acceleration as a function of magnitude used by Algermissen and Perkins (1976). Since it is the intent here to follow these authors insofar as conservatism allows, it was decided to use a focal depth of 5 kilometers in all source zones of this study including that of the site. For smaller hypocentral distances, the form of the attenuation law adopted here deviates significantly from that suggested by Algermissen and Perkins in such a way as to severely exaggerate the importance of very small but very close shocks in the estimation of probabilistic acceleration at the site pertinent to design. This may be seen from Figure 5.3-2.

The manner in which the irregular source zone geometry of Figures 5.3-3 and 5.3-4 may be adapted to the method of Cornell (1968) is shown in Figure 5.3-5. As has been implied above, the seismicity of the site region is, at best, poorly related to observed faults - whether observed Quaternary faults do not occur, as in the case of the Central Basin Platform source zone (Rogers and Malkiel, 1978) or whether they do, as in the case of the Rio Grande Rift source zone (Sanford et al, 1972). Since the boundaries of the latter zone are so drawn as to be as close or closer than known recent faults, conservatism is served by allowing the largest earthquake postulated for specific faults within the region to occur randomly throughout the region. For these two reasons, lack of apparent fault control and additional conservatism, areal source zones were used (see subsection 5.3.1). Thus the object is to approximate the given source zones by a series of annular segments. This is done in such a way that total source zone area is conserved, and such that excluded area of the Algermissen and Perkins zones is replaced by annular areas closer to the source. Finally, closest approach distances are conserved. These criteria are followed in construction of the pattern in Figure 5.3-5. The site source region is drawn to be centered at the site and to include all area not already in another source zone. The radius of this site source zone will be determined by magnitude restrictions.

With the attenuation law and geometry defined for this hazard analysis, the question of the right recurrence formulas for each source zone is next addressed. A number of empirically fitted curves of the form $\log N = a - bM$ have been published for the site region in a broad sense (Sanford and Holmes, 1962; Algermissen, 1969). As before, N is the number of earthquakes of magnitude greater than or equal to M in some area and over some time period. The constants a and b are determined by fitting the data, usually in a least squares procedure. Although data for any time period may be used, all the formulas considered explicitly here will be normalized to one year. In addition, all formulas will be normalized to source areas of 10^5 square kilometers for ease of comparison. For these broad regional studies, b values around 1.0 have been found.

Several studies published recently regarding the immediate site region are not in good agreement with the previous results. For example, graphs of magnitude versus number of earthquakes for events within 300 kilometers of the site exclusive of shocks from the Central Basin Platform and aftershocks of the 1931 Valentine, Texas earthquake yield recurrence formulas of the form

$$\log N = 1.65 - 0.6M_L \quad \text{per yr per } 10^5 \text{ km}^2$$

using instrumental data only, and

$$\log N = 1.27 - 0.6M_L \quad \text{per yr per } 10^5 \text{ km}^2$$

using both historical and instrumental data (Sanford and Toppozada, 1974). Because the numbers of shocks used to establish the linear portions of these curves is very small (16 and 25, respectively), and the total time intervals over which data were collected is very short (11 and 50 years, respectively), an error in the slope (or b value) is quite possible. In fact, a certain dissatisfaction with these results on the part of Sanford and Toppozada is indicated by their development of alternate curves somewhat arbitrarily defined to have a slope of 1.0 instead of 0.6. Algermissen and Perkins (1976) calculate recurrence curves for a number of their source zones. For example, for source zone 45 (as defined in either Figure 5.3-3 or 5.3-4) they find the equivalent of

$$\log N = 0.53 - 0.52\, M_C \quad \text{per yr per } 10^5 \text{ km}^2$$

while for source zone 43, no formula is found, presumably for lack of data. Clearly, the difficulties of finding meaningful recurrence relations for such a short and areally restrictive interval in a region of low seismicity are formidable. Another problem is also implied by the last two equations. Magnitude M_C in the Algermissen and Perkins

formulation is somewhat vaguely defined, as mentioned above, as the magnitude corresponding to I_o in the equation:

$$M_c = 1.3 + 0.6\ I_o$$

where I_o is maximum intensity on the Modified Mercalli Scale. There seems to be no rigorous and straightforward way to relate this magnitude to the M_L of Sanford and Toppozada. Even the definition of M_L, upon which development of recurrence curves is fundamentally dependent, has been revised in the past few years as was seen in subsection 5.2.2

Fortunately, recent work (Sanford et al., 1976b) allows a preliminary treatment of the data that circumvents the worst of these problems. This recent study is based on eleven years of instrumental seismicity data which have been reinterpreted with respect to magnitude. In addition, recurrence formulas are computed for broad physiographic regions of New Mexico vastly increasing the data base. The criterion used in this current hazard analysis will be to use the Sanford et al. (1976b) recurrence formula for the physiographic province in which an individual source zone occurs with the value scaled down to reflect area differences. For example, Sanford et al. (1976b) find

$$\log N = 2.4 - 1.0\ M_L \quad \text{per yr per } 10^5 \text{ km}^2$$

for the High Plains province where the site is located, and

$$\log N = 2.5 - 1.0\ M_L \quad \text{per yr per } 10^5 \text{ km}^2$$

for the Basin and Range - Rio Grande Rift region. The area of the High Plains province of interest for this analysis is approximately 3.4×10^4 km^2 surrounding the site but exclusive of part of the Central Basin Platform. Thus the proper recurrence formula becomes

$$\log N = 1.93 - M_L \quad \text{Site source zone}$$

Similarly, the part of the Southern Basin and Range - Rio Grande Rift region of interest has been referred to in the above discussion as the Rio Grange Rift source zone and had an area of about 1.15×10^5 km^2. The proper recurrence formula becomes

$$\log N = 2.56 - 1.0\ M_L \quad \text{Rio Grande Rift source zone}$$

This leaves only the Central Basin Platform which is essentially a special case. Although the above two formulas were developed for areas near 2×10^5 km^2 in extent with the increase in confidence therefrom derived, this cannot be done for the Central Basin Platform source zone because it is unique and very limited in area. It, therefore, cannot be treated as simply a scaled-down version of some broader region. Although recent work using data from the Kermit array (Rogers and Malkiel, 1978) is available for this source zone, it was decided to use the recurrence formulation of Sanford et al., (1978) for this hazard analysis both for consistency in approach and because this treatment is the only one to calculate a recurrence formula for this source zone using revised magnitude estimates. Based on the seismicity detected in the Central Basin Platform since the installation of station CLN in April 1975, the cumulative number of shocks versus magnitude may be expressed as

$$\log N = 3.84 - 0.9\ M_L \quad \text{per yr per } 10^5 \text{ km}^2$$

Assuming that the active portion of the Central Basin Platform had an area of 8×10^3 km^2 during this period (Sanford et al, 1978) the proper recurrence relation becomes:

$$\log N = 2.74 - 0.9\ M_L \quad \text{Central Basin Platform source zone}$$

These are the recurrence relationships used in the current hazard analysis for the site.

One feature of several of these recurrence formulas is apparent: that is, they are very similar when normalized to equal source areas. This is

somewhat surprising in that the geologic indications of recent tectonism vary from source zone to source zone. One way in which the seismic and geologic data may be reconciled is to impose some upper limit on the magnitude of the earthquake that can occur in the geologically quiet areas that is less than the maximum magnitude event that can occur in source zones with evidence of Quaternary tectonism in the form of fault offset. This will be discussed in a later section but is mentioned here as a preface to the final aspect of source region characterization necessary to perform a hazard analysis: that is, maximum magnitude event within each source zone.

It is clear that a simple consideration of maximum historical magnitude within each of the three source zones as specified above will not be adequate to assure conservatism. This is particularly true of the northern part of the Rio Grande Rift source zone (Zone 43 of Algermissen and Perkins, 1976) where a maximum historical intensity of only V is known. As discussed above, the fault scarps in this area, particularly along the margins of the San Andres and Sacramento Mountains, indicate the strong possiblity that major earthquakes have occurred in this region within the past 5×10^5 years. The length of the faulting in these two areas (about 60 to 100 kilometers) suggests earthquakes comparable in strength to the Sonoran earthquake of 1887 (Sanford and Toppozada, 1974). This major earthquake (M=7.8) produced 80 kilometers of fault scarp with a maximum displacement of about 8.5 m extending southward from the U.S. - Mexico border at about 109° W longitude. Sanford and Toppozada (1974) assume that a similar event is possible in the future west of a line in good agreement with the eastern boundary of the Rio Grande Rift zone as shown in Figure 5.3-5. This eclipses the more southerly Valentine, Texas, earthquake whose magnitude has been variously estimated to be 6.1 (Algermissen and Perkins, 1976) and 6.4 (Sanford and Toppozada, 1974). For the purposes of this analysis, a maximum magnitude event of 7.5 will be assumed able to occur anywhere within the Rio Grande Rift source zone in general agreement with Sanford and Toppozada.

Selection of maximum magnitude events for the site source zone and the Central Basin Platform source zone is more difficult. Algermissen and Perkins (1976) assign a maximum historical intensity of VI to the Central Basin Platform. This is presumably the earthquake of August 14, 1966 which has been assigned this intensity in United States Earthquakes, 1966 (Von Hake and Cloud, 1968). On the basis of this intensity and the empirical relationship of Gutenberg and Richter (1942):

$$M = 1.3 + 0.6\ I_o$$

a maximum magnitude event of 4.9 has been selected for the Central Basin Platform by Algermissen and Perkins (1976) as appropriate for their probabilistic acceleration analysis. The magnitude scale was designed to give some indication of the elastic energy released at the earthquake source, and in this context, the 4.9 value above is almost certainly an exaggeration of the energy really released during this particular earthquake. This conclusion is based on both macroseismic and instrumental evidence. For example, one of the descriptions of this shock was, "Like a stick of dynamite being detonated several hundred feet away" (Von Hake and Cloud, 1968). This and a general consideration of felt effects are consistent with the contention that this earthquake has been assigned a relatively high epicentral intensity primarily because it occurred very near a population center. In addition, several magnitudes have been published for this earthquake (U.S.C.G.S. - 3.4; Sanford et al. 1978 - 2.8) which are substantially lower than the 4.9 value used by Algermissen and Perkins.

The maximum instrumental magnitude for an event in the Central Basin Platform source zone is open to some debate because of the apparently different application of magnitude scale by various agencies for this region. The largest earthquake in this region before installation of station CLN had a magnitude less than 3.25 according to the most recent calculations at New Mexico Institute of Mining and Technology (Sanford et al., 1978). Between 1974 and October 1977, during the operation period of CLN for which data is currently available, a number of earthquakes

have been located by Sanford and his colleagues, none of which have been assigned magnitudes greater than 3.2. In the Rogers and Malkiel (1978) study of data from the recently established Kermit array, events with magnitudes approaching 4 are listed. However, as was stated in subsection 5.2.4, a direct comparison of magnitudes for earthquakes listed in both the New Mexico Institute of Mining and Technology and Kermit array data sets shows that events are routinely assigned magnitudes almost one unit higher in the latter listing. Therefore, the maximum historical magnitude earthquake in the Central Basin Platform Source Zone is still a matter for conjecture although some value between 3.0 and 4.0 is most likely.

The features of this source zone that might bear on its possible maximum magnitude are the lack of recent geologic evidence of tectonism, and the high activity rate which may or may not be directly associated with secondary oil recovery efforts. Sanford and Toppozada (1974) conjecture that the maximum magnitude might be 6.0 for this source zone, and in this study of hazard their example will be followed for one set of calculations. Because this value may be exceptionally conservative, an alternate maximum magnitude of 5.0 is also considered.

With regard to the site source zone, there is even less indication that significant magnitude events are reasonably likely. There is no Quaternary fault offset (Bachman and Johnson, 1973) and seismic activity is low. However, recent studies (Caravella and Sanford, 1977) have shown that some level of background seismicity must currently be considered for the site area if conservatism is to be served. Apparently, an earthquake which may be tectonic in origin and with a magnitude of 3.5 has occurred within the site source zone itself (see subsection 5.2.5). Two maximum magnitudes were considered in the hazard analysis of this section: 4.5, that is the maximum historical event plus one magnitude unit; and 5.0, a rather ad hoc attempt to consider additional conservatism in general agreement with the size of a random event possible in the central United States and not associated with a particular source zone (Algermissen and Perkins, 1976).

All the parameters necessary to perform a probabilistic acceleration hazard calculation for the Los Medanos site after the method of Cornell (1968) have now been presented and discussed. In the next subsection the results of these calculations are considered.

5.3.3 Results

The basic results are shown in Figures 5.3-6 and 5.3-7. These are plots of the probabilities that the maximum annual acceleration will exceed some specified acceleration versus the specified acceleration. For example, in Figure 5.3-6, Curve 1, which shows the contribution to risk at the site due to earthquakes in the Rio Grande Rift source zone as shown in Figure 5.3-5, indicates that the probability that the maximum acceleration at the site from this source zone in any one year will exceed 0.05g is approximately 1.8×10^{-5} or 1.8 in one hundred thousand. Probabilities are similarly found for other values of acceleration.

In both Figures 5.3-6 and 5.3-7, six curves are shown. Curve 1 is the same in both figures and represents the probabilistic maximum acceleration distribution for the Rio Grande Rift source zone as described above. Curves 2 and 2' are also the same in both figures, representing the risk from the site source zone when its maximum magnitude is 5.0 and 4.5, respectively. Curve 3 in each figure is the risk distribution from earthquakes in the Central Basin Platform source zone. In Figure 5.3-6, the maximum magnitude event in this zone is assumed to be 6.0 while in Figure 5.3-7 it is given a value of 5.0. Finally, curves 4 and 4' are the total probabilistic maximum accelerations at the site from all source areas combined. For example, Curve 4 in Figure 5.3-6 is the risk at the site assuming the geometric and recurrence properties, and the acceleration attenuation, of the last subsection and a maximum magnitude of 6.0 in the Central Basin Platform source zone and 5.0 in the site source zone.

Probabilities for accelerations below 0.03g have not been calculated. This is because of a feature of the method used. For a given source geometry and minimum magnitude, the lower limit of validity of probabilistic acceleration is fixed (see Figure 5.3-1top) such that $a \geq a'$.

$$a' = 17 \exp 0.92 m_o d^{-1}$$

where m_o is the minimum magnitude and d is minimum distance to any source zone. For the worst case, d = 5 km. The value for m_o, 2.4, is the same for all source zones and is derived from an estimate of the smallest earthquakes recorded uniformly throughout the state of New Mexico (Sanford et al., 1978). Substituting these values into the above expression results in $a' = 30.9$ cm/sec^2 or $a' = 0.03g$.

There are several interesting features that may be derived from a comparison of the four curves, 4 and 4' in both Figures 5.3-6 and 5.3-7. First, it may be noted that in spite of the greater conservatism exercised in the selection of model parameters for this study than in the Algermissen and Perkins (1976) study--on which so much of the current risk evaluation depends--the basic conclusion of Algermissen and Perkins that the site is in an area with less than one chance in ten that an acceleration of 0.04g will be exceeded in any 50 year period is in very good agreement with the results shown in Figures 5.3-6 and 5.3-7. To see this it may be noted that the return period for the Algermissen and Perkins study is about 475 years. For the slightly more conservative curves of Figure 5.3-6, the maximum accelerations at this return period are around 0.045g while in Figure 5.3-7 they are 0.035g.

Secondly, it is interesting to note that under the assumptions of the previous section the significance of the Rio Grande Rift source zone to the total risk at the site is relatively small at all acceleration levels. Because of the earthquake recurrence relationships for the various source zones, this will be true at lower acceleration levels no matter what assumptions are made about the maximum magnitudes in the site

and Central Basin Platform source zones. At higher acceleration levels, this will be true unless the lowest maximum magnitude proper for the site source zone is lower than the 4.5 value considered here. Although probabilities are low at all site acceleration levels from the Rio Grande Rift source zone, the maximum acceleration at the site from a 7.5 shock at a distance of 115 kilometers using the attenuation law of subsection 5.3.2 is 0.15g. This is slightly greater than the 0.1g acceleration assumed to be the maximum at the site in previous studies (Sanford and Toppozada, 1974).

In the case of the Central Basin Platform source zone, a comparison of the two figures shows an interesting phenomenon. For the case where 6.0 is the maximum magnitude event, probabilities are largely controlled by earthquakes in this source zone up to accelerations of around 0.1g. For higher accelerations, the site source zone is more important. If 5.0 is a better maximum magnitude shock in the Central Basin Platform, its significance as a source of risk is completely eclipsed by the site source zone itself at all acceleration levels.

Perhaps the most universal feature of all four total risk curves is their dominance by the site source zone at higher accelerations. If the probabilities at which these higher acceleration levels occur are thought to be of interest, it is the assumptions that are made about the immediate site area that are most critical.

It is believed that the presentation in this section gives the broadest possible assessment of seismic risk at the site in a way that shows explicitly the assumptions used and, to a small extent at least, the effect of varying some of these assumptions. Acceleration is not the only parameter of design significance, of course, so that a plot of its probability is not the whole story even if such a plot is completely accurate.

3.4 SEISMOLOGICAL DATA AND SITE REGION TECTONISM

In previous sections the historical record of seismicity in the site region has been explored as well as the way this record, when combined with very general geologic arguments, can be used to estimate risk levels attached to various possible seismic design acceleration values. In this section the extent to which this seismological data may be used to draw inferences of a longer term nature is considered. The interval over which seismological data can be collected is still very brief; the total available earthquake record, and especially that fraction of it representing the period of instrumental observation, covers a period of time that is very short compared to the total geologic time scale. Thus, a comparison of the regional tectonism derived from a study of geologic processes and structures, with that derived from a study of earthquakes, involves a question of consistency: that is, are the characteristics of regional earthquakes consistent with known geologic structures and the large-scale stresses thought to have been active in their evolution?

Implicit in this concept of tectonics is the definition of tectonic earthquake that is used in this section. The subject of tectonics as it is used here is structural geology. Tectonic earthquakes are those believed to be associated with faulting. This is taken to exclude minor shocks due to less important causes (Richter, 1958). As mentioned in subsections 5.2.4 and 5.2.5 it is not clear that the detected earthquakes in either the site source zone or the Central Basin Platform are tectonic under this definition. There seem to be few geologic structures in either area that would lead one to expect significant tectonism either now or for vast times in the past. Nevertheless, conservatism suggests that these events should be considered tectonic at this stage of our knowledge, and this assumption was made for the seismic risk analysis of the previous section.

Seismology, in the context of tectonism, will be considered below under two general headings: implications about the regional stress regime from focal mechanism solutions, and implications about regional activity from

historic recurrence statistics. Although earthquakes are sometimes used to delineate specific active structures in a way important to discussions of regional tectonism this will not be attempted here, primarily because even in areas with recent faulting, such as occur in the southern Basin and Range province, or in areas with sophisticated seismic array location capabilities as in the Central Basin Platform, the known earthquakes are simply not well correlated with specific geologic structures on a detailed scale.

The ultimate association of seismic and geologic processes is derived from the observation that the structural behavior of an element of the earth's crust is often associated with the release of elastic strain energy in the form of earthquakes. The nature of this association itself, however, may be far from simple. This is especially true of small earthquakes whose characteristics are derived from processes taking place in a very small volume of a crust that, in this context, must be considered very inhomogeneous. As was seen in Section 5.2, the latest calculations show that only one instrumentally located earthquake within 300 kilometers of the site (the Valentine, Texas, event) has exceeded magnitude 4.6. Similarly, within 300 kilometers of the site but outside the Rio Grande Rift source zone as defined in Section 5.3 no earthquake has exceeded magnitude 3.5. This should be kept in mind throughout this section. It may also be noted that most empirical experience in relating tectonic features to seismicity, or vice versa, has been gathered in regions that are much more active than the site region. This too was mentioned in Section 5.2 and is made very clear by comparing earthquake recurrence statistics for the site region with similar statistics for an area such as California. The picture presented by a comparison of seismologic with structural geologic data appears confused for the site region. At least these two data sources are not consistent in the same way or to the same degree that is found in other regions characterized by larger historical earthquakes. It is premature to attempt a reconciliation here, if indeed one is necessary, so that in this section existing evidence (although often only preliminary) is outlined and briefly discussed.

5.4.1 Regional Stress Orientation

The catalog of published crustal stress measurements in the Los Medanos region is a short one. It consists of three focal mechanism solutions and one in situ hydrofracture determination. Another in-situ stress measurement was quoted recently in connection with west Texas studies (Rogers and Malkiel, 1978), but this measurement is some distance to the east, on the Llano uplift. In this very limited data collection, there is little agreement, and none should necessarily be expected since the measurements come from different structural blocks.

The earliest indication of the stress regime for a point within the general Los Medanos site region (when defined as it has been in this chapter as within 300 kilometers of the site) comes from an analysis of first motion polarities from the Valentine, Texas, earthquake of August 16, 1931. In his study of this event Byerly (1934), carefully noted the polarity, azimuth, and epicentral distances of waves at all stations recording this earthquake. He concluded that the observed polarity pattern could be explained by normal movement on a shallow fault striking N35^{o}W, and dipping very steeply to the west. He also noted that certain stations did not fit this pattern and attributed most of these discrepancies to difficulties in observing the true first arrival, which was apparently lost in the noise at these stations. Fortunately, all polarity readings were listed in Byerly's paper for this earthquake, which was recorded at distances ranging from 5.8^{o} to 104.8^{o}. Applying the recent techniques of stereographic projection to Byerly's data, Sanford and Toppozada (1974) obtained an independent but very similar solution shown in Figure 5.4-1a. This solution indicates predominantly dip-slip motion along a normal fault striking N40^{o}W and dipping 74° southwest, or motion of a similar nature on a fault striking N19^{o}W and dipping 18° northeast. The first possibility is preferred because of the structural fabric of the epicentral region with which it is consistent. The inconsistent polarity readings are those noted previously by Byerly. It is worth mentioning that the regional stresses implied by this solution (P-axis or axis of maximum compressive

stress striking N51°E and plunging 62° to the northeast and T-axis or axis of least compressive stress striking S61°W and plunging 28° to the southwest) are the only ones for this region that are incontrovertibly of some tectonic significance.

The remaining two focal mechanism solutions available at this time for the site region have been very recently determined from data recorded at the Kermit array. One solution is a composite of data from three small earthquakes that occurred within a 7-day period in January 1976 and is reproduced from Rogers and Malkiel (1978) in Figure 5.4-1b. The other solution is from a single earthquake on April 26, 1977, in the same area as the other three near array station KT5 (see Figure 5.2-5) and is reproduced, also from Rogers and Malkiel, in Figure 5.4-1c. These are the only events occurring during array operation that have produced a sufficient number of clear first motion polarities to allow focal mechanism solutions.

The earthquakes from which the composite solution of Fig. 5.4-1bottom was derived occurred on January 19, 22, and 25, 1976 and had U.S.G.S. assigned magnitudes of 3.47, 2.83, and 3.92, respectively. It has already been noted in Section 5.2 that these magnitudes appear to be almost a unit larger than those most recently calculated for shocks in this area by Sanford and his colleagues at the New Mexico Institute of Mining and Technology. The preferred fault plane, based on the geologic structure of the Central Basin Platform, strikes N19°W and dips to the west at 53°. The sense of fault motion is that of normal faulting. Similarity to the solution for the Valentine earthquake is clear. The data for the April 1977 event do not fit this type of solution and do not permit a unique mechanism to be obtained. Normal, thrust, and strike-slip mechanism are possible. The normal solution shown in Figure 5.4-1c is the only one considered by Rogers and Malkiel to be relatively consistent with the composite mechanism and the regional tectonics.

The tectonic significance of these last two focal mechanisms is confused by their occurrence in an area where both active fluid withdrawal and

injection are taking place. This confusion is apparently not lessened by considering the in situ stress data. Hydrofracture data from a well in Howard County, Texas to the east (Fraser and Pettit, 1962) indicate a tension axis that trends south-southeast. Overcoring data from Hooker and Johnson (1969) even further to the east in Burnet County, Texas, on the Llano uplift show reversion to a southwest trend for the tension axis. According to Rogers and Malkiel (1978), both the Howard and Burnet County data show a horizontal axis of maximum compression. This is in disagreement with the focal mechanisms, for which the greatest compressive stress is steeply plunging. Also, von Schonfeldt et al. (1973) have indicated that the greatest principal stress in this area is a vertically oriented, overburden induced compressive stress because hydrofracture experiments generally produce vertical fractures in Texas, except in some shallow wells (Hays, 1977). In the face of such a variety of interpretations, it is premature to speculate on the significance, or lack of it, of these data. Any such speculation will have to wait on the collection of new data or additional analysis of existing information.

5.4.2 Tectonism and Earthquake Recurrence Relations

In Section 5.2 the seismicity of the Los Medanos site region was studied. It was noted that most of the activity of recent years had occurred in the Central Basin Platform in two particular areas located such that Sg-Pg intervals at station CLN very near the site were 8 to 13 seconds and 22 to 24 seconds (Sanford, et al. 1978). Another group of epicenters for shocks with Sg-Pg intervals from 31 to 36 seconds were found by these authors to occur in several tectonically active regions to the southwest and west of the site--notably near Valentine, Texas, and in much of the Tularosa Basin. These three Sg-Pg intervals account for the most important peaks on the histogram appearing in Figure 5.2-5. Earthquakes at other distances contribute a general background occurrence level also apparent in this histogram. At least some of these events are known to have occurred in the general site region and not in association with either the Central Basin Platform or the Rio Grande Rift source

zones of the previous section. This characterization of the regional seismicity is interesting because there is abundant geologic evidence for recent tectonic activity for the source zones to the west and none for the Central Basin Platform.

This situation can be described more quantitatively by considering earthquake recurrence statistics. Relations of the form logN=a-bM for the three source zones of Section 5.3 have already been shown. These formulas, taken from Sanford et al. (1976b) and Sanford et al. (1978) may be normalized to equal time intervals and areas for comparison (assuming such a comparison is meaningful) to give:

$$\log N = 2.5 - M_L \quad \text{Rio Grande Rift zone}$$

$$\log N = 2.4 - M_L \quad \text{High Plains Province}$$

$$\log N = 3.84 - 0.9\, M_L \quad \text{Central Basin Platform}$$

where in each case the formulas give the number of occurrences, N, of events with magnitude M_L or greater per year in a 10^5 km^2 area. It is clear that if these relations truly indicated some measure of tectonic activity in effect for a long time period the relative tectonic importance of these areas would be in conflict with that implied by the geologic data. This is particularly true for the Central Basin Platform activity.

Several explanations have been offered to resolve this conflict (Sanford et al., 1978). One is that a recent change in regional stress may be responsible. In this view, the tectonic implications of very recent seismicity are preferred to those of the geologic record. The other extreme possibility is that the observed recent seismicity, especially in the Central Basin Platform, has little bearing on tectonism in the sense normally used in connection with magnitude recurrence relations. Thus, the geologic implications to past and recent (and, by extrapolation, future) tectonism are preferred to those of recent seismicity. Finally,

there is an intermediate position which attempts reconciliation of both the geologic and seismic data by prescribing some particular mode of crustal behavior in the High Plains physiographic province and the Central Basin Platform. The only explicit property of this mode of behavior is that large magnitude earthquakes do not occur; hence, extrapolation of the recurrence formulas above to large magnitudes is fundamentally inaccurate.

The first possibility, that the regional geology of the High Plains province and Central Basin Platform is in essence misleading, is the least satisfactory. There does not seem to be any implication of recent regional stress changes in the more active areas of New Mexico. Sanford et al. (1972) performed calculations comparing the implications to tectonic activity of recent fault offset in the Rio Grande Rift (where recent is defined as less than 4×10^5 years old) with similar implications from recurrence statistics both from historical earthquakes and from microearthquake studies (Sanford and Singh, 1968). These calculations show that if the fault scarps are less than 4×10^4 years old, the seismicity obtained is compatible with the historical earthquake activity in the Socorro region. If the age span of the fault scarps is increased to about 2×10^5 years. the seismicity becomes close to that indicated by the microearthquake studies. It may also be noted here that the focal mechanism solution obtained for the Valentine, Texas, earthquake is consistent with the sense of fault motion implied by the geologic structure of that area.

Using similar types of arguments some limits can be placed on how recently the change in stress postulated for the High Plains province and the Central Basin Platform must have taken place. Consider that part of the High Plains province designated as the site source zone in Section 5.3. Then the recurrence relation is, after Sanford et al. (1976b):

$$\log N = 1.93 - M_L$$

The use of this formula in an uncritical way leads to the conclusion that an earthquake of magnitude greater than or equal to 7.0 should occur in this zone on the average of once in about 10^5 years. Such an earthquake would certainly leave physical evidence of fault offset. If the High Plains province of New Mexico is taken as a whole, a similar earthquake would be expected on the average of once in slightly over 2×10^4 years. Assuming that earthquake occurrence is distributed as a Poisson process, it can be concluded that an earthquake of magnitude 7.0 or greater has a 63 percent likelihood of occurring in a given 2×10^4 year period and that it has a 90 percent likelihood of occurring in a given 2×10^5 year period. Nevertheless, no evidence is known of fault offset suggesting earthquakes of this size anywhere in the High Plains during comparable or longer time periods. Thus, if there have been changes in regional stress that are responsible for the observed conflict between geologic and seismic data, these changes probably have taken place more recently than within the last 2×10^4 to 2×10^5 years.

A similar calculation may be applied to the Central Basin Platform. In this case on the basis of seismic evidence the recurrence interval for a magnitude 7.0 earthquake is about 3500 years. As in the High Plains, there is no geologic evidence for such an earthquake. Thus, the geologic and seismic evidence appear to contradict one another unless the current seismicity is the result of a tectonic stress change that took place within the last several thousands or tens of thousands of years. The implications of recurrence intervals for large earthquakes developed from short term seismic data should not form the basis for rationally discarding contradicting geologic evidence.

The second possibility as it is presented here applies only to the Central Basin Platform. That is, the recurrence statistics for earthquakes in this small area are not related to tectonism in the usual sense of this concept and should not be used for tectonic implications of long time intervals. The principal support for this view is outlined in Sanford and Toppozada (1974). Basically, it has been postulated that the earthquakes on the Central Basin Platform are related to massive fluid

injection for secondary recovery of oil. Both the spatial and temporal association of this seismicity with these secondary recovery projects are very suggestive. This has already been discussed in greater detail in subsection 5.2.4 and will not be repeated here. The wide variety of hypotheses regarding the stress field in the area of the Central Basin Platform neither preclude nor prove any causal relationship between the earthquakes and secondary recovery operations (Hays, 1977), but, the widely observed phenomenon of increased seismic activity during fluid injection (Healy et al., 1968; Healy et al., 1972) argues strongly against the uncritical extrapolation of short term magnitude recurrence formulas under the present conditions.

The third possibility, that the geologic and seismic data are not really in conflict, is the most satisfying from a philosophical viewpoint. It is certainly simpler to derive meaningful conclusions about the physical properties of a system that is not changing than about one that is. It has already been mentioned that such consistency exists for the Rio Grande Rift, at least in gross terms. A similar reconciliation might be possible for the High Plains province or the Central Basin Platform by restricting the maximum magnitude of an earthquake that can occur in either the High Plains physiographic province or the Central Basin Platform.

The simplest restriction that can be applied to the magnitude of shallow seismic events that have occurred in the past is imposed by the size or absence of observed faulting. An argument of this type has been used above in considering the questions of recent stress regime changes. In very general terms, it is believed that where recent geologic faulting exists, even in the absence of observed large magnitude earthquakes, conservatism requires that such seismic activity should be anticipated (Allen et al., 1965; Sanford et al., 1972); that is, to a high level of confidence, large recent faults in an area imply large magnitude earthquakes must be considered there. The converse argument, that large magnitude shallow earthquakes always produce episodes of large scale shallow faulting is even more widely believed. This assertion appears so

absolute because the definitions of "large" earthquake and "large-scale" faulting have been left purposely vague. A more empirically useful statement might be that the largest recent fault offsets (in terms of both fault length and fault displacement) that are found in an area under a given set of geologic conditions and after an adequate search impose an upper limit on the magnitudes of past earthquakes.

The general relation between magnitude of shallow-focus earthquakes and size or volume of the deformed region and the length and amount of displacement of activated surface faults has long been recognized (Tsuboi, 1956; Richter, 1958). Tocher (1958) developed an early empirical relation between magnitude and fault length, and between magnitude and the product of fault length and maximum displacement. Many subsequent refinements have been formulated by adding additional data points (Iida, 1959 and 1965), applying the method to specific areas, as for southern California (Albee and Smith, 1966), and by refining the source data either for the western United States (Bonilla, 1967 and 1970; Bonilla and Buchanan, 1970) or for the world (Ambraseys and Tchalenko, 1968; Bonilla and Buchanan, 1970). Various dislocation models have been proposed by seismologists (Aki, 1967; Brune, 1968; Chinnery, 1969; King and Knopoff, 1968 and 1969; Press, 1967; and Wyss and Brune, 1968) one of which (King and Knopoff, 1968) was used by Sanford et al. (1972) in connection with fault offset-magnitude comparisons in the Rio Grande Rift as discussed above. A recent recompilation and reconsideration of fault offset data has been performed by Slemmons (1977). He finds, for North America data and faulting of all types that

$$\log D = -4.47 + 0.67M$$

$$\log L = 1.61 + 0.44M$$

where both D (fault displacement) and L (fault length) are in meters. Using these formulas, fault lengths of 6.46, 10.72, 17.78, 29.51, 48.98, and 81.28 kilometers are found for magnitudes from 5.0 to 7.5 in half magnitude increments. The respective displacements are 0.08, 0.16, 0.35,

0.77, 1.66, and 3.59 meters. Thus, if an area has been mapped so well that no fault of length about 18 kilometers and maximum displacement of about 1/3 meter could escape notice in strata of a given age, then it could be maintained that no event of magnitude greater than or equal to 6.0 had occurred in that area in the time since formation of the strata. Explicit statements of the kind necessary about the minimum observable fault are not generally available in the literature. If it is assumed that the conclusion of Bachman and Johnson (1973), that no recent fault scarps of a tectonic nature exist in the Permian Basin, is applicable at the scale of the minimum observable fault associated with a magnitude 6.0 earthquake, then the conflict between the geologic and seismic recurrence data is resolved. That is, the recurrence data may not be extrapolated beyond magnitude 6.0. Arguments of this type, although they are clearly over-simplified and depend on relationships between magnitude and fault offset derived from widely scattered data, are of interest at least for purposes of comparison with similiar studies made in other areas.

A more complete treatment of this type would have to address the issue of regional deformation. This involves not only the offset associated with a single earthquake but the deformation implied by summing the effects of all earthquakes. If total strain energy released as seismic waves is calculated from the magnitude recurrence relations, estimates of total available strain energy and total implied steady state deformation may be derived. These are both dependent on the maximum magnitude event allowed, since significant strain and most of the energy are associated with the larger events (Richter 1958). Thus, general deformation rates may be derived as a function of maximum magnitudes, and observed deformation rates may be used to infer an acceptable maximum magnitude for the region over which deformation is observed. Unfortunately, application of this type of analysis is subject to more complication and uncertainty than a simple fault argument. It seems clear, however, that deformation of a type that would be associated with accumulation and release of elastic strain energy has not been very important in the Permian Basin for very long periods of time.

Although other explanations cannot be precluded, it seems that the most reasonable interpretations of seismic implications to tectonism at this time are:

1) Observed geologic and seismic data are in general agreement in the Rio Grande Rift and Southern Basin and Range zones and that future significant earthquakes can be expected there.

2) The current level of activity on the Central Basin Platform is probably related to fluid injection for secondary recovery of oil. This fluid injection makes it unwise to question the geologic data of the area solely on the basis of this high seismic activity level (see Chapter 10).

3) The geologic data, principally the lack of recent geologic faulting, and the seismic data for the High Plains province, in which the site lies, can probably be reconciled by imposing a maximum magnitude limit on the earthquakes that may occur here.

5.5 SUMMARY

Non-instrumental and regional instrumental studies of earthquakes prior to 1972 in southeastern New Mexico indicate that the most significant sources of earthquakes were the Central Basin Platform region near Kermit, Texas, and the area about 200 km or more west and southwest of the site (Rio Grande Rift Zone). The strongest earthquake reported to occur within 300 km is the intensity VIII Valentine, Texas, event of August 16, 1931, at a distance of approximately 210 km. The closest shock (as of 1972) reported from these studies was a magnitude 2.8 event on July 26, 1972, about 40 km northwest of the site. The record from regional studies of events west and southwest of the WIPP site 200 km or more is consistent with the record of Quaternary faulting in that area.

Instrumental studies near the WIPP site since 1974 and near Kermit, Texas, since late 1975 have recorded additional evidence of the seismic activity for the site and region. The pattern obtained from near the site is similar to that from regional studies; about one-half of the located events in the data set occur on the Central Basin Platform while most of the rest occur to the west and southwest of the site in the Rio Grande Rift Zone. The data set also includes three events within about 40 km of the WIPP site since 1972. Two events have been assigned magnitudes of 2.8 and 3.6; the third event (from 1978) has only preliminary data available.

Data reported for the Central Basin Platform from the Kermit, Texas, array continue to show that location as the most active seismic area within 300 km of the site in terms of number of events. The largest earthquake known to occur in the Central Basin Platform had, by the most recent estimate, a magnitude of less than 3-1/4. The activity appears equally likely to occur anywhere along the Central Basin Platform structure without particular regard to small scale structural details such as pre-Permian buried faults. The spatial and temporal coincidence of this seismicity with secondary petroleum recovery projects suggest a close relationship, but this has not yet been satisfactorily established. The lack of known Quaternary faults from the seismically active region of the Central Basin Platform is suggestive that large magnitude earthquakes are not occuring or have not occurred within the recent geologic past in the area.

Analysis of the regional and local seismic data indicate that the 1000 year acceleration is less than or equal to 0.06 g and the 10,000 year acceleration is less than or equal to 0.1 g for all models tried. Probabilities at which higher acceleration levels occur depend almost exclusively on the assumptions made about the seismic potential of the immediate site area.

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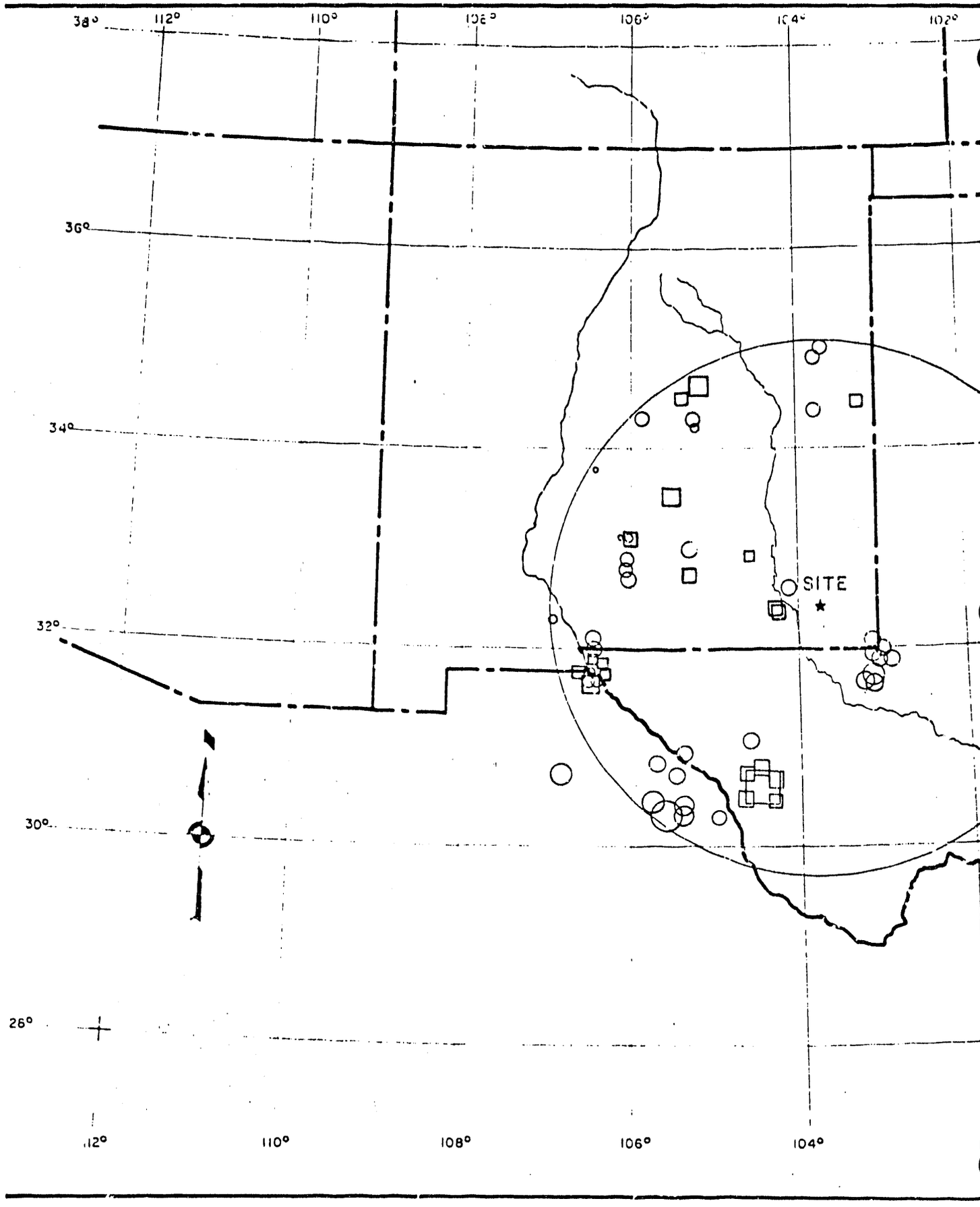
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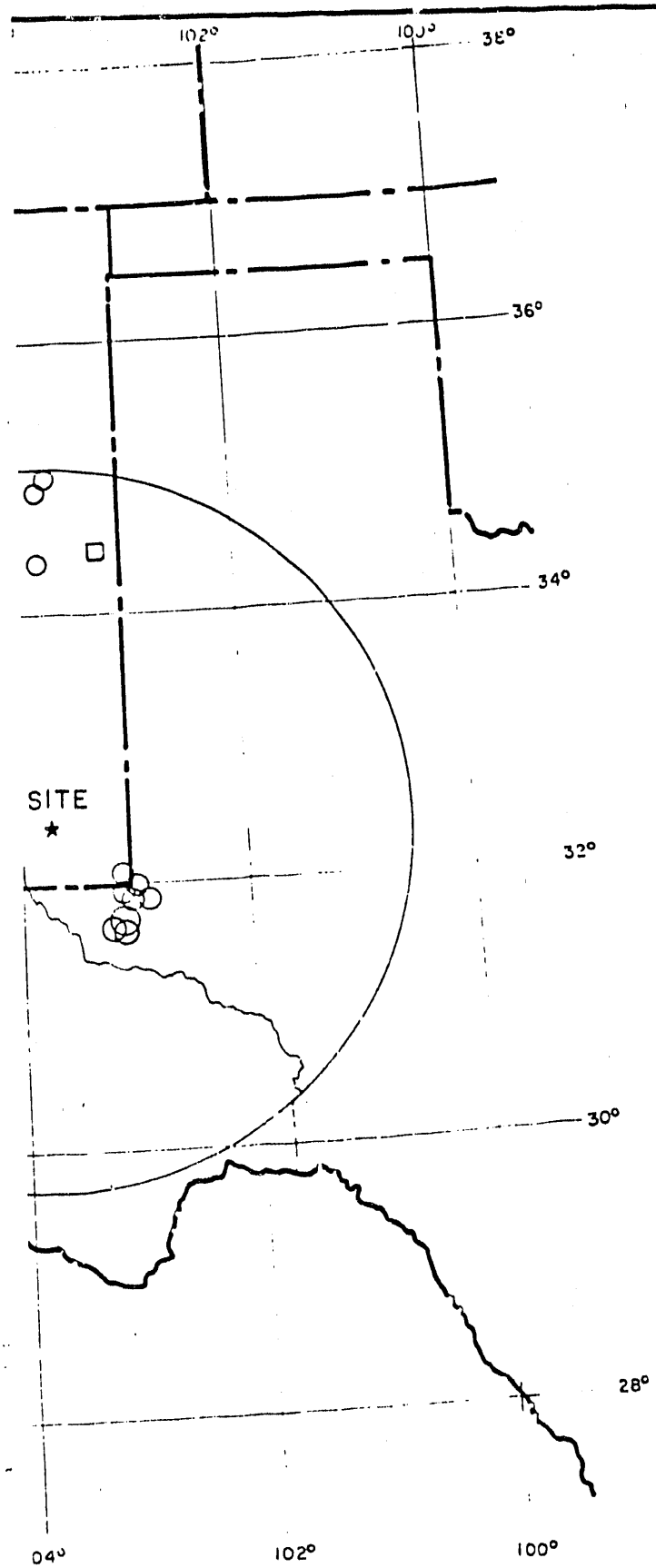


EXPLANATION

Locations of earthquakes within 300 km of the repository site. Locations shown with square symbols are based on reports of felt earthquakes prior to 1961. Epicenters shown with circles were determined instrumentally and cover the period 1961 through 1972. In the Central Basin Platform and Chihuahua areas where crowding occurs some epicenters are slightly offset for drafting convenience. The true epicenters are listed in Tables 5.2-1 and 5.2-3.

Local Magnitude	Maximum Intensity
∘ <1.5	□ III
○ 1.51-2.0	□ IV
○ 2.01-2.5	□ V
○ 2.51-3.0	□ VI
○ 3.01-3.5	□ VII
○ 3.51-4.0	□ VIII
○ 4.01-4.5	
○ 4.51-5.0	

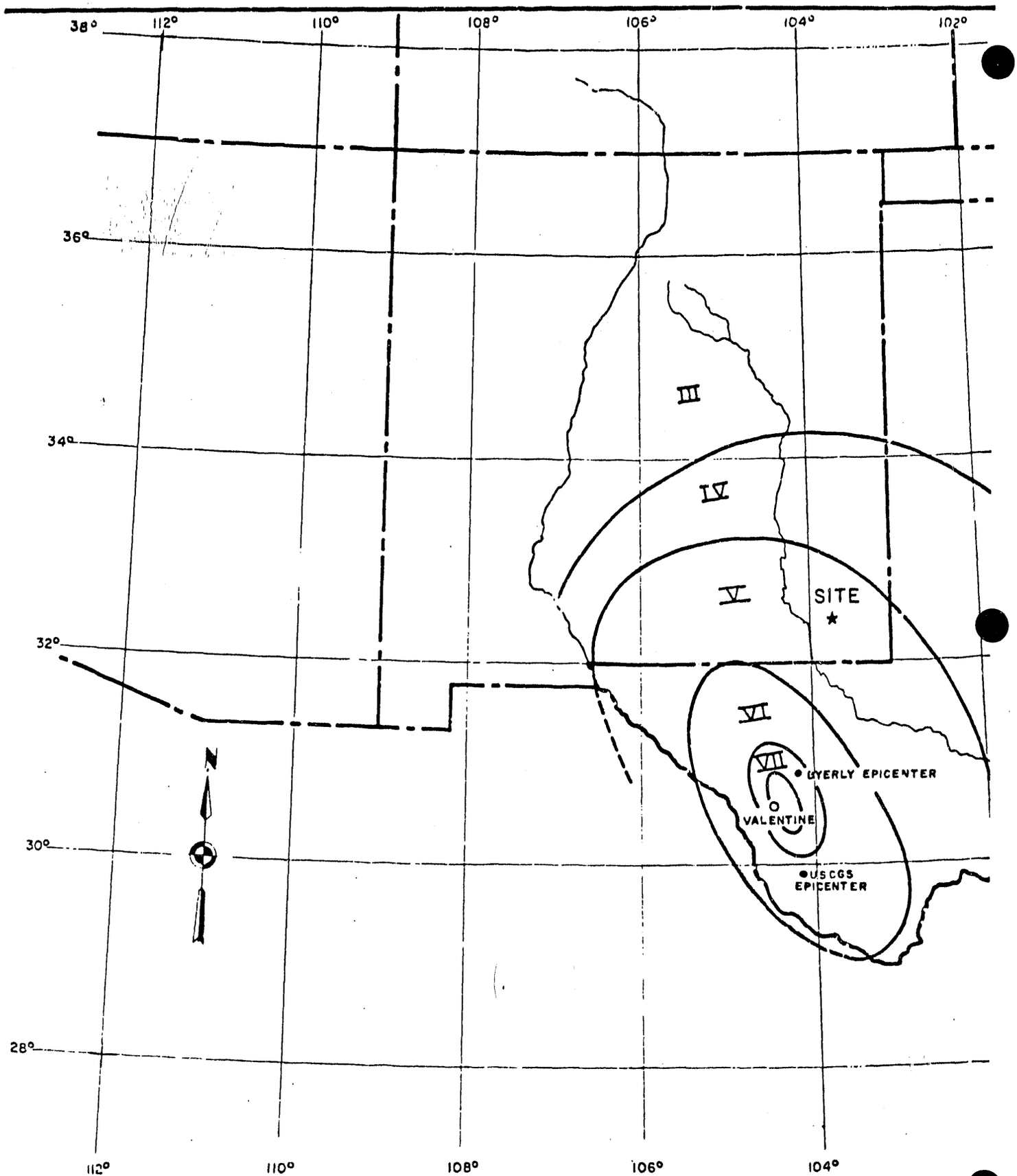
0 100 200 300 KM
0 50 100 150 200 MI
SCALE

REFERENCE:

SANFORD AND TOPPOZADA (1974)

REGIONAL SEISMICITY 1923-1972

FIGURE 5.2-1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IV
V
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VII
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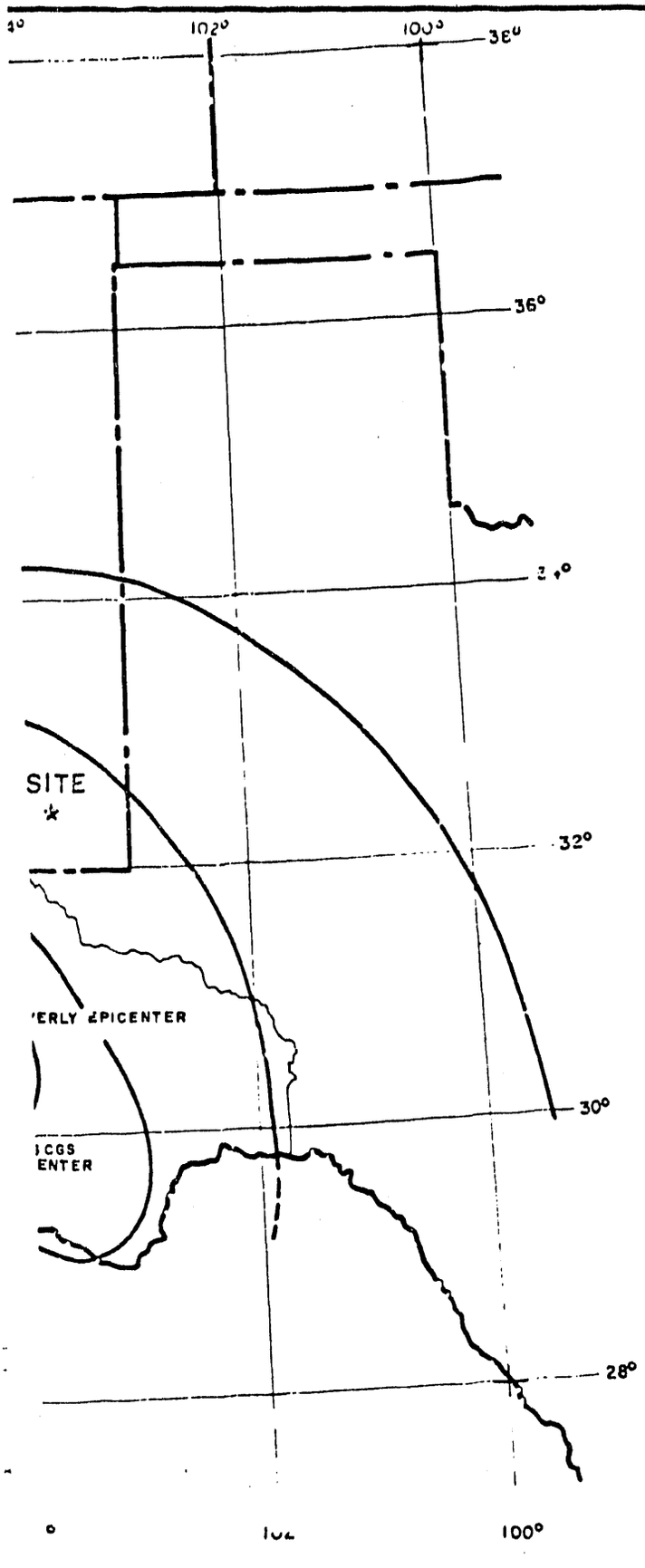
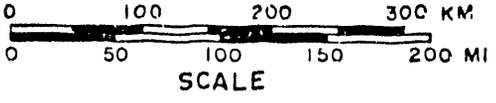
LYERLY EPICENTER
VALENTINE
USCGS EPICENTER
N



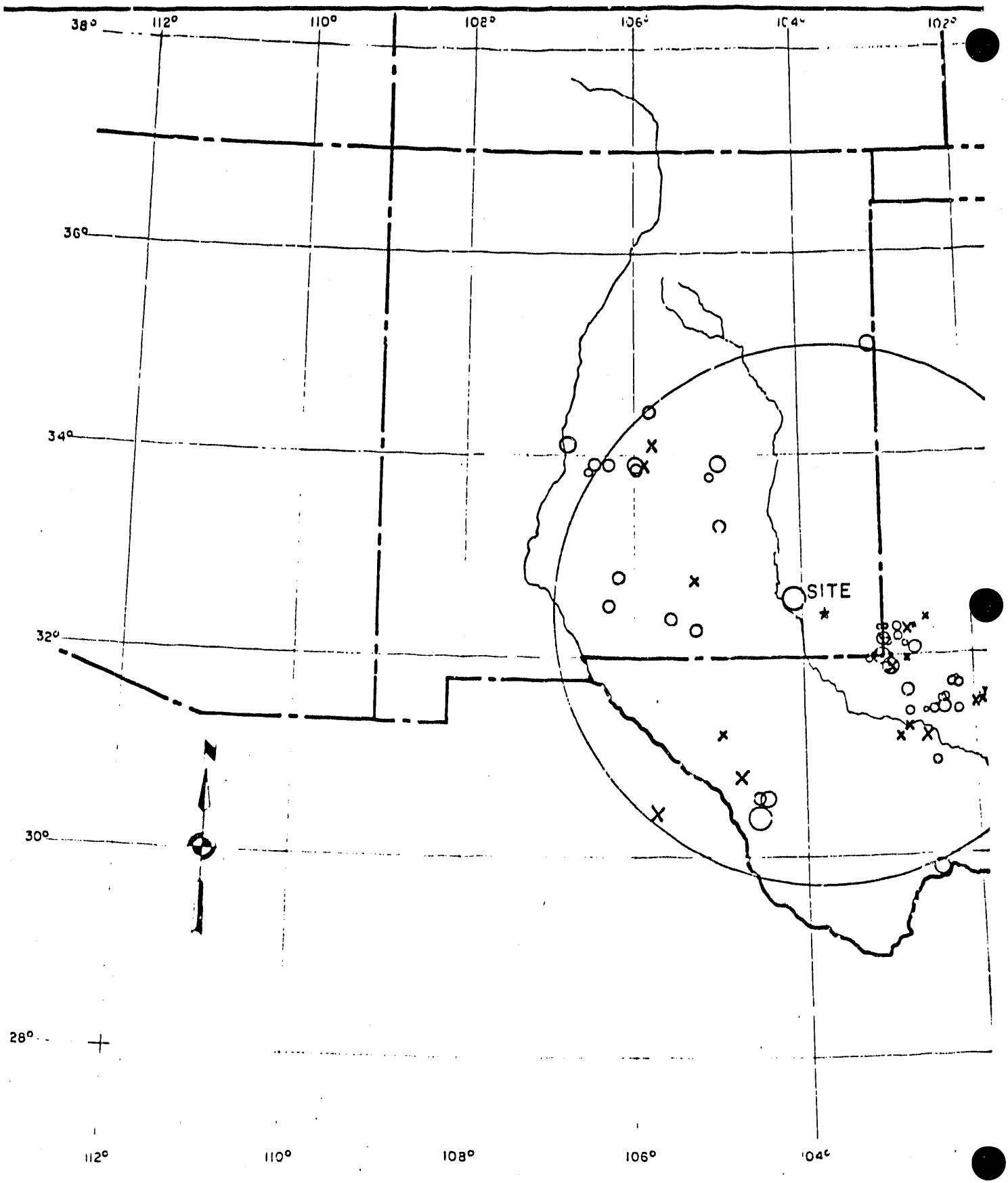
EXPLANATION

Isoseismal map for the Valentine, Texas earthquake of August 16, 1931 (after Sanford and Toppozada, 1974). Intensities are in the Modified Mercalli scale of 1931 (see Table 5.2-2). Also shown are the instrumental epicenters for this earthquake as determined by the U.S.C.G.S. (Neumann, 1932) and Byerly (1934).



VALENTINE, TEXAS EARTHQUAKE ISOSEISMALS

FIGURE 5.2-2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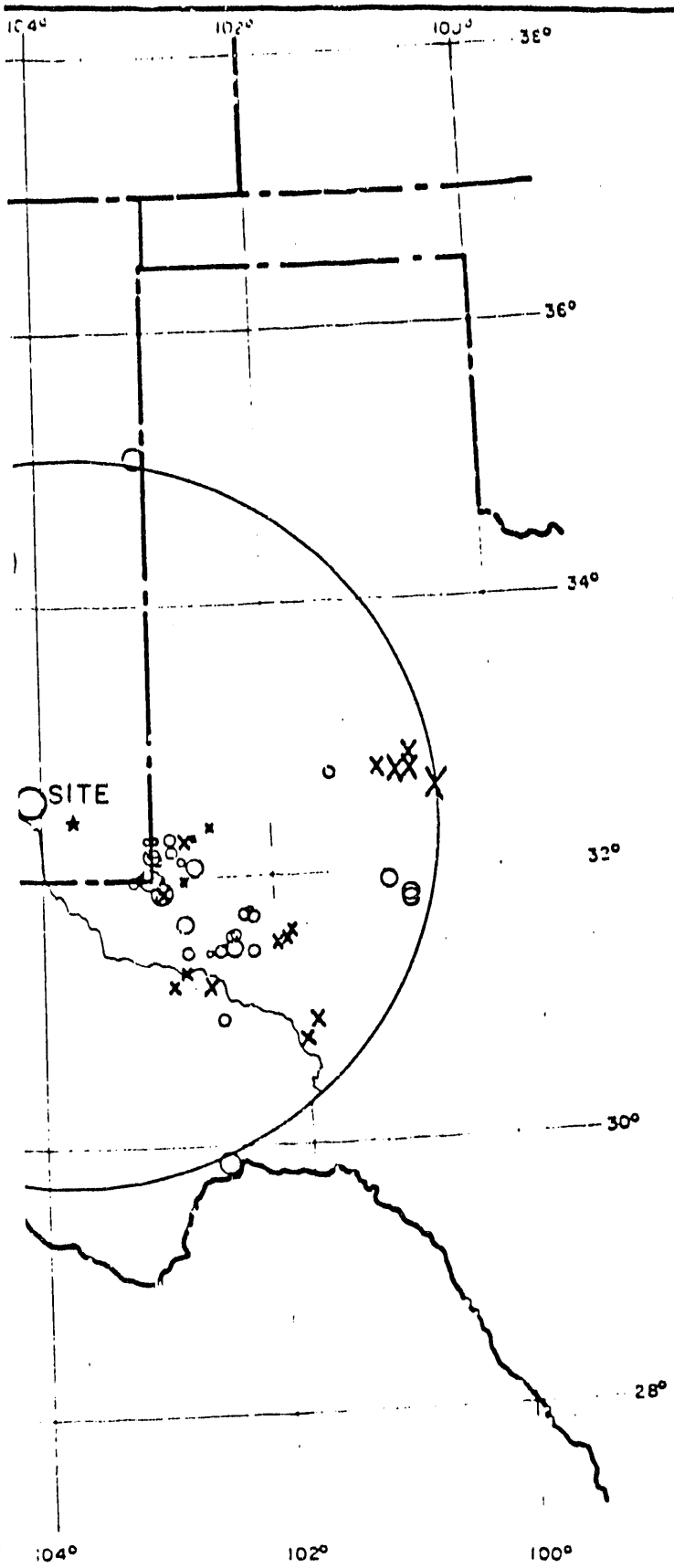


EXPLANATION

Epicenters of earthquakes within 300 km of the repository site located after the installation, and with the help, of Station CLN. Epicenters shown as circles are well located using phase arrival times from at least three and usually many more seismographic stations. Epicenters shown as X's are only tentative locations as explained in the text. In areas where crowding occurs some epicenters are slightly offset for drafting convenience. The true epicenters are listed in Tables 5.2-5 and 5.2-6.

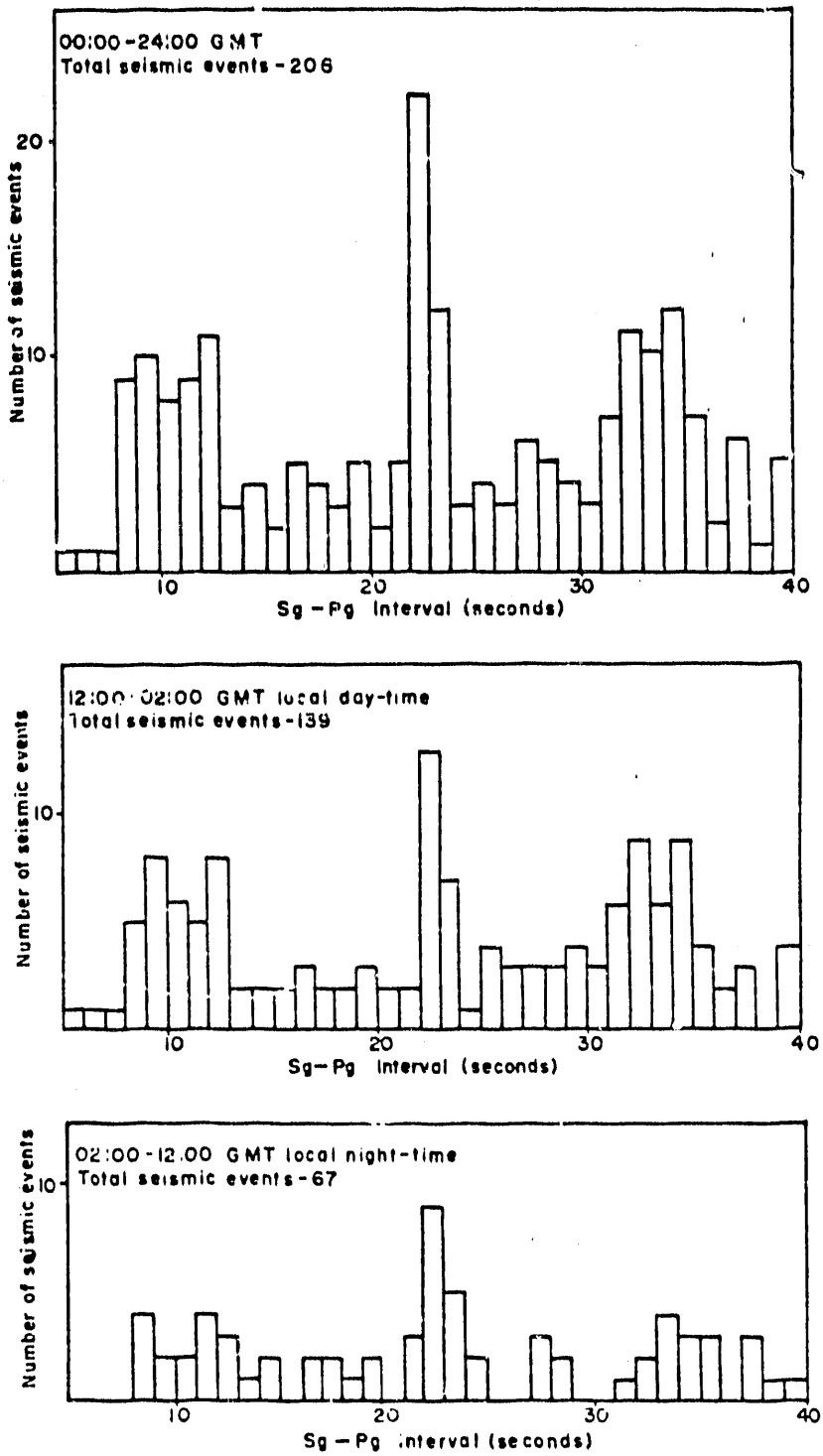
Local Magnitude	Well-Determined Locations	Tentative Locations
<1.5	∘	·
1.51–2.0	○	×
2.01–2.5	○	×
2.51–3.0	○	X
3.01–3.5	○	X
3.51–4.0	○	X
4.01–4.5	○	X

0 100 200 300 KM
0 50 100 150 200 MI
SCALE

REFERENCE:
SANFORD et al (1976)

EARTHQUAKES LOCATED AFTER INSTALLATION OF STATION CLN

FIGURE 5.2-3



EXPLANATION

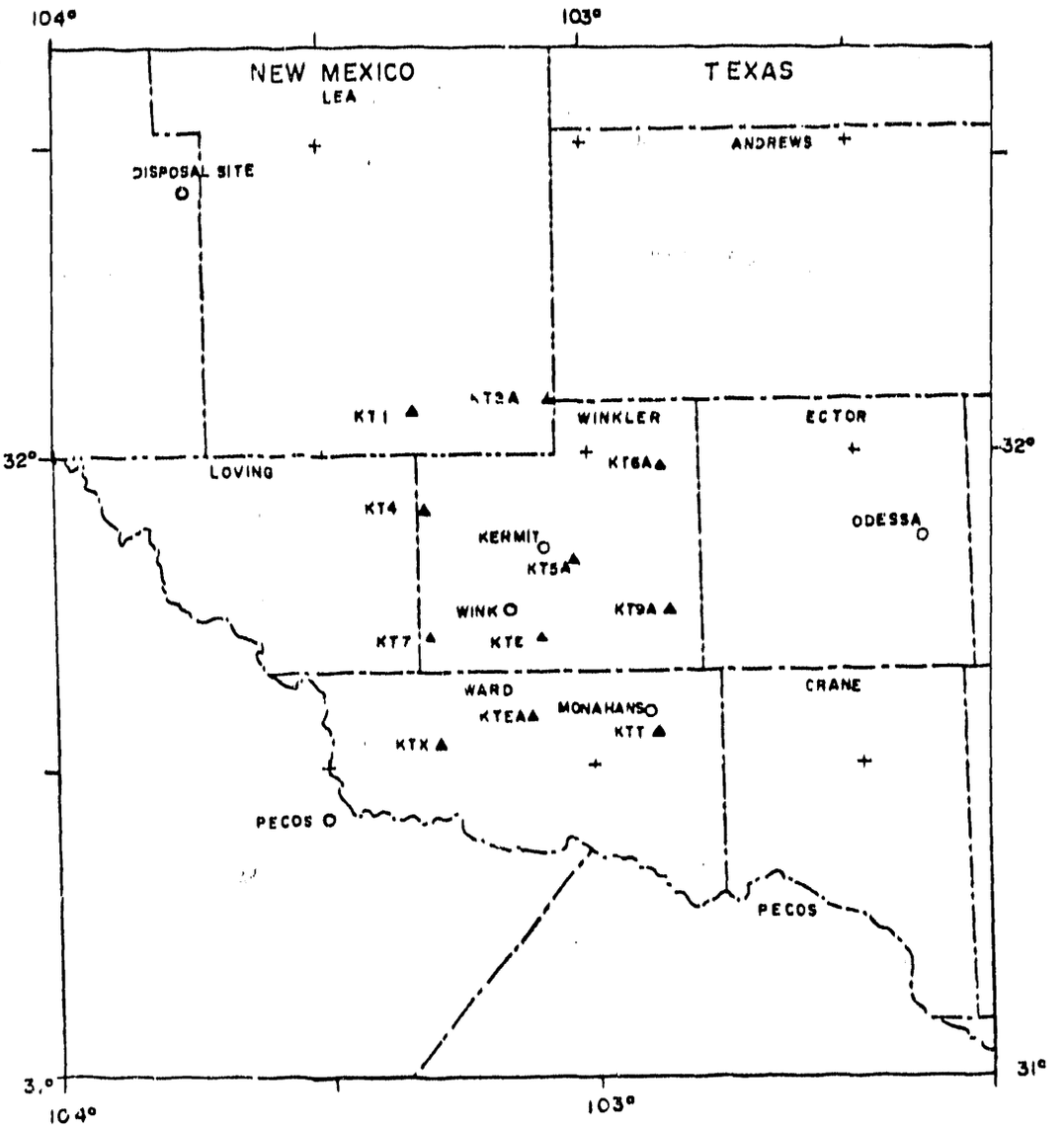
Histograms of the number of earthquakes versus Sg-Pg interval for data collected at station CLN from April 5, 1974 to October 29, 1977. Total number of events in top frame is separated into two subsets in the lower frames

REFERENCE:

Sanford et al., 1978

EVENT-DISTANCE HISTOGRAMS

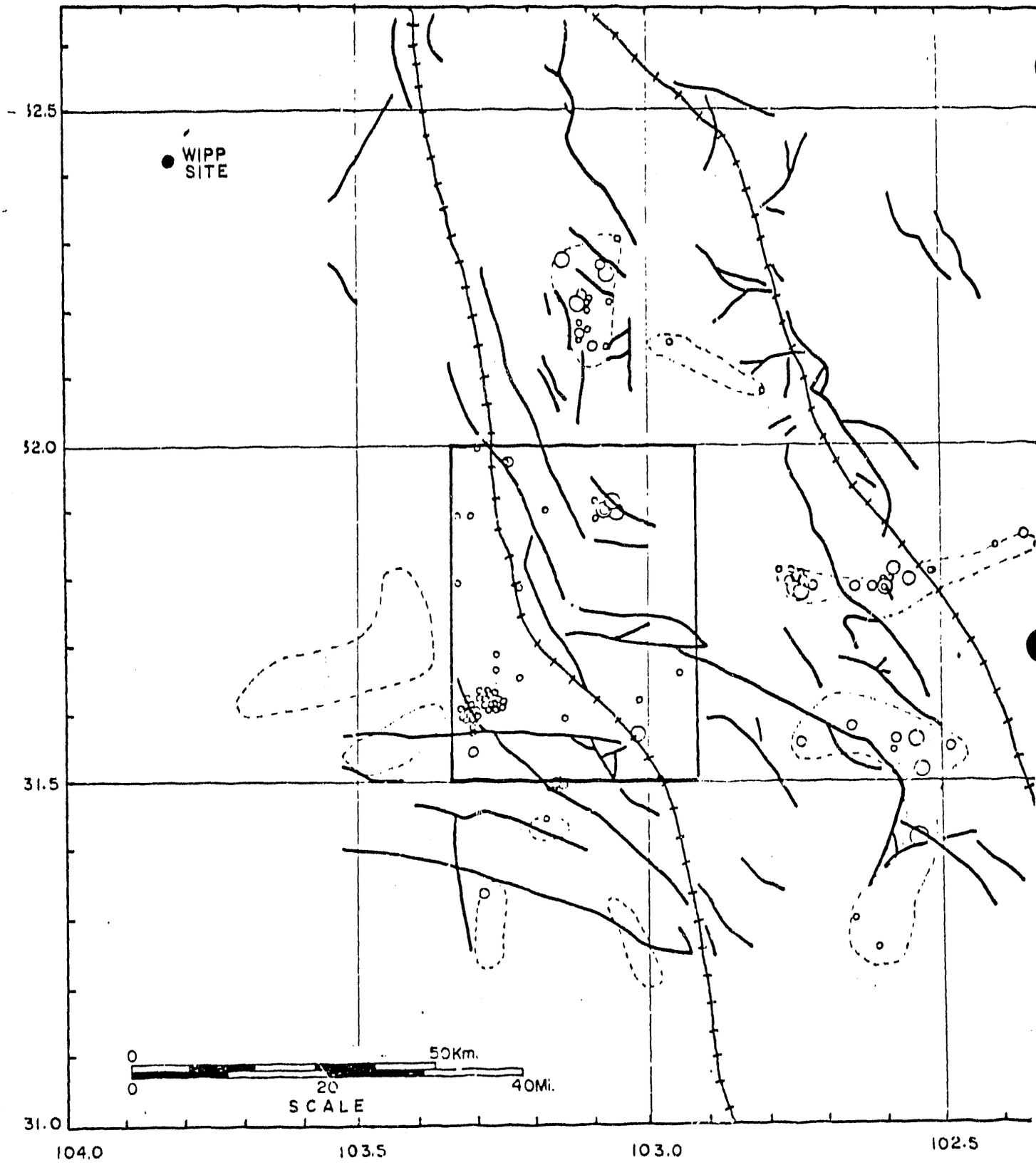
FIGURE 5.2-4



Current seismograph station locations in the Kermit array shown in relation to surrounding cultural features (from Rogers and Malkiel, 1978). Stations with an addended A have been moved from their original sites.

KERMIT ARRAY CONFIGURATION

FIGURE 5.2-5


32.5
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31.5
31.0
0
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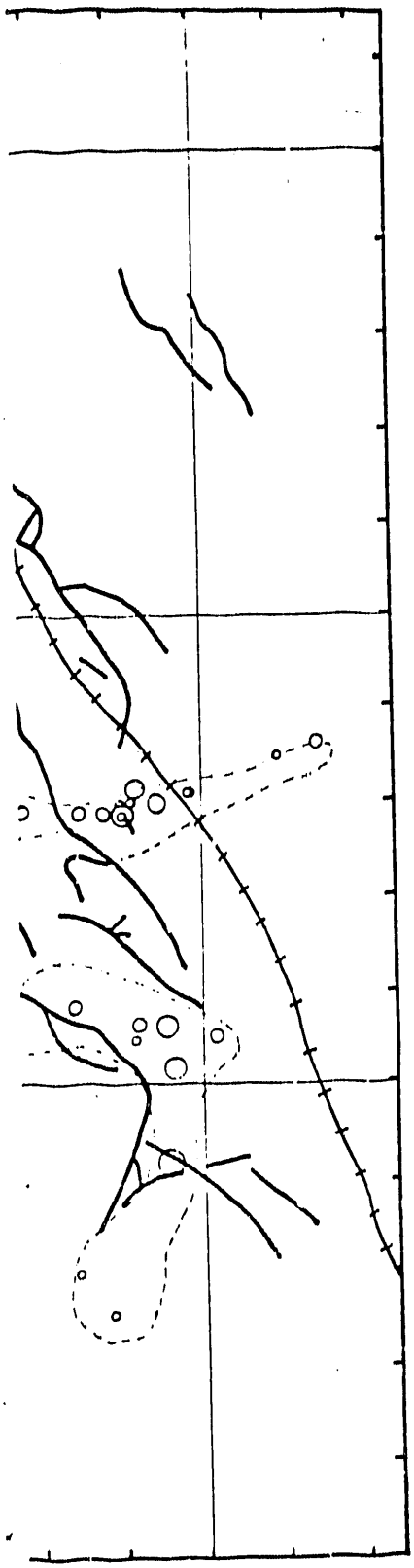
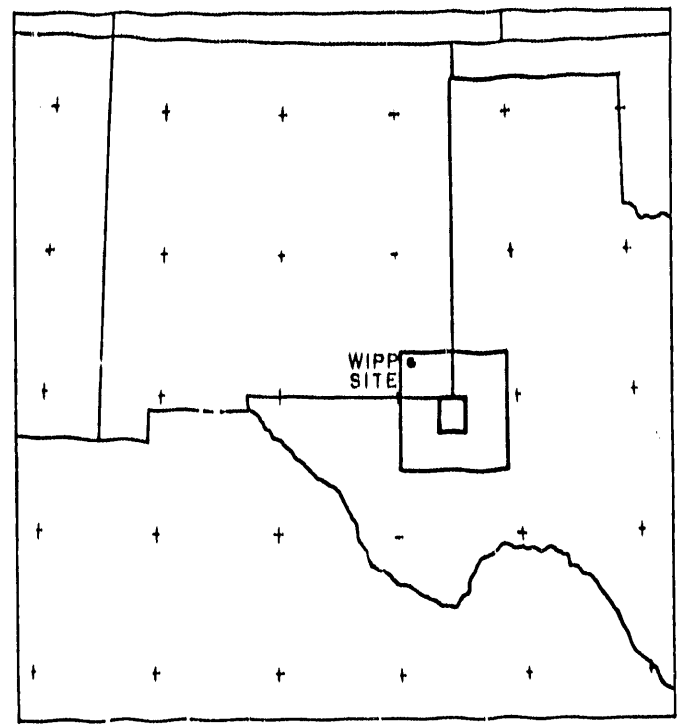
0
20
40Mi.
SCALE
104.0
103.5
103.0
102.5





EXPLANATION

Earthquakes located using the Kermit array network. All located events within the array, denoted by the small rectangular area in the map to the left, are shown as well as those shocks on the array's periphery located by five or more array stations. The light dashed lines enclose peripheral epicenters whether or not they satisfy the five station criterion. Solid lines are pre-Permian faults, and the cross hatched lines the boundary of the Central Basin Platform both after Rogers and Malkiel, 1978. The regional location map above shows both the total map area to the left and the Kermit array limits in a large scale context.

Magnitude

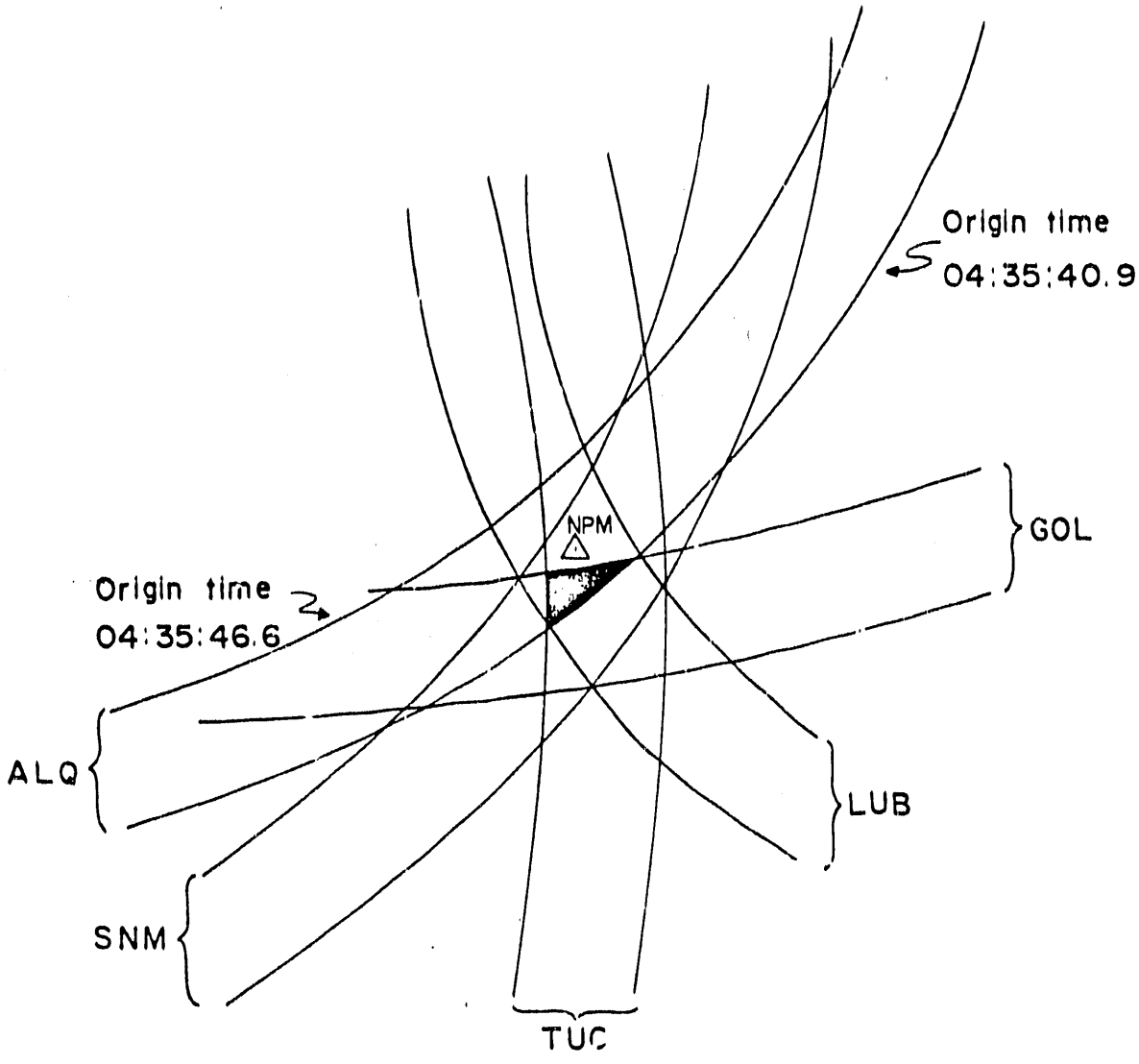
- ○ ≤ 2.35
- ○ 2.36 – 2.85
- ○ 2.86 – 3.35
- ○ ≥ 3.36

102.5

REFERENCE:
ROGERS AND MALKIEL (1978)

EVENTS LOCATED USING KERMIT ARRAY DATA

FIGURE 5.2-6



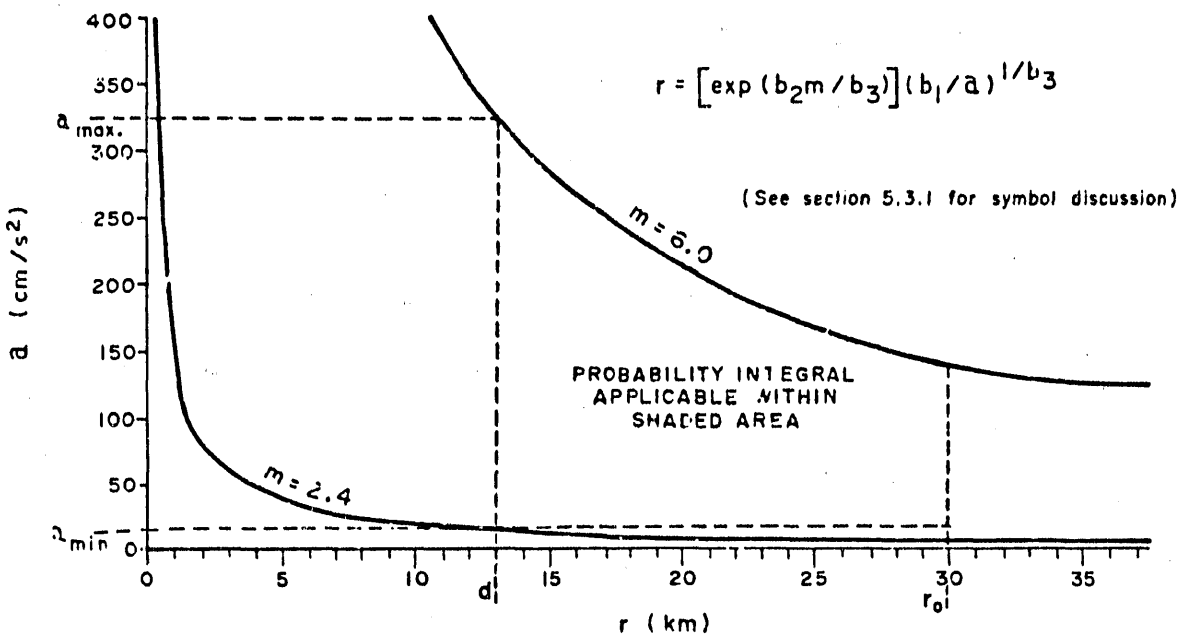
EXPLANATION

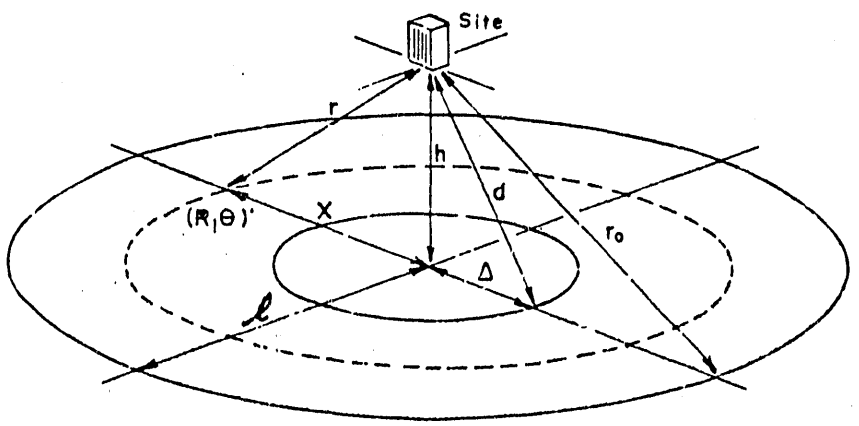
The area defined by arc intersections using the 95% confidence intervals for the origin time. NPM is the National Potash Company Eddy County Mine location. All arcs shown are for Pg waves. Actual area of mutual intersection is shaded.

REFERENCE: Caravella and Sanford, 1977.

LOCATION UNCERTAINTY
FOR THE JULY 26, 1972 EVENT

FIGURE 5.2-7





EXPLANATION

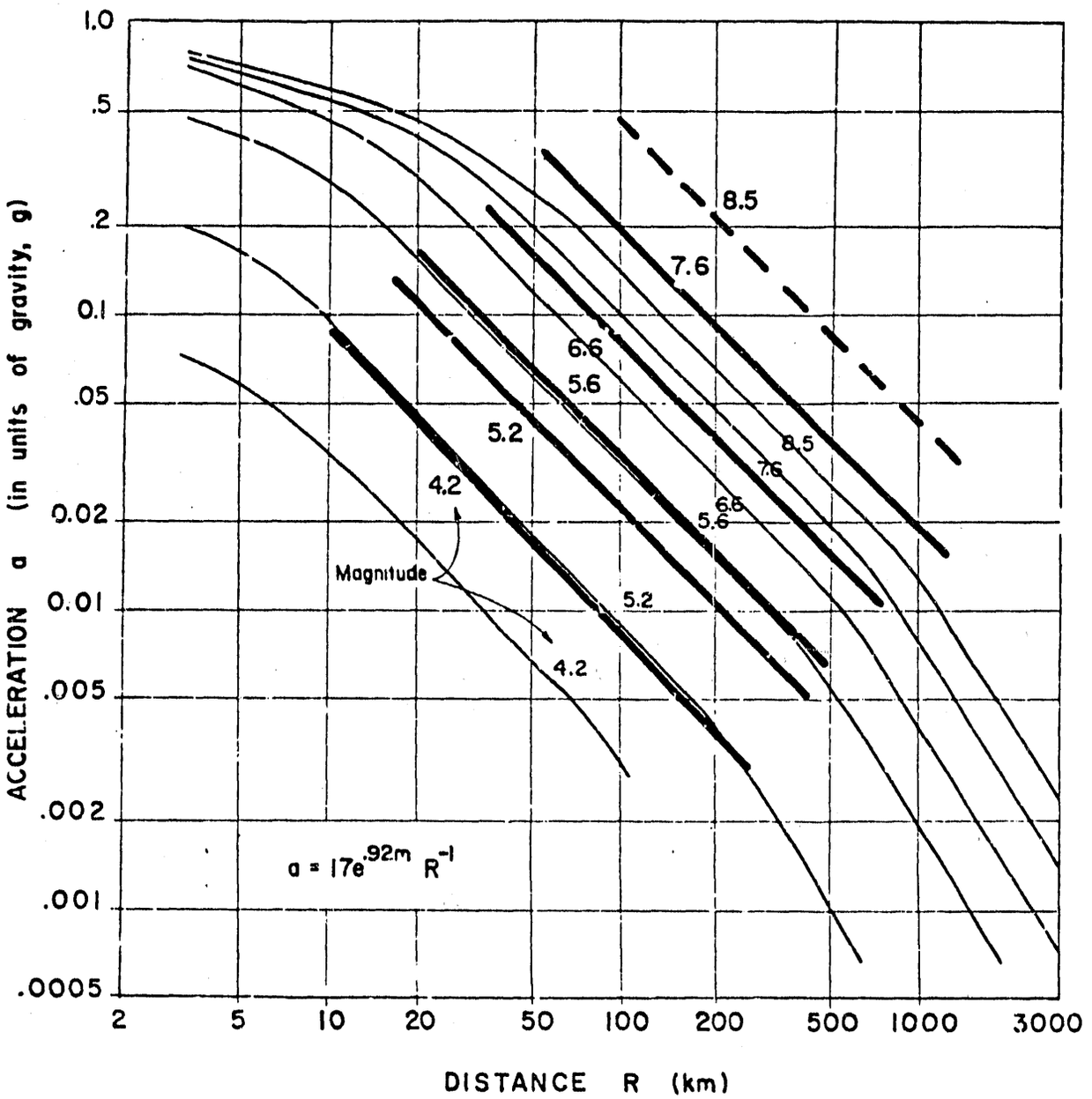
TOP - geometric and attenuation law constraints on limits of integration for the annular area probability integral. The shaded region represents values over which the probability is valid.

BOTTOM - schematic of annular source area showing variables of integration.

(After Cornell, 1968).

PARAMETERS FOR THE DETERMINATION OF PROBABILISTIC ACCELERATION

FIGURE 5.3-1



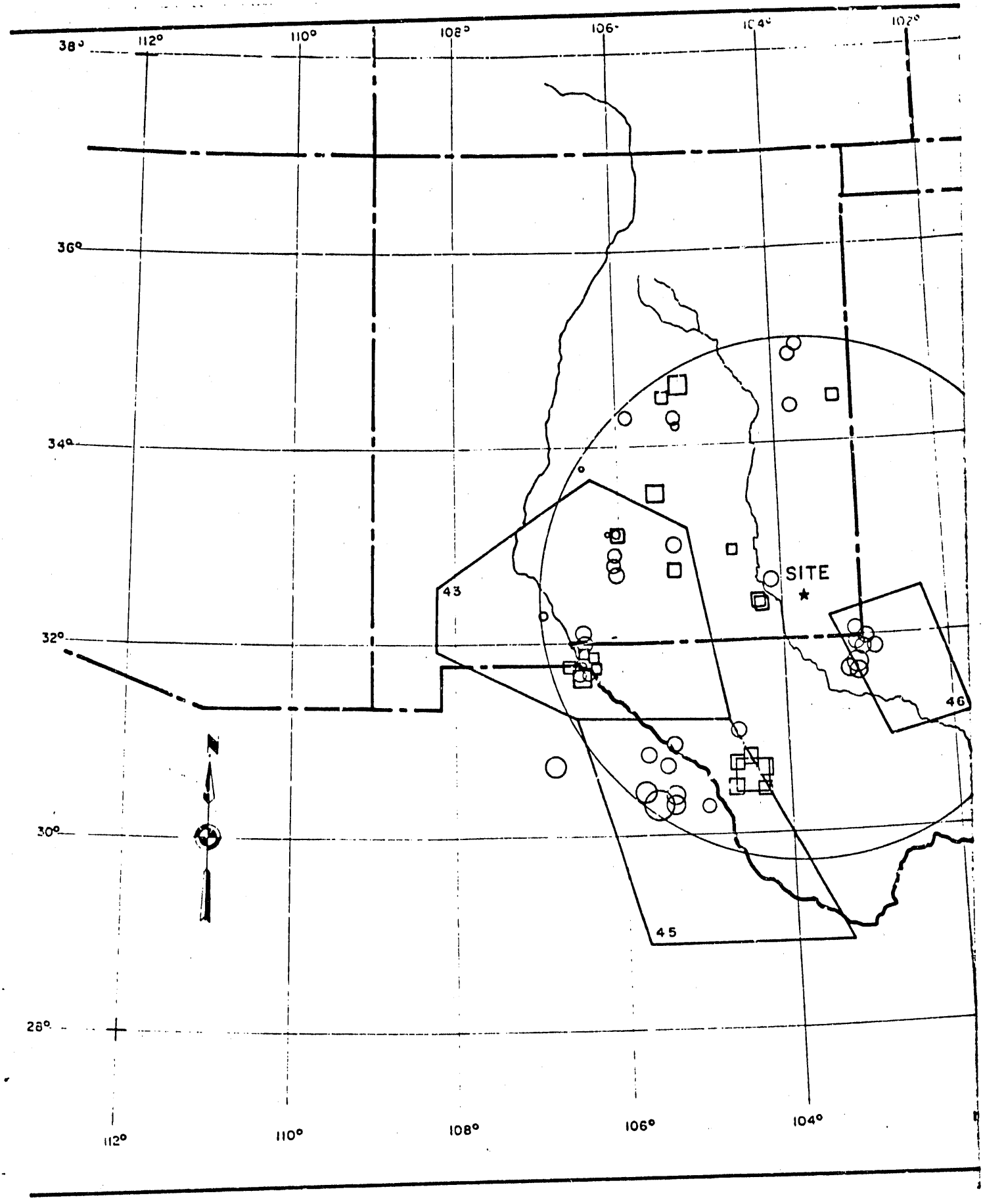
EXPLANATION

Comparison of acceleration attenuation curves for areas of the United States east of 105°W longitude after Algermissen and Perkins (1976) (light lines) with those used in the site hazard analysis of this report (heavy lines). The equation for the recommended attenuation curves is shown in the inset.

RECOMMENDED

ATTENUATION CURVES

FIGURE 5.3-2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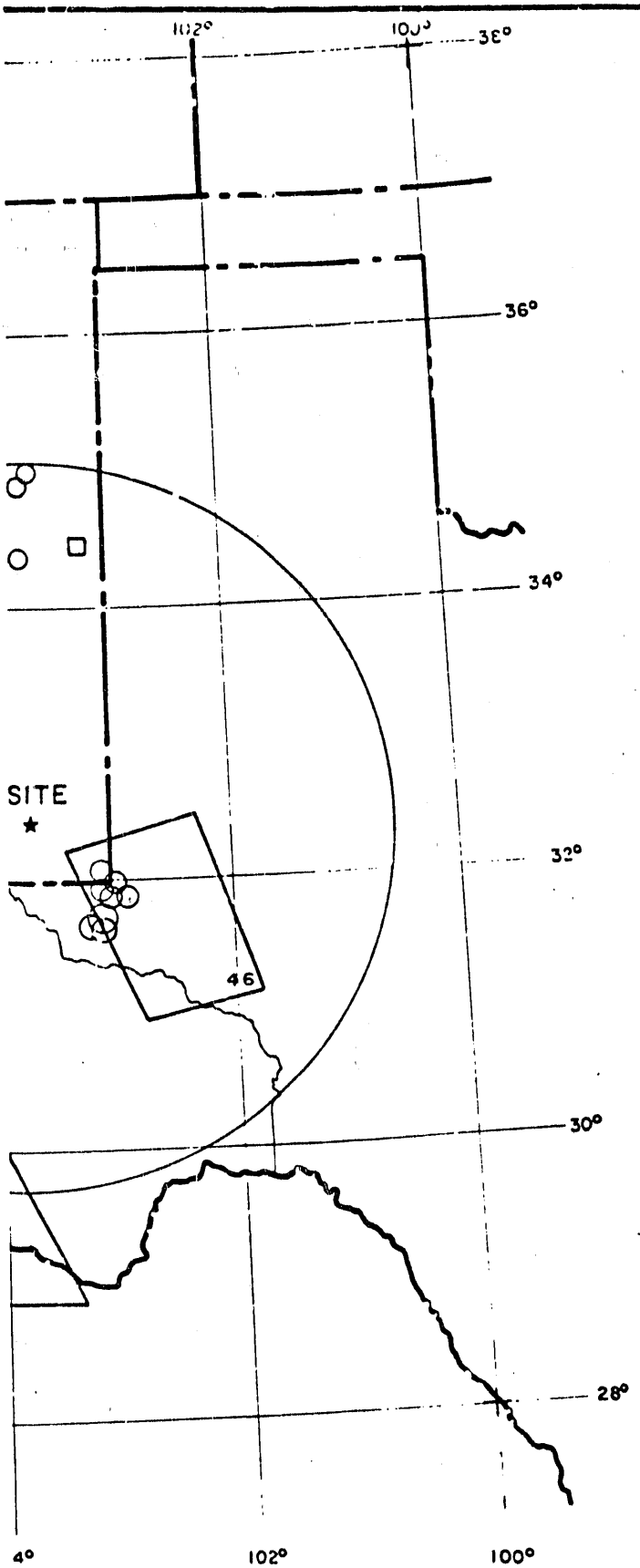


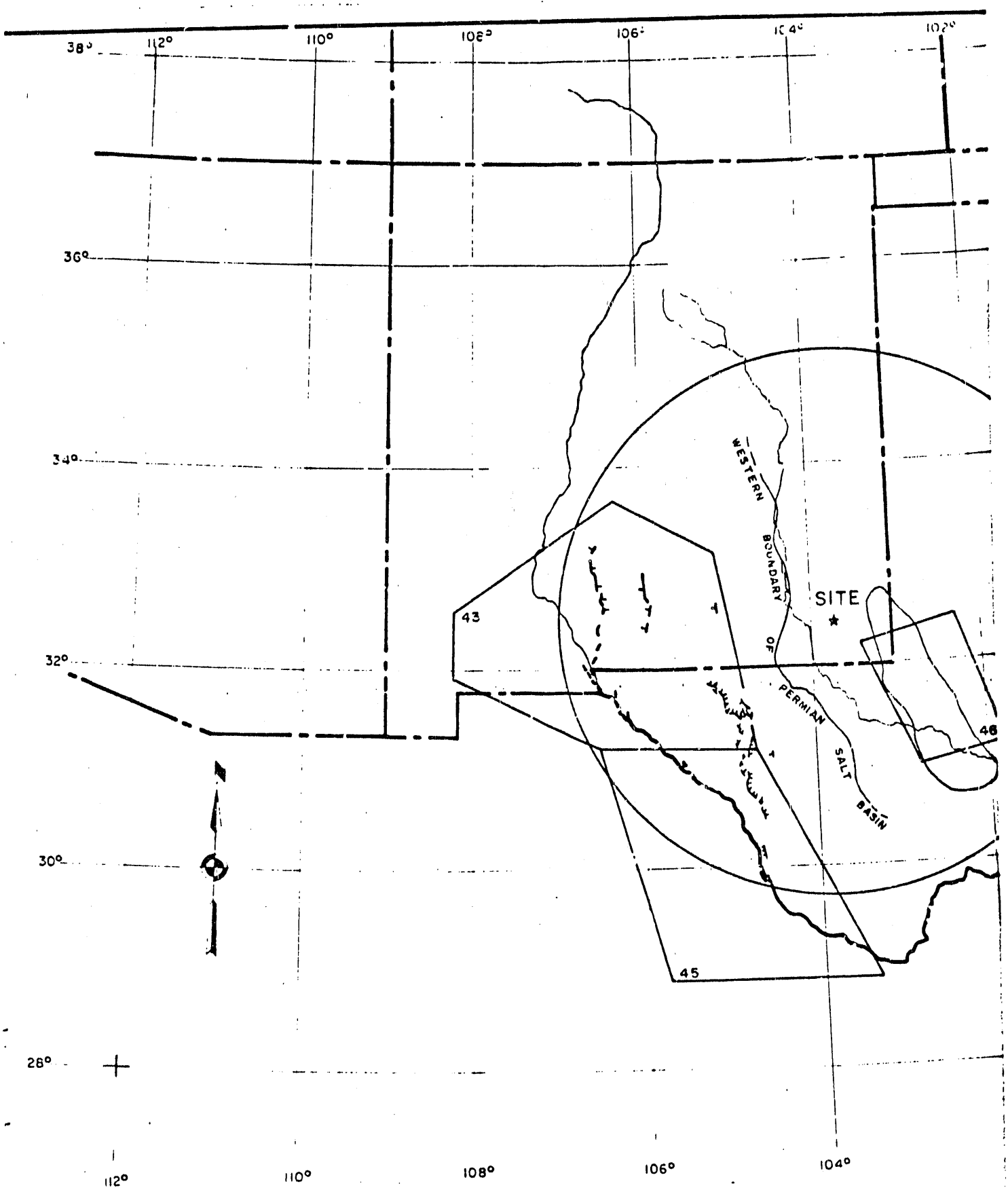
EXPLANATION

Seismic source zones are taken from Algermissen and Perkins (1976). The numbering of the three zones shown is in conformity with that study. For purposes of discussion Zones 43 and 45 are the Southern Basin and Range-Rio Grande rift source zones (northern and southern region respectively). Zone 46 is the Central Basin Platform source zone. Earthquake epicenters are exactly as shown in Figure 5.2-1 of this report. All information concerning them may be found in the explanation for that figure.

0 100 200 300 KM
0 50 100 150 200 MI
SCALE

SEISMIC SOURCE ZONES

FIGURE 5.3-3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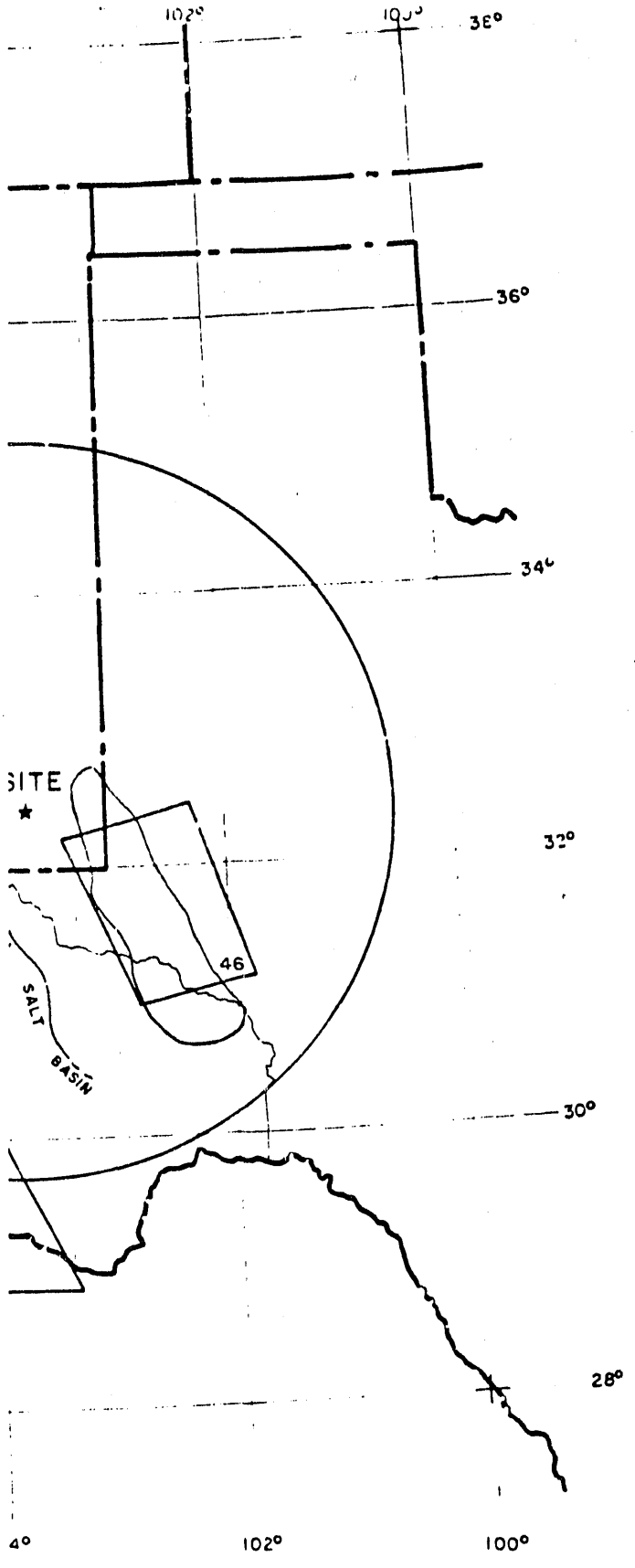


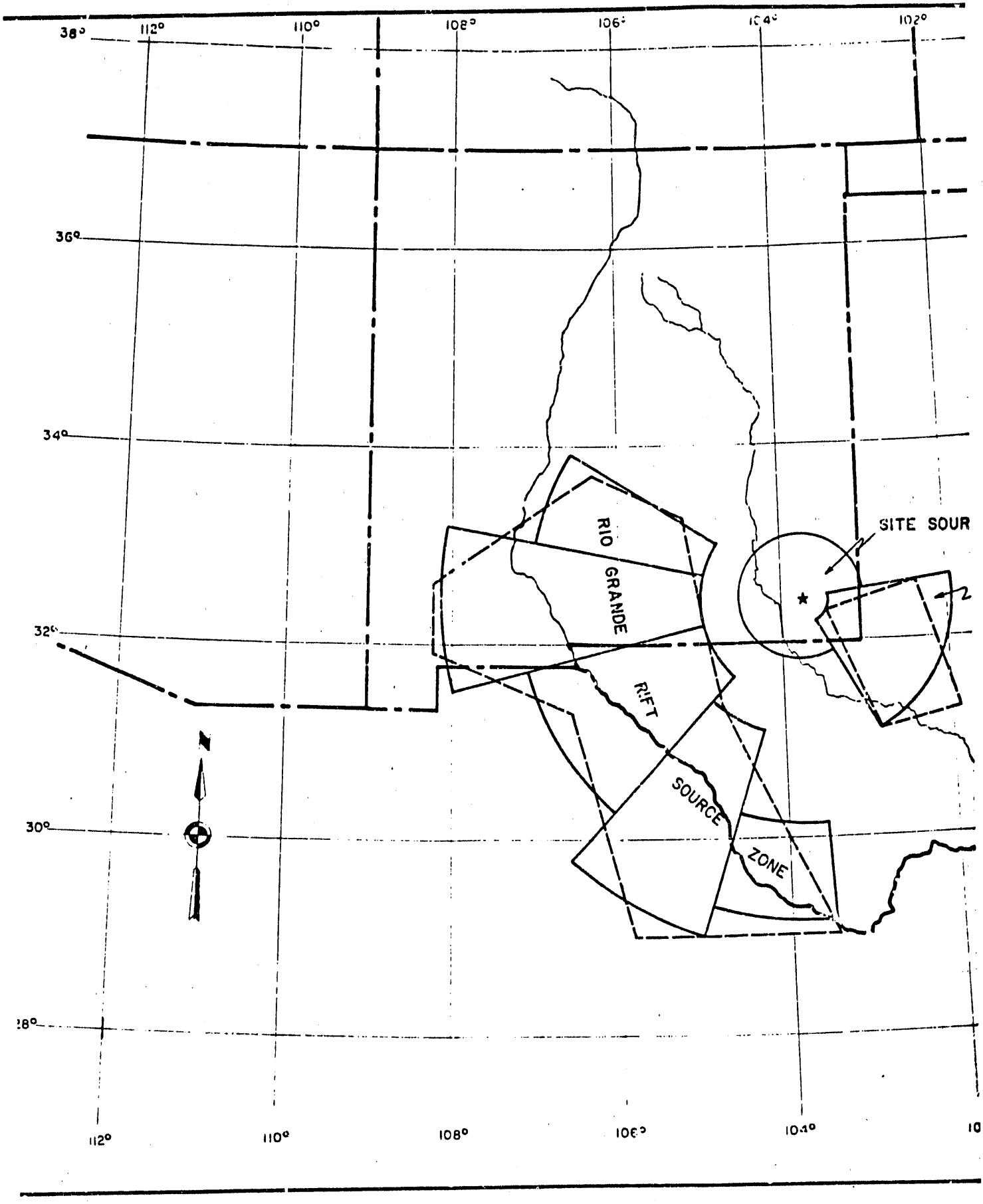
EXPLANATION

Seismic source zones are as shown in Figure 5.3-3 of this report. Plotted Quaternary faulting features are taken from Sanford and Toppozada (1974; Fig. 6) and Muehlberger et al (1978; Fig. 2). The western boundary of the Permian Salt Basin is taken from Figure 6 of Sanford and Toppozada (1974). The outline of the Central Basin Platform shown is taken from Rogers and Malkiel (1978).

0 100 200 300 KM
0 50 100 150 200 MI
SCALE

STRUCTURAL FEATURES IN THE SITE REGION

FIGURE 5.3-4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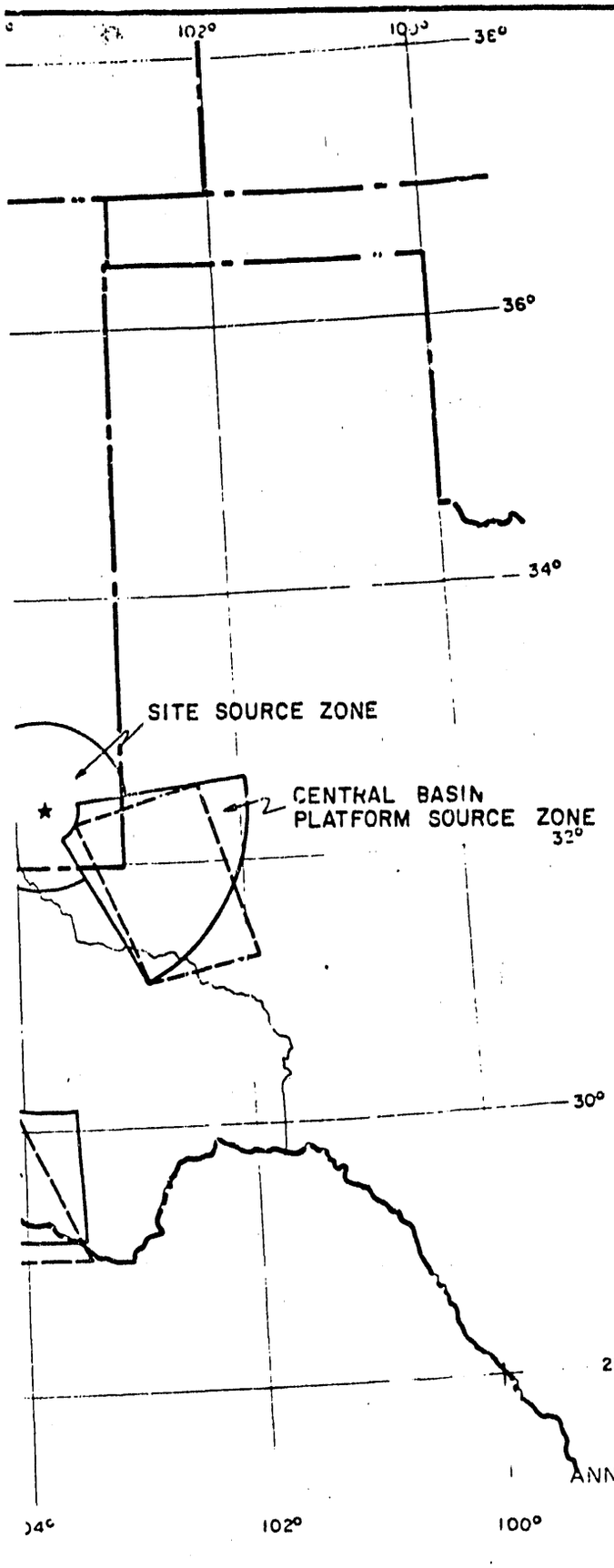
RIO GRANDE
RIFT
SOURCE
ZONE
SITE SOUR
112°
110°
108°
106°
104°



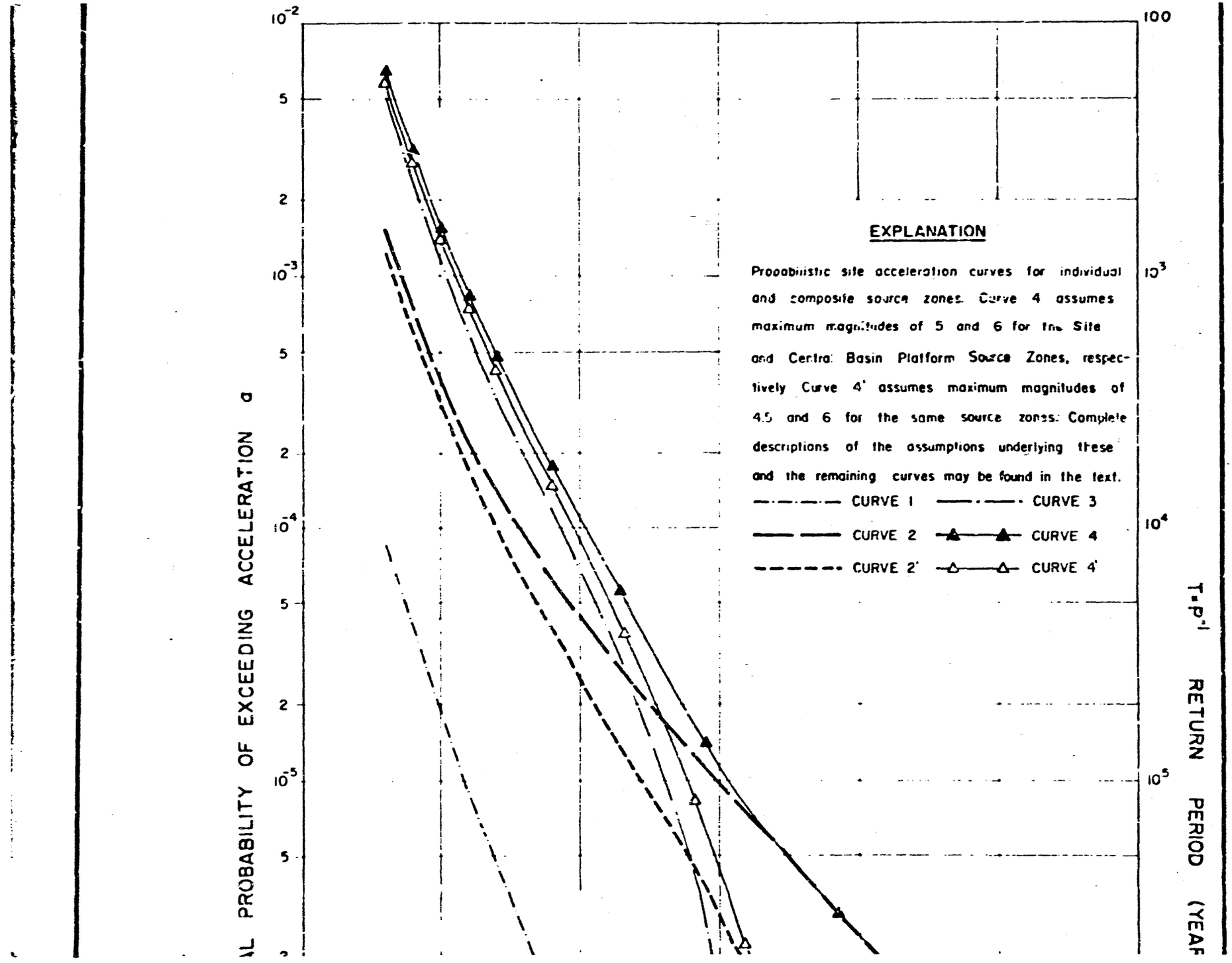
EXPLANATION

Annular segment source zones used in the seismic risk study. These source zones approximate the irregular polygon zones of Figure 5.3-3 which are also shown in dashed lines.

0 100 200 300 KM
0 50 100 150 200 MI
SCALE

ANNULAR SEGMENT APPROXIMATION OF SOURCE ZONES

FIGURE 5.3-5


10^{-2}
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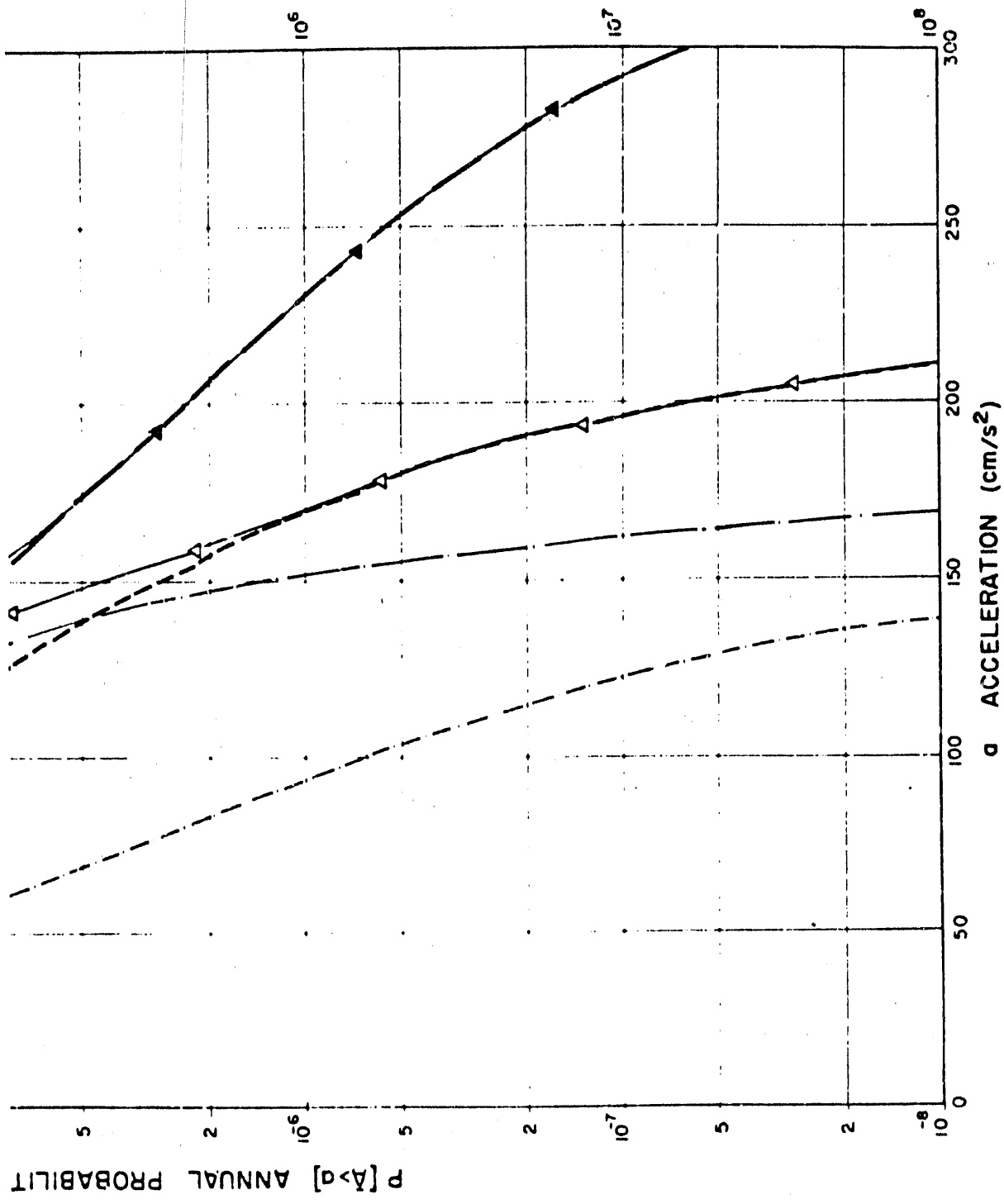
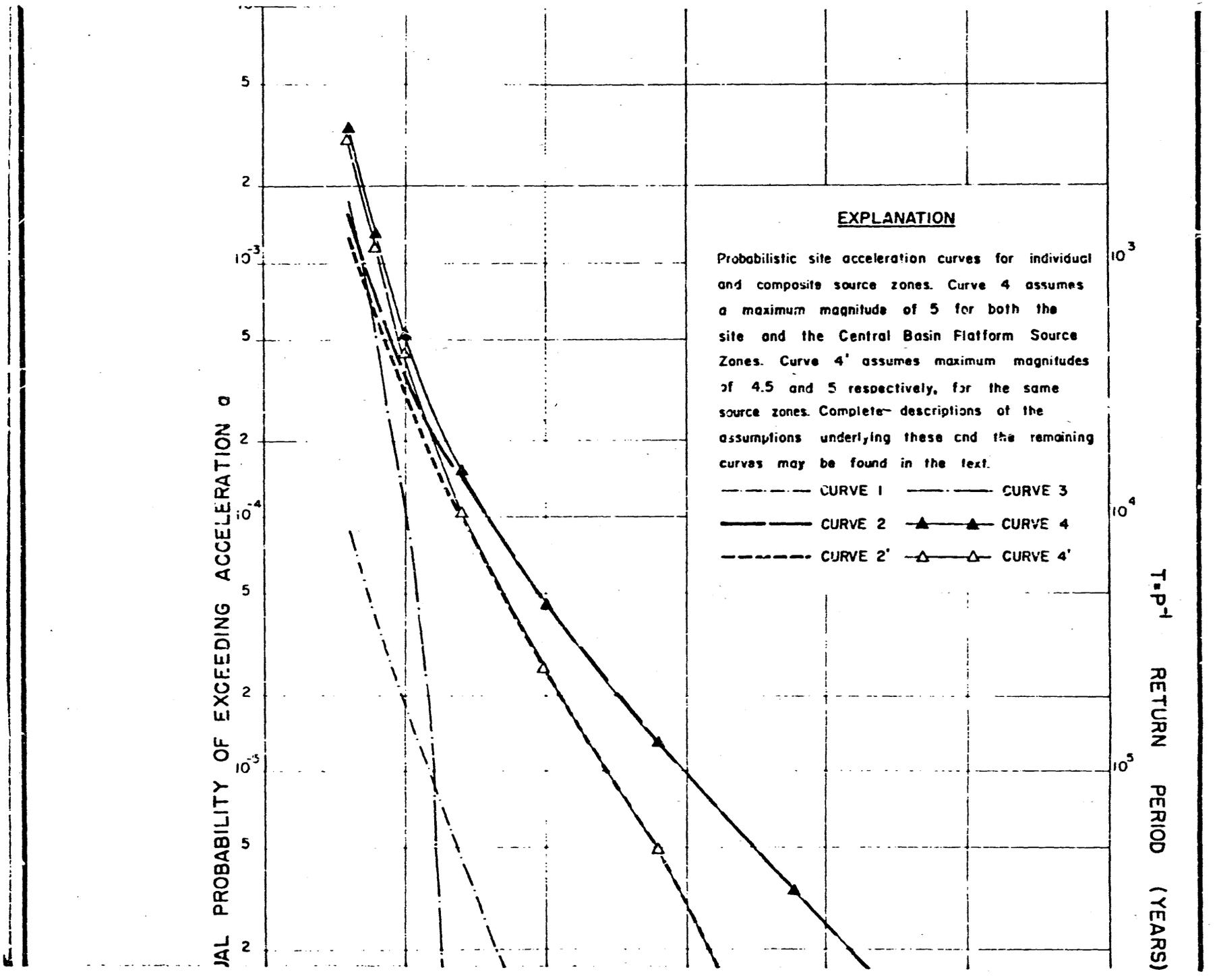
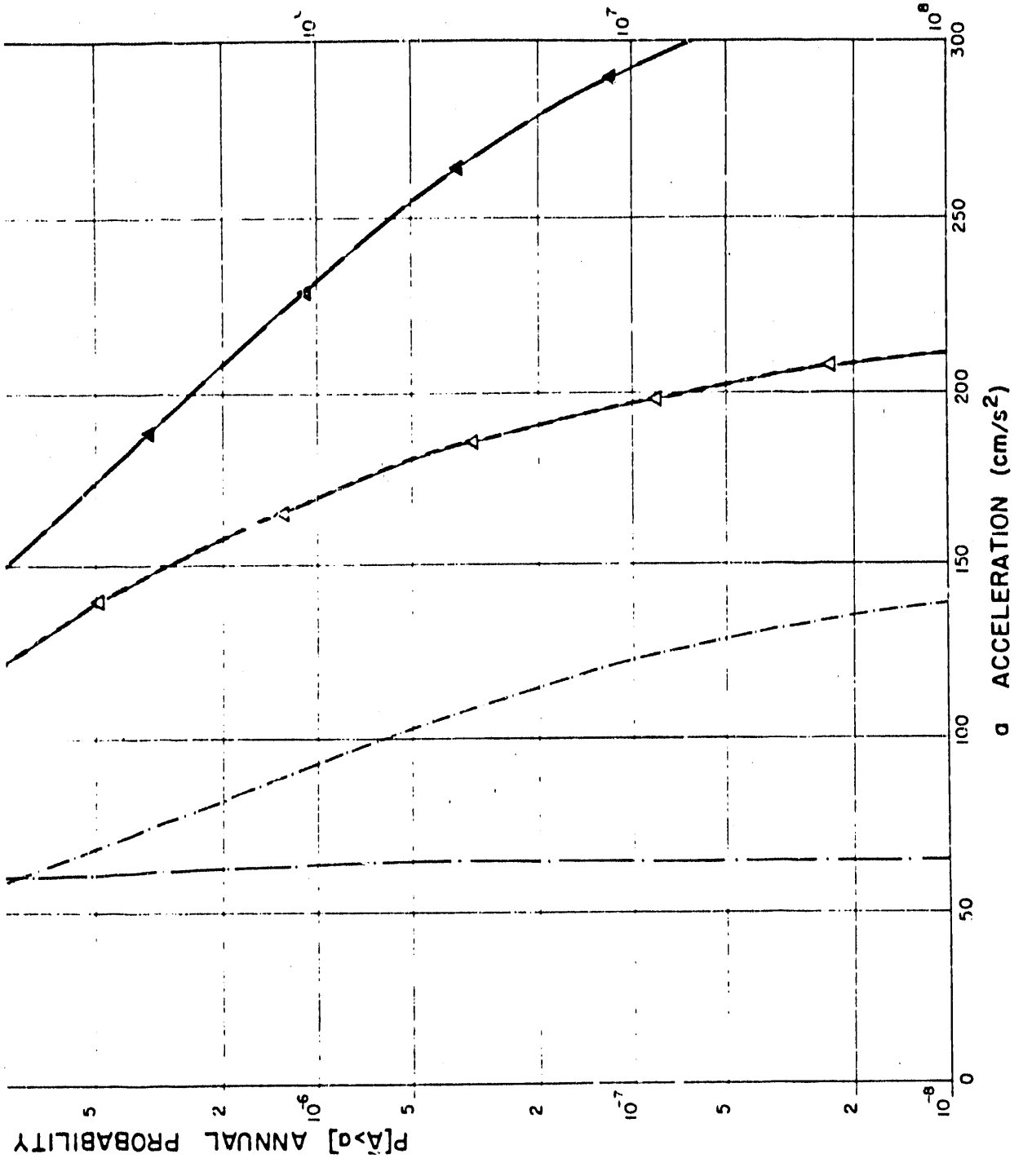
10^{-3}
5
2
10^{-4}
5
2
10^{-5}
5
100
10^{3}
10^{4}
10^{5}
AL PROBABILITY OF EXCEEDING ACCELERATION a
T=P⁻¹ RETURN PERIOD (YEAR
EXPLANATION
Prooabilistic site acceleration curves for individual and composite source zones. Curve 4 assumes maximum magnitudes of 5 and 6 for the Site and Central Basin Platform Source Zones, respectively Curve 4' assumes maximum magnitudes of 4.5 and 6 for the same source zones. Complete descriptions of the assumptions underlying these and the remaining curves may be found in the text.
CURVE 1
CURVE 3
CURVE 2
CURVE 4
CURVE 2'
CURVE 4'



ACCELERATION PROBABILITY CURVES - SET 1

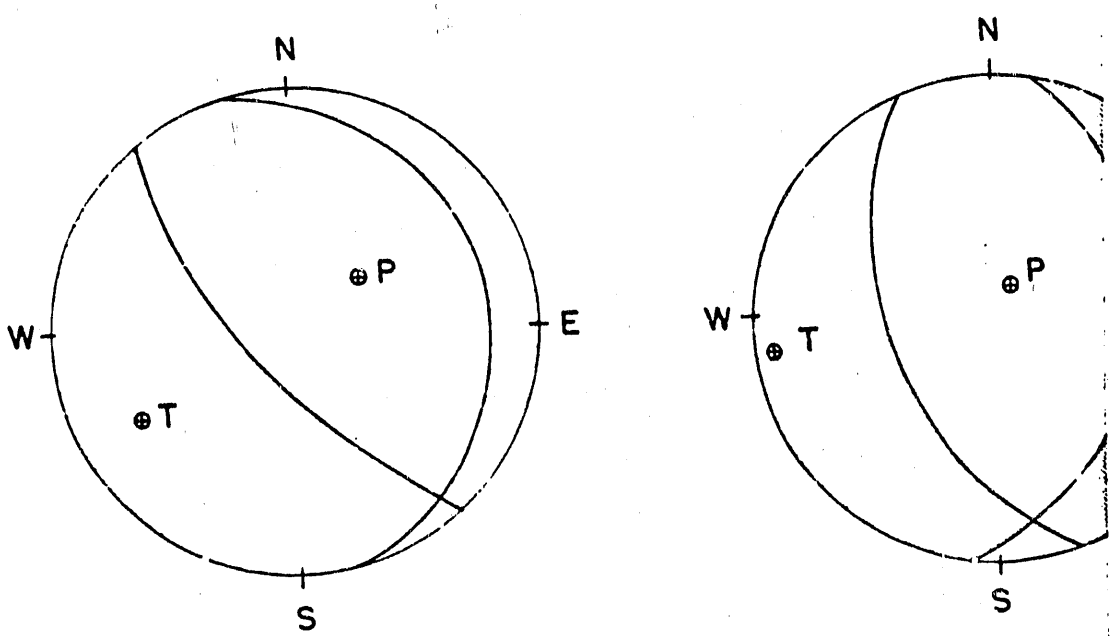
FIGURE 5.3-6


EXPLANATION
Probabilistic site acceleration curves for individual and composite source zones. Curve 4 assumes a maximum magnitude of 5 for both the site and the Central Basin Platform Source Zones. Curve 4' assumes maximum magnitudes of 4.5 and 5 respectively, for the same source zones. Complete descriptions of the assumptions underlying these and the remaining curves may be found in the text.
CURVE 1
CURVE 2
CURVE 2'
CURVE 3
CURVE 4
CURVE 4'
JAL PROBABILITY OF EXCEEDING ACCELERATION a
T=P⁻¹ RETURN PERIOD (YEARS)
10⁻³
10⁻⁴
10⁻⁵
10³
10⁴
10⁵



ACCELERATION PROBABILITY CURVES – SET 2

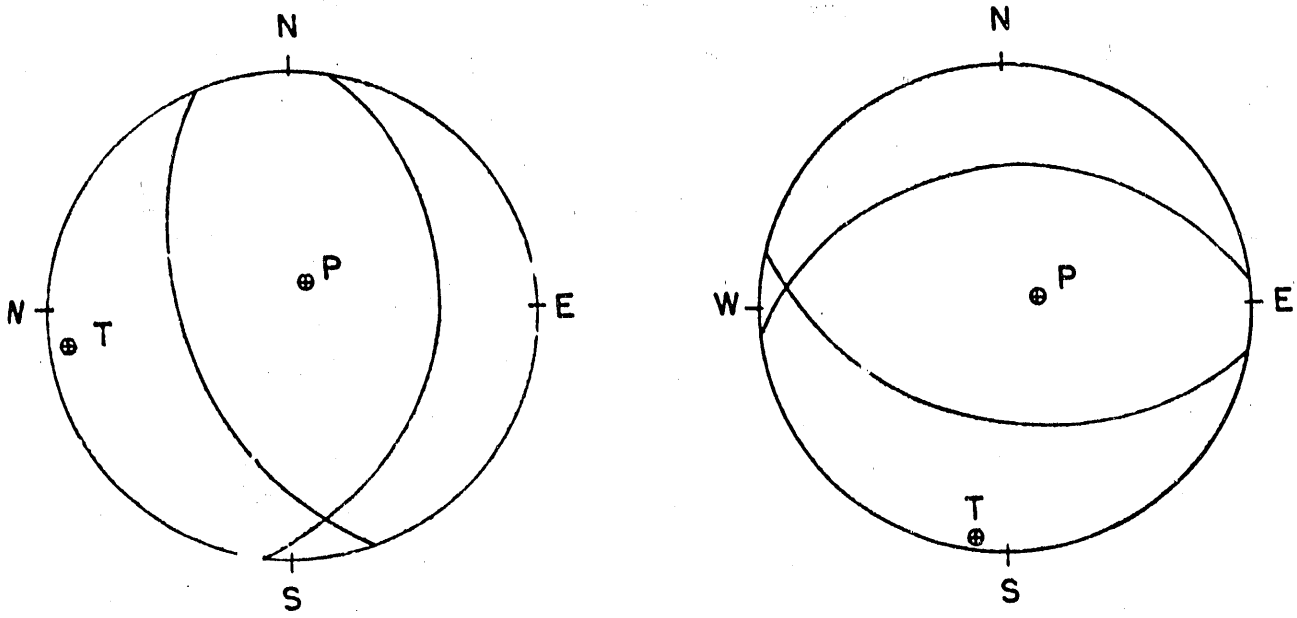
FIGURE 5.3-7



a b

EXPLANATION

Plots of lower focal hemisphere projections of P-wave polarities for a) the August 16, 1931 Valentine, Texas earthquake, b) a composite solution for three small earthquakes on the Central Basin Platform which occurred in January, 1976, and c) one possible solution for an earthquake in the same area of the CBP ocurring on April 26, 1977. P is the maximum and T the minimum compressive stress axes for each solution.



b

c

P-wave polarities for
uake, b) a composite
entral Basin Platform
possible solution
BP ocurring on
minimum compressive

REGIONAL FOCAL MECHANISM SOLUTIONS

FIGURE 5.4-1

Table 5.2-1

EARTHQUAKES OCCURRING BEFORE 1961 AND CENTERED WITHIN 300 KILOMETERS OF THE SITE

DATE Yr/Mo/Day	ORIGIN TIME (GMT)	LOCATION	INTENSITY	DISTANCE (km)
23/03/07	04:03	El Paso, Tex.	V	260
26/07/17	22:00	Hope and Lake Arthur, N.M.	III	90
30/10/04	03:25	34.5°N 105.4°W	(IV)	280
31/08/16	11:40	Valentine, Tex.	VIII	210
31/08/16	19:33	Valentine, Tex.	(V)	210
31/08/19	19:33	Valentine, Tex.	V	210
31/08/19	01:36	Valentine, Tex.	(V)	210
31/10/02	?	El Paso, Tex.	(III)	260
31/11/03	14:50	29.9°N 104.2°W	(V)	295
35/12/20	05:30	34.4°N 103.2°W	III-IV	230
36/01/08	06:46	Carlsbad, N.M.	(IV)	40
36/08/08	01:40	El Paso, Tex.	(III)	260
36/10/15	~18:00	El Paso, Tex	(III)	260
37/03/31	22:45	El Paso, Tex.	(IV)	260
37/09/30	05:15	Ft. Stanton, N.M.	(V)	200
43/12/27	04:00	Tularosa, N.M.	IV	220
49/02/02	23:00	Carlsbad, N.M.	(IV)	40
49/05/23	07:22	34.6°N 105.2°W	IV	280
52/05/22	04:20	Dog Canyon, N.M.	IV	150
55/01/27	00:37	Valentine, Tex.	IV	210

Table 5.2-2

MODIFIED MERCALLI INTENSITY SCALE OF 1931

[Abridged]

I. Not felt except by a very few under especially favorable circumstances. (I Rossi-Forel scale.)

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to II Rossi-Forel scale.)

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel scale.)

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rock noticeably. (IV to V Rossi-Forel scale.)

V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel scale.)

VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. (VI to VII Rossi-Forel scale.)

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars. (VIII Rossi-Forel scale.)

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbs persons driving motor cars. (VIII+ to IX Rossi-Forel scale.)

IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+Rossi-Forel scale.)

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks. (X Rossi-Forel scale.)

XI. Few, if any (masonry), structures remain standing. Bridges destroyed, Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Table 5.2-3 Page 1 of 2

INSTRUMENTALLY LOCATED EARTHQUAKES WITHIN 300 KM OF THE LOS MEDANOS SITE: 1962-1972

DATE Yr/Mo/Day	ORIGIN TIME GMT	LOCATION Lat N/Long W		MAGNITUDE M L
62 Mar 3	18:16:47	33.8	106.4	1.2
62 Mar 6	09:59:10	31.1	104.6	3.0
64 Feb 11	09:24:10	34.4	103.7	2.5
64 Mar 3	01:26:27	35.0	103.6	2.2
64 Jun 18	20:20:18	33.1	106.1	1.2
64 Jun 19	05:28:39	33.1	106.0	1.7
64 Oct 20	00:53:00	30.7	106.8	3.1
64 Nov 8	09:26:00	31.9	103.0	2.7
64 Nov 21	11:21:24	31.9	103.0	2.5
65 Feb 3	19:59:32	31.9	103.0	3.0
65 Apr 13	09:35:46	30.3	105.0	2.5
65 Aug 30	05:17:30	31.9	103.0	2.6
66 Aug 14	15:25:47	31.9	103.0	2.8
66 Aug 17	18:47:21	30.7	105.5	2.9
66 Aug 19	04:15:44	30.3	105.6	4.6
66 Aug 19	08:38:21	30.3	105.6	3.6
66 Sep 17	21:30:13	34.9	103.7	2.2
66 Nov 26	20:05:41	30.9	105.4	2.6
66 Nov 28	02:20:57	30.4	105.4	3.3
66 Dec 5	10:10:37	30.4	105.4	3.3
67 Sep 29	03:52:48	32.3	106.9	2.0
68 Mar 9	21:54:26	32.7	106.0	2.9
68 Mar 23	11:53:39	32.7	106.0	2.3
68 May 2	02:56:44	33.0	105.3	2.6
68 Aug 22	02:22:26	34.3	105.8	2.1

Table 5.2-3 Page 2 of 2

INSTRUMENTALLY LOCATED EARTHQUAKES WITHIN 300 KM OF THE LOS MEDANOS SITE: 1962-1972

DATE Yr/Mo/Day	ORIGIN TIME GMT	LOCATION Lat N/Long W		MAGNITUDE M L
69 May 12	08:26:18	32.0	106.4	3.0
69 May 12	08:49:16	32.0	106.4	2.6
69 Jun 1	17:18:24	34.2	105.2	2.0
69 Jun 8	11:36:02	34.2	105.2	2.4
69 Oct 19	11:51:34	30.8	105.7	2.8
71 Jul 30	01:45:50	31.7	103.1	3.1
71 Jul 31	14:53:48	31.6	103.1	3.2
71 Sep 24	01:01:54	31.6	103.2	3.0
72 Feb 27	15:50:04	32.9	106.0	2.3
72 Jul 26	04:35:44	32.6	104.1	2.8
72 Dec 9	05:58:39	31.7	106.4	2.2
72 Dec 10	14:37:50	31.7	106.5	2.2
72 Dec 10	14:58:02	31.7	106.5	1.8

Table 5.2-4

INTERRUPTIONS IN OPERATION OF SEISMOGRAPH STATION CLN.

From		To		Cause
Time	Date	Time	Date	
Records were not obtained for the following periods:				
08:34	April 29, 1974	20:39	May 1, 1974	Recorder ran out of film.
13:13	May 18, 1974	07:03	May 19, 1974	Developing error.
07:18	May 31, 1974	13:32	June 12, 1974	Operating error changing film.
03:31	June 20, 1974	15:47	June 25, 1974	Developing error.
08:08	Sept 1, 1974	07:05	Sept. 2, 1974	Ran out of film.
17:09	Sept. 27, 1974	21:35	Sept. 28, 1974	Ran out of film.
03:23	Dec. 24, 1974	19:20	Jan. 5, 1975	Film broke.
07:37	May 28, 1975	18:08	June 7, 1975	Galvanometer light burned out.
20:23	June 21, 1975	18:20	July 4, 1975	Film broke.
17:50	Oct. 12, 1975	19:16	Oct. 26, 1975	Programmer-chronometer removed for repair.
19:31	Nov. 8, 1975	23:22	Jan. 12, 1976	Loss of power from thermal-electric generator.
12:40	Nov. 20, 1976	19:35	Jan. 17, 1977	Failure of voltage regulator on thermal-electric generator.
19:35	May 23, 1977	18:49	June 4, 1977	Film advance inoperative.
19:18	Sept. 13, 1977	18:20	Sept. 17, 1977	Film advance inoperative.
22:20	Oct. 6, 1977	18:47	Oct. 8, 1977	Film advance inoperative.
Station was operating without internal time for the following periods:				
22:01	May 1, 1974	07:18	May 31, 1974	Programmer-chronometer malfunction.
23:55	Aug. 18, 1974	23:55	Sept. 1, 1974	" " "
22:30	Nov. 28, 1974	03:23	Dec. 24, 1974	" " "

Table 5.2-5

WELL DETERMINED EPICENTRAL LOCATIONS
FOR
EARTHQUAKES AFTER INSTALLATION OF STATION CLN

DATE Yr/Mo/Day	ORIGIN TIME	LOCATION Lat°N/Long°W	DISTANCE to CLN (km)	CLN MAGNITUDE
74/08/26	07:33:22.0	34.4 105.8	305.9	2.4
74/09/26	23:44:08.5	32.8 106.2	235.8	2.4
74/10/15	10:07:57.9	33.9 106.5	316.9	2.3
74/11/01	10:45:49.6	33.8 106.6	314.9	2.0
74/11/12	02:31:57.3	31.9 100.8	288.9	2.5
74/11/12	07:14:28.5	31.9 100.8	273.7	2.2
74/11/21	16:22:58.6	32.5 106.3	240.3	2.4
74/11/21	18:59:05.8	32.1 102.7	105.7	2.1
74/11/22	08:54:05.1	32.8 101.5	213.6	2.0
74/11/22	14:11:13.2	33.8 105.1	211.7	1.9
74/11/28	03:35:20.5	32.6 104.1	43.1	3.6
75/02/02	20:39:22.6	35.1 103.1	317.3	2.7
75/07/25	08:11:40.0	29.9 102.5	309.8	2.8
75/08/01	07:27:47.3	30.4 104.6	239.3	3.9
75/10/10	11:16:55.9	33.3 105.0	160.4	2.1
76/01/10	01:49:57.0	31.7 102.8	123.4	2.1
76/01/14	07:01:31.5	34.1 106.8	353.7	2.0
76/01/19	04:03:30.4	31.9 103.0	93.8	2.4
76/01/22	07:21:57.8	31.9 103.0	89.1	2.0
76/01/25	04:48:27.5	32.0 103.1	80.2	2.9
76/01/28	07:37:48.5	32.0 101.0	262.9	2.4
76/03/18	23:07:04.8	32.2 102.9	77.9	1.6
76/03/20	16:15:58.0	32.2 103.1	63.8	1.4
76/03/27	22:25:22.0	32.2 103.1	64.1	1.8

Table 5.2-5 (Continued)

DATE Yr/Mo/Day	ORIGIN TIME	LOCATION Lat°N/Long°W	DISTANCE to CLN (km)	CLN MAGNITUDE
76/04/01	14:46:58.0	33.9 106.0	275.5	2.6
76/04/06	18:09:00.2	33.9 105.0	208.6	2.7
76/04/18	03:48:18.5	33.9 106.0	271.2	2.1
76/04/21	08:40:05.5	32.3 102.9	81.4	1.7
76/05/03	06:52:59.0	32.4 105.6	182.4	2.4
76/05/06	17:18:23.8	32.0 103.2	71.9	1.8
76/05/21	13:17:35.0	32.3 105.3	149.0	2.2
76/06/15	02:19:58.3	31.6 102.4	158.4	1.7
76/06/15	08:50:20.0	31.5 102.4	164.0	2.1
76/08/10	09:03:11.6	31.8 102.2	158.0	1.4
76/08/10	10:15:13.8	31.8 102.2	166.0	1.7
76/08/25	01:27:48.5	31.5 102.5	156.3	1.8
76/08/26	15:22:12.7	31.8 102.2	160.8	1.7
76/08/30	11:51:25.2	31.5 102.6	145.9	1.4
76/08/30	13:07:47.5	33.9 106.3	297.8	2.3
76/08/31	12:46:22.4	31.5 102.8	130.6	1.9
76/09/05	10:39:45.7	32.2 102.8	93.8	1.4
76/09/17	02:47:46.9	32.2 103.1	62.7	2.1
76/09/19	10:40:46.4	30.6 104.5	222.9	3.0
76/10/14	11:02:59.7	32.3 103.1	63.9	0.9
76/10/22	05:06:11.8	31.5 102.2	176.2	2.0
76/10/23	12:51:36.9	31.6 102.4	161.6	1.6
76/11/03	23:24:14.7	31.0 102.5	199.3	1.8
77/01/29	09:40:43.5	30.6 104.6	220.0	2.1
77/02/10	01:22:49.4	32.3 103.1	60.2	1.0

Table 5.2-6

TENTATIVE EPICENTRAL LOCATIONS FOR
EARTHQUAKES AFTER INSTALLATION OF STATION CLN

DATE Yr/Mo/Day	ORIGIN TIME	LOCATION Lat°N/Long°W		DISTANCE TO CLN (km)	CLN MAGNITUDE
74/08/17	07:35:18	30.4	105.8	300	3.5
76/03/20	12:42:20	31.2	105.0	180	2.3
76/04/01	14:40:26	34.1	105.8	280	2.8
76/04/01	14:51:17	33.9	105.9	270	2.8
76/05/04	15:05:40	32.0	103.2	70	1.9
76/05/08	11:46:38	32.0	102.8	100	1.8
76/05/11	23:04:38	32.3	102.8	90	1.9
76/05/26	11:52:26	32.4	102.6	110	1.7
76/06/14	23:29:50	31.6	101.9	200	2.3
76/06/16	14:05:12	31.6	101.9	200	2.3
76/08/05	22:23:29	30.8	101.8	260	3.0
76/08/25	01:21:01	32.8	101.1	250	2.8
76/09/10	23:17:48	30.9	101.7	260	2.8
76/10/13	19:11:06	32.0	102.0	90	1.5
77/03/14	10:10:22	32.9	100.8	290	3.5
77/03/19	21:27:49	31.3	102.8	160	2.2
77/03/20	07:54:05	32.3	102.8	90	2.3
77/04/12	23:18:27	31.2	102.6	170	2.9
77/04/16	06:44:22	31.2	102.9	160	2.1
77/04/17	21:47:07	31.5	102.0	190	2.1
77/04/26	09:03:05	31.9	103.0	100	2.6
77/06/07	23:01:17	32.7	100.6	300	4.5
77/06/08	00:51:29	32.8	100.8	280	4.0
77/06/17	03:37:05	32.8	100.9	270	3.9
77/08/03	02:11:48	32.8	105.3	150	2.5
77/08/21	03:01:16	30.8	104.8	210	3.4

Table 5.2-7

Central Basin Platform earthquakes recorded at Ft. Stockton Station (FOTX) from June 21, 1964 through April 12, 1965*

Date Yr/Mo/Day	FOTX-P Arrival Time GMT	FOTX-S-P Interval Secs.	LC-P Arrival Time GMT
64/06/22	07:07:47	14	07:08:22
64/07/13	12:20:03	14	
64/07/13	16:18:17	14	
64/07/19	02:34:16	13	
64/08/14	14:56:37	14	14:57:11
64/09/07	13:42:36	14	13:43:10
64/09/08	22:06:20	15	
64/09/11	12:33:08	14	
64/11/08	09:26:19	S**	09:26:53
64/11/16	02:06:05	15	
64/11/17	08:05:14	14	
64/11/18	10:20:30	14	
64/11/19	11:39:59	14	
64/11/19	11:40:30	14	
64/11/21	11:21:42	S**	11:22:17
64/11/23	03:30:18	14	
64/11/25	23:18:43	14	
64/11/26	00:03:13	14	
64/11/27	16:29:53	14	16:30:28
64/11/28	23:46:55	14	
64/12/01	20:59:50	13	
64/12/01	06:49:47	13	
64/12/05	23:09:43	14	
64/12/07	06:24:12	14	
64/12/07	06:31:40	14	
64/12/08	17:16:02	14	
64/12/13	19:19:19	13	
64/12/14	15:20:26	14	
64/12/26	00:08:29	14	
65/01/08	14:01:13	14	
65/01/12	20:35:19	14	
65/01/12	20:49:38	14	
64/01/21	11:51:51	14	
65/02/02	09:59:19	13	
65/02/03	19:59:52	S**	20:00:27
65/03/08	21:00:01	14	
65/03/09	03:46:18	14	
65/04/02	07:30:58	14	

* Listing of shocks restricted to events whose maximum peak to peak amplitudes exceeded 20 mm.

** Earthquake too strong on the seismogram to read S-P interval

Table 5.2-8

EARTHQUAKES IN THE CBP LOCATED WITH REGIONAL STATIONS BETWEEN 1962-1972

DATE Yr/Mo/Day	ORIGIN TIME (GMT)	LOCATION Lat°N/Long°W		MAGNITUDE
64/11/08	09:26:00	31.9	103.0	2.7
64/11/21	11:21:24	31.9	103.0	2.5
65/02/03	19:59:32	31.9	103.0	3.0
65/08/30	05:17:30	31.9	103.0	2.6
66/08/14	15:25:47	31.9	103.0	2.8
71/07/31	01:45:50	31.7	103.1	3.1
71/07/31	14:53:48	31.6	103.1	3.2
71/09/24	01:01:54	31.6	103.2	3.0

Table 5.2-9 Page 1 of 3
EARTHQUAKES LOCATED WITHIN THE
KERMIT ARRAY NOV 75-JUL 77

Date	Origin time	Lat N	Long W	Depth	M_L	#Sta
1976						
Jan 19	04:03:30.4	31.91	103.07	0.12	3.47	6
22	07:21:57.0	31.90	103.08	0.01	2.83	9
25	04:48:27.7	31.90	103.08	0.89	3.92	9
Feb 25	22:22:59.4	31.78	103.23	0.03	-	4
May 03	08:00:40.1	31.99	103.29	5.56	1.96	5
03	11:27:41.8	32.00	103.27	6.54	2.00	5
04	15:05:39.1	31.97	103.24	0.16	2.32	5
06	17:18:23.6	31.97	103.23	6.88	2.59	6
08	11:46:41.8	31.90	103.18	1.17	1.90	6
27	21:16:06.9	31.89	103.30	5.00*	1.60	3
28	16:15:23.6	31.89	103.32	5.00*	1.49	3
Jun 18	16:51:18.4	31.79	103.32	5.00*	1.68	3
Aug 05	18:53:09.2	31.57	103.02	9.29	3.01	4
Sep 05	16:10:27.7	31.61	103.31	5.00*	2.24	3
10	19:18:43.4	31.91	103.09	5.00*	2.25	3
Nov 04	23:27:54.0	31.67	103.26	0.12	1.74	4
05	22:55:30.4	31.65	103.22	5.00*	1.63	3
06	22:30:23.6	31.68	103.26	0.16	1.64	4
Dec 18	18:27:45.7	31.62	103.02	0.17	2.26	6
24	07:34:53.3	31.61	103.30	5.00*	1.45	3
25	12:58:34.9	31.63	103.29	0.41	1.18	4
26	12:15:04.6	31.63	103.26	0.00	1.17	4

Table 5.2-9 Page 2 of 3
EARTHQUAKES LOCATED WITHIN THE
KERMIT ARRAY NOV 75-JUL 77

Date	Origin time	Lat N	Long W	Depth	M_L	# Sta
1977						
Jan 08	20:20:27.2	31.50	102.98	5.00*	1.95	3
14	13:33:33.4	31.60	103.31	5.00*	1.12	3
18	04:39:59.5	31.61	103.27	0.52	0.25	4
20	23:01:01.2	31.61	103.27	5.00*	1.75	3
Mar 12	00:05:23.8	31.62	103.29	5.00*	1.90	3
24	10:31:36.3	31.61	103.27	3.93	0.81	4
24	21:13:10.4	31.67	102.95	2.65	1.77	4
29	00:35:34.9	31.62	103.27	3.43	1.67	5
Apr 03	13:48:09.2	31.49	103.17	0.12	2.36	5
03	14:24:07.1	31.49	103.17	0.04	2.43	6
04	00:44:05.3	31.48	103.17	0.29	2.37	5
04	04:35:56.8	31.50	103.17	0.41	2.11	6
04	04:47:29.9	31.49	103.17	0.17	1.77	5
04	21:40:16.3	31.59	103.31	5.00*	1.68	3
04	22:55:54.0	31.59	103.30	5.00*	1.77	3
05	19:23:03.2	31.58	103.30	5.00*	1.60	3
06	23:22:30.9	31.59	103.31	5.00*	1.66	3
07	18:56:55.6	31.59	103.30	5.00*	1.67	3
07	22:32:29.3	31.60	103.30	5.00*	1.78	3
09	09:44:39.5	31.62	103.28	4.12	0.64	4
09	11:04:14.2	31.62	103.27	1.80	0.56	4
16	01:21:11.4	31.61	103.30	5.00*	0.51	3
16	06:44:22.0	31.62	103.26	3.91	1.26	4
16	14:38:39.6	31.61	103.25	0.34	0.52	7
17	20:52:38.3	31.63	103.31	5.00*	0.63	3

Table 5.2-9 Page 3 of 3
EARTHQUAKES LOCATED WITHIN THE
KERMIT ARRAY NOV 75-JUL 77

Date	Origin time	Lat N	Long W	Depth	M_L	# Sta
18	18:08:24.1	31.61	103.27	6.63	2.14	7
20	12:59:58.7	31.61	103.31	5.00*	0.74	3
23	18:58:46.7	31.59	103.14	0.01	0.69	4
26	09:03:07.3	31.90	103.07	4.02	3.10	8
26	09:05:50.4	31.89	103.09	2.67	1.06	5
May 19	04:25:30.6	31.62	103.26	0.20	1.00	4
Jun 09	11:37:35.4	31.61	103.26	5.00*	1.33	3
29	23:59:46.6	31.54	103.30	0.14	2.76	5
Jul 25	17:45:48.1	31.57	103.30	5.00*	1.27	3

* Focal depths constrained to 5 km

Table 5.2-10 Page 1 of 3

EARTHQUAKES LOCATED AROUND THE PERIPHERY OF THE KERMIT ARRAY BY 5 OR MORE ARRAY STATIONS

Date	Origin time	Lat N	Long W	Depth	M_L	# Sta
1976						
Mar 15	02:30:48.3	32.15	102.96	0.12	1.56	5
20	16:15:55.5	32.30	103.05	0.35	1.70	5
27	22:25:21.0	32.21	103.10	0.06	1.49	9
Apr 12	08:02:35.9	32.17	103.11	0.45	2.38	5
21	08:40:07.4	32.21	103.10	0.25	2.53	6
May 01	11:13:40.8	32.27	103.14	9.92	3.04	8
Jun 15	02:20:00.5	31.58	102.65	0.76	2.39	7
15	08:50:20.9	31.55	102.48	6.85	2.67	13
Aug 10	09:03:12.2	31.86	102.35	0.14	2.39	7
10	10:15:18.2	31.80	102.55	0.55	2.87	9
25	01:27:49.3	31.56	102.58	3.89	2.79	9
26	15:22:17.7	31.79	102.59	0.75	3.03	11
31	12:46:21.1	31.56	102.73	7.84	2.78	9
Sep 05	10:39:49.4	32.16	103.11	0.18	1.68	5
17	02:47:45.4	32.21	103.10	0.20	2.98	10
17	03:56:29.9	31.42	102.54	1.66	3.44	7
19	10:23:24.4	32.14	103.09	7.29	2.41	6
Oct 14	11:03:00.1	32.21	103.07	2.74	2.32	6
22	05:06:15.9	31.57	102.54	3.03	2.94	7
25	00:27:04.2	31.81	102.58	6.59	2.95	7
25	10:52:27.3	31.85	102.40	0.17	2.15	5
26	10.44:44.1	31.33	103.28	0.46	2.81	7
Dec 12	23:00:14.0	31.52	102.53	7.59	3.21	11
12	23:25:56.0	31.55	102.58	0.13	2.33	7
19	21:26:16.0	31.79	102.64	0.25	2.61	5

Table 5.2-10 Page 2 of 3
EARTHQUAKES LOCATED AROUND THE PERIPHERY OF THE KERMIT ARRAY BY 5 OR MORE ARRAY STATIONS

Date	Origin time	Lat N	Long W	Depth	M_L	# Sta
19	23:54:22.7	32.18	103.11	1.48	2.26	6
19	23:56:46.5	32.26	103.08	1.04	2.85	6
1977						
Feb 10	01:22:50.5	32.17	103.10	2.04	2.03	6
18	14:10:36.8	32.20	103.10	3.89	1.17	5
Mar 05	22:56:10.0	31.30	102.65	2.14	2.35	9
17	15:14:13.3	32.14	103.07	2.21	0.95	6
20	07:54:08.0	32.21	103.10	0.99	2.22	8
23	11:02:51.8	31.81	102.51	4.69	1.93	6
Apr 04	01:47:50.4	31.44	103.18	3.96	2.11	5
07	05:45:39.4	32.24	103.17	1.53	2.91	7
12	23:18:26.4	31.26	102.61	0.21	2.24	9
25	10:12:51.1	32.08	102.80	5.94	1.35	6
28	12:54:36.9	31.81	102.51	0.46	2.16	7
28	12:55:40.5	31.79	102.59	4.21	2.17	7
28	12:57:20.3	31.80	102.59	4.77	1.73	7
28	15:22:37.7	31.79	102.61	3.14	2.46	8
29	03:09:40.4	31.80	102.58	1.25	1.73	6
Jul 11	12:31:55.7	31.79	102.73	2.93	2.74	10
11	13:29:49.8	31.79	102.73	2.49	2.19	9
12	17:06:06.3	31.79	102.71	4.86	2.44	9
18	12:37:30.6	31.80	102.74	0.97	2.90	8
22	04:01:10.1	31.80	102.73	3.42	3.35	8
22	04:18:10.5	31.80	102.73	2.30	2.50	7
22	04:36:51.0	31.81	102.75	0.38	1.67	6

Table 5.2-10 Page 3 of 3
EARTHQUAKES LOCATED AROUND THE PERIPHERY OF THE
KERMIT ARRAY BY 5 OR MORE ARRAY STATIONS

Date	Origin time	Lat N	Long W	Depth	M_L	# Sta
24	09:23:00.5	31.80	102.73	2.04	2.49	10
26	02:01:09.3	31.81	102.77	0.27	1.45	9

Table 5.2-11 Page 1 of 1

DIFFERENCES IN ARRIVAL TIMES BETWEEN THE EARTHQUAKES ON JULY 26, 1972 AND NOVEMBER 28, 1974

Station	Phase	Earthquake on July 26, 1972	Earthquake on Nov. 28, 1974	ΔT
LUB	Pn	04:36:20.3	03:35:58.25	22.05
ALQ	Pn	04:36:36.8	03:36:13.35	23.45
SNM	Pg	04:36:36.9	03:36:13.85	23.05

END

DATE

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GEOLOGICAL CHARACTERIZATION REPORT WASTE ISOLATION PILOT PLANT (WIPP) SITE, SOUTHEASTERN NEW MEXICO

SAND78-1596

VOLUME II

Dennis W. Powers, Steven J. Lambert, Sue-Ellen Shaffer,
Leslie R. Hill, Wendell D. Weart, Editors

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GEOLOGICAL CHARACTERIZATION REPORT

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GCR CHAPTER 6
HYDROLOGY

6.1 INTRODUCTION

The location of the proposed WIPP site is within the surface water boundaries of the Rio Grande Water Resources Region and the groundwater boundaries of the Unglaciated Central region of the Permian Basin. In addition, the site lies within the boundaries of the Delaware Basin, a portion of the Unglaciated Central region that includes some of the least productive aquifers in the United States. The Delaware Basin is characterized by a semiarid climate with low rainfall and runoff, high evaporation, and frequent strong winds. The proposed site contains neither perennial streams nor surface water impoundment, and the water bearing strata beneath the site do not yield large quantities of water to wells. Shallow wells in the local area are generally used only for watering livestock and typically produce non-potable groundwater with total dissolved solids (TDS) concentrations in excess of 3,000 parts per million (ppm).

Hydrologic studies of the water resources surrounding the site have been supported by universities and state and federal agencies since the late 1930's (Robinson and Lang, 1938; Theis and Sayre, 1942; Hendrickson and Jones, 1952; Bjorklund and Motts, 1959; Nicholson and Clebsch, 1961; Brokaw et al., 1972; Hiss, 1975a). The early studies were primarily concerned with the control of water quality in the Pecos River for agricultural usage downstream from the brine discharge at Malaga Bend (Robinson and Lang, 1938; Hale et al., 1954). The first investigations of hydrogeologic parameters describing the occurrence and flow of groundwater in close proximity to the proposed WIPP location began in the late 1950's with Project Gnome (Cooper, 1962; Gard, 1968; Cooper, 1971).

Hydrologic studies at the site and adjacent site areas have concentrated on defining the hydrogeology and associated salt dissolution phenomena (Griswold, 1977; Lambert and Mercer, 1977; Mercer and Orr, 1977; Mercer and Orr, 1978; Anderson, 1978). These investigations are directed toward a more quantitative evaluation of the salt dissolution process, the

hydrogeologic parameters affecting groundwater movement, and the major elements of surface and groundwater quality affecting water resource use and local ecology. The collection of hydrologic data is projected to continue for several years to provide site-specific information for a detailed safety analysis of the WIPP.

Hydrologic test results to date have been used to make bounding calculations of hypothetical occurrences based upon simplifying assumptions of the physical system. Future measurements obtained from the experimental programs and analysis of the test data will be used to refine the initial bounding calculations and to provide a more detailed description of the physical system and system dynamics. The use of computer models as predictive tools is expected to be closely coordinated with current test results from an established monitoring network. Compatible chemical tracers will be injected directly into the groundwater system as a test of the predictive computer results. Also, the use of chemical tracers during construction phases of the WIPP may provide an early indication of leaky borehole plugs or faulty repository seals, if any, far in advance of radionuclide concentrations in the groundwater system.

6.2 SURFACE WATER HYDROLOGY

The area proposed for the Waste Isolation Pilot Plant (WIPP), located in southeastern Eddy County, New Mexico, lies at an average elevation of 3410 feet above mean sea level (MSL) in the Northern Chihuahuan Desert. Although the area belongs to the drainage basin of the Pecos River, surface drainage patterns at the site are not well defined. Preliminary studies indicated that areal requirements for the surface facilities, underground storage, and safety considerations during the operation of the repository would be as shown in Table 6.2-1 (see also Table 2.1).

6.2.1 Surface Water Features

The Rio Grande Water Resources Region, which includes the Pecos River basin, is an area of 88,968 square miles. The Pecos River basin has a

total drainage area of about 44,535 square miles (approximately 20,500 square miles of which do not contribute to river flow), a maximum basin width of about 130 miles, and an overall length of about 500 miles before combining with the Rio Grande River. The Pecos is generally perennial, except in the reach below Anton Chico and in the reach between Fort Sumner and Roswell, where the low flows percolate into the stream bed. About 60 percent of the annual flow occurs between April and September.

The Pecos River is located west of the site and flows southeast through Carlsbad. At the closest point (river mile 430), the Pecos River is approximately 14 miles west of the WIPP site center. The total drainage area of the river at this location is 19,000 sq. miles. A few small unnamed creeks and draws constitute all tributaries flowing westward of the Pecos River within 20 miles north or south of the site. From the west, the Black River (drainage area of 400 square miles) joins the Pecos at a point approximately 16 miles southwest of the site near river mile 436. The Delaware River (drainage area of 700 square miles) joins the Pecos near river mile 446, and a number of small unnamed creeks and draws join at various points along this reach. Pecos River flow in this reach is regulated by storage in Lake Sumner (river mile 401.9), Lake McMillan (river mile 404.2), Lake Avalon (river mile 407.2) and several other smaller upstream dams that divert water for irrigation. The salient features of the five existing dams on the Pecos River in a reach extending 25 miles upstream and 25 miles downstream of the WIPP site are listed in Table 6.2-2. The approximate slope of the Pecos riverbed in the vicinity of the WIPP site is 4.5 ft/mile (U.S.G.S. Topographic Maps NI 13-11 & NI 13-12).

There are no major lakes or ponds within 10 miles of the WIPP site center. Laguna Gatuna, Laguna Tonto, Laguna Plata and Laguna Toston are lakes located to the north more than 10 miles from the site. All these lakes are at or above elevation 3,450 feet. Therefore, surface runoff from the site would not flow toward any of the lakes to the north. To the west and northwest, Red Lake, Lindsey Lake, Salt Lake, and a few unnamed ponds are located more than 10 miles from the site, between elevations 3,000 and 3,300 feet (U.S.G.S. Topo. Maps, 1:250,000).

Surface water and groundwater withdrawals in the Pecos River basin are listed in Table 6.2-3.

6.2.2 Precipitation Patterns

The nearest station to the WIPP site for which climatological records are available is located at Carlsbad, about 26 miles west of the site, at an elevation of 3,120 feet MSL (U.S. Weather Bureau, 1961). Over a period of more than 71 years (NOAA. 1977), the annual precipitation at Carlsbad ranged from 2.95 inches to 33.94 inches. The average annual precipitation over a period of 30 years (1931-1960) was 12.43 inches (U.S. Weather Bureau, 1961). The average annual precipitation from 1951 to 1974 was 9.78 inches at Artesia (elevation 3320 feet), which is about 48 miles northwest of the WIPP site. At Hobbs (elevation 3615 feet), which is about 44 miles northeast of the site, the average annual precipitation for the period 1951-1974 was 14.29 inches. Interpolation of precipitation data for Carlsbad, Artesia and Hobbs indicates that the average annual precipitation at the site should be approximately 12 inches, which is nearly equal to the average annual precipitation at Carlsbad. Therefore, the precipitation patterns at Carlsbad are assumed to be representative of the conditions at the WIPP site.

Maximum, average, and minimum monthly precipitation at Carlsbad over a period of 30 years (1931-1960) are given in Table 6.2-4. The maximum monthly precipitation, 12.28 inches, occurred in May. With the exception of May and August, when the record minimum monthly precipitation were 0.18 and 0.01 inch, respectively, the record minimum precipitation for all other months has been 0.00 inch. The maximum daily precipitation since 1905 occurred in August, 1916, and was 5.12 inches.

The maximum daily and monthly snowfalls at Carlsbad since 1905 have been 10 inches (December, 1923) and 17.8 inches (February, 1905), respectively (U.S. Weather Bureau, 1961).

In general, summer rain is more abundant than that of other seasons and is caused by thunderstorms generated by the southeasterly circulation of moist air from the Gulf of Mexico. Approximately 75 percent of the total annual precipitation occurs from April through September. Winter rainfall is least abundant and is caused mainly by frontal activity associated with the movement of the Pacific storms across the country from west to east (NOAA, 1977).

6.2.3 Drainage

The site is located between elevations 3,250 and 3,570 feet MSL (Griswold, 1977). General ground slope in the vicinity is approximately 39 feet/mile from the northeast to southwest. Average ground slope from north to south is approximately 13 feet/mile. A topographic and surface water divide (Antelope Ridge) exists approximately 8 miles east of the site center and 4 miles from the exterior boundary of Zone IV (Refer to Table 6.2-1).

In general, the surface in the site vicinity is hummocky and covered by sand dunes. The local slope is poorly defined, and rain collects in pools between sand dunes and evaporates, is transpired, or sinks into the sand. Surface runoff from an area of about 10 sq. miles to the northeast, along with that from the site area, drains through a number of small draws which terminate in unnamed ponds to the southwest. Runoff is typically 0.1 to 0.2 inches annually.

6.2.4 Floods

Historically, floods for the Pecos River are reported to have occurred in 1904, 1905, 1915, 1916, 1919, 1937, 1941, 1942, and 1966 (NOAA, 1977). The earliest flood for which discharge information is available occurred on October 2, 1904, following the failure of Avalon Dam. During this flood, the flow at Avalon gaging station (river mile 406.3) exceeded 90,000 cfs. The corresponding river stage is not available. The river stage at Red Bluff (river mile 459.8) is reported to have reached 28 feet

(gage datum of 2850.05 feet) during this flood. Another major flood occurred on August 7, 1916, when the discharge at Carlsbad Station (river mile 419.1) reached 70,000 cfs.

A third major flood occurred in September, 1919, when the river stage at Malaga gaging station (river mile 432.2) was recorded as 29.4 feet (gage datum of 2895.64 feet). The corresponding discharge was 40,400 cfs. The highest flood of record (through 1976) for the Pecos River occurred on August 23, 1966, when the discharge and stage at Malaga were 120,000 cfs and 42.1 feet, respectively (U.S. Geological Survey, 1976). The minimum surface elevation of the site is more than 310 feet above this maximum historic flood level.

6.2.5 Evaporation and Transpiration

In New Mexico, potential evaporation is much greater than the average annual precipitation. In the southeastern valleys, evaporation from a class A pan is on the order of 110 inches per year. During the warm months, May through October, evaporation in the southeast portion of the state is approximately 73 inches.

The record high temperature at Carlsbad is 112°F (June, 1902). The record low temperature at this station is 7°F (January, 1911). The maximum, average and minimum monthly temperatures at this station over a period of 30 years (1931-1960) are given in Table 6.2-5 (U.S. Weather Bureau, 1961). June, July and August are the warmest (average temperature of 80.7°F) while December and January are the coldest months of the year (average temperature of 44.3°F).

In this type of desert climate, more than 90 percent of all infiltrated water evaporates or transpires. The high rate of evapotranspiration is aided by the frequent winds, the low relative humidity (typically 36 percent during daylight hours), and the high mean annual temperature (61°F).

6.2.6 Infiltration

Soils at the site are generally comprised of sands extending to a depth of as much as 25 feet. Actual sand dunes cover a good portion of the site area. With pervious sand on the surface, infiltration rates are high and probably similar to the 1.6 inch-per-hour intake rate of Harkey Sand Loam (75 percent sand) near Carlsbad (Blaney and Hanson, 1965). Groundwater in the area of the site is more than 50 feet below surface elevations. Because the surface sands are underlain by a caliche layer about 2 to 8 feet thick, percolation of rainfall through the sands to the nearest groundwater would be only a portion of the total infiltration. Most infiltration will return to the atmosphere by evapotranspiration.

6.2.7 Surface Water Quality

Water quality in the Pecos River basin is affected by mineral pollution from natural sources and from irrigation return flows. Springs near the headwaters of the basin below Colonias, New Mexico, are estimated to discharge approximately 707 tons per day of dissolved solids into the Pecos River. Below Lake McMillan, springs flowing into the river are usually submerged and difficult to sample; however, dissolved solids concentrations between 3350 and 4000 ppm have been measured in springs that could be sampled. The chemical quality of these mineral discharges indicates the nonpotable character of the ground water in contributing source beds. Inflow of concentrated brine solutions at Malaga Bend increases the chloride content of the Pecos River by an estimated 370 tons per day (see account by Swenson in Bachman and Johnson, 1973). Time-weighted averages of water quality parameters for three sampling stations on the Pecos River between Carlsbad and Malaga Bend are shown in Table 6.2-6. In general, natural spring flows and irrigation return flows progressively concentrate salts downstream. Further downstream at Red Bluff Reservoir, the water is useable occasionally during high flow periods.

6.3 GROUND WATER HYDROLOGY

Detailed investigations of ground water conditions at the proposed site are being conducted to identify the presence of ground water, to measure ground water quality, and to determine hydraulic conductivity and other characteristics of the stratified rocks. The data will provide a basis for assessment of the continued isolation of the proposed repository from ground water circulation. The thick halite beds of the Salado Formation at the WIPP site are isolated from circulating ground water by beds of low hydraulic conductivity, both above and below the formation. In the vicinity of the proposed site, fresh or potable ground water is not present except in small, isolated, near-surface perched bodies.

Investigations to evaluate the transport of radionuclides by ground water flow in the southeastern New Mexico portion of the Delaware Basin were made by the Water Resources Division of the U.S. Geological Survey for Project Gnome in the late 1950's. Since that time, several studies have been carried out by individual consultants, the U.S. Geological Survey, Oak Ridge National Laboratories, and Sandia Laboratories. These studies have been directed to the specific task of providing a better understanding of the relationship between the proposed waste repository and ground water movement. The following is a description of ground water occurrence and flow as understood from the studies completed to date. Ground water is first described on a regional basis, then the results of site specific studies are reviewed, and, finally, dissolution of salt evaporites is discussed.

6.3.1 Regional Ground Water Conditions

Ground water within the Delaware Basin is predominantly of poor quality, with total dissolved solids concentrations in excess of 3,000 ppm. The only large quantities of potable ground water are found in aquifers west of and along the Pecos River. To the west in the Guadalupe Mountains, many rock units of the basin crop out, and the soluble salts have been leached from the Ochoan evaporites.

Important aquifers of the region are the San Andres Limestone and the Capitan Limestone and related reef limestones. The San Andres is a major source for irrigation waters in the Roswell basin, and other areas to the north and northwest of the site. The Capitan aquifer southwest of the community of Carlsbad is the primary source of municipal water. An important aquifer in the region east of the proposed site is the Ogallala Formation. Unconsolidated alluvium along the Pecos River yields large amounts of relatively fresh ground water in some areas, although it is commonly of marginal quality for drinking purposes.

From the outcrop areas west of the Pecos River, ground water moves eastward. The shallow aquifers, those cut by the Pecos River, discharge to the river, either directly or to alluvium of the river channel. The Capitan aquifer is the oldest permeable formation that may have contact with the river. Ground water in permeable formations older than the Capitan is not directly affected by the river, is present under confined conditions, and migrates eastward into the Delaware Basin.

East of the Pecos River, thick beds of evaporites are present at depth, and brines are common in the underlying permeable formations. Ground water in any of the rock units east of the river in Eddy County is of brackish quality, at best. Fresh meteorically-derived ground water does not flush out the poor quality waters in these aquifers. Consequently, the major utilization of ground water in the central and eastern Delaware Basin is for oil-field flooding. The predominant source of the ground water is the Capitan aquifer.

The shallow aquifers east of the Pecos River are limited in extent, are low yielding, and usually contain water of poor quality. Recharge to these shallow aquifers is presumed to be from precipitation on outcrop areas or from overlying formations, and migration of the water generally follows surface drainage patterns, eventually reaching the Pecos River.

In discussing ground water occurrences in relation to the proposed repository, it is convenient to relate them to the Salado Formation because the Salado and its associated evaporite formations have very low hydraulic conductivities and form a barrier to vertical flow (see Table 9.2.3-1). Aquifers stratigraphically below the Salado are widespread and contain large quantities of brine under confined conditions. Aquifers present above the Salado in the proposed site area are either limited in extent or very low-yielding. This upper ground water is of poor quality (TDS concentrations greater than 3,000 ppm) and occurs under unconfined, as well as confined, conditions.

6.3.2 Hydrology of Rocks Underlying the Salado Formation

The halite beds of the Salado Formation that are proposed for the repository are underlain by thick anhydrite and salt beds of the Castile Formation. They act as an aquiclude, separating the Salado from the underlying sandstones of the Delaware Mountain Group. The sandstones are present at a depth of about 4,200 feet in the site area. The hydraulic conductivity of the sandstones of the Delaware Mountain Group, associated with the relatively high hydraulic conductivity of the shelf-margin facies (the Capitan Limestone) and the shelf facies (which includes the San Andres Limestone) make this group the most important hydrologic system underlying the Salado. The hydrology of these Guadalupian-age rocks has been investigated in detail by Hiss (1975a).

Considerable information derived from hydrocarbon exploration in the basin is available on the hydrologic properties of the formations underlying the Permian evaporites. As reported by Lambert and Mercer (1977), the Delaware Mountain Group is the uppermost of the oil- and gas-producing horizons, which extend to the Ellenburger Group at a depth of about 18,000 feet. Several zones are encountered that contain water, oil, and/or gas that are under sufficient pressure to maintain a potentiometric surface at an elevation above that of the Salado Formation. Some of the zones have sufficient hydraulic conductivity to allow flow rates of several hundred barrels per day. In addition to the

Delaware Mountain Group, the Atoka zone at a depth of about 13,150 feet, and the Strawn (Desmoinesian) zone at about 12,900 feet are other oil and gas production zones that are considered deep aquifers by Lambert and Mercer (1977).

Deep Hydrologic Units. The hydrologic parameters of pre-Guadalupian zones are not as well defined, nor are they as hydrologically significant to the proposed repository as the Guadalupian-age rocks. Nevertheless, a review of them is presented, based primarily on McNeal's (1965) analysis of hydrodynamics of the Permian Basin. He described the potentiometric surfaces of seven zones, using elevations of outcrops where cut by a stream or body of water, static water levels in cable tool holes or water wells, and formation pressures converted to potentiometric surface elevations. McNeal prepared maps showing the regional potentiometric surfaces in terms of fresh water, using density differences of the various brine concentrations and depths of the nearby wells. The three deep hydrologic units reviewed are the Ellenburger Group, the Devonian zone, and the Mississippian- Pennsylvanian zone.

1) Ellenburger Group. The Ellenburger Group consists mainly of chert-bearing limestones and dolomites. It is a widespread unit, covering some 100,000 square miles in southeastern New Mexico and northwestern Texas (McNeal, 1965, Figure 1). The unit is estimated to be 350 feet thick at the proposed site (Lambert and Mercer, 1977) and as much as 1000 feet thick elsewhere in the region. The potentiometric surface compiled by McNeal for the Ellenburger indicates an altitude range from 4,200 feet MSL southwest of the site to less than 1,400 feet MSL in central Texas. In the vicinity of the WIPP site, the ground surface elevation is about 3200 feet MSL. The average gradient of the potentiometric surface is about 8 feet per mile in an easterly direction. Water in the Ellenburger is a brine solution, with a dissolved solids range of 50,000 ppm to more than 200,000 ppm. No water production data are available for this group.

2) Devonian Zone. McNeal's potentiometric surface for the Devonian hydrodynamic zone ranges in altitude from 4,000 feet MSL in the vicinity of the Glass Mountains to 3,200 MSL feet along the Lea County - Texas line. In the Midland Basin, there are nearly hydrostatic conditions at an elevation range of 2,800 to 3,200 feet MSL. A high potentiometric nose extending across southeast Eddy County indicates a potentiometric surface at the proposed site of about 3,700 feet MSL. Salinity of the formation water is less than 50,000 ppm in most of southeast New Mexico. In west Texas, salinity reaches 200,000 ppm in one area.

The Devonian, as inferred from McNeal's potentiometric map, extends throughout southeast New Mexico and northwest Texas. He has included Silurian data in the eastern (Texas) subcrop area. The potentiometric surface generally slopes to the east, and the average gradient appears to be about 7 feet per mile.

3) Mississippian-Pennsylvanian Zone. Mississippian rocks are thin and few data are available on the occurrence of fluids under the Delaware Basin. McNeal (1965) delineated a potentiometric surface for the Mississippian zone of West Texas, but has not extended it into New Mexico.

There are three water-bearing zones in Pennsylvanian age rocks. In ascending order they are the Morrow, the Atoka, and the Strawn (Desmoinesian). Lambert and Mercer (1977, p. III-2) report that the Morrow may be a high pressure, low capacity reservoir with water-production rates ranging from 10 to 20 barrels per day. The Atoka also may be an overpressured reservoir with enough head to yield fluid columns of 3375 to 6552 feet MSL at gradients of 0.47 psi per foot. The water is produced from gas wells at rates ranging from 21.6 barrels per day to as much as 214.4 barrels per day (Texas American's Todd Federal Well No. 1).

Lambert and Mercer (1977) report that several wells have been drill stem tested in the Desmoinesian age Strawn zone and several others have been completed a oil wells. On five drill stem tests, the calculated heads

ranged from 3350 to 6203 feet MSL. Water production was reported to be as much as 416 barrels per day in one drill-stem test, and one well (Phillip's James "E" No. 1) produced an average of 106 barrels per day. A potentiometric surface of the Strawn zone is presented by McNeal (1964, Figure 4), but the only area in the Delaware Basin for which data were available was in the southwestern part of Eddy County. Elevation of levels in that area range from 3,200 feet to 3,800 feet MSL. The gradient is easterly at about 20 feet per mile.

Bone Spring Formation. According to Lambert and Mercer (1977), the Bone Spring Formation (Leonardian Series) can be considered an aquiclude. They report that bottom-hole pressure data from the majority of seven wells tested had insufficient heads to prevent downward movement of shallower water. They suggest the pressure data indicate the formation has a low capacity and contains reservoirs of limited volume.

Guadalupian Age Rocks. The most important aquifers of the Delaware Basin are part of a hydrologic system that incorporates rocks of Guadalupian age. The system comprises three interconnected aquifer groups; the shelf aquifers (including the San Andres Limestone and the Artesia Group), the Capitan aquifer (including primarily the reef deposits - Capitan and Goat Seep Limestones), and the basin aquifers (sands of the Delaware Mountain Group). These aquifers are depositionally juxtaposed, but are distinguished in most areas by contrasting hydraulic conductivities, water salinities, and potentiometric levels. Along the north and northwest interface, hydraulic conductivity of the shelf aquifer, although lower, is near the hydraulic conductivity of the Capitan aquifer. The basin aquifers have the lowest values of hydraulic conductivity, and the Capitan is a discharge point for ground water flows in them. Recharge to these basin aquifers probably occurs in outcrop areas along the west flank of the Delaware Basin. Ground water then moves generally eastward, downdip in the tilted beds. Data on aquifer characteristics, compiled by Hiss (1975a), are summarized in Table 6.3-1. Hydrologic, lithologic, and physical properties of the formations in which these aquifers occur are discussed below.

1) Delaware Mountain Group Aquifer. The Delaware Mountain Group includes, in ascending order, the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations and comprises the basin facies of the system. The combined thickness of these formations ranges from less than 2,000 feet in the southern part of the Delaware Basin to more than 4,000 feet in southwestern Lea and eastern Eddy Counties, New Mexico (Hiss, 1975a).

The Brushy Canyon Formation is as much as 1,000 feet thick and consists chiefly of sandstone with limestone lenses and occasional conglomerate at the base. No wells are known to be extracting water from this formation in Eddy County (Hendrickson and Jones, 1952).

The Cherry Canyon Formation is also as much as 1,000 feet thick and consists of thin-bedded, fine-grained sandstone and some persistent limestone beds. The lower one-fourth of the formation persists as a sandstone tongue striking northwestward into the Guadalupe Mountains which may yield water to some wells and springs in that area (Hendrickson and Jones, 1952).

The Bell Canyon Formation ranges in thickness from 670 to 1,040 feet and consists mainly of sandstone and thin beds of limestone (King, 1948). The formation interfingers to the northwest with the reef limestone of the Capitan Formation, providing the potential hydrologic interconnection of the Guadalupian Age rocks. Large springs near the base of the reef escarpment west of the Pecos River are probably supplied by ground water moving through the upper beds of the Bell Canyon Formation (Hendrickson and Jones, 1952).

An average hydraulic conductivity of 0.016 ft/d (feet per day) and a porosity of 15.65 percent were determined by Hiss (1975a) from analyses of approximately 4,500 samples of rock core cut from the Delaware Mountain Group in Eddy and Lea Counties, New Mexico, and Ward and Winkler Counties, Texas. Hiss also computed a similar hydraulic conductivity from productivity indexes (approximately equivalent to specific

capacities) obtained from an oil company for two wells in the El Mar field located on the boundary between Lea County, New Mexico, and Loving County, Texas.

Hiss (1975a) indicated that similar values of hydraulic conductivity were reported by earlier writers for much of the same part of the Delaware Basin.

Hiss compiled a potentiometric surface map of the Delaware Mountain Group, of which the northern Delaware Basin portion is shown in Figure 6.3-1. The data used by Hiss in compiling the map were taken at different times over a period of about 25 years between the late 1940's and early 1970's. However, he believes the contours are representative of conditions during the period 1960 and 1970. Although some local changes to the potentiometric surface are due to oil and water withdrawals during that period, no data suggest that the regional directional trend has changed. The potentiometric surface data for the brines have been corrected to "fresh-water" density, indicating a potentiometric elevation of 3350 feet MSL in the vicinity of the proposed WIPP site. The hydraulic gradient in the northern portion of the basin dips northeasterly at approximately 15 feet per mile.

Quality of the water in the Delaware Mountain Group is generally poor. An isochlor map compiled by Hiss (1975a, Figure 25) shows a chloride-ion concentration range from 50,000 to 150,000 ppm in the east half of the Delaware Basin. Concentration diminishes to approximately 1,000 ppm southward in the vicinity of the Glass Mountains and northwestward in the vicinity of the Guadalupe Mountains. These are outcrop areas where the Guadalupian Age rocks probably have been recharged by precipitation. However, analyses of water samples taken from the hydrologic system in the vicinity of the repository site indicate that the brine solutions do not contain oxygen and hydrogen isotopes in ratios characteristic of meteoric waters. The relative proportions of O^{18}/O^{16}, and deuterium/hydrogen ratios have probably been altered through interaction with the rock of the formation (Lambert, 1978; see also Chapter 7 of this report).

According to Hiss, recharge to the basin aquifers is through precipitation on the outcrops in the Guadalupe, Delaware, Apache, and Glass Mountains, and from downward leakage through the younger rocks in areas where the overlying soluble Ochoan evaporites have been removed. The potentiometric surface (Figure 6.3-1) indicates water moves north and northeastward, and discharge is to the overlying Capitan and shelf aquifers.

2) Capitan Aquifer. The Capitan Limestone and the underlying Goat Seep Limestone constitute the main body of the Capitan aquifer, which is the reef facies of the Guadalupian rocks. Hiss (1975a) describes the aquifer as a long continuous unit that extends in an arcuate strip along the north and east margins of the basin, with exposures in the Guadalupe and Glass Mountains, as well as the Delaware and Apache Mountains. The thickness of the aquifer ranges from a few hundred to more than 2,000 feet, and the average width is approximately 10 miles (Hiss, 1975a, Figure 11). It is one of the most important aquifers of the region and is a major control in the hydrologic system (Mercer and Orr, 1977).

Relatively few aquifer tests have been performed to measure the hydraulic conductivity of the Capitan aquifer. The data compiled by Hiss (1975a) are summarized in Table 6.3-1. Hiss calculated that the hydraulic conductivity of the Capitan aquifer along the western margin of the Central Basin Platform in Texas and New Mexico ranges from 1 to 25 ft/d and estimated that for most of southern Lea County and for about 15 miles east of the Pecos River valley from Carlsbad it is about 5.0 ft/d. Although Hiss was unable to conduct any aquifer tests in the area west of the Pecos River, he concluded that high production wells, the presence of caverns, and high porosity suggest that the hydraulic conductivity of the Capitan is higher west of the river than east of the river. The hydraulic conductivity is probably very high, as well, in the Glass Mountains, because of numerous small caverns (Hiss, 1975a). The coefficient of transmissivity of the Capitan aquifer along the northern and eastern margins of the Delaware Basin is estimated by Hiss to range from 10,000 ft^2/d (square feet per day) in thick sections to less than 500 ft^2/d in the vicinity of eroded, thin sections of the reef.

The Capitan aquifer receives some recharge by direct infiltration on outcrops in the Guadalupe and Glass Mountains, and probably more by percolation of discharge from the basin and shelf aquifers along the north and east margins of the basin. Water-table conditions exist in the aquifer west of the Pecos River and in the Glass Mountains, but to the north of the Glass Mountains and east of Carlsbad water in the aquifer is confined. Hiss believes that water entering the Capitan aquifer in the Guadalupe Mountains moves northeastward toward Carlsbad where most of the water discharges into the Pecos and Carlsbad Springs. The Pecos River controls the movement of ground water in the Capitan aquifer in the vicinity of Carlsbad, and east to the ground-water divide near the Eddy-Lea County line (figure 6.3-1).

Hiss (1975a) believes that a deep submarine canyon cut into the Capitan Limestone is present near the Eddy-Lea county line, and a hydraulic restriction is formed to constrain the eastward movement of water in the aquifer from the vicinity of the Pecos River. Apparently there is little movement of water between the Pecos River and the Eddy - Lea County line. East of the hydraulic restriction, the potentiometric surface declines with an eastward gradient. Hydrographs of observation wells, established by the U. S. Geological survey in the Capitan aquifer from Carlsbad east and south to the Texas - New Mexico state line have recorded these water level differences. Water levels during the years 1967 through 1972 indicate that from Carlsbad eastward to near the Eddy - Lea County line, the potentiometric surface has remained nearly constant, responding to minor fluctuations of the Pecos River. East of the county line, water levels declined more than 100 feet, at a constant rate, during those 6 years (Hiss, 1975a, Figure 24). The eastward gradient and decline in potentiometric surface are caused primarily by the large withdrawals of water for oil-field water flooding in eastern New Mexico and western Texas (Mercer and Orr, 1977). These withdrawals are apparently the primary discharge from the aquifer at the present time. The similar potentiometric heads and directions of movement of the Capitan and shelf aquifers along the northeast and east sides of the basin (Figure 6.3-1) suggest some discharge from the shelf aquifer also

occurs. In analyzing potentiometric data prior to 1950, when large extractions of water from the Capitan had not developed, Hiss (1975a), concluded that discharge at the time was east, into the shelf aquifers.

Water of good quality, although hard, is available in the Capitan aquifer in the area west of Carlsbad (Hendrickson and Jones, 1952), and apparently in the Glass Mountains. However, in the major portion of the aquifer, east of the Pecos River, quality is poor. Chloride-ion concentration increases from 200 ppm just west of Carlsbad to as much as 23,000 ppm east of the community. Along the east flank of the basin, salinity of Capitan water is significantly lower than that in the adjacent shelf and basin aquifers, ranging from about 1,100 to 5,000 ppm in most wells (Hiss, 1975a, Figure 26).

3) Shelf Aquifers.

The shelf aquifers do not have a direct impact on hydrologic conditions underlying the proposed site because the Capitan aquifer is a hydrologic boundary. Nevertheless, they are in close hydraulic connection with that aquifer, and would apparently accept some discharge from the Capitan, should the extensive pumping from the Capitan be discontinued.

The lowermost unit of the Guadalupian age shelf or "back-reef" facies, known as the San Andres Limestone, extends over much of southeast New Mexico and into northwest Texas. The average thickness of the unit is about 1500 feet. Overlying the San Andres are formations of the Artesia Group. Strata in these formations that yield significant quantities of water are the shelf aquifers. The contact between the Capitan and shelf aquifers is gradational and difficult to differentiate in some areas. In the Pecos River Valley between Carlsbad and Roswell, and to the west of that area, the shelf aquifers are quite porous and yield large quantities of potable water to wells (Hendrickson and Jones 1952). The hydraulic conductivity of the aquifers east of the river and in the Central Basin Platform are significantly less than those to the west, and water quality is poor (Hiss, 1975a).

Measurements of hydraulic conductivity and porosity of core samples of the shelf aquifers were collected by Hiss (1975a) and the data are summarized in Table 6.3-1. It can be seen that the hydraulic conductivities in this area are at least one order of magnitude less than hydraulic conductivities of the Capitan aquifer. Potentiometric levels of the shelf aquifer, shown on Figure 6.3-1, are similar to those of the Capitan aquifer along the east side of the Delaware Basin. In the vicinity of Carlsbad, however, the levels are as much as 200 feet higher than those of the Capitan, suggesting poor interconnection between aquifers in that area.

The major areas of recharge to the shelf aquifers are probably north and west of Carlsbad in the Guadalupe mountains and areas west of the Roswell basin. Water in the shelf aquifers to the north moves either southwestward to the Pecos River, or southeastward onto the Central Basin Platform. Water quality in the shelf aquifers varies considerably from one area to another, but is generally poor east of the Pecos River. Chloride-ion concentrations in excess of 150,000 ppm are indicated by Hiss (1975a, Figure 26) north of the Capitan aquifer and along the east flank of the Delaware Basin. However, a narrow band of better quality water (salinity less than 10,000 ppm) in the San Andres Limestone is indicated to the northeast, between the shelf and the Central Basin Platform.

Castile Formation. The Castile Formation overlies the Delaware Mountain Group and consists predominantly of anhydrite with halite interbeds, and subordinate limestone. Its thickness ranges from 1,300 to 2,000 feet over most of the Delaware Basin. In most of the basin hydraulic conductivity of the Castile is very low so that this formation acts as a confining layer for the underlying Delaware Mountain Group (Mercer and Orr, 1977). However, west of the Pecos River, the salt beds have been removed, hydraulic conductivity of the residuum is higher and water is available to wells (Bjorklund and Motts, 1959).

In the central Delaware Basin, isolated pockets of brine and associated hydrogen-sulfide gas have been encountered by various oil companies in

the Castile, and also in the Sandia Laboratories exploratory hole, ERDA-6 (Mercer and Orr, 1977). High-pressured brines encountered in three oil wells east of the proposed site reportedly have had flow rates as high as 20,000 barrels per day. These brines are present near the top of the formation, suggesting a brine zone, but since no other wells have encountered brines, the zone is apparently not continuous (Rose, 1977). Brine from ERDA-6 further suggests a long isolation time on the order of one million years for that pocket (Barr, Lambert and Carter, 1978).

Salado Formation. Massive beds of halite of the Salado Formation are the intended host rock for the WIPP repository. The formation extends more than 100 miles both north and east of the Delaware Basin and underlies an area of approximately 25,000 square miles (Pierce and Rich, 1962). Formation thickness in the Los Medanos area is 1,976 feet, as measured at ERDA-9, and the depth to the top is 848 feet.

Porosity of the halite is very low and interconnected pores are virtually non-existent. Lack of open fractures is assured because of the high plasticity of the material. As a result, hydraulic conductivity of the beds is effectively zero. As reported by C. L. Jones (1973), microscopic to very small angular cavities in grains of halite contain very minor amounts of brine and gas. Less common are much larger cavities or pockets in the halite beds that contain halite-saturated brine and nitrogenous gas confined under pressure sufficient to produce a "blow-out" when encountered during drilling. Nevertheless, the brine pockets do not appear to be interconnected, but seem to be isolated fluid bodies within the rock.

Because halite is quite soluble, it would readily dissolve if the beds came in contact with circulating, unsaturated solutions. West of the proposed site, where the Salado rises to the surface, progressively less halite is present as a result of leaching by percolating ground water. Where exposures existed, all of the salt has been removed (see Section 4.3.2.).

As discussed in Section 4.3.2., removal of salt from the Salado Formation in the western portion of the basin where it is exposed, or near the surface, has formed a residuum of clay, gypsum and sand. In the Carlsbad area along the Pecos River and to the west, Bjorklund and Motts (1959) report that these clays are dense, and are referred to as "red beds". They suggested that the residue has slowed ground-water infiltration and subsequent salt removal.

Underlying Nash Draw, a salt dissolution zone is present in the residuum at the contact between the Salado and the overlying Rustler Formation. As reported by Mercer and Orr (1977), the dissolution zone extends from the recharge area north of Nash Draw to its termination in the vicinity of Malaga Bend. Water penetrates the overlying units through fractures and solution zones in the recharge area and moves southward along the top salt, and discharges into the Pecos River at Malaga Bend (Figure 6.3-2). The dissolved solids content of the brine at the river has been reported to be in excess of 300,000 ppm. Theis and Sayre (1942) calculated the discharge from the brine aquifer into the Pecos River at Malaga Bend to be about 200 gpm. Hale (in Hale, Hughes, and Cox, 1954) calculated a value of transmissivity of 8,000 ft^2/d from aquifer tests in the area between Malaga Bend and Laguna Grande de la Sal. Apparently, as salt has been progressively leached from the overlying beds, the residuum has developed a base of low hydraulic conductivity, preventing further downward leaching, and the dissolution zone has developed along the same structural control as Nash Draw (Robinson and Lang, 1938).

6.3.3 Hydrology of Rocks Overlying the Salado Formation

Nearly all of the water bearing formations overlying the Salado in the Delaware Basin are of materials with low hydraulic conductivity and which contain limited amounts of poor-quality water. The major hydrologic unit in the area that yields moderate quantities of marginal-quality water to wells is the alluvium of the Pecos River valley. Information on the hydraulic characteristics of these water bearing formations is limited, and only regional descriptions of potentiometric levels and hydraulic conductivity can be established.

Rustler Formation The Rustler Formation extends laterally beyond the limits of the Salado Formation and consists of interbedded anhydrite, dolomite, siltstones, clays, and halite. Two dolomite beds in the formation are water-bearing units, other than the Rustler-Salado contact, discussed above. The thickness of the dolomite beds ranges from 20 to 30 feet; these beds are areally extensive. The Magenta Dolomite is a finely crystalline, dense dolomite, and the Culebra Dolomite is vuggy and commonly associated with some anhydrite. The Magenta transmits only minor amounts of water and is not considered an important aquifer (Lambert and Mercer, 1977).

Although the Culebra Dolomite is areally persistent, yields of water vary considerably from place to place. Cooper and Glanzman (1971) suggested that the variability of yields is related to the size and number of fractures and openings in the dolomite, which in turn, could be related to its depth. In the northern part of Nash Draw, the dolomite is near the surface and is reported to yield as much as 700 gpm. East of Nash Draw, where the dolomite is covered with Triassic and younger rocks, yields are typically at least two orders of magnitude less.

Measurements of the hydraulic properties of the Culebra in the region are scarce, primarily originating from studies related to Project Gnome investigations (Cooper and Glanzman, 1971). Aquifer-performance tests in holes drilled for Project Gnome studies indicate a transmissivity of 460 ft^2/d, an average hydraulic conductivity of 16 ft/d, a storage coefficient of about 10^{-4}, and an average effective porosity of 10 percent.

Mercer and Orr (1977) prepared a map of the potentiometric surface from water levels measured in wells open to the Rustler Formation in the north portion of the Delaware Basin (Figure 6.3-2). The data were taken from several sources and represent a composite of the Culebra and Magenta dolomites, or other zones. However, it is believed that most wells are open to the Culebra dolomite bed because it is the most consistently producing rock in the vicinity.

These data indicate that water in the Rustler Formation moves west and southwestward across the Lea - Eddy County line, and southeastward from the community of Carlsbad toward Nash Draw, and the Pecos River to the south. Only the Magenta is exposed locally on the flanks of Nash Draw, and both the Culebra and the Magenta form the floor of wide sections of Nash Draw in the vicinity of Laguna Grande de la Sal.

A single water well in Lea County is reportedly deep enough to have reached Permian beds (Nicholson and Clebsch, 1961); otherwise no additional information is available on occurrence of water in the Rustler Formation in the area.

The Dewey Lake Redbeds. The youngest formation in the Ochoan Series, the Dewey Lake Redbeds, consists of orange-red siltstone with some mudstone and sandstone. This formation has been removed from the western and southern parts of the Delaware Basin by post-Permian erosion but is present in the subsurface throughout most of the site area. The thickness of the formation varies from about 200 feet to as much as 600 feet (Hiss, 1975a).

The Dewey Lake Redbeds are not an aquifer, although some permeable sand lenses are present and yield small quantities of water to a few wells. Regionally, the beds act as an aquiclude, restricting water at the surface from percolating downward to more permeable units in the underlying Rustler Formation.

Dockum Group. The Dockum Group consists of three formations. In ascending order, they are, 1) the Tecovas Formation, which consists of up to 300 feet of red shale, siltstone, and fine-grained sandstone, 2) the Santa Rosa Sandstone, which is composed of 100 to 650 feet of red, brown, and gray sandstone, and 3) the Chinle Formation equivalent, which consists of up to 1,300 feet of red, maroon, and purple shales and siltstones with lenses of fine-grained red-to-gray sandstone (Hiss, 1975a). The group is present only as a thin wedge in Eddy County, thickening to the east in Lea County and in Texas.

Both the Chinle Formation equilvalent and the Tecovas Formation are present only as thin, isolated remnants in southeastern New Mexico, primarily in Lea County. The few wells drilled into these formations yield small quantities of poor-quality water (Hiss, 1975a). In contrast, the Tecovas and Chinle are not considered aquifers in the Delaware Basin. The Santa Rosa Sandstone is a principal aquifer in several areas, particularly in Winkler and Ward Counties, Texas (Hiss, 1975a). It produces both fresh and saline water, depending on location. The westernmost extent of the Santa Rosa Sandstone is just into Eddy County, as shown in Figure 6.3-3. Water levels in wells open to the Santa Rosa Sandstone, reported by several sources, are the basis of the potentiometric surface by Mercer and Orr (1977) shown in Figure 6.3-3. Wells completed in the Santa Rosa Sandstone have low yields with specific capacities of 0.14-0.2 gpm per foot of drawdown (Nicholson and Clebsch, 1961); the formation porosity is about 13 percent.

Ground water recharge to the Santa Rosa Formation is from precipitation on the outcrop and percolation through sand dunes and the overlying Ogallala Formation to the east (Nicholson and Clebsch, 1961). Movement is generally southwest, but additional recharge apparently occurs along the potentiometric high that trends southwest along the eastern side of Eddy County. Discharge is to underlying formations at the edge of outcrops and reportedly downward through collapse zones such as San Simon Swale.

Ogallala Formation. The High Plains (Llano Estacado) region south of the Canadian River is mantled by the Ogallala Formation, which consists of Pleistocene sediments from 0 to 500 feet thick. South of Mescalero Ridge in Lea County the formation becomes discontinuous, and there are no definite remnants of the Ogallala west of easternmost Eddy County. Recharge to the Ogallala is by direct precipitation on the outcrop and by percolation through overlying sand dunes and alluvium. Nicholson and Clebsch (1961) reported that the saturated thickness of the Ogallala ranges from 25 to 175 feet. This variability can be attributed to the very irregular Triassic surface that underlies it. Movement of water in

the Ogallala is controlled to a great extent by the generally southeastward slope of the underlying Triassic red beds (Mercer and Orr, 1977).

Quaternary Deposits The Gatuna Formation is the oldest known Quaternary formation in the area and fills channels and steep-walled valleys cut primarily into the Dewey Lake red beds and Rustler Formation. In the type section and in the vicinity of Nash Draw where the Gatuna is readily recognizable, it is overlain by an extensive caliche zone that marks the Mescalero surface (Bachman, 1974). East of Nash Draw, there are few outcrops of the formation.

The Gatuna Formation yields limited amounts of water to wells where the water is in isolated gravel and sand lenses. Yields of one to five gpm are small but are usually sufficient for stock and domestic use. Ground water from the Gatuna probably percolates downward into Triassic sandstone or the Rustler Formation (Mercer and Orr, 1977).

Younger quaternary deposits are represented by alluvium. The most extensive alluvial deposits are along the west side of the Pecos River north of Malaga. Isolated patches of alluvium, however, occur along the Pecos to the south. In some areas the thickness is nearly 300 feet, and yields are reported to be as much as 3,000 gpm (Hendrickson and Jones, 1952). The source of water is primarily underflow from west of the Pecos River augmented by leakage from canals and from irrigation return flow.

Alluvium east of the Pecos River is restricted to relatively small closed depressions. Nash Draw and Clayton Basin contain Quaternary alluvium, and, in places such as Laguna Grande de la Sal, contain lake or playa deposits. The thickest alluvial deposits occur within San Simon Swale where they are in excess of 500 feet. Ground water present in the San Simon alluvium may be derived from discharge from the Santa Rosa Sandstone (Mercer and Orr, 1977). The lake and playa deposits often yield some water, although it is generally highly mineralized.

6.3.4 Regional Ground Water Use

Ground water is used in the region for irrigation, municipal supplies, rural domestic supplies, stock watering, a few industrial purposes, and for secondary oil recovery (usually referred to as "oil field flooding"). In southeastern New Mexico and western Texas almost all the ground water produced is used for this latter category. The Capitan aquifer is the largest source, but supplies are also taken from the Santa Rosa Sandstone and the Rustler Formation (Hiss, 1975a).

Demand for water throughout the region has increased steadily over the past three decades and is expected to continue into the 1980's. Production from the Capitan aquifer alone increased from approximately 80,000 acre-feet in 1950 to about 700,000 acre-feet in 1970 (Hiss, 1975a, Figure 38). The increase has been fairly linear over the 20 year period. Most of the increased demand has been for oil-field flooding which began in the early 1950's. The largest amount of pumping for this purpose is in Ward and Winkler Counties, Texas, and is primarily extracted from the Capitan aquifer. The other major source is the San Andres Limestone. According to Hiss (1975a), the cumulative total of water produced from these aquifers for the period 1920-1969, in thousands of acre-feet, is as follows:

	Eddy County	Lea County	West Texas	Total
Industrial	65.4	-	-	65.4
Irrigation	151.0	-	223.7	374.7
Municipal	162.0	-	-	162.0
Secondary Recovery	0.6	2.8	293.0	296.4
TOTAL	379.0	2.8	516.7	898.5

Listed below (in acre-feet) is a summary of usage in Eddy County for the year 1949 (Hendrikson and Jones, 1952) and in Lea County for the year 1954 (Nicholson and Clebsch, 1961). It is reasonable to assume that the quantities reported for industrial, irrigation, municipal, and rural use

have increased a moderate amount. The quantity listed for secondary recovery has increased moderately in southeastern New Mexico and dramatically in west Texas, as noted above.

	Eddy County (1949)	Lea County (1954)
Industrial	4,000	2,710
Irrigation	130,000	2,600
Secondary Recovery	0	40
Rural Domestic/Stock	2,000	450
TOTAL	141,000	6,350

Occurrence of large quantities of potable ground water is restricted to west of the Pecos River, and most of this water is extracted from the Capitan aquifer. Hiss (1975a) reported that the municipal water supplies for the communities of Carlsbad and White's City are obtained from wells completed in the Capitan aquifer. Hiss also reported that water pumped from the Capitan aquifer is used to irrigate about 2,300 acres of farmland in the Pecos River valley, the immediate vicinity of Carlsbad.

In addition, water pumped from the Capitan aquifer at Carlsbad is transported by pipeline to a potash refining plant located about 18 miles east of Carlsbad. Approximately 3,740 acre-feet of water per year was used to refine potash ore during the period 1965-1969.

Oil Field Secondary Recovery. In the early 1950's, the petroleum companies operating in the region initiated a process to recover crude oil that could no longer move to wells under existing reservoir pressure. This secondary recovery technique is one in which water is injected under pressure into the oil-bearing formation to drive the residual oil to the pumping wells. Injection may be into existing depleted wells or into wells constructed specifically for this purpose.

According to Hiss (1975a, Table 15), a cumulative total of nearly 300,000 acre-feet of water has been produced from the Capitan aquifer for

secondary recovery versus a total of about 725,000 acre-feet actually used in the flooding process. The difference of 425,000 acre-feet has been supplied from other sources including the San Andres Limestone and the Ogallala and Rustler Formations. The major areas of extraction for this use are in Ward and Winkler Counties, Texas.

Ground Water Utilization East of the Pecos River, Southeast New Mexico. In this area, small amounts of ground water are used for rural domestic supplies, stock watering, gasoline plants, and gas stripping. The Rustler Formation, the Santa Rosa Sandstone, and the Artesia Group are the principal hydrologic units pumped for those purposes. In the Nash Draw area, relatively large quantities of ground water have been taken from the Rustler Formation for use in potash refining. In the past, considerable amounts were pumped for irrigation in Lea County, but this has apparently been discontinued (Nicholson and Clebsch, 1961).

Gasoline plants use a considerable amount of water for their cooling and boiler systems. Nicholson and Clebsch (1961) report that in Lea County a total of 2400 acre-feet of ground water was used for this purpose in 1959. Gas stripping plants in the area also use water for extracting hydrogen sulfide and carbon dioxide from residual gas. Nicholson and Clebsch (1961) estimated that 150 acre-feet per year is used for this purpose.

In 1972, Cooley (1973, Table 4) inventoried the existing and abandoned wells in a nine-township block in east-central Eddy and west-central Lea Counties, New Mexico. Most of these wells are of low yields and are used mainly for domestic supplies and stock watering. Table 6.3-2 is extracted from the Cooley survey; well locations are shown on Figure 6.3-4.

6.3.5 Ground-Water Occurrence at the Proposed Site

The wells in the vicinity of the site (Figure 6.3-4) indicate that ground water above the Salado Formation is found only in limited quantities, and

is commonly of such poor quality, that it is not usable. Where the quality is marginal, it is utilized for watering stock, and is considered a valuable resource (Nicholson and Clebsch, 1961). Below the Castile Formation, at considerable depth, the Bell Canyon Formation might yield large quantities of water, but it would be brine. Although these units are technically regarded as aquifers, in the following discussion, only the hydrologic characteristics of fluid-bearing zones underlying the proposed site will be described. These zones are not identified as aquifers because an aquifer readily yields good quality water to wells.

Fluid-bearing Zones. The hydrologic exploration at the proposed site performed by the U. S. Geological Survey to date has been directed primarily to the fluid-bearing rocks of the Rustler Formation, and to the Rustler-Salado contact zone. They directly overlie the Salado salt and furnish a potential, although remote avenue for salt dissolution and radionuclide transport (Mercer and Orr, 1978). Additionally, brines in the sands of the underlying Bell Canyon Formation have been tested. These fluids are under sufficient head to allow them to reach the Salado salt. Because the brines are undersaturated, they could dissolve the salt. However, to reach the Salado, these fluids would have to first penetrate the Castile Formation. Permeabilities (or lack of permeability) of the Castile and Salado Formations at the site have been determined by drill-stem tests in two exploratory holes: ERDA No. 9 and AEC No. 8. The tests, summarized by Lambert and Mercer, 1977, Tables 1 and 2, indicate that the two formations are extremely tight. The tests gave no indication of fluid content in either formation.

Other zones that were briefly tested include zones in the Dewey Lake red beds where circulation was lost during drilling, or where hydraulic conductivity was believed to be measurable. However, no appreciable amounts of fluid were encountered (Mercer and Orr, 1978).

When the exploration and testing were completed, Mercer and Orr (1978) made several conclusions concerning the occurrence of fluids in the rocks. These include the following:

Monitoring of fluid-bearing zones in the Rustler Formation indicate that stabilized heads decrease with depth; consequently, potential fluid movement would be downward in rocks above the salt. However, the large head differences between fluid-bearing units within the Rustler indicate little or no vertical connection.

Head distribution determined for the Culebra dolomite indicates fluid movement to the southeast across the site. Gradients range from 7 to 120 ft/mi and vary as a function of hydraulic conductivity.

Head distribution within the Magenta dolomite has been determined only in three holes and indicates fluid movement to the southwest. The hydraulic gradient is 50 ft/mi.

Fluids in the Culebra and Magenta are expected to move primarily along fracture systems, and measurements of the effective porosities and hydraulic conductivities in low-yielding fractured rocks are very difficult to obtain.

Brines were found at some locations along the Rustler-Salado contact, but extremely low yields were measured.

Although evaluation of the testing of Bell Canyon sands is not complete, preliminary results at AEC-8 indicate the potentiometric surface, corrected to fresh-water density, is higher than similarly corrected levels of fluid zones in the Rustler Formation.

Hydrologic Testing. The geologic and geophysical exploration performed at the site provides a detailed understanding of the stratigraphy and structure of the underlying formations. This work was described in previous sections. In coordination with the exploratory drilling, a program of hydrologic testing and monitoring was established. As a result, considerable data on the occurrence of ground water have been collected. The ground-water studies are continuing and the data collected will further our understanding of the site conditions.

In addition to continued monitoring of the existing observation wells, long-term pumping tests to measure vertical connection between zones, and other tests have been planned. Also, some hydrologic information is available from the recently completed ERDA 10 test hole, located approximately 8.5 miles southwest of the proposed site.

One of the major problems faced in this program is the difficulty of measuring hydrologic parameters in materials of extremely low hydraulic conductivity in the field. Thorough testing of even the more permeable zones, such as the Culebra Dolomite, requires long periods of time, as well as close control of the interval being tested. To collect a sufficient quantity of water from these materials for proper water quality sampling requires long periods of time. Recovery of water levels in observation wells to static conditions is very slow; levels in some of the wells on site had not stabilized after more than 12 months of monitoring. Nevertheless, the data collected are sufficient to provide a good measure of the hydraulic characteristics and an understanding of ground-water occurrence at the proposed site. Hydrologic test data as of August, 1978, are available from 9 exploratory holes within the proposed land withdrawal boundary, and from the hole designated AEC 8, which is just outside the boundary, as shown on Figure 6.3-5. The U. S. Geological Survey Water Resources Division has been directing the testing program. A summary of drilling and testing operations is given for each hole in Section 6.4. A full description of the testing program and the data collected is presented in Mercer and Orr, 1978. The following discussion is extracted from that report.

The objectives of the program have been to determine the static head or reservoir pressure, the water-yielding potential (i.e., hydraulic conductivity and transmissivity) of the rock strata, and the chemistry of formation waters. These hydrologic tests are made in the exploratory test holes both during drilling and after the hole has been drilled to total depth.

Five of the test holes were specifically designed for hydrologic testing (H-1, H-2 complex, and H-3); the others were drilled for other purposes as well (potash mineral evaluation and/or geologic exploration) but were adapted for hydrologic testing. After drilling and testing wells H-1 and H-3, triangular arrays H-4, H-5, and H-6 complexes were designed similar to the H-2 complex but with a 100-foot well spacing. The additional sets of triangular arrays (H-4, H-5, and H-6) have been completed recently and testing has started.

The H-series test holes were drilled with air and detergent to avoid the undesirable mudcake that occurs when drilling with gel. This method also allows detection of fluid-producing zones that are encountered during drilling. When detected, some of these zones were tested before completion of drilling for a preliminary estimate of yield. On completion of drilling, geophysical logging was performed in all holes. These logs provided detailed information on lithologic changes, formational characterstics, potencial zones of water yield, and borehole diameter changes. These data are used to select intervals to be tested, as well as provide information on hole conditions in the selection of packer seats.

Following logging, each potential zone of water yield was isolated with packers, and a drill-stem test (DST) was conducted. The DST is a temporary well completion designed to furnish hydrologic data, such as representative samples of formation fluid, undisturbed formation pressures, and indications of the formation permeablity, and/or transmissivity. The standard DST, as used in oil-field exploration, was run in test holes AEC 8 and ERDA 9, but in the other tests the procedures were modified. The modification most commonly made was in the method of recording formation pressures. In the standard DST, pressures are recorded throughout the test by a Bourdon-tube pressure recording gage (pressure bomb) located near the bottom of the drill string. Data from this pressure bomb cannot be retrieved until after completion of the test. In the modification DST used in these investigations, the fluid was initially removed from the tubing, and the stabilizing fluid levels

were measured in the drill string. This modification allowed for continuous monitoring throughout the test. Additionally, pressure-monitoring devices were placed above and below packers to determine the degree of isolation of the zone from the rest of the borehole.

The test zones were bailed or swabbed until temperature, conductivity, and density of fluid in the casing stabilized to assure that the fluid was representative of formation fluid. Samples were then collected, treated according to standard U. S. Geological Survey techniques, and chemically analyzed for the major and trace elements and for radiochemistry. Results of these analyses are listed in Table 6.3-3. The geochemistry of these fluids is discussed in Chapter 7.

During the bailing, the volume and rate of fluid withdrawal were monitored. The rate of recovery following withdrawal was measured, and yields from test zones were then calculated. The results of these tests are summarized in Table 6.3-4.

After all potential water zones were tested in the open hole, casing was installed and grouted in all holes except ERDA 9. Selected intervals were perforated for monitoring potentiometric levels, and provision was made for long-term hydrologic testing. Radioactive tracer tests were conducted in some of the holes after they had been cased and perforated to examine the cement-bond for leaks between casing and the borehole wall. These tests also yielded some information on vertical distribution of permeability across the test interval. The perforated zones were then tested for yield by bailing or swabbing, as was done in the open hole, and results are summarized in Table 6.3-4.

When the testing of the cased holes was completed, the holes were prepared as multiple observation wells. The holes are used to monitor potentiometric levels of two separate zones with the use of packers and inner tubing. In some wells, a third zone was perforated, but a bridge plug was set above it, and the zone is not available for periodic

monitoring. Figure 6.3-6 illustrates the method of completing the wells, and Table 6.3-5 indicates the zones monitored at each observation well.

Periodic monitoring of the fluid levels in the wells began after completion of testing. Because of the low yield of the zones tested, considerable time is required after bailing for the recovery of fluid to reach a stabilized level. Most levels had stabilized by October 1977, as indicated in Table 6.3-6. These levels provide a measure of the potentiometric surfaces of the monitored zones, and an indication of hydraulic gradients.

Bell Canyon Formation. During the WIPP hydrologic testing program, cores were taken in the Bell Canyon Formation in exploratory hole AEC 8. Analyses of these cores indicated the presence of two sandstone units whose permeabilities were higher than those of the surrounding rocks. These units are referred to as the lower sand and upper sand; their depths are, respectively, 4,844 to 4,860 feet, and 4,821 to 4,827 feet.

Hydrologic testing of the two sand units was made only in cased, perforated zones. There was no open-hole testing. These tests included formation pressure testing, fluid level monitoring, aquifer yields, recovery rates, water sampling, and geophysical logs. Radioactive tracer logs were also run on this hole. Analysis of the data had not been completed at the time of the report by Mercer and Orr (1978).

After the fluid in the casing had been removed by swabbing to a depth of approximately 4,200 feet, the lower sand yielded 31 gallons of fluid in 166 minutes (average 0.2 gpm), recovering to a depth of 4,095 feet. The zone was then shut-in, and a static formation pressure of 2,037 lbs/in^2 was reached in 44-1/2 hrs. The upper sand was not tested for yield. Static formation pressure was 2,044 lbs/in^2 after 57 hours.

Samples collected from the two sand units indicate that these units contain dense brines. For example, the upper sand contains 189,000 ppm of total dissolved solids, 175,000 ppm of which is sodium chloride

(Mercer and Orr, 1978, p. 80). The major constituents from the analyses are listed in Table 6.3-3. Density of the brines of each zone was determined to be 1.11 gm/cm^3 for the upper sand, and 1.12 gm/cm^3 for the lower sand. These values were used to correct static heads to fresh-water equivalents (Table 6.3-6).

Rustler-Salado Contact. The contact zone between the Rustler and Salado Formations was tested in holes H-1, H-2c, H-3, P-14, P-15, P-17, and P-18.

Both open-hole and cased-hole tests were run on the Rustler-Salado contact in H-1 and H-3, and cased hole tests were run in H-2c, P-14, P-15, P-17, and P-18. Without exception, all tests showed very low yields, typically producing a few gallons per day in the cased holes and only slightly more in the open holes (Table 6.3-4). A yield of 9.1 gallons in a 20-hour period (in H-1) was the highest yield recorded. Based on the collected data, Mercer and Orr (1978, p. 83) calculated transmissivities from the yield data, ranging from 10^{-1} ft^2/day (in P-14) to 10^{-4} ft^2/day (in P-18). Recovery rates in the monitoring wells are so slow that the level had not stabilized in P-18, after 4 months (Table 6.3-6).

Samples were taken from all of the test wells except P-18. Analyses of these samples show that the fluid in the Rustler-Salado contact zone is a saturated brine containing more than 300,000 ppm total dissolved solids (Table 6.3-3).

Culebra Dolomite. The Culebra dolomite was tested in holes H-1, H-2b, H-2c, H-3, P-14, P-15, P-17, and P-18. Logs of these holes indicate that the thickness of this unit is about 28 feet and that its depth ranges from 410 to 940 feet below ground level.

Both open-hole and cased-hole tests were run in the Culebra in H-1 and H-3, and cased hole tests were run in H-2c, P-14, P-15, P-17, and P-18. Yields varied considerably. At P-14, 720 gallons of fluid were bailed with no noticable drawdown, while P-18 produced only 16 gallons of fluid

in 33 days of monitoring. Preliminary transmissivity values calculated by Mercer and Orr (1978) also reflect the variability with values of 140 ft^2/day at P-14, 10^{-1} ft^2/day at H-1, and 10^{-4} ft^2/day at P-18.

Mercer and Orr (1978) reported that fluids in the Culebra have a total dissolved solid range of 2[illegible]700 to 118,300 ppm, and a sodium chloride range of 17,900 to 89,200 ppm. The major constituents of samples taken from the Culebra are listed in Table 6.3-3.

Magenta Dolomite. The Magenta Dolomite was tested only in H-1, H-2a, and H-3. In these holes the Magenta is 25 feet thick and the top of the unit is 502 feet below ground level.

Both open-hole and cased-hole modified drill stem tests were run on the Magenta in H-1 and H-3; well number H-2a was constructed as an observation well for the Magenta. The open-hole drill-stem test on the Magenta in H-1 produced only 23 gallons of fluid in 13 hours. A subsequent swabbing of the permeable zone produced 107 gallons of fluid, which indicated higher productivity than the DST displayed. In the cased-hole test, the Magenta zone was bailed constantly until a pumping level of 424 feet (depth) was attained. After bailing was stopped, the fluid level recovered to a depth of 340 feet in 33 days. In H-3, an open hole drill-stem test produced 23 gallons of fluid in 38 hours, but 442 gallons were swabbed from the hole after the DST was discontinued. In the cased hole test, 1 hour of bailing produced 6 feet of drawdown, and recovery was from 405 to 401 feet in 33 days of monitoring. Preliminary transmissivity values computed by Mercer and Orr (1978) range from 40 ft^2/d to less than 1 ft^2/d.

The quality of the Magenta fluids is poor (Table 6.3-3), with a total dissolved solids range of 10,300 to 29,700 ppm. The sodium chloride range is from 6800 to 24,300 ppm.

Salt-Residue Zone. Rocks of the Rustler Formation in which halite beds have been removed by leaching--salt-residue zones--were considered to be

areas for possible fluid retention. A potential zone was identified from geophysical logging and drill stem tests performed in H-1 and H-3. Results show that very little fluid now exists in those zones. In H-1, the suspected zone yielded 11.2 gallons of fluid in 12 hours of monitoring.

6.3.6 Dissolution of Salt in the Permian Evaporites

Features apparently caused by solution and/or subsidence are common in southeastern New Mexico. The extensive karst plain of the Llano Estacado (the High Plains or Caprock region) indicate the prominence of rock solution as a geologic process. Depressions near the WIPP site range from small features no more than a few meters in diameter to large features such as Laguna Grande de la Sal (Salt Lake), 11 miles to the west-southwest of the WIPP site, and Laguna Plata and Laguna Gatuna, 14 miles to the north. Not all depressions in the region, however, have been formed by solution and collapse. Some have been formed by wind action, and others are the result of solution or etching of the caliche. Salt Lake does appear to occupy an area of coalesced collapse dissolution sinks, but Laguna Plata and Laguna Gatuna appear to have formed as solution blowouts in windborne sand deposits.

A report to Sandia Laboratories by R. Y. Anderson was prepared in early 1978. This report served to assemble and summarize available data regarding the dissolution of evaporites in the Delaware Basin. The Anderson (1978) report also proposed a set of working hypotheses for the origin of various dissolution features, in order to guide future Sandia investigations of evaporite dissolution relevant to the potential integrity of the WIPP horizons and adjacent evaporites. In the text that follows, an attempt is made to distinguish available data from working hypothesis, whenever Anderson (1978) is cited.

It has been estimated that as much as 50 percent of the original salt of the Delaware Basin evaporites has been removed (Anderson, 1978) either by surface erosion or by subsurface dissolution and transport by ground

water. These processes have been in progress intermittently through more than 100 million years (Bachman, 1974). At least four erosional periods, in which the removal of salt could have been accomplished, can be recognized. These include: 1) Early Triassic time, 2) Jurassic through Early Cretaceous time, 3) a Late Cretaceous through mid-Tertiary period, and 4) post-Ogallala uplift and erosion.

Of the processes which accomplished the removal, two types of salt dissolution have been recognized in the Delaware Basin. The more familiar dissolution is the removal of salt by waters percolating downward from above (primarily from precipitation falling directly on the ground surface above the salt). The percolating water removes soluble salts, leaving behind a residuum of insoluble material that is referred to as a leached zone (Vine, 1963). The shallow dissolution beneath Nash Draw is such a zone and is apparently the route of lateral migration of the leached salts that discharge into the Pecos River.

A second type of salt dissolution has been recognized as having dissolved salt from somewhere within the body of evaporites, generally resulting in the collapse and lowering of the overlying stratigraphic units. Anderson (1978) recognized the resulting insoluble residue as a blanket dissolution breccia which occurs to the west of the present salt edge in the basin. In addition, deep dissolution phenomena within the evaporites may have developed more localized collapse features that have been recognized around the margin of the basin and within the basin (Maley and Huffington, 1953). The origin of these deep dissolution features and breccias is more problematical than the origin of surface dissolution and the rates of dissolution more difficult to assess. Source of the water to dissolve the salt is hypothetically assumed to be aquifers underlying the salt beds, communicating through fracture systems in the intervening anhydrite beds.

Shallow Dissolution. The depth of shallow dissolution in the evaporites (base of leached zone) is highly irregular, but is usually less than 300 feet in the vicinity of the proposed site (see Section 4.3.2). It is

developed in the western part of the Delaware Basin where the evaporites are exposed, or near the surface. For example, in Nash Draw, where the Rustler Formation is exposed, leaching extends into the Salado, and the permeable residuum contains brine (Vine, 1963). It appears that percolating ground waters move laterally toward Nash Draw, eventually discharging to the Pecos River after becoming saturated with salt.

East of Nash Draw, down dip into the basin, the evaporite formations become progressively deeper, and the present-day top of salt becomes progressively higher in the stratigraphic section. The top of salt is at the top of the Salado Formation about 2 miles west of the center of the proposed site, and becomes progressively higher in the Rustler Formation across the site (Figure 6.3-7, also see Figure 2-6).

Jones (1972) reported the solution front in the Salado Formation to be between 2 and 3 miles west of the center of the site. Bachman (1974) described a thinning of the upper member of the Salado Formation to the west and north that he attributed to a combination of thinning inherent in the original deposition processes and thinning due to subsosion "during the middle and late Cenozoic. West of the line marked "edge of Salado salt" in Figure 6.3-8, there is almost a fourfold reduction in thickness of the upper member of the Salado Formation to as little as 150-170 feet in some places. This is the residue of a 500-foot thick section from which the soluble portions have been leached by circulating ground water. Wherever the upper member of the Salado has been thinned by dissolution, the section of rock between the upper surface of the remaining salt and the top of the formation consists of clay with crudely interlayered seams of broken gypsum (from rehydration of anhydrite) and fine-grained sandstone.

As dissolution progresses and the salts are carried away, voids develop and the residual layer is weakened until it is no longer able to support the overlying material. Slumping of the residue and the associated collapse of the roof can extend to surface elevations, resulting in a

topographic sink. The distinctive pitted topography that results is termed karst. Such topography, in which surface drainage is poorly defined, is extensive in southeastern New Mexico.

Bachman (1974) reported that dolines (that are believed to develop into shallow sinks on the rock surface beneath the soil mantle) are very common, and suggested that the course of the Pecos River southward from Carlsbad to the proximity of the New Mexico-Texas state line lies in a major belt of collapsed sinks. For example, along the east side of the Pecos River, southeast of Carlsbad at Malaga Bend, a linear scarp is believed to have formed along a collapse structure that is now occupied by the river. Other major collapse features mentioned by Bachman include Clayton Basin and Nash Draw. Bachman believes that these features formed as coalescing sinks, probably during Pleistocene time.

Another large depression cited by Bachman is San Simon Sink, located 22 miles east of the proposed site. Shallow dissolution is a factor in the development of this sink, which is apparently still in process. The last recorded collapse in San Simon Sink occurred approximately 40 years ago (Nicholson and Clebsch, 1961). Many sinks along the Pecos River Valley have collapsed in historic time (Bachman, 1974). As recently as 1973 a small collapse sink formed at Lake Arthur, N.M., about 50 miles (80 km) north of Carlsbad.

Deep Dissolution. Large, deep dissolution features filled with Cenozoic sediments overlying the inner margin of the Capitan reef (Figure 6.3-8) were recognized by some of the first geologists working in the Delaware Basin (Maley and Huffington, 1953). The source of water to dissolve the salt was assumed to be the Capitan aquifer.

The extent of large-scale dissolution structures is shown on Figure 6.3-8. The dissolution wedges were identified through varve correlation across the basin in the Castile Formation and recognition of dissolution breccia beds in the western part of the basin (Anderson et al., 1972). These studies suggest that deep dissolution wedges in the Castile

Formation occurred in the lower Salado and upper Castile salt beds (Anderson, 1978). The position of the eastern margin of the western wedge coincides with the location of dissolution features containing deep Cenozoic fill (Figure 6.3-8). The development of these features and the wedge was apparently a complex process. It probably included initial wedge development adjacent to the reef, similar to that seen in the eastern wedge (Anderson 1978), and later combined with shallow dissolution.

The most prominent small-scale, (less than 1 mile across) dissolution features in the vicinity of the Delaware Basin have been described by Vine (1960) as "domal karst features". The subsurface projection of one of these (dome "C") was encountered at the level of the McNutt potash zone by Mississippi Chemical Corporation. It was found to be a chimney in the Salado Formation filled with clay-cemented brecciated rock belonging to strata above the 7th ore zone. There are other erosion-breached domes similar to Vine's dome "C" in the vicinity of Nash Draw. The subsurface expression of the domes, if any, is virtually unknown. A chimney containing cemented rubble (incorrectly termed a "breccia pipe") was encountered in commercial exploratory drilling within the proximity of a low circular hill near the Wills-Weaver Mine, but this chimney was not associated with a breached-dome at the surface. Recent geophysical surveys of the region have revealed that some of these hills, including the "Weaver Pipe" and dome "C", are associated with resistivity lows. Both Vine (1960) and Anderson (1978) have proposed mechanisms for origin of these features, all of which remain to be tested by field investigations of their subsurface structure and composition (see Chapter 10). These mechanisms involve various combinations of differential solution, hydration of anhydrite to gypsum, and salt intrusion. An attempt to reconcile these mechanisms and apply them to the origin of domes near Queen Lake southwest of Nash Draw was made by Reddy (1961).

Anderson believes that the dissolution giving rise to these features is an ongoing process. The proposed site is in an area of the Delaware Basin that is free of regional deep dissolution, but localized features

are present in the vicinity. Nevertheless, the extensive investigation carried out at and near the proposed site, including exploratory holes, ERDA-10, ERDA-11, ERDA-9, and AEC-8, indicate that deep dissolution is not taking place there. ERDA 10 was located and drilled specifically to evaluate the suggestion of Anderson that the absence of Halite III in the Castile south of the WIPP site was due to deep dissolution. Examination of the core revealed no apparent solution residue or collapse breccia; the recently collected data indicate nondeposition rather than dissolution since this was the nearest probable location of regional deep dissolution, its absence implies a lack of threat to the WIPP site from this phenomenon.

Rates of Dissolution. It is evident that dissolution is an active process, and can be expected to continue in the future. The potential hazard to the proposed site by continued dissolution in nearby places such as Nash Draw, 7 to 8 miles west of the site, can be evaluated if the rates of dissolution are known. In relation to human activity, the rate of dissolution is almost immeasureably slow. However, in terms of geologic processes, an attempt to estimate the rate is not altogether impractical. As stated by Bachman (1974): "Active geologic processes have not changed since the close of Tertiary Ogallala time, about 3-4 m.y. (million years) ago. However, the rates of these processes have varied considerably. It is assumed that the rates of these processes will continue to vary and that prediction of future events can be made by assuming that the extremes of past conditions will not be exceeded in the future."

With this in mind, Bachman analyzed the rate of dissolution in Nash Draw since the development of the Mescalero caliche, estimated to be 600,000 years ago. The following summarizes his analysis (Bachman, 1974):

Collapse of the Mescalero caliche along the margins of Nash Draw indicates that this depression has formed, at least in part, since the deposition of the caliche.

Along Livingstone Ridge on the east side of Nash Draw, the Mescalero caliche is undeformed at elevations above 3,300 feet. It dips steeply into the depression along the ridge and occurs at elevations of 3,200 feet, and less, within the depression. Along Quahada Ridge on the west side of Nash Draw the Mescalero is likewise undeformed at elevations about 3,300 feet, but it dips steeply into Nash Draw and occurs as collapsed fractured masses within the depression (NE 1/4 sec. 1, T. 22 S., R. 29 E.).

A cross section through potash exploratory holes in Nash Draw indicates the approximate extent of salt dissolution in the Salado Formation since Mescalero time (Figure 6.3-9).

Nash Draw appears to have subsided between Livingstone and Quahada Ridges as much as 180 feet since Mescalero time. At one locality the surface of Nash Draw is 180 feet below the projected altitude of the Mescalero caliche (See figure 6.3-9). However, the interval between the top of the Salado Formation and the top of marker bed 124 at the same location is 420 feet, or 730 feet less than at Livingston Ridge where relatively little Salado salt has been removed. It is therefore interpreted that about 150 feet of Salado salt was removed before Mescalero time and about 180 feet has been removed since Mescalero time. At another locality, Nash Draw subsided approximatley 160 feet below the projected elevation of the Mescalero caliche while about 120 feet of Salado salt was being removed. There is a discrepancy here of about 40 feet that could be explained by surficial erosion.

Thus, in the area of Nash Draw that subsided 180 feet, the average rate of vertical dissolution over the 600,000 years was about 0.33 feet per 1000 years (Bachman, 1974).

These conclusions are based on the available geologic evidence, but the assumption should not be made that this rate of dissolution is a constant for the region. At least two other factors must be considered in this interpretation, but geologic information is not currently available to permit evaluation of them. The factors are:

Dissolution and subsidence rates probably have not been constant in Nash Draw during the past 600,000 years. A major part of this subsidence may have occurred during periods of high humidity in late Pleistocene (Wisconsin time).

The subsidence in Nash Draw, whenever it occurred in the Pleistocene, is not an average rate for the region. In the area of "the Divide," between Antelope and Livingstone Ridges, the Mescalero caliche is relatively undisturbed and probably no dissolution has occurred there since Mescalero time.

Calculations have also been made of the removal of salt from the Rustler and Salado Formations in Nash Draw based on the rates of discharge of dissolved sodium chloride and calcium sulfate into the Pecos River by brine seeps at Malaga Bend. Active dissolution of halite from the upper part of the Salado Formation occurs in the solution breccia zone at the base of the Rustler Formation in Nash Draw (Brokaw et al. 1972). The brine solution is believed to be recharged by aquifers in the Rustler and above, and its discharge is thought to be primarily at the Malaga Bend brine seeps and the salt lakes in Nash Draw. Piper (1973) calculated that the salts discharged into the Pecos River between Malaga Bend and a point 6 miles (10 km) downstream amount to 310,000 tons (10^8 kg) of NaCl and 170 tons (1.5 X 10^8 kg) of $CaSO_4$ each year. is equivalent to a loss of 0.16 vertical feet of salt sec thousand years, a rate of the same order of magnitude as that ed from the subsidence of Nash Draw.

An alternative approach of estimating vertical dissolution was used by F.A. Swenson (Bachman and Johnson 1973). He investigated the tonnage of salt dissolved and discharged by springs and streams along the east flank of the basin and found the maximum tonnage for the many subbasins to be 955 tons per square mile of drainage area each year. If the discharge continued at that rate it would mean a vertical dissolution of about 0.5 foot of salt in 1,000 years, provided the dissolution was distributed evenly over the area drained.

A rate of lateral shallow dissolution of salt in the western part of the Delaware Basin has been estimated to be about 6 to 8 miles per million years horizontally (Bachman and Johnson 1973). These estimates were based on the assumption that the salt-bearing Salado Formation extended to the Capitan reef escarpment on the western edge of the basin at the end of Ogallala time. It is now recognized that dissolution of this salt could have occurred at previous times in the past, and the average rate of salt removal by shallow dissolution is believed to be much slower than those estimates which establish an upper bound.

As stated previously, it is estimated that about 50 percent of the original volume of salt has been removed from the Basin. In considering the rate at which the salt was removed, it is generally recognized that much of the erosion and dissolution probably occurred since the beginning of Cenozoic time. This is a period of major uplift and erosion. Anderson pointed out (1978) that the dissolution features are closely associated with Cenozoic and postuplift hydrologic and structural controls. Nevertheless, as early as Jurassic time the basin was tilted and the western portion shown on Figure 6.3-8 was exposed and subject to erosion (Bachman, 1976). The hydrologic and structural conditions were apparently similar at that time to those of the Cenozoic, and the Jurassic climate is recognized to have been wet. Thus, it seems quite likely that the deep dissolution and erosional processes of salt removal could have been significantly accelerated during the Jurassic period.

The rate of deep dissolution is difficult to assess, and Anderson (1978) does not believe that estimates can be made with any degree of confidence, considering the available data. He suggests that if it is assumed that 1) deep dissolution progresses at a constant rate, and 2) that significant dissolution did not begin until after stripping of the Ogallala Formation from the basin (3-4 million years ago), projection of that rate would imply all of the lower Salado salt would be removed in about another million years. However, he does not believe the assumptions are valid.

Deep dissolution, as hypothesized by Anderson, would seem to have been a significant geologic process in Jurassic time, as well as in the Cenozoic. It is apparent that further study of these factors is needed to fully assess the impact on the proposed site. Sandia Laboratories and the U.S. Geological Survey are currently performing studies to provide data which should aid in this evaluation (see Chapter 10).

6.4 HYDROLOGY DRILLING AND TESTING SUMMARY

6.4.1 HOLE NO. H-1

LOCATION: T.22 S., R.31 E., Sec. 29

ELEVATION: 3,403.2 feet (ground level)

DEPTH DRILLED: 848 feet

DATE COMPLETED: June 9, 1976

DRILLING CONTRACTOR: Sonora Drilling Co., Carlsbad, N. Mexico

DRILLING METHOD: Auger 18 inch hole (0-40 feet)
Rotary 7.88 inch hole with air-air/mist (40-731 feet)
Core 4.75 inch hole with air mist (731-842 feet)
Ream 9.88 inch hole (40-848 feet)

CASING RECORD: 10.75 inch O.D. steel surface pipe, (0-40 feet) cemented to surface
7 inch O.D. steel casing (0-848 feet), cemented to surface (cement plug to 797 feet, drilled to 831 feet)

GEOPHYSICAL LOGS: Differential Temperatures
BHC Acoustic
Compensated Densilog
Dual -Laterolog

Micro-Laterolog
Compensated Neutron-Gamma
Sperry-Sun Magnetic Survey

HYDROLOGIC TESTING (OPEN HOLE):

A. 699-842 feet: DST, of Rustler-Salado Contact, 9.1 gallons of water in 20 hours

B. 667-699 feet: DST of Culebra Dolomite, 10.6 gallons of water in 11.5 hours

C. 626-667 feet: DST, of suspected salt residue, 11.2 gallons of water in 12 hours.

D. 562-592: DST of Magenta Dolomite, 13 gallons of water in 13.5 hours; after hole was drilled to 592 feet inflow of 490 gpd was observed.

HYDROLOGIC TESTING (CASED HOLE):

E. 803-837 feet: Perforated zone, Rustler-Salado contact, water level rose from 826.5 to 811 (25 gallons) in 33 days.

F. 675-703 feet: Perforated zone, Culebra Dolomite, fluid level rose from 665 to 406 (416 gallons) in nine days.

G. Tracer, ^{131}I, no annulus leaks, no flow in 694-703 interval, major loss in 675-694 interval, tracer injection rate of 8 gpm, total 1634 gal. injected.

H. 562-590 feet: Perforated zone, Magenta Dolomite, after bailing, water rose from 424.5 to 340.7 feet in 33 days (53 gallons), could not bail below 424 feet.

I. Culebra water level stable at 390 feet depth. (October 1977)

J. Magenta water level stable at 249 feet depth. (October 1977)

DRILLING & TESTING SUMMARY

6.4.2 HOLE NO. H-2a

LOCATION: T.22 S., R.31, E., Sec. 29

ELEVATION: 3,377.1 feet (ground level)

DEPTH DRILLED: 563 feet

DATE COMPLETED: February 19, 1977

DRILLING CONTRACTOR: Pennsylvania drilling Co., Carlsbad, N. Mexico

DRILLING METHOD: Auger 18 inch hole (0-33 feet)
Rotary 8.75 inch hole with air-air/mist (33-513 feet)
Core 4.75 inch hole with air/mist (513-563 feet)
(cut 2.25 inch diameter core)

CASING RECORD: 10.75 inch O.D. steel casing (C-33 feet) cemented to surface
6.63 inch O.D. steel casing, (0-511 feet), cemented to surface

Geophysical Logs: None. Available from H2C, 90 feet away.

HYDROLOGIC TESTING:

A. 0-188 feet: Stopped drilling after encountering wet zone at 185 feet; interval produced no appreciable fluid in 5 hours

B. 513-563 feet: Open hole, Magenta Dolomite, water rose from 556.8 to 538.7 in one day (22 gallons).

C. Magenta static level at 249 feet, October, 1977

DRILLING & TESTING SUMMARY

6.4.3 HOLE NO. H-2b

LOCATION: T.22 S., R. 31 E., Sec 29

ELEVATION: 3,377.1 feet (ground level)

DEPTH DRILLED: 661 feet

DATE COMPLETED: February 12, 1977

DRILLING CONTRACTOR: Pennsylvania Drilling Co., Carlsbad, N. Mexico

DRILLING METHOD: Auger 18 inch hole (0-33 feet)
Rotary 8.75 feet hole with air-air/mist (33-611 feet)
Core 4.75 inch hole with air/mist (611-661 feet) (cut 2.25 inch diameter core)

CASING RECORD: 10.75 inch O.D. steel casing (0-33 feet) cemented to surface
6.63 inch O.D. steel casing, (0-609 feet)., cemented to surface

Geophysical Logs: None. Available from H2C, 75 feet away.

HYDROLOGIC TESTING:

A. 611-661 feet: Open hole, Culebra cored interval, water rose from 636.9 to 458.0 feet in one day (260 gallons). Level stable at 352 feet (February 1977)

B. dole # H-2c was bailed from the Culebra while monitoring H-2b in the Culebra. First response in H2b was detected 50 minutes after bailing of H2C started.

C. 510-538 feet: Perforated zone, Magenta Dolomite, water rose from 560 to 420 feet in one day (210 gallons).

D. Well constructed for monitoring at Culebra Dolomite via tubing and Magenta via annulus. Culebra static level at 351 feet, Magenta static level at 292 feet (perforations may be blocked).

DRILLING & TESTING SUMMARY

6.4.4 HOLE NO. H-2c

LOCATION: T.22 S., R.31 E., Sec 29

ELEVATION: 3,377.1 feet (ground level)

DEPTH DRILLED: 795 feet

DATE COMPLETED: February 5, 1977

DRILLING METHOD: Auger 18 inch hole (0-33 feet)
Rotary 8.75 inch hole with air/mist (33-743 feet)
Core 4.75 inch hole with air/mist (743-795 feet)
(cut 2.25 inch diameter core)

CASING RECORD: 10.75 inch steel casing (0-33 feet) cemented to surface
6.63 inch O.D. steel casing, (0-742 feet), cemented to surface.

Geophysical Logs: Compensated Densilog
Dual-Laterolog
BHC Acoustilog
Micro-Laterolog

Compensated Neutron-Gamma
4-Arm Caliper
USGS Lithologic-log

HYDROLOGIC TESTING:

A. 743-795 feet: Open hole, Rustler-Salado cored interval produced 14 gallons in 18 days.

B. 624-652 feet: Culebra perforated zone, water rose from 656.4 to 446.6 in one day (310 gallons). Static level at 352 feet. (March 1977)

C. Tracer ^{131}I, no flow below 642 in casing, fluid loss zone was between 631 and 644, especially 640-644 where core indicates pitted and fractured dolomite, tracer injection rate was 8 gpm, total 697 gal. injected.

D. Dual completion monitoring (Rustler-Salado via tubing and Culebra via annulus) shows Culebra stable at 355 feet (October 1977) and Rustler-Salado still recovering at 34 feet per month. (June 1978)

DRILLING AND TESTING SUMMARY

6.4.5 HOLE NO. H-3

LOCATION: T.22 S., R.31 E., Sec. 29

ELEVATION: 3,388.7 feet (ground level)

DEPTH DRILLED: 894 feet

DATE COMPLETED: August 12, 1976

DRILLING CONTRACTOR: Pennsylvania Drilling Co., Carlsbad, New Mexico

DRILLING METHOD: Auger 18 inch hole (0-38 feet)

Rotary 7.88 inch hole with air-air/mist (38-894 feet)

Ream 8.75 inch hole (38-894 feet)

CASING RECORD: 10.75 inch O.D. steel surface pipe (0-38 feet) cemented to surface.
6.63 inch O.D. steel casing, (0-891 feet), cemented to surface (cement plug to 804 feet drilled to 864 feet)

Geophysical Logs: Compensated Densilog
Micro-Laterolog
Dual-Laterolog
BHC Acoustilog
Compensated Neutron-Gamma
Differential Temperature

HYDROLOGIC TESTING (OPEN HOLE)

A. 800-868 feet: DST, Rustler-Salado contact, produced 1.8 gallons of water in 16.5 hours;

B. 672-703 feet: DST, Culebra, produced 2.1 gallons of water in 21.5 hours.

C. 703-780 feet: DST, salt residue, 2 gallons of water in 26 hours.

D. 558-608 feet: DST, Magenta, 23 gallons after 37.5 hours. after developing operation via swabbing.

HYDROLOGIC TESTING (CASED HOLE)

E. 813-837 feet: Perforated Rustler-Salado contact; produced 37 gallons in 32 days.

F. 675-703 feet: Perforated Culebra, bailed hole and monitored, recovery was up to 410 from an initial level of 550 feet (200 gallons in 8 days).

G. Tracer ^{131}I, showed no flow below 696 feet; major fluid losses in intervals 684-692 and 692-695; tracer injection rate was 8 gpm, total injected 450 gal.

H. 562-590 feet: Perforated Magenta, bailed 360 gallons in one hour with 6 feet of drawdown.

I. Dual-completion monitoring (Culebra via tubing and Magenta via annulus) indicate Culebra static level at 404.5 and Magenta static level at 245.1 as of October 1977.

DRILLING & TESTING SUMMARY

6.4.6 HOLE NO. P-14

LOCATION: T.22 S., R.30 E., Sec. 24

ELEVATION: 3,358.1 feet (ground level)

DEPTH DRILLED: 1,545 feet.

DATE COMPLETED: October 3, 1976

DRILLING CONTRACTOR: Boyles Brothers Drilling Co., Las Cruces, New Mexico

DRILLING METHOD: Rotary 8.75 inch hole with air (0-20 feet)
Rotary 7.88 inch hole with air-air/mist (20-784 feet)
Rotary with air/mist (784-1,168 feet)
Core with brine mud (1,168-1,545 feet)

CASING RECORD: 8.63 inch O.D. steel casing (0-20 feet)
4.50 inch O.D. steel casing, (0-775 feet) cemented to surface, hole plugged back from 1,345 feet to 759 feet with cement.

Geophysical Logs: Gamma
Gamma-Gamma
Neutron
Caliper

HYDROLOGIC TESTING (CASED HOLE)

A. 676-700 feet: Perforated Rustler-Salado, fluid level rose from 730 to 620 feet in one day (75 gallons).

B. 573-601 feet: Perforated Culebra, bailed 720 gallons of water in three hours with no drawdown.

C. Tracer ^{131}I, showed 63 percent fluid loss in interval 583-590, remaining loss in interval 573-583; no loss below 590 feet. Injection rate 7 gpm. Total injected 1634 gal.

D. Dual-completion monitoring (Rustler-Salado via tubing and Culebra via annulus); Rustler-Salado stabilized at 386 feet, Culebra stabilized at 324 feet (October 1977)

DRILLING & TESTING SUMMARY

6.4.7 HOLE NO. P-15

LOCATION: T.22 S., R.31 E., Sec. 31

ELEVATION: 3,309.7 feet (ground level)

DEPTH DRILLED: 1,465 feet

DATE COMPLETED: October 14, 1976

DRILLING CONTRACTOR: Boyles Brothers Drilling Co., Las Cruces, New Mexico.

DRILLING METHOD: Rotary 8.75 inch hole with air (0-20 feet)
Rotary 7.88 inch hole with air-air/mist (20-515 feet)
Core 4.75 inch hole with air/mist (515-600 feet) (cut 2.25 inch diameter core)
Ream 7.88 inch hole with air/mist (515-637 feet)
Rotary 5 inch hole with air/mist (637-1,038 feet)
Core with brine mud (1,038-1,465 feet)

CASING RECORD: 8.63 inch O.D. steel casing (0-20 feet)
4.50 inch O.D. steel casing, (0-635 feet), cemented to surface, hole plugged back from 1,465 to 600 feet with cement, cement drilled out to 620 feet.

Geophysical Logs: Gamma
Gamma-Gamma
Neutron
Caliper
Spectralog

HYDROLOGIC TESTING:

A. 532-556 feet: Perforated Rustler-Salado contact, fluid rise from 618 to 497 in 42 days (81 gallons).

B. 410-438 feet: perforated Culebra, fluid rose from 496 to 420 feet in one day (50 gallons); 125 gallons in 33 days

C. Dual Completion monitoring (Rustler-Salado via tubing and Culebra via annulus) shows Rustler-Salado static level at 324 feet and Culebra at 308 feet as of October, 1977.

DRILLING AND TESTING SUMMARY

6.4.8 HOLE NO. P-17

LOCATION: T.23 S., R.31 E., Sec. 4

ELEVATION: 3,339.5 feet (ground level)

DEPTH DRILLED: 1,660 feet

DATE COMPLETED: October 26, 1976

DRILLING CONTRACTOR: Boyles Brothers Drilling Co., Las Cruces, New Mexico.

DRILLING METHOD: Rotary 8.75 inch hole with air (0-20 feet)
Rotary 7.88 inch hole with air-air/mist (20-755 feet)
Rotary with air/mist (755-1,220 feet)
Core with brine mud (1,220-1,660 feet)

CASING: 8.63 inch O.D. steel casing (0-20 feet)
4.50 inch O.D. steel casing, (0-751 feet), cemented to surface, hole plugged back from 1,660 feet to 720 feet with cement, cement drilled out to 731 feet.

Geophysical Logs: Gamma
Gamma-Gamma
Neutron
Caliper

HYDROLOGIC TESTING (CASED HOLE)

A. 702-726 feet: Perforated Rustler-Salado contact; fluid rose from 726 to 622 feet (71 gallons in 73 days).

B. 558-586 feet: Perforated Culebra, single packer set at 683 feet, bailed and monitored for 29 days with fluid rise from 622 to 372 feet.

C. Dual Completion monitoring (Rustler-Salado via tubing and Culebra via annulus) indicates fluctuating levels; problem could be leaking bridge packer or communication in cemented annulus.

DRILLING & TESTING SUMMARY

6.4.9 HOLE NO. P-18

LOCATION: T.22 S., R.31 E., Sec. 26

ELEVATON: 3,478.7 feet (ground level)

DEPTH DRILLED: 1,998 feet

DATE COMPLETED: November 5, 1976

DRILLING CONTRACTOR: Pennylsvania Drilling Co., Carlsbad, New Mexico.

DRILLING METHOD: Rotary 8.75 inch hole with brine mud (0-18 feet)
Rotary 7.88 inch hole with brine mud (18-1139 feet) to casing depth.
Rotary with brine mud (1,139-1,630 feet)
Core with brine mud (1,630-1,999 feet)

CASING RECORD: 8.63 inch O.D. steel casing (0-18 feet)
4.50 inch O.D. steel casing, (0-1, 138 feet), cemented to surface, hole plugged back from 1,998 feet to 1,125 feet with cement.

Geophysical Logs: Gamma
Gamma-Gamma
Neutron
Caliper

HYDROLOGIC TESTING (CASED HOLE)

A. 1076-1100 feet: Perforated Rustler-Salado contact, fluid rise from 1123 to 1073 feet in 73 days (34 gallons)

B. 912-940 feet: Perforated Culebra, bailed and monitored recovery for 33 days with fluid rise from 1045 to 1022 feet (16 gallons).

C. Dual completion (Rustler-Salado via tubing, Culebra via annulus) indicated Rustler-Salado at 755 feet and still recovering as of October, 1977.

DRILLING & TESTING SUMMARY

6.4.10 HOLE NO. AEC-8

LOCATION: T.22 S., R.31 E., Sec. 11

ELEVATION: 3,531.9 feet (ground level)

DEPTH DRILLED: 3,019 feet (1974), deepened to 4,910 feet (1976)

DATE COMPLETED: August 5, 1976

DRILLING CONTRACTOR: Sonora Drilling Co., Carlsbad, New Mexico

DRILLING METHOD: Core, ream, rotary 7.88 inch hole with brine mud (31-3,019 feet)
Core, ream, rotary 7.88 inch hole with brine mud (3,018.5-4,910.5 feet)

CASING RECORD: 8.63 feet O.D. steel casing (0-874 feet), cemented to surface.
5.50 inch O.D. steel casing, (0-4,907 feet), cemented to 880 feet.

Geophysical Logs; Compensated Neutron
Micro-Laterlog
Dual-Laterolog
Gamma

HYDROLOGIC TESTING (CASED HOLE)

A. 4,844-4,860 feet: Perforated lower sand lense of Bell Canyon Formation; fluid level rose from 4106 feet to 4095 feet in 166 minutes (31 gallons).

B. 4,832 - 4,910 feet: Production packer with sentry monitoring device showed formational pressure of 2037 lbs/ in^2 reached in 44.5 hours; fluid density was 1.11 g/cm^3.

C. Tracer ^{131}I, along with temperature logs, indicated major fluid loss in interval 4839 to 4860 feet; minor communication down casing to 4870 feet; tracer injection rate was 14 gpm. Total injected 2289 gal.

D. 4,821-4,827 feet: Perforated upper sand lense of Bell Canyon Formation; single packer set at 4835 feet; swabbed fluid to 2600 feet; pressure monitor installed at 4805 feet; shut-in pressure recovered to 2037 lbs/in^2 in 57 hours, fluid density was 1.12 gm/cm^3,

E. Tracer ^{131}I, showed no upward or downward communication; injection rate at tracer was 11 gpm. Total injected 300 gal. Injection was occurring uniformly in the lower 4 feet of perforations.

F. Dual completion monitoring (lowering sand via tubing and upper sand via annulus) indicate lower sand stablized at 615 feet and upper sand at 560 feet as of November, 1977.

6.5 SUMMARY

The proposed site contains neither perennial streams nor surface water impoundment, and the water bearing strata above and below the evaporite section do not yield large quantities of water to wells. At its closest point, the Pecos River is approximately 14 miles southwest of the WIPP site. Water bearing strata in the local site area at stratigraphic horizons above the proposed repository include the Santa Rosa Sandstone and the Culebra and Magenta members of the Rustler Formation. Hydrologic units below the repository horizons include the Bell Canyon Formation of the Delaware Mountain Group. Ground water velocities vary with porosity, hydraulic conductivity, and head gradient but are typically 0.3 ft/d in the Santa Rosa Sandstone, 0.5 ft/d in the Rustler Formation, and 0.0006 ft/d in the Bell Canyon Formation. Shallow wells in the local area are generally used only for watering livestock and typically produce nonpotable ground water with total solute concentrations in excess of 3,000 ppm.

Natural potentiometric levels of fluids from rocks above and below the evaporites at the WIPP site (from the Rustler and Bell Canyon Formations, respectively) are comparable (about 2950 to 3050 above mean sea level). The head differential between upper and lower units varies within about 200 feet on the periphery of the site, the sign and magnitude of the differential depending upon precise geographic location.

Gentle eastward tilting of the Delaware Basin resulting in the exposure of the Salado Formation to near-surface waters has given rise to the removal of a wedge-shaped mass of soluble salts between the Guadalupe escarpment (30 miles due west of the site), where there remains no rock salt, and a point about 3 miles due west of the site center, where the Salado Formation is intact.

The proposed site is in an area of the Delaware Basin that is free of regional deep dissolution, but localized shallow features are present in the vicinity. A shallow salt dissolution zone (called the "brine aquifer") occurs in Nash Draw at the contact between the Salado and

Rustler Formations. This local shallow dissolution area ranges in width from 2 to 10 miles and has a length of approximately 30 miles. The brine solution flows southwesterly at a rate of about 0.2 ft/d and discharges into the Pecos River at Malaga Bend. The average rate of vertical dissolution has been estimated to be between 0.33 and 0.5 feet per 1,000 years, and the average rate for lateral dissolution has been estimated to be between 6 and 8 miles per million years.

Climatological records show that mean annual precipitation of the site is approximately 12 inches per year. Aided by the low relative humidity (typically 36% during daylight hours) and high mean annual temperature (51°F), most of the annual precipitation returns to the atmosphere through evaporation and transpiration. Runoff is typically 0.1 to 0.2 inches annually.

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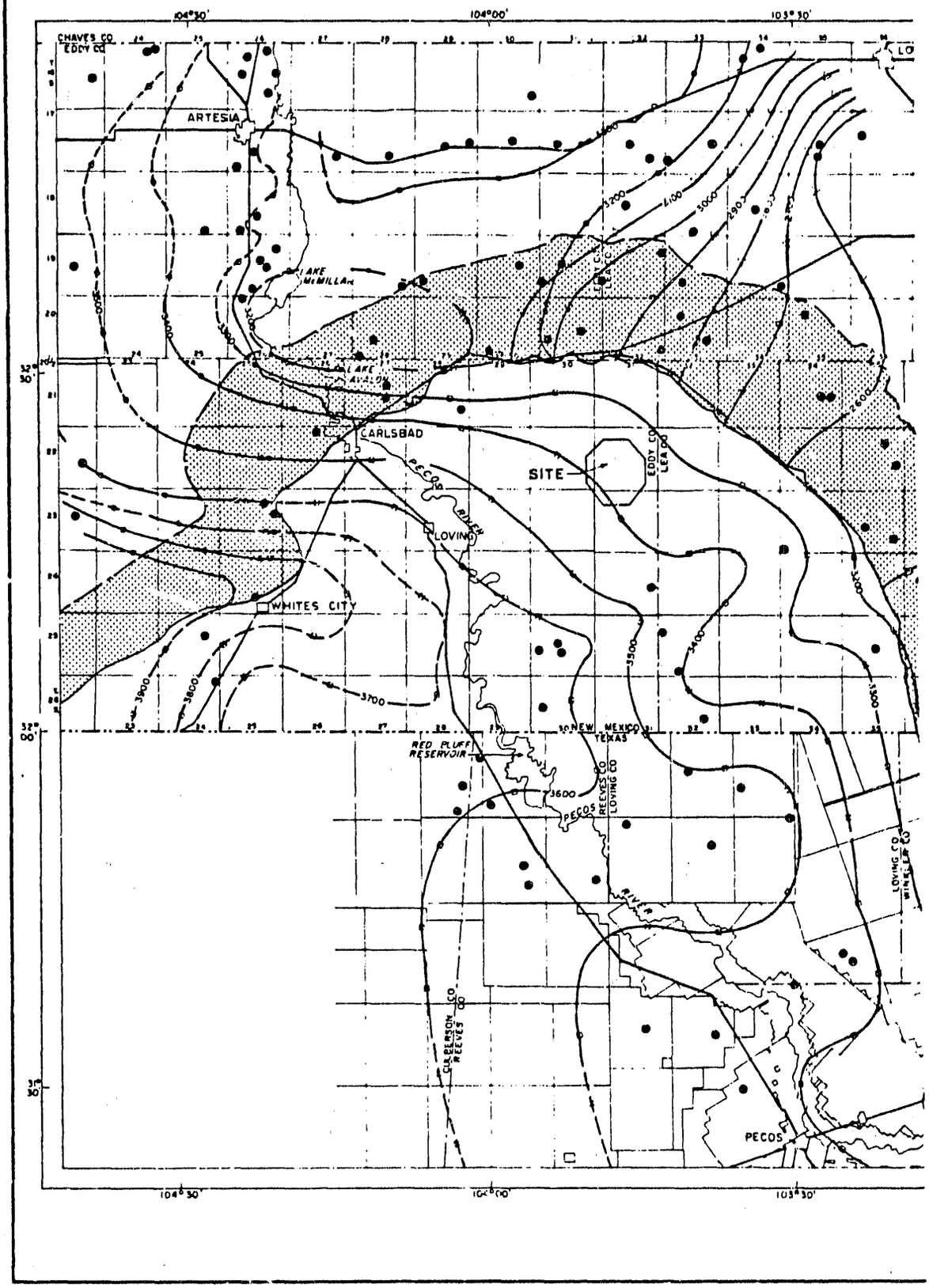
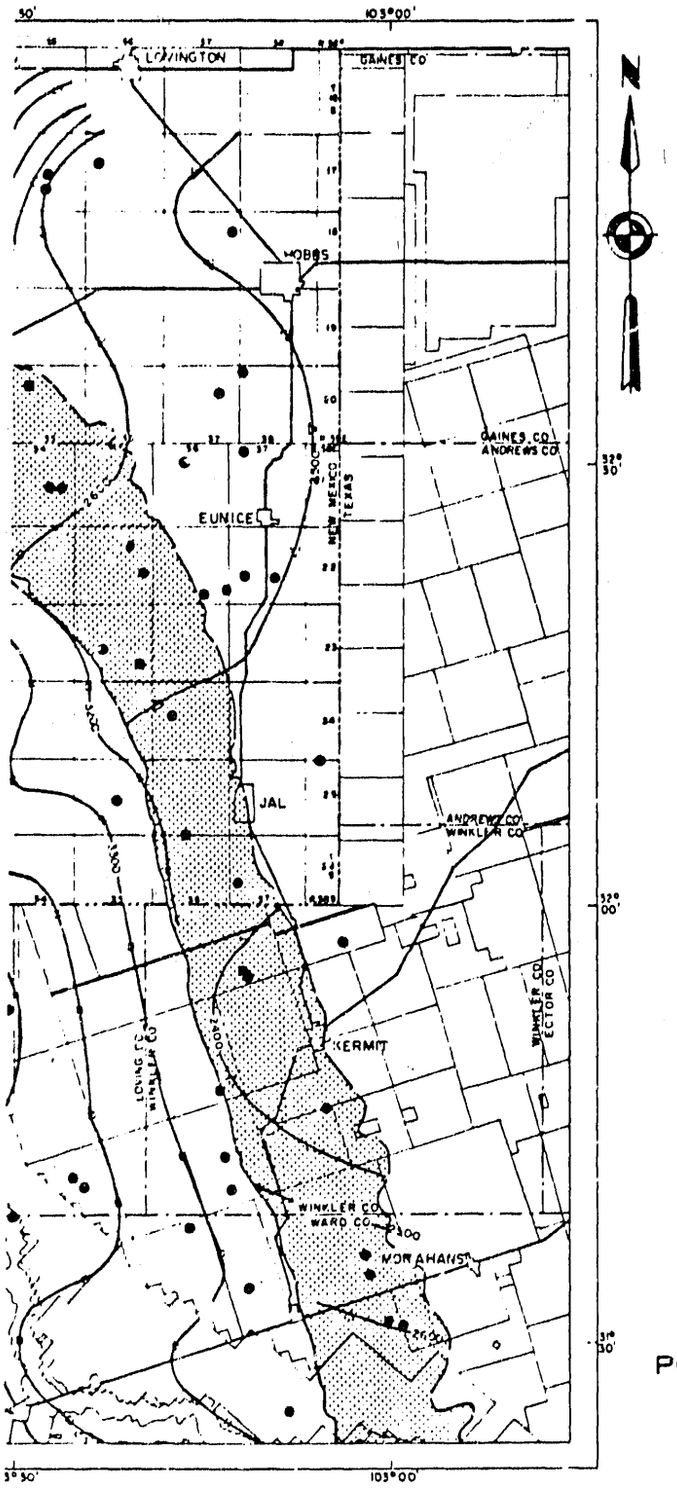

104°30'
104°00'
103°30'
CHAVES CO
EDDY CO
ARTESIA
LAKE McMILLAN
LAKE ARTESIA
CARLSBAD
PECOS RIVER
SITE
EDDY CO
LEA CO
LOVING
WHITES CITY
NEW MEXICO
TEXAS
RED BLUFF RESERVOIR
REEVES CO
LOVING CO
PECOS
CULBERSON CO
PECOS



EXPLANATION

Position of Capitan aquifer

Approximate position of extreme shelfward edge

Basinal edge

CONTOURS OF HEAD (in feet above sea level) Values of head are expressed as water with specific gravity of 1.00. Contours are dashed wherever data are sparse or of doubtful reliability

Head measured in shelf aquifer system where the hydraulic communication with the Capitan aquifer is relatively poor

Head measured in the Capitan aquifer system where the hydraulic communication between the two aquifers is relatively good.

Head measured in basin aquifer system where the hydraulic communication with the Capitan aquifer is relatively poor

The contours express a generalized regional head considered to be representative for basin and shelf aquifers during the period 1960 to 1970. Similarly, contours in the Capitan aquifer are an interpretation of the head representative for the latter part of 1972

Considerable subjective judgment was used in contouring the data points. In general two factors were weighed in considering each data point.

(1) The year in which the head was measured. This is important because prior fluid withdrawl from the oil and water fields causes a decline in head in nearby areas.

(2) The reliability of the data. In general the data were ranked according to reliability in the following order: fluid level in water wells, initial oil field bottom-hole pressures, and analysis of pressures from drill-stem tests.

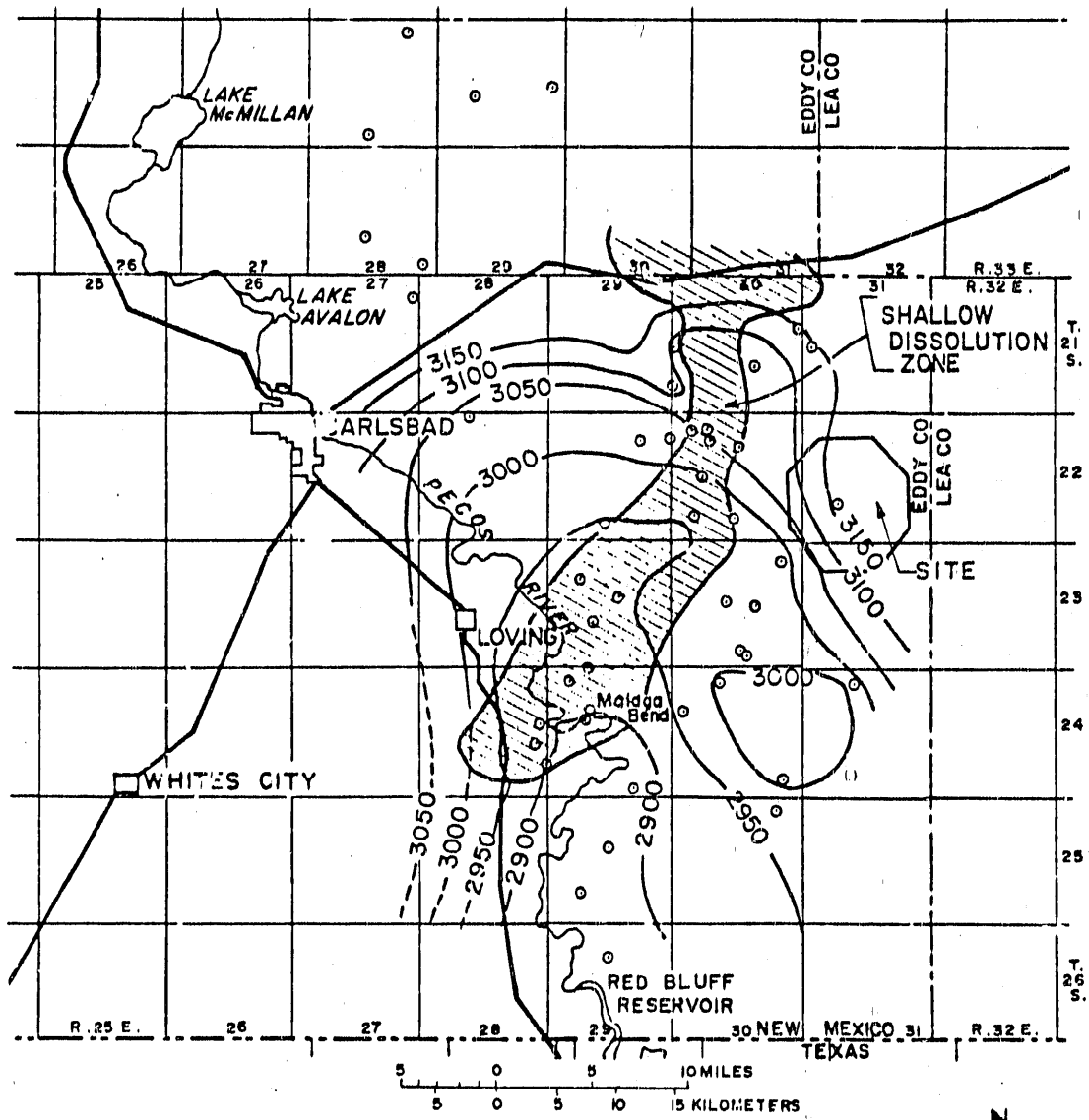
Well penetrating sediments of Permian, Ochoan, Guadalupian, or Leonardian age in which pressure or water level was measured

Reference: Fig 22 Hiss, W L., 1975

5 0 5 10 MILES
5 0 5 10 15 KILOMETERS

POTENTIOMETRIC SURFACE OF THE GUADALUPIAN AQUIFER SYSTEM

FIGURE 6.3-1



EXPLANATION

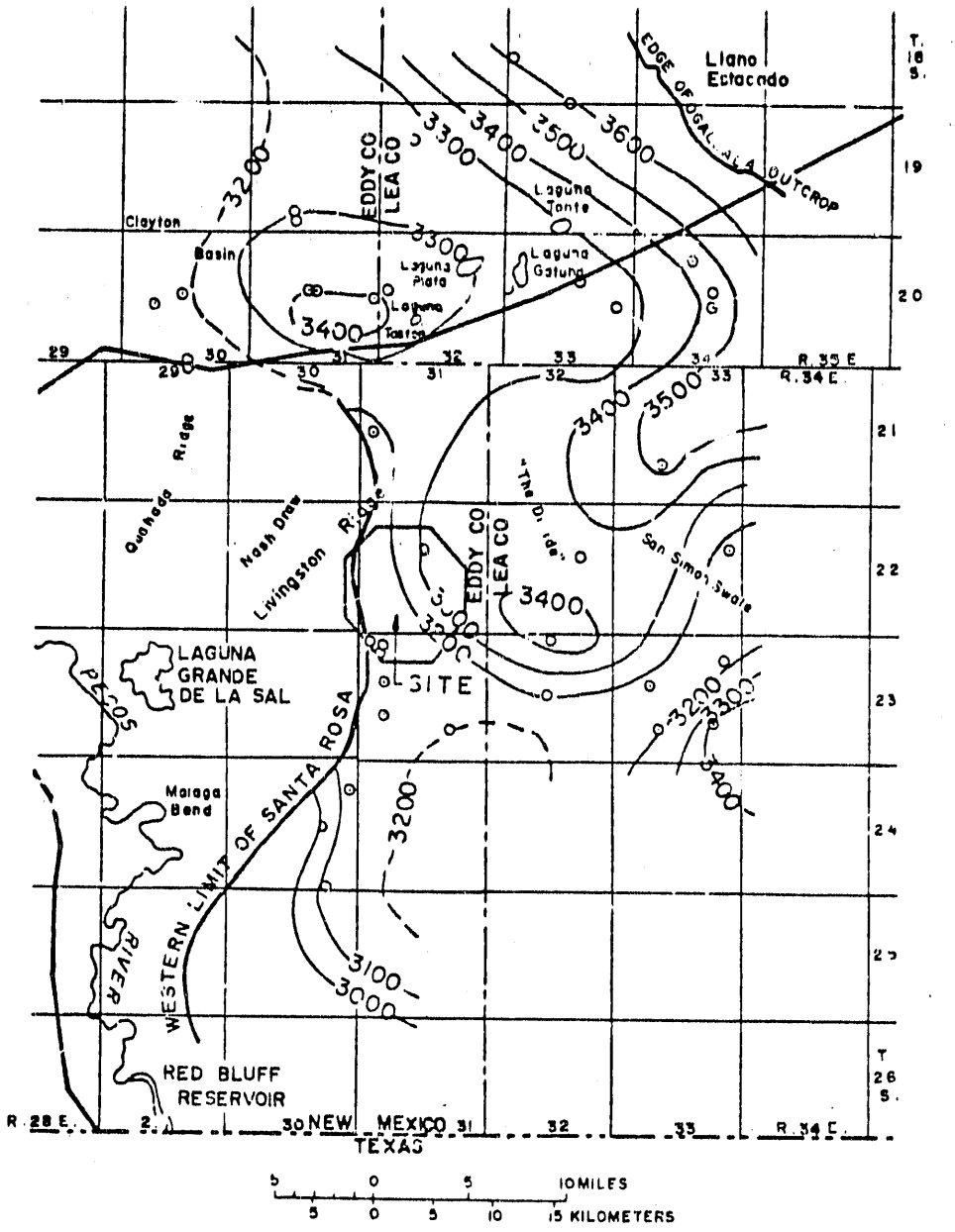
⊙ Well or exploratory hole open to the Rustler Formation

3000 -- Potentiometric elevation contour based on water levels measured in wells, 1952 – 1973. Dashed where approximately located. Datum is mean sea level.

Reference: Figures 5 & 6, U.S.G.S. Open File Rpt. 77-123, 1977

POTENTIOMETRIC SURFACE
RUSTLER FORMATION AND AREAL
EXTENT OF SHALLOW DISSOLUTION ZONE

FIGURE 6.3-2



EXPLANATION

⊙ Well open to Triassic rocks

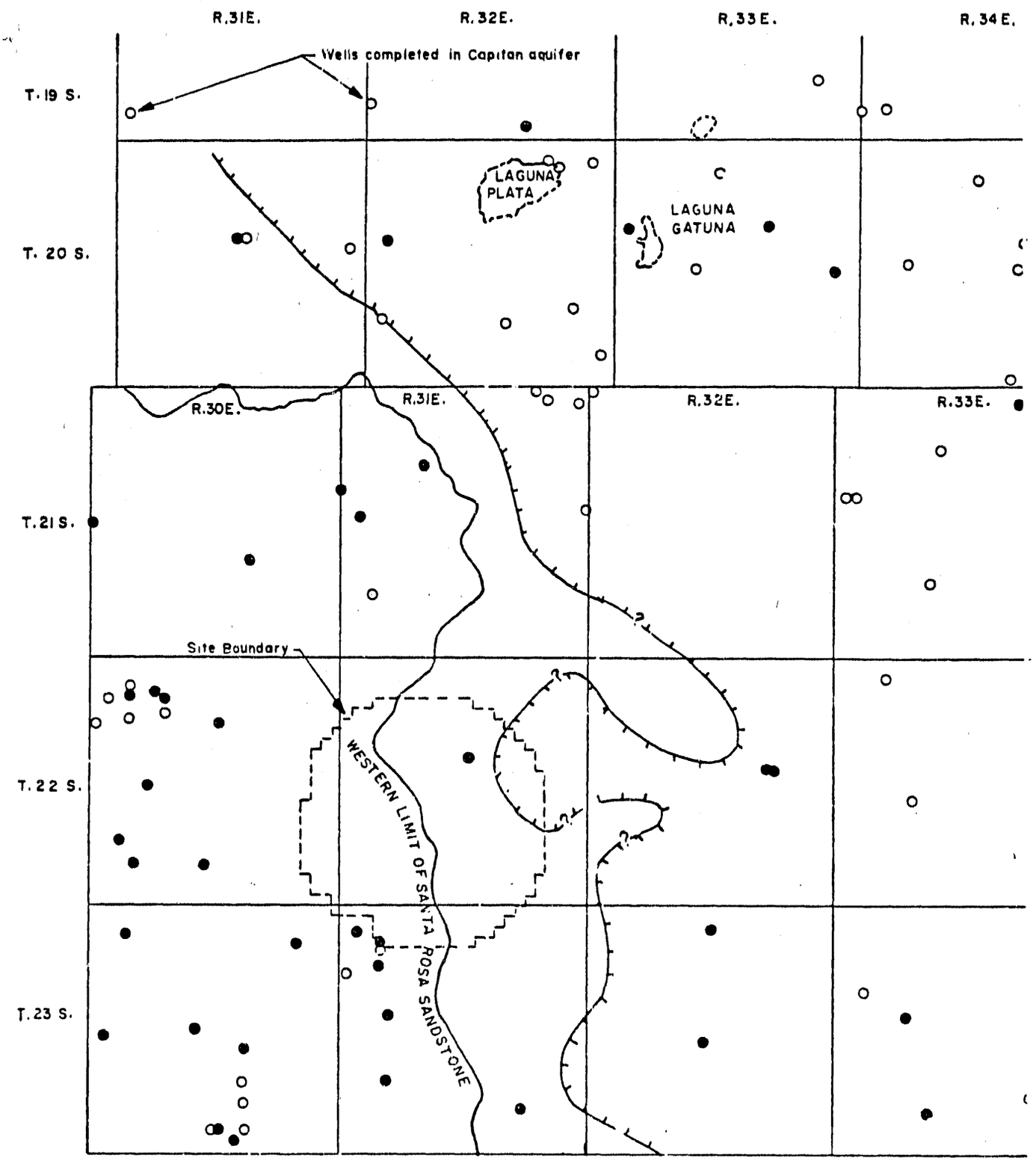
Potentiometric elevation contour, based on water levels measuerd in wells, 1952 - 1973. Dashed where approximately located. Datum is mean sea level.

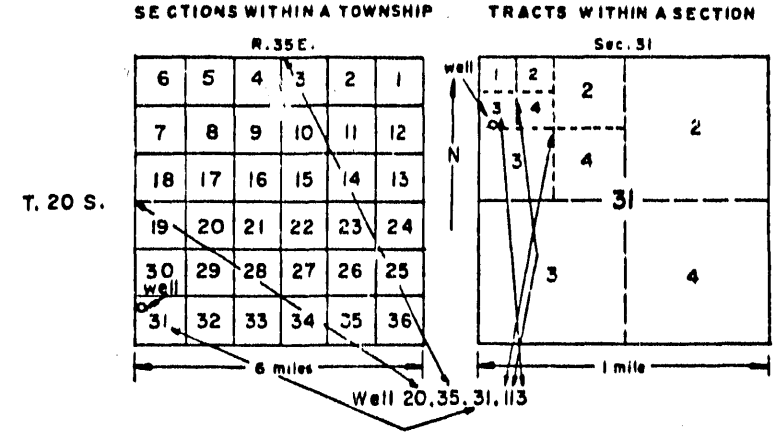
POTENTIOMETRIC SURFACE
SANTA ROSA SANDSTONE

Reference:

Mercer and Orr, 1977, figure 7.

FIGURE 6.3 3


R.31E.
R.32E.
R.33E.
R.34E.
Wells completed in Capitan aquifer
T. 19 S.
T. 20 S.
LAGUNA PLATA
LAGUNA GATUNA
R.30E.
R.31E.
R.32E.
R.33E.
T. 21 S.
Site Boundary
T. 22 S.
WESTERN LIMIT OF SANTA ROSA SANDSTONE
T. 23 S.



WELL-NUMBERING SYSTEM

The well number consists of four parts separated by periods. The first part is the township number, the second part is the range number, and the third part is the section number. The fourth part of the number consisis of three digits which denote the particular 10-acre tract within the section in which the well is located.

EXPLANATION

Approximate western limit of occurrence of ground water in the Santa Rosa Sandstone.

o Water well completed in surfical deposits or upper sandstone beds of the Chinle Formation.

● Water well completed in lower sandstone beds of the Chinle Formation, Santa Rosa Sandstone, Dewey Lake Redbeds, or Rustler Formation.

NOTE:

See Table G.3—2 for descriptions of wells.

Reference: USGS Open File Report 4339-7, Jones, C.L., et al, 1973

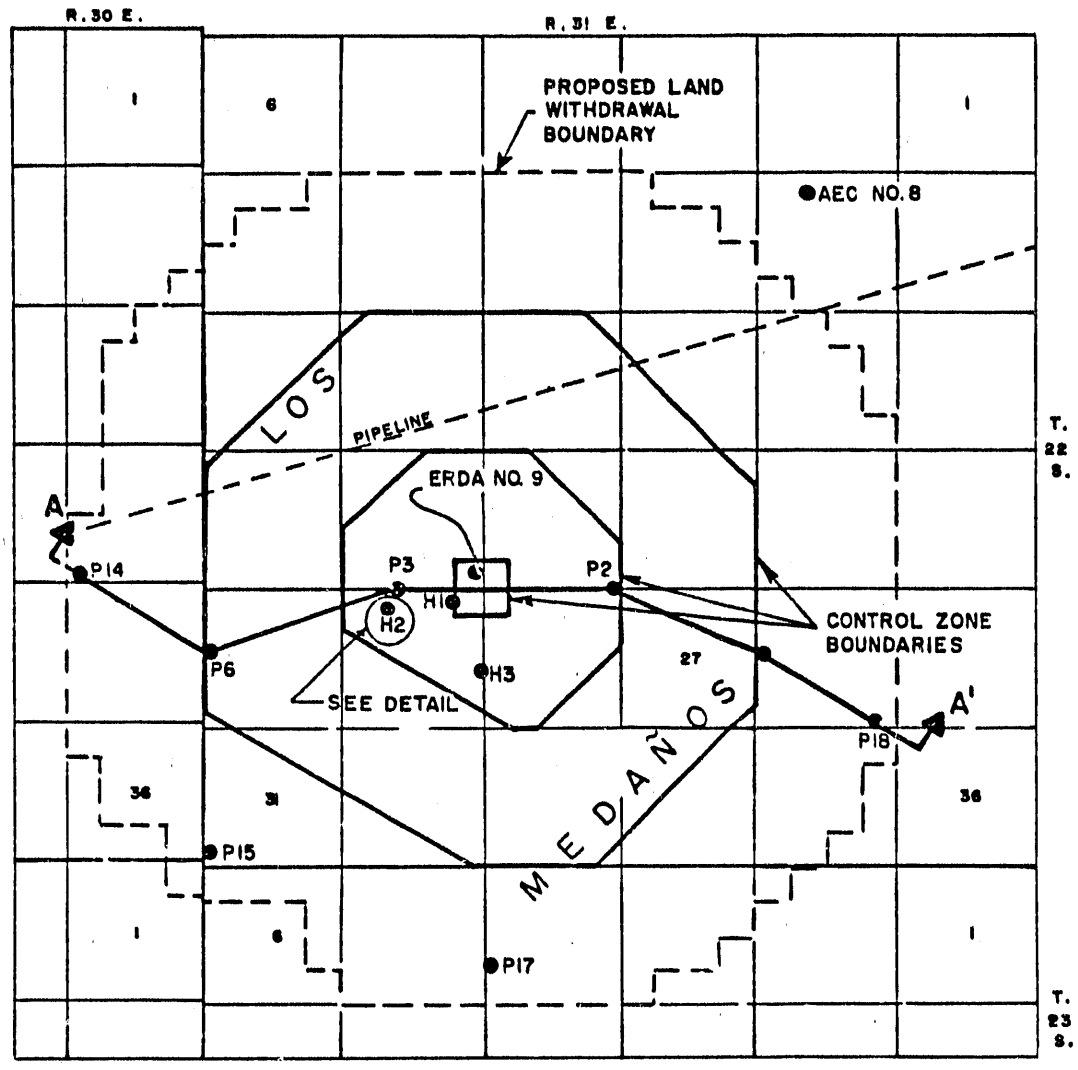
0 1 2 3 4 5

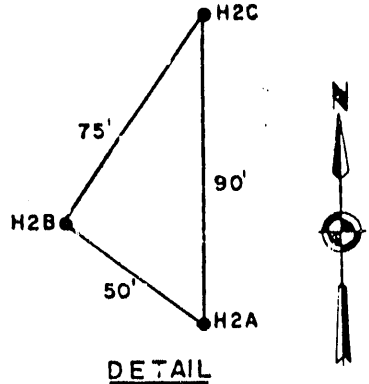
SCALE IN MILES

N

WATER WELL SURVEY

FIGURE 6.3-4





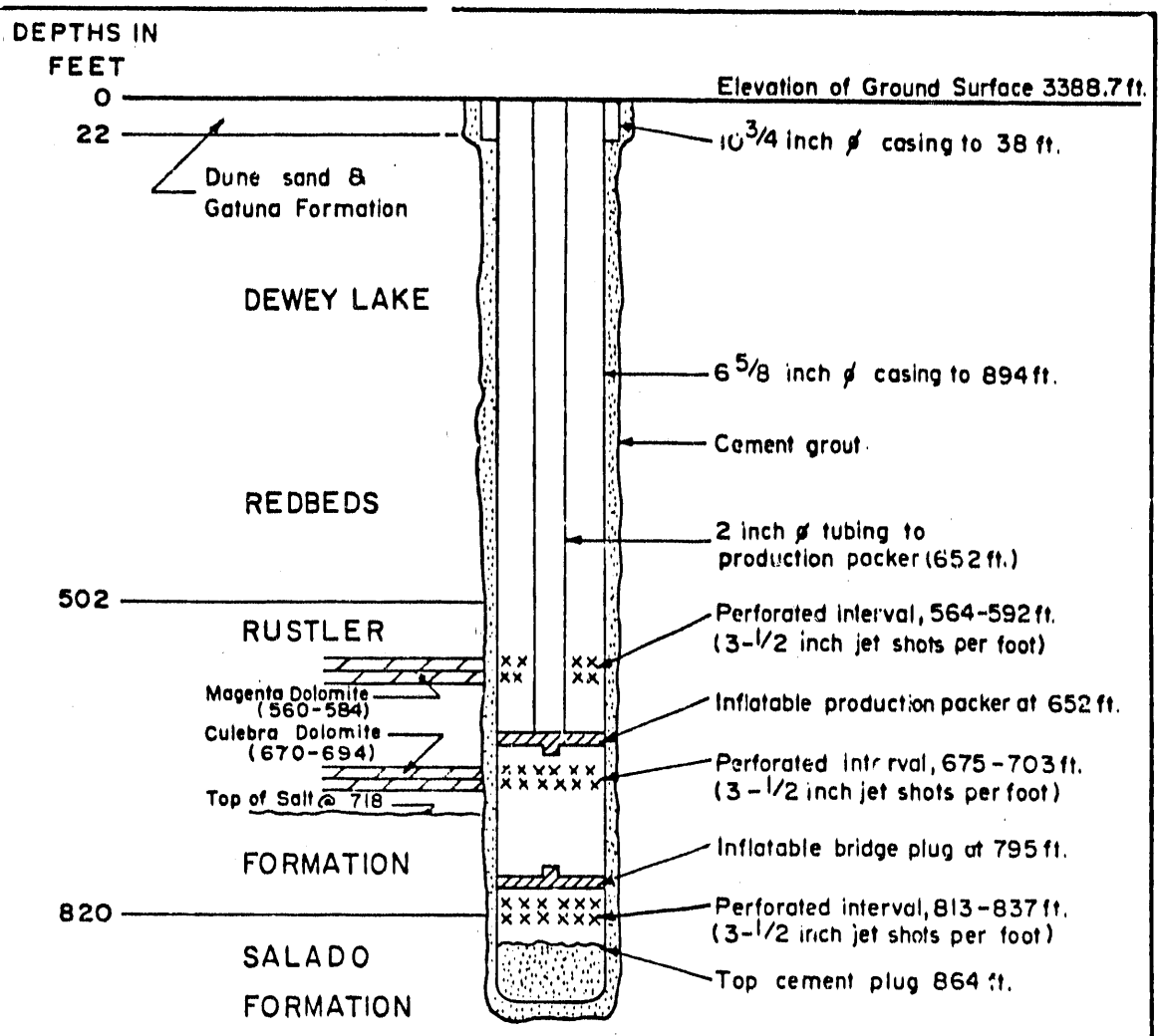
DETAIL

(H2 Configuration)

See figure 6.3-7 for Section A-A'

HYDROLOGIC TEST HOLES

FIGURE 6.3-5

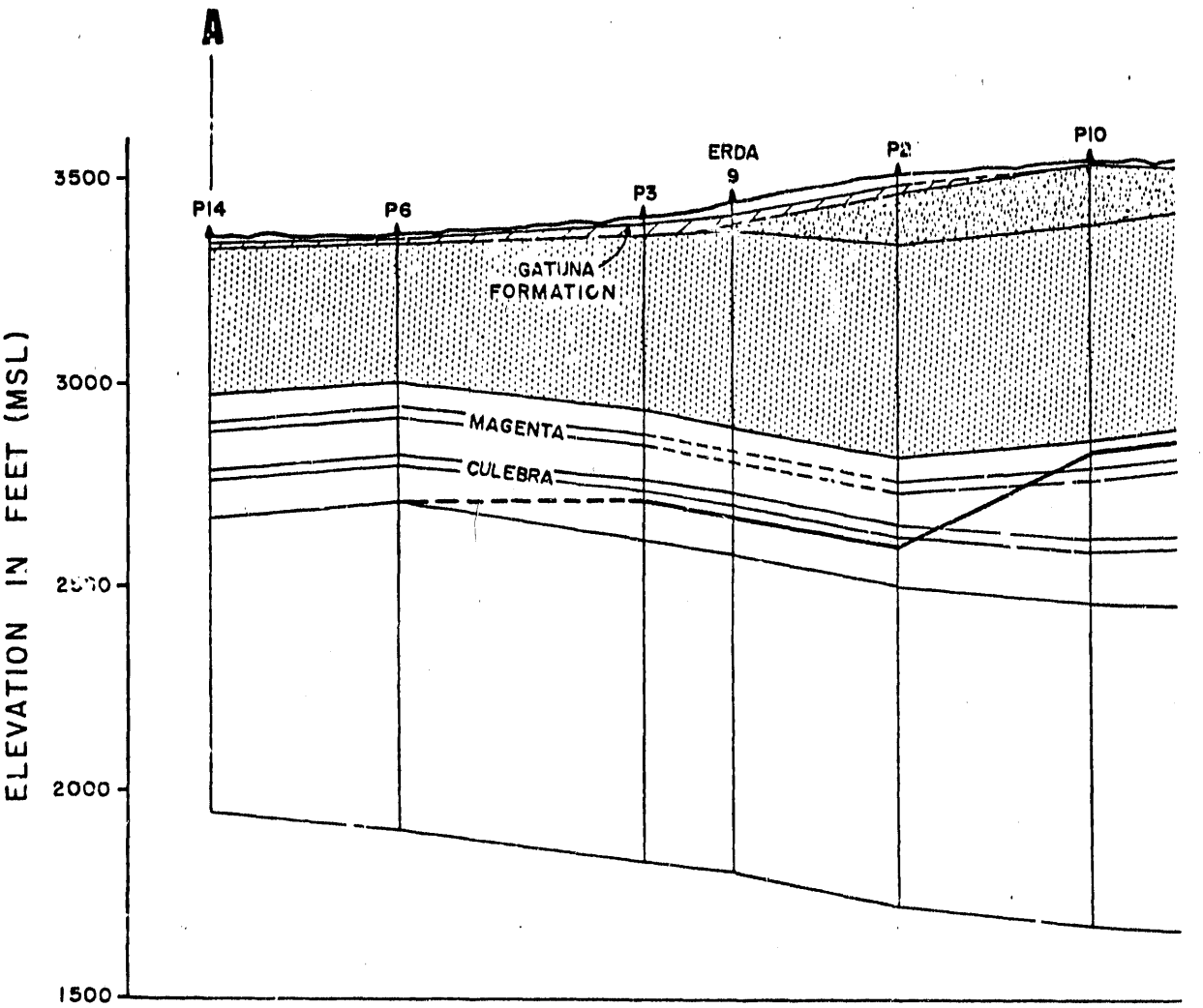


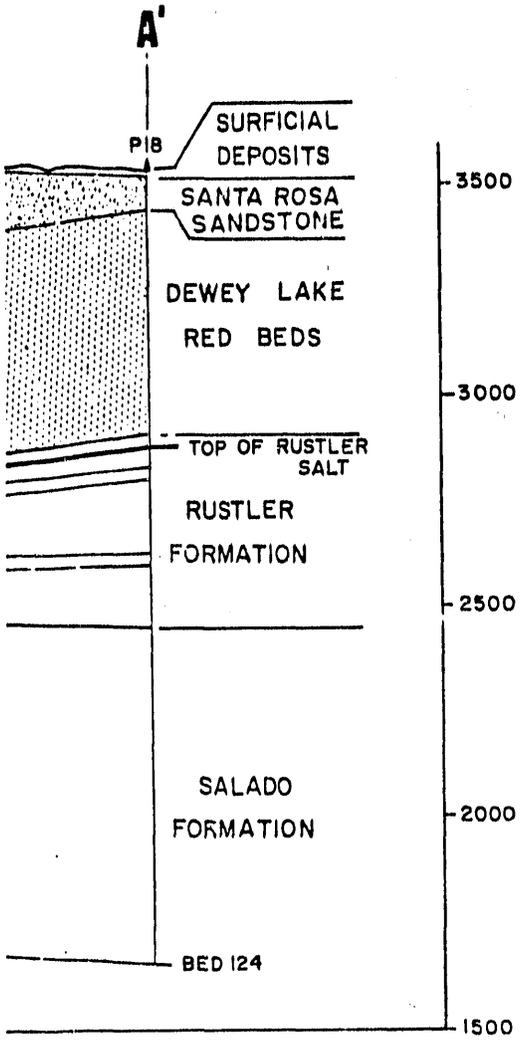
Status October 1977:

Total depth drilled: 894 ft.
Diameter of drilled hole: 9 7/8 inch
Monitoring Culebra through tubing
Monitoring Magenta in annulus
Contact zone not accessible (bridge plug)

CONSTRUCTION OF OBSERVATION WELL H-3

FIGURE 6.3-6


A
P14
P6
P3
ERDA 9
P2
P10
GATUNA FORMATION
MAGENTA
CULEBRA
ELEVATION IN FEET (MSL)
3500
3000
2000
1500

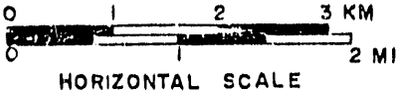


REFERENCES:

Lambert and Mercer, 1978 fig. 4, p. I-15

NOTE:

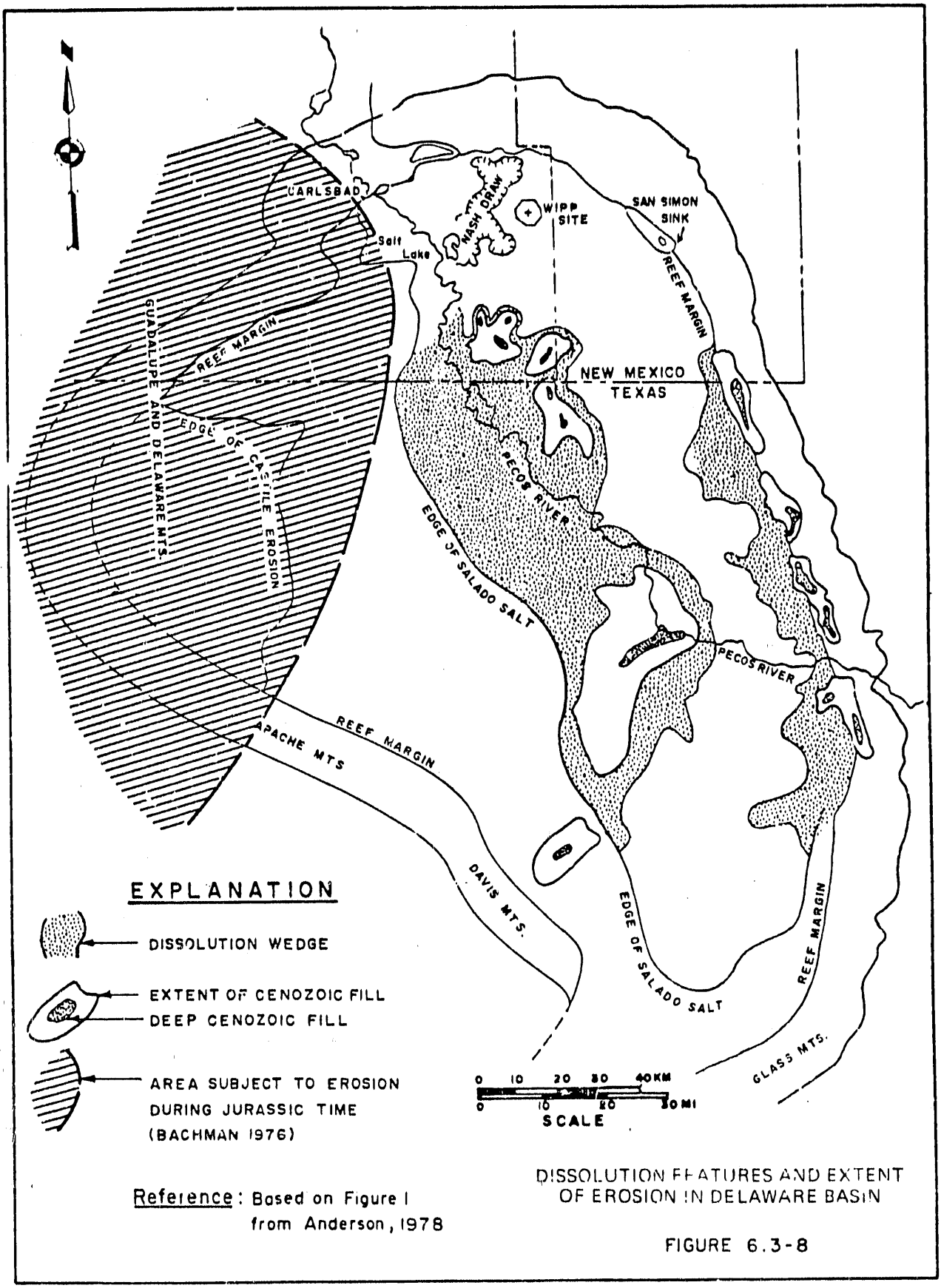
For location of Section see Figure 6.3-5.



GEOLOGIC SECTION
THROUGH THE LOS MEDANOS AREA

FIGURE 6.3-7

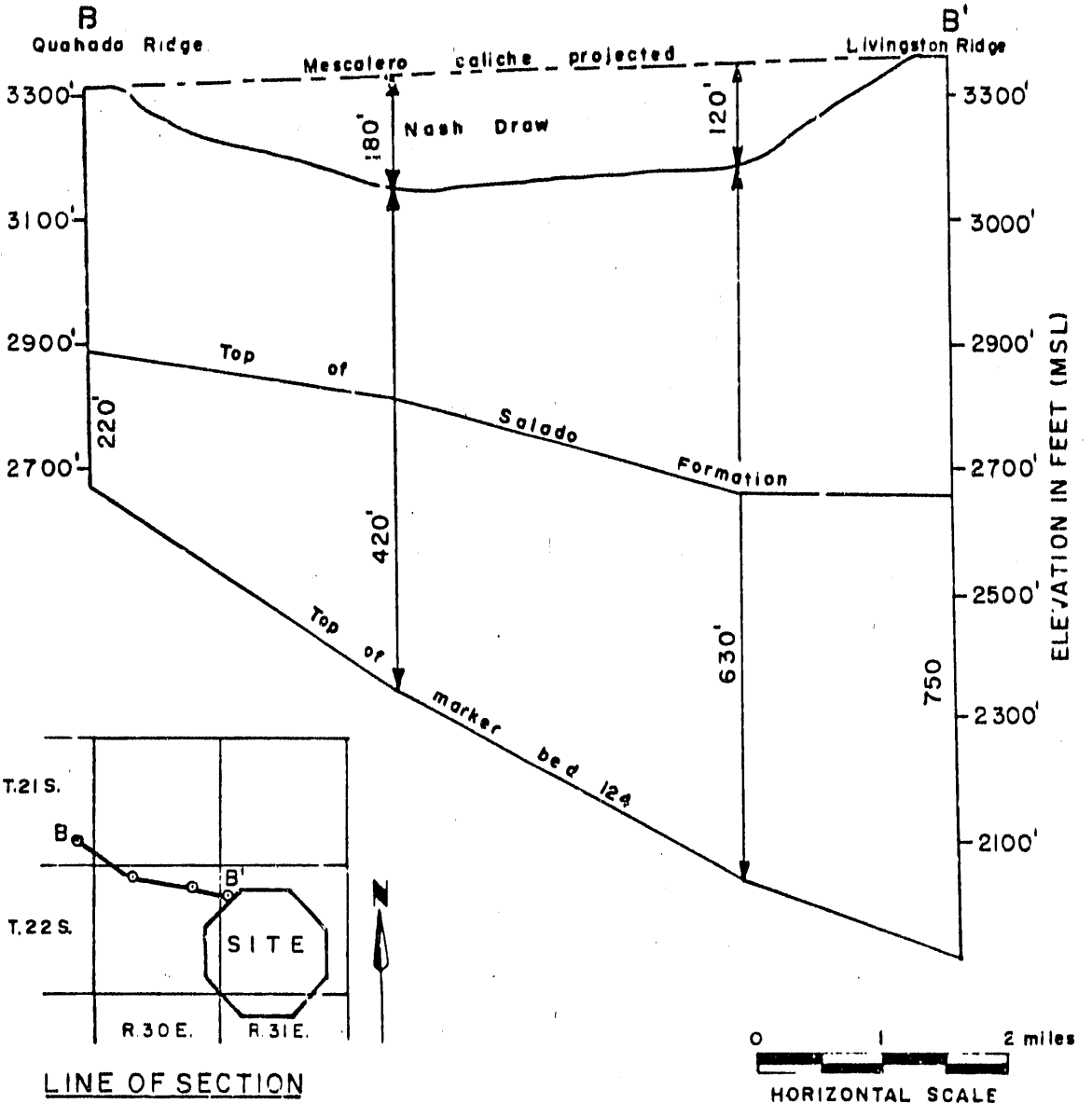
11 x 17 "B" SIZE



Reference: Based on Figure 1 from Anderson, 1978

DISSOLUTION FEATURES AND EXTENT OF EROSION IN DELAWARE BASIN

FIGURE 6.3-8



Reference: Fig. II, USGS Open File Report 74-194, 1974

RELATIONSHIP OF NASH DRAW TO DISSOLUTION IN SALADO FORMATION

FIGURE 6.3-9

Table 6.2-1. AREAL REQUIREMENTS OF THE WIPP SITE

Zone	Zone Use	Approximate Acreage
I	Surface Facilities	60-(100)
II	Underground Storage	1,860
III	1-mile wide zone surrounding Zone II No mining or drilling.	6,230
IV	1-mile wide zone surrounding Zone III. Mining and drilling in conformance with ERDA specifications are allowed.	10,810
	TOTAL	18,960
		29.6 square miles

TABLE 6.2-2

SALIENT FEATURES OF MAJOR DAMS UPSTREAM AND

DOWNSTREAM FROM WIPP SITE

Name of Reservoir	River	Drainage Area (sq. mi.)	Type of Dam	Year Completed	Height (ft.)	Max. Storage Capacity (AF)	Purpose
Sumner	Pecos	4,390	earth	1937	143	258,500	Irrigation
McMillan	Pecos	16,990	earth	1908	40	65,500	Irrigation
Avalon	Pecos	18,070	earth	1907	40	36,600	Irrigation
Red Bluff	Pecos	20,720	earth	1937	98	405,000	Irrigation & Hydro-power
Two Rivers	Rio Hondo	963	earth	1963	93	262,221	Flood Control
	Rocky Arroyo	64	earth	1963	116		

TABLE 6.2-3

WATER USE DATA FOR THE PECOS BASIN

Use category	Surface-water and groundwater withdrawals (mgd) 1975[a]
Agriculture	1546
Steam-electricity	12
Manufacturing	0
Domestic	47
Commercial	8
Mining	151
Public lands	4
Fish hatcheries	3
Total	1771

SOURCE: U.S. Water Resources Council, Second National Assessment of Water and Related Land Resources, in press.

[a]The total groundwater withdrawal for 1975 was 1079 mgd.

TABLE NO. 6.2-4

PRECIPITATION AT CARLSBAD, N.M. (in inches)

Period of Record 1931-1960

MONTH	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	ANNUAL
Max. Precip	2.31	1.93	4.27	3.99	12.28	6.24	5.48	4.41	7.36	6.13	1.55	2.12	33.94
Av. Precip.	0.44	0.37	0.46	0.54	1.76	1.33	1.56	1.60	1.94	1.61	0.35	0.47	12.43
Min. Precip.	0	0	0	0	0.18	0	0	0.01	0	0	0	0	4.40

SOURCE: U. S. Weather Bureau, 1961.

TABLE NO. 6.2-5

TEMPERATURES AT CARLSBAD, N.M. (in °F)

Period of Record 1931-1960

MONTH	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	ANNUAL
Max. Temp	50.4	54.8	61.2	69.1	74.6	83.6	84.2	84.6	80.6	70.8	57.4	52.6	66.3
Av. Temp.	43.8	48.4	54.8	63.3	71.4	79.8	81.4	80.8	74.2	64.1	51.5	44.7	63.2
Min. Temp.	35.2	43.6	47.8	60.1	68.4	73.4	77.4	76.7	70.2	58.2	45.8	37.5	60.3

SOURCE: U. S. Weather Bureau, 1961.

TABLE NO. 6.2-6

WATER QUALITY PARAMETERS (TIME-WEIGHTED AVERAGE)
FOR SAMPLING STATIONS ON THE PECOS RIVER,
OCTOBER, 1975, TO SEPTEMBER, 1976

Station No.	Discharge (cfs)	pH	Dissolved-solids concentration (mg/l) Total	Chloride	Sulfate	Sodium	Calcium
08405000 (Carlsbad)	12	7.7	2,500	531	1100	322	334
08406500 (Near Malaga)	26	7.7	5,390	1690	1820	1030	524
08407000 (Pierce Canyon Crossing)	28	7.5	13,900	6500	2200	4020	551

SOURCE: U. W. Geological Survey, Water-Data Report NM-76-1.

TABLE NO. 6.3-1 AQUIFER CHARACTERISTICS OF THE GUADALUPIAN AGE ROCKS (ADAPTED FROM HISS, 1976, TABLES 6 AND 7)

Geologic Unit	Avg. Hydraulic Conductivity (ft/day)	Average Porosity (%)	No. of samples or tests	
			Conductivity	Porosity
Rock Core Analysis				
Tansill Fm.	0.006	4.23	399	381
Yates Fm.	0.026	9.74	11,287	11,387
Seven River Fm.	0.140	6.56	4,367	4,485
Queen Fm.	0.029	7.79	7,324	7,648
Grayburg Fm.	0.032	7.15	1,971	1,973
Grayburg-San Andres (Und.)	0.033	5.76	7,062	7,313
Glorieta Sandstone	0.027	9.16	3,128	3,115
Delaware Mt. Gp.	0.016	15.65	4,549	4,493
Pumping Tests (San Andres)				
T.20S, R.38E, Sec. 7	0.20		(Drawdown Test)	
Same well as above	0.20		(Recovery Test)	
T.22S, R.37E, Sec. 29	0.30		(Drawdown Test)	
Pumping Tests (Capitan)				
T.21S, R27E, Sec. 5	2.4		(Recovery Test)	
T.21S, R.28E, Sec. 30	16.0		(Recovery Test)	
T.21S, R.34E, Sec. 24	3.0		(Specific Capacity)	
T.21S, R34E, Sec. 14	1.7		(Specific Capacity)	
Same Well	1.9		(Drawdown Test)	
Same Well	1.4		(Recovery Test)	
T.24S, R36E, Sec 4	24.0		(Drawdown Test)	
T.24S, R36E, Sec. 16	7.4		(Specific Capacity)	

TABLE 6.3-2 -- Records of Wells in the Los Medanos Area, New Mexico
(Adapted from Cooley, 1972, Table 4)

Location Number	Altitude Above Mean Sea Level (feet)	Depth of Well (feet)	Diameter of Well Casing (inches)	Depth Below Land Surface (feet)	Date of Measurement	Geologic Source	Use and Remarks
19.32.34.434	3560	260	--	Dry	9-22-72	QTs, Trc, Trsr(?)	Unused; 3 wells at this locality; no access for entering casing in the other 2 wells.
19.33.26.244	3609	--	6	90.58	9-25-72	QTs, Trc(?)	Electric Submersible; stock.
26.244a	3609	101	--	90.93	9-25-72	QTs, Trc(?)	--
19.34.31.131	3620	53	6	Dry	9-25-72	QTs	Unused; 2 ft. of water in bottom of hole--probably does not represent true water level.
31.232	3632	120R	6	--	9-25-72	QTs, Trc(?)	Windmill; stock; "Hardin Well," no access to enter casing.
20.31.13.412	3440	30	6	1.12	9-18-72	QTs	Unused.
15.130	3460	105	6	62.10	9-18-72	QTs(?), Trsr	Unused.
15.130a	3460	79	6	63.39	9-18-72	QTs(?), Trsr	Unused; 5 wells at this location of which only 1 is an operating well.
15.130b	--	--	--	--	--	QTs(?), Trsr	Windmill; stock.
20.32. 1.312	3510	20	6	Dry	9-22-72	QTs	Unused; deepest of 4 wells at this location, all wells are dry.
24.333	3555	67	5	37.67	9-11-72	QTs	Unused
24.333a	3555	--	--	--	--	QTs(?)	Windmill; stock.
27.144	3545	30	--	23.67	9-18-72	QTs	Unused; no casing present.
36.214	3585	--	--	P43.88	9-18-72	QTs	Windmill; stock; 3 wells at this location at Bingham ranch, well pumping estimated at 2 gallons per minute.

TABLE 6.3-2 (continued)-- Records of Wells in the Los Medanos Area, New Mexico

Location Number	Altitude Above Mean Sea Level (feet)	Depth of Well (feet)	Diameter of Well Casing (inches)	Depth Below Land Surface (feet)	Date of Measurement	Geologic Source	Use and Remarks
20.33. 4.432	3555	4		Dry	9-22-72	QTs	Unused.
18.123	3521	249	6.5	245.58	9-25-72	Trc	Unused.
21.111	3530	49	6	36.90	9-25-72	QTs	Unused.
24.124	3630	680	12	405.15	9-22-72	Trc, Trsr(?)	Windmill; stock; "West Windmill," watersand at about 300 feet as reported by driller.
20.34. 4.444	3633	200	8	P174.08	10-2-72	Trc	Windmill; stock; "Robert's Well," old oil test drilled before 1939.
14.133	3648	230		196.25	10-2-72	Trc	Windmill; stock.
17.334	3640	220(?)	8	P129.68	10-2-72	Trc	Windmill; stock; "City Service Well," possibly oil test.
22.224	3655	220	12	196.49	10-2-72	Trc	Windmill; stock; "North Well," old oil test
34.432	3770	96	6	89.50	10-2-72	QTs	Windmill; stock.
21.30.18.333	3220	156	6	129.54	9-25-72	Pru	Unused.
22.423	3180	150	6	111.50	9-25-72	Pru	Unused.
21.31. 1.131	3580	30R	6	20.80	9-18-72	QTs	Windmill; domestic & in stock; at Campbell Ranch.
1.241	3600	—	—	—	—	—	"Grave Well."
2.221	3570	35	—	29.80	9-18-72	QTs	Windmill; stock.
7.331	3350	367	14	192.10	9-14-72	Pru, Prc (?)	Unused.
13.244	3600	68	6	Dry	9-13-72	QTs, Trc	Unused.
18.411	3310	—	6	158.32	9-14-72	Pru	Windmill; stock; "New Well."
30.421	3300	176	6	Dry	9-25-72	Pru	Unused.

TABLE 6.3-2 (continued)-- Records of Wells in the Los Medanos Area, New Mexico

Location Number	Altitude Above Mean Sea Level (feet)	Depth of Well (feet)	Diameter of Well Casing (inches)	Depth Below Land Surface (feet)	Date of Measure-ment	Geologic Source	Use and Remarks
21.32. 6.111	3598	54R	—	44.00R	9-18-72	QTs	Windmill; domestic & stock; at Allred Ranch; 2 wells at this location.
21.33. 2.231	3810	1150R	—	—	9-22-72	Trsr	Unused; could not pass tape below 550 feet in 1972.
2.420	3770	94	6	79.58	9-22-72	QTs	Windmill; stock.
4.434	3805	147	—	129.66	10-2-72	QTs(?), Trc	Unused.
4.434a	3805	127	—	Dry	10-2-72	QTs(?), Trc	Unused.
18.114	3890	150	—	140.75	9-12-72	QTs	Windmill; stock.
18.114a	3896	175	—	142.86	9-12-72	QTs	Unused.
18.123	3855	—	—	—	9-12-72	QTs(?)	Windmill; stock.
18.123a	3855	145	8	117.30	9-12-72	QTs	Unused.
18.131	3895	11	—	Dry	9-12-72	QTs	Unused.
25.421	3670	67	—	56.58	9-22-72	QTs	Windmill; stock; "West Well."
28.124	3688	210	8	179.00	9-22-72	Trc	Windmill; stock; "Standard Wells," 3 wells at this location.
22.30. 5.431	3120	225	14	53.25	9-19-72	Pru, Prc(?)	Unused.
6.444	3140	176	22	92.40	9-19-72	Pru	Unused.
7.244	3110	58	12	Dry	9-19-72	Pru	Unused.
10.311	3135	68	6	63.70	9-12-72	Pru	Unused; at Crawford Ranch.
20.120	3076	10	5	Dry	9-19-72	QTs, Pru	Unused.
32.111	3010	35	6	32.70	9-19-72	Pru	Unused.
22.31.15.130	3460	—	—	144.07	9-12-72	Trsr(?) Pdl	Windmill; stock.
15.130a	3460	—	—	145.50	9-12-72	Trsr(?) Pdl	Unused.

TABLE 6.3-2 (continued)— Records of Wells in the Los Medanos Area, New Mexico

Location Number	Altitude Above Mean Sea Level (feet)	Depth of Well (feet)	Diameter of Well Casing (inches)	Depth Below Land Surface (feet)	Date of Measurement	Geologic Source	Use and Remarks
22.32.14.323	3717	380	—	367.80	9-13-72	Trsr	Jenson Jack; stock; "Comanche Wells."
14.324	3720	380(?)	—	370.40	9-13-72	Trsr	Windmill; stock; "Comanche Wells."
22.33. 5.321	3650	10	6	0.0	9-22-72		Windmill; stock; well on edge of Dagger Lake.
13.231	3515	490	6	383.05	9-21-72	Trc	Windmill; stock; "Roger's Well."
13.231a	3515	500	6	388.05	9-21-72	Trc	Windmill; stock.
20.244	3602	—	—	—	—		Unable to locate well in 1972.
23.30. 2.444a	3250	315	7	257.73	9-20-72	Prc	Windmill; stock; "Little Windmill," well 344 destroyed.
6.424	2980	—	6	0.0	9-20-72	—	Unused; "Nash Well," area flooded by lake.
19.123	3045	—	7	68.55	9-20-72	Prc	Windmill; stock.
21.122	3165	—	5	—	9-20-72	Pru, Prc(?)	Windmill; stock; "Indian Well," no access for
		204	5	179.25	4-6-59	Pru, Prc(?)	water level measurement.
22.234	3210	244	—	227.32	9-20-72	Pru, Prc(?)	Unused.
33.244	3438	696	—	—	—	Pru, Prc	Abandoned; at Gnome Site, plugged 6-25-69, USGS No. 5.
34.133	3413	518	—	433.91	9-25-72	Pru, Prc	Observation; at Gnome Site, USGS No. 4.
				433.67	12-12-61	Pru, Prc	
34.133a	3413	—	—	427.03	9-25-72	Pru, Prc	Unused; at Gnome Site, USGS No. 8.
34.234	3401	568	6	415.70	4-14-62	Pru, Prc	Observation; at Gnome Site, USGS No. 6, drld to 1499' & plugged back to 568'.
34.234a	3402	563	6	418.10	4-16-62	Pru, Prc	Observation; at Gnome Site, USGS No. 7, drld to 1507' & plugged back to 563'.
34.324	3426	567	—	441.67	9-25-72	Pru, Prc	Observation; at Gnome Site, USGS No. 1.
				442.40	9-22-60	Pru, Prc	

TABLE 6.3-2 (continued)— Records of Wells in the Los Medanos Area, New Mexico

Location Number	Altitude Above Mean Sea Level (feet)	Depth of Well (feet)	Diameter of Well Casing (inches)	Depth Below Land Surface (feet)	Date of Measurement	Geologic Source	Use and Remarks
23.31. 6.320	3300	213	8	144.72	2-4-59	Pdl	Windmill; domestic.
6.320a	3300	400R	—	—	—	Pdl, Pru	Windmill; domestic; tape will not pass 222' in 1972.
6.444	3310	—	6	106.35	9-20-72	Pdl	Windmill; domestic.
7.240a	3315	—	6	62.27	9-20-72	Pdl	Windmill; stock.
17.310	3305	—	—	—	9-20-72	Pdl, Pru	Windmill; stock.
26.340	3451	—	6	250.47	9-20-72	Pdl	Windmill; stock.
29.113	3335	—	4	139.90	9-20-72	Pdl	Windmill; stock.
23.32. 3.311	3660	550R	8	—	9-13-72	Trsr	Windmill; stock.
3.311a	3660	—	10	204.18	9-13-72	Trsr	Unused.
21.241a	3680	515	—	480.75	9-21-72	Trsr	Windmill; stock.
		550	6	510.00R	4-13-59	Trsr	
23.33.12.312	3530	388	12	351.45	9-21-72	Trsr	Windmill; stock; "Allred Well."
17.423	3702	650(?)	8	504.40	9-21-72	Trc(?), Trsr	Submersible; stock "Graham Wells."
26.421	3645	173	6	165.15	9-21-72	Trc	Windmill; stock; "Tip Top Wells."
26.421a	3645	189	6	P184.00	9-21-72	Trc	Windmill; stock; "Tip Top Wells."
28.334	3675	544(?)	—	500.00R	11-27-53	Trc(?), Trsr	Windmill; stock & domestic; at Brinninstool Ranch, 2 wells at this location, tape will not pass 220' in either well.

Explanations

(1) Geologic source: QTs, surficial deposits; Trc, sandstone beds in the Chinle Formation; Trsr, Santa Rosa Sandstone; Pdl, Dewey Lake Redbeds; Pru, Rustler Formation above Culebra Dolomite Member, including Magenta Dolomite Members; Prc, Culebra Dolomite Member of Rustler Formation.

(2) Altitute: From topograhical maps.

(3) Depth of well: All depths of wells were obtained in 1972; all depths to water in the wells measured in 1972 or before are listed; R, reported depth; P, pumping level; < , less than.

TABLE 6.3-3: Water Quality Data (from Table 2, Mercer and Orr, 1978)
reported in parts per million

Monitor Well	Date of Sample	pH Units	Temperature (Celsius)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonite (CO_3)	Sulfate (SO_4)
Magenta Dolomite										
H-1	5/10/77	7.2	22.0	1,000	460	6,200	840	93	0	3,600
H-2a	2/22/77	8.6	22.0	820	170	2,700	81	74	0	2,400
H-3	5/10/77	8.0	22.5	1,200	480	9,300	250	51	0	3,400
Culebra Dolomite										
H-1	3/17/77	7.3	22.5	820	1,800	29,000	5,600	100	0	11,000
H-2b	2/22/77	8.4	21.5	690	160	2,100	91	59	5	3,000
H-2c	3/16/77	8.1	20.5	680	120	3,600	120	62	0	3,200
H-3	3/17/77	7.4	21.5	1,500	670	19,000	630	115	0	5,700
P-14	3/14/77	6.0	21.5	3,100	760	7,600	600	357	0	1,400
P-15	5/10/77	10.2	21.5	770	63	6,900	1,700	63	24	3,200
P-17	5/10/77	7.4	22.5	1,700	1,600	30,000	120	77	0	5,000
P-18	5/10/77	7.2	24.5	5,600	16,000	9,200	6,200	310	0	920
Rustler-Salado Contact										
H-1	2/22/77	7.9	21.0	13,000	30,000	56,000	17,000	675	0	520
H-2c	2/23/77	5.9	20.5	9,200	25,000	66,000	9,100	199	0	1,300
H-3	2/24/77	7.6	21.5	18,000	25,000	59,000	14,000	467	0	370
P-14	2/24/77	7.2	24.5	570	1,200	120,000	1,300	222	0	10,000
Delaware Sand										
ERDC-8	9/22/77	6.0	30.0	10,000	2,300	55,000	660	420	0	240

Table 6.3-3 Continued

Monitor Well	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Dissolved Solids (Sum of constitents)	Nitrate* +Nitrate (N)	Ortho* Phosphorus (P)	Boron* (B)	Iron* (Fe)	Manganese* (Mn)
Magenta Dolomite									
H-1	10,000	2.0	1.7	22,200	0.04	0.03	3.3	0.22	0.95
H-2a	4,100	-	6.0	10,300	0.04	0.01	0.22	0.06	<0.05
H-3	15,000	1.8	6.4	29,700	0.08	0.04	13.0	0.04	0.22
Culebra Dolomite									
H-1	49,000	0.8	0.6	97,300	0.03	0.00	18.0	0.79	2.8
H-2b	2,800	2.0	1.7	8,390	0.01	0.03	9.5	0.02	0.2
H-2c	4,700	1.6	3.5	12,500	0.16	0.00	10.9	0.11	0.14
H-3	29,600	0.5	1.2	57,200	0.07	0.00	20.0	0.05	0.12
P-14	20,000	0.9	33	33,700	0.01	0.02	0.7	17	0.5
P-15	11,000	1.2	1.6	23,700	0.04	0.03	4.7	0.1	0.02
P-17	54,000	1.5	1.0	92,500	0.06	0.11	1.7	1.2	3.0
P-18	80,000	1.2	1.0	118,000	0.81	0.40	100.0	0.54	4.5
Rustler-Salado Contact									
H-1	210,000	-	0.0	327,000	0.29	0.00	110	1.5	52
H-2c	200,000	-	2.0	311,000	1.1	0.00	150	2.5	78
H-3	210,000	-	1.0	327,000	0.77	0.00	1.9	1.5	3.8
P-14	180,000	-	2.0	313,000	0.34	0.08	1.7	2.1	3.4
Delaware Sand									
AEC-8	120,000	1.2	3.6	189,000	0.11	0.05	53	23	14.0

* Due to sampling conditions, analyses of NO_3^{-1}, PO_4^{-3}, BO_3^{-3}, Fe^{+2}, and Mn^{+2} are probably no more precise than ±15%. The others have a precision of about ±5%.

TABLE 6.3-4 Fluid Yield From Test Zones
(gallons per day)

Hole No.	Test Interval (depth in ft)	Magenta Dolomite	Culebra Dolomite	Salt Residue Zone in Rustler Fm.	Rustler-Salado Contact	Bell Canyon Sand
	Open hole, drill stem tests (1)					
H-1	562 - 592	23.1				
	626 - 667			22.4		
	667 - 669		22.1			
	669 - 842				10.9	
H-3	558 - 608	14.1				
	672 - 703		2.3			
	703 - 780			1.8		
	800 - 868				2.6	
	Open hole, bailing tests (2)					
H-2a	513 - 563	27				
H-2b	611 - 661		260			
H-2c	743 - 795				0.8(3)	
	Cased hole with perforated interval, bailing tests (2)					
H-1	562 - 590	66				
	675 - 703		46(4)			
	803 - 827				1.0(5)	
H-2b	510 - 538	210				
H-2c	624 - 652		310			

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TABLE 6.3-4 (continued) Fluid Yield From Test Zones
(gallons per day)

Hole No.	Test Interval (depth in ft)	Magenta Dolomite	Culebra Dolomite	Salt Residue Zone in Rustler Fm.	Rustler-Salado Contact	Bell Canyon Sand
	Cased hole with perforated interval, bailing tests (2)					
H-3	562 - 590	(8640)(6)				
	675 - 703		200			
	813 - 837				11/32d(8)	
P-14	573 - 601		(5760)(7)			
	676 - 700				75	
P-15	410 - 438		50		2.0/42d(8)	
P-17	558 - 586		170			
	702 - 726				1.0/72d(8)	
P-18	912 - 940		0.5/33d(8)			
	1076 - 1100				0.5/73d(8)	
AEC-8	4844 - 4860					269(9)

NOTES:

(1) Inflows measured over periods ranging from 11.5 to 37.5 hours.
(2) Inflows monotired for periods ranging from 8 days to 217 days. Rate based on inflow during first 24 hours.
(3) Inflow of 14 gallons in 18 days (no other data).
(4) Inflow of 416 gallons in 9 days (no other data).
(5) Average trend after 33 days recovery.
(6) Bailed 360 gallons in 1 hour with 6 feet of drawdown.
(7) Bailed 720 gallons in 3 hours with no drawdown.
(8) Early measurements inconclusive; inflow for period of days (d) indicated.
(9) Recovery measured for only 2.8 hours.

TABLE NO. 6.3-5

OBSERVATION WELLS - MONITORING ZONES

WELL NO. (GROUND ELEV.)	ZONE TESTED	ACCESSIBLE DEPTH	INTERVALS ELEV.
H-1	Magenta	562-590	2841-2813
(3403)	Culebra	675-703	2728-2700
	Rustler-Salado	803-827	2600-2576
H-2a	Magenta	No tests except levels	
H-2b	Culebra	510-538	2867-2839
H-2c	Culebra	624-652	2753-2725
(3377)	Rustler-Salado	743-795	2634-2582
H-3	Magenta	562-590	2837-2799
(3389)	Culebra	675-703	271"-2686
	Rustler-Salado	813-837	257o-2552
P-14	Culebra	573-601	2785-2757
(3358)	Rustler-Salado	676-700	2682-2658
P-15	Culebra	410-438	2900-2872
(3310)	Rustler-Salado	532-556	2778-2754
P-17	Culebra	558-586	2782-2754
(3340)	Rustler-Salado	702-726	2638-2614
P-18	Culebra	912-940	2567-2539
(3479)	Rustler-Salado	1076-1100	2403-2379
AEC-8	Bell Canyon (Upper)	4821-4827	[1289-1295]*
(3532)	Bell Canyon (Lower)	4844-4860	[1312-1328]*

*Elevations in brackets are below mean sea level; all other elevations are above msl. All depths and elevations are given in feet.

TABLE NO. 6.3-6

POTENTIOMETRIC LEVELS
OCTOBER 1977
(Elevation in Feet)

Observation Well	Ground Surface Elevation	Magenta Dolomite	Culebra Dolomite	Rustler-Salado Contact	Delaware Sands "Upper"	Delaware Sands "Lower"
H-1	3,403	3,154	3,013	Not Monitored[1]		
H-2a	3,377	3,128	Not Penetrated	Not Penetrated		
H-2b	3,377	3,081	3,026	Not Penetrated		
H-2c	3,377	Not Screened	3,021	34'/Month[2]		
H-3	3,389	3,141	2,984	Not Monitored[1]		
P-14	3,358	Not Screened	3,034	2,970		
P-15	3,310	Not Screened	3,002	2,975		
P-17	3,340	Not Screened	2,968	2,970		
P-18	3,479	Not Screened	6'/month[2]	40'/month[2]		
AEC-8	3,532	Not Screened	Not Screened	Not Screened	2,927	2,933

NOTES:

[1]The Rustler-Salado contact is accessible, but is temporarily off.

[2]Recovery Rate: Level in tubing had not reached static level in October, 1977.

SWG :

GCR CHAPTER 7
GEOCHEMISTRY

7.1 INTRODUCTION

In the context of this Geological Characterization Report, "geochemistry" is taken here to include a description of chemical properties of geologic media presently found in the surface and subsurface environments of southeastern New Mexico in general, and of the proposed WIPP withdrawal area in particular. "Chemical properties of geologic media" might be extended to include a description of present understanding of chemical processes which have taken or are taking place in southeastern New Mexico rocks. This geochemistry chapter of the WIPP Geological Characterization Report does not consider any aspect of artificially-introduced material, temperature, pressure, or any other physico-chemical condition not native to the rocks of southeastern New Mexico. These as-yet hypothetical considerations belong in the realm of interactions between radioactive waste and rock, a subject of the experimental programs initiated as part of the WIPP studies that are not yet completed. Early experimental results of radionuclide interactions with southeast New Mexico rocks and fluids are reported in Chapter 9.

A substantial fraction of this chapter consists of original source material, never before published in any format aside from reports of investigations resulting from research contracts. Much of this material is, however, in the process of being recast so as to be suitable for presentation in various professional forums. Some material has already been so presented.

Information contained herein was offered if the work involved was at a suitable stage of completion so as to allow conclusions to be drawn. Some subjects of investigation related to geochemistry require several years more investigation, even for final site characterization, and are discussed in Chapter 10, "Continuing Studies." Subjects of the present chapter are those which provide background data of relevance to (1)

experimental programs involving radioactive waste and its interaction with geomedia, (2) borehole plugging, (3) the intrinsic physico-chemical stability of southeastern New Mexico rocks in the geologic past, and (4) safety assessment, which is described in other major documents relating to the proposed WIPP. These data include mineralogy, volatile constituents of rocks, the constitution, origin and history of liquids and gases found in rocks, and the lengths of time which have passed since the latest episodes of thermodynamic instability resulting in rock/fluid interactions.

In the absence of a satisfactory theoretically-formulated mathematical model which can accurately predict phase equilibria among complex evaporite minerals, an empirical approach, based on observed assemblages, is adopted here. Such modelling is beyond the scope of this document.

It will be noted that volatile contents of evaporites were determined by three different methods: static heating (Section 7.5.3), thermogravimetric analysis (Section 7.5.2) and counting of fluid inclusions (Section 7.6). Each set of data was collected for a different geochemical purpose, but results from all techniques show comparable amounts of volatile constituents in the evaporites. The most accurate results, however, are probably those derived from static heating.

7.2 THE MINERALOGY OF DELAWARE BASIN EVAPORITES AND RELATED ROCKS OF THE LOS MEDANOS AREA

7.2.1 Introduction

The foregoing sections on geology and stratigraphy have briefly mentioned generalized mineralogies of Delaware Basin rocks of the Los Medanos area. Here it becomes of interest to present a more thorough exposition of mineralogies. This is done for a variety of reasons: (1) mineralogies affect properties of rocks important to physical aspects of mining, (2) soluble minerals in rocks potentially give rise to solutions which can interact with waste and its containers, and (3) minerals in

rocks have various degrees of sorptive affinities for radionuclides and can serve to decrease their mobility. While this section is devoted mainly to an account of the minerals found in the main Ochoan evaporite section (Castile and Salado Formations), mineralogies of some Guadalupian rocks and some rocks above the main evaporite section are included. This information is particularly useful to the consideration of radionuclide mobility in rocks containing substantially more fluid than the evaporites, and is of fundamental importance to in situ experiments involving waste-rock interactions. Also, investigations of fluid inclusions, sources of volatiles, groundwater geochemistry and age-dating of rocks and waters are closely related to mineralogy.

7.2.2 Previous Work

Southeastern New Mexico evaporites have been economically important for many years because they contain the well-known McNutt Potash Zone in the middle part of the Salado Formation. Descriptions of mineralogies of the McNutt and adjacent portions of the Salado have been given in several previous reports covering much of the Permian Basin, and environs of southeastern New Mexico (Brokaw et al., 1972; Jones, 1973; Jones, 1974a; Jones, 1974b; Jones, 1975). A detailed review of the economic mineralogy of the McNutt Potash Zone underlying Los Medanos appears in Chapter 8 of this report. This section on mineralogy has been developed as background critical to mine design, waste-rock-fluid interactions, and other aspects of geochemistry, such as age-dating and radionuclide migration.

7.2.3 Overview of Evaporite Mineralogy

X-ray powder diffraction examination of 50 core samples from ERDA #9 in the center of the study area (Figure 4.1-2) has been completed. Only qualitative information was obtained from these preliminary cores in order to assess mineralogical variations among selected horizons.

As-received cores were crushed and ground to bulk powder to provide a representative sample of that zone, x-ray specimen mounts weres scanned

at 1°/min on a diffractometer equipped with copper x-ray source, graphite monochrometer and scintillation detector.

Eight minerals were identified in the 50 samples:

1.	anhydrite	$CaSO_4$
2.	clay	$Al_2Si_4O_{10}(OH)_2 \quad xH_2O$
3.	halite	$NaCl$
4.	loeweite	$Na_{12}Mg_7(SO_4)_{13} \quad 15H_2O$
5.	magnesite	$MgCO_3$
6.	polyhalite	$K_2Ca_2Mg(SO_4)_4 \quad 2H_2O$
7.	quartz	SiO_2
8.	sylvite	KCl

Their occurrence is given qualitatively in Table 7.1 with a corresponding graphical distribution shown in Figure 7.1. Trace amounts of the potassium minerals sylvite and polyhalite were found in the proposed TRU horizon (2034-2110'), and the high-level horizon (2594-2692') was void of potash.

7.2.4 Mineralogy of Fluid-Bearing Zones in the Rustler Formation and Delaware Mountain Group

Mineralogies of certain fluid-bearing rocks above and below the main evaporite sequence have been determined as background information for radionuclide sorption studies.

Magenta Member, Rustler Formation (AEC No. 8). The Magenta member of the Rustler Formation is largely ferroan dolomite, probably containing minor ankerite which gives rise to the reddish color in weathered outcrops. This rock also contains detrital quartz, and gypsum forms as crystals, filling the vugs in the dolomite, which can be up to several cm across.

Culebra Member, Rustler Formation (AEC No. 8). Like the Magenta, the Culebra member is largely dolomite, with traces of detrital quartz. In addition, small amounts of calcite are found.

Bell Canyon Sandstone (AEC No. 8). The Bell Canyon Formation is the uppermost unit in the Delaware Mountain Group immediately underneath the main evaporite sequence. It is mostly detrital quartz and major feldspar with a matrix of kaolinite and chlorite cemented with calcite and minor amounts of dolomite.

Cherry Canyon Sandstone (Pine Springs Outcrop). Although the Cherry Canyon Formation was not sampled in any WIPP exploratory borehole, its stratigraphic position directly underneath the Bell Canyon made it of interest in preliminary radionuclide sorption measurements. The detrital component is largely quartz, and the cement is mostly dolomite. Minor amounts of albite and microcline contribute to the detrital component, and minor amounts of gypsum and calcite are found in the cement.

7.3 DETAILED CHEMISTRY AND MINERALOGY OF SOLUBLE AND INSOLUBLE COMPONENTS OF THE SALADO FORMATION

7.3.1 Introduction

While this section deals primarily with results obtained from cores from AEC No. 7 and AEC No. 8, exploratory holes three miles northeast of the present study area (Figure 4.1-2), these holes provided material of sufficient lithologic similarity to ERDA No. 9 so as to be of value. The analytical strategy employs a normative-type calculation, in which mineralogical compositions are derived mathematically from bulk chemical compositions. The results of those calculations then can be compared to mineralogies determined petrographically or by x-ray diffraction. This section serves as fundamental background information for the chapters on silicate mineralogy and sources of volatile components within the evaporites.

7.3.2 Materials and Methods

Sample Preparation and Handling. The core samples as received were halved and one-half was retained while the remaining half was crushed and ground. The ground sample was size-distributed as shown in Table 7.2.

The samples were all double-wrapped for storage in plastic bags due to their hygroscopic nature. A portion of the crushed sample weighing approximately 20 grams was accurately weighed and dried in an oven at 70°C for two hours to determine weight loss. The dried sample was then added to 200 ml of distilled water, stirred for 1 hour, and filtered. The filtered material was dried and weighed to determine the insoluble portion of the sample while the filtrate contained the soluble portion of the sample.

Analysis of Soluble Portion. The elements potassium, calcium, magnesium, silicon, iron, aluminum, and strontium were analyzed by standard atomic absorption methods using a Perkin-Elmer 403 Atomic Absorption Spectrophotometer. Sodium, typically difficult to analyze precisely, was analyzed using an Orion Specific Ion Sodium electrode and an Orion Research Model 801 pH meter. Sulfate was determined gravimetrically as barium sulfate; chloride was determined volumetrically by titrating with mercuric nitrate (Vogel, 1961)

Analysis of Insoluble Portion. The insoluble portion was separately analyzed only if the insoluble percentage was greater than 0.5% of the total sample weight. Samples containing less than 0.5% insolubles did not provide sufficient material for analysis, and it was deemed that even a major constituent in such a small percentage of the total would not contribute significantly to the sample behavior. A portion of the water-insoluble material weighing about 100 mg was dissolved in HF, using the following procedure in a teflon-lined high pressure bomb (Bernas, 1968; 1973) obtained from Parr Instruments. Nitric acid (1 ml) was added

to wet the sample and 3 ml of 50% HF were added. The bomb was assembled and placed in a 70°C oven for 2 hours. The contents of the bomb were quantitatively transferred to a polypropylene beaker containing 2.8 g of boric acid and about 30-40 ml deionized water. The boric acid was allowed to dissolve with stirring and the solution diluted to 100 ml in a volumetric flask and stored in a polyethylene bottle. A solution containing all of the matrix material was prepared for use in making standards for the atomic absorption spectrophotometer. All analyses were performed as described in the preceding section. Samples were tested for the presence of carbonates using concentrated HCl but only occasionally was a trace amount detected.

Thermal Analysis. Samples analyzed for weight loss upon heating were ground so that greater than 90% of the sample was smaller than 100 mesh. Each sample was dried for at least 3 days at 65°C in a thermostatically regulated oven. This temperature was chosen to avoid the long-term dehydration of gypsum described elsewhere in this report. Low temperature weight loss (70°C for 2 hours) was used to measure absorbed water. This weight loss is probably higher than for rock distant from the sample collection point owing to absorption of drilling water. Samples of 100 mg weight were heated for differential thermal analysis (DTA) using a Fisher 200A DTA apparatus at a rate of 10°C/min from 25°C to 500°C.

Thermogravimetric analysis was carried out with a Fisher 100A TGA apparatus and a Cahn Model R6 electrobalance at a rate of 5°C/min from 60°C to 500°C using 100 mg of sample material. A few samples were heated to 800°C and are described elsewhere in this subsection.

Results of Analyses. Whole-rock chemical analyses, soluble-insoluble fractions, and weight losses upon heating are presented in Appendix 7.A. These analyses are converted to relative numbers of moles of components by multiplying weight percents by appropriate values of 1000/molecular weight. The results are listed in Appendix 7.B. If the insoluble fraction of a sample exceeds 0.5 weight percent, separate calculations are provided for both the soluble and insoluble fractions of the sample.

7.3.3 Results and Discussion

Distribution of Mineral Phases. Chemical analyses may be used to estimate, semiquantitatively, the amounts of constituent minerals present in a rock. This is accomplished by distributing the quantitatively determined chemical components among mineral phases known qualitatively to be present in the rock. The method was as follows:

The distribution of the total number of moles (Nt) of a given chemical component (c) among the various mineral phases (p) present in a rock is described by the equation

$$Nt,c = \Sigma\ (Np)\ (Nc,p)$$

where:

Nt, c = the total number of moles of the component c in the rock

Np = the total number of moles of each of the mineral phases p in the rock,

Nc,p = the number of moles of the component c in one mole of phase p.

This equation is simply a statement of conservation of mass, indicating that the total amount of a given chemical component must be distributed among the minerals containing that component; this distribution is controlled by the specific chemical compositions of the minerals. An expression of the form of the above equation may be written for each of the components present in a rock sample. For a given rock, one of three conditions are possible for the set of simultaneous equations describing the distribution of all components in that rock:

1) if the number of equations (1 for each component) is equal to the number of unknowns (the moles of each of the phases), an exact solution to the equations may be determined.
2) if the number of components exceeds the number of phases (more equations than unknowns) the system is overdetermined and a solution to the equations may be evaluated by a method such as least squares regression.
3) if the number of components is less than the number of phases (more unknowns than equations), the system is indeterminate.

If either of the first two criteria are met, the chemical composition of the rock can be employed to calculate the quantitative amounts of minerals known, qualitatively, to be present.

An important assumption for the treatment described above is that the chemical composition of all mineral phases is known. This is necessary in order to define $N_{c,p}$ for all phases in the mass balance equations. If a mineral of variable composition is present in a rock sample (i.e., a solid solution), an additional variable is introduced to the set of equations; that is, the composition of the solid solution. This additional variable may change a set of N equations and N unknowns (condition 1 above) to an indeterminate set containing N + 1 unknowns. If such is the case, it is necessary to employ some additional analytical technique to determine the actual composition of the unknown. On the other hand, if the solid solution is present in a rock meeting condition 2 above, it will suffice to simply introduce two values of Np for the phase; in other words, an unknown for the number of moles of each of the pure end-members of the solid solution present. The composition of the mineral is then defined by the relative number of moles of each of the end-members present.

Qualitative mineralogy may be carried out by a variety of methods such as x-ray diffraction and thin-section analysis in addition to straight-forward examination. The chemical data obtained during this study have been used to attempt to estimate relative amounts of minerals present in the various samples. With only a few exceptions, the rocks are made up essentially of halite, and other mineral phases are present in comparatively minor or trace amounts.

Samples from the Carlsbad boreholes consist of two chemically distinct fractions: (1) water-soluble chlorides and sulfates of sodium, potassium, calcium, and magnesium, and (2) water-insoluble silicates of potassium, magnesium, and aluminum with quartz and iron oxide. Minerals of the first group generally contain stoichiometric compositions, whereas those of the second group exhibit extensive compositional variation. In

the case of the soluble portion, sodium occurs mainly with chloride as halite, while the other cations combine in various proportions with sulfate (and only occasionally chloride) forming minerals such as polyhalite, anhydrite, and kainite. These sulfates are of importance because they contain hydrate water which may be released upon heating. Silicates also undergo dehydration at elevated temperatures, but generally much higher temperatures are required than for the soluble salts because the water must be derived through destruction of hydroxyl groups. Compositions of minerals from these two classes are listed in Table 7.3.

Recognizing that soluble potassium, calcium, and magnesium are combined with sulfate, a semiquantitative estimate of various sulfate phases may be made by plotting the relative numbers of moles of the cations on triangular composition diagrams. The compositions of various stoichiometric mineral phases in the sulfate group are shown on such a diagram in Figure 7.2. No sulfate of potassium alone is common in nature, so sylvite is placed at the potassium apex of the triangle. Also shown on this diagram are the chloride and chloride-sulfate of potassium and magnesium. Not shown on Figure 7.2 are the soluble sulfates containing sodium. After plotting a given sample composition in terms of relative numbers of moles of soluble K_2O, CaO, and MgO, the total number of moles of these cations is compared to the number of moles of sulfate determined analytically; if the two are equal, then the minerals in the rock are estimated using the location of the sample on the diagram. If the cation sum is greater than available sulfate, an appropriate amount of chloride is added to make up the charge balance. Relative amounts of chloride and sulfate are then used in conjunction with the cations to determine appropriate amounts of carnallite, kainite and/or sylvite. If on the other hand, cations are deficient relative to sulfate, then sodium is added to the sulfate group to form bloedite, glaserite and/or glauberite.

The addition of sodium or chloride must be compatible with the relative amounts of these two components in the analysis. Generally, these are

present in such large amounts that a small error in their contents provides sufficient amounts for addition to the potassium-calcium-magnesium-sulfate fraction. In many instances, it is found that when it is necessary to do such addition, the appropriate component (sodium or chloride) is present in excess of the other necessary to form halite. Where such addition is not compatible with the chemical analysis, examination must be made of the insoluble portion of the sample. Where anhydrite-gypsum is present in significant amounts in a sample, the relatively low solubility of $CaSO_4$ (and possibly polyhalite) causes this phase to appear in both the soluble and insoluble fractions.

Minerals of the insoluble fraction consist of quartz, iron oxide, and a variety of clay minerals which are difficult to identify due to fine-grain-size and compositional variability. Iron probably occurs chiefly as either hematite (much of the halite is tinted orange) or an equivalent hydrated form although it may substitute for aluminum to a minor extent in clay minerals.

According to our chemical analyses, the remainder of the insoluble fraction is made up of the components K_2O, Al_2O_3, MgO, and SiO_2. Because the first three of these generally occur combined with the fourth, potential mineralogy of the samples may be evaluated by comparing insoluble analyses to mineral compositions plotted on the compositonal triangle K_2O-Al_2O_3-MgO shown in Figure 7.3. On this diagram, mixed-layer solid solution among potassium and magnesium montmorillonites and seawater-illite is indicated by the shaded area between these three endmember components. It should be noted that the chlorite composition plotted on Figure 7.3 is that which has been observed in present day seawater sediments and evaporites. Relative proportions and amounts of minerals occurring in a given sample are evaluated by distributing potassium, aluminum, and magnesium along appropriate limiting phase compositions. Silica is then distributed among these phases according to stoichiometry, and any excess occurring in the sample analysis is considered to be free quartz.

Halite is by far the most abundant mineral in the soluble fractions of the samples. In only a few cases is halite a minor or trace constituent. Polyhalite and anhydrite/gypsum are accessory minerals in most samples, and in two of these, $CaSO_4$, is a major component. In normative calculations for sulfate deficient samples, kainite and carnallite are included, whereas thenardite, glaserite, bloedite, and kieserite appear in sulfate-excess and balanced samples. These phases are rarely present in more than trace amounts and are calculated to occur in such small quantities as to be insignificant in terms of contributions to hydrate water. Sample 8-1652 (i.e., 1652 feet depth in AEC No. 8) is significantly different from other soluble material in that it is calculated to contain relatively large amounts of the soluble salts sylvite, polyhalite, leonite, and glaserite. The drilling log reports loss of mud at this point, so it is uncertain as to whether a rock is of exotic mineralogy, or one from which certain cations have been leached by moving drilling mud, or one which has exhibited the incongruent solubility of polyhalite, leaving a sample of abnormal chemistry.

Most of the insoluble analyses plot within the triangle bounded by the phases Mg chlorite-K feldspar-talc on Figure 7.3. These minerals are recognized to occur in evaporite sequences which have undergone mild diagenesis ($P < 100$ atm, $T < 100^{\circ}C$), forming as a result of interaction of brine with amorphous aluminosilicate detrital material (Braitsch, 1971). The only other phases calculated to occur in the insoluble fraction are mixed-layer illite-montmorillonite, quartz, and iron oxide. It should be noted that the presence of the mixed layer silicate as well as chlorite and talc may be difficult to establish if they occur in very fine grain size. None of the observed silicate phases undergo dehydration below $500^{\circ}C$, according to the DTA.

Effects of Heating Samples. A number of different responses to heating were exhibited by the samples. Heating to $70^{\circ}C$ was designed to measure absorbed water recognizing that gypsum dehydrates, according to thermochemical data, at about $70^{\circ}C$. In normal differential thermal analysis, gypsum undergoes stepwise dehydration to hemihydrite and

anhydrite at about 150° and 185°C, respectively. Kopp, (University of Tennessee, pers. comm.) has observed that gypsum dehydrates upon fine grinding and prolonged heating at 70°C, hence the observed DTA breakdown is probably a result of kinetic factors. Consequently, samples analyzed using thermogravimetric analysis were powdered and placed in an oven at 70°C for several days prior to analysis of weight loss at elevated temperatures. Samples 7-1171 and 8-2563 both contain major $CaSO_4$, but only the latter showed gypsum-type dehydration. This appears to indicate that sample 7-1171 actually contained anhydrite whereas sample 8-2563 contained gypsum since only 8-2563 showed significant weight loss at 70°C but both analyses summed to near 100%.

Essentially isothermal dehydration was observed over a continuum of temperatures from 100° to 500°C for a large number of samples. In addition, weight loss over a 50° to 100°C span in temperature was observed for most samples, but generally at temperatures above 300°C. These two types of weight loss probably indicate single-mineral dehydration for isothermal loss, and dehydration as a result of mineral-mineral chemical interaction for the weight loss occurring over a large temperature span. Such solid interaction is demonstrated by sample 8-1953 which contains both anhydrite and polyhalite but minimal bloedite. Figure 7.4 shows the DTA curves for pure polyhalite and gypsum. Comparison of these two curves to that of sample 8-1953 shows the 325°C exotherm of polyhalite to be lacking while the lower temperature endotherms of gypsum are present. We suggest the missing polyhalite endotherm is a result of chemical interaction between polyhalite and anhydrite somewhere between 200° and 325°C. Such interaction among evaporite minerals should probably be investigated in some detail in terms of retention of hydrate H_2O.

A few samples were heated to 800°C to get an indication of how much weight might be lost from samples at high temperatures (>500°C). Of the nine samples examined under these "extreme" conditions, four began gaining weight at about 700°C. One sample increased in weight by about 15% between 725° and 800°C. This gain in weight is not a result of

oxidation of iron (eg. Fe^{+2} in chlorite) since sample 8-2050 did not contain any iron. That the gain in weight may be caused by formation of an extremely hygroscopic phase at high temperatures as a result of solid-solid chemical interaction upon heating. Whether or not such a phase forms would undoubtedly depend upon the initial mineralogy of the rock to provide the correct reactant phases since not all sample exhibited this weight gain. The water necessary for this rehydration is probably a result of the fact that the testing laboratory is cooled during the summer months (the analyses were run in early June) by evaporation which results in high relative humidity.

A composite histogram of weight loss of all samples at elevated temperatures is shown in Figure 7.5. The distribution appears to be log-normal with the maximum density near 0.25% weight loss upon heating 500°C. Over half of the samples (56%) show weight loss of 0.5% or less, and only 15 samples exceed 1%. Figures 7.6A and 7.6B are plots of sample weight loss vs depth for the two drill holes. Samples showing more than 1% weight loss upon heating are scattered throughout the depth range but are generally separated by more than one hundred feet of low-water-loss material. There is a broad correlation between higher weight loss and increasing insoluble content of sample, but no clearcut relationship is seen between weight loss and silica content. It is concluded that high temperature weight loss is contributed by both silicate and sulfate minerals. It can be stated in general, however, that samples showing less than 1% weight loss contain less than 10 wt % insoluble material.

7.3.4 Conclusion

Most of the samples showed very little water loss between 200° and 300°C and there were only small water losses at temperatures 200°C and 300°C. As can be seen by examining the data, there are several zones where there is essentially no change in sample behavior with heating to moderate temperatures. These areas show good potential as burial sites for nuclear waste.

7.4 DETAILED PETROLOGY AND SILICATE MINERALOGY OF SOME PERMIAN BASIN ROCKS

7.4.1 Introduction

The purpose of this section is to describe and evaluate the petrologic, mineralogic and geochemical properties of designated core samples, primarily from the ERDA - 9 drill hole and various grab samples exposed in mines and at the surface, in connection with the WIPP (Waste Isolation Pilot Plant) site evaluation.

ERDA - 9 penetrates the Mescalero Caliche, Gatuna Formation Santa Rosa Sandstone, Dewey Lake Red Beds, Rustler Formation, Salado Formation and the uppermost 50 feet of the Castile Formation (Figure 4.3-3). Primary interest is focused on selected intervals within the Salado and uppermost Castile Formations.

The general problems under study are: 1) the genesis of the dominantly evaporite succession with associated silicates and 2) the extent of post-depositional alteration of these sediments. The basic approach (and analytical method) is broadly threefold. First, detailed study of the occurrence and mineralogy of silicates, particularly clay minerals, in the evaporite succession (disaggregation, size fractionation, x-ray diffractometry). Second, bulk chemical analysis of whole rock, water soluble, acid insoluble, and clay size fraction (x-ray fluorescence, atomic absorbtion spectroscopy, other rapid procedures). Third, macroscopic and microscopic petrography (handspecimen and microscope mineral identification, description of form, texture and lithology of mineral associations, and x-ray diffractometry of bulk samples).

7.4.2 Procedure

After core intervals were selected for study, cores were cut lengthwise, mostly in the form of 1/2, less commonly 1/4, of the core. Criteria for selection and additional procedures for analysis of these samples are

described in the following sections on the silicate mineralogy, geochemistry and petrography.

7.4.3 Silicate Mineralogy and Geochemistry

Systematic logging of ERDA - 9 core and accompanying gross mineralogy have been described in Chapter 4. This section is focused on selected segments of the core and examination of the paragenesis of minor constituents, namely the silicate minerals, their composition, and their interpretation in terms of depositional and postdepositional phenomena.

Silicate mineralogy and geochemistry have not been comprehensively studied within the Ochoan rocks and the Permian Basin. Adams (1969) has reported briefly on the occurrences of talc in argillaceous rocks as a part of this extensive study of bromine distribution throughout the section; specialized clay mineral determinations by Grim et al. (1961) and Fournier (1961) have been undertaken on a limited number of samples and with minimal regard to their detailed stratigraphic setting and geneses.

In an effort to provide substantially more complete understanding of the silicates associated with the Permian evaporites, some 70 samples of the ERDA - 9 core ranging from 300 feet below the Salado-Rustler contact (1163.3 foot depth) down to a few tens of feet below the Salado-Castile contact (2867.6 foot depth) were selected. The following criteria were used in the selection: (1) representation of major lithologies; (2) detailed representation of an apparent "cycle" of evaporite deposition which occurs repeatedly through the Salado Formation section; (3) representation of intervals under consideration for waste storage sites; (4) detailed representation of selected polyhalite-anhydrite occurrences toward interpreting the genesis of the unusually abundant polyhalite; and (5) representation of the sequences which may provide data for interpreting postdepositional solution and recrystallization phenomena. In Table 7.4, we list the samples by depth, gross lithology, and stratigraphic position, as well as by character of data obtained; Table 7.5 provides a cross-listing for relating sample number to depth.

Sample Preparation and Analysis. The core was split and one split rebagged for future reference. One to 10 cm segments of the remaining half were selected for analysis (petrographic, mineralogic, and/or chemical) and sectioned off. A 1 cm slab of this was retained for petrographic examination; the remainder was coarsely crushed and a split retained for whole rock analysis. The larger fraction of the sample was leached with excess demineralized water to dissolve the halite host. This was repeatedly centrifuged, decanted, and rewashed to remove all traces of dissolved halite from the residue. The residue was dried, reweighed, and a split suspended in boiling EDTA solution in order to separate the "acid-soluble" salts (sulfate and carbonate minerals) following the procedure of Bodine and Fernalld (1973). Again, after repeated centrifuging, decanting and washing to remove EDTA and to dissolve solid components from the insoluble residue, the suspension was dried and reweighed. Table 7.6 depicts the quantities of sample residues insoluble in water and EDTA. A split of this fraction was resuspended in water, thoroughly disaggregated with an ultrasonic probe, and separated into the $> 2\ \mu m$ and $< 2\ \mu m$ (effective spherical diameter) fractions by timed gravity settling. Oriented diffractometer mounts of the fine fraction were prepared by pipetting several drops of each suspension onto glass slides and air-drying. Smear (paste) mounts and mounts using the conventional commercial powder mounts were used for the $< 2\ \mu m$ insoluble fraction as well as for the other fractions. In addition, pellet or uniformly compressed mounts or "briquettes" of these fractions prepared for x-ray fluoresence were also used for diffraction.

Where sufficient sample was available, normal procedure for the silicate fraction included: (1) diffraction data for the whole EDTA-insoluble fraction using the briquettes or paste mounts; (2) oriented (sedimented) clay-size mounts on glass which were air-dried, glycol saturated, heated to 300°C, and heated to 500°C. Conventional x-ray diffractometer traces were obtained at a scanning speed of $2^{\circ}2\theta$/min with Cu-radiation and a curved crystal monochromator.

X-ray fluorescence work involved briquette mounts using the vacuum-path Norelco fluorescence goniometer with quartz and gypsum analyzing crystals. In this study, standard regression procedures are used along with matrix evaluation for calculating abundances from the raw data. However, at this time the data can only be reported in terms of a unit-slope regression from one standard. Because of the severe errors such a procedure may induce, only "semi-quantitative" chemical results are claimed for this report.

Silicate Mineralogy. The following silicate minerals have been identified in the course of this study; their distribution is given in Table 7.7.

Quartz - Quartz occurs throughout the entire interval of the stratigraphic section analyzed; however, it does not occur in every sample. Quartz is generally fine-grained ($<10\mu m$), subhedral to anhedral, and readily identified in diffraction traces by its very strong peak at 3.34 Å and moderate peak at 4.26 Å; interference by the micas and mica-clays with the former and by potash feldspar for the latter only rarely preclude its ready identification.

Illite (mica-clay) - Illite also occurs throughout much of the stratigraphic interval. It is readily observable in diffraction traces with its strong 10 Å and 3.34 Å peaks and its moderate 5.0 Å peak (001, 003, and 003 respectively). All illites observed in the core are dioctahedral as based upon (060) < 1.52 Å and (001, 002, and 003) <1.0, 5.1, and 3.44 Å respectively. Many of the illites contain recognizable but small quantities of interlayered smectite, presumably saponite or other trioctahedral varieties, based on the slight asymmetry of the (001) reflection.

Feldspar - Feldspar occurs frequently, but generally in small quantities, throughout the section and its identification is based principally on one or more diffraction maxima in the 3.17 - 3.30 Å range. Unfortunately, its abundance is usually low and when coupled with the presence of other

minerals its diffraction maxima for resolving its composition and its thermal character are not interpretable; both plagioclase and K-feldspar have, on occasion, been recognized.

Chlorite - Chlorite is commonly a minor constituent and its presence is often difficult to establish. With a 14 Å periodicity its maxima can be masked by smectities, various interlayered species, and by the 7 Å minerals, kaolinite and serpentine. In glycol saturated specimens, the 14 Å peak from expandable clays can be removed and at 500°C the 7 Å peak from kaolinite is lost. Even so with only a small amount present in such an assemblage it can remain undetected.

Talc - Talc is rare throughout the core. It is common in the ore zones (Adams, 1969) but appears to be nearly absent from the other lithologies. Talc is identified by very sharp, strong reflections at 9.5 and 3.15 Å (001 and 003); the former is quite distinct from the broad reflection at 9.0 - 9.7 from a regular interlayered chlorite-saponite (corrensite).

Serpentine - Serpentine, like talc, is relatively rare in the section and is confined to the lowermost interval (below 2820.3 and at or below the Salado-Castile contact) in rock salt and anhydrite. Serpentine is identified by strong peaks at ~7.3Å and ~3.6Å (001 and 002 respectively for a single-layered variety). These maxima are noticeably greater than the 7.0 - 7.2 Å and 3.5 - 3.65 Å reflections attributable to chlorite. In our samples, these larger spacings are characteristically sharp and are not accompanied by the odd (00) reflections of the 14Å minerals.

Expandable Clays - Expandable clays, the smectities, vermiculites, and mixed-layer clays containing either of these constituents, are the dominant clays of the section and are ubiquitous (Table 7.8). We have recognized at least four such clays; however, their definitive identity has not yet been resolved.

a. Saponite (e.g. JS-CS-9 at 1466.9') expands to >16Å with glycol saturation and collapses to <14Å upon heating, (further heating would yield an ~9.5 Å peak).

b. (?) Illite-saponite (e.g. JL-CS-2 at 1440.5' JL-CS-10 at 1325.3') with an air-dried maximum at 10.2 - 10.3 Å, glycol saturation at 10.0 Å and with or without a less intense shoulder or separate peak at 11.3 - 12.1Å, and collapsing to 9.8Å at 300°C. We have not ruled out a mixed-layer talc saponite identification for this phase.

c. Chlorite-saponite (e.g. MB-CS-21 at 1404.6' and MB-CS-32 at 2541.5') exhibits a 14 Å peak expanding to 15.5Å with glycol saturation and collapse to <14 Å upon heating. The chlorite-vermiculite phase described by Fournier (1961) and Grim et al. (1961) is probably this chlorite-saponite; the expansion with glycol is too great for this to be a chlorite-vermiculite. In some cases the interlaying is random; in others it is regular and produces a distinct superlattice peak (~29Å); in most there is some regularity with a slight shoulder present in the 25-30° 2θ present (these shoulder "maxima" are exceedingly difficult to plot precisely and all contain ±0.3-0.5° 2θ definition).

Nearly all of the diffraction data in Table 7.8 can be assigned to one of these three clay phases, yet data from several samples are not yet resolved, e.g. MG-CS-13 at 2518.3. It should be noted that smectities are smectite-bearing mixed-layer clays which commonly appear to be "stripped" by the EDTA-dissolution of nonsilicates; they commonly show 12-13.8Å air-dried spacings. However, suspending these clays in $MgCl_2$ or NaCl solutions and then rewashing and redrying restores the appropriate 14-15 Å spacing.

In Appendix 7.C, we present a number of the diffraction diagrams illustrating these silicate assemblages.

Distribution of Clay Materials. Some general but tentative observations regarding these minerals throughout the section are:

(1) Serpentine appears to be restricted to the lower 40 feet of the analyzed section; it most commonly occurs in anhydrite and associated rock salt.

(2) Talc is not restricted to assemblages from bitterns as suggested by Adams (1969).

(3) Interlayered illite-saponite (or talc-saponite) appears to be restricted to polyhalite lithologies or adjacent anhydrite. It appears to be absent from clay beds and associated rock salts and from the polyhalite-free remainder of the section.

(4) Expandable clays appear to show somewhat less relative abundance in clay beds (1244.8, 1247.2, 1328.6, 1441.7, and 1468.1 ft.) than in the silicate assemblages from the evaporite rocks.

(5) Furthermore, the mixed-layered clay species in each of these clay seams consists solely of the well developed regularly interstratified chlorite-saponite (corrensite).

7.4.4 Mineralogy of Duval Mine Samples

Several samples of wall-rock were taken from the 4th ore zone (langbeinite level) of the Duval Nash Draw potash mine, about 5 miles west-by-southwest from the study area. These samples include a dark brown clay parting (the DV-4 series) taken from the upper boundary of the 4th ore zone.

Untreated oriented powders were scanned from 2 to 60 degrees two theta. The untreated slide was glycolated by vapor-soaking on a rack in a container filled partially with ethylene glycol. An additional oriented powder was heated at 450°C. Both the glycolated and the heated specimens were scanned from 2 to 3 degrees two theta.

Whole rock samples were analyzed by loading a small amount of randomly oriented rock powder in a Norelco powder holder. This powder was scanned from 5 to 80 degrees two theta and the resulting diffractogram compared to values compiled in the Joint Committee on Powder Diffraction Standards file to determine bulk mineralogic composition. Mineralogic abundances noted were estimates based on comparative peak intensities.

All samples x-rayed (both clays and whole rocks) were scanned with Ni-filtered CuKα radiation. A time constant of two seconds was used with a scintillation counter detector and pulse height analyzer. The goniometer slit system consisted of a divergent and anti-scatter slit of 1 degree and a 0.003 inch receiving slit.

The results for Duval Mine samples appear in Table 7.9. For comparison, "dirty salt" from about 2100 feet depth in ERDA No. 9 has about 8% by weight insolubles.

7.4.5 Chemical Composition

Since appropriate regressions for each component based on several standards have not yet been calculated and matrix effect corrections have not yet been made, the analyses in Table 7.10 must be considered as only semiquantitative. In most cases, most totals are between 85 and 98%; perfectly reasonable totals with the remainder being chiefly water. A few totals exceed 100% and a few others are less than 85%; these are unquestionably in error. These data, however, do illustrate a number of important relations and are compatible with the mineralogic data.

Thus for example, those analyses with high alkali content (JS-CS-2 at 1440.5', JC-CS-6 at 1441.5, MB-CS-27 at 2067.0, MB-CS-31 at 2512.5, MB-CS-13 at 2518.3, MB-CS-10 at 2705.8, and MB-CS-36 at 2758.4) show substantial feldspar with or without abundant mica-clay.

In general, the chemical data support the mineralogic determinations. The silicate fractions are extraordinarily high in MgO (~20-30 wt % MgO)

and correspondingly low in CaO (~1 wt % CaO); Al_2O_3 is low (~8-12 wt % Al_2O_3) for clay mineral assemblages. Thus, except for illite, our clays are trioctahedral with only chlorite containing appreciable Al_2O_3.

7.4.6 Petrography

Petrographic analysis, both macroscopic and microscopic, is used in three ways: first, determination of the mineralogy of samples; second, given the mineralogy of a sample, description of lithology; third, the primary utility of petrographic analysis in this study, description of the texture of the sample. Texture refers to grain or crystal size, shape (habit or form), orientation, relationships (such as nature of contacts between crystals or grains) among different minerals and lithologies.

Macroscopic Petrography.

Sample Preparation and Procedures - Slabs, approximately 1 cm thick, were cut lengthwise using a band saw, from the 1/2 or 1/4 core samples. One face of a remaining core sample was then polished using a sander with various grit sandpapers. The sample was not to be used for silicate mineralogy-geochemistry analysis in order to avoid contamination. The polishing enhanced textural detail. Faces were also polished on some slabs.

Samples were selected from the core in which mineralogy based on macroscopic identification was obscure or uncertain for x-ray diffractometry of the bulk sample. Conventional diffractometry methods, as described previously, were used.

Macroscopic Petrographic Description - The mineralogy, lithology and texture in the polished sections of all the core intervals selected were described. Appendix 7.D is a brief extract from 54 pages of sketches accompanied by textural descriptions of these core intervals. Table 7.11 is a summary of the gross lithology reported largely as macroscopic

mineral identification and core footage. Table 7.11 indicates that macroscopic mineral identifications are generally reliable, especially for coarse-grained minerals, but visual estimation of the relative minerals abundances are less reliable. Estimates of relative abundances based on x-ray diffraction analysis are regarded as "semi-quantitative" and maybe in error, but it is still more reliable because of its greater precision, if not accuracy, compared to visual estimation.

Plates 7.1 through 7.6 are photographs of polished faces of cores or slabs illustrating typical textures. Plate 7.1 shows a variety of shapes of halite in anhydrite. The occurrence as beds or laminae or irregular lenses is inferred to be primary because halite and anhydrite can precipitate jointly or alternately from evaporating seawater. The apparent swallow-tail form of halite in laminated anhydrite is a problem because no primary occurrence of this form of halite is known. The swallow-tail form can occur as a twinned crystal of gypsum, but coprecipitation of gypsum and anhydrite is thermodynamically impossible. One interpretation is primary precipitation of calcium sulfate only as gypsum in the form of rapidly growing swallow-tail twins and finely crystalline aggregates. Then post-depositional alteration of the finely crystalline aggregates to anhydrite takes place, and the twinned crystals alter either directly to halite or first to anhydrite which then alters to halite, with preservation of the primary swallow-tail forms. This interpretation is favored by the almost exclusive dominance of gypsum rather than anhydrite as the primary precipitate in modern environments and lab experiments. Controversial thermodynamic analyses also favor gypsum as the primary precipitate, even metastably.

Plate 7.2 also illustrates occurrence of halite in well laminated anhydrite. This is interpreted as primary coprecipitation of halite and gypsum with these textures followed by post-depositional alteration of gypsum to anhydrite with preservation of primary texture.

Plate 7.3 illustrates an occurrence of halite and polyhalite. The triclinic crystal system of polyhalite is unlikely to produce a rectangular outline in cross section whereas the cubic habit of halite or

the orthogonal morphology of anhydrite would. Thus, the rectangular outline of the polyhalite body suggests post-depositional alteration of anhydrite, (to a lesser extent of halite) to polyhalite as does the occurrence of most polyhalite in irregular masses among halite masses. Thermodynamic and experimental considerations as well as observation of modern evaporites indicate that polyhalite does not precipitate from evaporating seawater.

Plate 7.4 illustrates coarse, relatively pure halite with anhedral, granular texture. The halite contains small crystals of anhydrite, probably a post-depositional alteration product of a primary coprecipitate of halite and gypsum.

Plate 7.5 illustrates another texture of halite in anhydrite with traces of magnesite. As previously indicated, it is believed to result from primary co-precipitation of halite and gypsum with post-depositional alteration of gypsum to anhydrite with preservation of primary texture. Magnesite is not known to precipitate from evaporating seawater but calcite does, suggesting post-depositional alteration of a primary (probably calcium) carbonate to magnesium carbonate.

Plate 7.6 illustrates textures in a dominantly anhydrite rock. The occurrence of the swallow-tail form near the stratigraphic top of the specimen as well as previously related discussions suggest primary precipitation of gypsum followed by post-depositional alteration of anhydrite, which could occur shortly after deposition, with preservation of primary textures.

Microscopic Petrography.

Sample Preparation and Procedure - The 1 cm thick slabs were converted to standard and oversize thin sections following conventional procedures (with the following exceptions) to minimize chemical alteration of the sample. Fluid in contact with the sample was a pure vegetable cooking

oil. Temperatures during the thin sectioning process did not exceed 30°C. Samples were put in dessication jars during impregnation to minimize contact of fluid acetone with the sample.

Microscopic Petrographic Description - Plates 7.7 through 7.12B are photomicrographs of thin sections of rock samples from the Permian Basin of southeast New Mexico. The samples are not from ERDA-9 core but are representative of mineralogies, lithologies and textures commonly encountered in the core.

Plate 7.7 is a photomicrograph of relatively finely crystalline euhedral to subhedral halite. The crystal form, relative clarity (although containing very fine crystals of anhydrite) and occurrence of fluid inclusions as both negative crystals and subspherical forms all suggest little post-depositional alteration with the exception of alteration of primary gypsum to anhydrite.

In Plate 7.8 also dominantly of halite (typical of the rock in Plate 7.4), there is a startling contrast to the texture in Plate 7.7. Crystals in Plate 7.8 are anhedral to subhedral, cloudy, coarser and devoid of fluid inclusions (the apparent void in the lower left was produced by plucking of a cleavage fragment from the specimen during sectioning). Because the texture shown in Plate 7.7 is regarded as indicative of little post-depositional alteration, the texture in Plate 7.8 is considered as indicative of extensive alteration, greater than that required for the postulated gypsum to anhydrite alteration which is also postulated for very fine crystals of anhydrite within the halite in Plate 7.8. These contrasting textures are also apparent in thin sections of carbonate rocks. Bathurst, (1975, especially Chapter 12), deals with recognition of chemically precipitated calcite (analogous to Plate 7.7) versus calcite post-depositionally altered from argonite or some other form of pre-existing calcite (analogous to Plate 7.8). Bathurst uses and builds upon terminology and concepts of the causes and processes of these alterations developed by Folk (1965).

Plate 7.9 shows an occurrence of halite with sylvite. The irregular bodies and irregular contacts of the sylvite (as well as the anhedral nature of the halite and bodies of intimately mixed halite and sylvite) are interpreted to be the product of post-depositional alteration. This interpretation is also favored by the fact that sylvite does not occur as a primary precipitate in the marine evaporite succession.

Plates 7.10A and 7.10B show the irregular and gradational nature of the contact between polyhalite and halite and the concentration of opaques, probably hematite, along the contact. These observations and those discussed under Plate 7.3 are interpreted to be products of post-depositional alteration of either anhydrite or halite to polyhalite.

Plate 7.11 shows the microscopic texture typical of many laminated or banded anhydrites of the Castile and Salado Formations. Neither x-ray diffractometry nor staining techniques have been used to determine the mineralogy of the carbonate. This texture is interpreted as annual varves by Anderson et al. (1972).

Plate 7.12A and 7.12B show dominately massive anhydrite, typical of much of the unlaminated anhydrite in the Salado Formation but atypically cut by a veinlet of gypsum. The rock sample was taken from outcrop and the gypsum veinlet is interpreted to have been produced by alteration of anhydrite to gypsum during uplift and exposure.

The petrographic descriptions and interpretations generally agree with those in the classic and relevant report of Schaller and Henderson (1932).

7.4.7 Interpretations and Tentative Conclusions

1. All of the samples discussed under macroscopic and microscopic petrography exhibit mineralogy, lithology and textures which are indicative of post-depositional alteration of the sediments (dated at 204 million years in Section 7.8). It is believed that fluids

migrating through the sediments are responsible for most of these alterations. Interestingly, the alteration of primary gypsum to anhydrite would liberate abundant volumes of fluid.

2. The abundance of polyhalite and the atypical mineral assemblages (sylvite-langbeinite vs kainite/carnallite-kieserite) of the ore zones suggest either drastic recrystallization or a former primary evaporite depositional environment. The areal extent of the Ochoan rocks and their great thickness coupled with paleogeographic evidence and the marine character of the underlying Permian strata appear to preclude the second alternative. Further evidence of the post-depositional origin of the present assemblage includes the low and highly variable bromine values in the Salado Formation rock salts (Holser, 1966; Adams, 1969). Age dates on K-bearing salts, discussed later in this chapter, further suggest recrystallization shortly after deposition.

3. The general mineralogy and chemistry of the EDTA-insoluble (silicate) fractions of the evaporite beds throughout the Salado and uppermost Castile Formations preclude their detrital origin.

4. The silicate assemblages and their chemistry further supports the hypothesis of post-depositional alteration of these rocks -- at least throughout much of the Salado Formation.
   a. The predominance of smectities (saponite) and trioctahedral smectite-bearing clays suggest relatively immature assemblages. The silicate assemblages of the Zechstein (Permian) of Germany are almost entirely nonsmectitic except for the well-crystallized, well-ordered regular interstratified chlorite-(smectite/vermiculite) mineral corrensite (Fuchtbauer and Goldschmidt, 1969). The Haselgebrige (Permo-triassic) of the Austrian alps similarly contains no smectites nor even smectite-bearing mixed-layered clays (Bodine, 1972), and the same is true for the Silurian salts of New York (Bodine and Standaert, 1977). The development of the unusual illite-saponite/talc/saponite phase with polyhalite suggests immaturity of the silicate

phase with respect to the evaporite phase. Any further phase changes that would take place in the silicate appear to be kinetically inhibited.

b. The variability of the clay assemblages and their lack of correlation with major evaporite lithologies bespeaks strongly of recrystallization accompanying migrating post-depositional pore fluids. Except for the unusual 10.3 Å phase with polyhalite, the only other lithic correlations are: (1) reasonably well crystallized corrensite as the only expandable clay in the discreet clay seams and (2) the occurrence of serpentine in the uppermost Castile Formation. The former is tentatively attributed to the "closed system" nature of the impermeable salzton beds; they were not subject to the attacks by a variety of migrating pore fluids of different composition. The latter relates to the vertical distance between K-Mg-bearing salt beds and the Castile Formation, which essentially comes in contact only with less mobile fluids in equilibrium with halite-anhydrite.

c. It is very tentatively suggested that many of the salzton seams formed through accumulation of silicate debris included in salts which have been dissolved; their association with the soluble K-Mg salt ore zones and with the extensive polyhalite replacement of anhydrite beds appears remarkable and may provide the geometry for the "plumbing system" in which migrating pore fluids circulated. It is also recognized that some of the salzton beds may well represent recrystallized detrital accumulations during periods of no evaporite deposition as suggested by Adams (1969). If migrating groundwaters do flow in some such controlled pattern, ore mineral distribution in each ore zone should reflect this, i.e. remnants of the primary carnallite-kieserite farthest from the source of the brines, enveloped by langbeinite and langbeinite-sylvite assemblages, in turn enveloped by langbeinite and langbeinite-sylvite assemblages, in turn enveloped by sylvite, and finally by barren halite. Similarly polyhalite

crystallization should be at a maximum under the langbeinite-sylvite assemblage within a given "cell" and would likely decrease both away from and toward the lateral pore fluid source.

In summary, substantial evidence has been accumulated that there has been extensive salt recrystallization, most noticeably within the McNutt ore zone. This is considerably less noticeable in the lower Salado and Castile Formations, but may simply reflect the far simpler evaporite mineralogy and persistence of substantially more homogeneous compositions within the pore fluids.

Preliminary computer modeling does, for example, substantiate that a typical primary marine evaporite salt assemblage of carnallite-kieserite-halite can, when under continued attack by migrating halite-gypsum saturated pore fluids flowing down dip in a hypothetical cell, generate a progression of salt facies with remnants of the primary assemblages farthest from the source. Toward the source, the following succession of assemblages would be found: langbeinite-carnallite-halite (or langbeinite-kieserite-halite) then langbeinite-halite, then langbeinite-sylvite-halite facies, then sylvite-halite, culminating toward the source in a barren halite facies. At the same time, the K-Mg rich pore fluids which were generated through ore mineral dissolution and alteration would no longer be in equilibrium with anhydrite; anhydrite would alter to polyhalite until the solution chemistry reached the polyhalite-anhydrite equilibrium composition. The precise thermodynamic conditions and mineralogic reactions which governed these alterations are not known; however, the age of this recrystallization of evaporites has been determined to be in excess of 204 million years. For more details regarding this recrystallization which closely followed deposition, the reader is referred to Section 7.8.

7.5 VOLATILES AND FLUID INCLUSIONS IN MINERALS OF THE SALADO FORMATION

7.5.1 Introduction

Sources of liquids and gases native to the evaporites must be considered. One source is the intergranular fluid to be found in the pore spaces between mineral crystals and lithic fragments. These fluids are discussed in detail in a subsequent section (7.7). Another fluid source is the water of crystallization chemically bound in hydrous minerals. Yet a third source is fluid inclusions inside the mineral crystals themselves, which can behave as separate micro-geochemical systems.

Data presented in the overview Section 7.5.2, and Section 7.5.3 result from heating bulk rock samples to recover all types of fluid. In the major portion of the Salado, the total recovered amounted to less than 0.5 weight percent of the rock. As discussed in the overview section, it was possible to separately identify: (1) loosely-bound volatiles, (2) chemically-bound volatiles, and (3) fluid inclusions.

The sections on mineral sources of water and on fluid inclusions endeavor to place the data in the context of the mineralogy of the rocks serving as hosts for the volatiles. It will be noted that geochemistry in the context of the mineralogy is a pervasive theme in all parts of the geochemistry section of this report. This is true for the sections which follow on groundwater geochemistry and radiometric age-dating also. It will also be noted that the characterization of geochemical properties of solutions in the Salado confirm the qualitative measurements of fluid inclusion solute contents.

This chapter contains considerable data which will assist in the anticipation of short and long term physico-chemical conditions likely to arise during the experiments involving heat-producing radioactive wastes.

7.5.2 Overview of Volatile Conterts of Evaporites

Themogravimetric analyses of 35 selected core samples from ERDA No. 9 were made. These were many of the same samples which were qualitatively examined for mineralogy by x-ray diffraction (refer to Section 7.2.3).

These analyses were made by suspending powdered samples from a microbalance while dry nitrogen flowed above the sample. The samples were heated by 5°C/minute until the temperature reached 500°C and were held there until gas evolution had ceased. A hygrometer was inserted downstream to register qualitatively whenever moisture was evolved.

The as-received salt core specimens were massive pieces approximately 4 inches in diameter and 1-2 inches thick. No attempt was made to obtain homogenized samples by powdering the entire piece. Instead nuggets were chiseled from the center of the specimen. The nuggets were crushed and ground to a powder just prior to the weighing and transferring to the microbalance system. A maximum of ten minutes elapsed between the start of crushing and the start of analysis. Thus, the possible loss or gain of moisture prior to testing was minimized. Powdered samples were necessary to minimize decrepitation.

The complete test results are presented in Table 7.12. Figure 7.7 illustrates the typical kinds of weight-loss curves observed. About half the specimens showed 0.5% weight-loss (curve A). Curve B is common with the rapid weight-loss occurring sometimes at 300° and sometimes above 400°C. Some samples show two stages. Only two samples followed curve C, where weight-loss was observed from the beginning of the run. The weight-loss curves for all samples are filed and are available for inspections.

Replicate runs were made in several cases, predominantly those which showed the larger weight-losses, and good agreement, i.e. within 5%, was observed.

All mass-loss is not due solely to water. Only the weight-loss below 300°C can be attributed largely to water; the weight-loss at higher temperatures is in part due to decomposition of carbonates or other volatile-bearing minerals.

Results were correlated with the x-ray diffraction results previously reported in an effort to identify which minerals may be decomposing. No definite conclusions could be reached so selected samples were analyzed for the evolved gases by gas chromatography/mass spectrometry. In particular, this was done for the samples 2302.6, 2516.3, 2658.5, 2786.5 and 2821.0.

The highest weight-loss was experienced by sample 2302.6. Its total ion chromatogram (Appendix 7.F) shows data channel numbers calibrated approximately in terms of temperature. Conspicious peaks occur at 100°C, 250°C and 300°C. Detailed mass spectra are given for 50°C, 100°C, 150°C, 200°C and 250°C; the most prominent mass peak is 18, corresponding to water. At higher temperatures, mass 14 (monoatomic nitrogen) becomes abundant. Even at lower temperatures, mass 28 (diatomic nitrogen) is present.

Sets of peaks separated by 12 mass units, corresponding to carbon, (95, 83, 71; 81, 69, 57, 45) probably represent fragments of hydrocarbons present in the diesel oil which was the lubricant used to core the hole. The contribution of mass 44 (CO_2) to the spectrum is a minimum at 200°C and rises again at higher temperatures. The low-temperature contribution is again probably due to the contaminant diesel oil.

At the highest temperatures, the mass peaks 15, 16, and 17 (CH_3, CH_4, O, OH) are accentuated along with 14, 18, and 28 (N, H_2O and N_2). All the individual ion chromatrograms for mass numbers 14, 18, 19, 20 and 44 have coincidental peaks at about 25°C and 300°C. Water and carbon dioxide are almost continuously evolved over the entire temperature range, but the coincidence of all the peaks for N, H_2O, F(?) and CO_2 (mass peaks 14, 18, 19, and 44, respectively) implies that evolution of

these components at 250°C and 300°C is related to a common source. Since halite decrepitates, releasing its fluid inclusions at about 250°C, those inclusions appear to be the most probable source of volatiles evolved at 250°C. Similarly since polyhalite dehydrates at a temperature slightly above 300°C, fluid inclusions in that mineral might be also released at that temperature (see Section 7.3). A detailed treatment of fluid inclusions appears in a subsequent discussion.

Mass numbers 32, 48, 64 and 80 have sharp coincidental chromatogram peaks at channel 517. These mass numbers most probably represent O_2, SO^{+2}, (possibly O_3 made inside the mass spectrometer) SO_2 and SO_3 released from the sudden decomposition of a sulfate. Similarly mass 36 (HCl) is released in major quantity at this point. All these phenomena occur at a slightly lower temperature than the main 200°C event, and their relationship with that event possibly indicates the presence of a very volatile sulfate phase rapidly decomposing when the halite fluid inclusions begin to rupture. Daughter crystals of gypsum in halite fluid inclusions would indicate a high concentration of sulfate in the inclusions (see subsequent discussion) and such a solution might give rise to the observed sulfur species in the mass spectrum.

The sample with the next greatest total mass loss (2786.5, 3.64%) is considered next. Many of the same features of the chromatograms in Appendix 7.E are observed here as in the previous sample. The main difference is the appearance of a large hump of many volatiles (H_2O, F, N_2, O_2) released at less than 100°C. This is consistent with the occurrence of clay minerals which can absorb various volatiles at surface and interlayer sites. Volatiles would be expected to be weakly bound at these sites. The same hump as before appears at 250°C, incorporating N, H_2O, HF(?), N_2, O_2, HCl, CO_2 and SO^{+2}, but only the postulated SO_2 species appears to be catastrophically released and is probably a product of ionization in the mass spectrometer.

A hump incorporating N, H_2O, HF, N_2, O_2, HCl, CO_2 and SO^{+2} occurs substantially below 300°C. This peak probably corresponds to release of water and other volatiles born of OH and fluid inclusions in the clay minerals, when the clays decompose upon dehydration.

Sample 2516.3 (2.15% mass loss) was unusual in that it contained magnesite. As is seen in the chromatograms in Appendix 7.E, the loss of H_2O and N_2 from various sources provides most of the pattern, which was not sampled at a temperature greater than about 240°C. There is almost a continuum of absorbed O_2 released. The most significant feature of this sample is the high-temperature loss of CO_2, presumably from the decomposition of magnesite.

Finally, the most abundant-type sample is considered: those which have mass losses less than 0.5%. These are characteristic of most of the main evaporite section and contain very little other than halite and anhydrite. Typical examples of these rocks are samples 2658.5 and 2821.0 (Appendix 7.E). The main difference between these two is the apparent larger number of types of volatile sites in the shallower sample. Absorbed N, H_2O, N_2, and O_2 form a large, broad hump at low temperature, with catastrophic release (of fluid inclusions?) of H_2O, N_2, HCl, and CO_2 at higher temperature in 2821.0. In 2658.5, the catastrophic release of H_2O, N_2, HCl, and CO_2 (with possibly some SO^{+2}) appears to occur in smaller episodes as various sets of fluid inclusions are ruptured at higher temperature.

7.5.3 Mineral Sources of Water in the Salado Evaporite Sequence

Introduction. The purpose of this section is to describe the mineralogy and petrologic characteristics of samples taken from two coreholes of the Salado salt from the boreholes AEC Nos. 7 and 8 in Lea and Eddy Counties, near Carlsbad, New Mexico, and the degree to which the evaporite rocks present would dehydrate if subjected to the heat generated by containers of radioactive wastes (radwaste). In a previous study, (Fallis, 1973) the general characteristics of evaporite deposits and their minerals were

described and a detailed mineralogic and petrologic study of two cores from the Hutchinson Salt near Lyons, Kansas, was made. The results at that time indicated that water losses ranging from 0.4 to 19.0 weight % might be anticipated if the surrounding rocks were heated to 100°C.

Sample splits corresponding to ones in this section were also discussed in Section 7.3. A comparison of those results and these is presented in the following section.

Sampling and Sample Preparation. Segments of the original 4 inch (10.2 cm) cores were split in half, lengthwise, for chemical analysis and weight loss determination by thermogravimetric analysis (previous section). Eighty-three samples (coded by core number and depth) arrived wrapped in plastic to reduce the possibility of absorption of moisture during shipping and handling. Core AEC-7 was drilled in Lea County, New Mexico, and core AEC-8 in Eddy County, New Mexico.

Throughout the sample preparation, care was taken to not expose any of the samples to water; however, since it was necessary to cut, grind and sieve various portions of the samples, it was not possible to completely protect them from exposure to moisture in the air. During those periods when samples were not actively being worked upon, they were kept in plastic bags, tightly-stoppered bottles, etc.

Since several different analyses were to be made, it was necessary to obtain representative sample splits which would correspond to each other as closely as possible. A more complete discussion of sample preparation is given in the thesis by Combs. However, for convenience, a brief summary of the methods used in sample preparation is given below:

1. A representative segment of each core sample was chosen and removed by sawing the original core (normal to the axis of the core) with a dry blade, masonry-type saw. This new segment was typically about three inches (8 cm) long.

2. Next, a slice was cut from each core segment (parallel to the axis of the core) with the approximate dimensions 3 x 2 x 1/2 inches (8 x 5 x 1 cm) for use in preparing the thin sections. The sections were prepared by Fred Roberts Petrographic Section Service, Monterey Park, California. They were cut using oil rather than water and mounted with an epoxy cement which was not heated.

3. About one-half of the remainder of each core segment was crushed and sieved, and representative portions selected to be analyzed by x-ray diffraction, x-ray spectroscopy and by static heating methods for water loss determination. (Later, some additional separations were made and portions of the samples selected for bromine analysis using x-ray spectrocopy. These procedures will be described briefly in the following sections.)

Analytical Methods Used in This Study. Several different kinds of analyses were performed on the samples received. The methods used include static weight loss determinations (water loss), mineralogical and petrological analysis, and some chemical analyses using x-ray spectrocopy.

The weight loss determinations were made in essentially the same manner as for samples studied from Lyons, Kansas, and which was reported previously (Fallis, 1973). Splits of the several samples (sample size generally ranged from 1.5 to 2.0 gms and in the 60 to 120 mesh size fraction) were heated to $102\pm5^{\circ}C$ for periods ranging from 2 to 42 days. The results of repeated analyses indicated that the precision of weight loss determinations was generally $\pm$ 0.1 to 0.2%. When new sample splits were used, the "precision" dropped to approximately $\pm$ 0.2 to 0.3%. Some data concerning precision are presented in Appendix 7.F.

In addition to the weight loss determinations performed near $100^{\circ}C$, weight loss determinations were also made for several samples which had been heated to $170\pm5^{\circ}$ (for 2 days) and $300\pm10^{\circ}C$ for (2 to 3 days). The results of the weight loss analyses are reported in Appendix 7.G and discussed in the following section.

Mineralogical and petrological analyses were made using x-ray diffraction and standard petrological techniques. A summary of important mineralogical and petrological data is given in Appendix 7.H and discussed following the next section. The chemical analyses were made using two variants of the x-ray spectrographic method, x-ray fluorescence analysis (wave length dispersive) and x-ray emission spectroscopy (non-dispersive). The chemical analyses were made primarily for bromine, which can be used to aid in the interpretation of the origin of evaporite deposits, and semi-quantitative analyses were made for chlorine, sulfur and iron.

Weight Losses for Cores, AEC NO. 7 and 8. Weight loss data for the samples studied are tabulated in Appendix 7.G and illustrated in Figure 7.8. In general, the weight losses are much less than those found for samples from the site at Lyons, Kansas. The range of weight loss values at 102±5°C for the Carlsbad samples (Salado salt), Cores Nos.7 and 8 was from 0.0 to 3.5% with the majority of samples showing losses less than 0.5%, while the Hutchinson salt, Cores Nos. 1 and 2 was from 0.5 to 19.0%, and most of the samples showed weight losses from 1 to 5%. A plot of approximate range of water loss at 102±5°C to be expected at various depths is shown in Figure 7.9. This is based on data from both Lyons, Kansas and Carlsbad, New Mexico sites.

Based on the results of the various heat treatments, the following conclusions can be drawn concerning the behaviour of the samples from Carlsbad:

1. Samples consisting almost entirely of halite and/or anhydrite show weight losses (up to 200°C) which are typically less than 0.5% and probably less than 0.3%. The final total loss will depend on the amounts of clay minerals and minor hydrated evaporite minerals, such as polyhalite, which are present.

2. Larger water losses (>1% at 102±5°C) are generally associated with the presence of clay minerals (and/or gypsum) in more than trace amounts. The exact losses will depend on

the kinds and amounts of clays present, the temperatures to which they are heated and the length of time for which they are heated.

3. At some temperatures between 170° and 300°C, polyhalite, which is a common accessory mineral constituent in some parts of the Salado salt, will start to break down. It can contribute water to the extent of about 6% of its weight in the rock being heated.

4. Although present in only minor amounts (or absent) in the samples that were analyzed, there are other evaporite minerals such as carnallite, kainite, leonite, etc., near the potash ore zones (the McNutt potash zone at approximately 1600' to 1800').

The weight losses determined in Section 7.3 are compared with these in Appendix 7.G. It should be noted that the earlier data were determined by thermogravimetric analysis; hence, weight losses were not determined at any fixed temperatures but at the actual temperatures at which the decompositions were detected. In order to make the data more comparable, the previous data were rearranged and weight losses taking place within certain temperature ranges were combined. The reader is referred to Section 7.3 for the specific temperatures at which weight losses occurred. It should also be noted that the two sets of data are not directly comparable, since the weight losses of this section were accomplished by heating under static heating conditions for periods of 2 or more days, while the previous data were obtained under dynamic conditions (much more rapid heating). As a general rule, the decomposition temperature of any given mineral will be higher under conditions of dynamic heating rather than static heating.

Even so, there is generally good agreement between the two sets of data which were obtained by different investigators using different techniques. Most minor discrepancies can be explained on the basis of

differences in the methods of analysis. Only a few real discrepancies seem to exist (such as for sample at 1697 in Core #7). This is to be expected since each group received different halves of the core and since Section 7.3 involved sample splits of the entire core segment while this work involved only a sample split corresponding to the portion of the core used in preparing the thin section. Since there are both vertical and lateral variations in mineral content within the cores, samples might occasionally have been analyzed which were mineralogically different.

The rocks being considered at the proposed WIPP site, New Mexico, appear to be much more favorable than those from Lyons, Kansas. Even so, some mineral water is still present and is apt to be released during the period when the rocks are heated by the waste containers. It will be important to determine the maximum temperatures to be reached, the volume of rock which will be heated, and the probable maximum volume of water which will be released.

Mineralogy and Petrology of Cores No. 7 and 8. In some respects the mineralogy and petrology of the core samples from Carlsbad are similar to those of the core samples from Lyons. Both cores were taken through evaporite sequences and hence encountered sedimentary sequences containing typical saline minerals such as halite, anhydrite and polyhalite. In addition, clay minerals, magnesite, gypsum, quartz, feldspar, carnallite, celestite (?), glauconite and kainite (?), were detected in smaller amounts. The presence of any of the other less common evaporite minerals in the samples studied is uncertain. In general, they only occur in such small amounts and/or such fine grain sizes that positive identification was not possible using the diffractometer and petrographic miscroscope. In Section 7.3 it was noted that several of these less common minerals are apparently present in many of the samples analyzed. Readers of this section should be aware that the analyses are based on the actual minerals observed (modal analysis) in thin section as supplemented by X-ray diffraction while the analyses presented in Section 7.3 were done by computer manipulation of the chemical analyses determined for each sample (normative analysis). Such

normative analyses can be quite useful, especialy when working with very fine grained or glassy materials. However, it should be noted that normative analyses may generate mineral assemblages which do not agree with the actual minerals present, as was pointed out in section 7.3.

Summaries of the mineralogic and petrologic features of the individual samples studies are presented in Appendix 7.H. For the reader's convenience, some general comments about the mineralogy and petrology of these samples are presented below. An excellent study of the mineralogy and petrology of the rocks in this region is given by Schaller and Henderson, 1932. Brief description of the major minerals noted in the Carlsbad samples follow.

Halite. Most of the halite is colorless and shows excellent cubic cleavage. These features, coupled with less low relief and isotropic optical character, make its identification easy. Sometimes the halite is colored red or orange by minute inclusions of hematite (or other iron oxides) or other minerals such as polyhalite. The grain size showed a wide range, from less than 1 mm (fine grained), to greater than 1 cm (coarse grained). Grains between 1 mm and 1 cm are considered to be medium grained.

Because halite fractures and cleaves so readily, it is difficult to determine whether the numerous breaks observed in thin sections were already present at depth or whether they developed during the coring operation, shipping, handling, thin section preparation, etc. More fractures are noted at the outer margins of each of the thin sections. However, some of them must have occurred prior to the taking of the core because they are filled (at least in part) with other minerals, petroliferous material, etc. In several cases fracture zones could be traced across the entire width of a thin section.

Inclusions (liquid, solid and gas) are common in the halite. During the preparation of some samples hydrogen sulfide (gas) was released. In many cases the inclusions are oriented with respect to the cubic crystal

planes. These oriented inclusions appear to represent hopper crystals which grew at the water surface in times of quiet water and are inferred to represent deposition from shallow water.

Intergrowths of relatively well-formed, cubic crystals of halite with clay and silt-size minerals are likewise inferred to represent very shallow conditions, perhaps even subaerial exposure for brief period.

"Patches" (regular to irregular, more or less equidimensional areas) and "stringers" (regular to irregular areas which are generally elongated in one direction) of anhydrite, polyhalite, clay and silt-sized minerals are common in halite. Sometimes these patches and stringers follow grain boundaries, but often they cut across grains. Where they follow grain boundaries, they may represent (nearly) simultaneous growth of the halite crystals and smaller amounts of the other mineral phase(s). Where they cut across grains, they presumably represent deposition of the minerals along zones of weakness or along which solutions passed. Enough of this latter material is present to demonstrate that there were opportunities for solutions to migrate through these relatively impermeable rocks, even though it is not possible to determine just how far the solutions actually traveled.

Anhydrite. Anhydrite was recognized on the basis of its relatively high birefringence, differences in relief upon rotation and cleavages at right angles. Normally, anhydrite shows parallel extinction, too, but because of twinning, replacement phenomena, etc., this characteristic was not always useful.

Anhydrite occurs in three major types. "Primary" anhydrite, which is commonly bedded, is very fine grained (much less than 1 mm) and somewhat fibrous in character. It also occurs in coarser-grained crystals and twinned crystals (sometimes over 1 cm long). At least some of those larger crystals appear to be pseudomorphs (replacement) after previously-existing gypsum crystals. Sometimes, very small amounts of questionable gypsum are noted nearby, perhaps as a result of partial

rehydration of the anhydrite. Finally, there are more or less isolated crystals and crystal clusters of anhydrite which occur in patches and stringers within the halite or are intergranular with halite. These may be associated with polyhalite and/or clay and silt-sized minerals. This type of anhydrite is thought to be authigenic (formed in place from fluids contained in the pores of the rock or passing through the rock).

Anhydrite can be replaced by polyhalite if fluids containing potassium, magnesium and additional sulfate ions are present. Many examples of this replacement were observed.

A few examples of bedded, nodular anhydrite were observed. The nodules may have originally been composed of gypsum which was later replaced by anhydrite. The origin of such bedded nodules is thought by some workers to represent depositions in very shallow water which was periodically exposed (Sabkha facies).

Polyhalite. Polyhalite was recognized on the basis of its relatively low birefringence, inclined extinction and complex twinning. (Unfortunately in some fine-grained material and/or mixtures, polyhalite and anhydrite can be confused because their optical properties of relief and birefringence are almost the same in certain orientations).

Much of the polyhalite observed is rather fine grained (much less than 1 mm in size for the individual cyrstallites) and often fibrous. However, some larger crystals are numerous, isolated crystals and crystal clusters were observed. Polyhalite is often reddish due to iron oxide inclusions, but this is not universally true.

Some of the polyhalite appeared to be a bedded form associated primarily with halite and lesser anhydrite. Polyhalite also is found replacing anhydrite and associated with nearby patches and stringers of clay and silt-sized minerals. Whether the clay, etc., provided some of the ions necessary for formation of polyhalite or just acted as a pathway for solutions passing through the rock cannot be determined.

Minor Minerals. Minor minerals were identified on the basis of their optical properties and X-ray diffraction analyses, which were occasionally aided by information contained in the well logs for the cores. Just a few brief comments for each mineral are given here.

Clay minerals. Overall, much less clay is present in the samples from Carlsbad than was present in the Lyons samples. X-ray diffraction peaks attributed to clay minerals were noted in nine samples from Core #7 and in fourteen samples from Core #8. Based on the X-ray patterns and peaks noted at approximately 7, 10, 11.5, 14 and 15 angstroms, major clay minerals present include illite, chlorite, mixed-layer clays and possibly some kaolinite.

Magnesite. Although well-crystallized magnesite was not detected in thin sections, some very fine-grained, relatively high birefringent phase was noted in some thin sections and magnesite peaks were detected in some thin sections and magnesite peaks were detected in a number of X-ray patterns. Schaller and Henderson (1932) stated that many of the clays in the samples they studied were magnesitic. The common association of polyhalite with clay and silt-sized minerals may be due in part to the magnesium ions in the magnesitic shales and clays.

Gypsum. Gypsum is monoclinic and in thin section has low birefringence and low, negative relief. Twins ("swallowtail") are fairly common. Well-crystallized gypsum was detected in only one thin section among the samples studied. In addition, several of the sections contained small amounts of questionable gypsum in association with anhydrite and/or polyhalite. However, the amounts present were much less than 1% and could not be confirmed by X-ray diffraction.

Quartz and feldspar. These minerals are present in two forms, as detrital (silt and very fine sand-sized) material deposited along with the clays, and also as authigenic minerals which formed in or near patches and stringers of clay and silt-sized minerals.

Sylvite. A few thin sections contain small amounts of sylvite which was recognized on the basis of its distinctive reddish purple color (due to iron oxide inclusions) and lower relief than halite. Most of the sylvite observed was associated with polyhalite as well as with halite. There were no samples from the sylvinite (mixed halite and sylvite) zones. Adams (1967) reported that not all sylvite is colored; however, in the thin sections studied, the distinctive color was useful in locating the small amounts present.

Carnallite. Only one section contains detectable carnallite. This mineral was suspected on the basis of nearby carnallite as noted in the well log. Its high negative relief and "metallic" luster due to inclusions were used to confirm its presence.

Celestite (?). In two or three thin sections some isolated spear-shaped crystals and clusters of crystals with relatively high relief were noted. Although no positive identification could be made, it is suspected that these are celestite, which is the most common strontium mineral present in evaporite deposits.

Glauconite. A few greenish, rounded grains of glauconite were noted, generally associated with the clay and silt-sized minerals. Not enough of this material was present to attempt to determine its origin or source.

Kainite(?). Kainite (?) was observed in only one thin section. It is a monoclinic mineral with moderate birefringence and negative relief.

Summary and conclusions. The results of this study indicate that the Salado Salt in the samples received is composed primarily of fine to coarse-grained halite with polyhalite, anhydrite, and clay minerals. Other minerals detected in small amounts include gypsum, magnesite, quartz, feldspar, sylvite, carnallite, celestite (?), glauconite, and kainite(?). It should be noted that the samples received for analysis were selected from halite-rich zones in most cases; hence, some of the rarer evaporite minerals such as kieserite, langbeinite, leonite,

bischofite, etc., noted by Schaller and Henderson (1932) were not detected either because they were absent from the specimens analyzed or present in amounts too small (or too fine grained) to identify.

There is much petrographic evidence that the Salado salt was deposited in rather shallow water and may have been exposed subaerially at times. This evidence includes the presence of numerous hopper crystals (which can develop at the air-water interface of quiet, shallow seas) and the intergrowth of euhedral grains of halite with clay and silt-sized minerals, anhydrite, and polyhalite. The latter texture can develop in an exposed, mud-flat type environment. Previous workers, such as Anderson, et al. (1972), have concluded that the underlying, Castile Formation was deposited in deep water, perhaps as much as 2100' (650 m) deep. Hence, there must have been a major change in environmental conditions between the deposition of Castile and that of the Salado.

Petrographic evidence also suggests that local fluids native to the Salado have been able to move through the Salado salt (during recrystallization) along beds and seams of clay and silt, and to a lesser degree along fractures (see Section 7.8). These paths are now marked by entrapped fluid inclusions, zones of altered minerals and zones along which new minerals have been deposited.

Water loss determinations for over eighty samples from cores #7 and #8, indicate a range of water loss (upon heating to $102\pm5^{\circ}C$) from 0.0 to 3.5%, which is considerably below the water losses for samples from Lyons, Kansas. It should be noted that the samples from the Lyons site came from much shallower depths than those from the Carlsbad area. In the section on weight losses, the ranges of dehydration to be anticipated with respect to depth are shown graphically. It appears that the ranges determined for the relatively shallow Lyons site merge with the ranges determined for the deeper Carlsbad site.

Most of the dehydration water at relatively low temperatures (near $100^{\circ}C$) appears to come from clay minerals, although gypsum may make a

contribution for samples taken at shallow depths. At higher temperatures, polyhalite will start to contribute to the dehydration of water. This dehydration takes place somewhere between 170° and 300°C. Pure polyhalite rock can lose up to 6% water. In general, the purer halite beds have weight losses below 0.3 to 0.5%.

As far as can be determined from the samples available for study, the rock units present in the Salado salt seem to release much less water when dehydrated than do the rocks of the Hutchinson salt from Lyons. Hence, the site near Carlsbad would seem to be more favorable (in so far as dehydration water goes) than Lyons. However, these rocks are not totally without water, and most units will lose from 0.0 to 0.3% water when heated and some units may lose up to 3.5% water.

Finally, it was noted during the preparaton of some of the samples that H_2S (and possibly some natural gas) was released when the samples were crushed. No H_2S was detected mass spectrometrically (previous section), which probably attests to a sensitivity of the human nose for H_2S that is unapproachable even with the most sophisticated available instrumentation.

7.6 FLUID INCLUSIONS IN CORE SAMPLES FROM ERDA NO. 9

7.6.1 Introduction

Fluid inclusions in the host rock are of interest to several aspects of nuclear waste disposal. First, determination of their origin and nature may provide insight into the complex sequence of processes and events from original deposition of the salt through to the present; such insight may well be of value in site evaluation. Second, fluid inclusions provide one source of water (and other volatiles) that would certainly aid in the corrosion and eventual breach of the waste containers, and subsequent leaching of the waste itself. Third, fluid inclusions, and their reaction under the thermal pulse from hot wastes, could have an effect on important physical properties of the hot host rock, such as deformation rates and particularly melting.

7.6.2 Samples Studied

Most samples studied were taken from ERDA core No. 9, and came from the following footage intervals:

From	To
1799.0	1799.5
1902.0	1902.3
2065.0	2065.4
2095.1	2095.5
2272.4	2272.7
2391.0	2391.3
2611.5	2611.8
2658.7	2659.0
2760.0	2760.2
2820.8	2821.2
2058.8	2059.0
2070.4	2070.6
2606.5	2606.9
2617.2	2617.7
2626.7	2627.0
2659.0	2659.2
2665.0	2665.1
2692.4	2692.6
2699.8	2700.0

In addition to the above "representative" samples, four nonrepresentative samples from ERDA No.9 were selected because they contained plainly visible large inclusions, suitable for special tests:

2051.2 - 2061.0

2064.5 - 2065.0

2614.7 - 2615.0

2518.5 - 2619.0

In order to test certain sample preparation and inclusion extraction procedures with no loss of important core, two pieces of core from AEC 8 were also picked:

2059.5 - 2059.8
2462.0 - 2462.9

In the Kerr-McGee potash mine, Lea County, New Mexico, northwest of the WIPP site a 4-m igneous dike has cut potash ore beds. As this represents a natural simulation of some of the heat effects of canister storage, it is instructive to examine the fluid inclusions in samples taken at measured distances from this dike:

MB-77-8	White halite 1-2 cm from dike
MB-76-3	Barren salt 0.2 m from dike
MB-76-4	"Ore" horizon 2.5 m from dike
MB-76-5	"Ore" -21 m from dike

Of these samples, the field evidence indicates that only MB-77-9 has been molten. The others show some mineralogical effects of the heating, but as sedimentary structures are preserved, they have presumably not melted (M. Bodine, personal communication).

7.6.3 Sample Preparation

Sections. A thick slice was cut from each sample using a diamond saw and ethyl alcohol lubricant. One side was fine ground with an alcohol slurry of abrasive (1200 grit), ultrasonically cleaned in alcohol, mounted on glass with cold-setting epoxy resin, and cured in 16 hrs. at room temperature. The section was then ground down on a lap, using an alcohol slurry, to 3-8 mm thickness (depending on opacity) and then polished by finer abrasives, ending with either 1200 grit or 0.3 μm Al_2O_3. Plates with fine-ground surfaces were examined using a matching silicone oil or saturated brine and coverglass. Coarse cleavages could be examined directly, without polishing.

A small section (~ 2 X 4 cm) was cut first, perpendicular to the core axis (when nature of sample permitted orienting), then one or more larger plates (5 X 8 cm) were cut parallel with the core axis.

Coarse water-soluble residues. 100- to 150- gram samples were dissolved in tap water at room temperature with frequent stirring. The solution was decanted frequently to remove dissolved salts and finely divided solids such as clays.

7.6.4 Methods of study

Petrographic Examination. All slides and preparations were examained with the petrographic microscope, but phases present other than halite were not determined due to the short time available and the redundancy with extensive mineralogical work by others. Most examination time wac spent on finding and characterizing the nature, size, frequency and distribution of the fluid inclusions.

Considerable time was spent determining the volume of fluid inclusions in the plates, through counts of representative portions. This determination was based on measurements with a graduated ocular (calibrated with a stage micrometer) and several assumptions. First, the inclusions were considered to be cubes (based on observation); one edge was measured and then the volume calculated. Larger inclusions (~ 1mm edge length) that were obviously not cubes were estimated from the summation of a series of smaller cubes. Second, since bubbles were very rare (only about 0.1% of the inclusions), and small (~ 1% of inclusion volume), they were ignored. Third, most inclusions in these samples were of one or the other of two types (essentially the same as the types "A" and "B" discussed in a later section on Results), and any given small portion of salt contained only one type. As the bulk of the sample in any plate could be characterized easily into these two types the approximate volume percent of the samples for each type could be estimated. A ~500 mm^3 volume of the plate was then selected from each type, visually estimated to be representative of that type in that plate, and the volume percent of inclusions determined in it by measurement and counting, using a transparent grid template at 500X. The total volume percent of inclusions was then calculated from the weighted average. The weight percent of inclusion fluid was calculated, assuming the salt to have a density of 2.2 and the brine to be 1.3 g/cm^3. Large numbers of very tiny inclusions were estimated from counts and estimates of small

but visually representative volumes. Although the relative errors involved in this step are large, the total contribution by these small inclusions, even though they are extremely abundant, was very small. Most of the fluid found was present as a small number of large inclusions that could be measured more accurately. All inclusions over 200 μm (edge length) in the count volume were measured. The overall measurement error in volume percent of inclusions present is believed to be on the order of ±5% of the value stated for a given plate. Other variables, particularly rare, still larger, centimeter-sized inclusions that were opened during coring or sample preparation (and hence not counted), and the large difference between different plates from the same sample, introduced much larger errors.

Heating Stage. The liquid in inclusions trapped as homogenous fluid at above surface temperature shrinks on cooling, forming a bubble that provides a measure of the amount of differential shrinkage of liquid and host crystal. As the bubbles in the inclusions were small, relatively little heating was needed to cause homogenization. Hence a new heating stage was set up, consisting of a bath of silicone oil with an electric immersion heater and thermometer. Temperature equilibration was achieved through convection and frequent stirring. The individual runs were approximately 2-3 hrs. in length. Many inclusions that had no bubble as received developed one on cooling the silicone to $\sim -6^{\circ}C$ with solid CO_2. On subsequent heating this bubble would decrease in volume but persist as a very small bubble at room temperature. Heating was done on the stage of a low power binocular microscope, since the inclusions were large and scattered.

Freezing stage. The depression of the freezing point of the fluid in an inclusion (i.e., the "freezing temperature") is a function of the composition of the fluid. Using this techique under the microscope can permit a quick measure of the salinity of 10^{-10} g of fluid, a far smaller sample than can be measured by any other method. Metastable supercooling is common, so most inclusions had to be cooled to very low temperatures (three hours in CO_2-acetone at -78° or even LN_2 at $-196^{\circ}C$) to cause freezing. Subsequent slow warming of the sample while

surrounded by rapidly circulating refrigerated acetone of known temperature under the microscope permits recording the temperature of disappearance of the various solid phases formed on freezing (salts, hydrates, and ice), under equilibrium conditions.

If an inclusion is frozen completely to a mixture of solids, with no liquid, it becomes rather opaque. On warming, the first melting wets the crystal interfaces, suddenly making the mass more translucent, and permitting recrystallization to coarser crystals with time. This is called the "first melting temperature." It ranges from -21°C for pure NaCl solutions to -51°C for $CaCl_2$ solutions.

Crushing stage. If a host crystal containing an inclusion with a bubble is surrounded by a fluid and gradually crushed while under the microscope so that the behavior of the bubble can be observed, the presence of noncondensable gas in the bubble, and its pressure, can be determined. The test is only crudely quantitative in terms of pressure (based on the volume precent expansion), but it is extremely sensitive as a detector of small amounts of gas. Less than one billion molecules of gas can be detected readily. Numerous cleavage fragments of salt containing various types of inclusions were crushed on several models of crushing stages to determine the amount and pressure of any noncondensable gases present.

Coarse water-soluble residues. These were studied in oil immersion mounts in hopes that some of these phases were sufficiently coarse to contain fluid inclusions that would provide data on their conditions of formation.

Decrepitation. A portion of the core weighing approximately 100 g was split out with a rock splitter; where possible the outside core surface was avoided, due to the probability of physical deformation and resultant leakage of incluions. This piece was wrapped loosely in aluminum foil, weighed, and heated to the run temperature (150-250°C) over a period of 8 hours to avoid thermal shock, held at run temperature for 3-4 days, cooled and reweighed to determine weight loss. Following this the homogenization temperature range was redetermined for a series of

inclusions that appeared, on petrographic examination, to be representative. Crushing tests were also repeated on the heated samples to detect the presence of noncondensable gases under pressure.

7.6.5 Results of Petrographic Examination

Inclusions type A. This is the most abundant type by far. It consists of slightly rounded cubic cavities (Plates 7.13 and 7.14) filled with liquid and generally no other phase, except for rare tiny vacuum (shrinkage) bubbles that comprise ~ 1% by volume of those inclusions having bubbles. Only about 0.1% of the inclusions have bubbles, usually the larger inclusions only, but there are exceptions (see below). Type A inclusions occur as dense irregularly shaped clouds of randomly distributed but crystallographically oriented inclusions (e.g., Plate 7.16). In such dense arrays, individual inclusions are rarely over 20 μ m on an edge (Plate 7.18), few are > 5 μ m, and most are in the range 0.5-2.0 μ m, with the highest concentrations in the smallest sizes (Plate 7.19). Estimates of the maximum number of such inclusions, based on counts of representative volumes, show about one inclusion per 100 μ m^3, or 10^{10} per cm^3. If these are assumed to average one μ m^3 in volume, such cloudy halite would contain about one volume percent of fluid.

In addition to these irregular clouds, abundant type A inclusions occur in crystallographically arranged (cubic) planes and zones in the host halite, frequently with parallel inclusion-free zones (Plates 7.13 and 7.14).

In some zones type A inclusions grade into more sparsely distributed but larger inclusions ($\leq$ 100 μ m), as seen in Plates 7.14 and 23-24. These coarser inclusions may represent incipient recrystallization of the host. The distinction between these larger type A inclusions and type B (next section) may seem inexact, but actually there is little overlap.

Inclusion type B. Type B inclusions, although far less abundant than type A, carry most of the inclusion fluid in these samples, since they are much larger ($\geq$ 100 μ m to several millimeters). Although large, many have no bubble as found (Plate 7.20), but may develop one if cooled slightly ($\sim -7^{\circ}C$) and warmed back to room temperature. They are generally irregular if large ($\geq$ 500 μ m) and are more nearly euhedral negative cubes if smaller (Plates 7.15 and 7.17). They occur as single isolated inclusions in otherwise almost optically clear halite, and as dense groups of many inclusions, in part interconnected with tubular extensions (Plate 7.15).

The host halite for type B inclusions may occasionally have cloudy wisps of type A inclusions, but they are never immediately adjacent to a large inclusion (Plates 7.15 and 7.17). These features suggest that salt originally containing only clouds of "primary" type A inclusions has been partly or completely recrystallized to form coarser crystals of clear salt with type B inclusions. This interpretation is supported by the grain size of the host salt, which is almost always coarser in those parts of a sample containing type B inclusions (see Table 7.13 in next section on weight percent of fluid). The boundary between cloudy primary and clear recrystallized salt is sometimes curved (Plate 7.16). If it were straight, it might not be possible to distinguish it from a primary growth zone boundary between fast cloudy and slow clear growth. Most areas of type A occur as irregular masses within single crystals of mainly recrystallized halite (Plates 7.15 and 7.17).

Relatively few samples, particularly sample 1902.2, show birefringent crystals of an unidentified phase inside what appear otherwise to be type B inclusions. These are equant to bladed crystals of moderately high birefringence ($\sim$ 0.06) and moderate index of refraction (but well above that of the surrounding brine). Many are twinned (Plates 7.25 and 7.26), and when prismatic or bladed, the extinction positions are strongly inclined to the crystal elongation. As the distribution of these crystals is irregular, and as a similar birefringent phase occurs in some of the same samples (Plate 7.27) the occurrence in the inclusions might be interpreted as accidental trapping of solids present at the time of

trapping of the inclusions. All 10 inclusions in one group in sample 1902.2 (Plate 7.27) contain these crystals, in roughly the same amount (estimated at ~ 5% by volume), thus suggesting that they are true daughter crystals, formed by precipitation from the trapped fluid. Another plane of inclusions in this same sample, only 400 μ m away, contains only liquid (Plate 7.28) so it is concluded that the fluids present during recrystallization changed in composition with time.

Inclusions Type C. This type is similar to type B in size, shape, and occurrence, but rarer, and differs only in containing a relatively larger gas bubble, of variable volume, but > 1% by vol. (Plate 7.29). A larger gas bubble can originiate by several processes -- leakage, necking down, higher temperature of trapping, or primary gas. The gas bubbles in these inclusions are found to be under pressure (see "Results of crushing stage studies"), so it is believed that such inclusions have trapped a mixture of gas and liquid (i.e., primary gas). In some (e.g., Plate 7.30), such inclusions have apparently formed by a refilling of an earlier type B inclusion with a gas-liquid mixture along a crack.

Inclusion Type D. This type occurs in curving planes outlining some of the individual crystal boundaries (Plates 7.31 and 7.32). It was probably full of fluid under natural conditions, but as the grain boundary permitted leakage and desiccation, these are now full of gas (presumably air).

7.6.6 Weight Percent of Fluid

A summary of the results of measurements of the volume percent of fluid in the inclusions is given in Table 7.13. In calculating these volumes some simplifying assumptions had to be made, in addition to those mentioned in Section 7.6.5. For simplicity the host salt volume counted was categorized as type A or B on the basis of the maxiumum si. of inclusions it contained. If these were $\leq$ 1 mm, it was called type A. This division is not the same as given in the descriptions of type A and B inclusions, where ~ 100 μ m inclusions are considered as probably indicative of recrystallization, but this has little effect on the results, since on the average, over 90% of the fluid is present as type B

inclusions > 1mm in about 30% of the volume of the salt. Table 7.13 shows that these samples now contain a total of from 0.17 to 2.86% fluid by volume, and average 0.61. These values correspond to 0.1 to 1.7 weight percent fluid as extremes, and average 0.36 weight percent. These results are compatible with those reported in Sections 7.5.2 and 7.5.3.

These values have a measurement error of about ± 5% of the amount found. Much larger, however, is the variability introduced by the samples themselves. Thus three parallel plates were cut at ~ 3-cm intervals through samples 2272, and yielded 1.23, 0.36, and 0.20 volume percent fluid.

Even more important to consider is the bias inherent in these measurements due to substantial and unpreventable loss of inclusions. Examination of the cores showed some centimeter-sized cavities, the sites of former fluid inclusions. No inclusion this size could possibly be included in our count since the plates counted had to be <1 cm in thickness to be translucent. In addition, in situ all natural intergranular porosity in these salt beds was possibly full of fluids. The type B inclusions found represent probably only a trivial part of the total in situ water content present as such "imperfectly sealed fluid inclusion." Large scale in situ porosity tests would be needed to evaluate this variable.

7.6.7 Results of Heating Stage Studies

Only 35 inclusions were run, as listed in Table 7.14. These are mostly from type B inclusions. Some of these inclusions had to be cooled to below room temperature to nucleate a bubble before the run (Plates 7.20, 33 and 34). Why some very tiny inclusions have vapor bubbles (Plate 7.36), yet many large ones have persisted metastably as stretched liquid (i.e., one phase) is puzzling. The data are too sparsely distributed to determine whether the range of values (20.4 to 45.5°C) represents a real difference between samples. One group of inclusions in sample 2821 with birefringent daughter crystals showed no change in the crystals on heating to 24.5°C.

7.6.8 Results of Freezing Stage Studies

Inclusions in NaCl have a special type of behavior on freezing, as a result of reaction of the water of the inclusions with the walls to form the new incongruently-melting phase hydrohalite ($NaCl.2H_2O$), at temperatures below +0.15°C. As a result, the inclusion enlarges and becomes full of birefingent crystals upon being held at low temperatures. Evidence of this expansion remains on warming to room temperature. Furthermore, the volume resulting from expansion to form ice is frequently larger than the original volume of the inclusion, and the inclusion's walls crack to relieve the pressure (Plate 7.35).

The freezing data are summarized in Table 7.15. If the solution present is simply NaCl and H_2O, the last crystal of hydrohalite will melt at +0.15°C, assuming equilibrium has been obtained (which is an extremely slow process for this phase). Although only relatively few large type B inclusions were run, many smaller type A inclusions were also watched at the same time. None were found to have either first melting at -21° or freezing at +0.15°C, so none consist of essentially pure NaCl solutions. Much hydrohalite formed in these inclusions, but as there were birefringent crystals (generally with birefringence less than that of hydrohalite) that persisted well above +0.15°C, the last solid is a phase other than hydrohalite, and the solutions must contain significant quantities of materials other than NaCl (Plate 7.37). This is also very evident from the first melting temperatures.

7.6.9 Results of Crushing Stage Studies

Bubbles in types B and D inclusions from several samples were examined on the crushing stage. All disappeared immediately on opening, indicating that they consist of water vapor (at ~ 20 mm pressure), and hence collapse at one atmosphere. The bubbles in several type C inclusions showed considerable expansion, however, indicating gas under pressure. Thus the bubble in the inclusions shown in Plate 7.38 expanded 270% by volume on opening (Plate 7.39), indicating that nearly three atmospheres of noncondensable gas is present. The composition of this gas is unknown at present.

A previously unrecorded inclusion deformation phenomenon was also observed in some inclusions that were in a sample that was under uniaxial stress on the crushing stage at room temperature but had not been broken to release the inclusions. These inclusions developed a scalloped pattern along the corners (Plate 7.40), presumably due to solution at points of stress concentration and redeposition elsewhere. This pattern developed over a relatively few minutes at effectively constant stress. At least some volume change occurred in this process, since the bubble in the inclusion disappeared at constant temperature.

7.6.10 Results of Study of Coarse Water-Insoluble Residues

The weight percent of such residues ranged from 0.005% (sample 2391 to 0.3% (sample 2821). Unfortunately, however, although there were a variety of phases present in the residues, none of the crystals contained visible fluid inclusions. Some samples emitted a petroliferous odor and showed oily films on the water surface during leaching; it is not known whether these represent contamination from the oil-based drilling mud used in part of the coring, or natural oil in the samples (as is present in other salt deposits, as integranular films and inclusions). No oil inclusions were seen in this work.

7.6.11 Decrepitation Tests

These tests were run only on the last nine samples of the first 19. A summary of the test data and results is given in Table 7.16. On examination of the material after the decrepitation tests, several general features were evident. The nature of the test is such that systematic inclusion counts before and after the test on the same sample are impossible. It was obvious that although most of the larger inclusions had decrepitated, and were empty, many small inclusions ($\leq \sim 100$ μm) had not. These small inclusions appear perfectly normal in distribution, but almost all had developed appreciable vapor bubbles (Plate 7.41), with a vapor/liquid ratio that is obviously higher after heating than that present in two-phase inclusions before heating. Only the 150°C sample still had inclusions without bubbles; a few 10-20 μm one-phase liquid inclusions were found there. All three samples showed some "steam" inclusions - cubic negative crystals with fillets of liquid

in the corners. No gas under pressure was found in any of the heated inclusions. In most cases, the weight losses increase with increasing run temperature; the several exceptions are probably a result of nonhomogeneous distribution of inclusion in the sample aliquots taken.

Homogenization temperatures were determined on two-phase inclusions remaining in the samples after the decrepitation tests. The results are given in Table 7.17, along with the volume percent of vapor phase, estimated from measurements of bubble diameters.

7.6.12 Study of Suite of Samples from Kerr-McGee

The three samples closest to the lamprophyre dike (See Chapter 3) yielded usable inclusions. (Sample MB-76-5 was too fine grained and opaque to be usable by the sample preparation techniques used here, and will not be considered futher in this report.) In all three samples about 15% of the small inclusions ($< \sim 20$ μm) were without bubbles as received. Most inclusions in all three samples were normal, two-phase inclusions with a small bubble. Homogenization temperatures were determined on a representative group of these two-phase inclusions in each, with results as shown in Table 7.18.

Freezing runs were made on inclusions in two of these samples. In both cases the first melting temperatures were well below that of a pure $NaCl-H_2O$ system ($< -28^{\circ}C$ for MB-77-8 and $< -31.0^{\circ}C$ for MB-76-4). On warming, the last solid phase to dissolve in both samples was an unidentified phase, presumably a hydrate other than $NaCl \cdot 2H_2O$. This dissolved at +11 to $+18^{\circ}C$ (MB-77-8) and at +4 to $+7.2^{\circ}C$ (MB-76-4).

One 75- μm inclusion was found in MB-77-8 that yielded an entirely different freezing behavior. This inclusion contains a single homogenous fluid at room temperature, presumed to be gas (Plate 7.43a). On cooling to the range -70 to $-75^{\circ}C$ this inclusion develops a number of grains of an unidentified solid (Plate 7.43f). On warming to about $-68^{\circ}C$, a liquid/vapor meniscus becomes visible (Plate 7.43e), with solid grains

still present. The last of these grains disappears at $\sim -56^{\circ}C$ (Plate 7.43d); on further warming the liquid/gas meniscus becomes faint (Plate 7.43c) and the two homogenize, by expansion of the liquid, at $-20.9^{\circ}C$ (Plate 7.43b). This behavior is difficult to interpret in terms of composition. CO_2 has its triple point at $-56^{\circ}C$, in exact agreement with the disappearance of the solid phase at $-56^{\circ}C$ observed here, but obviously the inclusions cannot contain just CO_2, as there is liquid present at a lower temperature. The nature of the mixture of gases can only be guessed at this time.

The crushing tests in the Kerr-McGee mine samples were most revealing. The normal, small-bubble inclusions contain a vacuum bubble (i.e., water vapor at ~ 20 mm pressure). Many inclusions that either had a very large bubble or appeared to contain gas only, from all three samples, were found to contain either vacuum (Plates 7.44 and 7.45), or a partial vacuum (Plates 7.46 and 7.47). These are probably from the trapping of bubbles of steam, with or without some noncondensable gas and brine. All three samples also contained a few inclusions with gas under greater than atmospheric pressure. These inclusions were one-phase as first observed, and except under special circumstances, it is not possible to distinguish between a vacuum, dense gas, or even liquid, in such single inclusions. It is only on crushing, when these inclusions formed bubbles of noncondensable gas in the surrounding fluid, that the internal pressure became evident. By measuring the size of the inclusions before crushing, and the diameter of the bubbles evolved, we obtain a crude measure of the internal pressure, assuming each unit volume expansion corresponds to one bar pressure. In a few inclusions, the contents changed to a two-phase, liquid + vapor system during the expansion (Plate 7.48), but usually the pressure release was too sudden to reveal if there was a transient two-phase condition. The volume expansion varies for different inclusions, from 30- to 40-fold (Plates 7.49 and 7.50) to a maxiumum of perhaps 100-fold (Plate 7.51). As the immersion medium used is an oil in which methane is probably readily soluble, this gas is more likely CO_2, since the bubbles dissolve in the oil very slowly.

Interpretation of the data from the Kerr-McGee mine samples is difficult at this time. The presence of an inclusion filled with a dense CO_2-rich (?) gas in sample MB-77-8, (in halite that was probably molten at the time of intrusion of the dike) is not unexpected, since there is a small amount (0.2-2%) of magnesite in the adjoining rock (M. Bodine, personal communication). The dike shows no evidence of carbonate alteration, however, and there is a problem in explaining the presence of inclusions of low-temperature, gas-free brine, apparently pure steam, and dense CO_2 in the same sample. Formation of these types at different times is obviously required, but there is no other indication of differences in conditions or time of origin.

The temperature at which the dense gas inclusion was trapped is of interest. Although the melting point of pure NaCl is 800°C, other materials present here in the potash ore zone (such as KCl) will lower this temperature. If we assume that the gas inclusion contains pure CO_2, the -21°C homogenization indicates a filling density of about 1.03 g/cm^3 (Roedder, 1965). Combining this with the estimate of confining pressure of ~ 38 MPa (380 bars) yields an obviously erroneous "trapping temperature" of 0°C. The several inconsistencies and difficulties in interpretation of the data from the Kerr-McGee samples cannot be resolved until additional studies are made.

7.6.13 Discussion

Geological Significance. Several aspects are evident from these various results. First, the fluids in all the inclusions, both type A in primary salt crystals and type B in recrystallized salt, are strongly saline brines, with significant amounts of other salts present in addition to NaCl. These brines differ from one inclusion to another, indicating that a range of fluids has been present at various times in these beds, but inclusions with simple NaCl solutions were found, as are found in other salt beds and as might be expected if pure salt beds have been fractured in the presence of meteroically-derived (fresh) ground water. The original deposition of salt occurred from highly-concentrated brines, and

presumably all waters that have passed through these samples since have had dissolved in them amounts of other minerals in addition to NaCl. Such fluids have caused extensive recrystallization of the salt, and presumably other mineralogical changes, so that little of the original salt texture remains. Second, at some stage in this recrystallization, gas-liquid mixtures were present in the pores of these beds. Third, this recrystallization occurred at near-surface temperatures (20-45°C). Fourth, the movement of these fluids must have been slow, as the evidence of extensive inclusion metastability indicates very clean solutions, free from the solid nuclei present in most fast-moving near-surface waters.

The fluids from which the salt crystals making up these beds originally crystallized were exceedingly saline brines with much material other than NaCl in solution, as shown by the freezing data on primary inclusions in hopper salt. These hopper crystals appear to have grown on the surface and then to have sunk, as described by Dellwig (1955). All but about 1% of this original hopper salt texture has been eliminated by recrystallization at some unknown later time, yielding coarser, clearer crystals of salt, and presumably gross changes in the mineral assemblage other than halite. Some of the clear salt surrounding the chevron structures may represent crystallization of these hopper nuclei on the bottom of the basin, but most is believed to be from recrystallization. This recrystallization occurred in the presence of exceedingly saline brines and with much material other than NaCl in solution. The brine may have been composed essentially of fluids from the primary fluid inclusions, released during the recrystallization. It was trapped as large inclusions in the recrystallized salt and comprised the bulk of the liquid now present in the samples as studied in the laboratory. Although the salt beds now appear dry to the eye, the samples contain 0.1 to 1.7 weight % fluid as examined, and may contain more in situ. At some stage or stages early in the history of these beds, the fluids present in these rocks varied in composition. (See section 7.7) A very few were saturated with organic gases such as methane and actually contained bubbles of a separate gas phase. Others contained additional salts in solution, resulting in the precipitation of various crystalline solids

from the liquid within inclusions in halite. The relative time sequence of these various fluids is not known, and most inclusions have neither methane nor crystalline solids. The latest episode of any recrystallization has been dated at 204 million years, slightly younger than Permian.

Homogenization temperatures of inclusions in recrystallized salt range from 20.4 to 45.5°C. During burial, creep from recrystallization in a salt bed with intergranular films of solution should result in the hydrostatic pressure on fluids (during trapping in a crystal) being essentially equal to the lithostatic pressure. If an overburden of 5000 ft. (1524 m) is assumed to have been present during the recrystallization, the maxiumum pressure (lithostatic) would have been ~ 38 MPa (380 bars). There are no PVT data on the specific fluids present in the inclusions, but if the data on a 25-percent NaCl solution are used, this pressure would suggest a maximum pressure correction of 36°C (Potter, 1977), and hence trapping (i.e., recrystallization) temperatures of 56-82°C. However, the true pressure correction may be lower, particularly since the fluids are more saline than 25-percent NaCl. Thus there is a drop of 12°C in the pressure correction on changing from 20-percent NaCl to 25-percent NaCl.

The presence of smooth planes of primary hopper salt inclusions of various sizes, separated by planes of inclusion-free salt, with the plane orientation horizontal, proves that these minute inclusions have not moved measurably since deposition, although they have been in a geothermal gradient presumably similar to that of the present for about 225 m.y.

The widespread occurrence of metastable phenomena in these inclusions, even in some large ones, suggests that fluid flow in the past through these beds has been very slow. Also, the fact that <u>all</u> inclusions that have been frozen prove to contain bitterns, and none was found with just $NaCl-H_2O$ solution, proves that at no time during the history of these samples did ground water, saturated <u>only</u> with respect to NaCl, ever penetrate into these particular samples.

Nuclear Waste Disposal Significance. The most signficant aspects at this stage in the study are as follows: First, the amount of fluid water solution now present in the samples as fluid inclusions averages 0.36 weight percent. Second, although noncondensable gases are present under pressure in some inclusions, the total amount is very small. Third, the inclusions change dimensions signficantly within minutes at room temperatures when the host crystal is subjected to uniaxial stress; this might suggest more rapid movement of inclusions in a thermal gradient if simultaneously under stress, as in mine pillars. Fourth, and possibly most significantly, the distribution of primary inclusions indicates that they have not moved visibly (i.e., less than a few micrometers at most), in the 225 million years since they formed, yet they have been in the small but finite geothermal gradient all this time. All fluid inclusions can be expected to move when placed in a thermal gradient. Since there is usually a thermal coefficient of solubility, material will dissolve on one wall and precipitate on the other. The rate of movement is a complex function of numerous variables (including inclusion size), but the temperature coefficient of solubility is probably the most limiting parameter in the case of NaCl. In the pure system $NaCl-H_2O$, the solubility change per 100g H_2O is low, only 0.03gm/^{o}C in the range of 0-100°C. This increases by approximately a factor of two at the elevated temperatures expected near the wastes. This coefficient is comparable in the $NaCl-MgCl_2-H_2O$ system.

All these aspects will now be treated in expanded detail.

Amount of Water in the Beds. Although this is the most important single datum that might be obtained from inclusion studies, fluid inclusion counting can provide only approximate values. The nature of the samples and the necessary sample preparation are such that there is a bias toward low values built into these data. Superimposed on this uncertainty in accuracy is poor precision in the measurement, due to variability of the sample material. For example, adjacent slabs of the same sample showed a five-fold range. It is probable that precisely calibrated neutron logs, reflecting the amount of hydrogen in the beds, give a more accurate

evaluation of the total water present, since they would effectively integrate over a much larger sample and would include the effects of the liquid-filled intergranular cavities which these tests miss.

One important aspect of the inclusions on the properties of the salt is the effect of the constitutents present on the lowering of the temperature of melting, and on the amount of liquid present at any given temperature. In this connection it is important to note that the inclusions' fluid is not water, but a strong bittern with probably significant quantities of magnesium ions. This will certainly affect the temperature coefficient of solubility of NaCl in these liquids, and will have important effects on the vapor pressure of these liquids (see below).

Corrosive Gases in the Inclusions. Although gas analyses by mass spectrometry are still to be made on the inclusion fluids, it is evident from the crushing studies that the inclusions in these samples, at least, contain very little noncondensable gases. Although hydrogen sulfide was found as an important constituent of gases in a gas pocket in another drill hole, (ERDA-No. 6, Section 7.7), there can be very little, if any, in these inclusions. The human nose is a rather sensitive detector of H_2S, ordinarily responding to a minimum of $\sim 10^{-10}$g. No odor of H_2S was detected during preparation of these samples, when relatively large volumes of inclusion liquid were exposed to the air. Gases such as HCl formed within the inclusions or by reactions of inclusion fluids with other minerals during heating, and under intense gamma radiation, may be a much more important cause for corrosion than those now present in the inclusions.

Effects of Water on Physical Properties of the Salt. The intergranular porosity in these salt beds, <u>in situ</u>, possibly contains some aqueous solution. Such fluids will tend to be squeezed out of the salt beds over geological time as recrystallization along grain boundaries and other processes permit compaction, just as the residual water in a sandstone is eliminated during the formation of a quartzite. Such flow will occur, however, only if there is an escape route for the fluid to take. As

pointed out very aptly by Baar (1977), there is much evidence from high pressure fluid pockets that salt rocks in situ are generally impermeable at depths exceeding about 300 m. It may well be that under such conditions, which preclude further "dewatering", the fluid in these intergranular films is still able to migrate short distances, enough to permit it to coalesce into "pockets", perhaps at points of slightly reduced pressure, just as a plastic shale will flow to the crest of folds in firmer rocks. These "pockets" might be represented in part as the short-lived seeps observed in potash mines.

Even if the intergranular liquid were to be removed completely, yielding a polycrystalline texture with salt crystals in true contact with each other, there is no driving force to remove the fluid inclusions from within the individual halite crystals. If such a salt bed is deformed to the point of rupture of salt crystals, any inclusions along the rupture will provide water to "lubricate" the fracture and hence lower the apparent strength of the rock. Although one might expect that a new fracture would preferentially follow planes of inclusions, as from the healing of former fractures, Gerlach and Heller (1966) have shown that the salt recrystallized in the vicinity of such a healed fracture is actually stronger than the adjacent unrecrystallized salt, and new fractures could not be made through the inclusions. Actually, most of the fluid in inclusions in the Carlsbad salt is in large, apparently randomly arrayed inclusions in recrystallized salt, and examination of fractures through such samples suggests that cracks induced in the laboratory experiments reported here have preferentially taken routes through such inclusions.

One example of the surprising effects of inclusion fluids on the properties of salt crystals is found in the behavior of fluid inclusions in single crystals of salt under uniaxial stress (Plate 7.40). Under these conditions, fluid inclusions visibly change shape, and volume, within a few minutes, at room temperature. This is a new inclusion phenomenon, never reported before.

Evidence of Previous Solution Movement in These Beds. The fluid inclusion evidence obtained so far on solution movements is encouraging in that it indicates at most only very slow movement, and suggests that part of the fluids now present in these beds may even be nearly Permian in age. The lack of any pure $NaCl-H_2O$ inclusions also argues against any previous sudden inrush of groundwater that could be trapped as inclusions in halite before it had time to acquire a full complement of other salts.

Movement of Inclusions in a Thermal Gradient. All fluid inclusions should move when the host crystal is placed in a thermal gradient. The nature and rate of such movement has been the subject of numerous studies, since it is of consequence in the chemical industry. Wilcox (1968) summarizes this extensive work (citing 111 references). Similar migration of inclusions is also an important cause for degradation of laser crystals grown at high temperatures by the Czochralski technique (Hopkins et al., 1976). Most liquid inclusions move up the thermal gradient, but if the vapor bubble is large relative to the liquid, and particularly if boiling occurs, the movement may be in the reverse direction (Wilcox, 1969; Anthony and Cline, 1972; Chen and Wilcox, 1972). The rate of movement is independent of inclusion size in many systems, but strongly (and directly) dependent on inclusion size in others (Wilcox, 1969); there may be a threshold size below which no movement occurs (~ 10 μ m in KCl; Anthony and Cline, 1971a). Large inclusions may break up during movement (Wilcox, 1968; Anthony and Cline, 1973). Many factors may affect the rate of migration, even in a given host, including gravity, composition, surface tension, inclusion shape, crystal anisotropy and imperfections, presence of a foreign gas, etc. In salt, since the thermal coefficient of solubility is small at surface temperatures, but increases greatly with increase in temperature, the rate of movement in a given gradient can be expected to increase with increase in ambient temperature. Higher ambient temperature also increases the travel rate by increasing the solubility, the diffusion coefficient, and the interface kinetics, and the increase in rate was found to be particularly striking in NaCl (Wilcox, 1968, p. 20). The

ract that the inclusions in Carlsbad salt have not moved measurably during geological time in the geothermal gradient is perhaps an indication of exceedingly slow rate, or perhaps a result of a very weak driving force.

Accurate prediction of behavior of in situ inclusions in the thermal gradient around a canister in salt cannot be obtained at this time, as there are too many uncontrolled variables. Since most inclusions at Carlsbad contain no bubble or only a very small bubble, they will move toward the canister, as was shown to occur at Project Salt Vault (Holdoway, 1974). The rate of this movement will depend most particularly on the inclusion size, the ambient temperature of the grain, the temperature gradient, and the temperature coefficient of solubility of NaCl in the particular inclusion fluid involved. The average distance that an inclusion must travel before it intersects a grain boundary will vary with the grain size of the salt, but seldom would be over 1 cm.

What can be expected when the inclusion reaches a grain boundary? Anthony and Cline (1971b) showed that grain boundaries in crystal aggregates tend to trap migrating droplets, but Anthony and Sigsbee (1971) showed that gas bubbles (10-50 μm) migrating in polycrystalline camphor could cross grain boundaries. However, migrating bubbles were observed to drag grain boundaries when the bubble concentration on the grain boundary was large. In Project Salt Vault, Holdoway (1974) says only that "little migration across grain boundaries appears to have occurred." Obviously, if a grain boundary is very tight, a large inclusion could cross it without effect. But if the grain boundary is composed of different material, the fluid could spread out along it as a film. Any such film should act as an inclusion, with material diffusing across it away from the heat source.

The behavior of an inclusion migrating to the wall of an open cavity (e.g., that holding the canister) will be different. On contacting the cavity, Anthony and Cline (1974) and Wilcox (1968, 1969) have shown that

some evaporation occurs, a vapor bubble forms, the inclusion seals itself, and now that it has a large bubble, it reverses direction and moves back the way it came, this time going down the gradient.

Decrepitation Release of Liquid Inclusions. In view of the expected slow migration rates of liquid inclusions in the thermal gradients established by the canisters, it seems probable that release of inclusion fluid by decrepitation will be an important process. An individual inclusion, if it is assumed to have rigid walls, to contain 25-percent NaCl solution, and to homogenize at 40°C, will develop 70.0 MPa (700 bars) internal pressure when heated to 100°C, and 200 MPa (2000 bars) at 200°C (Potter, 1977). However, salt cannot stand such internal pressures without yielding. Even a strong, hard mineral such as quartz starts to decrepitate when the internal pressure in its fluid inclusion reaches 80 ± 3 MPs (800 ± 3 bars) (Khetchikov and Samoilovich, 1970), and halite can be expected to decrepitate when the internal (inclusion) pressure reaches four times the yield stress for monolithic halite, under no confining stress (Cline and Anthony, 1971).

When Carlsbad halites were heated, some of the inclusions decrepitated in part causing the samples to fragment, and yielding an average weight loss of 0.13% (150°C), 0.22% (200°C), and 0.73% (250°C). This means that this much volatiles left the system. More inclusion fluid may well have been exposed, and merely lost water until its concentration of salts was such that the vapor pressure of H_2O at that temperature was less than one atmosphere. Salts in solutions in these brines (including materials other than NaCl as well) have effects on the vapor presure and hence on any vapor transport.

In addition to those inclusions that decrepitated, however, many inclusions remain sealed as liquid inclusions in the sample after heating, albeit in a changed form. These have permanently deformed their walls to form a larger chamber, and now have a much larger shrinkage bubble, proportional to the amount of expansion. (Why some decrepitate and others expand is at present unanswered; residual stresses in the host

crystal may be involved.) This expansion phenomenon is not new - it has been reported at various times in the past. It is the net result of several volume changes during heating of the inclusion. On heating, the host salt expands, enlarging the cavity as well. This effect is small, yielding a cavity volume increase of only 1.2% from 40 to 140°C. The fluid in the inclusion dissolves more salt from the walls on heating; the net volume effect of this (generally a decrease; i.e., an increase in cavity volume) will vary widely with the composition of the solution. Thermal expansion of the brine would develop high pressures if the walls were rigid, but instead, in the presence of liquid, the inclusion walls frequently just expand. The amount of expansion is roughly proportional to the temperature of heating, i.e., the inclusion fluid streches the walls until its internal pressure drops just below that needed to cause further stretching at that temperature. Nucleation of a vapor phase may even occur (Geguzin and Dzyba, 1973), in which case loss of water to the expanding vapor phase also helps to limit the expansion. Some of the thermodynamic variables of the process have been modeled by Cline and Anthony (1971) for the pure halite system.

7.7 THE GEOCHEMISTRY OF DELAWARE BASIN GROUNDWATERS IN RELATION TO THEIR HOST ROCKS

7.7.1 Introduction

Geochemical studies of waters found in Permian and younger rocks of the Delaware Basin (Southeast New Mexico, West Texas) have assumed a new importance in recent years. This began in 1975 when Sandia Laboratories, in cooperation with the United States Energy Research and Development Administration undertook studies of the suitability of Delaware Basin evaporite deposits for the long-term storage of radioactive wastes generated by the national nuclear defense program.

In particular, three aspects of fluid geochemistry have bearing on an understanding of the geology of the area:

1. Rock history - the relationships between dissolution features and nearby fluids which may have dissolved evaporites.

2. Fluid history - evidence of rock/fluid interactions preserved in fluid chemistry, indicating the complexities of fluid movement.

3. Fluid origins - the ultimate sources of fluids which have participated or have potential for participating in dissolution of evaporites.

Many of the waters considered here were bailed from preexisting wells with the assistance of the United States Geological Survey, between December, 1975, and June, 1976. In addition, boreholes for subsurface exploration of Los Medanos (the ERDA study area) tapped some fluid producing zones. These holes include ERDA No. 6,. which at a depth of 2711 feet produced saturated brine associated with H_2S-rich gas from the Castile Formation. In this hole, stratigraphic marker beds were found several hundred feet above their expected positions (Anderson and Powers, 1978). Nine holes penetrating the Rustler Formation have facilited hydrological testing and sampling of Rustler waters. Finally, samples of waters were collected from pools in Carlsbad Caverns. Table 7.19 is an inventory of water samples, together with their collection locations. New Mexico locations are given in Figure 7.10, showing their distribution with respect to the Capitan Limestone.

Three geochemical approaches will be followed in this subchapter. Each approach will consider a few examples of various "types" of water:

1. Solute chemistry - dissolved solids content.

2. Thermodynamics - equilibia and non-equilibria of a fluid-gas system.

3. Stable isotope ratios - variations in deuterium and oxygen - 18 content.

7.7.2 Data

Analytical results for the 29 waters are given in Table 7.20. Solute analyses are expressed in mg/l, performed according to APHA (1971) methods, with modifications by Collins (1975). Analyses by Martin Water Laboratories have a precision of about ± 5 to 10%; others ± 3% (Table 7.19).

Stable isotope analyses were made according to Epstein and Mayeda (1953) and Bigeleisen et al (1952), and are reported in " δ " notation as deviation of the D/H or $^{18}O/^{16}O$ ratio from the corresponding ratio of Standard Mean Ocean Water (SMOW) (Craig, 1961b, Epstein and Mayeda, 1953), in parts per thousand (‰, "per mille") for example:

$$\delta D = \frac{(D/H)\ sample - (D/H)\ SMOW}{(D/H)\ SMOW} \times 1000$$

The precision of $\delta\ ^{18}O$ values is better than ± 0.1‰ and that of δ D is better than ± 1‰ .

Solutes. In this discussion "fresh water" is taken to contain less than 3000 mg/l total dissolved solids (TDS), and is potable at least to local cattle. "Brackish water" refers to TDS contents between 3000 and 30000 mg/l. Brines are waters containing more than 30000 mg/l TDS. According to these definitions, number 1, probably 18 and 26 through 29 (Table 7.19) are fresh waters, found in the Capitan and Santa Rosa Formations. Numbers 2, 6, 11, 17, 22, 24 and probably 19 through 21 are brackish, and include most Rustler waters, one Capitan and one Castile. The fresh and brackish waters contain the solutes expected to be found in carbonate and anhydritic or gypsiferous aquifers. All the other waters are brines, and include the Salado, Morrow, Delaware (Bell Canyon) waters. two Castile, one Capitan, and even two Rustler waters; these Rustler samples came from the Culebra dolomite member, adjacent to halite-bearing parts of the Rustler Formation.

Brines are treated in the most detail here, since their presence has implications regarding either their representation of original evaporite mother-liquors, or their solutes having been derived through rock-water interaction. Their geochemical complexity cannot be understood from solute chemistry alone, and a brine occurrence in a particular rock unit does not necessarily imply that the brine has interacted with its host rock.

The chloride/bromide ratios, where obtainable, of all the brines were between 430 and 900, compared to 292 for modern sea water (Collins, 1975). If the Permian Basin water had a Cl/Br ratio similar to that of sea water, as suggested by Holser (1963) for fluid inclusions in Kansas salt, then these Delaware Basin brines do not contain "original" Permian water as a major component. Since halite crystallizing from sea water selectively excludes bromide from the NaCl lattice, halite has a Cl/Br greater than 300 (Adams, 1969), as would brine resulting from the dissolution of halite. Hence, the sodium chloride in these brines has been dissolved from rocks, but not necessarily the rocks in which the brines were found.

Rather than discuss abundances of individual ions in brine solutions, it is more instructive to consider solute ions combined as solids which might be expected to precipitate from solution upon complete evaporation. Following the crystallization sequences compiled by Braitsch (1971), not only some similarities will be noted between the resulting normative mineral assemblages, but also some significant differences. Waters 16, 9, and 14 (Salado, Bell Canyon, Castile) will be presented as examples.

Water from the Duval Mine Vent Hole is similar to the other potash mine seeps (Numbers 3, 4 and 5) all of which are saturated solutions. Table 7.21 shows the relative proportions of minerals expected to precipitate from this solution. This assemblage is similar to that expected to precipitate from sea water, even though the relative proportions are different (note the overwhelming preponderance of carnallite). In view

of the incongruent dissolution of polyhalite resulting in a calcium-poor solution, this brine is what one would expect for water which has dissolved a potash deposit. Note the presence of normative borax, an evaporite mineral not commonly reported in the Carlsbad potash district (cf. Jones, 1975).

Waters from the more saline portions of the Capitan aquifer (numbers 11, 12 and 13) contain the normative assemblage dolomite-anhydrite-kainite(or carnallite)-halite±sylvite, in various proportions, and are also indicative of solutes obtained by dissolution of adjacent evaporites.

Water number 9, from the Bell Canyon Formation, is examined in Table 7.22. The solution is calcium-rich, as indicated by the less common minerals tachyhydrite and antarcticite. These two minerals are not known to precipitate from sea water, and together with a magnesium deficit distinguish this water from a simple solution of primary evaporites. Graf et al. (1966), have given attention to the origin of calcium chloride waters, and emphasized shale ultrafiltration as an explanation. Other possibilities include diagenetic reactions in which magnesium in solution displaces calcium in carbonates to form dolomite, or in which Mg-rich sheet silicates are formed, having given up more easily replaceable cations such as Na and Ca (Grim, 1968), which were present in the original minerals (kandites and smectities). Mg-rich sheet silicates are present in the Ochoan evaporites overlying the Bell Canyon (see subsection 7.4). Since brine number 9 is a saturated solution, and since calcite, not dolomite is the prevalent carbonate mineral of the Bell Canyon, neither dolomitization nor shale ultrafiltration (which tends also to produce a low-Ca water, which has not yet been found) appears to be a satisfactory model for the in situ evolution of Bell Canyon brine. The sulfate deficiency could have arisen from biogenic degradation of sulfate. The most likely explanation for the in situ Ca-enrichment is ion exchange. This brine probably did not originate in the Bell Canyon, but its solutes probably came from nearby evaporites.

Waters 8 and 10 have a much lower TDS content than does 9, but otherwise yield most of the same minerals. The high strontium content of all three could be taken to indicate that these waters have indeed participated in the recrystallization of carbonates, but probably not within the Delaware Mountain Group of sandstones, which includes the Bell Canyon Formation. According to the Sr/Ca studies of Oxburgh et al. (1959), this solution would have been in equilibrium with a calcite containing about 4000 ppm Sr, a value too high for most natural calcites and dolomites. The Sr in solution could easily have come from the diagenetic alteration of aragonite outside the Bell Canyon.

On July 30, 1975, borehole ERDA No. 6 produced saturated brine (number 14, Table 7.19) and H_2S-rich gas (0.16 cubic feet STP per gallon) from a fractured, gray, laminated Castile anhydrite unit 2711 feet below the surface. Similar phenomena in the Castile have been reported by oil companies, but with an order of magnitude more gas. The analysis of one other such brine (Shell Bootleg, number 15 in Table 7.19) is given in Table 7.20, and is quite similar to the ERDA No. 6 brine. The solutes are resolved in Table 7.23, and aside from thenardite and LiCl (resulting from an almost economic concentration of lithium) are similar to the case of the dissolved potash deposit. Na_2SO_4 has been previously reported in subsurface brines (Reeves, 1963), and thenardite is known to precipitate from local surface lakes. Lithium is a common component of evaporites formed near igneous rocks, but the nearest igneous rock is several kilometers away (Calzia and Hiss, 1978). The brine is sodium-rich and magnesium poor. Once again in terms of ion exchange, a loss of evaporite-derived magnesium into silicates, which give up sodium, appears to be the mechanism here, although this need not have taken place in the Castile. Such like processes may account both for magnesium depletion in the solution and the formation of magnesium silicates in the evaporite sequence.

Thermodynamics. The ERDA No. 6 gas and brine are the only fluids which lend themselves to multiphase thermodynamic considerations. The gas amounted to 1.22 liters (STP) per liter of liquid, and consisted of

55% CO_2, 28% H_2S, 15% C_4, 1.5 N_2 and 0.5% C_2H_6, determined mass spectrometrically. The H_2S is not saturated in the solution, even in the light of the salting-out effect of high TDS content (Randall and Failey, 1927), and amounts only to 0.02 molal. In order to examine the role of sulfur in this system (the only multivalent element common to both liquid and gas phases) a predominance area diagram (cf. Garrels and Christ, 1965), was constructed for the system S-O-H with the variables pH and oxygen partial pressure, and with total sulfur equal to 0.36 molal (approximating the sulfate and H_2S in solution). The resulting diagram is Figure 7.11, for the field-temperature of 25°C. The field-measured pH is 6.3, and samples of the brine containing dissolved H_2S were observed to precipitate elemental sulfur upon standing at atmospheric conditions. The diagram shows that at pH 6.3, the sulfur field occurs between the sulfate and H_2S fields. Thus, the diagram correctly predicts the oxidation of H_2S to sulfur, and the sulfate and H_2S cannot be in thermodynamic equilibrium with one another at pH < 7. Unfortunately, the oxidation potential was not measured, and the precise position of the ERDA No. 6 system on the diagram is not known. The most probable origin of the H_2S is biogenic reduction of sulfate, an ion abundant in the surrounding rocks as anhydrite as well as in solution. Kuznetsov et al (1963), have indicated that bacteria such as Desulfovibrio aestuarii can exist in saturated NaCl solutions, although their activity is inhibited by bivalent cations, which are not prevalent in the ERDA No. 6 brine.

Stable Isotopes. Analysis of water samples for their $^{18}O/^{16}O$ and D/H ratios has been found to be a useful method of identifying the source of water molecules, and to some degree identifying the types of interactions the water has undergone in the presence of other phases.

Figure 7.12 is a δ D versus $\delta\ ^{18}O$ plot for Delaware Basin groundwaters. Most of the earth's meteoric waters have isotopic compositions which fall between the lines described by the equations:

$$\delta D = 8\ \delta\ ^{18}O + 5 \text{ (Epstein et al., 1965; 1970)}$$

and

$$\delta D = 8\ \delta\ ^{18}O + 10 \text{ (Craig, 1961a).}$$

These lines are included in Figure 7.12, and the area between them is labelled "Meteoric Field."

Most of the points in Figure 7.12 lie in or near the meteoric field. Except for Carlsbad Caverns, a $\delta\ ^{18}O$ value of -7‰ and a δD value of -50 ‰ appears to be a good approximation to local meteoric water in the Delaware Basin. The Caverns are part of the hydrologic system independent of the rest of the Capitan. Their enrichment in D and ^{18}O reflects the water's origin from air mass conditions different from those which produce other Basin rains.

Bracketing the cluster of meteoric points are two dashed lines whose intervening field is labelled "evaporation." This field is the trajectory of isotopic compositions that the meteoric waters would follow during evaporation. The trajectory slope is 5, according to Craig et al. (1963). The few points that lie in or near the evaporation field (4 Rustler and 1 Castile) may indeed have suffered partial evaporation prior to infiltration, but definitely originated as metoric water.

The dashed line through the origin, also of slope 5, is the trajectory of isotopic compositions of evaporating sea water. This line is also valid for the evaporation of warm-climate coastal meteoric waters ($\delta\ ^{18}O \approx -2$‰, $\delta D \approx -10$‰, as indicated by the intersection of this line with the meteoric field. Such waters were postulated by Holser (1963; 1966) to have been potential contributors to the Delaware Basin. The figure shows that the waters of positive $\delta\ ^{18}O$ values are not the products of partial evaporation either of Delaware Basin water or of modern meteoric water. This conclusion is the same as that drawn from the Cl/Br ratios.

The environments in which the Salado, Morrow and Delaware (Bell Canyon) waters were found involved a rock/water ratio that was very large, as deduced from the low productivity of these reservoirs. Consequently, any interaction involving isotopic exchange between these waters and host rocks would tend to alter the isotopic composition of the water toward δ D and $\delta^{18}O$ values consistent with equilibrium isotopic fractionation between water and minerals in the rock. Calcite in the Bell Canyon Sandstone had a $\delta^{18}O$ value of +25.1‰, a value only slightly less than typical marine carbonate. This implies only minor isotopic alteration of easily exchanged carbonate oxygen in the rock through the action of water, and indicates lack of calcite-water isotopic equilibrium in the Bell Canyon. The oxygen and hydrogen in clay minerals are known to be readily exchangeable with water (O'Neil and Kharaka, 1976). The Delaware, Morrow and Salado waters have isotopic compositions that are suggestive of at least partial isotopic exchange between local meteoric waters and clay minerals in the sediments, in which the mineral/water ratio was very large (cf. Savin and Epstein, 1970) for at least several thousand years. Other mineral sources of exchangeable oxygen and hydrogen are fluid inclusions, whose stable isotopes have yet to be studied, and the water of crystallization of many evaporite minerals. The potash seep waters may have interacted with hydrous minerals. However, gypsum-water is the only such mineral-water system for which the $^{18}O/^{16}O$ and D/H fractionation factors are known.

None of the waters have resulted directly from the dehydration of gypsum to form anhydrite. If ERDA No. 6 were such a water, the point marked "G" in Figure 7.12 would be the isotopic composition of the water from which that gypsum precipitated (using the gypsum-water fractionation factors of Fontes and Gonfiantini, 1967). "G" is not consistent with evaporating Delaware Basin water, whose anticipated δ D - $\delta^{18}O$ trajectory was discussed above. The isotopic composition of ERDA No. 6 brine is consistent with an approach to isotopic equilibrium between water and clay minerals, not necessarily in the Castile. Its isotopic exchange, together with its history of cation exchange, has resulted in a brine whose history appears to be similar to that of oil field brines of Alberta and the Gulf Coast (cf. Clayton et al., 1966).

7.7.3 Summary

Many types of rock/fluid interactions are evident in the geochemistry of groundwaters found in the Delaware Basin. It is not possible to completely characterize these interactions from solutes or stable isotopes alone, nor through a study of water alone without a similar study of rock. In addition to fresh and brackish waters, which have acquired solutes from their host rocks, the brines have here illustrated three examples of various types of rock/fluid interactions:

1. dissolution of evaporites (saline Capitan waters).

2. dissolution of evaporites with isotopic exchange between fluid and rock (Salado potash seeps).

3. dissolution of evaporites, isotopic exchange, and cationic exchange (Delaware, Morrow and ERDA No. 6 waters).

The latter two types indicate more profound interaction than the first, since these involve changes in the water molecules themselves.

No original Permian waters could be identified. If much of the evaporite section has been recrystallized, as Holser (1963) suggests, not even the fluid inclusions are expected to preserve such waters.

7.8 RUBIDIUM-STRONTIUM SYSTEMATICS OF THE SALADO FORMATION, SOUTHEASTERN NEW MEXICO

7.8.1 Introduction

One of the important reasons for studying bedded salt deposits for a radioactive waste repository is to determine their intrinsic geological stability and to understand the behavior of alkali and alkaline earths in such a system assuming leakage of isotopes such as ^{90}Sr and ^{137}Cs.

If it can be demonstrated that such isotopes are likely to be retained at or very near the possible leakage area, then the potential danger of such leakage is minimized. Alternately, if it is found that there has been widespread migration of alkali and alkaline earth elements in the prospective storage sites, then these sites may be unfavorable for retention of ^{90}Sr, ^{137}Cs, etc. assuming leakage occurs. Furthermore, if the latest episode of diagenetic evaporite recrystallization can be dated, arguments can be made for the geochemical requilibration of the evaporite assemblage into a thermodynamically stable configuration, reducing the liklihood of such events in the future.

To address this problem the WIPP study area and nearby sites were chosen for investigation, utilizing the well-established Rb-Sr geochronologic method of age determinations. This method is especially well suited for addressing alkali and alkaline earth retention and/or migration because of the species involved and its simplicity. Because of geochemical similarities (ionic radii, ionization potential, charge) Rb can be used as an analogue for Cs, and ^{90}Sr will behave as any other Sr isotope. Hence the Rb-Sr ages will allow, in theory, meaningful interpretation of the stability of the Salado Formation in terms of Rb and Sr retention and/or migration.

The basic age equation is:

$$T = \frac{(^{87}Sr/^{86}Sr)_m - (^{87}Sr/^{86}Sr)_o}{(^{87}Rb/^{86}Sr)_m \quad (\lambda)}$$

where:

T = age in years

$(^{87}Sr/^{86}Sr)_m$ = measured isotopic ratio normalized to $(^{86}Sr/^{88}Sr) = 0.1194$ (the average abundance ratio in the earth)

$(^{87}Sr/^{86}Sr)_o$ = initial isotopic ratio before $^{87}Rb\ (\beta^-)\ ^{87}Sr$ radiogenic decay (R_o) occurs.

$(^{87}Rb/^{86}Sr)_m$ = measured isotopic ratio (calculated from Rb/Sr ratio).

(λ) = decay constant for ^{87}Rb = 1.42×10^{-11}/y.

The $(^{87}Sr/^{86}Sr)_m$ term is the sum of $(^{*87} + ^{87}N)_{Sr}/^{86}Sr$ where *87 and ^{87}N refer to radiogenic and normal mass 87 respectively.

The initial ratio $(^{87}Sr/^{86}Sr)_o$ can either be assumed, determined by measurements on Rb-free phases formed at T =0, or determined by extrapolation from an isochron (i.e. line of slope $e^{T\lambda} - 1$ along which all samples of the same age and initial ratio but with different Rb/Sr ratios will fall; see Faure and Powell, 1972). The last of these choices is considered the most reliable due to natural variations of the initial ratios in nature, even from supposedly uniform, Rb-free, reservoirs.

7.8.2 Previous Work

K-Ar dating of evaporites has been shown by numerous investigators to be extremely risky (see discussion in Faure, 1977) due to loss of radiogenic ^{40}Ar by diffusion and other processes. Some K-Ar ages have beeen attempted for salts from the WIPP study area at Los Medanos (Shell Dev. Co.; 1973). For sylvites, minimum dates from 18 ± 8 to 74 ± 8 m.y. were obtained while two langbeinite-sylvite mixtures yielded nearly identical dates of 137 ± 8 and 147 ± 8 m.y. Only one very pure langbeinite (18%K) yielded a date of 245 ± 10 m.y.; this date is in excellent agreement with the 225-240 m.y. age range assigned to the Late Permian evaporites of the Castile and Salado formations.

The only other officially reported work is that by E. L. Tremba (1973; unpub. Ph.D. dissertation) in which he reports widely scattered data for evaporites from the Los Medanos area. Tremba's (1973) work was not directed toward problems of local alkali or alkaline earth migration, however, and composite samples were commonly taken which would, in

effect, mask any such local effects. He reports two model Rb-Sr dates of 241 ± 23 m.y. and 208 ± 8 m.y. respectively for (1) a K-ore zone from the Saunders Mine and (2) two separate aliquots of a water-soluble K-ore. An initial ratio of 0.7077 was used in both cases. For water soluble samples from mine faces within the Saunders Mine, Tremba reports a 129 ± 5 m.y. isochron but, without adequate justification, one point (#3SS) is omitted from the isochron calculation. As a model age for this one point yields an apparent model date of 330 m.y. (R_o = 0.708), then the significance of the 129 ± 8 m.y. date, based on only 4 of 5 samples, is difficult to interpret.

Similarly, five samples from Tremba's core 184, first ore zone, yield an apparent isochron date of 120 ± 28 m.y. but with an extremely high initial ratio of 0.7226 ± 0.0092. The argument is made that the two 120 to 129 m.y. isochrons can be explained by some type of Cretaceous "rehomogenization event". This interpretation can be criticized because 27 low-K samples from core 184 yield a mean $(^{87}Sr/^{86}Sr)_m$ = 0.7077 ± 0.0001; and any hypothesized rehomogenization event must explain how selective parts of the core can be affected whereas others are not. For example, Tremba argues that recrystallization involving polyhalite may have taken place at approximately 120 m.y. ago at which time the initial ratio was increased by rehomogenization to above 0.72; yet the data in Table 7.24 yield at least one sample (ERDA-9, 1759.1-1759.8) with $^{87}Sr/^{86}Sr_m$ = 0.7064. Furthermore, if one uses the individual points for Tremba's 129 m.y. isochron and assumes an initial ratio of 0.7077 (based on his data), a range in model dates results from about 185 m.y. to 100 m.y. (not counting sample EV-13 with a very low $^{87}Rb/^{86}Sr$ ratio). The reason for this apparent scatter is unanswered by Tremba's work.

7.8.3 Analytical Procedure

Sample Preparation. Samples studied thus far have been core segments from WIPP exploratory holes. The core segments were about four inches in diameter and ranged in length from 4 to 12 inches. These samples first

were trimmed by air saw to remove all outer surfaces that may have contacted drilling brines or been otherwise contaminated. Only the remaining prism of rock was retained for analysis; the outer portions were stored for possible use in the future.

Enough of the remaining inner portions were ground to -100 mesh to produce approximately 200 g of rock powder. About 30 g of this powder was quartered out and saved for whole rock analysis.

Separation of Water-Insoluble From Water-Soluble Material. The concentration of water-insoluble residue in a sample was determined during the separation of the soluble from the insoluble material. Approximately 60 g of powdered sample, weighed to the nearest 0.01 g, was placed in a 250 ml glass centrituge tube together with about 175 ml of distilled and deionized H_2O. The bottle was then capped and the mixture shaken vigorously for about 3 minutes, centrifuged for 15 minutes and decanted into S and S 576 filter paper. This procedure was repeated with 175 ml of H_2O followed by a third leaching of 150 ml of H_2O.

The resulting solution was transferred into a Pyrex 600 ml beaker, which was placed on a 150°C hotplate until no more liquid remained. The salt residue was then quantitatively removed from the beaker, weighed, and stored for analysis.

Separation of the < 2 Micron Fraction. The < 2 micron fraction was separated from the insoluble residue remaining from the above procedure. The insoluble residue was repeatedly washed and centrifuged until a disperson of the clay-sized material was obtained. The washed slurry was then put into 1000 ml cylinders for gravity settling. The length of time necessary for settling was calculated from the equation noted by Folk (1968). Fractions finer than 2 microns were siphoned off after the proper length of time had passed. A portion of the < 2 micron fraction was used for oriented slides (for x-ray diffraction analysis); the remainder was dried, ground to -100 mesh and used for Rb-Sr isotopic and other geochemical analyses.

X-ray Diffraction Analysis of Clay and Evaporite Minerals. Thus far, identification of clay minerals has been based solely on x-ray diffractograms, obtained from a Norelco wide range diffractometer. Untreated oriented powders were scanned from 2 to 60 degrees two theta. The untreated slide was glycolated by vapor-soaking on a rack in a container filled partially with ethylene glycol. An additional oriented powder was heated to 450°C. Both the glycolated and the heated specimens were scanned from 2 to 30 degrees two theta.

Whole rock samples were analyzed by loading a small amount of randomly oriented rock powder in a Norelco powder holder. This powder was scanned from 5 to 80 degrees two theta and the resulting diffractogram compared to values compiled in the Joint Committee on Powder Diffraction Standards file to determine bulk mineralogic composition. Mineralogic abundances noted were estimates based on comparative peak intensities.
All samples x-rayed (both clays and whole rocks) were scanned with Ni-filtered CuK radiation. A time constant of two seconds was used with a scintillation counter detector and pulse height analyzer. The goniometer slit system consisted of a divergent and anti-scatter slit of 1 degree and a 0.003 inch receiving slit.

Rb-Sr Isotopic Analysis. Procedures for the dissolution of samples for Rb-Sr isotopic analyses varied dependent on the samples mineralogic composition. All samples were first weighed accurately and placed into a 100 ml teflon evaporating dish; the amount of sample to be dissolved was determined to ensure at least 10 mg Sr and Rb would be in solution. The sample was then spiked with ^{84}Sr and ^{87}Rb solutions. Samples which contained silicate minerals were dissolved with 30 ml reagent grade HF and 3 ml vycor distilled $HClO_4$ on a hot plate. Samples containing only water soluble material were dissolved with 50 ml of distilled and deionized H_2O and 10 ml of vycor distilled 6N HCl. Samples containing large amounts of sulfate minerals were first dissolved in aqua regia and then treated with HF and $HClO_4$.

After complete dissolution of the powder and evaporation of all HF and $HClO_4$, the samples were digested with 25 ml of H_2O and 25 ml of HCl.

The mixture was then reduced to about 5 ml by slow evaporation and allowed to cool overnight. After cooling the solution was filtered through S and S #576 filter paper and loaded onto the top of a chromatography column charged with sulfonated polystyrene, a chromatographic grade cation exchange resin.

The column was washed with 2N HCl repeatedly while the effluent was flame tested for cationic composition. Rb and Sr fractions were collected at the appropriate intervals indicated by the flame test. The collected fractions were subsequently dried, redissolved and transferred to precleaned quartz microvials. The microvials, containing the samples, were fused, cooled and stored for mass spectrometric analysis.

All Rb and Sr concentrations were determined by standard isotope dilution techniques. All Rb and Sr isotopic ratios were measured using a 23 inch, 90 degree sector, solid source, single filament Nuclide mass spectrometer equipped with an electrometer and strip-chart recorder.

7.8.4 Results

Samples for the present study were provided from Sandia Laboratories drill cores AEC-8, ERDA--6, and ERDA 9 drill cores. Samples were studied for their Rb-Sr systematics by mass spectrometer and (Table 7.24, 7.25), mineralogy by x-ray diffraction (Table 7.26). Additional geochemical studies are planned (i.e., rare earth elements, by instrumental neutron activation analysis).

Samples have been divided into whole rocks, water soluble portions, and the minus-two micron fractions. This approach varies significantly from Tremba's (1973) approach in that he worked with water soluble and total water insoluble fractions; the latter were not treated for separation of authigenic from allogenic fraction. This will be discussed later.

Whole rocks may yield uncertain results due to the unknown nature of water insoluble fractions within them. Similarly, the water scluble fractions are meaningful only if the nature of the water insoluble

fraction is studied. This last point can best be addressed by detailed study of the clay-size (minus-two micron), authigenic minerals common to evaporites.

(1) Whole rocks: the water insoluble content of whole rocks varies from less than 1 percent to 32 percent, with a mean of 6.5 percent if sample Dv-4D (clay rich) is omitted. The basic mineralogy of these samples is a halite rich assemblage with some samples rich in sylvite and/or polyhalite as well. Langbeinite-rich samples are rare. The Rb-Sr isochron for eleven samples is shown in Figure 7.13. The date of 132 m.y. must be considered very approximate as nine of the eleven samples plot essentially on the ordinate. Of these last eleven, nine are used to yield a reasonable estimate of initial ratio = 0.7081 $\pm$ 0.0005 (in agreement with Tremba's 1973 value of 0.7077).

(2) Water soluble samples: in working with water soluble samples the assumption is made that ions released into solution will not be absorbed onto the surface of the insoluble material. This is probably true only if the insoluble material consists of allogenic quartz, feldspars, etc. but <u>not</u> clay minerals. An isochron for five water soluble samples yields an apparent date of 206 m.y. with R_o = 0.7084 (Figure 7.14). While this date is not unreasonable for the Permian-Triassic boundary, it is slightly low.

(3) Minus-two micron fraction: the authigenic clay minerals which one might predict for an evaporite sequence are present in this fraction (Table 7.26). Of interest is that this material is (a) authigenic as demonstrated by the x-ray diffraction work and (b) is also the dominant part of the water insoluble fraction. Thus the apparent

isochron date (Figure 7.15) of 325 m.y. needs explanation. If one remembers that many of the clay partings in the potash mines are interpreted as being of aeolian origin, then it is very likely that such aeolian clay minerals will, in part, reflect their provenance. This has been noted before by Hurley et al. (1962) for minus-two micron clay minerals from the Bermuda Rise. Of interest here is that our 325 m.y. date (Figure 7.15) is virtually identical with Tremba's (1973) 331 m.y. date for total water-soluble material.

7.8.5 Discussion

There are several ways to treat the data gathered so far. First a composite of whole rocks, water soluble and minus-two micron size clay minerals yields an isochron date (Figure 7.16) of 165 ± 20 m.y. with R_o = 0.7115. This date must be interpreted as a minimum due to the fact that the best estimate of R_o is 0.7081 ± 0.0004 according to the data presented in Table 7.24.

It is also apparent that the whole rocks by themselves are, in general, too halite-rich and possess Rb/Sr ratios which are too low for isochron work. When to this is added the uncertainty introduced by the insoluble material mixed with possible pre-T_s (i.e. time of sedimentation) material smaller than two microns, plus some detrital feldspar, quartz, etc., then the whole rocks can be assumed to be unsuitable for the isochron work.

If the clay minerals in the minus-two micron fraction are aeolian, pre-T_s material may account for the pre-Permian date of 325 m.y. (Figure 7.15). Similarly, since the clay mineralogy (Table 7.26) is very typical of evaporite clay minerals, then an alternate explanation is that these clay minerals have acted as local sinks for some $^{*87}Sr$ presumably remobilized during and after lithification and diagenesis. A lower age limit for this event is set by the 206 m.y. date from the water soluble fraction.

When only the water soluble and minus-two micron clay mineral fractions are considered together, a 204 m.y isochron (Figure 7.17) results with R_o = 0.7137. This date is only somewhat lower than the Permian-Triassic boundary and can safely be interpreted as a minimum due to the high initial ratio (0.7137). This interpretation assumes, however, that the clay minerals equilibrated with the evaporite medium (i.e. salts plus brine plus remnant sea water) at the time of sedimentation and this point remains to be unequivocally demonstrated.

Many of the above mentioned uncertainties will almost certainly be resolved by additional samples now in various stages of analysis for Rb-Sr systematics plus additional samples not yet treated. Furthermore, scanning electron microscope studies are planned to help resolve the problems of aeolian versus non-aeolian authigenesis hypotheses regarding clay mineral occurrences. Finally, rare earth element (REE) data, when complete, will greatly enhance understanding of the evaporite-insoluble material systematics of the Los Medanos area.

7.8.6 Concluding Statements

These data are of importance to he WIPP in the Los Medanos area because: (1) Widespread recent rehomogenization of radiogenic ^{87}Sr would be obvious if consistently high $^{87}Sr/^{86}Sr$ ratios were determined either from Rb-poor phases or by extrapolation from all samples with high Rb/Sr to the ordinate (Figures 7.13-7.17). This is not the case, and in fact values for whole rocks yield a mean of 0.7081, and several isochrons yield extrapolated values from approximately 0.709 to 0.713. The entire set of data argues against large amounts of radiogenic ^{87}Sr-enriched brine, having been formed post-200 m.y. ago, subsequently leaving its imprint in the recrystallized minerals. (2) the Rb-Sr isochron based on water soluble fractions and clay minerals. Figure 7.17 yields a date of 204 m.y. This date, in view of R_o = 0.7137 (i.e. higher than 0.7084), must be interpreted as a minimum date pending further analyses. (3) The clay minerals (Table 7.26) are of special interest in that they are typical of evaporite clay minerals formed during evaporite diagenesis,

yet they have been interpreted as aeolian. If they are aeolian, then some mixture of kaolinite-montmorillonite-illite would be expected rather than the saponite-chlorite-montmorillonite-serpentine-talc-illite assemblage noted. Since the clay minerals yield (Figure 7.15) a pre-sedimentation apparent date of 325 m.y. with high R_o (0.7123), then it is possible that these clays acted as local sinks for radiogenic ^{87}Sr (and Rb?) released during early diagenesis from roughly 235 m.y to 204 m.y.; such an interpretation is consistent with the data obtained to date. Tremba (1973) has argued for some mid-Cretaceous "rehomogenization event" at about 120 m.y. ago but inspection of his data coupled with these data do not support such an hypothesis. (4) REE are especially sensitive as geochemical tracers and forthcoming data, coupled with continued Rb-Sr and other work, should permit resolution of some of the problems concerning alkali and alkaline earth retention/migration in the geologic past at the Los Medanos site.

7.9 URANIUM ISOTOPE DISEQUILIBRIUM IN GROUNDWATERS OF SOUTHEASTERN NEW MEXICO AND IMPLICATIONS REGARDING AGE-DATING OF WATERS

7.9.1 Introduction

History. Regional exploration of bedded salt deposits for a radioactive waste repository in the Delaware Basin (Permian, New Mexico) included boreholes into the evaporites and associated rocks. These rocks contained various amounts of fluids, already described (Lambert, 1978). Although the halite deposits of the Ochoan Epoch are the prime target of consideration for waste storage, the older rocks of the Guadalupian Epoch are included in the present study, because of the Capitan reef, a body of cavernous limestone which encircles the Basin. The Capitan not only is the dominant rock in the Carlsbad Caverns, but also supplies potable water to the city of Carlsbad. Therefore, it is appropriate to consider possible connections between the Capitan and accumulations of water found in pockets in the evaporites. Brine and gas pockets are known to occur in the Carlsbad district potash mines and in the Castile Formation (anhydrite and halite) underlying the Salado Formation.

One exploration hole, ERDA No. 6, drew national attention (Boffey, 1975), when it encountered an accumulation of saturated NaCl brine laced with Na_2SO_4, accompanied by H_2S-rich gas at 826 m below the surface. Discovery of this artesian fluid, together with bedding-plane dips in the host Castile Formation exceeding 70°, led to abandonment of that particular site. Geophysical investigations showed that this and other occurrences of brine and gas were associated with closed structure contours drawn for the Castile formation. These structures, restricted to a narrow strip of evaporites near the reef have been termed "salt anticlines" (Anderson and Powers, 1978). Core from the fluid-producing zone of ERDA No. 6 consisted of gray laminated anhydrite whose fractures were filled with massive crystalline white anhydrite (Plate 7.52). While isolated fluid accumulations are not rare in evaporites, the possible use of the region for radioactive waste disposal requires attention to the origin of this particular type of accumulation. In the extreme cases, the fluid originates directly from water from the Capitan Reef, or the water was entrapped in the Castile Formation at the time for evaporite deposition in the Permian. In the first case, the water would have an age little older than Capitan waters. In the second case, the water would be in excess of 230 million years old.

Implications. Indeed, the very presence of the ERDA No. 6 accumulation of fluid poses several questions:

1. How long has the water been confined in the pocket?
2. Does the time of the water's intrusion correspond to any significant known geologic events?
3. What is the source of the water?
4. How long has this pocket been disconnected from nearby aquifers such as the Capitan Reef, if it ever was connected?
5. What are the limits to rates of influx (if any) or recharge and discharge (if any) of this fluid pocket?
6. To what degree does the ERDA No. 6 occurrence (or any other in the area) represent a flowing system?
6. Which radiometric clock should be used to age-date the water and what should be taken as initial conditions for age-dating?

7.9.2 Analytical Approach

General Geochemistry of Groundwaters. A number of groundwaters from the Delaware Basin have been characterized in terms of their general geochemistry with respect to their host rocks (Lambert, 1978). In terms of solutes, all waters from below the fresh-saline interface in the Capitan were similar to each other. In addition all shallow ($\leq$300 m depth) waters were similar to one another and all deep ($\geq$ 1000 m depth) waters were similar to one another. The ERDA No. 6 water was unique in its solute content, indicative of profound disequilibrium between solution and host rock and also between solution and associated gas phase.

In terms of D/H and $^{18}O/^{16}C$ ratios, Capitan and shallow waters all are similar and are of meteoric origin. (Carlsbad Caverns waters are also of meteoric origin, but are not related to other waters in the Capitan.) Deep water stable isotope ratios are similar to one another, and are not characteristically meteoric. ERDA No. 6 has uniquely non-meteoric isotopic ratios among those of Delaware Basin waters. No waters were found which represent original evaporite mother-liquor.

Experimental Procedures. In spite of the evidence that this fluid has experienced profound interactions with rock (Lambert, 1978), radioisotopes were examined to establish that the ERDA No.6 fluid was not of relatively recent origin. Plutonium concentration was determined by isotope dilution employing a spike of ^{244}Pu. The actual measurement was made on a three-stage thermal emission solid source mass spectrometer equipped with pulse counting for ion detection. The instrument has a very high abundance sensitivity (10^7) and low background, allowing for the determination of precise isotopic ratios on small samples amounting to 0.1 to 1 nanograms of plutonium. The plutonium concentration of the ERDA No. 6 brine was found to be less than 10^{-15} grams per gram, corresponding to the lower limit of analytical detectability. The absence of plutonium suggests the brine has been isolated at least since 1945, a date corresponding to the first atmospheric detonation of nuclear weapons.

Carbon 14 was measured in the CO_2, which amounted to 55% of the total gas collected from ERDA No. 6. Carbon 14 content was counted in a gas proportional detector whose efficiency was calibrated with the NBS oxalate standard. The result was the same as the background, which was about 2 counts per minute in a 1.5 liter detector at 2 atmospheres pressure. From this it was concluded either that the brine is older than about 30,000 years or possibly that carbonates in the host rock have diluted the carbon in the system with non-radioactive carbon.

The disequilibrium of the activity of ^{234}U relative to ^{238}U in natural waters has been attractive as an indicator of the age of groundwaters (Osmond and Cowart, 1976). ^{234}U and ^{238}U are related by the decay scheme:

$$^{238}_{92}U \xrightarrow[4.5 \times 10^9 a]{\alpha} {}^{234}_{90}Th \xrightarrow[24d]{\beta-} {}^{234}_{91}Pa \xrightarrow[1\ min]{\beta} {}^{234}_{92}U \qquad (1)$$

It has been proposed that excess ^{234}U builds up in confined waters as an aging effect as a result of the alpha-recoil of ^{234}Th, which ejects ^{234}Th out of the host rock crystal lattice into the water (Kigoshi, 1971; Kronfeld et al., 1975). From a knowledge of decay constants and initial activity ratio α_0 ($\alpha = \lambda_{234} N_{234} / \lambda_{238} N_{238}$), the time of confinement is calculated. It cannot be assumed, however, that the earth's natural abundance ratio, $\alpha = 1.00$, is a priori valid for a confined rock-water system. The water carried in with it an initial uranium concentration and original activity ratio, α_0 . The water ultimately comes to thermodynamic equilibrium with its host rock and may leach or even deposit ^{234}U and ^{234}Th. Uranium concentrations and α -ratios of rocks and waters in this study were determined by isotope dilution mass spectrometry, described above. Figure 7.18 shows the locations of principal water samples of this study. Table 7.27 shows uranium conentrations and values of α for various waters.

7.9.3 Results and Discussion

The overleaf of Plate 7.52 shows the variations of U content and α in anhydrite of rock core taken from the zone which produced fluid in ERDA No. 6 (826 m, 2709 ft depth). Table 7.27 shows that in ERDA No. 6, both U concentration and α vary with time, until U concentration falls asymptotically to about 2 parts in 10^9, and α rises asymptotically to about 1.35. In the early part of a several-hour flow test, water samples were found to be contaminated with drill mud and spallations from metal pipe. By 1400 hours not only had the uranium reached steady state values, but the iron concentration had fallen from 260 parts in 10^6 (1130 hours) to a steady value of 5 parts in 10^6 (1400 hours), indicating the flushing out of drilling-introduced contaminants. Thus, the later samples are probably representative of the fluid accumulation.

The total variation in α among all water samples is relatively small (1.2 to 5.2). In contrast, absolute uranium content in the waters of Table 7.27 varies by more than two orders of magnitude. Similarly, rock material illustrated in Plate 7.52 shows a wide variation in U content: 1 to 2 parts in 10^6 for "original" laminated gray anhydrite down to 20 to 30 parts in 10^9 in the secondary white anhydrite fracture filling only a few centimeters away.

7.9.4 Applicaton of the Uranium Isotope Disequilibrium Model

If N_2 is the amount of ^{234}U present in a phase, and N_1 is the amount of ^{238}U, the change in ^{234}U content with time in the brine is

$$\left(\frac{dN_2}{dt}\right)_{brine} = \lambda_1 N_1 - \lambda_2 N_2 + Q_1 + Q_2, \qquad (2)$$

in which Q_1 is the rate of release of ^{234}Th (the parent of ^{234}U) from the rock, Q_2 is the rate of release of ^{234}U from the rock and λ_1 and λ_2 are decay constants for ^{238}U and ^{234}U, respectively.

Release rates Q_1 and Q_2 can be modeled in the fashion of Kigoshi (1971), who studied the release of ^{234}Th from zircon powder. He gave the accumulated activity of ^{234}Th in solution after time t as

$$(\lambda_{Th}\ N_{Th})_{brine} = 1/4\ L\ S\rho\ (N_{238}\ \lambda_1)_{rock}\ (1 - e^{-\lambda_{Th}t}), \tag{3}$$

in which λ_{Th} is for ^{234}Th, L is the recoil distance of ^{234}Th in decay scheme (1) above, S is the surface area of parent rock, ρ is its density, and N_{238} is expressed as the number of ^{238}U atoms per gram of rock. Thus, the activity of ^{234}Th in the brine is related to the activity of ^{238}U in the rock by a proportionality constant, and, of course, the time-dependent term. When t >> 24 days, (3) can be approximated as

$$(\lambda_{Th}\ N_{Th})_{brine} \approx f_1 \cdot (\lambda_1\ N_1)_{rock}, \tag{4}$$

in which f_1 is now the leach fraction of ^{234}Th, incorporating 1/4 L S ρ in (3). In general, ^{238}U activities in rock and coexisting brine will not be equal, but will be related by a distribution coefficient r, which is theoretically an equilibrium constant, neglecting the kinetics of dissolution and precipitation:

$$(\lambda_1\ N_1)_{rock} = r\ (\lambda_1\ N_1)_{brine} \tag{5}$$

In actual fact, the time required to achieve chemical equilibrium between rock and brine might be very long relative to the half-life of ^{234}Th. Q_1 now becomes

$$Q_1 = r \cdot f_1 \cdot (\lambda_1\ N_1)_{brine} \tag{6}$$

Similarly, the amount of ^{234}U released is dependent on the decay of its precursor ^{238}U, and on the equilibrium ratio r, and on the leach fraction for ^{234}U, f_2:

$$Q_2 = r \cdot f_2 \cdot (\lambda_1\ N_1)_{brine} \tag{7}$$

In addition, some fraction, f_3, of the ^{238}U will be leached from the rock,

$$\lambda_1 N_1 = r \cdot f_3 \cdot (\lambda_1 N_1)_{brine} + (\lambda_1 N_1)_{brine} \quad (8)$$

Now, equation (2) becomes:

$$\left(\frac{dN_2}{dt}\right)_{brine} = (\lambda_1 N_1)_{brine} \left[1 + r (f_1 + f_2 + f_3)\right] - \lambda_2 N_2 \quad (9)$$

If f is defined as a composite leach fraction $(f_1 + f_2 + f_3)$, the solution to (9) is:

$$N_2(t) = \frac{\lambda_1}{\lambda_2-\lambda_1} (1+fr) N_1(t) + N_1(t=0) \left[\frac{\lambda_2 N_2(t=0)}{\lambda_1 N_1(t=0)} - \frac{\lambda_1}{\lambda_2} (1+fr)\right] e^{-\lambda_2 t} \quad (10)$$

which allows us to express the solution in terms of $\alpha = \frac{\lambda_2 N_2}{\lambda_1 N_1}$:

$$\alpha_{brine} = \frac{\lambda_2}{\lambda_2-\lambda_1} (1 + fr) + \left[\alpha_o - \frac{\lambda_2}{\lambda_2-\lambda_1} (1 + fr)\right] e^{-(\lambda_2-\lambda_1)t} \quad (11)$$

and since $\lambda_2 >> \lambda_1$

$$\alpha_{brine} \approx 1 + fr + \left[\alpha_o - 1 + fr\right] e^{-\lambda_2 t} \approx \alpha_b \quad (12)$$

The corresponding equation for the rock is:

$$\left(\frac{dN_2}{dt}\right)_{rock} = \lambda_1 (1 - f) (N_1)_{rock} - \lambda_2 (N_2)_{rock} \quad (13)$$

Since for a closed system, the $^{234}U/^{238}U$ equilibrium activity ratio is 1.000, the solution to (13) is:

$$N_2(t)_{rock} = \frac{\lambda_1}{\lambda_2-\lambda_1} (1 - f) N_1(t)_{rock} + \frac{\lambda_1}{\lambda_2} N_1(0)_{rock} e^{-\lambda_2 t} - \frac{\lambda_1}{\lambda_2-\lambda_1} N_1(0)_{rock} (1 - f) e^{-\lambda_2 t} \quad (14)$$

which in terms of α is

$$\alpha_{rock} = \frac{\lambda_2}{\lambda_2-\lambda_1}(1 - f) + e^{-(\lambda_2-\lambda_1)t} - \frac{\lambda_2}{\lambda_2-\lambda_1}(1 - f)\, e^{-(\lambda_2-\lambda_1)t} \quad (15)$$

The approximation $\lambda_2 >> \lambda_1$ reduces the equation (15) to

$$\alpha_{rock} \approx 1 - f + f\, e^{-\lambda_2 t} \approx \alpha_r \quad (16)$$

Let us now assume that the geochemical conditions (i.e U content and α) observed in the ERDA No. 6 rock-fluid assemblage represent equilibrium conditions. This requires the mutual consistency of equations (12) and (16), and that

$$f = \frac{(\alpha_0 - 1)(\alpha_r - 1)}{\alpha_b - \alpha_0 + r(\alpha_r - 1)}. \quad (17)$$

Anhydrite found in the veins is the most recently formed phase in the core, and using the U values from 1709.4 white anhydrite (U = 33 parts in 10^9, α = 1.04); Plate 7.52 overleaf), and the averages of the last two ERDA No. 6 brines in Table 7.27, (U = 2.01 parts in 10^9, α = 1.35) equation (17) gives rise to the plot in Figure 7.19. Note the prominent singularity at $\alpha_0 = 2.01$, and that $\alpha_0 \leq 1.971$ at $f = 1$ (corresponding to 100% leaching, and $\alpha_0 \geq 2.052$ at $f = -1$ (corresponding to all the uranium in the rock having precipitated from the brine).

Solving equation (12) for t, we obtain an expression for the age of the brine:

$$t = \frac{\ln\left(\frac{\alpha_b - 1 - fr}{\alpha_0 - 1 - fr}\right)}{-\lambda}. \quad (18)$$

For values of $\alpha_0 \leq 1.971$, negative ages result. Only for values of $\alpha_0 \geq 2.052$ are realistic ages obtained. This result implies that there has been minimal leaching from the rock. Furthermore, it suggests rather that precipitation of uranium has occured from brine to rock which is consistent with reducing conditions implied by the presence of H_2S.

Clearly, the amount of precipitation which has occurred (negative leaching) is related to the original α_0 at the time of closure of the rock fluid system.

Values of α for nearby waters in the Capitan limestone (Table 7.27) which by proximity afford a possible source of water for the ERDA No. 6 brine pocket, are mostly in excess of 1.35. In addition, the ERDA No. 6 brine is not saturated in $CaSO_4$ (Lambert, 1978), and is not likely to have been responsible for the precipitation of substantial amounts of vein anhydrite. Furthermore, the limited volume of the brine pocket (Griswold, 1977) could not realistically be expected to dissolve and reprecipitate anhydrite in veins to the extent observed in the core. Therefore, the α_0 of the ERDA No. 6 brine must have been larger than 2.052, with very little interaction with the reservoir rock.

7.9.5 Model Ages Based on No Leaching

Values of α and α_0 will in this model allow an age determination of a water to be made. The highest α value thus far determined is 14.2, the result of isotope dilution mass spectrometry performed on a sample from Israel supplied by J. Kronfeld, which gave an α value of 10.1 $\pm$ 1.6 by alpha-spectroscopy (Kronfeld et al., 1975). In addition, the occurrence of waters elsewhere in the Delaware Basin (Table 7.27 suggests that a reasonable α_0 value might be 5.14 (in the Capitan limestone), the highest thus far found in the Basin. If the ERDA No. 6 brine represents water escaped from the Capitan, and its α_0 was on the order of 5, Figure 7.19 shows that its interaction with the ERDA No.6 reservoir rock (fractured Castile anhydrite) precipitated less than 6% of the rock's uranium from the brine.

Neither total concentration nor isotopic composition of uranium in the ERDA No. 6 brine was inherited through interaction with the Capitan limestone, for the ERDA No. 6 brine contains substantially more uranium that the Capitan waters (Table 7.27) presently do. Likewise, uniformity in the stable isotope composition of Capitan waters (Lambert, 1978) shows

that the peculiar stable isotope composition of ERDA No. 6 water cannot have arisen by interaction with the Capitan limestone. Composition of stable and unstable isotopes in ERDA No. 6 brine might have arisen from interaction between water and rocks encountered by the water if it moved from the Capitan to its ERDA No. 6 environment.

In its simplest form, equation (18), under conditions of no interaction between ERDA No. 6 brine and its reservoir rock, reduces to:

$$t = \frac{\ln\left(\frac{\alpha_b - 1}{\alpha_0 - 1}\right)}{-\lambda_2} \qquad (19)$$

which very nearly corresponds to the combination of the solutions to the equations $\frac{dN_1}{dt} = -\lambda_1 N_1$

$$\frac{dN_2}{dt} = -\lambda_2 N_2 + \lambda_1 N_1$$

for which

$$t \approx \frac{\ln\left(\frac{\alpha_b - 1}{\alpha_0 - 1}\right)}{-\lambda_2 + \lambda_1} \qquad (20)$$

The above conclusions allow limits to be assigned to the age of confinement of the ERDA No. 6 brine, and also to ages of waters in the Capitan. Equation (20) differs from equation (19) only by the approximation that

$$\frac{\lambda_2}{\lambda_2 - \lambda_1} \approx 1,$$

since $\lambda_2 = 2.806 \times 10^{-6}\ a^{-1}$ for ^{234}U
and $\lambda_1 = 1.537 \times 10^{-10}\ a^{-1}$ for ^{238}U.

Figure 7.20 shows the family of curves obtained from equation (20), using observed values of α from Table 7.29, and various values for α_0. The model ages indicated on Figure 7.19 for the ERDA No. 6 brine are less

than those in Figure 7.20 because 4 to 5 percent interaction between brine and rock (uranium precipitation) involves loss of uranium from solution by means other than radioactive decay. There is no evidence for any degree of chemical equilibrium between ERDA No. 6 rock and fluid. If we realistically limit f (Figure 7.19) to have a value between -0.02 and -0.50, the minimum age of the ERDA No. 6 occurrence is 570,000 years ($\alpha_0 = 6$). In actual fact, as the data of Kronfeld et al. (1975) suggest, maximum α_0 values are universally in the range 10 to 15, and the age is between 800,000 and 1,000,000 years. According to the no-interaction model, (Figure 7.20), if water escaped from the Capitan ($\alpha_0 = 5.14$) into the brine pocket, this must have occurred at least 880,000 years ago. The highest α_0 value (14.2) confirmed by isotope dilution mass spectrometry gives an age of 1,300,000 years.

If the Carlsbad area (near the Pecos River) is a major recharge area for much of the Capitan reef, and if Carlsbad water ($\alpha_0 = 5.14$) is the basis for age-dating other waters in the Capitan, ages between 300,000 and 1,100,000 years are obtained. The maximum α_0 (14.2) would imply that Capitan waters are at least 400,000 years old.

7.9.6 Implications and Conclusions

A mathematical model based upon analytical data has showed that the ERDA No. 6 occurrence of brine can be age-dated by the uranium-disequilibrium method. Combinations of leach fractions and ages were derived, and the interaction between rock and fluid was indicated to be minimal. If the brine pocket was once connected to the Capitan Reef, the most productive aquifer in the region, such connection was severed at least 500,000 years ago, and probably more than 900,000 years ago. The brine pocket has been stagnant ever since, and there is little evidence to indicate that chemical equilibrium has been established among the solid, liquid and gaseous phases involved in the brine pocket.

Even though the α value of the ERDA No. 6 brine was close to those of nearby meteoric waters taken from the northern apex of the Capitan Reef, these α values are far removed from those of more remote meteorically-derived saline Capitan waters from the east and west arms of the reef (Carlsbad No. 7 and Shell No. 28). In fact, the remote waters appear to be younger than apex waters (Hackberry and Middleton), implying the groundwater flow in the reef is indeed toward the apex and recharge is in the east and west part of the reef.

Fresh and saline Capitan Reef waters have retained their meteoric D/H and $^{18}O/^{16}O$ ratios, even though the ages of some of them are comparable to that of ERDA No. 6. Although reef apex waters and ERDA No. 6 brine are radiometrically similar, the solutes and stable isotopes of ERDA No. 6 reflect a more profound rock/fluid interaction than Capitan waters have experienced. This interaction, however, is more likely to have taken place in rocks between the Capitan and the brine pocket than in the brine pocket itself.

The ERDA No. 6 reservoir rock has not replenished ^{234}U to the brine in spite of long contact. Furthermore, uranium mobility into the white recrystallized anhydrite from the gray laminated anhydrite from the gray laminated anhydrite was shown to be very low in this anoxic environment.

Dating by the uranium-disequilibrium method is not necessarily dependent on a closed system, and bounds on ages can be assigned. Requirements for $^{234}U/^{238}U$ dating include: α values of fluid and rock, leach rate, and knowledge of a value for original activity ratio, α_0. The α value for the rock is necessary to evaluate the degree of rock-fluid disequilibrium. The leach rate might be negligible even in a closed system. A unique solution to an age-dating problem, however, requires knowledge of initial conditions, just as in case of the well-established uranium-lead and carbon 14 age-dating techniques.

7.10 SUMMARY

Geochemical investigations of the WIPP site have been undertaken to characterize and quantify the mineralogy and petrology of the Delaware Basin evaporites and associated non-evaporites, volatile constituents and fluid inclusions native to the evaporites, the geochemistry of groundwaters native to the rocks, and the lengths of time that the evaporites and groundwaters have existed in their present environments. While these investigations have utilized a number of techniques of analytical chemistry, the choice and analysis of samples, together with interpretations of results, are carried out in the context of the WIPP geology.

The most common mineral in the Permian (Ochoan) Salado Formation, which is proposed for radioactive waste emplacement, is halite. Some of the halite contains minor amounts of anhydrite, and traces of trioctahedral clays and detrital minerals. Locally throughout the Salado Formation marker beds of anhydrite and polynalite occur at intervals of a few tens of meters. Local accumulations of potassium and magnesium sulfates occur in the McNutt potash zone in the upper part of the Salado.

The petrographic textures, geochronology, and the presence of minerals which are not primary precipitates of sea water, such as sylvite and polyhalite, indicate that much of the evaporite section last underwent recrystallization more than 200 million years ago, shortly after Permian deposition. The trace clay mineral fraction of the rock salt has efficiently entrapped and held radiogenic strontium for at least the last 200 million years. The aqueous solutions involved in this recrystallization were not in communication with fluids outside the evaporite section.

Volatiles presently occur in the evaporite section as the chemically-combined water of crystallization, hydroxyl-groups bound in sheet silicates, short-lived seeps exposed in mines, and as physically-entrapped inter- and intracrystalline fluid inclusio s. The

total volatiles recovered from rock salt heated to 600°C typically amount to less than 0.5 weight percent (about 1.5% by volume). In addition to water, traces of nitrogen, CO_2 and contaminants from the coring operation are recovered from subsurface evaporite cores taken from boreholes. The fluid inclusions appear to have been entrapped at 20 to 45°C, and contain NaCl, $MgCl_2$ and other amounts of other solutes. Fluid inclusions not affected by recrystallization have not moved in the ambient geothermal gradient since the Permian deposition.

Isolated pockets of aqueous solutions now found in the evaporites have no geochemical relationship to surface-derived meteoric waters or to groundwaters above and below the evaporites; neither do they represent original evaporite mother liquors. Such pockets probably are relicts of the post-depositional recrystallization which took place more than 200 million years ago, at which time they might have inherited their geochemically distinct solute assemblages and stable isotope compositons.

Stable isotope and solute content studies of meteorically-derived groundwaters west of the WIPP site and peripheral to the Delaware Basin indicate that simple uptake of solutes from rocks with which they have come in contact did not alter their meteoric isotope ratios. Thus, waters participating in active dissolution of salt, which has not occurred in the Salado Formation at the WIPP site, could be readily identified by their geochemistry.

The origin and age of an artesian brine pocket in the Castile Formation, northeast of the WIPP site was evaluated by a uranium isotope disequilibrium model. It was concluded that this accumulation (encountered in borehole ERDA No. 6) has no connection with any other known groundwaters, and has been in its present environment for at least 880,000 years.

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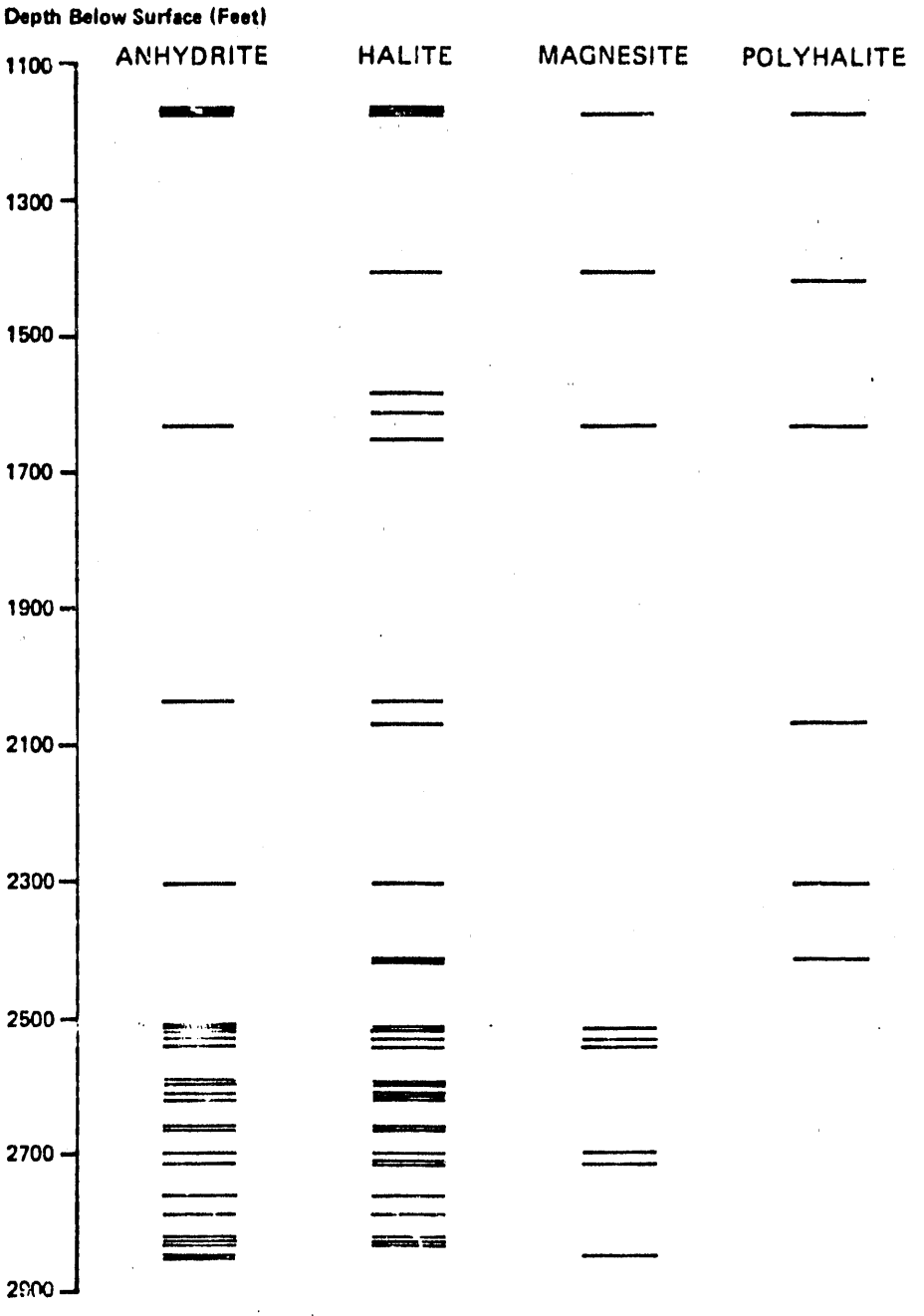


FIGURE 7.1

DISTRIBUTION OF MINERALS IN ERDA #9 CORE SAMPLES

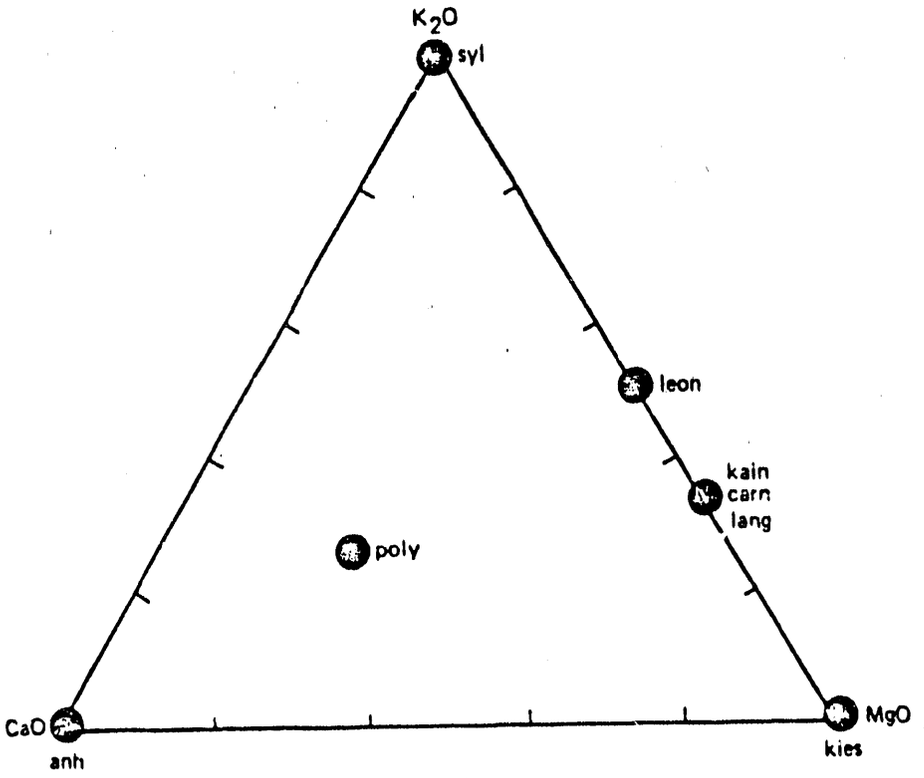


FIGURE 7.2

TRIANGULAR COMPOSITION DIAGRAM OF

SOLUBLE SULFATE-GROUP MINERALS

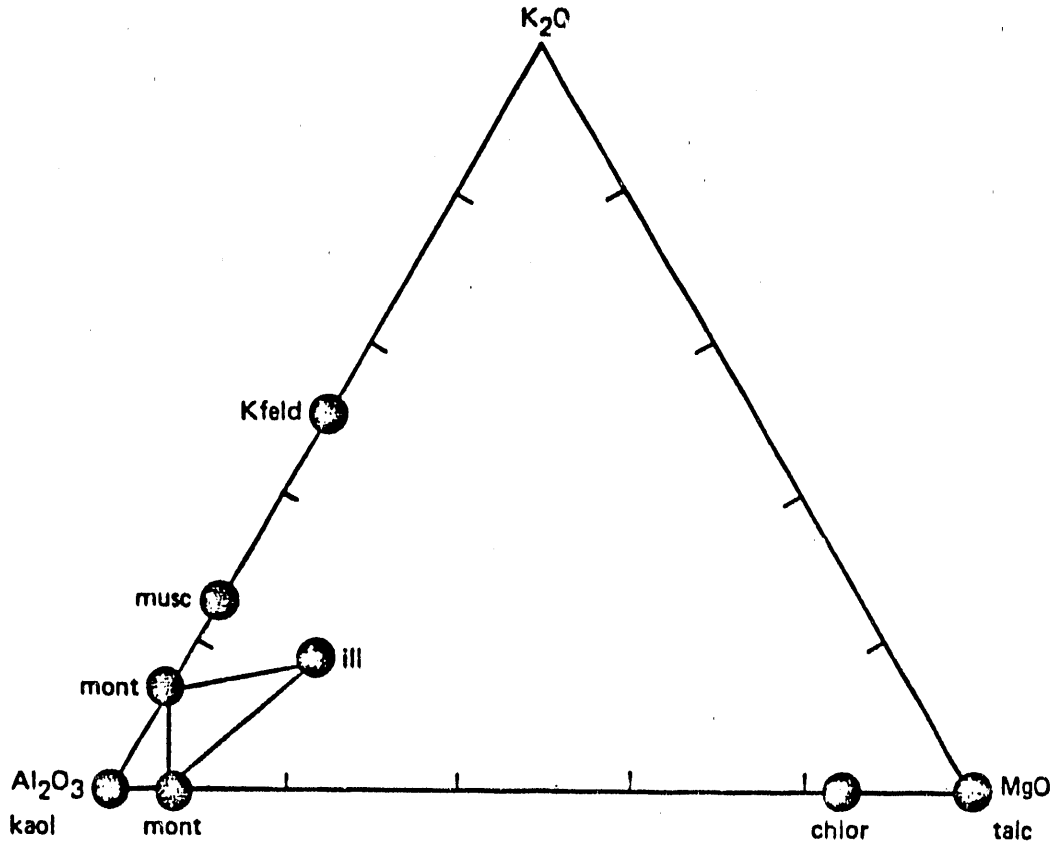


FIGURE 7.3

TRIANGULAR DIAGRAM OF

INSOLUBLE SILICATE-GROUP MINERALS

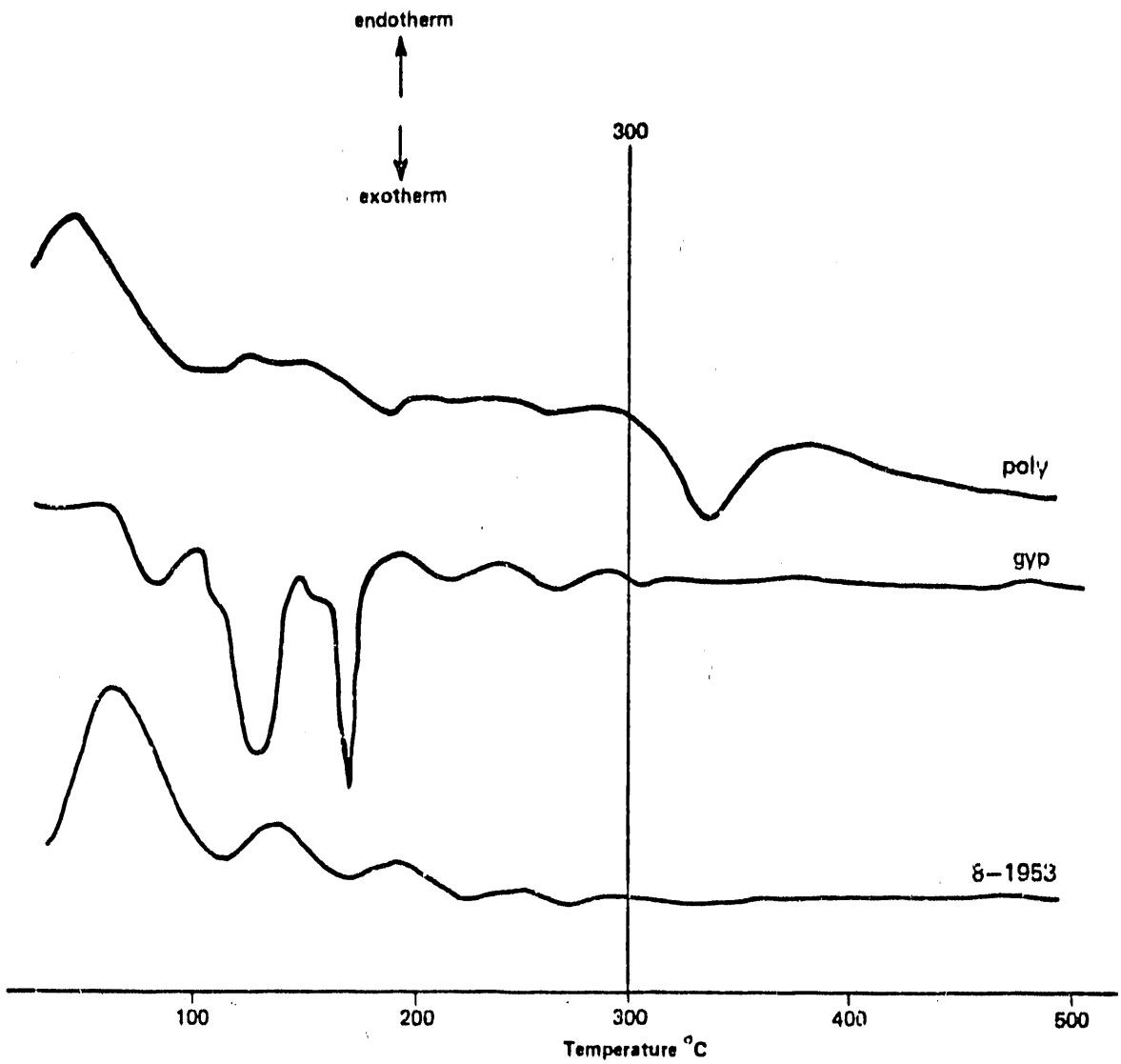


FIGURE 7.4

DIFFERENTIAL THERMAL ANALYSIS CURVES

FOR GYPSUM AND POLYHALITE

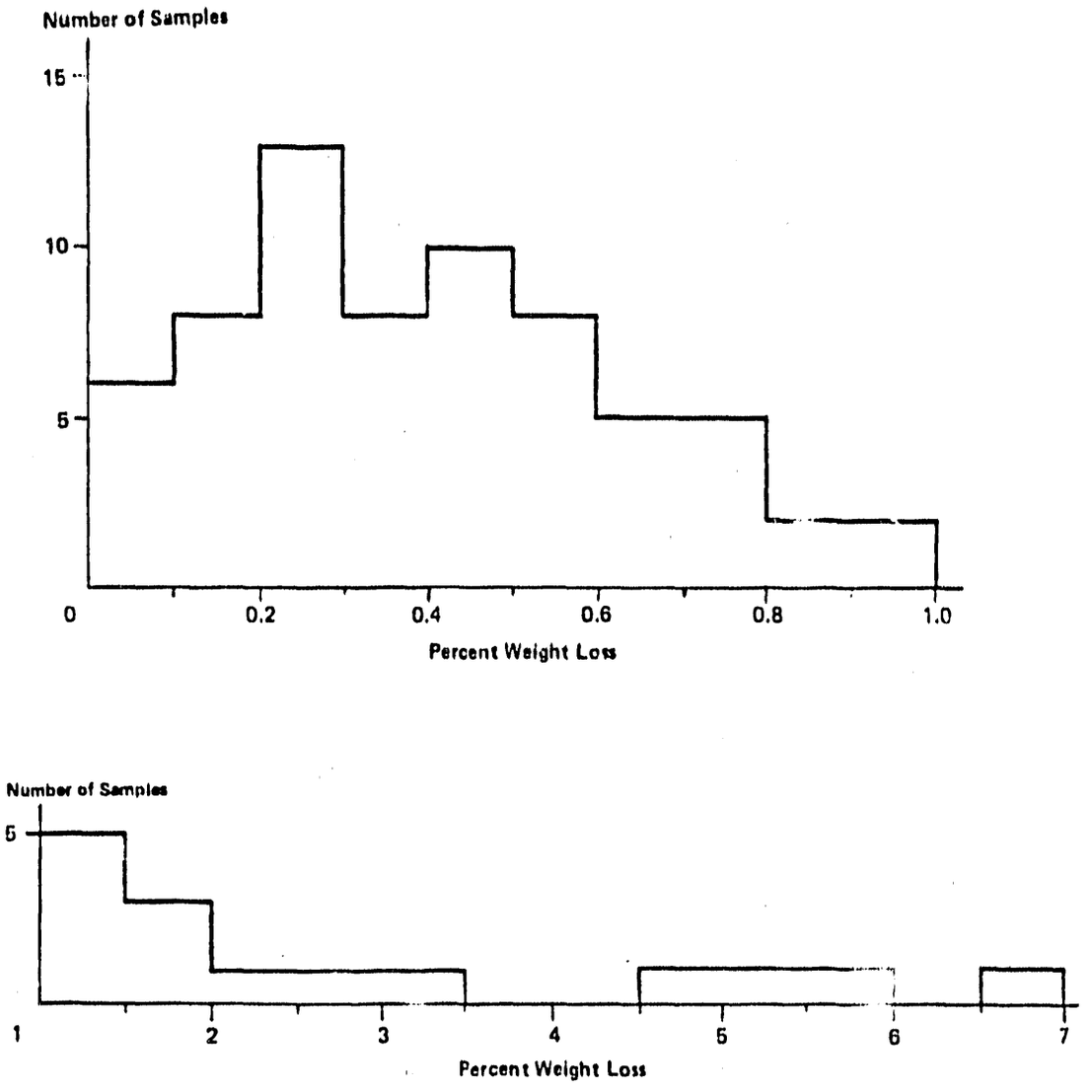


FIGURE 7.5

TOTAL WEIGHT LOSSES AT ELEVATED TEMPERATURES

(500°C) FOR COKES FROM AEC NOS. 7 AND 8

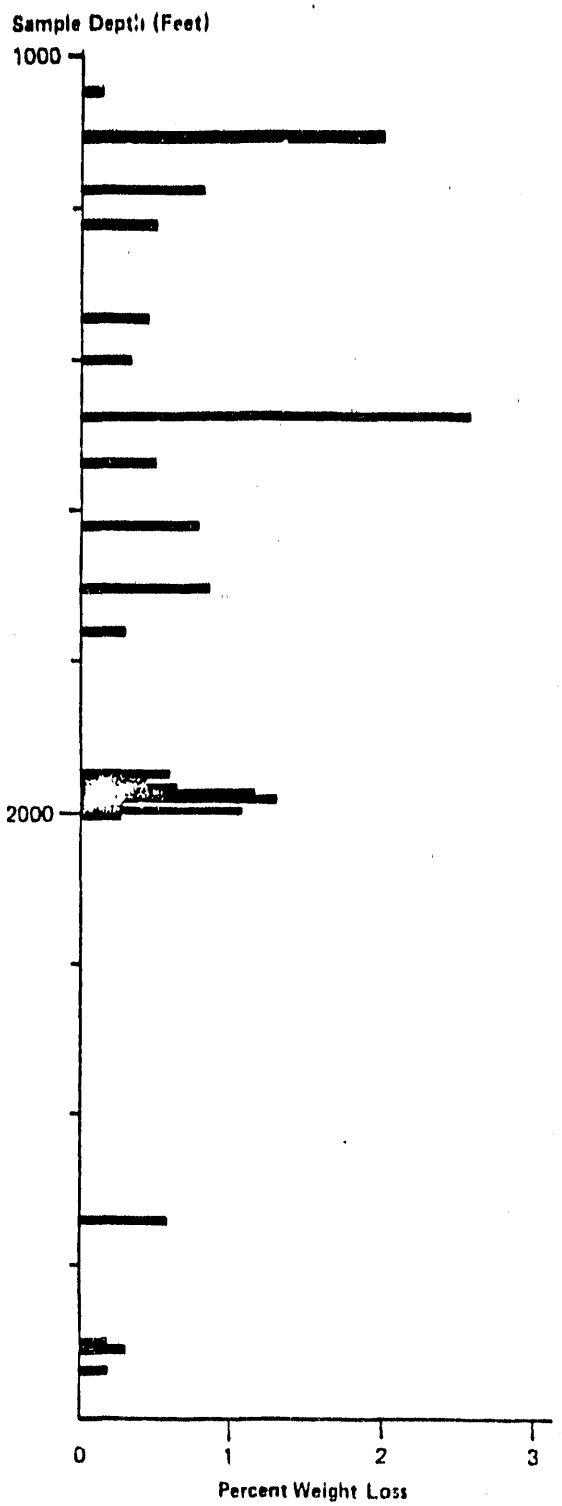


FIGURE 7.6A

AEC NO. 7 SAMPLE WEIGHT LOSSES VS. DEPTH

AT ELEVATED TEMPERATURES (500°C)

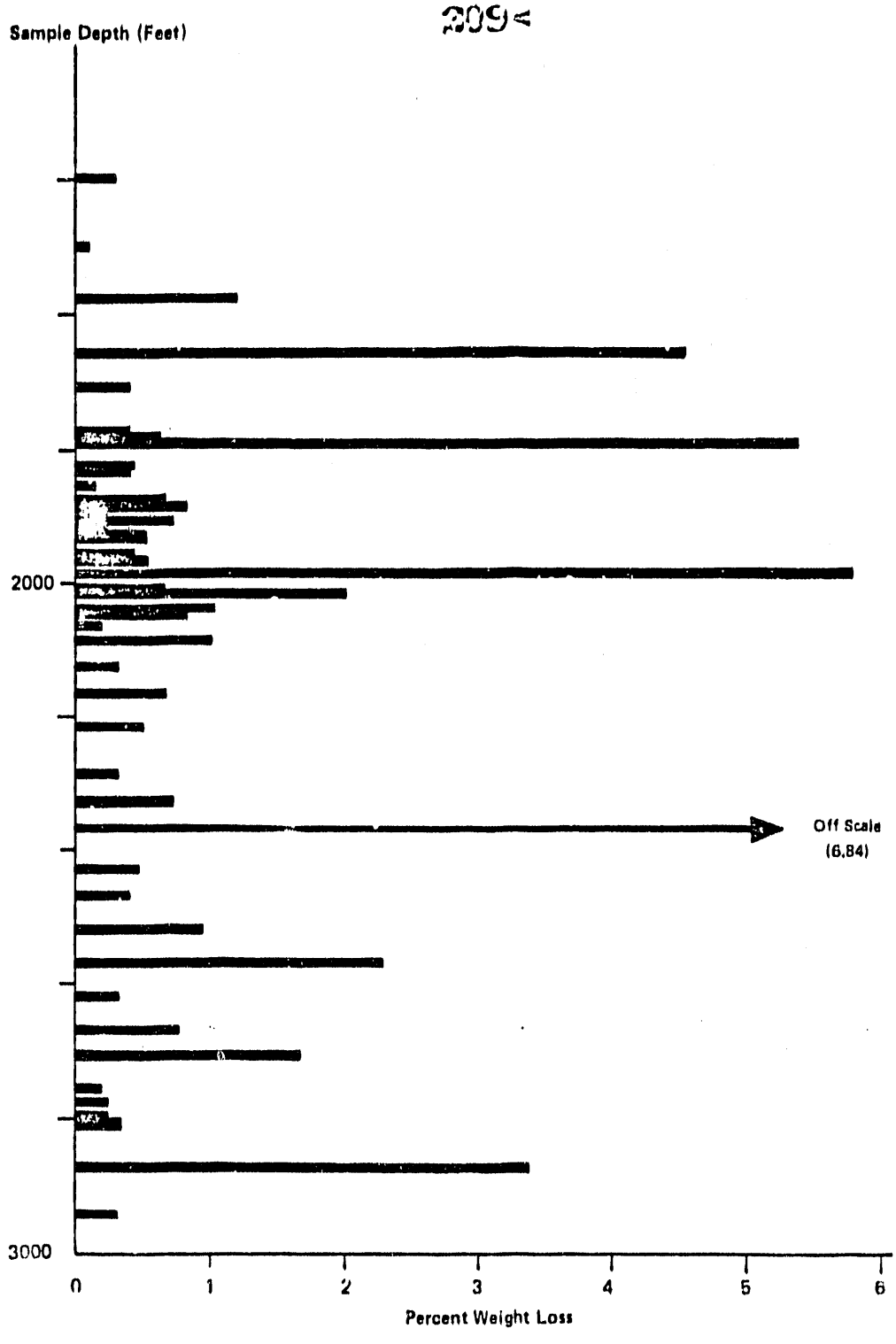


FIGURE 7.6B

AEC NO. 8 SAMPLE WEIGHT LOSSES VS. DEPTH

AT ELEVATED TEMPERATURES (500°C)

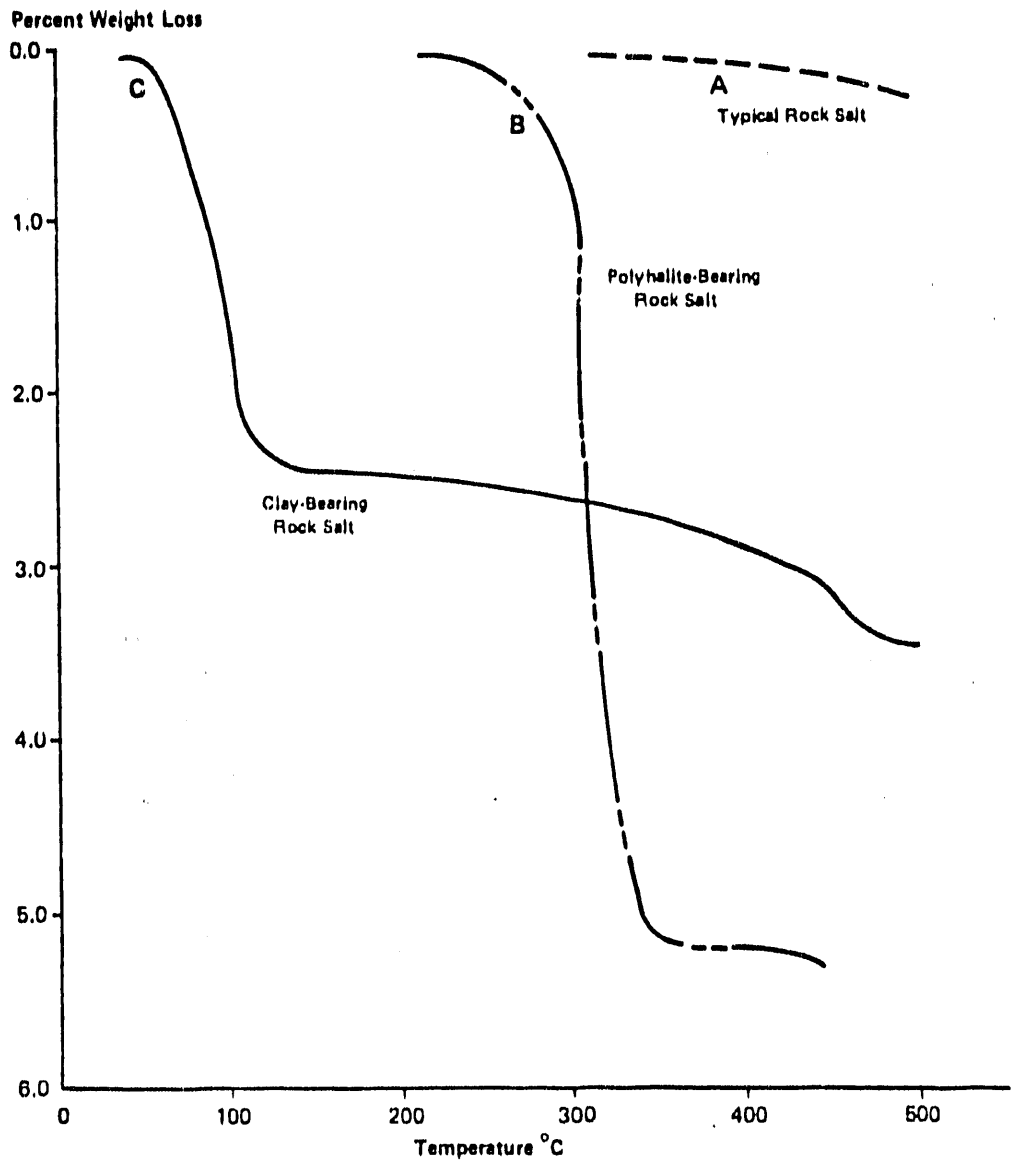


FIGURE 7.7

TYPICAL WEIGHT-LOSS CURVES FOR ERDA #9 EVAPORITE CORE

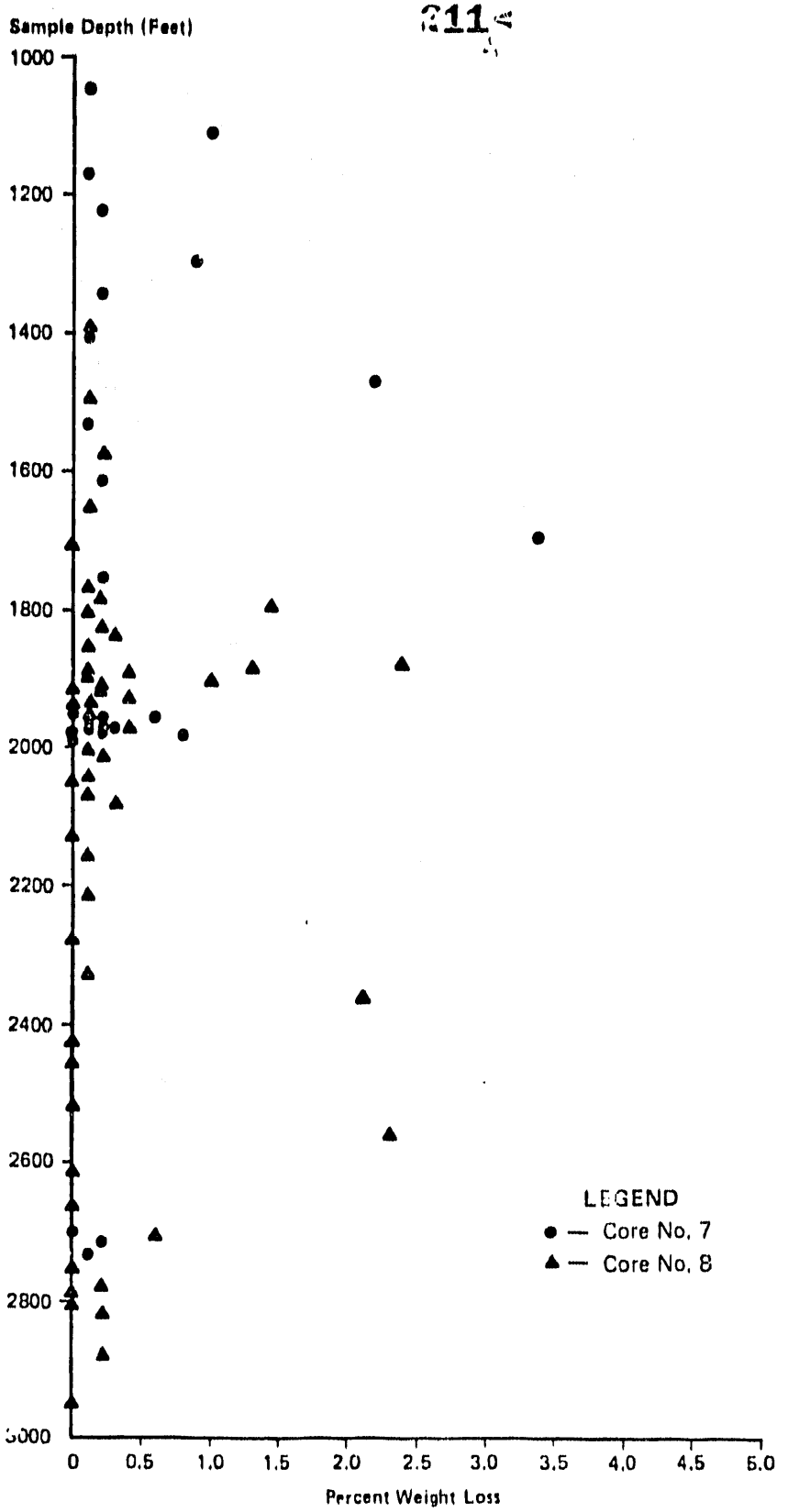


FIGURE 7.8 WEIGHT LOSS DATA FOR SAMPLES (102±5°C)

FROM CORES NO. 7 AND NO. 8 NEAR CARLSBAD, NEW MEXICO

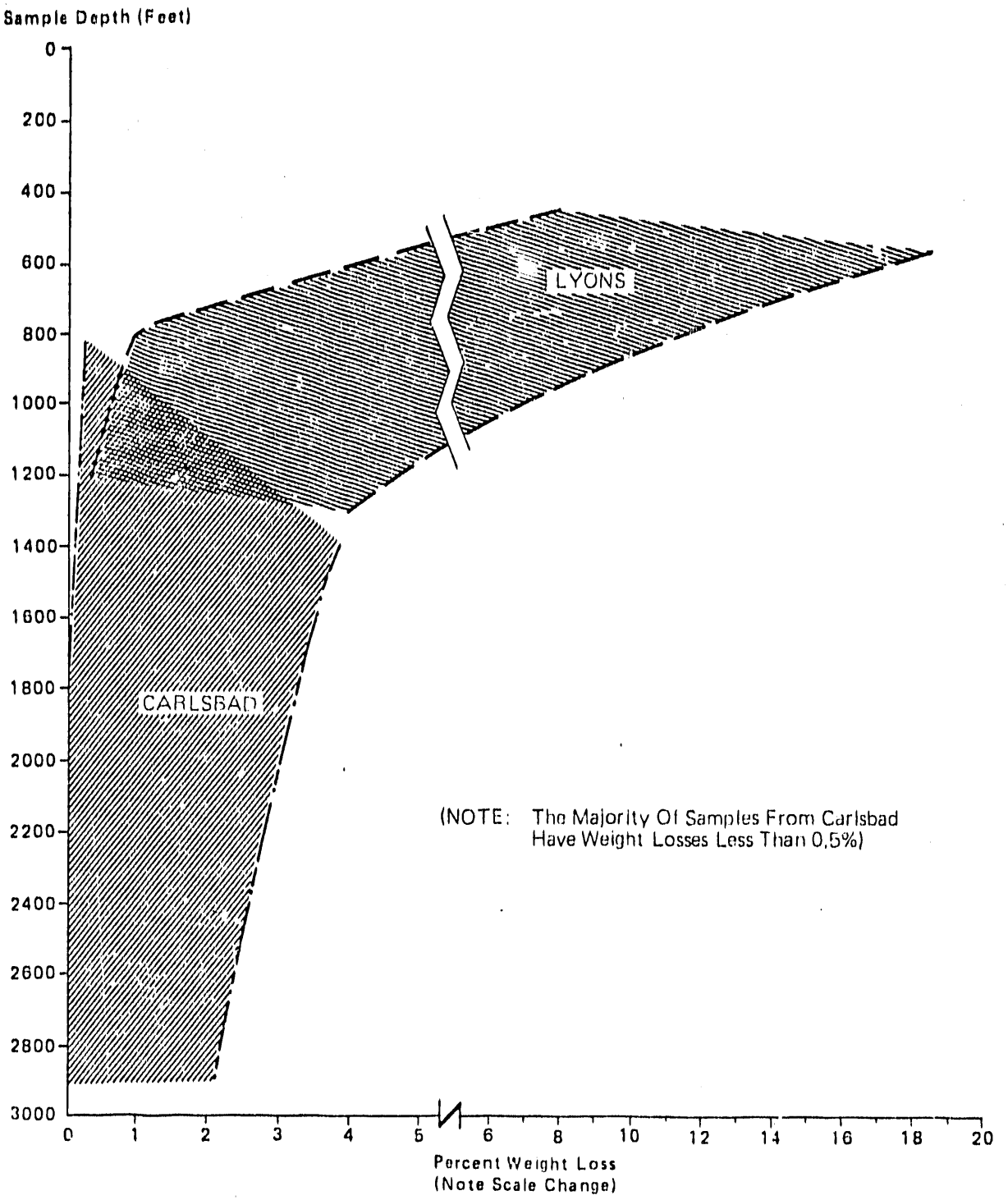


FIGURE 7.9 APPROXIMATE RANGE OF WEIGHT LOSS TO BE EXPECTED AT 102 + 5°C VS. DEPTH FOR SAMPLES FROM LYONS, KANSAS AND CARLSBAD, NEW MEXICO

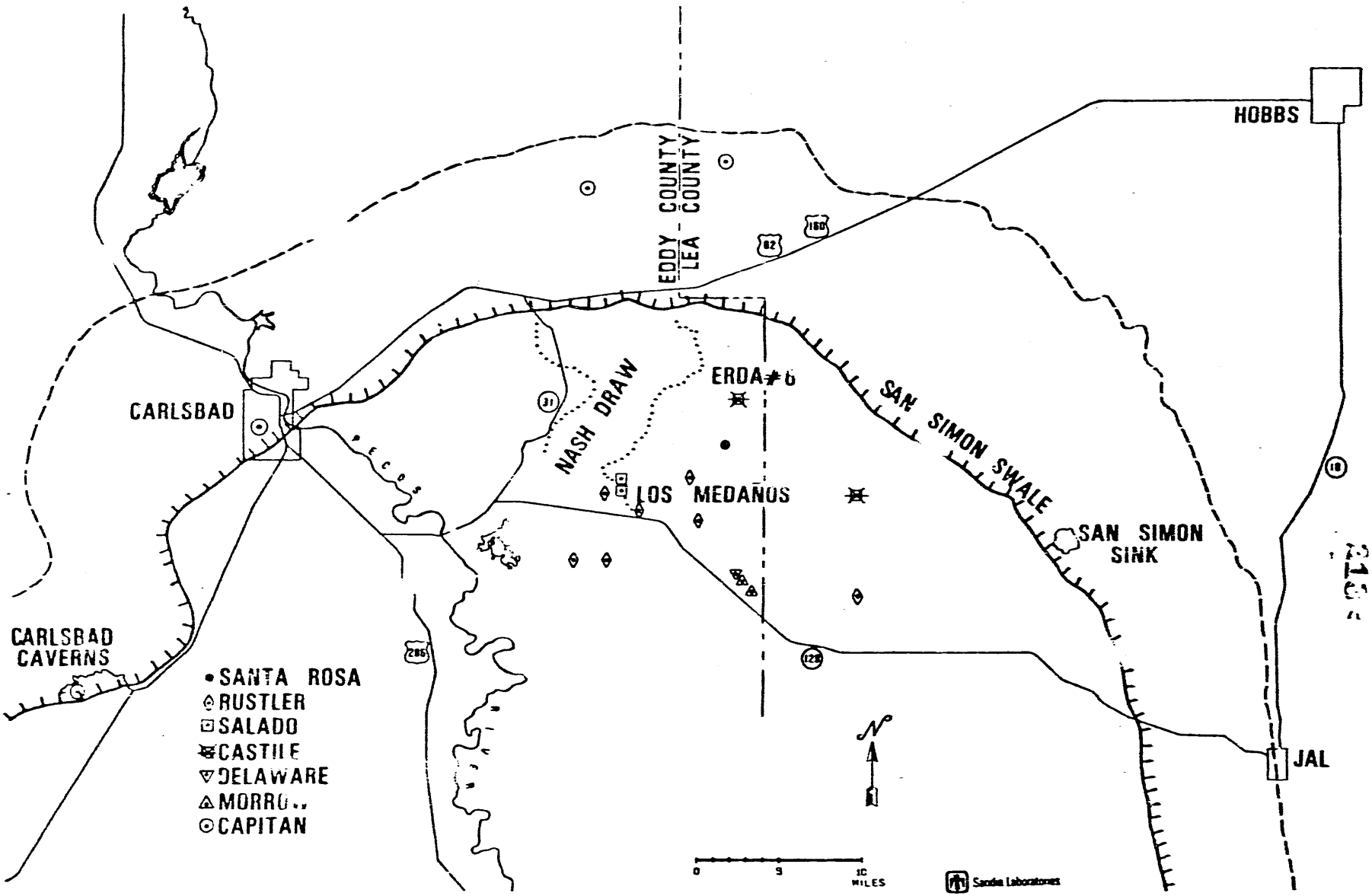


FIGURE 7.10 Map of the New Mexico portion of the Delaware Basin, showing locations of water sampling points in this study. The solid hachured line is the inward margin of Capitan Reef; the dashed line is the shelfward edge.

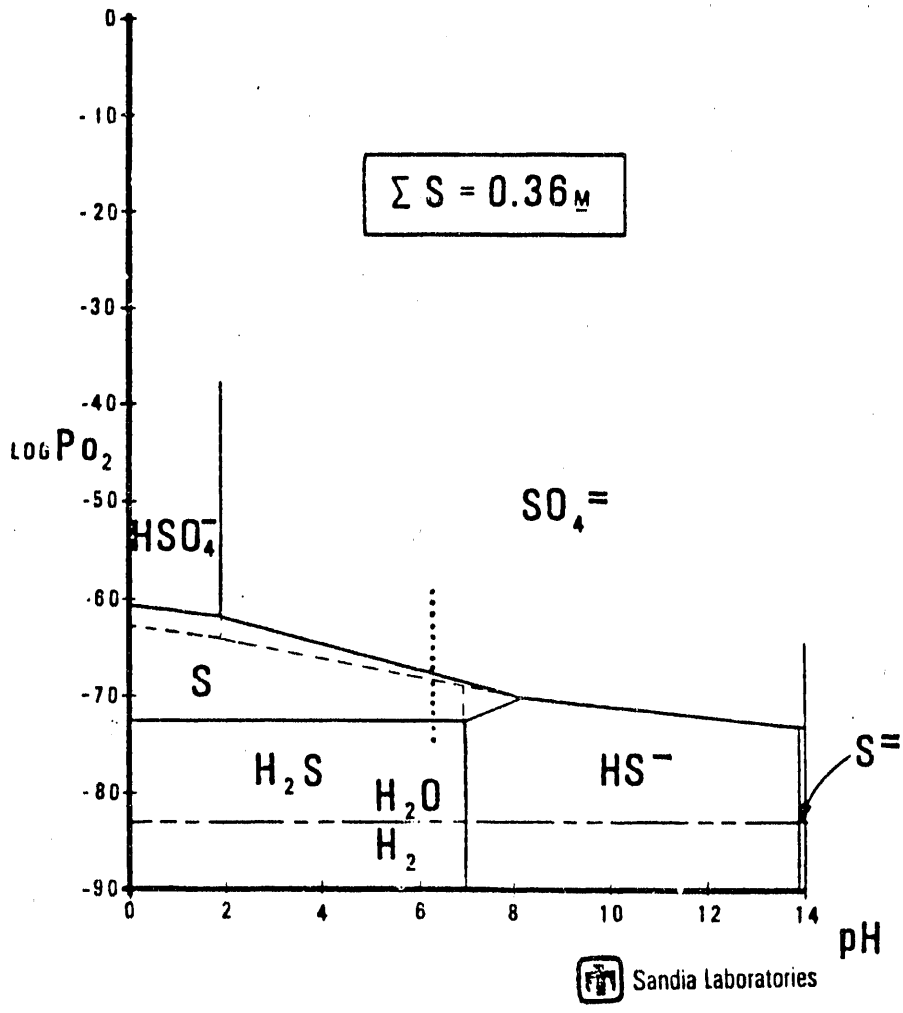


FIGURE 7.11 Predominance area diagram, oxygen partial pressure versus pH, for the System S-O-H at 25°C, 1 atmosphere and total sulfur concentration of 0.36m. Dashed lines are metastable extensions of boundaries. Dotted line represents the field-measured pH of ERDA No. 6, 6.3.

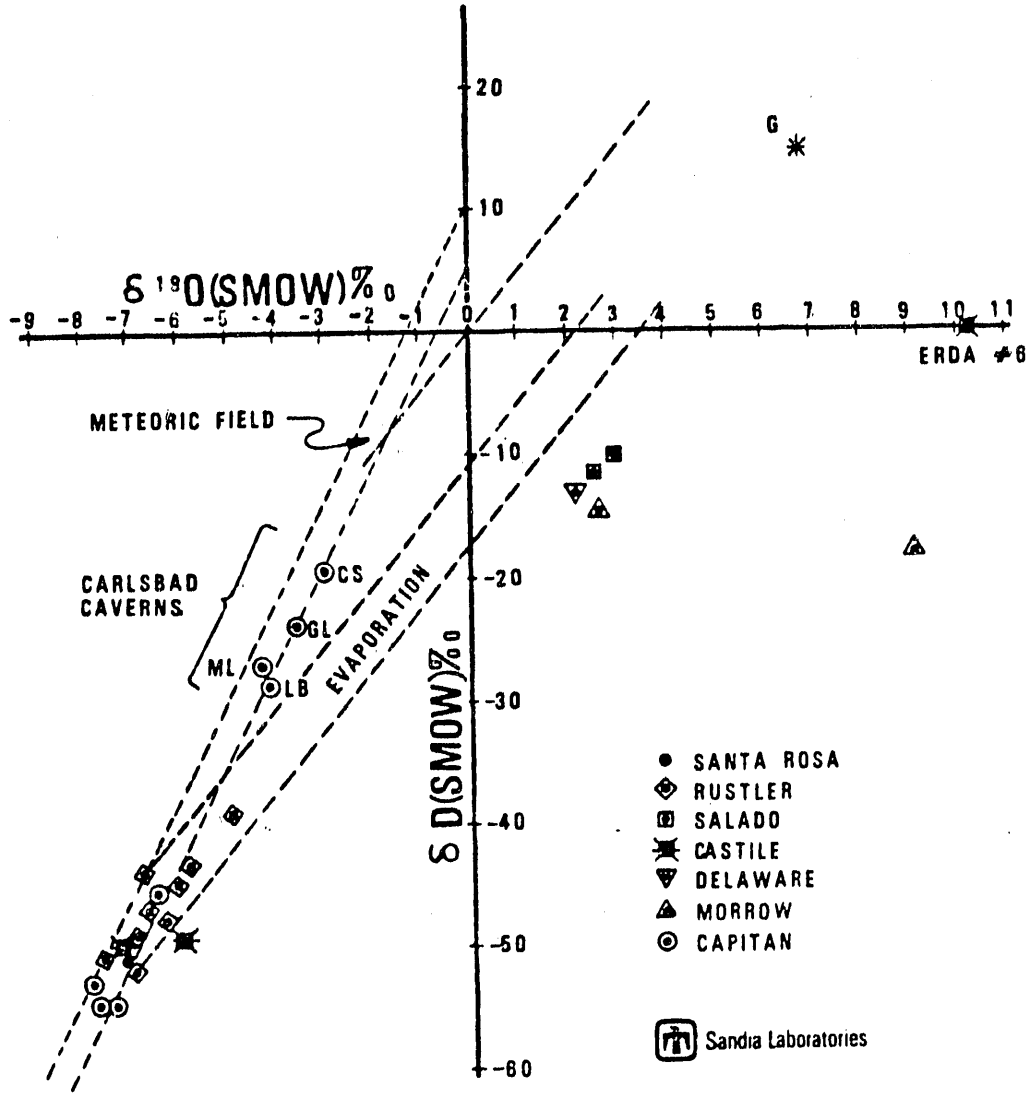


FIGURE 7.12 Stable isotope compositions, δD versus $\delta^{18}O$, for Delaware Basin groundwaters. Relationships are shown for meteoric waters, evaporating meteoric and sea waters. Hypothetical evaporite mother liquor for gypsum (G) is shown for the case in which ERDA No. 6 is taken to be the water of crystallization for that gypsum.

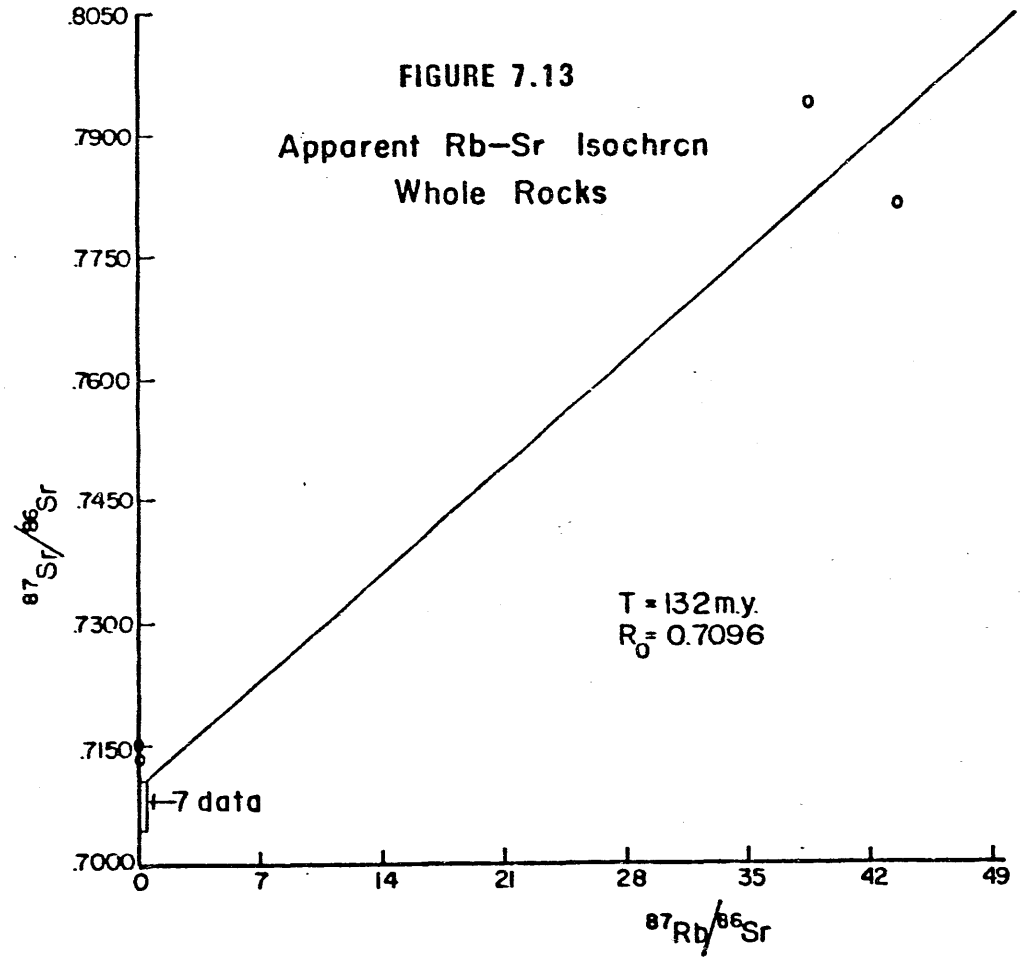


FIGURE 7.13

Apparent Rb–Sr Isochron
Whole Rocks

FIGURE 7.14

Apparent Rb–Sr Isochron
Water Soluble Fraction

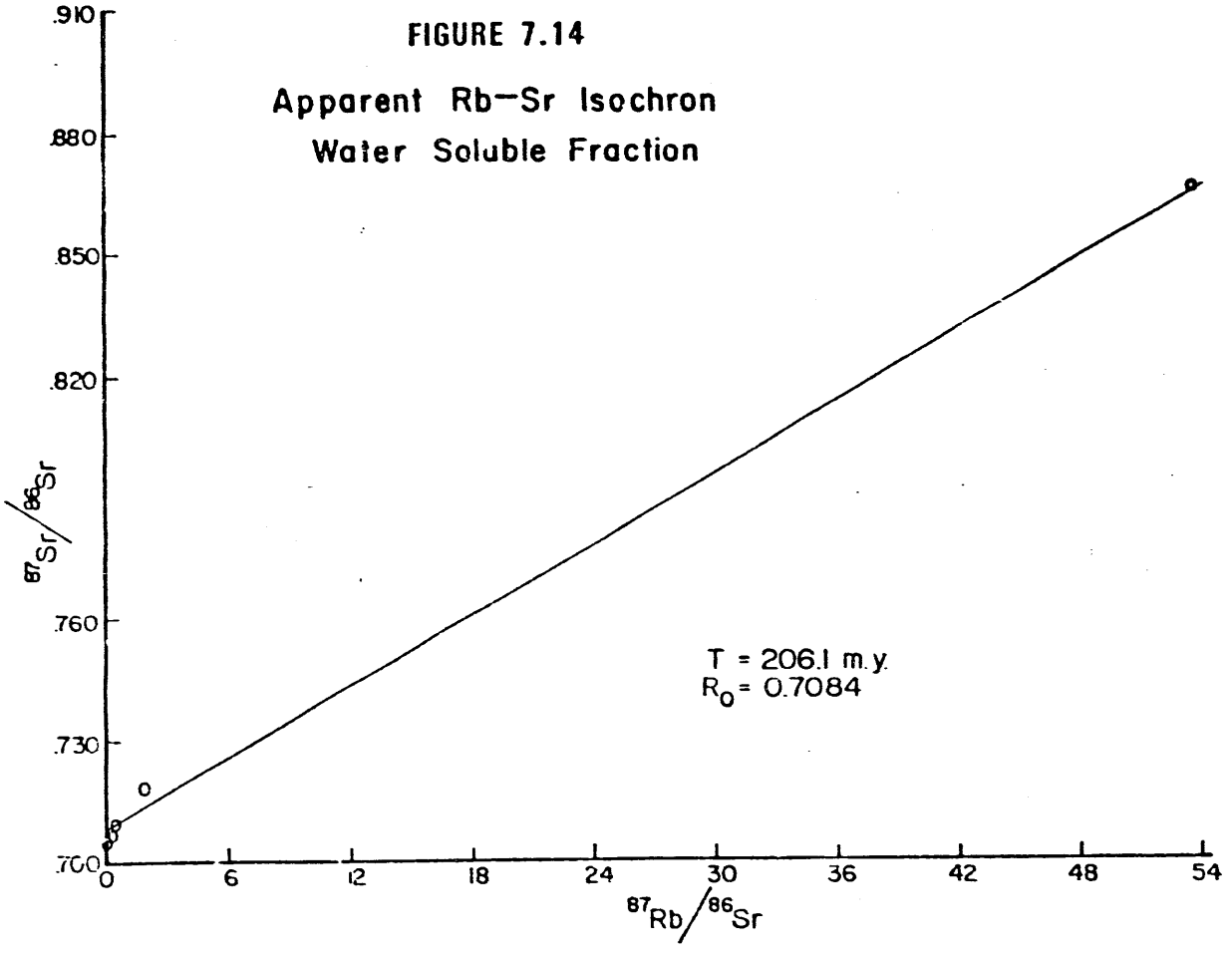
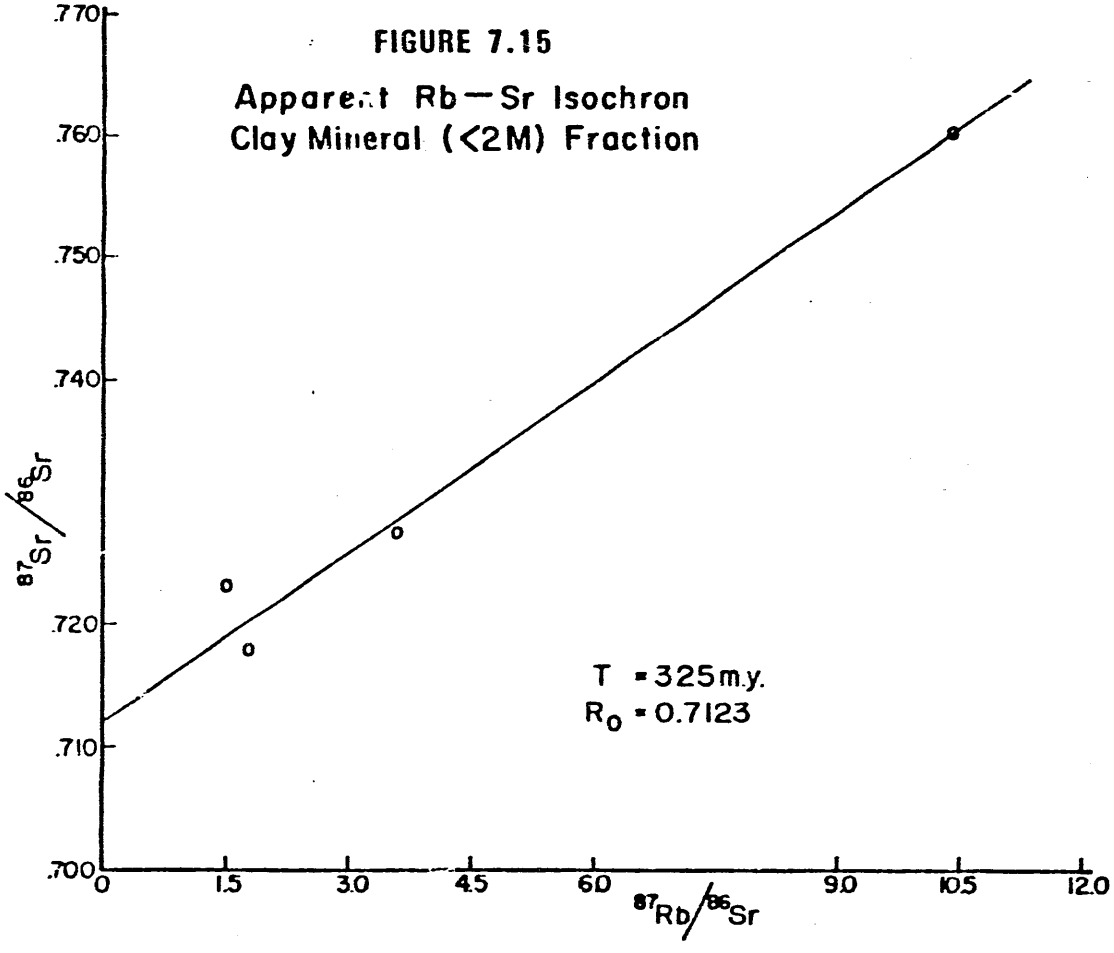


FIGURE 7.15

Apparent Rb—Sr Isochron
Clay Mineral (<2M) Fraction



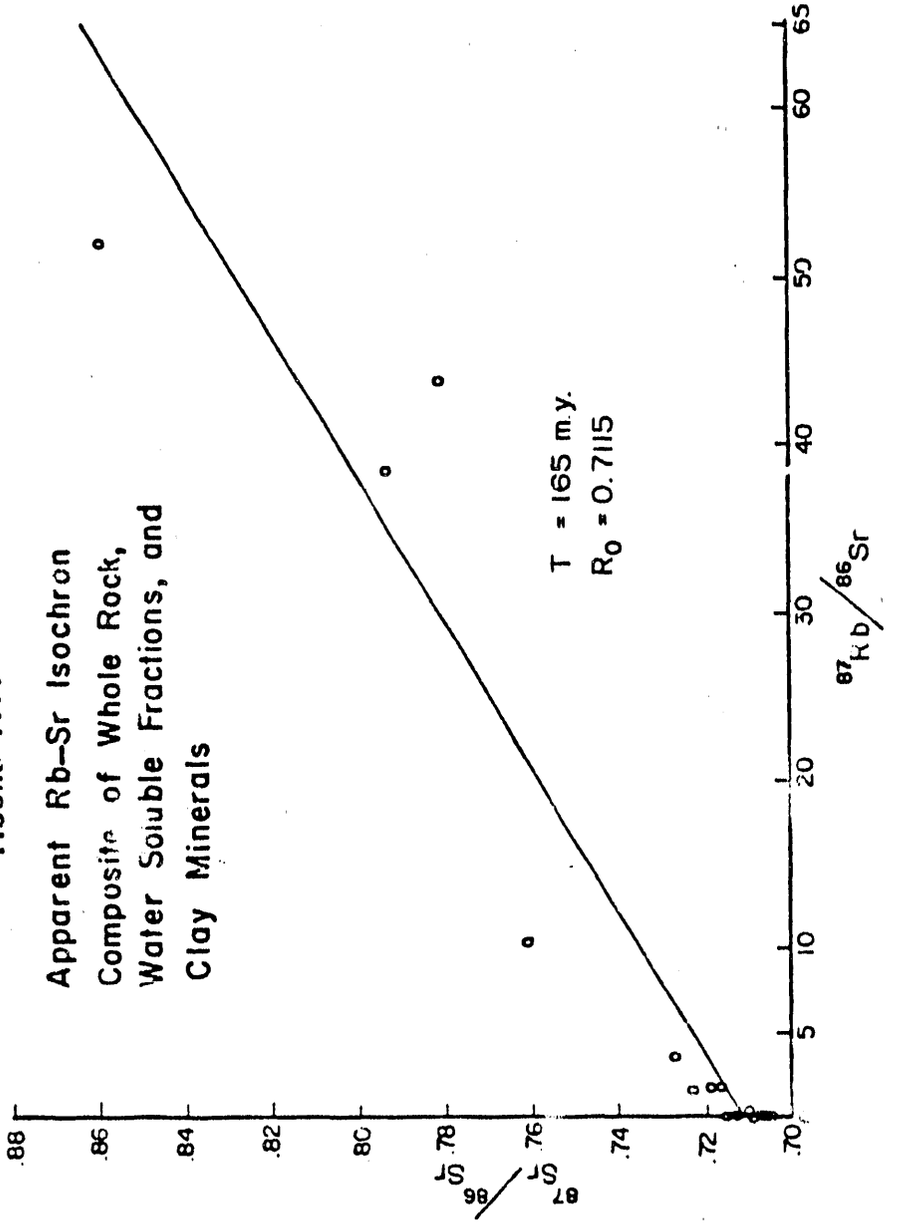
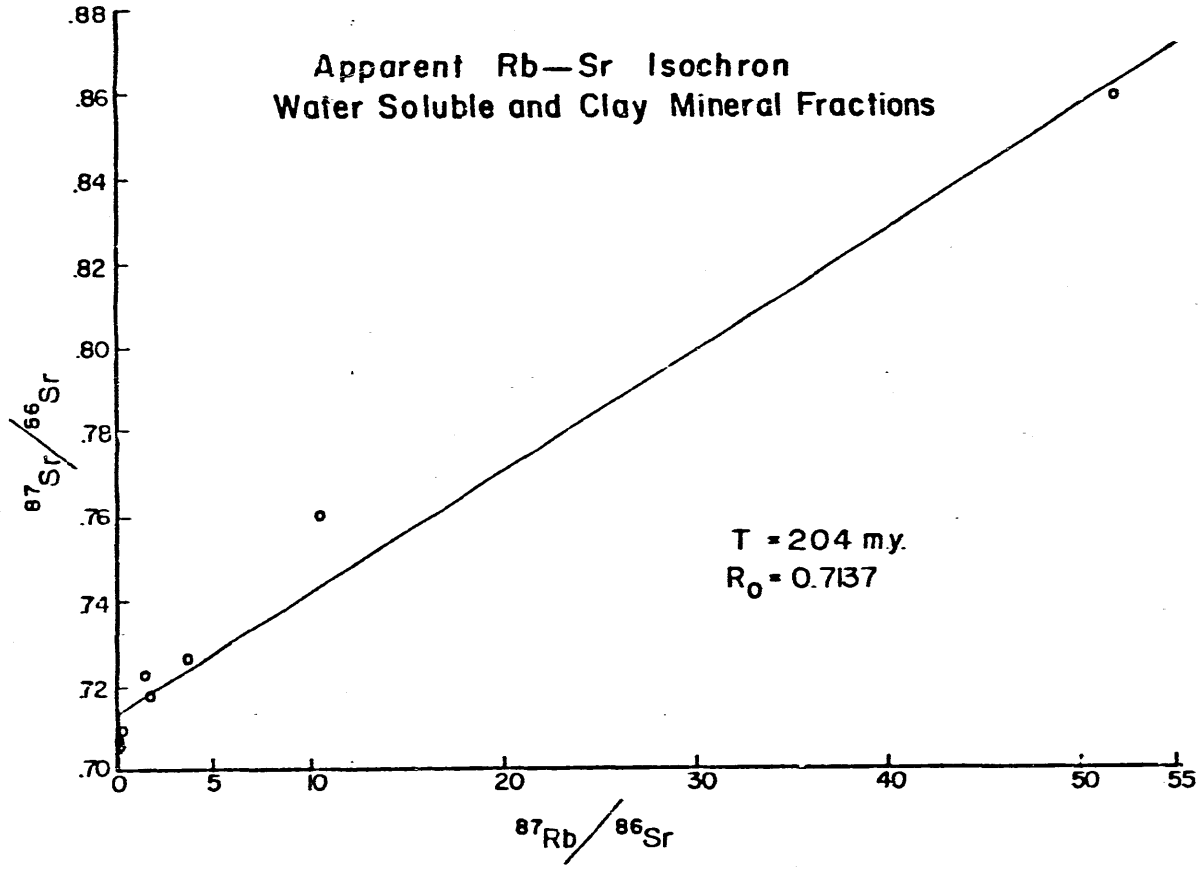


FIGURE 7.16

Apparent Rb–Sr Isochron
Composite of Whole Rock,
Water Soluble Fractions, and
Clay Minerals

FIGURE 7.17


Apparent Rb—Sr Isochron
Water Soluble and Clay Mineral Fractions
T = 204 m.y.
R_o = 0.7137
$^{87}Sr/^{86}Sr$
$^{87}Rb/^{86}Sr$
.88
.86
.84
.82
.80
.78
.76
.74
.72
.70
0
5
10
20
30
40
50
55

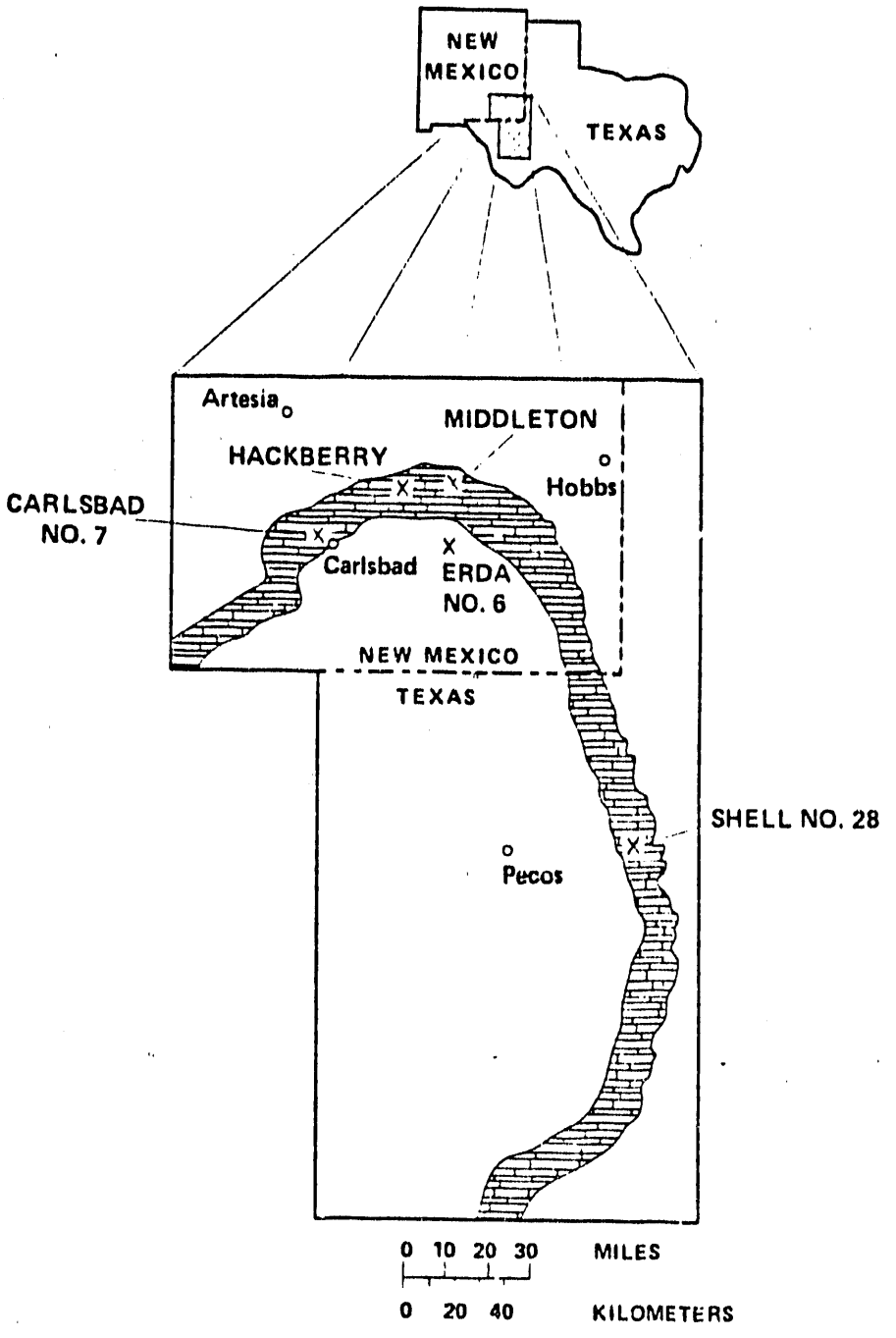


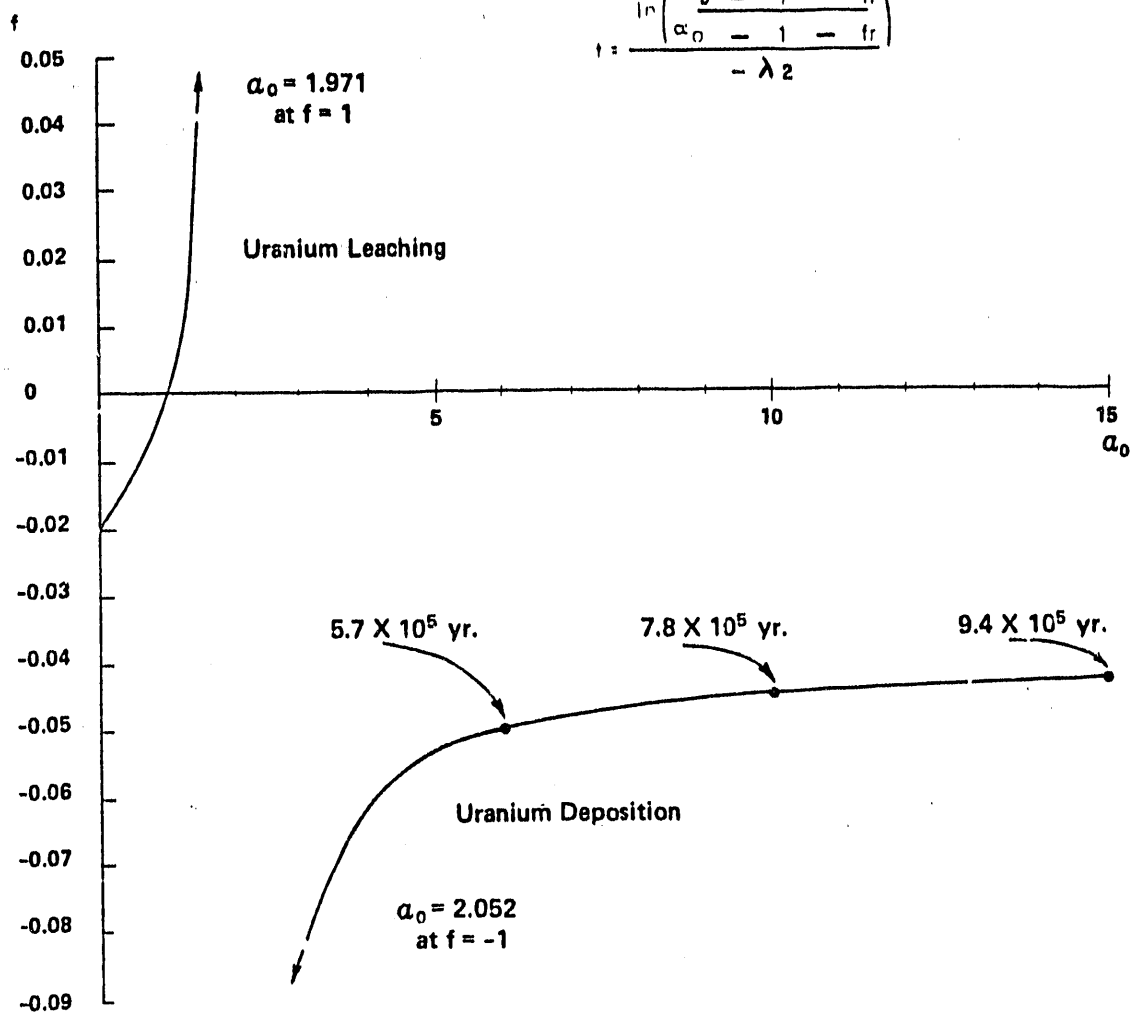
FIGURE 7.18 Map of a portion of the Delaware Basin (southeast New Mexico, west Texas) showing locations of holes whose fluids are sampled for $^{234}U/^{238}U$-disequilibrium age-dating. The brick-pattern shows the surface projection and outcrop of the capitan reef limestone. (from Hiss, 1975)

FIGURE 7.19 Graph of the equation $f = \frac{(\alpha_0 - 1)(\alpha_r - 1)}{\alpha_b - \alpha_0 + r(\alpha_r - 1)}$

for the ERDA No. 6 assemblage of rock and brine, in which $r = 16.42$, $\alpha_r = 1.04$, $\alpha_b = 1.35$.

Uranium disequilibrium ages for the brine are shown according to the equation

$$t = \frac{\ln\left(\frac{\alpha_b - 1 - fr}{\alpha_0 - 1 - fr}\right)}{-\lambda_2}$$



Note that the ERDA No. 6 assemblage is indicative of uranium deposition ($f < 0$) rather than uranium leaching.

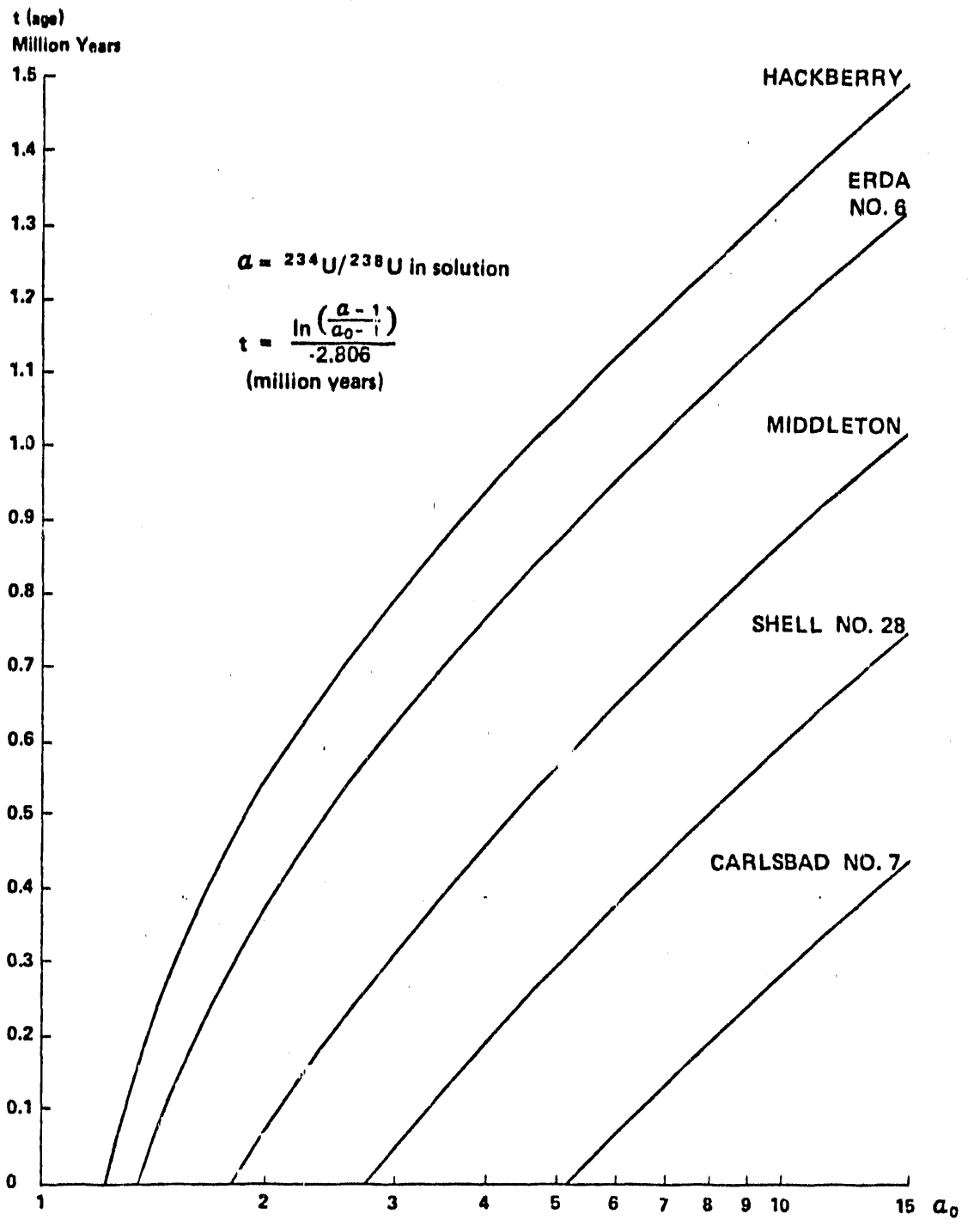


FIGURE 7.20 Uranium disequilibrium ages as a function of original $^{234}U/^{238}U$ ratio, for Delaware Basin groundwaters. These curves are derived from a model involving no exchange or uranium between rock and water.

TABLE 7.1. MINERAL CONTENT OF ERDA #9 CORE SAMPLES (M=MAJOR, T=TRACE).

ERDA 9
CORE #

(DEPTH IN FEET)	ANHYDRITE	CLAY	HALITE	LOEWEITE	MAGNESITE	POLYHALITE	QUARTZ	SYLVITE
1162.7	T	.	M	.	.	.	.	.
1165.7	M	.	M	.	.	.	.	.
1168.0	M	.	T	.	.	.	.	.
1168.8	.	.	M	.	.	.	.	.
1172.8	.	.	M	.	.	M	.	.
1173.4	M	.	.	.	M	.	T	.
1174.1	.	.	M	.	.	M	.	.
1405.7	.	.	M	.	T	.	.	.
1418.8	.	.	.	.	.	M	.	.
1584.0	.	.	M	.	.	.	.	.
1610.0	.	.	M	.	.	.	.	.
1632.4	M	.	.	.	M	.	.	.
1632.8	.	.	.	.	.	M	.	.
1643.5	.	.	M	T	.	.	.	.
2034.7	M	.	M	.	.	.	T	.
2035.7	T	.	M	.	.	.	.	T
2036.3	.	.	M	.	.	.	.	.
2065.0	.	.	M	.	.	.	.	.
2067.5	.	.	M	.	.	T	.	.
2302.6	M	.	T	.	.	M	.	.
2413.7	.	.	M	.	.	M	.	.
2414.2	.	.	M	.	.	M	.	.
2415.6	M	.	M	.	.	.	.	.
2512.0	M	.	M	.	.	.	.	.
2516.3	M	.	M	.	T	.	.	.
2518.8	M	.	.	.	.	.	.	.
2528.7	M	.	.	.	T	.	.	.
2529.0	M	.	T	.	.	.	.	.
2538.5	M	.	.	.	T	.	.	.

TABLE 7.1. MINERAL CONTENT OF ERDA #9 CORE SAMPLES (M=MAJOR, T=TRACE), continued

ERDA 9
CORE #

(DEPTH IN FEET)	ANHYDRITE	CLAY	HALITE	LOEWEITE	MAGNESITE	POLYHALITE	QUARTZ	SYLVITE
2541.0	.	.	M	.	.	.	.	.
2542.0	.	.	M	.	.	.	.	.
2593.2	M	.	.	.	.	.	.	.
2594.5	.	.	M	.	.	.	.	.
2597.0	T	.	M	.	.	.	.	.
2608.9	T	.	M	.	.	.	.	.
26[illegible].7	.	.	M	.	.	.	.	.
2619.6	T	.	M	.	.	.	.	.
2658.5	M	.	M	.	.	.	.	.
2663.3	T	.	M	.	.	.	.	.
2696.4	[illegible]	.	M	.	T	.	.	.
2706.5	.	.	M	.	.	.	.	.
2711.9	T	.	M	.	T	.	.	.
2759.0	T	.	M	.	.	.	.	.
2768.5	M	T	M	.	.	.	.	.
2820.7	M	.	M	.	.	.	.	.
2820.6	T	.	M	.	.	.	.	.
2821.0	T	.	M	.	.	.	.	.
2826.5	T	.	M	.	.	.	.	.
2845.3	M	.	.	.	T	.	.	.
2848.8	M	.	.	.	.	.	.	.

525

TABLE 7.2

Size Distribution of Ground Samples

Mesh	% of Sample *
> 20	5.2
20-28	8.8
28035	19.9
35-65	57.0
65-100	6.1
100-200	2.9
< 200	0.2

*Total ≠ 100 due to rounding

TABLE 7.3

Listing of Minerals Named in Subsection 7.3

Mineral Name	Chemical Composition
Anhydrite	$CaSO_4$
Bloedite	$Na_2 Mg(SO_4)_2 \cdot 4H_2O$
Carnallite	$K Mg Cl_3 \cdot 6 H_2O$
Chlorite	$Mg_5Al_2Si_3O_{10}(OH)_8$
Glaserite	$K_3Na(SO_4)_2$
Glauberite	$Na_2Ca(SO_4)_2$
Gypsum	$CaSO_4 \cdot 2H_2O$
Halite	$NaCl$
Illite	$K_{0.6}Mg_{0.25}Al_{2.3}Si_{3.5}O_{10}(OH)_2$
Iron Oxides (FEOX)	$Fe_2O_3 \cdot XH_2O$
Kainite	$KMgCl\ SO_4 \cdot 11/4\ H_2O$
K-Feldspar	$K\ Al\ Si_3O_8$
Kieserite	$MgSO_4 \cdot H_2O$
Langbeinite	$K_2Mg_2\ (SO_4)_3$
Leonite	$K_2Mg(SO_4)_2 \cdot 4\ H_2O$
Montmorillonite	$Mg_{0.16}\ Al_{2.33}\ Si_{3.67}\ O_{10}(OH)_2$
Polyhalite	$K_2Mg\ Ca(SO_4)_4 \cdot 2\ H_2O$
Quartz	SiO_2
Sylvite	KCl
Talc	$Mg_3\ Si_4\ O_{10}\ (OH)_2$
Thenardite	$Na_2\ SO_4$

TABLE 7.4

ERDA No. 9 Samples Chosen for Silicate Mineralogy

Depth (ft)	Sample	Gross Lithology	Stratigraphic Position
1163.3-1163.6	MB-CS-18	Rock salt	SALADO Fm.
1165.1	MB-CS-16	Anhydrite	
1166.17	MB-CS-17	o Anhydrite	
1167.5	MB-CS-1	Anhydrite	
1168.31	MB-CS-6	Anhydrite w/ halite	
1169.4-1169.5	MB-CS-19	Rock salt	
1172.9	MB-CS-5	Polyhalite	
1173.7-1173.8	MB-CS-20	Rock salt	
1242.5	JL-CS-24	Rock salt	
1242.9-1243.1	JL-CS-18	Polyhalite w/ halite	
1243.6-1243.7	JL-CS-27	Polyhalite w/ halite	
1244.2-1244.5	JL-CS-15	Rock salt w/ polyhalite	
1244.5-1244.8	JL-CS-16	Polyhalite w/ halite and clay	
1244.8	JL-CS-12	o Clay	
1245.0-1245.3	JL-CS-20	Rock Salt	
1246.7-1247.1	JL-CS-21	Rock Salt	
1247.1-1247.2	JL-CS-5	o Clay	
1325.2-1325.4	JL-CS-10	o Polyhalite w/ anhydrite veins	
1327.0-1327.2	JL-CS-23	Polyhalite	
1327.7-1327.8	JL-CS-26	Polyhalite w/ halite	
1328.2-1328.4	JL-CS-25	Polyhalite w/ halite and clay	
1328.6	JL-CS-3	o Clay	
1328.7-1329.8	JL-CS-17	Rock Salt	

TABLE 7.4, continued

Depth (ft)	Sample	Gross Lithology	Stratigraphic Position
1404.6-1404.7	MB-CS-21	Rock Salt	11th ore zone
1418.2	MB-CS-7	Anhydrite with clay seam	
1418.6	MB-CS-8	Polyhalite	marker bed 117
1440.4-1440.6	JL-CS-2	o Polyhalite w/ halite	
1441.0-1441.3	JL-CS-6	o Polyhalite	
1441.7	JL-CS-4	o Clay	
1466.4-1466.6	JL-CS-11	o Polyhalite w/ clay	
1466.3-1467.1	JL-CS-9	o Polyhalite w/ clay	
1467.7-1468.1	JL-CS-22	Rock salt w/ clay	
1468.1	JL-CS-14	o Clay	
1535.6-1535.8	JL-CS-8	Polyhalite w/ anhydrite	
1536.5	JL-CS-7	Anhydrite	
1536.5-1536.6	JL-CS-19	Polyhalite w/ clay	
1537.8-1537.9	JL-CS-18	o Polyhalite w/ anhydrite	
1584.4-1584.5	MB-CS-22	Rock salt	near 5th ore zone
1609 1609.8	MB-CS-23	Rock salt	
1649.4-1649.6	MB-CS-24	Rock salt	near 4th ore zone
2034.5	MB-CS-14	Anhydrite	
2035.6-2035.9	MB-CS-25	Rock salt	
2036.5-2036.7	MB-CS-26	Rock salt	
2037.3	MB-CS-1	o Anhydrite	

TABLE 7.4, continued

Depth (ft)	Sample	Gross Lithology	Stratigraphic Position
2065.3-2065.4	MB-CS-29	Rock salt	
2066.1	MB-CS-28	Rock salt	
2067.0	MB-CS-27	o Rock salt	
2414.8	MB-CS-30	Rock salt	~16 ft above marker bed 143
2512.5	MB-CS-31	o Rock salt	
2517.9	MB-CS-12	Anhydrite)	
2518.3	MB-CS-13	o Anhydrite)	
		)	Cowden Anhydrite
2528.0	MB-CS-11	Anhydrite)	
2541.2-2541.9	MB-CS-32	o Rock salt	
2608.9-2609.5	MB-CS-33	Rock salt	
2615.9-2616.4	MB-CS-41	Rock salt	
2616.4-2616.8	MB-CS-34	Rock salt	
2617.2-2617.7	MB-CS-35	Rock salt	
2705.2-1705.6	MB-CS-37	Rock salt	
2705.8	MB-CS-10	o Rock salt	

TABLE 7.4, continued

Depth (ft)	Sample	Gross Lithology	Stratigraphic Position
2758.2-2758.6	MB-CS-36	o Rock salt	
2819.1-2819.6	MB-CS-39	o Rock salt	
2820.2	MB-CS-15	o Anhydrite	
2[illegible]0.3	MB-CS-2	Anhydrite	
2821.1-2821.7	MB-CS-38	Rock salt	
2827.3-2827.5	MB-CS-40	o Rock salt	
			2829
2846.0	MB-CS-9	o Anhydrite	
2848.4	MB-CS-3	o Anhydrite	CASTILE Fm.
2867.4-2867.6	MB-CS-42	Anhydrite	

o Samples subjected to semi quantitative analysis (see Table 7.10).

TABLE 7.5

Core depths of samples selected for mineralogic-geochemical analysis.

Sample	Depth (ft)
MB-CS-1	1167.5
-2	2820.3
-3	2848.4
-4	2037.3
-5	1172.9
MB-CS-6	1168.3
-7	1418.2
-8	1418.6
-9	2846.0
-10	2705.8
MB-CS-11	2528.0
-12	2517.9
-13	2518.3
-14	2034.5
-15	2820.2
MB-CS-16	1165.1
-17	1166.2
-18	1163.3-1163.6
-19	1169.4-1169.5
-20	1173.7-1173.8
MB-CS-21	1404.6-1404.7
-22	1484.4-1584.5
-23	1609.5-1609.8
-24	1649.4-1649.6
-25	2035.6-2035.9
MB-CS-26	2036.5-2036.7
-27	2067.0
-28	2066.1
-29	2035.3
-30	2414.8

Sample	Depth (ft)
MC-CS-36	2758.2-2758.6
-37	2705.2-2705.6
-38	2821.1-2821.7
-39	2819.1-2818.6
-40	2827.3-2827.5
MC-CS-41	2615.9-2616.4
-42	2867.4-2867.6
JL-CS-1	1441.5
-2	1440.4-1440.6
-3	1328.6
-4	1441.7
-5	1247.1-1247.3
JL-CS-6	1441.0-1441.3
-7	1536.5
-8	1535.6-1535.8
-9	1466.8-1467.1
-10	1325.2-1325.4
JL-CS-11	1466.4-1466.6
-12	1244.8
-13	1467.5
-14	1468.1
-15	1244.2-1244.5
JL-CS-16	1244.5-1244.8
-17	1328.7-1329.8
-18	1537.8-1537.9
-19	1536.5-1536.6
-20	1245.0-1245.3

TABLE 7.5, continued

Core depths of samples selected for mineralogic-geochemical analysis.

Sample	Depth (ft)
MB-CS-31	2512.5
-32	2541.2-2541.9
-33	2608.9-2609.5
-34	2616.4-2616.8
-35	2617.2-2617.7

Sample	Depth (ft)
JL-CS-21	1246.7-1247.1
-22	1467.7-1468.1
-23	1327.0-1327.2
-24	1242.5-1242.8
-25	1328.2-1328.4
JL-CS-26	1327.7-1327.8
-27	1343.6-1343.7
-28	1242.9-1243.1

TABLE 7.6

Quantities of water-leach and EDTA-leach residues in samples from the ERDA-9 core. Sulfate lithologies (anhydrites and polyhalites) and salztons were not subjected to water leach.

Hole Depth (ft)	Sample Number	Bulk wt. (g)	LEACH RESIDUES (Percent of bulk) WATER	EDTA	EDTA Residue wt. (g)	Lithology
1163.5	MB-CS-18	1820	0.005	neg	neg+	rock salt
1165.1	MB-CS-16	40	>90	0.11	.043	anhydrite
1166.2	MB-CS-17	1229	>90	0.20	2.33	anhydrite
1167.5	MB-CS-1	38	>90	0.074	0.027	anhydrite
1168.3	MB-CS-6	358	>75	0.23	0.81	anhydrite
1169.4	MB-CS-19	209	0.36	0.005	0.011+√	rock salt
1172.9	MB-CS-5	40	>90	0.13	0.050	polyhalite
1173.7	MB-CS-20	259	0.012	neg	neg+	rock salt
1242.5	JL-CS-24	655	1.89	*	*	rock salt
1242.9	JL-CS-28	200	>75	0.76	1.52	polyhalite
1243.6	JL-CS-27	200	>75	0.60	1.21	polyhalite
1244.4	JL-CS-15	537	0.013	0.003	0.018	rock salt
1244.6	JL-CS-16	400	>75	1.13	4.51	polyhalite
1244.8	JL-CS-12	#	>90	>90	8.40	salzton
1245.1	JL-CS-20	400	6.18	1.15	4.60	rock salt
1246.8	JL-CS-21	747	0.21	*	*	rock salt
1247.2	JL-CS-5	#	>90	>90	2.70	salzton
1325.3	JL-CS-10	641	29.8	0.26	1.68	rock salt
1327.0	JL-CS-23	350	>75	0.25	0.89	polyhalite
1327.8	JL-CS-26	200	>75	0.30	0.61	polyhalite
1328.3	JL-CS-25	200	>75	1.13	2.26	polyhalite
1328.6	JL-CS-3	#	>90	>90	1.46	salzton
1328.7	JL-CS-17	1765	0.18	0.12	2.09	rock salt

TABLE 7.6, continued

Hole Depth (ft)	Sample Number	Bulk wt. (g)	LEACH RESIDUES (Percent of bulk) WATER	EDTA	EDTA Residue wt. (g)	Lithology
1404.6	MB-CS-21	244	2.5	1.0	2.43	rock salt
1418.2	MB-CS-7	40	>90	20.80	8.32	anhydrite
1418.6	MB-CS-8	1120	>90	0.62	6.94	polyhalite
1440.5	JL-CS-2	200	>75	0.83	1.66	polyhalite
1441.2	JL-CS-6	600	>75	0.13	0.80	polyhalite
1441.7	JL-CS-4	#	>90	>90	2.92	salzton
1466.5	JL-CS-11	400	>75	0.42	1.67	polyhalite
1466.9	JL-CS-9	200	>75	3.99	7.97	polyhalite
1467.9	JL-CS-22	860	4.17	1.22	10.5	rock salt.
1468.1	JL-CS014	#	>90	>90	3.30	saltzon
1535.7	JL-CS-8	400	>75	0.44	1.76	polyhalite
1536.5	JL-CS-7	320	>75	2.63	8.41	anhydrite
1536.6	JL-CS-19	360	>75	0.37	1.33	polyhalite
1537.8	JL-CS-18	400	>75	0.55	2.19	polyhalite
1584.4	MB-CS-22	248	0.53	0.42	1.20+√	rock salt
1609.6	MB-CS-23	473	0.037	0.017	0.081	rock salt
1649.5	MB-CS-24	176	1.6	1.1	1.90+√	rock salt
2034.5	MB-CS-14	104	>90	3.9	4.07	anhydrite
2035.7	MB-CS-25	891	0.23	0.009	0.078+√	rock salt
2036.6	MB-CS-26	810	0.23	0.025	0.20+√	rock salt
2073.3	MB-CS-4	145	>90	5.0	7.28	anhydrite
2065.3	MB-CS-29	1085	0.18	0.11	1.17+√	rock salt
2066.1	MB-CS-28	220	3.3	1.5	3.38	rock salt
2067.0	MB-CS-27	229	2.8	0.83	1.40	rock salt
2414.3	MB-CS-30	421	36.3	0.049	0.21	rock salt

TABLE 7.6, continued

Hole Depth (ft)	Sample Number	Bulk wt. (g)	LEACH RESIDUES (Percent of bulk) WATER	EDTA	EDTA Residue wt. (g)	Lithology
2512.5	MB-CS-31	1073	1.79	0.074	0.074	rock salt
2517.9	MB-CS-12	40	>90	0.024	0.010+	anhydrite
2518.3	MB-CS-13	586	>90	0.55	3.20	anhydrite
2528.0	MB-CS-11	40	>90	0.23	0.094	anhydrite
2541.5	MB-CS-32	891	0.70	0.21	1.83	rock salt
2609.2	MB-CS-33	901	0.043	0.015	0.14+√	rock salt
2616.2	MB-CS-41	811	0.165	0.076	0.62+√	rock salt
2616.6	MB-CS-34	660	0.071	0.004	0.027+√	rock salt
2617.5	MB-CS-35	1015	1.17	0.18	1.83	rock salt
2705.4	MB-CS-37	638	13.3	0.65	4.14	rock salt
2705.8	MB-CS-10	450	>90	2.2	9.87	anhydrite
2758.4	MB-CS-36	421	6.6	0.77	3.25	rock salt
2819.3	MB-CS-39	982	2.2	0.27	2.65	rock salt
2820.2	MB-CS-15	520	>90	0.82	4.25	anhydrite
2820.3	MB-CS-2	640	>90	0.59	3.79	anhydrite
2821.4	MB-CS-38	916	1.25	0.039	0.36	rock salt
2828.7	MB-CS-40	920	1.22	0.13	1.17	rock salt
2846.0	MB-CS-9	200	>90	1.2	2.45	anhydrite
2848.4	MB-CS-3	656	>90	0.90	5.93	anhydrite
2867.5	MB-CS-42	240	>90	0.85	2.04	anhydrite

* Water-leach and EDTA-leach dissolutions of this sample not complete.
# Sample is hand-picked fragment of saltzton.
+ Reported as containing "negligible insoluble residue" Table 7.7.
√ A subsequent second dissolution of a substantially greater quantity of

TABLE 7.7

Relative Abundances of minerals in EDTA-insoluble residues.

Sample	Depth (ft)	EDTA-insoluble residue qtz	feld	hem	clay	<2 μm fraction of residue il	ch	serp	talc	exp
MB-CS-18	1163.5	Negligible insoluble residue								
MB-CS-[illegible]	1165.1	XX	--	--	X	X	a	--	--	XX
MB-CS-17	1166.2	XX	x	--	XX	x	a	--	--	XX
MB-CS-1	1167.5	--	--	--	XX	X	--	--	--	XX
MB-CS-6	1168.3	XX	x	--	XX	x	a	--	--	XX
MB-CS-19	1169.4	Negligible insoluble residue								
MB-CS-5	1172.9	XX	--	--	x	x	--	--	--	XX
MB-CS-20	1173.7	Negligible insoluble residue								
JL-CS-12	1244.8	XX	x	--	XX	X	X	--	--	X
JL-CS-5	1247.2	XX	x	--	XX	XX	X	--	--	X
JL-CS-10	1325.3	a	--	--	XX	--	--	--	--	XX
JL-CS-3	1328.6	XX	X	--	XX	X	X	--	--	X

TABLE 7.7, continued

Relative Abundances of minerals in EDTA-insoluble residues (cont'd).

Sample	Depth (ft)	EDTA-insoluble residue				< 2 μm fraction of residue				
		qtz	feld	hem	clay	il	ch	serp	talc	exp
MB-CS-21	1404.6	XX	a	--	XX	x	x	--	X	XX
MB-CS-7	1418.2	--	x	--	XX	XX	X	--	--	X
MB-CS-8	1418.6	--	a	x	XX	x	x	--	--	XX
JL-CS-2	1440.5	X	XX	a	XX	a	a	--	--	XX
JL-CS-6	1441.2	X	XX	X	XX	XX	X	--	--	X
JL-CS-4	1441.7	--	X	--	XX	XX	X	--	--	X
JL-CS-11	1466.5	--	x	X	XX	XX	X	--	--	X
JL-CS-9	1466.9	XX	x	x	X	XX	X	--	--	XX
JL-CS-14	1468.1	X	X	--	XX	XX	X	--	--	XX

TABLE 7.7, continued

Relative Abundances of minerals in EDTA-insoluble residues (cont'd).

Sample	Depth (ft)	EDTA-insoluble residue qtz	feld	hem	clay	<2 μm fraction of residue il	ch	serp	talc	exp
JL-CS-8	1535.7	--	X	x	XX	XX	x	--	--	XX
JL-CS-7	1536.5	a	--	--	XX	--	--	--	--	XX
JL-CS-18	1537.8	X	--	x	XX	XX	x	--	--	X
MB-CS-22	1584.4	Negligible insoluble residue								
MB-CS-23	1609.6	XX	X	x	XX	XX	X	--	--	XX
MB-CS-24	1649.5	Negligible insoluble residue								
MB-CS-14	2034.5	XX	--	--	x	x	x	--	--	XX
MB-CS-25	2035.7	Negligible insoluble residue								
MB-CS-26	2036.6	Negligible insoluble residue								
MB-CS-4	2037.3	XX	--	--	X	x	x	--	--	XX

TABLE 7.7, continued

Relative Abundances of minerals in EDTA-insoluble residues (cont'd).

Sample	Depth (ft)	EDTA-insoluble residue qtz	feld	hem	clay	< 2 μm fraction of residue il	ch	serp	talc	exp
MB-CS-29	2065.3	Negligible insoluble residue								
MB-CS-28	2066.1	XX	a	--	XX	a	a	--	--	XX
MB-CS-27	2067.0	XX	X	x	XX	x	x	--	--	XX
MB-CS-30	2414.8	XX	X	--	X	a	x	--	--	XX
MB-CS-31	2512.5	X	--	a	XX	x	x	--	--	XX
MB-CS-13	2518.3	X	x	--	XX	a	a	--	--	XX
MB-CS-11	2528.0	--	--	--	XX	--	--	--	--	XX
MB-CS-32	2541.5	X	a	--	XX	X	X	--	--	XX

TABLE 7.7, continued

Relative Abundances of minerals in EDTA-insoluble residues (cont'd).

Sample	Depth (ft)	EDTA-insoluble residue qtz	feld	hem	clay	< 2 µm fraction of residue il	ch	serp	talc	exp
MB-CS-33	2609.2	Negligible insoluble residue								
MB-CS-41	2616.2	Negligible insoluble residue								
MB-CS-34	2616.6	Negligible insoluble residue								
MB-CS-35	2617.5	XX	X	a	XX	XX	X	--	--	XX
MB-CS-37	2705.4	XX	X	a	X	XX	X	--	--	XX
MB-CS-10	2705.8	XX	X	a	X	X	x	--	--	XX
MB-CS-36	2756.4	XX	X	a	X	XX	X	--	--	XX

TABLE 7.7, continued

Relative Abundances of minerals in EDTA-insoluble residues (cont'd).

Sample	Depth (ft)	EDTA-insoluble residue qtz	feld	hem	clay	< 2 μm fraction of residue il	ch	serp	talc	exp
MB-CS-39	2819.3	XX	X	--	X	XX	x	--	--	XX
MB-CS-15	2820.2	XX	--	--	XX	--	a	--	XX	X
MB-CS-2	2820.3	a	X	--	XX	XX	--	--	--	XX
MB-CS-38	2821.4	--	--	--	XX	--	--	XX	--	XX
MB-CS-40	2827.4	--	--	--	XX	--	--	XX	--	XX
MB-CS-9	2846.0	a	--	a	XX	--	--	XX	--	XX
MB-CS-3	2848.4	--	--	--	XX	--	--	X	--	XX

TABLE 7.7, continued

Relative Abundances of minerals in EDTA-insoluble residues (cont'd).

Sample	Depth (ft)	EDTA-insoluble residue				< 2 μm fraction of residue				
		qtz	feld	hem	clay	il	ch	serp	talc	exp
MB-CS-42	2867.5	--	--	--	XX	--	x	X	--	X

Minerals: qtz = quartz; feld = feldspar; hem = hematite; il = illite; ch = chlorite; serp = serpentine; exp = expandable (smectite-bearing).

Relative abundances: XX = dominant constituent; X = major constituent; x = minor constituent; a = accessory constituent. All abundances based on relative intensities of major diffraction maxima.

TABLE 7.8

Low-angle diffraction maxima (Å) of expandable clays in the < 2 μm fraction of the EDTA-insoluble residues.

Sample	Depth (ft)	Air-dried	Glycol-saturated	375°C (> 1hr)	500°C (> 1hr)
MB-CS-16	1165.1	14.5	n.d.	n.d.	n.d.
MB-CS-17	1166.2	13.8, 30.5	15.5, 32.7	13.8, (29.4)	13.6, (25.2)
MB-CS-1	1167.5	14.5	n.d.	n.d.	n.d.
MB-CS-6	1168.3	14.5, (25.2)	15.5, (35.3)	13.6, 31.6	13.2, 11.8, (27.6)
MB-CS-5	1172.9	14.3	n.d.	n.d.	n.d.
JL-CS-16	1244.6	13.8, 29.4	15.5, 11.2, 31.6	n.d.	n.d.
JL-CS-12	1244.8	13.6, 29.4	15.5, 31.5	13.6	13.2
JL-CS-20	1245.1	13.8, (30.5)	15.5, 34.0	n.d.	n.d.
JL-CS-5	1247.2	14.5, 30.5	15.5, 11.2, 31.6	14.3	13.6
JL-CS-10	1325.3	10.2	10.4, (12.1)	9.8	9.8, 11.0-11.9
JL-CS-3	1328.6	14.0, 30.5	15.5, 11.2, 31.6	14.5, (31.6)	12.6-14.7, (22.21)
MB-CS-21	1404.6	13.8, 31.6	15.8, 34.0	13.8, (32.7)	13.4, (29.4)
MB-CS-7	1418.2	13.8, (30.5)	n.d.	n.d.	n.d.
MB-CS-8	1418.6	13.4	15.5, (34.0)	13.6, (27.6)	11.6, (27.6)

TABLE 7.8, continued

Low-angle diffraction maxima (Å) of expandable clays in the < 2 μ m fraction of the EDTA-insoluble residues (cont'd).

Sample	Depth (ft)	Air-dried	Glycol-saturated	375°C (> 1hr)	500°C (> 1hr)
JL-CS-2	1440.5	10.3	10.2, 11.8	9.8	n.d.
JL-CS-6	1441.2	10.7, 13.6, (29.4)	11.3, 15.5, (31.6)	10.2, 13.0-14.3	10.0
JL-CS-4	1441.7	13.8, 31.6	15.5, 31.6	13.8, (29.4)	13.2
JL-CS-11	1466.5	13.8, 11.2, (30.5)	15.2, (32.7)	13.6, (26.0)	n.d.
JL-CS-9	1466.9	14.7	16.1	13.8	13.8
JL-CS-22	1467.9	14.1, 31.6	15.5, 34.0	n.d.	n.d.
JL-CS-14	1468.1	13.6, 30.5	15.5, 32.7	13.6	13.2
JL-CS-8	1535.7	10.3, 13.6	9.4, 11.5, 16.1	9.8, 13.6	9.7
JL-CS-7	1536.5	10.3	9.3, 11.3	9.9	9.8
JL-CS-18	1537.8	14.3, 32.7	15.8, 34.0	n.d.	n.d.
MB-CS-23	1609.6	12.3	n.d.	n.d.	n.d.
MB-CS-14	2034.5	13.8, 30.5	15.2, 31.6	14.0, 11.9, (31.6)	11.3, 13.2, 29.4
MB-CS-4	2037.3	13.5	15.5, 31.6	13.2, (28.5)	13.0

TABLE 7.8, continued

Low-angle diffraction maxima (Å) of expandable clays in the < 2 μm fraction of the EDTA-insoluble residues (cont'd).

Sample	Depth (ft)	Air-dried	Glycol-saturated	375°C (> 1hr)	500°C (> 1hr)
MB-CS-28	2066.1	14.5, 30.5	15.5, 31.6	14.0, (29.4)	13.6, (30.5, 22.1)
MB-CS-27	2067.0	14.7, 29.4	16.7, 32.7	14.0, (29.4)	12.6, (26.0)
MB-CS-30	2414.8	13.8, 11.8, (29.4)	15.8, 12.8, (31.6)	13.8, 11.6, (24.5)	11.6, (26.0)
MB-CS-31	2512.5	12.6	n.d.	n.d.	n.d.
MB-CS-12	2517.9	12.8, 31.6	15.5, 31.6	n.d.	n.d.
MB-CS-13	2518.3	12.6, 26.0	17.0, 25.2	13.2, (26.8)	12.3, 10.3, 26.0
MB-CS-11	2528.0	13.2	n.d.	n.d.	n.d.
MB-CS-32	2541.5	13.8, 29.4	15.5, 31.5	13.4, (26.8)	14.2, (31.6)
MB-CS-35	2617.5	13.8, (29.4)	16.7, 32.7	13.8, (26.8)	12.6, 27.6
MB-CS-37	2705.4	14.5, 30.5	16.4, 34.0	13.8, (29.4)	12.5
MB-CS-10	2705.8	13.4	16.7, (35.3)	14.3, (30.5)	14.3, 11.8, (27.6)
MB-CS-36	2753.4	14.0, 29.4	16.4, 32.7	13.8, (29.4)	12.5, (29.4)

TABLE 7.8, continued

Low-angle diffraction maxima (Å) of expandable clays in the < 2 μm fraction of the EDTA-insoluble residues (cont'd).

Sample	Depth (ft)	Air-dried	Glycol-saturated	375°C (> 1hr)	500°C (> 1hr)
MB-CS-39	2819.3	14.5, 29.4	16.1, 31.6	14.5	13.6, (22.0)
MB-CS-15	2820.2	11.6, (26.8)	14.7, (27.6)	11.6, (24.5)	11.6, (26.8)
MB-CS-2	2820.3	14.5	----	10.4	9.8-17.7
MB-CS-38	2821.4	14.7	----	13.8	13.8
MB-CS-40	2827.4	14.7, 11.3	17.0	14.7	n.d.
MB-CS-9	2846.0	12.3, (24.5)	17.0, (28.5)	10.0 - 13.6, (29.4)	13.4
MB-CS-3	2848.4	12.3, (24.5)	17.3, (27.6)	12.63, (27.6)	11.6, (24.5)
MB-CS-42	2867.5	11.8	17.7	14.7	----

n.d. - data not yet determined

Values in parentheses, e.g. (30.5) represent diffraction maximum present only as shoulder.

TABLE 7.9

Mineralogy of Duval Mine Samples
4th Ore Zone

A. Evaporites

Mine Wall Samples	Halite	Sylvite	Polyhalite	Langbeinite
DV-1A	t	-	VA	-
DV-1B	VA	VA	-	-
DV-1C	VA	-	VA	t
DV-1D	VA	VA	t	-
DV-2A	A	VA	-	t
DV-2B	VA	-	A	-
DV-4A	A	-	VA	t
DV-4B	VA	-	-	-
DV-4C	VA	-	-	t
DV-4D	VA	-	-	t
DV-4E	t	t	-	VA
DV-5A	VA	-	-	-
DV-5B	VA	A	t	-

B. 2 Micron Fractions (Silicates)

Mine Wall Samples	Chlorite	Saponite	Chlorite-Saponite	Illite	Talc	Serpentine	Insoluble Residue (Wt. %)
DV-4B	t	-	VA	VA	t	A	15.7
DV-4C	-	-	VA	VA	t	A	12.3
DV-4D	t	t	VA	A	-	t	32.3
DV-5A	t	t	VA	A	t	A	10.3

VA : very abundant
A : abundant
t : tract
- : not detected

TABLE 7.10

Semiquantitative chemical analysis of EDTA-insoluble fractions from ERDA-9 core.

	MB-CS-17	JL-CS-12	JL-CS-5	JL-CS-10	JL-CS-3	JL-CS-2	JL-CS-6	JL-CS-4
Depth (ft)	1166.2	1244.8	1247.1	1325.3	1328.6	1440.5	1441.2	1441.7
Lithology[+]	Anhydr.	Clay	Clay	Polyhal.	Clay	Polyhal.	Polyhal.	Clay
Weight Percent								
SiO_2	59.	50.	50.	59.	52.	56.	45.	38.
TiO_2	.8	.9	1.2	.2	1.4	.4	.7	1.4
Al_2O_3	12.	13.	15.	12.	15.	6.2	2.5	18.
$FeO^{@}$	1.2	2.4	3.8	1.3	3.2	5.3	14.	4.5
MgO	20.	25.	20.	32.	18.	20.	15.	19.
CaO	.01	.01	.04	.002	.008	.02	.03	.06
Na_2O	1.2	1.2	1.0	1.0	.5	2.4	1.4	1.6
K_2O	1.8	2.3	3.0	.3	3.3	2.9	2.0	4.6

TABLE 7.10, continued

Semiquantitive* chemical analysis of EDTA-insoluble fractions from ERDA-9 core.

	MB-CS-17	JL-CS-12	JL-CS-5	JL-CS-10	JL-CS-3	JL-CS-2	JL-CS-6	JL-CS-4
Depth (ft)	1166.2	1244.8	1247.1	1325.3	1328.6	1440.5	1441.2	1441.7
Lithology+	Anhydr.	Clay	Clay	Polyhal.	Clay	Polyhal.	Polyhal.	Clay
Atom Proportions (al = 1.0)								
Si	4.2	3.2	2.9	4.3	3.0	7.6	15.	1.8
Ti	.04	.04	.05	.01	.06	.04	.2	.05
Al	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Fe	.07	.13	.18	.08	.15	.61	4.0	.17
Mg	2.1	2.3	1.7	3.5	1.6	4.0	7.4	1.3
Na	.16	.15	.11	.14	.06	.64	92	.14
K	.16	.19	.22	.03	.24	.51	.87	.27

TABLE 7.10, continued

Semiquantitive* chemical analysis of EDTA-insoluble fractions from ERDA-9 core.

	JL-CS-11	JL-CS-9	JL-CS-14	JL-CS-18	MB-CS-4	MB-CS-27	MB-CS-31	MB-CS-13
Depth (ft)	1466.5	1467.0	1468.1	1537.8	2037.3	2067.0	2512.5	2518.3
Lithology+	Polyhal.	Polyhal.	Clay	Polyhal.	Anhydr.	Halite	Halite	Anhydr.
Weight Percent								
SiO_2	34.	42.	41.	43.	54	65.	41.	54.
TiO_2	.6	.6	1.2	.6	.8	1.0	.9	.4
Al_2O_3	10.	9.0	14.	8.8	12.	14.	14.	7.0
$FeO^{@}$	23.	3.7	3.3	8.2	3.7	4.7	N.D.	2.1
MgO	19.	29.	22.	21.	21.	9.3	18.	22.
CaO	.005	.005	.001	.03	.062	.02	.02	.04
Na_2O	1.3	.4	1.6	1.2	1.0	3.9	2.2	2.7
K_2O	2.9	2.6	4.1	2.0	1.5	4.1	2.6	2.5

TABLE 7.10, continued

Semiquantitive* chemical analysis of EDTA-insoluble fractions from ERDA-9 core.

	JL-CS-11	JL-CS-9	JL-CS-14	JL-CS-18	MB-CS-4	MB-CS-27	MB-CS-31	MB-CS-13
Depth (ft)	1466.5	1467.0	1468.1	1537.8	2037.3	2067.0	2512.5	2518.3
Lithology+	Polyhal.	Polyhal.	Clay	Polyhal.	Anhydr.	Halite	Halite	Anhydr.
Atom proportions (Al = 1.0)								
Si	2.9	3.9	2.5	4.2	4.0	3.9	2.5	6.2
Ti	.04	.04	.05	.04	.04	.04	.04	.03
Al	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Fe	1.7	.29	.17	.66	.23	.23	--	.20
Mg	2.4	4.0	2.0	3.1	2.3	.83	1.7	3.8
Na	.21	.07	.19	.22	.14	.45	.26	.60
K	.31	.31	.32	.25	.14	.31	.21	.37

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TABLE 7.10, continued

Semiquantitive* chemical analysis of EDTA-insoluble fractions from ERDA-9 core.

	MB-CS-32	MB-CS-10	MB-CS-36	MB-CS-39	MB-CS-15	MB-CS-40	MB-CS-9	MB-CS-3
Depth (ft)	2541.5	2705.8	2758.4	2819.3	2820.2	2827.4	2846.0	2848.4
Lithology+	Halite	Halite	Halite	Halite	Anhydr.	Halite	Anhydr.	Anhydr.
Weight Percent								
SiO_2	37.	61.	70.	67.	52.	33.	42.	44.
TiO_2	.8	.8	.8	.8	.1	.3	.2	.2
Al_2O_3	13.	12.	12.	12.	3.4	5.0	3.1	3.6
$FeO^{@}$	3.4	4.4	3.4	3.3	.7	1.4	2.6	1.5
MgO	30.	17.	11.	13.	33.	29.	35.	37.
CaO	.002	.01	.1	.06	.007	1.0	.003	.003
Na_2O	1.0	2.9	2.3	2.1	1.6	.9	2.6	1.9
K_2O	1.7	1.8	1.4	1.8	.6	.9	3.3	.7

TABLE 7.10, continued

Semiquantitive* chemical analysis of EDTA-insoluble fractions from ERDA-9 core.

	MB-CS-32	MB-CS-10	MB-CS-36	MB-CS-39	MB-CS-15	MB-CS-40	MB-CS-9	MB-CS-3
Depth (ft)	2541.5	2705.8	2758.4	2819.3	2820.2	2827.4	2846.0	2848.4
Lithology+	Halite	Halite	Halite	Halite	Anhydr.	Halite	Anhydr.	Anhydr.
Atom proportions (Al = 1.0)								
Si	2.5	4.5	5.1	4.7	13.	5.6	11.	10.
Ti	.04	.04	.04	.04	.02	.04	.04	.04
Al	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Fe	.19	.27	.21	.19	.15	.20	.59	.30
Mg	2.8	1.8	1.2	1.3	12.	7.3	14.	13.
Na	.13	.41	.33	.29	.77	.30	1.4	.87
K	.15	.17	.13	.16	.19	.19	1.1	.21

* Calculated from 1:1 linear regression; matrix effects and other than unit regression slope not yet included.

\+ Anhydr. = anhydrite; polyhal. = polyhalite.

@ Total iron as FeO.

TABLE 7.11

Mineralogy of Cores from ERDA No. 9

Core Footage	Gross Lithology (listed in decreasing order of (trace amount)	Bulk Mineralogy by X-ray Diffraction abundance, lower case indicates
1168.1	Anhydrite Halite Magnesite	Anhydrite Magnesite
1168.55	Anhydrite Halite Polyhalite	Anhydrite Halite Polyhalite
1173.5	Halite "Brown Material"	Halite Polyhalite trace 12A° (expandable) clay
1173.5	silty claystone or anhydrite	Anhydrite Polyhalite
1584.4	Halite "brown material" anhydrite	Halite polyhalite
1649.7	Halite polyhalite anhydrite	Halite polyhalite
2066.8	Halite '"brown material"	Halite [illegible]ydrite quartz [illegible]gnesite [illegible]ace 10A° clay (illite) trace 14A° clay (chlorite)

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TABLE 7.11, continued

Mineralogy of Cores from ERDA No. 9

Core Footage	Gross Lithology (listed in decreasing order of abundance, lower case indicates (trace amount)	Bulk Mineralogy by X-ray Diffraction
2067.4	see 2066.8	Halite polyhalite quartz? trace 12A° (expandable) clay
2302	Polyhalite "White Material"	Anhydrite Polyhalite
2414.7	Polyhalite Halite Anhydrite	Halite Polyhalite
2415.0	see 2414.7	Polyhalite Anhydrite
2415.4	see 2414.7	Anhydrite
2529.5	Anhydrite magnesite?	Anhydrite Halite Magnesite
2538.5	Anhydrite Halite	Anhydrite Halite
2619.5	Halite anhydrite or magnesite	Halite Anhydrite
2820 B	Anhydrite Halite magnesite	Anhydrite Halite

TABLE 7-12

Weight Losses Observed Upon Heating of ERDA No. 9 Cores

Specimen No. (depth)	Total Weight-Loss (%)	Mass-Loss (%) At Mean Temperature Ranges		
		100°C	300°C	450°
2034.7	1.60	0.70	0.36	.057
2035.7	0.20	----	----	----
2065.0	0.35	----	----	----
2067.5	0.52	----	----	----
2302.6	5.40	----	5.10	0.17
2413.7	1.38	----	1.00	----
2414.2	3.13	----	2.90	----
2415.6	0.10	----	----	----
2512.0	0.14	----	----	----
2516.3	2.15	----	----	1.55
2518.8	0.32	----	----	----
2528.7	2.12	----	----	1.52
2529.0	3.12	----	----	2.94
2538.5	1.55	----	----	1.20
2542.0	6.39	----	6.19	0.20
2593.2	1.47	----	----	1.20
2594.5	0.36	----	----	----
2597.0	0.37	----	----	----
2608.9	0.17	----	----	----
2614.4	0.13	----	----	----
2619.6	0.22	----	----	----
2658.5	0.48	----	0.10	0.17
2663.3	0.50	----	----	0.29
2696.4	1.12	----	----	0.80
2706.5	0.37	----	----	----
2711.9	0.47	----	----	0.21
2759.0	0.28	----	----	----
2786.5	3.64	2.27	----	0.90
2820.7A	0.36	----	----	0.17
2820.6B	0.35	----	----	0.12
2821.0	0.40	----	0.19	----
2826.5	0.36	----	0.27	----
2845.3	1.42	----	----	1.21
2848.8	0.80	----	----	0.53

TABLE 7.13

Data on the volume percent of fluid now present in the salt cores from ERDA No. 9.

Depth interval (feet)	Type Sampled	Volume sampled (mm^3)	Approx. grain size (mm)	Fraction of total slide	Fluid % by vol.	Total % by vol., whole slide
1799.0-1799.5	B	500	5 to 10	1/4	1.66	0.54
	A	500	1 to 5	3/4	[illegible]17	
1902.0-1902.3	B	500	2 to 8	1/5	0.866	0.26
	A	500	0.5 to 3	4/5	0.11	
2065.0-2065.4	B	500	20 to 50	5/6	3.4	2.86
	A	500	20 to 50	1/6	0.20	
2095.1-2095.5	B	500	3 to 15	1/10	2.58	0.29
	A	500	3 to 15	9.10	0.039	
2274.4-2272.7	(B	470	10 to 15	1/2	2.29	1.23
	(A	470	5	1/2	0.17	
" "	(B	510	5 to 7	2/5	0.86	0.36
	(A	510	1 to 3	3/5	0.02	
" "	(B	520	5 to 7	1/3	0.55	0.20
	(A	520	1 to 3	2/3	0.02	
2391.0-2391.3	B	460	10 to 15	1/10	[illegible].17	0.22
	A	460	3 to 10	9/10	0.12	
2611.5-2611.8	B	530	5 to 25	1/5	0.79	0.17
	A	530	2 to 5	4/5	0.015	
2658.7-2659.0	B	360	5 to 10	1/4	1.18	0.32
	A	360	2 to 8	3/4	0.039	

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TABLE 7.13, continued

Data on the volume percent of fluid now present in the salt cores from ERDA No. 9.

Depth interval (feet)	Type Sampled	Volume sampled (mm^3)	Approx. grain size (mm)	Fraction of total slide	Fluid % by vol.	Total % by vol., whole slide
2760.0-2760.2	B	460	5 to 8	1/5	0.96	0.40
	A	460	3 to 5	4/5	0.27	
2820.8-2821.2	B	490	3 to 8	1/4	0.87	0.4
	A	490	2 to 5	3/4	0.31	

TABLE 7.14

Homogenization temperatures (°C) of two-phase liquid + gas inclusions from ERDA No. 9 core (numbers of inclusions run given in parentheses)

Depth interval	Homogenization temperatures
1799.0-1799.5	20.5(1), 21.0(1), 25(3)
1902.0-1902.3	25.1(1)
2065.0-2065.4	(none)
2095.1-2095.5	25.6(2), 34.5(1), 44.0(1), 45.5(2)
2272.4-2272.7	41.25(1), 42.5(1), 42.6(3)
2391.0-2391.3	23(4), 39(1)
2611.5-2611.8	(none)
2658.7-2659.0	43.0(1), 43.25(1), 43.5(1), 44(2), 45.0(1)
2760.0-2760.2	20.4(1), 21.6(1), 21.8(2)
2820.8-2821.2	22.5(1), 23.0(1), 25.5(1)

TABLE 7.15

Summary of freezing data (°C), mainly on type B inclusion in samples from ERDA No. 9 core

Depth	First melting temp.	Freezing temp.	Notes
1799	<-31.9	> +10	~20% liquid at -31.9
1902	<-32	> +10	
2095	<-28.4	+15	~20-25% xls at 0°C
"	-32.2	"	
2272	<-32.8	+11.8	~50% xls at 0°C
2391	< -26.1	> +12.8	
2760	<-32	> +12.7	

TABLE 7.16

Test data and weight loss (in %) from decrepitation tests.
Roman numerals indicate amount of sample breakup after run:
I - unbroken; II - broken into 2 or 3 pieces;
III - broken into more than 3 pieces.

	Temperature, °C		
Core interval (ft)	150	200	250
2058.8 - 2059.0	0.16 II	0.23 II	0.76 III
2070.4 - 2070.6	0.16 II	0.12 I	0.35 III
2606.5 - 2606.9	0.02 I	0.24 II	0.95 III
2617.2 - 2617.7	0.06 I	0.30 I	0.62 II
2626.7 - 2627.0	0.19 I	0.28 I	1.04 III
2659.0 - 2659.2	0.14 I	0.13 I	0.59 III
2665.0 - 2665.1	0.19 I	0.18 I	0.75 III
2692.4 - 2692.6	0.06 I	0.26 I	0.83 III
2699.8 - 2700.0	0.19 I	0.24 II	0.65 III
Average	0.13	0.22	0.73
Heating schedule (hours)			
Room T to run T	7	9.5	8
Hold at run T	79	95	79
Run T to room T	~9	~9	~10

LE 7.17

Temperature of homogenization and volume % vapor of two-phase inclusions in salt of samples after decrepitation tests.

Decrepitation run temp. (°C)	Homogenization temp. (°C) Minimum	Maximum	Number of inclusions runs	Volume % vapor phase; avg. for ~25 inclusions
150	90	120	16	0.8
200	110	180	21	1.8
250	180	273	28	5.0

Note: Birefringent crystals, present in some of these inclusions, do not disappear during homogenization runs.

TABLE 7.18

Temperature of homogenization of two-phase inclusions in salt from near dike in Kerr-McGee mine, Lea County, New Mexico.

Sample no.	Distance from dike (m)	Temp. of homogenization (°C)		Number of inclusions run
		Minimum	Maximum	
MB-77-8	0.01 - 0.02	71	116	7
MB-76-3	0.2	60	110	6
MB-76-4	2.5	85	88*	9

* Two birefringent crystals remained unchanged, and a cubic crystal (KCl ?) dissolved at 82°C. (See Plate 7-42 for a similar inclusion.)

TABLE 7.19

INVENTORY OF FLUIDS SAMPLED FOR GEOCHEMICAL STUDIES
OF DELAWARE BASIN GROUNDWATERS

Sample No.	Sample Name	Formation Sampled	Location	Solutes	Stable Isotopes	Solute *Analyst
1	Carlsbad City #7	Capitan	T22S-R26E-S1	X	X	M
2	Duval Mine/Collector Ring	Rustler	T22S-R30E-S33	X	X	M
3	Duval Mine/Seep-BT26	Salado	T22S-R30E-S33	X	X	S
4	Duval Mine/Seep-BT48	Salado	T22S-R30E-S33	X	X	M
5	Duval Mine/Seep-BT58	Salado	T22S-R30E-S33	X		M
6	James Ranch	Rustler	T23S-R31E-S5	X	X	M
7	Fairview	Rustler	T23S-R32E-S36	X	X	M
8	Todd State 36-1	Morrow	T23S-R31E-S36	X	X	M
9	Todd Federal 26-4	Bell Canyon	T23S-R31E-S26	X	X	M
10	Todd Federal 26-1	Morrow	T23S-R31E-S26	X	X	M
11	Shell No. 28	Capitan	PSL Blk 74-S34 (Texas)	X	X	M
12	Middleton	Capitan	T19S-R32E-S21	X	X	M
13	Hackberry	Capitan	T19S-R31E-S31	X	X	M
14	FRDA #6	Castile	T21S-R31E-S35	X	X	S
15	Shell Bootleg	Castile	T22S-R32E-S36	X		Sh
16	Duval Mine/Vent Hole	Salado	T22S-R30E-S33	X		M
17	UNM Pokorny	Castile	PSL Blk 61-S3, Texas)	X	X	M
18	Smith Livingston Ridge	Santa Rosa	T22S-R31E-S15		X	
19	Indian	Rustler	T22S-R30E-S[illegible]		X	
20	Mobley	Rustler	T22S-R30E-S19		X	
21	Mobley #3	Rustler	T22S-R30E-S2		X	
22	H1-Magenta	Rustler	R22S-R31E-S29	X	X	U
23	H1-Culebra	Rustler	T22S-R31E-S29	X	X	U
24	H3-Magenta	Rustler	T22S-R31E-S29	X	X	U
25	H3-Culebra	Rustler	T22S-R31E-S29	X	X	U
26	Green Lake	Capitan	Carlsbad Caverns		X	
27	Mirror Lake	Capitan	Carlsbad Caverns		X	
28	Longfellow's Bathtub	Capitan	Carbsbad Caverns		X	
29	Celery Stalk Pool	Capitan	Carlsbad Caverns		X	

* Analysts: M - Martin Water Laboratories
S - Sandia
Sh - Shell
U - U.S. Geological Survey

TABLE 7.20

GEOCHEMICAL ANALYSES OF DELAWARE BASIN GROUNDWATERS
(Solutes in mg/l)

No.	pH	$\delta^{18}O$ °/oo	δD °/oo	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	Br^{-}	SO_4^{+}	HCO_3^{-}	TDS	Other Information
T 1	7.2	- 7.9	-54	74	29	8	1	10	0	72	285	474	NO_3:5
2	7.4	- 6.4	-48	1100	280	3600	405	6400	0	2500	122	14380	Sr:30
3	5.5	+ 3.0	-10	640	55400	27500	3000	236500	305	3650	1090	355085	BO_3:660
4	5.4	+ 2.6	-12	500	62600	44400	30250	251500	530	3300	1170	395000	BO_3:840
5	5.5			520	62000	46300	30250	250000	582	3100	1170	395000	BO_3:990
6	7.6	- 5.0	-40	590	175	68	5	400	0	1570	190	3240	NO_3:225
7	7.6	- 7.1	-53	590	200	120	3	142	0	2140	130	3350	
8	6.4	+ 2.7	-15	1600	240	11300	500	20600	23	300	380	35600	Sr:240
9	7.1	+ 2.2	-13	27600	6075	76700	1700	18500	410	210	215	295400	Sr:1750
10	6.6	+ 9.2	-18	4880	920	28700	200	55400	90	30	300	92400	Sr:1750
11	7.1	- 7.7	-56	940	280	2280	57	3900	0	2400	550	11300	
12	7.4	- 7.5	-55	1100	570	10600	330	17050		3720	300	33800	Sr:64
13	6.0	- 6.5	-46	2200	1680	68700	2950	110800		5150	132	192000	Sr:140,Fe:312
14	7.3	+10.3	0	130	350	112600	5100	186100	240	16000	1310	321000	BO_3:650,Li:160
15	7.7			550	1860	124500		185000		16800	1480	330700	
16	5.8			1260	38500	49000	52500	241500	385	3600	700	388650	BO_3:1160
17	1.6	- 6.0	-50	190	100	200	18	2700	0	570	0	3800	
18		- 7.2	-52										
19		- 6.3	-46										
20		- 6.9	-44										
21		- 5.9	-44										
22	7.4	- 6.8	-48	890	270	5700	70	8000		3900	92	18922	
23	7.6	- 7.0	-50	780	280	9400	190	12000		7400	105	30155	
24	7.4	- 7.3	-53	760	190	4200	100	5800		2600	1150	14800	
25	7.4	- 7.0	-53	1500	720	19000	450	33000		5200	88	60000	
26		- 3.6	-24										
27		- 4.3	-28										
28		- 4.2	-29										
29		- 3.0	-20										

TABLE 7.21

DUVAL MINE VENT HOLE WATER #16

One liter of solution might be expressed as the following amounts of common evaporite minerals:

0.006 moles	(1 gm)	$CaMg(CO_3)_2$	Dolomite
0.026 moles	(4 gm)	$CaSO_4$	Anhydrite
0.012 moles	(3 gm)	$KMgClSO_4 \cdot 11/4H_2O$	Kainite
1.343 moles	(370 gm)	$KMgCl_3 \cdot 6H_2O$	Carnallite
0.224 moles	(46 gm)	$MgCl_2 \cdot 6H_2O$	Bischofite
0.005 moles	(2 gm)	$Na_2B_4O_7 \cdot 10H_2O$	Borax
2.121 moles	(121 gm)	$NaCl$	Halite

TABLE 7.22

TODD FEDERAL 26-4 WATER #9

One liter of solution might be expressed as the following amounts of common evaporite minerals:

0.10 moles	(52 gm)	$CaMg_2Cl_6 \cdot 12H_2O$	Tachyhydrite
0.04 moles	(4 gm)	$KMgCl_3 \cdot 6H_2O$	Carnallite
0.59 moles	(129 gm)	$CaCl_2 \cdot 6H_2O$	Antarcticite
3.34 moles	(195 gm)	NaCl	Halite

TABLE 7.23

ERDA 6 WATER #14

One liter of solution might be expressed as the following amounts of common evaporite minerals:

0.003 moles	(1 gm)	$CaMg(CO_3)_2$	Dolomite
0.009 moles	(1 gm)	$MgCO_3$	Magnesite
0.011 moles	(3 gm)	$KMgClSO_4 \cdot 11/4H_2O$	Kainite
0.130 moles	(9 gm)	KCl	Sylvite
0.155 moles	(22 gm)	Na_2SO_4	Thenardite
0.048 moles	(14 gm)	LiCl	?
4.521 moles	(265 gm)	NaCl	Halite

TABLE 7.24

Rb-Sr Data for Evaporites from the Salado Formation

A. Whole Rocks

Core hole Interval	$(^{87}Sr/^{86}Sr)_N$	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$
AEC-8				
1622.4-1622.9	0.7056	5.0	112.4	0.13
1636.6-1637.1 (sylvite rich portion)	0.7816	120.1	8.0	43.77
1645.0-1645.3	0.7150	0.40	48.2	0.02
1671.2-1671.8	0.7097	5.6	39.8	0.41
1715.4-1715.7	0.7089	0.07	90.9	0.02
1762.0-1762.3	0.7099	1.3	37.9	0.10
1782.2-1782.4	0.7137	0.30	5.7	0.15
ERDA-9				
1404.8-1405.8	0.7934	67.1	5.1	38.41
1648.5-1649.0	0.7079	0.47	44.7	0.03
1759.1-1759.8 (polyhalite rich portion)	0.7064	4.9	793.5	0.02
ERDA-6				
1421.0-1421.7	0.7095	0.60	156.2	0.01

B. Water Soluble Portions

ERDA-8				
1607.0-1608.0	0.7173	26.7	44.7	1.73
ERDA-9				
1408.8-1405.8	0.8601	70.8	4.0	51.87
1709.0-1709.5	0.7094	0.99	8.5	0.34
1713.6-1714.0	0.7072	2.0	34.1	0.17
1772.0-1772.4	0.7067	1.5	57.7	0.07

C. <2 Micron Fractions (Clays)

AEC-8				
1607.0-1608.0	0.7229	42.9	82.2	1.51
1671.2-1671.8	0.7273	43.9	35.2	3.62
ERDA-9				
1404.8-1405.8	0.7608	84.5	23.6	10.40
1772.0-1772.4	0.7181	29.4	48.1	1.76

TABLE 7.25

% Insoluble Residue in Whole Rock

Core hole Interval	Insoluble Residue (percent)
AEC-8	
1607.0-1608.0	9.0
1610.8-1611.3	9.0
1622.4-1623.9	2.0
1636.6-1637.1	3.7
1645.0-1645.3	0.8
1671.2-1671.8	11.3
1715.4-1715.7	1.1
1782.2-1782.4	12.5
ERDA-9	
1404.8-1405.8	7.2
1621.9-1622.2	0.8
1633.6-1634.1	0.4
1648.5-1649.0	2.1
1652.8-1653.1	0.3
1709.0-1709.5	1.1
1713.6-1714.0	18.2
1759.1-1759.8	0.7
1772.0-1772.4	12.6

TABLE 7.26

Mineralogical Data

Core hole Interval	Halite	Sylvite	Polyhalite	Langbeinite
A. Whole Rocks (Evaporite Mineralogy by XRD)				
AEC-8				
1607.0-1608.0	VA	VA	-	-
1610-8-1611-3	VA	A	-	-
1622.4-1622.9	VA	A	-	-
1636.6-1637.1	VA	VA	t	-
1645.0-1645.3	VA	t	-	-
1671.2-1671.8	VA	t	t	-
1715.4-1715.7	VA	t	-	-
1762.0-1762.3	VA	t	-	-
1782.2-1782.4	A	A	A	t
ERDA-9				
1404.8-1405.8	A	t	VA	VA
1621.9-1622.2	VA	t	-	-
1633.6-1634.1	VA	t	-	-
1648.5-1649.0	VA	A	-	-
1652.3-1653.1	VA	t	-	-
1709.0-1709.5	VA	A	-	-
1713.6-1714.0	VA	A	-	-
1759.1-1759.8	VA	A	t	-
1772.0-1772.4	VA	A	t	-
ERDA-6				
1421.0-1421.7	VA	t	-	-

TABLE 7.26, continued

Mineralogical Data

Core hole Interval	Halite	Sylvite	Polyhalite	Langbeinite

B. 2 Micron Fractions (Clays, Minerals)

Core Hole Interval	Chlorite	Saponite	Chlorite/ Saponite	Illite	Talc	Serpentine
AEC-8						
1607.0-1608.0	-	-	VA	A	t	A
1610.8-1611.3	t	-	A	A	-	A
1622.4-1622.9	-	-	t	A	A	t
1636.6-1637.1	-	-	A	VA	t	t
1645.0-1645.3	t	-	A	A	t	A
1671.2-1671.3	-	-	VA	A	-	t
1715.4-1715.7	A	-	t	VA	-	VA
1762.0-1762.3	t	t	-	A	A	t
1782.2-1782.4	A	-	t	VA	VA	A
ERDA-9						
1404.8-1405.8	-	-	A	VA	t	A
1648.5-1649.0	A	-	A	VA	VA	VA
1713.6-1714.0	-	-	VA	A	A	VA
1772.0-1772.4	-	-	VA	A	t	A
ERDA-6						
1421.0-1421.7	-	-	t	t	VA	t

VA: very abundant
A: abundant
t: trace
-: not detected

TABLE 7.27

URANIUM CONCENTRATIONS AND ISOTOPIC RATIOS IN DELAWARE BASIN WATERS

Sample	U Concentration	$\alpha(^{234}U/^{238}U)$	$\delta^{18}O$ (SMOW)‰	δD (SMOW)‰
Shell	0.60 parts in 10^9	2.75	-7.7	-56
Middleton	0.54 parts in 10^9	1.81	-7.5	-55
Hackberry	0.02 parts in 10^9	1.22±0.05	-6.5	-46
Carlsbad 7	0.05 parts in 10^9	5.14	-7.9	-54
ERDA 6 1140 hr.	69 parts in 10^9	1.11±0.04		
ERDA 6 1212 hr.	4.8 parts in 10^9	1.26±0.05		
ERDA 6 1445 hr.	2.14 parts in 10^9	1.37±0.07	+10.3	0
ERDA 6 1520 hr.	1.88 parts in 10^9	1.33±0.07		
ERDA 6 Drill Mud	67.2 parts in 10^9	1.19		
Brine Lake (Mud Ingredient)	56.3 parts in 10^9	2.04		

Arrows in these photographs point stratigraphically upward.

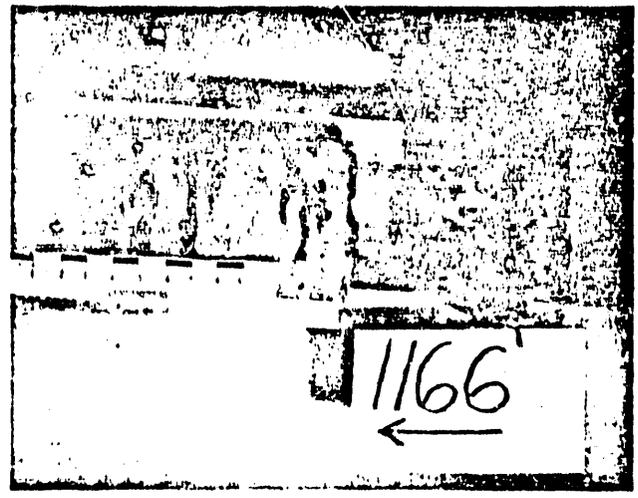


Plate 7.1. Core footage: 1165.4 to 1177.1 ft. (including 0.1 ft. gap) Brownish halite in gray anhydrite. Halite occurs as a thin bed at top of specimen, then as irregular lenses and thin laminae, finally as vertically elongate crystals, some with "swallow tail" form, near bottom of specimen. Locally horizontal laminae occur within the anhydrite due either to color change of the anhydrite or laminae of magnesite.

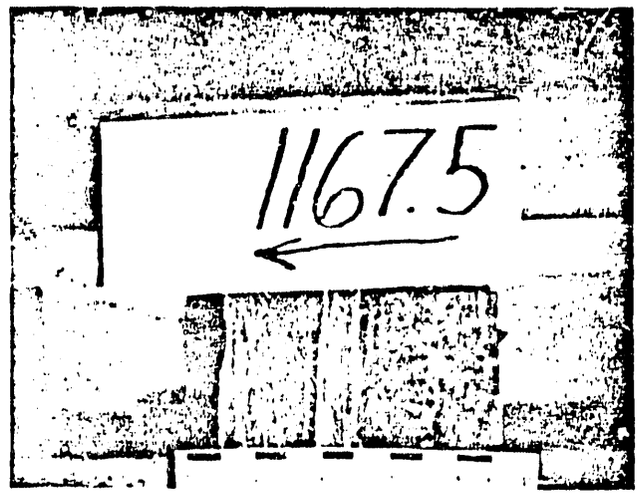


Plate 7.2. Core footage: 1167.5 ft. Dominantly light to dark gray, laminated anhydrite with thin, locally discontinuous, laminae of white magnesite and brownish, elongate halite oriented perpendicular to convex-upward, discontinuous laminae of light gray to white anhydrite.

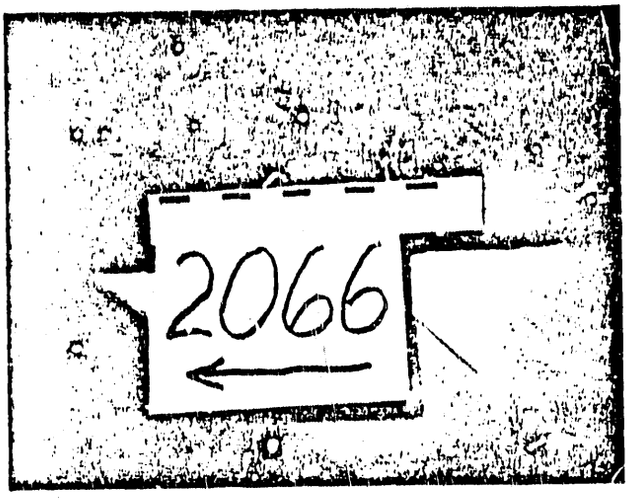


Plate 7.3. Core footage: 2065.8 to 2066.6 ft. Dominantly clear to milky white halite crystals, approximately 10 mm in size, and reddish brown to pinkish brown polyhalite. Note rectangular outline of polyhalite body stratigraphically above the first 6 in 2066; but most polyhalite occurs around halite crystal boundaries below 2066 label.

Plate 7.4. Core footage: 2615.0 to 2615.6 ft. Dominantly coarse (ranging from 3 to 40, average 20 mm in size) halite crystals, some with cubic form but most anhedral, locally separated by microcrystalline white anhydrite.

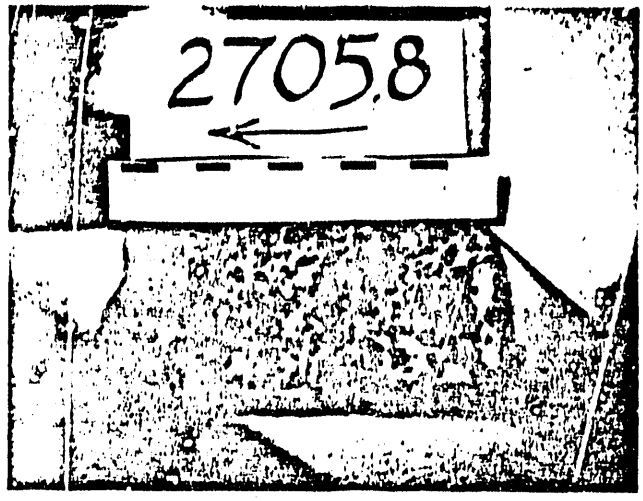


Plate 7.5. Core footage: 2705.8 ft. Coarse, ranging from 2 to 15 mm, light gray to black halite in white microcrystalline anhydrite and rare 1 to 2 mm bodies of pure white magnesite.

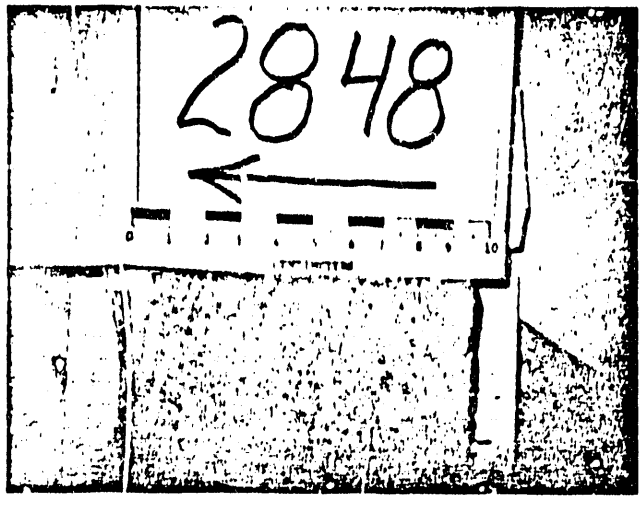


Plate 7.6. Core footage: 2848 ft. Varicolored (white and all shades of gray) anhydrite, some crystals near stratigraphic top of sample exhibit "swallow tail" form.

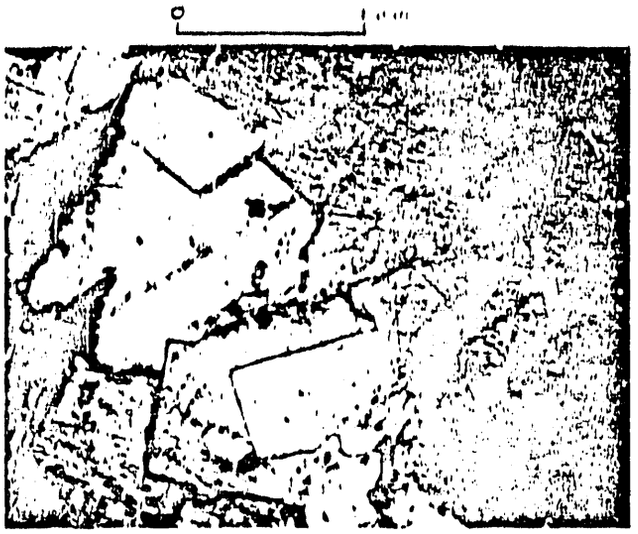
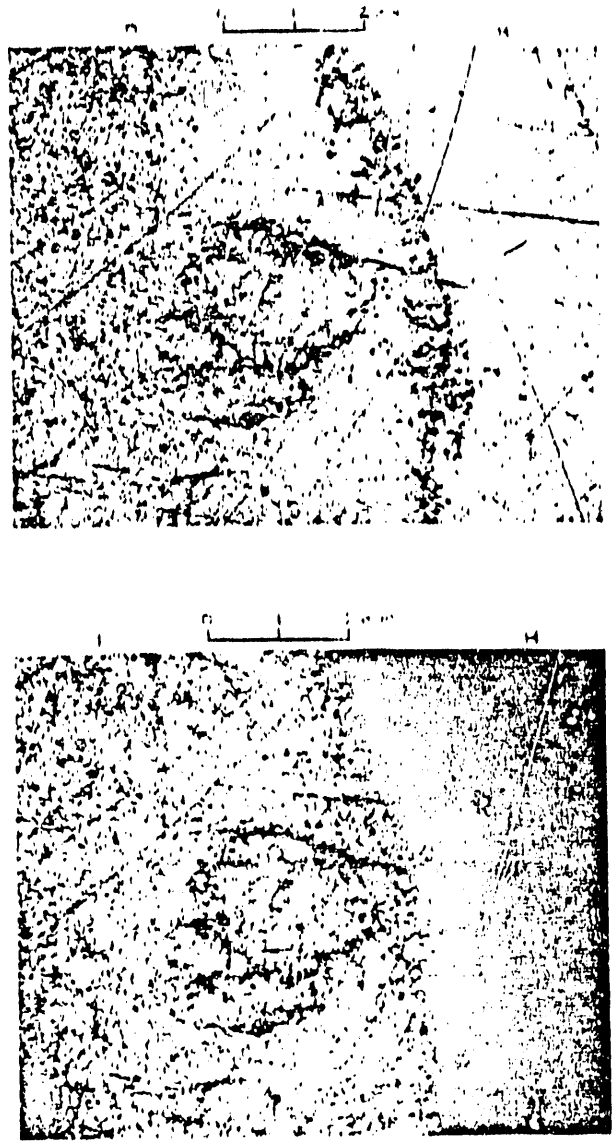


Plate 7.7. Photomicrograph (25X, plane light) of halite: many euhedral (cubic) to subhedral, relatively clear crystals locally containing fluid inclusions. Crystal size ranges from 0.5 to 1.5 mm. Compare with Plate 7.8.

Plate 7.8. Photomicrograph (10X, plane light) of halite: subhedral to anhedral, cloudy crystals devoid of fluid inclusions. Crystal size ranges from 1.5 to 4.5 mm.

Plate 7.9. Photomicrograph (10X, plane light) of sylvite (reddish, translucent to black, opaque in photo) and halite: halite anhedra size ranges from 0.4 to 5 mm. Two subhedra dominantly of sylvite occur within halite anhedra, one subhedron/anhedron of mixed sylvite and halite occurs within a coarse halite subhedron, but most sylvite occurs as anastomosing bodies having gradational contacts with halite between halite anhedra.



Plates 7.10A and 7.10B. Photomicrographs (10X, plane light in 7.10A, crossed nicols in 10B) of polyhalite (P) and halite (H): Polyhalite occurs as a cloudy anhedron (pinkish in hand specimen) locally containing smaller anhedra which are apparent due to concentrations of opaque (black in the photo, red under microscope reflected light) material, probably hematite. Concentrations of hematite also occur along the contact of polyhalite with halite which becomes extinct (black in 10B) under crossed nicols. The contact is irregular and gradational.

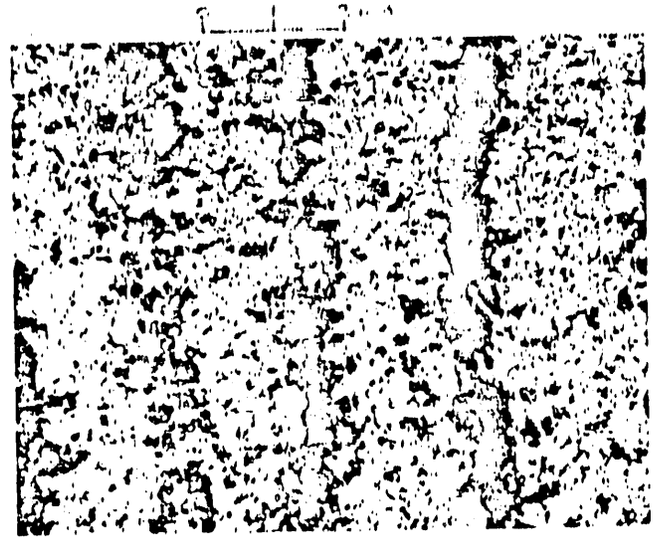
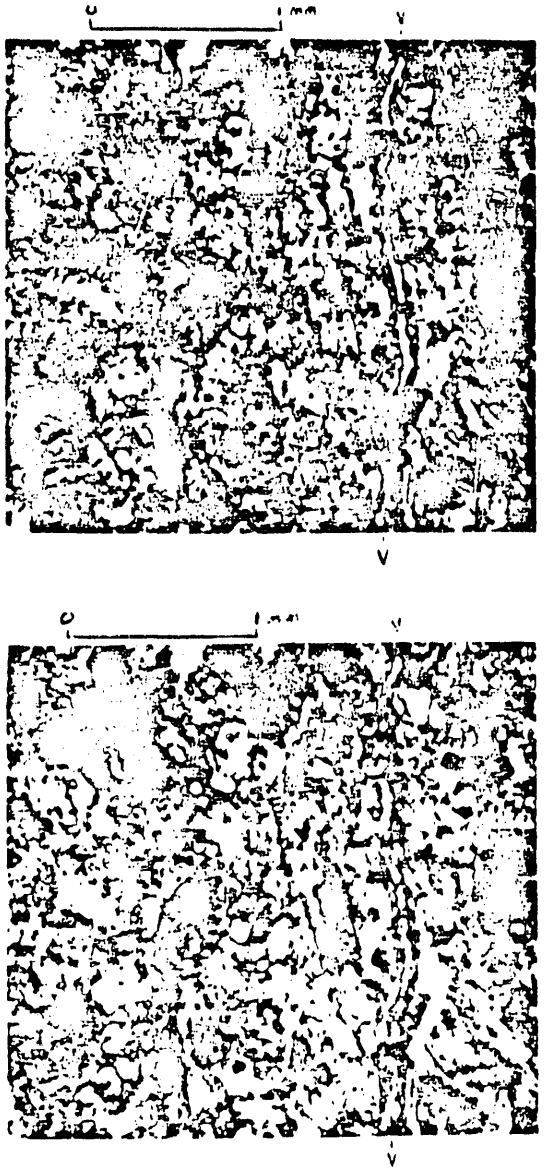


Plate 7.11. Photomicrograph (10X, plane light) of laminated anhydrite and calcium or magnesium carbonate: Dark thin laminae (approximately 1 mm thick) of dominantly carbonate anhedra separate thin laminae (approximately 2 mm thick) of dominantly anhydrite anhedra.



Plates 7.12A and 7.12B. Photomicrographs (25X, plane light in Plate 7.12A, crossed nicols in Plate 7.12B) of anhydrite with veinlet (V) of gypsum. Anhydrite occurs as a mosaic of 0.04 to 0.4 mm anhedra and subhedra with high order interference colors in 12B. Veinlet somewhat discontinuous, is more apparent in 12A and consists of very elongate irregular anhedra of relatively clear gypsum with lower order interference colors than the anhydrite in 12B. The veinlet is approximatedly stratigraphically horizontal and is 0.06 mm thick, the width of a single elongate gypsum anhedron.

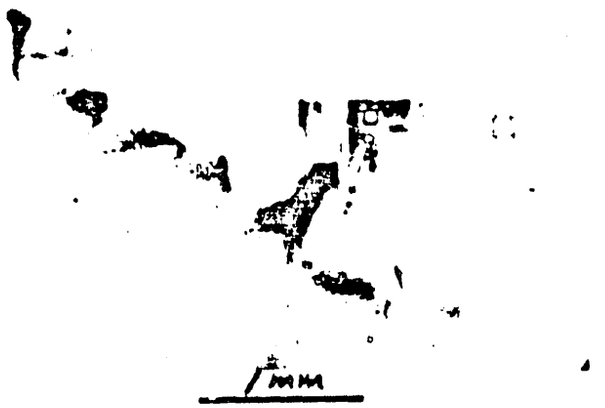


Plate 7.13 Group of dark unrecrystallized zones in essentially inclusion-free single crystal of halite of sample 2065. For detail on central area see Plate 7.14.

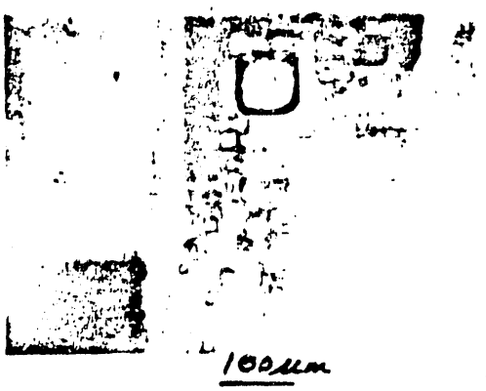


Plate 7.14 Detail of area in Plate 7.13 showing sharp crystallographically controlled boundaries of inclusion-rich zones (type A). Such boundaries may represent primary crystallization features rather than recrystallization fronts.

Plate 7.15 Recrystallized part of sample 2065 with large numbers of type B inclusions with small bubbles (e.g., see arrow) and some dark, cloudy unrecrystallized portions (details in Plate 7.16).

Plate 7.16 One of the dark areas in Plate 7.15 showing dense cloud of primary type A inclusions with some primary banding (arrow), and sharp but curving (solution?) contact with crystallographically parallel but almost inclusion-free recrystallized salt (at top).

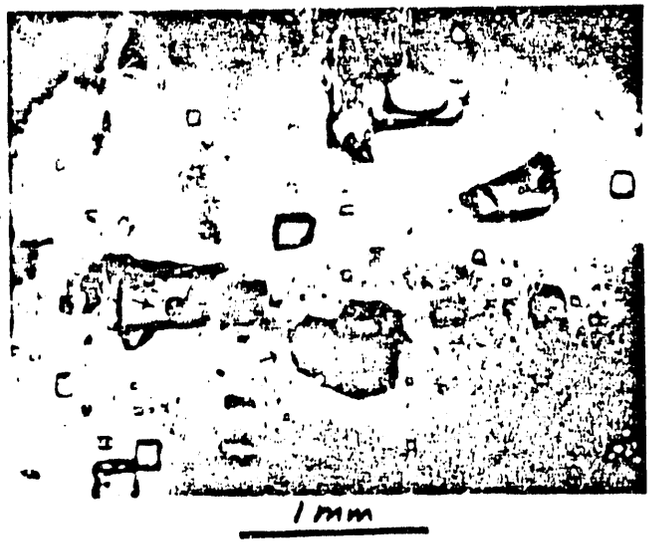


Plate 7.17 Coarsely recrystallized part of sample 2760, with many large type B inclusions, each with bubbles (arrows). Dark clouds are masses of unrecrystallized salt with large numbers of tiny type A primary inclusions (see Plates 7.18 and 7.19).

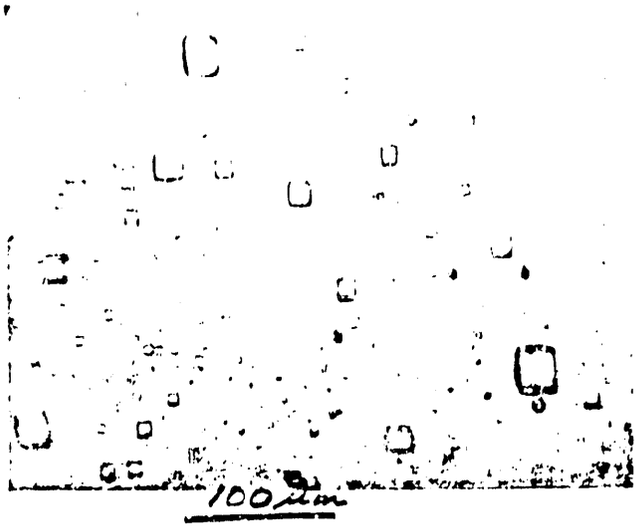


Plate 7.18 Detail of one of the cloudy areas in Plate 7.17, showing high concentration of tiny type A inclusions. Most of these inclusions are < 1µm (see Plate 7.19).

Plate 7.19 Detail of portion of Plate 7.18 that is relatively free of larger inclusions. The smallest inclusions are ≈ 0.5μm. All are type A. None of these inclusions contain a bubble.

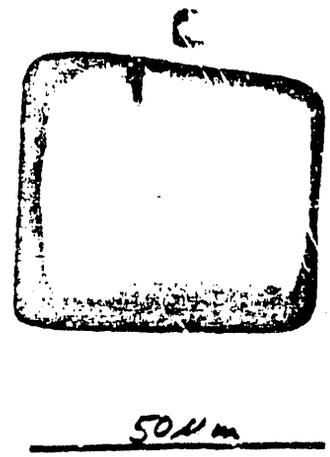


Plate 7.20 Inclusion in sample 2272.5 that contains only liquid, with no bubble, even though fairly large. Type B.

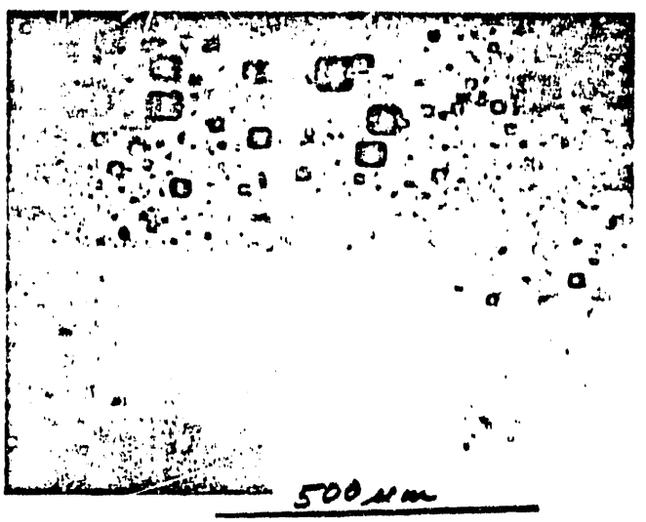


Plate 7.21 Unrecrystallized part of sample 1902 showing primary cubic growth zone feature, delineated by a cloud of tiny type A primary inclusions.

Plate 7.22 Unrecrystallized part of sample 1902 showing thin inclusion-free zone through dense cloud of tiny type A primary inclusions.

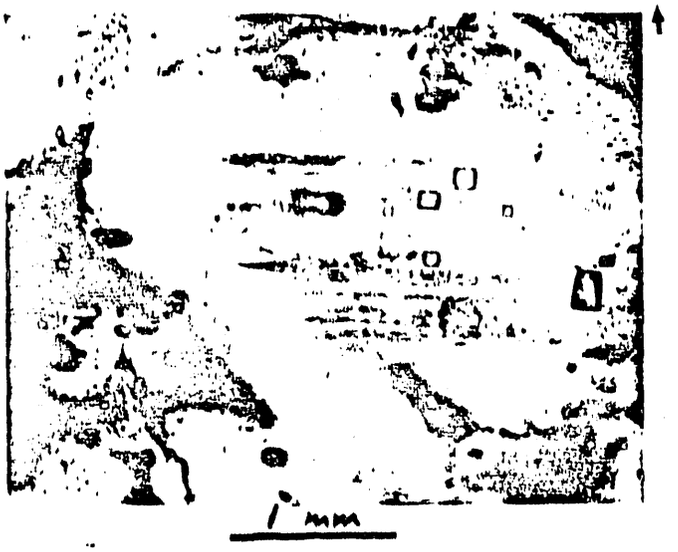


Plate 7.23 Oval grain of salt from sample 2760 containing unrecrystallized core with tiny type A primary inclusions. See Plate 7.24 for detail. Top of core is shown by arrow.

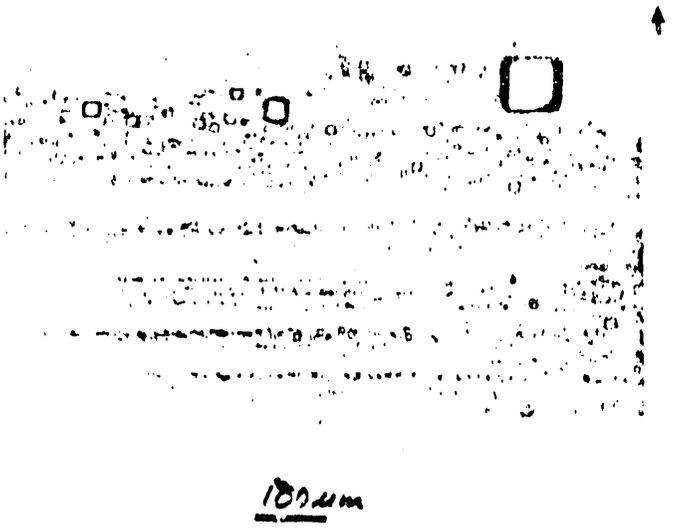


Plate 7.24 Enlgarged view of right central portion of Plate 7.23, showing extremely fine banding of primary type A inclusions, with inclusion-free zones between. Top of core is shown by arrow.

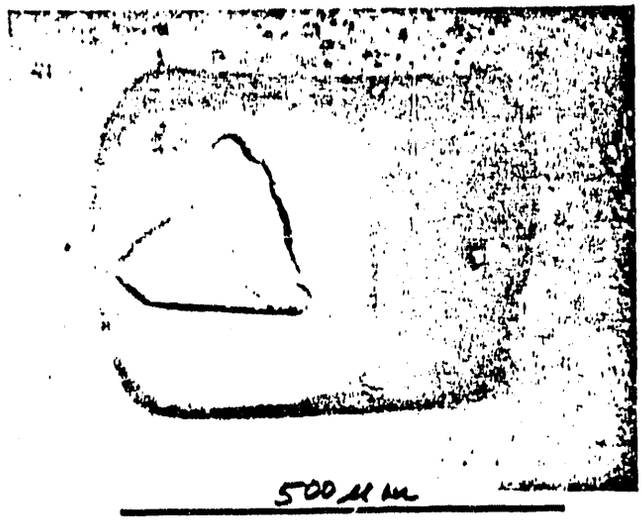


Plate 7.25 Inclusion (type B) in sample 1902 showing twinned birefringent daughter crystal of unidentified phase.

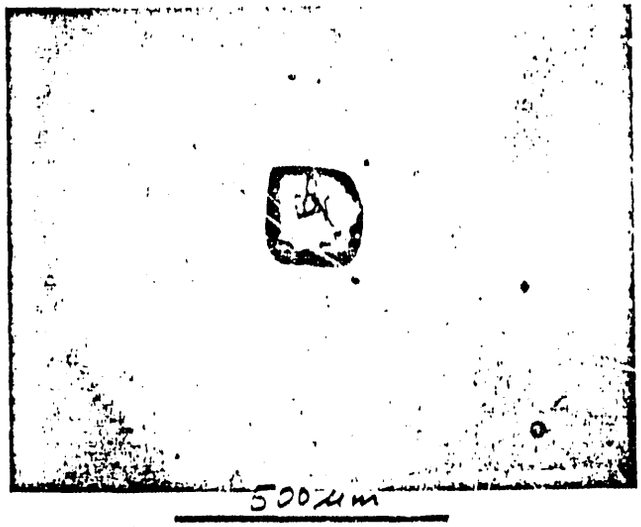


Plate 7.26 Daughter crystals of unidentified phase in type B inclusion in sample 1902.2, with partly crossed polarizers. Note twinning in largest crystal. Many inclusions in this same sample have no daughter crystal or just a few tiny crystals (see Plate 7.28).

Plate 7.27 Plane of type B liquid inclusions each with a large number of unidentified bladed birefringent daughter crystals, just 400 μm below another plane of inclusions with no daughter crystals (Plate 7.28). Inclusion in Plate 7.26 with daughter crystals is similar in phase ratio but not in same plane (out of focus in lower left here). Sample 1902.2 partly crossed polarizers; birefringent mass embedded in salt crystal at top may be the same phase.

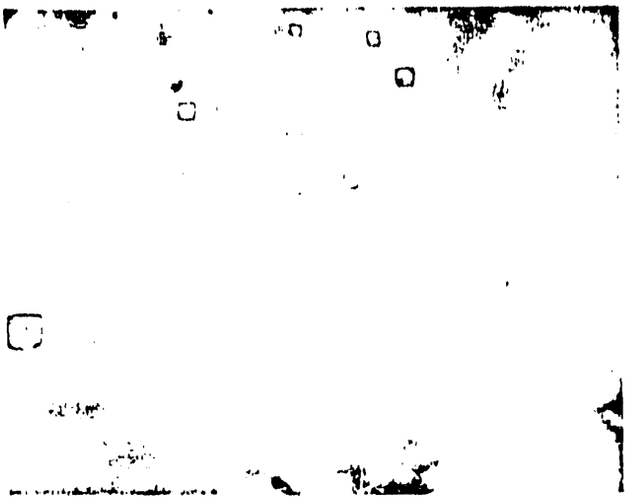


Plate 7.28 Plane of liquid type B inclusions, several with bubble, but without daughter crystals, about 400 μm above a plane of type B inclusions with a large number of unidentified daughter crystals (Plate 7.27). This lower plane is visible but out of focus. Sample 1902.2. Inclusion of Plate 7.26 is visible in lower left.

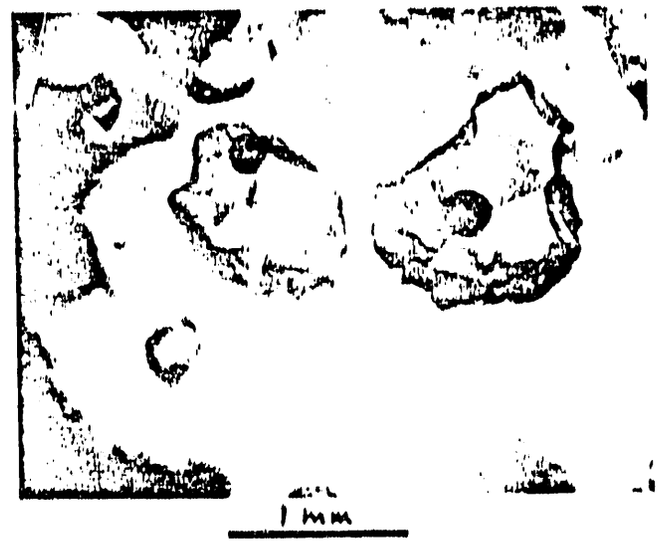


Plate 7.29 Large irregular type C inclusions in sample 2065 with "too large" bubbles.

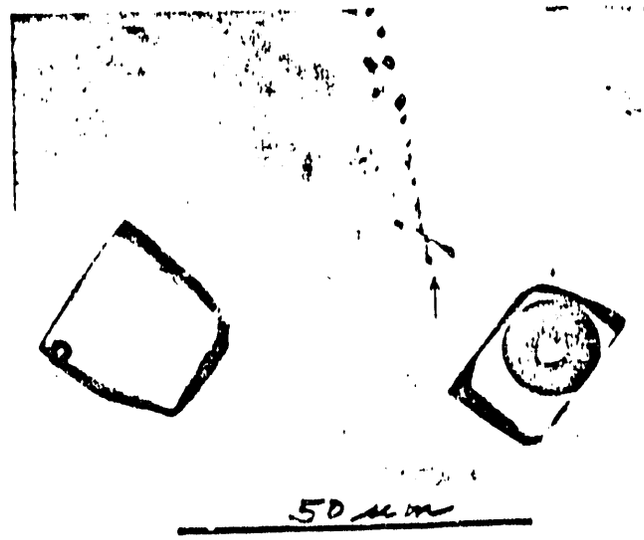


Plate 7.30 Pair of inclusions in sample 1902. The one on left (Type B) with small bubble is typical of those in this sample; that on right (Type C) is on a healed fracture (see arrow) and has apparently been opened and the original fluid replaced with a gas-rich mixture under pressure.

Plate 7.31 Single crystal of salt in sample 2760 with curving planes, outlined by type D inclusions, separating it from adjacent grains. Note also large type B inclusions and mass of tiny type A primary inclusions in central core of crystal. Sample has probably undergone two stages of recrystallization (see text). Top of core is shown by arrow.

Plate 7.32 Fluid inclusions (gas; type D) on interface between recrystallized salt crystals in sample 2760. Note 120° junction. Top of core is shown by arrow.

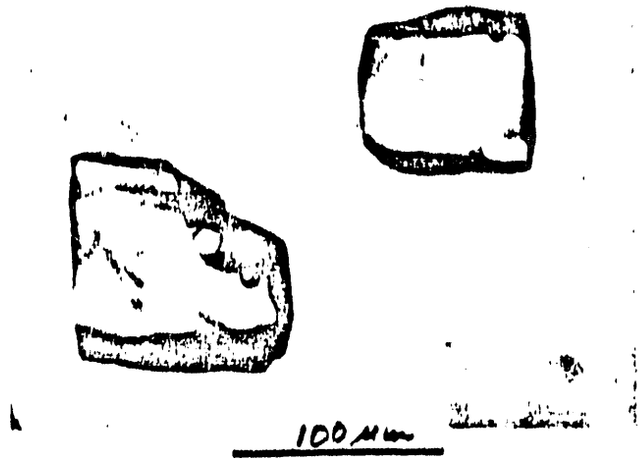


Plate 7.33 Large type B inclusions in sample 1799.1 homogenizing at 20.5°C (lower left) and 21°C (upper right). Photographed at ≈ 19°C.

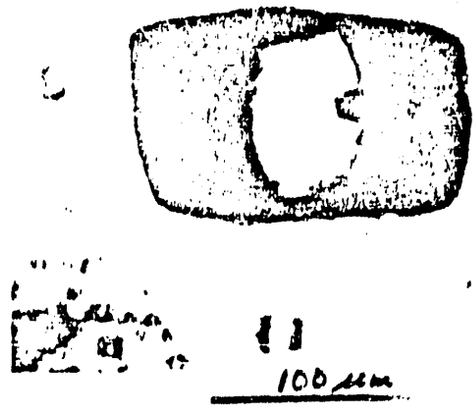


Plate 7.34 Large type B inclusion in sample 2760.1 homogenizing at 20.5°C. Photographed at ≈ 19°C.

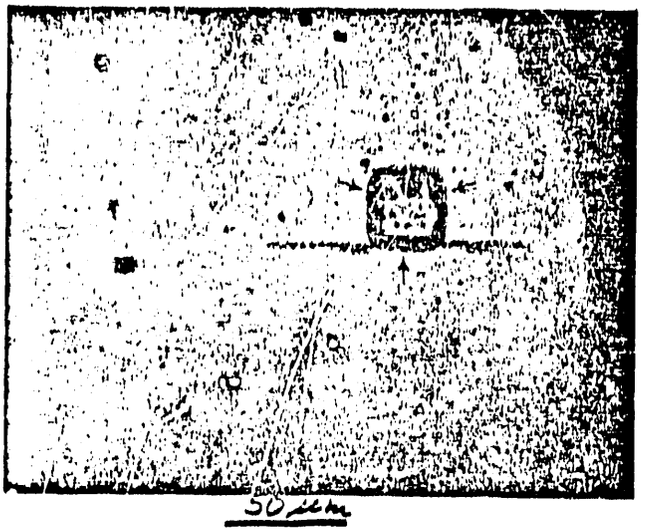


Plate 7.35 Inclusion (type B) in sample 1902 after freezing run, showing horizontal crack formed by expansion on freezing, that is now a plane of tiny secondary fluid inclusions; larger bubble than originally was present (due to volume increase); and rounded halo of tiny inclusions formed during freezing run (arrows), as a result of water in inclusion reacting with halite of walls to form $NaCl \cdot 2H_2O$, thus increasing inclusion volume. See text.

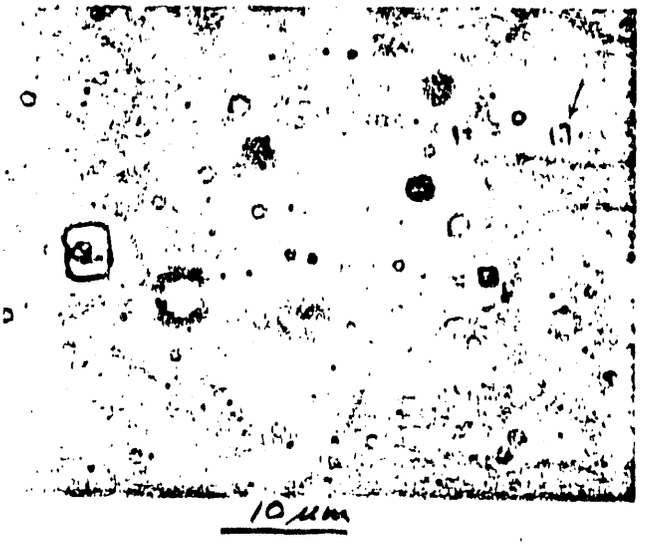
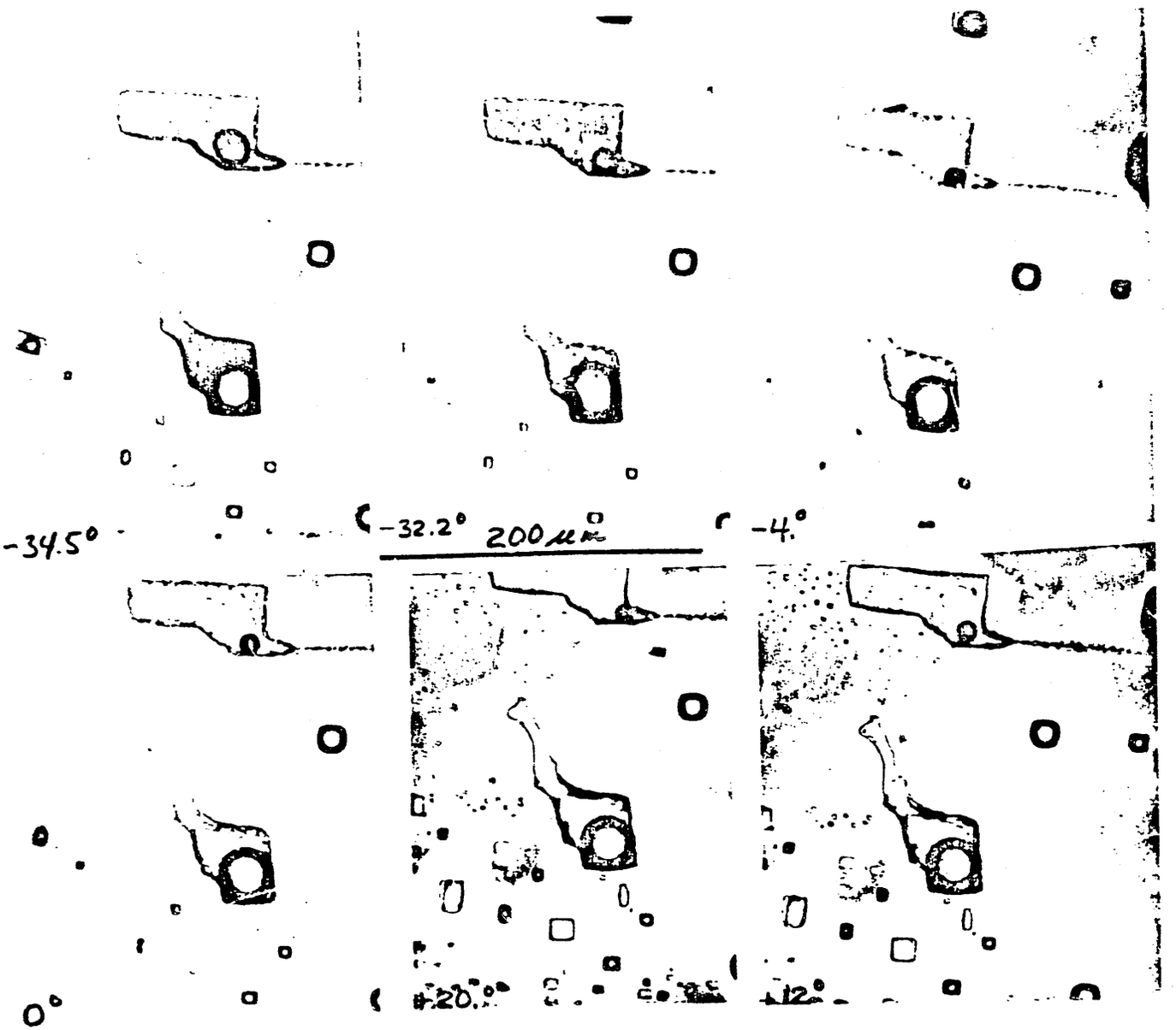


Plate 7.36 Minute primary inclusion in unrecrystallized salt from sample 1902 at high magnification (1560 X). The inclusion in upper right is about 1.8 μm on an edge, and contains a bubble of <0.5μm. Resolution of bubble is poor as it is generally in rapid motion even with an IR filter in optical system and exposures must be long. Many inclusions with no bubble area are ≈ 0.5μm on an edge.

Plate 7.37 Sequence of photographs of type B inclusions in sample 2095.3 taken at the temperatures indicated during a freezing run. At -75.5°C the inclusions contain a partly opaque mixture of solid grains of ice and salts. No change was visible on warming to -34.5°C, but at -32.2°C the mixture suddenly became more translucent and the grain size started to increase, indicating first melting. Extensive melting occurred around -4°C, and the remaining crystals decreased to ≈ 20-25% at 0°C. These were probably a hydrate but not all Nacl $2H_2O$, since a few were present at +12°, and the last dissolved at +15°C. The room temperature photo was taken after the run. The bubble size varies with phases present and temperature.


-34.5°
-32.2°
200 μm
-4°
0°
+20°
+12°

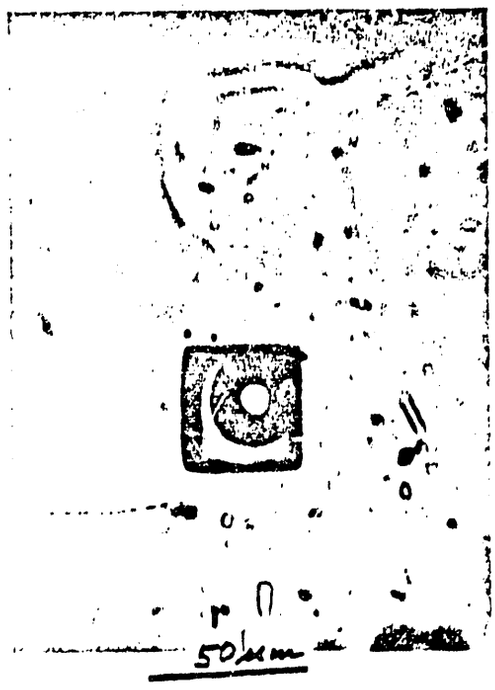


Plate 7.38 Inclusion from sample 2760, as found, with large bubble, viewed on crushing stage. The bubble contains gas under pressure (see Plate 7.39).

Plate 7.39 Same inclusion as seen in Plate 7.38, on crushing stage, after fracture has reached it. The bubble has expanded approximately 270% (vol) on pressure release.

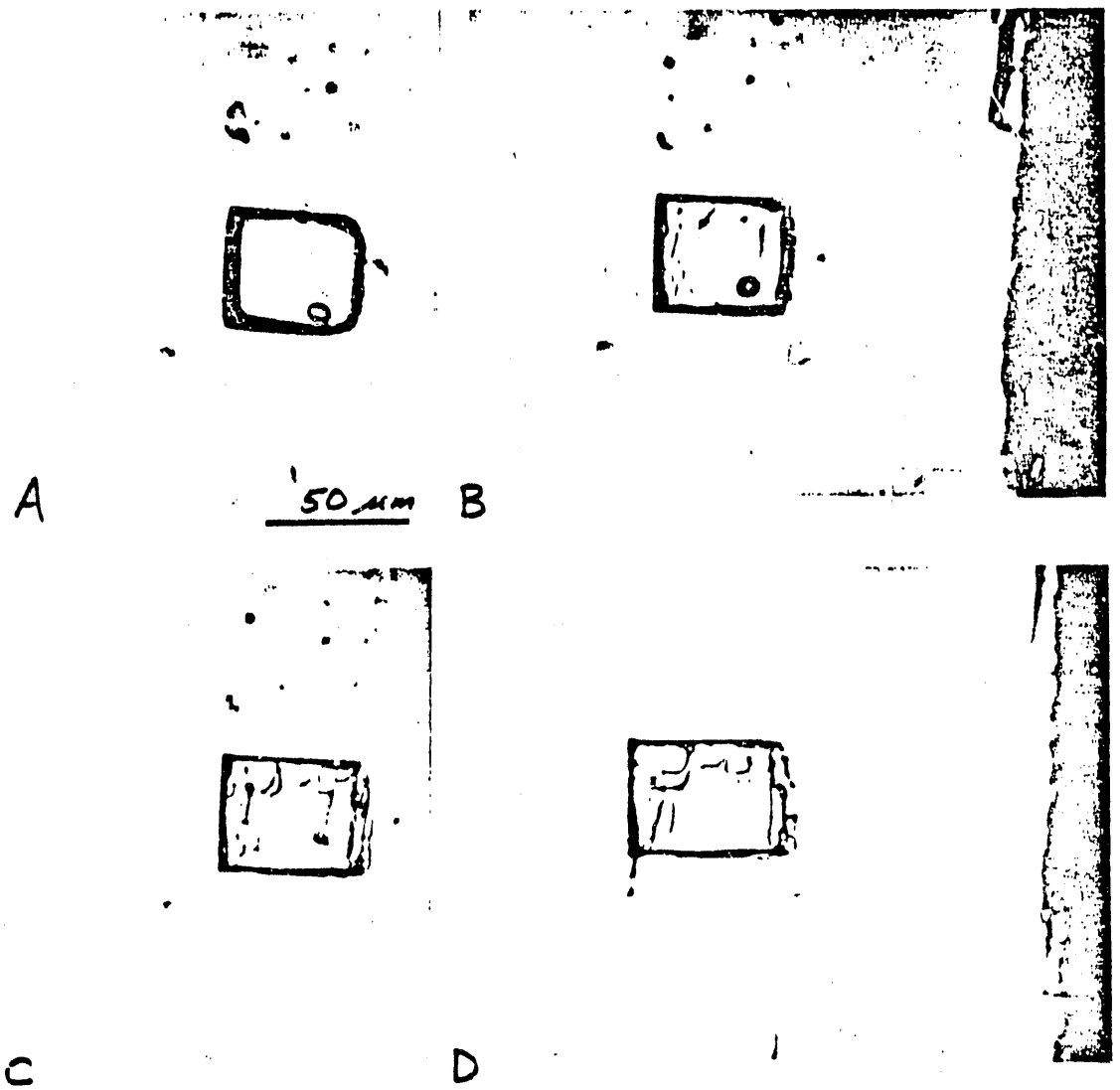


Plate 7.40 Sequence of photographs of inclusion in sample 2760 on crushing stage. A shows the inclusion as found. The sample was then stressed and immediately cracked (at right in B), but the area of inclusion was still under stress, since changes took place along edges of inclusion during next 10 minutes at constant stress (photo B). After 16 minutes at constant stress (C) changes are more pronounced and bubble is smaller: after 18 minutes bubble is gone (D).

In each of the following plates, the length of the scale bar is 100 μm.

Plate 7.41 (Photo 1) Group of small primary hopper-growth inclusions in ERDA-9 sample 2699.8-2700.0, after 250°C decrepitation run. These inclusions probably had no bubble originally, and now have one as a result of plastic deformation of the host salt. They now homogenize at temperatures as high as 273°C (Table 7.17).

Plate 7.42 (Photo 2) Solid phases (daughter crystals?) in inclusion in Kerr-McGee mine sample MB-76-4. The small rod-like crystal has parallel extinction, and the large cubic(?) crystal (KCl?) appears isotropic.

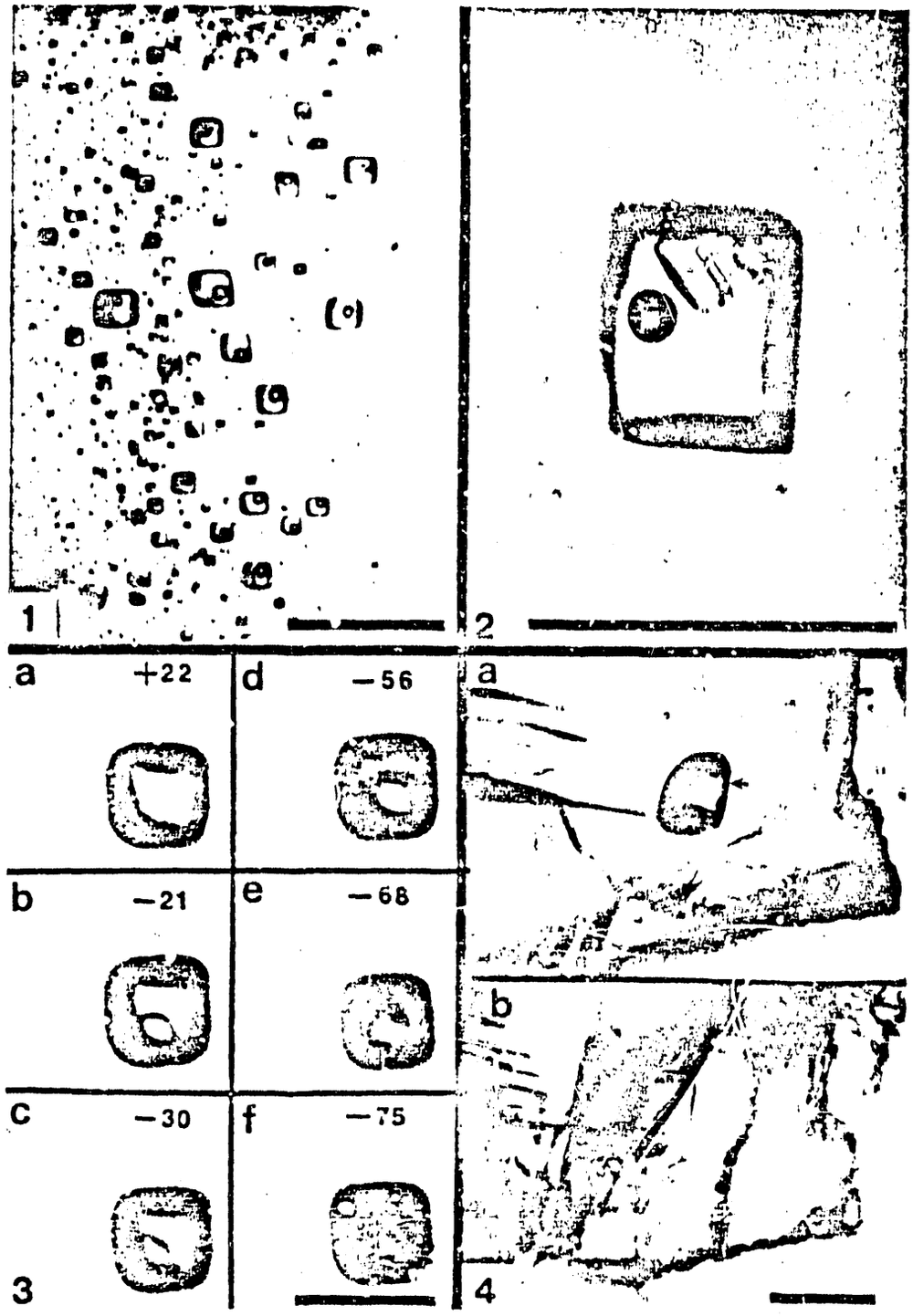
Plate 7.43 (Photo 3) Dense gas inclusion in Kerr-McGee mine sample MB-77-8, photographed at the approximate temperatures indicated (°C). See text, subchapter 7.5.

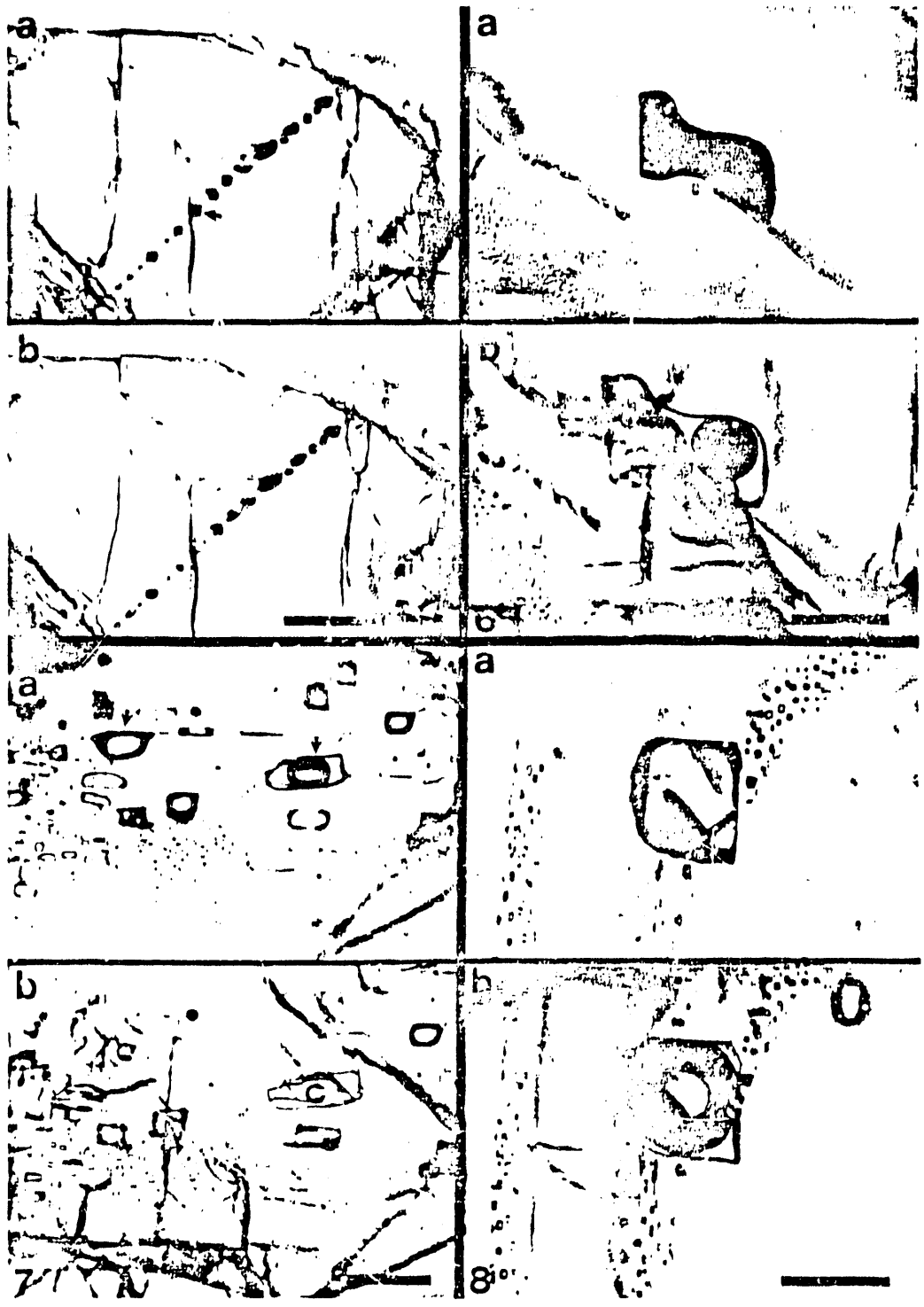
Plates 7.44 and 7.45 (Photos 4 and 5) Steam inclusions (arrows) in Kerr-McGee mine samples MB-76-3 (7.44) and MB-77-8 (7.45), now containing essentially vacuum, before (a) and after (b) being intersected by a fracture during crushing tests. The surrounding oil has filled the inclusions completely in (b).

Plates 7.46 and 7.47 (Photos 6 and 7) Gas inclusions in Kerr-McGee mine sample MB-77-8 containing gas at less than one atmosphere pressure, before (a) and after (b) being intersected by a fracture during crushing tests.

Plate 7.48 (Photo 8) High pressure gas inclusion in Kerr-McGee mine sample MB-76-4 before (a) and after (b) being intersected by a fracture during crushing.

Plates 7.49, 7.50 and 7.51 (Photos 9, 10, and 11) High pressure gas inclusions in Kerr-McGee mine samples MB-77-8 (7.49 and 7.51) and MB-76-3 (7.50), before (a) and after (b) being intersected by a fracture during crushing. The approximate volume expansion is 30-fold in 7.49, 40-fold in 7.50, and 100-fold in 7.51. Two bubbles formed in 7.49, and one in 7.50 (arrows).


1
2
a +22
b −21
c −30
d −56
e −68
f −75
3
a
b
4


a
a
b
b
a
a
b
b

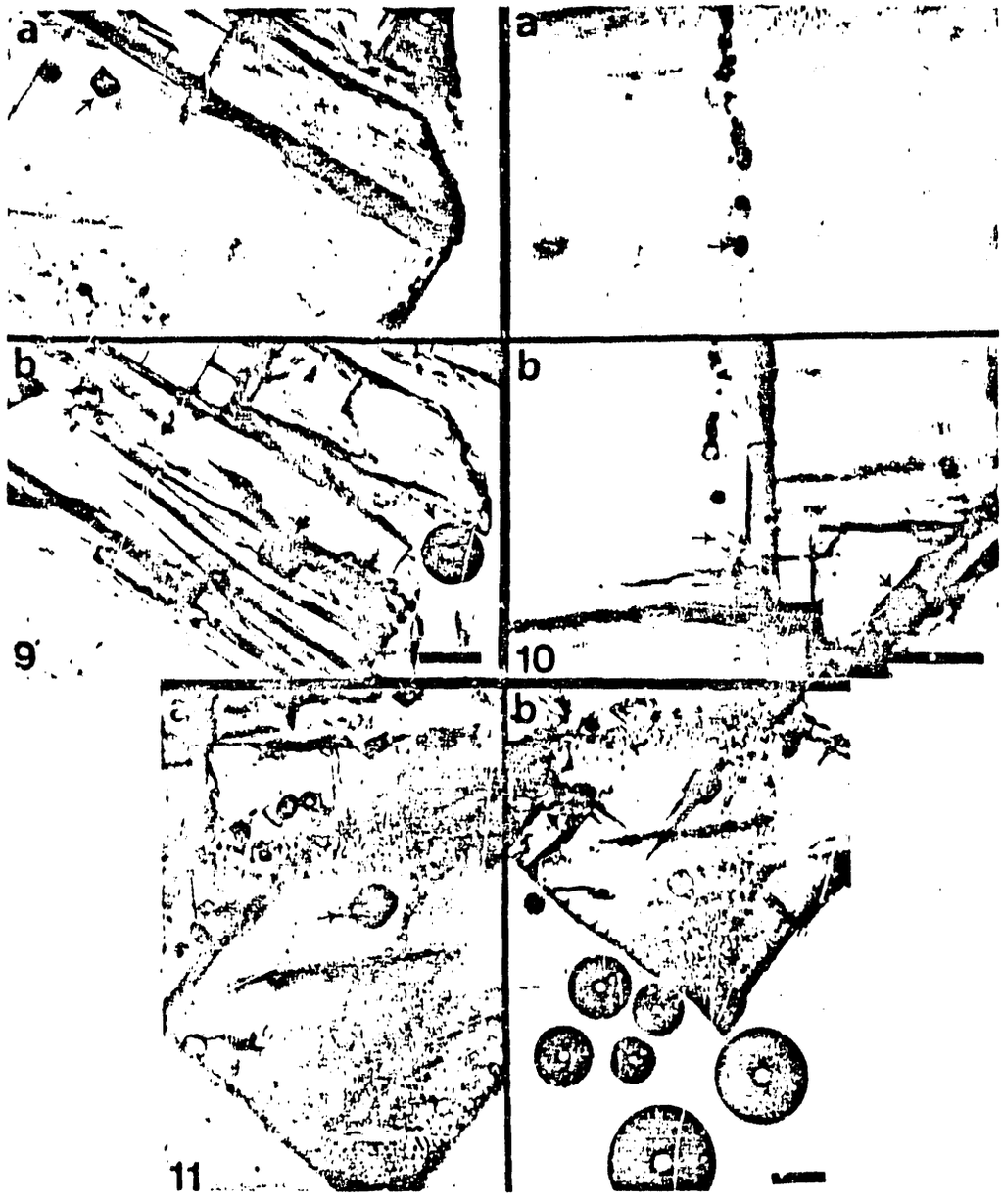
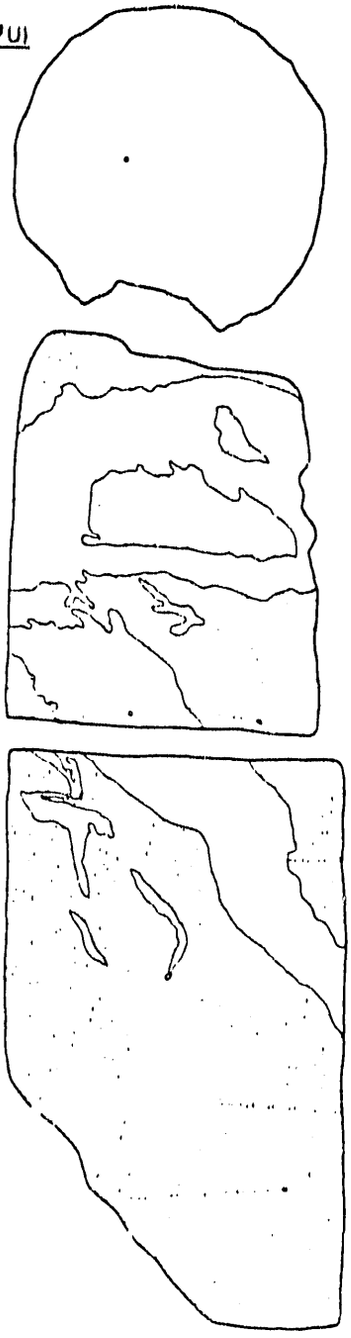

a
b
9
a
b
10
c
11
b

PLATE CAPTION

Plate 7.52 and Overleaf: Core fragments from Castile anhydrite serving as host rock for the ERDA No. 6 brine reservoir. Depths of origin, uranium contents and $^{234}U/^{238}U$ ratios are given in the overleaf for various parts of the core fragments.

TOTAL U	$(^{234}U/^{238}U)^{a}$	DEPTH (Ft.)
19.2 ppb	1.09	2708
1.61 ppm	1.02	
33 ppb	1.04	2709.4
2.17 ppm	1.04	2709.9



coarsely crystalline anhydrite (white)

laminated calcite and anhydrite (gray)

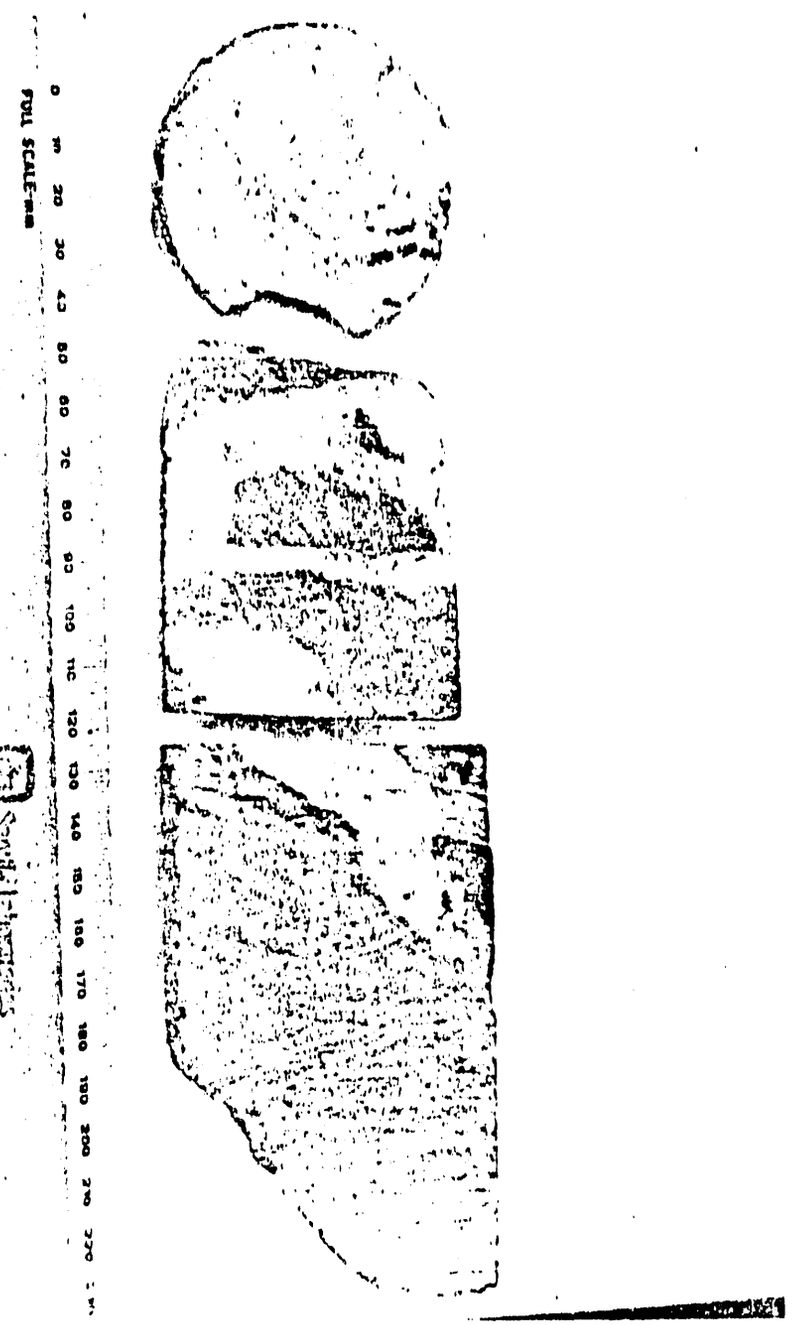

FULL SCALE mm
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230

PLATE 7.52

GCR CHAPTER 8
RESOURCES

8.1 INTRODUCTION

The northern portion of the Delaware Basin is known for production of potassium salts and fluid hydrocarbons. An effort was made to select a location for the WIPP that would minimize conflict with these resources. It is likely, however, that some of these potash and hydrocarbon resources underlie the site. The extent of potash mineralization has been fairly well established because the potash mining industry has released information concerning their exploratory drilling in the area. Those findings were supplemented by information from 21 additional holes drilled by the Department of Energy. Site selection criteria described in Chapter 2 prescribe that the site be no closer than one mile from a deep drill hole. This means that the potential hydrocarbon resource must be evaluated by inference utilizing subsurface information from surrounding areas. An investigation was also carried out to determine the significance of other possible industrial minerals such as caliche, gypsum, salt, uranium, sulfur, and lithium at or very near the WIPP site. Table 8-1 summarizes the principal findings of resource studies. Only potash and natural gas are considered to be significant exploitable deposits as shown in Table 8-2. The economic resources denied in Zones I-III are shown in Table 8-3.

8.2 ORGANIZATIONS INVOLVED IN RESOURCE EVALUATION, AND THEIR REPORTS

Numerous contractors representing both government and private companies were engaged in the resource evaluation at the WIPP site. An outline of work accomplished during this phase of the site characterization is given in Table 8-4.

The listed studies quantify in-place resources and evaluate what portion of those resources would be extractable. A legal determination is now under way to establish values to the various mineral and oil and gas

lease holders within the site area. However, these studies deal with the present value of specific land tracts and as such are not pertinent to site chacterization.

8.3 POTENTIAL RESOURCES IN RELATIONSHIP TO STRATIGRAPHY AT THE WIPP SITE

Resource evaluation at the WIPP site took into consideration the existing stratigraphy of the site area. Each formation was evaluated for mineral deposits that were either known or that could exist based on the characteristics of the sediments present.

A stratigraphic column is given in Table 8-5 that indicates where in the geologic section specific types of deposits are considered to have a reasonable likelihood of occurrence. The table briefly describes the character, thickness, and median depth of each formation.

8.4 RESOURCE DESCRIPTION BY SPECIFIC COMMODITIES

The description of resources commences with the shallowest formation and proceeds down the stratigraphic column to the Precambrian.

8.4.1 Caliche

A thin layer of caliche (a whitish, calcium carbonate-rich material) underlies most of the site area. Exposures are normally obscured by dune sand, but it has been estimated that the caliche blanket covers approximately 80% of the site area. The average thickness is 4.3 feet, and the total resource has been estimated at 185 million tons (Siemers et al., 1978). The quality of caliche as determined by insoluble content (ranging from 21 to 69%) appears to be typical for caliche for this region.

Caliche is often used to surface dirt roads in southeast New Mexico. Small quarries dot the landscape, and several provided material for road construction to various drill locations within the WIPP site. This is the sole use for caliche in this region. Caliche is so extensive in this region that it can not be considered as either a limited resource or one that has significance to road construction of surrounding areas if land is withdrawn for the WIPP site.

8.4.2 Uranium

Uranium could occur in sediments such as those of the Gatuna, Santa Rosa or Dewey Lake Formations. However, no significant occurrence of uranium has been found within the Delaware Basin. Reducing environments favoring uranium deposition are absent as evidenced by the lack of organic debris, pyrite or humates in these formations. No signal indicative of economic or even marginal uranium concentrations was observed on gamma ray logs of the 36 holes drilled through these beds during site evaluation. The conclusion is that significant uranium deposits are most unlikely, even in beds which are considered to be the most favorable.

8.4.3 Gypsum

Dissolution of salt from the Rustler Formation has occurred over much of the site area. Waters accompanying this dissolution have caused partial conversion of anhydrite within the Rustler to gypsum. The conversion is not complete, however, and it is doubtful that high-quality gypsum would be persistent in any single bed. The maximum amount that could be present, assuming an aggregate thickness of 40 feet, amounts to 1.3 billion tons (Siemers et al., 1978). The quality and bed thickness are inferior to those in beds west of the WIPP site. Still farther west and south, extensive outcrops of high quality gypsum of the Castile Formation occur. The nearby availability of superior quality gypsum that can be mined by open pit methods leads to the conclusion that gypsum in the Rustler Formation can not be considered a likely economic resource.

8.4.4 Halite (Salt)

Halite is the dominant constituent of the Ochoan evaporites. The shallowest salt is in the Rustler, but dissolution of this formation has removed much of the Rustler salt except in the southeast quadrant of the WIPP site. On the other hand, salt beds persist under the site in the Salado and Castile Formations. The thickest and purest salt beds in the region are in the Castile. The State Bureau of Mines and Mineral Resources estimated 118 billion tons of salt in the Salado within the WIPP boundary (Siemers et al., 1978). The Castile Formation would add approximately 80 billion tons of additional salt resource.

As with gypsum and caliche, the immense halite deposits are not considered to have economic significance because of the prevalence of these deposits throughout the general area and the existence of adequate supplies closer to areas where salt is in demand.

8.4.5 Sulfur

A significant deposit of native sulfur is being exploited by the Frasch process approximately 50 miles south of the WIPP site in northeastern Culberson County, Texas. The occurrence is associated with brecciated and carbonatized anhydrite beds of the Castile Formation. Considerable exploration has been under way since discovery of the Culberson deposit, but that exploration has been aligned along the southern and western parts of the Delaware Basin where the Castile Formation either lacked halite during deposition or the halite has been removed by dissolution. The genesis of the deposits is believed to depend on a combination of bacterial action, induced fracture permeability and a source of hydrocarbons (presumably from upward escape of natural gas or crude oil along fractures from the Delaware Mountain Group). The closest analogy to such a setting in the northern part of the Delaware Basin and the vicinity of the WIPP site would be either "breccia pipes" or H_2S-laden brine reservoirs. Careful attention was given in selecting the WIPP site to avoid such structures; further investigation has not revealed any such structures, therefore, no sulfur deposits are expected.

8.4.6 Lithium

Lithium occurs in a concentration of 140 mg/L in a saturated brine reservoir that was encountered during the drilling of ERDA 6. The hole was located 2 miles northeast of the outer boundary of the WIPP site. A similar reservoir was found in the Belco Hudson Federal No.1 gas well 1/4 mile outside Zone IV on the southwest side of the site. No analyses were done for lithium in the latter well, but both reservoirs were at equivalent stratigraphic positions (middle Castile), contained H_2S, and were fully saturated brines. The concentration of 140 ppm lithium in ERDA 6 verges on being economically extractable if the reservoir is of sufficient size. Griswold (1977) estimated the reservoir volume at ERDA 6 to be on the order of 100,000 to 1 million bbl. If reservoirs are limited to this size, they would not warrant development. At current market price the in-place value of the lithium would not exceed $1 million.

There has been a deliberate attempt to locate the WIPP site in an area free of brine reservoirs in the Castile. Extensive seismic surveys have been run across the area to ensure that no anomalous structures occur in the Castile Formation. The occurrences at ERDA 6 and at the Belco well are associated with complex anticlinal structures and are easily recognizable on seismic survey traces.

8.4.7 Potash

Method of Evaluation. Sylvite (KCl) and langbeinite ($K_2Mg_2(SO_4)_3$) exist under portions of the WIPP site (see Figures 8.2, 8.3, 8.4). Although an attempt was made to avoid such deposits during the site selection process, it was not possible to do so completely because other site selection factors such as avoiding deep oil and gas test wells and the desire for uniform and thick salt beds at reasonable depth took precedence.

The potash evaluation commenced in August, 1976, after the site was chosen for detailed characterization. When chosen, the site was located mostly outside the Known Potash Area defined by the Conservation Division of the U.S. Geological Survey. Considerable potash exploratory drilling had been done on the flanks of the site area by private industry, but it is a requirement that the results of that drilling be held in confidence by the USGS. However, Sandia Laboratories contacted each mining company that had drilled in the vicinity and was granted access to the drill records on a private basis. These records indicated that deposits of commercial quality probably extended into the site area. The Department of Energy (then ERDA) authorized an exploratory drilling program to evaluate the potash deposits within the WIPP site. Technical direction of this exploratory drilling program was given to the USGS. The drilling program commenced in August and was completed by the end of November, 1976.

The Roswell, New Mexico, office of the Conservation Division of the USGS was given the task of determining potash resources by combining the results of DOE-sponsored drilling with records of drilling in the vicinity of the site. Findings have been reported by John et al. (1978).

The DOE also engaged the services of the U.S Bureau of Mines (USBM) to evaluate the extent to which the resources defined by the USGS could be produced at a profit using existing mining and beneficiation practices. The results of the study have been reported by the USBM (1977). The essential conclusion was that langbeinite in the 4th ore zone could be profitably mined in the northeast quadrant of the WIPP site. A band of sylvite, contained mostly within the 10th ore zone on the north and west sides of the sites, verged on being economically exploitable. Profitable mining of the sylvite would require a higher price for muriate (KCl) than current market value ($52/ton versus a current price of $43/ton).

Description of the Potash Exploration Drilling Phase. Figure 8-1 is a map showing a land block, centered on the WIPP site, that measures 8 miles on a side. This land block constitutes the area investigated by

the USGS and USBM. All locations of drill holes are shown from which information was available as to the depth, thickness, grade, and mineral suite of ore beds. Note that a different symbol is used to denote holes drilled by DOE from those drilled by mining companies. Examination of the distribution of hole locations reveals that the drilling plan directed by the USGS included testing the entire WIPP area on a spacing of not less than one hole per square mile. The objective was to completely cover the site area following industry practice for reconnaisance exploration. The density of the holes is judged to be quite adequate for resource appraisal.

Drilling closely followed standard industry practices (Jones, 1978). Rotary techniques were used from the surface down to a point just above the uppermost ore zone. Drilling operations were then converted to coring using a brine saturated with potassium chloride as the drilling fluid. Core recovery was excellent in all 21 holes. The core recovered was examined, and zones of interest were "split" for chemical analysis. Routine check analyses were done by an independent laboratory. All cores, including the remaining half of sample splits and sample rejects (excess after assay), have been permanently stored.

The results of the analyses of the 21 exploratory holes are attached as Appendix 8A. Included in the list are hole AEC 8 (drilled at the old ORNL site) and 17 holes for which information is available for release either by permission of the mining company involved or because the lease or permit on which the hole was drilled has expired.

Calculation of Potash Resource Distribution, Volume and Grade. As previously stated, calculation of the in-place volume and grade was undertaken by the Roswell office of the Conservation Division of the USGS. Technical assistance was also provided by the Special Projects Branch of the USGS.

There are 61 exploratory holes in the 8 x 8 mile land block shown in Figure 8-1. Ore intercept information was available to the USGS on all

of these holes. Thus, while their calculations used all available data, some specific information pertaining to 22 industry drilled holes is not reported in Appendix 8A to protect proprietary information of individual companies as they so requested.

The reserve calculation commenced with assigning depth intercepts to significant mineralization within the various ore zones. There are 11 such ore zones within the McNutt member of the Salado Formation (see Figure 4.3-3b). The next step consisted of extrapolating continuity of individual ore zones between holes. The final step was to calculate the volume and grade for continuous blocks of mineralization. In addition, the Conservation Division utilized criteria they have established for classifying resources as either measured, indicated, unevaluated, or barren. The criteria are:

Measured potash reserves - Tonnage is computed from dimensions revealed in workings and drill holes. The grade is computed from the results of detailed sampling and analyses. A minimum of three data points in any one ore zone meeting quality and thickness standards, no more than 1 1/2 miles (2.4 km) apart, have been used to delineate measured reserves.

Indicated potash reserves - Tonnage and grade are computed partly from specific measurements, samples, or production data and partly from projection for a reasonable distance on geologic evidence. The sites available for inspection, measurement, and sampling are too widely or inappropriately spaced to permit the mineral bodies to be outlined completely or the grade established throughout.

Unevaluated potash areas - Tonnage and grade have not been computed due to low density drilling and sampling, but are surrounded by measured and (or) indicated reserves.

Barren and/or minor potash mineralization areas - Subeconomic resources that would require a substantially higher market value or a major cost-reducing technology for economical production.

Subeconomic resources also include other bittern minerals not presently being recovered.

Potash resources were then quantified at three minimum grade and thickness levels. Standard conditions for each class are shown in Table 8.6.

The intermediate conditions, termed "lease", conform with established policy of the Department of Interior that any area known to contain potash mineralization meeting or exceeding that standard and located on Federal land can be acquired only through competitive bid. The standard is based on judgment along with recognition that ores as low as these grades have been successfully treated from time to time at one or more of the potash refineries in the Carlsbad district. The conditions termed "high" are roughly equivalent to the grade of langbeinite and sylvite ores currently being mined in the district.

Results of the USGS Resource Estimate. The essential results of the USGS resource calculations are best shown by three consecutive maps (Figures 8-2, 3 and 4) which commence with the lowest resource grade standards and progress to the highest. For simplicity, measured and indicated resources were combined. The majority of the resource meets the criteria for "measured" because the entire WIPP site has been drilled on one mile centers. The resource maps do not segregate the several mineralized ore zones, and at times they are "stacked", e.g. the 4th and 10th may be mineralized in the same area in plan even though they are stratigraphically separated by about 180 feet.

Most of the WIPP site area is underlain by potash resources that meet the low standards. No significant planimetric change occurs on raising the standard to lease grades. However, at the high standard, which is roughly equivalent to the current standard of producing mines, the WIPP is nearly clear of potash deposits of interest (particularly Zones I-III). Mining operations may be allowed in Zone IV, the outer boundary of the WIPP site, under controlled conditions.

As grade standards are increased, the potash resources reduce, at more rapid rate on a mass weight basis than on a planimetric basis. Table 8-7 lists the tonnage of by ore zone, type, and location by Zone boundaries within the WIPP site.

For ease in interpretation, the data in Table 8-7 has been charted on Figures 8-5 and 8-6 for langbeinite and sylvite resources, respectively. The USGS recognized the 4th ore zone (langbeinite) and the 10th (mainly sylvite) as the two major mineralized ore zones in the WIPP site area (John et al., 1977). At lease grade, the 4th ore zone contains 115.4 million tons of langbeinite resource, of which only 24 million tons (21%) lies inside the outer boundary of Zone III. At the higher grade (8% K_2O as langbeinite) the tonnage under the WIPP reduces to 59 million tons, of which only 14.6 million tons (25%) lies inside the outer boundary of Zone III.

The 10th ore zone contains mostly sylvite, but a mixed assemblage containing both langbeinite and sylvite exists on the east side of the withdrawal area. At present only one operator in the Carlsbad district has a refinery capable of handling such ores. This operator is the leaseholder over part of this mixed ore zone. However, the langbeinite in the 10th ore zone would be difficult to beneficiate according to the USBM study (USBM, 1977, p.103). Therefore, the 10th ore zone is considered to be viable only for its sylvite content. With this restriction, the 10th ore zone contains 53.5 million tons of ore at lease standard under the entire WIPP site, of which 30.4 million tons (57%) are located within the outer boundary of Zone III. At the high standard, the total tonnage reduces to 38.8 million tons, of which only 9.8 million tons (25%) are inside Zone III.

Results of the USBM Valuation of Potash Resources. The USBM has perfoimed an economic assessment of the potash resources that were defined by the USGS. The USBM study included beneficiation testing to determine the amenability of the various mineral assemblages to refining into marketable products. The USBM engineers visited most of the mines in the district to gather data concerning mining and refining techniques, power consumption, water use, etc. Then, knowing the location and grade

of potash deposits in the WIPP site area, they devised conceptual designs of various mining and processing facilities that would provide both the highest profit and efficient recovery of marketable products from the potash deposits. The approach followed what private industry would do in an evaluation of a potash prospect. No restriction was placed as to where physical mining could be done, or problems related to land acquisition or permitting. Resources adjacent to the WIPP site were considered in the mine development plans. In all, the USBM conceived 12 different conceptual plans for exploiting potash in this area. Each plan, called a mining unit, was evaluated leading to a conclusion that 8 were worthy of full cost analysis. The full findings have been reported by the USBM (1977).

The USBM concluded that only one mining unit (Unit B-1) could be considered economic under existing market conditions and technology (see Table 8.8).

Unit A-1 almost meets the economic requirement of 15% rate of return on invested capital set by the USBM. To make it viable one needs a price of $52.04 per ton of muriate without any increase in production costs. Muriate is currently selling at $43.40 for standard grade containing 62% K_2O (Source: July 1978 issue of Engineering and Mining Journal); however, the price for muriate has exceeded $60 per ton in the past.

Data within the USBM report indicate that the langbeinite resources associated with the Unit B-1 that lie within the boundary of WIPP amount to 48.46 million tons, of which only 13.33 million tons (27.5%) lie inside the outer boundary of Zone III. For Unit A-1 the corresponding numbers are 27.41 million and 0.9 million tons.

Summary of Conclusions Concerning Potash Resources in the WIPP Site. The site contains economically mineable reserves of langbeinite and possibly sylvite. If total rights withdrawal is a requirement to satisfy waste isolation, then the relevant quantities of potash resources are much greater than if mining is allowed in the Zone IV, the outer buffer zone. The relevant quantities are presented in Table 8-9.

The USGS has estimated that potash resources in southeast New Mexico (excluding the WIPP site) that meet lease standards are on the order of 5000 million tons of combined sylvite and langbeinite ores. Therefore, total withdrawal of potash lease rights at the WIPP site would account for about 7% of those resources; withdrawal of Zone I, II, and III rights would account for about 2%. No data are available for the Carlsbad potash district regarding what percentage of these resources would meet the standards deemed by the USBM to be mineable under today's conditions. In addition, the principal potash resource at the WIPP site consists of langbeinite. No estimates, either by USGS or USBM standards, are available for this ore alone. The Carlsbad district is the only area mining langbeinite in the free world. Langbeinite equivalent is produced in quantity, however, by combining sulfates of potassium and magnesium obtained from brine lakes. When the site was initially selected, most of the WIPP lay outside the Known Potash Area, however the 21 hole drilling program conducted as part of the WIPP potash evaluation resulted in discoveries sufficient to warrant expansion of that boundary (see Figure 8-1). The expansion conforms with USGS policy that potash resources meeting the lease standard must be placed within the enclave.

8.4.8 Hydrocarbons

Method of Evaluation. The WIPP site selection criteria dictated that deep drill holes (defined as those that penetrate through the Ochoan) be excluded from Zones I, II, and III. The objective was to maintain a one mile buffer between deep holes and Zone II, the zone in which waste is to be stored. This particular criterion is restrictive, because much of the Delaware Basin has been penetrated by wildcat test holes with an average density of about one hole per square mile. The present site is one of the few remaining portions of the Delaware Basin in New Mexico which will satisfy the criterion pertaining to deep holes. The absence of extensive drilling is due in part to the great depth (greater than 10,000 feet) to potentially favorable gas formations. In addition, potash deposits north and west of the site area precluded oil and gas exploration in those directions. Federal and State regulations have set aside potash

mineralized areas to protect underground mining operations from accidental entrance of methane gas. Therefore, most of the WIPP site is untested for deep reservoirs that might contain crude oil and natural gas. The evaluation must rely on projection of surrounding subsurface geologic information into the site area. There are four petroleum test holes in Zone IV of the WIPP site. Three holes tested the Delaware sands and were unproductive. The fourth was a deep gas test (15,000 feet) that was also unproductive.

The State Bureau of Mines and Mineral Resources performed a regional evaluation of the hydrocarbon resources in southeast New Mexico which was then used to further evaluate a four township area centered on the original ORNL site (Foster, 1974). This report is useful for the current WIPP site because, as indicated in Figure 8-7, the present site is still within the area studied.

Data contained in Foster's report provide a basis for estimating total hydrocarbon resources that might underlie the site area. By using a statistical approach, Foster arrived at a possible hydrocarbon content for each potential productive zone, commencing with the "Ramsey Sand," down to the top of the Precambrian basement. The Ramsey, the first potential pay zone, is located in the upper part of the Delaware Mountain Group. The lowest zones he considered to be potentially productive were dolomitic reservoirs in the Silurian/Devonian. His estimate was based on full development of any prospective area; therefore, total resources were estimated rather than the economics associated with their extraction. His resource estimate was based on the premise that geologic conditions beneath the site were as favorable as elsewhere in the study area and that each potential zone beneath an untested section would contain a proportionate share of the statistical average of hydrocarbons for that zone. The average was derived from success ratios and a conservative estimate of primary recovery of hydrocarbons as established by past exploration, development and production.

A consulting petroleum engineering firm, Sipes, Williamson and Aycock, Inc (SW&A), was engaged by Sandia Laboratories to conduct an economic evaluation of hydrocarbons in the site area. Based on known drilling costs and market conditions, they made a judgment as to what portion and which formations under the site were worthy of testing. The basic criterion was reasonable prospect for discovery with an economic reward to the operator of at least 10% return on his investment plus full recovery of costs. The essential conclusion of the SW&A study was that the Morrow unit has a high potential for successful discovery of natural gas. All other formations present were considered too high a risk to be the objective of a prudent wildcat test. Naturally, once a Morrow well was drilled it could encounter shallower productive pay zones, but the odds of such happening were deemed too speculative to be considered in the overall economics. The full findings of this study have been reported by Keesey (1976).

Structure maps of several horizons beneath the Ochoan evaporites have been compiled from seismic surveys that were either purchased from existing surveys or conducted as part of the WIPP site study. While the main purpose of these seismic surveys has been to understand the geologic aspects of the site area, they are also valuable for interpretation of potential hydrocarbon reservoirs. These structure maps were not available to Foster for his 1974 study, but they were to SW&A during their 1976 evaluation. The seismic studies have been reported by McMillan (1976) and G. J. Long & Associates (1976). Updated structural interpretations based on later seismic studies are now available. The recent changes have had little impact on the overall hydrocarbon evaluation.

Total Hydrocarbon Resources at the WIPP Site. The New Mexico Bureau of Mines study forms the basis of the evaluation of the total hydrocarbon resources in the site area (Foster, 1974). We assume there is a reasonable probability that Foster's estimated resources could exist under the site. However, this probably represents the upper bound of exploitable hydrocarbons.

The validity of the resource estimate rests on the subsurface geology and statistical probability. The geologic setting under the Ochoan evaporites is considered to be quite typical for this portion of the Delaware Basin; therefore the chance of finding oil or gas should approximate what has been found in similar areas near the site which have been more fully tested. However, since it is a regional statistical approach, it is possible that much more or much less than the average expected resource would be found if the site was actually drilled. The hydrocarbon evaluation is not as definitive as that for potash, which was actually confirmed by exploratory drilling. This would be self-defeating in the case of the deeper hydrocarbon resources since the area was selected to avoid such deep drill holes.

Foster's evaluation (Foster, 1974) took into account the occurrence of all known oil and gas accumulations in much of southeast New Mexico (Figure 8-7). The statistical base encompassed about 42 full townships equivalent to almost 1 million acres. The reserves for each oil pool or gas reservoir were estimated from the standpoint of actual or, where possible, projected production. Areas were then classed as developed or undeveloped based on the density and depth of drilling. From these data, Foster (1974) then determined the expected resource per section of land by assuming that the success of future drilling would have the same success ratio as in the past. A coincident assumption was that, while past wildcat drilling avoided the current WIPP site, the past economic incentive for drilling was low. Also, drilling restrictions pertaining to the Known Potash Enclave have prevented drilling, particularly on the west side of the WIPP area. There were more attractive areas available throughout the basin that satisfied the availability of private venture for exploration capital. These past constraints do not enter into the hydrocarbon potential estimates because the characterization of the site must take into consideration the long-term needs for mineral resources.

Figure 8-8 is taken from Foster (1974). Formations that be considered as potentially productive are shown opposite the stratigraphic column of sedimentary rocks underlying the Ochoan evaporites. Table 8-10 then

shows the potential resource he assigned to the various specific intervals but which were composited to more gross intervals. Further explanation is required pertaining to "wildcat" and "acreage" assignment of reserves.

The acreage method tests the success ratio of producing acreage versus the acreage considered to have been tested by wildcat drilling. The wildcat method considered a field, regardless of the number of wells in that field, as a single discovery. A success ratio was then determined by dividing the number of wildcat discoveries by the number of dry holes that were drilled to that formational depth. The acreage method normally results in a higher success ratio and, therefore, higher reserve estimates. In-place hydrocarbon resources for each zone within the WIPP site can be readily calculated from Foster's data by combining his estimate of in-place hydrocarbon resources per section (640 acres) with the known area for each zone of the WIPP site. The acreage method was used to prepare Table 8-11.

While the quantities given in Table 8-11 may appear large, they are brought into perspective by stating that all of the nearby region, i.e., the area studied by Foster, would contain 51 times the resource quantity under the WIPP site. The factor is simply the ratio of the total area evaluated by Foster (1512 square miles) divided by the area of the WIPP site (29.62 square miles). In addition, if hydrocarbon development is allowed in Zone IV, e.g., by deviated drilling, then the resource that would be withdrawn is reduced in proportion to the excluded area, i.e., from 29.62 square miles down to 12.73 square miles for a 43% reduction in restricted resources. The hydrocarbon resources remaining in Zones I, II, and III would account for only 0.84% of the total hydrocarbon resources Foster has estimated in the area immediately surrounding the WIPP site.

Estimate of the Economically Recoverable Hydrocarbon Resources. Sipes, Williamson, and Aycock, Inc. (SW&A) estimated the potentially economic hydrocarbon resources (Keesey, 1976). Their approach was to review the

existing geologic information pertaining to the area in and around the site and then to determine if the probability of oil and gas occurrences justified the risk of drilling and completing a well. The base area studied by SW&A consisted of a 20 x 20 mile block centered on the WIPP site (Figure 8-7). All available data were evaluated on each test that had been drilled within this 400 square mile area, with particular emphasis placed on deliverability and recoverable reserves.

SW&A found that 60 wells in this area were producing oil and/or gas from reservoirs in the Delaware Mountain, Bone Spring, Wolfcamp, Strawn, Atoka and Morrow. With the exception of the Atoka and Morrow, all other zones were considered as presenting too high a risk to justify the cost of wildcat drilling. Furthermore, even though an Atoka reservoir is being produced from a well located near the southwest corner of the WIPP site, SW&A concluded that that particular reservoir is being effectively drained by the single well. Offset drilling would enhance recovery rate but not total recovery.

The Morrow was considered to be worthy of testing, because of the high success ratio of wells drilled to that formation in the area around the site. Of 26 wells drilled to sufficient depth to test the Morrow, 23 were successfully completed as gas wells. A study of those wells revealed that the projected ultimate recovery ranged from insignificant to as much as 5.20 billion cubic feet (bcf) of natural gas. From the distribution of recoveries they concluded that the average successful Morrow well would recover 2.074 bcf of gas. This is in fair agreement with Foster's estimate for Pennsylvanian gas wells; he estimated 3.2 bcf per Morrow gas well if spaced at 320 acres per well.

Drilling and completion costs were then estimated for wells drilled to the Morrow (approximately 14,000 ft.). The estimate was $1.4 million. Using discounted cash flow analysis and the expected delivery rate and current gas price ($1.42 per 1,000 cu. ft. with 4% yearly escalation) they concluded that if a well produced 0.7 bcf over its lifetime it would

recover costs. Since the average well was more than twice this production, it was apparent that drilling in the site area could be justified.

Use was then made of the structure map on a limestone reflector horizon in the Morrow based on data from seismic surveys (Figure 8-9) (Long, 1976). Tentative drilling sites were picked with weight given to the flanks of anticlines because local experience indicates that productive sand lenses would more likely occur at such localities. A total of 20 drill sites was selected (Figure 8-9). In favorable structural areas wells were placed on a spacing of 320 acres per well. This spacing is standard practice for wells of this depth in New Mexico. Depending on proximity to producing wells and structural favorability, the 20 wells were ranked as proven, probable or possible. The proven category was limited to locations that would offset producing wells in the Los Medanos field. Two locations were designated as proven, nine as probable, and nine as possible.

The ultimate recovery of wells was adjusted to take into account the risk factor associated with wildcat drilling. Proven wells were assigned production of 2.07 bcf, probable wells 1.64 bcf, and possible wells 1.33 bcf per well for the southwest quadrant of the WIPP site. The estimated reserves for locations in other parts were placed at 2.09 bcf for probable and 1.67 bcf for possible reserves. No locations could be considered as proven. The higher reserves assigned to these locations were considered justifiable because shallower pay zones may be discovered on the way down to the Morrow. This calculation yielded a total reserve of 36.85 bcf of natural gas under the WIPP site (Table 8-12). Some distillate would accompany this gas production. Foster (1974) estimated that Pennsylvanian gas is accompanied by 14,950 barrels of distillate per bcf of natural gas produced. Therefore, the 36.85 bcf of reserve under the site should be expected to be accompanied by 550,900 bbl distillate.

Of the 20 drilling sites selected, 7 lie in Zone IV, 2 of which are ranked as proven, 4 as probable, and 1 as possible. The aggregate

reserve of these 7 wells is 13.38 bcf of natural gas and 200,000 bbl of distillate. If drilling is allowed into Zone IV these hypothetical reserves could be recovered. The net balance that would be non-recoverable because of restrictions on drilling in Zones I, II, and III is 23.47 bcf of natural gas and 350,000 bbl of distillate.

Summary of Conclusion Concerning Hydrocarbon Resources. Table 8-13 summarizes the findings of the New Mexico Bureau of Mines resource study and the SW&A economic evaluation of the part of those resources considered attractive enough to be developed by the petroleum industry at 1977 prices and drilling costs.

The hydrocarbon resources remaining under the WIPP, if Zone IV is developed, amount to about 0.84% of that projected by Foster for the vicinity of the WIPP site. The total economic reserve, including Zone IV, amounts to approximately 90 days production of dry gas from southeast New Mexico.

8.4.9 Metalliferous Deposits in the Precambrian

Even the deepest oil/gas test near the WIPP site has not penetrated deep enough to encounter the Precambrian basement. A regional survey of test holes has been done by Foster and Stipp (1961). The basement may consist of slightly metamorphosed rhyolites and tuffs known as the Panhandle Volcanic Complex (Flawn, 1954). Such rocks hold potential for sulfide deposits. Geophysical techniques (induced polarization or electromagnetics) have a detection capability scarcely exceeding 1000 feet, while the Precambrian is at median depth of 18,000 feet beneath ground level at the WIPP site. No evaluation, therefore, is feasible for sulfide deposits. The depth is greater by a factor of almost two over the deepest mines in the world. Therefore, resources in the basement rocks, should they exist, are not likely to be attractive targets for exploitation.

8.5 SUMMARY

Potassium salts and fluid hydrocarbons are the only two resources thought to be economically significant in the WIPP site area. The depth, volume and richness of the deposits are the principal factors which will determine when and if they might be exploited by a free-enterprise system. Such economic evaluation has been conducted and reported in the WIPP Environmental Impact Statement. Because economic aspects change, they are not so relevant to site characterization as they are to assessing the impacts of constructing the WIPP facility. Hence, in this chapter, amounts and types of resources will be discussed rather than their present economic value. The principal findings of resource studies are summarized in Table 8-1.

If reasonable technologic and economic restraints are considered for extracting, processing and marketing the resources then both the amounts and types of exploitable deposits are greatly reduced. Only potash and natural gas are considered to be significant in this respect (see Table 8.2). Even these reduced quantities should be considered as upper estimates because of these assumptions: 1) complete mineral lease ownership by a single company and 2) no conflict between the simultaneous development of the shallow potash deposits and the deep gas reservoirs.

Economic resources are further reduced by allowing the mining of potash and recovery of oil and gas by deviated drilling in Zone IV, the outer buffer zone. If this is the case, then economic resources lying in the inner zones are limited to those given in Table 8-3.

Caliche, salt, and gypsum are also present, but the abundance of these minerals throughout the region leads to the conclusion that land withdrawal for the WIPP will have little effect on present or future requirements for them. Consideration was also given to the possible presence of uranium in redbed-type sediments that overlie the evaporites. The conclusion is that no significant uranium deposit exists. Lithium occurs in a brine reservoir within the Castile Formation

northeast of the present site and may be present in a similar reservoir to the southwest. However, care has been taken to avoid such brine reservoirs within the site area. Consideration was also given to the possible existence of metalliferous deposits in the Precambrian basement under the site. However, the depth (about 18,000 feet below the ground surface) to Precambrian rocks would preclude mining even if mineral concentrations were present. No geologic or geophysical evidence exists to suggest that deposits are any more likely in the basement rock of the WIPP area than elsewhere in the region.

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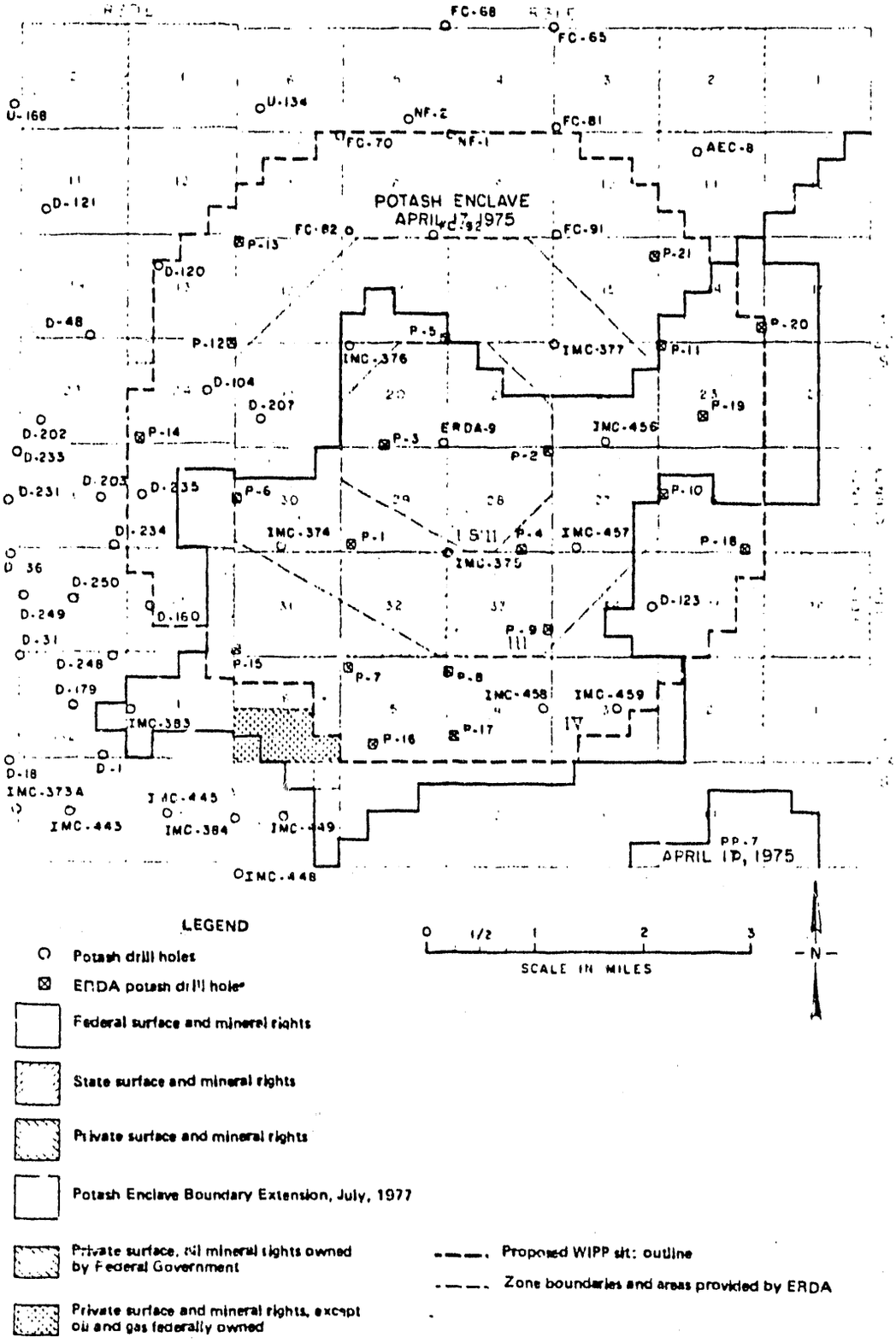


FIGURE 8-1
LOCATION OF POTASH EXPLORATION DRILL HOLES

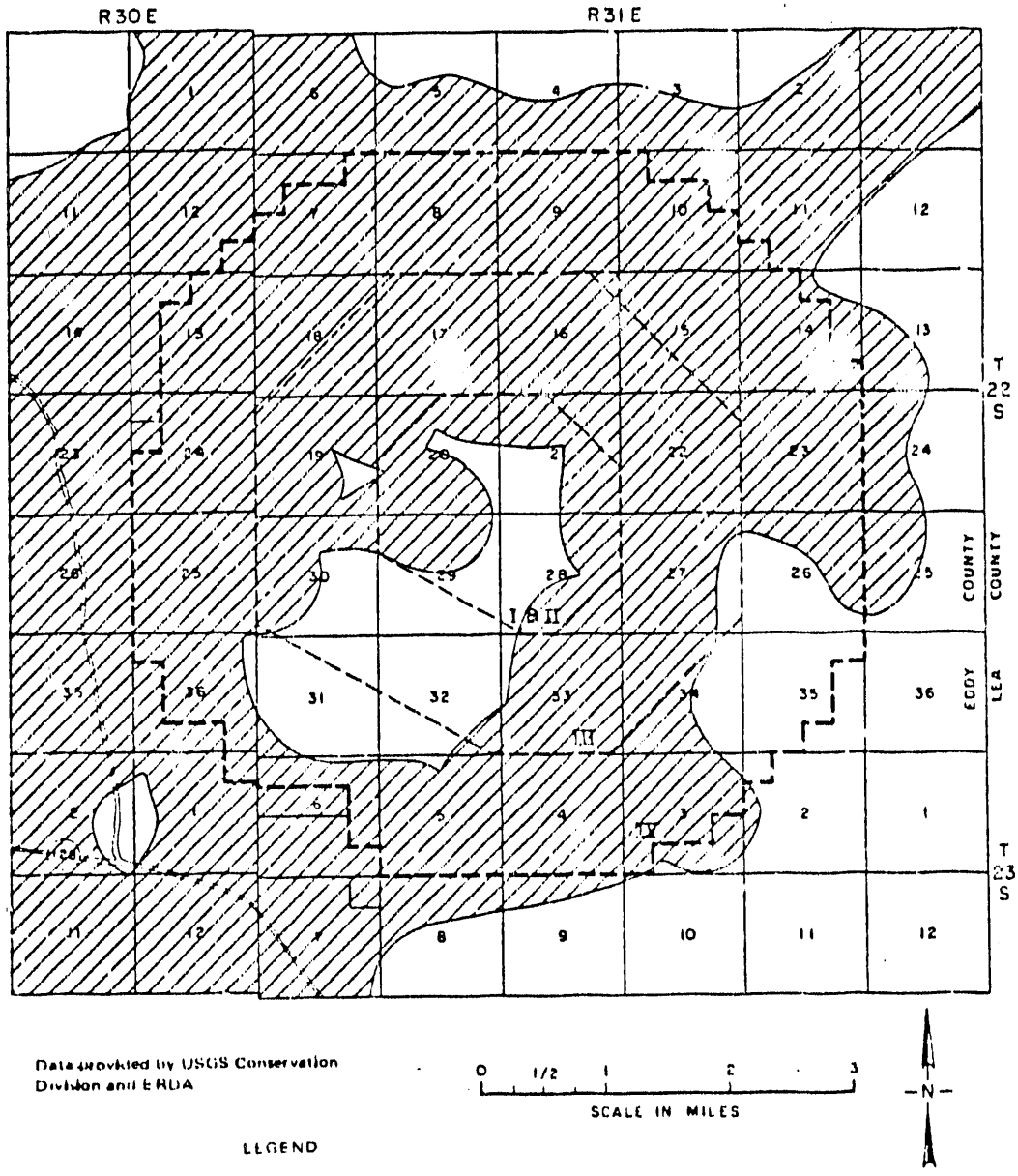


FIGURE 8-2 LOW STANDARD POTASH RESOURCES

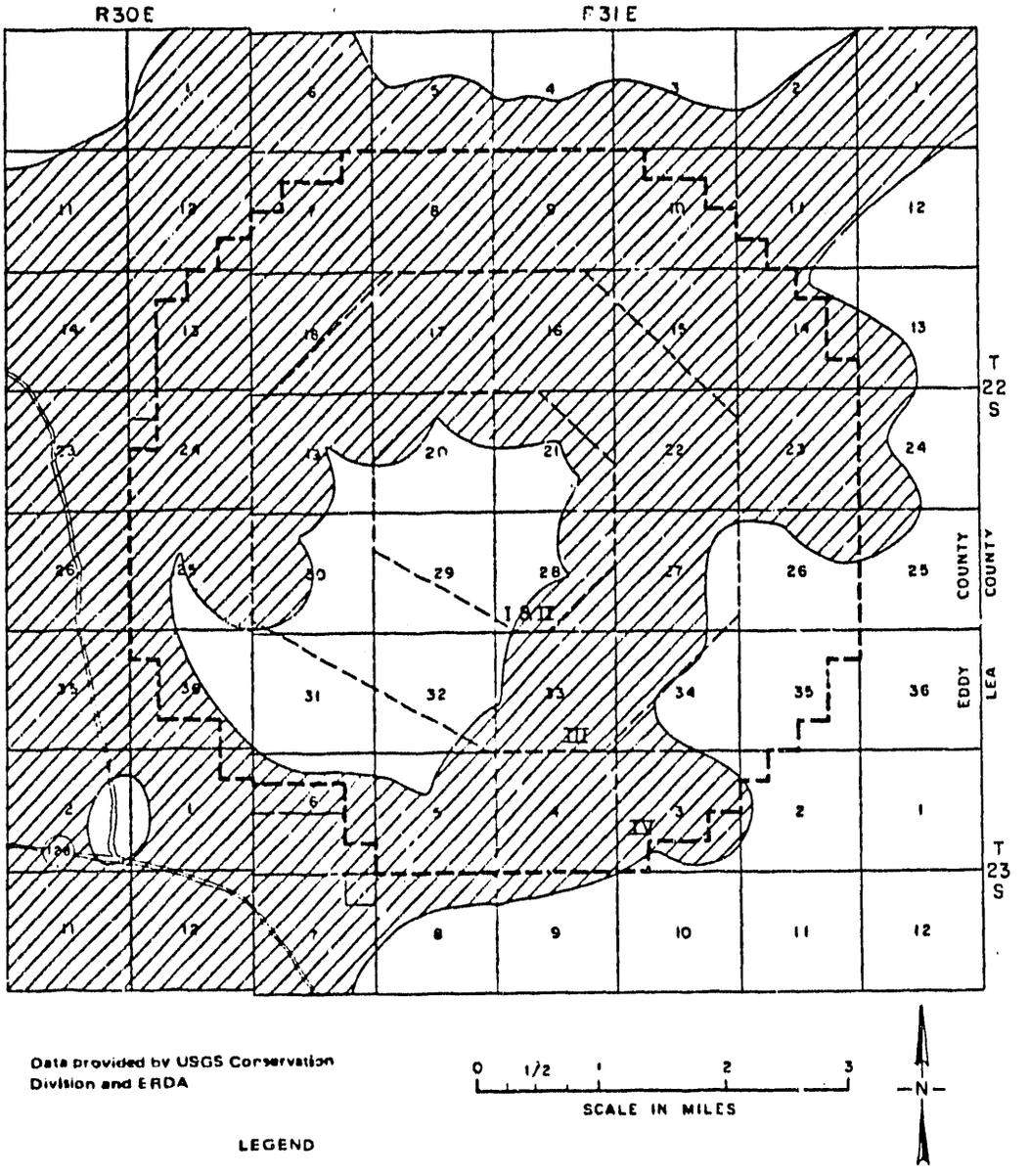


FIGURE 8-3 LEASE STANDARD POTASH RESOURCES

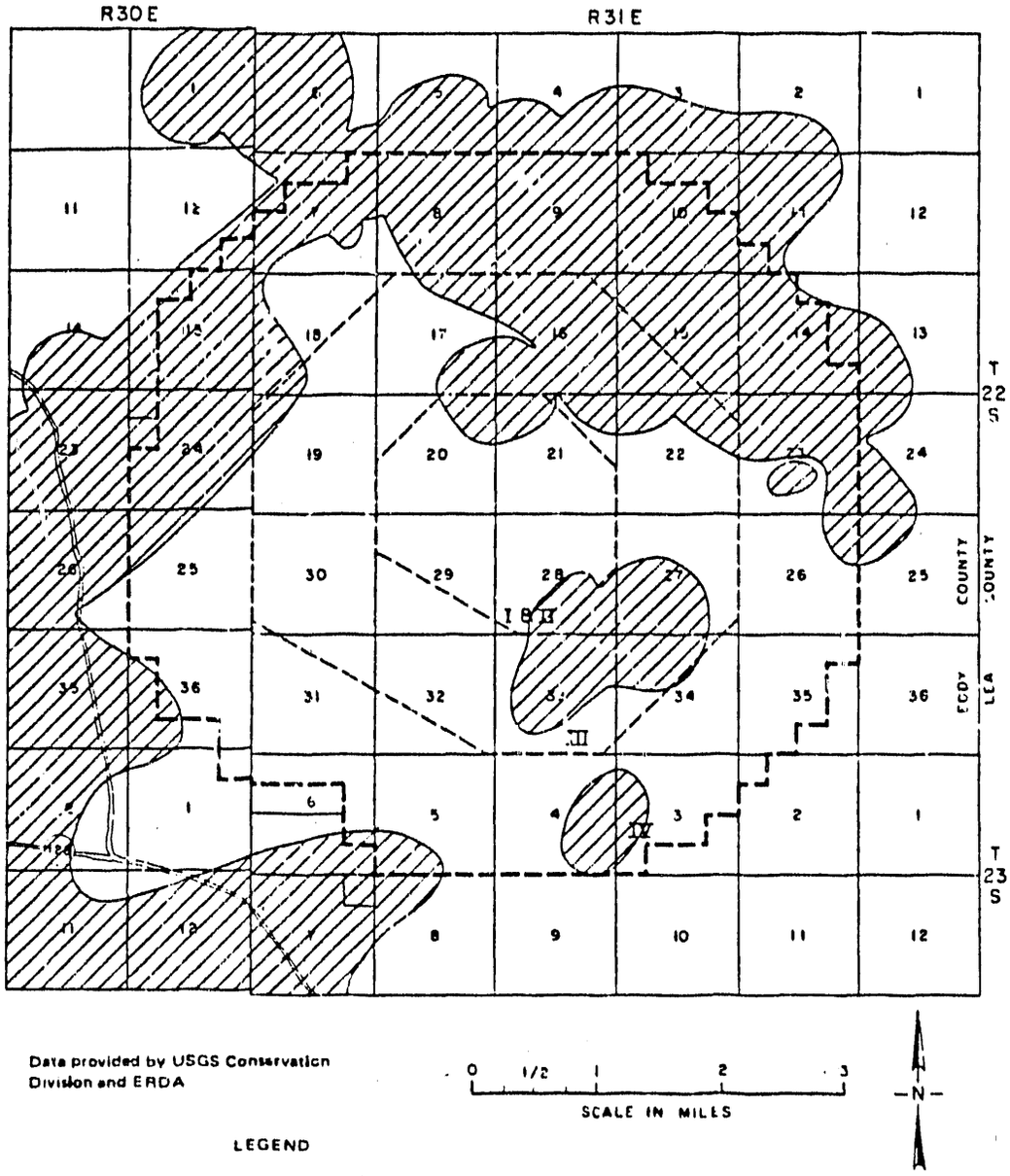


FIGURE 8-4 HIGH STANDARD POTASH RESOURCES

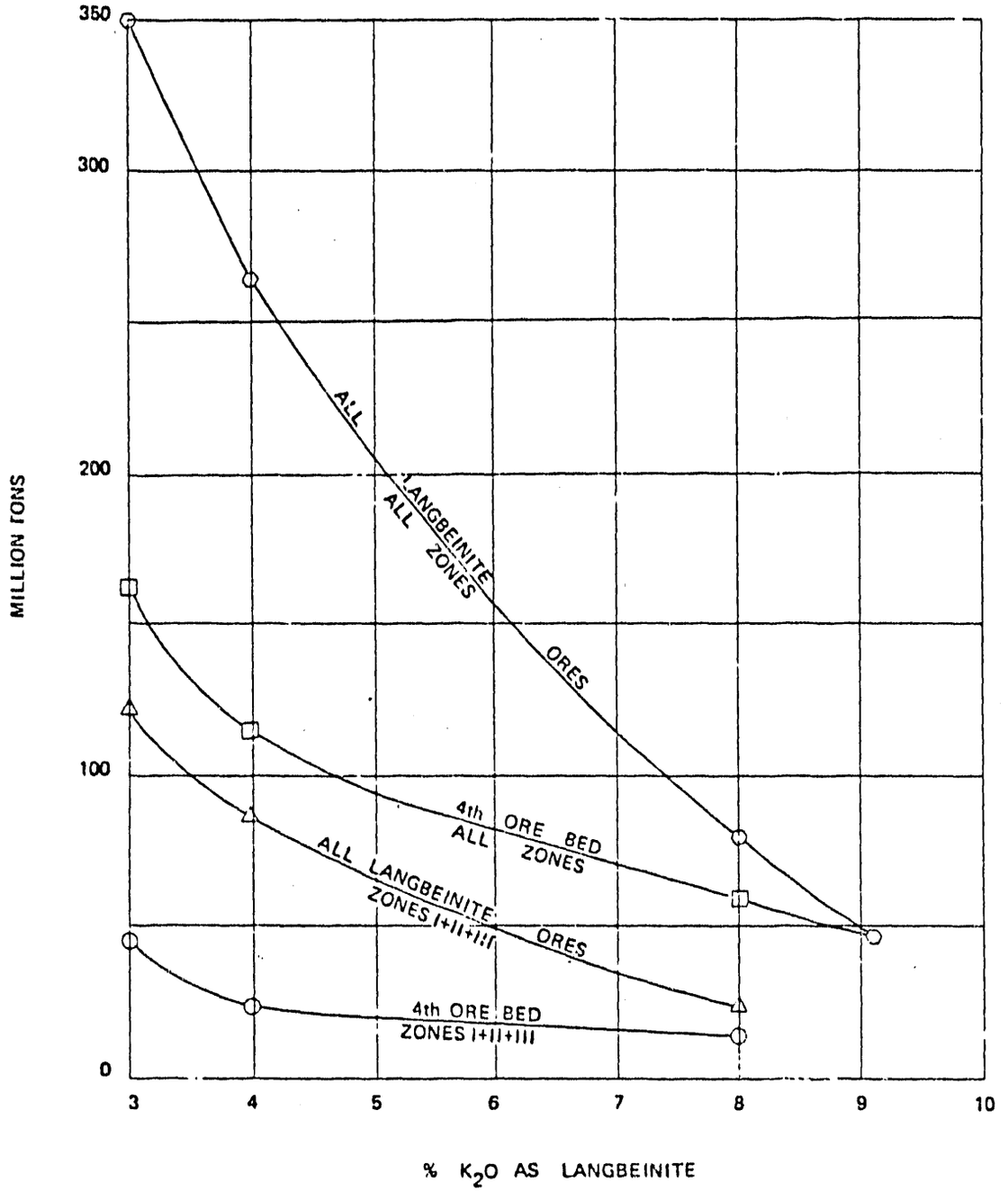


FIGURE 8-5. LANGBEINITE RESOURCES

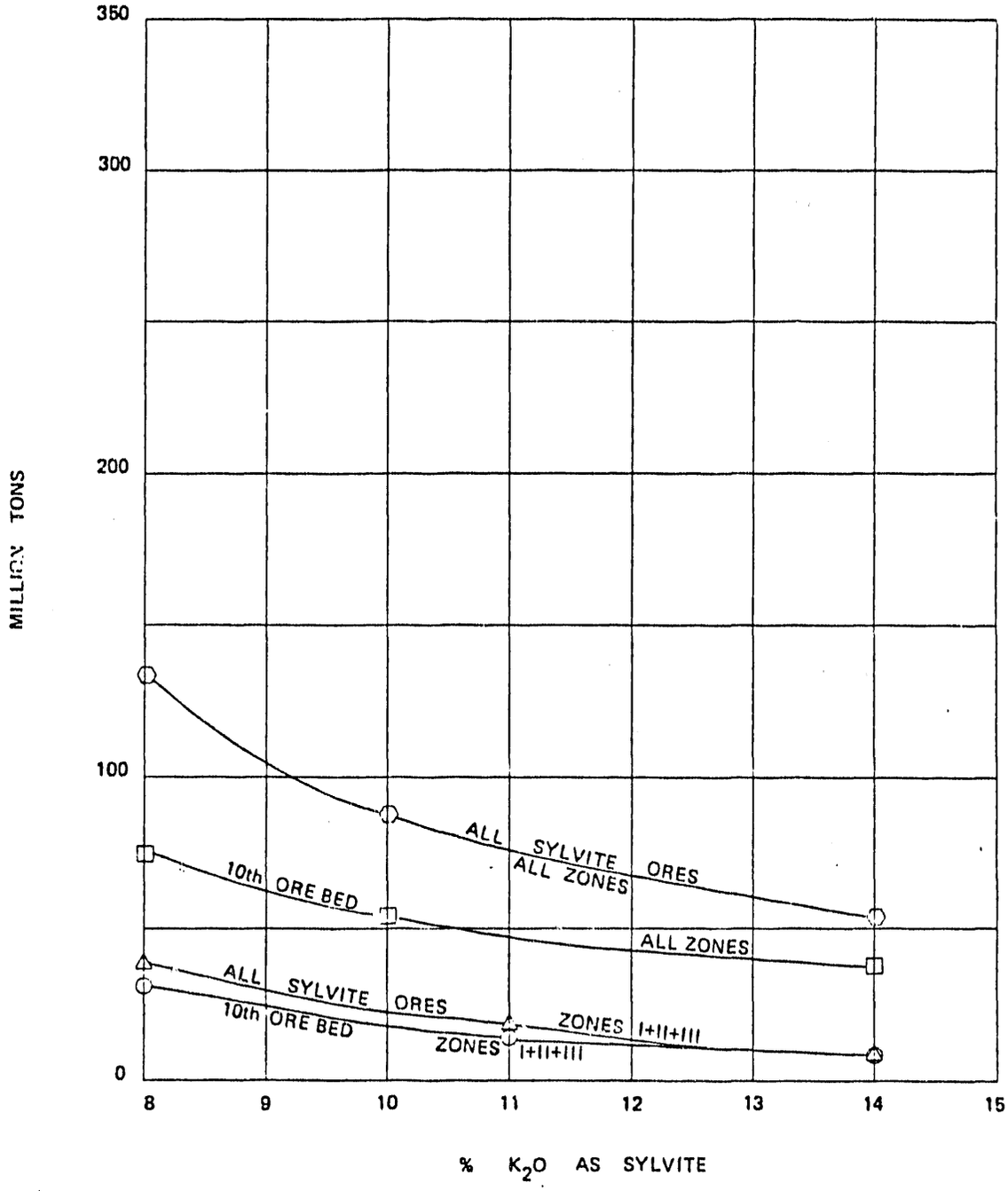
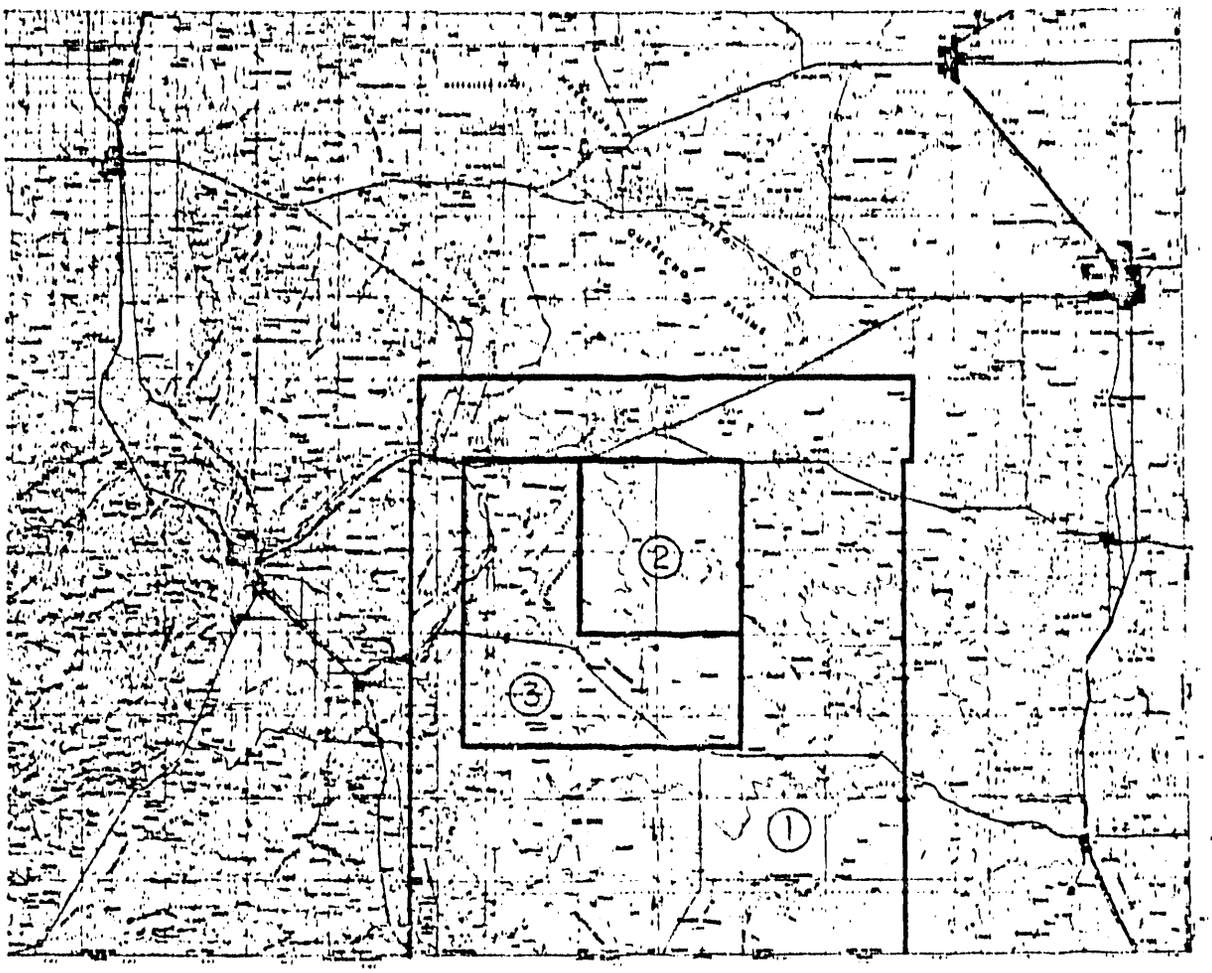


FIGURE 8-6. SYLVITE RESOURCES



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(1) NEW MEXICO BUREAU OF MINES STUDY AREA

(2) NEW MEXICO BUREAU OF MINES DETAILED STUDY CENTERED ON OLD ORNL SITE

(3) SIPES, WILLIAMSON AND AYCOCK STUDY AREA CENTERED ON WIPP SITE

FIGURE 8-7
LOCATION OF HYDROCARBON RESOURCE STUDY AREAS

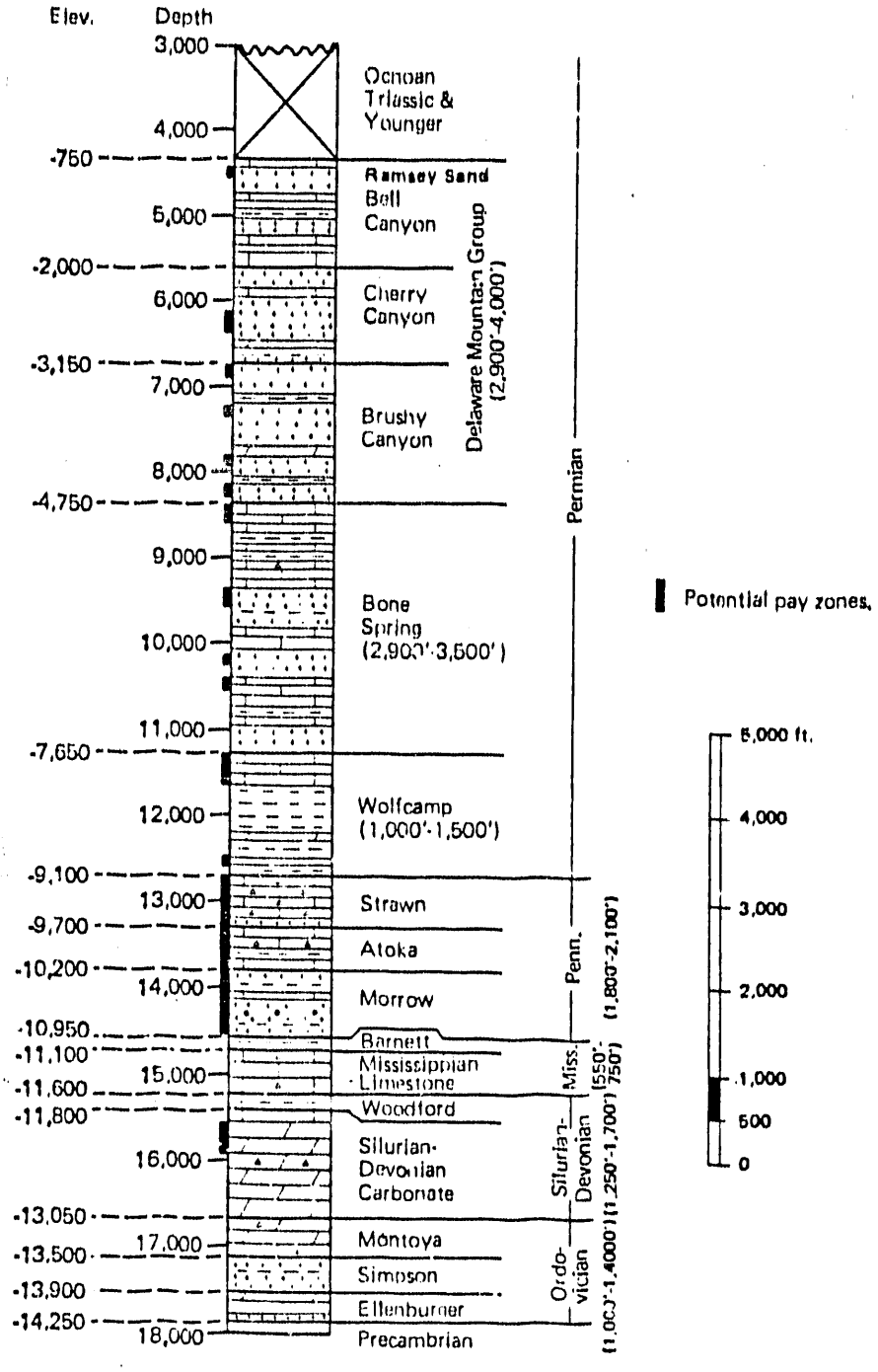

FIGURE 8-8. GEOLOGIC COLUMN AND POTENTIAL HYDROCARBON RESERVOIRS (ADAPTED FROM FOSTER, 1974)

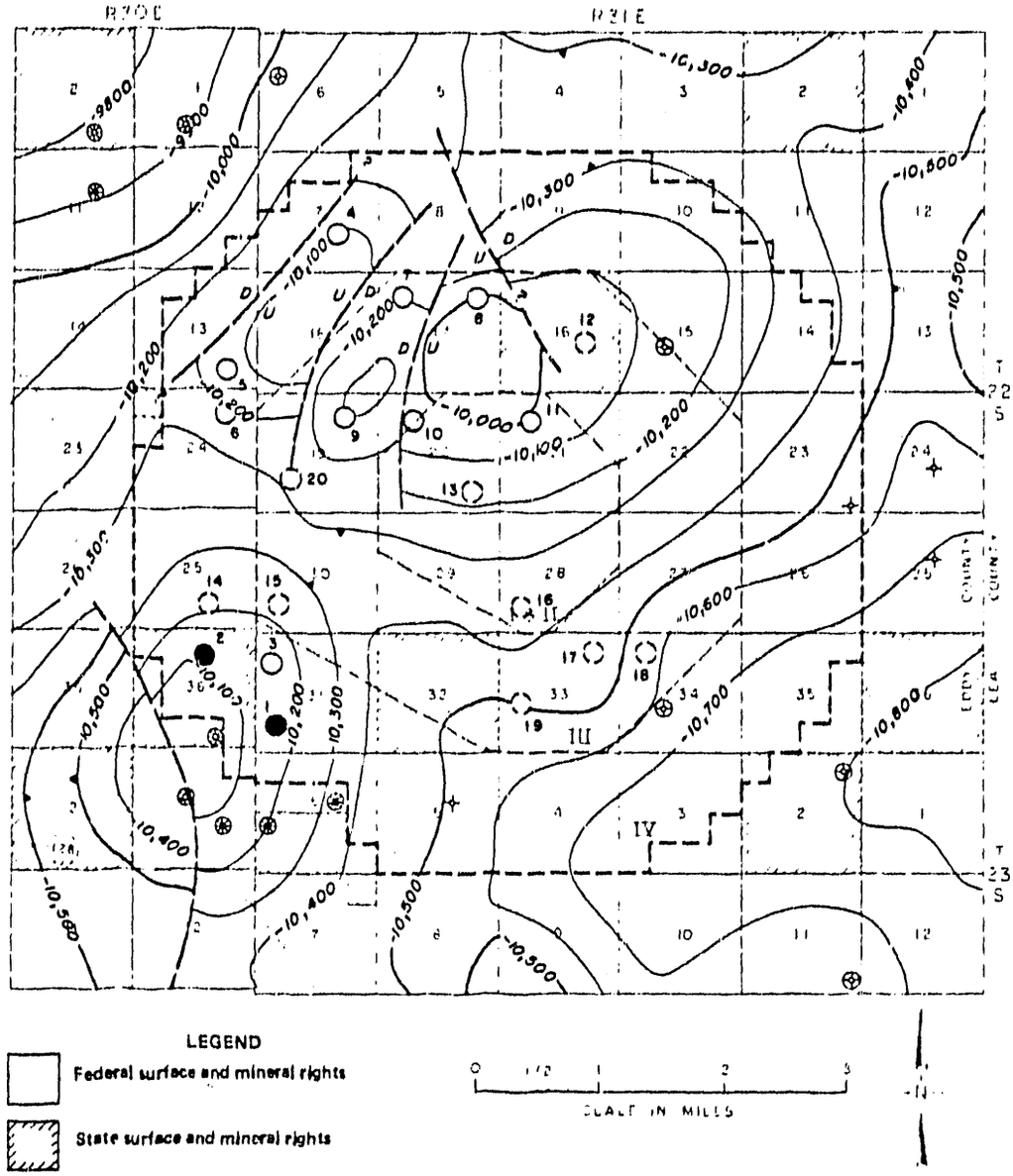

FIGURE 8-9

HYPOTHETICAL DRILLING SITES TO DEVELOP
POTENTIAL MORROW GAS RESERVOIRS

TABLE 3-1

TOTAL ESTIMATED RESOURCES AT WIPP SITE

Resource	Quantity	Depth	Richness
Caliche	185×10^6 tons	at surface	21-69% Insol.
Gypsum	1.3×10^9 tons	300-1,500 feet	Pure to mixed
Salt	198×10^9 tons	500-4,000 feet	Pure to mixed
Sylvite	88.5×10^6 tons	1600 feet	11.8 K_2O
Langbeinite	264.8×10^6 tons	1800 feet	6.10 K_2O
Crude Oil	37.7×10^6 bbls	4,000-20,000 feet	31-46° API
Natural Gas	490×10^9 cu. ft.	4,000-20,000 feet	1100 BTU/cu ft
Distillate	5.72×10^6 bbls	4,000-20,000 feet	53-56° API

TABLE 8-2

POTENTIAL ECONOMIC RESOURCES AT WIPP SITE

Resource	Quantity	Depth	Richness
Sylvite	27.43×10^6 tons	1,600 feet	13.33% K_2O
Langbeinite	48.46×10^6 tons	1,800 feet	9.11% K_2O
Natural Gas	36.85×10^9 cu ft	14,000 feet	1,100 BTU/cu ft
Distillate	0.55×10^6 bbls	14,000 feet	53° API

TABLE 8-3

ECONOMIC RESOURCES WITHIN ZONE I, II AND III AT WIPP SITE

Resource	Quality	Depth	Richness
Langbeinite	10×10^6 tons	1,800 feet	10% K_2O
Natural Gas	20×10^9 cu ft	14,000 feet	1,100 BTU/cu ft
Distillate	132×10^3 bbls	14,000 feet	53° API

TABLE 8-4

ORGANIZATIONS RESPONSIBLE FOR RESOURCE EVALUATION AND KEY REPORTS CONCERNING RESOURCES

Organization	Responsibility	Reports
U.S. Geol Surv.	Potash Resources as related to ore grade and volume	John et al. (1978) Jones (1978)
U.S. Bur. of Mines	Determination as to what extent the potash resources reported by U.S.G.S could be economically mined and refined under today's technology and market	USBM (1977)
N.M. Bur. of Mines	Definition of resources and economics for caliche, salt, gypsum, brine, sulfur and uranium	Siemers et al. (1978)
N.M. Bur. of Mines	Oil and gas resources of a four township area which includes the WIPP site	Foster (1974)
Sipes, Williams and Aycock, Inc.	Determination of the economic viability of hydrocarbons under the WIPP site	Keesey (1976)
G.J. Long & Assoc. Inc., Permain Exploration Co.	Intrepretation of structure of Paleozoic sediments beneath Ochoan evaporites. These studies were useful in evaluation of hydrocarbons	Long (1976), McMillan (1976)

Table 8-5

POTENTIAL RESOURCES CORRELATED WITH STRATIGRAPHY

Formation	Thickness(ft)	General Character	Potential Resources	Evaluation
Mescalero Sand	0-15	Dune sand, fine grained	None	No resource
Caliche	0-5	Limestone, chalky	Caliche (in road construction)	Caliche is abundant throughout the area
Gatuna	0-375	Sandstone and siltstone	Uranium	Conditions apparently were oxidizing during deposition, and no uranium is apt to occur in the vicinity
Santa Rosa Sandstone		Sandstone	Uranium	Conditions apparently were oxidizing during deposition, and no uranium is apt to occur in this vicinity
Dewey Lake	487	Siltstone and sandstone some claystone	Uranium	Minor occurrences have been reported outside the WIPP site area. Gamma ray logs of 36 holes drilled within the site area showed no anomalies.
Rustler	310	Anhydrite and rock salt with subordinate dolomite, sandstone, claystone and polyhalite	Gypsum and salt	Abundant throughout the area, no advantage for site resources.
Salado	1976	Rock salt with subordinate anhydrite, polyhalite, potassium ores sandstone, and magnesite	Potassium salts, salt and gypsum	Langbeinite and sylvite occur in commercial quantities

Table 8-5 (Continued)

Formation	Thickness(ft)	General Character	Potential Resources	Evaluation
Castile	1400	Anhydrite and rock salt with subordinate limestone	Sulfur, salt, lithium in brine reservoirs	Salt is abundant throughout the area. Lithium concentration in brine is subeconomic today. Care has been taken to exclude brine reservoirs from site. Conditions and structures for sulfur deposits not known to exist at site.
Delaware Mtn. Group	3800	Fine grained sandstone (possibly a siltstone), shale, limestone, and dolomite	Oil and associated gas. Most favorable zone is the Ramsey sand	Reservoirs may exist, but small in comparison with the Morrow Formation
Bone Spring	3400	Limestone, fine-grained sandstone, and black shale	Oil and asscciated gas	Reservoirs may exist, but are small in comparison to the Morrow Formation
Wolfcamp (Hueco)	1480	Limestone, black shale, red or green shale, sandstone, and conglomerate	Oil and gas	Reservoirs may exist, but are small in comparison to the Morrow Formation
Strawn	300	Limestone, oolitic limestone and gray to black shale	Oil and associated gas	Reservoirs may exist, but are small in comparison to the Morrow Formation
Atoka	640	Limestone, oolitic limestone and gray to black shale	Natural gas	Commercial gas is being produced from near site. Atoka reservoirs are restricted in size, therefore, small likelihood of existence under the site
Morrow	1300	Limestone, oolitic limestone, gray to black shale, and sandstone	Natural	Commercial quantities of gas probably exist

Table 8-5 (Continued)

Formation	Thickness(ft)	General Character	Potential Resources	Evaluation
Mississippian	740	Black, angillaceous shale, black calcareous shale or shaly limestone, some sandstone	None	None likely
Siluro Ordovician	2100	Limestone, dolomite, chert, shale, black shale with rounded quartz grain inclusions, and small amounts of sandstone	Oil and gas. Most favorable zone is beneath the Woodford Shale	Oil and gas may be present in anticlinal situations
Precambrian		Not tested with in the WIPP site locality. Regional inference is that it consists of acidic volcanics or metasediments	Sulfide deposits	Considered too deep to exploit.

References: Siemers et al., 1978; Foster, 1974.

TABLE 8-6
STANDARD CONDITIONS FOR POTASH RESOURCES

Class	Type Ore	% K_2O	Thickness, ft
Low	Langbeinite	3	4
	Sylvite	8	4
Lease	Langbeinite	4	4
	Sylvite	10	4
High	Langbeinite	8	4
	Sylvite	14	4

Reference: John et al, 1978.

Table 8-7

POTASH RESOURCES, TONS x 10^6

I. Sylvite Ores

Ore Zone	Low Grade			Lease Grade			High Grade		
	I+II+III	IV	Total	I+II+III	IV	Total	I+II+III	IV	Total
10	30.4	44.4	74.8	16.5	37.2	53.7	9.8	28.9	38.7
9	3.7	6.6	10.3	1.2	4.8	6.0	--	0.7	0.7
8	5.0	43.1	48.1	1.0	27.8	28.8	--	13.7	13.7
Total	39.1	94.1	133.2	18.7	69.8	88.5	9.8	43.3	53.1

II. Langbeinite Ores

Ore Zone	Low Grade			Lease Grade			High Grade		
	I+II+III	IV	Total	I+II+III	IV	Total	I+II+III	IV	Total
10	25.0	30.6	55.6	24.6	24.8	49.4	9.7	0.9	8.8
5	11.6	14.6	26.2	10.9	13.3	24.2	--	1.6	1.6
4	46.5	114.5	161.0	24.0	91.4	115.4	14.6	44.4	59.0
3	14.6	19.9	34.5	9.6	16.0	25.6	--	--	--
2	24.2	49.5	73.7	18.7	31.5	50.2	1.9	7.9	9.8
Total	121.9	229.1	351.0	87.8	177.0	264.8	24.4	54.8	79.2

III. All Ores

Ore Zone	Low Grade			Lease Grade			High Grade		
	I+II+III	IV	Total	I+II+III	IV	Total	I+II+III	IV	Total
10	55.4	75.0	130.4	41.1	62.0	103.1	17.7	29.8	47.5
9	3.7	6.6	10.3	1.2	4.8	6.0	--	0.7	0.7
8	5.0	43.1	48.1	1.0	27.8	28.8	--	13.7	13.7
5	11.6	14.6	26.2	10.9	13.3	24.2	--	1.6	1.6
4	46.5	114.5	161.0	24.0	91.4	115.4	14.6	44.4	59.0
3	14.6	19.9	34.5	9.6	16.0	25.6	--	--	--
2	24.2	49.5	73.7	18.7	31.5	50.2	1.9	7.9	9.8
Total	161.0	323.2	484.2	106.5	246.8	353.3	34.2	98.1	132.3

Reference: John et al., 1978.

Table 8-8

ECONOMIC POTASH RESOURCES, TONS x 10^6

Mining Unit	Products	Recoverable Ore in Mining Unit	Recoverable Ore in WIPP Site	Percent in Zones I,II,III	Price[1] that Provides a 15 Percent ROR[2], $
B-1	Langbeinite	79.78	48.46	27.5	35.00
	Sulphate			27.5	88.50
A-1	Muriate	57.60	27.41	3.2	52.04
D-2	Langbeinite	87.93	23.57	0.7	36.51
	Sulphate			0.7	92.31
A-2	Muriate	98.32	51.80	7.6	61.73
C-2	Muriate	57.19	36.49	54.2	61.74
D-3	Langbeinite	140.27	42.45	23.5	42.26
	Sulphate			23.5	106.86
C-3	Muriate	70.64	52.87	57.5	67.52
A-3	Muriate	135.02	73.77	14.9	70.28

[1]Market price assuming no increase in production costs. Estimated weighted average annual price per ton of product, f.o.b., Carlsbad, New Mexico, used for evaluation.

[2]Rate of return

Reference: U.S. Bureau of Mines, 1977.

Table 8-9

SUMMARY OF POTASH RESOURCES, 10^6 TONS

	In Place Resources (USGS Study)				Mineable Today (USBM Study)	
	Lease Standard		High Standard			
	Langbeinite	Sylvite	Langbeinite	Sylvite	Langbeinite	Sylvite
Total Withdrawal	204.8	88.5	79.2	53.1	48.46	27.41*
Mining Permitted in Zone IV	87.8	10.7	24.4	9.6	13.35	0.9

*The USBM does not consider the sylvite contained in Unit A-1 to be mineable under today's market. To do so would require the price for muriate to be $52.04 per ton, or the investor must be willing to accept a rate of return less than 15%.

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Table 8-10

POTENTIAL HYDROCARBON RESOURCES
EXPECTED IN VARIOUS FORMATIONS WITHIN THE DELAWARE BASIN

Stratigraphic Unit	Rating Geological Oil	Rating Geological Gas	Rating Statistical Oil	Rating Statistical Gas	P.O.F.	Production Estimate Section (640 Acres) Acreage Oil (bbls)	Acreage Assoc. Gas (MCF)	Acreage Dist. (bbls)	Acreage Gas (MFC)	Wildcat Oil (bbls)	Wildcat Assoc. Gas (MFC)	Wildcat Dist. (bbls)	Wildcat Gas (MCF)	Adjusted Rating Oil	Adjusted Rating Gas
Ramsey	IV		V		62	472,350	756,324			75,052	120,141			IV	
Delaware Mtn. Gp.	II		II		21	51,686	19,546			34,462	13,029			II	
Bone Spring	III		IV		39	193,952	379,738			88,170	172,610			III	
Wolfcamp	III	III	II	II	23	20,800	228,462	32,544	633,984	20,475	224,953	19,530	383,969	III	III
Pennsylvanian	III	V	III	V	88	265,455				299,788	1,784,799	94,596	6,441,672	IV	IV
Mississippian	I	I	I	I	14										
Silurian/ Devonian	III	III	IV	IV	72	1,368,330	656,676	36,720	4,244,310	343,422	164,804	36,562	4,225,491	I	IV
Ordovician	I	II	I	III	63										

Table 8-10 (Continued)

Adjusted Production Estimate Section (640 Acres)

Ramsey	472,350	756,324			75,052	120,141		
Delaware Mtn. Gp.	25,843	9,773			17,231	6,515		
Bone Spring	45,464	284,804			66,128	129,458		
Wolfcamp	15,600	171,347	24,408	475,488	15,356	168,715	14,648	287,979
Pennsylvanian	265,455	1,580,826	132,440	8,857,200	299,788	1,784,799	118,245	8,052,090
Mississippian								
Silurian Devonian	342,083	164,169	36,720	4,244,310	85,856	41,201	36,562	4,225,495
Ordovician								
	1,266,795	2,967,243	193,568	13,576,998	559,411	2,250,829	169,455	12,565,558

Ratings		Calculated %
I:	Very low	25
II:	Low	50
III:	Moderate	75
IV:	High	100
V:	Very High	125

Taken from: R. W. Foster, 1974

Table 8-11

IN PLACE HYDROCARBON RESOURCES AT WIPP SITE*

Formation	Zone I+II+III			Zone IV			Total		
	Oil (bbls)	Nat. Gas (C.F.) ($\times 10^9$)	Dist. (bbls)	Oil (bbls)	Nat. Gas (C.F.) ($\times 10^9$)	Dist. (bbls)	Oil (bbls)	Nat. Gas (C.F.) ($\times 10^9$)	Dist. (bbls)
Ramsey	6.0×10^6	9.6		8.0×10^6	12.8		14.0×10^6	22.4	
Delaware Group	3.3×10^5	0.1		4.4×10^5	0.2		7.7×10^5	0.3	
Bone Spring	1.9×10^6	3.6		2.5×10^6	4.8		4.4×10^6	8.4	
Wolfcamp	2.0×10^5	8.2	3.1×10^5	2.6×10^5	10.9	4.0×10^5	4.6×10^5	19.1	7.1×10^5
Pennsylvanian	3.4×10^6	132.9	1.7×10^6	4.5×10^6	176.3	2.2×10^6	7.9×10^6	309.2	3.9×10^6
Mississippian									
Silurian/ Devonian	4.4×10^6	56.1	4.7×10^5	5.8×10^6	74.5	6.3×10^5	10.2×10^6	130.6	1.1×10^6
Ordovician									
Total	16.2×10^6	210.5	2.5×10^6	21.5×10^6	279.5	3.2×10^6	37.7×10^6	490.0	5.7×10^6

* Based on Adjusted Production Estimate per Section (640 acres), Acreage method, Table 8-10. WIPP site contains 29.6 square miles or sections.

TABLE 8-12
ESTIMATE OF ECONOMIC HYDROCARBON RESOURCES AT WIPP SITE

Well Number	Natural Gas (BCF) Zone I, II, III			Natural Gas (BCF) Zone IV			Natural GAS (BCF) Total		
	Proven	Probable	Possible	Proven	Probable	Possible	Proven	Probable	Possible
1	---	---	---	2.07	---	---	2.07	---	---
2	---	---	---	2.07	---	---	2.07	---	---
3	---	---	---	---	1.64	---	---	1.64	---
4	---	---	---	---	2.09	---	---	2.09	---
5	---	---	---	---	2.09	---	---	2.09	---
6	---	---	---	---	2.09	---	---	2.09	---
7	---	2.09	---	---	---	---	---	2.09	---
8	---	2.09	---	---	---	---	---	2.09	---
9	---	2.09	---	---	---	---	---	2.09	---
10	---	2.09	---	---	---	---	---	2.09	---
11	---	2.09	---	---	---	---	---	2.09	---
12	---	---	1.67	---	---	---	---	---	1.67
13	---	---	1.67	---	---	---	---	---	1.67
14	---	---	---	---	---	1.33	---	---	1.33
15	---	---	1.33	---	---	---	---	---	1.33
16	---	---	1.67	---	---	---	---	---	1.67
17	---	---	1.67	---	---	---	---	---	1.67
18	---	---	1.67	---	---	---	---	---	1.67
19	---	---	1.67	---	---	---	---	---	1.67
20	---	---	1.67	---	---	---	---	---	1.67
	---	10.45	13.02	4.14	7.91	1.33	4.14	18.36	14.35
		Total	23.47		Total	13.38		Total	36.85
	Plus Distillate 350,900 BBLS			Plus Distillate 200,000 BBLS			Plus Distillate 550,960 BBLS		

Reference: Keesey, 1976.

TABLE 8-13
SUMMARY OF IN-PLACE AND ECONOMIC HYDROCARBON RESOURCES AT THE WIPP

	IN PLACE RESOURCES (NMBM STUDY)			ECONOMIC RESOURCES (SW&A STUDY)		
	Zone I,II,III	Zone IV	Total	Zone I,II,III	Zone IV	Total
Crude Oil 10^6BBLS	16.2	21.5	37.7	---	---	---
Natural Gas 10^9CUFT	210.5	279.5	490	23.47	13.38	36.85
Distillate 10^6BBLS	2.5	3.2	5.7	0.35	0.20	0.55

GCP Chapter 9

SPECIAL STUDIES

9.1 INTRODUCTION

The special studies presented in Chapter 9 cover issues of particular interest because the site is being characterized for radioactive waste isolation (the WIPP). The first special study presented is that of determining the thermophysical behavior of Southeastern New Mexico (SENM) rocks for mine design and the effects of heat-producing wastes, if placed in the WIPP. The second special study is to determine the site-specific sorptive capacities of SENM rocks for radionuclides flowing with SENM groundwaters. Characterization of the sorptive capacities of SENM rocks is required for safety assessment analysis of hypothetical failure events, not for site selection. Both of these studies are by no means complete and are continuing. The information presented here is an indication of the status of these studies in midyear 1978. Tabulations of test data are left to the references and future reports on specific subjects.

9.2 THERMOPHYSICAL PROPERTIES

9.2.1 Introduction

The thermophysical properties of New Mexico rock salt are being investigated to support the structural mine design and to evaluate the overall stability of bedded salt for the WIPP. A goal of this program is to develop constitutive relations which can be used in design and long-term stability calculations, commonly by finite element analyses (Dawson and Tillerson, 1977). Specific concerns are the stability of the facility during its life, the influence of ground motions on waste retrieval capabilities, and the effect of waste emplacement on the long term containment potential. The program was initiated in 1975.

Rock salts are weak, anelastic geological materials. They exhibit nonlinear response under practically all loading conditions at temperatures and pressures normally encountered in mining. Since salt

can experience large strains prior to failure, openings even at very shallow depths have been known to completely close and heal (Baar, 1977).

In long-established active mining districts, careful in situ observations and measurements have provided a basis for making reasonably reliable predictions of room deformation and failure (Baar, 1977). Some of this knowledge is applicable to the WIPP, although it cannot be directly applied to the WIPP because the behavior of rock salt is dependent upon the site, facility design, temperature and time involved. The rock mechanics program considers the particular problems posed by the longevity of the WIPP and by the unusual combination of mechanical and thermal loading anticipated in the repository.

Laboratory experiments have been severely criticized by some for not realistically representing in situ conditions, (Baar, 1977). However, laboratory experiments on rock salt are a useful step in material characterization, to establish limits of behavior. Ultimately, laboratory and in-situ test data coupled with modeling should lead to representative descriptions of material and structural behavior. As the WIPP is developed, in situ monitoring should enhance the validity of laboratory and modeling results.

The thermophysical behavior of rock salt has been modeled through various approaches, (e.g., Bradshaw and McClain, 1975; Fossum, 1977; Langer, 1967; Mraz, 1978; St. John, 1978; Serata, 1966, 1968, 1970; Serata and Cundey, 1978; Thompson and Ripperger, 1964; Thoms et al., 1973; Wahi et al., 1978). A widely accepted model which can translate laboratory data into a prediction of in situ salt behavior has not been developed.

Three broad areas were studied to identify the relative and site specific importance of various southeast New Mexico rock salt thermophysical properties. These three areas of study consist of: 1) petrography relevant to physical and mechanical properties, 2) general physical properties (density, moisture content, resistivity, etc.), and 3) thermal-mechanical properties (quasi-static and creep parameters).

Petrographic studies were conducted on mineralogically characterized core from AEC 7, AEC 8 and ERDA 9 to investigate structural petrographic changes between natural and experimentally-deformed samples (Callender & Ingwell, 1977). Identification of failure mechanisms by petrographic analyses will assist in selecting models to describe rock behavior.

Physical properties being measured for selected core include density, moisture content, porosity, permeability, electrical resisitivity, ultrasonic velocity, and thermal conductivity. Additional gas and brine permeability measurements are in progress at Sandia both on experimentally undeformed and deformed samples.

The following mechanical properties are being measured: uniaxial compressive strength, indirect (Brazilian) tensile strength, stress-strain behavior and ultimate stress in quasi-static triaxial compression, elastic moduli, principal strain ratios, elastic limit ("yield" stress), and creep rates. Additional tests address the effects of specimen machining, specimen aging due to stress relief during and after core retrieval, and specimen size, all of which could limit the field applicability of laboratory-determined results. The influence of sample size may be partially inferred from published data (e.g., Uhlenbecker, 1968; Dreyer, 1972; Szeki, 1978).

The data base for physical and thermal properties determined from core from the WIPP study area is still being compiled, and tests are continuing. Moreover, most of the results obtained to date pertain to rock salt alone, as opposed to other members of the stratigraphic column above and below the proposed repository horizons.

9.2.2 Petrography

Approximately 35 samples of experimentally undeformed and deformed salt were macroscopically and microscopically examined for mineralogy, fabric, and induced structure by J.F. Callender and T. Ingwell of the University of New Mexico (1977). Mineralogy of rock salt from southeast New Mexico has been described in detail in Chapter 7.

Between the depths of 1,000 and 2,000 feet, the samples are predominantly halite (NaCl) (range 47-98 percent) with lesser amounts of anhydrite ($CaSO_4$) (range 0-15 percent), polyhalite ($K_2MgCa_2(SO_4)_4 \cdot 2H_2O$) (range 0-18 percent), and clay and silt range 0-44 percent). Halite is usually present in the core, except in samples from anhydrite layers and polyhalite seams. Anhydrite, clay and silt are generally present, while polyhalite occurs less commonly. Detailed stratigraphy of the WIPP study area is presented in the ERDA 9 corehole lithologic log, Figure 4.3.3.b.

Fabric In general, the undeformed rock salt specimens do not show well-developed linear or planar fabrics, aside from uncommonly observed bedding. Locally, however, halite crystals show a faint to strong elongation, probably due to readjustment to local stresses. Certain fabric features within the cores may presumably have important local effects on salt deformation. These features include bubble trains, hopper crystals, cleavage, glide planes, grain boundaries, and clay zones (Callender and Ingwell, 1977).

Bubble trains are commonly aligned along cleaveage traces or grain boundaries in halite. The bubbles generally contain fluid, although some may also be gas or partially solid-filled (see section 7.6). Fracturing in experimentally deformed cores locally follows the bubble trains, and they are likely the site of small-scale structural weaknesses within halite. Once such fractures heal, the zones they followed become stronger than before section 7.6) Hopper crystals, generally filled with clay, also tend to grow and be aligned along halite cleavage planes. In a number of samples, small-scale fracturing, induced by sample preparation or by disturbance during the coring operation in the field, is associated with zones of hopper crystals.

Cleavage, and fracture related to cleavage, is observed in halite. In euhedral, generally recrystallized, halite, the cleavage direction and grain boundary are coincident. In these cases, deformation along trends parallel to grain boundaries should certainly be facilitated. Similar relations, though less common, exist in subhedral halite. Translation

glide in halite is an important dislocation mechanism and has been described in the literature (c.f., Buerge, 1930; Clabaugh, 1962). Two glide planes, (110) and (001), have been recognized in both undeformed and deformed salt.

In summary, a local concentration of discrete fabric elements (e.g., hopper crystals, bubble trains) may be as statistically significant as planar or linear elements (such as bedding, cleavage alignment, or elongation) for the structural evaluation of the core, and local zones in deformed salt may play an important role in establishing fracture patterns.

Fracture. Analyses of fracture patterns in salt to date have been complicated by induced fracture during sample preparation and the field coring procedures used to obtain samples. The recognition of these induced fractures is generally fairly straightforward; however, the persistent question of local induced fracture arises during detailed study, and is a problem which cannot be easily resolved. Fortunately for the petrographer, many fractures are filled with clay, anhydrite, and polyhalite; these filled fractures give some insight into patterns in material before laboratory testing since they are clearly not a result of sample handling.

In general, fracture in undeformed salt core is relatively minor and is commonly associated with cleavage or grain boundary adjustments. It appears that fractures may have remained open at some stages of diagenesis for a sufficiently long period of time to be filled by sulfate or other solutions. A few unusual fracture geometries have been noted: en echelon fractures, generally with their major trend parallel to cleavage; circular fractures commonly around hopper crystals; fracture refraction across grain boundaries; jog and kink fractures; and fracture and local extension along glide planes. The number of fractures observed in the laboratory resulting from relief of the in situ confining stresses is unknown. Clay, anhydrite, and polyhalite have apparently flowed in some undeformed samples. Perhaps the best evidence for this statement is

local well-defined linear fabric in polyhalite and anhydrite, and the inclusion of halite in clay along grain boundaries.

In samples severely deformed by laboratory testing, fracture patterns are easily observed. In one sample a well-defined zone of cleavage and glide-plane fracture developed at about 40° to the compressional axis. Apparently, a network of interconnected fractures has been established in this zone which respects neither grain boundaries nor grain size. In contrast, another sample suggests that local fabric elements, particularly clay-rich zones, may affect fracture geometry and that planar fracture fabrics may not be as well-developed in clay-rich samples.

Fracturing of halite can be generated in the laboratory at relatively low confining pressures ($\leq$ 1500 psi) and moderately high strains (5 to 12 percent); this fracturing induces a fracture porosity in the material. At higher confining pressures, rock salt displays ductile behavior and it is difficult to induce fracturing. The position of the fracture pattern observed in the laboratory is related to both the stress direction and the local fabric elements. In addition, the crystal lattice of halite permits, through defects and crystallographic constraints (c.f., Hirth and Lothe, 1968), a complex dislocation system to develop.

9.2.3 Physical Properties

Measurements of physical properties of rock salt pertinent to the design of the WIPP have been conducted by several investigators. Some representative data are summarized in Table 9.2.3-1.

Density and Resistivity. Measurements were made on full dimension (4-1/2 inch diameter) core. The density determinations were performed following conventional laboratory procedures for determing bulk rock densities utilizing the buoyancy method. Commercial grade kerosene was used for buoyancy measurements. Direct current resistivity determinations were made using current densities of less than 0.20 microamperes per square centimeter (Elliot, 1976), and by downhole geophysical measurements (Graswold, 1977).

Volatile Mass Loss. Total volatiles, including water, were obtained by heating samples of Salado salt from the proposed repository levels to 300°C in several stages. Static weight loss determinations were made at each stage of heating (Kopp & Combs, 1975) and were reported in section 7.5.3.. In addition, thermogravimetric analyses were made by suspending powdered samples from a microbalance while dry nitrogen flowed over the sample. The samples were heated at 5°C/minute until the temperature reached 500°C and held there until gas evolution had ceased (see section 7.5.2 for details and data).

Permeability. Gas permeability of SENM rock salt has been measured for pressures up to 5000 psi and at room temperature to determine the tightness of the host rock to any gases evolved in the WIPP. The data developed by Sutherland (1978), are for argon gas at confining pressures to 2000 psi. A plot of permeability test results is shown on Figure 9.2.3-1. Sutherland's data demonstrate the influence of confining pressure (crack closure and healing) on permeability. Preloading of samples to near lithostatic confining pressures is required to obtain reproducible data in laboratory experiments. Other gases (air, nitrogen, argon) were measured by Core Labs (1977), Terra Tek (1978), and Shelby (1978). The Core Labs' tests followed API standards, however, they did not allow for crack healing. Shelby tested single crystal NaCl. The results of these measurements illustrate the following:

(1) There is no correlation between measured permeabilities for as-received (stress-relieved) core samples;

(2) Samples behave as if they are "healing" when subjected to a confining pressure on the order of their original in situ pressure (illustrated on Figure 9.2.3-1).

(3) After an initial "healing" or "consolidation" period, the polycrystalline samples tested by Sutherland (1978) and Terra Tek (1978) have measured permeabilities of less than 0.05 microdarcys (the limit of resolution of their permeability measurement systems);

(4) There is little or no gas flow through the salt single crystals (less than 1 picodarcy) in the single crystal test apparatus of Shelby (1978). Therefore, the preferred flow channels through a core sample are believed to be along crystalline boundaries.

Thermal Conductivity. The thermal conductivity of several rock salt samples from core of AEC 8 were determined by a longitudinal heat flow apparatus. This apparatus was designed specifically for use with geologic core sections. Constant power is supplied to a heater at one end of the specimen until thermal equilibrium is established. The heat flux transducer and thermocouple outputs are then recorded allowing the thermal conductivity to be calculated from the readings (Acton, 1977). A plot of test results is shown on Figure 9.2.3-2.

Sonic Pulse Velocity. Measurements of compressional wave velocity were made both on laboratory samples (Kent and Wawersik, 1976) and by down hole geophysical methods (Griswold, 1977). Laboratory measurements were made both parallel and perpendicular to the core axis. No signficant variations (less than 0.02 Km/sec) were observed between the axial and transverse values of twenty measurements. The laboratory data were within 15% of the downhole geophysical values.

Summary of Data. Some physical properties are summarized in Table 9.2.3-1. In addition, permeability data are plotted on Figure 9.2.3-1 and thermal properties are shown in Figure 9.2.3-2. The experimental data are presented in the referenced documents.

9.2.4 Thermomechanical Properties

Introduction. It is the goal of laboratory stress-strain tests to develop constitutive relations which can be used in structural calculations. As the program progresses, a combination of finite element calculations using data obtained in the laboratory, empirical mine design methods and in-situ validation studies will serve to evaluate, in detail, certain aspects of the final WIPP design.

To achieve a valid and practical description of the behavior of rock salt from experiments in the laboratory, several programs are being conducted. These are: (1) Measurement of the mechanical response of SENM rock salts and other nearby rocks (e.g., anhydrite) over the domain of stresses and temperatures which may be expected in the WIPP; (2) Development of general models based on test results that are applicable to differing stress deformation and/or temperature histories; (3) Determination of mechanisms governing salt response in sufficient detail to allow the extrapolation of laboratory measurement in time; and finally (4) Establishment of relationships between laboratory samples of rock salt and salt masses in-situ.

This report summarizes the first series of laboratory tests, consisting primarily of short term "quasi-static" tests. These tests served to compare the response of WIPP salt with rock salts from other horizons and locations and to effectively scope the rock behavior for planning the long term creep tests. It is recognized that short term test behavior may be only partially indicative of long term behavior. Not all of the data developed is presented, particularly where detailed information has been published elsewhere. Instead, test values have been selected which are felt to best represent the behavior of the WIPP rock salt. Too few repetitive tests have been performed thus far to determine statistical significance of the data. This is due to the long times required to perform tests and the limited amount of rock salt core available to this test program from specific horizons of interest to WIPP.

A deliberate attempt was made to encompass a broad range of parameter variations including confining pressure and principal stress difference, i.e., mean stress and deviator stress, as well as temperature, time, loading rate, loading path, handling history, and specimen size. These variations covered a wider spectrum than might ordinarily be required to support the design of conventional mines or solution cavities. The approach is predicated on the unusual combination of anticipated mechanical and thermal loadings associated with WIPP. The experimental program plan also tried to address specific questions, for example,

concerning the effect of loading path, which were raised by critics of conventional quasi-static experiments in the past (Baar, 1977).

Testing was primarily conducted on rock salt samples from three horizons in the Salado Formation. The two horizons at 2,100+ feet and 2,600 to 2,700 feet represent the relatively pure halite from the proposed contact-handling (CH) and remote-handling (RH) levels, while the third horizon at 1,900 feet was chosen for study because it is clay rich salt.

The testing program through the summer of 1978 was generally divided into two segments, quasi-static tests and creep tests. Quasi-static properties were generated over a range of loading rates from d/dt $(\sigma_1 - \sigma_3)$ of 150 to 215 psi/min (RE/SPEC Inc. data, Gnirk et al., 1973, Hansen and Mellegard, 1977) to loading rates of 30 to 60 psi/min (Sandia data, Wawersik, 1977, 1978c). The 30 psi/min loading rate was chosen to match that of published data (Dreyer, 1972, Munzel and Schreiner, 1977). Creep tests were carried over a range of confining pressure $0 \leq \sigma_3 \leq$ 3,000 psi, deviator stresses $1{,}500 \leq (\sigma_1 - \sigma_3) \leq$ 6,000 psi, and temperatures of $24^\circ \leq T \leq 100^\circ$C with a duration of up to 70 days. These loading rates were arbitrarily chosen as a means of scoping the behavior of SENM rock salt under conditions that may be encountered in the WIPP.

Apparatus, Experiments, Capabilities, and Data Handling. To support the determination of material properties of WIPP site rocks, a new triaxial facility was developed (Wawersik et al., 1976). Based on earlier experience (Wawersik and Brown, 1973; Gnirk et al., 1973; Wawersik, 1975), the present apparatus has the following capabilities.

> The apparatus accepts cylindrical specimens up to 4-1/4 inches diameter by 8.5 inches in length to accomodate the coarse grain size or rock salt.
>
> The system has a pressure rating of 10,000 psi; this is adequate to perform variable load path tests, for example, in triaxial compression, in triaxial extension, at constant maximum compression, etc.

The equipment is suitable to conduct both quasi-static tests and creep experiments.

Specimens can be heated uniformly to approximately 250°C in short-term tests and to 200°C to 220°C in long-term experiments.

Controlled, known temperature gradients can be applied for studies of fluid migration.

The equipment provides access to both specimen ends for possible venting or for measurements of pore pressure and permeability and for application of pore pressure, etc.

It provides both axial and radial deformation measurements. For uniform lateral deformation, this combination of strain measurements yields shear and volumetric strains.

The apparatus is equipped with multiple feed-throughs for use of instrumentation inside the pressure vessel.

Normally, hydrostatic and deviatoric loading are decoupled so that the hydrostatic response of all specimens can be defined and, more importantly, so that linear and bulk thermal expansion measurements can be determined as a function of temperature and pressure.

The apparatus and procedures allow for large, relatively unrestrained sample deformation.

Details of the test equipment (ranges, calibration procedures and precisions) are discussed elsewhere (Wawersik, 1975; Wawersik et. al., 1977; Wawersik, 1978a).Material and Test Specimens - The rock salt studied was machined from 4-1/4 inch diameter core obtained from zones at depths of 1,900 feet, 2,100 feet and 2,600 to 2,700 feet. Sample machining consisted of cylindrical and flat-end grinding following documented procedures which were designed to minimize the thickness of any shatter zones at the specimen surfaces. Alternatively, specimens were obtained by means of standard coring tools. Final specimen dimensions were nominally 2 inches or 4 inches in diameter, with a

length-to-diameter ratio of at least two. After machining, the cylindrical surfaces of all samples were coated with a protective layer of RTV silastic.

Quasi-static Rock Salt Properties. Quasi-static testing was conducted on WIPP salt under hydrostatic pressures to 5,000 psi. Deviatoric loading tests were performed to 3000 psi confining pressure and to temperatures of 200°C. Variables of interest were: pressure (confining pressure, mean stress), principal stress difference (deviator stress), time (loading rate), temperature and load path. A separate study of the role of the intermediate principal stress will also be initiated. The importance of the foregoing variables was suggested by prior mine measurements and by existing laboratory data (for example Schmidt, 1937; U.S. Corps of Engineers, 1963; Le Comte, 1965; Hofer and Thoms, 1968; Schlichta, 1969; Carter and Heard, 1970; Bradshaw and McClain, 1971; Dreyer, 1972; Heard, 1972, Serata et al., 1972; Kern, 1973; Menzel and Schreiner, 1977; Baar, 1977).

The term quasi-static is used in the conventional sense to denote a fixed slow rate of loading. To avoid misunderstandings and undue generalizations of these data, it is emphasized that most quasi-static experiments were carried out at particular loading rates, e.g., 30 psi/min. It is important to realize that any data concerning the mechanical behavior of WIPP rock salt under different loading conditions must be inferred with proper regard to the time-dependent nature of the material (Wawersik and Hannum, 1978).

Quasi-static data available to date include approximately 75 uniaxial compression and indirect Brazilian tension tests at ambient temperature on core from drill holes AEC 7 and 8 (Hansen and Gnirk, 1975). These experiments were performed under the direction of Oak Ridge National Laboratory prior to June, 1975. They include approximately 20 experiments on anhydrite and 5 tests on polyhalite. More recent quasi-static data include approximately 50 tests on selected specimens from the potential WIPP repository horizons (Wawersik et al., 1976;

Hansen, 1977; Hansen and Mellegard, 1977, Wawersik and Hannum, 1978). Samples were machined from core of drill holes AEC 7 and ERDA 9. Emphasis was placed on the response of rock salt from the storage horizon at 2600 feet because of the added complexities of elevated temperatures if heat producing wastes are placed in WIPP.

Selected representative mechanical properties in uniaxial compression and indirect tension are listed in Table 9.2.4-1.

Quasi-static Triaxial Properties - Representative triaxial data are listed on Table 9.2.4-2 for a range of confining pressures and temperatures. Note that both tables 9.2.4-1 and 9.2.4-2 list secant moduli (stress/total strain) and principal strain ratios ($\varepsilon_3/\varepsilon_1$) rather than the elastic constants, that is, Young's modulus, E, and Poisson's ratio. To calculate the intrinsic elastic constants it is necessary to separate the nonelastic portion from the total deformation or to move through stress states where elastic response dominates. This was accomplished for New Mexico rock salt recently during unload/reload cycles.

The constants obtained were $4.55 \times 10^6 \leq E \leq 5.2 \times 10^6$ psi and $0.17 \leq \nu \leq 0.24$ (Wawersik and Hannum, 1978). These values agree to within 15% with those which were determined from borehole geophysical data.

During initial deviatoric loading in the laboratory, nearly all deformation of WIPP salt was nonelastic (Wawersik and Hannum, 1978). The actual magnitude of this nonelastic deformation is likely to be sensitive to the magnitude of the deviatoric stress which the core experienced during drilling (Wawersik and Hannum, 1978), associated core damage and subsequent core "relaxation" during core storage and handling. Combinations of these factors probably account for the variations in secant moduli and principal strain ratios in tables 9.2.4-1 and 9.2.4-2.

It is common practice in engineering to plot triaxial test data in the form of Mohr's circles at the ultimate stress. The plots are made in the

stress space (σ,T) where σ and T denote normal and shear stresses, and an envelope is drawn tangent to the circles representing the ultimate shear stress of any value of confining pressure.

When the data from Tables 9.2.4-1 and 9.2.4-2 are plotted, three Mohr's circles which are normal for SENM rock salt are obtained in Figure 9.2.4-2A in stress space (σ,T) . The ultimate stresses can be approximated by a straight line (Coulomb) envelope of the form $T = C + \sigma \tan \phi$. In conventional engineering terminology, C is called the cohesion and ϕ , the angle of internal friction. In this case, at ambient temperatures, rock salt from the 2,700 foot level has an apparent cohesion of approximately 1,000 psi and an angle of internal friction of 33°. Similar data for other rocks are being used for mine pillar design. However, it should be recognized that the validity of these ultimate stress analyses rests on two assumptions: (1) failure is independent of the intermediate principal stress, and (2) failure is defined solely in terms of stresses and independent of strain, strain rate and time. Both of these assumptions are currently being evaluated for rock salt.

In contrast to other rocks it is important to remember that rock salt undergoes large deformations long before the ultimate stress is reached. Since these deformations can exceed 15% even at ambient temperature, it is conceivable that a practial failure condition might incorporate a maximum deformation criterion. To illustrate this case, a Coulomb envelope was constructed (Figure 9.2.4-2B) which defines the stress magnitudes at an arbitrarily chosen constant value of strain ($\varepsilon_1 = 2.5\%$). This value is the average strain at the ultimate stress of samples tested in uniaxial compression at ambient temperature and a loading rate of 30 psi/min. It can be seen that Figure 9.2.4-2B is different from the ultimate stress envelope in Figure 9.2.4-2A. Clearly, the shapes of the Mohr envelopes are highly dependent on failure criteria. The values obtained also depend on the manner in which the Mohr's envelope is drawn. In Figure 9.2.4-2A, a "best fit" straight line tangent to the circles was drawn; while in B, a parabola was drawn tangent to the circles.

Detailed Quasi-static Stress-Strain Relationships. Elastic constants, ultimate stresses, and stress or strain envelopes are useful for conventional failure stability analyses where rock is treated either as an elastic or as an elastic-plastic material. While such analyses have proven valuable in combination with careful engineering judgement, they are not always accurate. In view of the time-dependent nature of rock salt it is especially important that design calculations be based on a more comprehensive constitutive model. To initiate the development of such a model, detailed short-term quasi-static stress strain observations were made to identify the effects of pressure, deviatoric stress, (shear stress), temperature, and loading history. The influence of time as a discrete parameter is mainly considered in creep experiments.

Deviatoric Loading at Constant Confining Pressure. Deviatoric loading at constant confining pressure is the process of increasing the principal stress difference (deviator stress) from an initial state of hydrostatic compression. It is a necessary condition to induce substantial salt flow.

Typical quasi-static deviatoric loading data are shown in Figures 9.2.4-3 through 9.2.4-15. The key to these curves indicates sample depth in feet and (confining pressure in ksi and temperature in degree C). These stress strain curves depict complete continuous experimental records which indicate the manner in which all specimens were loaded. Deviator stress was applied incrementally rather than continuously. Actual force was raised quickly by some predetermined amount and then held constant for between 4 and 15 minutes while axial and lateral strains ε_1 and ε_2 $(= \varepsilon_3)$ were monitored in time. The stepwise loading procedure made it relatively easy to control the mean applied loading rate while monitoring time dependent strains during load hold periods with a minimum of experimental error (Wawersik and Hannum, 1978). In most figures, these details of loading are omitted. As illustrated by the curve for sample 9-2601 in Figure 9.2.4-3, where smooth fits are made to the endpoints of each step in the actual stress strain record. Note that large changes in specimen cross sectional area at constant force during

all load hold intervals lead to considerable decreases in principal stress difference with time (Wawersik et al., 1977, 1978c). Conventional plots $(\sigma_1 - \sigma_3)$ versus ε_1 such as Figure 9.2.4-3 relate the present data to virtually all similar results for rock salt in the literature (for example, Schmidt, 1937; Heard, 1972; Dreyer, 1972, Menzel and Schreiner, 1977).

Considering Figures 9.2.4-3 through 9.2.4-6, three observations are particularly noteworthy.

1. Laboratory specimens of New Mexico rock salt have an initial elastic limit close to zero. Furthermore, this initial elastic limit appears to be the same following all hydrostatic pressure histories up to 5000 psi (Wawersik and Hannum, 1978).

2. Pressure appears to have a considerable effect on all properties of New Mexico rock salt except the elastic constants (Wawersik and Hannum, 1978). Specifically pressure controls the strain magnitudes, the ultimate stress and the relationships between the principal strain (Figures 9.2.4-5 and 9.2.4-6). Pressure effects are particularly evident at $(\sigma_1-\sigma_3)$ greater or equal 1200 psi.

3. New Mexico rock salt subjected to quasi-static laboratory compression can undergo substantial dilatancy which is associated with cataclasis, i.e., microfracturing. The magnitudes of the observed volume changes were significant particularly at low confining pressure and amounted to sizeable fractions of the observed shear strains near the ultimate stress (Wawersik and Hannum, 1978). Isovolumetric conditions of deformation are approached only at 3000 psi confining pressure. However, data at elevated temperature demonstrate that even comparatively minor amounts of dilatancy can have a considerable effect on the rate at which New Mexico rock salt deforms (Wawersik and Hannum, 1978).

Elevated Temperature Data. Elevated temperature experiments were carried out in two groups. First, the influence of temperature was considered at fixed confining pressures, for example, 500 psi (Figs. 9.2.4-7, 8 and 9). Then, the effect of pressure was evaluted at 200°C (Figs. 9.2.4-10, 11 and 12). As expected (Bradshaw and McClain, 1971; Heard, 1972; Dreyer, 1972), temperature reduced the ultimate stress and increased the ductility (Fig. 9.2.4-7). Increasing the temperature is qualitatively equivalent to increasing confining pressure at ambient temperature. Cataclastic effects with considerable dilatancy are suppressed in favor of deformation modes which proceed at constant, or nearly constant, volume (Figs. 9.2.4-8 and 9.2.4-9). (Wawersik and Hannum, 1978)

Influence of Loading History. Effects of loading history are noted in several studies in the literature (for example, Schmidt, 1937; Sereta et al., 1972; Baar, 1977). To consider such effects, three sets of experiments were performed early in the experimental program. First, the influence of differing hydrostatic loading histories was tested. The results indicated no measurable effects on the behavior of rock salt from southeastern New Mexico during subsequent deviatoric loading (Wawersik and Hannum, 1978).

In the second group of experiments, quasi-static strains were measured as a function of load path in a conscious effort to separate the influences of load path and loading history as much as possible. The load paths employed are shown in Figure 9.2.4-15. They consist of:

1. Conventional triaxial tests at constant confining pressure (load path I).

2. Triaxial loading at constant mean stress ($\sigma m = \frac{1}{3} (\sigma_1 + \sigma_2 + \sigma_3)$ load path II).

3. Deviatoric loading at approximately constant maximum compression (load path III).

Figure 9.2.4-13 also identifies one test which combined load path III and I passing through points A, D, E, G, and H (Wawersik and Hannum, 1978). Table 9.2.4-3 provides a comparison of strains at several common stress states of Figure 9.2.4-13 with the strains ε_1 and ε_3 are numerically greatest along the path of constant confining pressure (load path I). The smallest ε_1 and ε_3 were obtained along the path of maximum pressure, either confining pressure or mean stress (load path III) (Wawersik and Hannum, 1978).

To evaluate load history even further, a third set of tests was performed. In these experiments, one sample was deformed in three successive stages at 3000, 500, and again at 3000 psi confining pressure. The response of this specimen was then compared with the strain behavior of individual samples which had been loaded deviatorically at 3000 psi and 500 psi confining pressure (Wawersik and Hannum, 1978). The results of the latter tests are shown in Figures 9.2.4-14 and 9.2.4-15. Notice particularly, that the stress strain record for the third load cycle of sample 7-2740.5 does not immediately converge to the stress strain records of specimens 7-2745 and 9-2601.5. Differences in results are obviously due to the influence of loading history (Wawersik and Hannum, 1978).

Interpretation of Quasi-static Data - In view of the quasi-static testing to date, as illustrated in the figures, the following observations were made repeatedly and establish broad guidelines which should be observed in modeling the thermomechanical behavior of New Mexico rock salt up to fracture and/or massive flow (ε_1 greater or equal 20%).

Rock salt from SENM in the laboratory is nonlinear under all loading conditions with an initial elastic limit $(\sigma_1 - \sigma_3)$ approximately zero. Its intrinsic elastic properties can be evaluated accurately only in load/unload/reload cycles provided restrictions are imposed either on the loading (strain) rate or on the range of deviator stresses. However, given comparatively nonelastic strains, the intrinsic elastic behavior does not appear to be very important.

In the low confining pressure domain $\sigma_3 \leq 3000$ psi, rock salt behavior depends strongly on pressure and temperature. Both dependencies are reflected in ductility, ultimate stresses and in the variation between maximum and minimum principal strains or in the variations between volumetric strains and shear strains (Figures 9.2.4-4, 5, 8, 11, and 15).

A brittle mode of deformation (microfracturing) dominates rock salt deformation at ambient temperature, low confining pressure, and deviator stress in excess of approximately 1000 to 1500 psi. Accordingly, the overriding pressure effect under these conditions is pressure dependent dilatancy (Figures 9.2.4-4, 6 and 9). Brittle fracture, including creep fracture, i.e., macroscopic collapse and loss in load bearing ability are possible. At low (less than 1,000 to 1,500 psi) deviator stress, high temperature, and/or high pressure, salt deformation proceeds in a predominantly ductile manner at nearly constant volume. Particularly at high temperatures, pressure does not appear to further influence the nature of the governing deformation mechanisms. This is indicated by a pressure invariance (Figure 9.2.4-11) of the relationship between maximum and minimum compressive strains (shear and volumetric strains). However, observed differences in induced strain rate at a fixed loading rate but different confining pressures indicate that pressure influences the rate at which the governing deformation mechanisms, cataclastic or ductile flow, proceed.

It is recognized that available quasi-static stress strain data do not necessarily describe the properties of New Mexico rock salt over long periods of time. However, for lack of other information, quasi-static tests have been used to define the matrices of future creep experiments and to anticipate phenomena which might occur during creep. For example, emphasis is being placed on triaxial creep experiments as opposed to uniaxial tests. Simultaneous measurements are being made of both volumetric strains and shear strains in creep. Similar tests are not conducted routinely elsewhere and the apparatus to perform these tests is at the state-of-the-art in experimental rock mechanics.

Creep of Rock Salt Creep tests on rock salt are continuing to evaluate the long-term time-dependent behavior of New Mexico rock salt. Since August, 1977, two sets of triaxial creep tests have been performed on core from drill holes AEC 7 and ERDA 9, emphasizing the interval of 2600 to 2800 feet depth. Experiments were carried out over the range

$$0 \leq \sigma_3 \leq 3000 \text{ psi}, \quad 1500 \leq (\sigma_1 - \sigma_3) \leq 6000 \text{ psi}, \text{ and } 24^{\circ} \leq T \leq 130^{\circ}\text{C}.$$

Results indicate that in principle WIPP salt can undergo both transient and steady state creep. Furthermore, limited data suggest that steady state creep rates lie in the range from 10^{-10} sec^{-1} to 10^{-7} sec^{-1}, depending strongly on stress state and temperature. Steady state creep may have to be considered in WIPP design calculations; it was not included in earlier wastes repository analyses which were conducted in conjunction with in situ experiments during Project Salt Vault, Kansas (Bradshaw and McClain, 1971).

To evaluate the nature of transient creep of the WIPP salt, 34 tests were carried out on NX sized (two inch nominal diameter) core. Tests durations vary between 0.5 and 500 hours (Hanson, 1977, and Hanson and Mellegard, 1977). Initial efforts served to evaluate the significance of transient creep on the possible repository conditions, to establish upper (conservative) bounds for steady state creep rates at relatively low deviator stress and temperature, and to test the applicability of a pillar creep formula which has been widely used (Bradshaw and McClain, 1971):

$$E(t) = A(\sigma_1 - \sigma_3)^{a} T^{b} t^{c} \qquad (9.1)$$

The results of present transient creep data demonstrate significant pressure effects which are consistant with all quasi-static observations but are not predicted by equation 9.1.

Beyond that, however, at least one block of data ppears to support equation 9.1 which in its generalized form is:

$$\varepsilon = F_1(p)F_2(\sigma_1-\sigma_3)F_3(T)F(\text{strain or time}) \quad (9.2)$$

Work is now in progress to estimate the error magnitudes which are associated with the use of equation 9.2 even under restricted conditions, e.g., $(\sigma_1 - \sigma_3) \leq 2{,}500$ psi and $\sigma_3 \leq 1{,}000$ psi. To accomplish this, numerical simulations are compared with the results of independent laboratory experiments which combine multiple creep runs with intermittent short-term stress variations at two different temperatures.

Time Dependent Fracture. To determine the long term strength of New Mexico rock salt, two approaches are being take. First, long-term laboratory creep tests are conducted to establish a relationship between strength and time. Obviously such tests are time consuming. Second, failure times may be calculated from creep flow and from estimates of the amount of nonelastic strain at the point of fracture. The nonelastic failure strain can be estimated by means of an empirical procedure which establishes a relationship between creep, time dependent fracture and quasi-static post failure characteristics (Wawersik, 1972). If this technique is applied to New Mexico rock salt, it appears that the range of stable creep prior to fracture at ambient temperature is:

$$\varepsilon_1 \leq 2.5 \text{ to } 6\% \text{ at } \sigma_3 = 0 \text{ psi}$$

$$\varepsilon_1 \leq 17 \text{ to } 20\% \text{ at } \sigma_3 = 500 \text{ psi}$$

Substantially greater stable creep occurs at $\sigma_3 = 3000$ psi confining pressure (Wawersik 1977). On Figure 9.2.4-18, photographs of core samples from ERDA #9 are shown that were deformed during triaxial testing (Hansen and Mellegard, 1977). Notice the large amount of strain test Numbers 6 and 7 have undergone without apparent major physical damage.

Applicability of Laboratory Measurements. Several investigations are underway to define the qualitative and quantitative applicability of laboratory experiments on WIPP salt to in-situ design predictions. Apart from numerical validation studies, measurements are in progress to determine the relaxation of core after drilling and to assess whether rock salt is damaged during field coring, recovery and storage. The latter efforts are supported by repeated tests on specimens with known laboratory stress histories to further define the effects of stress history, aging and specimen machine. In addition, numerical simulation are being conducted to balance the magnitude of deviatoric loading of salt core during drilling.

9.2.5 Summary and Conclusions

Data from the petrographic and physical properties studies show the WIPP horizon rock salt has low moisture content ($< 0.5\%$), is essentially impermeable ($< 5 \times 10^{-8}$ darcy) and has a high thermal conductivity (≈ 5.75 watts/$m^{o}k$). These properties along with the studies of fabric and fracture indicate this rock salt is ideally suited from a physical standpoint for the storage of high temperature nuclear waste.

The initial elastic limit is close to zero for rock salt for any confining pressure. Although strengths for rock salt are substantial (unconfined compressive strength to 3700 psi and modulus to 2×10^{6} psi) the load bearing ability is dependent on time, temperature and confining pressure.

It has been shown that rock salt can experience large creep strains (25%) prior to loss of load bearing capacity. Gradual creep is an acceptable feature in the design of underground openings in rock salt as it allows the structure to close without a sizeable reduction in bearing strength and without the physical damage which is associated with fracture.

Laboratory testing is continuing to develop a constitutive model to describe the behavior of SENM rocks. The model will be used in computer codes to study the structural response of the geologic media to WIPP.

9.3 RADIONUCLIDE SORPTION ON WIPP ROCKS

9.3.1 Introduction

An important mechanism in retarding nuclide movement in groundwater is sorption. In the following discussion, this term will be used to encompass all mechanisms pertinent to interaction between nuclides and geomedia which include ion exchange, adsorption, and precipitation.

The ability of rocks to adsorb adionuclides and hinder their migration away from a geologic repository for radioactive waste is not a factor in site selection criteria (Chapter 2). Also, since sorptive affinity is not a fundamental invariant property of a rock sample, such as is mineralogy or total volatile content, radionuclide sorption properties were not discussed in Chapter 7 (Geochemistry). Nevertheless, quantification of rocks' affinities for radionuclide sorption, however, is NOT a generic problem which can be solved simply for all rocks. Since the only rational approach to the problem is to conduct experiments to determine radionuclide sorption properties for site-specific rocks and site-specific aqueous solutions, preliminary results of such experiments are reported as special studies. The results of special studies of radionuclide sorption are entirely dependent upon experimental conditions, just as in the measurement of quasistatic mechanical properties.

In some safety assessment modeling scenarios described for the escape of radionuclides from WIPP repository horizons, groundwters contact and leach the waste form, and eventually find their way out of the salt deposit into the surrounding rock and mineral strata. During this exit, the nuclide-bearing liquid would contact clay-containing halite in the repository horizon, polyhalite formations, anhydrite ormations, and

finally the sandstone and dolomite formations which are the bounds of the evaporites. To a rough approximation, the concentration per unit mass of a given nuclide, sorbed on a solid mineral phase C_{solid} can be related to the concentration per unit volume, in the liquid phase C_{liquid}, by the relation:

$$C_{solid} = KC_{liquid}$$

where K is generally known as the distribution coefficient, Kd, with units of ml/g. The use of the term Kd implies an equilibrium condition for a given reaction which is both instantaneous and reversible. In the interaction of a nuclide with a complex mineral assemblage, neither condition may apply and the nuclide sorption observed can result from one or more sorption phenomena on one or more phases. To prevent confusion in nomenclature, the term Kd is used in this report, but with the understanding that what is being measured is a sorption coefficient which applies only to the system described and for the particular set of conditions used in making the measurement. Thus, the measurement of "Kd" does not reflect a fundamental thermodynamic property of rocks and/or solutions; it is rather a function of the experiment in which it is measured.

Ideally, sorptive affinities for radionuclides would be measured in situ in the geological formation of interest using long path lengths and available groundwater. This is not generally feasible and must be supplanted with data generated in a laboratory. Most of this section is an extract of SAND78-0297, "Interaction of Radionuclides with Geomedia Associated with the Waste Isolation Pilot Plant (WIPP) site in New Mexico" by R. G. Dosch and A. W. Lynch. It provides the results of a series of laboratory Kd measurements for various radionuclides and samples of different geological media from the vicinity of the WIPP site, and a discussion of the conditions used in making the measurements. The nuclides chosen for study have either a high potential for leaching and/or migration, a high radiotoxicity, or a chemistry similar to that of a nuclide with these properties. They included ^{137}Cs, ^{85}Sr, ^{131}I, ^{125}Sb, ^{144}Ce, ^{152}Eu, ^{153}Gd, ^{106}Ru, ^{243}Am, ^{244}Cm and ^{239}Pu.

A given set of conditions including pH, Eh, particle size, nuclide concentrations, and brine and/or groundwater simulant composition was defined prior to starting the work and maintained throughout. The Kd values reported are considered to be a set of preliminary baseline data for use in evaluating the effects of changes in those conditions which will undoubtedly be necessary as more information about the WIPP site itself and interactions of the waste forms with bedded salt become available.

The results of some parametric studies with lanthanide elements are also given. Significant differences in Kd's were observed as a result of varying pH and nuclide concentrations, and from the addition of trace quantities of organic contaminants to simulant solutions.

9.3.2 Geological Media

Sample Selection. The geological samples used in this work were taken from four inch diameter core samples from AEC #8 and ERDA #9 boreholes. (See Chapters 4 and 7 for descriptions of stratigraphy and mineralogy.) These include three samples from various rock formations (including the water-bearing rocks above and below the evaporites), four halite samples from the Salado Formation, and samples of polyhalite and Cowden anhydrite also from the Salado Formation.

The selection of the geological media for study was based on both the hydrology of the WIPP site and surrounding area and on a reasonable scenario for radionuclide transport from a bedded salt repository. The Magenta, Culebra, and Bell Canyon formations represent actual or potential aquifers.

Any path to the biosphere for water which may have contacted and leached a waste form would involve migration through halite formations, and also through anhydrite and polyhalite strata interspersed in the halite. Thus, these materials, along with the clay contained in the halite, are included in this study as they represent potential barriers to nuclide migration.

Sample Preparation. Culebra, Magenta, Bell Canyon, polyhalite, and anhydrite samples were reduced to a powder prior to use. Clays from the halite samples were obtained by dissolving core samples in deionized water, filtering and washing the insoluble residue, and drying at ambient temperature in air or vacuum.

9.3.3 Brine and Groundwater Simulants

The bulk of the Kd measurements reported herein were done using simulated brines and groundwater of the compositions given in Table 9.3-1. The Brine A composition is based on that expected in an aqueous solution in contact with potash deposits found in the vicinity of the WIPP site. The Brine B composition is typical of water in contact with halite deposits in the repository horizons. The groundwater Solution C composition is based on analyses of shallow groundwaters from the Los Medanos area (Lambert, 1978) above the evaporites and is intended to represent an "average" composition.

In determining Kd values for halite particles, saturated brines prepared from the particular core sample from which the halite had been taken were used as the liquid phase.

9.3.4 Solution Chemistry

Solutes. The use of simulated brines became necessary as both naturally occurring brines and core samples from repository horizons are currently available in very limited quantities. Simulants do offer the advantage of providing a reproducible matrix which allows for direct comparison of Kd data generated in different laboratories.

Potential problems in using simulants could arise from the absence of trace constituents which may be present in natural waters. If these are common inorganic species, the effect on Kd's would probably be negligible. However, trace quantities of organic compounds or dissolved gases such as hydrogen sulfide could produce significant changes in Kd

values should they tend to form stable complexes with some nuclides. The effect of trace quantities of organics which may be introduced into the repository as radwaste is being addressed and is discussed in Section 9.3.8.

Oxidation Potential. In aqueous migration from a deep geologic storage site, nuclides would most likely encounter both anoxic and aerobic conditions, in that order, as the biosphere is approached. The potential effect on Kd values could be many orders of magnitude; however, this should be limited to nuclides such as U, Np, and Pu which may undergo oxidation-reduction reactions in the potential range encountered.

Oxidizing conditions have been used to date as they are believed to produce the "worst case" with respect to migration, i.e., the higher valence states of the previously mentioned actinides tend to have lower Kd's, and they will be encountered in any scenario leading to contamination of the biosphere.

Hydrogen Ion Activity. The effect of the pH is believed to be extremely important in both the solution chemistry and the adsorption mechanism involved in the Kd for a given geological media. Problems encountered in determining Kd values in systems where solution pH is varying are discussed in Section 9.3.8. Changes in the adsorption characteristics of clays, oxides, and some zeolite materials as a function of pH are well documented (Amphlett, 1964).

The initial pH values of 6.5, 6.5 and 7.5 for Brine A, Brine B and solution C simulants, respectively, were chosen as being representative of field pH measurements of natural brines and groundwaters in the Los Medanos area.

Radionuclide Concentation. Ideally, a distribution coefficient should be independent of concentration. This condition usually exists only over a narrow concentration range and, therefore, nuclide concentrations should be chosen which are somewhat representative of those expected in a

repository. The problem lies in the fact that little or no data exists to aid in estimating leaching rates under conditions expected after closure of a repository. These include glass or other waste forms at elevated temperature (70-200°C) and lithostatic pressure (2000 psi) in contact with "wet" salt or brine. Another presently unknown variable is the effect of radiolysis on leaching mechanisms and rates. Available leaching data primarily result from laboratory leaching experiments with simulated waste in distilled water at ambient temperature.

In order to simplify both sampling and counting operations in the initial work, an activity of approximately 1 μ Ci/ml was used for all determinations unless stated otherwise. The corresponding nuclide concentrations based on the suppliers' analyses of the isotopes used are listed in Table 9.3-2.

Unless otherwise stated, all distribution coefficient measurements were made using a single nuclide in the brines or groundwater to eliminate competing ion effects. The effect of the nuclide concentration on Kd's is of concern and some initial work in this regard is presented in Section 9.3.8.

9.3.5 Experimental Procedures

Apparatus, Sample Size and Sampling. Samples of rock, clay, anhydrite, polyhalite, or halite were weighed directly into polyethylene dropping bottles volumes of doped brine or groundwater were added. The ratio of liquid to solid was typically in the range of 30 to 35. Due to limited quantities of the clay samples, higher ratios (50-150) were used in experiments with clays.

The bottles were sealed by placing a piece of polyethylene film over the opening and replacing the bottle top. Agitation was provided by orbital, reciprocating, or wrist-action shakers. Samples for analysis were taken by replacing the polyethylene film with a 0.8 μ pore size Gelman filter, tightening the dropping bottle top down over the filter, and squeezing

the bottle to force 0.5 to 1.0 ml volumes into pre-weighed polyethylene vials. Quantitative volumes were determined from weight and density measurements. The filters were replaced with polyethylene film and the agitation continued.

Portions of all "feed" solutions were put in identical polyethylene dropping bottles, agitated, and sampled at the same time and in the same manner. The activity in the filtered "feed" samples were used as the initial solution activity in the Kd calculations.

Analyses. The activity in solutions containing ^{137}Cs, ^{85}Sr, ^{106}Ru, ^{131}I, ^{125}Sb, ^{152}Eu, ^{144}Ce, or ^{153}Gd was determined by x-ray spectroscopy. A Harshaw 3" x 3" NaI(Tl) scintillation crystal or an Ortec VIP Series Coaxial Ge(Li) solid state detector was used. Data was accumulated and processed by a PDP-11/20 computer system. ^{99}Tc beta activity was measured using a mica end-window Geiger tube or by liquid scintillation counting. Alpha activities were determined by liquid scintillation counting. Since only relative activities are needed to determine Kd's, units of cpm/ml were used in all calculations.

Equilibration Time. Samples of fission product nuclides were generally taken after 14-20 and 30-35 day equilibration periods. In some instances, more frequent sampling was done. Variation in Kd's between the two sampling times were generally within a factor of two and are believed to result from changes in concentration due to adsorption on container walls, filters, or pH changes in both the sample and feed solutions rather than from rock-nuclide sorption kinetics.

Equilibration times of 170 days were used in the actinide experiments. This extended period was dictated by delays in acquiring laboratory facilities rather than by experimental design.

9.3.6 Kd Data

The results of Kd measurements using the conditions described in previous sections are given in Tables 9.3-3 through 9.3-11. Each table represents a different geological sample and contains the Kd's determined for the various brine/groundwater-nuclide combinations listed and a pH range including the initial feed pH and final sample pH values. The Kd ranges given for the fission product nuclides include two or more measurements made during the course of the experiment. Error associated with these measurements is certainly the most significant at the high ($>10^4$) and low (<1) ends of the Kd range, where background to signal ratios are high or calculations are based on small differences in large numbers. Two-to-fivefold variations of Kd's between duplicate analyses in these regions were not uncommon. Another obvious source of uncertainty is sampling, both in picking a section of core to represent a geological formation and in taking small samples to represent the core. The magnitude of error due to heterogeneity in a given core sample is unknown, as multiple samples were not used in this survey.

9.3.7 Discussion of Kd Data

Cesium. Cesium adsorption from brines "A" and "B" on Culebra and Magenta samples, representing a potential aquifer region overlying the repository horizons, is minimal or non-existent with Kd's ranging from 0 to 2. Adsorption from groundwater C is slightly higher (Kd's from 4 to 10). In the potential aquifer underling the repository, the Bell Canyon Formation, Cs adsorption is significantly higher in the groundwater "C" simulant than in brine "B". This trend tends to support an ion exchange mechanism for Cs adsorption.

Similar results are observed on the samples associated with the repository horizons with the exception of the polyhalite sample, which did not adsorb Cs from any of the solutions used.

Strontium. The adsorption of Sr on the rock samples from potential aquifer regions was very low with a Kd of 5 being the highest value observed in both brines and groundwater simulant.

Of the materials associated with the repository horizons, only the polyhalite sample showed any appreciable adsorption of Sr from the brine solutions that would be associated with the region.

The interstitial clay in the halite formation shows no tendency to adsorb Sr from the brine solutions (Tables 9.3-6 and (.3-9), and this may be attributed in part to the relatively high concentration of stable Sr used in the simulants. However, the same behavior was observed in an experiment where a brine prepared by dissolving a halite core and doped with < 0.3 ppm ^{85}Sr was cycled through a column of the halite particles from the same core (Tables 9.3-1 and 9.3-11). In this case, only a slight reduction in Sr activity was observed (which may have resulted from adsorption on the glass column or Tygon tubing used to circulate the brine), while ^{144}Ce was quantitatively removed by the halite.

Europium, Gadolinium and Cerium. These nuclides have been grouped together for discussion because their chemistries are very similar, particularly with respect to hydrolysis, and secondly, because they exhibited similar behavior in their interactions with the geomedia from the WIPP site.

With the exception of polyhalite samples, Kd's of greater than 10^3 for these nuclides were observed on all the geological samples with which they were contacted. Any interpretation of these data with respect to mechanism or comparison of the effects of different brines or geological media is difficult because of the contribution of hydrolysis and subsequent precipitation to the overall adsorption observed in the experiments.

For example, the polyhalite sample which was singled out as having Kd's of less than 10^3 for these nuclides (Table 9.3-7), also had final pH values which were lower than the rock or clay samples. Thus, the

apparent difference in Kd's may be a hydrolysis effect rather than be related to the polyhalite. The effect of hydrolysis is further discussed in Section 9.3.8.

Technetium and Iodine. Both of these nuclides are expected to exist as anionic species in natural groundwaters or brines and were used in the form of pertechnetate, TcO_4^-, and iodide, I^-, in this work.

Natural ion exchangers typically exhibit extremely low anion capacities, particularly in neutral or basic solution. In this work, the only material which showed significant adsorption of pertechnetate and iodide was a clay sample taken from a halite core (Table 9.3-9). The adsorption was observed in Brine A and groundwater C, but neither species appeared to be adsorbed from Brine B. The relatively high concentration of Tc used may have far exceeded the anion exchange capacity of some or all of the samples and this possibility is being investigated.

Ruthenium and Antimony. Difficulty was encountered in preparing the doped "A", "B", and "C" solutions due to the high concentrations of stable Ru and acid (4NHCl) in the ^{106}Ru solution used. Adjustment of pH after doping resulted in precipitation of > 95% of the Ru. The final feed solutions were estimated to contain approximately 0.10 μCi/ml of ^{106}Ru in "B" and "C" or 25 ppm total Ru.

General trends observed in the Kd measurements include: 1) higher Kd's for the clay minerals than for the rock samples, 2) higher Kd's in simulants "B" and "C" than observed in "A". The latter effect may be the result of brine composition, but more likely is a hydrolysis effect as the final equilibrium pH of "B" and "C" is higher than that in the "A" brine.

Antimony was added to the group of nuclides being studied late in this work, and there are not sufficient data available on which to base any general statements.

Actinides. The actinides used in this work were supplied as Am(III), Cm(III), and Pu(IV) solutions and used at face value. No attempts were made to determine the Pu species present in the simulant solutions after doping. The nominal activity of the actinides in the solutions used in this work was 1 μCi/ml, however, the final activities in the "feed" solutions were lower. The doping was done by adding the isotope solutions to containers and evaporating to dryness at room temperature The brines or groundwater solutions were then added to the containers and the solutions were set aside for several days. The amount of isotope used was sufficient to provide an activity of 1.0 μCi per milliliter of solution if the entire amount was dissolved.

In general, the actinide concentrations in groundwater "C" at a pH of 7.3-7.4 are greater than those in the brine solutions in the 6.9-7 pH range. This is particularly true for ^{244}Cm, where the concentrations are 2 to 3 orders of magnitude lower in the brine solutions.

Kd values for the actinides of 300 or greater are observed for all the geological samples if the halite Kd's are based on weight of insoluble material rather than the weight of the total halite sample. In general, the Kd values in the groundwater "C" are higher than in Brine "B" which could result from hydrolysis due to higher pH in the "C" solutions; however, there are some cases where this Kd order is reversed.

The reasonably good agreement between the Kd values for the clay samples (Table 9.3-6) and the halite containing interstitial clay particles (Tables 9.3-5 and 9.3-11) suggests that the halite in the vicinity of the repository can serve as a barrier to actinide migration.

9.3.8 Parametric Effects

pH and Nuclide Concentration Effects on Kd. The first investigation into the contribution of the pH of the aqueous phase and effect of nuclide concentration on the sorption coefficient involved ^{152}Eu sorption from brines A and B and groundwater C on samples from the Magenta and Culebra Formations.

The experimental procedure used was the same as that described previously, except two blank samples of each feed solution were included instead of one. At the end of a two week equilibration period, the pH of the samples and feed solutions were measured. One of the feed B and C solutions was then adjusted so that its pH was equal to that observed in sample solutions containing that feed. A sodium carbonate solution was used for the pH adjustment, which was done over a period of three days. By the time analytical samples of the adjusted feeds were taken, the pH of some of them had increased and was higher than the corresponding sample. The pH of the Brine A feeds was not adjusted as the final values were the same as those in the samples.

The pH of the adjusted feeds decreased significantly during the first three months, probably due to adsorption of atmospheric carbon dioxide (Garrels and Christ, 1965). The pH of the solutions contacting the rock also varied with some increasing and others decreasing; however, the change was consistent within a given set of samples containing the same rock and solution.

Distribution coefficients calculated from both the feed activities and pH adjusted feed activities after two week and three month periods are listed in Table 9.3-12.

Europium is apparently more soluble in Brine A than in Brine B at the same pH or in the C composition at higher pH. The effect of adjusting the pH in B and C solutions definitely resulted in hydrolysis and formation of some species which did not pass through a 0.8μ filter. It is also of interest that sigrificant decreases in activity in the pH-adjusted feeds were observed for all Eu concentrations used.

The Effect of Trace Organic Contaminants of Kd's of ^{152}Eu, ^{153}Gd and ^{144}Ce. One of the concerns in estimating migration rates of radionuclide in aqueous media is the ion form of the nuclide of interest. Experiments have shown that the simple ionic forms of most polyvalent cations interact quite readily with geologic media from the

WIPP site via ion exchange or other sorption phenomena. These interactions serve to retard the movement of the ionic species relative to the aqueous matrix containing them.

The extent of the nuclide-geologic media interaction can be significantly altered by changes in the ionic form of the nuclide. Examples of such changes are redox reactions which may result in species of zero or negative charge types and reactions with available inorganic or organic ligands to form complex species with different chemical properties. One such change in properties might be enhanced mobility over that of the bare ion.

Investigations of the sorption changes due to complexation between organic ligands and radionuclides have been initiated by Robert T. Paine of the University of New Mexico. One source of organic ligands which may be present in large quantities in the repository is the plywood used in containers for shipping TRU waste. Samples of these containers are being refluxed in synthetic Brine B at 70°C, the maximum temperature expected in the transuranic (TRU) waste horizon in the repository. The initial samples of this brine, subsequently referred to as B*, were taken after 5 weeks of refluxing.

Although no significant physical degradation of the plywood was observed after this time period, chemical leaching did occur as evidenced by the coffee brown appearance of the brine. Gas chromatograph-mass spectrometer analysis of the brine indicated the presence of organic material, but identificaton was inconclusive. Infrared spectroscopy was used to examine carbon tetrachloride and benzene-acetone extracts from the brine. The extracted organic material fell into the general class of esterified rosin compounds, but no specific indentification was possible. Qualitative observation indicated that the brine contained extremely small amounts of organic material. Neither solvent system extracted the colored species from the brine.

The effect of plywood extract on lanthanide distribution coefficients (Kd's) was determind by measuring Kd's for ^{153}Gd, ^{144}Ce and ^{152}Eu between five geologic media from the WIPP site and the brine B* containing the plywood extract and comparing these values with Kd's obtained in identical experiments using pure Brine B. The results are given in Table 9.3-13.

Although both the B and B* brines were doped initially with the same concentrations of tracers, there is a significant difference in the activity of the final samples taken. This could result from adsorption on the polyethylene containers or hydrolysis and subsequent filtration of hydrated oxides of the tracer elements through the 0.8 μ filters. In either case, the effect occurs to a significantly lesser extent in the brine B*, which is probably the result of interaction between the tracers and some ligand extracted from the plywood to form complexes which are less susceptible to hydrolysis.

The difference in Kd values could also result from complex formation. The complexing ligand may be a rosin derivative, many of which form very stable compounds with heavy metals. It may also be the species which causes the brown coloration of the brine. Observation of the analytical samples taken from the brine B* samples showed that the clay material had completely decolorized the brine. The other materials decolorized the B* samples to varying degrees, as given below in order of decreasing color intensity remaining in solution:

Weed > Magenta > Culebra ≈ Bell Canyon > Cowden > Clay solution

Similar work will be done using extracts which are being prepared from other organic materials expected to be associated with TRU waste such as rubber gloves, swipes, detergents, etc. Based on lanthanide results, an experimental matrix will be designed to study the actinide elements.

The Effect of Oxidation State on Radionuclide Sorption. An additional approach to understanding the behavior of actinides under site specific conditions in WIPP is the study of the behavior of various oxidation

states of the actinides (particularly plutonium) in the presence of various components of the WIPP strata. This work is being performed at Argonne National Laboratory by Sherman Fried and Arnold Friedman.

Relatively concentrated solutions of actinides (0.01 M) whose oxidation states were determined by inspection of their optical absorption spectra were prepared and allowed to react with saturated WIPP brines, and with rocks from the WIPP site. Since it was assumed that in the final stages of a WIPP repository oxygen might be absent in the rock salt, the preparations were made in vacuo to identify species present under such conditions.

Solutions of plutonium were prepared in such a way that samples sealed in optical absorption cells at approximately 10^{-6} atmosphere of O_2 could be examined from time to time to observe changes in absorption peaks (if any) and thus determine the stability of the particular oxidation state as a function of time.

In the case of plutonium preparations, the isotope ^{242}Pu was employed. This was done to minimize radiolysis effects (specific activity Pu^{242} = 4.5×10^3 d/m/μg vs. $1/15 \times 10^5$ d/m/μg for ^{239}Pu). It is felt that while the behavior of plutonium in these concentrated solutions may be substantially different than tracer Pu migrating in an aquifer where the radiation field will be much less, it is nevertheless a good approximation to the conditions immediately in the vicinity of the canister when an amount of radioactivity has just leached out.

The various oxidation states of Pu were prepared by electrolytic means or oxidation by ozone as the case required, in order to avoid the introduction of extraneous ions which might affect the results.

The solutions of Pu compounds ($PuCl_3$, $PuCl_4$, and PuO_2Cl_2) were prepared directly in the absorption cell. The concentrations were generally of the order of 0.01 M. In a typical case, 4 ml of saturated WIPP brine "A" (Table 9.6-1) was introduced into the optical cell and

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evaporated to dryness in a stream of nitrogen. After this operation, the proper amount of Pu compound was pipetted in the cell and evaporated to dryness with the salts from the WIPP brine.

The cell was attached to the vacuum line and evacuated until the pressure was $\sim 10^{-6}$ atm. De-aerated water was then distilled under vacuum until the amount of solution equals that which originally pipetted into the cell.

These samples of various Pu compounds were examined from time to time observing any changes in intensity or wavelength of absorption peaks corresponding to the oxidation state in question.

The resulting samples prepared for measurement of changes in intensity of the optical absorption spectra are Pu(III), Pu(IV) and Pu(VI) in water, and in saturated WIPP brine solution.

No definite changes in absorption peaks corresponding to changes in oxidation state were observed. The Pu(IV) solutions were so dilute, because of precipitation from the hydrolysis of Pu(IV), that little or no characteristic absorption peaks could be observed at all. The Pu(III) solutions, whose absorption peak is at about 6000 Å , also showed little or no detectable change over the time interval of the experiment (2-4 months).

The Pu(VI) as PuO_2Cl_2, surprisingly, is insoluble in saturated WIPP brine. The level of solubility is so small that no absorption peaks could be seen at all. In order to be sure that this case is not one of very slow rate of solution, the sealed absorption cells are being rotated with periodic absorption spectrum determinations.

Some absorption studies have already been carried out with Pu(IV) and Am(III) on anhydrite and dolomite from the WIPP site (see previous sections).

Work is presently underway with the Argonne National Laboratory Analytical Chemistry Group to develop procedures for the determination of the oxidation potential of WIPP salt, dolomite and anhydrite slurries, particularly those employing oxidation-reduction indicators.

Crude reaction rates and K_D values of Pu(III) and Am(III) with Magenta and Culebra dolomites in waters that have been equilibrated with the individual rock are in the table.

Rock Type	Radionuclide	Reaction Time (hr)	K_D
Magenta (gypsiferous dolomite)	Pu	50	41
	Am	400	47
Culebra (silty dolomite	Pu	1	19
	Am	1	84

It should be understood that these reaction rates are crude and that the K_D values are somewhat indeterminable because of varying quantities of radionuclides "plating out" on the walls of the containers. These experiments will be repeated as a function of temperature. Since these determinations were made on tablets of rock of known dimensions, the surface absorption coefficients can be calculated, these perhaps being more applicable to migration along fissures and cracks, where the surface absorption coefficient is

$$S_c = \frac{\text{activity/ml liquid}}{\text{activity/cm}^2 \text{ solid}}$$

The installation of a controlled atmosphere box has made it possible to study the absorption of the various oxidation states of Pu without the perturbing effects of atmospheric oxygen.

9.3.9 Summary

A survey of the potential of geological media from the vicinity of the Waste Isolation Pilot Plant site in Southeastern New Mexico for retardation of radionuclide migration via an aqueous carrier has been completed. Solution simulants representing water in equilibrium with potash minerals or halite zones and a typical groundwater were spiked with radionuclides and contacted with geological samples to obtain sorption coefficients, Kd's. The samples were taken from potential aquifers above and below the repository horizons and from bedded salt deposits in the repository horizons. The nuclides chosen for study represent those with a high potential for leaching and/or migration, high radiotoxicity, or those with a chemistry similar to nuclides with the aformentioned properties. They included ^{137}Cs, ^{85}Sr, ^{131}I, ^{99}Tc, ^{125}Sb, ^{144}Ce, ^{152}Eu, ^{153}Gd, ^{106}Ru, ^{243}Am, ^{244}Cm and ^{238}Pu.

A very general summation of the Kd results in brine simulants is as follows: Anionic species, TcO_4^- and I^-, showed little or no tendency to adsorb on any of the geological media (Kd's $\leq$ 1), with the possible exception of a clay material from a halite stratum (Kd < 5). Cs and Sr Kd's were also generally less than 1, but values in the range of 10-20 were observed on several minerals. Ru Kd's ranged from 25 to $>10^3$, depending on the brine and geological materials. The lanthanide and actinide Kd's were typically > 10^3, with only polyhalite showing significantly lower adsorption.

In the groundwater simulant, Tc and I showed the same behavior. The Kd's of the other nuclides were slightly higher, particularly those of Cs and Sr. This would be expected if the sorption were due to an ion exchange mechanism, but, in the case of the lanthanides and actinides, may also result from an increased contribution of hydrolysis to the Kd due to the higher pH of the groundwater simulant.

Important parameters in Kd measurements include solid sample form, simulant compositon, Eh and pH, and radionuclide concentration. In the Kd survey measurements, an initial set of these parameters was selected and, wherever possible, was used throughout the work. Parametric studies with Eu involving pH, trace organic constituents in the simulant solutions, and radionuclide concentrations have shown that significant differences in Kd's can be observed by varying any of those parameters.

A general observation which can be made from data obtained to date is that a Kd represents an empirical value for nuclide adsorption, which includes the effects of physical adsorption, ion exchange, and hydrolysis or other precipitation processes. The utility of a given Kd value is unambiguous only for that set of conditions used in making the measurement. Kd information which is used in modeling radionuclide migration should be in the form of a range of values generated in parametric studies under the variety of conditions postulated for a specific repository site.

For the WIPP site, rock salt, anhydrite, polyhalite and water-bearing dolomites and sandstones show an affinity for radionuclide sorption. Sorptive capacity as measured by batch Kd experiments generally expressed $Kd > 0$. Even small values of Kd ($0 < Kd < 1$) are effective in retarding the movement of radionuclides in groundwater.

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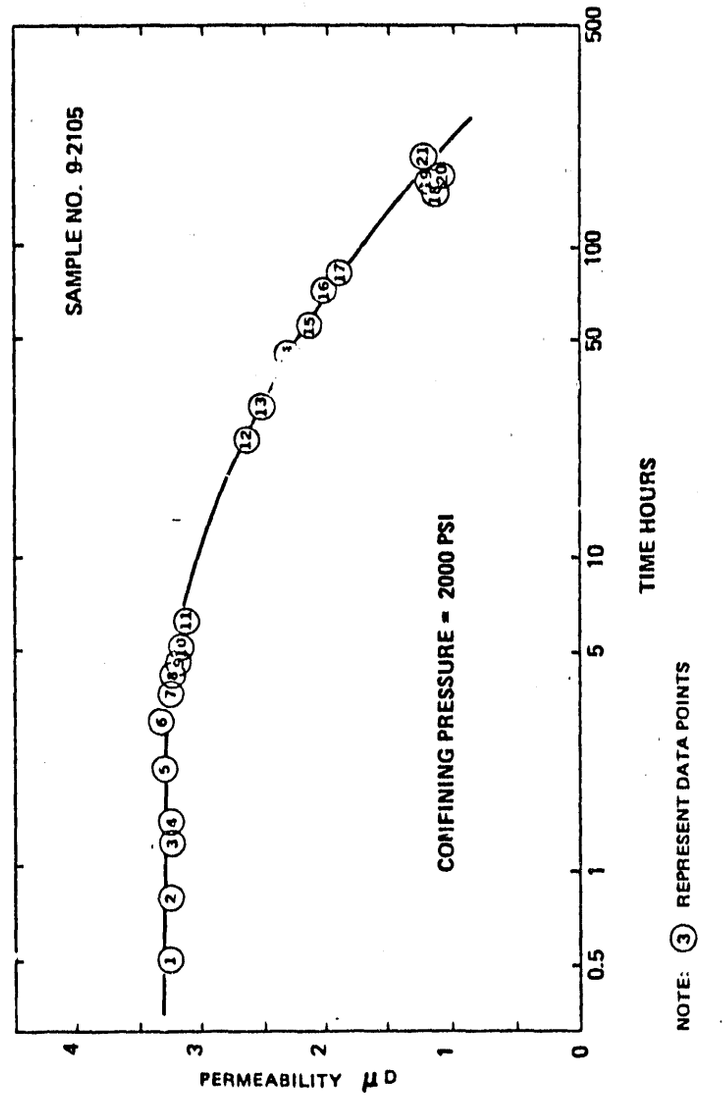
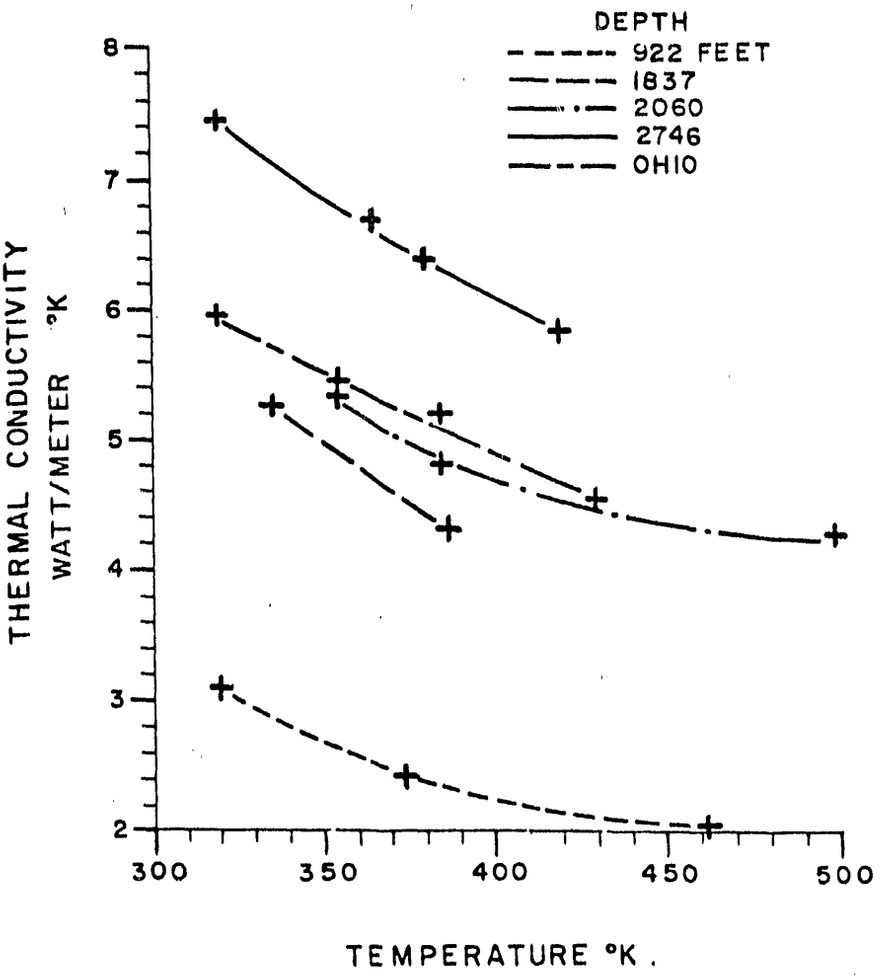


ARGON PERMEABILITY OF ROCK SALT SAMPLE AT 2000 PSI CONFINING PRESSURE

FROM: SUTHERLAND, 1978

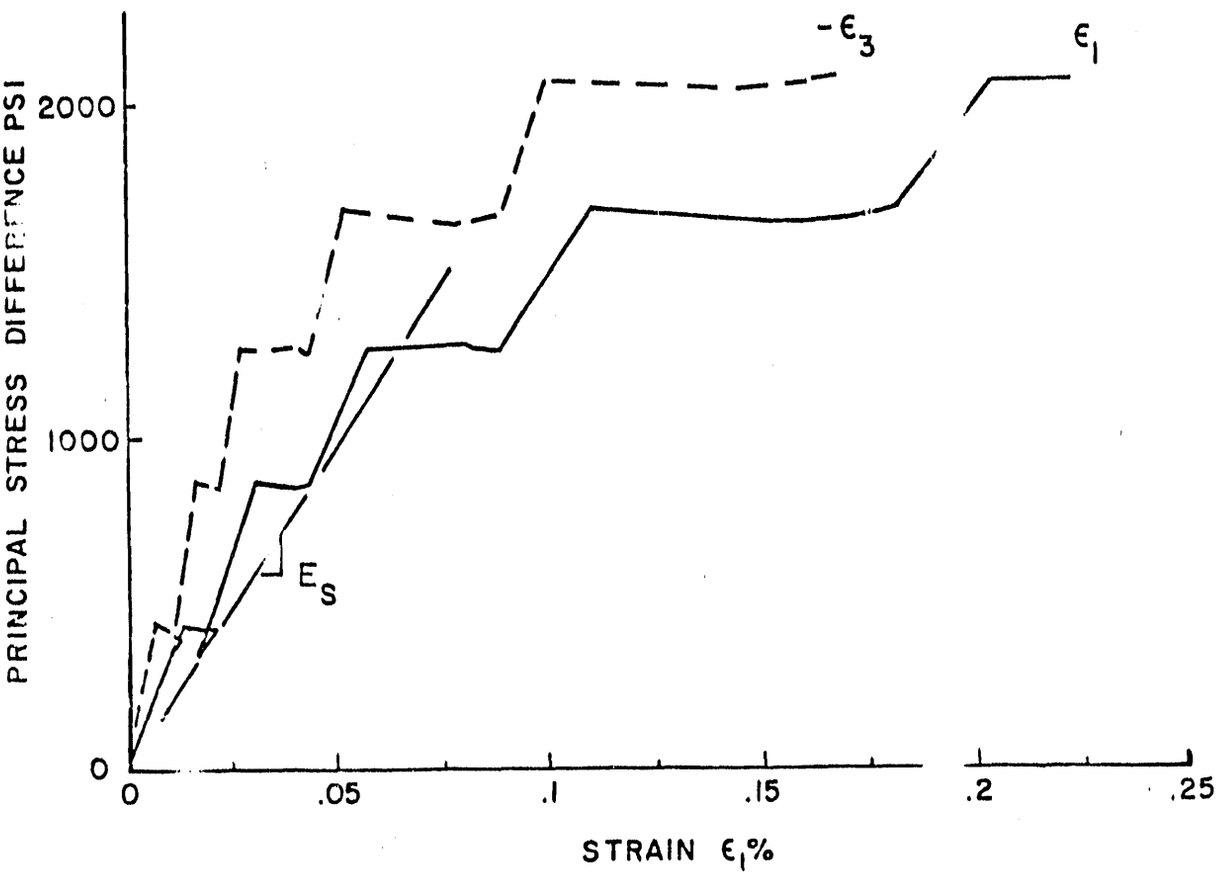
FIGURE 9.2.3-1



THERMAL CONDUCTIVITY OF ROCKSALT CORE SECTIONS CONTAINING 50% OR MORE HALITE, WELL AEC 8

From: Acton, 1977

FIGURE 9.2.3-2



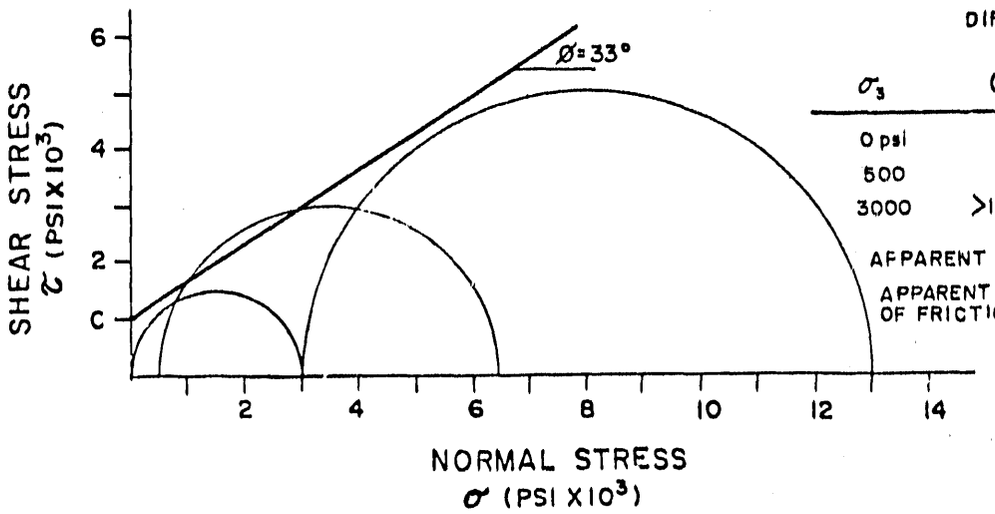
KEY

7-2745 (3.0, 23)
Hole No. – Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)

TRIAXIAL STRESS-STRAIN CURVES IN REGIME OF SMALL PRINCIPAL STRESS DIFFERENCES AND STRAIN

From: Wawersik and Hannum, 1978

FIGURE 9.2.4-1

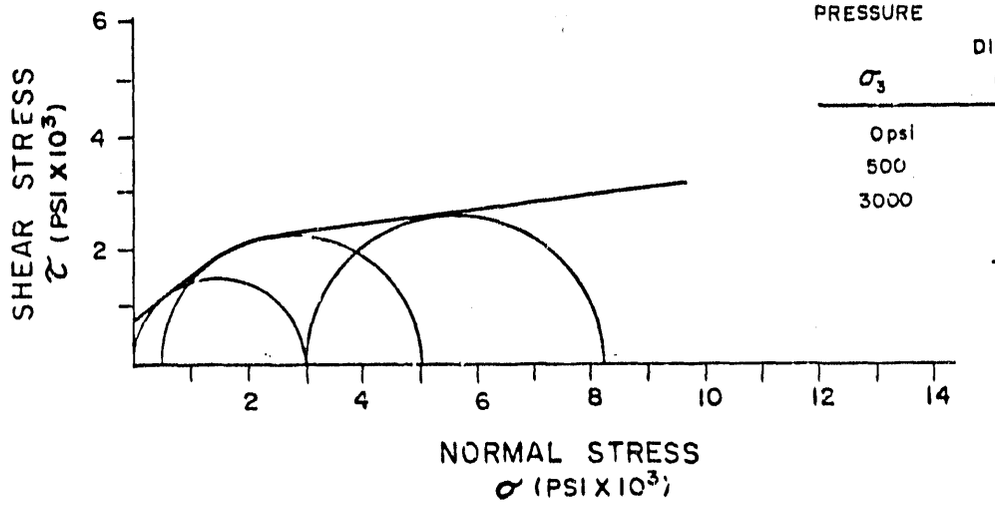


CONFINING PRESSURE σ_3	PRINCIPAL STRESS DIFFERENCE $(\sigma_1-\sigma_3)$	AXIAL STRAIN AT FAILURE ε_1
0 psi	3000psi	2.5%
500	6000	15
3000	>10,000	>20

APPARENT COHESION C=1000psi

APPARENT ANGLE OF FRICTION Ø = 33°
T = 23°

A. MOHR'S ENVELOPE AT ULTIMATE STRENGTH



CONFINING PRESSURE σ_3	PRINCIPAL STRESS DIFFERENCE $(\sigma_3-\sigma_1)$	AXIAL STRAIN ε_1
0psi	3000psi	2.5%
500	4500	2.5
3000	5250	2.5

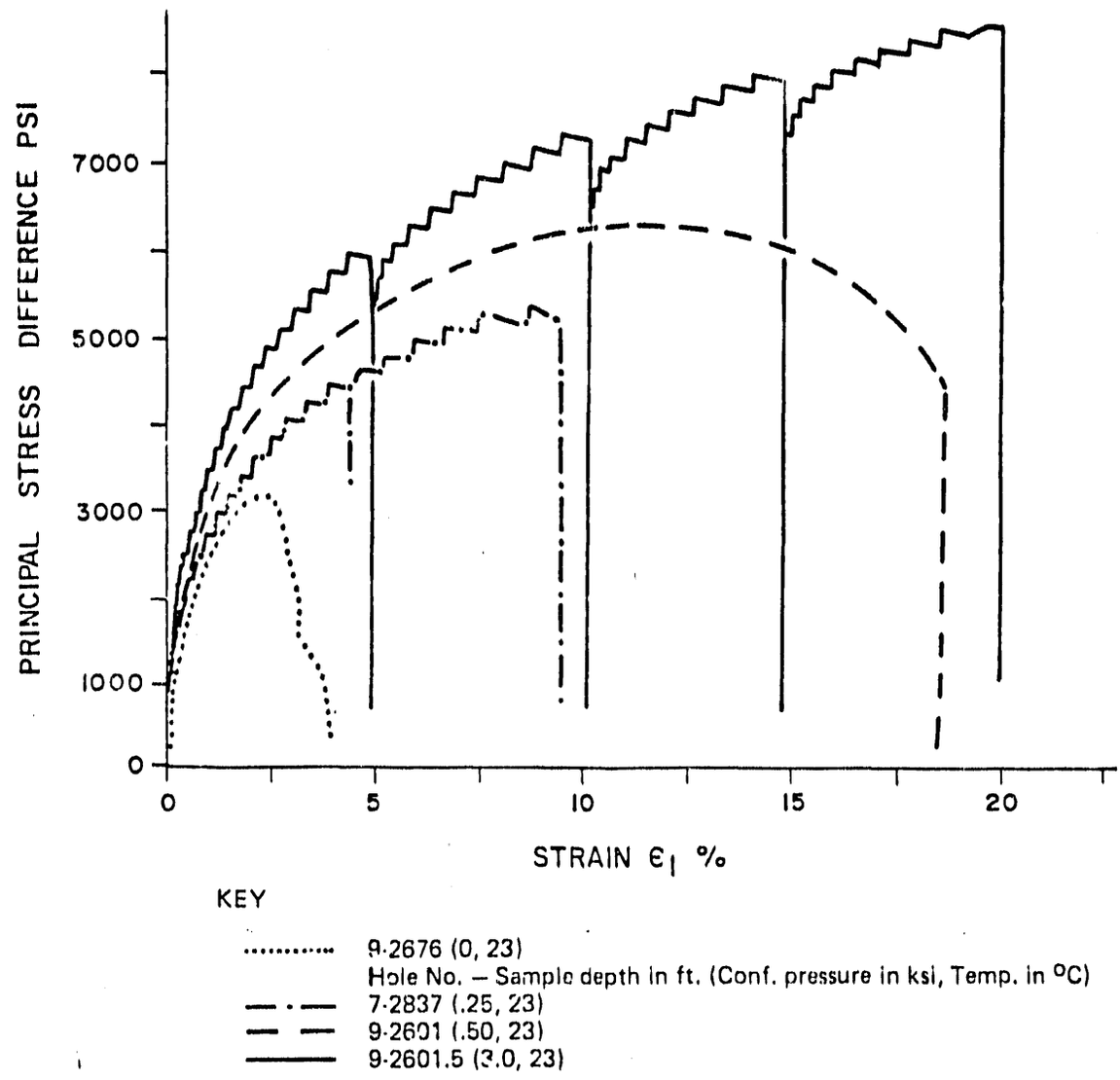
T = 23°

B. MOHR'S ENVELOPE AT CONSTANT STRAIN

NOTES:

1. THE SAME TEST DATA WERE USED TO GENERATE BOTH ENVELOPES. (TABLE 9 III., 9 III; WAWERSIK 1977)
2. THESE QUASI-STATIC PROPERTIES DO NOT ACCOUNT FOR ANY STRENGTH DETERIORATION WITH TIME.

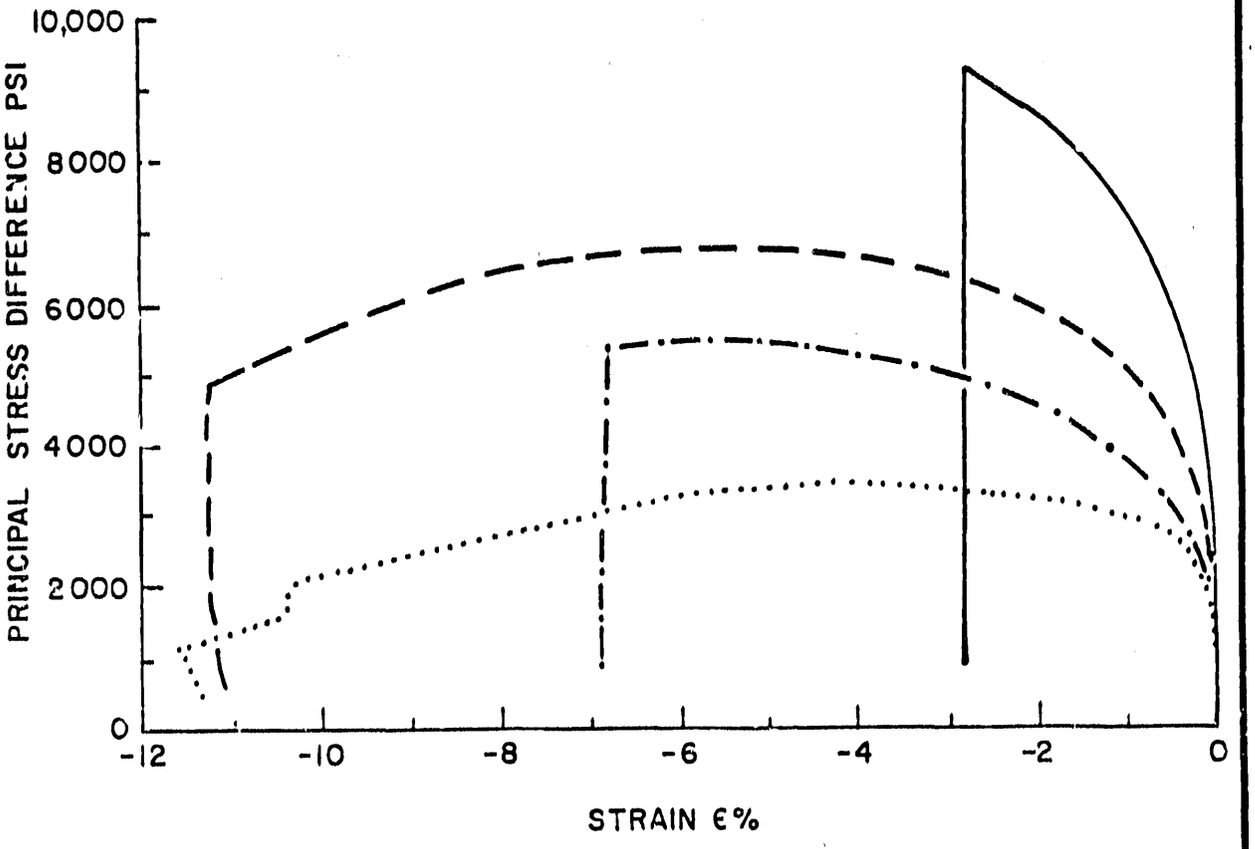
FIGURE 9.2.4-2



CONVENTIONAL QUASI-STATIC TRIAXIAL STRESS-STRAIN DATA AT AMBIENT TEMPERATURE EFFECT OF PRESSURE

From: Wawersik and Hannum, 1978

FIGURE 9.2.4-3



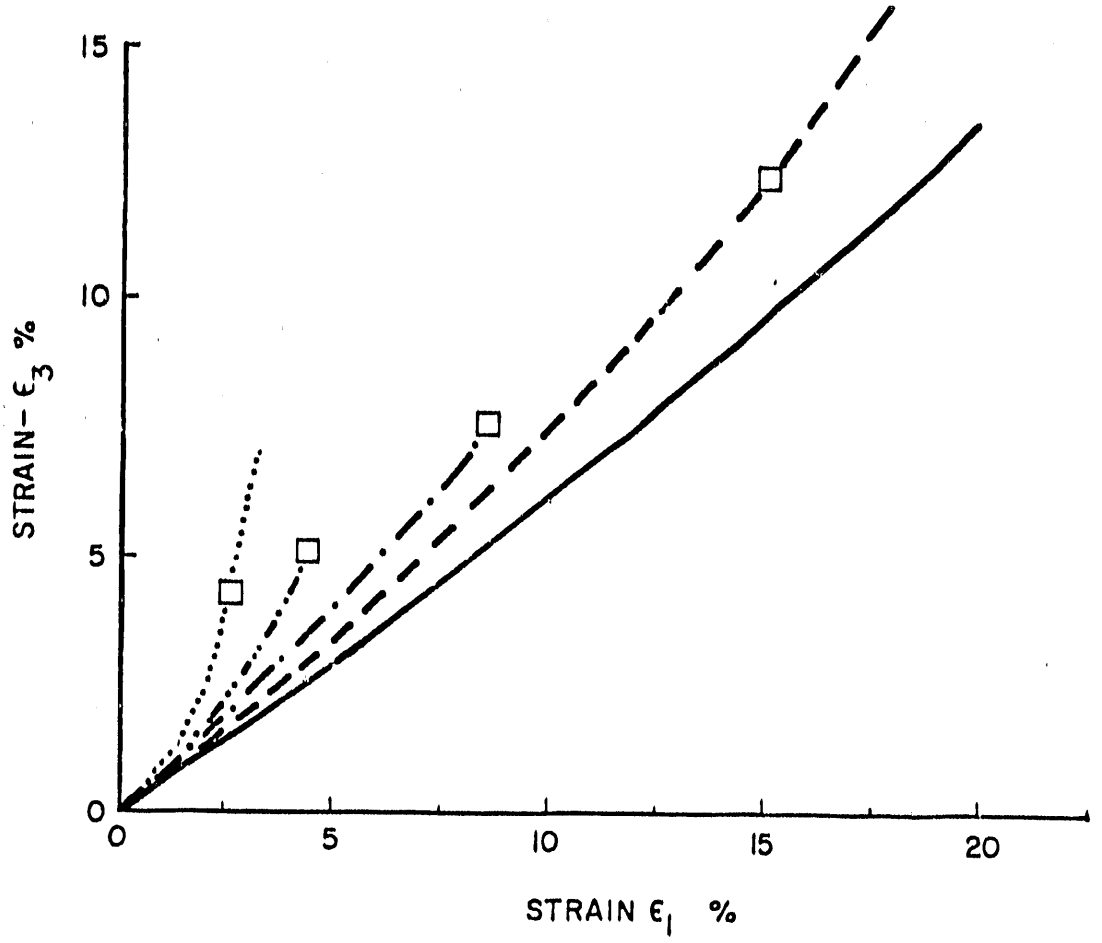
KEY

..... 9-2676 (0, 23)
Hole No. – Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)
— · — 7-2837 (.25, 23)
— — 9-2601 (.50, 23)
——— 9-2601.5 (3.0, 23)

PRINCIPAL STRESS DIFFERENCE VS. VOLUMETRIC STRAIN FOR TEST OF FIGURE 9.2.4-3

From: Wawersik and Hannum, 1978

FIGURE 9.2.4-4



KEY

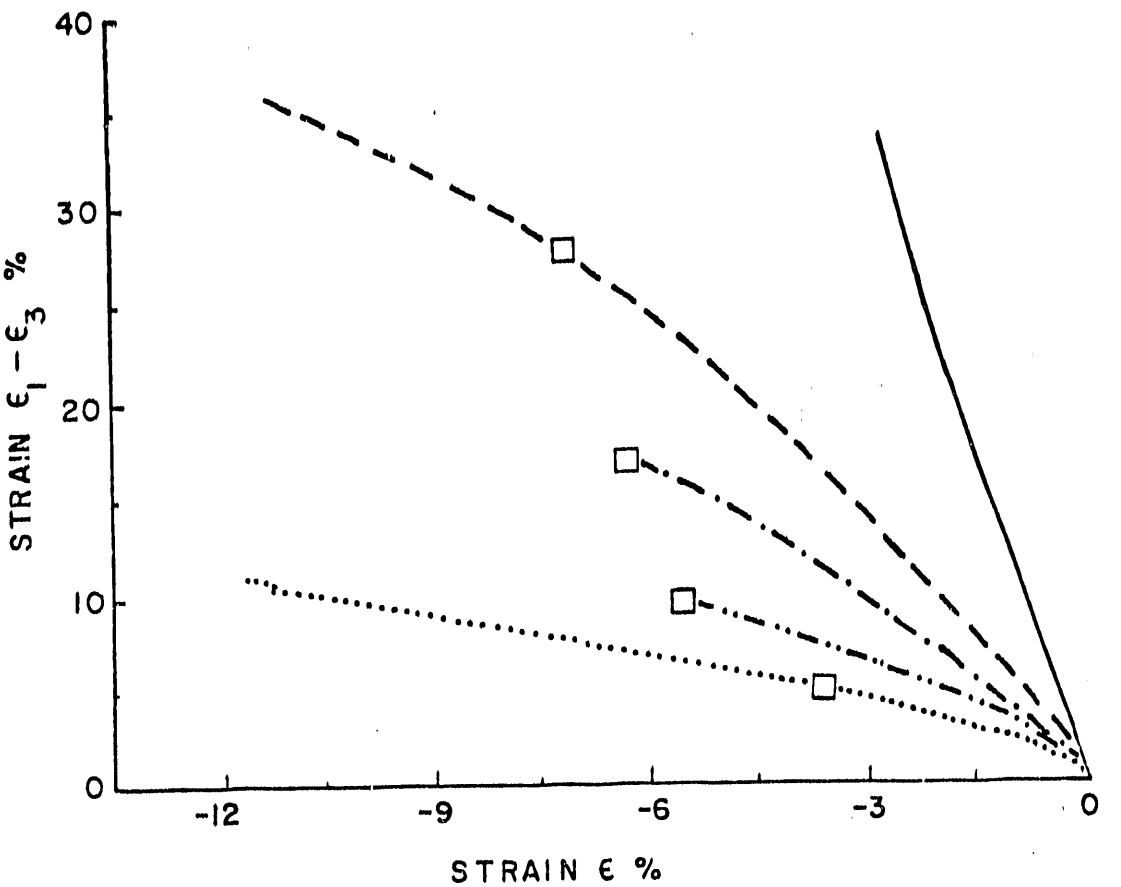
.....	9-2676 (0, 23)
	Hole No. – Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)
—··—	9-2689 (.10, 23)
—·—	7-2837 (.25, 23)
— —	9-2601 (.50, 23)
———	9-2601.3 (3.0, 23)

NOTE: Open squares identify approximate strains at ultimate stresses.

TRIAXIAL VARIATION OF LATERAL STRAIN VS. AXIAL STRAIN FOR TEST OF FIGURE 9.2.4-3

From: Wawersik and Hannum, 1978

FIGURE 9.2.4-5



KEY

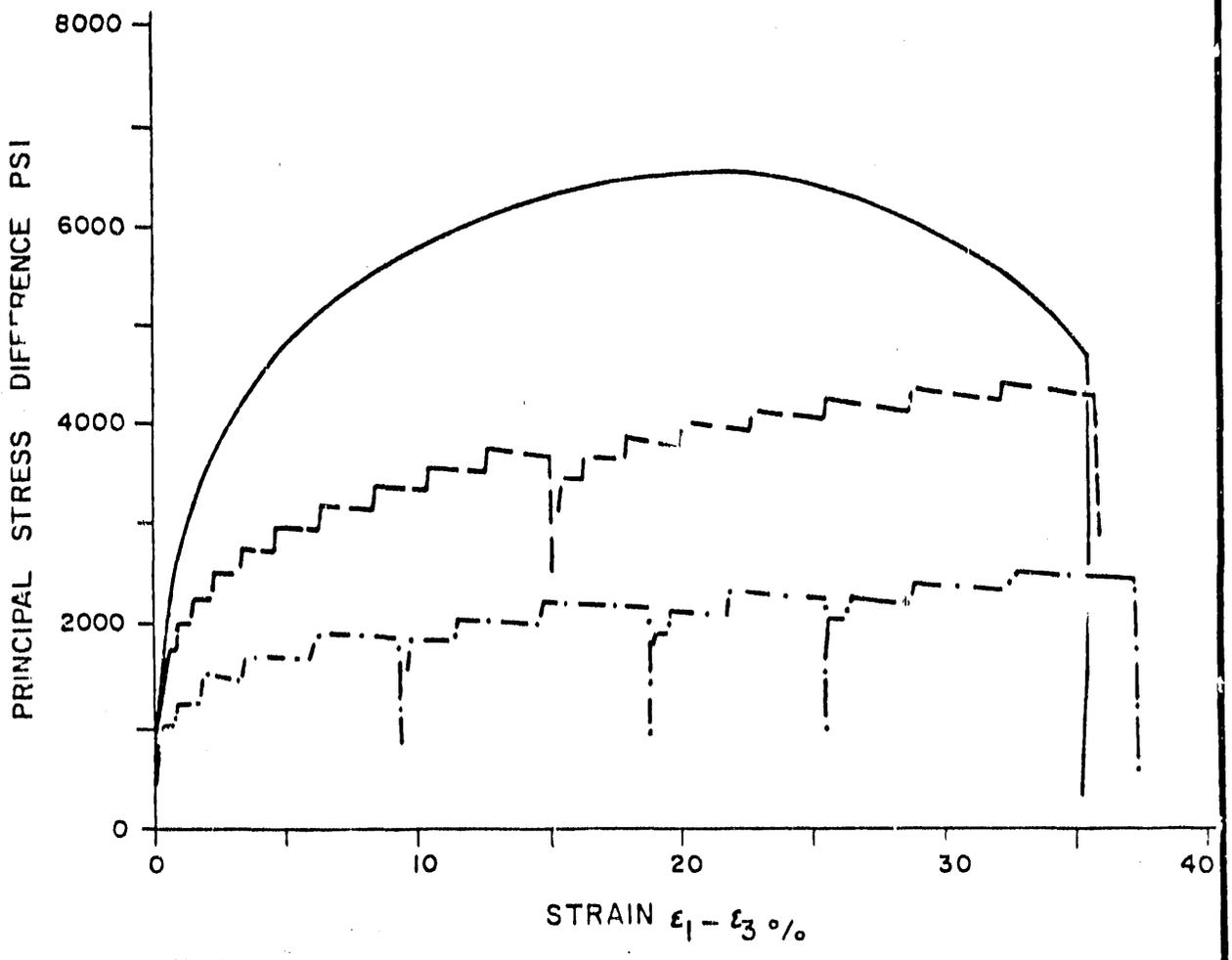
.....	9-2676 (0, 23)
	Hole No. – Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)
—·—	9-2689 (.10, 23)
—·—	7-2837 (.25, 23)
——	9-2601 (.50, 23)
——	9-2601.5 (3.0, 23)

NOTE: Open squares identify approximate strains at ultimate stresses.

TRIAXIAL VARIATION OF SHEAR STRAIN VS VOLUMETRIC STRAIN FOR TESTS OF FIGURE 9.2.4-3

From: Wawersik and Hannum, 1978

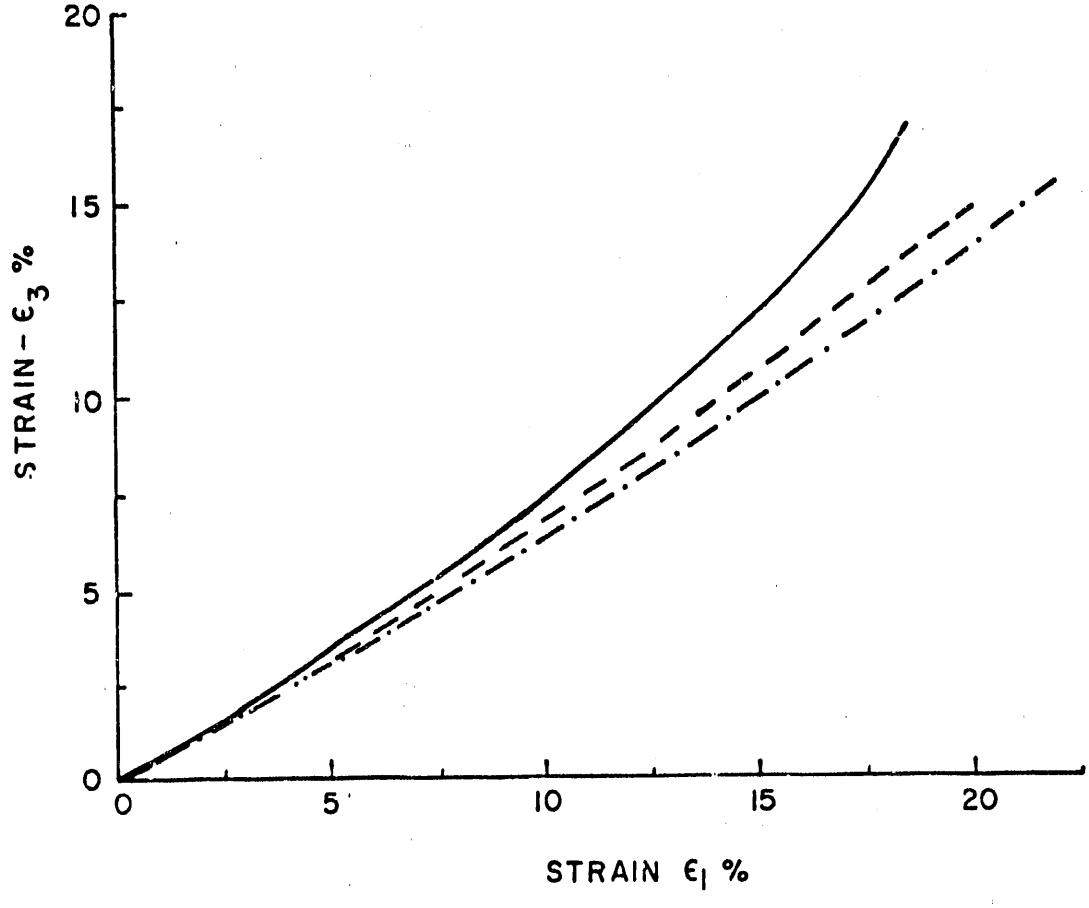
FIGURE 9.2.4-6



TRIAXIA STRESS-STRAIN CURVES AS A FUNCTION OF TEMPERATURE AT CONSTANT CONFINING PRESSURE

From : Wawersik and Hannum, 1978

FIGURE 9.2.4-7



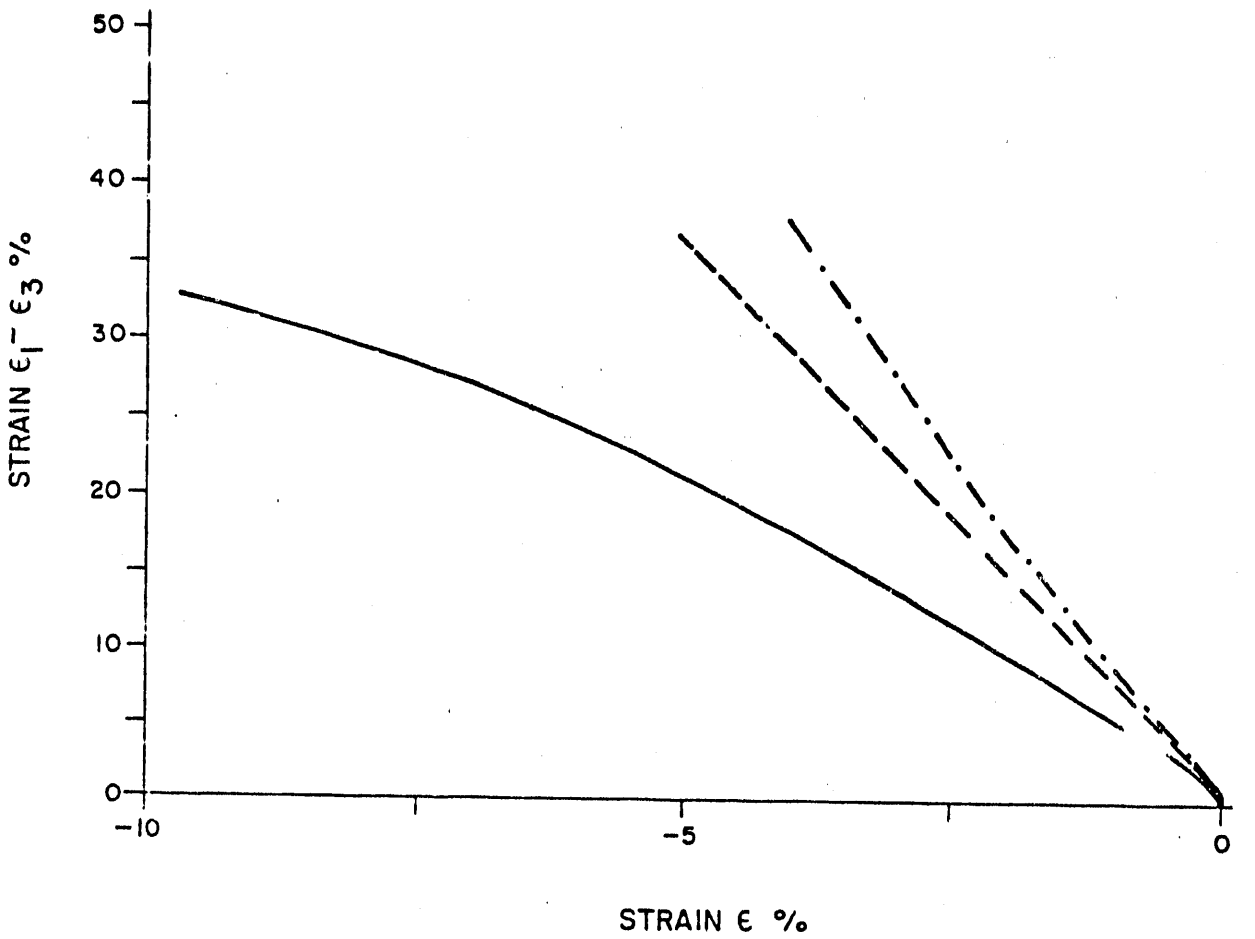
KEY

9-2601 (.50, 23)
Hole No. – Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)
9-2673.4 (.50, 100)
9-2604 (.50, 200)

VARIATION OF LATERAL VS. AXIAL STRESS FOR TESTS OF FIGURE 9.2.4-7

From: Wawersik and Hannum, 1978

FIGURE 9.2.4 - 8



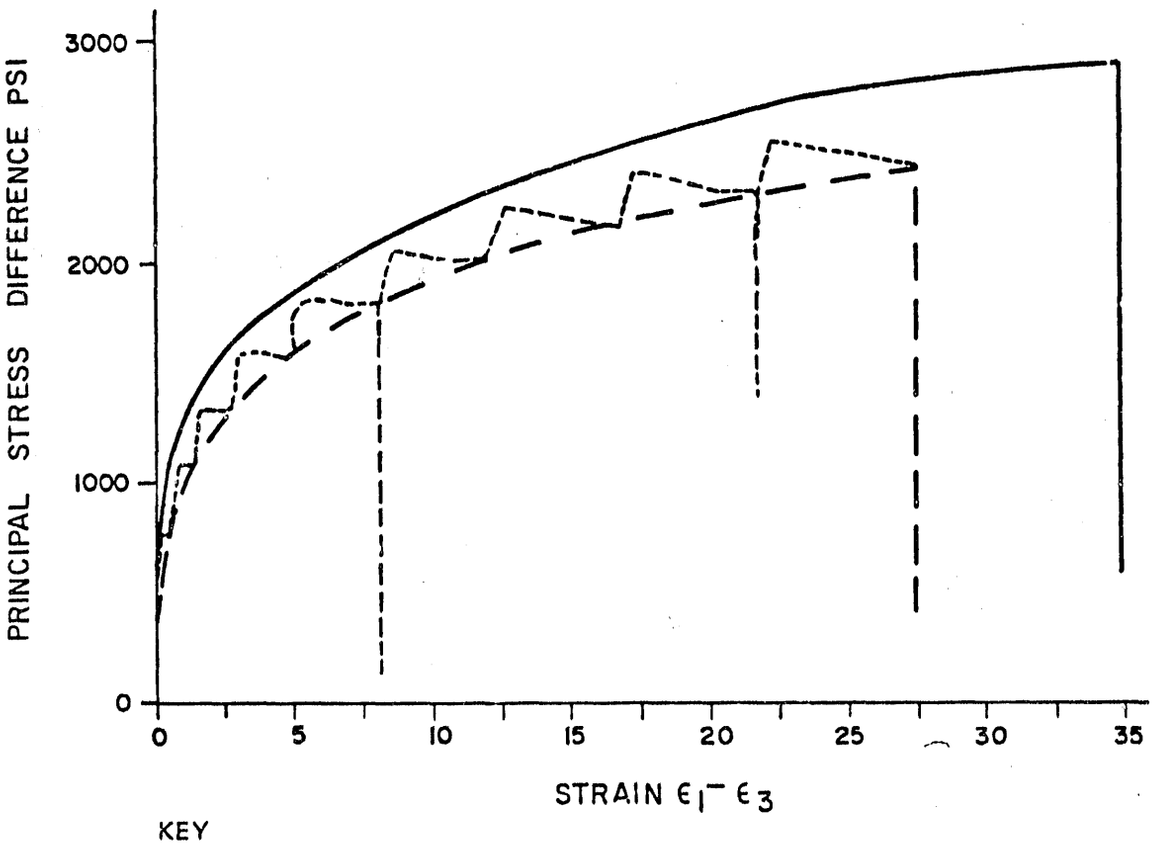
KEY

——— 9-2601 (.50, 23)
Hole No. – Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)
— — 9-2673.4 (.50, 100)
—·— 9-2604 (.50, 200)

VARIATION OF SHEAR-STRAIN VS. VOLUMETRIC STRAIN FOR TESTS OF FIGURE 9.2.4-7

From Wawersik and Hannum, 1978

FIGURE 9.2.4-9



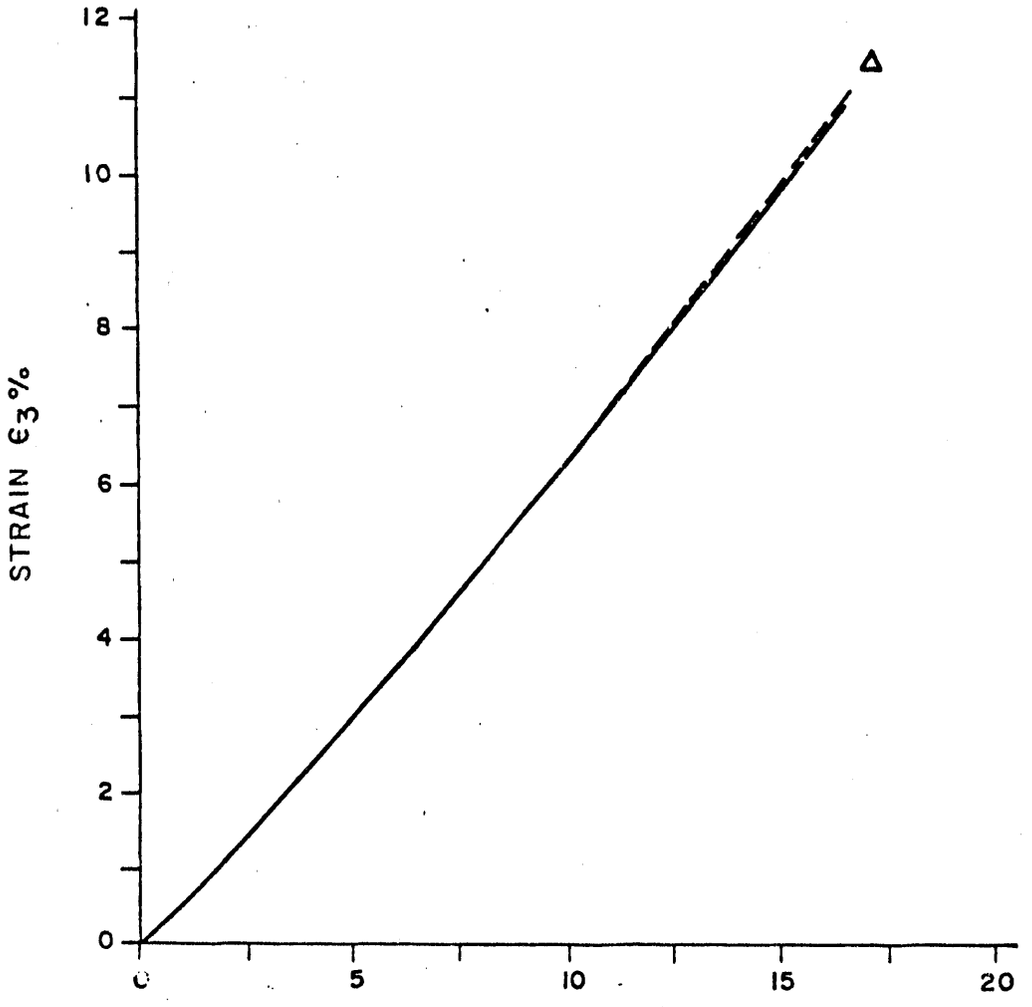
KEY

7-2740 (.50, 200)
Hole No. – Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)
7-2744 (3.0, 200)
Actual load path

TRIAXIAL STRESS STRAIN CURVES AS A FUNCTION OF CONFINING PRESSURE AT 200°C

From: Wawersik and Hannum, 1978

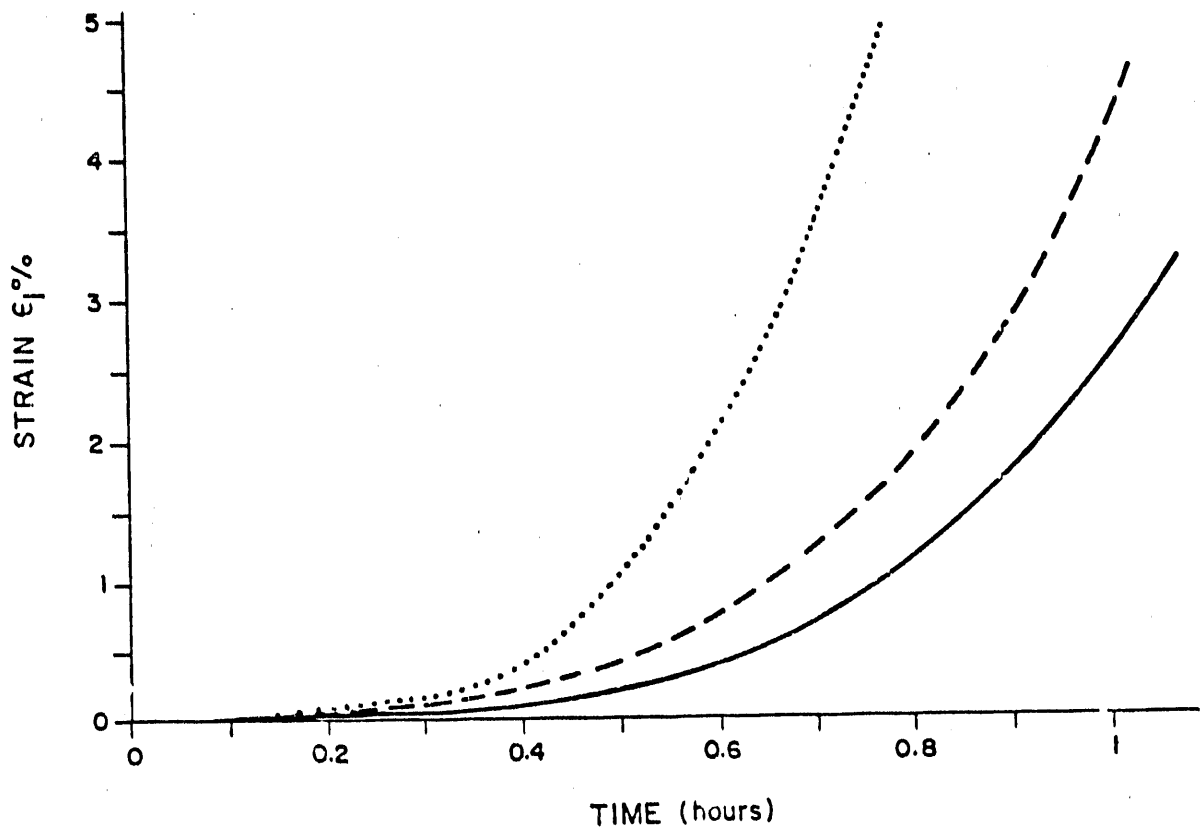
FIGURE 9.2.4-10



VARIATION OF LATERAL STRAIN VS. AXIAL STRAIN FOR TESTS OF FIGURE 9.2.4-10 (PLUS ONE ADDITIONAL TEST IN UNIAXIAL COMPRESSION)

From: Wawersik and Hannum, 1978

FIGURE 9.2.4-11



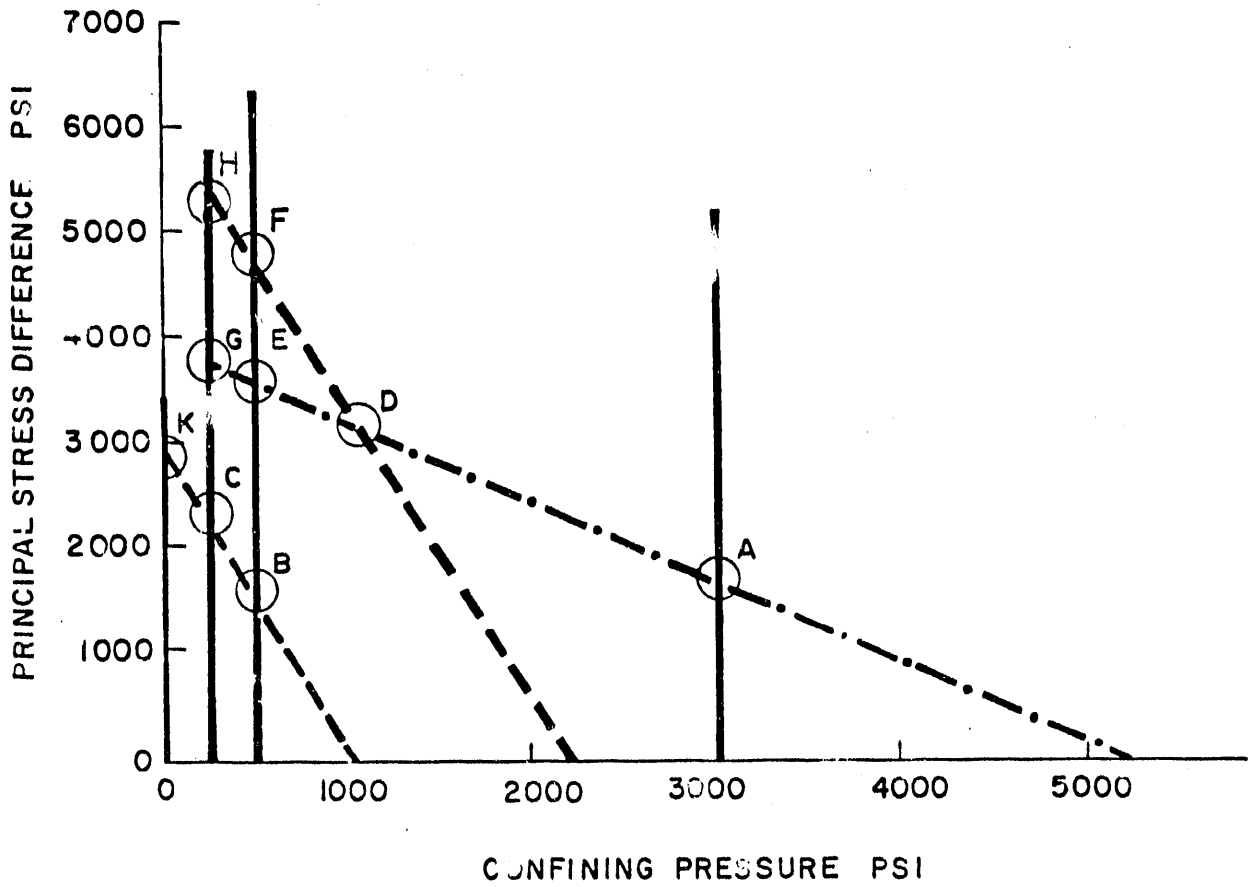
KEY

..... 7-2836 (0, 200)
Hole No. – Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)
— — 7-2740 (.50, 200)
——— 7-2744 (3.0, 200)

AXIAL STRAIN VS. TIME FOR TEST OF FIGURES 9.2.4-10 AND 9.2.4-11

From: Wawersik and Hannum, 1978

FIGURE 9.2.4-12



KEY

——— Load Path I ($\sigma_2 = \sigma_3$ = const.)

— — Load Path II (σ_m = const.) $\sigma_m = \frac{\sigma_1 + \sigma_2 + \sigma_3}{3}$

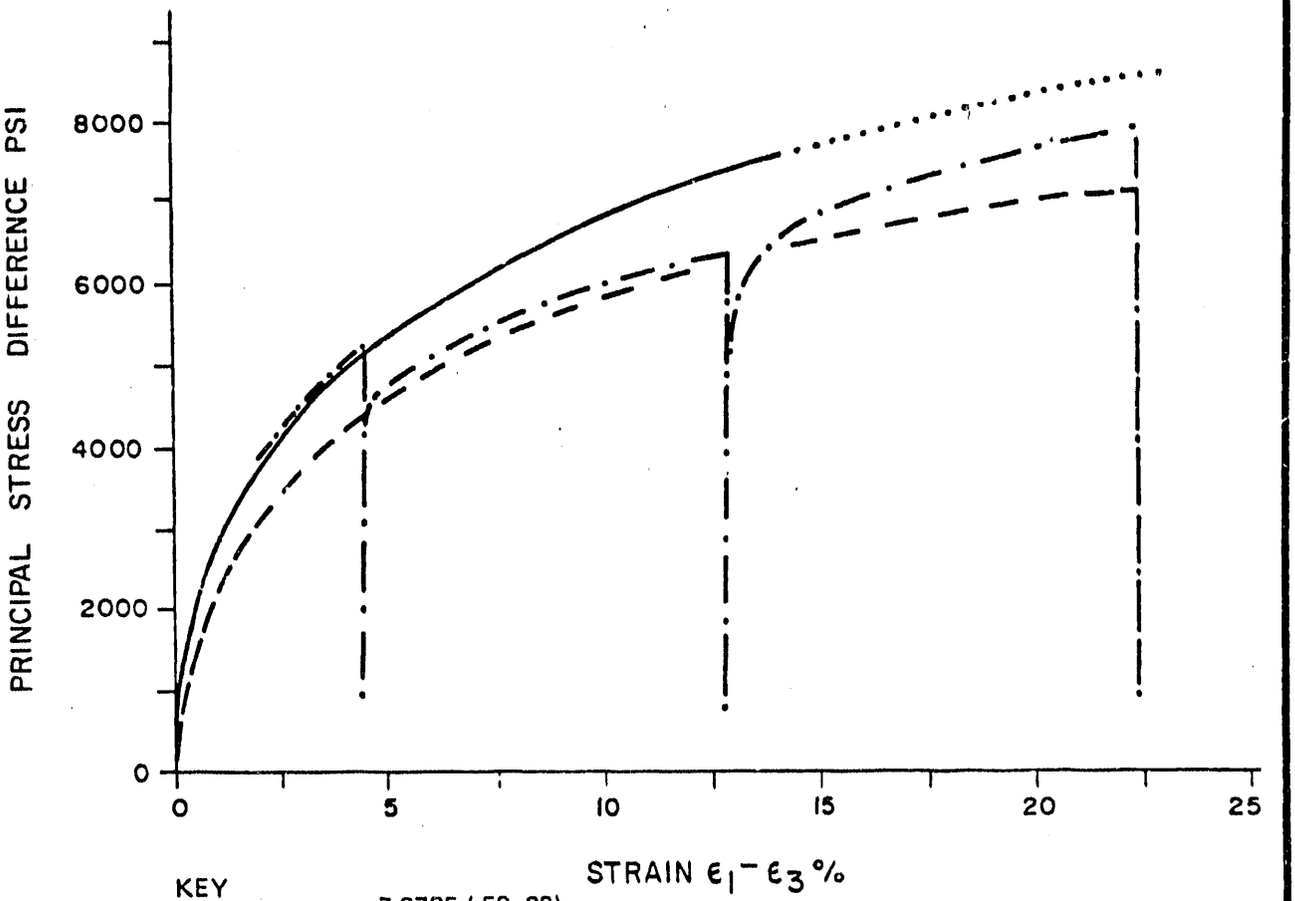
—·— Load Path III ($\sigma_1 \approx$ const)

NOTE: See table 9.2.4-3 for tabulated data.

MAP OF THREE NON-PROPORTIONAL LOAD PATHS AND COMMON STRESS STATES (POINTS A THROUGH K)

From: Wawersik and Hannum, 1978

FIGURE 9.2.4-13



KEY

- 7-2725 (.50, 23)
  Hole No. – Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)
- 7-2745 (3.0, 23)
- 7-2740.5 (3.0/.50/3.0, 23)
- 9-2601.5 (3.0, 23)

NOTE: The partial code 3.0/.50/3.0 identifies prevailing confining pressures between $(\sigma_1 - \sigma_3) = 0$ and first unload/reload cycle, first and second unload/reload cycle, and between second unload/reload cycle and final unloading trace.

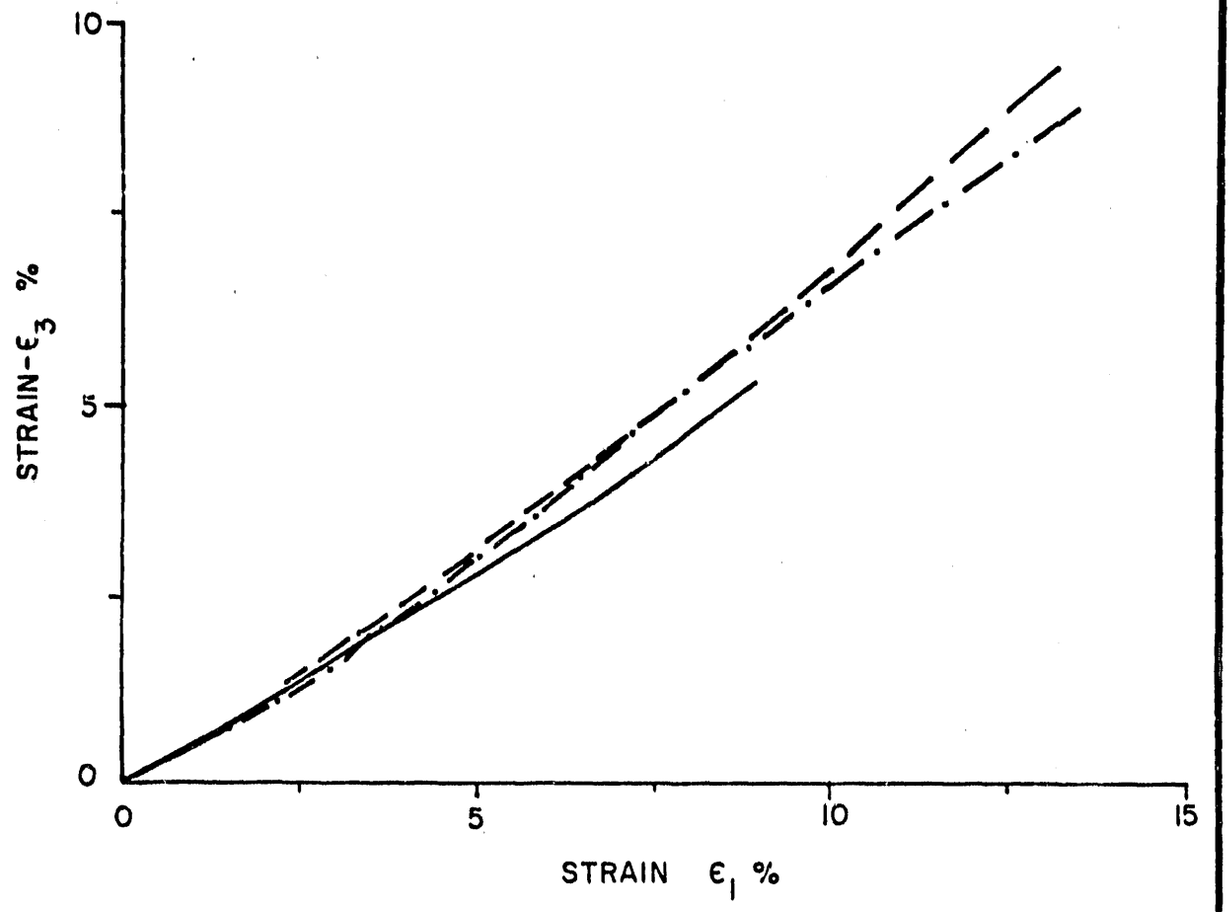
STRESS-STRAIN CURVES

FOR SAMPLE SUBJECTED TO

ONE OR MORE CONFINING PRESSURES

From : Wawersik and Hannum, 1978

FIGURE 9.2.4 - 14



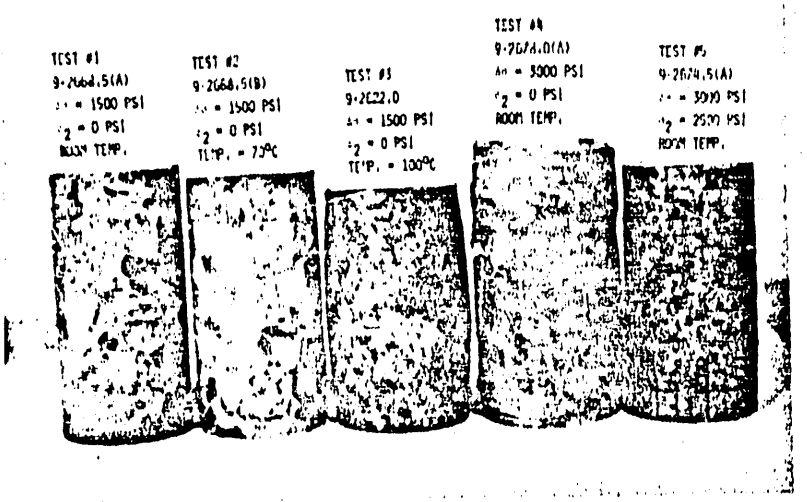
KEY

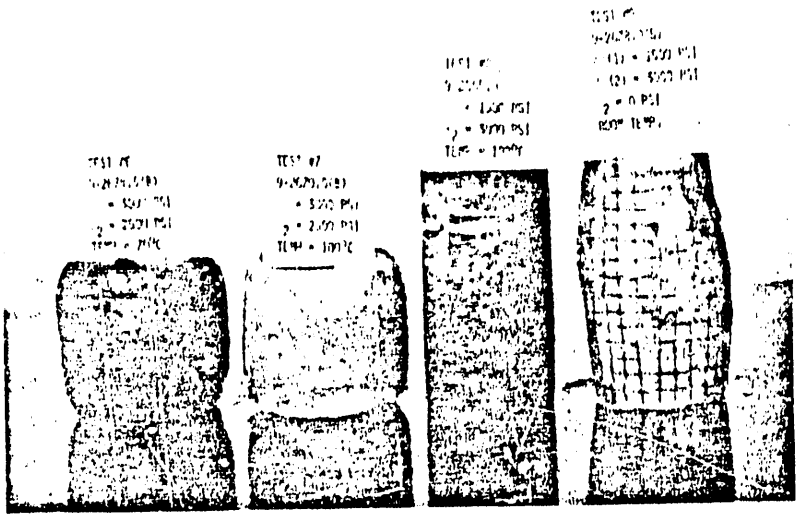
— — 7-2725 (.50, 23)
Hole No. – Sample depth in ft. (Conf. pressure in ksi, Temp. in °C)
——— 7-2745 (3.0, 23)
—·— 7-2740.5 (3.0/.50/3.0, 23)

VARIATION OF LATERAL STRAIN VS. AXIAL STRAIN FOR TESTS OF FIGURE 9.2.4-14

From : Wawersik and Hannum, 1978

FIGURE 9.2.4-15





DEFORMED CORE SAMPLES OF ROCK SALT
FROM DRILL HOLE ERDA #9

FROM: HANSEN and MELLEGARD, 1977

FIGURE 9.2.4–16

Table 9.2.3-1: Physical properties of rock from WIPP study area

Material	Depth (ft)	Density (gm/cc)	Avg. Porosity (Range) (%)	Mass (Moisture) Loss (% to $\leq 300^{o}C$)	Resistivity in Ohm Meters	Avg. Air Permeability (Range) in (md)[2]	(P) Wave[3] Velocity (Km/sec)
Rock Salt	2000-2100	2.18	0.4 (0.1-0.8)	N[1] - 1.0	58,100	0.01 (0.0003-0.17)	(4.42-4.62)
Rock Salt	2600-2700	2.18	0.5 (0.3-0.7)	N - 0.4	(4,900-230,000)	-	-
Anhydrite		2.80	-	-	-	-	-
Polyhalite	-	2.70	-	-	-	-	-
Siltstone	-	2.26	-	-	-	-	-

[1]N - None Measured

[2]Core Labs Data; see also Figure 9.2.3-1

[3]Note: P Wave velocities determined in the lab agree to 15% with those measured downhole on borehole ERDA 9 (Griswold, 1977).

Table 9.2.4.-1 - Representative unconfined mechanical properties of rock salt from the WIPP study area

Material	Drillhole/ Approx. Depth (ft)	Uniax. Compr. Strength (psi)	Strain at failure percent	Brazilian Tensile Strength (psi)	Initial Elastic Limit ($\sigma_1 - \sigma_3$) (psi)	Secant Modulus $x10^6$ (psi)	Principal Strain Ratio	Principal Strain Ratio, $\varepsilon_3/\varepsilon_1$ at Failure
Rock Salt	AEC 7,8/1900	2450	$\geq$ 1.7	200	$\leq$ 750	1.94	0.33	-
Rock Salt	AEC 7,8/2700	3700	3.6	240	$\leq$ 750	1.94	0.34	-
Rock Salt	ERDA 9/2100	2400	1.6	-	< 200	-	-	1.6
Rock Salt	ERDA 9/2700	3300	2.9	-	< 200	-	-	2.1

Note: Loading rates - $30 \leq \frac{d}{dt} (\sigma_1 - \sigma_3) \leq 215$ psi/min

1 Megapascal (MPa) equals about 145 psi
Symbols < and > denote experimental uncertainty.

Table 9.2.4-2 - Representative triaxial compression data for rock salt from the WIPP study area

Drillhole/ Depth (ft)	Confining Pressure (psi)	Temp. (°C)	Ultimate (max) Princ. Stress Diff. (psi)	Ultimate (max) Strain, ε_1 Percent	Initial Elastic Limit ($\sigma_1 - \sigma_3$) (psi)	Secant Modulus $x10^6$ (psi)	Princ Strain "Poissons'" Ratio	Max. Obs. Princ. Strain Ratio
ERDA 9/2100	500	23	6000	12	$\leq$100	2.7	0.20	- 0.72
ERDA 9/2100	3000	23	> 9000	>20	$\leq$100	2.7	0.20	- 0.65
ERDA 9/2600-2700	500	23	6300	15	$\leq$100	2.7	0.20	0.80
ERDA 9/2600-2700	3000	23	> 8900	>20	$\leq$100	2.7	0.20	- 0.67
AEC 7/2700-2800	500	23	> 6200	>13	$\leq$100	2.7	0.21	- 0.71
AEC 7/2700-2800	500	100	$\approx$ 4200	$\geq$18	$\leq$100	-	-	- 0.69
AEC 7/2700-2800	500	200	$\approx$ 2400	>17	$\leq$100	2.4	-	- 0.68
AEC 7/2700-2800	300	200	> 2750	>17	$\leq$100	-	-	-
ERDA 9/2600	500	200	> 2500	>22	$\leq$100	-	-	- 0.68

Note: Loading rate d/dt $(\sigma_1 - \sigma_3)$ = 30 to 60 psi/min.

Table 9.2.4-3 Deviatoric Load Path Data For Figure 9.2.4-13

Reference Point In Figure 15	Load Path	$(\sigma_1 - \sigma_3)$ PSI	$\sigma_2=\sigma_3$ PSI	σm PSI	ε_1 %	$-\varepsilon_3$ %
A	I	1600	2970	3550	0.17	0.07
	III	1640	3020	3570	0.075	0.05
B	I	1520	520	1015	0.357	0.175
	II	1500	520	1015	0.3	0.168
C	I	2200	260	1040	o.782	0.441
	II	2250	250	1015	0.769	0.476
D	II	3190	1120	2180	1.35	0.786
	III	3150	1120	2160	0.73	0.454
E	I	3540	520	1670	1.38	0.828
	II	3580	510	1700	1.12	0.705
F	I	4700	490	2090	4.04	2 434
	II	4740	510	2120	3.92	2.430
G	I	3840	250	1490	2.486	1.85
	III	3780	250	1500	1.49	1.01
H	I	5240	250	1990	8.58	7.81
	III & I	5140	260	2000	6.41	5.46
	II	5320	276	2070	5.71	3.79
K	I	2950	0	990	1.49	1.47
	II	2950	15	1000	1.58	1.19

Table 9.3-1

REPRESENTATIVE BRINES/SOLUTIONS FOR WIPP EXPERIMENTATION

Ion	Brine "A" (mg/liter) (± 3%)	Brine "B" (mg/liter) (± 3%)	Solution "C" (mg/liter) (± 3%)
Na^+	42,000	115,000	100
K^+	30,000	15	5
Mg^{++}	35,000	10	200
Ca^{++}	600	900	600
Fe^{+++}	2	2	1
Sr^{++}	5	15	15
Li^+	20	-	-
Rb^+	20	1	1
Cs^+	1	1	1
Cl^-	190,000	175,000	200
SO_4^{--}	3,500	3,500	1,750
$B(BO_3^{---})$	1,200	10	-
HCO_3^-	700	10	100
NO_3^-	-	-	20
Br^-	400	400	-
I^-	10	10	-
pH (adjusted)	6.5	6.5	7.5
specific gravity	1.2	1.2	1.0

Table 9.3-2

Nominal Concentration of Nuclides Used in Kd Measurements

Nuclide	Concentration, ppm
^{137}Cs	0.012
Stable Cs	1.0
^{85}Sr	0.03 - 0.3
Stable Sr	5 - 15
^{106}Ru	2500
^{99}Tc	59
^{152}Eu	0.1 - 1.0
^{144}Ce	3×10^{-4}
^{131}I	5×10^{-5}
^{153}Gd	0.2 - 2.0
^{125}Sb	$\leq$ 0.01
^{243}Am	5.4
^{244}Cm	0.012
^{238}Pu	0.058

Table 9.3-3

Distribution Coefficients on Samples From the Magenta Dolomite

Fission Product
Distribution Coefficients

	pH range	Cs	Sr	I,Tc	Eu,Gd	Ru
Brine A	6.5 - 6.9	< 1	1	0 - 1.5	$> 5 \times 10^3$	40-50
Brine B	6.5 - 7.5	< 1	1	< 1	$> 5 \times 10^3$	500-600
Sol'n C	7.5 - 8.2	4	5	0 - 1.5	$> 10^4$	400-550

Actinide
Distribution Coefficients

	pH range	Pu	Am	Cm
Brine B	6.5 - 7.8	5.4×10^3	3.1×10^2	1.3×10^3
Sol'n C	7.5 - 8.2	2.4×10^3	2.4×10^3	4.2×10^4

Table 9.3-4

Distribution Coefficients on Samples From the Culebra Dolomite

Fission Product
Distribution Coefficients

	pH range	Cs	Sr	I,Tc	Eu,Gd	Ru
Brine A	6.5 - 6.9	< 1	< 1	< 1	$> 10^4$	25 - 35
Brine B	6.5 - 7.6	1-2	1-2	< 1	$> 10^4$	640 - 660
Sol'n	7.5 - 8.2	7-10	4-5	< 1	$> 10^4$	240 - 400

Actinide
Distribution Coefficients

	pH range	Pu	Am	Cm
Brine B	6.5 - 7.8	2.1×10^3	2.6×10^3	1.2×10^4
Sol'n C	7.5 - 8.3	7.3×10^3	2.2×10^4	1.1×10^5

Table 9.3-5

Distribution Coefficients on Halite From The 2056' Horizon of ERDA #9 Borehole

Actinide Distribution Coefficients [1]

pH range	Pu	Am	Cm
7.0 - 7.1	17	306	354
	(1.0×10^4)	(1.8×10^5)	(2.1×10^5)

1) The Kd values in parentheses were calculated from the weight of water insoluble material in the halite. The lower values are based on the total weight of halite taken.

Table 9.3-6

Distribution Coefficients on Samples of Clay From The 2186.6' Horizon of AEC #8 Borehole

Fission Product
Distribution Coefficients

	pH range	Cs	Sr	I,Tc	Gd,Eu	Ru
Brine A	6.5 - 7.0	< 1	< 1	< 2	$> 2.5 \times 10^3$	150-180
Brine B	6.5 - 7.7	4-6	< 1	< 1	$> 10^4$	$> 2 \times 10^3$
Sol'n C	7.5 - 7.8	80-120	3-6	< 1	$> 10^4$	$> 1 \times 10^3$

Actinide
Distribution Coefficients

	pH range	Am	Pu	Cm
Brine B	6.5 - 8.0	1.1×10^3	4×10^4	1.9×10^4
Sol'n C	7.5 - 8.4	3.5×10^3	1.8×10^5	4.2×10^5

Table 9.3-7

Distribution Coefficients on Samples of Polyhalite From the 2304' Horizon of EPDA #9 Borehole

Fission Product
Distribution Coefficients

	pH range	Cs	Sr	Eu,Ce [1]	Sb	Tc
Brine A	6.5 - 7.0	< 1	5-10	10-20	< 1	< 1
Brine B	6.5 - 7.2	< 1	19-22	430-700, 50-55	0.9-1.5	< 1
Sol'n C	7.5 - 7.6	< 1	35-40	100-200, 40-60	3-4	< 1

1) Where two ranges of values are given, the first refers to Eu and the second to Ce.

Table 9.3-8

Distribution Coefficients on Sample of Cowden Anhydrite From the 2562' Horizon of AEC #8 Borehole

Fission Product Distribution Coefficients

	pH range	Gd, Eu, Ce
Brine B	6.5 - 7.9	$\sim 10^3$

Actinide Distribution Coefficients

	pH range	Am	Pu	Cm
Brine B	6.5 - 7.9	2.9×10^2	6.7×10^3	4.2×10^3
Sol'n C	7.5 - 8.2	2.2×10^3	7.7×10^4	1.8×10^5

Table 9.3-9

Distribution Coefficients on Samples of Clay from the 2725' Horizon of AEC #8 Borehole

Fission Product Distribution Coefficients

	pH range	Cs	Sr	Eu,Gd [1]	Tc,I [1]	Ru
Brine A	6.6 - 7.0	4-9	< 1	$> 10^3$, $2.8\text{-}4 \times 10^2$	3.5-4.5, 0-3.5	90-120
Brine B	6.7 - 7.4	3-6	< 1	$> 10^4$	< 1	$> 10^3$
Sol'n C	7.5 - 8.0	34-40	30-45	$> 10^4$, $> 3 \times 10^3$	0.7-1.5, 0.5-4	$> 10^3$

Actinide Distribution Coefficients

	pH range	Am	Pu	Cm
Brine B	6.5 - 7.8	310	7.2×10^4	2.7×10^3
Sol'n C	7.4 - 8.4	2.3×10^3	4.0×10^4	1.6×10^5

1) Where two ranges of values are given, the first refers to the first element listed and the second range is for the second element listed.

Table 9.3-10

Distribution Coefficients on Samples of Bell Canyon Formation

Fission Product Distribution Coefficients

	pH range	Cs	Sr	Eu	Sb	Tc
Brine B	6.5 - 7.4	14-16	< 1	$> 10^4$	5-8	< 1
Sol'n C	7.5 - 7.9	130-140	1-5	$> 10^4$	20-25	< 1

Table 9.3-11

Distribution Coefficients on Halite Samples From the 2611' Horizon of ERDA #9 Borehole

Column Experiment

Column Bed: 7.5 g of Halite in 1 cm diameter column

Solution: Saturated Halite Solution, 200 ml

Flow: 1 Bed volume/min.

Time (days)	% of Initial Activity in Solution ^{85}Sr	^{144}Ce
0	100	100
1	98.0	26.7
4	96.8	0.9
8	98.4	0

Actinide Distribution Coefficients(1)

pH range	Am	Pu	Cm
7.0 - 7.3	11	59	56
	(3.8×10^3)	(2.11×10^4)	(2×10^4)

(1) The Kd values in parentheses were calculated using the weight of water insoluble material in the clay. The lower values are based on the weight of halite taken.

Table 9.3-12

^{152}Eu Distribution Coefficients (Kd's)

Rock	Simulant	Nominal ^{152}Eu(μCi/ml)	Kd(1) 2 week	Kd(1) 3 month	Kd(2) 2 week	Kd(2) 3 month
Culebra	A	0.01	1.7×10^{4}	1.5×10^{4}	--	--
"	A	0.1	3.6×10^{4}	2.1×10^{4}	--	--
"	A	1.0	1.8×10^{4}	4.3×10^{4}	--	--
"	B	0.01	3.4×10^{3}	1.6×10^{3}	--	7.6×10^{3}
"	B	0.1	1.1×10^{4}	3.6×10^{3}	--	1.3×10^{3}
"	B	1.0	3.7×10^{3}	3.9×10^{3}	8.8×10^{2}	1.4×10^{3}
"	C	0.01	2.8×10^{4}	1.3×10^{4}	--	1.1×10^{4}
"	C	0.1	2.7×10^{4}	2.6×10^{4}	--	1.9×10^{4}
"	C	1.0	2.0×10^{4}	1.4×10^{4}	1.2×10^{3}	9.6×10^{3}
Magenta	A	0.01	1.4×10^{4}	6×10^{3}	--	--
"	A	0.1	1.9×10^{4}	2.0×10^{4}	--	--
"	A	1.0	1.2×10^{4}	1.4×10^{4}	--	--
"	B	0.01	2.8×10^{3}	8.6×10^{2}	--	4×10^{2}
"	B	0.1	8.3×10^{3}	3.7×10^{3}	--	1.3×10^{3}
"	B	1.0	1.1×10^{3}	1.2×10^{3}	3.5×10^{2}	4.0×10^{2}
"	C	0.01	2.0×10^{4}	1.7×10^{4}	--	1.3×10^{4}
"	C	0.1	3.6×10^{4}	2.2×10^{4}	--	1.6×10^{4}
"	C	1.0	1.4×10^{4}	1.5×10^{4}	7.7×10^{2}	1.3×10^{4}

(1) Kd based on activity in feed solutions.

(2) Kd based on activity in pH adjusted feed solutions.

Table 9.3-13

Comparison of ^{153}Gd, ^{144}Ce, and ^{152}Eu Kd's in Brine B and Brine B* Containing Plywood Extract

14 Day Equilibration

Sample	Brine	^{153}Gd cpm/ml	^{153}Gd Kd	^{152}Eu cpm/ml	^{152}Eu Kd	^{144}Ce cpm/ml	^{144}Ce Kd
Feed	B	24,200	-	20,230	-	5,120	-
Feed	B*	38,090	-	38,090	-	7,080	-
Culebra	B		4.2×10^3		9.9×10^3		1.5×10^3
"	B*		6.3×10^2		6.6×10^2		6.0×10^2
Magenta	B		2.5×10^3		3.4×10^3		1.4×10^3
"	B*		6.5×10^1		7.0×10^1		1.1×10^2
Bell Canyon	B		3.4×10^3		3.4×10^3		3.2×10^3
"	B*		1.3×10^2		1.5×10^2		2.3×10^2
Cowden	B		2.6×10^3		2.2×10^4		2.2×10^3
"	B*		3.7×10^2		4.0×10^2		5.1×10^2
High Clay	B		6.8×10^3		8.5×10^4		1.2×10^3
"	B*		8.7×10^3		2.8×10^4		2.5×10^3

28 Day Equilibration

Sample	Brine	^{153}Gd cpm/ml	^{153}Gd Kd	^{152}Eu cpm/ml	^{152}Eu Kd	^{144}Ce cpm/ml	^{144}Ce Kd
Feed	B	23,260	-	20,170	-	4,800	-
Feed	B*	33,350	-	35,210	-	5,910	-
Culebra	B		4.3×10^3		8.3×10^3		3.3×10^3
"	B*		2.1×10^3		1.8×10^3		1.3×10^3
Magenta	B		3.5×10^3		2.5×10^3		$\geq 10^4$
"	B*		1.4×10^2		1.6×10^2		2.5×10^2
Bell Canyon	B		4.2×10^3		2.7×10^3		3.2×10^3
"	B*		1.5×10^2		1.7×10^3		3.2×10^2
Cowden	B		$\geq 10^5$		5.4×10^3		1.8×10^3
"	B*		4.7×10^2		4.8×10^2		5.3×10^2
Hi Clay	B		6.5×10^3		8.7×10^3		6.1×10^3
"	B*		1.9×10^4		3.2×10^4		5.9×10^3

GCR CHAPTER 10
CONTINUING STUDIES

10.1 INTRODUCTION

Continuing studies for the WIPP primarily encompass those geological processes that need to be understood in order to more quantitatively assess the safety of converting the WIPP to a repository. The processes of importance are tectonic, geochemical, hydrologic, and climatic. The studies indicated within this chapter generally relate to these major processes. In addition, a few studies indicated in this chapter relate to minor continuing efforts of site characterization. This chapter will serve to enumerate issues which remain to be addressed relevant to the safety of converting WIPP to a repository. It is not intended here that specific plans and schedules be presented.

The organization of Chapter 10 follows that of previous chapters.

10.2 SITE SELECTION

In line with the differentiation made in Chapter 2 between site selection, site characterization, and site confirmation, the activities of site selection and site characterization are nearly complete. The confirmation of the WIPP site for a repository will necessitate the continuing studies indicated in Sections 10.3 through 10.9.

10.3 REGIONAL GEOLOGY

Continuing studies of the regional geology focus mainly on the processes of tectonics and climate through studies of paleoclimates and various manifestations of past tectonic activity.

10.3.1 Paleoclimatology

The purpose of paleoclimatic studies in southeastern New Mexico is to develop the local timing and magnitude of past climatic changes and their relation to observed geology to help assess the possible effects of future changes on a repository.

The primary method of paleoclimatic study is to examine cores of Pleistocene or Recent sediments for fauna and flora which are indicative of past climatic conditions. In addition, organic matter or ash falls may, if suitable, be dated radiometrically to provide time control.

Studies of paleoclimate are underway with preliminary analysis of core taken in San Simon Sink from borehole WIPP 15. Fauna and flora are being separated from the sediment for paleontological analyses, and suitable organic material is being separated for radiocarbon analysis. These studies of the San Simon material will be completed in 1979 to yield an initial profile of climatic changes. Further coring in other locations may be undertaken at that time, if necessary, to supplement the record. The final stage of this study will be to integrate the local climatic changes into the information about regional climates and to determine the relationship between climatic changes and related processes such as subsurface salt dissolution and resultant subsidence (see Section 10.6).

10.3.2 Regional Tectonic Studies

The purpose of various studies of regional tectonics is to assess the long-term effects of tectonic forces on a repository.

Several studies together contribute to information about regional tectonics and include the seismological studies discussed in Section 10.5.

LANDSAT. A preliminary examination of LANDSAT photos has been completed and is reported in Chapter 3. In addition, the WIPP site and surrounding regions will be re-examined in 1979 with more sophisticated image

enhancement to determine the presence and location of more subtle lineaments. Field evaluation of the interpretations will be undertaken as required.

Leveling Surveys. Releveling of some existing first-order vertical control lines was carried out in 1977, and about 300 km of new lines were established. These new lines, some of which traverse Nash Draw and the WIPP site, will be periodically releveled to establish a data base for separating regional tectonic effects from local effects perhaps due to dissolution (see Section 10.6).

West Texas Salt Flats Graben. Releveling and seismology studies indicate active tectonic displacement on the west Texas salt flats graben. Seismic reflection records will be examined and test coring conducted in 1979 to determine if the sediments will yield a record of tectonic disturbance that will contribute to information about the tectonic forces likely to affect a repository located in the Delaware Basin.

10.4 SITE GEOLOGY

The purpose of continuing studies of site geology are to refine the data base for assessment of the safety of a repository there, and to contribute some additional details of site characterization. The methods and studies as such are quite varied.

10.4.1 Geologic Mapping

Geologic mapping continues on the WIPP site and in the area, particularly under a study of the stability of the WIPP site. This study, being conducted by the USGS, is concerned with mapping caliche and related sediments to provide more conclusive data on the length of time the area has been stable, and the rates at which areas around the site have been disturbed.

10.4.2 Aeromagnetic Survey

A very high resolution aeromagnetic survey will be initiated during FY79 to examine the WIPP site and several special features. The survey of the site will primarily be to determine if any dikes have intruded the evaporites at the site since dikes might form a pathway for fluid flow. Several of the domal features mentioned in Chapters 3, 4, and 6, two of which are considered to be breccia pipes, will be examined to determine if a magnetic signature is associated with disturbance of the magnetic red beds. The tool, if proven applicable, might then be used for prospecting to support continuing studies of breccia pipes as indicated in 10.6.

10.5 SEISMOLOGY

The purpose of continuing seismological studies is to provide data for facility design and to expand the data base contributing to an understanding of tectonic processes affecting a repository in the Delaware Basin. Seismological studies are supported by arrays of stations near points of interest.

10.5.1 Near-Site Activity

The careful characterization of near-site background activity, as indicated in Chapter 5, is the dominant seismic issue affecting the WIPP site. Station CLN has been operating near the site since 1974, and continues to operate. It is planned to augment this station so that at least three stations will be operating at the site to better define near-site seismicity.

10.5.2 Central Basin Platform

An array of stations has been operating near Kermit, Texas, since 1976 to evaluate the seismic activity on the Central Basin Platform and to explore the relationship, if any, between this activity and the massive

fluid injection for secondary oil recovery operations occurring in that area. This array will continue to operate both for this purpose and because the assessment of seismic activity at the WIPP site may partly depend on an understanding of the relationship between fluid injection and seismic activity should injection occur in oil fields near the site.

10.6 CONTINUING STUDIES IN HYDROLOGY

10.6.1 Introduction

Hydrology is a major consideration when examining the feasibility for locating a nuclear waste disposal site. Two factors are directly related to hydrology: (1) the geologic stability of the formation in which the waste products will be stored, and (2) the occurrence of water as a transport medium for radionuclides. Unsaturated waters migrating along the surfaces of the salt beds will dissolve salt; therefore, an examination of magnitude and direction of fluid flow and fluid chemistry in formations above and below the salt is necessary. Additionally, the direction and rate of fluid movement both above and below the storage horizon should be evaluated to predict the movement of radionuclides should they be accidentally discharged into the aquifers.

10.6.2 Purpose of Hydrologic Testing

Two hydrology-related questions are to be answered in evaluating the suitability of the proposed WIPP site.

1. What is the geologic stability of the Salado Formation?

2. Should the primary containment barrier (the salt) fail or an accident occur, where and how rapidly will radionuclides be transported by groundwater?

Three factors need to be investigated to examine the integrity of the Salado within the site: (1) the Rustler-Salado contact is to be examined

geophysically and petrologically within the WIPP area to determine if dissolution is presently occurring, (2) the dissolution front (as defined by the edge of the shallow dissolution zone in the Nash Draw) needs to be located more precisely, (3) the estimated rate of dissolution is to be refined.

The hydraulic gradients and rates of fluid movement in the series of fluid bearing zones that overlie the Salado require further definition. Estimates of concentrations of aqueous species (and when and where they might appear) may then be refined for specific safety-assessment modeling scenarios describing radionuclide escape into these groundwater systems and migration out of the area. In addition, formations which do not presently contain water but exhibit some degree of permeability to be tested to see what rates of movement would be, should they contain water or other fluids at some later time.

10.6.3 Direction and Rate of Fluid Migration

If radionuclides were to reach fluid bearing zones in the Rustler, they would be transported away from the site by the groundwater system. To evaluate the impact of such an accident on the surrounding area, hydraulic gradients and hydraulic conductivities of fluid bearing zones overlying the salt beds will be determined or modified. Data for these determinations will be acquired by pumping tests on hydrologic test holes or measurements of the recovery time of fluid levels in bailed holes. Tracer tests will be conducted where they may contribute useful information.

A series of hydrologic tests is planned in holes placed near the periphery of the proposed land withdrawal area. After additional testing of some existing holes, control points for the potentiometric surfaces and for hydraulic conductivities will have been established for the periphery with a spacing of 2 to 3 miles. These data will allow construction of more detailed potentiometric surface maps for the site area. The potentiometric contours will be meshed with the results from

the Nash Draw program to the west. Consequently, the potentiometric surface and hydraulic conductivity data required for modeling efforts of long-term safety assessment will be obtained for an area extending from the northeast part of the study area to Malaga Bend on the Pecos River (an area of about 200 square miles).

The borehole plugging program requires data from both laboratory and in situ permeability measurements. These permeability measurements, both in the evaporites and in aquifers, will provide additional data for the safety assessment work.

10.6.4 Dewey Lake Redbeds

The Rustler Formation and the shallow dissolution zone in Nash Draw have demanded the attention of this program because they are fluid-bearing. The Dewey Lake Redbeds are also of some significance since fluids are present in sandstone lenses. Although the redbeds are only locally saturated, two possibilities exist for additional water to enter the formation: a climatic change to a high rainfall period, or migration of fluids from below into the redbeds.

Tests in two types of holes are being considered: existing holes, and at least one new hole specifically designed for Dewey Lake testing. The casing in existing holes will be perforated opposite permeable zones as identified from analyses of logging and drilling records.

The standard hydrologic testing procedures will allow calculation of the transmissivity of fluid bearing strata in the Dewey Lake Redbeds or other permeable zones that might be expected to contain fluids at some future time.

10.6.5 Long-Term Monitoring

The peripheral hydrologic test holes, which now include four potash holes, will be configured for long-term monitoring. This long-term

monitoring may show what changes are taking place in the hydraulic gradients which in turn may indicate increased or decreased flow, and variations in rates of recharge or discharge. Moreover, depending on the extent of the monitoring system, a warning network for information on fluid threats to the integrity of the repository is obtained.

The Dewey Lake Redbed hole(s) can be monitored to detect fluid movement that may not be present except during high precipitation cycles of long or short duration.

The test holes drilled in Nash Draw would be monitored to detect changes in the hydrologic regime along the Rustler-Salado contact. Because the Culebra is the main producer of water west and south of the WIPP area, it is desirable to monitor this fluid-bearing strata to determine its relationship with the shallow dissolution zone and to provide additional data for modeling the safety assessment modeling scenarios.

10.6.6 Surface Hydrology

Surface hydrology must be examined climatologically with the aid of surface mapping. Records of annual rainfall and intensity and duration of storms (particularly high intensity, 24 hour, 50 and 100 year recurring storms) are available. This information, in conjunction with surface mapping (from aerial photographs, topographic maps, or both) of contributory drainage will provide the basis to estimate amounts of runoff and amounts of infiltration in the study area. Because of the high evapotranspiration and the caliche layer below surficial sands, infiltration estimates are expected to be only a small portion of the calculated recharge.

Photogrammetric and field mapping is planned to locate and describe springs which may issue from the Dewey Lake Redbeds or the shallow dissolution zone. Several springs are suspected to be located west of the site, and discharge measurements could aid in the identification of the formations from which they issue. Geochemical monitoring of many

such springs, including the Malaga Bend seeps and the Pecos River salt load, will add to this overall understanding of hydrologic system dynamics.

10.6.7 Overview of Deep Hydrologic Testing

Three objectives for deep aquifer testing to complement the site-specific shallow aquifer investigations in the WIPP study area are:

(1) To obtain static bottom-hole pressure measurements in the deep aquifer zones, for the refinement of previous estimates of local potentiometric surfaces, hydraulic gradients, and hydraulic conductivities.

(2) To determine the bounds of the formational reservoirs.

(3) To obtain fluid samples for geochemical analyses.

Three wells suitable for hydrologic testing (Badger, Cabin-Baby, Cotton-Baby) are located within the site area. Each well will have to be re-entered and plugged, in accordance with methods now under study, or maintained as monitoring wells. Deep hydrologic data will be developed from these well to obtain site-specific information on the Delaware zones. Testing outside the study area involves two additional wells (AEC No. 8 and ERDA No. 6).

10.6.8 Long-Term Monitoring of Deep Wells

A number of wells could be equipped for long-term monitoring of the Delaware zone to show what changes, if any, are taking place in the hydraulic gradient, which in turn indicate fluid movement in the reservoir. Periodic fluid samples can be obtained to identify increased flow or chemical changes in the ground water system.

10.6.9 Continuing Studies in Salt Dissolution and Overburden Subsidence

Program Objectives. The program of investigation of dissolution and subsidence has four fundamental purposes, and one special-case consideration:

1. To correlate surficial collapse features and deposits with subsurface dissolution, in order to develop criteria for an evolutionary pattern of collapse.

2. To characterize subsurface dissolution products adjacent to the WIPP site.

3. To determine the behaviour of fluids in dissolution products adjacent to the WIPP site.

4. To analyze potential impacts of evolution of dissolution products at and near the WIPP site with respect to repository breachment and radionuclide transport.

The special case is to determine the nature of subsidence over mines in salt, and its effects on the overlying groundwater system.

An elaboration of these purposes follows.

Nash Draw Investigations. Nash Draw is believed to have originated by some combination of surface erosion and subsidence following subsurface dissolution. If the process of formation is overwhelmingly erosion, then the potential for removal of overburden at the WIPP site is probably about the same as it has been in Nash Draw. If, however, the process is overwhelmingly dissolution of salt and subsequent collapse of the overburden, the potential extension of Nash Draw toward the WIPP by dissolution will be more quantitatively described. At present, there is no conclusive way of defining an instantaneous rate of growth of Nash Draw toward the WIPP site; therefore, the only alternative is to

understand the processes which have resulted in Nash Draw, and incorporate their implications into the mathematical modeling efforts directed toward safety assessment involving the WIPP site in general, and radionuclide escape and migration in particular.

First, the Nash Draw program is a series of core holes, which will be geophysically logged. This operation will obtain data to serve three purposes: 1) reveal the subsurface of Nash Draw stratigraphy at carefully chosen points, 2) reveal the relationships between the subsurface structure and surface features and deposits, 3) reveal how much halite and anhydrite (or gypsum) has been removed by dissolution.

Second, the Nash Draw program is a source of geologic material for petrographic and geochemical examination. Examination of thin sections of recovered rock will allow the mineralogy of dissolution products to be determined, i.e. identification of what was dissolved and what remains. Mineralogy and textures of dissolution residues and cemented collapse fill can then be compared with those of dissolution features sampled in other programs, such as the one to investigate the cemented rubble chimneys (often called "karstic domal features" or "breccia pipes"). Geochemical analyses of core materials for trace constituents will reveal their degree of interaction with groundwaters, and possibly an age of formation. Also, permeabilities to fluids can be obtained from cores.

Third, the Nash Draw core holes will become a series of hydrology test holes. The brine flow underlying Nash Draw has been attributed responsibility for much of the dissolution and collapse observed today. The safety assessment scenarios for radionuclide escape and migration involve movement from WIPP into Rustler Formation waters into the shallow dissolution zone and out at Malaga bend on the Pecos River. It behooves us to understand the hydrologic relationships between the shallow dissolution zone and the Rustler water-bearing rocks in Nash Draw in order to verify that models of radionuclide transport are epresentative of the physical system.

Cemented Rubble Chimney Investigations. One of the "karstic domal features" described by J. D. Vine (called Hill "C") was encountered at the level of the McNutt potash zone by Missis ppi Chemical Corporation. It was found to be a chimney in the Salado Formation filled with clay-cemented brecciated rock belonging to strata above the McNutt. Similarly a breccia-filled chimney was encountered in drilling near a circular hill near the Wills-Weaver Mine. There are numerous other erosion-breached domes such as Vine's Hill "C" in the vicinity of Nash Draw; the subsurface expression of them, if any, is virtually unknown. It is desirable that a hole be drilled to a depth at which no more brecciated rock is found. ydrologic observation (including water sampling and static water-level measurements) in fluid-bearing zones of the structure itself and in "bedrock" and in nearby rocks will help to determine the degree of hydraulic connection of the structure with aquifers of regional extent.

Petrographic analyses of recovered core will allow comparisons to be made with dissolution products recovered from Nash Draw investigations, described previously. Such material also lends itself to geochemical analyses for the determination of rock-water interaction history and age. Similarly, fluid analyses will provide an indication of how the fluids have interacted with their host rocks, helping to determine the processes at work in such structures.

Since modeling of radionuclide escape and migration must take into account fluid movement, cemented rubble chimneys should be evaluated for their potential as paths for such movement. They should also be evaluated as members of the evolutionary pattern of dissolution and collapse features, and might be generically related to the development of Nash Draw. Consequently, it is desirable to measure in situ the permeability of the structure. In addition, the hydrologic relationships between the chimney and surrounding rocks should be understood in order to formulate a complete hydrologic model for risk assessment.

Mine Subsidence Investigations. The potash producers in southeastern New Mexico mine in two stages -- the primary recovery which leaves rooms separated by large pillars, and the secondary recovery in which they may "rob the pillars" and ultimately remove almost 95% of the ore. Second-mining requires abandonment almost immediately thereafter, because there is no longer a large enough local pillar system to hold up the roof. And so, the roof slowly sags, and subsidence is propagated to the surface.

While investigations of subsidence over mines do not bear directly on the four program objectives, mining is certainly a particular cause of subsidence and perhaps an indirect agent for initiating dissolution. If subsidence over a mine causes fracturing of water bearing rocks above, locally increased permeability might allow circulation of groundwater to underlying evaporites through the fractures to start dissolution.

The amount of subsidence and its potential for enhancement of salt dissolution of the Salado Formation over the WIPP if the McNutt potash zone were to be mined is unknown. If this subsidence program were to lead to a satisfactory means to predict subsidence and its effects, in particular dissolutioning, the control zone restrictions currently prescribed around the WIPP could possibly be relaxed. It is possible that minor subsidence will occur over the closed WIPP mine because it will not be possible to backfill the repository to the same packing density as original rock. Therefore, it is desirable to evaluate the effect of mining and subsequent subsidence on the local groundwater system in the subsiding overburden.

10.6.10 Modeling of Regional Hydrology

Hydrologic modeling has one basic objective, to support risk assessment work by describing the movement of fluids in this region in as much detail as possible. The movement of fluids affects the expected period of integrity of the repository and the movement of radionuclides from the repository. To fulfill this objective, the modeling emphasizes several

aspects. The first aspect is interpretation and explication of the data collected in field programs designed to delineate the regional flows. The second is to suggest where data are insufficient and more field or laboratory work is required. The third aspect is the simulation of experiments which cannot be performed in the field. Two examples for simulations are: consequences of perturbations to regional flow patterns caused by the existence of a repository, and consequences of changes in regional flow patterns due to alterations in rainfall patterns or due to man's activities.

The fourth aspect is prediction of the movement and concentrations of radionuclides consistent with fluid movement determined in part by the release scenarios developed for WIPP.

Implementation is based on the modification and use of certain 2-D and 3-D computer codes available for hydrologic modeling. Code verification based on field data already collected is in process. Supporting laboratory programs designed to provide parameters as absorption coefficients, permeabilities, etc., are already underway.

10.7 CONTINUING STUDIES IN GEOCHEMISTRY

10.7.1 Introduction

Detailed accounts of geochemical data reported in Chapter 7 have provided the pressing need of fundamental information for (1) conceptual design of WIPP operational facilities, and (2) formulation of site-specific process scenarios to be used in the consequence safety assessment effort. An evaluation of the available data has shown that the completed studies are not entirely sufficient to support WIPP experimental programs. These programs include borehole plugging, laboratory rock mechanics, in-mine rock mechanics, in-mine heater experiments, in-mine high-level waste emplacement experiments, laboratory waste-rock interaction experiments, radionuclide transport through rocks, and waste encapsulation studies.

In addition, the long-term safety assessment effort has lacked information about geological processes associated with so-called "geological anomalies" such as igneous dikes and cemented rubble chimneys.

10.7.2 Mineralogy and Petrology

The data concerning assemblages of evaporite minerals in the Salado Formation which were presented in Chapter 7 have addressed the types of minerals found and their relative (qualitative) abundances. While this has been useful in selection of candidate horizons for waste emplacement, it has been of limited use to the quantitative measurements of thermal and physical properties of evaporite rocks (see Chapter 9).

It has been found that a small change in the quantitative mineralogical proportions in a rock sample has a large non-linear effect on thermal properties, for example. Chapter 7, together with its executive summary in Chapter 1, has pointed out the variability in the mineralogical composition of rocks in the Permian evaporite section.

In addition, quantitative mineralogy and petrology is required for development of materials to be used in the plugging of shafts and boreholes. The long-term thermodynamic stability of a grout plug, for example, cannot be evaluated without an intimate knowledge of mineral phases in both grout and rock, so that free energy calculations can be made for degradation reactions which might occur between the two. Compatibility of grout with rock and groundwater will be an essential factor requiring thorough evaluation to provide confidence in the long-term sealing of boreholes and shafts which penetrate from surface to repository horizons.

10.7.3 Volatiles Characterization

Chapters 7 and 9 have alluded to the variability in volatile content of evaporites and how the variation affects fundamental rock properties. Chapter 7 has addressed the volatile component in detail mostly in view

of mass loss experienced by heated rock. The entire mass loss cannot be ascribed to water alone. Indeed, Chapter 7 briefly addressed the chemical species which were found in a few selected rock samples, and even so, considerable variation was observed. Experiments are planned to simulate high-level-waste-canister heat in a potash mine, in order to quantize the devolatilization products. Unambiguous interpretations of the experimental results derived therefrom require an understanding of the volatile components native to the rock before heating begins. Furthermore, the interpretations also require an understanding of the fundamental differences between potash ore zones and actual repository zones, since the results of devolatilization in one will certainly not be directly applicable to the other without taking into consideration the native differences.

10.7.4 Origins of Evaporite Assemblages

It was pointed out in Chapter 7 that many of the evaporite mineral assemblages observed in the Permian section cannot have precipitated from a seawater-like solution. Furthermore, the thermodynamic properties of some minerals, such as the almost ubiquitous polyhalite, are virtually unknown. Similarly its mode of origin is entirely unknown, and has been long regarded wholly as a product of recrystallization, commonly replacing anhydrite.

The present assemblages not only contain non-primary evaporite minerals, but also have a magnesium deficiency relative to other evaporites in the world. The sink for this magnesium presumably lost during recrystallization has not been identified. The observations of Chapter 7 urge that a thermodynamic understanding of the environments and processes of evaporite recrystallization be sought. In this way the water loss that the evaporites have experienced (during recrystallization) can be estimated, and confidence can be gained regarding what mineralogical changes (if any) are likely to take place in response to waste emplacement.

The techniques used in deducing the origins of evaporite assemblages include chemical quantitative analyses of minerals, petrographic paragenetic examination, and stable isotope, radioisotope and trace element analyses.

10.7.5 Igneous Dike

In Chapter 4, there was mention of a northeast-trending igneous dike intruding the evaporites on the west side of Nash Draw west of the WIPP study area. The characterization of the dike was based on the Yeso Hills and Kerr-McGee mine occurrences, together with an aeromagnetic survey. In order to come to an understanding of the marginal effects (i.e., dike-salt-fluid interactions), the following pursuits are recommended:

1. Collection and study of additional samples from farther away from the Kerr-McGee dike occurrence.
2. Determination of:
   a. K-Ar ages of the alteration micas in the dikes
   b. Drilling angle holes with coring at appropriate intervals, to sample the dike and the effects of the dike upon the host rock system.

The dike appears to be a natural laboratory experiment involving high-temperature interactions among salts, groundwaters, and "alien" mineralogies such as emplaced waste would also represent.

10.7.6 Trace Elements and Age-Dating

A continued effort is desirable in age-dating and trace element studies, in order to support investigative efforts contemplated for the so-called "geologic anomalies." The activities are, specifically:

1. Chemical and isotopic study of exposed collapse structure in underground workings of Mississippi Chemical Mine.

a. If waters have percolated through this structure in very recent times then this may be reflected in oxygen isotopic study of grain coatings, etc. Rb-Sr studies of clay minerals should give an indication of Rb, Sr and ($^{87}Sr/^{86}Sr$) redistribution relative to clay minerals removed from the collapse structure.

b. Scanning electron microscope/microprobe study of grain boundaries: supplemented by instrumental neutron activation analysis (INAA) for adsorbed elements (alkalies, alkaline earths, rare earth elements).

c. Rare Earth Elements (REE) distribution in all primary and secondary phases most likely to have been affected by solutions.

2. REE (and other key trace element) abundance in major facies of drill core from WIPP site. At present trace element data are very sporadic and obtained by different techniques so that real difference due to analytical precision and accuracy are suspect. Detailed INAA study of various phases from the same stratigraphic horizons over a wide lateral extent are desirable to establish realistic background data for the REE (i.e. because the REE are commonly used as analogues for the transuranics) so that REE data from dike-salt contact zones and elsewhere can be proprly assessed. If the REE distribution is extremely variable then local variations due to solution, recrystallization, contact effects will be difficult to interpret; if the REE show a more or less uniform distribution pattern and abundance then such effects can be closely scrutinized.

3. Dike-evaporite contact effects. Samples from the lamprophyre dike (T = ~ 35 MYBP) which is observed in the underground workings of the Kerr-McGee Mine offers a unique chance to examine the effects of a local, high temperature source in contact with several evaporite phases.

10.7.7 Reef and Back-Reef Waters

There is at present some degree of confusion surrounding the source and discharge of water in the Capitan Reef surrounding the Delaware Basin. Chapter 7 has shown that the greater portion of the water in the Reef cannot have come from direct infiltration into outcrops in the Guadalupe and Glass Mountains, nor from rocks in the Basin. Therefore, the relationships between the Reef and its lagoonal facies (back-reef) stratigraphic equivalents are likely source and sink candidates. These relationships are best deduced by combinations of stable isotope, uranium isotope, and solute analyses of reef and back-reef waters. An extensive water-sampling of these areas is required for this. The results of this geochemical mapping of regional groundwater flow would be used in the long-term safety assessment modelling effort and the final publication of the regional groundwater mathematical model.

10.7.8 Future Work on Fluid Inclusions

In addition to the obvious necessity of making studies on samples from the actual strata to be used for high level waste storage, a variety of approaches need to be explored. Fluid inclusions near the waste canisters might decrepitate in the thermal pulse; the conditions under which this will occur can and should be explored experimentally. (studies are continuing of inclusions in a suite of salt samples collected at various distances from a dike penetrating the salt horizons; this provides a natural analog.) The identification of the daughter minerals in some inclusions, and their thermal behavior, as well as bubble movement in a thermal gradient, will provide additional compositional information. The gases released on crushing or heating should be explored, as well as the leakage of gases (or water) out of inclusions. This would be pertinent both for interpretation of K/Ar ages and in corrosion problems. The actual chemical composition of the larger inclusions and their isotopic composition (particularly H/D and O^{16}/O^{18}) can be determined by existing methods. This would help in

understanding the complex sequence of interactions of pore (and inclusion) fluid with the original salt beds to yield the present mineralogy.

10.8 RESOURCES

Sandia Laboratories has no continuing studies of resources at the WIPP site.

10.9 SPECIAL STUDIES

10.9.1 Purpose. The objective of thermophysical and radionuclide sorption studies on SENM rocks is to determine their characteristics as required by the structural mine design, in situ experimental, and long-term safety analyses programs. As with other continuing studies, these special studies are a means to an end, not an end in themselves.

10.9.2 Thermophysical Properties

Scope. A continuing assessment of the thermophysical properties of SENM rocks is envisioned because of the broad range of questions posed about radioactive waste isolation. These problems range from the plasticity of salt to the migration of brine in salt; many are not answered by a cursory investigation. Establishing a data base, for instance, for the analyses of long-term creep, is time consuming. It is not anticipated that evaluation of physical rock properties will be pivotal in mine, experiment or repository design; however, that is intrinsically impossible to guarantee. Such evaluations may very well be pivotal in considerations of retrievability of high-level waste experiments, in which high temperatures tend to accelerate creep. Thus, physical rock property determinations, such as the micromechanics of rock deformation, are a prudent pursuit to provide additional confidence in geologic isolation.

Continuing Studies. The primary object of the continuing experimental rock mechanics program is to understand and model the thermomechanical behavior of the WIPP salt. This will be accomplished through studies of transient creep data at pressures exceeding 1500 psi and at a principal stress difference less than 2000 psi where there is a paucity of data. In addition, petrographic investigations will continue to identify the governing deformation mechanisms.

Other studies relevant to the long-term stability of the WIPP include measurements of gas and brine permeabilities on previously deformed core and measurements of gas permeabilities at elevated temperatures. Studies are also planned in the area of thermal expansion coefficients and brine migration in salt under thermal gradients. Migration of fluid inclusions is being given attention, because of the brine's corrosive potential and because the capacity of fluid inclusions to carry radionuclides through rock salt is not known.

Rock mechanic programs will also be initiated to determine the mechanical properties of the WIPP site rock other than rock salt. These studies will be directed toward the engineering performance and construction characteristics of the non-salt rock which will influence the design and construction of shafts to the repository levels.

Mineralogic and petrographic studies will be conducted on core to support the physical rock properties determinations as required. This information is required to determine the phase systems in the rocks being investigated. A similar set of studies support the geochemical analyses, Chapter 7. The variations in mineral assemblage, grain size, fluid inclusion content, and petrofabric which have been observed in evaporite rocks have also given rise to variations in physical properties, which could only qualitatively be taken into account in the investigations reported here.

The arbitrary separation of mineralogical and physical rock properties from geology and hydrology that has often occurred in other studies is

being avoided in the comprehensive studies being performed for the WIPP. The relations of rocks found at the proposed repository horizons to those found in an *in situ* test bed located elsewhere (e.g., nearby potash mine) are being evaluated. Quite possibly, mineralogic and fabric changes may cause discrepancies in results from one site to another.

10.9.3 Radionuclide Sorption Properties

Scope. A continuing assessment of WIPP rocks ability to inhibit the migration of radionuclides away from the repository is envisioned to augment the batch Kd determinations, which were used in preliminary calculations of radionuclide travel time in site-specific escape scenarios. A realistic approach to safety assessment requires data to be generated (mostly in the laboratory) under simulated physiochemical conditions anticipated in subsurface evaporites and related rocks of southeast New Mexico. The laboratory experiments in radionuclide migration would ultimately be evaluated by SENM field experiments involving the emplacement and observation of movement of non-radioactive tracers which are chemically analogous to radionuclides.

Continuing Studies. Whereas previous "Kd" measurements reflect the degree to which radionuclide soprtion on rocks takes place in static, closed systems, scenarios involving the entrainment of radionuclides in moving groundwater imply that a variety of physiochemical conditions will be encountered in the subsurface.

Now that the radionuclides of interest have been identified, different oxidation states of those radionuclides which might give rise to different mobilities in WIPP environments will next be identified. Investigations of effects on sorption of parameters such as pH, radionuclide concentration in solution, and oxidation potential will then proceed with the oxidation states of species of interest. These parameterization experiments will culminate in the simulation of radionuclide migration in flow-through experiments involving actual WIPP rocks and solutions, at the anticipated physiochemical conditions.

Appendix 7.A (Ref. sec. 7.3)

Whole Rock Chemical Analyses, Soluble-Insoluble Fractions, Mineralogy, and Weight Losses upon Heating.

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1044.2 FEET

SOLUBLE = 99.72 %
INSOLUBLE = 0.28 %

COMPONENT	WT %
SO3	0.55
NA	38.56
NA2O	0.0
K	0.03
K2O	0.0
MGO	0.04
CAO	0.43
SIO2	0.0
FE2O3	0.0
AL	0.0
C	60.40
WEIG LOSS ON HEATING	
70	0.10
HI TEMP	0.0
TOTAL	100.39

MAJOR: HAL
MINOR: ANH
TRACE: CARN

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1107.5 FEET

SOLUBLE = 69.47 %
INSOLUBLE = 30.53 %

COMPONENT	WT %
SO3	20.88
NA	20.28
NA2O	6.63
K	0.0
K2O	4.48
MGO	4.57
CAO	1.84
SIO2	8.30
FE2O3	0.27
AL2O3	1.24
CL	30.78
WEIGHT LOSS ON HEATING	
70	0.12
125	0.10
200	0.40
350-400	1.37
TOTAL	101.26

MAJOR: HAL
MINOR: POLY, LANG, K FELD, TALC, QTZ
TRACE: CHLOR, PEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1171.5 FEET

SOLUBLE = 37.10 %
INSOLUBLE = 62.90 %

COMPONENT	WT %
SO3	39.73
NA	12.56
NA2O	0.88
K	1.91
K2O	0.0
MGO	0.70
CAO	25.13
SIO2	0.63
FE2O3	0.06
AL2O3	0.0
CL	18.87
WEIGHT LOSS ON HEATING	
70	0.14
300-400	0.58
425	0.08
TOTAL	101.27

MAJOR: HAL, ANH
MINOR: POLY
TRACE: SYL, BLOED, QTZ, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1221.0 FEET

SOLUBLE = 99.51 %
INSOLUBLE = 0.49 %

COMPONENT	WT %
SO3	2.02
NA	38.79
NA2O	0.0
K	0.06
K2O	0.0
MGO	0.10
CAO	0.88
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	58.31
WEIGHT LOSS ON HEATING	
70	0.30
100-200	0.14
375-425	0.07
TOTAL	101.17

MAJOR: HAL
MINOR: ANH
TRACE: POLY, LANG, QTZ

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1343.0 FEET

SOLUBLE = 99.74 %
INSOLUBLE = 0.36 %

COMPONENT	WT %
SO3	0.99
NA	38.60
NA2O	0.0
K	0.35
K2O	0.0
MGO	0.15
CAO	0.66
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	59.40
WEIGHT LOSS ON HEATING	
70	0.27
300-350	0.16
TOTAL	100.95

MAJOR: HAL
MINOR: ANH, POLY
TRACE: QTZ

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1402.5 FEET

SOLUBLE = 99.97 %
INSOLUBLE = 0.03 %

COMPONENT	WT %
SO3	0.11
NA	39.67
NA2O	0.0
K	0.06
K2O	0.0
MGO	0.06
CAO	0.02
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	59.78
WEIGHT LOSS ON HEATING	
70	0.19
400-500	0.12
TOTAL	100.04

MAJOR: HAL
MINOR:
TRACE: POLY

TOTAL ANALYSIS

HOLE # = 7
DEPTH = 1468.5 FEET

SOLUBLE = 99.66 %
INSOLUBLE = .34 %

COMPONENT	WT %
SO3	2.88
NA	34.44
NA2O	0.0
K	0.37
K2O	0.07
MGO	1.85
CAO	0.19
SIO2	2.15
FE2O3	0.24
AL2O3	0.07
CL	53.61
WEIGHT LOSS ON HEATING	
70	1.27
100-150	0.36
175	0.10
250	0.07
375	0.34
400-500	0.45
TOTAL	98.46

MAJOR: HAL
MINOR: KAIN, KIES
TRACE: POLY, KFELD, TALC, QTZ

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1534.0 FEET

SOLUBLE = 99.86 %
INSOLUBLE = 0.14 %

COMPONENT	WT %
SO3	1.67
NA	36.10
NA2O	0.0
K	0.52
K2O	0.0
MGO	0.22
CAO	0.64
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	57.76
WEIGHT LOSS ON HEATING	
70	0.22
200	0.01
400-500	0.24
TOTAL	97.53

MAJOR: HAL
MINOR: POLY
TRACE: KAIN, QTZ

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1615.0 FEET

SOLUBLE = 98.69 %
INSOLUBLE = 1.31 %

COMPONENT	WT %
SO3	4.56
NA	35.06
NA2O	0.0
K	1.05
K2O	0.0
MGO	0.71
CAO	1.47
SIO2	0.23
FE2O3	0.04
AL2O3	0.07
CL	55.95
WEIGHT LOSS ON HEATING	
70	0.34
100	0.09
350-400	0.37
TOTAL	99.94

MAJOR: HAL
MINOR: POLY, KAIN
TRACE: CHLOR, MONT

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1698.0 FEET

SOLUBLE = 95.35 %
INSOLUBLE = 4.65 %

COMPONENT	WT %
SO3	0.58
NA	36.47
NA2O	0.0
K	0.06
K2O	0.07
MGO	1.20
CAO	0.34
SIO2	2.07
FE2O3	0.25
AL2O3	0.61
CL	58.35
WEIGHT LOSS ON HEATING	
70	0.82
350	0.03
TOTAL	100.85

MAJOR: HAL
MINOR: ANH, CARN, KIES
TRACE: POLY, ILL, QTZ, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1155.0 FEET

SOLUBLE = 99.60 %
INSOLUBLE = 0.40 %

COMPONENT	WT %
SO3	0.65
NA	38.12
NA2O	0.0
K	0.23
K2O	0.0
MGO	0.13
CAO	0.08
SIO2	0.02
FE2O3	0.0
AL2O3	0.0
CL	59.54
WEIGHT LOSS ON HEATING	
70	0.19
200	0.04
300-400	0.05
TOTAL	99.45

MAJOR: HAL
MINO :
TRACE: LEON, QTZ

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1952.5 FEET

SOLUBLE = 99.30 %
INSOLUBLE = 0.70 %

COMPONENT	WT %
SO3	3.18
NA	37.14
NA2O	0.0
K	0.75
K2O	0.03
MGO	0.54
CAO	0.79
SIO2	0.34
FE2O3	0.03
AL2O3	0.05
CL	57.00
WEIGHT LOSS ON HEATING	
70	0.14
350-450	0.44
TOTAL	100.43

MAJOR: HAL
MINOR: POLY
TRACE: LEON, CHLOR, KFELD, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1954.0 FEET

SOLUBLE = 97.46 %
INSOLUBLE = 2.54 %

COMPONENT	WT %
SO3	0.73
NA	37.94
NA2O	0.0
K	0.18
K2O	0.06
MGO	0.56
CAO	0.52
SIO2	1.34
FE2O3	0.09
AL2O3	0.23
CL	58.38
WEIGHT LOSS ON HEATING	
70	0.32
350-400	0.09
TOTAL	100.44

MAJOR: HAL
MINOR: POLY
TRACE: ANH, CHLOR, KFELD, TALC, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1957.5 FEET

SOLUBLE = 99.16 %
INSOLUBLE = 0.84 %

COMPONENT	WT %
SO3	1.72
NA	38.38
NA2O	0.0
K	0.36
K2O	0.01
MGO	0.41
CAO	2.18
SIO2	0.37
FE2O3	0.04
AL2O3	0.11
CL	59.00
WEIGHT LOSS ON HEATING	
70	0.20
300-400	0.12
TOTAL	102.90

MAJOR: HAL
MINOR: ANH
TRACE: POLY, CHLOR, KFELD, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1961.0 FEET

SOLUBLE = 99.10 %
INSOLUBLE = 0.90 %

COMPONENT	WT %
SO3	0.49
NA	39.14
NA2O	0.0
K	0.21
K2O	0.01
MGO	0.25
CAO	0.19
SIO2	0.42
FE2O3	0.04
AL2O3	0.08
CL	58.83
WEIGHT LOSS ON HEATING	
70	0.07
100	0.16
150-200	0.16
TOTAL	100.05

MAJOR: HAL
MINOR: POLY
TRACE: CHLOR, KFELD, TALC, QTZ, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1967.0 FEET

SOLUBLE = 99.94 %
INSOLUBLE = 0.06 %

COMPONENT	WT %
SO3	3.03
NA	39.58
NA2O	0.0
K	0.90
K2O	0.0
MGO	0.23
CAO	0.94
SIO2	0.0
FE2O3	0.01
AL2O3	0.0
CL	58.74
WEIGHT LOSS ON HEATING	
70	0.20
300-350	0.28
450-500	0.65
TOTAL	104.62

MAJOR: HAL
MINOR: POLY
TRACE: FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1969.0 FEET

SOLUBLE = 98.05 %
INSOLUBLE = 1.95 %

COMPONENT	WT %
SO3	0.32
NA	38.76
NA2O	0.0
K	0.08
K2O	0.0
MGO	0.22
CAO	0.06
SIO2	0.15
FE2O3	0.02
AL2O3	0.04
CL	60.60
WEIGHT LOSS ON HEATING	
70	0.43
100	0.08
400-500	0.20
TOTAL	100.98

MAJOR: HAL
MINOR:
TRACE: ANH, KAIN, CHLOR, TALC, QTZ, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1973.0 FEET

SOLUBLE = 98.63 %
INSOLUBLE = 1.37 %

COMPONENT	WT %
SO3	0.26
NA	38.46
NA2O	0.0
K	0.06
K2O	0.03
MGO	0.53
CAO	0.07
SIO2	0.66
FE2O3	0.01
AL2O3	0.13
CL	59.58
WEIGHT LOSS ON HEATING	
70	0.19
170	0.07
380	0.02
450+	0.12
TOTAL	100.19

MAJOR: HAL
MINOR: POLY, KIES
TRACE: KAIN, CHLOR, FKELD, TALC, QTZ, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1975.0 FEET

SOLUBLE = 99.93 %
INSOLUBLE = 0.07 %

COMPONENT	WT %
SO3	0.19
NA	38.93
NA2O	0.0
K	0.06
K2O	0.0
MGO	0.07
CAO	0.09
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	60.38
WEIGHT LOSS ON HEATING	
70	0.17
400-500	0.07
TOTAL	100.03

MAJOR: HAL
MINOR:
TRACE: ANH, KAIN

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1978.5 FEET

SOLUBLE = 91.07 %
INSOLUBLE = 8.93 %

COMPONENT	WT %
SO3	2.82
NA	32.52
NA2O	1.96
K	0.44
K2O	0.13
MGO	2.62
CAO	0.98
SIO2	2.89
FE2O3	0.37
AL2O3	1.06
CL	51.89
WEIGHT LOSS ON HEATING	
70	0.30
200	0.04
300-400	0.17
450-550	1.10
TOTAL	99.35

MAJOR: HAL
MINOR: POLY, CHLOR
TRACE: ANH, LANG, DLOED, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1983.0 FEET

SOLUBLE = 100.00 %
INSOLUBLE = 0.0 %

COMPONENT	WT %
SO3	1.11
NA	36.00
NA2O	0.0
K	0.61
K2O	0.0
MGO	0.40
CAO	0.46
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	59.20
WEIGHT LOSS ON HEATING	
70	0.29
125	0.03
275	0.05
350-400	0.14
TOTAL	96.30

MAJOR: HAL
MINOR: DOLY, KAIN
TRACE: QTZ

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1986.5 FEET

SOLUBLE = 99.71 %
INSOLUBLE = 0.29 %

COMPONENT	WT %
SO3	0.17
NA	38.20
NA2O	0.0
K	0.04
K2O	0.0
MGO	0.03
CAO	0.21
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	60.66
WEIGHT LOSS ON HEATING	
70	0.10
TO 500	0.0
TOTAL	99.71

MAJOR: HAL
MINOR: ANH, POLY
TRACE: KAIN, QTZ

TOTAL ANALYSIS

HOLE # 7
DEPTH = 1993.5 FEET

SOLUBLE = 99.55 %
INSOLUBLE = 0.45 %

COMPONENT	WT %
SO3	2.96
NA	38.25
NA2O	0.0
K	1.68
K2O	0.0
MGO	0.79
CAO	2.30
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	53.81
WEIGHT LOSS ON HEATING	
70	0.19
100	0.05
350--400	0.80
TOTAL	101.28

MAJOR: HAL
MINOR: POLY
TRACE:

TOTAL ANALYSIS

HOLE # 7
DEPTH = 2537.0 FEET

SOLUBLE = 91.43 %
INSOLUBLE = 8.57 %

COMPONENT	WT %
SO3	46.62
NA	0.93
NA2O	4.93
K	0.90
K2O	0.0
MGO	13.02
CAO	4.37
SIO2	13.98
FE2O3	1.13
AL2O3	3.26
CL	7.63
WEIGHT LOSS ON HEATING	
70	0.47
100	0.09
TO 500	0.0
HI TEMP	8.68
TOTAL	109.56

MAJOR: ANH
MINOR: HAL, KIES
TRACE: BLOED, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 2703.0 FEET

SOLUBLE = 98.97 %
INSOLUBLE = 1.03 %

COMPONENT	WT %
SO3	1.46
NA	38.36
NA2O	0.0
K	0.02
K2O	0.01
MGO	0.26
CAO	0.79
SIO2	0.25
FE2O3	0.06
AL2O3	0.05
CL	58.89
WEIGHT LOSS ON HEATING	
70	0.24
150	0.03
550	0.12
TAL	100.54

MAJOR: HAL
MINOR: ANH
TRACE: POLY, CHLOR, KFELD, TALC, FEOX

TOTAL ANALYSIS

HOLE # 7
DEPTH = 2716.3 FEET

SOLUBLE = 99.63 %
INSOLUBLE = 0.37 %

COMPONENT	WT %
SO4	0.44
NA	39.44
NA2O	0.0
K	0.01
K2O	0.0
MGO	0.01
CAO	0.18
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	61.00
WEIGHT LOSS ON HEATING	
70	0.22
350	0.04
TOTAL	101.72

MAJOR: HAL
MINOR: ANH
TRACE: POLY, TALC

TOTAL ANALYSIS

HOLE # 7
DEPTH = 2736.0 FEET

SOLUBLE = 99.67 %
INSOLUBLE = 0.33 %

COMPONENT	WT %
SO3	0.42
NA	39.75
NA2O	0.0
K	0.01
K2O	0.0
MGO	0.06
CAO	0.51
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	59.88
WEIGHT LOSS ON HEATING	
70	0.08
TO 450	0.03
TOTAL	101.08

MAJOR: HAL
MINOR: ANH
TRACE:

TOTAL ANALYSIS

HOLE # B
DEPTH = 1391.5 FEET

SOLUBLE = 98.99 %
INSOLUBLE = 1.01 %

COMPONENT	WT %
SO3	1.14
NA	39.34
NA2O	0.0
K	0.31
K2O	0.02
MGO	0.27
CAO	0.53
SIO2	0.40
FE2O3	0.27
AL2O3	0.10
CL	58.07
WEIGHT LOSS ON HEATING	
70	0.04
110	0.03
350-400	0.19
TOTAL	100.71

MAJOR: HAL
MINOR: POLY
TRACE: CHLOR, ILL, QTZ, FLUX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1495.3 FEET

SOLUBLE = 99.83 %
INSOLUBLE = 0.17 %

COMPONENT	WT %
SO3	1.12
NA	30.00
NA2O	0.0
K	0.12
K2O	0.0
MGO	0.13
CAO	1.62
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	59.97
WEIGHT LOSS ON HEATING	
70	0.05
200	0.03
TOTAL	101.22

MAJOR: HAL
MINOR:
TRACE: CARN

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1573.0 FEET

SOLUBLE = 97.72 %
INSOLUBLE = 2.28 %

COMPONENT	WT %
SO3	5.11
NA	34.63
NA2O	0.0
K	0.18
K2O	0.02
MGO	1.71
CAO	0.45
SIO2	0.02
FE2O3	0.0
AL2O3	0.01
CL	54.11
WEIGHT LOSS ON HEATING	
70	0.04
100	0.20
160	0.09
350-450	0.85
TOTAL	97.42

MAJOR: HAL
MINOR: (?) POLY, KIES
TRACE: (?) ILL

TOTAL ANALYSIS

HOLE # R
DEPTH = 1652.0 FEET

SOLUBLE = 48.61 %
INSOLUBLE = 51.39 %

COMPONENT	WT %
SO3	51.04
NA	4.07
NA2O	4.24
K	18.59
K2O	0.99
MGO	4.58
CAO	3.93
SIO2	0.35
FE2O3	0.07
AL2O3	0.04
CL	7.35
WEIGHT LOSS ON HEATING	
70	0.
300+	4.43
TOTAL	99.77

MAJOR: HAL
MINOR: POLY-(?) SYL, LEON, GLAS
TRACE: ILL, QTZ, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1705.0 FEET

SOLUBLE = 99.71 %
INSOLUBLE = 0.29 %

COMPONENT	WT %
SO3	1.18
NA	38.79
NA2O	0.0
K	0.35
K2O	0.0
MGO	0.17
CAO	0.44
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	58.64
WEIGHT LOSS ON HEATING	
70	0.15
170	0.02
400-500	0.15
TOTAL	100.19

MAJOR: HAL
MINOR:
TRACE: POLY

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1770.0 FEET

SOLUBLE = 98.79 %
INSOLUBLE = 1.21 %

COMPONENT	WT %
SO3	1.95
NA	35.75
NA2O	0.33
K	0.56
K2O	0.02
MGO	0.55
CAO	1.75
SIO2	0.48
FE2O3	0.0
AL2O3	0.12
CL	57.29
WEIGHT LOSS ON HEATING	
70	0.09
170	0.06
400	0.20
TOTAL	99.15

MAJOR: HAL
MINOR: ANH, KAIN
TRACE: ILL, QTZ

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1787.0 FEET

SOLUBLE = 99.43 %
INSOLUBLE = 0.57 %

COMPONENT	WT %
SO3	3.01
NA	37.24
NA2O	0.0
K	0.69
K2O	0.01
MGO	0.54
CAO	0.70
SIO2	0.21
FE2O3	0.03
AL2O3	0.04
CL	58.00
WEIGHT LOSS ON HEATING	
70	0.32
100	0.04
300-400	0.23
TOTAL	101.06

MAJOR: HAL
MINOR: POLY, KAIN
TRACE: CHLOR, QTZ, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1794.5 FEET

SOLUBLE = 75.34 %
INSOLUBLE = 24.66 %

COMPONENT	WT %
SO3	0.70
NA	29.75
NA2O	1.16
K	0.42
K2O	0.63
MGO	6.65
CAO	0.04
SIO2	7.80
FE2O3	0.46
AL2O3	1.91
CL	45.14
WEIGHT LOSS ON HEATING	
70	0.44
150	0.27
425+	4.70
TOTAL	100.07

MAJOR: HAL
MINOR: CARN, CHLOR, KFELD, TALC, QTZ
TRACE: POLY, FEOX

TOTAL ANALYSIS

HOLE # B
DEPTH = 1804.0 FEET

SOLUBLE = 99.74 %
INSOLUBLE = 0.26 %

COMPONENT	WT %
SO3	0.28
NA	39.43
NA2O	0.0
K	0.06
K2O	0.0
MGO	0.04
CAO	0.70
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	59.94
WEIGHT LOSS ON HEATING	
70	0.02
200	0.05
TOTAL	100.79

MAJOR: HAL
MINOR: ANH
TRACE: CARN

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1829.0 FE

SOLUBLE = 99.03 %
INSOLUBLE = 0.97 %

COMPONENT	WT %
SO3	0.02
NA	39.87
NA2O	0.0
K	0.05
K2O	0.2
MGO	0.29
CAO	0.01
SIO2	0.29
FE2O3	0.04
AL2O3	0.08
CL	58.81
WEIGHT LOSS ON HEATING	
70	0.16
200	0.23
TOTAL	99.87

MAJOR: HAL
MINOR:
TRACE: ANH, CARN, CHLOR, KFELD, TALC, FLOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1838.0 FEET

SOLUBLE = 97.53 %
INSOLUBLE = 2.47 %

COMPONENT	WT %
SO3	0.80
NA	37.58
NA2O	0.0
K	0.26
K2O	0.10
MGO	0.48
CAO	0.05
SIO2	0.13
FE2O3	0.16
AL2O3	0.27
CL	58.38
WEIGHT LOSS ON HEATING	
70	0.39
TO 500	0.0
TOTAL	98.60

MAJOR: HAL
MINOR:
TRACE: POLY, SLY, LEON, CHLOR, KFELD, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1856.7 FEET

SOLUBLE = 99.96 %
INSOLUBLE = 0.04 %

COMPONENT	WT %
SO3	2.70
NA	36.08
NA2O	0.0
K	1.62
K2O	0.0
MGO	0.03
CAO	1.56
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	56.66
WEIGHT LOSS ON HEATING	
70	0.07
350	0.03
TOTAL	98.79

MAJOR: HAL
MINOR: ANH, SYL, POLY
TRACE:

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1875.0 FEET

SOLUBLE = 70.94 %
INSOLUBLE = 29.06 %

COMPONENT	WT %
SO3	0.42
NA	25.64
NA2O	0.0
K	0.31
K2O	2.28
MGO	9.55
CAO	0.63
SIO2	15.30
FE2O3	1.23
AL2O3	3.00
CL	40.92
WEIGHT LOSS ON HEATING	
70	0.22
125-200	0.42
TOTAL	99.92

MAJOR: HAL
MINOR: CARN, KFELD, TALC
TRACE: POLY, CHLOR

TOTAL ANALYSIS

HOLE # B
DEPTH = 1804.0 FEET

SOLUBLE = 90.58 %
INSOLUBLE = 19.42 %

COMPONENT	WT %
SO3	3.76
NA	27.10
NA2O	0.0
K	6.98
K2O	1.60
MGO	5.09
CAO	1.66
SIO2	9.02
FE2O3	0.60
AL2O3	1.99
CL	44.06
WEIGHT LOSS ON HEATING	
70	0.36
350-400	0.44
TOTAL	102.66

MAJOR: HAL
MINOR: ANH, CARN, KFELD, TALC, FEOX
TRACE: CHLOR

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1890.0 FEET

SOLUBLE = 99.98 %
INSOLUBLE = 0.02 %

COMPONENT	WT %
SO3	0.77
NA	36.78
NA2O	0.0
K	0.10
K2O	0.0
MGO	0.10
CAO	0.95
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	59.33
WEIGHT LOSS ON HEATING	
70	0.05
300-400	0.08
TOTAL	100.18

MAJOR: HAL
MINOR:
TRACE: ANH, CARN

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1894.3 FEET

SOLUBLE = 95.43 %
INSOLUBLE = 4.57 %

COMPONENT	WT %
SO3	0.12
NA	37.90
NA2O	0.0
K	0.06
K2O	0.13
MGO	0.74
CAO	0.03
SIO2	2.43
FE2O3	0.20
AL2O3	0.43
CL	57.78
WEIGHT LOSS ON HEATING	
70	0.30
TO 500	0.0
TOTAL	100.12

MAJOR: HAL
MINOR: QTZ
TRACE: ANH, CARN, CHLOR, KFELD, TALC, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1898.5 FEET

SOLUBLE = 98.53 %
INSOLUBLE = 1.47 %

COMPONENT	WT %
SO3	0.55
NA	30.81
NA2O	0.71
K	0.07
K2O	0.01
MGO	0.26
CAO	0.12
SIO2	0.45
FE2O3	0.02
AL2O3	0.07
CL	57.97
WEIGHT LOSS ON HEATING	
70	0.16
TO 500	0.0
TOTAL	99.20

MAJOR: HAL
MINOR:
TRACE: POLY, BLOED, CHLOR, TALC, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1900.0 FEET

SOLUBLE = 99.96 %
INSOLUBLE = 0.04 %

COMPONENT	WT %
SO3	3.20
NA	38.14
NA2O	0.0
K	0.98
K2O	0.0
MGO	0.47
CAO	0.39
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	57.60
WEIGHT LOSS ON HEATING	
70	0.17
300-400	0.64
TOTAL	101.63

MAJOR: HAL
MINOR: LEON
TRACE: POLY

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1905.0 FEET

SOLUBLE = 96.98 %
INSOLUBLE = 3.02 %

COMPONENT	WT %
SO3	0.20
NA	38.67
NA2O	0.0
K	0.13
K2O	0.03
MGO	0.93
CAO	0.45
SIO2	0.91
FE2O3	0.14
AL2O3	0.25
CL	57.91
WEIGHT LOSS ON HEATING	
70	0.36
375	0.26
TOTAL	100.24

MAJOR: HAL
MINOR:
TRACE: POLY, CHLOR, KFELD, TALC

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1910.0 FEET

SOLUBLE = 99.02 %
INSOLUBLE = 0.98 %

COMPONENT	WT %
SO3	0.53
NA	39.64
NA2O	0.0
K	0.0
K2O	0.30
MGO	0.31
CAO	0.44
SIO2	0.34
FE2O3	0.04
AL2O3	0.08
CL	57.04
WEIGHT LOSS ON HEATING	
70	0.06
375	0.04
TOTAL	100.82

MAJOR: HAL
MINOR: POLY
TRACE: ANH, CHLOR, KFELD, TALC, QTZ, FEOX

TOTAL ANALYSIS

HOLE # B
DEPTH = 1913.1 FEET

SOLUBLE = 97.71 %
INSOLUBLE = 2.29 %

COMPONENT	WT %
SO3	0.06
NA	36.48
NA2O	0.0
K	0.06
K2O	0.05
MGO	0.55
CAO	0.01
SIO2	0.91
FE2O3	0.13
AL2O3	0.21
CL	59.27
WEIGHT LOSS ON HEATING	
70	0.11
120	0.03
260	0.03
400+	0.04
TOTAL	99.94

MAJOR: HAL
MINOR:
TRACE: KAIN, CHLOR, KFELD, TALC, QTZ, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1916.2 FEET

SOLUBLE = 99.85 %
INSOLUBLE = 0.15 %

COMPONENT	WT %
SO3	0.92
NA	36.48
NA2O	0.0
K	0.21
K2O	0.0
MGO	0.13
CAO	0.44
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	57.71
WEIGHT LOSS ON HEATING	
70	0.13
250	0.02
350-400	0.10
TOTAL	98.29

MAJOR. HAL
MINOR: POLY
TRACE: ANH

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1923.0 FEET

SOLUBLE = 98.30 %
INSOLUBLE = 1.70 %

COMPONENT	WT %
SO3	1.06
NA	38.03
NA2O	0.0
K	0.05
K2O	0.08
MGO	0.09
CAO	0.20
SIO2	0.60
FE2O3	0.10
AL2O3	0.16
CL	58.43
WEIGHT LOSS ON HEATING	
70	0.19
300	0.06
450+	0.24
TOTAL	99.29

MAJOR: HAL
MINOR: POLY
TRACE: KAIN, CHLOR, ILL, KFELD, QTZ, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1930.0 FEET

SOLUBLE = 98.99 %
INSOLUBLE = 1.01 %

COMPONENT	WT %
SO3	2.81
NA	35.71
NA2O	0.08
K	1.03
K2O	0.01
MGO	0.46
CAO	0.20
SIO2	0.18
FE2O3	0.07
AL2O3	0.04
CL	56.74
WEIGHT LOSS ON HEATING	
70	0.05
350-400	0.42
TOTAL	97.80

MAJOR: HAL
MINOR: POLY
TRACE: LEON, CHLOR, KFELD, TALC, FEOX

TOTAL ANALYSIS

HOLE # B
DEPTH = 1933.0 FEET

SOLUBLE = 99.62 %
INSOLUBLE = 0.38 %

COMPONENT	WT %
SO3	0.78
NA	38.03
NA2O	0.0
K	0.15
K2O	0.0
MGO	0.09
CAO	0.65
SIO2	0.01
FE2O3	0.01
AL2O3	0.0
CL	59.61
WEIGHT LOSS ON HEATING	
70	0.19
200	0.09
TOTAL	100.19

MAJOR: HAL
MINOR: ANH, POLY, KAIN
TRACE: QTZ, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1938.0 FEET

SOLUBLE = 99.86 %
INSOLUBLE = 0.14 %

COMPONENT	WT %
SO3	2.91
NA	35.63
NA2O	0.0
K	0.68
K2O	0.0
MG	0.84
CAO	.02
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	59.45
WEIGHT LOSS ON HEATING	
70	0.13
125	0.14
275	0.05
350-400	0.17
TOTAL	101.16

MAJOR: HAL
MINOR: POL . KAIN
TRACE:

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1953.2 FEET

SOLUBLE = 99.91 %
INSOLUBLE = 0.09 %

COMPONENT	WT %
SO3	2.30
NA	39.50
NA2O	0.0
K	0.30
K2O	0.0
MGO	0.42
CAO	1.23
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	57.63
WEIGHT LOSS ON HEATING	
70	0.05
250	0.05
375	0.03
425	0.29
TOTAL	101.90

MAJOR: HAL
MINOR: ANH, POLY
TRACE: BLOED, TALC

TOTAL ANALYSIS

HOLE # B
DEPTH = 1967.0 FEET

SOLUBLE = 95.13 %
INSOLUBLE = 4.87 %

COMPONENT	WT %
SO3	1.25
NA	35.99
NA2O	2.73
K	0.57
K2O	0.09
MGO	1.21
CAO	0.41
SIO2	0.76
FE2O3	0.10
AL2O3	0.20
CL	57.52
WEIGHT LOSS ON HEATING	
70	0.28
190	0.04
400-500	0.20
TOTAL	101.35

MAJOR: HAL
MINOR: POLY, KAIN, TALC
TRACE: CHLOR, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 1986.0 FELT

SOLUBLE = 36.72 %
INSOLUBLE = 63.28 %

COMPONENT	WT %
SO3	60.87
NA	0.36
NA2O	5.83
K	0.0
K2O	26.07
MGO	1.83
CAO	5.12
SIO2	0.54
FE2O3	0.17
AL2O3	0.85
CL	0.15
WEIGHT LOSS ON HEATING	
70	0.07
300-400	5.81
TOTAL	107.67

MAJOR: (?) GLAS, ANH, LEON
MINOR:
TRACE: HAL, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2006.0 FEET

SOLUBLE = 99.50 %
INSOLUBLE = 0.50 %

COMPONENT	WT %
SO3	2.37
NA	37.59
NA2O	0.0
K	1.03
K2O	0.0
MGO	0.31
CAO	0.06
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	57.17
WEIGHT LOSS ON HEATING	
70	0.20
350-400	0.29
450	0.13
475	0.04
TOTAL	99.70

MAJOR: HAL
MINOR: KAIN, BLOED
TRACE: POLY, QTZ

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2017.0 FEET

SOLUBLE = 95.20 %
INSOLUBLE = 4.80 %

COMPONENT	WT %
SO3	0.62
NA	35.66
NA2O	0.0
K	0.06
K2O	0.04
MGO	0.53
CAO	1.02
SIO2	2.02
FE2O3	0.28
AL2O3	0.70
CL	57.09
WEIGHT LOSS ON HEATING	
70	0.22
100	0.02
300-400	0.17
ORGANIC	1.59
TOTAL	100.02

MAJOR: HAL
MINOR: ANH
TRACE: SYL, CAIN, CHLOR, FEOX, ILL

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2039.0 FEET

SOLUBLE = 98.94 %
INSOLUBLE = 1.06 %

COMPONENT	WT %
SO3	5.50
NA	35.02
NA2O	0.0
K	1.56
K2O	0.03
MGO	0.70
CAO	1.58
SIO2	0.27
FE2O3	0.07
AL2O3	0.05
CL	54.01
WEIGHT LOSS ON HEATING	
70	0.21
100	0.05
300-400	0.49
425	0.27
TOTAL	99.81

MAJOR: HAL
MINOR: POLY, KAIN
TRACE: KFELD, TALC, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2050.0 FEET

SOLUBLE = 28.61 %
INSOLUBLE = 71.39 %

COMPONENT	WT %
SO3	54.99
NA	8.00
NA2O	4.90
K	0.05
K2O	0.04
MGO	0.31
CAO	7.10
SIO2	0.33
FE2O3	0.0
AL2O3	0.0
CL	12.44
WEIGHT LOSS ON HEATING	
70	0.11
475	0.68
TOTAL	88.95

MAJOR: ANH
MINOR: HAL
TRACE: QTZ

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2068.0 FEET

SOLUBLE = 98.84 %
INSOLUBLE = 1.16 %

COMPONENT	WT %
SO3	2.49
NA	37.41
NA2O	0.0
K	0.08
K2O	0.01
MGO	0.31
CAO	0.89
SIO2	0.38
FE2O3	0.05
AL2O3	0.07
CL	55.99
WEIGHT LOSS ON HEATING	
70	0.04
250	0.10
TOTAL	97.82

MAJOR: HAL
MINOR: ANH, TALC, BLOED
TRACE: POLY, CHLOR, FLUX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2084.0 FEET

SOLUBLE = 92.00 %
INSOLUBLE = 8.00 %

COMPONENT	WT %
SO3	2.64
NA	34.46
NA2O	1.87
K	1.02
K2O	0.19
MGO	1.48
CAO	0.73
SIO2	2.07
FE2O3	0.25
AL2O3	0.37
CL	52.19
WEIGHT LOSS ON HEATING	
70	0.17
140	0.05
350-400	0.27
450-550	0.22
TOTAL	97.98

MAJOR: HAL
MINOR: CHLOR, TALC, QTZ
TRACE: KFELD, FLUX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2130.0 FEET

SOLUBLE = 99.61 %
INSOLUBLE = 0.39 %

COMPONENT	WT %
SO3	2.31
NA	37.79
NA2O	0.0
K	0.42
K2O	0.0
MGO	0.25
CAO	0.75
SIO2	0.03
FE2O3	0.0
AL2O3	0.0
CL	57.16
WEIGHT LOSS ON HEATING	
70	0.11
125	0.07
350-400	0.10
TOTAL	99.38

MAJOR: HAL
MINOR: POLY
TRACE: ANH, QTZ

TOTAL ANALYSIS

HOLE # B
DEPTH = 2162.0 FEET

SOLUBLE = 98.90 %
INSOLUBLE = 1.10 %

COMPONENT	WT %
SO3	1.56
NA	36.77
NA2O	0.55
K	1.23
K2O	0.03
MGO	0.65
CAO	0.93
SIO2	0.23
FE2O3	0.06
AL2O3	0.05
CL	59.99
WEIGHT LOSS ON HEATING	
70	0.14
300-400	0.48
TOTAL	102.67

MAJOR: HAL
MINOR: ANH, POLY, SYL
TRACE: KFELD, TALC, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2217.0 FEET

SOLUBLE = 99.7 %
INSOLUBLE = 0. %

COMPONENT	WT %
SO3	0.0
NA	39.14
NA2O	0.0
K	0.07
K2O	0.0
MGO	0.02
CAO	0.12
SIO2	0.01
FE2O3	0.0
AL2O3	0.0
CL	59.75
WEIGHT LOSS ON HEATING	
70	0.04
300 0	0.0
TOTAL	99.77

MAJOR: HAL
MINOR:
TRACE: ANH, POLY, SLY, QTZ

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2280.0 FEET

SOLUBLE = 100.00 %
INSOLUBLE = 0.0 %

COMPONENT	WT %
SO3	0.39
NA	37.91
NA2O	0.0
K	0.12
K2O	0.0
MGO	0.09
CAO	0.25
SIO2	0.02
FE2O3	0.0
AL2O3	0.0
CL	60.23
WEIGHT LOSS ON HEATING	
70	0.19
350	0.08
TOTAL	99.28

MAJOR: HAL
MINOR: ANH, CARN
TRACE: POLY, QTZ

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2320.0 FEET

SOLUBLE = 95.44 %
INSOLUBLE = 4.56 %

COMPONENT	WT %
SO3	0.18
NA	37.83
NA2O	0.0
K	0.06
K2O	0.03
MGO	1.39
AU	0.17
SIO2	1.15
FE2O3	0.12
AL2O3	0.25
CL	57.93
WEIGHT LOSS ON HEATING	
70	0.11
100-150	0.03
450+ MIN	0.56
TOTAL	99.01

MAJOR: HAL
MINOR: TAL
TRACE: HAL, CARN, CHLOR, FLUX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2366.3 FEET

SOLUBLE = 31.37 %
INSOLUBLE = 68.63 %

COMPONENT	WT %
SO3	47.32
NA	0.62
NA2O	3.76
K	0.0
K2O	10.67
MGO	6.40
CAO	3.37
SIO2	10.68
FE2O3	0.01
AL2O3	1.57
CL	1.17
WEIGHT LOSS ON HEATING	
70	0.43
200-375	4.81
375-500	1.00
TOTAL	92.41

MAJOR:
MINOR: KAIN, KFELD, TALC, QTZ
TRACE: HAL, SYL

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2427.5 FEET

SOLUBLE = 99.36 %
INSOLUBLE = 0.64 %

COMPONENT	WT %
SO3	2.58
NA	39.42
NA2O	0.0
K	0.01
K2O	0.01
MGO	0.05
CAO	0.35
SIO2	0.10
FE2O3	0.01
AL2O3	0.01
CL	59.88
WEIGHT LOSS ON HEATING	
70	0.03
300-400	0.40
TOTAL	102.85

MAJOR: HAL
MINOR: ANH
TRACE: POLY, BLOED, KFELD, TALC, QTZ, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2460.0 FEET

SOLUBLE = 99.21 %
INSOLUBLE = 0.79 %

COMPONENT	WT %
SO3	1.14
NA	38.75
NA2O	0.0
K	0.03
K2O	0.01
MGO	0.20
CAO	0.62
SIO2	0.19
FE2O3	0.03
AL2O3	0.06
CL	57.00
WEIGHT LOSS ON HEATING	
70	0.17
125	0.05
350	0.08
450	0.07
TOTAL	98.40

MAJOR: HAL
MINOR: ANH
TRACE: KAIN, CHLOR, KEELD, TALC, FLOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2519.6 FEET

SOLUBLE = 99.36 %
INSOLUBLE = 0.64 %

COMPONENT	WT %
SO3	0.17
NA	40.42
NA2O	0.0
K	0.02
K2O	0.0
MGO	0.01
CAO	0.03
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	60.31
WEIGHT LOSS ON HEATING	
70	0.08
480	0.06
TOTAL	101.74

MAJOR: HAL
MINOR:
TRACE: POLY

TOTAL ANALYSIS

HOLE # B
DEPTH = 2563.0 FEET

SOLUBLE = 7.11 %
INSOLUBLE = 92.89 %

COMPONENT	WT %
SO3	40.59
NA	1.47
NA2O	6.06
K	0.05
K2O	0.54
MGO	14.73
CAO	24.37
SIO2	6.25
FE2O3	0.96
AL2O3	1.86
CL	1.05
WEIGHT LOSS ON HEATING	
70	1.87
100-150	0.19
175	0.07
450+ MIN	0.11
TOTAL	100.17

MAJOR: ANH
MINOR: CHLOR, KFELD, TALC, FEOX
TRACE: HAL, LANG

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2615.5 FEET

SOLUBLE = 99.74 %
INSOLUBLE = 0.26 %

COMPONENT	WT %
SO3	0.86
NA	38.58
NA2O	0.0
K	0.05
K2O	0.0
MGO	0.02
CAO	0.58
SIO2	0.0
FE2O3	0.01
AL2O3	0.0
CL	59.37
WEIGHT LOSS ON HEATING	
70	0.21
300-350	0.06
TOTAL	100.00

MAJOR: HAL
MINOR: ANH
TRACE: POLY, FEOX

TOTAL ANALYSIS

HOLE # = 8
DEPTH = 2665.5 FEET

SOLUBLE = 99.08 %
INSOLUBLE = 0.92 %

COMPONENT	WT %
SO3	0.98
NA	36.68
NA2O	0.0
K	0.02
K2O	0.01
MGO	0.22
CAO	0.35
SIO2	0.23
FE2O3	0.04
AL2O3	0.06
CL	59.14
WEIGHT LOSS ON HEATING	
70	0.25
400-500	0.48
TOTAL	100.46

MAJOR: HAL
MINOR: ANH, CHLOR
TRACE: POLY, KFELD, TALC, FLOX

TOTAL ANALYSIS

HOLE # B
DEPTH = 2706.0 FEET

SOLUBLE = 98.75 %
INSOLUBLE = 1.25 %

COMPONENT	WT %
SO3	1.13
NA	37.09
NA2O	0.64
K	0.03
K2O	0.03
MGO	0.19
CAO	0.68
SIO2	0.27
FE2O3	0.27
AL2O3	0.07
CL	58.60
WEIGHT LOSS ON HEATING	
70	0.16
300	0.05
380	0.75
400+	0.70
TOTAL	100.66

MAJOR: HAL
MINOR: ANH
TRACE: POLY, CHLOR, KFELD, TALC, FEOX

TOTAL ANALYSIS

HOLE # B
DEPTH = 2758.0 FEET

SOLUBLE = 99.22 %
INSOLUBLE = 0.78 %

COMPONENT	WT %
SO3	1.70
NA	37.20
NA2O	0.83
K	0.08
K2O	0.01
MGO	0.18
CAO	1.14
SIO2	0.06
FE2O3	0.01
AL2O3	0.02
CL	58.07
WEIGHT LOSS ON HEATING	
70	0.11
250	0.05
TOTAL	99.46

MAJOR: HAL
MINOR: ANH
TRACE: POLY, CHLOR, KFELD, TALC, FEOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2779.0 FEET

SOLUBLE = 99.62 %
INSOLUBLE = 0.38 %

COMPONENT	WT %
SO3	1.09
NA	37.41
NA2O	0.0
K	0.01
K2O	0.0
MGO	0.03
CAO	1.80
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	58.53
WEIGHT LOSS ON HEATING	
70	0.21
HI TEMP	0.0
TOTAL	99.46

MAJOR: HAL
MINOR: CARN, ANH
TRACE:

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2794.0 FELT

SOLUBLE = 99.79 %
INSOLUBLE = 0.21 %

COMPONENT	WT %
SO3	0.99
NA	37.86
NA2O	0.0
K	0.02
K2O	0.0
MGO	0.01
CAO	0.68
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	60.58
WEIGHT LOSS ON HEATING	
70	0.18
HI TEMP	0.0
TOTAL	100.53

MAJOR: HAL
MINOR: ANH
TRACE: POLY

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2802.5 FEET

SOLUBLE = 99.55 %
INSOLUBLE = 0.45 %

COMPONENT	WT %
SO3	1.76
NA	38.39
NA2O	0.0
K	0.02
K2O	0.0
MGO	0.01
CAO	0.22
SIO2	0.0
FE2O3	0.0
AL2O3	0.0
CL	58.19
WEIGHT LOSS ON HEATING	
70	0.10
170	0.02
375	0.02
TOTAL	99.16

MAJOR: HAL
MINOR: ANH
TRACE: BLOED, POLY

TOTAL ANALYSIS

HOLL # 8
DEPTH = 2809.0 FEET

SOLUBLE = 99.09 %
INSOLUBLE = 0.91 %

COMPONENT	WT %
SO3	2.02
NA	38.56
NA2O	0.0
K	0.01
K2O	0.01
MGO	0.04
CAO	1.09
SIO2	0.04
FE2O3	0.0
AL2O3	0.01
CL	59.70
WEIGHT LOSS ON HEATING	
70	0.15
150-200	0.09
400	0.24
TOTAL	101.95

MAJOR: HAL
MINOR: ANH
TRACE: POLY, BLOED, PCLY, KFELD, QTZ

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2820.5 FEET

SOLUBLE = 99.46 %
INSOLUBLE = 0.54 %

COMPONENT	WT %
SO3	1.67
NA	38.42
NA2O	0.0
K	0.01
K2O	0.0
MGO	0.03
CAO	0.29
SIO2	0.06
FE2O3	0.0
AL2O3	0.0
CL	58.50
WEIGHT LOSS ON HEATING	
70	0.18
400+	0.18
TOTAL	99.34

MAJOR: HAL
MINOR: THEN, ANH
TRACE: POLY, TALC

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2879.0 FEET

SOLUBLE = 96.41 %
INSOLUBLE = 3.59 %

COMPONENT	WT %
SO3	4.15
NA	32.65
NA2O	0.93
K	0.02
K2O	0.01
MGO	0.13
CAO	1.54
SIO2	0.13
FE2O3	0.01
AL2O3	0.01
CL	55.79
WEIGHT LOSS ON HEATING	
TO 70	0.06
TO 500	0.0
500+	3.31
TOTAL	98.74

MAJOR: HAL
MINOR: GLAS, ANH
TRACE: POLY, KFELD, TALC, FLOX

TOTAL ANALYSIS

HOLE # 8
DEPTH = 2948.0 FEET

SOLUBLE = 97.32 %
INSOLUBLE = 2.68 %

COMPONENT	WT %
SO3	5.34
NA	37.30
NA2O	0.0
K	0.01
K2O	0.01
MGO	0.03
CAO	0.79
SIO2	0.06
FE2O3	0.01
AL2O3	0.0
CL	55.51
WEIGHT LOSS ON HEATING	
70	0.20
150	0.02
450	0.02
500	0.02
TOTAL	99.32

MAJOR: HAL
MINOR: GLAUB, ANH
TRACE: LANG, TALC, QTZ, FEOX

Appendix 7.B (Ref. sec. 7.3)

Whole Rock Chemical Analyses in Soluble and Insoluble Fractions & Moles times 1000

HOLE # 7
DEPTH = 1044.2 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	0.55	6.87
NA	38.56	1677.25
NA2O	0.0	0.0
K	0.03	0.77
K2O	0.0	0.0
MGO	0.04	0.99
CAO	0.43	7.67
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	60.40	1703.61

HOLE # 7
DEPTH = 1107.5 FEET

SOLUBLE
69.47 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	9.24	115.41
NA	20.28	882.12
NA2O	0.0	0.0
K	0.0	0.0
K2O	3.70	39.28
MGO	2.24	55.57
CAO	1.61	28.71
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.01	0.10
CL	30.78	868.26
SUBTOTAL	67.86 %	
MEASURED =	69.47	

HOLE # 7
DEPTH = 1107.5 FEET

INSOLUBLE
30.53 WT % OF TOTAL

WT %	MOLES
11.63	145.27
0.0	0.0
6.63	106.97
0.0	0.0
0.77	8.17
2.33	57.80
0.23	4.10
8.30	138.13
0.27	1.69
1.24	12.16
0.0	0.0
31.40 %	
30.53	

	HOLE # 7 DEPTH = 1171.5 FEET SOLUBLE 37.10 WT % OF TOTAL		HOLE # 7 DEPTH = 1171.5 FEET INSOLUBLE 62.90 WT % OF TOTAL	
COMPONENT	WT %	MOLES	WT %	MOLES
SO3	1.92	23.98	37.81	472.27
NA	12.56	546.32	0.0	0.0
NA2O	0.0	0.0	0.88	14.20
K	1.91	48.85	0.0	0.0
K2O	0.0	0.0	0.0	0.0
MGO	0.47	11.66	0.23	5.71
CAO	1.65	29.42	23.48	418.69
SIO2	0.01	0.17	0.62	10.32
FE2O3	0.0	0.0	0.06	0.38
AL2O3	0.0	0.0	0	0.0
CL	18.87	532.30	0.0	0.0
SUBTOTAL	37.39 %		63.08 %	
MEASURED =	37.10		62.90	

HOLE # 7
DEPTH = 1221.0 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	2.02	25.23
NA	38.79	1687.26
NA2O	0.0	0.0
K	0.06	1.53
K2O	0.0	0.0
MGO	0.10	2.48
CAO	0.88	15.69
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	58.31	1644.65

HOLE # 7
DEPTH = 1343.0 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	0.99	12.37
NA	38.60	1678.99
NA2O	0.0	0.0
K	0.35	8.95
K2O	0.0	0.0
MGO	0.15	3.7[illegible]
CAO	0.66	11.77
SIO2	0.01	0.17
[illegible]2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.40	1675.60

HOLE # 7
DEPTH = 1402.5 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	0.11	1.37
NA	39.67	1725.53
NA2O	0.0	0.0
K	0.06	1.53
K2O	0.0	0.0
MGO	0.06	1.49
CAO	0.02	0.36
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.78	1686.32

HOLE # 7
DEPTH = 1468.5 FEET

SOLUBLE
93.66 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.98	12.24
NA	34.44	1498.04
NA2O	0.0	0.0
K	0.37	9.46
K2O	0.0	0.0
MGO	0.52	12.90
CAO	0.18	3.21
SIO2	0.03	0.50
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	53.61	1512.27
SUBTOTAL	90.13 %	
MEASURED =	93.66	

HOLE # 7
DEPTH = 1468.5 FEET

INSOLUBLE
6.34 WT % OF TOTAL

WT %	MOLES
1.89	23.61
0.0	0.0
0.0	0.0
0.0	0.0
0.07	0.74
1.32	32.75
0.01	0.18
2.12	35.28
0.24	1.50
0.07	0.69
0.0	0.0
5.72 %	
6.34	

HOLE # 7
DEPTH = 1534.0 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	1.67	20.86
NA	36.10	1570.25
NA2O	0.0	0.0
K	0.52	13.30
K2O	0.0	0.0
MGO	0.22	5.46
CAO	0.64	11.41
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.76	1629.34

	HOLE # 7 DEPTH = 1615.0 FEET SOLUBLE 98.69 WT % OF TOTAL		HOLE # 7 DEPTH = 1615.0 FEET INSOLUBLE 1.31 WT % OF TOTAL	
COMPONENT	WT %	MOLES	WT %	MOLES
SO3	3.58	44.72	0.98	12.24
NA	35.06	1525.01	0.0	0.0
NA2O	0.0	0.0	0.0	0.0
K	1.05	26.85	0.0	0.0
K2O	0.0	0.0	0.0	0.0
MGO	0.69	17.12	0.02	0.50
CAO	1.39	24.79	0.08	1.43
SIO2	0.03	0.50	0.21	3.49
FE2O3	0.0	0.0	0.03	0.19
AL2O3	0.0	0.0	0.07	0.69
CL	55.95	1578.28	0.0	0.0
SUBTOTAL	97.75 %		1.39 %	
MEASURED =	98.69		1.31	

	HOLE # 7 DEPTH = 1698.0 FEET SOLUBLE 95.35 WT % OF TOTAL		HOLE # 7 DEPTH = 1698.0 FEET INSOLUBLE 4.65 WT % OF TOTAL	
COMPONENT	WT %	MOLES	WT %	MOLES
SO3	0.58	7.24	0.0	0.0
NA	36.47	1586.34	0.0	0.0
NA2O	0.0	0.0	0.0	0.0
K	0.06	1.53	0.0	0.0
K2O	0.0	0.0	0.07	0.74
MGO	0.28	6.95	0.92	22.82
CAO	0.33	5.88	0.01	0.18
SIO2	0.04	0.67	2.03	33.78
FE2O3	0.0	0.0	0.25	1.57
AL2O3	0.0	0.0	0.61	5.96
CL	58.35	1645.98	0.0	0.0
SUBTOTAL	96.11 %		3.89 %	
MEASURED =	95.35		4.65	

HOLE # 7
DEPTH = 1755.0 FEET
TOTAL

COMPONENT	WT %	MOL
SO3	0.65	8.12
NA	38.12	1658.11
NA2O	0.0	0.0
K	0.23	5.88
K2O	0.0	0.0
MGO	0.13	3.23
CAO	0.08	1.43
SIO2	0.02	0.33
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.54	1679.55

HOLE # 7
DEPTH = 1952.5 FEET

SOLUBLE
99.30 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	3.03	37.85
NA	37.14	1615.49
NA2O	0.0	0.0
K	0.75	19.18
K2O	0.0	0.0
MGO	0.42	10.42
CAO	0.78	13.91
SIO2	0.01	0.17
FE2O3	0.01	0.06
AL2O3	0.0	0.0
CL	57.00	1607.90
SUBTOTAL	99.14 %	
MEASURED =	99.30	

HOLE # 7
DEPTH = 1952.5 FEET

INSOLUBLE
0.70 WT % OF TOTAL

WT %	MOLES
0.15	1.87
0.0	0.0
0.0	0.0
0.0	0.0
0.03	0.32
0.12	2.98
0.01	0.18
0.33	5.49
0.02	0.13
0.05	0.49
0.0	0.0
0.71 %	
0.70	

	HOLE # 7 DEPTH = 1954.0 FEET SOLUBLE 97.46 WT % OF TOTAL		HOLE # 7 DEPTH = 1954.0 FEET INSOLUBLE 2.54 WT % OF TOTAL	
COMPONENT	WT %	MOLES	WT %	MOLES
SO3	0.73	9.12	0.0	0.0
NA	37.94	1650.28	0.0	0.0
NA2O	0.0	0.0	0.0	0.0
K	0.18	4.60	0.0	0.0
K2O	0.0	0.0	0.06	0.64
MGO	0.17	4.22	0.39	9.68
CAO	0.51	9.09	0.01	0.18
SIO2	0.02	0.33	1.33	22.13
FE2O3	0.0	0.0	0.09	0.56
AL2O3	0.0	0.0	0.23	2.26
CL	58.38	1646.83	0.0	0.0
SUBTOTAL	97.93 %		2.11 %	
MEASURED =	97.46		2.54	

HOLE # 7
DEPTH = 1957.5 FEET

SOLUBLE
99.16 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	1.32	16.49
NA	38.38	1669.42
NA2O	0.0	0.0
K	0.36	9.21
K2O	0.0	0.0
MGO	0.24	5.95
CAO	2.18	38.87
SIO2	0.03	0.50
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.09	1664.32
SUBTOTAL	101.51 %	
MEASURED =	99.16	

HOLE # 7
DEPTH = 1957.5 FEET

INSOLUBLE
0.84 WT % OF TOTAL

WT %	MOLES
0.41	5.12
0.0	0.0
0.0	0.0
0.0	0.0
0.01	0.11
0.17	4.22
0.0	0.0
0.35	5.82
0.04	0.25
0.10	0.98
0.0	0.0
1.08 %	
0.84	

HOLE # 7
DEPTH = 1961.0 FEET

SOLUBLE
99.10 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.49	6.12
NA	39.14	1702.48
NA2O	0.0	0.0
K	0.21	5.37
K2O	0.01	0.11
MGO	0.07	1.74
CAO	0.19	3.39
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	58.83	1659.52
SUBTOTAL	98.95 %	
MEASURED =	99.10	

HOLE # 7
DEPTH = 1961.0 FEET

INSOLUBLE
0.90 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.01	0.11
0.18	4.47
0.0	0.0
0.42	6.99
0.04	0.25
0.08	0.78
0.0	0.0
0.73 %	
0.90	

HOLE # 7
DEPTH = 1967.0 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	3.03	37.85
NA	39.58	1721.62
NA2O	0.0	0.0
K	0.90	23.02
K2O	0.0	0.0
MGO	0.23	5.71
CAO	0.94	16.76
SIO2	0.0	0.0
FE2O3	0.01	0.06
AL2O3	0.0	0.0
CL	58.74	1656.98

HOLE # 7
DEPTH = 1969.0 FEET

SOLUBLE
98.05 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.32	4.00
NA	38.76	1685.95
NA2O	0.0	0.0
K	0.08	2.05
K2O	0.0	0.0
MGO	0.11	2.73
CAO	0.08	1.43
[illegible] 2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	60.60	1709.45
SUBTOTAL	99.96 %	
MEASURED =	98.05	

HOLE # 7
DEPTH = 1969.0 FEET

INSOLUBLE
1.95 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.11	2.73
0.0	0.0
0.14	2.33
0.02	0.13
0.04	0.39
0.0	0.0
0.31 %	
1.95	

HOLE # 7
DEPTH = 1973.0 FEET

SOLUBLE
99.63 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.26	3.25
NA	38.46	1672.90
NA2O	0.0	0.0
K	0.06	1.53
K2O	0.0	0.0
MGO	0.13	3.23
CAO	0.06	1.07
SIO2	0.03	0.50
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.58	1680.68
SUBTOTAL	98.58 %	
MEASURED =	99.63	

HOLE # 7
DEPTH = 1973.0 FEET

INSOLUBLE
1.37 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.03	0.32
0.40	9.92
0.01	0.18
0.62	10.32
0.01	0.06
0.13	1.28
0.0	0.0
1.20 %	
1.37	

HOLE # 7
DEPTH = 1975.0 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	0.19	2.37
NA	38.73	1693.35
NA2O	0.0	0.0
K	0.06	1.53
K2O	0.0	0.0
MGO	0.07	1.74
CAO	0.09	1.60
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	60.38	1703.24

HOLE # 7
DEPTH = 1978.5 FEET

SOLUBLE
91.07 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	2.74	34.22
NA	32.52	1414.53
NA2O	0.0	0.0
K	0.44	11.25
K2O	0.0	0.0
MGO	0.37	9.18
CAO	0.96	17.12
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	51.89	1463.75
SUBTOTAL	88.92 %	
MEASURED =	91.07	

HOLE # 7
DEPTH = 1978.5 FEET

INSOLUBLE
8.93 WT % OF TOTAL

WT %	MOLES
0.08	1.00
0.0	0.0
1.96	31.62
0.0	0.0
0.13	1.38
2.25	55.82
0.02	0.36
2.89	48.09
0.37	2.32
1.06	10.40
0.0	0.0
8.76 %	
8.93	

HOLE # 7
DEPTH = 1983.0 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	1.11	13.86
NA	36.00	1565.90
NA2O	0.0	0.0
K	0.61	15.60
K2O	0.0	0.0
MGO	0.40	9.92
CAO	0.46	8.20
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.20	1669.96

HOLE # 7
DEPTH = 1986.5 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	0.17	2.12
NA	38.20	1661.59
NA2O	0.0	0.0
K	0.04	1.02
K2O	0.0	0.0
MGO	0.03	0.74
CAO	0.21	3.74
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	60.66	1711.14

HOLE # 7
DEPTH = 1993.5 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	2.96	36.97
NA	38.25	1663.77
NA2O	0.0	0.0
K	1.68	42.97
K2O	0.0	0.0
MGO	0.79	19.60
CAO	2.30	41.01
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	53.81	1517.91

HOLE # 7
DEPTH = 2537.0 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	46.62	582.31
NA	0.93	40.45
NA2O	4.93	79.54
K	0.90	23.02
K2O	0.0	0.0
MGO	13.02	323.00
CAO	4.37	77.92
SIO2	13.98	232.65
FE2O3	1.13	7.08
AL2O3	3.26	31.97
CL	2.63	74.19

HOLE # 7
DEPTH = 2703.0 FEET

SOLUBLE
98.97 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.73	9.12
NA	38.36	1668.55
NA2O	0.0	0.0
K	0.02	0.51
K2O	0.0	0.0
MGO	0.06	1.49
CAO	0.78	13.91
SIO2	0.04	0.67
FE2O3	0.01	0.06
AL2O3	0.0	0.0
CL	58.99	1661.21
SUBTOTAL	98.89 %	
MEASURED =	98.97	

HOLE # 7
DEPTH = 2703.0 FEET

INSOLUBLE
1.03 WT % OF TOTAL

WT %	MOLES
0.74	9.24
0.0	0.0
0.0	0.0
0.0	0.0
0.01	0.11
0.20	4.96
0.01	0.18
0.21	3.49
0.05	0.31
0.05	0.49
0.0	0.0
1.27 %	
1.03	

HOLE # 7
DEPTH = 2716.3 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	0.44	5.50
NA	39.44	1715.53
NA2O	0.0	0.0
K	0.01	0.26
K2O	0.0	0.0
MGO	0.01	0.25
CAO	0.18	3.21
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	61.00	1720.73

HOLE # 7
DEPTH = 2736.0 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	0.42	5.25
NA	39.75	1729.01
NA2O	0.0	0.0
K	0.01	0.26
K2O	0.0	0.0
MGO	0.06	1.49
CAO	0.51	9.09
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.88	1689.14

HOLE # 8
DEPTH = 1391.5 FEET

SOLUBLE
98.99 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	1.07	13.36
NA	39.34	1711.18
NA2O	0.0	0.0
K	0.31	7.93
K2O	0.0	0.0
MGO	0.21	5.21
CAO	0.52	9.27
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	58.07	1638.08
SUBTOTAL	99.52 %	
MEASURED =	98.99	

HOLE # 8
DEPTH = 1391.5 FEET

INSOLUBLE
1.01 WT % OF TOTAL

WT %	MOLES
0.07	0.87
0.0	0.0
0.0	0.0
0.0	0.0
0.02	0.21
0.06	1.49
0.01	0.18
0.39	6.49
0.27	1.69
0.10	0.98
0.0	0.0
0.92 %	
1.01	

HOLE # 8
DEPTH = 1495.3 FEET
TOTAL

COMPONENT	WT %	MOLE
SO3	1.12	13.99
NA	38.00	1652.89
NA2O	0.0	0.0
K	0.12	3.07
K2O	0.0	0.0
MGO	0.1[illegible]	3.23
CAO	1.62	28.89
SIO2	0.01	0. 7
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.97	1691.68

HOLE # 8
DEPTH = 1573.0 FEET

SOLUBLE
97.72 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	3.40	42.47
NA	34.63	1506.31
NA2O	0.0	0.0
K	0.18	4.60
K2O	0.0	0.0
MGO	1.65	40.93
CAO	0.29	5.17
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	54.11	1526.38
SUBTOTAL	94.26 %	
MEASURED =	97.72	

HOLE # 8
DEPTH = 1573.0 FEET

INSOLUBLE
2.28 WT % OF TOTAL

WT %	MOLES
1.1	21.36
0.0	0.0
0.0	0.0
0.0	0.0
0.02	0.21
0.06	1.49
0.16	2.85
0.02	0.33
0.0	0.0
0.01	0.10
0.0	0.0
1.98 %	
2.28	

HOLE # 6
DEPTH = 1652.0 FEET

SOLUBLE
48.61 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	19.80	247.31
NA	4.07	177.03
NA2O	0.0	0.0
K	18.59	475.45
K2O	0.0	0.0
MGO	4.12	102.21
CAO	0.19	3.39
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	7.34	207.33
SUBTOTAL	54.12 %	
MEASURED =	48.61	

HOLE # 8
DEPTH = 1652.0 FEET

INSOLUBLE
51.39 WT % OF TOTAL

WT %	MOLES
31.24	390.21
0.0	0.0
4.24	68.41
0.0	0.0
0.99	10.51
0.46	11.41
3.74	66.69
0.34	5.66
0.07	0.44
0.04	0.39
0.0	0.0
41.12 %	
51.39	

HOLE # 8
DEPTH = 1705.0 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	1.18	14.74
NA	38.79	1687.26
NA2O	0.0	0.0
K	0.35	8.95
K2O	0.0	0.0
MGO	0.17	4.22
CAO	0.44	7.85
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	56.64	1654.16

HOLE # 8
DEPTH = 1770.0 FEET

SOLUBLE
98.79 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	1.78	22.23
NA	35.75	1555.02
NA2O	0.0	0.0
K	0.56	14.32
K2O	0.0	0.0
MGO	0.52	12.90
CAO	1.75	31.21
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.29	1616.08
SUBTOTAL	97.66 %	
MEASURED =	98.79	

HOLE # 8
DEPTH = 1770.0 FEET

INSOLUBLE
1.21 WT % OF TOTAL

WT %	MOLES
0.17	2.12
0.0	0.0
0.33	5.32
0.0	0.0
0.02	0.21
0.03	0.74
0.0	0.0
0.47	7.82
0.0	0.0
0.12	1.18
0.0	0.0
1.14 %	
1.21	

HOLE # 8
DEPTH = 1787.0 FEET

SOLUBLE
99.43 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	3.01	37.60
NA	37.24	1619.84
NA2O	0.0	0.0
K	0.69	17.65
K2O	0.0	0.0
MGO	0.40	9.92
CAO	0.70	12.48
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	58.00	1636.11
SUBTOTAL	100.05 %	
MEASURED =	99.43	

HOLE # 3
DEPTH = 1787.0 FEET

INSOLUBLE
0.57 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.01	0.11
0.14	3.47
0.0	0.0
0.21	3.49
0.03	0.19
0.04	0.39
0.0	0.0
0.43 %	
0.57	

HOLE # 8
DEPTH = 1794.5 FEET

SOLUBLE
75.34 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.70	8.74
NA	29.75	1294.04
NA2O	0.0	0.0
	0.42	10.74
K2O	0.0	0.0
MGO	0.44	10.92
CAO	0.03	0.53
SIO2	0.02	0.33
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	45.14	1273.54
SUBTOTAL	76.50 %	
MEASURED =	75.34	

HOLE # 8
DEPTH = 1794.5 FEET

INSOLUBLE
24.66 WT % OF TOTAL

WT %	MOLES
0	0.0
0.0	0.0
1.16	18.72
0.0	0.0
0.63	6.69
6.20	153.81
0.01	0.18
7.78	129.47
0.46	2.68
1.91	18.73
0.0	0.0
18.15 %	
24.66	

HOLE # 8
DEPTH = 1804.0 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	0.28	3.50
NA	39.43	1715.09
NA2O	0.0	0.0
K	0.06	1.53
K2O	0.0	0.0
MGO	0.04	0.99
CAO	0.70	12.48
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.94	1690.83

HOLE # 8
DEPTH = 1829.0 FEET

SOLUBLE
99.03 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.02	0.25
NA	39.87	1734.23
NA2O	0.0	0.0
K	0.05	1.28
K2O	0.0	0.0
MGO	0.06	1.49
CAO	0.01	0.18
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	58.81	1658.96
SUBTOTAL	98.83 %	
MEASURED =	99.03	

HOLE # 8
DEPTH = 1829.0 FEET

INSOLUBLE
0.97 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.02	0.21
0.23	5.71
0.01	0.18
0.29	4.83
0.04	0.25
0.08	0.78
0.0	0.0
0.67 %	
0.97	

HOLE # 8
DEPTH = 1838.0 FEET

SOLUBLE
97.53 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.80	9.99
NA	37.58	1634.62
NA2O	0.0	0.0
K	0.26	6.65
K2O	0.0	0.0
MGO	0.11	2.73
CAO	0.05	0.89
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	58.38	1646.83
SUBTOTAL	97.19 %	
MEASURED =	97.53	

HOLE # 8
DEPTH = 1838.0 FEET

INSOLUBLE
2.47 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.10	1.06
0.37	9.18
0.0	0.0
0.12	2.00
0.16	1.00
0.27	2.65
0.0	0.0
1.02 %	
2.47	

HOLE # 8
DEPTH = 1856.7 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	2.70	33.72
NA	36.08	1569.38
NA2O	0.0	0.0
K	1.62	41.43
K2O	0.0	0.0
MGO	0.03	0.74
CAO	1.56	27.82
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	56.66	1598.31

HOLE # 8
DEPTH = 1875.0 FEET

SOLUBLE
70.94 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.42	5.25
NA	25.64	1115.27
NA2O	0.0	0.0
K	0.31	7.93
K2O	0.0	0.0
MGO	0.33	8.19
CAO	0.43	7.67
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	40.92	1154.30
SUBTOTAL	68.06 %	
MEASURED =	70.94	

HOLE # 8
DEPTH = 1875.0 FEET

INSOLUBLE
29.06 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
2.28	24.20
9.22	228.73
0.20	3.57
15.29	254.45
1.23	7.70
3.00	29.42
0.0	0.0
31.22 %	
29.06	

HOLE # 8
DEPTH = 1884.0 FEET

SOLUBLE
80.58 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	3.76	46.96
NA	27.10	1178.77
NA2O	0.0	0.0
K	6.98	178.52
K2O	0.0	0.0
MGO	1.44	35.72
CAO	1.65	29.42
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	44.06	1242.88
SUBTOTAL	85.00 %	
MEASURED =	80.58	

HOLE # 8
DEPTH = 1884.0 FEET

INSOLUBLE
19.42 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
1.80	19.11
3.65	90.55
0.01	0.18
9.01	149.94
0.60	3.76
1.99	19.52
0.0	0.0
17.06 %	
19.42	

HOLE # 8
DEPTH = 1890.0 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	0.77	9.62
NA	38.78	1686.82
NA2O	0.0	0.0
K	0.10	2.56
K2O	0.0	0.0
MGO	0.10	2.48
CAO	0.95	16.94
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.33	1673.62

HOLE # 8
DEPTH = 1894.3 FEET

SOLUBLE
95.43 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.12	1.50
NA	37.90	1648.54
NA2O	0.0	0.0
K	0.06	1.53
K2O	0.0	0.0
MGO	0.08	1.98
CAO	0.03	0.53
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.78	1629.90
SUBTOTAL	95.97 %	
MEASURED =	95.43	

HOLE # 8
DEPTH = 1894.3 FEET

INSOLUBLE
4.57 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.13	1.38
0.66	16.37
0.0	0.0
2.43	40.44
0.20	1.25
0.43	4.22
0.0	0.0
3.85 %	
4.57	

HOLE # 8
DEPTH = 1898.5 FEET

SOLUBLE
96.53 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.55	6.87
NA	38.81	1688.13
NA2O	0.0	0.0
K	0.07	1.79
K2O	0.0	0.0
MGO	0.08	1.96
CAO	0.11	1.96
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.97	1635.26
SUBTOTAL	97.60 %	
MEASURED =	98.53	

HOLE # 8
DEPTH = 1898.5 FEET

INSOLUBLE
1.47 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.71	11.46
0.0	0.0
0.01	0.11
0.18	4.47
0.01	0.18
0.44	7.32
0.02	0.13
0.07	0.69
0.0	0.0
1.44 %	
1.47	

HOLE # 8
DEPTH = 1900.0 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	3.20	39.97
NA	38.14	1658.98
NA2O	0.0	0.0
K	0.98	25.06
K2O	0.0	0.0
MGO	0.47	11.66
CAO	0.39	6.95
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.60	1624.82

HOLE # 8
DEPTH = 1905.0 FEET

SOLUBLE
96.98 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.26	2.50
NA	38.67	1682.04
NA2O	0.0	0.0
K	0.13	3.32
K2O	0.0	0.0
MGO	0.10	2.48
CAO	0.44	7.85
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.31	1633.57
SUBTOTAL	97.45 %	
MEASURED =	96.98	

HOLE # 8
DEPTH = 1905.0 FEET

INSOLUBLE
3.02 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.03	0.32
0.83	20.59
0.01	0.18
0.91	15.14
0.14	0.88
0.25	2.45
0.0	0.0
2.17 %	
3.02	

HOLE # 8
DEPTH = 1910.0 FEET

SOLUBLE
99.02 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.53	6.62
NA	39.64	1724.23
NA2O	0.0	0.0
K	0.0	0.0
K2O	0.29	3.08
MGO	0.10	2.48
CAO	0.44	7.85
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.04	1665.44
SUBTOTAL	100.05 %	
MEASURED =	99.02	

HOLE # 8
DEPTH = 1910.0 FEET

INSOLUBLES
0.98 % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.01	0.11
0.20	4.96
0.0	0.0
0.33	5.49
0.04	0.25
0.08	0.78
0.0	0.0
0.66 %	
0.98	

HOLE # 8
DEPTH = 1913.1 FEET

SOLUBLE
97.71 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.06	0.75
NA	38.48	1673.77
NA2O	0.0	0.0
K	0.06	1.53
K2O	0.0	0.0
MGO	0.06	1.49
CAO	0.0	0.0
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.27	1671.93
SUBTOTAL	97.94 %	
MEASURED =	97.71	

HOLE # 8
DEPTH = 1913.1 FEET

INSOLUBLE
2.29 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.05	0.53
0.48	11.91
0.0	0.0
0.90	14.98
0.13	0.81
0.21	2.06
0.0	0.0
1.77 %	
2.29	

HOLE # 8
DEPTH = 1916.2 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	0.92	11.49
NA	38.48	1673.77
NA2O	0.0	0.0
K	0.21	5.37
K2O	0.0	0.0
MGO	0.13	3.23
CAO	0.44	7.85
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.71	1627.93

HOLE # 8
DEPTH = 1923.0 FEET

SOLUBLE
98.30 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.10	1.25
NA	38.03	1654.20
NA2O	0.0	0.0
K	0.05	1.28
K2O	0.0	0.0
MGO	0.05	1.24
CAO	0.08	1.43
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	58.43	1648.24
SUBTOTAL	96.75 %	
MEASURED =	98.30	

HOLE # 8
DEPTH = 1923.0 FEET

INSOLUBLE
1.70 WT % OF TOTAL

WT %	MOLES
0.95	11.87
0.0	0.0
0.0	0.0
0.0	0.0
0.08	0.85
0.03	0.74
0.12	2.14
0.59	9.82
0.10	0.63
0.16	1.57
0.0	0.0
2.03 %	
1.70	

HOLE # 8
DEPTH = 1930.0 FEET

SOLUBLE
96.99 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	2.81	35.10
NA	35.71	1553.28
NA2O	0.0	0.0
K	1.03	26.34
K2O	0.0	0.0
MGO	0.33	8.19
CAO	0.19	3.39
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	56.74	1600.56
SUBTOTAL	96.81 %	
MEASURED =	98.99	

HOLE # 8
DEPTH = 1930.0 FEET

INSOLUBLE
1.01 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.08	1.29
0.0	0.0
0.01	0.11
0.13	3.23
0.01	0.18
0.18	3.00
0.07	0.44
0.04	0.39
0.0	0.0
0.52 %	
1.01	

HOLE # B
DEPTH = 1933.0 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	0.78	9.74
NA	38.03	1654.20
NA2O	0.0	0.0
K	0.15	3.84
K2O	0.0	0.0
MGO	0.09	3.23
CAO	0.65	11.59
SIO2	0.01	0.17
FE2O3	0.01	0.06
AL2O3	0.0	0.0
CL	59.81	1687.17

HOLE # 8
DEPTH = 1938.0 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	2.91	36.35
NA	35.63	1549.80
NA2O	0.0	0.0
K	0.68	17.39
K2O	0.0	0.0
MGO	0.84	20.84
CAO	1.02	18.19
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.45	1677.01

HOLE # 8
DEPTH = 1953.2 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	2.30	28.73
NA	39.50	1718.14
NA2O	0.0	0.0
K	0.30	7.67
K2O	0.0	0.0
MGO	0.42	10.42
CAO	1.23	21.93
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.63	1625.67

HOLE # 8
DEPTH = 1967.0 FEET

SOLUBLE
95.13 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	1.25	15.61
NA	35.99	1565.46
NA2O	0.0	0.0
K	0.57	14.58
K2O	0.0	0.0
MGO	0.23	5.71
CAO	0.40	7.13
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.52	1622.57
SUBTOTAL	95.96 %	
MEASURED =	95.13	

HOLE # 8
DEPTH = 1967.0 FEET

INSOLUBLE
4.87 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
2.73	44.05
0.0	0.0
0.09	0.96
0.98	24.31
0.0	0.0
0.76	12.65
0.10	0.63
0.20	1.96
0.0	0.0
4.86 %	
4.87	

HOLE # 8
DEPTH = 1986.0 FEET

SOLUBLE
36.72 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	22.99	287.16
NA	0.36	15.66
NA2O	0.0	0.0
K	0.0	0.0
K2O	14.68	155.84
MGO	0.62	15.38
CAO	0.87	15.51
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	0.15	4.23
SUBTOTAL	39.67 %	
MEASURED =	36.72	

HOLE # 8
DEPTH = 1986.0 FEET

INSOLUBLE
63.28 WT % OF TOTAL

WT %	MOLES
37.88	473.15
0.0	0.0
5.83	94.06
0.0	0.0
11.39	120.91
1.20	29.77
4.25	75.78
0.54	8.99
0.17	1.66
0.85	6.34
0.0	0.0
62.11 %	
63.28	

HOLE # 8
DEPTH = 2006.0 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	2.37	29.60
NA	37.5[illegible]	1635.06
NA2O	0.0	0.0
K	1.03	26.34
K2O	0.0	0.0
MGO	0.31	7.69
CAO	0.06	1.07
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.17	1612.69

HOLE # 8
DEPTH = 2017.0 FEET

SOLUBLE
95.20 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.55	6.87
NA	35.66	1551.11
NA2O	0.0	0.0
K	0.06	1.53
K2O	0.0	0.0
MGO	0.08	1.98
CAO	0.96	17.12
SIO2	0.02	0.33
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.09	1610.44
SUBTOTAL	94.42 %	
MEASURED =	95.20	

HOLE # 8
DEPTH = 2017.0 FEET

INSOLUBLE
4.80 WT % OF TOTAL

WT %	MOLES
0.07	0.87
0.0	0.0
0.0	0.0
0.0	0.0
0.04	0.42
0.44	10.92
0.06	1.07
2.01	33.45
0.28	1.75
0.70	6.87
0.0	0.0
3.60 %	
4.80	

HOLE # 8
DEPTH = 2039.0 FEET

SOLUBLE
98.94 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	4.88	60.95
NA	35.02	1523.27
NA2O	0.0	0.0
K	1.56	39.90
K2O	0.0	0.0
MGO	0.50	12.40
CAO	1.57	28.00
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	54.01	1523.55
SUBTOTAL	97.54 %	
MEASURED =	98.94	

HOLE # 8
DEPTH = 2039.0 FEET

INSOLUBLE
1.06 WT % OF TOTAL

WT %	MOLES
0.62	7.74
0.0	0.0
0.0	0.0
0.0	0.0
0.03	0.32
0.21	5.21
0.01	0.18
0.26	4.33
0.07	0.44
0.05	0.49
0.0	0.0
1.25 %	
1.06	

HOLE # 8
DEPTH = 2050.0 FEET

SOLUBLE
28.61 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	3.92	46.96
NA	8.00	347.98
NA2O	0.0	0.0
K	0.05	1.28
K2O	0.0	0.0
MGO	0.02	0.50
CAO	0.55	9.81
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	12.44	350.92
SUBTOTAL	24.98 %	
MEASURED =	28.61	

HOLE # 8
DEPTH = 2050.0 FEET

INSOLUBLE
71.39 WT % OF TOTAL

WT %	MOLES
51.08	638.02
0.0	0.0
4.90	79.06
0.0	0.0
0.04	0.42
0.29	7.19
6.55	116.80
0.33	5.49
0.0	0.0
0.0	0.0
0.0	0.0
63.19 %	
71.39	

HOLE # 8
DEPTH = 2068.0 FEET

SOLUBLE
98.84 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	2.49	31.10
NA	37.41	1627.23
NA2O	0.0	0.0
K	0.08	2.05
K2O	0.0	0.0
MGO	0.03	0.74
CAO	0.87	15.51
SIO2	0.02	0.33
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	55.99	1579.41
SUBTOTAL	96.89 %	
MEASURED =	98.84	

HOLE # 8
DEPTH = 2068.0 FEET

INSOLUBLE
1.16 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.01	0.11
0.28	6.95
0.02	0.36
0.37	6.16
0.05	0.31
0.07	0.69
0.0	0.0
0.80 %	
1.16	

HOLE # 8
DEPTH = 2064.0 FEET

SOLUBLE
92.00 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	2.45	25.61
NA	34.46	1498.91
NA2O	0.0	0.0
K	1.02	26.09
K2O	0.0	0.0
MGO	0.35	8.68
CAO	0.72	12.84
SIO2	0.01	0.17
FE2O3	0.01	0.06
AL2O3	0.0	0.0
CL	52.19	1472.21
SUBTOTAL	90.81 %	
MEASURED =	92.00	

HOLE # 8
DEPTH = 2064.0 FEET

INSOLUBLE
8.00 WT % OF TOTAL

WT %	MOLES
0.59	7.37
0.0	0.0
1.87	30.17
0.0	0.0
0.19	2.02
1.13	28.03
0.01	0.18
2.07	34.45
0.24	1.50
0.37	3.63
0.0	0.0
6.47 %	
8.00	

HOLE # 8
DEPTH = 2130.0 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	2.31	28.85
NA	37.79	1643.76
NA2O	0.0	0.0
K	0.42	10.74
K2O	0.0	0.0
MGO	0.25	6.20
CAO	0.75	13.37
SIO2	0.03	0.50
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.16	1612.41

HOLE # 8
DEPTH = 2162.0 FEET

SOLUBLE
98.90 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	1.31	16.36
NA	36.77	1599.39
NA2O	0.0	0.0
K	1.23	31.46
K2O	0.0	0.0
MGO	0.45	11.16
CAO	0.93	16.58
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.99	1692.24
SUBTOTAL	100.68 %	
MEASURED =	98.90	

HOLE # 8
DEPTH = 2162.0 FEET

INSOLUBLE
1.10 WT % OF TOTAL

WT %	MOLES
0.25	3.12
0.0	0.0
0.55	8.87
0.0	0.0
0.03	0.32
0.20	4.96
0.01	0.18
0.23	3.83
0.06	0.38
0.05	0.49
0.0	0.0
1.38 %	
1.10	

HOLE # 8
DEPTH = 2217.0 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	0.0	0.0
NA	39.14	1702.48
NA2O	0.0	0.0
K	0.07	1.79
K2O	0.0	0.0
MGO	0.02	0.50
CAO	0.12	2.14
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.75	1685.47

HOLE # 8
DEPTH = 2280.0 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	0.39	4.87
NA	37.91	1648.98
NA2O	0.0	0.0
K	0.12	3.07
K2O	0.0	0.0
MGO	0.09	2.23
CAO	0.25	4.46
SIO2	0.02	0.33
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	60.23	1699.01

HOLE # 8
DEPTH = 2326.0 FEET

INSOLUBLE
4.56 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.0	0.0
NA	0.0	0.0
NA2O	0.0	0.0
K	0.0	0.0
K2O	0.03	0.32
MGO	1.31	32.50
CAO	0.03	0.53
SIO2	1.14	18.97
FE2O3	0.12	0.75
AL2O3	0.25	2.45
CL	0.0	0.0
SUBTOTAL	2.88 %	
MEASURED =	4.56	

HOLE # 8
DEPTH = 2366.3 FEET

SOLUBLE
31.37 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	16.19	202.22
NA	0.62	26.97
NA2O	0.0	0.0
K	0.0	0.0
K2O	7.47	79.30
MGO	2.77	68.72
CAO	0.16	2.85
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	1.17	33.00
SUBTOTAL	28.39 %	
MEASURED =	31.37	

HOLE # 8
DEPTH = 2366.3 FEET

INSOLUBLE
68.63 WT % OF TOTAL

WT %	MOLES
31.13	388.83
0.0	0.0
3.76	60.66
0.0	0.0
3.19	33.85
3.63	90.05
3.21	57.24
10.67	177.57
0.01	0.06
1.57	15.40
0.0	0.0
57.17 %	
68.63	

HOLE # 8
DEPTH = 2427.5 FEET

SOLUBLE
99.36 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	2.2	27.73
NA	39.42	1714.66
NA2O	0.0	0.0
K	0.01	0.26
K2O	0.0	0.0
MGO	0.01	0.25
CAO	0.31	5.53
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.88	1689.14
SUBTOTAL	101.85 %	
MEASURED =	99.36	

HOLE # 8
DEPTH = 2427.5 FEET

INSOLUBLE
0.64 WT % OF TOTAL

WT %	MOLES
0.36	4.50
0.0	0.0
0.0	0.0
0.0	0.0
0.01	0.11
0.04	0.99
0.04	0.71
0.09	1.50
0.01	0.06
0.01	0.10
0.0	0.0
0.56 %	
0.64	

HOLE # 8
DEPTH = 2460.0 FEET

SOLUBLE
99.21 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	1.14	14.24
NA	38.75	1685.52
NA2O	0.0	0.0
K	0.03	0.77
K2O	0.0	0.0
MGO	0.03	0.74
CAO	0.62	11.06
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	57.00	1607.90
SUBTOTAL	97.57 %	
MEASURED =	99.21	

HOLE # 8
DEPTH = 2460.0 FEET

INSOLUBLE
0.79 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.01	0.11
0.17	4.22
0.0	0.0
0.19	3.16
0.03	0.19
0.06	0.59
0.0	0.0
0.46 %	
0.79	

HOLE # 8
DEPTH = 2519.6 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	0.17	2.12
NA	40.42	1758.16
NA2O	0.0	0.0
K	0.02	0.51
K2O	0.0	0.0
MGO	0.01	0.25
CAO	0.03	0.53
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	60.31	1701.27

HOLE # 8
DEPTH = 2563.0 FEET

SOLUBLE
7.11 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	1.49	18.61
NA	1.47	63.94
NA2O	0.0	0.0
K	0.05	1.28
K2O	0.0	0.0
MGO	0.07	1.74
CAO	0.60	10.70
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	1.05	29.62
SUBTOTAL	4.73 %	
MEASURED =	7.11	

HOLE # 8
DEPTH = 2563.0 FEET

INSOLUBLE
92.89 WT % OF TOTAL

WT %	MOLES
39.10	488.38
0.0	0.0
6.06	97.77
0.0	0.0
0.54	5.73
14.66	363.68
23.77	423.86
6.25	104.01
0.96	6.01
1.86	18.24
0.0	0.0
93.20 %	
92.89	

HOLE # 8
DEPTH = 2615.5 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	0.86	10.74
NA	38.58	1678.12
NA2O	0.0	0.0
K	0.05	1.28
K2O	0.0	0.0
MGO	0.02	0.50
CAO	0.58	10.34
SIO2	0.0	0.0
FE2O3	0.01	0.06
AL2O3	0.0	0.0
CL	59.37	1674.75

HOLE # 8
DEPTH = 2665.5 FEET

SOLUBLE
99.08 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	0.98	12.24
NA	38.66	1682.47
NA2O	0.0	0.0
K	0.02	0.51
K2O	0.0	0.0
MGO	0.01	0.25
CAO	0.35	6.24
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.14	1668.27
SUBTOTAL	99.19 %	
MEASURED =	99.08	

HOLE # 8
DEPTH = 2665.5 FEET

INSOLUBLE
0.92 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.01	0.11
0.21	5.21
0.01	0.18
0.22	3.66
0.04	0.25
0.06	0.59
0.0	0.0
0.55 %	
0.92	

HOLE # 8
DEPTH = 2706.0 FEET

SOLUBLE
98.75 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	1.12	13.99
NA	37.09	1613.31
NA2O	0.0	0.0
K	0.03	0.77
K2O	0.0	0.0
MGO	0.01	0.25
CAO	0.68	12.13
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	58.60	1653.03
SUBTOTAL	97.54 %	
MEASURED =	98.75	

HOLE # 8
DEPTH = 2706.0 FEET

INSOLUBLE
1.25 WT % OF TOTAL

WT %	MOLES
0.01	0.12
0.0	0.0
0.64	18.33
0.0	0.0
0.03	0.32
0.18	4.47
0.0	0.0
0.27	4.49
0.27	1.69
0.07	0.69
0.0	0.0
1.47 %	
1.25	

HOLE # 8
DEPTH = 2758.0 FEET

SOLUBLE
99.22 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	1.70	21.23
NA	37.20	1618.10
NA2O	0.0	0.0
K	0.08	2.05
K2O	0.0	0.0
MGO	0.01	0.25
CAO	1.14	20.33
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	58.07	1638.08
SUBTOTAL	98.20 %	
MEASURED =	99.22	

HOLE # 8
DEPTH = 2758.0 FEET

INSOLUBLE
0.78 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.83	13.39
0.0	0.0
0.01	0.11
0.17	4.22
0.0	0.0
0.06	1.00
0.01	0.06
0.02	0.20
0.0	0.0
1.10 %	
0.78	

HOLE # 8
DEPTH = 2779.0 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	1.09	13.61
NA	37.41	1627.23
NA2O	0.0	0.0
K	0.01	0.26
K2O	0.0	0.0
MGO	0.03	0.74
CAO	1.80	[illegible].10
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	58.53	1651.06

HOLE # 8
DEPTH = 2794.0 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	0.99	12.37
NA	37.86	1646.80
NA2O	0.0	0.0
K	0.02	0.51
K2O	0.0	0.0
MGO	0.01	0.25
CAO	0.68	12.13
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	60.58	1708.89

HOLE # 8
DEPTH = 2802.5 FEET
TOTAL

COMPONENT	WT %	MOLES
SO3	1.76	21.98
NA	38.39	1669.86
NA2O	0.0	0.0
K	0.02	0.51
K2O	0.0	0.0
MGO	0.01	0.25
CAO	0.22	3.92
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	58.19	1641.47

HOLE # 8
DEPTH = 2809.0 FEET

SOLUBLE
99.09 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	2.02	25.23
NA	38.56	1677.25
NA2O	0.0	0.0
K	0.01	0.26
K2O	0.0	0.0
MGO	0.01	0.25
CAO	0.96	17.12
SIO2	0.0	0.0
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	59.70	1684.06
SUBTOTAL	101.26 %	
MEASURED =	99.09	

HOLE # 8
DEPTH = 2809.0 FEET

INSOLUBLE
0.91 WT % OF TOTAL

WT %	MOLES
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.01	0.11
0.03	0.74
0.13	2.32
0.04	0.67
0.0	0.0
0.01	0.10
0.0	0.0
0.22 %	
0.91	

HOLE # 8
DEPTH = 2820.5 FEET

SOLUBLE
99.46 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	1.30	16.24
NA	38.42	1671.16
NA2O	0.0	0.0
K	0.01	0.26
K2O	0.0	0.0
MGO	0.01	0.25
CAO	0.10	1.78
SIO2	0.03	0.50
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	58.50	1650.21
SUBTOTAL	98.37 %	
MEASURED =	99.46	

HOLE # 6
DEPTH = 2820.5 FEET

INSOLUBLE
0.54 WT % OF TOTAL

WT %	MOLES
0.37	4.62
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.01	0.25
0.19	3.39
0.03	0.50
0.0	0.0
0.0	0.0
0.0	0.0
0.60 %	
0.54	

HOLE # 8
DEPTH = 2879.0 FEET

SOLUBLE
96.41 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	2.17	27.10
NA	32.65	1420.18
NA2O	0.0	0.0
K	0.02	0.51
K2O	0.0	0.0
MGO	0.01	0.25
CAO	0.59	10.52
SIO2	0.02	0.33
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	55.79	1573.77
SUBTOTAL	91.25 %	
MEASURED =	96.41	

HOLE # 8
DEPTH = 2879.0 FEET

INSOLUBLE
3.59 WT % OF TOTAL

WT %	MOLES
1.97	24.61
0.0	0.0
0.93	15.00
0.0	0.0
0.01	0.11
0.12	2.98
0.95	16.94
0.12	2.00
0.01	0.06
0.01	0.10
0.0	0.0
4.12 %	
3.59	

HOLE # 8
DEPTH = 2948.0 FEET

SOLUBLE
97.32 WT % OF TOTAL

COMPONENT	WT %	MOLES
SO3	3.41	42.59
NA	37.30	1622.45
NA2O	0.0	0.0
K	0.01	0.26
K2O	0.0	0.0
MGO	0.01	0.25
CAO	0.54	9.63
SIO2	0.01	0.17
FE2O3	0.0	0.0
AL2O3	0.0	0.0
CL	55.51	1565.87
SUBTOTAL	96.79 %	
MEASURED =	97.32	

HOLE # 8
DEPTH = 2948.0 FEET

INSOLUBLE
2.68 WT % OF TOTAL

WT %	MOLES
1.92	23.98
0.0	0.0
0.0	0.0
0.0	0.0
0.01	0.11
0.02	0.50
0.25	4.46
0.05	0.83
0.01	0.06
0.0	0.0
0.0	0.0
2.26 %	
2.68	

Appendix 7.C (Ref. sec. 7.4)

Selected x-ray diffraction traces of EDTA-insoluble residues from the ERDA-9 core.

I-2. MB-CS-42: Serpentine and saponite; the sharp maxima at 12.2 and 24.5°2θ are basal spacings of serpentine's 7Å periodicity. The broad peak at 7.25°2θ (air-dried) becomes a broad weak shoulder at ~5°2θ upon glycol saturation and is saponite.

A. <2μm EDTA-insoluble residue, air-dried.
B. Bulk EDTA-insoluble residue, glycol-saturated.

I-3. MB-CS-15: Talc and smectite (saponite); sharp peaks at 9.5 and 28.5°2θ are basal spacings of talc's 9.5Å periodicity; they do not shift with glycol-saturation. The broad low-angle peak again is saponite; accessory amounts of serpentine also present.

A. <2μm EDTA-insoluble residue, air-dried.
B. Bulk EDTA-insoluble residue, glycol-saturated.

I-4. MB-CS-17: Regularly interstratified mixed-layer chlorite-saponite (corrensite); distinct strong superlattice reflection at 2.9°2θ (air-dried) which expands to 2.7°2θ with glycol-saturation. The peak at 6.4°2θ (air-dried) expands to 5.6°2θ.

A. <2μm EDTA-insoluble residue, air-dried.
B. <2μm EDTA-insoluble residue, glycol-saturated.

I-5. JL-CS-9: Randomly interstratified mixed-layer chlorite-saponite; air-dried peak at 6.1°2θ expands to 5.5°2θ with glycol saturation. Illite (8.7, 17.6, and 26.6°2θ), minor serpentine (12.3 and 13.1°2θ), and minor feldspar (27.4°2θ) also present.

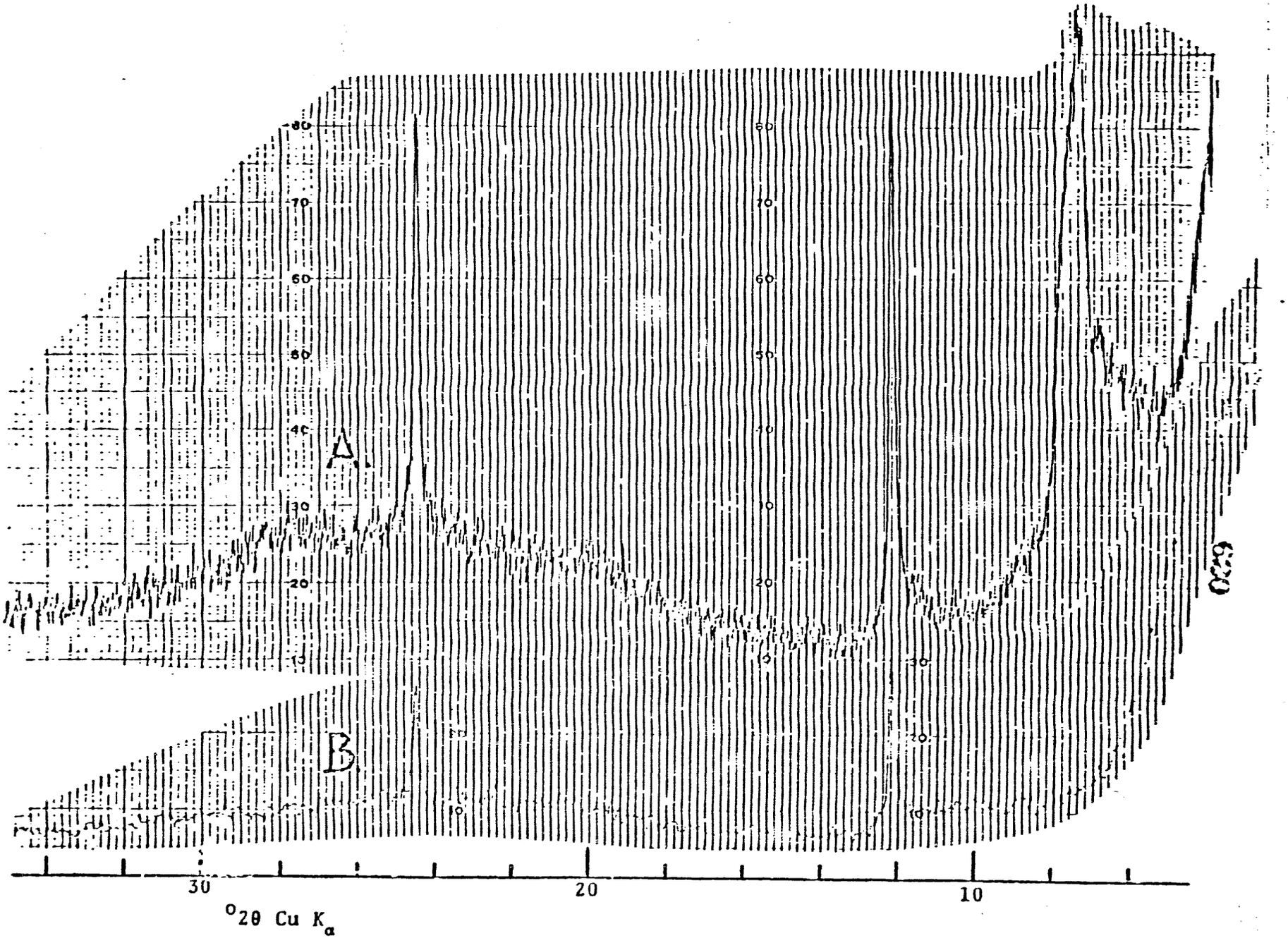
A. <2μm EDTA-insoluble residue, air-dried.
B. <2μm EDTA-insoluble residue, glycol-saturated.

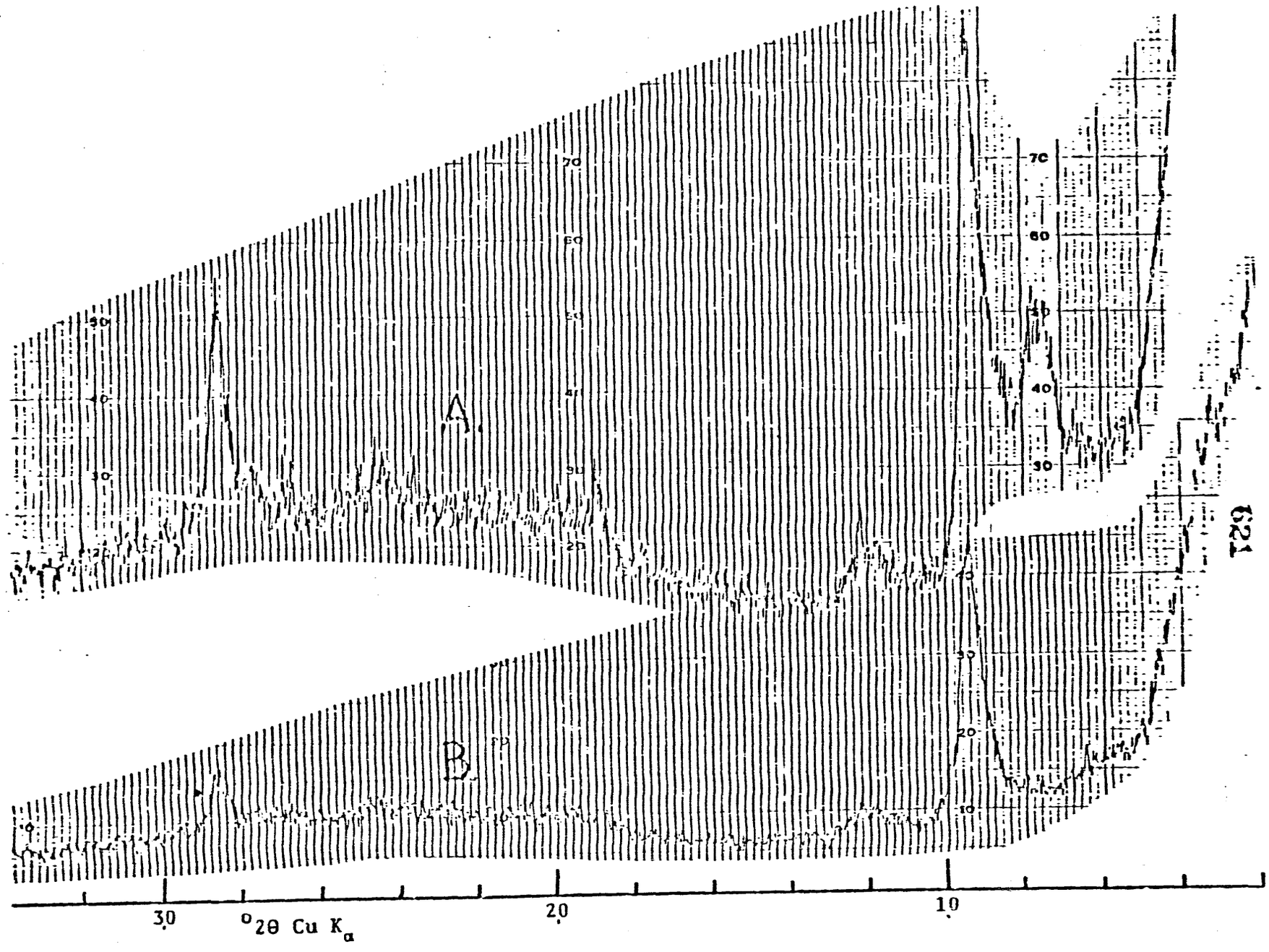
I-6. MB-CS-13: Saponite; reflections at 6.1 and 27.3°2θ which expand to 5.2° 2θ upon glycol saturation. A small quantity of a regularly interstratified mixed-layer clay (small superlattice peak at 2.4°2θ) also present.

A. <2μm EDTA-insoluble residue, air-dried.
B. <2μm EDTA-insoluble residue, glycol saturated.

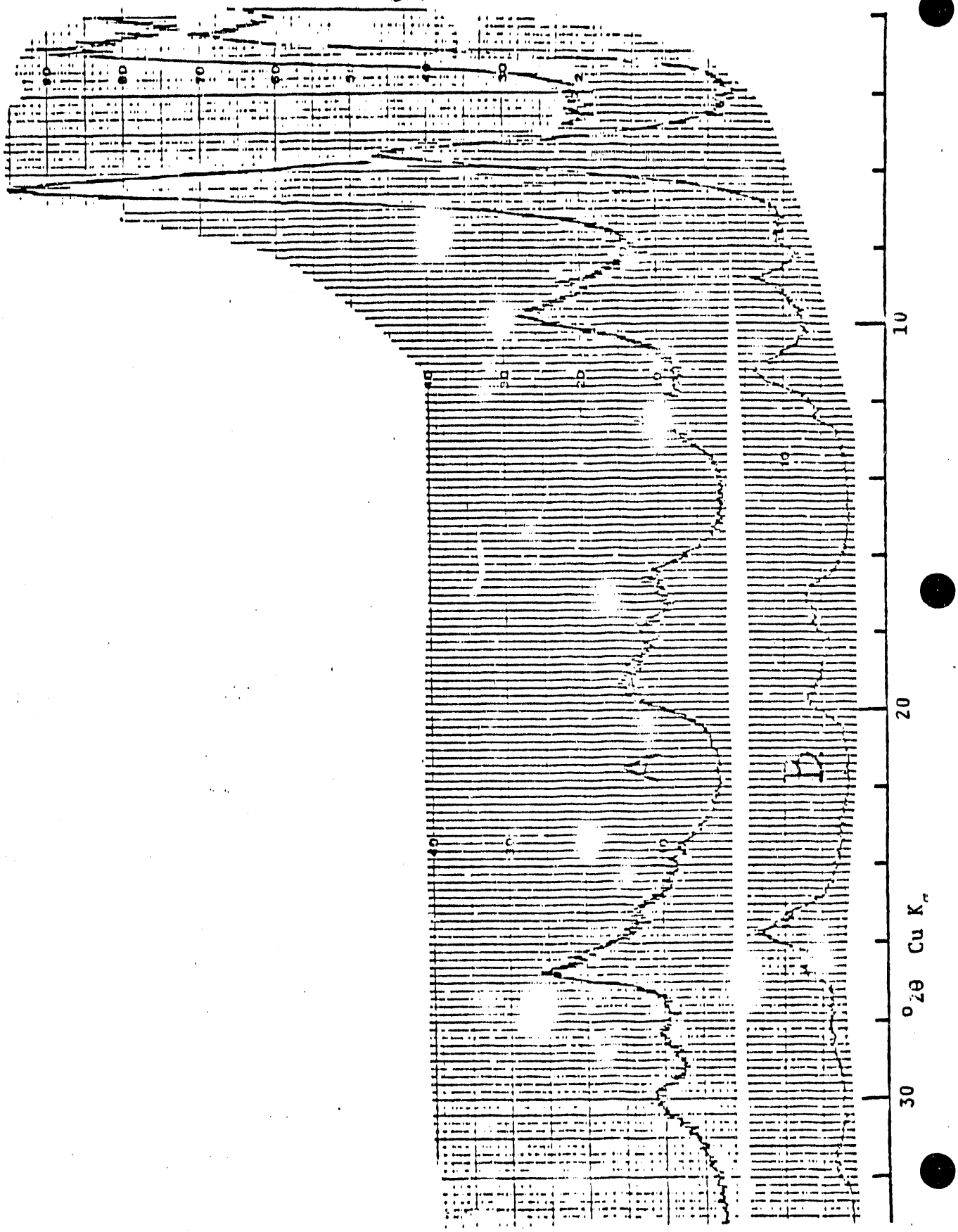
I-7. JL-CS-2: Randomly interstratified mixed-layer clay, either talc-saponite or illite-saponite; single strong maximum at 8.6°2θ becomes pronounced doublet at 9.6 and 7.6°2θ with glycol saturation.

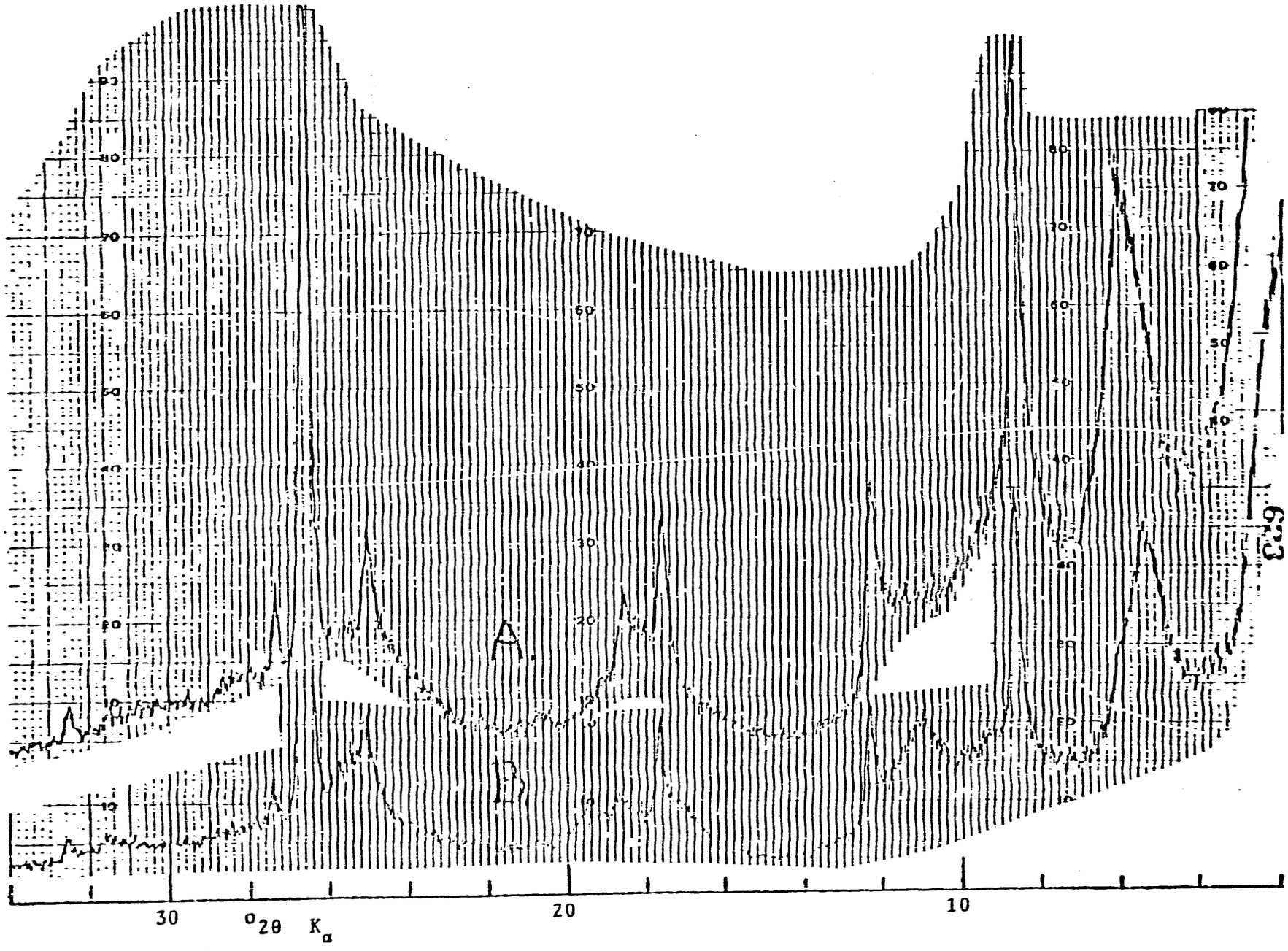
A. <2μm EDTA-insoluble residue, air-dried.
B. <2μm EDTA-insoluble residue, glycol-saturated.

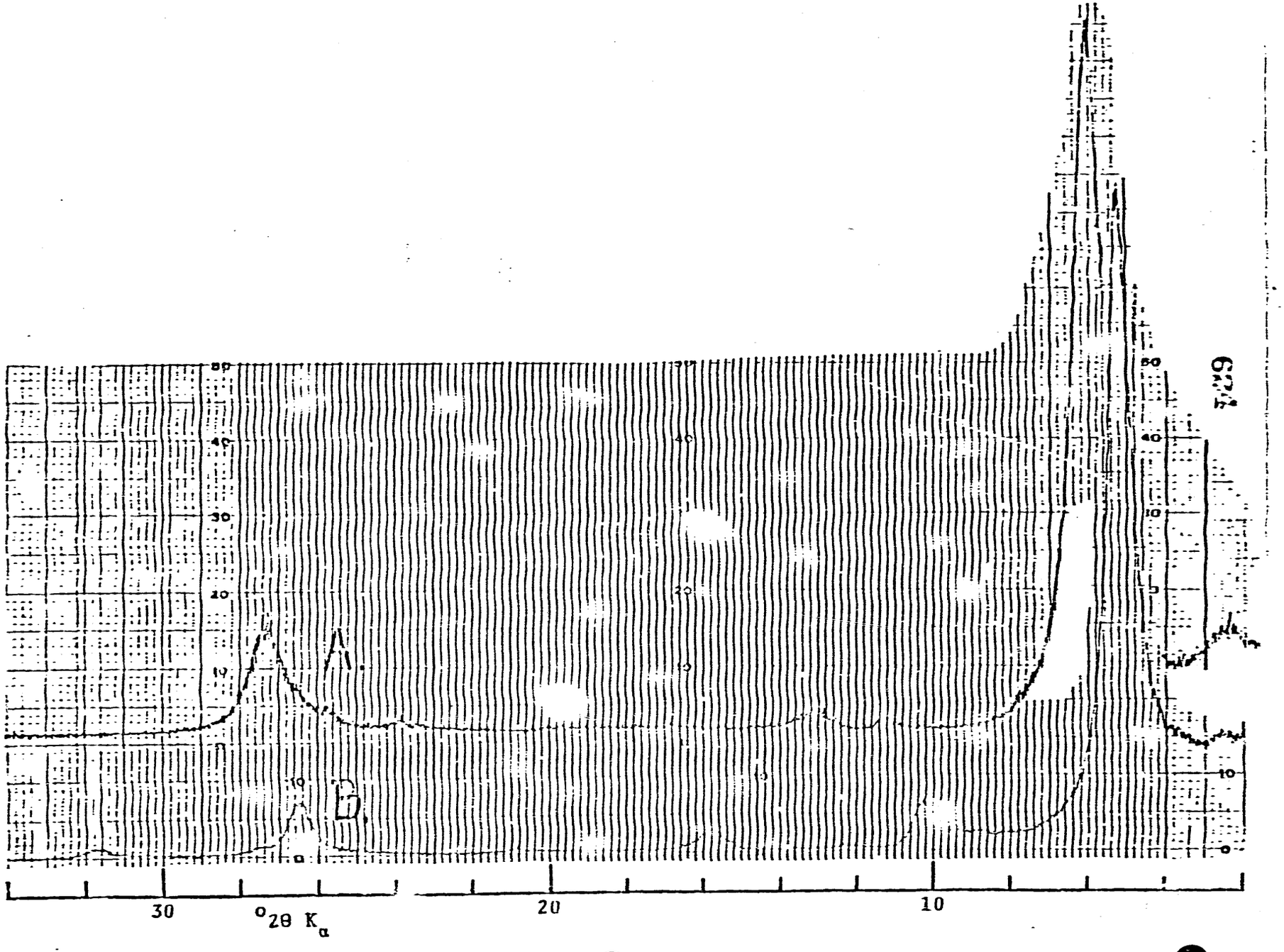

A
B
30
20
10
°2θ Cu K_α

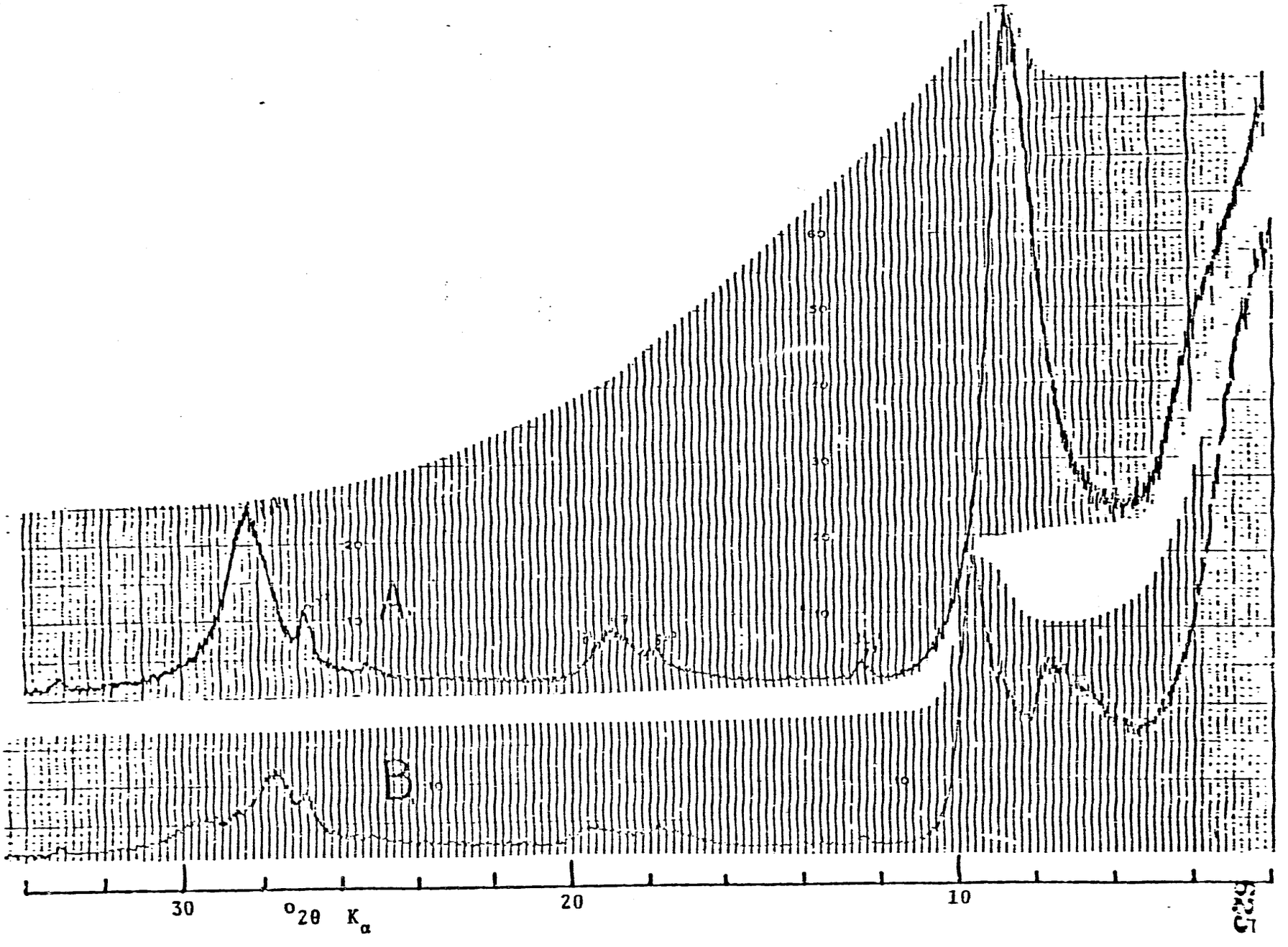


621


10
20
30
°2θ Cu K


30
$^{o}2\theta$ K_{α}
20
10
A
623


A
B
30
$^{o}2\theta$ K_{α}
20
10


A
B
30
20
10
$^{o}2\theta$ K_{α}

APPENDIX 7.b (Ref. sec. 7.4)

Core Footage (Sandia Core Photo #), Informal Lithology and Detailed Macroscopic Core Description

FI in left column indicates abundant fluid inclusions.

† just to left of right column indicates description incorporates stratigraphic variation within that interval.

Abbreviations and Meanings used in Core Description (right column)

anhy or anhyd	anhydrite
ave	average
brwn	brown
dom	dominant
fg	fine grained or finely crystalline
inc	increasing
irreg	irregular
L	length
lams	laminae or laminations
lite or lt	light
loc	local or locally
max	maximum
repl	replacement
struc	structure
thk	thick or thickness
W	Width
w/	with
Xtals or Xtalline	crystals or crystalline
μX	microcrystalline

Core Footage (Sandia Photo #)	Informal Lithology	Macroscopic (aided by binocular microscope) Core Description
1162.7 (27) 1163.7	Halite	lite brwn, clear, anhedral Xtals (1cm), sharp Xtal boundaries of halite minor 1-4mm thk, lenses of lite gray, μX, anhydrite rimmed with polyhalite
1165.2 (28) 1166.6	Anhydrite w/ halite "crystal growth"	dominantly gray, μX anhydrite w/ slight color banding (gray-lite gray) with: lenses (1/2 to 1 cm thk.) of brown, clear to opaque, poorly defined anhedral Xtals. of halite layers (1 to 4 cm thk) of vertically elongate (L/W=2 to 3, L=2mm to 3 1/2 cm), locally swallow-tail, Xtals of halite
1167.3 (28) 1168	Banded Anhydrite	banding of dominantly gray, μX anhydrite laminae (5-10mm thk) with white, thin (<1mm) laminae of μX magnesite locally a few anhedral (some swallow tail) Xtals of halite, locally vertically elongate or radiating
1168 (29) 1168.25	Anhydrite	similar to 1165.2 - 1166.6 but including laminae (~1mm thick) of magnesite
1168.25 (29) 1169.9	brick-red Polyhalite and Halite	dominantly anhedral (rare euhedral) 1/2 cm Xtals of halite, clear to cloudy with red, μX polyhalite between and in halite crystals
1172.6 (30) 1173.5	Banded Polyhalite	prominant banding but mineralogy obscure - "brown mineral" typically opaque, microcrystalline or massive halite, orange to orange brown poorly bounded anhedra ~1/2 cm - silty claystone or anhydrite? locally contorted banding

Core Footage (Sandia Note #)	Informal Lithology	Macroscopic (aided by binocular microscope) Core Description
1173.5 (31) 1174.7	Halite	halite - clear to red, anhedral Xtals (ave 1/2 cm, max 2 cm) red from polyhalite stain; minor anhydrite
1404.7 (103) 1405.7	11th ore zone (leonite, kainite?)	polyhalite (± halite?) white & cloudy to blood red, massive w/ irreg. patches of dark gray claystone and irreg patches of pale yellow mineral (kainite-leonite?) massive patches a: both vertically and horizontally elongate
1418 (106-107) 1418.8	Marker Bed 117, polyhalite plus mud	dominantly massive red polyhalite (w/ microscopic granular texture) laminations 1/2 to 1 1/2 cm thk alternating w/ clay laminae (<2mm thk) which are black & wavy [near 1418 - claystone w/ poor horizontal fissility plus "brown mineral" which looks like halite but has bitter taste]
1584 (160) 1584.9	5th ore zone, very dirty	dominantly halite - clear anhedra ~1 cm (max 2 cm) locally stained by "brown mineral" μXtalline coatings & locally patche. a few mm in size; minor patches of gray μX anhydrite
1609.1 (168) 1610.3	Clear Halite (~2 ft above polyhalite)	dominantly halite - brwn (due to polyhalite stain?) indistinct anhedral about 1 1/2 cm; minor evenly dispersed polyhalite stain, and [illegible]s (~2mm) of gray material (anhydrite or clay?)
1632 (175) 1632.8	Mudstone	near top: banded anhydrite - claystone; anhydrite dark gray, μX - laminae up to 2mm thk, locally vertically elongate masses or Xtals; claystone lite grey, laminae from 1/2mm to 1/2 cm (th[illegible]c. upward) near base: polyhalite w/ gray clay

Core Footage (Sandia Photo #)	Informal Lithology	Macroscopic (aided by binocular microscope) Core Description
1648.5 (180-181) 1649.7	4th ore zone kelite, bloedite, vanthoffite	dominantly halite - lite brown anhedra ~3/4 cm locally red, μXtal polyhalite as stain & repl. of halite - some lenses and Xtal coatings of gray μX anhydrite?
2034.3 2037.3	Halite	† dominantly halite: finely crystalline & clayey near top - coarsely crystalline & banded anhydrite &/or polyhalite near center - finely crystalline & banded † w/ anhydrite near base
2065.2 2067.6	Halite	dominantly coarsely Xtalline (~2 cm) clear, anhedral halite w/ patches, lenses & stains of "brown material" (polyhalite, carnallite, glauberite?) loc w/ radiating acicular texture
2301.6 (384) 2302.7	lite colored Polyhalite	dominantly red, μX polyhalite - locally crinkly flakes & irreg. patches of white fg. material
2413.6 FI (418-41°) 2415.7	pure & impure Polyhalite	† dominantly poorly thickly banded polyhalite w/ sub-equal lenses of anhydrite & halite polyhalite: pinkish brown to red, μX halite: med. to coarsely Xtal, usually anhedral but some euhedra, typically clear anhydrite: layers, lenses and interXtalline patches, † gray, μX, locally brown
2512 (450) 2512.5	dirty Halite	dominantly halite-gray, clear to cloudy, anhedral, 1 cm Xtal; minor light gray anhydrite as interXtalline patches
2515.o (452+) 2519.2	typical massive Cowden Anhy.	† (halite above 2516.9) faintly banded gray, μX, anhydrite w/ wispy lenses of magnesite † very minor halite

Core Footage (Sandia Photo #)	Informal Lithology	Macroscopic (aided by binocular microscope) Core Description
2527.7 (456+) 2529.2	typical laminated Cowden Anhy.	laminations of gray, μX, anhydrite - lam up to 1 1/2 cm (some needle like & loc radiating into magnesite) white, opaque μX magnesite lams, wavy, <1mm to 3mm thk
2538.5 (459) 2539.4	base of Cowden Anhy.	top: faintly banded (color) μX anhydrite, minor patches of halite † dominantly, coarsely Xtalline (~1 cm) clear, anhedral halite w/ lenses of interXtalline anhydrite base: similar to above but halite Xtal size decreases to ~1mm
2541 (460) 2542.5	dirty halite just below Cowden	dominantly halite - gray, clear to cloudy, anhedral Xtals (ave 1 cm, <1mm to 3 cm) minor anhydrite (or magnesite?) - interXtalline patches (1 or 2 cm by 2mm)
2606.5 2608.8	Halite	dominantly halite - typically clear but some cloudy, white to gray anhedra typically ~1 cm but three 3 cm thk zones of ave size ~2mm which tend to be gray; minor anhydrite - interXtalline gray, μX
2614.7 2615.6	Halite	dom. halite - clear white euhedra & subhedra, most anhedra, ave 2 cm (<1mm to 4 cm); minor anhydrite - lt gray to white, μX, interXtalline
2615.9 FT 2619.5	Halite	† 15.9 - 16.5 dom halite - clear, white to gray, anhedra, ave 2 cm (1/2 - 6 cm) w/ v minor gray-white, μX, interXtalline anhyd or magnesite 16.5 - 18.4 dom halite - clear to cloudy, white to gray anhedra, ave 1 cm (<1mm - 2 cm) locally "chevron struc" within (& across) Xtals w/ minor gray-white, μX, interXtalline anhyd or magnesite † 18.4 - 19.5 similar to 15.9 - 16.5

Core Footage (Sandia Photo #)	Informal Lithology	Macroscopic (aided by binocular microscope) Core Description
(2705.7) 2704.8 (509) (2706.8) 2706.5	mottled Anhy & Halite	dominantly halite - coarsely Xtalline (1 to 1 1/2 cm) anhedral, clear to white cloudy cut at ~45° by zones more finely Xtalline halite and mixed w/ up to 30% interXtalline gray, μX, anhydrite (w/ minor magnesite)
2758 (526) 2759.3	dirty Halite	dom halite - light to dk gray, anhedra, ave ~1 cm (<1mm to 3 cm) w/ minor anhydrite - dk gray, μX (but some microlites) as interXtall material
2819.1 (545) 2819.8	clean Halite, slightly banded	dom halite - cloudy, white to lt. gray, anhedral; faint banding by ave Xtal size variation from 1/2 to 1 cm, finer Xtalline tends to be whiter; minor thin horizontal lenses (rare patches), white, μX (rare microlites)
2819.9 (545) 2820.9A	see above	dom anhydrite - lt gray to dk gray (locally banded), μX; subordinate halite - irreg lenses & patches (frequently thin & horiz elongate) unusually sharp contacts between anhydrite & halite
2820 B (545-546) 2820.6B	see above	same as 19.9 - 20.9A except anhydrite locally brown and may contain magnesite
2820.6B (546) 2821.9	see above	dom halite - cloudy, white, anhedral, ave 1 cm (<1mm to 2 cm); very rare lense of wh to lt gray, μX anhydrite possibly w/ magnesite
[illegible].5 2827.5	dirty Halite	dom halite - poorly developed banding from clear, to cloudy white, to opaque dk gray, anhedral crystals ave 1/2 - 1 cm some magnesite (or anhydrite) - thin irreg seams & wavy lams (both horiz), white, μX

Core Footage (Sandia Photo #)	Informal Lithology	Macroscopic (aided by binocular microscope) Core Description
2845.6	massive light Anhydrite (in Castile)	dom anhydrite - mottled from clear to white & cloudy to gray to dk gray
2846.4		sub. magnesite - thin seams and irreg patches, µX
2847.8	banded light Anhydrite	dom anhydrite - banded from clear, to white & cloudy, to gray to dk gray, to black; clear tends to occur in laminae & lenses, locally "enterolithic" contortions and w/ smooth lower contacts & irreg "swallow-tail" upper contacts; subordinate magnesite
2849.1		

Appendix 7.E (Ref. sec. 7.5)

Gas Chromatograms and Mass Spectra
of Volatiles from Selected Samples
of Core from ERDA No. 9

Mass spectra are reported as intensity (normalized to the highest mass peak) as a function of mass/charge ratio (in atomic mass units).
Gas chromatograms are reported as intensity of elution peaks (normalized to the highest elution peak) as a function of relative elution time (in arbitrary units).

SALT SAMPLE 2302.6

TOTAL ION CHROMATOGRAM X6

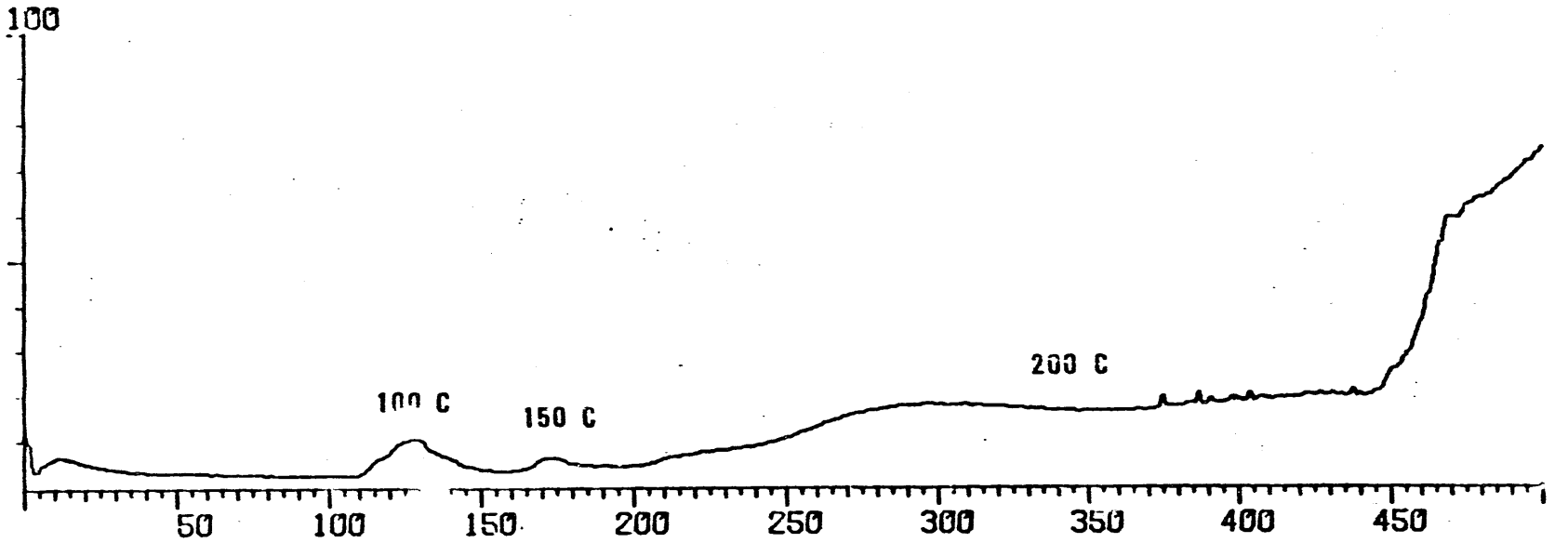
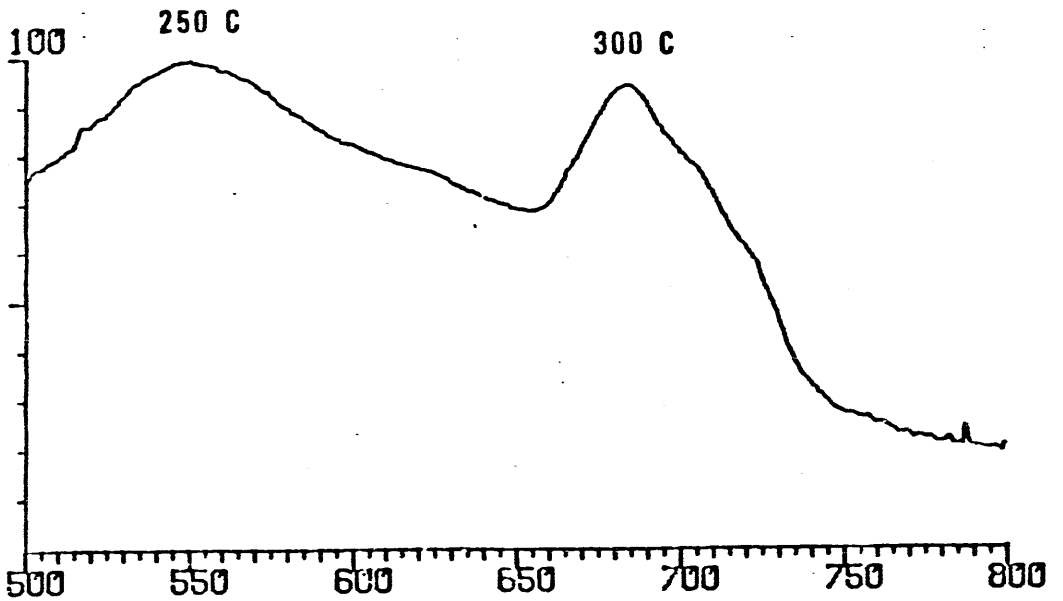
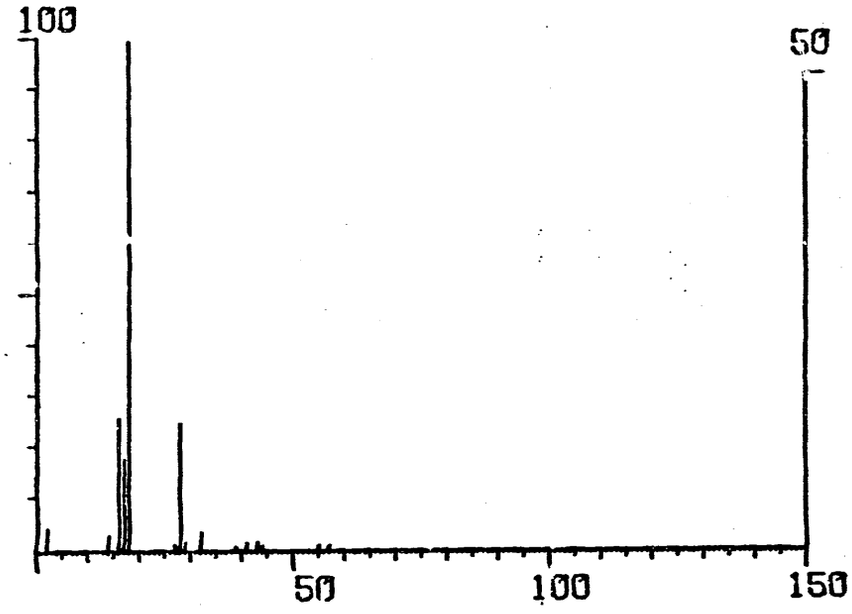


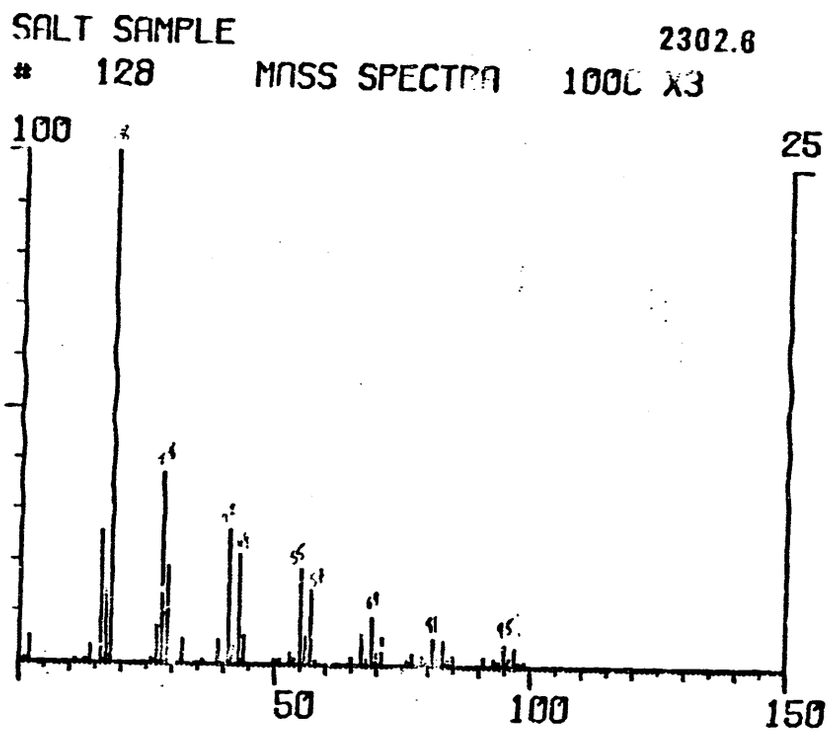
Fig 9



SALT SAMPLE 2302.6

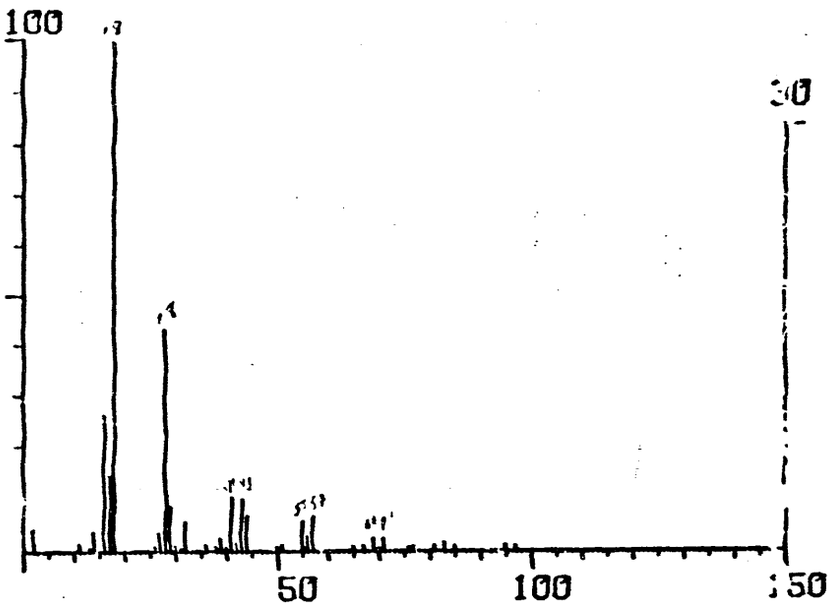
* 12 MASS SPECTRA 50C X3

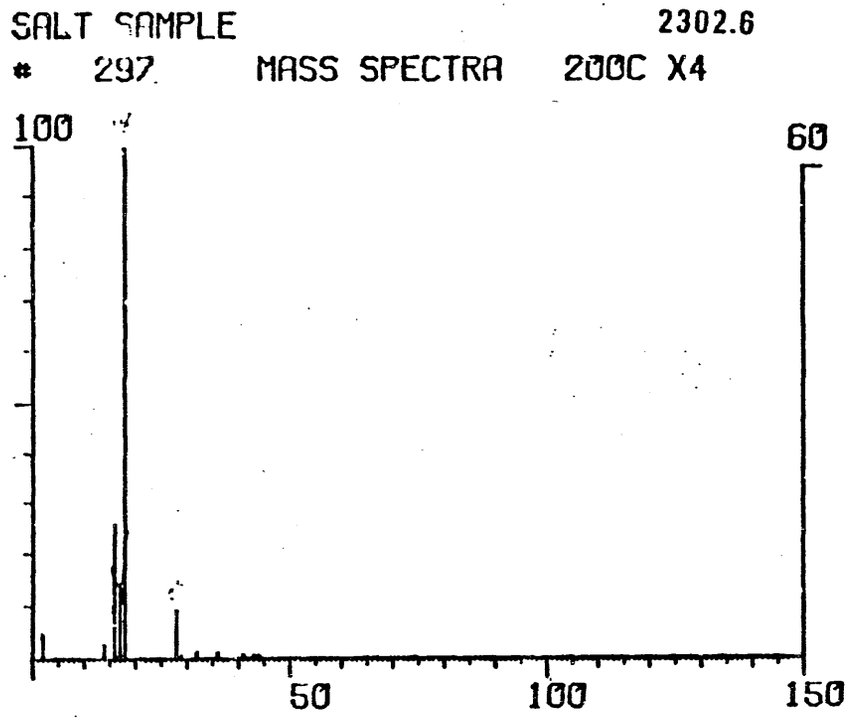



SALT SAMPLE
2302.6
128 MASS SPECTRA 100C X3
100
25
50
100
150

SALT SAMPLE 2302.6

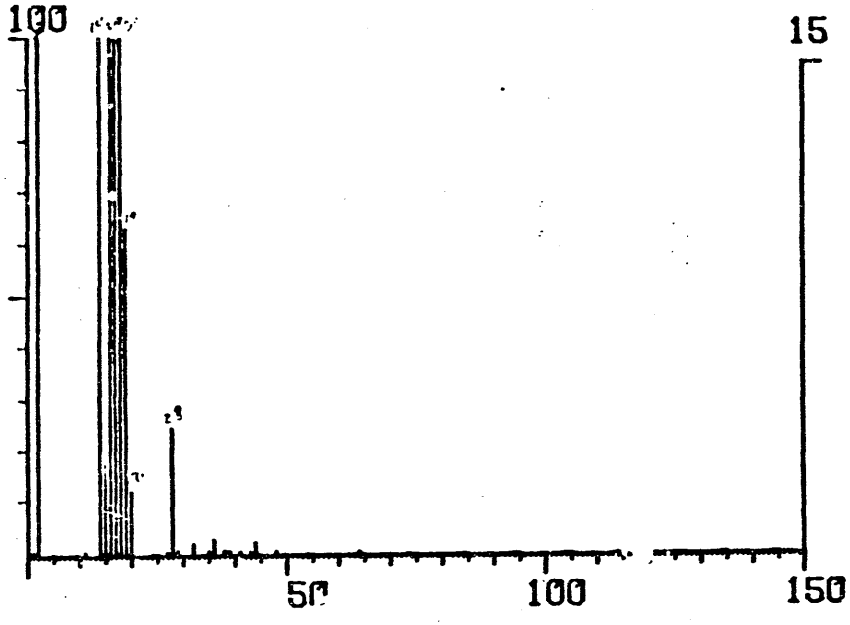
174 MASS SPECTRA 150C X3

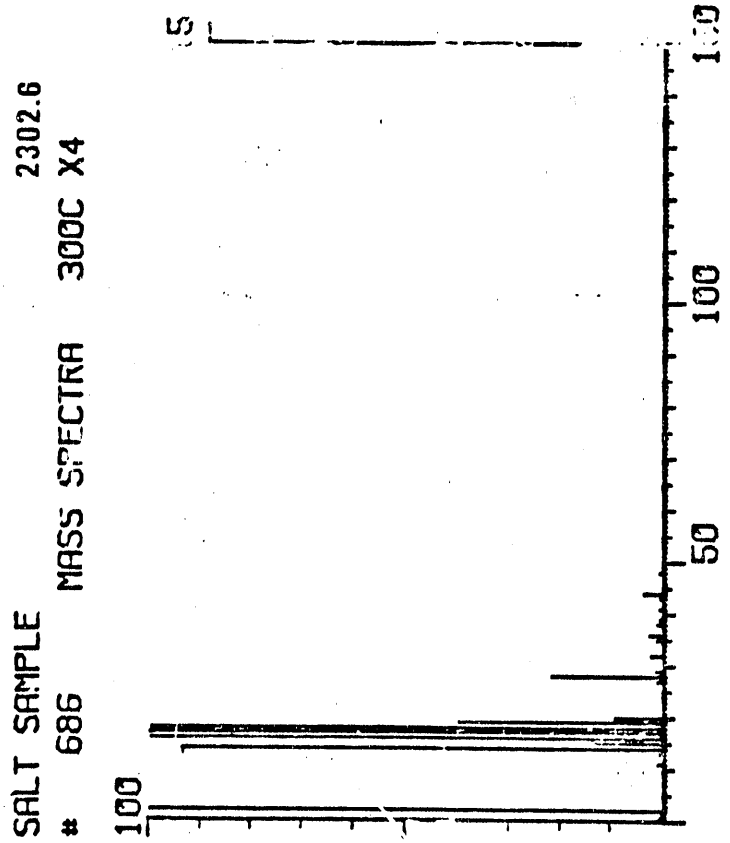



SALT SAMPLE
2302.6
297 MASS SPECTRA 200C X4
100
60
50
100
150

SALT SAMPLE 2302.6

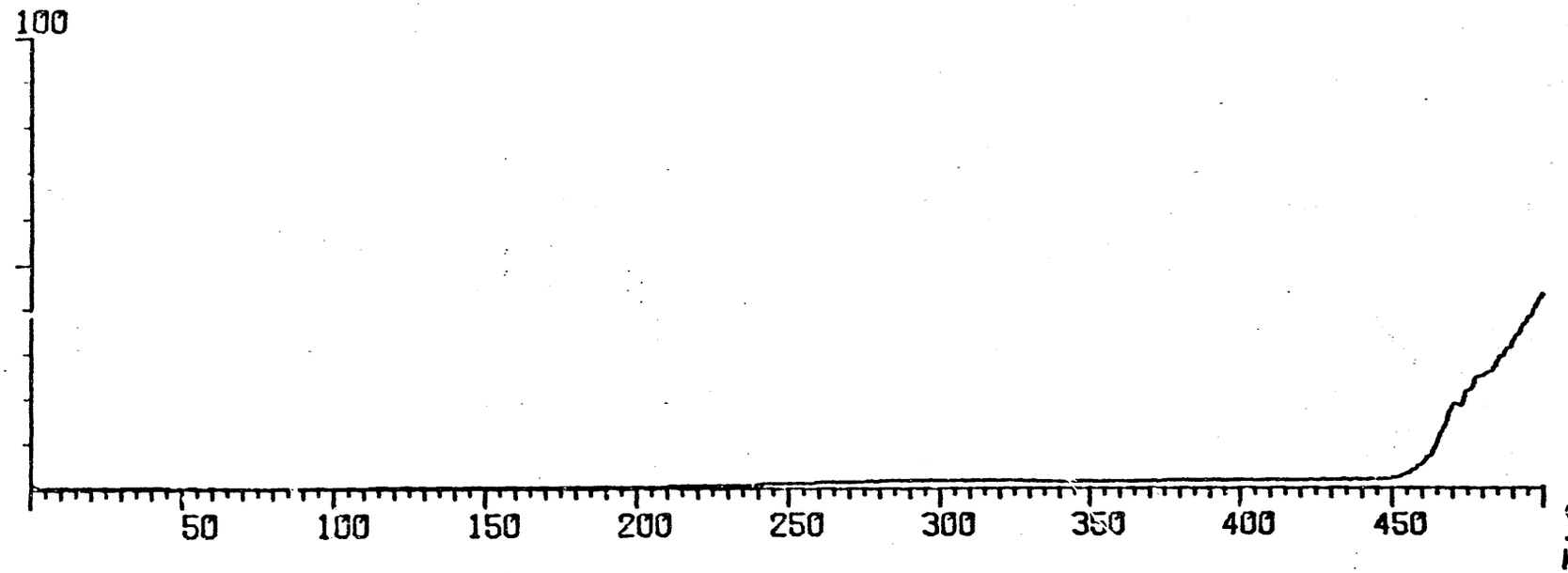
550 MASS SPECTRA 250C X4




SALT SAMPLE
686 MASS SPECTRA 300C X4
2302.6
100
50
100

SALT SAMPLE 2302.6

MASS 14 SEARCH X5



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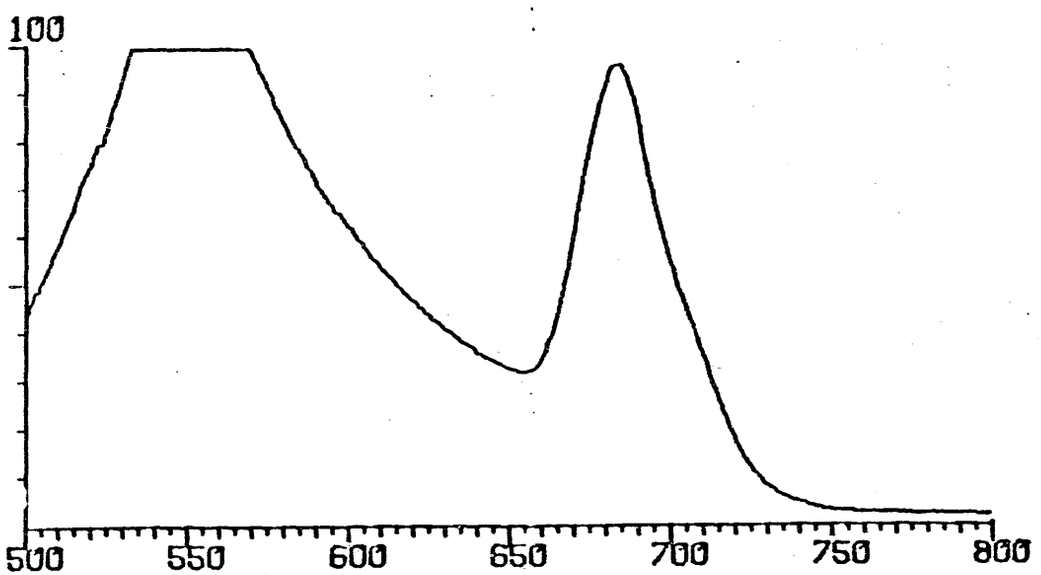
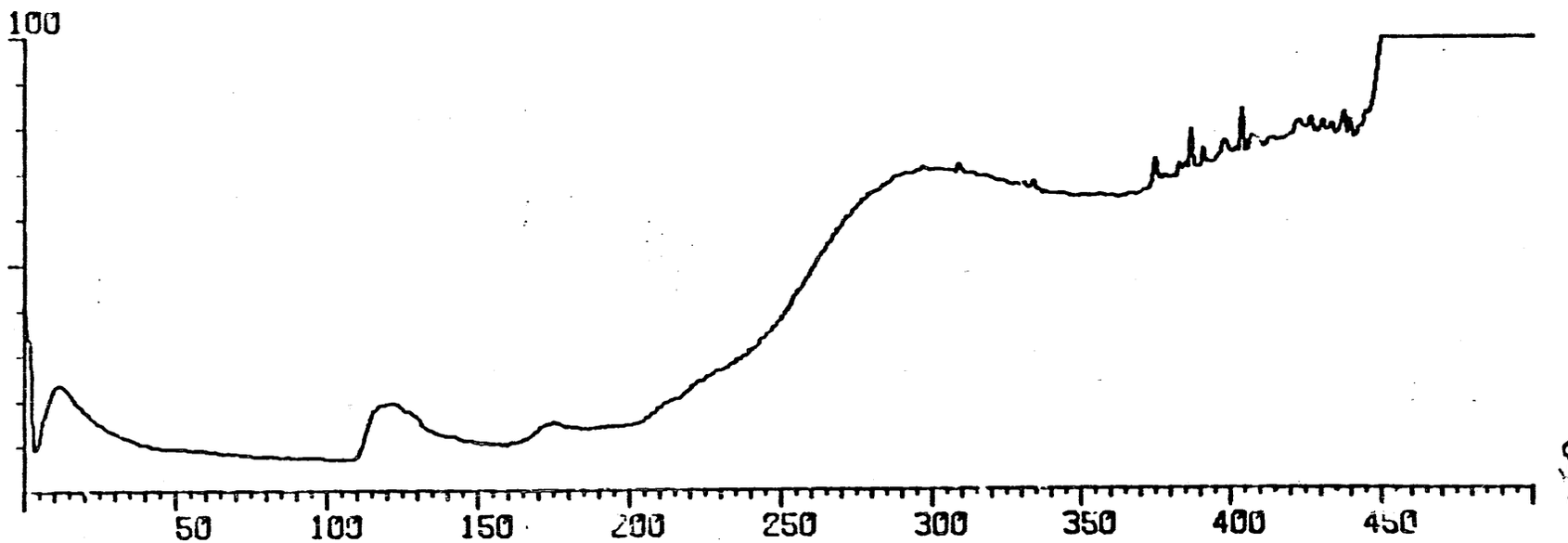
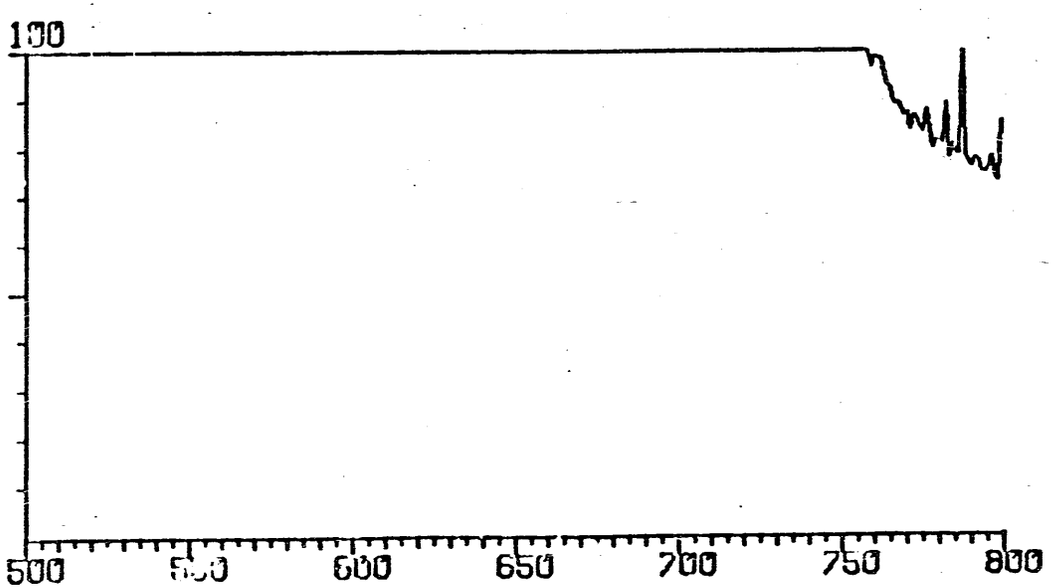


SALT SAMPLE 2302.6

MASS 18 SEARCH X4

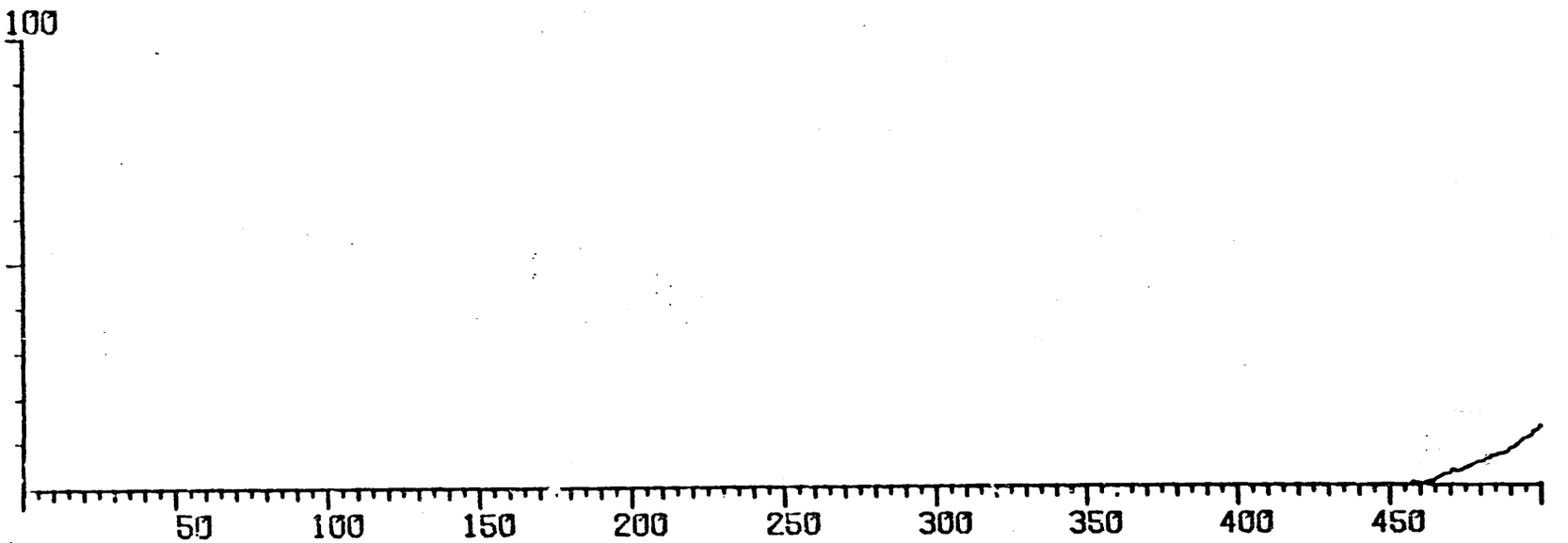


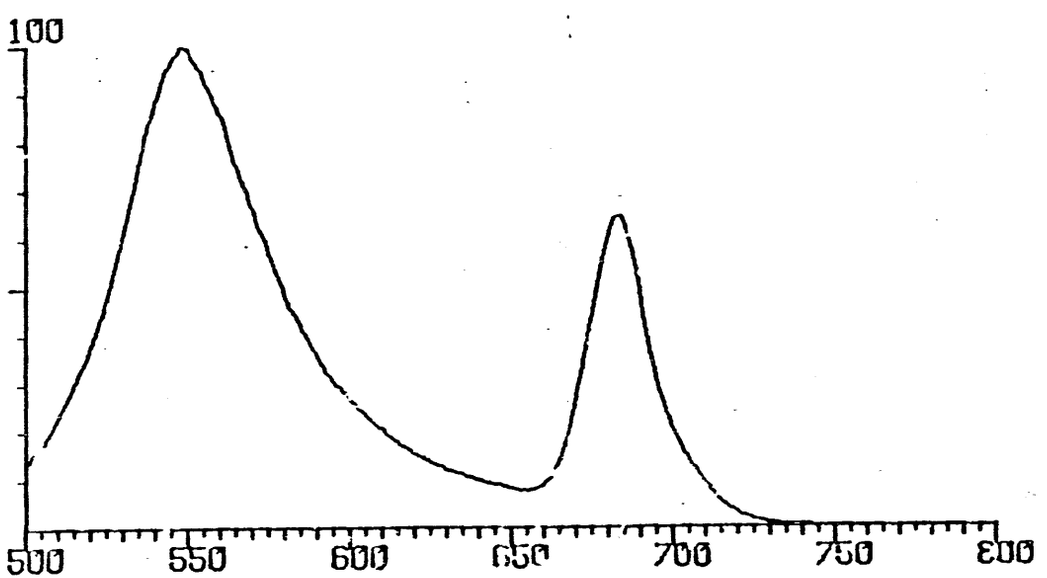


279

SALT SAMPLE 2302.6

MASS 19 SEARCH X4

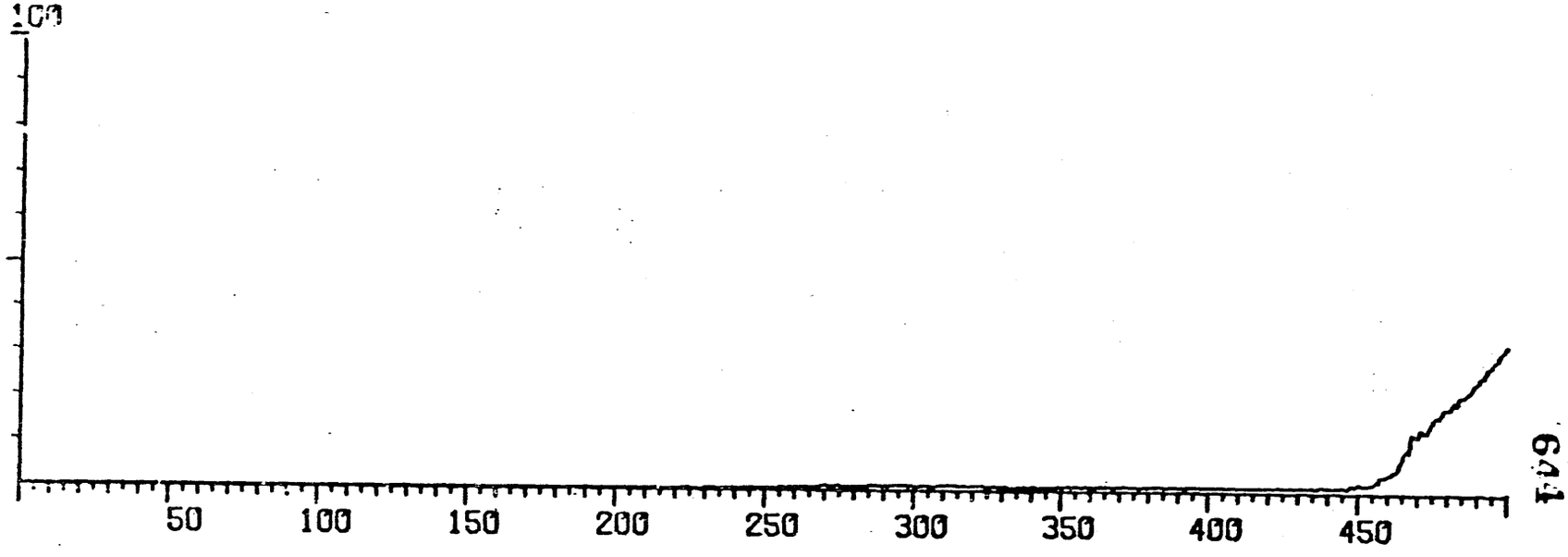




643

SALT SAMPLE 2302.6

MASS 20 SEARCH X3



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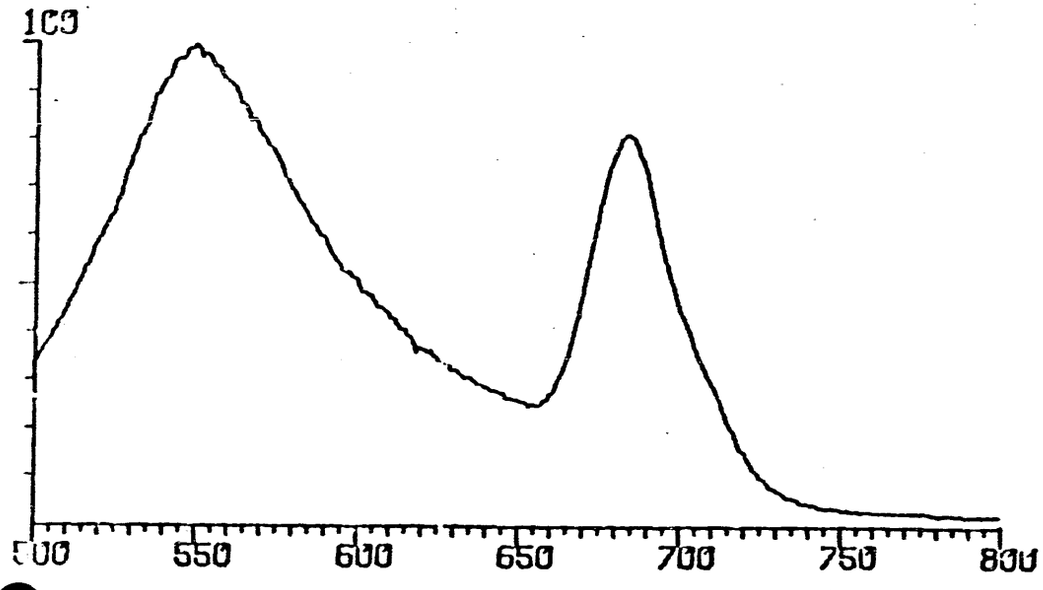
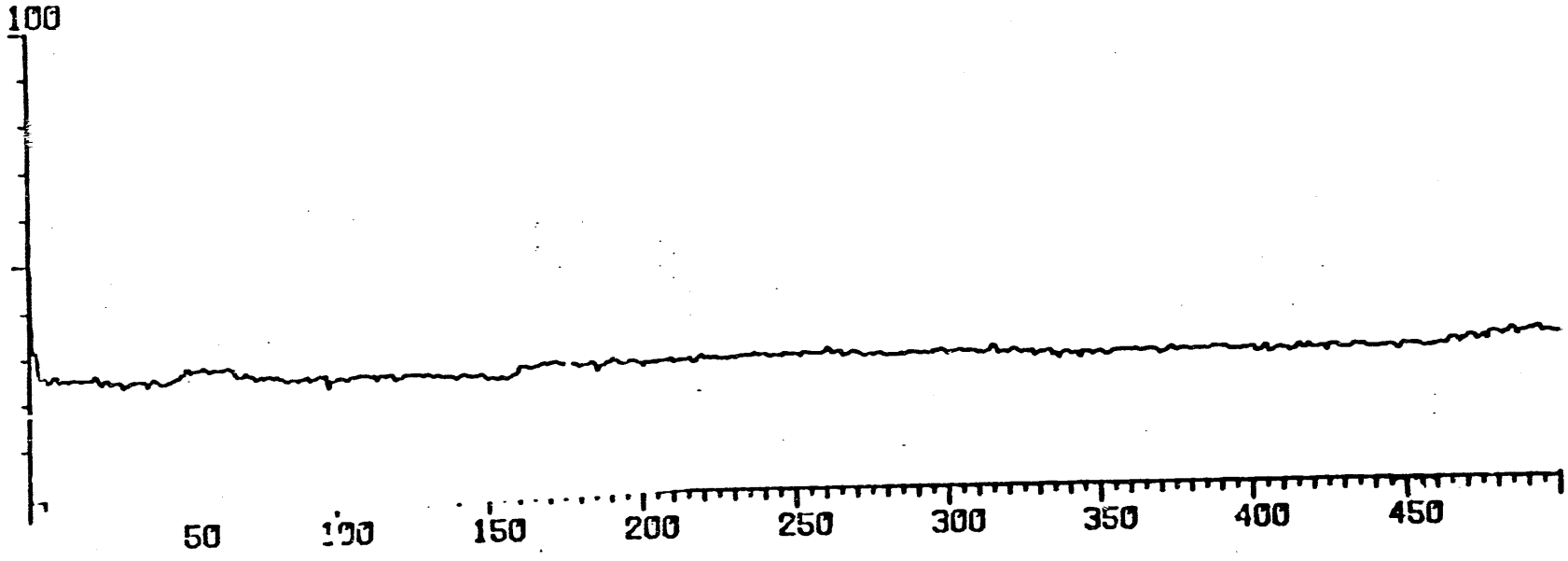
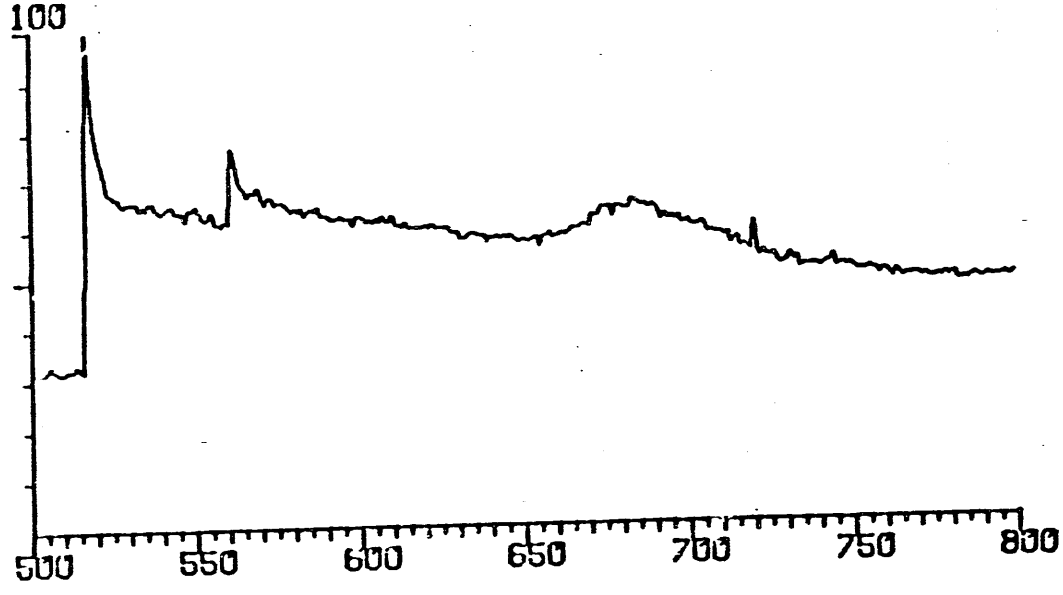


SALT SAMPLE 2302.6

MASS 32 SEARCH X2





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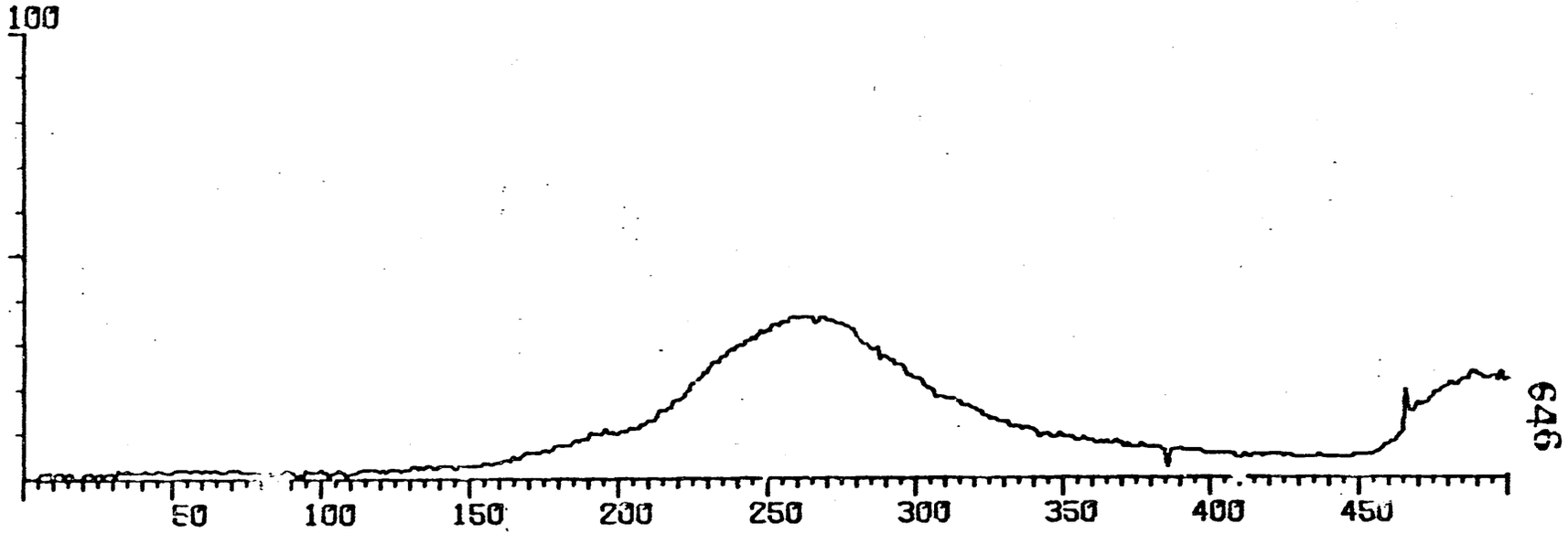
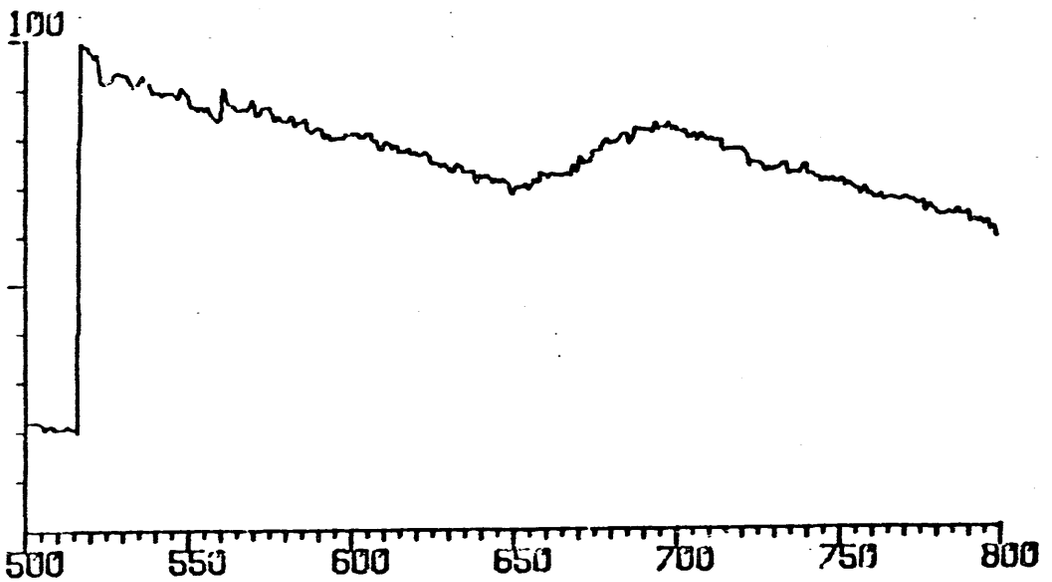
SPLIT SAMPLE 2302.6

MASS 36 SEARCH X2





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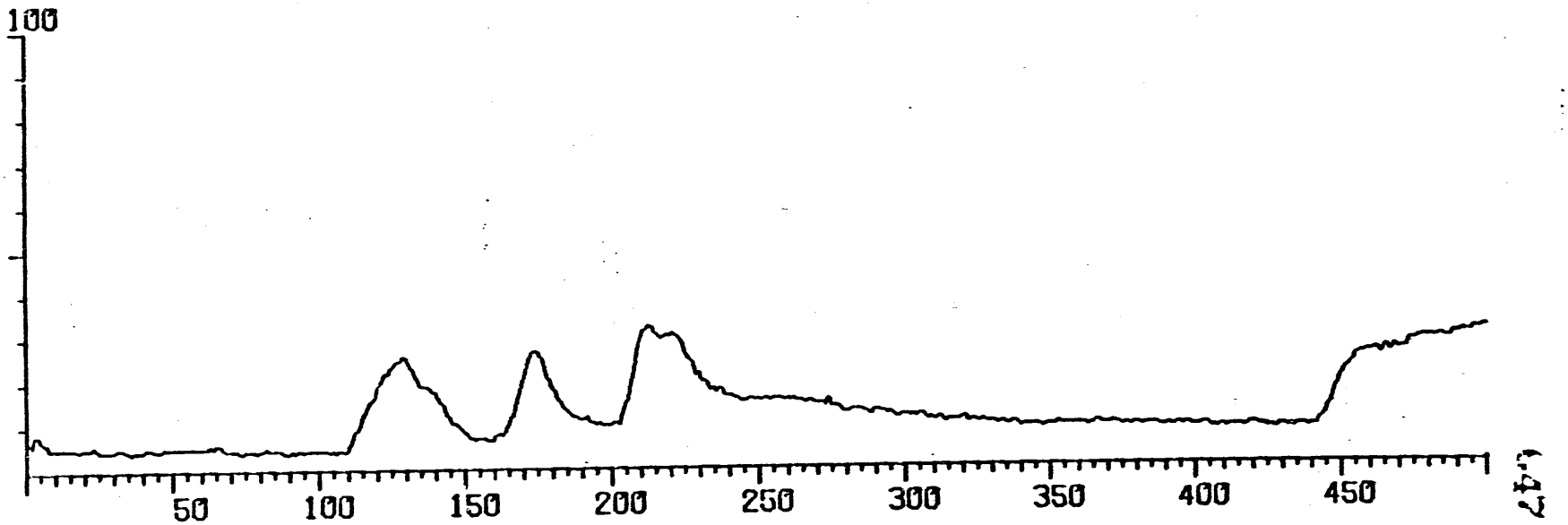
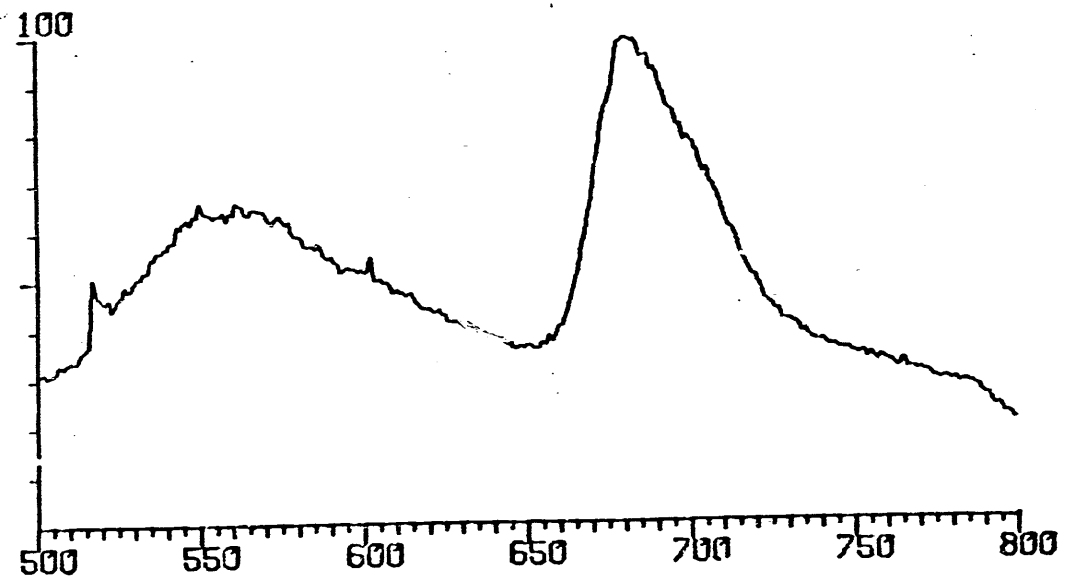
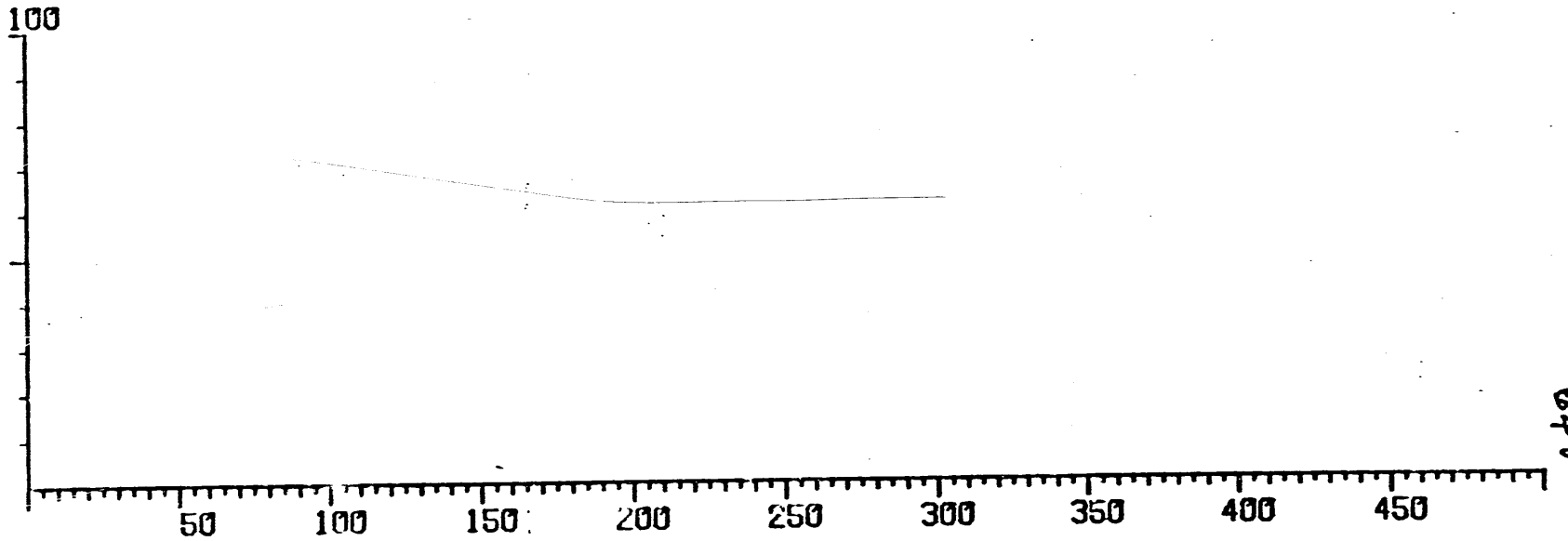
MASS 44 SEARCH X2





SALT SAMPLE 2302.6

MASS 48 SEARCH X1



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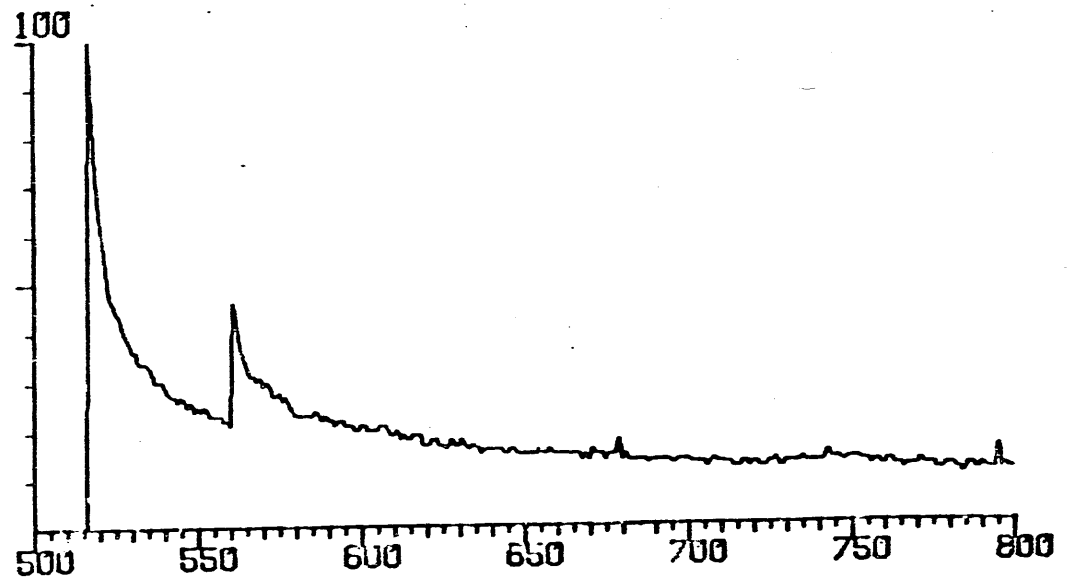
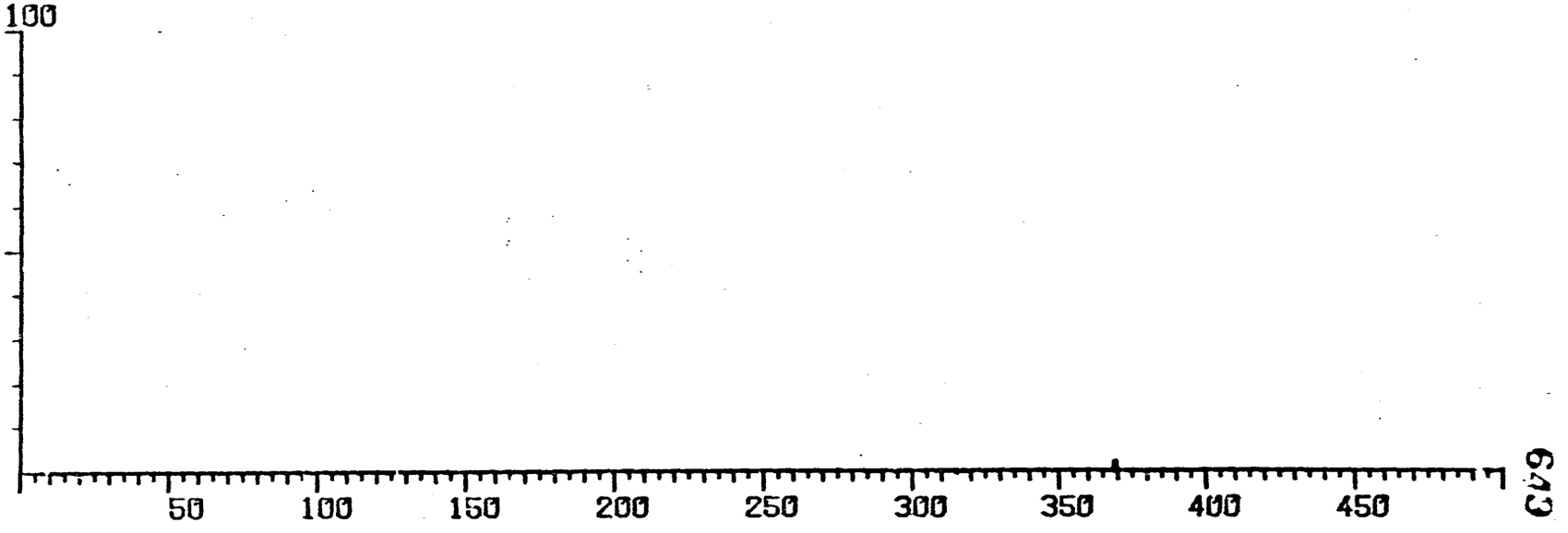
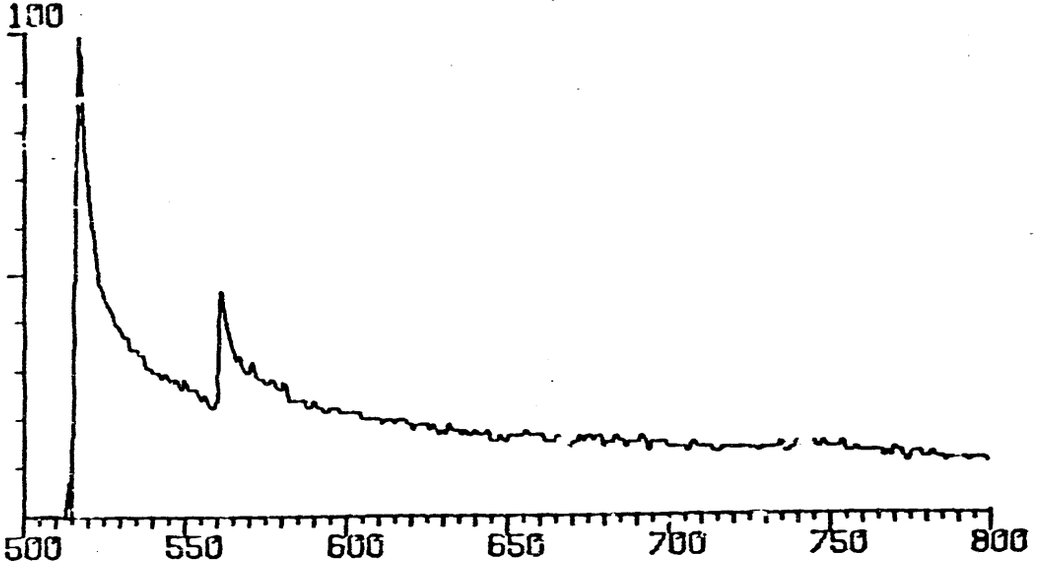


SALT SAMPLE 2302.6

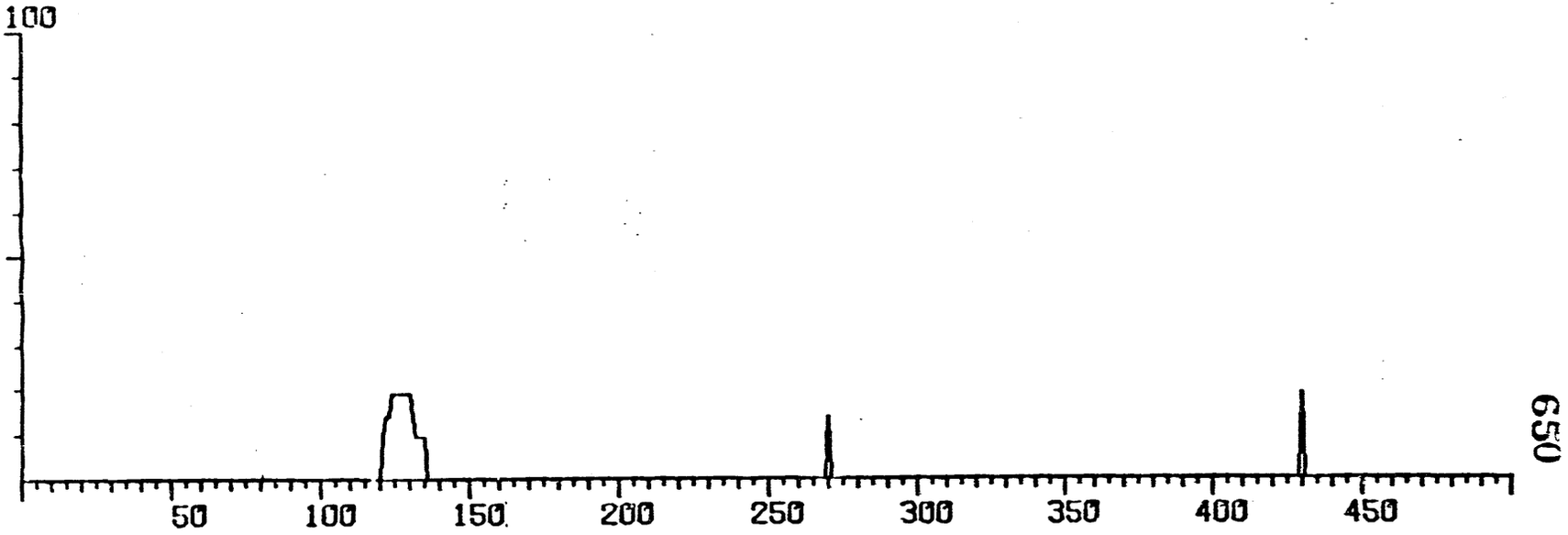
MASS 64 SEARCH X1

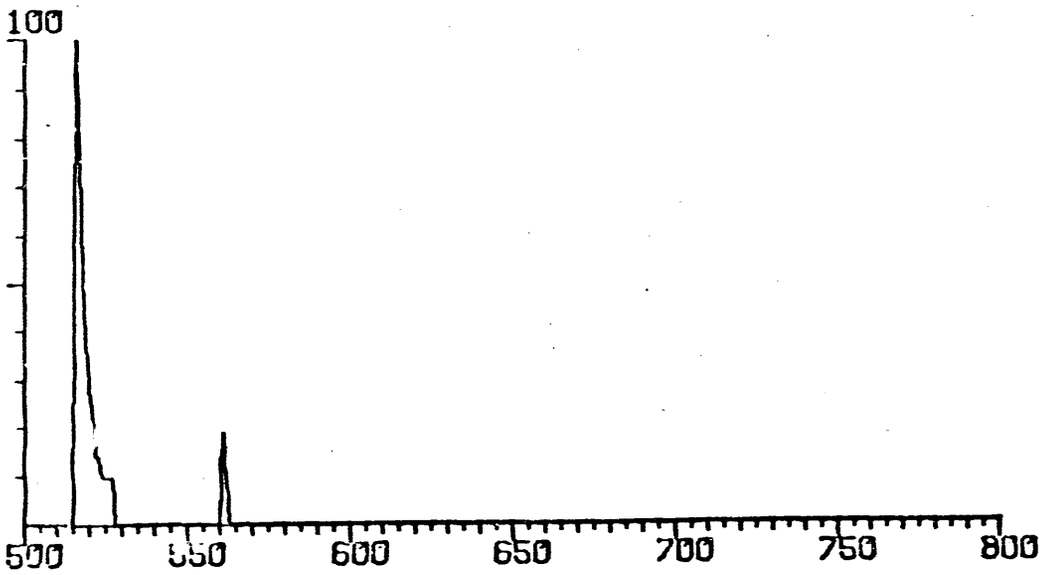


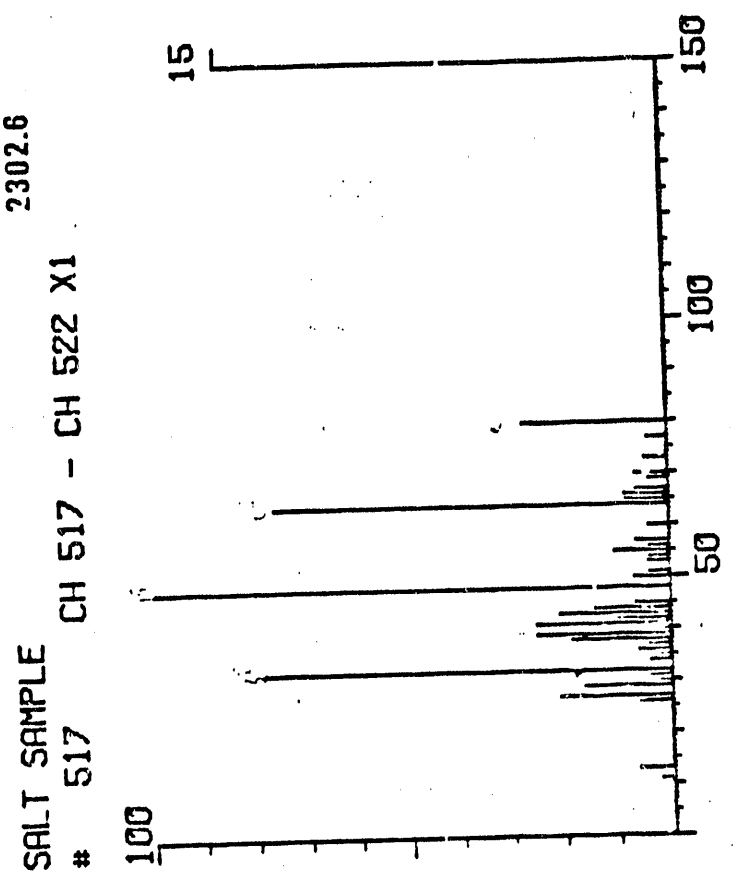


SALT SAMPLE 2302.6

MASS 80 SEARCH X1

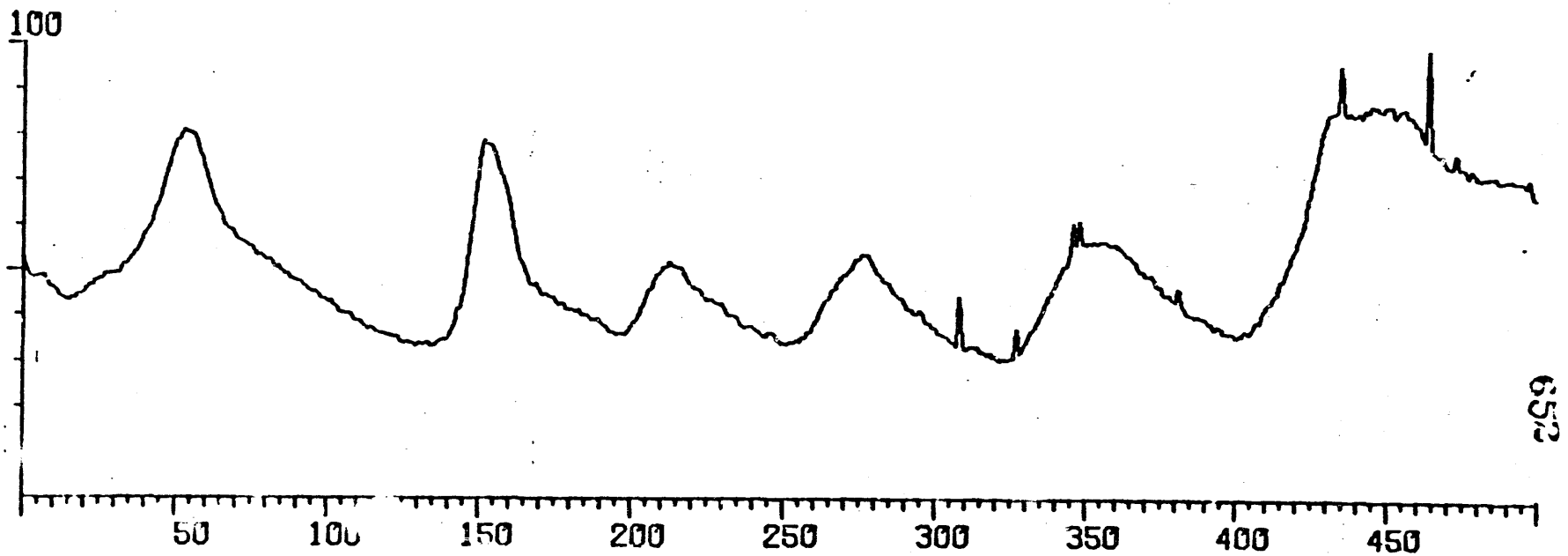





SALT SAMPLE
517
CH 517 - CH 522 X1
2302.6
15
150
100
50
100

SALT SAMPLE 2516.3

TOTAL ION CHROMATOGRAM



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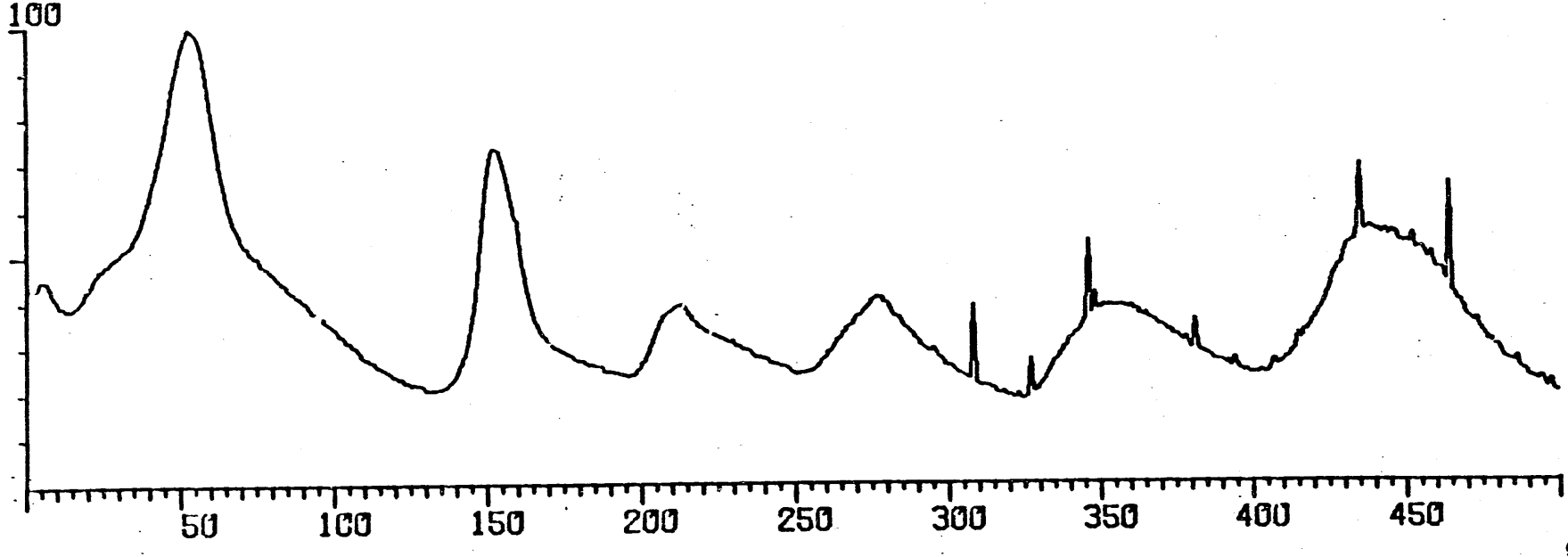
SALT SAMPLE 2516.3

MASS 18 SEARCH X3



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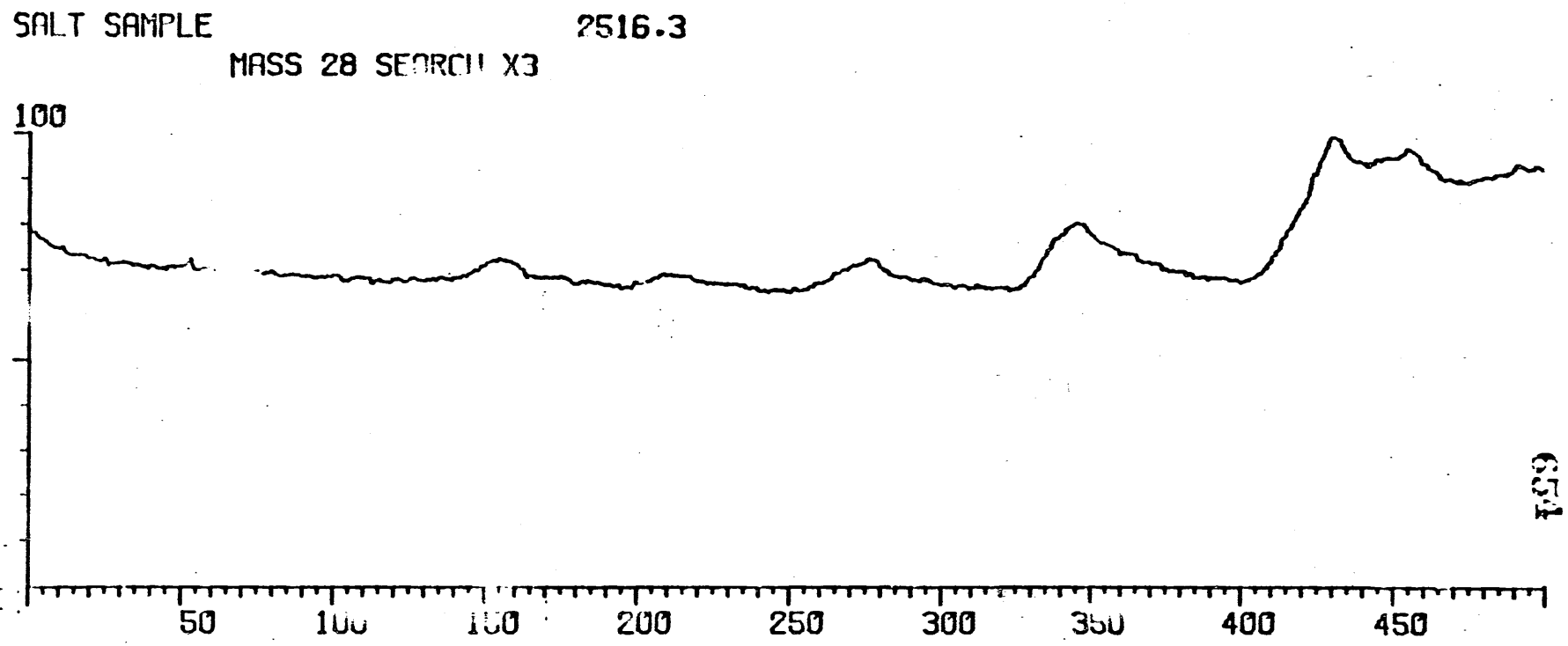
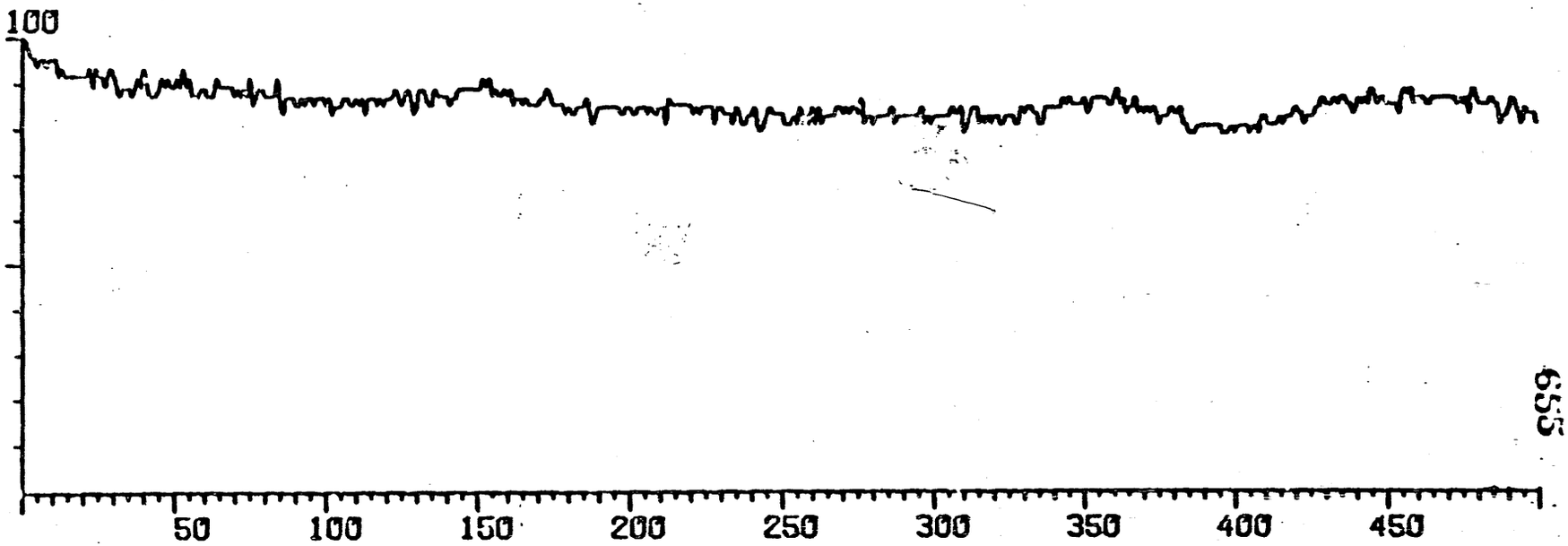

SALT SAMPLE
2516.3
MASS 28 SEARCH X3
100
50
200
250
300
350
400
450

SALT SAMPLE 2516.3

MASS 32 SEARCH X2



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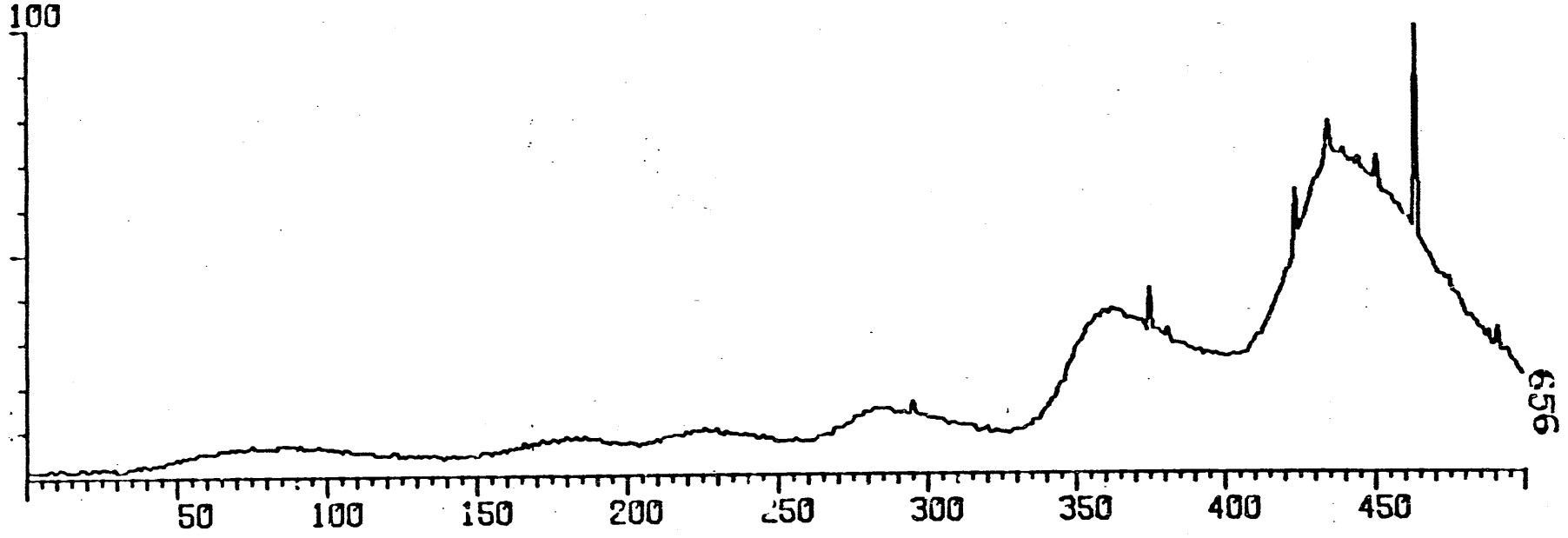
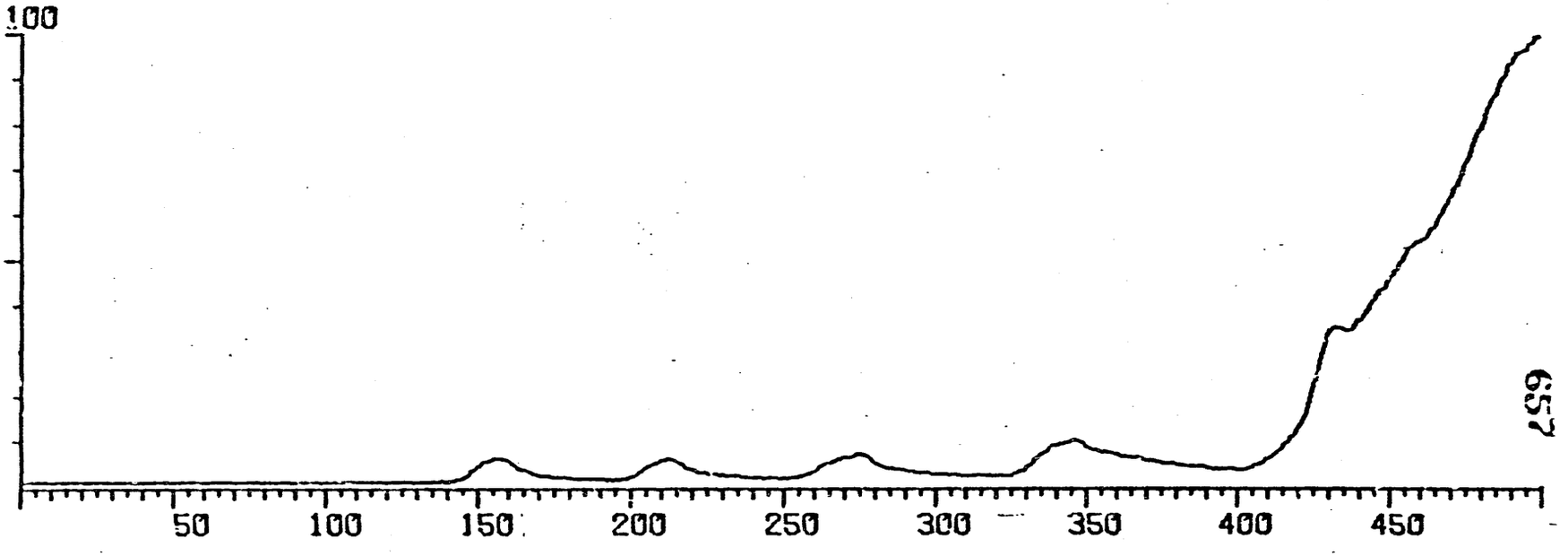
SALT SAMPLE 2516.3

MASS 36 SEARCH X2



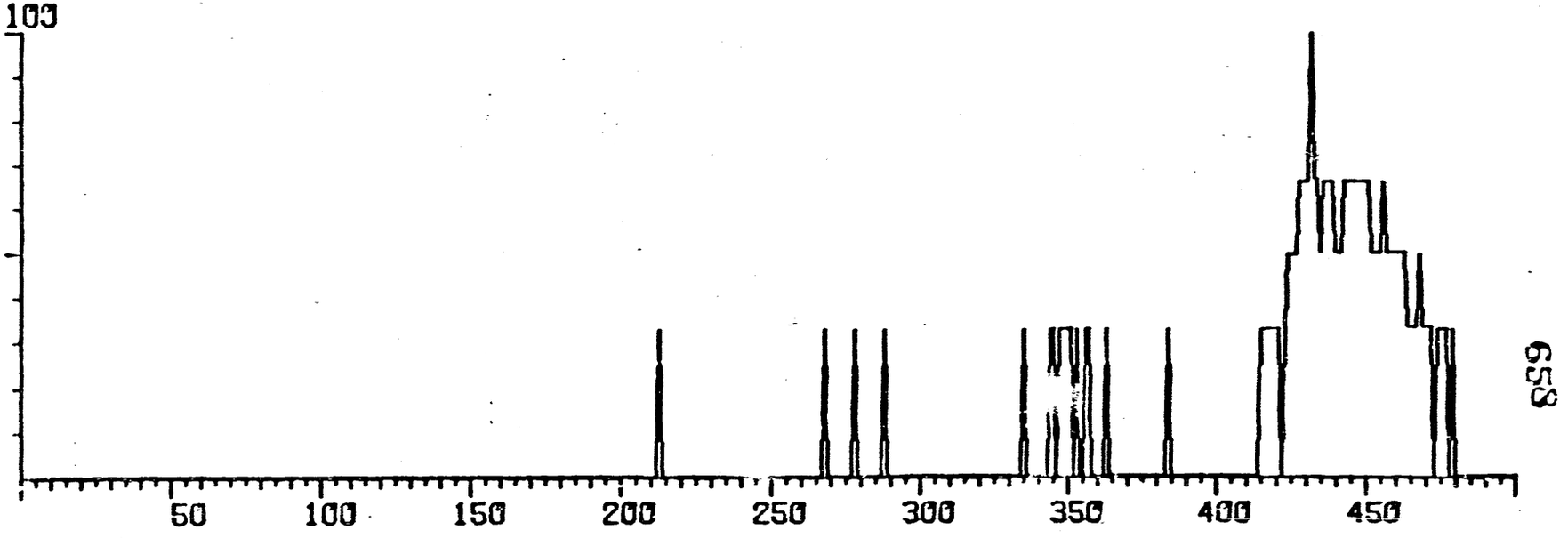
SALT SAMPLE 2516.3

MASS 44 SEARCH X3



SALT SAMPLE 2516.3

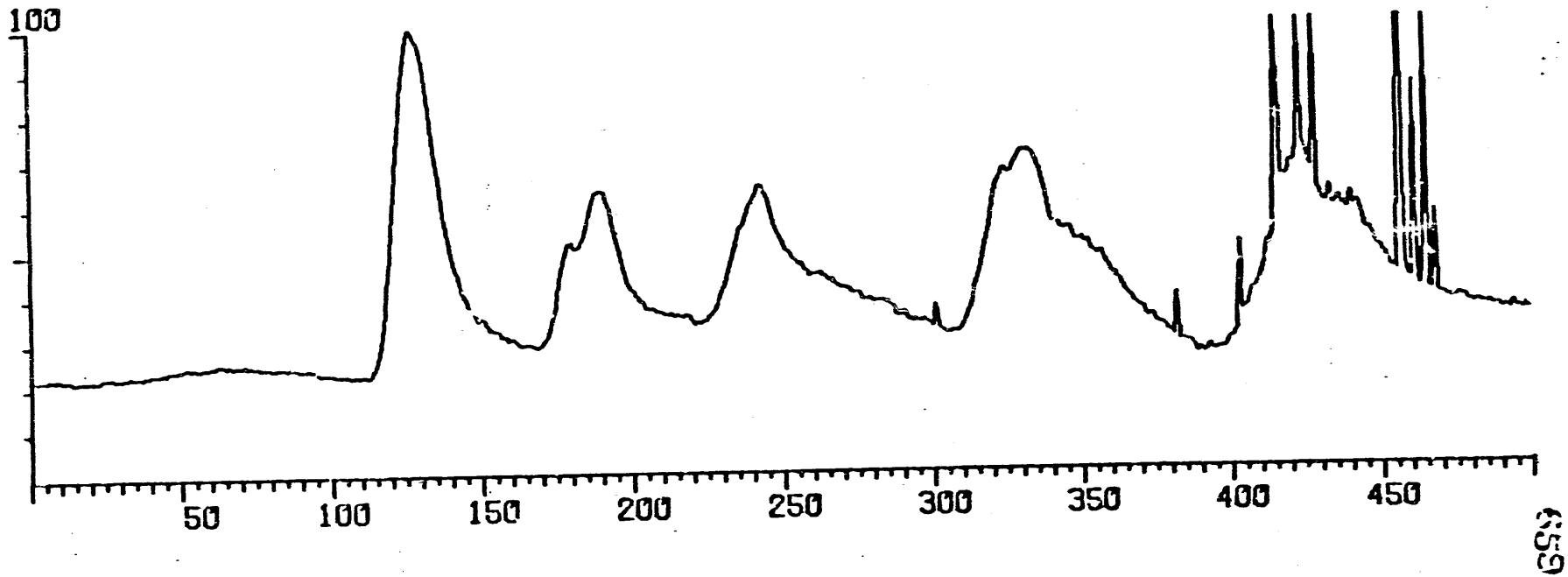
MASS 48 SEARCH X1

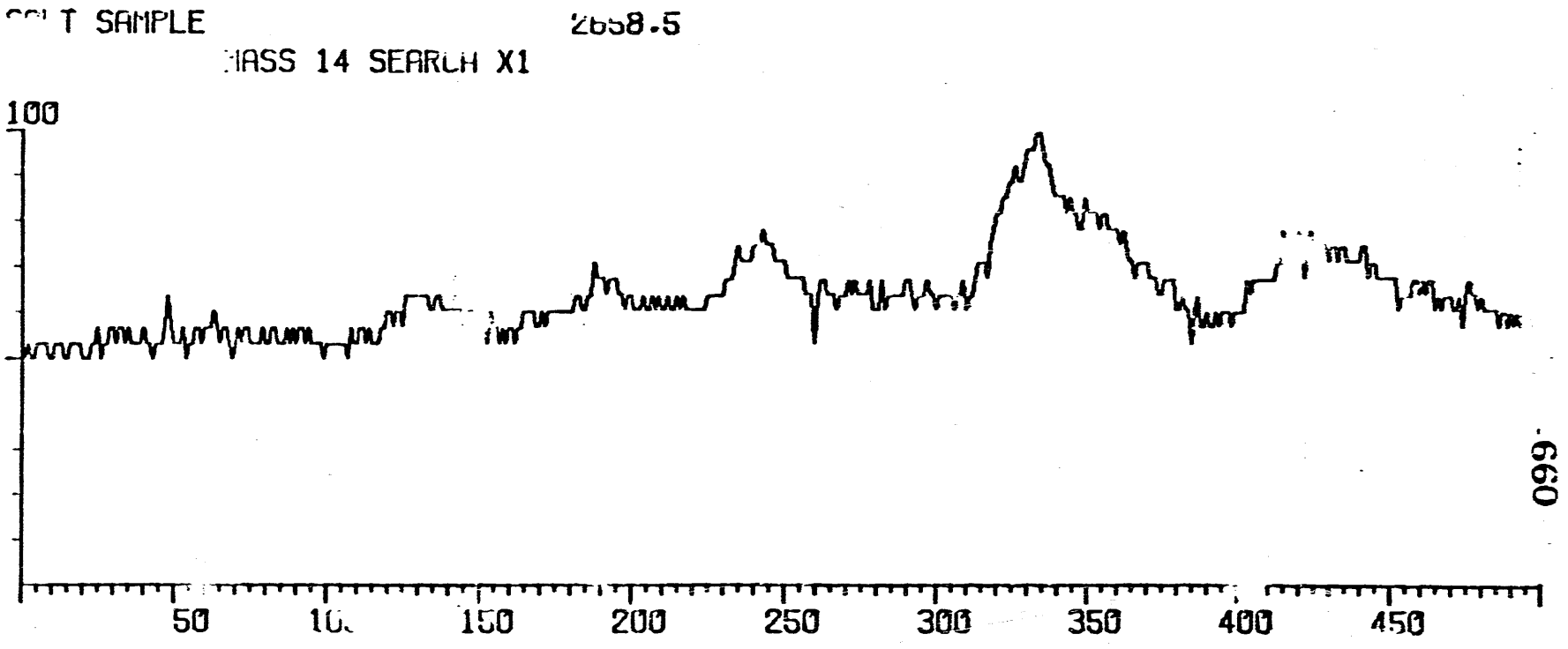


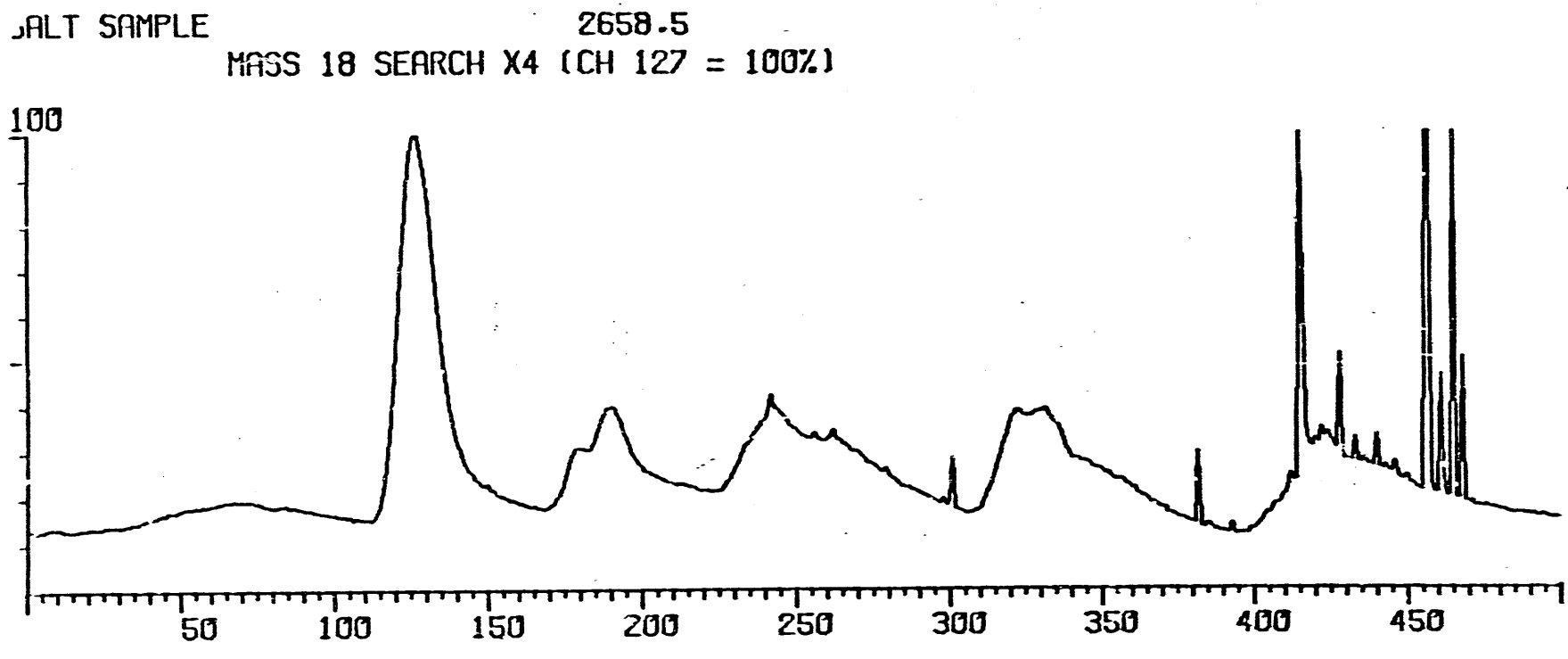
658

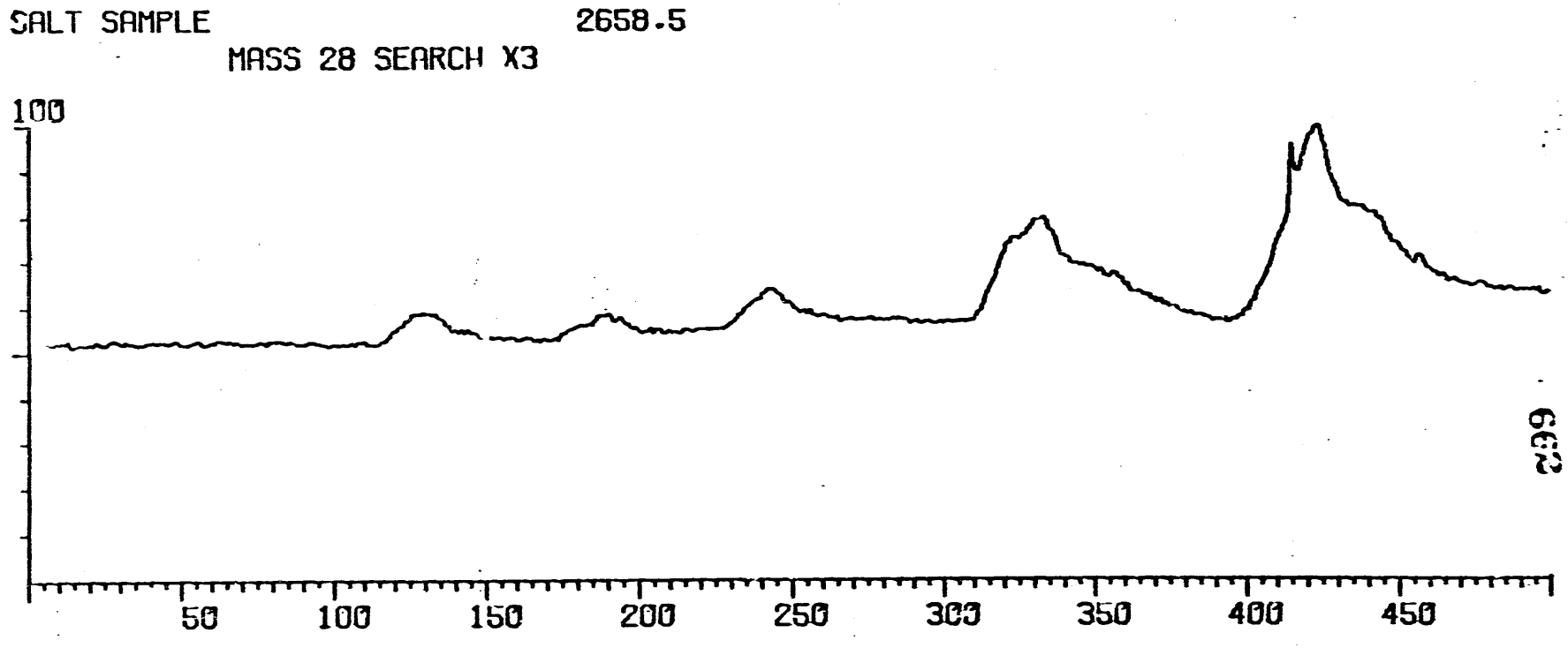
SALT SAMPLE 2658.5

TOTAL ION CHROMATOGRAM



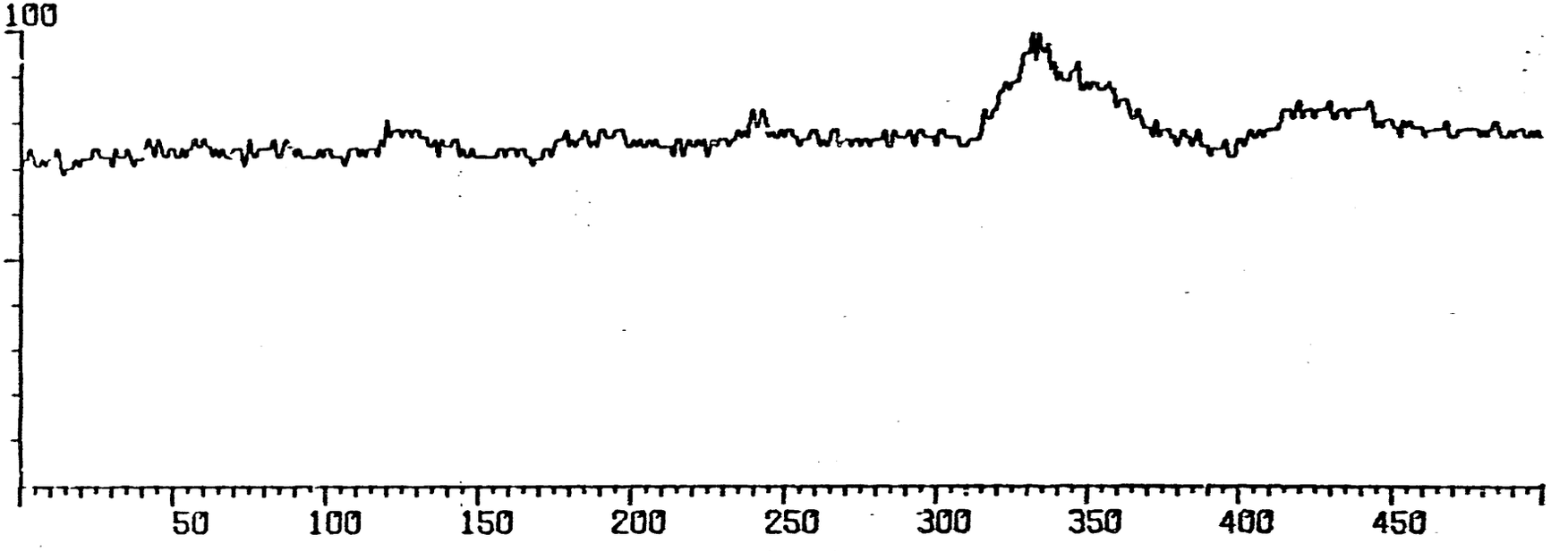

T SAMPLE
2658.5
MASS 14 SEARCH X1
100
50
150
200
250
300
350
400
450
660


SALT SAMPLE
2658.5
MASS 18 SEARCH X4 (CH 127 = 100%)
100
50
100
150
200
250
300
350
400
450


SALT SAMPLE
2658.5
MASS 28 SEARCH X3
100
50
100
150
200
250
300
350
400
450
239

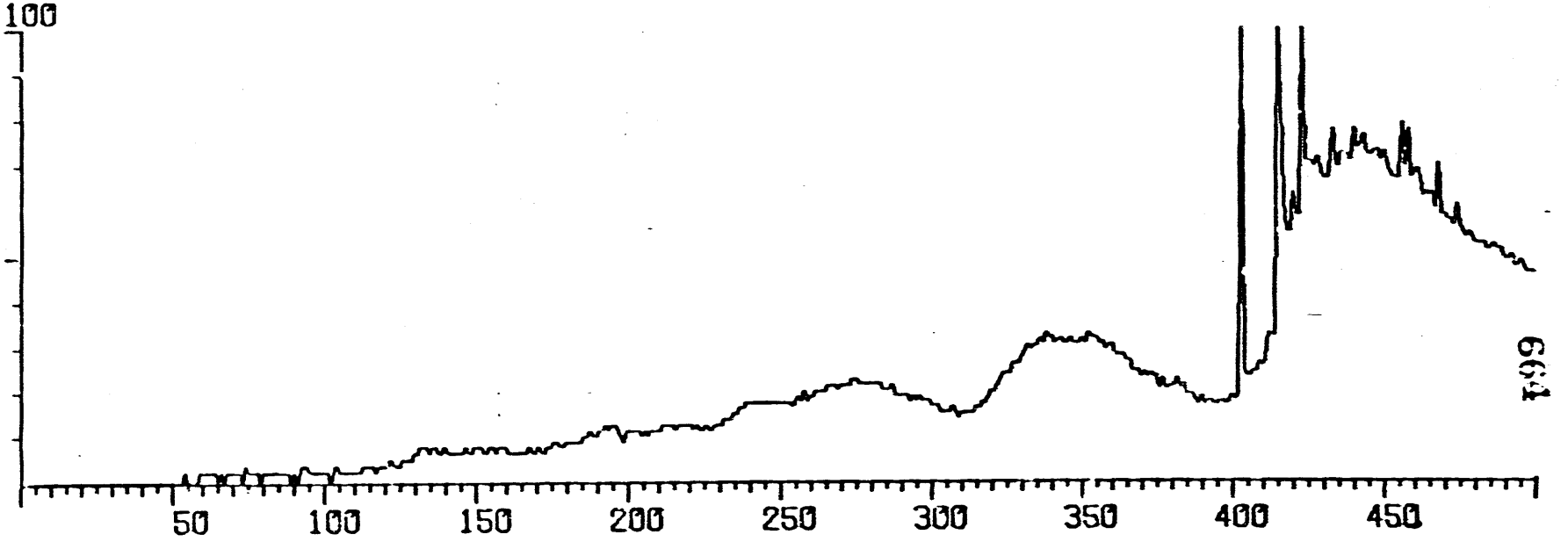
SALT SAMPLE 2658.5

MASS 32 SEARCH X1



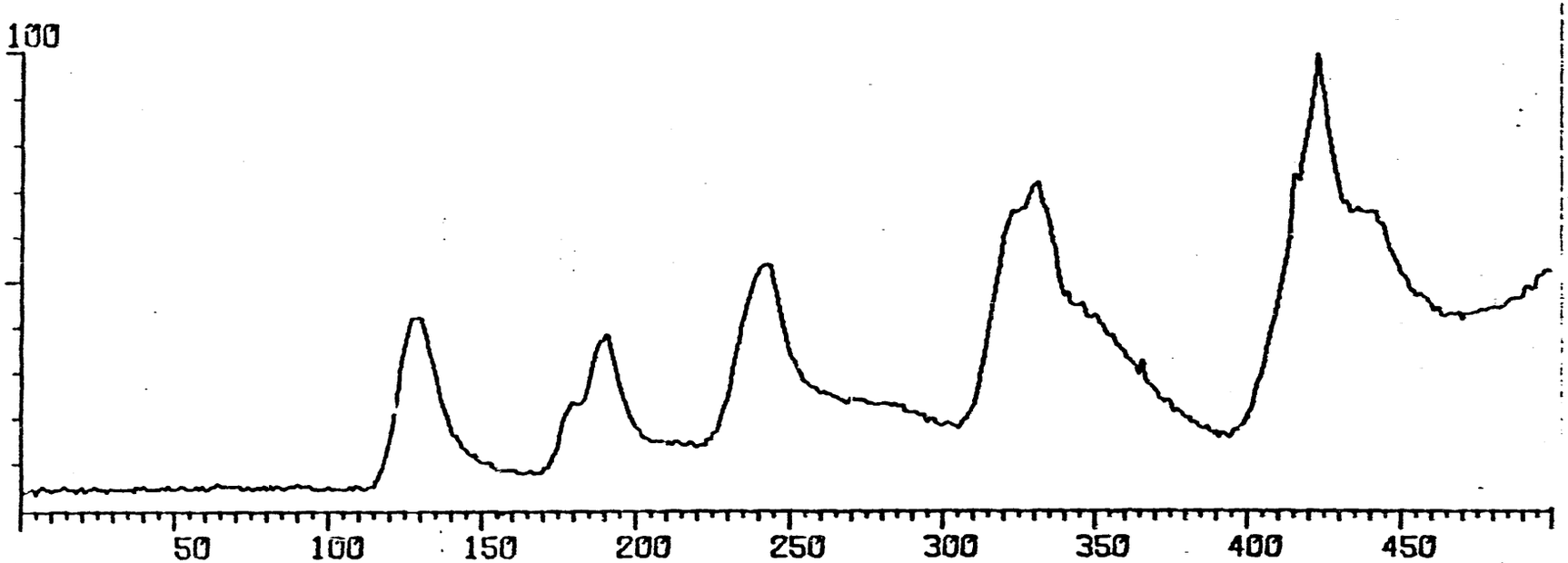
SALT SAMPLE 2659.5

MASS 36 SEARCH X2 (CH 415 = 100%)



SALT SAMPLE 2658.5

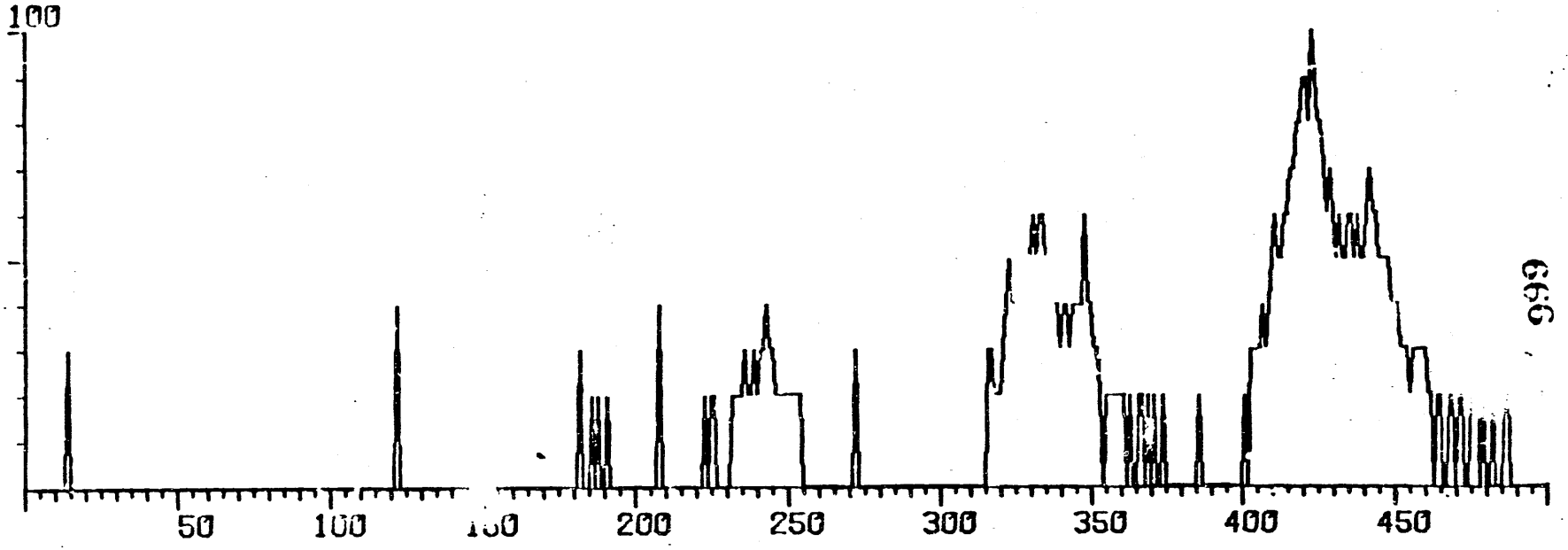
MASS 44 SEARCH X2



665

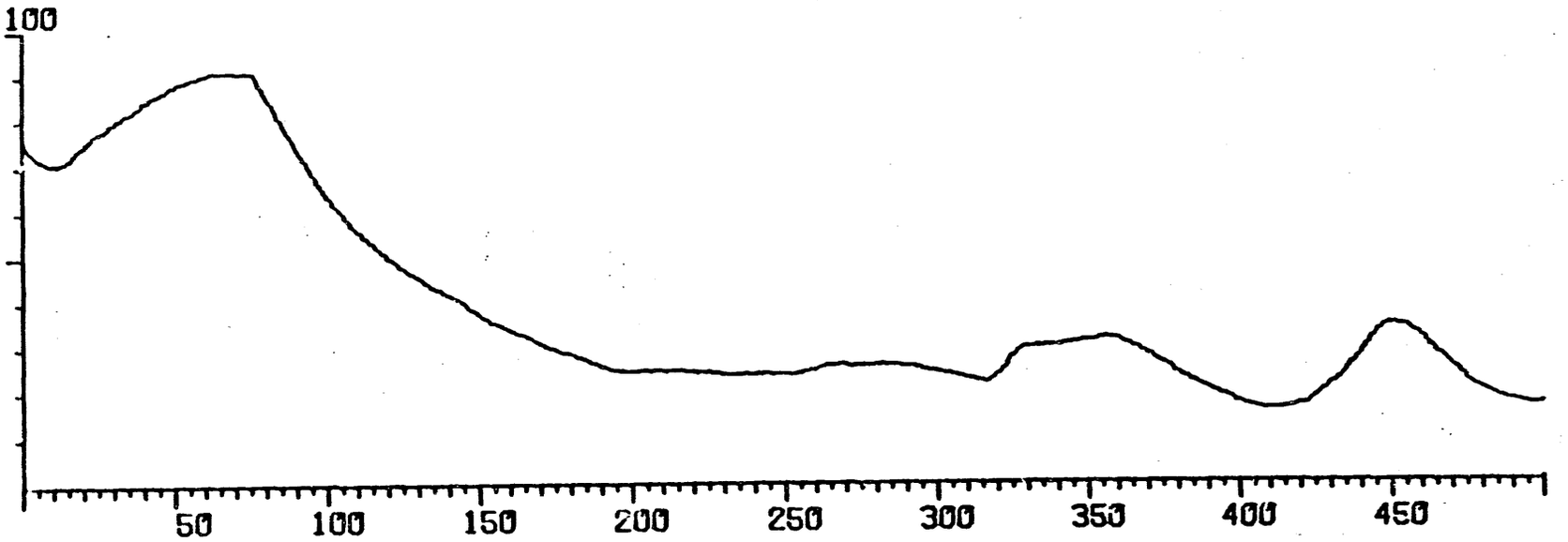
SALT SAMPLE 2658.5

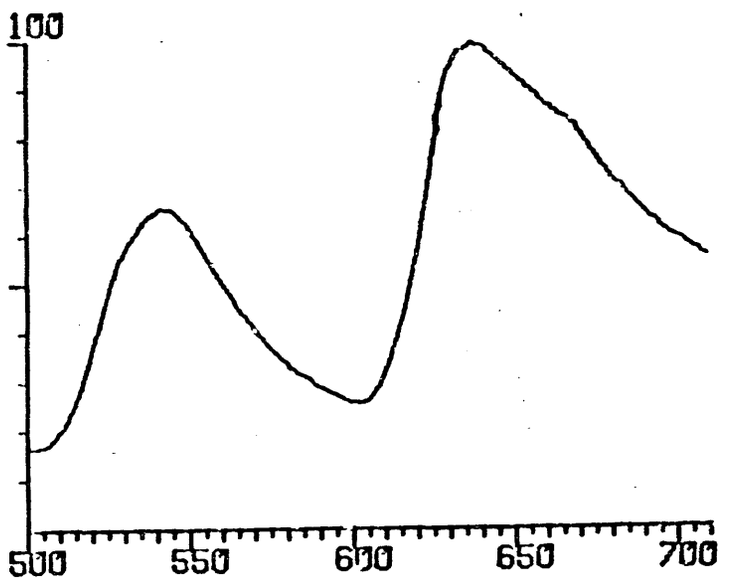
MASS 48 SEARCH X1



SALT SAMPLE 2786.5

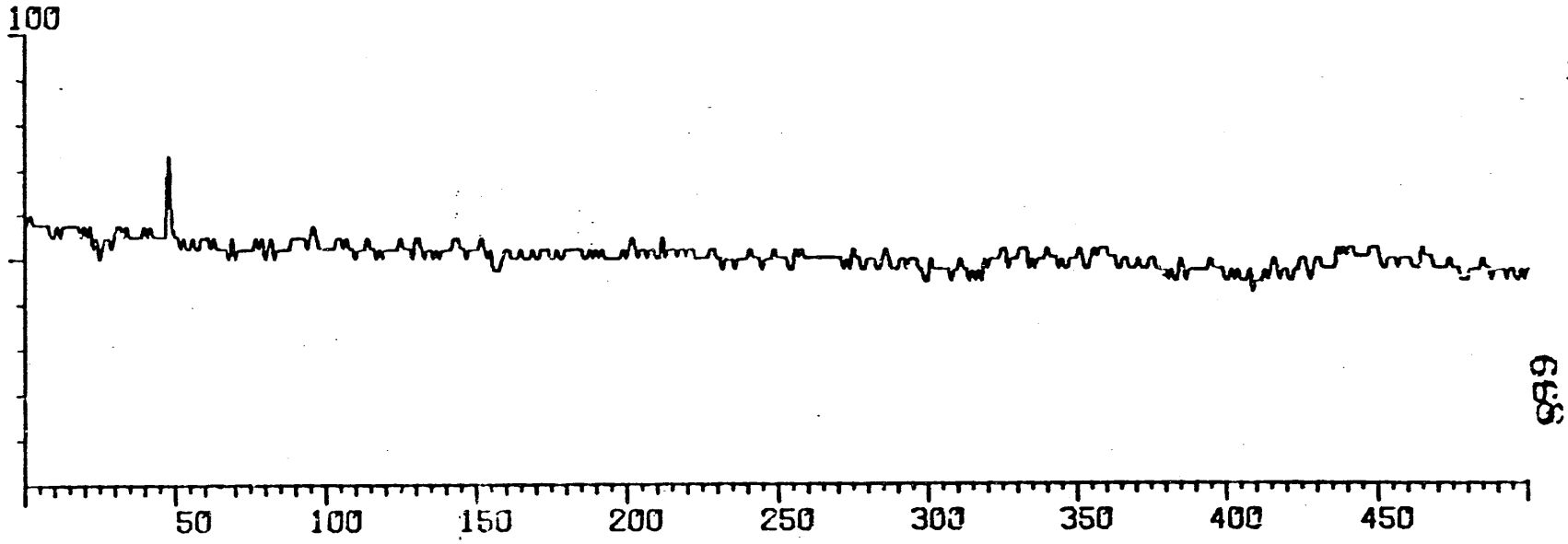
TOTAL ION CHROMATOGRAM

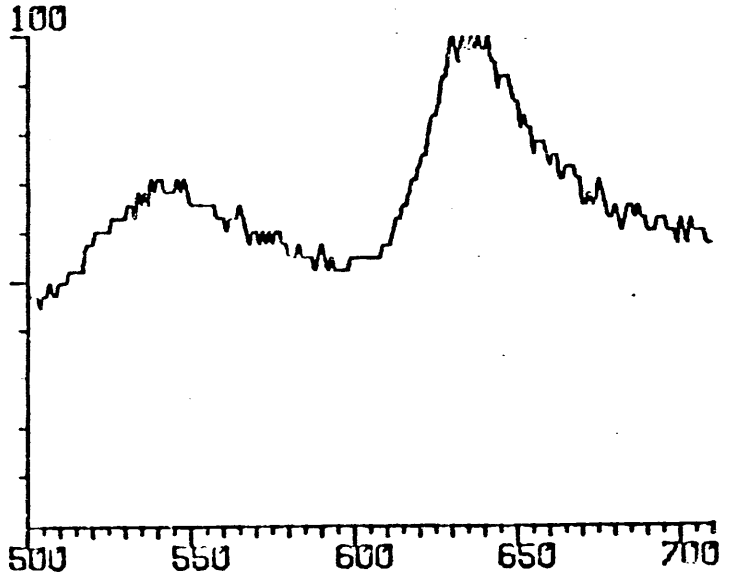




SALT SAMPLE 2786.5

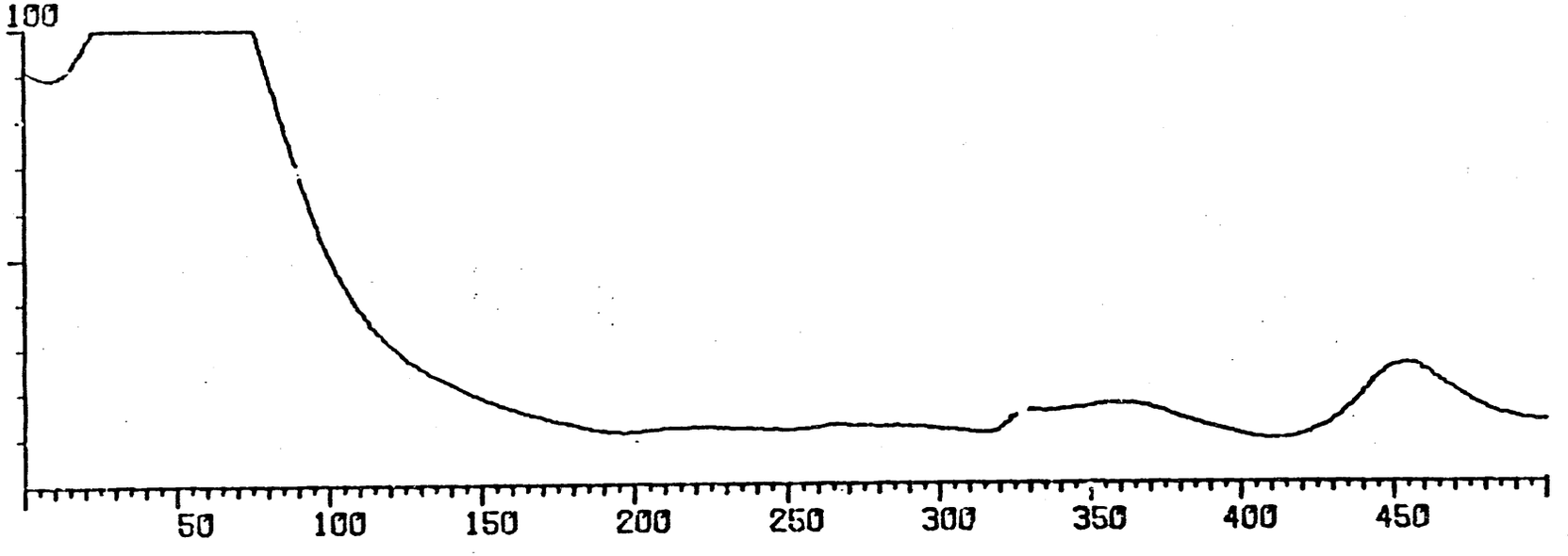
MASS 14 SEARCH X1

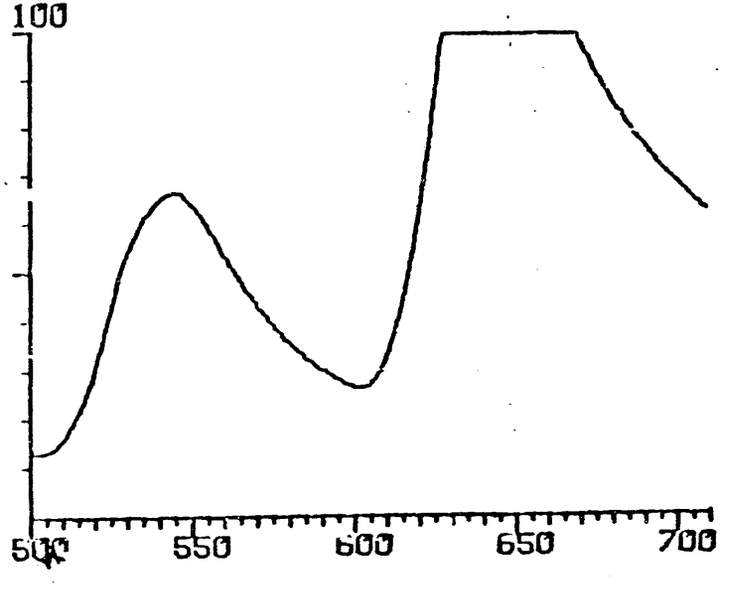


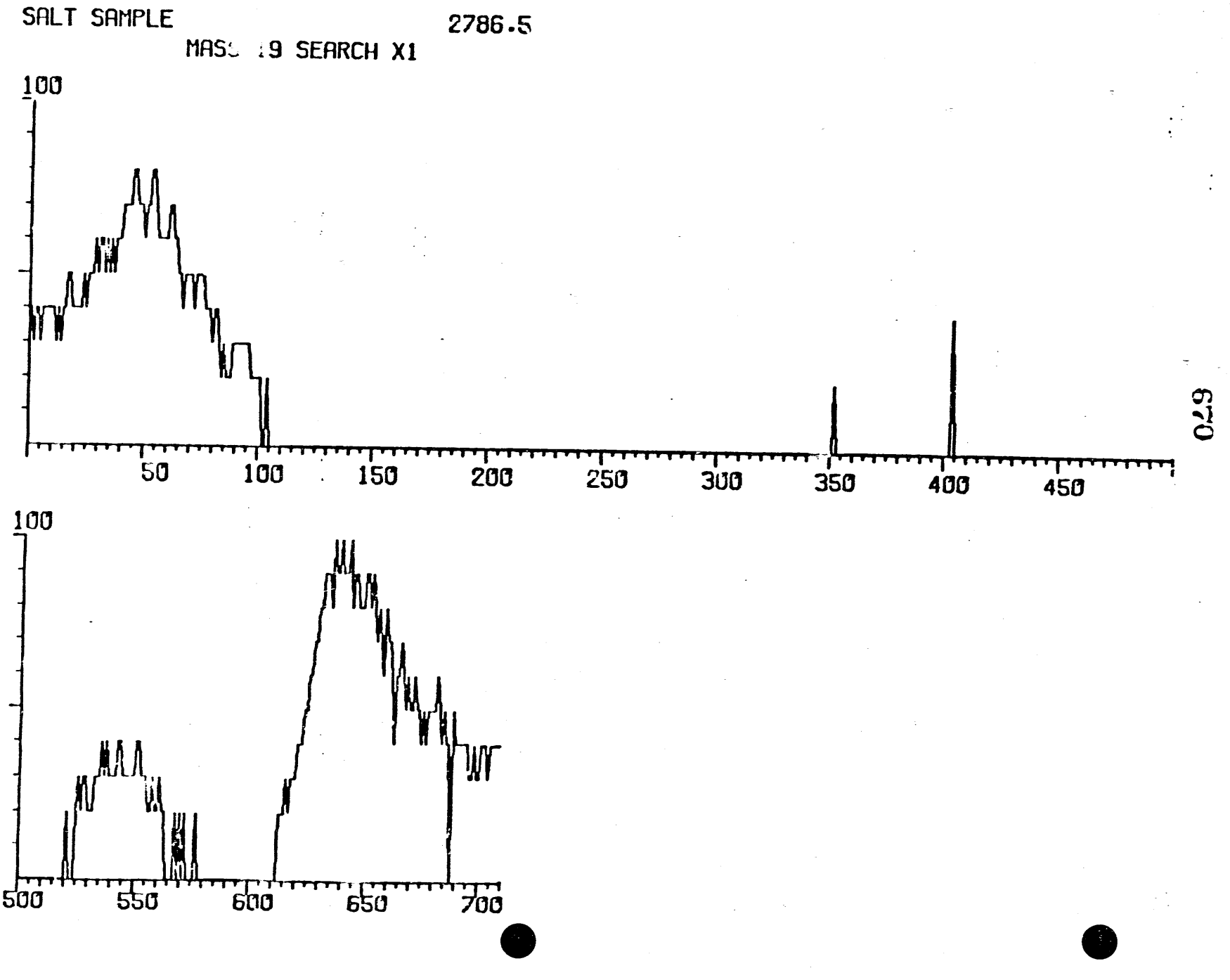


SALT SAMPLE 2786.5

MASS 18 SEARCH X4






SALT SAMPLE
2786.5
MASS :9 SEARCH X1
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150
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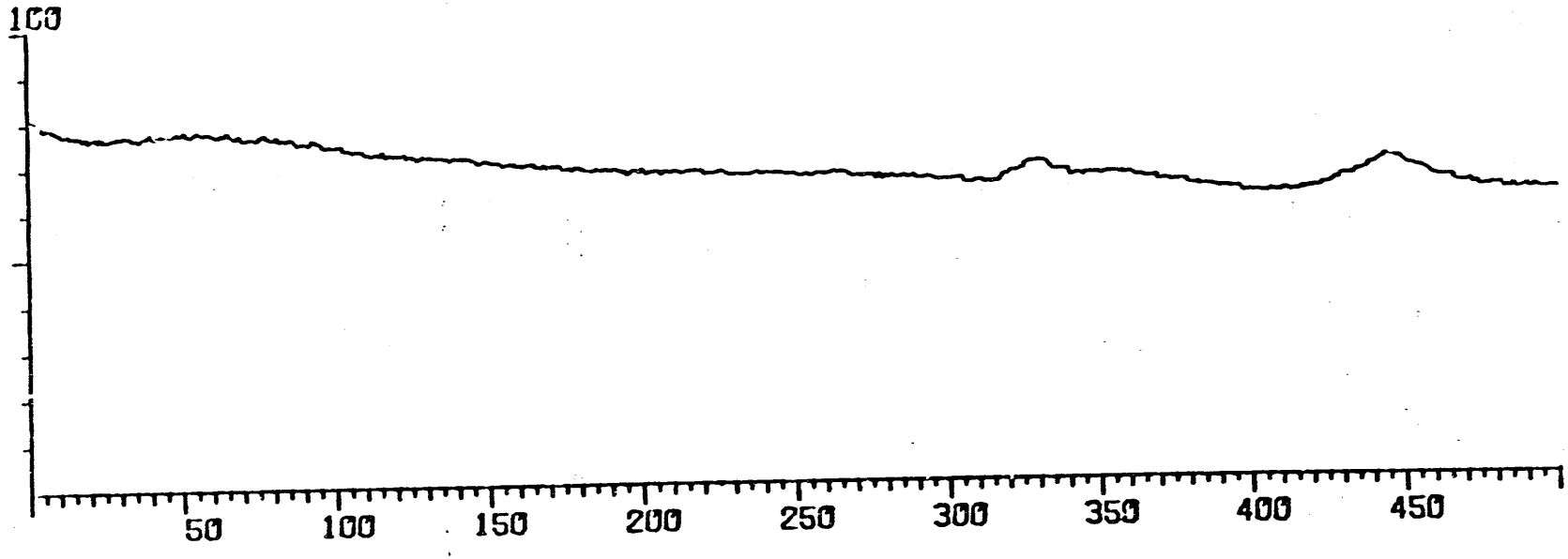
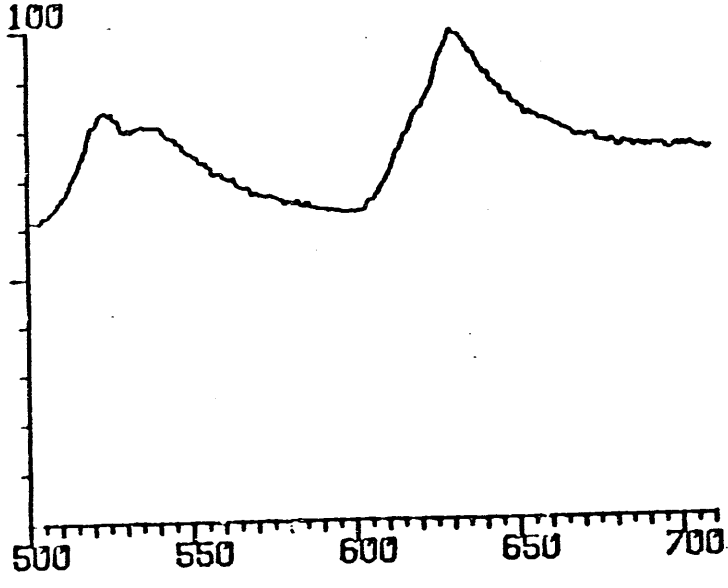
250
300
350
400
450
100
500
550
600
650
700

SALT SAMPLE 2786.5

MASS 28 SEARCH X3

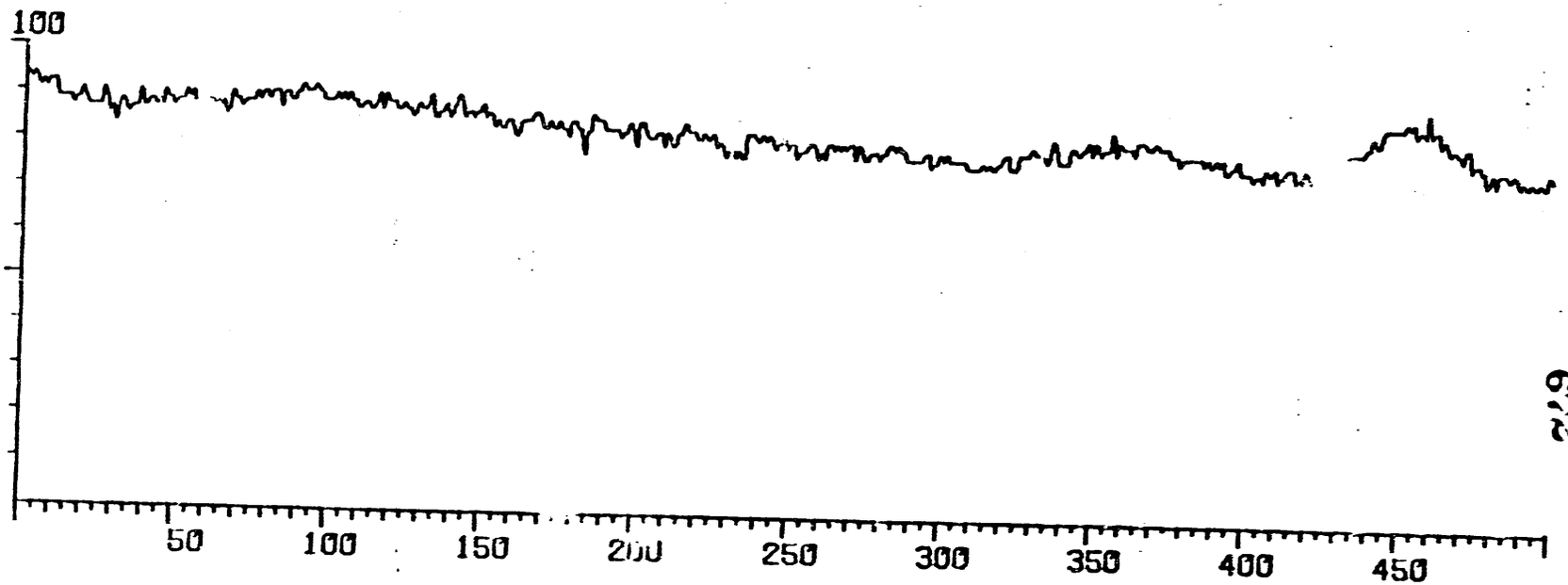


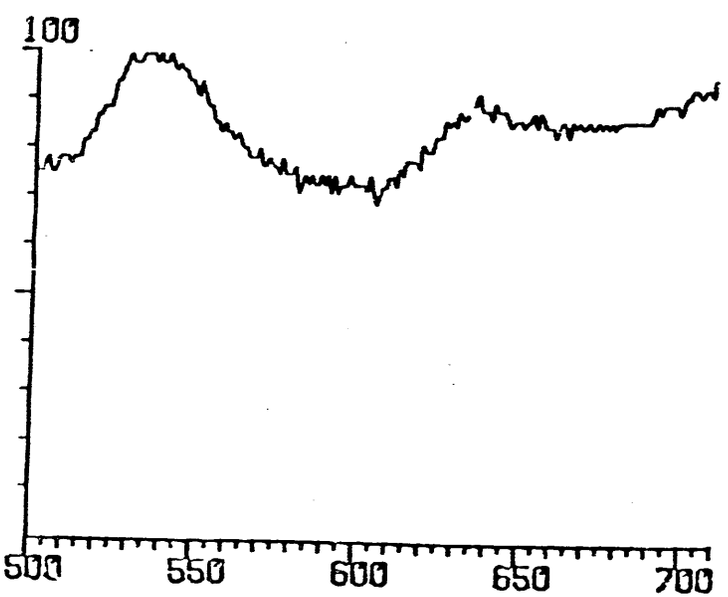


6.71

SALT SAMPLE 2786.5

MASS 32 SEARCH X1





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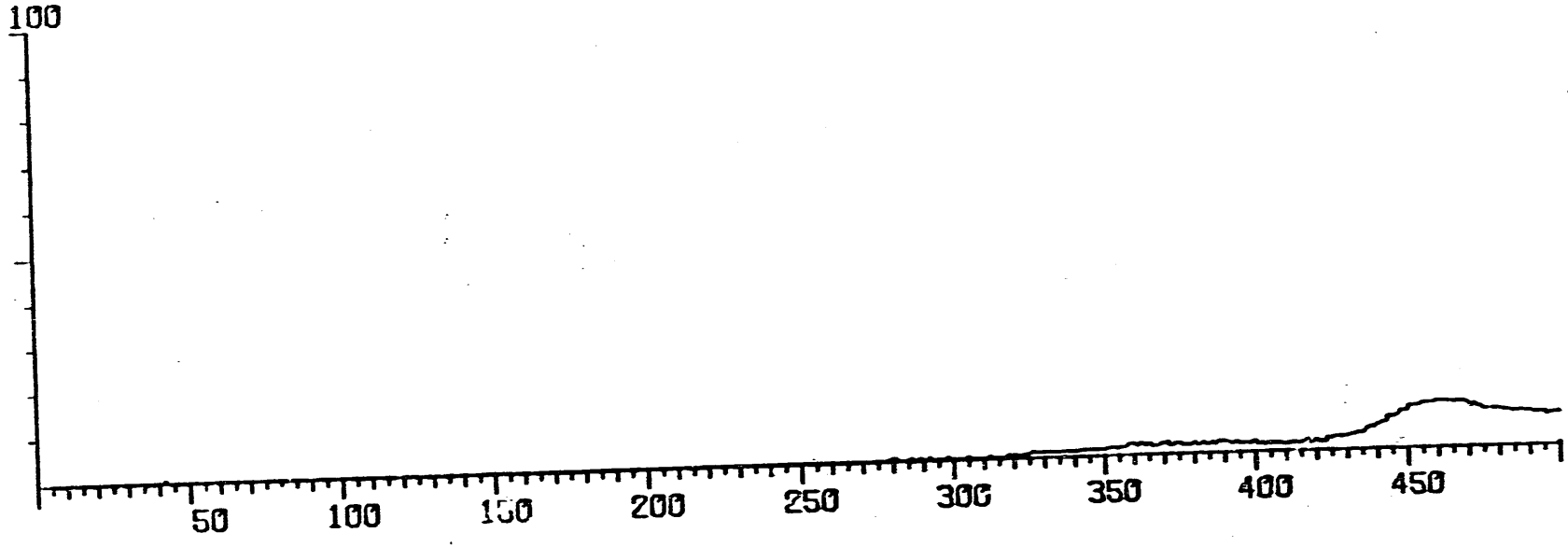
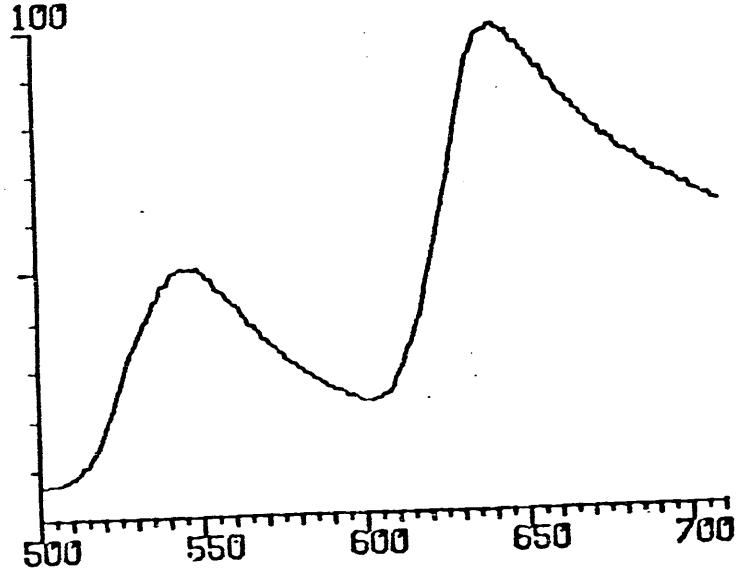
SALT SAMPLE 2786.5

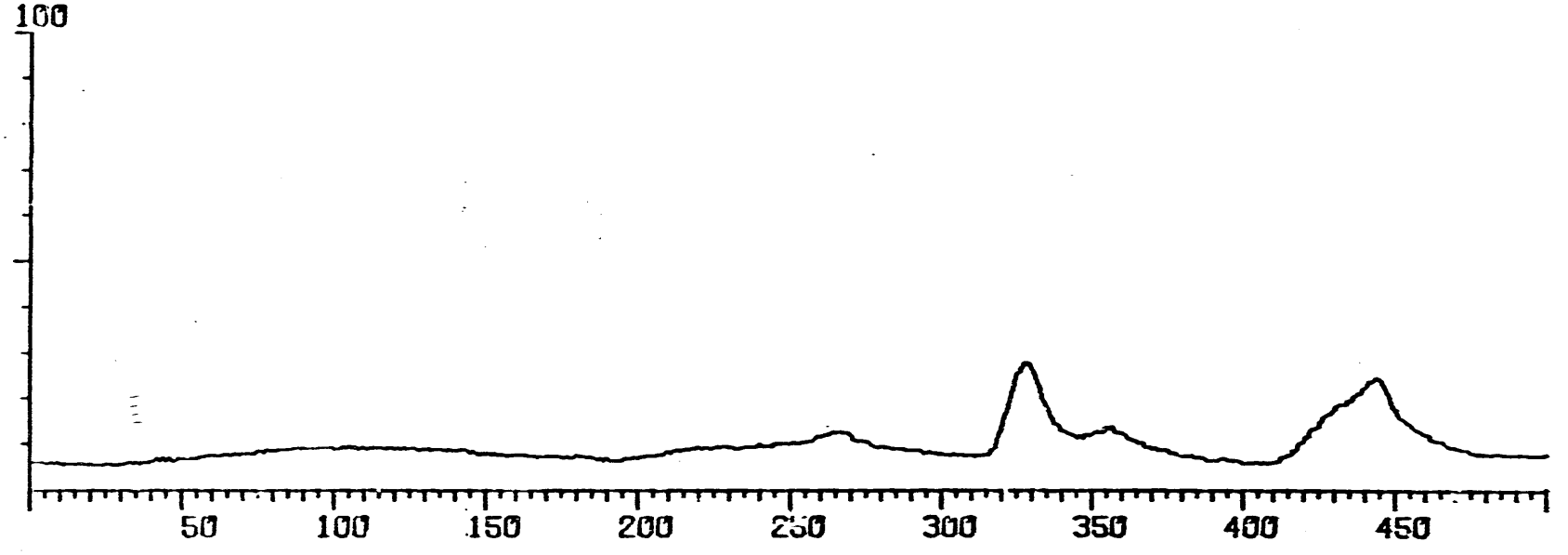
MASS 36 SEARCH X2

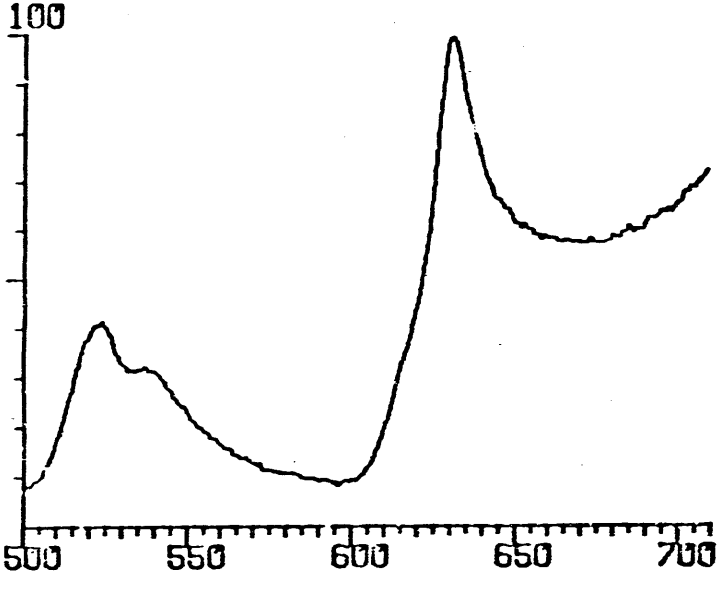




SALT SAMPLE 2786.5

MASS 44 SEARCH X2

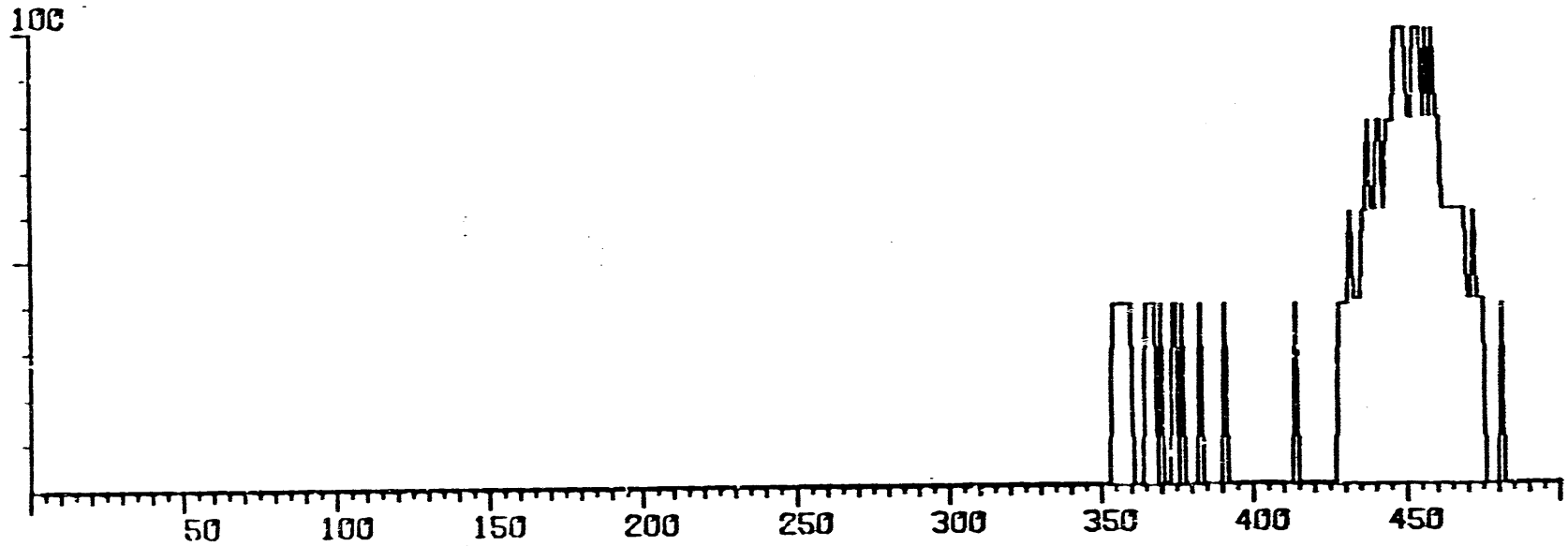


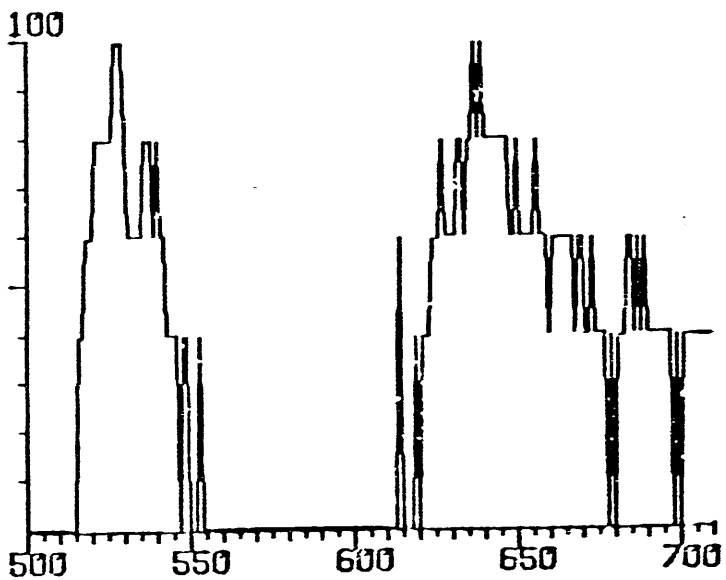


674

SALT SAMPLE 2786.5

MASS 48 SEARCH X1

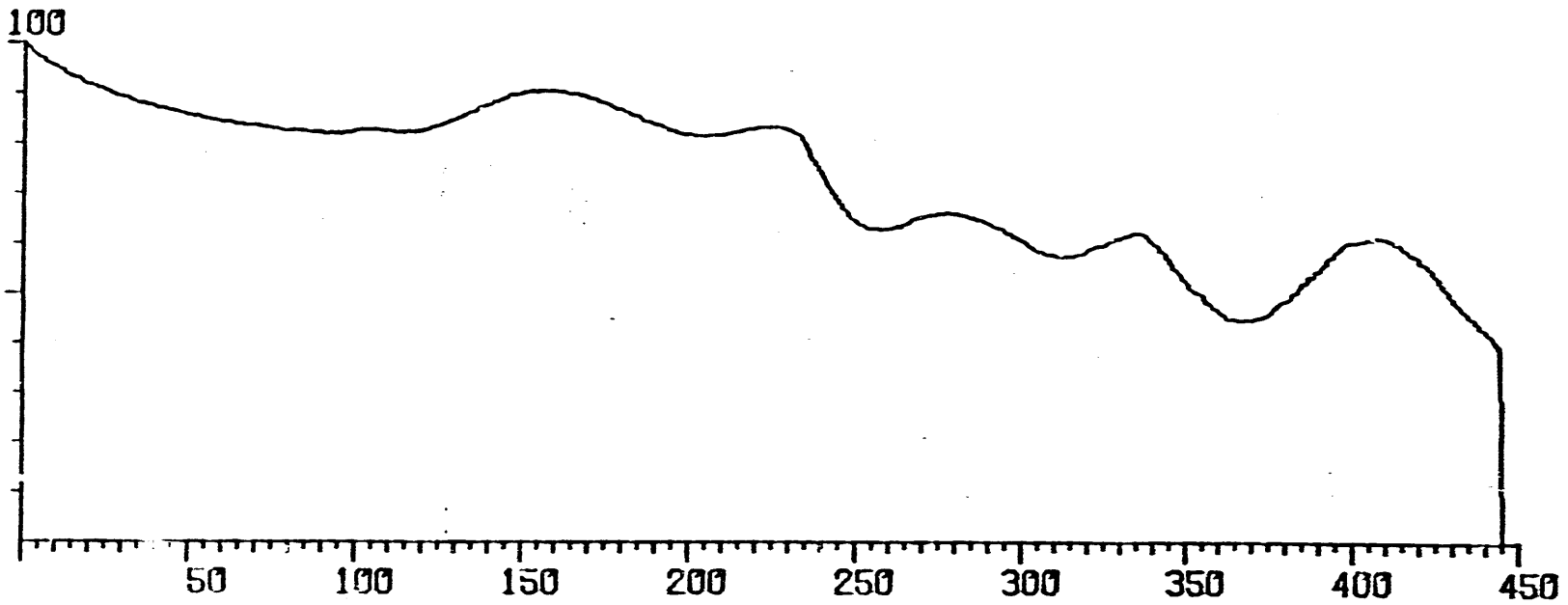




6795

SALT SAMPLE 2821.0

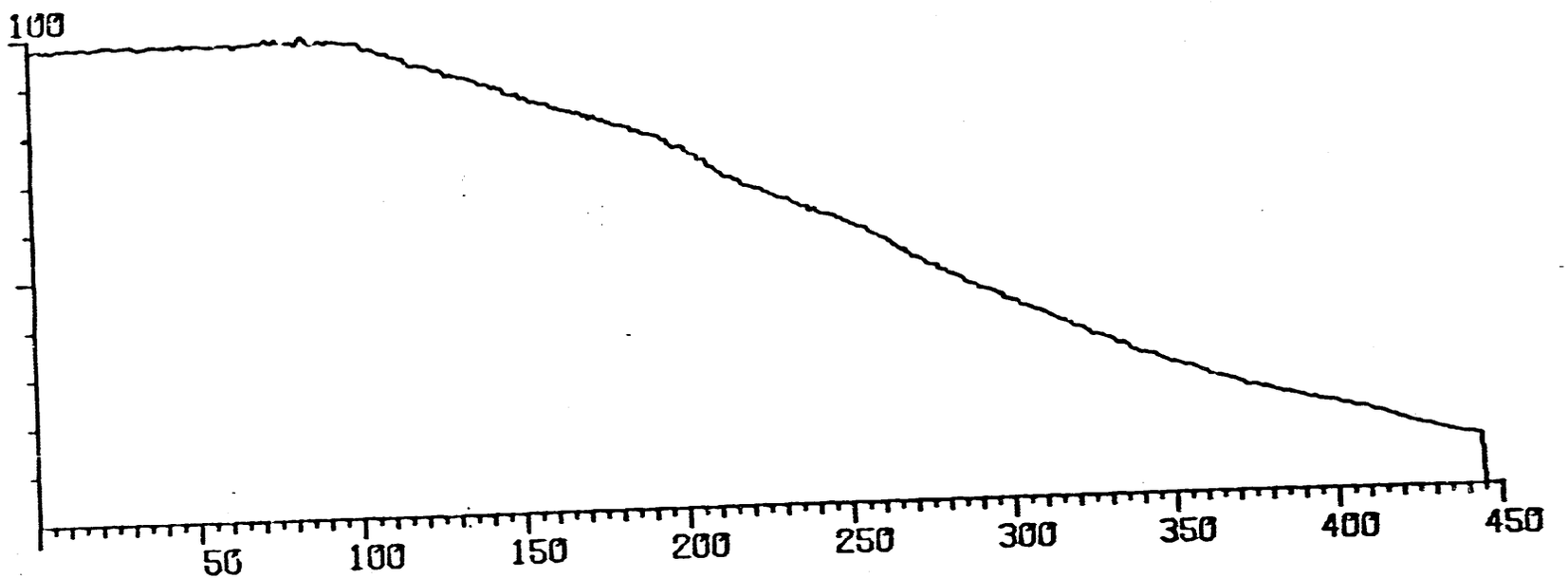
TOTAL ION CHROMATOGRAM



SALT SAMPLE

2821.0

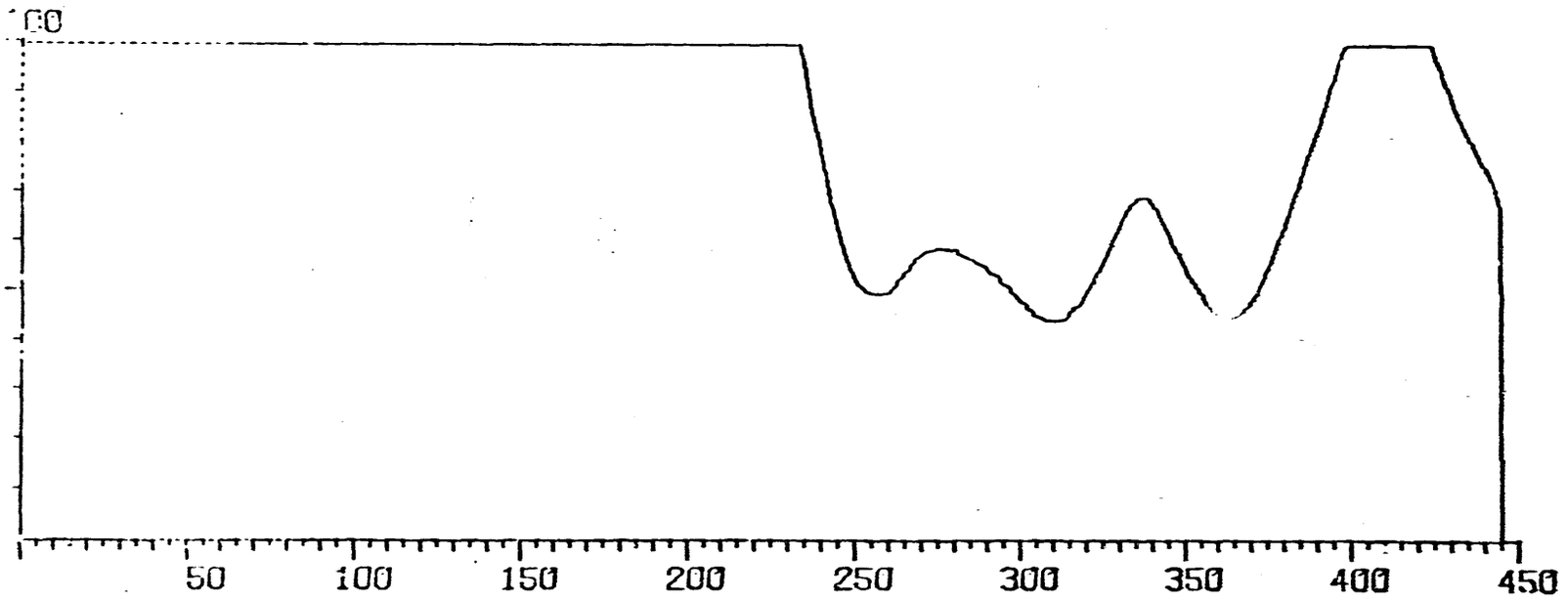
MASS 14 SEARCH X3



677

SALT SAMPLE 2821.0

MASS 18 SEARCH X4



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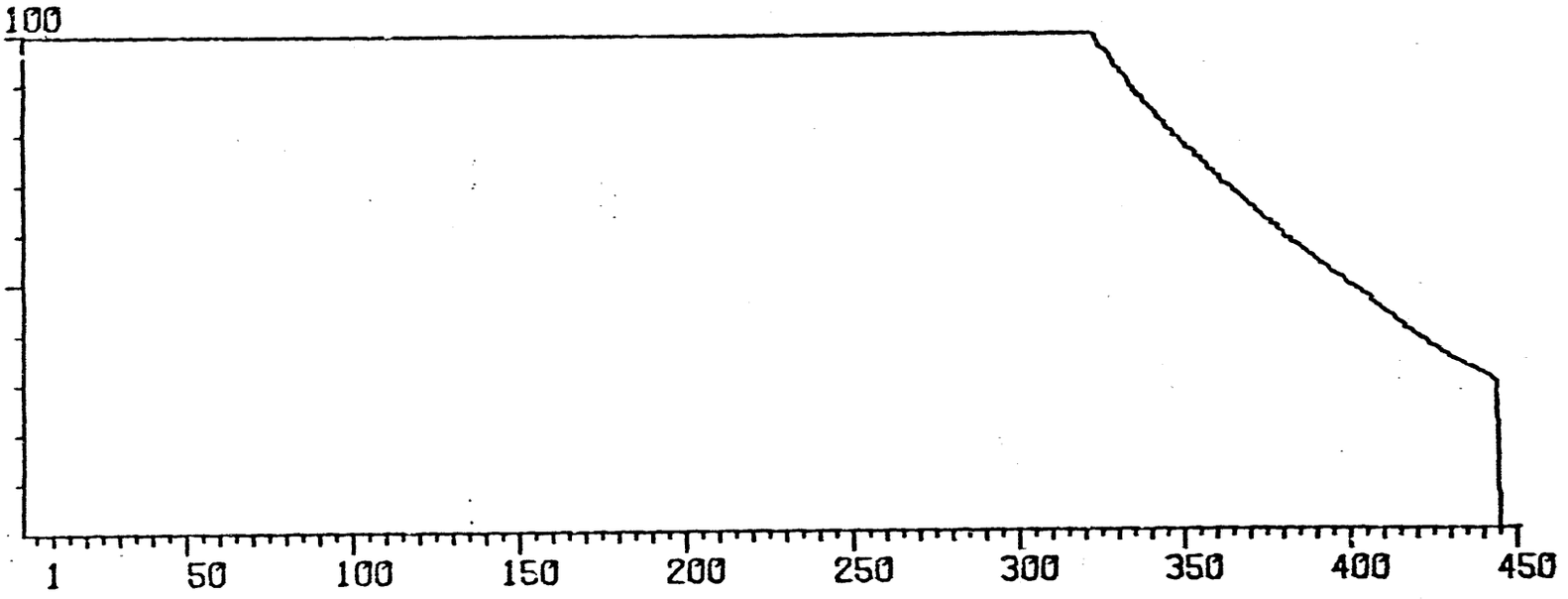
SALT SAMPLE 2821.0

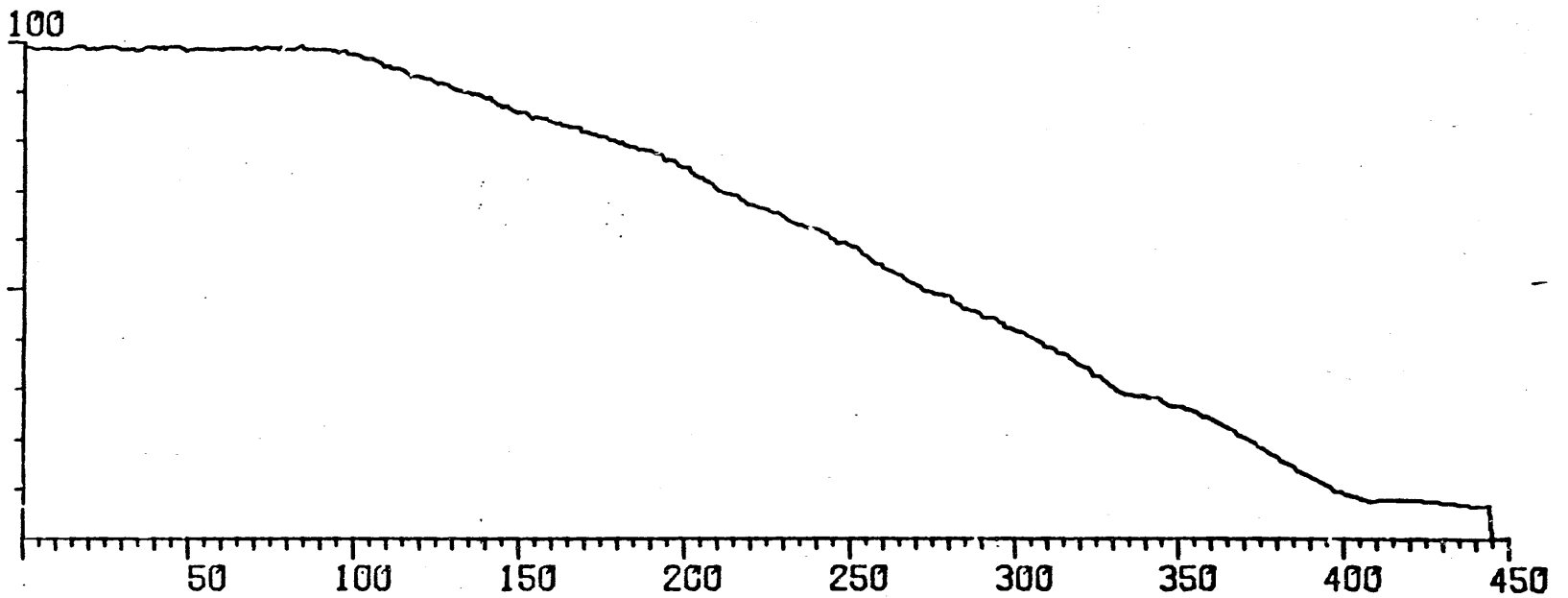
MASS 28 SEARCH X4



679

SALT SAMPLE 2821.0

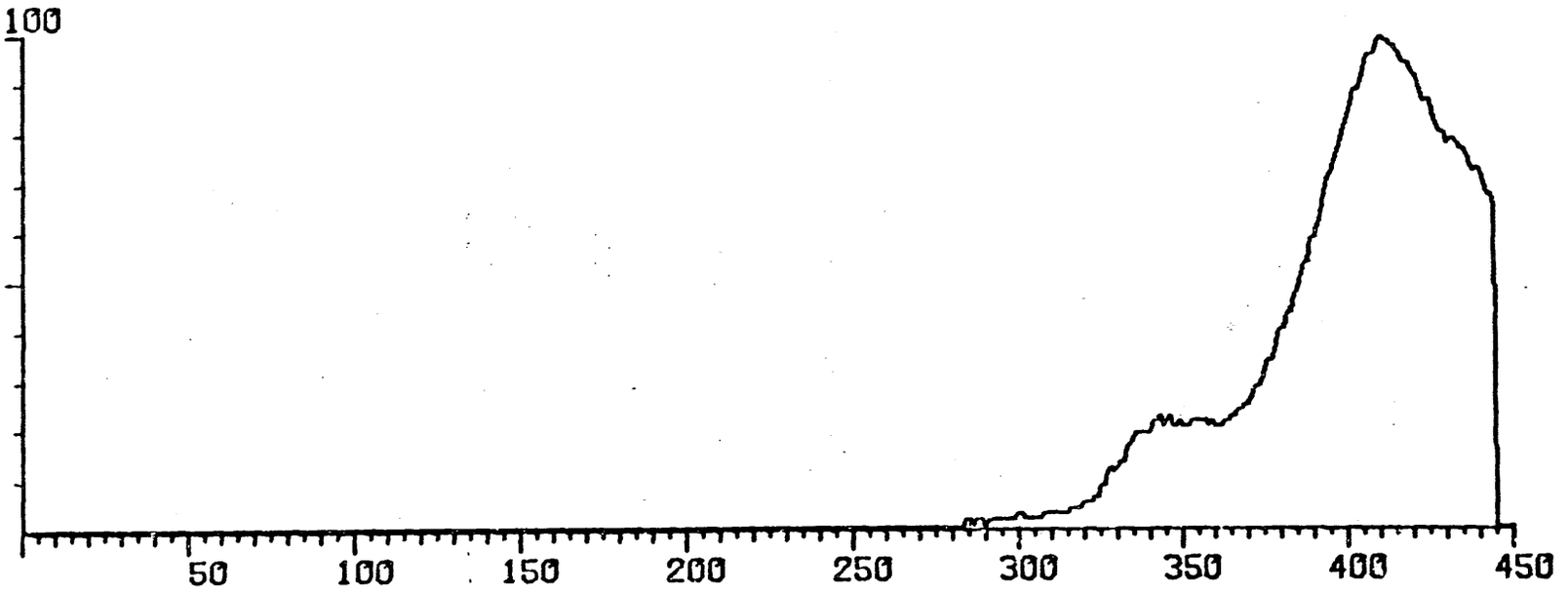
MASS 32 SEARCH X4



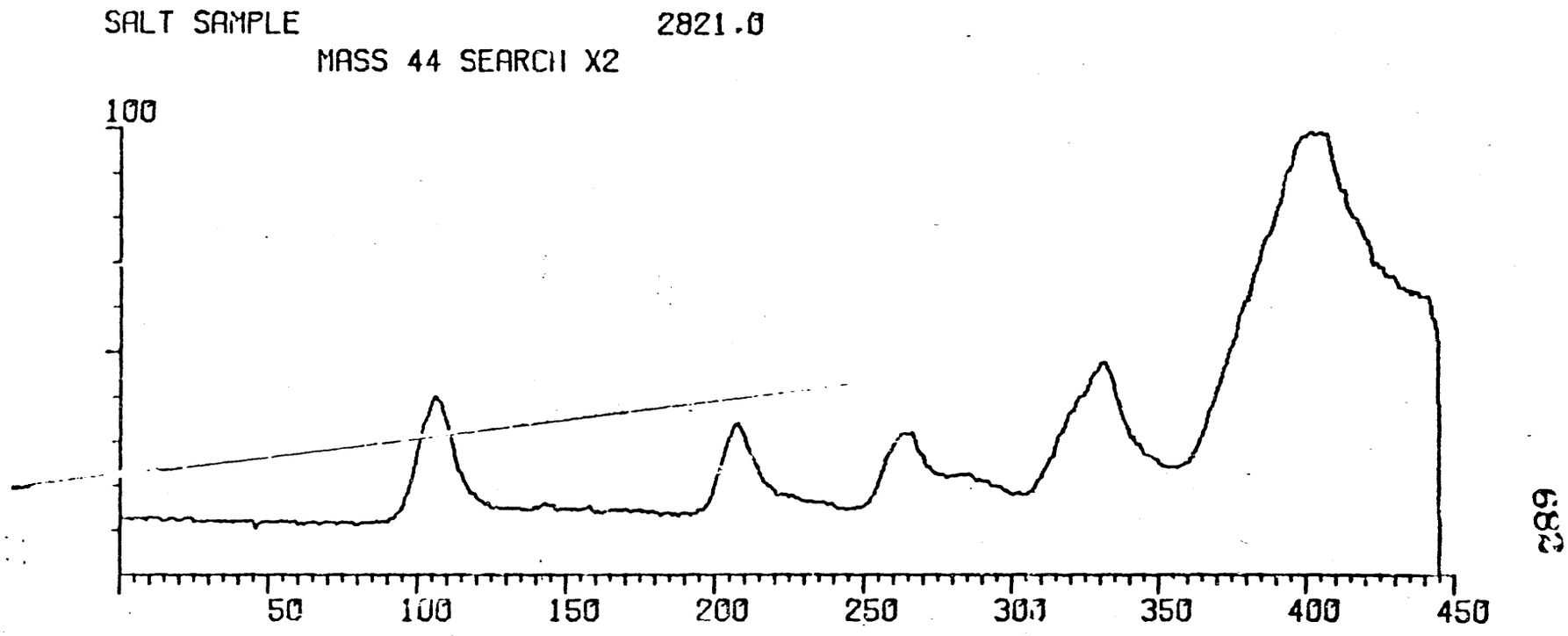
CS3

SALT SAMPLE 2821.0

MASS 36 SEARCH X2



691


SALT SAMPLE
2821.0
MASS 44 SEARCH X2
100
50
100
150
200
250
300
350
400
450

APPENDIX 7.F. Analytical Precision. (Ref. Sec. 7.5)

1. General statement concerning sample sizes, weigning errors, etc.

The sample weights used in this study ranged from approximately 0.5 to 2.5 grams, but typically were from 1.5 to 2.0 grams. The sample bottles were weighed before each new batch of samples was prepared, and both the sample bottles and the combined sample bottle and sample were weighed two times or more. Replicate weighings errors should result in a precision of no worse than ±0.1 to 0.2 weight %.

2. Results of triplicate analyses on selected samples.

Triplicate analyses were performed on separate splits taken from the sample vial using different initial sample weights each time. The results are tabulated below:

Sample	Weight Losses Determined (Wt. %)			Mean to Nearest 0.1%
7-1044	0.1	0.1	0.3	0.2
7-1296	1.3	0.9	1.3	1.2
8-1794	1.2	1.4	1.2	1.3
8-1986	0.0	0.0	0.1	0.0
8-2563	2.0	2.3	1.9	2.1
8-2616	0.0	0.0	0.0	0.0

The results of these analyses indicate that most weight losses determined from replicate samples (taken from the same sample bottle) fall within ±0.2 to 0.3 of the mean value. Because of vertical and lateral variation in mineral content typical of sedimentary rocks the range anticipated for different samples of the same core would be larger, but it is not possible to estimate the precision under such non-reproducible conditions. In the case of relatively uniform samples (such as some halite or anhydrite beds) the precision might be anticipated to remain fairly good. On the other hand, samples which contain varying amounts of clays or other hydrous minerals might be expected to show much larger variations in their weight losses upon heating.

APPENDIX 7.G. Weight Loss Data for Cores #7 and #8, Carlsbad, New Mexico, Including Comparisons with the Data of Section 7.3. (Ref. Sec. 7.5)

1. Core #7.

Sample (ft)	Depth (m)	Weight Losses at 102 ± 5°C (Wt.%)	@70°C	Data from Section 7.3 To 200°C	To Above 400°C
1044	318.2	0.1	0.10	0.10	0.10
1107	337.4	1.0	0.12	0.22	1.99
1171	356.9	0.1	0.14	0.14	0.80
1221	372.2	0.2	0.30	0.44	0.51
1342	409.0	0.2	0.27	0.27	0.43
1402	427.3	0.1	0.19	0.19	0.31
1468	447.4	2.2	1.27	1.73	2.59
1533	467.3	0.1	0.22	0.23	0.47
1615	492.3	0.2	0.34	0.43	0.80
1697	517.2	3.4	0.82	0.82	0.85
1755	534.9	0.2	0.19	0.23	0.28
1952	595.0	0.0	0.14	0.14	0.58
1954	595.6	0.6	0.32	0.32	0.41
1958	596.8	0.2	0.20	0.20	0.32
1960	597.4	0.1	0.37	0.39	0.39
1967	599.5	0.1	0.20	0.20	1.13
1969	600.2	0.2	0.43	0.51	0.71
1973	601.4	0.3	0.19	0.26	0.40
1975	602.0	0.2	0.17	0.17	0.24
1978	602.9	0.8	0.36	0.40	1.67
1983	604.4	0.0	0.29	0.32	0.51
1986	605.3	0.0	0.10	0.10	0.10
1993	607.5	0.0	0.19	0.24	1.04
2702	823.6	0.0	0.24	0.27	0.39
2716	827.8	0.2	0.22	0.22	0.26
2736	833.9	0.1	0.08	0.08	0.11

APPENDIX 7.G. Weight Loss Data, Continued.

2. Core #8

Sample (ft)	Depth (m)	Weight Losses at 102 ± 5°C (Wt.%)	Data from Section 7.3 @70°C	To 200°C	To Above 400°C
1391	424.0	0.1	0.04	0.07	0.26
1495	455.7	0.1	0.05	0.08	0.08
1573	479.5	0.2	0.04	0.33	1.18
1652	503.5	0.1	0.09	0.09	4.52
1705	519.7	0.0	0.15	0.17	0.32
1769	539.2	0.1	0.09	0.15	0.35
1787	544.7	0.2	0.32	0.36	0.59
1794	546.8	1.4	0.44	0.71	5.41
1804	549.9	0.0	0.02	0.07	0.07
1829	557.5	0.1	0.16	0.39	0.39
1838	560.2	0.3	0.39	0.39	0.39
1857	566.0	0.1	0.07	0.07	0.10
1875	571.5	1.2	0.22	0.64	0.64
1884	574.2	0.9	0.36	0.36	0.80
1890	576.1	0.1	0.05	0.05	0.13
1894	577.3	0.4	0.30	0.30	0.30
1899	578.8	0.1	0.16	0.16	0.16
1900	579.1	0.1	0.17	0.17	0.81
1905	580.6	1.0	0.36	0.36	0.62
1911	582.5	0.2	0.06	0.06	0.10
1913	583.1	0.2	0.11	0.14	0.21
1916	584.0	0.0	0.13	0.13	0.25
1923	586.1	0.1	0.19	0.19	0.49
1930	588.3	0.4	0.05	0.05	0.47
1933	589.2	0.1	0.19	0.28	0.28
1938	590.7	0.0	0.13	0.27	0.49
1953	595.3	0.1	0.05	0.10	0.42
1967	599.5	0.5	0.28	0.32	0.52
1986	605.3	0.0	0.07	0.07	5.81

APPENDIX 7.G. Weight Loss Data, Continued.

2. Core #8

Sample (ft)	Depth (m)	Weight Losses at 102 ± 5°C (Wt.%)	Data from Section 7.3 @70°C	To 200°C	To Above 400°C
2006	611.4	0.1	0.20	0.20	0.66
2017	614.8	0.2	0.22	0.24	0.41
2039	621.5	0.1	0.21	0.26	1.02
2050	624.8	0.0	0.11	0.11	0.79
2068	630.3	0.1	0.04	0.04	0.14
2084	635.2	0.3	0.17	0.22	0.71
2130	649.2	0.0	0.11	0.18	0.28
2152	659.0	0.1	0.14	0.14	0.62
2217	675.7	0.1	0.04	0.04	0.44
2280	694.9	0.0	0.19	0.19	0.27
2326	709.0	0.1	0.11	0.14	0.70
2366	721.2	1.9	0.43	0.43	6.84
2427	739.7	0.0	0.03	0.03	0.43
2460	749.8	0.0	0.17	0.22	0.37
2519	767.8	0.0	0.08	0.08	0.14
2563	781.2	2.3	1.87	2.13	2.24
2616	797.4	0.0	0.21	0.21	0.27
2666	812.6	0.0	0.25	0.25	0.73
2707	825.1	0.6	0.16	0.16	1.66
2758	840.6	0.0	0.11	0.11	0.16
2779	847.0	0.2	0.21	0.21	0.21
2793	851.3	0.0	0.18	0.18	0.18
2803	854.4	0.0	0.10	0.12	0.14
2809	856.2	0.0	0.15	0.24	0.48
2821	859.8	0.2	0.18	0.18	0.36
2879	877.5	0.2	0.06	0.06	3.37
2948	898.6	0.1	0.20	0.22	0.26

APPENDIX 7.G. Weight Loss Data, Continued.

3. Weight losses determined at higher temperatures for selected samples from Core #8.

Sample (ft)	Depth (m)	Weight Losses (± 0.1 to 0.2 Weight %) 102 ± 5°C	170 ± 5°C	300 ± 10°C
1804	549.9	0.0	0.0	0.2
1829	557.5	0.1	0.2	0.4
1875	571.5	1.2	1.8	2.2
1884	574.2	0.9	1.0	1.3
1923	586.1	0.1	0.1	0.2
1967	599.5	0.5	0.5	1.4
2050	624.8	0.0	0.0	0.7
2366	721.2	1.9	2.0	4
2948	898.6	0.1	0.2	0.2

Note: In this set of weight loss determinations, one split from each sample selected was heated to successively higher temperatures.

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APPENDIX 7.H. Mineralogy and Petrology of Core #7 and #8.

1. Abbreviations used.

Minerals In the summaries which follow the approximate amounts of the minerals present are indicated by upper and lower case letters. AN + MAJOR (> 25%); An + Minor (5 to 25%); an = trace (< 5%. Often less than 1%)

AN	=	Anhydrite	HA	=	Halite
CAR	=	Carnallite	KAIN	=	Kainite
CEL	=	Celestite	PH	=	Polyhalite
CSSM	=	Clay and silt-sized minerals (often magnesitic)	QTZ	=	Quartz
			SYL	=	Sylvite
FELD	=	Feldspar(s)			
GLAU	=	Glauconite			
GYP	=	Gypsum			

Grain Sizes

fg	=	Fine grained (< 1 mm)
mg	+	medium grained (1 mm to 1 mm)
cg	=	coarse grained (> 1 cm)

With the exception of halite, which shows a wide range of grain sizes, most of the minerals observed are fine grained.

APPENDIX 7.H. Mineralogy and Petrology, Continued.

2. Core #7

Depth (ft)	Description
1044	cg HA with An and cssm in patches and stringers. An also in isolated crystals and crystal clusters.
1107	f- to mg HA with mg gyp which is partially replaced by An. fg to mg ph in patches and stringers along with cssm.
1171	Appears macroscopically bedded. Primarily vuggy AN. Voids filled with radial ("starbursts") of ph and also with ha and cssm.
1221	cg HA. Patches and stringers filled with ph (radial in part) and an. Some evidence of ph replacing an.
1296	mg to cg HA with Cssm, ph and possibly some an in patches and stringers. Some of the Cssm appears intergranular among HA crystals. May represent subaerial deposition.
1342	mg to cg HA with ph and cssm in patches and stringers.
1402	mg HA. ph (radial in part) and an in patches and stringers and as crystal clusters.
1468	mg HA with much intergranular Cssm. Possibly represents subaerial deposition. Trace an and ph as isolated crystals and crystal clusters. Some authigenic quartz and feldspar.
1533	mg to cg HA with poorly preserved hoppers. Ph in patches and stringers, some possibly intergranular with HA. Trace Cssm associated with the Ph.
1615	mg to cg HA with hoppers. fg to mg An and ph in patches and stringers. ph appears to be replacing An, some of which may be psuedomorphic after gypsum.
1697	Appears to be macroscopically bedded. Large. nodular masses of AN (possibly pseudomorphic after gypsum nodules) with voids filled with Cssm, Ph, ha and syl. Ph associated with Cssm; syl associated with Ph.

APPENDIX 7.H. Mineralogy and Petrology, Continued.

2. Core #7, continued

Depth (ft)	Description
1755	mg to cg Ha with poorly preserved hoppers. ph and an in patches and stringers. ph replaces an in part. Perhaps a little syl is present.
1952	Appears macroscopically bedded. mg to cg HA with hoppers. Ph and an in patches, stringers and as isolated crystals and clusters. Ph replacing an in part.
1954	mg to cg HA with Cssm in patches and stringers. Some Cssm is intergranular with HA. May represent subaerial deposition. Some isolated crystals and clusters of ph associated with Cssm.
1958	mg to cg HA. cssm in patches and stringers. (Some cssm may be intergranular). ph and possible an in patches and stringers associated with cssm and also in isolated crystals and clusters.
1960	Possibly macroscopically bedded. fg to cg HA with hoppers. Intergranular Cssm with associated authigenic qtz and feld. May represent suberial deposition. Some isolated crystals and clusters of ph and an.
1967	mg to cg HA with poorly preserved hoppers. ph in patches and stringers shows some evidence of flow or deformation. A few isolated crystals and clusters of an.
1969	fg to cg HA with poorly preserved hoppers. Intergranular Cssm with associated authigenic qtz and feld. Isolated crystals and clusters of an and lesser ph.
1973	cg HA with very few patches and stringers of cssm, ph and even some ha crystals.
1975	cg HA with ph, cssm and an in patches and stringers. ph appears to be replacing an. ph associated with cssm.
1978	mg to cg HA with intergranular Cssm and ph. May represent subaerial deposition. Some ph in patches and stringers and as isolated crystals and clusters. Some ph is mg. Isolated crystals of an are associated with the ph.

APPENDIX 7.H. Mineralogy and Petrology, Continued.

2. Core #7, continued

Depth (ft)	Description
1983	mg to cg HA with hoppers. Ph and an in patches and stringers Ph replacing an.
1986	mg to cg HA with small amounts of ph, an and cssm in patches and stringers.
1993	cg HA with hoppers. Ph and an in patches and stringers. (Some Ph and an may be intergranular). Ph appears to replace an.
2702	mg to cg HA with An and cssm in patches and stringers.
2716	mg to cg HA with hoppers. an and cssm in patches and stringers, some possibly intergranular with HA. May represent subaerial deposition.
2736	mg to cg HA with hoppers. An and cssm in patches and stringers, some possibly intergranular with HA. May represent subaerial deposition.

APPENDIX 7.H. Mineralogy and Petrology, Continued.

3. Core #8

Depth (ft)	Description
1391	cg HA with ph and possibly some an in patches and stringers.
1495	mg to cg HA with hoppers. Ph associated with cssm in patches and stringers. Some may be intergranular. Ph shows evidence of flowage or deformation.
1573	Appears macroscopically bedded. mg to cg HA with Ph and fg to mg An in large patches. Ph appers to be replacing An.
1652	Appears macroscopically bedded. fg to mg AN with Ph. mg Ha in patches or voids. Some syl associated with Ph. Algal laminations may be present in the An.
1705	fg to cg HA with hoppers. Ph in patches and stringers; some may be intergranular. Small amount of an associated with Ph.
1769	mg to cg HA with poorly preserved hoppers. fg to mg Ph in patches and stringers and intergranular with HA. In part, Ph appears to be replacing HA. Some gyp (?) may be present in very small amounts. There also may be trace amounts of cel (?).
1787	mg to cg HA with hoppers. Ph in patches and stringers and some intergranular with HA. Some mg, acicular an crystals and mg, acicular cel (?) crystals noted. There may be a small amount of gyp (?) present in this slide.
1794	Appears macroscopically bedded. fg to mg HA with hoppers. CSSM is intergranular with HA. May represent subaerial deposition. Also noted: a few isolated ph crystals, some authigenic qtz and feld, and a trace of glau (?).
1804	fg to cg HA with poorly presrved hoppers. CSSM is intergranular with HA. May represent subaerial deposition. ph in isolated crystals and cluters.
1829	cg HA with hoppers. Cssm in patches and stringers and some intergranular. Possible subaerial deposition. Trace of ph.

APPENDIX 7.H. Mineralogy and Petrology, Continued.

3. Core #8, continued

Depth (ft)	Description
1838	fg to mg HA with poorly preserved hoppers. Cssm intergranular with HA. Ph and An in patches and stringers and associated wtih the Cssm. May represent subaerial deposition.
1857	cg HA with poorly preserved hoppers. ph along stringers.
1875	Apperas macroscopically bedded. fg to mg HA intergranular with CSSM. May represent subaerial deposition. Isolated crystals and clusters of ph and fg to mg an. Traces of authigenic qtz and feld.
1884	fg to mg HA with hoppers, intergranular with CSSM. May represent subaerial deposition. Some isolated crystals and clusters of fg to mg an (some may be pseudomorphic after gyp . Possible trace of syl.
1890	mg to cg HA with hoppers. ph and an in patches and stringers.
1894	mg to cg HA with poorly preserved hoppers. ph and an in patches and stringers. cssm in patches and stringers with authigenic qtz and feld.
1900	fg to cg HA with hoppers. Ph, An and cssm in patches and stringers and some intergranular with HA. May represent subaerial deposition. Some Ph appears to be deformed or to have flowed.
1905	mg to cg HA with patches and stringers and some intergranular Cssm. (May represent subaerial deposition). Scattered, isolated crystals of ph and an.
1910	mg to cg HA with poorly preserved hoppers. Ph, an and cssm intergranular with HA and in patches and stringers. Ph apperas to be replacing an.
1911	mg to cg HA with hoppers. Ph, An and cssm in patches and stringers, some intergranular with HA. (May represent subaerial deposition). Ph appears to be replacing an.

APPENDIX 7.H. Mineralogy and Petrology, Continued.

3. Core #8, continued

Depth (ft)	Description
1913	fg tc cg HA with intergranular Cssm. Inclusions of ha in Cssm. May represent subaerial deposition. Isolated crystals of ph. A few authigenic grains of qtz and feldspar.
1916	cg HA with poorly preserved hoppers. ph and an in patches and stringers.
1923	fg to cg HA with intergranular Cssm. May represent subaerial deposition. ph and an in patches and stringers and as isolated crystals. Trace authigenic feld
1930	mg to cg HA with poorly presrved hoppers. Ph and an in patches and stringers, some as isolated crystals. cssm in patches and stringers. Possible trace gyp (?).
1933	cg HA with hoppers. cssm, ph and an in patches and stringers. Small amounts of authigenic qtz and feld (?).
1938	cg HA with poorly preserved hoppers. Ph and an in patches and stringers.
1953	fg to mg HA with hoppers. Cssm intergranular with HA and in patches and stringers. May represent subaerial deposition. Isolated crystals and clusters of ph and an.
1967	fg to cg HA with hoppers. Cssm intergranular with HA and in patches and stringers. May represent subaerial deposition. Isolated crystals and clusters of ph and an.
1986	Appears cross-bedded. PH with mg AN. Ph appeas to be replacing AN. Some fine laminations may be algal lamination or traces of cssm seams. ha in patches or filling void places.
2006	fg to cg HA with hoppers. Ph and an in patches and stringers. Trace of syl associated with Ph.

APPENDIX 7.H. Mineralogy and Petrology, Continued.

3. Core #8, continued

Depth (ft)	Description
2021	mg to cg HA with hoppers. Ph and an in patches and stringers. Ph appears to be replacing an. cssm in patches.
2039	mg to cg HA with hoppers. Ph and an with cssm in patches and stringers. Much of the Ph is radial. Ph appears to be replacing an.
2050	mg AN with numerous inclusions. AN apperas to be replacing ha with former cubic crystal outlines preserved.
2068	fg to cg HA. Patches and stringers and intergranular A cssm and possible ph (?). May represent subae l deposi on.
2084	fg to cg HA with much intergranular Cssm, ph and poissible an (?). May represent subaerial deposition. Some Ha crystals appear to be growing n the Cssm.
2130	fg to mg HA with intergranul r An and minor cssm. Some ph (?) may be replacing An.
2162	cg HA with intergranular Cssm and Ph. May represent subaerial deposition. Trace of an associated with Ph. Trace of syl associated with Ph.
2217	cg HA with patches and stringers of Ph and an. Some Ph rad and replacing an. Possible syl associated with Ph.
2280	fg to cg HA with patches and stringers of Ph and an. POssible trace of kain (?).
2326	fg to cg HA with poorly preserved hoppers. Cssm intergranular with HA. May represent subaerial deposition. Isolated crystals and clsuters of ph and an. Trace authigenic feld (?).
2366	Possibly macroscopically bedded fg, radial PH with minor an. cssm scattered throughout.

APPENDIX 7.H. Mineralogy and Petrology, Continued.

3. Core #8, continued

Depth (ft)	Description
2427	fg to cg HA with poorly preserved hoppers. An and cssm in patchers, stringers, and intergranular with HA. May represent subaerial deposition, in part. Possible fossil (bryozoan) fragment.
2460	mg to cg HA with hoppers. Patches, stringers, and intergranular An and cssm. mg an in isolated crystals and clusters along the margins of the patches and stringers.
2519	mg to cg HA with poorly preserved hoppers. Patches, stringers and intergranular an ofter associated with cssm. May represent subaerial deposition.
2563	Possibly macroscopically bedded. Nodular AN with patches of Cssm. Possible mudcrack or burrow along one edge of slide normal to the bedding.
2616	fg to mg HA with poorly preserved hoppers. An intergranular with HA and as patches and stringers. May represent subaerial deposition.
2666	fg to cg HA with poorly preserved hoppers. Patches, stringers, and intergranular Cssm and an. May represent subaerial deposition.
2707	cg HA with hoppers. Patches and stringers of Cssm and an.
2758	fg to mg HA with poorly preserved hoppers. An associated wtih cssm in patches, stringers (some intergranular). May represent subaerial deposition. Some An in isolated crystals.
2779	fg to cg HA with hoppers. An and cssm in patches, stringers and intergranular with HA. May represent subaerial deposition.
2793	fg to cg HA with trace evidence of hoppers. Intergranular AN and cssm. May represent subaerial deposition. Patches and stringers of An. Traces of ph and authigenic qtz (?).

APPENDIX 7.H. Mineralogy and Petrology, Continued.

3. Core #8, continued

Depth (ft)	Description
2803	fg to cg HA with hoppers. Intergranular An and cssm. Some An in patches with possible ph (?). A few large, isolated crystals of An. May represent subaerial deposition.
2809	fg to mg HA with trace evidence of hoppers. An and cssm in patches, stringers and as intergranular material. May represent subaerial deposition.
2821	mg to cg HA with hoppers. Intergranular An and cssm. Some An in patches and stringers. May represent subaerial deposition.
2879	Possible macroscopic evidence of bedding. fg to mg HA with hoppers. Patches and stringers of An and cssm. Possible trance of ph (?). An unknown minerals with lower birefringence and positive relief was observed. Also present are some large, isolated crystals of An.
2948	Possible macroscopic evidence of bedding. mg to cg HA with hoppers. Some patches and stringers of An present. Some may be nodular (?) (possibly pseudomorphic after gyp). a few isolated crystals of ph (?) were noted.

APPENDIX 8A

Analyses of Potash for Department of Energy
(then ERDA) and Industry Boreholes in the WIPP Area

Source is Table 3, John et al., 1978

Table 1 - Calculated mineral content of selected samples

[Drill-hole no., Drill-hole designations, E, Energy Research and Development Administration; F, [illegible] Chemical Res. Dev. Corp.; IMC, International Minerals and Chemical Corp.; SPC, [illegible] and U.S.G.S., Union of America; D, [illegible]; S, [illegible]; T, Total; U.S. Potash Co., Inc.; Ar, [illegible]; Ar, arcanite; Bi, bischofite; Bl, bloedite; [illegible], Gl, glaserite; Gu, [illegible]; K, kainite; Ki, kieserite; L, langbeinite; [illegible], La, [illegible]; S, sylvite; Va, vanthoffite]

Drill-hole no.	Ore zone	Sample no.	Depths of interval (feet)	Thickness (feet)	Calculated minerals present (weight percent)						Weighted average K2O as ore zone for all intervals in ore zone (feet and percent)
					Polyhalite	Halite	Sylvite	[illegible]winite	Other minerals	[illegible] minerals (percent)	
P-1	5	9	1[illegible]9 [illegible]7-1[illegible]41.15	0.88	8	76	---	15.0	Tr/Ka	3.6/L	
	5	10	1[illegible]1 15-1[illegible]2.30	0.95	9	86	---	[illegible]4		1.0/L	
	5	11	1[illegible]2.30-1[illegible]3.50	1.20	---	79	---	---	1-2.0 Ka 1Y/81	---	
	5	12	1[illegible]3.50-1444.35	0.85	---	95	---	2.34	---	0.53/L	
	5	13	1[illegible].35-1445.30	0.95	1	79	---	17.07	---	3.83/L	4.83×1.6[illegible]/L
P-2	10	14	1627.15-1628.35	1.20	1	39	---	59.9	1.9 Ka 1.0 Le	9.05/L	
	10	15	1[illegible]6.35-1629.52	1.17	1	46	---	43.1	2.6 Ka 0.5 Le	9.78/L	2.37×9.61/L
	4	5	1[illegible]02.20-1[illegible]03.00	1.30	1	39	---	38.2	12.9 Ka	6.6/L	
	4	6	1[illegible]04.00-1[illegible]05.00	1.05	6	80	---	---	---	---	
	4	7	1[illegible]5.00-1[illegible]5.85	0.85	5	69	---	---	---	---	
	4	8	1805.85-1806.30	0.45	6	60	---	20.0	Ka Le	4.54/L	3.60×3.67/L
	2	1	1833.08-1834.00	0.92	2	7[illegible]	---	4.4	Ka	2.14/L	
	2	2	1834.00-1834.50	0.50	---	38	---	52.9	Ka	12.0/L	1.62×6.26/L
P-3	4	3	1[illegible]9[illegible] [illegible]6-1[illegible]97.60	1.30	2	72	---	24.7	0.5 Ka	5.6/L	
	4	4	1[illegible]9[illegible] 60-[illegible]95.70	1.10	2	62	---	18.6	0.5 Ka	4.2[illegible]/L	
	4	5	1[illegible]94.70-1[illegible]98.53	0.83	14	38	---	23.4	---	5.31/L	3.23×5.00/L
P-4	10	2	1572.60-1574.97	2.37	1	56	46.0	---	---	29.40/S	
	15	3	1574.[illegible]-1575.17	1.20	4	6[illegible]	27.6	---	---	17.[illegible]/S	
	10	4	1576.17-1577.77	1.60	3	86	7.0	---	---	4.1[illegible]/S	
	10	5	1577.77-1578.69	0.92	4	6[illegible]	26.0	---	---	17.66/S	6.09×18.66/S
P-5	10	6	1564.69-1566.65	1.96	6	65	28.0	---	---	18.28/S	
	10	7	1565.65-1567.[illegible]6	1.01	4	78	13.3	---	---	8.42/S	
	10	8	1566.66-1551.40	1.74	3	60	...0	---	---	13.41/S	
	11	9	1551.40-1552.[illegible]	1.35	2	65	14.5	---	---	8.14/S	6.06×13.2/S
P-6	4	12	1476.00-1477.65	1.65	6	74	---	20.0	1.0/L	5.01/L	
	4	13	1477.65-1478.57	0.92	1	83	2.0	8.0	0.0/Ka	1.90/L	
	4	14	1478.57-1480.00	1.43	3	84	---	13.0	---	1.6.5 2.78/L	4.00×3.39/L
	2	18	1510.50-1511.32	0.85	1	37	2.0	54.0	6.0 Ki	12.31/L	
	2	19	1511.3[illegible]-1512.10	0.76	---	53	---	42.2	---	9.65/L	
	2	20	1512.10-1513.05	0.95	7	29	3.0	1.0	18.6 Ka	0.19/L	2.55×6.98/L
P-7	4	2	1479.73-1481.20	1.47	2	65	1.0	29.0	---	6.53/L	
	4	3	1481.20-1482.00	1.80	---	89	2.0	1.0	---	1.79/L	
	4	4	1482.00-1482.48	0.48	3	69	2.0	3.8	5.7 Ka 1.1 Le 1.0 Bl	1.8/L	3.75×3.41/L
P-8	10	2	1361.20-1365.00	4.30	---	52	29.0	25.0	---	38.42/S	
	10	3	1365.00-1366.72	1.72	1	46	3.0	45.0	4.0 Ka 2.0 Le	5.92/L 20.1/L 1.45/S	
	10	4	1366.72-1368.05	1.33	1	96	---	14.0	---	9.23/L	4.35×6.76/L 4.35×9.17/S Mixed ore equivalent 4.35×9.27/L

Table 3 - Calculated mineral content of selected samples [illegible] (continued)

Drill-hole no.	Ore zone	Sample no.	Depths of intervals (feet)	Thickness (feet)	Calculated minerals present (weight percent)					K2O as ore minerals (percent)	Weighted average K2O as ore mineral for all intervals in ore zone (feet and percent)
					Polyhalite	Halite	Sylvite	Langbeinite	Other minerals		
P-9	10	8	1523.56-1525.41	0.85	1	42	7.0	48.0	0.0 Ka	4.73/5 10.8/L	
	10	9	1525.41-1526.07	0.66	1	93	2.0	---	3.0 Kl	0.99/5	
	10	10	1526.07-1526.70	0.63	7	17	7.0	63.37	---	8.42/5 14.33/L	
	10	11	1526.70-1526.04	1.34	1	95	---	1.10	---	0.24/L	
	10	12	1526.04-1526.74	0.70	2	65	---	31.31	---	7.17/L	4.18-5.67/L 2.14-3.44/5 mixed ore equivalent = 10.6 %-L
	4	17	1703.65-1705.23	1.58	2	70	---	28.70	---	6.51/L	
	4	18	1705.23-1706.85	0.62	1	89	---	6.83	3.0 Ka	1.55/L	2.00-3.47/L
P-10	11	1	1650.33-1651.22	0.84	6	89	1.8	---	1.0 Ka	1.13/5	
	11	2	1651.22-1652.01	0.81	7	81	6.1	---	2.0 Kl	3.83/5	
	11	3	1652.01-1653.43	1.85	5	85	7.7	---	1.0 Kl	4.85/5	3.45-3.70/5
	11	4	1653.43-1654.18	0.75	6	94	---	---	---	---	
P-11	11	2	1601 90-1603.56	1.66	---	56	5.0	---	3.63/Kl 2.0 C	3.36/5	
	11	3	1603.56-1604.64	1.08	3	61	2.0	---	31.0 Ka 2.0 C	1.48/5	
	11	4	1604.64-1605.38	0.74	4	84	3.0	---	7.0 Ka 2.0 C	2.29/5	3.48-2.52/5
	10	7	1670.70-1671.84	1.14	1	71	10.0	8.0	1.0/Kl	12.0/5 1.82/L	
	10	8	1671.84-1673.42	1.58	2	66	10.0	18.0	1.0/Kl	11.32/5 3.44/L	
	10	9	1673.42-1674.70	1.28	5	71	16.7	---	1.0/Kl	20.33/5	4.00-9.29/5 2.72-5.04/L mixed ore equivalent = 00-14.51/5
	9	14	1668.72-1669.60	0.88	1	76	22.0	---	---	13.76/5	
	9	15	1669.60-1670.84	1.24	1	64	36.9	---	---	23.30/5	
	9	16	1670.84-1671.95	1.06	1	71	21.3	---	2.0/C	13.43/5	
	9	17	1671.95-1673.28	1.33	2	92	2.0	---	1.0 C	1.24/5	4.56-12.73/5
	4	19	1842.60-1842.35	1.75	1	58	---	40.0	5.0/Kl	9.14/L	
	4	20	1842.35-1843.40	1.05	4	76	5.0	4.9	---	1.11/L 2.98/5	2.80-6.0/L
	2	22	1868.87-1870..8	1.61	1	38	2.0	60.0	2.0/Kl	13.65/L	
	2	23	1870.28-1871.13	0.85	---	54	5.0	35.0	1.0 Kl	13.53/L	
	2	24	1871.10-1872.30	1.20	---	27	---	58.3	8.0 Ka, Tr Blalo	13.2-/L	3.63-13.49/L

Table 3 - [illegible]lated mineral content of selected samples [illegible] intervals [illegible] Carlsbad [illegible] (Continued)

Drill-hole no	Ore zone	Sample no	Depths of interval (feet)	Thickness (feet)	Use (Associated minerals present (weight percent) Polyhalite	Halite	Sylvite	Langbeinite	Other minerals	K2O as ore mineral (percent)	Weighted average K2O as ore mineral for all intervals in ore zone (feet and percent)
	10	24a	[illegible]	0.3	4	36	42.3	---		1.0 KCl	39.38 S
	10	24b	[illegible]	0.63	---	10	2.0	---		58.0 KCl	15.09 S
	10	3	[illegible]	1.45	1	59	18.0	---		18.0 KCl	11.39 S
	10	4	[illegible]	1.45	3	64	18.0	---		19.0 KCl	11.36 S
	10	5	1348 60-1349 01	1.01	2	66	22.0	---		8.0 KCl	
										8.2 Kieserite	1.61 S
	10	6	1349 01-1350 00	0.99	3	67	18.0	---		2.0 Kieserite	1.42 S 5.81-13.29 S
	8	14	1349 10-1350	0.78	4	59	15.5	---		---	0.72 S
	8	15	1349 85-1350	1.69	7	66	7.0	---		---	1.32 S
	8	16	1350 00-1351	1.63	4	68	10.5	---		---	0.45 S
	8	17	1350 20-1351 63	0.61	8	51	15.5	---		---	22.45 S 6.21-8.26/S
	6	21	1520 00-1521 55	1.55	1	22	23.5	45.0		9.5 KCl	14.47 S
											10.11 L
	6	22	1521 55-1522 39	0.84	10	48	7.0	6.0		16.5 Kieserite	1.44 L 2 10.7 OR L
										10.0 Langbeinite	4.47 S 2 10.10 S-/S mixed ore equivalent
											2 00.8 23/L
	3	26	1533 53-1535 05	1.25	---	40	11.0	49.0		---	1.01 S
											0.50 L
	3	27	1535 05-1535 59	0.54	36	66	1.0	6.0		1.0 KCl	1.63 L
											0.62 S 3 51.5 98/L
	1	28	1535 [illegible]-1537 71	1.42	2	47	10.0	21.0		---	0.70 L 3 51.5 74/S
											0.32 S mixed ore equivalent: 3 51.8 27/L
	2	34	1549 70-1550 65	0.84	3	85	---	11.0		---	3.54 L
	2	35a	1550 65-1551 29	0.64	---	20	5.0	70.0		--- Kieserite	
										5.0 Langbeinite	15.93 L
	2	35b	1551 29-1551 61	0.32	---	21	5.0	30.0		5.0 Kieserite	
										14.0 Langbeinite	
										17.0 KCl	12.4 L 1 52.8 05/L
P-13	10	29	1330 02-1330 60	0.98	1	46	49.5	---		---	51.0 S
	10	30	1330 60-1331 42	1.22	1	62	17.0	2.0		15.0 KCl	10.92 S
	10	31	1331 22-1332 98	0.66	3	91	---	---		---	---
		32*	1331 88-1332 87	0.99	1	33	41.0	10.0		15.0 KCl	12.6 S 3 65.14 67/S
										15.0 Kieserite	2.2 L
	9	36	1334 62-1335 16	1.54	2	94	4.0	---		---	2.12 S
	9	37	1335 16-1335 [illegible]	0.96	2	62	34.0	---		---	21.88 S
	9	38	1335 [illegible]-1338 04	1.32	---	91	1.0	---		---	2.41 S 3 82.6 2/S
	8	21	1355 65-1356 63	0.98	2	77	11.0	---		---	19.11 S
	8	22	1356 63-1358 [illegible]	1.37	8	82	4.0	---		---	4.67 S 2 05.11 74/S
	4	2	1440 20-1441 [illegible]	1.51	2	82	2.0	3.0		3.0 KCl	2.74 L
	4	3	1441 [illegible]-1442 [illegible]	1.73	1	61	---	2		2.0 Langbeinite	1.54 L 3 51.4 06/L
	4	4	1442 [illegible]-1443 73	0.95	1	64	---	5		5.0 KCl	1.58 L

Table 3 - Calculated mineral content of selected samples from classified stratigraphic intervals with correlation of percent K_2O as ore mineral--Continued

Drill-hole no.	Ore zone	Sample no.	Depths of interval (feet)	Thickness (feet)	Calculated minerals present (weight percent)					K_2O as ore minerals (percent)	Weighted average K_2O as ore mineral for all intervals in ore zone (feet and percent)
					Polyhalite	Halite	Sylvite	Langbeinite	Other minerals		
	3	8	1493.23-1493.88	0.65	1	86	---	7.0	---	1.59/L	
	3	9	1493.88-1494.58	0.70	---	15	---	53.0	---	12.06/L	
	3	10	1494.58-1495.50	0.92	3	86	---	10.0	---	2.21/L	2.27-5.07/L, 4.00-2.88/L[3]
P-14	10	2	1255.24-1255.64	0.40	---	41	57.0	---	---	36.03/L	
	10	3	1255.64-1257.56	1.92	---	41	57.3	---	---	26.76/S 8.84/S	
	10	4	1257.56-1259.07	1.51	3	64	14.0	18.0	Tr/Ka[1]	3.99/L	
	10	5	1259.07-1260.15	1.08	4	74	7.0	22.0	---	4.36/S 4.88/L	
	10	6	1260.15-1261.05	0.90	2	53	22.0[6]	---	16.0/Ka	6.21/S	5.81-18.47/S 2.59-6.76/L mixed ore equivalent: 5.81-23.33/S
	5	10	1364.44-1366.11	1.67	5	74	5.0	15.0	1.0/Ka	3.35/L 1.00/S	
	5	11[4]	1366.11-1367.86	1.75	3	83	---	10.0	Tr/Ka[1]	4.3/L	
	5	12[4]	1367.86-1369.26	1.40	1	80	---	15.0	Tr/Ka[1]	5.03/L	4.82-5.40/L 1.6*-3.0/S mixed ore equivalent: 4.82-4.02/L
	4	18	1440.79-1441.98	1.19	4	46	6.0	38.5	---	8.74/L 3.99/S	
	4	19	1441.98-1442.84	0.86	5	95	---	---	---	---	
	4	20	1442.84-1443.98	1.14	16	56	4.0	23.0	Tr/La 2.0/Ka	5.23/L 2.53/S	
	4	21	1443.98-1444.61	0.63	3	88	---	11.0	---	2.50/I	3.82-4.69/L 3.19-2.39/S
P-13	4	7	1371.94-1372.81	0.87	6	76	---	25.0	---	5.59/L	
	4	8	1372.81-1374.77	1.96	8	89	---	4.0	---	1.00/L	
	4	9	1374.77-1375.80	1.03	9	64	---	28.0	---	6.37/L	3.84-5.45/L
	2	13	1399.66-1400.38	0.72	3	64	---	32.0	4.0/Ka	7.8/L	
	2	14	1400.38-1401.51	1.13	---	78	---	17.0	3.0/Ka 3.0/La	4.18/L	1.85-5.61/L
P-16	10	4	1301.94-1302.57	0.63	3	53	0.7	4.0	---	0.73/S 0.89/L	
	10	5	1302.57-1303.91	1.34	3	79	---	21.0	---	4.77/L	
	10	6	1303.91-1304.39	0.48	---	61	---	34.0	5.1/Ka 8.0/La Tr/Ki[1]	7.77/L	2.45-4.63/L
	4	10	1476.76-1478.40	1.64	---	36	2.0	51.0	Tr/Ka&La[1]	12.01/L 1.28/S	
	4	11	1478.40-1478.95	0.55	2	86	---	8.7	---	1.98/L	2.19-9.49/L
	4	12	1490.12-1491.00	0.88	1	83	1.0	14.1[7]	---	4.94/L	
	4	13	1491.00-1491.56	0.56	0	39	7.0	19.7[7]	---	4.40/L 4.13/S	
	4	14	1491.44-1492.64	1.08	7	79	---	12.0	---	2.75/L	
	4	15	1492.64-1493.89	1.25	2	56	3.0	31.0	6.0/La 2.0/Ka	7.0?/L 3.09/S	3.77-4.93/L

Table 1 [illegible] mineral content of selected samples [illegible] as ore mineral [illegible]

Drill-hole no.	Ore zone	Sample no.	Depths of interval (feet)	Thickness (feet)	Calculated minerals present (weight percent)						Weighted average H_2O as ore mineral for all intervals in ore zone (feet and percent)
					Carnallite	Halite	Sylvite	Langbeinite	Other minerals	H_2O as ore mineral (wt. percent)	
P-16	2	19	1526.90-1528.00	1.10	1	51	1.0	43.0	2.0% kainite	5.09%	1.10×9.60/L
P-17	10	2	1365.60-1367.20	1.6	1	37	...	58.8	...	15.81 L	
	13	3	1367.20-1368.45	1.25	1	76	...	12.6	2.0% kainite	2.81% L	
	10	4	1368.45-1369.70	1.25	1	44	...	6.64	10.0% Langbeinite, 0.5% Tr/Ka	1.91 L	4.10×1.43/L
	4	8	1542.90-1543.68	0.78	...	44	...	36.0	13.0% Langbeinite, Tr/Ka	6.62% L	
	4	9	1543.68-1544.46	0.78	...	43	...	53.0	2.0% Langbeinite	12.03% L	1.56×10.33/L
	2	18	1591.19-1592.71	1.52	1	44	...	46.0	1.0% Kainite	10.49 L	
	2	19	1592.71-1594.21	1.50	4	83	...	2.6	2.0% Kainite	0.53% L	2.12×5.18/L
P-18	10	3	1728.40-1728.78	0.38	2	61	33.0	34.0	...	23.63% 7.94% L	
	10	4	1729.78-1730.45	1.67	3	86	3.0	...	...	5.61% L	
	13	5	1730.45-1731.49	1.04	6	62	0.72	...	...	0.45% L	
	10	6	1731.49-1732.29	0.80	4	74	0.81	...	...	0.51% L	3.89×.46% 14.7 4. L Mixed ore equivalent 3.89×6.4%
P-19	13	7	1741.80-1742.35	0.55	1	55	6.70	38.0	...	23.5% 8.[illegible] L	
	10	8	1742.35-1743.73	1.38	1	36	2.0	59.0	...	1.2% L	
	10	9	1743.73-1745.04	1.17	4	61	1.0	15.0	...	2.5% L	
	10	10	1745.04-1746.00	0.41	2	53	...	39.0	8.0% Langbeinite, 2.0% Kainite	9.21%	4.20×1.03/L
	4	21	1925.20-1925.90	0.70	1	74	...	11.0	1.0% Kainite	2.5% L	
	4	22	1925.90-1926.70	0.80	1	27	...	57.0	2.0% Kainite	12.93 L	
	4	23	1926.70-1927.94	1.24	2	62	...	3.6	9.0% Langbeinite, 5.0% Kainite, Tr/Ka	0.82% L	2.24×.29/L
	2	26	1956.40-1957.36	0.96	6	64	1.0	16.0	13.0% Kainite, Tr/Ka	3.54% L	
	2	27	1957.36-1958.71	1.35	1	29	...	65.0	Tr/Ka	14.63 L	
	2	28	1958.71-1959.21	0.50	0.5	61	...	25.0	Tr/Ka	5.72% L	2.51×0.42/L
P-20	10	2	1725.00-1726.15	1.15	2	32	31.2	Tr/L	...	13.43%	
	10	3	1726.15-1727.10	1.45	4	65	7.0	35.0	...	4.62% 8.[illegible] L	
	10	4	1728.10-1729.62	1.52	1	60	28.0	...	6.0% Langbeinite	17.63%	1.45 8.01/L
	10	5	1729.62-1731.46	1.84	3	69	14.0	...	...	21.48%	6.51×1.03/L Mixed ore equivalent: 6.51×2.01/L
	14	10	1898.90-1900.45	1.45	5	33	1.0	37.0	5.0% Kainite	8.35 L	
	4	11	1900.45-1901.77	1.32	16	55	...	1.3	...	3.30 L	
	4	12	1901.77-1902.35	1.58	10	74	...	17.7	...	4.07% L	4.55×.57/L

Table 3.--Calculated mineral content of selected samples from potassium-bearing intervals with [illegible] of K_2O as ore mineral--continued

Drill-hole no.	Ore zone	Sample no.	Depths of interval (feet)	Thickness (feet)	Calculated minerals present (weight percent): Polyhalite	Halite	Sylvite	Langbeinite	Other minerals	K_2O as ore minerals (percent)	Weighted average K_2O as ore mineral for all intervals in ore zone (feet and percent)
P-20	2	14[4]	1925.08-1926.30	1.22	3	95	...	0.88	...	0.2/L	
	2	15	1926.30-1927.75	1.45	1	61	...	35.5	...	8.05/L	2.67-4.40/L
P-21	10	2	1644.03-1644.8	0.81	4	80	17.0	...	...	10.82/S	
	10	3	1644.34-1646.03	1.16	4	81	11.8[6]	...	2.0/Kl	7.46/S	
	10	4	1646.00-1646.33	0.33	1	28	20.2[6]	...	42.0/Kl	12.76/S	
	10	5	1646.33-1647.20	0.87	1	41	25.5[6]	...	18.0/Kl	16.14/S	
	10	6	1647.20-1648.22	1.02	1	62	29.5[2]	...	1.0/Kl	18.64/S	
	10	7	1648.22-1649.23	1.01	3	64	31.3	...	...	19.31/S	5.10-14.37/S
	8	15	1685.17-1686.48	1.31	0	55	45.0[6]	...	...	2[illegible]/S	
	8	16	1686.48-1687.20	0.72	4	83	6.0[6]	...	...	3.72/S	
	8	17	1687.20-1688.24	1.04	5	92	3.0	...	...	1.95/S	
	8	18	1688.24-1688.77	0.53	4	95	0.8	...	...	0.52/S	
	8	19	1688.77-1690.19	1.42	6	86	9.9	...	...	6.24/S	
	8	20	1690.19-1691.26	1.07	8	90	1.0	...	...	0.75/S	
	8	21	1691.26-1692.40	1.14	3	65	33.0	...	...	21.11/S	
	8	22	1692.40-1693.34	0.94	5	65	13.0	...	...	8.18/S	8.17-10.24/S
	4	24	1809.90-1811.50	1.60	0	31	3.0	64.0	2.5/Ka 3.9 Le	14.60/L	1.92-14.69/L
	4	25	1811.50-1811.82	0.32	0	18	5.0[2]	54.66	9.0/Kl 10.63/Le	15.12/L	4.00-7.05/L
	4	30	1815.51-1816.10	0.59	11	51	5	27.0	9.0/K[illegible]	6.08/L	
	4	31	1816.10-1817.25	1.15	3	42	5	44.0	5.0/K[illegible]	9.95/L	1.74-8.64/L[5] 4.00-7.76/L[5]
AEC-8	10	10	1589.10-1589.70	0.60	1	85	5	...	5/Kl 2 An	2.97/S	
	10	11[6]	1589.70-1591.70	2.00	...	43	16	...	40/Kl	10.32/S	
	10	12[6]	1591.70-1592.20	0.50	...	37	24	...	6/C 33/Kl	15.16/S	
	10	13[6]	1592.20-1594.50	2.30	...	49	32	...	0.1/An 2 C 9 Ka 3.8/An	20.31/S	
	10	14	1594.50-1594.70	0.20	...	38	4	...	51/C 2/Ka 1/Kl 3.1/An	2.34/S	
	10	15[6]	1594.70-1595.50	0.80	2	85	3	...	4/C 2/Kl 9/Ka 0.9/An	2.18/S	6.6-12.33/S
	4	2	1752.70-1753.40	0.70	...	95	...	4	...	0.86/L	
	4	3	1753.40-1754.00	0.60	1	65	2	31	3/Ka	7.39/L	
	4	4	1754.00-1755.00	1.00	...	31	2	61	2/Ka	13.00/L	
	4	5	1755.00-1756.70	1.70	...	24	...	69	3/Le	15.38/L	4-11.27/L

Table 3.- Calculated mineral content of selected samples from [illegible] drill holes with [illegible] of potash and ore minerals

Drill-hole no.	Ore zone	Sample no.	Depths of interval (feet)	Thickness (feet)	Calculated minerals present (weight percent)					K_2O of ore minerals (percent)	Weighted average K_2O as ore mineral for all intervals in ore zone (feet and percent)
					Polyhalite	Halite	Sylvite	Langbeinite	Other minerals		
FC-70	10	2	1377.67-1379.00	1.33	2	65	11.2	---	20.0/Kl	7.11/S	
	10	3	1379.00-1381.00	2.00	2	51	19.1[b]	---	1.0/Kl	24.73/S	
	10	4	1381.00-1382.00	1.00	2	4	9.4[b]	---	3.0/C 3 /Kl	12.29/S	4.33-16.44/L
	9	6	1391.50-1393.40	1.50	1	53	21.00	---	---	17.76	1.5-17.76/S
	8	7	1415.08-1415.75	0.67	2	70	25	---	Tr/Kl	16.10/S	
	8	8	1415.75-1416.50	0.75	5	69	7	---	Tr/Kl	1.35/	
	8	9	1416.50-1418.00	1.50	2	97	1	---	1.0/Ea Tr/Kl	0.57/S	
	8	10	1418.00-1419.50	1.50	3	91	3	---	---	1.62/S	
	8	11	1419.50-1420.42	0.92	2	80	16	---	1.0/Ea Tr/Kl	10.04/S	
	8	12	1420.42-1421.50	1.08	1	71	16	---	1.0/Ea	10.21/S	6.42-5.5/S
	5	16	1466.00-1467.33	1.58	---	74	---	19.6	---	4.43/L	
	5	17	1467.58-1469.00	1.42	1	53	---	40.7	---	9.2-/L	
	5	18	1469.00-1469.67	0.67	1	70	---	24.2	---	5.69/L	5.67-6.48/L
	5	19	1529.92-1531.42	1.50	1	36	---	52.6[b]	---	11.91/L	
	4	20	1531.42-1532.42	1.00	---	45	---	33.0[b]	---	7.42/	2.5-10.13/L
FC-81	8	7	1564.17-1564.92[b]	0.75	2	58	36.6	---	3.0/C	23.16/S	
	8	8	1564.92-1566.13	1.21	2	79	13.3	---	4.0/C	9.71/S	
	8	9	1566.13-1567.38	1.25	5	66	8.9	6.1	10.0/C	5.62/S 1.38/L	3.21-11.26/S 1.21-0.34 - mixed ore equivalent: 3.21-12.61/S
	4	10	1687.00-1688.21	1.21	---	20	---	76.9	4.0/Ea Tr/Va	16.71/L	
	4	11	1688.21-1689.46	1.25	1	25	---	67.0	Tr/Va	15.31/L	2.46-16.0/L
	2	15	1713.88-1714.46	1.58	1	40	---	56.0	4.0-Ea	12.7/L	
	2	16	1714.46-1715.46	1.00	---	65	---	30.3	3.0/Ea Tr/La	6.9/L	
	2	17	1715.46-1716.00	0.54	4	45	---	42.8	Tr/La	9.71/L	3.12-10.4/L
FC-8.	5	1	1541.42-1541.79	0.37	---	17	---	72.2	2.0/La 6.0/C	16.54/L	
	5	2	1541.79-1542.29	0.50	---	91	7.0	2.0	---	1.61/L	
	5	3	1542.29-1543.96	1.67	2		---	49.8	4.0/La	11.3/L	
	5	4	1543.96-1544.50	0.54	1	59	5.0	20.0	20.0/C Tr/La	4.54/L	3.08-9.37/
	4	5	1613.42-1615.08	1.66	---	17	---	63.0	9.3/El Tr/L	14.3/L	
	4	6	1615.08-1615.92	0.84	1	48	0.7	12.8	17.7-a 12.3/Kl	2.9/L	2.5-10.52/L

Table 3 - Calculated mineral content of selected samples from potash-bearing intervals in core from [illegible] (continued)

Drill-hole no.	Ore zone	Sample no.	Depths of interval (feet)	Thickness (feet)	Calculated minerals present (weight percent)					K2O as ore minerals (percent)	Weighted average K2O as ore mineral for all intervals in ore zone (feet and percent)
					Polyhalite	Halite	Sylvite	Langbeinite	Other minerals		
FC-82	3	7	1624.33-1625.58	1.25	2	51	---	31.1	1.3/Bl 1.7/Ka	7.06/L	
	3	8	1625.58-1627.00	1.42	2	67	---	29.9	0.6/C	6.78/L	
	3	9	1627.00-1627.75	0.75	1	28	---	64.2	Tr/Bl 5.0/Gl	14.11/L	3.42-8.49/L
FC-91	4	34	1712.25-1712.66	0.42	1	18	---	50.0	11.0/Ka 7.5/Le 6.0/Kl	11.15/L	
	4	35	1713.66-1713.08	0.42	---	62	---	---	5.0/Ka 3.4/Kl	---	
	4	36	1713.08-1714.17	1.08	1	25	---	66.6	5.0/Kl	14.66/L	
	4	37	1714.17-1714.75	0.58	4	33	---	58.7	5.0/Ka 1.3/Kl	13.32	
	4	38	1714.75-1715.75	1.00	20	38	---	41.0	5.0/Ka Tr/Gu	10.66	
	4	39	1715.75-1716.33	0.58	6	31	---	54.0	6.3/Ka 4.0/Gl 1.3/Kl	12.25/L	4.08-11.3/L
	4	40	1718.66-1719.42	0.75	3	81	---	8.0	3.0/Ka 9.0/Ba	1.82/L	
	4	41	1719.42-1720.75	1.33	2	37	---	59.5	---	13.5/L	
	4	42	1720.75-1722.00	1.25	---	60	---	37.09	Tr/Gu 1.4/Ba	8.41/L	
	4	43	1722.00-1722.58	0.58	---	71	---	13.5	0.4/Ka 6.0/Ka Tr/Gu	3.06/L	3.41-8.08/L
	2	44	1742.75-1743.25	0.50	---	15	---	62.0	8.8/Ka Tr/Ca	14.07/L	
	2	45	1743.25-1744.25	1.00	---	47	---	33.5	10.0/Kl 10.0/Ca	6.92/L	
	2	46	1744.25-1745.00	0.75	---	61	---	1.0	3.2/Ka 10.1/Kl 24.0/Ca Tr Gu	0.73/L	2.25-6.44/L
FC-92[3]	8	5	1604.92-1606.04	1.12	1	51	17	Tr	Tr/Ca	29.0/S	
	8	6	1606.04-1606.50	0.46	---	50	19	Tr	Tr/C	11.0/S	
	8	7	1606.50-1606.75	0.25	---	60	29	1	5.7/C	18.5/S	1.83-28/S
	4	57	1740.66-1741.58	0.92	1	51	---	46.7	---	10.6/L	
	4	58	1741.58-1742.75	0.66	1	36	---	61.0	---	13.65/L	
	4	59	1742.25-1743.25	1.00	1	36	---	61.3	0.1/Kl	13.89/L	
	4	60	1743.25-1744.08	0.83	1	36	---	62.3	---	13.91/L	
	4	61	1744.08-1745.00	0.92	2	38	---	48.8	1.8/Kl	11.07/L	4.33-12.6/L
	2	62	1769.42-1770.08	0.66	1	42	---	55.4	3.0/Ka	12.37/L	
	2	63	1770.08-1771.42	1.33	1	51	---	45.7	2.3/Ka 1.0/Anr	10.37/L	
	2	64	1771.42-1772.08	0.66	---	39	---	33.9	17.0/Ka 8.0/Kl 1.0 Gu	7.49/L	
	2	65	1772.08-1772.38	0.5	---	73	---	1.5	14.0/Ka 1.0/Gu	0.36/L	3.16-8.64/L

Table 3 - Calculated mineral content of selected samples from potassium-bearing intervals with summation of percent K_2O as ore mineral--continued

Drill-hole no.	Ore zone	Sample no.	Depths of interval (feet)	Thickness (feet)	Calculated minerals present (weight percent)					K_2O as ore mineral (percent)	Weighted average K_2O as ore mineral for all intervals in ore zone (feet and percent)
					Polyhalite	Halite	Sylvite	Langbeinite	Other minerals		
IMC-374	4	8	1430.70-[illegible].10	1.40	6	86	0.7	2.0	0.7 Kl 0.3 Ka	0.46/L 0.44/S	
	4	9	1432.10-1433.10	1.00	13	68	1.0	6.4	1.35/La	1.46/L 0.63/S	2.4-0.88/L 2.4-0.51/S
IMC-375	4	7	1627.90-1629.00	1.10	2	78	---	6.6	4.0/Ka	1.50/L	
	4	8	1629.00-1630.50	1.50	4	70	2.0	11.2	2.0/La 1.0/Ka	3.0/L 1.3/S	2.5-2.46/L 1.5-1.3/S
IMC-376	10	2	1427.00-1427.70	0.7	---	60	35.4	---	---	24.5/S	
	10	3	1427.70-1428.30	0.6	---	98	0.2	---	---	0.1/S	
	10	4	1428.30-1429.20	0.9	1	96	0.4	---	---	0.26/S	
	10	5	1429.20-1431.50	1.8	2	86	11.2	---	---	7.8/S	4.0-7.52/S
	5	13	1528.00-1528.90	0.9	2	89	1.0	2.8	---	2.63/L	
	5	14	1528.90-1530.90	2.0	0	45	---	51.3	1.0/La	11.65/L	3.7-6.5/L
	5	15	1530.90-1531.70	0.8	2	93	1.0	1.05	---	0.25/L	(4.0-7.33/L)[5]
NFU-1[10]	8		1536.25-1540.17	3.92	---	---	---	---	---	19.67/S	3.92-19.67/S
	4		1644.75-1649.08	2.33	---	---	---	---	---	11.96/L	2.33-11.96/L
NFU[10]	10		1441.08-1445.17	4.09	---	---	---	---	---	0.8/S	4.08-0.8/S
	8		1479.80-1483.80	4.00	---	---	---	---	---	9.1/S	4.0-9.1/S
	4		1598.50-1602.70	4.20	---	---	---	---	---	13.1/L	4.2-13.1/L
D-120[10]	10		1248.30-1249.30	1.00	---	---	---	---	---	31.63/S	
	10		1249.80-1251.10	1.30	---	---	---	---	---	10.4/S	
	10		1251.10-1252.50	1.40	---	---	---	---	---	7.34/S	4.2-15.3/S
	4		1419.60-1421.30	1.70	---	---	---	---	---	13.8/S	2.. 10.7/S
	4		1421.10-1421.80	0.50	---	---	---	---	---	0.5/S	2.2-7.5/L mixed ore equivalent: 2.2-29.4/S
D-48[10]	10		1236.60-1240.00	4	---	---	---	---	---	---	4.0-11/S 4.0-2.1/L (visual estimate)
	8		1285.52-1289.78	9.26	---	---	---	---	---	---	9.26-17.3/S
	4		1414.20-1416.20	2.00	---	---	---	---	---	---	2.0-8.8/L (visual estimate)

Table 3 - Calculated mineral content of selected samples from potash-bearing intervals and calculation of percent K_2O as ore mineral--Continued

Drill-hole no.	Ore zone	Sample no.	Depths of interval (feet)	Thickness (feet)	Calculated minerals present (weight percent)					K_2O as ore minerals (percent)	Weighted average K_2O as ore mineral for all intervals in ore zone (feet and percent)
					Polyhalite	Halite	Sylvite	Langbeinite	Other minerals		
D-207	10	24	1358.60-1359.60	1.00	4	87	5	---	2/Ka	3.36/S	
	10	25	1359.60-1360.20	0.60	4	89	5	1	1/Ka	3.36/S 0.25/L	
	10	26	1360.20-1360.60	0.40	1	75	4	1	6/Ka	0.31/L	
	10	27[4]	1360.60-1361.20	0.60	1	47	6	16	5/Ka	3.79/S 3.79/L	
	10	28	1361.20-1361.80	0.60	2	69	2	9	2/Ka	2.04/L	
	10	29	1361.80-1362.30	0.50	7	62	5	17	7/Ka	3.34/S 2.31/L	
	10	30	1362.30-1363.10	0.80	6	83	4	---	1/C 3/Ka	2.66/S	4.1-4.56/S 2.7-3.6/L mixed ore equivalent: 4.5-5.26/S
	4	33	1533.10-1533.50	0.40	2	53	36	7	---	1.51/L 22.74/S	
	4	34	1533.50-1533.80	0.30	4	86	7	11	---	2.43/L	
	4	35	1533.80-1534.40	0.60	2	85	1	2	---	0.59/L	
	4	36	1534.40-1534.70	0.30	2	95	---	2	---	0.5[illegible]/L	
	4	37	1534.70-1535.00	0.30	2	74	4	1	3 9/El	9.14/L	
	4	38	1535.00-1539.80	4.80	6	87	2	4	---	0.8[illegible]/L	6.7-9.95/L [illegible]/S mixed ore equivalent: 6.7-1.4[illegible]/L
	3	44	1545.90-1546.30	0.40	2	68	---	12.0	0.74/La	7.5/L	
	3	45	1546.30-1546.66	0.30	1	11	---	73.2	9.0/El	16.6/L	
	3	46	1546.66-1548.00	1.40	2	62	---	30.3	3.8/La	6.89/L	
	3	47	1548.00-1548.60	0.60	1	43	---	54.7	---	12.4/L	2.7-9.26/L
	2	52	1552.20-1553.00	0.80	11	83	---	5.3	---	1.75/L	
	2	53	1553.00-1553.20	0.20	11	45	---	41.5	2.0/La	9.41/L	
	2	54	1553.20-1553.60	0.40	4	81	---	15.5	---	3.59/L	
	2	55	1553.60-1554.00	0.40	1	47	---	49.4	1.32/La	11.19/L	
	2	56	1554.00-1554.83	0.83	18	86	2.4	8.5	---	3.0/L 0.9/S	2.6-3.94/L 11/S
D-104[10]	10		1340.40-1341.70	1.30	---	---	---	---	---	---	
	10		1341.70-1343.20	1.50	---	---	---	---	---	---	
	10		1343.20-1344.00	0.80	---	---	---	---	---	---	
	10		1344.00-1344.70	0.70	---	---	---	---	---	---	6.9-5.5/S
	10		1344.70-1346.40	1.70	---	---	---	---	---	---	3.2-4.71/L mixed ore equivalent: [illegible].0-11.78/S
	8		1391.10-1392.00	0.90	---	---	---	---	---	---	
	8		1392.00-1395.30	3.30	---	---	---	---	---	---	
	8		1395.30-1396.30	1.00	---	---	---	---	---	---	5.2-10.8/S
	4		1519.90-1522.80	2.90	---	---	---	---	---	---	2.9-9.4/L

Table 3 - Calculated mineral content of selected samples from potash-bearing intervals with summation of weighted K_2O as ore minerals--Continued

Drill-hole no.	Ore zone	Sample no.	Depths of interval (feet)	Thickness (feet)	Calculated minerals present (weight percent): Polyhalite	Halite	Sylvite	Langbeinite	Other minerals	K_2O as ore minerals (percent)	Weighted average K_2O as ore mineral for all intervals in ore zone (feet and percent)
D-104[10]	3		1527.50-1528.90	1.40	---	---	---	---	---	---	1.4-5.0/L
	3		1528.90-1530.50	1.60	[illegible]	---	---	---	---	---	2.[illegible]/S mixed [illegible] equivalent 2.9-[illegible]/L
	2		1539.50-1540.20	1.20	---	---	---	---	---	---	1.2-15.0/L
U-134[10]	10		1319.58-1321.25	1.69	3	---	6.0	---	2.0/La		
			1321.75-1322.83	1.58	2	---	---	---	0.7 C; 12.3/La	3.79/S; 17.22/S	3.27-10.28/S
	8		1361.10-1362.17	1.08	---	---	---	---	---	---	
	8		1362.17-1364.50	2.33	---	---	---	---	---	---	
	8		1364.50-1366.50	2.00	---	---	---	---	---	---	6.33-7.89/S
	8		1366.50-1367.42	0.92	---	---	---	---	---	---	(4.0-12.5/S)[3]
	5		1406.75-1409.42	2.66	---	---	---	---	---	14.44/L	
	5		1409.42-1413.00	3.58	---	---	---	---	---	[illegible]/L	
	5		1413.00-1414.66	1.66	---	---	---	---	---	7.05/L	4.9-11.2/L
	4		1471.66-1474.00	2.53	--	---	---	---	---	8.56/L	2.33-8.56/L
	3		1484.91-1487.33	2.42	---	[illegible]	---	---	---	3.6/L	
	3		1487.33-1490.25	2.92	---	---	---	---	---	3.64/L	
	3		1490.25-1491.33	1.08	---	---	---	---	---	8.7/L	6.42-3.7/L[3]

*Values in table for percent mineral and K_2O equivalent are not consistent owing to independent rounding of assays and conversion factors by numerous authors and investigators

1 Trace amount, equals 0 to 2.0 percent
2 Incomplete dissolution of sample
3 [illegible] percent insolubles [illegible]
4 Incomplete or unreliable assay
5 Grade adjusted to [illegible]-foot interval
6 High insoluble content
7 [illegible] percent potassium assay used
8 Outside of the [illegible] area by 300 feet, included due to influence
9 Raw data unavailable, these are company figures
10 Company interval data, raw data unavailable, no sample numbers assigned

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Volume III of VII

Waste Isolation Pilot Plant
Carlsbad, New Mexico

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WASTE ISOLATION PILOT PLANT
DESIGN VALIDATION
EXECUTIVE SUMMARY

INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is being developed by the U.S. Department of Energy (DOE) as a research and development facility to demonstrate the safe disposal of radioactive waste from U.S. defense programs. The facility is located in southeastern New Mexico, about 25 miles east of the city of Carlsbad. Underground development is at a depth of about 2,150 feet in thick deposits of bedded salt. The facility operation will include in situ experiments addressing technical issues for defense waste programs and storage of defense related contact-handled (CH) and remote-handled (RH) transuranic (TRU) waste.

In 1979, the DOE established a Site and Preliminary Design Validation (SPDV) Program to provide additional confidence in the siting and design of the WIPP facility. On July 1, 1981, the DOE entered into an agreement with the State of New Mexico whereby the DOE would perform certain work to validate the reference design of the WIPP underground openings. The results of the site validation portion of the program are presented in the report titled Results of Site Validation Experiments, Volumes I and II, TME document 3177, dated March 1983. The results of the preliminary design validation portion of the program are presented in the report titled Waste Isolation Pilot Plant Preliminary Design Validation Report, dated March 30, 1983.

Design validation of the WIPP is defined as the process by which the reference design of the underground openings is confirmed by determining the compatibility of the design criteria, design bases and reference design configurations using site specific information. The design validation process consists of an assessment of the condition and behavior of shafts, drifts and a full-sized, four-room test panel

excavated during the SPDV Program and full WIPP construction. Based on this assessment of these excavations, and on predictions of their future behavior, any modifications to the design criteria, design bases or design configurations required to achieve a validated reference design will be developed. In addition, the validated reference design may be modified in the future as still more data and experience are gained during a 5-year demonstration period (period during which all waste must be retrievable) and permanent storage operations.

The WIPP Preliminary Design Validation Report was an interim report prepared as part of the overall validation of the WIPP underground opening reference design. The WIPP Design Validation Final Report contains additional information gathered after completion of the SPDV Program. This information has been analyzed and evaluated to complete the design validation process for the WIPP.

Four types of information were gathered for the WIPP Design Validation Final Report:

(1) observations of the behavior of the underground openings;

(2) descriptions of the geologic conditions encountered during underground construction;

(3) descriptions of core samples from instrumentation and other holes in the roof and floor of the underground openings; and

(4) data from installed geomechanical instrumentation.

The design validation process provides for the collection, analysis and evaluation of in situ data. This process is designed to permit determination of the need to modify elements of the underground opening reference design so that construction and operation of the full facility can proceed in a timely, safe, environmentally acceptable and cost effective manner. Observation and instrumentation data have been

collected and evaluated for each of the underground design elements. Tables I through VI at the end of this summary present the evaluation results for the design criteria, design bases and design configurations of the shafts and horizontal openings.

BACKGROUND OF UNDERGROUND DESIGN

Geologic characterization of the site began with a literature review and continued with the collection of field data. Special emphasis was placed on correlating data obtained from seismic reflection and resistivity surveys and borehole drilling. Design information regarding site stratigraphy from the ground surface to about 250 feet below the underground facility level was developed from geologic data obtained from drill holes ERDA-9, WIPP-12 and DOE-1, and from the SPDV exploratory and ventilation shafts.

The engineering designs for the WIPP surface and underground facilities began with the conceptual design, initiated in 1975 and completed in 1977. The conceptual design provided the basis for the development of the preliminary design of both the surface and underground facilities, which was completed in January 1980. The preliminary design incorporated the conventional room and pillar method for underground development.

Design of the WIPP provided for the access and storage openings to remain stable and provide minimum clearance for equipment during waste emplacement and the 5-year demonstration period, even though these openings will eventually close due to salt creep. Modeling techniques were used to estimate the geomechanical behavior and structural stability of the openings. The preliminary design included numerical modeling of the selected underground opening configurations. These models were used to predict opening closures and augmented other conventional mining industry methods of stability evaluation.

UNDERGROUND FACILITIES

Seven stratigraphic horizons were identified in 1979 as potential locations for the facility level. These horizons were chosen from examinations of available geotechnical data and on horizon selection criteria established by the WIPP project participants. Selection of the final underground development level was made by the DOE following the recommendation of WIPP project participants.

The WIPP facility is composed of three shafts connected to a single underground facility level. The C & SH shaft provides the principal means of access and also serves as the primary air intake opening. The waste shaft is designed to permit the transport of radioactive waste between the surface waste-handling facilities and the underground storage area. The exhaust shaft is the primary opening for exhaust air from the underground facility. All three shafts have three principle constituents: a lined section penetrating the rock overburden; an unlined section penetrating the salt; and a key at the rock/salt contact to act as a transition from the lined section to the unlined section.

The storage level contains all of the underground facilities for waste handling, waste storage, operations and maintenance. All of the underground horizontal openings are rectangular in cross section. The drift configurations range from 8 feet to 12 feet high and 12 feet to 25 feet wide.

Underground construction was accomplished in two phases. The initial (SPDV) phase was conducted from May 1981 through March 1983. The second phase, full construction, was accomplished from October 1983 through February 1985. Both phases included the excavation and outfitting of shafts, drifts and rooms.

SUPPORTING VALIDATION DOCUMENTS

The primary documents supporting design validation are the WIPP Preliminary Design Validation Report and quarterly geotechnical field data reports (GFDR).

The objective of preliminary design validation was to provide initial evaluation of the design criteria and design bases, and initial confirmation of the underground reference design. Geologic mapping, core drilling and logging, and geomechanical instrumentation data were assimilated to provide an early, short-term evaluation. The preliminary conclusions presented in the WIPP Preliminary Design Validation Report stated that the shafts and underground openings were performing as expected and were stable. In addition, gas had not been encountered in any significant quantity during excavation and no brine pockets had been encountered.

The GFDRs were initiated by the DOE to provide data from the SPDV Program and full construction in a timely manner. The GFDRs were intended to present in situ data on the geomechanical behavior of the strata surrounding the underground openings along with visual observations of opening behavior and analyses of selected underground design elements.

METHODOLOGY

Design validation is accomplished by determining the compatibility of the design criteria, design bases and reference design using site specific information. The design validation process consists of three major steps: data collection; analysis and evaluation; and prediction of future behavior.

The data collection program was designed to provide information on the geologic conditions encountered throughout the underground facility and on the structural behavior of the underground openings. The program

included geologic mapping, core drilling and logging, laboratory testing, visual inspections, and geomechanical instrumentation measurements. The data collected from these activities were analyzed and evaluated to determine the behavior of the various components of the underground facility and predict their future behavior by projecting the results of both finite element model and regression analyses.

The geomechanical instrumentation measurements provided in situ data on the behavior of the underground openings. These data were then used in empirical equations relating time and closure. Laboratory test results were used to calculate the salt creep and elastic parameters. Salt creep parameters were also determined by the regression analysis of in situ data. Long-term behavior of the underground openings was predicted by extrapolation of the results of the regression analysis.

GEOLOGIC CHARACTERIZATION

Geologic characterization of the WIPP underground openings began in June 1981. Data collection activities included geologic mapping, core drilling and logging, and fluid measurements. The SPDV exploratory shaft was mapped prior to selecting the storage horizon. The waste shaft was mapped, first as the SPDV ventilation shaft and again after it was enlarged to its final diameter. Geologic mapping was also conducted in the exhaust shaft.

Geologic mapping of the horizontal openings was conducted during design validation. This mapping was performed primarily to determine stratigraphic continuity. Mapping was conducted along one wall of the drifts to the northern extent of the facility and along the full length of the south exploratory drift. Geologic mapping was also conducted to the east and west facility boundaries in the experimental area and in the test rooms.

Geologic mapping confirmed the continuity of the stratigraphy within the horizontal openings to the facility boundaries. Core drilling and logging confirmed this stratigraphic continuity for a distance of 50 feet above and below the facility level. The geologic mapping and core logging did not detect any significant geologic structures. Data from the core holes were also used to establish the WIPP reference stratigraphy.

Fluid inflow measurements were obtained by various activities designed to characterize the two water-bearing dolomite members of the Rustler formation and the potential for the occurrence of gas and brine at the facility level. Measurements in the three shafts showed that water inflow from the Rustler formation is essentially negligible due to liner and seal performance.

Small amounts of pressurized gas have been encountered by some underground core holes. Brine has also been encountered in small quantities and is sometimes associated with gas occurrences. There has been no occurrence of gas or brine in quantities significant enough to jeopardize the stability or safety of the facility. Two programs, the brine testing program and the gas testing program, are being conducted to further characterize these occurrences. Neither program is associated with design validation.

Subsidence monuments have been installed on the surface over the shaft pillar area. The design criteria require that subsidence due to underground excavation not exceed 1 inch within a 500-foot radius of the waste shaft. It is not possible at this time to determine actual subsidence; this will occur over the next 25 years. Subsidence calculations used in the reference design indicate that the criteria limits will not be exceeded.

C & SH SHAFT

The C & SH shaft consists of a lined section, a shaft key, an unlined section and a shaft station. The shaft liner is made of structural steel that increases in thickness with depth to withstand increasing hydrostatic pressure. The reinforced concrete shaft key serves as a transition between the lined and unlined sections of the shaft. Chemical water seals behind the concrete key are designed to prevent ground water from flowing behind the key, into the unlined section of the shaft. The shaft station is excavated near the bottom of the unlined section.

Validation of the C & SH shaft reference design was accomplished by acquiring a variety of geotechnical data for analysis, evaluation and prediction of future behavior. The condition of the shaft liner and key are monitored by geomechanical instrumentation and visual inspections. Convergence points measure diametric closure; piezometers monitor ground-water pressures; strain gauges and pressure cells monitor the effect of salt creep on the concrete key. Telltale pipes in the shaft key provide information on the effectiveness of the chemical water seals. The unlined section of the shaft is monitored by extensometers and convergence points and is visually inspected for fracturing and rock slabbing. The shaft station has an extensive geomechanical instrumentation monitoring system and is inspected regularly.

The design basis hydrostatic pressure is suitable. Piezometer measurements indicate that the hydrostatic pressure is currently much less than the design pressure. Analysis of the shaft key indicates that lateral pressure on the key at the end of the operating period will be much less than the design basis lateral pressure requirement. Diametric closure of the key will be minimal. Computational analyses of stresses and strains indicate that the shaft will be stable and remain within the required safety limits during its operating life. Analysis of computed diametric closure near the bottom of the shaft

indicated that, while the closure will be within the design criteria and design basis limits, the lower buntons will be impacted.

The shaft design complies with the design criteria requirements for ground-water control. Regular inspections of shaft conditions show no signs of deterioration or instability.

The C & SH shaft station exhibits the highest degree of deterioration in the underground facility. The fracturing and separation observed has been stabilized, but will continue to develop. Closure during the 25-year operating life of the station will be on the order of 8 feet vertically and 5 feet horizontally. These conditions will require maintenance to ensure safety and to maintain the required minimum clearances for equipment and operations.

WASTE SHAFT

The waste shaft also consists of a lined section, a key, an unlined section and a shaft station. The shaft is lined with unreinforced concrete from the surface to the top of the Salado formation. The shaft liner terminates with a reinforced concrete key at the Rustler/Salado formation contact. The shaft is unlined, except for wire mesh, from the key to the bottom of the shaft.

Data collection activities in the waste shaft have consisted of geologic mapping, ground-water inflow measurements, geomechanical instrumentation measurements and periodic visual inspections. Except for convergence points, the geomechanical instruments are monitored remotely by the datalogger.

The waste shaft data was analyzed with respect to design parameters for each component of the shaft. As part of the engineering analysis, predictions of future behavior were made for each of the components.

Stability of the shaft liner has been confirmed. The water pressure exerted on it is significantly below the design hydrostatic pressure. If the pressure should reach the design hydrostatic pressure, the liner will still be stable. The shrinkage cracks in the liner do not present a structural problem.

The shaft key was designed to withstand a lateral pressure due to salt creep equivalent to 50 percent of the vertical overburden pressure. A numerical analysis was utilized to simulate the long-term effect of salt creep on the concrete key. It showed that the computed lateral pressure at the end of the operating period will be slightly higher than the design lateral pressure, but well below the total lateral pressure capacity of the key.

Observations of the waste shaft key have determined that only one minor seep occurs in the key and that no water seepage is occurring from the base of the key. This supports the conclusion that the water seals are functioning, that no water is seeping along the concrete/salt contact, and that salt dissolution is not occurring behind the key.

The design criteria require that no uncontrolled ground water reach the facility level through the shafts. Although minor amounts of fly water do reach the facility, this water has a negligible impact on operations and does not affect validation of this criterion.

The unlined section of the shaft was designed to be stable and maintain a diameter adequate for the operating life of the facility. The structural behavior of this section was analyzed using a finite element model and creep parameters determined from the C & SH shaft in situ data. The results indicate that the maximum stress occurred immediately after excavation and will decrease with time. Stress behavior will not cause a stability problem. Diametric closure due to salt creep will not exceed the design limits.

The design of the waste shaft station is based primarily on operational parameters. The closure and stability of the station was evaluated using in situ data from the C & SH shaft station. The estimated vertical closure rate will result in a total closure of over 7 feet during the 25 year operating life of the station. Actual closure may be less, but remedial work will still be required to maintain the proper clearances.

EXHAUST SHAFT

The exhaust shaft is constructed similarly to the waste shaft. It consists of a concrete lined section, a shaft key and an unlined section. The lined section is constructed of unreinforced concrete and the shaft key of reinforced concrete. The unlined section contains only rock bolts and wire mesh.

Data collection in the exhaust shaft has been on a much smaller scale than in the other two shafts. Geomechanical instrumentation was not required by the original shaft design because geologic and structural conditions were assumed to be similar to the other two nearby shafts. However, remotely monitored instrumentation has been installed to provide shaft-specific information for use in the sealing program. Geologic mapping and visual inspections have confirmed that the geologic and geohydrologic environment is similar to that of the other two shafts. Data from these two shafts have been used to predict the future performance of the exhaust shaft.

Geohydrologic and geomechanical data from the C & SH shaft and the waste shaft have been compared to model simulations for each section of the exhaust shaft. These models, field observations and instrumentation data confirm that the exhaust shaft reference design is suitable for its 25 year operating life.

The shaft liner is stable and has a water pressure against it that is less than the design basis hydrostatic pressure. If the pressure

increases, the liner will remain stable. Shrinkage cracks will not result in structural instability.

As with the waste shaft, an analysis of the exhaust shaft key indicates that the lateral pressure calculated for 25 years will slightly exceed the design lateral pressure, but will be well below the maximum allowable lateral pressure. Computational analyses of the stresses and strains indicate that the unlined section of the shaft will be stable and remain within safety limits during its operating life. The computed diametric closure will be within design criteria and design basis limits.

Water is entering the exhaust shaft through cracks and construction joints in the concrete liner. A small amount of water still reaches the shaft even after a remedial grouting program. When the exhaust fans are on, this water evaporates before reaching the facility. The water seals in the key appear to be functioning and there is no evidence of salt dissolution behind the key.

DRIFTS

The discussion of drifts contained in this section pertains to all horizontal underground openings except the shaft stations, test rooms, and storage area rooms and their associated drifts. The drifts were designed in accordance with the design criteria and design bases. The largest drifts were initially excavated 8 feet high and 25 feet wide. These drifts have been or will be enlarged to 12 feet high. This drift height is dictated by the minimum 11-foot operating clearance required for the waste storage equipment.

A variety of geotechnical activities were conducted to evaluate the behavior of the excavated drifts. These activities included geologic mapping, core drilling and logging, visual inspections, and geomechanical instrumentation measurements.

Visual inspections consisted of qualitative observations and documentation of various aspects of drift behavior. These observations are divided into four categories: roof and wall spalling; pillar fracturing; roof displacements and separations; and floor fracturing, displacements and separations.

Deformational behavior consisting of spalling from the roof and walls of the drifts and fracturing and spalling at pillar corners has occurred. Separations and lateral displacements have been detected in the halite above the roof, primarily at clay seams. These types of behavior are expected and will continue to occur, but can be controlled by scaling and rock bolting.

Fracturing has occurred in marker bed 139 (MB-139) and in the overlying halite beneath the floor of the drifts. The fracturing is not well developed and occurs primarily beneath large intersections. Based on experience in local potash mines, this fracturing is not expected to cause stability or operational problems.

The comparison of measured closure behavior in drifts with different dimensions indicates that the maximum closure and closure rate will occur in 12 x 25-foot drifts. The closure rates are affected by the presence of nearby parallel drifts and crosscuts as well as differences in salt properties. Based on available measurement data and the results of modeling analyses, the closure rate in the 13 x 25-foot storage area drifts may be 30 percent greater than that of a single, infinitely long drift with the same dimensions.

Analyses of salt behavior around the 25-foot wide drifts has determined both the redistribution of stresses due to creep and the locations of effective creep strain concentrations. The stresses which develop immediately after excavation relax with time due to creep behavior and will not cause future stability problems. The strain will remain within the limit required for structural stability with respect to catastrophic failure.

The evaluation of field observations and analytical results have shown that the design criteria were appropriate for design of the horizontal openings. The criteria identified as requiring specific evaluation were determined to be suitable. The reference design for the horizontal openings is therefore validated.

Based on the results of design validation of the drifts, it is recommended that all drifts be inspected frequently for operational clearance and safety. If the clearance is insufficient, the drifts must be trimmed to the required dimensions. Scaling and rock bolting should be performed where necessary for safety purposes.

TEST ROOMS

The test rooms comprise a panel of four rooms having a similar configuration as the planned storage rooms. They have been instrumented, observed and analyzed to evaluate the behavior of the future storage rooms. Data collection activities have consisted of geologic mapping, core drilling and logging, visual inspections and geomechanical instrumentation measurements. The instrumentation includes borehole extensometers, inclinometers, convergence points, convergence meters and rigid-inclusion, vibrating-wire stressmeters.

Room deterioration has been minimal and consists of spalling from the roof and walls, vertical fracturing in the pillars, minor displacements and separations above the roof and beneath the floor, and fracturing beneath the floor. Areas of drummy rock detected by roof and wall inspections immediately following excavation were scaled and rock bolted. These areas have not increased noticeably in size since the test rooms were excavated, over 3 years ago.

Subhorizontal fracturing has developed beneath the test room floors. Separations and fractures are on a small scale except for one isolated location beneath Test Room 3. Fracturing in this area is well developed and occurs in two distinct zones. Studies have not shown

fracturing of this magnitude to occur anywhere else within the underground WIPP facility.

The analysis of closure of the test rooms using creep constants derived from laboratory data underestimate actual closure. The design criteria closure of 12 inches in 5 years has been exceeded within 3 years. Strains measured in the test rooms compare well with strains computed by numerical modeling.

STORAGE AREA

The storage area rooms and drifts are designed to permit the permanent storage of defense-related CH and RH TRU waste. The storage area is composed of eight panels consisting of seven rooms each. Each room is 13 feet high, 33 feet wide and 300 feet long. The storage area, including all rooms and drifts, is designed to provide storage space for 6,330,000 cubic feet of CH TRU waste and 1,000 canisters of RH TRU waste.

Validation of the storage room reference design depends primarily on the analysis of data from the four test rooms. Evaluation of the storage rooms was based on the results of a finite element model analysis using creep parameters determined from the test room analyses. The results of this analysis provided determinations of horizontal and vertical stresses, effective stresses, effective creep strains, principal stresses, room deformation and closure, and intersection closure.

The analyses show that the stress arch around the opening migrates away with time. The maximum stress occurs immediately after excavation and is reduced as the opening deforms over time due to salt creep. These stresses will therefore not cause a stability problem in the future. However, MB-139, the anhydrite bed approximately 4 feet below the floor, is expected to be subjected to gradually increasing stress and may exhibit local failure.

Effective creep strains will intensify and concentrate at some locations around the opening. While minor spalls and failures are expected to occur on the excavation surfaces, the rooms will remain structurally stable.

The storage room reference design of 13 feet high and 33 feet wide was based on calculations using laboratory-derived average creep parameters. This design allowed for 12 inches of vertical closure and 9 inches of horizontal closure 5 years after excavation. This accommodates the design bases requirements for a minimum of 16 inches of ventilation space above the stored waste and a 12-foot minimum height for storage equipment. The current predicted vertical closure at 5 years is about 22 inches. For permanent storage, the additional 10 inches of closure can be accommodated by excavating the storage rooms to a height of 13 feet 10 inches.

If a decision is made to retrieve the stored waste, the design criteria assumed, using a one-shift-per-day basis, that a room may be as much as 15 years old before removal of all of the waste is completed. A 15-year old room has a predicted vertical closure of 54 inches. This closure is 14 inches greater than the maximum acceptable closure and would result in crushing and possible breaching of the waste containers. Because this is not in compliance with the design criteria, other alternatives must be considered.

A 10 year maximum for retrieval is conservative. If three shifts per day were utilized, no room would be older than 7 years by the time its waste was removed. A 7 year old room would have 28 inches of vertical closure. Additional closure benefits can be gained by excavating a room to is maximum dimensions and then trimming the room to those maximum dimensions after 1 year of closure. This will allow the room to close at the rate determined by secondary creep and will result in 21 inches of vertical closure 7 years after trimming. This will meet the design criteria requirements.

The design bases provide for 9 inches of horizontal closure in the first 5 years after room excavation. The current prediction, based on in situ data, is 15 inches of closure in the 33- to 34-foot wide rooms. If the rooms are excavated 34-feet wide and backfilled with loose salt, this closure will be suitable for permanent storage.

For retrieval, the horizontal closure 15 years after excavation will be approximately 36 inches. This closure will result in some crushing and possible breaching of the waste containers. Even if retrieval is effected within 7 years, some containers may still be crushed and breached.

The timing of retrieval operations and two-stage excavation can be used to reduce wall-to-wall closure. Using a three-shift-per-day basis, a 7 year old room would close approximately 20 inches. If a first in/first out storage and retrieval operations is utilized, and waste is removed before a room reaches an age of 6 years, horizontal closure will be reduced to 18 inches. Both these changes would decrease the possiblity of crushing or breaching the containers. If a 34-foot wide room is trimmed after 1 year to its initial full dimensions, the horizontal closure at 7 years will be about 14 inches. This will further minimize crushing or breaching of the containers. The extent to which crushing will be minimized is unknown. This is because the space between the waste canisters and the room wall will be filled with loose salt. The load transferring capabilities of the backfill is not known at the present time.

The reference design also provides for permanent waste storage in all of the storage area drifts. Fifteen years after excavation a 13 x 25-foot drift is predicted to have a vertical closure of about 25 inches and a horizontal closure of about 20 inches. This is suitable for waste storage but trimming will be required for equipment clearance.

The storage area entry drifts will contain plugs for the isolation of the storage panels. The final design of these plugs is not yet

complete. However, the conceptual design envisions a multiple-component plug approximately 100 feet long.

The reference design for the storage rooms will be considered to be validated when any of the following recommended alternative modifications, or combination of these modifications, are incorporated:

(1) Maintain the reference design storage room dimensions of 13 to 14 feet high and 33 to 34 feet wide and maintain the salt backfill, but reduce the volume of waste to be stored and modify the container stacking configuration for the 5-year demonstration period. Revise the design criteria to require that waste be retrieved before a room exceeds an age of 7 years. This will meet the criteria that the waste containers not be crushed or breached, but it will require a significant number of additional storage rooms.

(2) Maintain the reference design storage room dimensions and maintain the planned waste volume. Revise the design criteria to delete the requirement for salt backfill and to require that waste be retrieved before a room exceeds an age of 7 years. This will meet the criteria that the waste containers not be crushed or breached without requiring additional storage rooms.

(3) Maintain the reference design storage room dimensions, planned waste volume, and salt backfill requirement. Revise the storage operations so that the first-emplaced waste is the first-retrieved waste with retrieval effected before the room exceeds 6 years of age. Excavate the room to 14 x 34 feet, then, 1 year later, trim the room to its initial 14 X 34 foot dimensions. This will minimize container crushing and breaching. More storage rooms will be utilized during the 5-year demonstration period, but the total number of rooms will remain the same as provided by the reference

design. This modification will require changing the design criteria to allow crushing and breaching of the CH waste containers prior to retrieval and to require a demonstration of the retrieval and handling of crushed and breached containers.

(4) Reduce the reference design storage room width from 33 feet to 28 feet, maintain the room height at 13 to 14 feet, and reduce the pillar width to 84 feet. Maintain the first room for RH waste emplacement at the original reference design dimensions. Reduce the planned waste volume and maintain the salt backfill requirement. Excavate the rooms to 14 x 28 feet, then trim them to this dimension after 1 year. Use a first-in/first-out storage operation. This will reduce the creep to approximately that of a 13 x 25-foot drift. Stability will be enhanced and crushing and breaching will be minimized. The volume of excavation will be approximately the same as for the reference design storage rooms, but with the advantage of a lower creep rate. If this alternative is selected, additional engineering evaluation will be required.

(5) Maintain the reference design storage room dimensions, the planned waste volume, the salt backfill requirement, and the reference design optimized excavation and storage plan. Revise the design criteria, as in alternative number 3, to allow crushing and breaching of the CH waste containers prior to their retrieval. Require a demonstration of the retrieval and handling of crushed and breached containers prior to the receipt of waste. This will not only demonstrate the safe retrieval of waste during the 5-year demonstration period, but also during permanent storage.

In addition to these recommended alternative modifications, the following modifications are recommended:

(6) The drifts used for storage will require maintenance and trimming to accommodate the required equipment and storage clearances. Their closure rates are not critical for storage because they will be used only for permanent storage near the end of the permanent storage period.

(7) Add additional rooms to compensate for the space occupied by the plugs in the storage area entry drifts.

(8) Install instrumentation in the storage rooms to obtain in situ data to monitor storage room behavior.

Table I

EVALUATION RESULTS FOR ABRIDGED DESIGN CRITERIA

ELEMENT	RESULT AND CHAPTER REFERENCE
(1) Facility design	
a. Designed for an operating life of 25 years.	*
b. Underground facilities and equipmentshall be designed to be compatible with retrieval operations for all contact-handled (CH) and remote-handled (RH) TRU waste, with a retrieval decision to be made within 5 years after the intial emplacement of each species.	Suitable 12.3.3
c. The facility will be decommissioned after it has fulfilled its intended purposes. This will include backfilling the underground facilities, sealing the shafts and decommissioning the surface facilities.	*
(2) CH TRU waste **	
a. Estimated annual volume is 500,000 cubic feet.	*
b. Estimated volume at the end of the 5 year retrieval decision period is 1,410,000 cubic feet.	*
c. Estimated total storage capacity is 6,330,000 cubic feet.	*
d. Heat generated from the waste is negligible; it will be less than 10 milliwatts for average drums, less than 20 milliwatts for average boxes, and 10 watts for few drums containing heat source plutonium.	*

* Indicates element for which evaluation is not required.
** See Foreword.

Table I (continued)

EVALUATION RESULTS FOR ABRIDGED DESIGN CRITERIA

ELEMENT	RESULT AND CHAPTER REFERENCE
e. Estimated annual quantities are 9,616 six-packs and 2,404 modular steel boxes.	*
f. Estimated total quantities are 121,700 six-packs and 30,430 modular steel boxes.	*
g. Underground facilities and equipment shall be designed to provide for a determination to effect retrieval of waste stored for a period up to 5 years after the initial emplacement and for a target of 5 to 10 years to reach the waste and retrieve it after the decision is made.	Suitable 12.6.1 12.6.2
(3) RH TRU waste **	
a. Assumed total receipt of 1,000 cansisters.	*
b. Assumed maximum receipt rate of two canisters per day and 250 canisters per year.	*
c. If assumed quantities are insufficient, additional RH waste storage will be accommodated within existing storage rooms.	*
d. Heat generated from the waste is on the order of 60 watts per canister.	*
e. Access shall be available to all emplacement positions throughout the retrievability period.	Suitable 12.3.3

Table I (continued)

EVALUATION RESULTS FOR ABRIDGED DESIGN CRITERIA

ELEMENT	RESULT AND CHAPTER REFERENCE
f. When both CH and RH waste are scheduled for the same room, the RH waste shall be emplaced first. After the 5 year retrievability period has terminated, CH waste may be emplaced in that room.	*
(4) Shaft design	
a. Shafts shall be designed to be structurally stable throughout the operating life of the underground facility and the decommissioning period.	Suitable 7.4.1 8.4.1 9.4.1
b. Time-dependent closure of shafts due to salt creep shall be considered. Shafts shall be designed so that minimum dimensions required for shaft functions are maintained during design life.	Suitable 7.4.1 8.4.1 9.4.1
c. Ground-water flow into the shafts shall be controlled so that no uncontrolled ground water reaches the storage horizon via the shafts.	Suitable 7.4.1 8.4.1 9.4.1
(5) Shaft liner design	
a. Help ensure that dimensions remain within limits required for shaft functions.	*
b. Prevent ground-water flow into the shaft.	Suitable 7.4.1 8.4.1 9.4.1
c. Protect wall rock from deterioration.	*

Table I (continued)

EVALUATION RESULTS FOR ABRIDGED DESIGN CRITERIA

ELEMENT	RESULT AND CHAPTER REFERENCE
d. Preclude risk of rock fall from shaft wall.	*
(6) Mine design	
a. The underground openings shall be designed so that deformation of excavations and pillars will remain within limits required for structural function, ventilation and safety.	Suitable 7.4.1 8.4.1 10.4.1
b. Rock bolts shall be used where necessary to provide positive support of roof and walls.	*
c. Surface subsidence resulting from underground excavation shall not exceed 1 inch within a 500-foot radius of the waste shaft.	Suitable 6.5
d. Excavations and pillars shall be located and dimensioned to avoid geologic discontinuities. If discontinuities are encountered, remedial action shall be engineered to correct the problem.	Suitable 3.4 6.3.1.2 6.3.3
e. Design shall be based on established mining procedures.	*
f. Predicted behavior of the salt shall be verified by in situ testing (SPDV) before proceeding with construction of the storage area.	*
g. Designed to accommodate creep closure and maintain the minimum dimensions required for the operating life of the opening.	Suitable 10.4.1 12.6.1

Table I (continued)

EVALUATION RESULTS FOR ABRIDGED DESIGN CRITERIA

ELEMENT	RESULT AND CHAPTER REFERENCE
h. Creep closure rates used for design shall be confirmed by instrument observations in the excavations.	Suitable 11.3.2 12.3.2
i. Excavation dimensions shall include allowance for creep closure sufficient to prevent container breaching by creep-induced stresses during the retrievability period.	Suitable 12.6.1 12.6.2
j. Minimize the potential for repository rock fracturing.	Suitable 11.4.1
k. Underground waste storage procedures shall include a designed backfill plan for fire protection. The backfill thickness shall be 1 to 2 feet.	Suitable 12.6.1
l. Permit isolation of panels of rooms with plugs after storage and backfilling are completed.	Suitable 12.6.1
m. Air locks, dampers, regulators and doors shall be designed and installed in such a manner that they can accommodate creep without impairment to their ability to maintain ventilation separation.	*
(7) Emplacement criteria	
a. The underground storage rooms and access drifts shall be designed to be compatible with the waste transport vehicle, with waste container sizes, shapes, weights and stacking configurations, and with waste emplacement equipment.	Suitable 12.6.1

Table 1 (continued)

EVALUATION RESULTS FOR ABRIDGED DESIGN CRITERIA

ELEMENT	RESULT AND CHAPTER REFERENCE
b. Provisions shall be made to accommodate backfilling over and around CH waste containers.	Suitable 12.6.1
c. Each storage panel shall have provisions for being isolated from other panels upon completion of storage operations in that panel.	Suitable 12.6.1
(8) Retrievability	
a. All wastes placed into the WIPP are retrievable, with retrievability to be demonstrated, until such time as the pilot plant is converted to an operational repository for permanent disposal of wastes.	Suitable 12.6.1 12.6.2
b. Each storage room shall allow for salt creep and shall be sized to minimize breaching of the CH waste containers for a period of 10 years.	Suitable 12.6.1 12.6.2
(9) Underground excavation and haulage	
a. Mining shall be performed with continuous miners or equivalent machine type devices. Drill and blast-type mining shall be prohibited except where authorized.	*
b. Underground design shall provide maximum stability for excavated rooms and entries.	Suitable 7.4.1 8.4.1 10.4.1 11.4.1 12.6.1

Table I (continued)

EVALUATION RESULTS FOR ABRIDGED DESIGN CRITERIA

ELEMENT	RESULT AND CHAPTER REFERENCE
c. Meet or exceed the intent of the applicable requirements of the MSHA in 30 CFR 57.9 and the New Mexico Mine Safety Code for All Mines.	*

Table II

EVALUATION RESULTS FOR C & SH SHAFT DESIGN BASES

ELEMENT	RESULT AND CHAPTER REFERENCE
(1) Shaft liner	
a. Hydrostatic pressure is considered to start 250 feet below the ground surface and extend to the top of the key.	Suitable 7.4.1
b. Water shall be prevented from flowing down the unlined shaft from behind the liner.	Suitable 7.4.1
(2) Shaft key	
a. Key shall be designed to resist the lateral pressure from the salt. (Assumed to be 75 percent of the overburden pressure.)	Suitable 7.4.1
b. Key shall be designed to resist the hydrostatic pressure from above the salt.	Suitable 7.4.1
(3) Unlined section	
Provide 11-foot 8-inch diameter to allow for future salt creep deformation.	Suitable 7.4.1

Table III

EVALUATION RESULTS FOR WASTE SHAFT DESIGN BASES

ELEMENT	RESULT AND CHAPTER REFERENCE
(1) Shaft liner	
Hydrostatic pressure is considered to start 250 feet below the ground surface and extend to the top of the key.	Suitable 8.4.1
(2) Shaft key	
Design lateral pressure shall be 50 percent of the vertical pressure due to soil, rock and salt overburden.	Suitable 8.4.1
(3) Unlined section	
Provide 20-foot diameter to allow for future salt creep deformation.	Suitable 8.4.1

Table IV

EVALUATION RESULTS FOR EXHAUST SHAFT DESIGN BASES

ELEMENT	RESULT AND CHAPTER REFERENCE
(1) Shaft liner	
Hydrostatic pressure is considered to start 250 feet below the ground surface and extend to the top of the key.	Suitable 9.4.1
(2) Shaft key	
Design lateral pressure shall be 50 percent of the vertical pressure due to soil, rock and salt overburden.	Suitable 9.4.1
(3) Unlined section	
Provide 15-foot diameter to allow for future salt creep deformation.	Suitable 9.4.1

Table V

EVALUATION RESULTS FOR STORAGE AREA DESIGN BASES

ELEMENT	RESULT AND CHAPTER REFERENCE
(1) Operational requirements	
a. The storage area rooms, drifts and crosscuts shall be designed to allow for retrieval of all CH and RH waste stored for a period of up to 5 years after the initial emplacement of each waste species.	Suitable 12.6.1 12.6.2
b. Excavation dimensions in the waste storage area shall be to a uniform height of 13 feet.	Suitable 12.6.1 12.6.2
(2) Essential features	
Provide 1 foot vertical and 9 inches horizontal allowance for creep closure to maintain the minimum design dimensions up to 5 years after initial emplacement.	Suitable 12.6.1 12.6.2
(3) Safety design requirements	
A minimum opening of 16 inches shall be left at the top of the rooms and drifts for air passage above the waste and backfill.	Suitable 12.6.1 12.6.2

Table VI

EVALUATION RESULTS FOR DESIGN CONFIGURATIONS

ELEMENT	RESULT AND CHAPTER REFERENCE
(1) C & SH shaft	
a. Provide 5/8 to 1 1/2-inch thick and 10-foot I.D. stiffened steel liner in upper 846 feet.	Suitable 7.3.2.1 7.3.3.1
b. Provide 30-inch thick, 10-foot I.D. and 39-foot long concrete key at rock/salt interface.	Suitable 7.3.2.2 7.3.3.2
c. Provide 11-foot 10-inch diameter unlined shaft below the key.	Suitable 7.3.2.3 7.3.3.3
d. Provide 17-foot high and 32-foot wide station.	Suitable 7.3.2.4 7.3.3.4
(2) Waste shaft	
a. Provide 10 to 20-inch thick and 19-foot I.D. concrete liner in upper 837 feet.	Suitable 8.3.2.1 8.3.3.1
b. Provide 51-inch thick, 19-foot I.D. and 63-foot long concrete key at rock/salt interface.	Suitable 8.3.2.2 8.3.3.2
c. Provide 20-foot diameter unlined shaft below the key.	Suitable 8.3.2.3 8.3.3.3
d. Provide 17-foot high and 30-foot wide station.	Suitable 8.3.2.4 8.3.3.4
(3) Exhaust shaft	
a. Provide 10 to 16-inch thick and 14-foot I.D. concrete liner in upper 844 feet.	Suitable 9.3.2.1 9.3.3.1

Table VI (continued)

EVALUATION RESULTS FOR DESIGN CONFIGURATIONS

ELEMENT	RESULT AND CHAPTER REFERENCE
b. Provide 42-inch thick, 14-foot I.D. and 63-foot long concrete key at rock/salt interface.	Suitable 9.3.2.2 9.3.3.2
c. Provide 15-foot diameter unlined shaft below the key.	Suitable 9.3.2.3 9.3.3.3
(4) Storage area	
a. Provide 13-foot high and 25-foot wide or smaller drifts.	Suitable 12.6.1 12.6.2
b. Provide 13-foot high and 33-foot wide storage rooms.	Suitable 12.6.1 12.6.2

CHAPTER 1
INTRODUCTION

1.1 PURPOSE

This report presents the results of validation of the underground opening reference design for the Waste Isolation Pilot Plant (WIPP). The basis for the report is defined in the Design Validation Plan (ref. 1-1) which, in part, includes certain data requirements defined in the Stipulated Agreement (ref. 1-2) reached between the U.S. Department of Energy (DOE) and the State of New Mexico on July 1, 1981.

Design validation of the WIPP is defined as the process by which the reference design of the underground openings is confirmed by determining the compatibility of the design criteria, design bases and reference design configurations using site specific information. The design validation process consists of an assessment of the condition and behavior of shafts, drifts and a full-sized, four-room test panel excavated during an initial stage known as the Site and Preliminary Design Validation (SPDV) Program and during full WIPP construction. Based on this assessment of these excavations, and on predictions of their future behavior, any modifications to the design criteria, design bases or design configurations required to achieve a validated reference design will be developed. In addition, the validated reference design may be modified in the future as still more data and experience are gained during a 5-year demonstration period (period during which all waste must be retrievable) and permanent storage operations.

In fulfilling the data requirements for design validation, this report provides documentation of actual underground conditions encountered as they relate to the design criteria, design bases and design configurations for the reference design of the underground openings. The contents of this report include all relevant data and field observations acquired for design validation. The underground openings excavated to date provide a firm basis for evaluation of the current and expected future behavior of the underground development.

The purpose of design validation is to:

- o validate the underground reference design, thus providing confidence in the safety and stability of the WIPP underground openings;

- o confirm the suitability of the design criteria, design bases and design configurations established specifically for the reference design of the underground openings;

- o re-confirm and expand upon the conclusions of the SPDV Program; and

- o comply with the DOE agreement with the State of New Mexico to validate the reference design of the WIPP underground openings.

This process was initially described in the WIPP Preliminary Design Validation Report (ref. 1-3) issued in March 1983. That report presented the results of a preliminary evaluation of the underground opening reference design based on activities conducted during the SPDV phase of underground development. That initial report was prepared in response to conditions contained in the Stipulated Agreement (Appendix A) between the DOE and the State of New Mexico which permitted a preliminary evaluation of design considerations at an early stage in underground development and allowed for any reference design modifications deemed necessary for full WIPP construction. The WIPP Design Validation Final Report (this report) is an extension of the preliminary report and presents further confirmation of the reference design based on additional data collected since completion of the SPDV Program in both old and new areas of underground excavation.

The WIPP Design Validation Final Report presents:

- o a summary of the background and development of the WIPP reference design;

- the design criteria and design bases used to develop the reference design for the underground openings;

- geologic characterizations of the shafts, drifts and test rooms;

- the methodology used for data collection, its analysis and evaluation, and the predictions of future behavior of the underground openings;

- the description of data collection activities in the shafts, drifts and test rooms;

- analyses and evaluations of the geologic behavior of the rock strata surrounding the shafts, drifts and test rooms based on visual inspections and geomechanical instrumentation measurements;

- predictions of expected future conditions of the underground openings based on model simulations using in situ data;

- an assessment of the suitability of the design criteria and design bases and validation of the reference design configurations, with recommendations for design modifications, if any;

- recommendations for operation and maintenance of the underground facility as they pertain to design validation; and

- all data and reference sources that support design validation.

1.2 SCOPE

Design validation of the WIPP underground openings has been accomplished through an assessment of their safety, stability and predicted future behavior. Observation and instrumentation data consistent with the Design Validation Plan objectives have been

collected and evaluated for each of the major design elements: shafts, drifts and test rooms.

Initial analyses and evaluations of the underground data obtained for design validation were provided in the WIPP Preliminary Design Validation Report. The WIPP Design Validation Final Report presents the results of activities whose objectives are outlined in the Design Validation Plan. These activities included field data collection and analyses of these data to determine the validity of the reference design.

Basically, four types of information were gathered for design validation. These are:

(1) observations of the behavior of the underground openings;

(2) descriptions of the geologic conditions encountered during underground construction;

(3) descriptions of core samples from instrumentation and other holes in the roof and floor of the underground openings; and

(4) data from installed geomechanical instrumentation.

Field tasks performed to gather this information included the following:

- establishment of survey control for underground excavations and reference points for geologic mapping;

- development of procedures and standards for activities such as geologic mapping/logging of underground excavations;

- geologic mapping in the shafts and horizontal openings;

- examination and logging of rock cores from boreholes to obtain geologic information;

- observation and measurement of ground-water flow into the shafts;

- measurement of hydrostatic and lateral pressures on the shaft liner and shaft key;

- monitoring the floor height of horizontal openings above the top of marker bed 139 (MB-139) and the height of clay seams above the roofs using core hole data;

- measurement of closure in the shafts and horizontal openings;

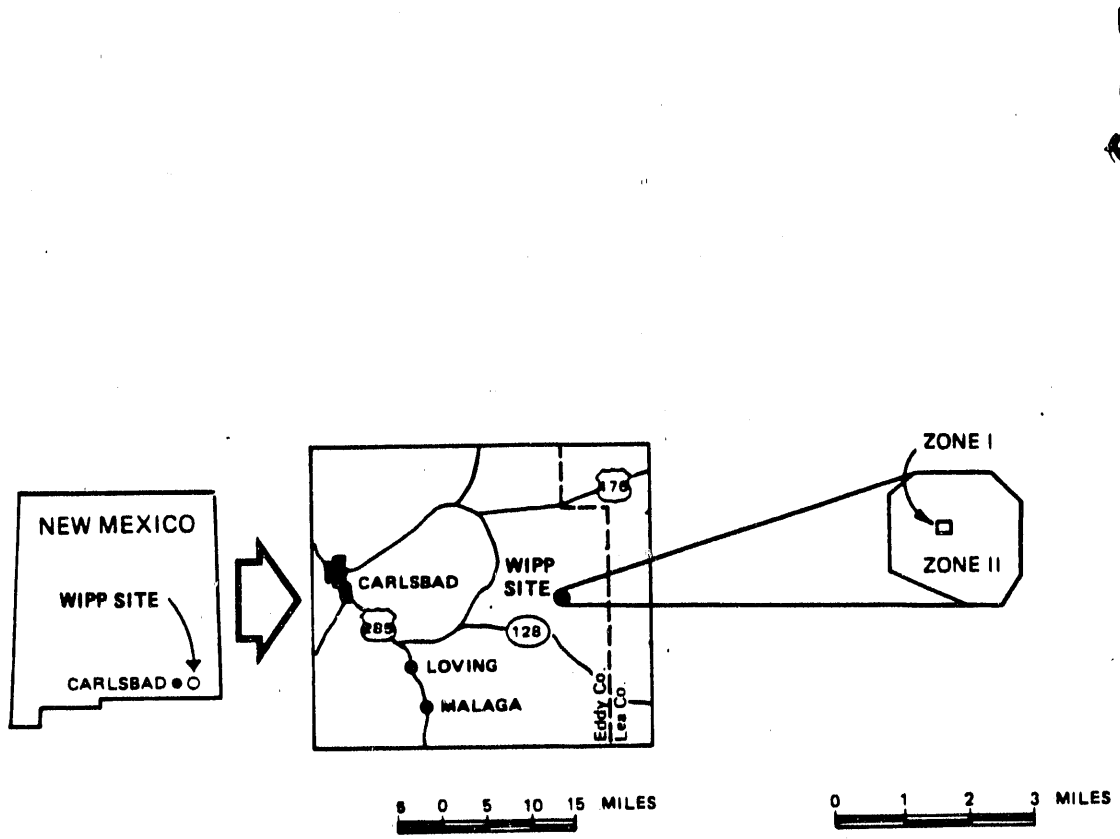
- determination of the presence of gases and fluids;

- survey of shaft verticality; and

- examination of all surfaces of underground openings for displacement of clay seams, fracturing, roof sagging, floor heaving, or other occurrences that may indicate unstable conditions.

1.3 HISTORICAL BACKGROUND

The WIPP is being developed by the DOE as a research and development (R & D) facility to demonstrate the safe disposal of radioactive waste from U.S. defense programs. The facility is located in southeastern New Mexico, about 25 miles east of the city of Carlsbad (Figure 1-1). The underground development level is at a depth of approximately 2,150 feet in thick deposits of bedded salt. The facility will include space for the permanent storage of defense related transuranic (TRU) waste and for in situ experiments addressing technical issues for high-level defense waste programs. The WIPP's phased design and construction resulted in initial confirmation of the underground opening reference design through the SPDV Program. Design



ZONE DESCRIPTION

ZONE I Surface Facilities Area
ZONE II Underground Storage Limits

Figure 1-1

LOCATION OF THE WIPP

validation will provide confirmation of the decision to continue facility construction with subsequent in situ experiments and defense TRU waste storage.

The WIPP project is the result of waste management program efforts that were started by the U.S. government as long ago as 1955 when the U.S. Atomic Energy Commission (AEC) requested that the National Academy of Sciences (NAS) evaluate methods for disposing of radioactive waste in geologic formations. The NAS recommended bedded salt as the geologic formation providing the highest confidence for long-term isolation of waste from the biosphere. As a result of these efforts, the DOE (formerly the AEC) initiated the WIPP program in 1975. The major accomplishments of the program are listed in Table 1-1.

Assessments that pertain to design of the WIPP include extensive analyses of the impact of the facility on present and future environments. A Final Environmental Impact Statement (FEIS) (ref. 1-4) was prepared which provides information about the environmental and safety consequences of the WIPP project. A Safety Analysis Report (SAR) (ref. 1-5) was also prepared to support construction and operation of the WIPP. The SAR addresses all aspects of industrial and nuclear safety of the project and is updated periodically.

The WIPP is being developed in phases. At the time this report was prepared, most of the site characterization, design and supporting technological development had been done. The engineering design of the underground openings began with a conceptual design followed by a preliminary design and finally a detailed reference design. Facility development at the site began with the SPDV Program which allowed direct observation of the underground facility geology through two shafts and associated underground drifts. This program provided data for preliminary evaluation and confirmation of the reference design of the proposed underground excavations. Design and construction of the surface facilities have proceeded virtually independent of the underground opening design validation and are not addressed in this report.

Table 1-1

MAJOR ACCOMPLISHMENTS OF THE WIPP PROGRAM

	ITEM	DATE STARTED	DATE COMPLETED
(1)	National Academy of Sciences recommends salt as best geologic formation for disposal of nuclear waste.	-	1957
(2)	Salt deposit studies conducted in New Mexico by U.S. Geological Survey and Sandia National Laboratories.	1972	1975
(3)	Conceptual design of the WIPP.	1975	1977
(4)	Characterization of the WIPP site.	1975	1983
(5)	Public law authorizes capital funding for the WIPP.	-	1977
(6)	Title I - Preliminary design of the WIPP.	1/78	1/80
(7)	Safety Analysis Report issued for the WIPP.	-	2/80
(8)	Final Environmental Impact Statement issued for the WIPP.	-	10/80
(9)	SPDV Preliminary Design Validation Program.	7/79	3/83
(10)	Detailed design for Site and Preliminary Design Validation (SPDV).	7/79	10/80
(11)	SPDV Site Validation Experiments Program.	8/80	3/83
(12)	Title II - Detailed design of the WIPP.	2/81	2/84
(13)	Construction of SPDV shafts.	5/81	3/82
(14)	Design validation.	4/81	10/86
(15)	SPDV shaft outfitting and test room development.	10/81	7/83
(16)	Authorization for full WIPP construction.	-	7/83

1.4 THE WIPP MISSION

The authorized mission for the WIPP emphasizes its role as an R & D facility to demonstrate safe disposal of radioactive waste from U.S. defense programs. Its mission is also to provide information from site characterization, laboratory experiments, geomechanical instrumentation and in situ tests which can be used to develop performance-assessment models for technological applications. Figure 1-2 shows the underground layout of the three R & D areas at the WIPP.

The WIPP R & D Program consists of three major program areas:

(1) site characterization and evaluation;

(2) repository development and operation; and

(3) waste package interactions.

In addition to providing for the permanent storage of defense related TRU waste, these program areas include technology development in waste isolation, in situ tests without radioactive material, and in situ tests with radioactive material. The WIPP will also serve as a laboratory for experiments with high-level defense waste. All high-level wastes will be removed from the WIPP at the conclusion of the testing period. These in situ waste experiments and associated activities are not part of design validation and, therefore, are not discussed in this report. An initial description of the in situ testing plan for the WIPP R & D Program was provided in Sandia National Laboratories' (SNL) Report 2628 (ref. 1-6).

1.5 DESIGN VALIDATION PROGRAM

Validation of the WIPP facility underground reference design is based on a strategy consisting of a detailed plan and approach for validating major reference design elements. A description of this strategy is

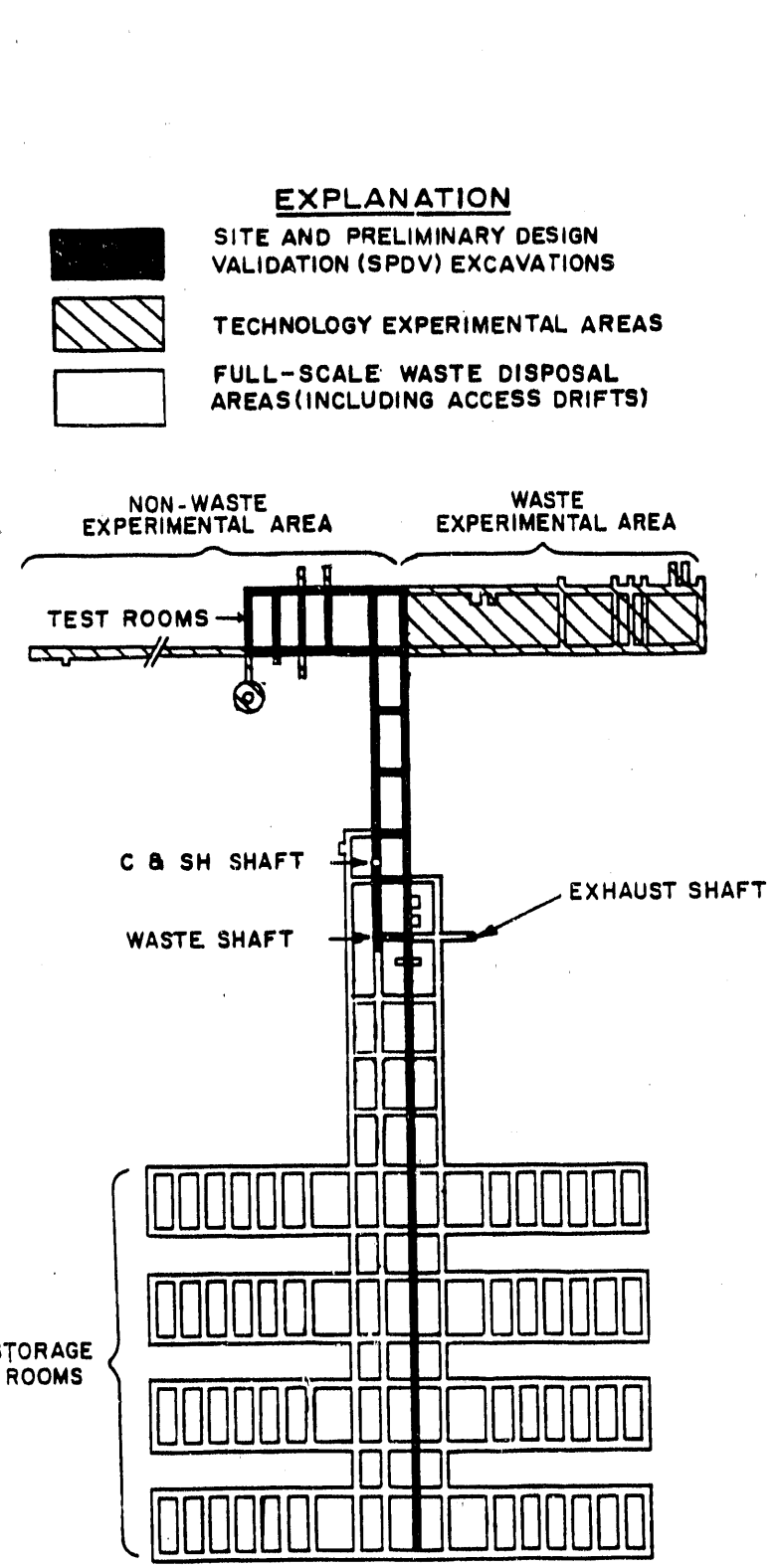


Figure 1-2

PLAN VIEW OF UNDERGROUND FACILITY

contained in the document titled Design Validation Strategy (ref. 1-7). The elements comprising the strategy for design validation are:

(1) Identify the design approaches and construction activities for the underground openings.

(2) Identify the design criteria, design bases and design configurations to be validated.

(3) Develop the methodology for validation.

(4) Acquire data on the underground development level from core samples, geologic mapping, laboratory tests, in situ tests, visual observations and mines in similar geologic formations.

(5) Synthesize the data obtained from the activities in element 4 to define the geologic environment of the facility level.

(6) Evaluate in situ geomechanical instrument measurements and visual observations to determine the response of the geologic materials to changes resulting from excavation or other disturbances.

(7) Predict the future behavior of the underground openings and salt surrounding the openings based on current in situ measurements, visual observations and computational analyses.

(8) Provide for comparisons of predicted and existing conditions at regular time intervals.

(9) Document design validation results and conclusions.

(10) Provide recommended design modifications as required.

(11) Provide data and reference sources to support the performance of the above activities.

Design validation efforts for the WIPP began with the SPDV Program. This program involved the excavation of underground openings, shafts, drifts and test rooms, representative of the full WIPP facility. These underground openings permitted the direct examination of geologic features and material behavior at the facility level. Additional observations and geomechanical instrumentation measurements were obtained following completion of the SPDV Program to complete the design validation program. A brief description of the design validation program is presented in the following subsections.

1.5.1 Site and Preliminary Design Validation (SPDV)

The SPDV Program was designed to further characterize and validate the WIPP site geology and provide preliminary validation of the underground opening reference design. The SPDV Program was composed of two integrated parts:

(1) site validation (ref. 1-8) to increase confidence in the process of site characterization and qualification; and

(2) preliminary design validation to assess the condition and behavior of excavated shafts, drifts and a full-sized, four-room test panel similar to those planned for the waste storage area.

The general SPDV underground layout is shown on Figure 1-3. The underground development level is located in Zone II, a WIPP site control zone that delineates the limits of underground storage. A preliminary design validation report was issued on March 30, 1983. This report presented the results of early observations and analyses of the condition and behavior of the SPDV excavations and is discussed in Chapter 4.

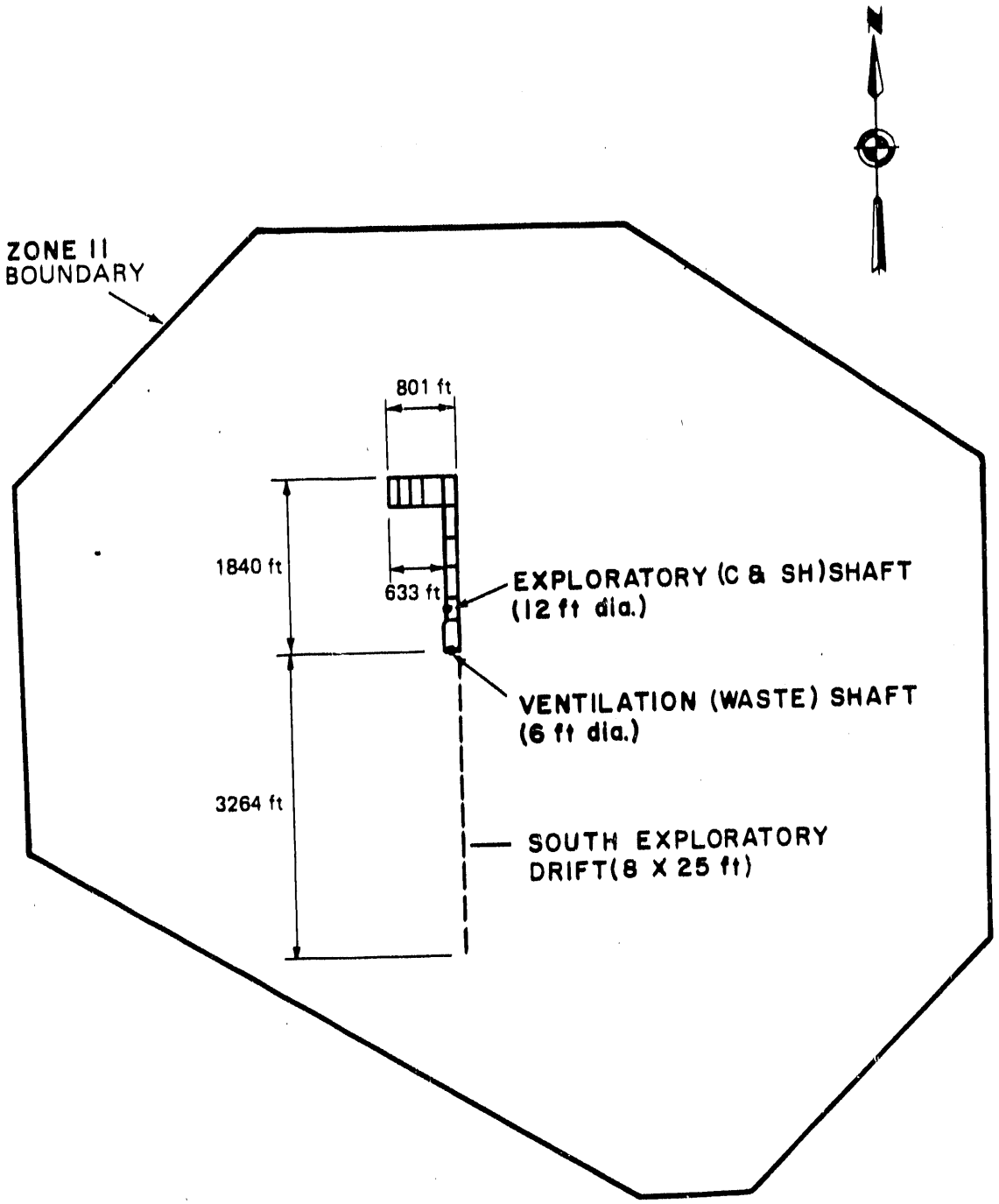


Figure 1-3

THE SPDV UNDERGROUND LAYOUT

1.5.2 Design Validation

Major activities related to design validation are cited in Table 1-2. As indicated by this table, field data collection activities that began with the SPDV Program were continued beyond the end of the program to provide additional data for design validation. The design validation process includes the evaluation and analysis of data obtained by these activities. The results of these evaluations and analyses have been presented in quarterly geotechnical field data reports (GFDR), each of which presents a discussion of different selected elements of the WIPP underground development. These reports provide supporting documentation for the WIPP Design Validation Final Report and are discussed in Chapter 4.

Some of the field data collection activities shown in Table 1-2 will continue after submittal of the WIPP Design Validation Final Report and beyond the completion of full WIPP construction. Collection of this data will provide additional information on the behavior of the underground openings through the 5-year demonstration period and through permanent storage operations. The data will also permit continuous monitoring of the safety of the openings. Underground facility reference design modifications will be made as required by an evaluation and analysis of these data. The data obtained will be periodically distributed to the project participants, the State of New Mexico, and will be placed in WIPP public reading rooms.

Table 1-2

DESIGN VALIDATION ACTIVITY SCHEDULE

	ACTIVITY	RESPONSIBILITY	SCHEDULE
(1)	Prepare and issue Design Validation Plan	B/DOE	7/82 - 1/83
(2)	Field data collection:		
	a. Geologic mapping of vertical and horizontal underground excavations	TSC/B	3/82 - 3/83
	b. Geomechanical instrumentation measurements and visual observations in shafts, drifts, and test rooms	TSC/B	4/82 - 3/83
	c. Log core from holes in horizontal underground openings	TSC/B	10/82 - 3/83
	d. Fluid inflow measurements	TSC/B	9/81 - 3/83
	e. Shaft verticality surveys	DOE/TSC	1/82 - 3/83
(3)	Evaluate field data; prepare Preliminary Design Validation Report	B	10/82 - 3/83
(4)	Issue Preliminary Design Validation Report	DOE	3/83
(5)	Continue with (2a), (2b), (2c), and (2d) above	TSC/B	3/83 - 7/86
(6)	Evaluate/analyze field data; prepare Design Validation Final Report	B	3/83 - 5/86
(7)	Design Validation Final Report review by Peer Review Panel	B	5/86 - 6/86
(8)	Issue Design Validation Final Report	DOE	10/86

B = Bechtel National, Inc.; DOE = U.S. Department of Energy; TSC = Technical Support Contractor (Westinghouse Electric Corp.)

CHAPTER 2
BACKGROUND OF UNDERGROUND DESIGN

2.1 SITE CHARACTERIZATION AND EVALUATION

WIPP site characterization programs have consisted of geologic and hydrologic studies as well as biologic, meteorologic and economic studies. Geologic and geohydrologic characterization of the site, which started with surveys of literature and existing data, continued with the collection of new data and had the greatest degree of influence on design of the underground facility. Special emphasis was placed on correlating data obtained by geophysical techniques and borehole drilling. The geophysical techniques most widely used were seismic reflection and resistivity. Borehole drilling programs included holes drilled primarily for stratigraphic information on or near the site and holes drilled at the edge of, or away from, the site to study salt dissolution. Three holes, WIPP-11, WIPP-12 and DOE-1, were drilled through the Salado formation to acquire geologic data on deeper strata outside the Zone II boundaries of the site (refs. 2-1, 2-2 and 2-3). Within Zone II, the drilling of deep exploratory holes, i.e., to the depth of the WIPP facility level, was restricted by siting criteria. Prior to the drilling of the SPDV exploratory and ventilation shafts (subsequently known as the C & SH and waste shafts, respectively), ERDA-9 was the only borehole within Zone II that extended below the facility level.

The generalized stratigraphic relationship of the geologic formations of interest beneath the WIPP site is shown on Figure 2-1. Siltstone and fine-grained sandstone are the main rock types forming the Dewey Lake red beds. The Rustler formation, composed primarily of anhydrite and fine-grained sandstone, siltstone and mudstone, contains two water-bearing dolomite beds. Saline water is found in these beds, the Magenta and Culebra members, and at the contact between the Rustler and Salado formations. The Salado formation consists largely of halite containing thin beds of anhydrite and polyhalite with occassional thin clay seams. The Castile is a thick anhydrite and halite formation

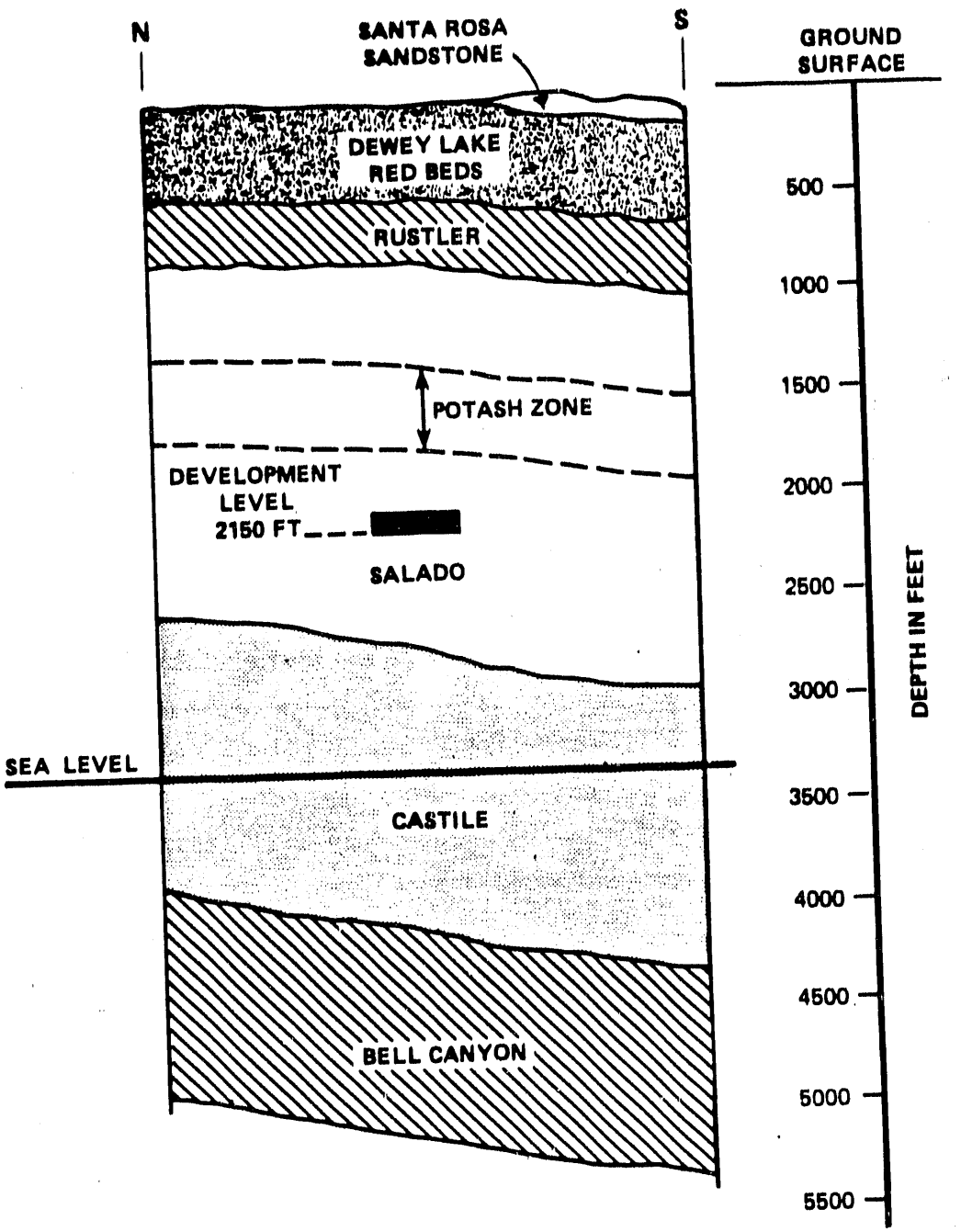


Figure 2-1

GENERAL SITE STRATIGRAPHY

underlying the Salado. The Bell Canyon formation consists primarily of sandstone, limestone and shale. No aquifers are present in the Salado or Castile formations beneath the site.

Site stratigraphy from the ground surface to about 250 feet below the underground facility level is presented in Appendix B, Figure B-1, Sheets 1 through 5. The stratigraphy shown is based on geologic data obtained from boreholes WIPP-12, ERDA-9 and DOE-1, and from the C & SH and waste shafts. An analysis of these data shows a strong correlation of the stratigraphy between the boreholes and shafts from the ground surface to below the underground facility level. This correlation is based primarily on the geophysical logs because core sample logging or "hands-on" mapping was not always carried out through the entire interval. Where possible, graphic lithologic descriptions based on logging or mapping of the rock strata have been included on Figure B-1 in Appendix B. This helps to more fully define the stratigraphic relationships shown by the geophysical logs.

The analysis between boreholes WIPP-12 to the north and DOE-1 to the south resulted in correlation of the major formation contacts and most marker beds in the Salado formation. Due to a lack of distinctive stratigraphic changes, the Dewey Lake red beds exhibit a relatively uniform profile in both the lithologic and geophysical logs. The Rustler formation, however, exhibits a much greater fluctuation in its geophysical profile as a result of the anhydrite, dolomite and fine-grained clastic beds it contains. Figure B-1 in Appendix B shows that the Rustler thickens slightly to the north with a slight rise in formation contacts occurring in the area of the WIPP facility.

Correlation of the Salado formation stratigraphy between WIPP-12 and DOE-1 verifies the consistency of most of the marker beds. The geophysical logs shows distinct breaks where polyhalite and anhydrite beds occur in the largely halitic rock strata. The major stratigraphic occurrence, in that portion of the Salado formation shown on Figure B-1 in Appendix B, is a thinning of strata to the north. This thinning

becomes apparent below marker bed 124 (MB-124) and is relatively well pronounced in the underground facility horizon. The effect of this thinning is to produce a reversal in the direction of dip of the strata above and below MB-124 between WIPP-12 and DOE-1. Above this marker bed the strata dip to the north, while below the marker bed the strata dip to the south. This thinning of strata controls the slope of the facility level excavation because the excavation must avoid encroachment on any stratigraphic horizons that could affect the stability or safety of the underground openings.

The figures in Appendix B show the continuity of rock strata across the WIPP site and in the area of underground excavation. These figures are intended to show that the major design assumptions which were made based on data from boreholes ERDA-9 and WIPP-12 remain valid, based on additional data obtained from geologic mapping of the underground openings and logging of underground core holes. Therefore, correlation of the site stratigraphy from the ground surface to below the underground facility level confirms the macroscopic continuity of stratigraphy beneath the WIPP site. Geologic characterization at the WIPP underground facility level is presented in Chapter 6.

Geohydrologic data pertaining to the site were obtained from conventional and special-purpose tests in many boreholes (ref. 1-5). Geophysical logging of these holes provided hydrogeologic information on the rock strata encountered. Pressure measurements, fluid samples and ranges of rock permeability were obtained for selected formations. Also, potentiometric surfaces of major aquifer systems were contoured by using measured water level elevations in boreholes.

Evaluation of data obtained from early site selection studies indicated that the current WIPP site was a suitable candidate for the establishment of a facility to demonstrate the safe disposal of radioactive waste. Additional studies have resulted in the issuance of numerous reports regarding the suitability of the WIPP site, including the Geological Characterization Report, Waste Isolation Pilot Plant

(WIPP) Site, Southeastern New Mexico (ref. 2-4), Final Environmental Impact Statement: Waste Isolation Pilot Plant (ref. 1-4), and the Waste Isolation Pilot Plant Safety Analysis Report (ref. 1-5). Final site validation was achieved in 1983 by an evaluation of the data contained in a report titled Results of Site Validation Experiments, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico (ref. 2-5) which presented the results of studies performed to fully satisfy all site qualification criteria. This report was followed by a confirmation of overall site suitability in a report titled Summary Evaluation of the Waste Isolation Pilot Plant (WIPP) Site Suitability (ref. 2-6).

2.2 DESIGN CRITERIA

The Design Criteria, Waste Isolation Pilot Plant (WIPP), Site and Preliminary Design Validation (SPDV) (ref. 2-7), and the Design Criteria, Waste Isolation Pilot Plant (WIPP), Revised Mission Concept-IIA (RMC-IIA) (ref. 2-8) were used as guides by the Architect-Engineer (Bechtel National, Inc.) in developing the reference design for the WIPP underground openings. The documents contain general requirements which were addressed in the reference design. The Design Criteria, RMC-IIA, is the highest level design document for the project. All other design documents, such as design bases, drawings and specifications, were required to be in compliance with this document.

The design criteria also stipulate the type and estimated or assumed rate of waste to be received at the WIPP. The majority of the criteria presented in the RMC-IIA document are requirements which do not need evaluation as to their suitability and have no impact on validation considerations for the underground opening reference design. The major criteria that governed development of the reference design are presented in Table 2-1. Although some of the criteria in this table are elements which cannot be evaluated, they are included because of their influence on the reference design configurations. Those criteria that can be evaluated are discussed in later chapters of this report as

Table 2-1

ABRIDGED WIPP DESIGN CRITERIA

(1) Facility design

a. Designed for an operating life of 25 years.

b. Underground facilities and equipment shall be designed to be compatible with retrieval operations for all contact-handled (CH) and remote-handled (RH) TRU waste, with a retrieval decision to be made within 5 years after the initial emplacement of each species. (Chapter 12)

c. The facility will be decommissioned after it has fulfilled its intended purposes. This will include backfilling the underground facilities, sealing the shafts and decommissioning the surface facilities.

(2) CH TRU waste *

a. Estimated annual volume is 500,000 cubic feet.

b. Estimated volume at the end of the 5 year retrieval decision period is 1,410,000 cubic feet.

c. Estimated total storage capacity is 6,330,000 cubic feet.

d. Heat generated from the waste is negligible; it will be less than 10 milliwatts for average drums, less than 20 milliwatts for average boxes, and 10 watts for few drums containing heat source plutonium.

e. Estimated annual quantities are 9,616 six-packs and 2,404 modular steel boxes.

f. Estimated total quantities are 121,700 six-packs and 30,430 modular steel boxes.

g. Underground facilities and equipment shall be designed to provide for a determination to effect retrieval of waste stored for a period up to 5 years after the initial emplacement and for a target of 5 to 10 years to reach the waste and retrieve it after the decision is made. (Chapter 12)

(3) RH TRU waste *

a. Assumed total receipt of 1,000 canisters.

b. Assumed maximum receipt rate of two canisters per day and 250 canisters per year.

* See Foreword.

c. If assumed quantities are insufficient, additional RH waste storage will be accommodated within existing storage rooms.

d. Heat generated from the waste is on the order of 60 watts per canister.

e. Access shall be available to all emplacement positions throughout the retrievability period. (Chapter 12)

f. When both CH and RH waste are scheduled for the same room, the RH waste shall be emplaced first. After the 5 year retrievability period has terminated, CH waste may be emplaced in that room.

(4) Shaft design (Chapters 7, 8 and 9)

a. Shafts shall be designed to be structurally stable throughout the operating life of the underground facility and the decommissioning period.

b. Time-dependent closure of shafts due to salt creep shall be considered. Shafts shall be designed so that minimum dimensions required for shaft functions are maintained during design life.

c. Ground-water flow into the shafts shall be controlled so that no uncontrolled ground water reaches the storage horizon via the shafts.

(5) Shaft liner design

a. Help ensure that dimensions remain within limits required for shaft functions.

b. Prevent ground-water flow into the shaft. (Chapters 7, 8 and 9)

c. Protect wall rock from deterioration.

d. Preclude risk of rock fall from shaft wall.

(6) Mine design

a. The underground openings shall be designed so that deformation of excavations and pillars will remain within limits required for structural function, ventilation and safety. (Chapters 7, 8 and 10)

Table 2-1 (continued)

ABRIDGED WIPP DESIGN CRITERIA

b. Rock bolts shall be used where necessary to provide positive support of roofs and walls.

c. Surface subsidence resulting from underground excavation shall not exceed 1 inch within a 500-foot radius of the waste shaft. (Chapter 6)

d. Excavations and pillars shall be located and dimensioned to avoid geologic discontinuities. If discontinuities are encountered, remedial action shall be engineered to correct the problem. (Chapters 3 and 6)

e. Design shall be based on established mining procedures.

f. Predicted behavior of the salt shall be verified by in situ testing (SPDV) before proceeding with construction of the storage area.

g. Designed to accommodate creep closure and maintain the minimum dimensions required for the operating life of the opening. (Chapters 10 and 12)

h. Creep closure rates used for design shall be confirmed by instrument observations in the excavations. (Chapters 11 and 12)

i. Excavation dimensions shall include allowance for creep closure sufficient to prevent container breaching by creep-induced stresses during the retrievability period. (Chapter 12)

j. Minimize the potential for repository rock fracturing. (Chapter 11)

k. Underground waste storage procedures shall include a designed backfill plan for fire protection. The backfill thickness shall be 1 to 2 feet. (Chapter 12)

l. Permit isolation of panels of rooms with plugs after storage and backfilling are completed. (Chapter 12)

m. Air locks, dampers, regulators and doors shall be designed and installed in such a manner that they can accommodate creep without impairment to their ability to maintain ventilation separation.

Table 2-1 (continued)

ABRIDGED WIPP DESIGN CRITERIA

(7) Emplacement criteria

a. The underground storage rooms and access drifts shall be designed to be compatible with the waste transport vehicle, with waste container sizes, shapes, weights and stacking configurations, and with waste emplacement equipment. (Chapter 12)

b. Provisions shall be made to accommodate backfilling over and around CH waste containers. (Chapter 12)

c. Each storage panel shall have provisions for being isolated from other panels upon completion of storage operations in that panel. (Chapter 12)

(8) Retrievability

a. All wastes placed into the WIPP are retrievable, with retrievability to be demonstrated, until such time as the pilot plant is converted to an operational repository for permanent disposal of wastes. (Chapter 12)

b. Each storage room shall allow for salt creep and shall be sized to minimize breaching of the CH waste containers for a period of 10 years. (Chapter 12)

(9) Underground excavation and haulage

a. Mining shall be performed with continuous miners or equivalent machine type devices. Drill and blast-type mining shall be prohibited except where authorized.

b. Underground design shall provide maximum stability for excavated rooms and entries. (Chapters 7, 8, 10, 11 and 12)

c. Meet or exceed the intent of the applicable requirements of the MSHA in 30 CFR 57.9 and the New Mexico Mine Safety Code for All Mines.

indicated in the table.

2.3 DESIGN BASES

The design bases identify the detailed design requirements for the WIPP underground facilities. They are derived from the more general concepts presented in the design criteria. The design bases cover all aspects of the design and facility operations. Design bases applicable to design validation are listed in references 2-9 through 2-20. The essential elements of the design bases pertaining to design validation of the C & SH shaft, waste shaft, exhaust shaft, drifts and storage area are discussed in Chapters 7 through 10 and Chapter 12. The discussions cover only those bases that require evaluation. All other bases are requirements determined during design reviews and need not be evaluated for their suitability.

2.4 DESIGN CONFIGURATIONS

The reference design configurations are the engineered facilities designed to comply with the design criteria and design bases. They are described in various contract drawings and specifications. The essential elements of the design configurations are discussed in Chapters 3 and 12.

2.5 DESIGN DEVELOPMENT

Design of the WIPP surface and underground facilities consisted of three stages:

(1) the conceptual design;

(2) the preliminary design; and

(3) the detailed design, including the underground opening reference design.

At both the conceptual and preliminary design stages, an extensive, independent review of the underground layout and design was made by the

DOE and its consultants, SNL and Westinghouse Electric Corporation. The review included assessment of the underground design concept and consultation with Carlsbad area potash mine operators to obtain information from their experience. The preliminary design was also reviewed by other Federal agencies, the State of New Mexico and the NAS.

From these reviews and consultations, the DOE concluded that the detailed design, based on the current state of the art, was sound. However, for further confirmation, it was decided that the impact of site-specific geologic conditions on the underground opening reference design should be verified by direct observation. Consequently, the DOE initiated the SPDV Program described in Chapter 1. The SPDV Program provided in situ data on the local geology and on the geomechanical response of the strata to the underground openings.

2.5.1 Conceptual Design

Design of the WIPP surface and underground facilities began with the conceptual design, initiated in 1975 and completed in 1977 (ref. 2-21). The conceptual design provided the basis for development of the preliminary design of both the surface and underground facilities.

2.5.2 Preliminary Design

The WIPP preliminary design was begun in 1978 and completed in 1980 (ref. 2-22). The preliminary design (Figure 2-2) was based on empirical methods and local mining practices, incorporating the conventional room and pillar method for underground development. It included analytical evaluations of underground openings in bedded salt using the finite element method and laboratory test data (refs. 2-23 and 2-24). The roof and floor of the rooms and entries were checked for stability by methods described in the SME Mining Engineering Handbook (ref. 2-25). In addition to Bechtel, SNL performed confirming numerical analyses (refs. 2-26 and 2-27). These analyses predicted short- and long-term stress distributions around the selected openings as well as elastic and creep deformations.

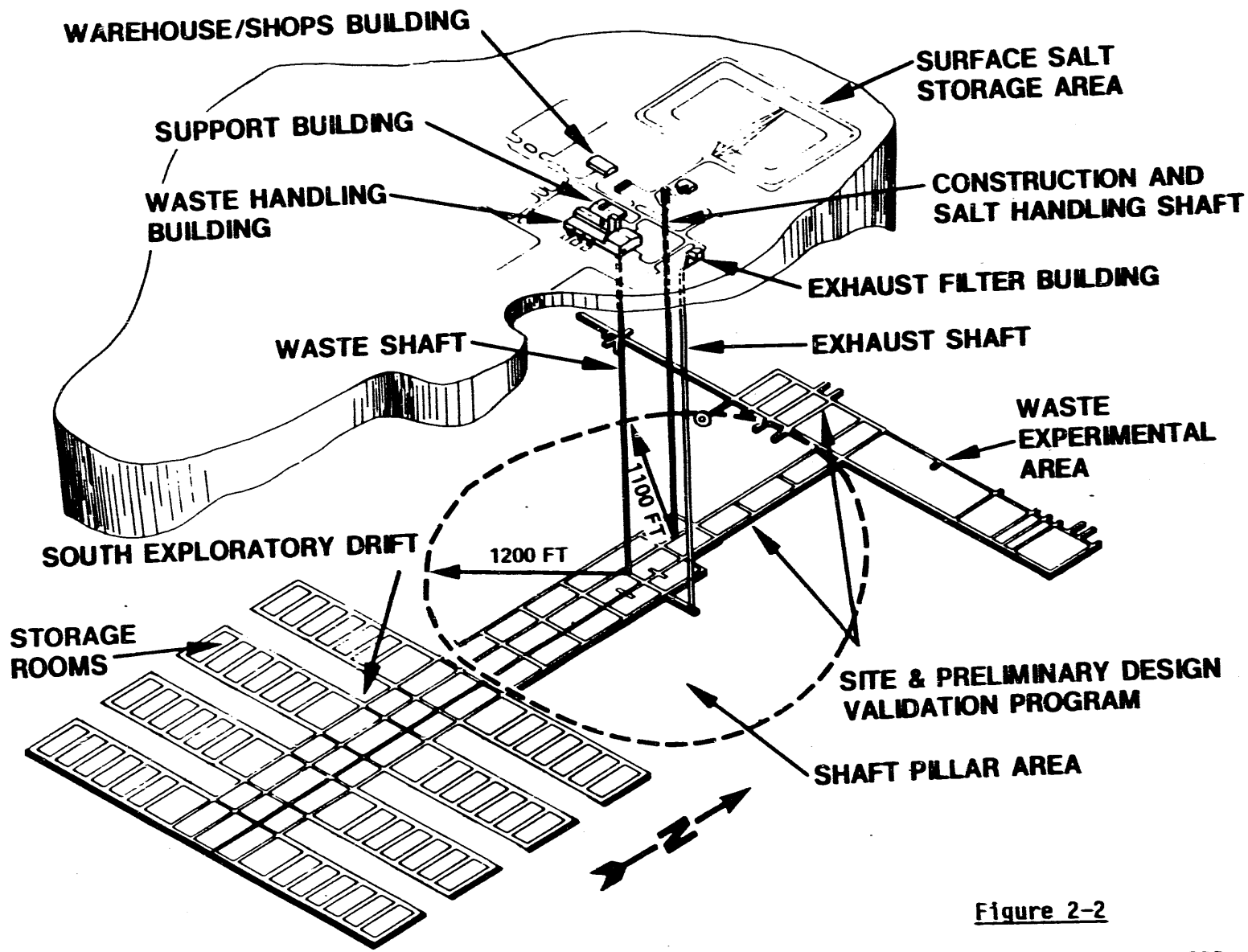


Figure 2-2

PERSPECTIVE VIEW OF THE WIPP

2.5.3 Detailed Design

Detailed design of the WIPP, begun in 1981 and completed in 1984, included design of the surface and underground facilities and the reference design for the underground openings. This was based on an extensive amount of data derived from the site characterization, including information from boreholes, surface geophysical measurements and laboratory tests. These data were used to establish the facility level and the design parameters. The number of holes drilled to the proposed facility level was restricted in order to retain its isolation from the surface. The layout and configuration of the underground openings were based mainly on empirical data which incorporates the room and pillar concept utilized in existing potash mines in Carlsbad and other mining areas, and on storage efficiency. The design was also based on mining and engineering standards universally applied to underground projects.

Analyses were performed to evaluate the stability of underground openings using material properties obtained from laboratory tests of core samples (ref. 2-28). Validation of the underground opening reference design with respect to the actual underground environment requires direct observation of geologic conditions at the facility level and the behavior of the underground openings. This interaction between observation of underground excavation and development of design is consistent with engineering practice for underground construction and with achieving the most cost-effective facility configuration.

Detailed design of the WIPP had sufficient flexibility to allow the incorporation of initial information obtained from excavation during the SPDV Program. This design flexibility was necessary for construction of the underground facilities. Calculations that applied material properties and analytical models developed from laboratory tests were performed to evaluate the behavior of the underground openings. Information obtained from the design validation program was used to confirm, refine, or alter the underground opening reference design as required to accommodate in situ conditions. The detailed

design included the development of construction details for the experimental areas and the full-scale waste storage area. It also included design of the surface facilities but this is not included in the design validation program.

2.6 DESIGN METHODS

Practical experience in the safe construction of salt and potash mines extends over many years. Empirical knowledge on the safe sizes of openings and pillars has been documented (ref. 2-29) and performance records of openings in salt are available. Different methods of analysis are required to determine the stability of openings in salt for different conditions of potential failure. The normal safety concepts of engineering, which relate a factor of safety to loads or stresses, cannot be transferred directly to the analysis of underground openings in salt. Therefore, postulated failure conditions were analyzed by other appropriate methods. In general, an opening in salt can be considered stable when the following two basic requirements are satisfied:

(1) the deformation of the opening conforms to the clearance envelope allowed for safe operation of the workings during design life; and

(2) the load bearing capacity of the salt around the opening is adequate to prevent sudden structural failure of the opening.

Subsections 2.6.1 through 2.6.3 discuss the empirical methods, closed form solutions and model simulations used for the reference design of the WIPP underground openings.

2.6.1 Empirical Method

Most of the seven potash mines in the Carlsbad area were visited by project participants on several occasions as the design evolved. The preliminary room and pillar configurations, including the width and

spacing of the rooms, drifts and pillars, were based primarily on experiences gained from general mining practices in those mines in areas with similar geology. The extraction ratio at the WIPP facility horizon is significantly less than that used in potash mines of similar depth in the Carlsbad area and in other parts of North America.

2.6.2 Closed Form Solutions

Closed form solutions in the SME Mining Engineering Handbook were used to check the design of the room-and-pillar system, including room dimensions, room spacing, pillar stresses and pillar width-to-height ratios. These types of solutions were also used to check room stability, including the stresses on the roof beams, and to estimate surface subsidence (ref. 2-30). Closed form solutions for steel and concrete structural design were used for design of the shaft liners and keys.

2.6.3 Model Simulation

To determine the geomechanical and structural behavior around the underground openings, mathematical models of the openings were generated and preliminary finite element analyses were performed to simulate this behavior. These analyses used material properties obtained from laboratory tests of drill core samples to estimate closure of the openings. In order to maintain the operational capability of the underground facility during its design life, allowances for roof, floor and wall closures were added to the operational clearance envelope of the underground openings. The design criteria require confirmation or modification of the estimated closure based on geomechanical instrument measurements obtained in the excavations.

Preliminary analyses were only considered parametric studies since important feedback from the design validation program observations and geomechanical instrument measurements was required to complete the understanding of the mechanism of creep deformation in the salt at the WIPP site.

CHAPTER 3
UNDERGROUND FACILITIES

3.1 INTRODUCTION

This chapter presents a brief history of the underground development level selection process. It also describes the configurations of the WIPP shafts, drifts and rooms, and summarizes their excavation history. The discussion of excavation history includes those details pertaining to the "as-built" openings which are considered significant with respect to the reference design. The reference design of the underground openings was based on requirements contained in the Design Criteria (refs. 2-7 and 2-8) and Design Bases (refs. 2-9 through 2-20) documents.

The WIPP underground facility is divided into three general areas (Figure 3-1). The northern portion is the experimental area containing the design validation test rooms and technology experiments. The central area is the shaft pillar. The number of drifts in this area is restricted to minimize subsidence around the shafts. This portion of the facility will primarily contain shops and personnel areas. The southern portion of the facility is the waste storage area. Although some mining has been conducted in this area, it remains largely unexcavated at the time of publication of this report.

3.2 SELECTION OF THE UNDERGROUND DEVELOPMENT LEVEL

Selection of the WIPP underground development level evolved over several years and various facility design concepts. Seven stratigraphic horizons were identified in 1979 as potential locations for the facility level and ranked in order of their preference. These seven horizons were chosen based on an examination of available borehole data, primarily geologic and geophysical logs from borehole ERDA-9, and on horizon selection criteria established by the WIPP project participants. The selection criteria consisted of recommended distances between the underground opening surfaces and the nearest overlying or underlying clay seams or partings.

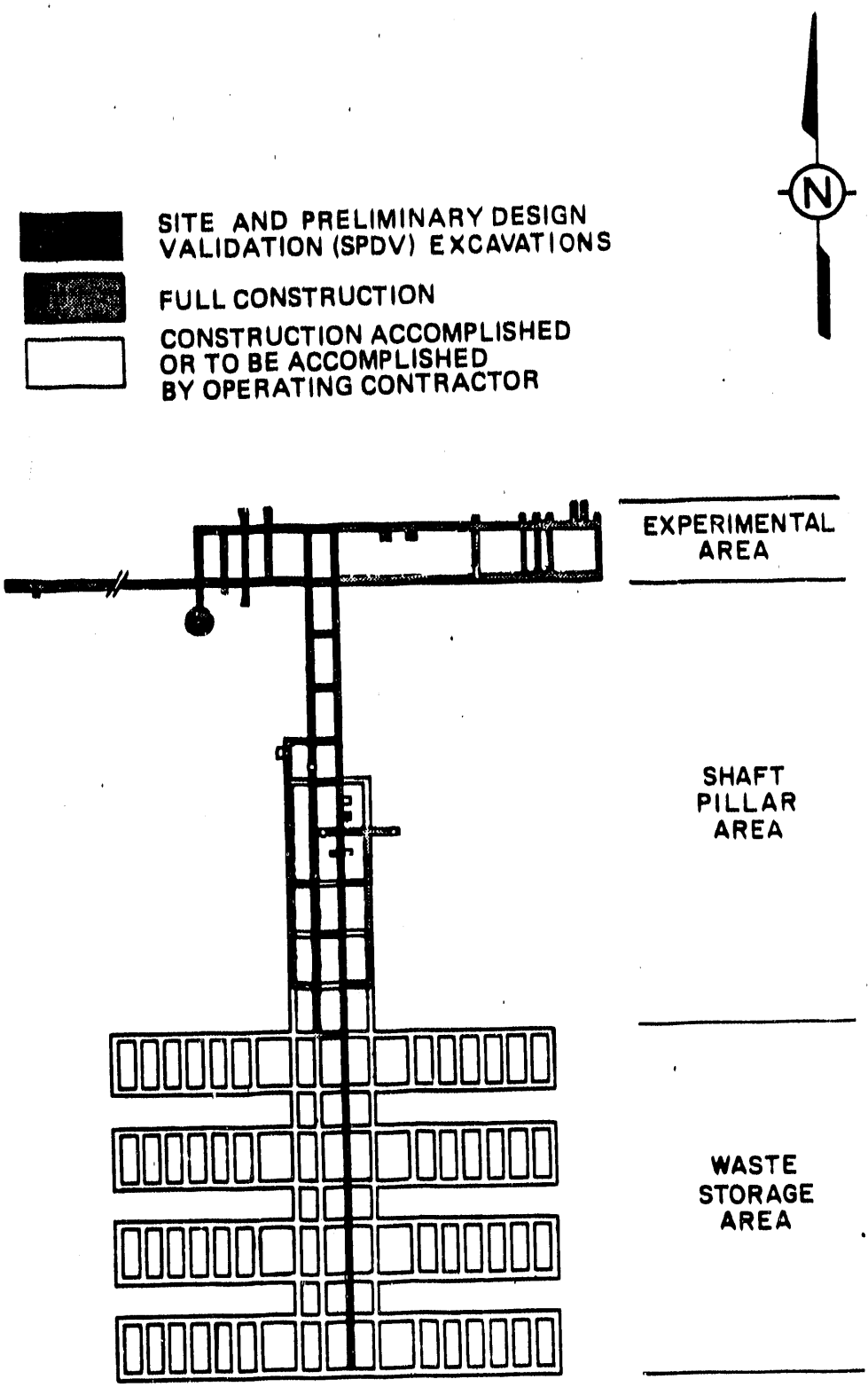


Figure 3-1

FUNCTIONAL AREAS OF THE UNDERGROUND FACILITY

Geologic mapping of the SPDV exploratory shaft in April and May 1982 permitted an assessment of the suitability of those intervals in the area of MB-139 preferred for the location of the facility level. This assessment included an evaluation of the intervals of interest against a modified version of the 1979 horizon selection criteria. These modified criteria were a result of changes to the initial WIPP facility concept, consisting of a reduction from two levels to one and alterations in the room size. The modified criteria were as follows:

(1) The rock comprising the underground facility horizon should contain no significant dissolution features, faults, or fractures. If any such features are noted, a detailed investigation must be conducted. (This element was not explicitly stated in the 1979 criteria.)

(2) There should be a minimum 4-foot thickness of halite between the top of MB-139 and the facility floor. The undulatory upper contact of MB-139 shall be considered in the selection of the facility floor level. (The 1979 criteria required a 5-foot thickness between the facility floor and the first underlying clay seam or parting.)

(3) There should be a minimum 14 1/2-foot section of halite for construction of nominal 13-foot high rooms. Minor impurities, such as argillaceous halite and polyhalite, may be acceptable. (The facility design in 1979 called for 12-foot high rooms.)

(4) There should be a minimum of 5 feet of halite between the facility roof and the first overlying clay seam (defined as 1/4 inch thick or greater) for purposes of roof stability. (This criterion was adjusted at the site to a 5- to 10-foot thickness at the verbal request of SNL personnel.)

(5) Horizons containing substantial amounts of polyhalite should be avoided. The minimum thickness of halite defined in the

third criterion listed above was increased from 14 1/2 feet to 17 feet or more to accommodate the 17-foot high SPDV exploratory shaft station.

Selection of the final underground development level was made following a series of meetings in which the interval ranked first was evaluated for its ability to satisfy these criteria. The selection was based primarily on the results of detailed geologic shaft mapping from a depth of 2,080 feet to 2,185 feet. A meeting, attended by representatives from the DOE, Westinghouse, SNL and Bechtel, was held on May 2, 1982, to discuss the results of the selection process and to present a recommendation for the facility level location to the DOE. The final level selected for the facility floor was at a preliminary depth of 2,149 feet (elev. 1258.4 feet). The recommendation was accepted by the DOE and later reviewed and concurred in by a representative of the New Mexico Environmental Evaluation Group (EEG).

Geologic mapping of the SPDV exploratory shaft and subsequent evaluation by the project participants showed that, as anticipated, the geology was similar to that encountered in borehole ERDA-9. One exception was the discovery of an additional anhydrite bed, anhydrite "b", and its underlying clay seam. Figures 3-2 and 3-3 show the preliminary design (pre-SPDV) of the shaft station and storage rooms. This preliminary design was based on the stratigraphy at the first-ranked alternative horizon. Figures 3-2 and 3-3 show that only one anhydrite layer and clay seam were expected above the facility level at this horizon, based on the interpretation of ERDA-9 core. This would have produced 12 feet of uninterrupted halite above the shaft station and 16 feet above the storage rooms. However, shaft mapping revealed an intermediate bed, anhydrite "b", approximately 7 feet below the known bed, anhydrite "a". This reduced the uninterrupted halite thickness above the facility level roof to 3.5 to 5 feet at the shaft station and 7 to 8.5 feet in the waste storage area. Despite this finding, the underground facility horizon chosen was judged to adequately meet all of the established criteria.

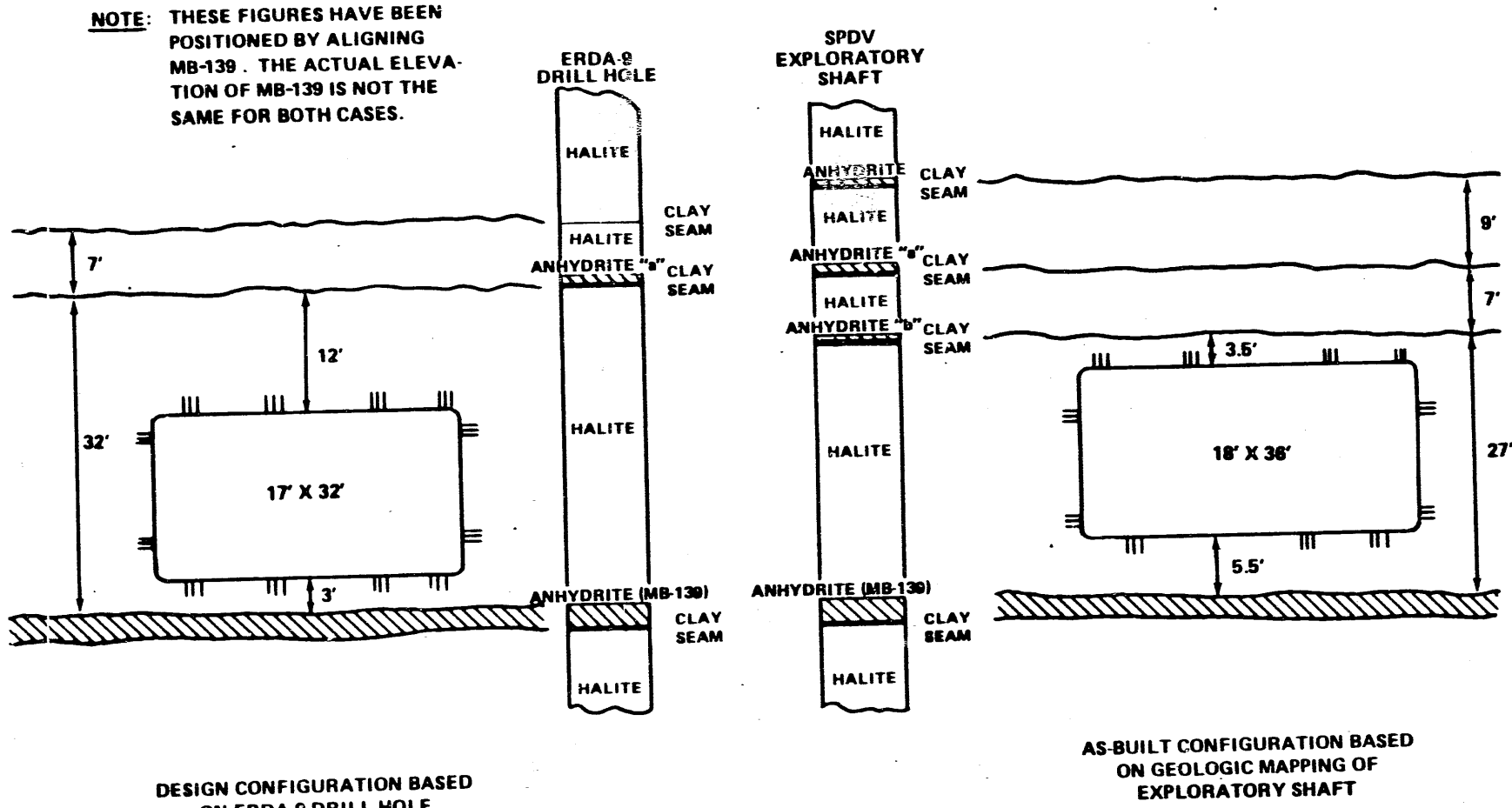
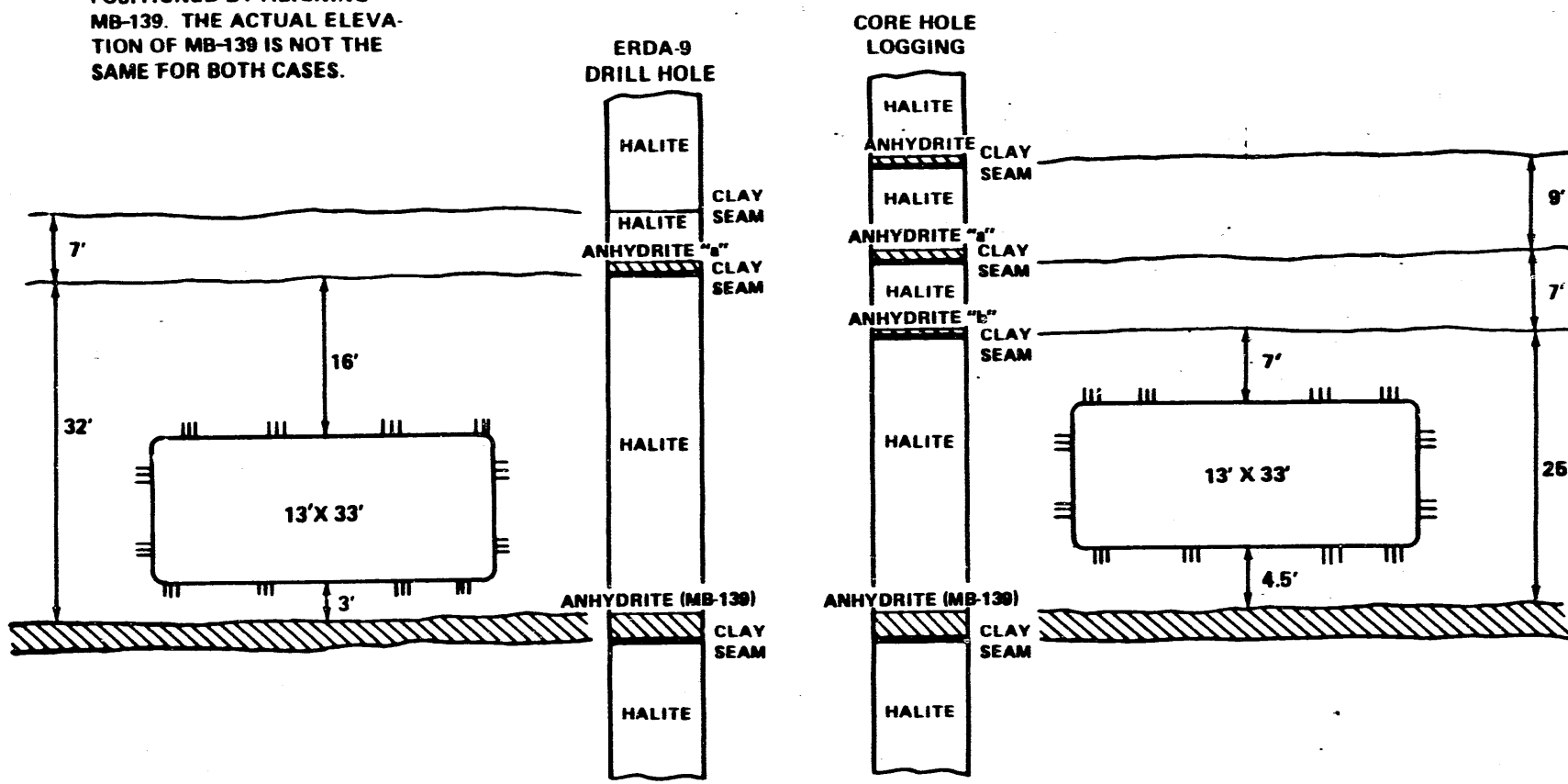


Figure 3-2

SPDV EXPLORATORY SHAFT STATION
DESIGN VERSUS AS-BUILT CONFIGURATION

NOTE: THESE FIGURES HAVE BEEN POSITIONED BY ALIGNING MB-139. THE ACTUAL ELEVATION OF MB-139 IS NOT THE SAME FOR BOTH CASES.



DESIGN CONFIGURATION BASED ON ERDA-9 DRILL HOLE

REVISED CONFIGURATION BASED ON CORE HOLE DATA

Figure 3-3

STORAGE ROOM
DESIGN VERSUS REVISED CONFIGURATION

At a meeting held on February 13, 1986, consideration was given to the desirability of relocating the facility level to a different stratigraphic horizon (ref. 3-2). The discussion was prompted by the following observations of the behavior of the underground openings:

(1) The effect of excavation on the strata surrounding the underground openings are being investigated by gas permeability testing. These tests indicate that zones of increased permeability due to fracturing, and proportional to the size of the opening, have developed between the floor of the openings and the base of MB-139 in the test rooms. These zones have also developed at intersections and other locations in the N1420 drift. Increased permeability has also been detected within anhydrite "b" above the roof of the test rooms. (Additional permeability testing is being conducted by SNL. The final results from this program are not yet available.)

(2) Fracturing has been encountered both within and above MB-139. It is especially well developed in the southern half of Test Room 3 (Room T). This fracturing is discussed in Chapter 10, subsection 10.3.2.1, and in Chapter 11, subsection 11.3.2.1.

(3) Both horizontal displacements and vertical separations have been observed above the roof of the underground openings. These occur primarily at anhydrite "b" and are associated with the underlying clay seam. This is discussed in Chapter 10, subsection 10.3.2.1, and in Chapter 11, subsection 11.3.2.1.

(4) In situ closure rates are almost three times greater than the rates originally predicted from laboratory test data. This is discussed in Chapters 10, 11 and 12.

The underground opening behavior occurring at the WIPP is similar to that of other openings excavated in areas with similar geologic formations. The conditions are understood and any problems encountered can be adequately mitigated using standard mining engineering procedures. The behavior experienced at the present facility level is likely to occur to some extent at any alternate horizon selected. These conclusions, and the fact that the behavioral characteristics and geologic environment at the existing level are known, resulted in a decision by the WIPP project participants to keep the facility level at its present location. Studies of the behavior of the rooms and drifts will continue beyond design validation as discussed in Chapter 1, subsection 1.5.2.

3.3 DESCRIPTION OF UNDERGROUND FACILITIES

3.3.1 C & SH Shaft

The construction and salt handling (C & SH) shaft is the principal means of access to the underground WIPP facility and is the primary fresh-air intake for the underground ventilation system. It was originally designated the exploratory shaft during the SPDV Program. The shaft provides a means of access for personnel and materials to and from the facility, and for the removal of excavated salt. Geomechanical instrumentation installed in the shaft provides important data for monitoring the behavior of the liner and key, the salt strata surrounding the shaft, and ground-water pressures.

The shaft is lined with steel casing having a 10-foot inside diameter from the ground surface to a depth of 846 feet. The 10-foot diameter extends through the concrete shaft key to a depth of 880 feet. From the key to the bottom of the shaft at 2,298 feet the shaft is a nominal 12 feet in diameter and is unlined.

The steel liner was designed to retain the rock formations above the salt and to prevent water seepage into the shaft. The liner was designed for both construction and permanent loads. The construction load was considered to be the hydrostatic pressure exerted on the liner

by the fluid used to "float" it into place for installation. The permanent load is the hydrostatic pressure exerted on the liner by ground water under artesian conditions in the water-bearing zones. Rock pressure was not used in design due to the controlling influence of the hydrostatic pressure. Since hydrostatic pressure increased with depth, the steel liner thickness was also increased. The liner is 5/8 inch thick at the top and increases to 1 1/2 inches thick at the bottom. The liner is held in place with cement grout.

The C & SH shaft key is a 37 1/2-foot long reinforced-concrete structure at the base of the steel liner. The key serves two important functions. First, it provides a transition from the lined to the unlined sections of the shaft. Second, as an integral part of the liner, it prevents ground water from the upper water-bearing members from dissolving the salt around and beneath the key. This water movement is obstructed primarily by two water seals installed behind the concrete. A third seal, installed at the interface of the steel liner and concrete key, prevents water from flowing out at the interface and down the inner surface of the key. A gravel-filled trench was constructed behind the concrete above the lower of the two seals to intercept water migration past the upper seal. This water is drained through four pipes, called "telltales", to the key surface and into a water collection ring at the base of the key.

The shaft is unlined below the concrete key. Excavation by the rotary drilling method has resulted in shaft walls that are smooth and undamaged. No support or protective wire mesh was required.

3.3.2 Waste Shaft

The waste shaft serves to connect the waste handling building on the ground surface with the WIPP underground facility. The shaft's primary function is to permit the transfer of radioactive waste from the surface to the underground storage area. It will also serve as an intake shaft for small volumes of air during storage operations and as an emergency escape route. The waste shaft was initially excavated as

a 6-foot diameter ventilation shaft, which was the primary exhaust route during the SPDV phase of construction. As in the C & SH shaft, geomechanical instruments installed in the waste shaft provide important geotechnical data with which to monitor the behavior of the shaft and its surrounding geologic environment.

The waste shaft is lined with unreinforced concrete from the ground surface to the top of the key at a depth of 837 feet. The purpose of the liner is to retain the surrounding rock and to prevent ground water from entering the shaft. The lined section of the shaft has a finished inside diameter of 19 feet. The liner thickness increases with depth from 10 inches at the surface to 20 inches at the key. A water collection ring was incorporated into the liner immediately beneath both the Magenta and Culebra water-bearing members. These rings are connected to another ring at the base of the key.

The waste shaft key is similar in construction to the C & SH shaft key. It serves as a transition from the concrete-lined section to the exposed salt section of the shaft and it prevents ground water from reaching the salt via the shaft opening. The key is 63 feet long, 4 1/4 feet thick and constructed of reinforced concrete. The bottom of the key is at a depth of 900 feet. In contrast to the C & SH shaft key, the waste shaft key has only two water seals.

A water collection ring at the base of the key collects water trickling down the surface of the key and conducts it, as well as water from the two upper rings, to the shaft station via a 2-inch diameter PVC pipe. Two guide pipes, consisting of 2-inch diameter polyvinyl chloride (PVC) pipe, were also installed in the concrete key at a depth of 843 feet at the request of SNL to serve as guides for drilling test holes across the contact of the Rustler formation with the Salado formation.

The section of the shaft below the key is 20 feet in diameter and consists of exposed salt lined with wire mesh anchored by rock bolts. The 20-foot diameter shaft enlarges to 23 feet just above the waste

shaft station. This 23-foot diameter extends to the bottom of the shaft, approximately 122 feet below the facility level.

3.3.3 Exhaust Shaft

The exhaust shaft is the primary ventilation exhaust for the underground facilities. It is designed as a duct to remove air from the underground areas up through the exhaust filter building at the ground surface. In addition, the exhaust shaft will serve as a backup escape route during emergencies. This shaft is also used to carry an auxiliary 15 kV power cable and signal cables underground. These redundant cables serve as emergency alternates should the primary cables in the C & SH shaft become inoperative. The exhaust shaft, like the C & SH and waste shafts, contains a suite of geomechanical instruments.

The exhaust shaft is lined with unreinforced concrete from the ground surface to the top of the shaft key at a depth of 844 feet. The purpose of the liner is the same as that in the other two shafts. The liner has an inside diameter of 14 feet. The liner thickness increases from 10 to 16 inches with depth.

The exhaust shaft key serves the same function as the keys in the other two shafts. It is a transition element between the concrete liner in the upper section of the shaft and the exposed salt in the lower section. It is also designed to prevent ground water in the upper water-bearing members from reaching the salt section of the shaft. The key is 63 feet long and 3 1/2 feet thick. The key contains eight telltale drains at a depth of 857 feet and nine drains each at 855 feet and 870 ft. The key also contains two water seals, a water collection ring, and two guide pipes for drilling test holes. The bottom of the key is at a depth of 907 feet.

The exhaust shaft below the key is 15 feet in diameter. It is lined with wire mesh anchored by rock bolts. The exhaust shaft terminates at the facility level; there is no shaft sump.

3.3.4 Drifts

The underground shaft stations and drifts have been designed to facilitate the handling and transport of radioactive waste. They also provide access for construction operations and experimental activities. The drifts are designed to provide adequate ventilation supply and exhaust for all areas of the underground facility.

All drifts are rectangular in cross section with typical dimensions that range from about 8 to 12 feet high and 14 to 25 feet wide. Access drifts serve as the main haulageways between the shafts and the experimental and waste storage areas. Cross-cut drifts (crosscuts) are designed to accommodate equipment, shops and traffic flow. The crosscuts are generally smaller in cross-sectional dimensions than the access drifts. The excavated dimensions of major drifts and rooms are presented in Table 3-1. The horizontal underground openings are oriented either north-south or east-west and are labeled based on a grid system having the centerline of the C & SH shaft as its origin. For example, the E0 drift runs north-south in line with the C & SH shaft and the N1100 drift is an east-west drift 1100 feet north of the C & SH shaft.

The northern part of the facility contains the experimental areas. Four test rooms were excavated west of the E0 drift as part of the SPDV Program. These rooms are discussed in subsection 3.3.5. The remaining experimental areas have been excavated for long-term experimental programs to be conducted under the direction of SNL. These experiments are not part of design validation and are addressed in this report only when necessary to clarify the discussion.

The shaft pillar area (Figure 3-1) is designed to protect the surface structures and shafts from settlement resulting from the natural closure of underground openings. The shaft pillar dimensions were derived in accordance with standard analyses developed by the U.S. Bureau of Mines (ref. 2-30). Excavation within the shaft pillar area was designed to maintain an extraction ratio of less than 15 percent.

Table 3-1

FACILITY LEVEL CONFIGURATIONS
NOMINAL EXCAVATED DIMENSIONS OF MAJOR DRIFTS AND ROOMS

Drift or Room						Width (ft)	Height (ft)
E0	From	N35	To	N1420		25	12
E140	From	N140	To	N1420		14	8
E140	From	N140	To	S2210		25	12
E140	From	S2210	To	S3264	(Exploratory Drift)	25	8
E300	From	S90	To	S1980		14	12
W30	From	S90	To	S700		20	12
W30	From	S700	To	S1950		14	12
W170	From	N140	To	S1300		14	12
N140	From	E0	To	E140		12	12/19
N140	From	E0	To	W170		12	12/19
N460	From	E0	To	E140	(Conference Room)	20	8
N780	From	E0	To	E140		12	12
N1100	From	E0	To	E1546		14	9
N1100	From	E0	To	W667		20	12
N1100	From	W667	To	W1800	(Room G Entry Drift)	20	9
N1100	From	W1800	To	W2990	(Room G)	20	10
N1420	From	E140	To	E1546		14	12
N1420	From	E140	To	W647		20	12
S90	From	E0	To	E140		12	12
S90	From	E140	To	E300		14	12
S400	From	E60	To	E140		20	12
S400	From	E140	To	E300		14/18	12/17
S400	From	E300	To	E500		20	12
S700	From	W170	To	W30		20/25	12
S700	From	W30	To	E140		20	12
S700	From	E140	To	E300		20/35	12
S1000	From	W170	To	W30		20	12
S1000	From	W30	To	E140		25	12
S1000	From	E140	To	E300		20	12
S1300	From	W170	To	W30		20	12
S1300	From	W30	To	E140		20	12
S1300	From	E140	To	E300		20	12
S1600	From	W170	To	W30		20	12
S1600	From	W30	To	E140		20	12
S1600	From	E140	To	E300		20	12
S1600	From	E300	To	E520		14	12
S1950	From	W30	To	E140		14	12
S1950	From	E140	To	E300		20	12
S2180	From	E140	To	E300		14	12

Table 3-1 (continued)

FACILITY LEVEL CONFIGURATIONS
NOMINAL EXCAVATED DIMENSIONS OF MAJOR DRIFTS AND ROOMS

Drift or Room	Width (ft)	Height (ft)
Test Rooms 1, 2, 3 & 4 (300 feet long)	33	13
Experimental Rooms A1, A2, A3, B & D (306 feet long)	18	18
Alcove I1 (43 feet long)	24	12
Alcoves I2, I3, I4, I5, I6 & I7 (33 feet long)	33	12
Rooms C1 & C2 (98 and 102 feet long)	18	18
Room J (98 feet long)	33	12
Rooms L1 & L2 (98 feet long)	33	12
Room H Entry	12	10
Room H (outside radius = 54 feet)	36	10

A geomechanical instrumentation program was implemented to gather geotechnical data from the underground drifts. The program was designed to monitor the stability of the openings, to assess deformational characteristics of the salt, and to measure closure rates of typical drifts, rooms and intersections. In addition, an extensive program of geologic mapping, core drilling, laboratory testing and visual observations has been conducted. The methodology used and the results of these programs are discussed in other chapters of this report.

3.3.5 Test Rooms

Four test rooms were excavated in the northern section of the facility during the SPDV phase of construction. These rooms represent full-scale models of the future waste storage rooms and have the same dimensions, 13 feet high, 33 feet wide and 300 feet long, as the planned storage rooms.

The test rooms are designed to permit an assessment of deformation and closure rates due to salt creep as well as the stability of the future storage rooms. This has been accomplished by evaluations and analyses of geotechnical data gathered from geomechanical instruments installed in each room and the results of geologic mapping, core drilling, laboratory testing of samples from the surrounding strata, and qualitative visual observations by project geotechnical personnel. The results of these evaluations and analyses are presented in Chapters 11 and 12.

3.3.6 Waste Storage Area

The waste storage area will be developed in the southern portion of the facility (Figure 3-1). The reference design for this area includes a series of eight panels with seven storage rooms in each panel. The room dimensions are 13 feet high, 33 feet wide and 300 feet long. The width of the pillars between rooms is 100 feet. This configuration results in a storage area extraction ratio of less than 25 percent based on a line 100 feet beyond the storage area excavation neat line.

Full development of the waste storage area will eventually encompass about 140 acres. The reference design is based on the assumption that the storage rooms and panels will be excavated in stages coordinated with the scheduled arrival of waste. Waste storage is designed not only for the rooms but also for all drifts and crosscuts in the waste storage area (south of the S1600 drift).

3.4 UNDERGROUND CONSTRUCTION

The existing WIPP underground facility was constructed in two phases. The first phase, SPDV (Figure 3-1), was conducted from 1981 to 1983 and consisted of the excavation of the exploratory and ventilation shafts as well as several drifts and a panel of four test rooms. SPDV accomplished two objectives: (1) it permitted the completion of experiments and geotechnical activities required for the Site Validation Program (ref. 2-5); and (2) it provided for the initial in situ confirmation of the underground facility reference design. This allowed construction of the underground facility to proceed in a timely and cost-effective manner.

Excavation associated with the second phase of underground construction was accomplished from October 1983 through February 1985 and is designated as full construction on Figure 3-1. This excavation included enlarging the ventilation shaft for its conversion to the waste handling shaft, constructing the exhaust shaft, and mining additional underground drifts and test rooms for conducting R & D experiments. The operational name of the exploratory shaft changed to the C & SH shaft during this period. Design validation has been an integral part of this construction activity.

A third phase of underground construction is currently in progress. This is the initial operations phase during which excavation of the storage rooms will occur concurrently with waste emplacement. Mining for this phase started in June 1985 with the excavation of crosscuts for the installation of shops in the shaft piller area. Partial excavation of some storage rooms will follow. However, initial waste

emplacement is currently not scheduled to begin until late 1988. No discussion of the operations phase is presented in this report, although it will be strongly affected by the design validation results presented herein.

3.4.1 C & SH Shaft

C & SH shaft construction was performed during 1981 and 1982. Construction started in May 1981 with the excavation of a 98-foot deep pilot hole. The pilot hole was augered using a crane-mounted drilling unit. Steel surface casing with an interior diameter of 12 feet was grouted into place to a depth of 93.4 feet.

Shaft drilling started on July 4, 1981, and was completed 112 days later. The drilling was performed using a jacknife derrick with draw works capable of supporting a suspended load of 500 tons. The drilling method used consisted of air-lifted reverse circulation performed through double-walled drill pipe. The drilling fluid (brine) was maintained at a relatively constant level above the drill bit. The drill bit consisted of a 142-inch diameter full-face rolling cutter head. Shaft drilling was completed to a depth of 2,298 feet on October 24, 1981. Table 3-2 contains an abridged history of the C & SH shaft drilling program.

Liner installation began on November 12, 1981, and was completed on December 3, 1981. A steel liner was installed in 20- and 40-foot sections in the shaft above the salt formation. The steel sections were connected during installation using full-penetration bevel welds. Nondestructive radiographic examination was performed on each welded section. The liner was partially floated into place by filling the shaft with brine and adding brine to the inside of the liner to overcome the effect of buoyancy. Additional support for installation was provided by the drilling derrick and draw works. After the liner was in place, the annular space was grouted by the tremmie method. The grouting was completed on December 8, 1981.

Table 3-2

C & SH SHAFT - ABRIDGED DRILLING HISTORY

Location:		Eddy County, New Mexico; New Mexico Grid Coordinates X 666894.89, Y 499687.23
Elevation:		Ground Surface = 3410.5 ft MSL
Drilling Contractors/Rig Types:		Meredith Drilling Company/Auger (11.0 ft to 97.5 ft*); Challenger Drilling Company/ National 125 Jacknife Rotary (97.5 ft to 2,298 ft)
Drilling Data	Augered:	May 18 to June 17, 1981
	Spudded:	July 4, 1981
	Completed:	October 24, 1981
	Casing:	180-in. corrugated metal pipe, ground surface to 11 ft; 144-in. steel casing, ground surface to 93.4 ft; 120-in. steel liner, ground surface to 846 ft
	Drill Hole:	142-in. (nominal) diameter uncased borehole to a total depth of 2,298 ft
	Drilling Fluid:	Brine
Directional Survey Contractor:		Sperry-Sun (Gyroscopic Multishot Surveys)
Bottom Hole Coordinates:		X 666893.45, Y 499686.56 at 2,276 ft
Horizontal Displacement:		1.59 ft S 65.03° W at 2,276 ft

Table 3-2 (continued)

C & SH SHAFT - ABRIDGED DRILLING HISTORY

Geophysical Logging Contractors:	Birdwell(B) and Dresser Atlas(D)
Geophysical Logs:	October 16 to December 17, 1981
Fluid Density (D)	1,200 ft to 550 ft
Fluid Density (B)	750 ft to 20 ft
Density (B)	2,294 ft to 50 ft
Caliper (3-diameter/aver.) (B)	2,294 ft to 50 ft
Epithermal Neutron (B)	2,294 ft to 50 ft
Gamma Ray (B)	2,300 ft to 0 ft
Fluid Density (B)	400 ft to 100 ft
Nuclear Cement Top Locator (NCTL) (B)	827 ft to 0 ft
Nuclear Annulus Investigation Log (NAIL) (B)	839 ft to 0 ft
Fluid Density (D)	2,250 ft to 2,003 ft

* All depths measured from ground surface.

A key was constructed at the base of the steel liner during March and April 1982. The key is 37 1/2 feet long and constructed of reinforced concrete. Key construction required additional excavation in the salt below the liner to enlarge the shaft diameter. After the installation of reinforcing steel, drains, geomechanical instruments, grout pipes and block-outs for the injection of chemical seals, concrete was placed in several lifts from the bottom of the key to the bottom of the liner. Finally, the chemical seals were placed by injection.

3.4.2 Waste Shaft

Drilling of the SPDV ventilation shaft started on December 24, 1981, and was completed to a depth of 2,196 feet on March 10, 1982. The drilling operation was performed with the same drill rig used to drill the C & SH shaft. The drill bit was a 72-inch diameter full-face rolling cutter head. An abridged history of the shaft drilling is presented in Table 3-3. Except for a 97-foot long surface casing, the ventilation shaft was unlined. The ventilation shaft, and later the waste shaft, served as the exhaust for the underground facility until excavation of the permanent exhaust shaft was completed.

Enlargement of the SPDV ventilation shaft to become the waste shaft began in October 1983 (Table 3-3). This enlargement was performed from the top to the bottom of the shaft using the smooth-wall drill and blast method. The blasting was accomplished in 10-foot rounds that permitted the muck to fall down the 6-foot diameter shaft to the facility level. The muck was removed from the waste shaft station and hauled to the surface via the salt-handling skip in the C & SH shaft.

Construction of the unreinforced concrete liner closely followed this excavation. Typically, the shaft crew would take out three rounds (30 feet) of rock before placing one 24-foot section of concrete. This arrangement normally left no more than 6 feet of unlined shaft below the concrete.

Table 3-3

WASTE SHAFT - ABRIDGED CONSTRUCTION HISTORY

Location:		Eddy County, New Mexico; New Mexico Grid Coordinates X 666920.76, Y 499286.92
Elevation:		Ground Surface = 3407.5 ft MSL Shaft Collar = 3407.9 ft MSL (ventilation shaft) Shaft Collar = 3409.0 ft MSL (waste shaft)
Ventilation Shaft		
Drilling Contractors/Rig Types:		Meredith Drilling Company/Auger (8.0 ft to 98.2 ft*); Challenger Drilling Company/ National 125 Jacknife Rotary (98.2 ft to 2,196 ft)
Drilling Data	Augered:	June 13 to 17, 1981
	Spudded:	December 24, 1981
	Completed:	March 10, 1982
	Casing:	108-in. corrugated metal pipe, ground surface to 8 ft; 74-in. steel casing, 0.5 ft above ground surface to 96.9 ft
	Drill Hole:	72-in. (nominal) diameter uncased borehole to a total depth of 2,196 ft
	Drilling Fluid:	Brine
Directional Survey Contractor:		Sperry-Sun (Gyroscopic Multishot Surveys)
Bottom Hole Coordinates:		X 666918.81, Y 499285.81 at 2,177 ft
Horizontal Displacement:		2.25 ft S 60.2° W at 2,177 ft

Table 3-3 (continued)

WASTE SHAFT - ABRIDGED CONSTRUCTION HISTORY

Shaft Survey Contractor:	Cementation West, Inc.
Horizontal Displacement:	1.37 ft SW at 2,150 ft
Geophysical Logging Contractor:	Birdwell
Geophysical Logs:	March 8 to 10, 1982
Caliper (3-diameter/aver.)	2,190 ft to 0 ft
Epithermal Neutron	2,190 ft to 0 ft
Density	2,190 ft to 0 ft
Gamma Ray	2,100 ft to 0 ft
Fluid Density	2,191 ft to 1,800 ft
Waste Shaft	
Excavation Contractor:	Ohbayashi Corporation
Excavation Method:	Smooth-wall drill and blast
Finished Shaft Diameter:	Lined = 19 ft Unlined = 20 ft minimum
Shaft Collar Excavation Began:	October 11, 1983
Liner Plate and Concrete Backfill Completed:	November 12, 1983
Collar Pads and Sinking Headframe Foundations Poured:	November 14, 1983
Concrete Liner Constructed: (including key)	November 30, 1983, to April 3, 1984
Liner Plate at Magenta Dolomite Grouted:	March 8 to 10, 1984
Liner Plate at Culebra Dolomite Grouted:	April 3 to 5, 1984
Salt Section Excavated:	April 7 to June 11, 1984
Sump Excavated:	June 20 to August 8, 1984
Liner Grouted:	August 11 to 25, 1984

* All depths measured from ground surface.

As part of the shaft design, both the Magenta and Culebra dolomite members of the Rustler formation were overexcavated and covered with steel liner plate prior to concrete placement. The space between the liner plate and the rock provided room for water from these water-bearing zones to accumulate. This allowed the concrete liner to reach full strength without damage from hydrostatic pressure buildup. After the concrete liner had reached full strength, this annular space was grouted with Portland cement grout at a 1:1 cement-to-water ratio.

Construction of the waste shaft key was nearly identical with that of the C & SH shaft key. The key is 63-feet long and composed of reinforced concrete. The shaft was overexcavated and the reinforcing steel, drainpipes, geomechanical instruments and chemical seal blockouts were installed. Unlike in the C & SH shaft, the chemical seals were placed between lifts of concrete. Concrete was placed from the bottom of the key to the top in several lifts, with construction joints at the top of each lift and at each chemical seal blockout. At the chemical seal locations the seal material was placed into the blockout prior to placing the next lift of concrete. Construction of the shaft liner and key was completed on April 3, 1984.

Excavation of the shaft to its 20-foot finished diameter below the key began on April 7, 1984. This section of the shaft is lined with wire mesh anchored by 3-foot long rock bolts. Mesh installation, like liner installation, was accomplished concurrently with excavation. The shaft enlargement reached the facility level on June 11, 1984. The shaft sump was excavated between June 30 and August 8, 1984. The sump extends approximately 122 feet below the facility level.

The concrete liner and grouting at both water-bearing zones did not completely prevent water from entering the shaft. Water seeped through the liner at construction joints and some cracks from a depth of about 560 feet to 835 feet. A grouting program was undertaken to seal these leaks in August 1984. A total of 628 bags of Portland Type V cement, 103 bags of MC-500 microfine cement, and 76 gallons of Scotch-brand

5600 foam chemical grout were injected into 293 drilled holes (ref. 3-3). The grouting significantly reduced, but did not eliminate, water seepage through the concrete liner.

3.4.3 Exhaust Shaft

The exhaust shaft was constructed in two phases over a 16 month period. The first phase was the excavation of a 6-foot diameter pilot shaft using upreaming techniques. The second phase consisted of enlargement of this shaft by conventional drill and blast methods and lining of the upper 907 feet. The construction history is summarized in Table 3-4.

Shaft excavation began on September 22, 1983, with the drilling of a pilot hole. The pilot hole was a 7 7/8-inch diameter hole drilled from the ground surface to intersect with the S400 drift at a depth of about 2,150 feet. Therefore, directional control of the hole was critical. The upper 80 feet of the pilot hole was augered, then lined with a surface casing. Drilling progressed to a depth of 744 feet using a tri-cone roller bit and compressed air. A "Dynadrill" was then used to correct hole alignment from 735 to 1,183 feet based on the results of gyroscopic hole surveys. The circulating medium was also changed at this time from air to brine. The tri-cone bit was used to complete the pilot hole. The hole diameter was then reamed to 11 inches from the surface to the facility level, again using a tri-cone roller bit. Pilot hole drilling was completed on December 16, 1983.

Excavation of the pilot shaft was performed by reaming the 11-inch diameter pilot hole to a diameter of 6 feet. This was accomplished by the raise-bore method. Reaming was performed from the facility level to the ground surface. The raise-boring operation was conducted from December 31, 1983, to February 10, 1984, using a Robbins series 61R1131 raise-bore machine. This machine utilizes a full-face rolling cutter head pulled to the surface with hydraulic jacks. Drill cuttings fell to the facility level and were hauled to the surface via the C & SH shaft.

Table 3-4

EXHAUST SHAFT - ABRIDGED CONSTRUCTION HISTORY

Location:	Eddy County, New Mexico; New Mexico Grid Coordinates X 667370.39, Y 499287.23
Elevation:	Shaft Collar = 3411.5 ft MSL Shaft Reference = 3409.0 ft MSL
Excavation Contractor:	Ohbayashi Corporation
Excavation Method:	Raise-bore 6-ft diameter pilot shaft; smooth-wall drill and blast to final dimensions
Subcontractors for Raise-Bore Excavation:	Raisebore, Inc., and J. S. Redpath Co.
Finished Shaft Diameter:	Lined = 14 ft Unlined = 15 ft
Pilot Hole Drilled:	September 22 to December 16, 1983
Raise-Bore Excavation:	December 31, 1983, to February 10, 1984
Shaft Collar Excavation Began:	July 15, 1984
Liner Plate and Concrete Backfill Completed:	July 17, 1984
Concrete Liner Constructed: (including key)	July 18 to November 29, 1984
Liner Plate at Culebra Dolomite Grouted:	December 2 to 4, 1984
Liner Plate at Magenta Dolomite Grouted:	December 4 to 5, 1984
Salt Section Excavated:	December 7, 1984, to January 17, 1985
Liner Grouted:	June 1 to July 31, 1985

Enlargement of the pilot shaft from 6 feet to the final exhaust shaft diameter of 15 feet began on July 15, 1984, and was accomplished by drilling and blasting in 10-foot rounds. Excavation was performed from the ground surface to the facility level. The rock was blasted into the open pilot shaft so that it fell to the facility level where it could be removed and hauled to the surface via the C & SH shaft.

The upper 844 feet of the exhaust shaft is lined with unreinforced concrete. As in the waste shaft, construction of the exhaust shaft liner occurred concurrent with the drill and blast excavation. Concrete placement for the liner was completed on November 29, 1984. The two water-bearing zones in the Rustler formation, the Magenta and Culebra dolomites, received the same special treatment that was performed in the waste shaft. Each zone was overexcavated and covered with steel liner plate prior to placing the concrete liner. After the liner had cured, grout was injected behind the liner plates.

Exhaust shaft key construction, similar to that in the waste shaft, was performed in November 1984. The key consists of reinforced concrete and extends from a depth of 844 to 907 feet. It initially contained 2 chemical seals, 8 telltale drains, 2 guide pipes for test hole drilling, and geomechanical instrumentation. Placement of the concrete and chemical seal material was identical to that performed in the waste shaft. Two additional sets of telltale drains were installed in the key by drilling after its construction. Each set contains nine drains. One set was installed above and one set below the initial eight-drain set.

The exhaust shaft is 15 feet in diameter from the bottom of the key to the facility level. For safety, the walls are covered with wire mesh anchored by rock bolts. Excavation of the shaft to its final dimensions was completed on January 17, 1985.

As in the waste shaft, water began seeping through the exhaust shaft liner at construction joints and small cracks. Total water inflow

through the liner was measured at 0.35 gallons per minute in January 1985. A grouting program, using Portland cement and chemical grout, was conducted from June 1 through July 31, 1985, to seal these leaks and to ensure that the integrity of the shaft key was maintained. A total of 164 bags of Class C cement and 826.9 gallons of Terragel 5531 chemical grout were used. The total water inflow was reduced by this grouting to an essentially non-measureable quantity.

3.4.4 Drifts

The exploratory (C & SH) shaft station was the first underground horizontal opening excavated after completion of the SPDV exploratory and ventilation shafts. The initial shaft station excavation was performed from May 2 to June 3, 1982, using the drill and blast method. The station was trimmed to its final dimensions using the Dosco continuous mining machine discussed later in this subsection. The station area north of the shaft is 32 feet long, 32 to 35 feet wide and 12 feet high. South of the shaft, the station is 90 feet long and 32 to 38 feet wide. The height of the station south of the shaft is 18 feet for a distance of 54 feet and 14 feet for the remaining 36 feet. Cartridge water-gel explosives detonated by electric detonators were used for the drill and blast excavation. A detailed description of the SPDV exploratory shaft station excavation is presented in the WIPP Preliminary Design Validation Report (ref. 1-3).

Following the initial excavation of this station, the drill and blast method was used to excavate a drift southward to provide a connection between the two shafts so ventilation could be established. This drift was approximately 310 feet long, 18 feet wide and 9 feet high. Excavation of the drift was accomplished from June 3 to June 13, 1982.

The only other major use of the drill and blast method at the facility level was for construction of the loading pocket in the SPDV exploratory shaft. This pocket was constructed from June 1 through 30, 1982, on the north side of the shaft below the facility floor level.

It was later outfitted with a steel hopper and other equipment associated with the salt handling system.

The initial (SPDV) underground construction phase was conducted by Cementation West, Inc., of Tucson, Arizona. A British-made Dosco LH 1300, boom-type continuous mining machine was mobilized underground to the SPDV exploratory shaft station during late summer of 1982. This machine was used to excavate the remaining horizontal underground openings during the SPDV Program. The Dosco was capable of excavation rates of 1,000 to 1,200 tons per 24 hours (excavation was conducted on a three-shifts-per-day, seven-days-per-week basis). However, the excavation rate was often much less due to numerous construction and engineering related constraints. The mining machine was demobilized in May 1983 at the completion of the SPDV Program.

A second underground construction contract for full WIPP construction was awarded to Ohbayashi Corporation of South San Franicsco, California. During this phase of construction, two Japanese Mitsui Miike, boom-type continuous mining machines were used for excavation of the underground horizontal openings. Each of these machines excavated at a rate of 300 to 400 tons per 24 hours. These machines were mobilized to the underground facility in October 1983 and demobilized in April 1985.

A summary of the excavation sequence for the underground horizontal openings is presented on Figure 3-4. This figure shows the mining progress on a daily basis from October 14, 1982, through March 31, 1986. The underground mining operation was performed in the same manner during both construction phases regardless of the type of mining machine being used. The rotating head on the boom of the mining machine cut the salt away from the working face. The "muck" was pulled through the machine on a conveyor and deposited in one of several types of haul vehicles. Typically, the haul vehicles were underground trucks capable of carrying about 5 tons of muck. Other vehicles used included LHDs (Load-Haul-Dump, a type of front-end loader) and a telescoping-bed haul truck. The trucks carried the muck to the C & SH shaft station

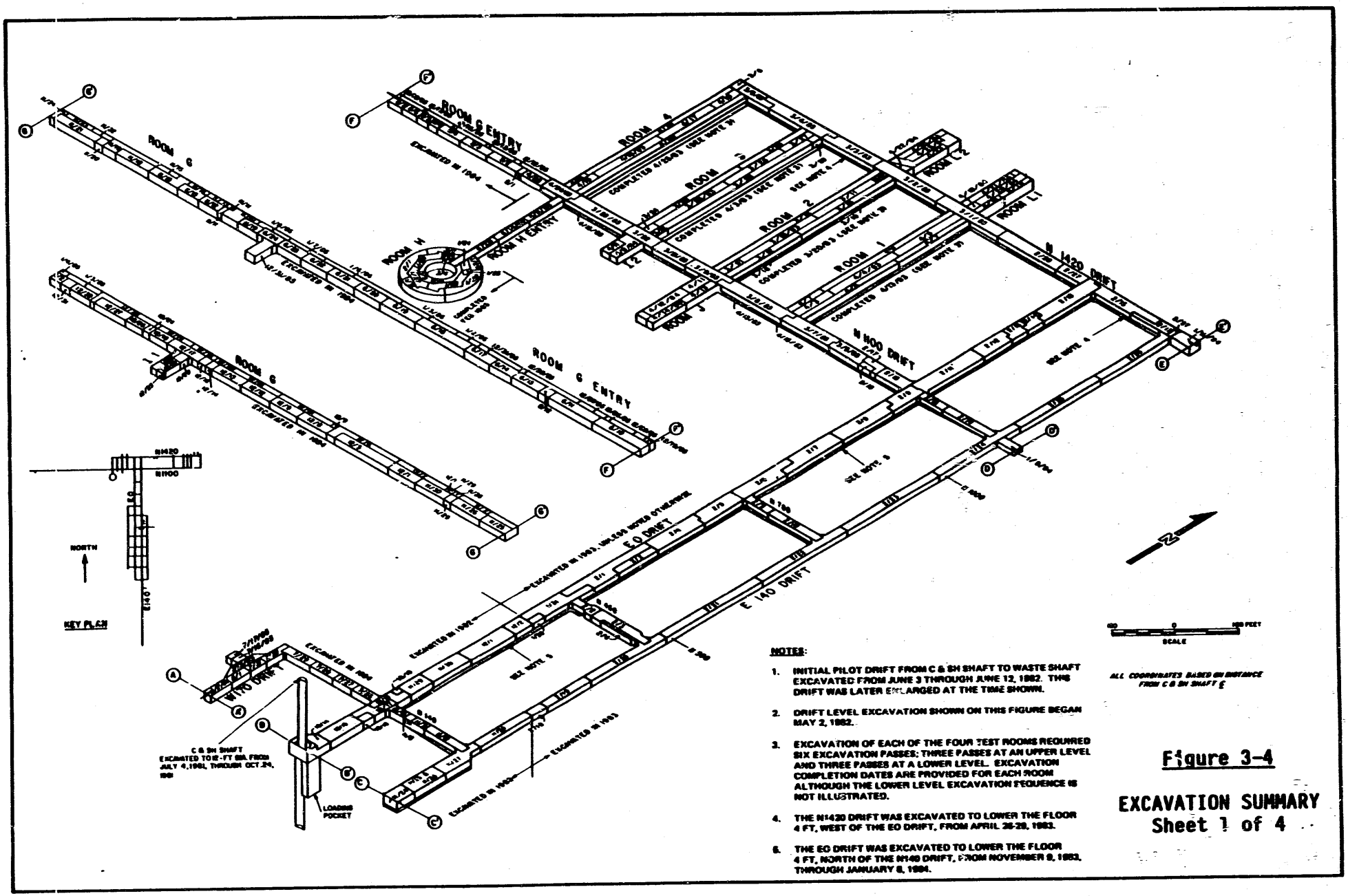
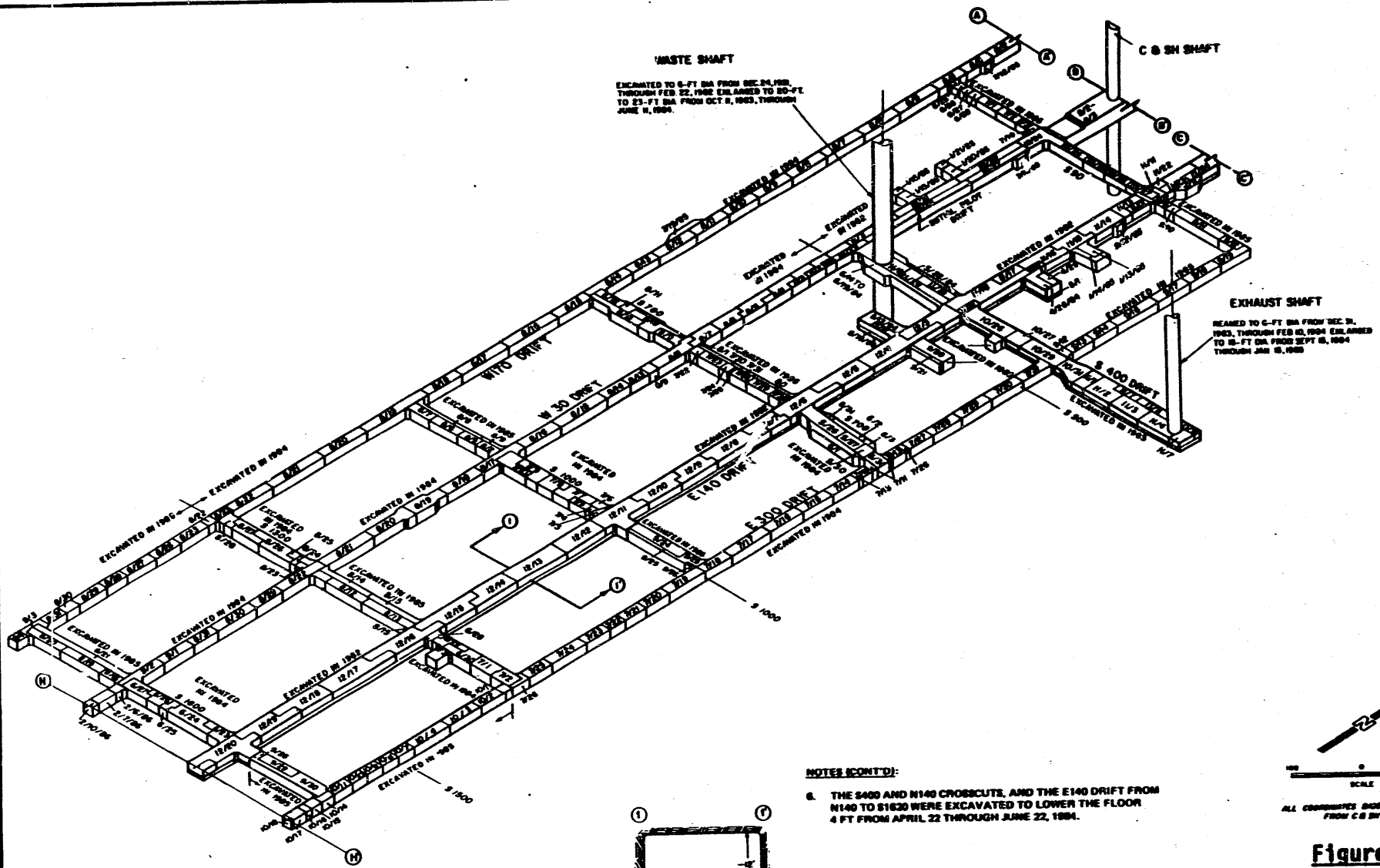
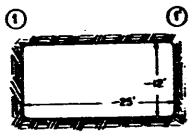


Figure 3-4

EXCAVATION SUMMARY
Sheet 1 of 4





SOUTH EXPLORATORY DRIFT
SECTION 1-1'

NOTES (CONT'D):

6. THE S400 AND N140 CROSSCUTS, AND THE E140 DRIFT FROM N140 TO S1620 WERE EXCAVATED TO LOWER THE FLOOR 4 FT FROM APRIL 22 THROUGH JUNE 22, 1984.

Figure 3-4

EXCAVATION SUMMARY
Sheet 2 of 4

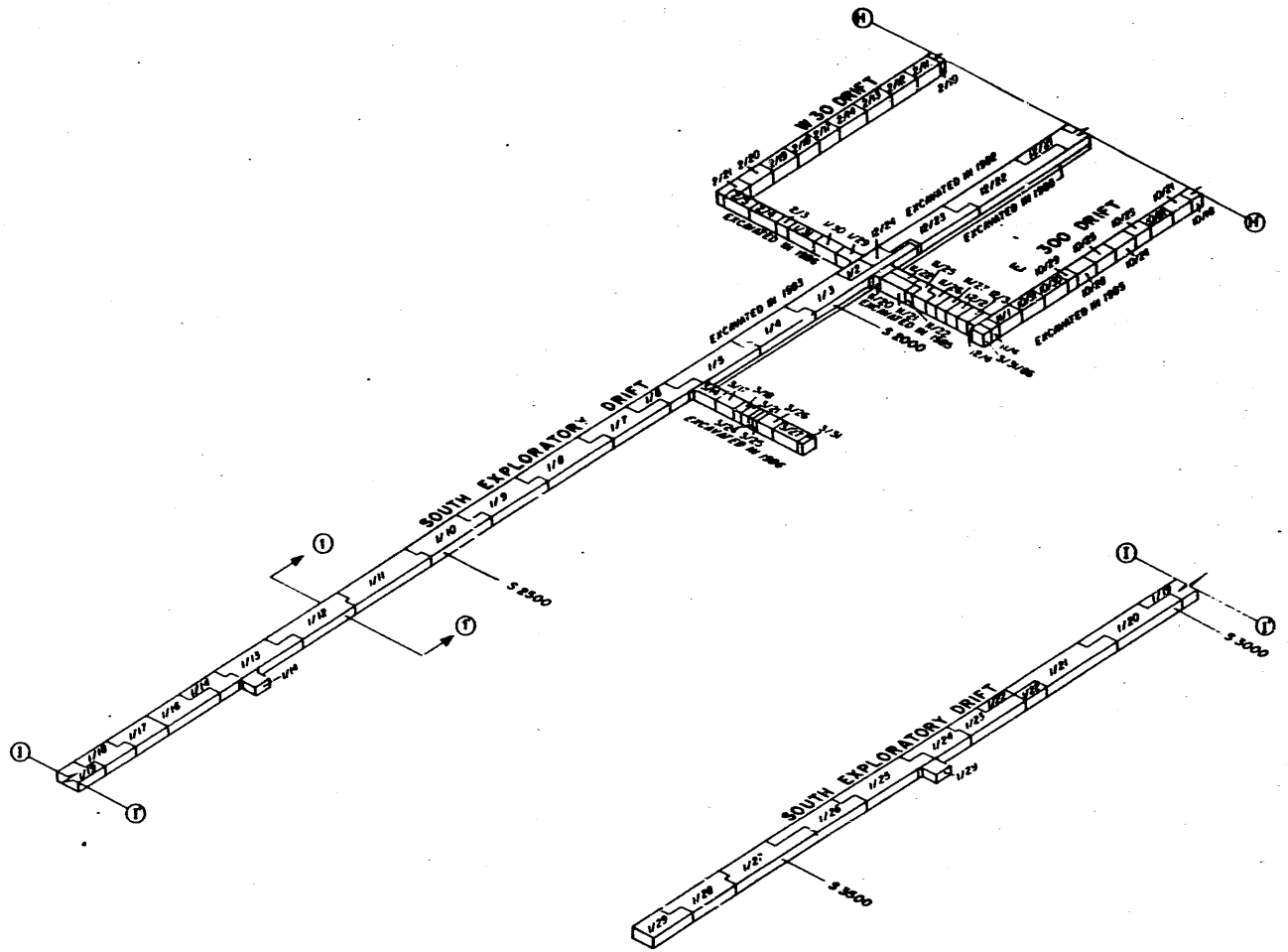
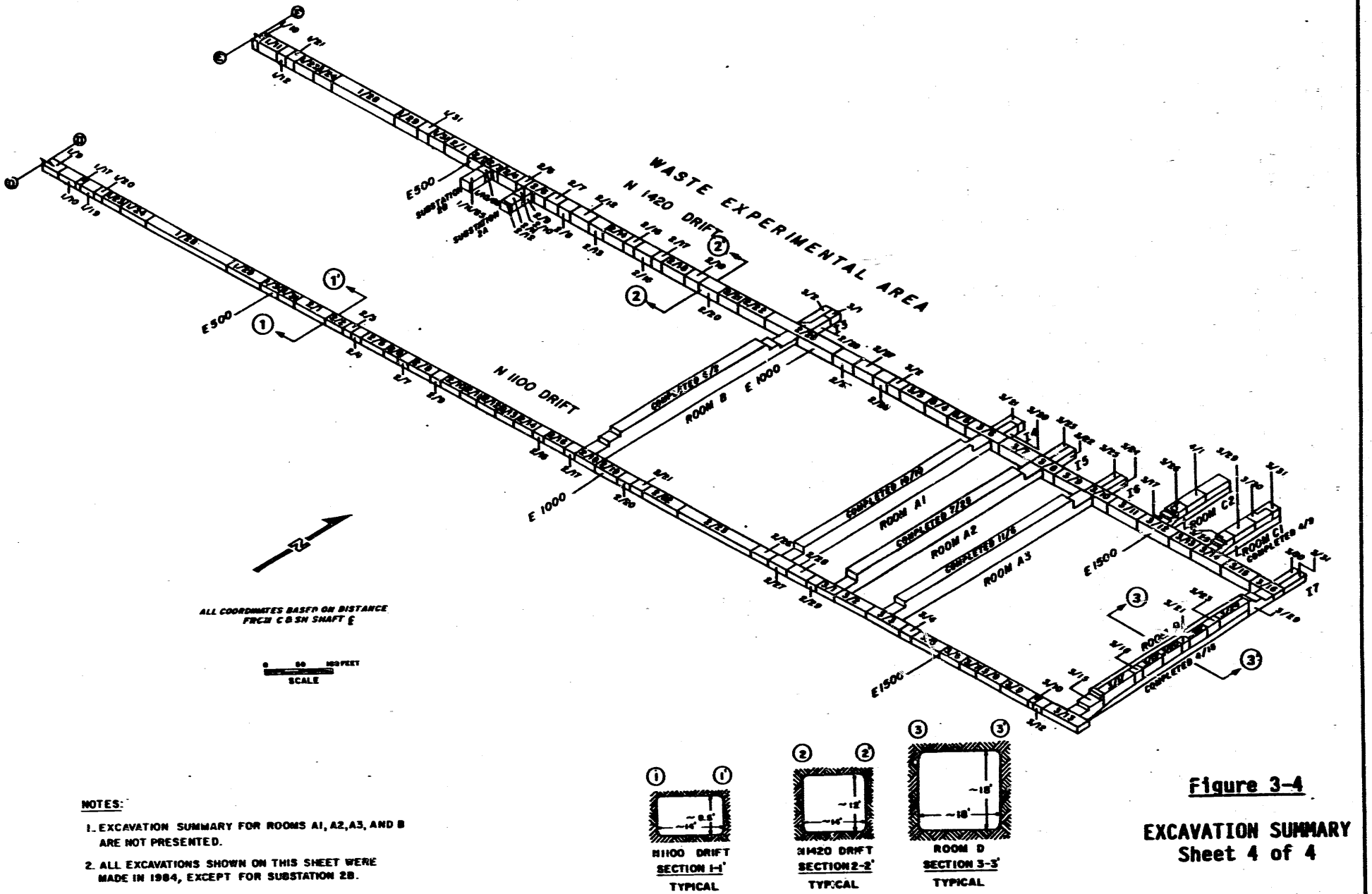


Figure 3-4

EXCAVATION SUMMARY
Sheet 3 of 4



NOTES:

1. EXCAVATION SUMMARY FOR ROOMS A1, A2, A3, AND B ARE NOT PRESENTED.
2. ALL EXCAVATIONS SHOWN ON THIS SHEET WERE MADE IN 1984, EXCEPT FOR SUBSTATION 2B.

Figure 3-4

EXCAVATION SUMMARY
Sheet 4 of 4

and dumped it into the loading pocket. From there, the muck was carried to the surface in 7- to 8-ton loads in the skip. The skip dumped the muck at the surface into 50-ton Caterpillar or Euclid haul trucks which then carried the muck to the surface salt storage area.

During and immediately after excavation, a sounding survey of the roofs in the horizontal openings was made using a scaling bar to identify areas of drummy or slabby rock which could pose safety or stability problems. Remedial work was performed immediately after sounding in any areas identified as potentially unstable. This work consisted of hand-scaling thin drummy areas, removing larger drummy areas up to 18 inches thick with the mining machine, or rock bolting. In addition, two follow-up surveys were made of the roofs in all of the horizontal openings excavated at the time of the survey. The first survey was completed in July 1983 and the second in November 1984. Remedial work was performed on problem areas identified during these surveys. This work consisted of scaling, excavation, or rock bolting. It should be noted that the drummy areas identified during the July 1983 survey were sounded again in the November 1984 survey and did not show any noticeable enlargement.

Rock bolts are used selectively throughout the underground drifts for both remedial work and safety. The roofs of many high-traffic personnel areas are pattern bolted and covered with wire mesh as an additional safety precaution.

The C & SH shaft station has presented the majority of problems associated with roof stability. Due to its initial excavation by the drill and blast method, and the proximity of overlying clay seams, the roof in the station has required support by a large number of rock bolts. The method of rock bolting has evolved through several phases due to the effect of salt creep on roof separation along the clay seams.

Rock bolts were initially installed in the C & SH shaft station roof

from May 9 to June 20, 1982. These bolts were 1 inch in diameter, 8, 10 or 12 feet in length, and made of grade 60 steel. They were anchored using resin cartridges.

These resin-anchor bolts began failing at the head assemblies shortly after their installation was completed. The failed bolts were replaced with 8-foot long, 5/8-inch diameter mechanical-anchor bolts with 2 x 12 x 12-inch wooden blocks installed between the steel head assembly plate and the salt. A total of over 400 resin-anchor and mechanical-anchor bolts were installed in the shaft station roof through April 1983.

During December 1983 and January 1984, 146 additional mechanical-anchor bolts, 5/8 inch in diameter and 8 feet long, were installed in the C & SH shaft station roof. In May 1984, another 91 similar anchor bolts were installed. After the mechanical-anchor bolts were installed, the nut and head assembly plate were cut off those older resin-anchor bolts showing evidence of excessive deformation. This was to prevent injury to personnel from falling nuts and plates should these resin-anchor bolts fail.

From mid-April through early August 1985, approximately 133 3/4-inch diameter mechanical-anchor bolts, 6 and 8 feet long, were installed in the station roof on approximately 3 1/2-foot centers. In addition, 245 resin-anchor bolts, 1 inch in diameter, were anchored above anhydrite "b" and across anhydrite "a". These bolts were 12 and 14 feet in length. The entire station roof was covered at this time with wire mesh secured with 2-foot long, 5/8-inch diameter mechanical-anchor bolts. Approximately 750 of the 2-foot long bolts were installed.

Although some resin-anchor bolts were used in the SPDV drifts and test rooms excavated in 1982 and 1983, mechanical-anchor bolts have been used in all subsequently excavated areas. Bolt lengths vary from 2 to 8 feet in the drifts and rooms. Wire mesh secured by 2-foot long mechanical-anchor bolts has been installed on the roofs of all high-traffic personnel areas. This includes instrument-shed and

electrical alcoves, many of the shop areas, and some of the brows above the entries to the waste experimental rooms. Rock bolts and wire mesh have also been installed in the roof of the N140 crosscut.

Rock bolts and wire mesh have been installed for roof support in the waste shaft station waste transfer area. The bolts, 3/4 inch in diameter and 12 feet long, are mechanical-anchor steel bolts set on nominal 4-foot centers.

3.4.5 Test Rooms

As part of the SPDV Program, four test rooms were excavated at the north end of the underground facility (Figure 3-4) by Cementation West, Inc., using the Dosco mining machine. The test room excavation was conducted from March 9 to April 25, 1983. Test Room 2 was excavated first, followed by Test Rooms 3, 1 and 4, in that order. Each room was excavated in a series of six passes along its longitudual axis (Figure 3-5). The first pass was the largest in cross section and was conducted down the center of the planned room along its roof. This pass was approximately 15 feet wide and 8 feet high. The second and third passes were conducted on either side of the first pass. Each of these passes were about 9 feet wide and 8 feet high. The last three passes lowered the floor 5 feet to complete the room excavation to its design height and width of 13 x 33 feet.

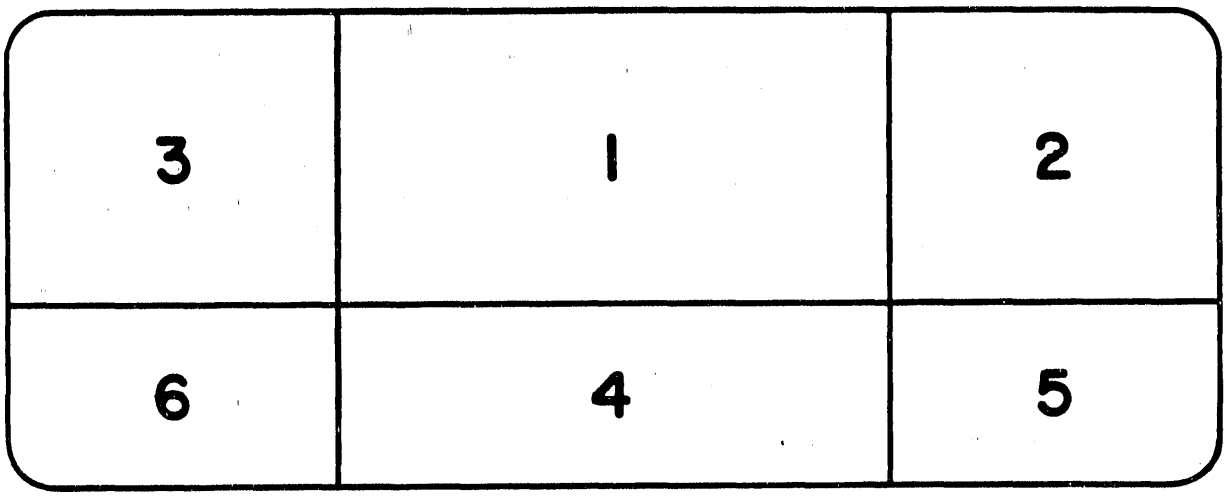


Figure 3-5

TEST ROOM EXCAVATION SEQUENCE

CHAPTER 4
SUPPORTING VALIDATION DOCUMENTS

4.1 INTRODUCTION

This chapter discusses the principle documents containing information used to support design validation. These documents are the Waste Isolation Pilot Plant Preliminary Design Validation Report (ref. 1-3) and geotechnical field data reports (refs. 4-1 thru 4-19). These documents contain all of the data which has been collected, analyzed and evaluated for design validation since site construction activities began in July 1981. Other documents pertaining to design and site characterization are referenced throughout this report. However, they are considered peripheral documents not directly related to the design validation process and, therefore, are not described in this report. Because these other reports are public documents, they are available to anyone interested in obtaining additional background information or detailed data on the WIPP project.

4.2 PRELIMINARY DESIGN VALIDATION REPORT

The following subsections present a summary of the WIPP Preliminary Design Validation Report produced for the SPDV Program described in Chapter 1.

4.2.1 Purpose and Objectives

The purpose of the WIPP Preliminary Design Validation Report was to provide documentation on the behavior of the initial underground openings. Four types of information were gathered for this purpose:

(1) observations of the behavior of the underground openings;

(2) descriptions of the geologic conditions encountered during SPDV underground construction;

(3) descriptions of core samples from instrumentation and exploratory holes in the roof and floor of the underground openings; and

(4) data from installed geomechanical instrumentation.

The objective of the report was to provide initial evaluations of the suitability of the design criteria and design bases and initial confirmation of the underground opening reference design in order to permit full facility construction. This initial confirmation was based on data obtained from geologic field activities and geomechanical instrumentation which were subjected to preliminary analysis and evaluation.

4.2.2 Data Acquisition Program

The preliminary design validation data acquisition program consisted of geologic field activities which provided information for initial validation of the WIPP underground opening reference design. Data was obtained from three principal activities:

(1) geologic mapping;

(2) vertical core hole logging; and

(3) geomechanical instrument measurements.

All of the data collected was verified at the site field office, then sent to the DOE/Technical Support Contractor (TSC) offices in Albuquerque, New Mexico, for preparation and inclusion into the GFDRs and other reports. Due to the qualitative nature of the geologic mapping and core hole data, efforts for preparation of this material generally required only limited evaluation, editing and drafting. The geomechanical instrumentation data, however, required more extensive preparation and analysis due to its applications to various aspects of underground opening behavior and the calculation of in situ salt properties.

4.2.3 Geomechanical Instrumentation

The SPDV geomechanical instrumentation program for the WIPP was designed to provide empirical data on the behavior of the salt around the underground openings and on the pressure developed behind the exploratory shaft liner and key by ground water and salt creep. The objective of the geomechanical instrumentation program for SPDV was to provide:

(1) short-term in situ measurements for assessment of the preliminary design performance of the underground openings;

(2) early detection of conditions that could affect the safety of personnel during construction; and

(3) data on adverse ground conditions that may be developing, in order to identify potential problems and plan and implement remedial measures.

Instruments were initially installed in the SPDV exploratory shaft, exploratory shaft station, ventilation shaft station, the E0, E140 and N1100 drifts, and the S90 crosscut to provide data input for the WIPP Preliminary Design Validation Report. The exploratory drift extending south of the ventilation shaft was added to the SPDV Program to provide additional information on the geology in the area proposed for excavation of the waste storage rooms. Geomechanical instruments were installed at several locations in this drift.

For the WIPP Preliminary Design Validation Report, borehole extensometer and convergence point data from the SPDV exploratory shaft, as well as data from the ventilation shaft station and drifts, were insufficient to estimate long-term closure rates. Most drift extensometers and convergence points had been installed only a relatively short time before the report was prepared. A period of 1 year or more was thought to be required before a relatively steady closure rate could be established. The data were useful in

demonstrating short-term stability of the excavations and for developing cumulative closure amounts. Instruments with the most extensive data typically showed a maximum of only 3 or 4 months of regular monitoring since installation.

4.2.4 Preliminary Conclusions

Preliminary conclusions presented in the WIPP Preliminary Design Validation Report were:

(1) The walls of the finished shafts are stable, both in the overburden and salt formations. The mapped shaft stratigraphy is generally comparable to the stratigraphy used in the design. Ground-water control is satisfactory. The shaft liner and shaft key are performing as expected. No major revision of design elements or parameters is foreseen for future WIPP shafts as a result of the findings of preliminary design validation.

(2) The underground horizontal openings are also stable. After excavation, repeated inspections of the exploratory and ventilation shaft stations, entry drifts, crosscuts and the south exploratory drift revealed essentially no deterioration in rock stability. The underground drifts and shaft stations are stable and provide safe working conditions.

(3) Encounters of gas were expected and are typical of nearby potash mines. The small amount of gas encountered is well below the limit permitted in the underground facility by MSHA regulations. No brine pockets have been encountered or detected during excavation of the shafts and underground openings.

4.3 GEOTECHNICAL FIELD DATA REPORTS

4.3.1 Background

The compilation of GFDRs was initiated by the DOE to provide geotechnical and related information from the WIPP underground activities to interested persons or groups in a timely manner. These reports provided data from the two major phases of WIPP development: SPDV and full construction. As discussed previously, SPDV was established as an early construction phase to permit validation of the WIPP site and preliminary validation of the reference design of the underground openings. The full construction phase following SPDV was utilized to continue visual inspections of the underground openings, monitoring and interpretation of data from geomechanical instruments, and evaluations and computational analyses of the behavior of the underground openings for design validation.

The GFDRs were eventually produced on a quarterly basis. These quarterly reports contain an evaluation of selected aspects of the WIPP underground environment based on preliminary interpretation and analyses of data collected from the above activities. The analyses and evaluations contained in the GFDRs provide the supporting documentation required for design validation.

4.3.2 Objectives

As stated in the GFDRs, the geomechanical instrumentation program for SPDV and design validation was designed and implemented to provide in situ data on the behavior of the rock (primarily salt) around the shafts and horizontal underground openings. More specifically, the instrumentation program was designed to provide:

(1) early detection of conditions that could affect operational safety;

(2) monitoring of closure rates to allow evaluation of waste storage and retrievability;

(3) a greater understanding of the in situ behavior of bedded salt by comparison of observed response with current facility reference design calculations; and

(4) measurements of salt deformation and stresses to confirm or indicate the necessity for revisions to the opening configuration and the parameters used in underground facility design based on clearance requirements.

4.3.3 Geomechanical Instrumentation

An extensive geomechanical instrumentation program was implemented to provide in situ data on the shafts and horizontal underground openings as part of the investigations performed at the WIPP site. These instruments have been providing data on deformation, pressure, loads and stress on a regular basis for analysis and evaluation. Instruments for measuring the geomechanical response of the shafts and horizontal underground openings include convergence points, convergence meters, multiple-point and single-point borehole extensometers, load cells, pressure cells, stressmeters, strain gauges, inclinometers, piezometers and lateral movement gauges.

Data from these geomechanical instruments are read remotely by an automatic datalogger system and/or collected manually. All data obtained are entered on magnetic tape for data reduction, tabulation, analysis and archiving. Data collected from the geomechanical instruments have been documented in the GFDRs. These data are the basis for analysis and evaluation by the project participants and other interested groups. The geomechanical instruments provide data for the analysis and evaluation of several phenomena at various locations, including strain in the C & SH shaft key, water pressure behind the C & SH and waste shaft liners, radial closure of shafts, pressures between shaft keys and wall rock, roof-to-floor and wall-to-wall closure in the shaft stations, drifts and rooms, and displacements at depth into the walls, roof and floor of shaft stations, drifts and rooms.

The frequency of data collection is determined on a per instrument basis and is dependent upon instrument location, method of instrument reading (manual or datalogger), and the number of days elapsed since excavation at the instrument location. After installation, the instrument is read frequently, but with time this reading frequency is decreased since the rate at which the salt mass responds following excavation also decreases with time.

The geomechanical instrumentation data are presented graphically in the GFDRs and represent readings collected from the WIPP site since April 1982. The data plots in the reports are grouped by areas within the underground facility and also by instrument type. The data plots are updated as new data become available. Summary tables of the instruments, with the latest readings and the operating histories, are also presented in the reports.

4.3.4 Geologic Data

Geologic data presented in the GFDRs have included the results of geologic mapping activities, core hole logging, and observations of the condition and behavior of underground opening surfaces. Geologic maps of the shafts and representative horizontal opening surfaces have been presented periodically in the GFDRs or in topical reports issued separately. Geologic logs containing descriptions of core samples obtained from core holes in the underground openings were presented in the GFDRs as they became available.

Frequent observations by project geotechnical personnel have provided qualitative determinations of the condition of the underground openings. These assessments were presented in the GFDRs to document changes in the condition of the underground openings and in salt behavior on a regular basis. Observations such as the condition of the roof and rock bolts in shaft stations, fractures in pillar corners at drift intersections and in the salt surrounding the drifts and rooms, behavior of the roof and walls of the drifts and rooms, and horizontal displacements, vertical separations and fracturing detected in open

boreholes were documented. This information has provided important input for design evaluation and safety assessments.

4.3.5 Geomechanical/Structural Analyses

The quarterly GFDRs contain sections on both geotechnical and computational analyses. These sections present analyses of various elements of the underground excavations. The analyses are updated periodically to include the most current data available at the time the reports are published. They have provided a significant amount of information related to the geomechanical and structural behavior of the underground openings.

CHAPTER 5
METHODOLOGY

5.1 INTRODUCTION

Design validation of the WIPP underground openings is accomplished by determining the compatibility of the design criteria, design bases and reference design configurations using site specific information. Design validation also allows for the development of recommendations to improve or optimize the reference design. The methods used to validate the reference design may also be used to validate any recommended design modifications. Mathematical models containing the modifications can be generated and analyses performed to predict the future behavior of the modified reference design.

The design validation process consists of three major steps:

(1) data collection;

(2) analysis and evaluation; and

(3) prediction of future behavior.

Sections 5.2 through 5.4 present the methods used for data collection, analysis and evaluation, and prediction of future behavior.

5.2 DATA COLLECTION

One of the principal areas of effort in support of design validation was the compilation of geotechnical data. This data formed the basis for later analysis and evaluation and for predictive modeling. Data collected from geologic mapping, core drilling and logging, laboratory testing, geomechanical instrumentation and field observations have provided information for validation of the underground opening reference design. These data can be categorized based on their relationship to observations of geologic conditions or to structural behavior. Geologic observations include an assessment of the rock

characteristics; stability of the openings in rock; reaction of the rock to excavation; and movements along clay seams. Structural behavior is the development or modification of stresses and strains in the salt created by excavation of the underground openings, and the pressures occurring at rock/structure interfaces.

5.2.1 Geologic Mapping

Geologic mapping of the shafts, drifts and test rooms was conducted by site geologists. The objectives of the mapping were:

(1) provide confirmation and documentation of the continuity of the stratigraphy, lithology and structure above and below the facility horizon;

(2) evaluate any geologic conditions which may affect the excavation, stability, or safety of the horizontal openings;

(3) support field adjustments and modifications to the reference design based on the geologic conditions encountered; and

(4) finalize geomechanical instrument locations.

5.2.2 Core Drilling and Logging

Information on stratigraphy and lithology was obtained from core holes drilled into the floor and roof of the underground openings. The objectives of the core drilling program were:

(1) confirm the thickness, lateral extent, mineralogy and stratigraphic continuity of the host rock beyond the limits of the excavations;

(2) confirm the continuity of the geologic structure and the absence of any unusual features within the immediate zone of influence of the excavations; and

(3) obtain stratigraphic information in order to determine extensometer anchor depths.

Details of the core drilling program are discussed in Chapter 6.

5.2.3 Laboratory Testing

Initial laboratory tests were performed on core samples of evaporite minerals and clay from exploratory boreholes AEC-7 and ERDA-9. These tests were performed by RE/SPEC, Inc., of Rapid City, South Dakota, and by SNL (refs. 5-1 and 5-2). The evaporite samples were tested in triaxial vessels at both room and elevated temperatures. Quasi-static compression tests were performed under different constant confining pressures and variable axial loads in steps, each load step being maintained for about 10 minutes. Quasi-static compression tests were considered as constant stress-rate tests for all practical purposes. Direct shear tests were performed on samples of clay to determine the coefficient of sliding friction.

5.2.4 Geomechanical Instrumentation

Geomechanical instruments in the WIPP underground facility provide data on deformation, pressure, loads and stress. Instruments for measuring the geomechanical response of the shafts and other underground openings include convergence points, convergence meters, multiple-point and single-point borehole extensometers, load cells, pressure cells, stressmeters, strain gauges, inclinometers, piezometers and lateral movement gauges. Data from the geomechanical instruments are collected manually as well as read remotely by an automatic datalogger system at the surface. All data are entered on magnetic tape for data reduction, tabulation, analysis and archiving. These data are a basis for the analysis and evaluation of underground opening behavior.

The geomechanical instrumentation program for design validation was designed and implemented to provide in situ data on the behavior of the

rock (primarily salt) around the shafts and underground openings. More specifically, the instrumentation program was designed to provide:

(1) early detection of conditions that could affect construction and operational safety;

(2) closure monitoring for evaluation of the ability of the underground openings to permit waste storage and retrieval;

(3) a greater understanding of the in situ behavior of bedded salt by a comparison of the observed responses with underground opening reference design calculations; and

(4) measurements of salt deformation to permit confirmation or revision of the opening configurations and the parameters used in the underground opening reference design based on clearance requirements.

Tables 5-1 through 5-5 present information on the distribution of geomechanical instruments installed at the WIPP. The instruments provide data for the evaluation and analyses of several phenomena at various locations, including strain in the C & SH shaft key, water pressure behind the C & SH and waste shaft liners, radial closure of the shafts, pressures between the concrete shaft keys and wall rock, roof-to-floor and wall-to-wall closure in the shaft stations, drifts and rooms, and displacements at depth into the walls, roof and floor of shaft stations, drifts and rooms.

Data from the geomechanical instruments are collected manually or read remotely by an automatic datalogger system. The datalogger is a computer system that automatically collects and records output from instruments at specified polling times. The signals from the instruments are first sent to local termination cabinets (LTC) where the signal is digitized and then transmitted to the datalogger for disk storage. Manual readings are manually entered into the computer system. Changes from initial readings and rates of change are

Table 5-1

C & SH SHAFT
INSTRUMENTS

Location and Type	Purpose
Lined Section	
Convergence points	Measure wall-to-wall closure of shaft
Piezometer	Measures fluid pressure buildup behind liner due to water accumulation
Key	
Piezometer	Measures fluid pressure buildup behind key due to water accumulation
Pressure cell	Measures contact pressure buildup between concrete key and wall rock
Welded strain gauge	Measures strain in reinforcing steel of shaft key
Embedment strain gauge	Measures strain in concrete of shaft key
Unlined Section	
Multiple-point extensometer	Measures salt creep deformation
Convergence points	Measure wall-to-wall closure of shaft
Station	
Convergence points (includes permanent and temporary convergence points and wall shortening points)	Measure roof-to-floor and wall-to-wall closure of openings and pillar shortening
Extensometer (single-point and multiple-point)	Measures salt creep deformation in roof, floor and walls
Rock bolt load cell	Measures tensile loads on rock bolts
Lateral movement gauge	Measures lateral movement in roof

Table 5-2

WASTE SHAFT
INSTRUMENTS

Location and Type	Purpose
Lined Section	
Piezometer	Measures fluid pressure buildup behind liner due to water accumulation
Key	
Piezometer	Measures fluid pressure buildup behind key due to water accumulation
Pressure cell	Measures contact pressure buildup between concrete key and wall rock
Unlined Section	
Convergence points	Measure wall-to-wall closure of shaft
Multiple-point extensometer	Measures salt creep deformation
Station	
Convergence points (includes permanent and temporary points)	Measure roof-to-floor and wall-to-wall closure of openings
Multiple-point extensometer	Measures salt creep deformation in roof, floor and walls

Table 5-3

EXHAUST SHAFT
INSTRUMENTS

Location and Type	Purpose
Lined Section	
Piezometer	Measures fluid pressure buildup behind liner due to water accumulation
Key	
Piezometer	Measures fluid pressure buildup behind key due to water accumulation
Pressure cell	Measures contact pressure buildup between concrete key and wall rock
Unlined Section	
Multiple-point extensometer	Measures salt creep deformation

Table 5-4

DRIFTS
INSTRUMENTS

Location and Type	Purpose
Convergence points (includes permanent and temporary convergence points and wall shortening points)	Measure roof-to-floor and wall-to-wall closure of openings and pillar shortening
Extensometer (single- and multiple-point)	Measures salt creep deformation in roof, floor and walls of openings

Table 5-5

TEST ROOMS
INSTRUMENTS

Location and Type	Purpose
Convergence points	Measure roof-to-floor and wall-to-wall closure
Multiple-point extensometer	Measures salt creep deformation in roof, floor and walls
Inclinometer	Measures direction and amount of salt movement above the roof, below the floor, and in the walls
Rigid-inclusion stressmeter	Monitors changes in stress within anhydrite
Convergence meter	Measures vertical closure

calculated and stored in the computer. The data is transferred monthly to magnetic tapes which are made available to project participants.

Instruments connected to the datalogger include extensometers, piezometers, strain gauges, pressure cells, convergence meters and stressmeters. All convergence points, inclinometers, rock bolt load cells, lateral movement gauges and some extensometers must be read manually. Strain gauges, piezometers and pressure cells have been read manually at times.

The frequency of data collection is determined on a per instrument basis and is dependent upon instrument location, method of instrument reading (manual or datalogger), and the number of days elapsed since excavation at the instrument location. After installation the instrument is read frequently, but with time this reading frequency is decreased since the rate at which the salt mass responds following excavation also decreases with time.

The frequency of readings has been influenced by access limitations caused by construction operations and by the volume of data to be collected. At a few convergence point stations in newly excavated areas, readings were taken frequently to record the early rock response. Monitoring periods in these instances were typically every 4 to 12 hours for 24 hours, then once daily. Most manually read instruments were initially read weekly, then once every 2 weeks, and then once every month. Instruments connected to the datalogger were initially read at 24-hour intervals, then several times per week, and then once every 2 weeks. The current schedule for obtaining readings is shown in Table 5-6. Each instrument's range, sensitivity, resolution and precision are also presented in this table. These parameters are important when interpreting and evaluating the data, especially those readings which reflect changes that are close to the resolution, sensitivity, or precision limits of the instrument.

Table 5-6

GEOMECHANICAL INSTRUMENTATION SPECIFICATION SUMMARY

Location	Instrument Type	Phenomenon Monitored	Parameters to be Evaluated	Scheduled Frequency of Readings as of this Report	Instrument Specifications: Range (R), Sensitivity (S) Resolution (E), Precision (P)
C&SH shaft	Borehole extensometers	Deformation	$\Sigma\delta$*, $\frac{\Delta L}{\Delta t}$**	Weekly (D)	(R): 0-2 in. (P): 0.001 in. (E): 0.001 in.
C&SH shaft key	Strain gauges	Strain	Σ Strain*	As accessible (M)	(R): 0-3000 μin./in.-embedded (R): 0-2500 μin./in.-spot welded (S): 1 μin./in.
C&SH shaft key	Pressure cells	Pressure	Σ Pressure*	As accessible (M)	(R): 0-1000 psi (S): 1 psi
C&SH shaft liner & key	Piezometers	Water pressure	Σ Pressure*	Monthly (M)	(R): 0-500 psig (E): ±0.5 psi
C&SH shaft	Convergence points	Deformation	$\Sigma\delta$*, $\frac{\Delta L}{\Delta t}$**	As accessible (M)	(R): 2-50 ft (P): ±0.005 in.
Waste shaft	Borehole extensometers	Deformation	$\Sigma\delta$*, $\frac{\Delta L}{\Delta t}$**	As accessible (D)	(R): 0-2 in. (P): 0.001 in. (E): 0.001 in.
Waste shaft Key	Pressure cells	Pressure	Σ Pressure*	Weekly (D)	(R): 0-1000 psi (S): 1 psi
Waste shaft liner & key	Piezometers	Water Pressure	Σ Pressure*	Weekly (D)	(R): 0-500 psig (E): ±0.5 psi
Waste shaft	Convergence points	Deformation	$\Sigma\delta$*, $\frac{\Delta L}{\Delta t}$**	As accessible (M)	(R): 2-50 ft (P): ±0.005 in.
Exhaust shaft	Borehole extensometers	Deformation	$\Sigma\delta$*, $\frac{\Delta L}{\Delta t}$**	Weekly (D)	(R): 0-2 in. (P): 0.001 in. (E): 0.001 in.
Exhaust shaft liner & key	Piezometers	Water pressure	Σ Pressure*	Monthly (M)	(R): 0-500 psig (E): ±0.5 psi
Exhaust shaft key	Pressure cells	Pressure	Σ Pressure*	As accessible (M)	(R): 0-1000 psi (S): 1 psi
Drifts	Rockbolt load cells	Load	Σ Load*, $\frac{\Delta p}{\Delta t}$**	Monthly (M)	(R): 0-300 kips (S): 16 lb
Drifts	Borehole extensometers	Deformation	$\Sigma\delta$*, $\frac{\Delta L}{\Delta t}$**	Weekly (D)/ Monthly (M)	(R): 0-2 in. (P): 0.001 in. (E): 0.001 in.
Drifts	Convergence points	Deformation	$\Sigma\delta$*, $\frac{\Delta L}{\Delta t}$**	Monthly to every 2 months (M)(1)	(R): 2-50 ft (P): ±0.005 in.
Drifts	Lateral movement gauges	Deformation	$\Sigma\delta$	No longer read	(R): 0-5 in. (E): 1/64 in. (P): ±1/64 in.
Test rooms	Vertical inclinometers	θ_x, θ_y	$\Sigma\delta_x$*, $\Sigma\delta y$*, $\Sigma\delta_{xy}$*, Azimuth*, $\frac{\Delta\Sigma w_x}{\Delta t}$, $\frac{\Delta\Sigma w_y}{\Delta t}$, $\frac{\Delta\Sigma\delta_{xy}}{\Delta t}$	Every 2 months (M)	(R): 0-30° (P): ±0.3 in./100 ft of casing (E): ±0.001 in./2 ft of casing (S): ±0.001 ft/2 ft of casing
Test rooms	Horizontal inclinometers	θ_z	$\Sigma\delta w_z$*, $\frac{\Delta\Sigma w_z}{\Delta t}$	Every 2 months (M)	(R): 0-30° (P): ±0.3 in./100 ft of casing (E): ±0.001 in./2 ft of casing (S): ±0.001 ft/2 ft of casing
Test rooms	Vibrating wire stressmeters	Stress	ΣS*, $\frac{\Delta S}{\Delta t}$*	Weekly (D, M)	(R): 12,000-44,000 psi wire stress
Test rooms	Convergence meters	Deformation	$\Sigma\delta$*, $\frac{\Delta L}{\Delta t}$**	Weekly (D)	(R): Approximately 2.5 ft (S): ±0.001 in.
Test rooms	Convergence points	Deformation	$\Sigma\delta$*, $\frac{\Delta L}{\Delta t}$**	Monthly (M)	(R): 2-50 ft (P): 0.005 in.
Test rooms	Borehole extensometers	Deformation	$\Sigma\delta$*, $\frac{\Delta L}{\Delta t}$*	Weekly (D)	(R): 0-2 in. (P): 0.001 in. (E): 0.001 in.

Notes:

(D) = read through datalogger
(M) = read manually
$\Sigma\delta$ = total change from t = 0
θ = angle
ΔL = change from last reading
Δt = elapsed time since last reading

(1) New convergence points are read weekly for the first month after installation.
*Design/validation parameter
**Safety/operational parameter

5.2.5 Field Observations

The determination of underground conditions includes a qualitative assessment based on frequent observations by WIPP site geotechnical personnel. Changes in rock conditions and in the behavior of the underground openings have been observed and documented on a regular basis in the GFDRs. In addition, quarterly inspections have been made by Bechtel home office design engineering personnel. These inspections augmented the site geologists' observations and helped highlight those changes which occurred so slowly that they were difficult to detect on a daily basis.

Periodic inspections of the C & SH shaft have been made since the shaft was completed. Conditions of the shaft walls, liner and key have been observed in addition to any water flow into the shaft. Similar inspections of the waste and exhaust shafts have also been made but less frequently due to limited accessibility.

Observations of the horizontal openings include such items as the condition of their roofs and walls; fracturing in pillar corners at drift and room intersections and in roofs and floors; and horizontal displacements and vertical separations measured in open boreholes. This information has provided important input for design and safety evaluations.

5.3 ANALYSIS AND EVALUATION

Data collected at the WIPP site have been analyzed and evaluated by qualified engineers and scientists. Engineering experience and judgement were used in the evaluation of field observed conditions. Laboratory tests were performed on core samples to determine the constitutive equations for the host rocks. Theoretical and applied aspects of measurements, statistics and physics were utilized to analyze and evaluate geomechanical instrument data.

5.3.1 Observations

The observations of geologic conditions documented during visual inspections are used to evaluate the performance of the underground openings. These evaluations are made in conjunction with the analytical techniques. The evaluations are qualitative, however, and are subjective assessments of the behavior of the salt surrounding the excavations.

5.3.2 Laboratory Tests

The results of the laboratory testing described in subsection 5.2.3 on samples of halite, argillaceous halite, anhydrite, polyhalite and clay from the facility level were evaluated and statistically analyzed to determine elastic and creep constants. Constitutive equations for each of these materials were established and their material property constants were determined (ref. 5-3). The material property constants based on the laboratory test results are presented in Chapter 6.

5.3.3 In Situ Measurements

Statistical and numerical methods were used to analyze in situ data and to evaluate the physical behavior of salt. Numerical models were used to compute creep parameters from the in situ data.

In situ measurement data from selected geomechanical instruments in the drifts and test rooms were fitted with analytical equations using regression procedures. Since early data are lacking for most of the instruments, one approach was to calculate the closure rates and fit an equation to the closure rate versus elapsed time relationship. An estimate of the early closure not measured by the instruments was independently derived.

5.4 PREDICTION OF FUTURE BEHAVIOR

Validation of the underground opening reference design requires predicting the future behavior of the openings. This was achieved by collecting in situ data consisting of field observations and

geomechanical instrument measurements. Statistical methods were then used to extrapolate the data obtained from the geomechanical instruments. Selected in situ data were fitted to analytical curves and predictions were made based on the extrapolated results. Closed form solutions and engineering experience were also utilized to substantiate the adequacy of the facility. A model simulation method was used to verify the creep model of salt based on creep constants derived from data obtained from laboratory material tests. After the determination of creep parameters using a statistical technique, the numerical model for simulating the facility was also utilized to predict and evaluate future behavior. This includes the closures, strain distributions and stress distributions over the operating life of the facility.

Design reviews were performed as required during design of the WIPP underground facility. Experience and judgment were an important adjunct in predicting the future behavior of the underground openings. More than 3 years of continuous data collection and analysis and evaluation have provided an adequate data base for predicting future behavior.

Subsections 5.4.1 through 5.4.3 describe the methods used for predicting the future behavior of the underground openings.

5.4.1 Extrapolation of In Situ Data

Selected in situ closure data were analyzed and fitted by analytical curves for extrapolation of future responses. Regression analyses by the Gauss-Newton or Marquardt compromise techniques were performed to determine the regression parameters. These regression parameters were assumed to be valid for the future behavior of the opening, and the equations were used to predict the future closure rate. To estimate the additional closure that could occur, the equation was integrated over the required time interval.

5.4.2 Closed Form Solutions

Closed form solutions provided in the SME Mining Engineering Handbook (ref. 2-25) were used to evaluate the selected room and pillar sizes and their stability. Closed form solutions for steel and concrete structural design were also used to substantiate the adequacy of the shaft liners and keys (refs. 5-4 thru 5-7).

5.4.3 Model Simulations

Numerical analyses were performed to compute the predicted responses of the underground openings. The constitutive laws discussed in Appendix C were used in these analyses. However, yield or failure criteria developed for halite and non-halitic materials based on the results of laboratory tests were not incorporated in the numerical modeling. Due to the idealization of the real system in a mathematical model, the uncertainty of in situ auxiliary conditions corresponding to the mathematical model, and deviations in the material properties obtained from the laboratory tests, analyses using laboratory test data did not provide suitable results for design validation. Therefore, an engineering approach using curve fitting methods was employed. Creep parameters computed by the following procedure were used for the analyses. Additional information pertaining to material property deviations based on laboratory tests is presented in Chapter 6.

Numerical models were generated for the locations of specific instruments to simulate the instrument response and compute the creep parameters.

After generating the numerical models for these locations, their creep parameters were computed and the structural behavior was simulated by performing an analysis using the statistical method presented in Appendix C and the following procedures:

(1) At the initial stage, the surface of the openings were restrained to simulate the unexcavated condition.

(2) An internal stress was applied at each element to represent the initial lithostatic stress state, which is defined as:

$$\delta_{xx} = \delta_{yy} = \delta_{zz} = -\int_0^y pgdy \qquad (5\text{-}1)$$

where: p is the rock mass per unit volume;
g is the gravitational constant; and
y is the depth.

(3) The overburden and support pressures at the boundaries and the weight of the rock were applied to compute the static solution.

(4) The restraints at the surface of the openings were then removed to simulate the excavation.

(5) The structural responses were computed using a time step integration scheme. Normalized time steps were used throughout the analysis. At the first time step, the time increment was calculated by an iterative scheme using a predetermined initial time increment.

(6) In subsequent time steps, the time increment for each time step was calculated based upon the previous time steps and the specified maximum tolerances of stress and strain increments at the previous and current time steps. The structural responses were computed at each normalized time step.

CHAPTER 6
GEOLOGIC CHARACTERIZATION

6.1 INTRODUCTION

Geologic characterization of the underground excavations for design validation of the WIPP began in June 1981. Initial characterization activities consisted of monitoring the drilling and geophysical logging of the SPDV exploratory shaft. As shaft outfitting and underground excavation progressed, the geologic work evolved into mapping of the shafts and underground horizontal openings, performing ground-water inflow tests, monitoring geomechanical instrumentation installations and taking subsequent readings or measurements, logging underground core hole samples, and performing other tasks related to defining the geologic integrity of the WIPP site. Data from these activities were evaluated in conjunction with information from previous site studies to more accurately define site geologic conditions as they related to design validation of the WIPP underground facility.

6.2 DATA COLLECTION ACTIVITIES

6.2.1 Geologic Mapping

An important aspect of validating the WIPP underground opening reference design included geologic mapping of the shafts and drifts. The objectives of this mapping were discussed in Chapter 5.

6.2.1.1 C & SH Shaft

Geologic characterization of the C & SH shaft began in late June 1981 with the drilling of the SPDV exploratory shaft (see Chapter 3, subsection 3.3.1, for an explanation of the two shaft names). The initial activity conducted to develop this characterization consisted of logging the drill cuttings at periodic intervals to permit a determination of rock types and to provide a description of the geologic formations penetrated (Appendix D, Figure D-1). These formations included, in descending order, the Dewey Lake red beds, the Rustler formation and the Salado formation.

After completion of the drilling operation, geophysical logging was performed in the shaft to determine the condition of the shaft wall and to more accurately define the stratigraphy penetrated. These logs were the caliper, gamma ray, density and epithermal neutron. The logs were analyzed to better determine the depths to various stratigraphic horizons and correlate them with those found in holes drilled during previous site investigation phases (Appendix B, Figure B-1).

Reconnaissance and detailed geologic mapping of the C & SH shaft was performed between March 31, 1982, and May 2, 1982, from a depth of about 846 feet (elev. 2564 feet) near the Rustler/Salado formation contact to a depth of 2,193 feet (elev. 1217 feet). Mapping above the 846-foot depth could not be performed due to the presence of the permanent steel liner, while drilling fluid and muck prevented mapping below the 2,193-foot depth. The results of this mapping, combined with criteria established as a result of previous site investigations, were used to select the final depth for the underground development level (Chapter 3, Section 3.2). The mapping results are shown in Appendix D, Figures D-2 through D-4. A detailed discussion of the mapping is contained in reference 3-1.

Vertical control for the shaft mapping was established by tape measure from a known elevation provided by the SPDV underground excavation contractor at the shaft collar. The scope of work and methodology for the shaft geotechnical activities are contained in reference 6-1.

Reconnaissance geologic mapping of the shaft from a depth of about 920 feet (elev. 2490 feet) to 2,083 feet (elev. 1327 feet) was accomplished after construction of the shaft key. The mapped area was limited to a strip 1 to 5 feet wide along the south side of the shaft. One interval from about 1,832 feet (elev. 1578 feet) to 1,892 feet (elev. 1518 feet) was not mapped due to the interference of shaft outfitting activities.

Detailed circumferential geologic mapping was performed in the key area from the base of the steel liner to a depth of about 920 feet.

Detailed mapping was also performed from a depth of about 2,083 feet to about 2,193 feet. Detailed mapping was carried out through this interval to obtain sufficient geologic information for use in making the final facility level selection. The facility level selection mapping was performed by several teams of geologists working over a 3-day period from April 30 to May 2, 1982. The detailed mapping was generally performed independently of shaft outfitting activities to permit better observation and interpretation of the shaft geologic characteristics.

Representative samples of the geologic strata surrounding the shaft were obtained during mapping for later, more detailed classification. Photographs were taken at various locations along the shaft wall for verification of the mapping results and record-keeping purposes. As mapping progressed, observations of the shaft wall were also made to determine the condition of the salt as a result of its behavior following excavation.

Based on the data obtained from the above activities, characterizations were made of the geologic formations penetrated by the C & SH shaft. The characterizations consisted primarily of descriptions of the stratigraphy, lithology and structure of the formations. Other detailed data were included, where relevant, to more accurately characterize the salt strata in areas of primary concern to the design of the WIPP underground facility.

The C & SH shaft geologic activities served to further refine and confirm the data obtained from previous site investigations. The geologic conditions observed in the C & SH shaft within the mapped interval corresponded to the conditions expected from previous investigations. Borehole ERDA-9, in particular, showed conditions similar to the C & SH shaft. Although some variation was observed, it was attributed to core loss in ERDA-9 which prevented the early detection of these conditions.

Only minor modifications to the reference design of the C & SH shaft key structure and the geomechanical instrumentation levels were made to accommodate the observed geology.

6.2.1.2 Waste Shaft

Drilling of the initial 6-foot diameter SPDV ventilation shaft (later to be enlarged to the waste shaft) was conducted from December 1981 to February 1982. Samples of the drill cuttings were obtained at periodic intervals from the drilling fluid to permit monitoring of the stratigraphy being penetrated. After the drilling was completed, a set of geophysical logs was run to determine the shaft wall conditions and to further define the boundaries of the rock strata penetrated.

Geologic mapping of the 6-foot diameter shaft began in July 1982 in conjunction with the initiation of shaft outfitting. Initially, five areas of weaker rock which had been washed out by the drilling operation were mapped between July and September 1982 before steel liner plate was placed over these areas for safety purposes. Geologic mapping of the SPDV ventilation shaft from the bottom of the steel surface casing at 97 feet (elev. 3312 feet) to the bottom of MB-139 was conducted during September and October 1982.

Both reconnaissance and detailed geologic mapping were performed in the 6-foot diameter shaft. The mapping extended from a depth of 97 feet below the ground surface to a depth of about 2,170 feet (elev. 1239 feet). The results of this mapping are shown in Appendix E, Figures E-1 through E-6. In addition, a lithologic log, based on the geologic mapping, and a geophysical density log are shown in Appendix B, Figure B-1, for correlation with the C & SH shaft and boreholes WIPP-12, ERDA-9 and DOE-1. A detailed description of the SPDV ventilation shaft geotechnical activities is contained in reference 4-3.

Mapping of the SPDV ventilation shaft was generally performed by a team of two geologists. Depth control was maintained by hanging a tape down the shaft wall at 100- to 200-foot intervals from the top of the

surface casing. Orientation in the shaft was maintained by following a steel guide installed on the southwest wall to control movement of the work platform used in the shaft. Most of the shaft was mapped in a strip about 2 to 3 feet wide along the steel guide. Although only a portion of the shaft wall was mapped, visual examination was made of the entire wall to determine if any geologic abnormalities existed. Below a depth of about 1,180 feet (elev. 2229 feet), mapping was performed on a limited basis due to salt incrustation on the shaft wall. This crust was apparently the result of dust from the facility level that was exhausting through the shaft and depositing on the wet shaft wall. Representative samples of the rock strata were collected to permit a more detailed description. Photographs were taken at various locations along the shaft wall for verification of the mapping results and record-keeping purposes. In addition to providing a description of the rock strata, observations of the shaft wall were made to determine, where possible, the reaction of the rock to excavation.

Detailed mapping around the full circumference of the 6-foot diameter shaft was performed at the following five intervals:

(1) Magenta dolomite member,
(2) Culebra dolomite member,
(3) Rustler formation fracture zone;
(4) Rustler/Salado formation contact; and
(5) MB-139.

Because of salt incrustation on the shaft wall immediately above the facility level, detailed circumferential mapping could not be performed in this area. However, two opposing strips about 1 foot wide were cut through the crust to permit mapping of the shaft wall for a distance of about 50 feet above the facility level. Depths in the facility level area were verified by a separate survey utilizing elevation points established in the C & SH shaft station.

The enlargement of the SPDV ventilation shaft into the waste shaft began in October 1983 and was completed in August 1984. Additional geologic mapping and visual inspections were conducted concurrently with this excavation. Mapping was conducted from December 9, 1983, to August 10, 1984. Visual inspections of the shaft surface were performed throughout the shaft enlargement operations. The lithology of the exposed shaft stratigraphy was described and compared with the description of the same stratigraphic interval mapped in the SPDV ventilation shaft. Any differences or additional detail were noted and the SPDV ventilation shaft geologic map was modified accordingly.

In the lined section of the waste shaft, the depth to the base of each successive concrete segment was provided by the shaft excavation contractor. Vertical control for mapping was then established from the base of the previous segment. During enlargement of the unlined section of the shaft, vertical control was established from occasional survey control points installed by the contractor and from the previously mapped SPDV ventilation shaft geology. In the shaft sump, vertical control was based on a contractor survey point installed at a depth of 2,167 feet (elev. 1242 feet).

Detailed, full circumference geologic mapping was performed in areas of specific geologic interest. These areas were selected because of their poor exposure in the SPDV ventilation shaft, the possible occurrence of dissolutioning, or their hydrologic significance. These areas of detailed mapping were:

(1) the Forty-niner member claystone;
(2) the Magenta dolomite member;
(3) the Tamarisk member claystone;
(4) the Culebra dolomite member;
(5) the upper portion of the unnamed lower member of the Rustler formation; and
(6) the Rustler/Salado formation contact and key area.

The detailed mapping in the waste shaft was generally conducted as outlined in reference 6-1. Mapping was conducted by teams of four to six people. Once vertical control was established by the contractor from the base of the previous concrete segment, a 5 x 5-foot grid was painted on the shaft surface around its circumference to permit the accurate location of any lithologic contacts and geologic features.

Reconnaissance geologic mapping was performed in the waste shaft sump. A vertical strip, approximately 5 feet wide, was cleaned and mapped along the entire length of the sump.

A detailed description of the geotechnical activities conducted in the waste shaft is contained in reference 6-2. The results of the mapping are shown in Appendix E, Figure E-1.

The geologic mapping and visual inspections of the SPDV ventilation/waste shaft has provided additional documentation of the strata above and below the WIPP underground development level. Based on the data obtained from the shaft mapping activities, a general characterization of the stratigraphy, lithology and structure of the geologic formations penetrated by the waste shaft was made.

The waste shaft penetrates five formations. In descending order, they are the Gatuna formation of Quaternary age, the Santa Rosa sandstone of Triassic age, and the Dewey Lake redbeds, Rustler formation and Salado formation, all of Permian age. In addition, the waste shaft also penetrates thin surficial Quaternary dune sands and the Mescalero caliche. In the WIPP site area, the Santa Rosa sandstone and the Gatuna formation are represented by thin layers of sandstone (ref. 6-3). They were not mapped in the waste shaft due to installation of the shaft collar facilities.

The results of the geologic mapping of the waste shaft correlate well with the SPDV ventilation shaft mapping results. The stratigraphic units penetrated by the waste shaft are the same as those encountered by the C & SH shaft.

Post-depositional dissolution features were not observed in any stratigraphic horizons in the waste shaft. Several zones previously identified as containing dissolution residues in borehole ERDA-9 are now considered to contain pronounced primary sedimentary features.

6.2.1.3 Exhaust Shaft

The exhaust shaft was enlarged from a 6-foot diameter raise-bored shaft to its finished 14- to 15-foot diameter using conventional drill and blast methods from July 1984 to January 1985. Geologic mapping of the shaft wall was conducted concurrently with excavation and construction activities.

Reconnaissance geologic mapping was performed along the entire length of the shaft with the exception of selected areas where detailed mapping was performed. A vertical strip, approximately 5 feet wide, was cleaned and mapped. The procedures used for the reconnaissance mapping are contained in reference 6-1.

Detailed circumferential mapping of specific areas of geologic interest was also performed. These areas included those previously described in the C & SH and waste shafts and four additional areas within the Dewey Lake redbeds, three of which contain gypsum filled fractures. The areas of detailed mapping in the exhaust shaft were:

(1) gypsum-filled fractures at a depth of 195.0 to 210.0 feet;
(2) gypsum-filled fractures at a depth of 269.0 to 280.5 feet;
(3) gypsum-filled fractures at a depth of 353.5 to 375.0 feet;
(4) the Dewey Lake/Rustler formation contact (546.4 feet);
(5) the Forty-niner member claystone (575.5 to 586.5 feet);
(6) the Magenta dolomite member (602.5 to 627.0 feet);
(7) the Tamarisk member claystone (689.0 to 695.5 feet);
(8) the Culebra dolomite member (713.5 to 736.0 feet);
(9) the upper portion of the unnamed lower member (736.0 to 800.0 feet); and
(10) the Rustler/Salado formation contact and key (845.0 to 912.0 feet).

The detailed geologic mapping was performed in a manner similar to that in the waste shaft, using a 5 x 5-foot grid. Vertical survey control was provided by the shaft excavation contractor. As the shaft liner was constructed, the depth to the base of each successive concrete segment was provided by the contractor. Vertical control for mapping was then established from the base of the previous segment. During excavation of the unlined section of the shaft, vertical control was established with survey chains suspended from contractor-installed survey control points.

The results of the exhaust shaft mapping are shown in Appendix F, Figure F-1. A detailed description of the geotechnical activities in the exhaust shaft are included in the report titled Geotechnical Activities in the Exhaust Shaft (ref. 6-4).

In general, the exhaust shaft mapping results correlate well with the results from the waste shaft. Slight lateral variations in the geology produce minor exceptions. The exhaust shaft geologic mapping activities have produced additional confirmation of data obtained from previous site investigations. This mapping confirms the suitability of the shaft reference design, with some minor modifications, based on the original design parameters.

6.2.1.4 Drifts and Test Rooms

Geologic mapping of the drifts and test rooms was performed to characterize the facility level geology, demonstrate its continuity, and provide permanent documentation of the geology exposed in the underground excavations. Those drifts and rooms that were not mapped were visually inspected by site geologists to verify that the stratigraphy is laterally continuous and similar to that exposed in the mapped areas of the facility. No unusual geologic features were observed.

Geologic mapping was conducted in accordance with the procedures established in reference 6-1. A horizontal level-line referenced to

the C & SH shaft station floor elevation was established in the drifts and rooms using an engineer's tripod level. All stratigraphic contacts and geologic features were referenced to this level-line datum. Horizontal distances were measured with an engineer's tape using the C & SH shaft centerline as the zero reference point. Detailed mapping was performed at 10-foot intervals along one wall of the drifts. Between these intervals, the continuity of the stratigraphic contacts and the nature of the individual units were observed and noted on the map. The mapped drifts were the E140 drift, the E0 drift, the N1100 drift and the N1420 drift. Selected figures showing the megascopic results of this mapping are contained in Appendix B.

Geologic Mapping in the test rooms consisted of describing a 6- to 10-foot wide strip surrounding the instrument array in the center of each room. Both walls and the roof in each room were mapped. The remainder of the room was carefully inspected to confirm lateral continuity of the stratigraphic units. The strip maps from the test rooms are presented in Appendix G, Figures G-1 through G-4.

6.2.2 Core Drilling

6.2.2.1 Purpose

Vertical core holes were drilled into the floor and roof of the underground openings to provide geologic information for design validation. The objectives of the vertical core holes are described in Supporting Document 3 of reference 2-5. The purpose of the program was discussed in Chapter 5 of this report.

6.2.2.2 Summary of Drilling

A total of 124 vertical core holes have been drilled and logged in the underground drifts and in the SPDV test rooms, excluding those drilled as part of SNL's in situ tests. This number includes 16 holes drilled to replace holes that had poor core recovery and four holes drilled to obtain information on non-cored sections in the original holes. The

holes were generally drilled in pairs, one hole drilled vertically into the roof and one hole drilled vertically into the floor. Core was obtained in each hole to a nominal depth of 50 feet. Table 6-1 presents a summary of the core hole data. A map showing the core hole locations is presented on Figure 6-1. Geologic cross sections at selected core hole locations in the drifts are contained in Appendix H. Geologic drill logs of all of the core holes are contained in Appendix I.

Drilling was performed by the underground excavation contractor. The drill rig was set up by the driller and the attitude of the core hole was checked by site geotechnical personnel. Logging and handling of the core were performed by geotechnical personnel in conformance with the procedures outlined in Supporting Document 3 of reference 2-5.

All core holes were drilled using rotary equipment and compressed air or saturated brine as the circulating medium. The holes were drilled with a diamond impregnated bit which produced 2-inch or 2 3/8-inch diameter core. A 5-foot long double-tube or split double-tube core barrel was used to retain the core.

The core was logged underground as it was removed from the core barrel or after the drilling of the hole was completed. Logging was generally performed by the same geologist to maintain consistency in the descriptions of the geologic materials. The following data are recorded on each log:

(1) location of core hole and direction of drilling (up or down);
(2) beginning and completion dates of drilling;
(3) length and number of core run;
(4) amount and percentage of core recovery;
(5) stratigraphic and lithologic descriptions (color descriptions are based on the Geological Society of America (GSA) Rock-Color Chart);
(6) graphic lithologic profile; and

Table 6-1

SUMMARY OF CORE HOLE DATA

Core Hole No.	Direction	Collar Elevation (ft-MSL)	Approximate Station (ft)		Facility Coordinates (ft)		Depth/ Penetration (ft)	Instrument Designation
MB-139-1	Down	1264.1	N79	W6	N9766	E6888	10.0	None
MB-139-2	Down	1251.2	S410	E150	N9277	E7044	15.7	None
MB-139-3	Down	1260.5	S101	E157	N9586	E7051	16.0	None
MB-139-4	Down	1258.7	S99	W17	N9588	E6877	16.2	None
DH-01	Up	1318.2	N1424	E439.5	N11110.9	E7335.5	50.8	None
DH-02(1)	Down		N1424	E440	N11110.9	E7336.06	50.2	None
DH-02A(1)	Down		N1424	E435	N11110.9	E7331.29	49.2	None
DH-02B	Down	1306.3	N1424	E442	N11110.9	E7331.29	53.0	None
DH-03	Up	1318.1	N1112	E444	N10799.2	E7335.4	48.8	None
DH-03A	Up	1317.4	N1112	E450.5	N10779.2	E7341.92	49.9	None
DH-04	Down	1309.6	N1112.5	E444	N10799.2	E7335.4	45.8	None
DH-04A(1)	Down	1309.6	N1113	E446			11.2	None
DH-04B	Down	1309.7	N1112	E450.5	N10799.70	E7341.85	51.4	None
DH-05	Up	1329.9	N1463	E972	N11149.6	E7865.0	51.0	None
DH-06	Down	1317.9	N1463	E972	N11149.7	E7864.9	49.75	None
DH-07	Up	1326.7	N1112	E976.5	N10799.3	E7870.8	49.8	None
DH-08	Down	1318.8	N1112	E976.5	N10799.4	E7870.9	38.3	None
DH-08A(1)	Down	1318.7	N1112	E975			50.7	None
DH-08B	Down	1318.0	N1112	E979.5	N10799.47	E7866.66	51.4	None
DH-09	Up	1324.5	N1432	E1332.5	N11108.71	E8227.11	51.1	None
DH-10	Down	1312.1	N1432	E1332.5	N11106.70	E8227.09	52.0	None
DH-11	Up	1320.5	N1112	E1332.5	N10799.8	E8227.3	50.9	None
DH-12	Down	1311.1	N1112	E1332.5	N10799.4	E8227.2	51.3	None
DH-13	Up	1311.4	N1424	E1690	N11112	E8585	13.8	None
DH-13A	Up	1311.5	N1424.5	E1691	N11112	E8586	49.0	None
DH-13B	Up	1311.4	N1425	E1695	N11112.6	E8590.1	21.0	None
DH-14	Down	1299.5	N1425	E1695	N11112.6	E8590.1	49.1	None
DH-15	Up	1308.9	N1104	E1688.5	N10793.26	E8589.96	51.0	None
DH-16	Down	1300.3	N1104	E1688	N10792.89	E8589.39	51.0	None
DH-17	Up	1316.5	N1427	E178	N11114.2	E7071.8	52.0	None
DH-18	Down	1305.1	N1429	E181	N11114.2	E7071.8	50.8	None
DH-19	Up	1314.7	N1107	E206.5	N10794.2	E7101.7	51.6	None
DH-20	Down	1306.2	N1109	E206	N10794.2	E7101.7	51.1	None
DH-21	Up	1331.0	N1421	E786	N11109.1	E7680.9	50.4	None
DH-22	Down	1318.8	N1421.5	E785.5	N11109.2	E7680.9	51.0	None
DH-23	Up	1328.0	N1112	E781	N10799.2	E7679.9	51.0	None
DH-24	Down	1319.5	N1112	E781	N10799.2	E7679.8	49.4	None
DH-24A	Down	1319.5	N1112	E780	N10799.08	E7678.59	50.4	None
DH-25	Up	1318.8	N1422	E1510	N11109.7	E8403.8	51.8	None
DH-26	Down	1307.2	N1427	E1510	N11114.3	E8403.8	53.0	None
DH-27	Up	1300.8	N1107	W682	N10793.7	E6218.4	50.5	None
DH-28	Down	1289.9	N1107	W682	N10793.8	E6218.3	50.5	None
DH-29	Up	1298.3	N1099	W982	N10785.4	E5932.4	50.4	None
DH-29A	Up	1298.1	N1099	W987	N10786.1	E5927.3	35.0	None
DH-30	Down	1289.2	N1099	W982	N10785.5	E5932.2	50.1	None
DH-31	Up	1298.5	N1099	W1282	N10784.9	E5632.3	50.5	None
DH-31A	Up	1298.5	N1099	W1280	N10784.8	E5630.5	49.2	None
DH-31B	Up	1298.5†	N1099	W1261	N10786.7	E5652.2	4.9	None
DH-32	Down	1289.6	N1099	W1282	N10784.9	E5632.2	50.0	None
DH-32A	Down	1289.5	N1099	W1261	N10786.7	E5652.2	5.5	None
DH-33	Up	1298.6	N1099	W1582	N10786.0	E5331.1	50.5	None
DH-33A	Up	1297.4	N1099	W1570	N10786.8	E5342.0	4.1	None
DH-34	Down	1289.4	N1099	W1582	N10786.5	E5331.7	51.5	None
DH-34A	Down	1289.2	N1099	W1570	N10786.8	E5341.9	3.6	None
DH-35	Up	1294.4	N1102	W1882	N10789.4	E5032.2	52.0	None
DH-36	Down	1284.6	N1102	W1882	N10789.4	E5032.2	51.5	None
DH-37	Up	1297.4	N1101	W2182	N10788.9	E4732.0	51.5	None
DH-38	Down	1287.0	N1101	W2182	N10788.8	E4731.9	47.5	None
DH-39	Up	1296.0	N1101	W2482	N10789.2	E4430.7	50.7	None
DH-40	Down	1286.1	N1101	W2482	N10789.2	E4431.0	51.0	None
DH-41	Up	1295.8	N1101	W2782	N10789.0	E4132.6	49.9	None
DH-42	Down	1285.9	N1101	W2782	N10789.0	E4132.4	51.2	None
DH-42A	Down	1285.7	N1101	W2789	N10789.2	E4125.5	40.5	None

(1) Survey data not available.

Table 6-1 (continued)

SUMMARY OF CORE HOLE DATA

Core Hole No.	Direction	Collar Elevation (ft-MSL)	Approximate Station (ft)		Facility Coordinates (ft)		Depth/ Penetration (ft)	Instrument Designation
DH-207	Up	1259.8	S697	E155	N8989.7	E7049.1	53.0	GE-246
DH-208	Down	1251.6	S698	E150	N8988.8	E7044.0	49.2	None
DH-211	Up	1270.5	S1320	E163	N8366.5	E7057.1	50.0	None
DH-212	Down	1261.7	S1320	E163	N8366.5	E7057.1	52.1	None
DH-215	Up	1272.0	S1960	E153	N7727.2	E7046.9	52.0	GE-247
DH-216	Down	1262.6	S1960	E153	N7727.2	E7046.9	54.2	GE-248
DH-219	Up	1266.3	S2422	E162	N7264.9	E7056.6	51.0	None
DH-219A	Up	1266.1	S2418	E162	N7268.5	E7056.2	11.3	None
DH-220	Down	1257.4	S2421	E162	N7265.5	E7055.9	51.8	None
DH-223	Up	1255.1	S3079	E154	N6607.2	E7048.5	52.6	GE-249
DH-224	Down	1246.6	S3079	E154	N6607.5	E7048.5	52.5	None
DH-227	Up	1247.0	S3656	E147	N6030.7	E7041.2	51.7	None
DH-228	Down	1237.8	S3656	E147	N6030.7	E7041.2	50.4	None
DH-301	Up	1276.9	N150	W170	N9830.5	E6724.5	50.75	None
DH-302	Down	1264.9	N150	W170	N9830.5	E6724.5	50.6	None
DH-303	Up	1267.2	S400	W170	N9282.3	E6726.1	51.4	None
DH-304	Down	1254.3	S400	W170	N9282.5	E6726.1	50.5	None
DH-306	Down	1244.1	S400	E140	N9287.3	E7049.9	52.0	None
DH-306A	Down	1244.0	S400	E125	N9287.9	E7034.6	8.5	None
DH-307	Up	1262.6	S400	E300	N9286.7	E7194.2	52.0	GE-263
DH-309	Up	1259.8	S700	E220	N8987.1	E7123.0	52.3	GE-265
DH-311	Up	1264.4	S1000	E300	N8686.3	E7194.9	52.0	GE-264
DH-313	Up	1270.6	S1300	E300	N8385.9	E7190.6	19.6	None
DH-313A	Up	1270.9	S1300	E299	N8386.6	E7189.5	50.2	None
DH-314	Down	1258.3	S1300	E300	N8386.5	E7189.5	50.75	None
DH-315	Up	1272.1	S1300	W170	N8387.3	E6725.5	50.3	None
DH-316	Down	1259.9	S1300	W170	N8387.2	E6725.3	50.1	None
DH-317	Up	1271.3	S1600	W33	N8077.4	E6875.9	50.1	None
DH-317A	Up	1271.2	S1600	W30	N8077.5	E6879.5	5.0	None
DH-317B	Up	1271.2	S1597	W30	N8080.3	E6881.0	51.0	None
DH-318	Down	1258.5	S1600	W30	N8077.3	E6876.1	50.0	None
DH-319	Up	1260.0	S700	E300	N8988.1	E7191.6	51.05	None
DH-321	Up	1261.4	S400	E0	N9792.0	E6891.8	52.0	GE-268
DH-323	Up	1261.2	S400	E55	N9291.7	E6952.5	52.5	GE-267
DO-45	Up	1285.5	N254	E147	N9941.0	E7041.3	52.4	GE-230
DO-46	Down	1276.5+	N254	E147	N9941.0	E7041.3	51.5	None
DO-52	Up	1280.4	N146	W4	N9832.5	E6890.5	51.6	GE-226
DO-53	Down	1266.6	N146	W4	N9832.5	E6890.5	49.2	None
DO-56	Up	1296.8	N621	E0	N10311.8	E6892.3	52.1	GE-234
DO-57	Down	1288.1	N621	E0	N10311.8	E6892.4	52.1	None
DO-63	Up	1310.6	N1110	E0	N10796.0	E6891.9	52.8	GE-243
DO-64	Down	1301.5	N1110	E0	N10796.0	E6891.6	52.8	GE-221
DO-67	Down	1296.8	N1265	W231.5	N10952.1	E6662.9	51.7	GE-220
DO-69	Up	1310.1	N1265	W231.5	N10951.9	E6662.5	51.4	GE-218
DO-77	Down	1294.6	N1270	W364.5	N10962.5	E6529.6	53.4	GE-216
DO-79	Up	1307.7	N1270	W364.5	N10962.6	E6529.5	51.8	GE-214
DO-88	Up	1305.9	N1265	W497.5	N10952.8	E6396.5	52.7	GE-212
DO-90	Down	1292.1	N1265	W497.5	N10952.6	E6396.4	53.6	GE-210
DO-91	Down	1292.1	N1275	W630.5	N10961.5	E6263.9	51.8	GE-209
DO-93	Up	1304.9	N1275	W630.5	N10961.1	E6263.9	52.0	GE-207
DO-201	Up	1262.2	S406	W19	N9280.6	E6874.9	51.7	None
DO-202	Down	1248.6	S406	W19	N9280.6	E6874.9	51.4	None
DO-203	Up	1298.2	N624	E140	N10308.6	E7041.7	52.0	GE-235
DO-204	Down	1290.5	N640	E140	N10308.5	E7041.5	51.6	None
DO-205	Up	1316.5	N1410	E0	N11095	E6892	50.7	None
DO-206	Down	1308.0	N1410	E0	N11095	E6892	50.6	None
DO-229	Up	1259.8	S401	E153	N9287	E7049	50.6	None
OH-9	Up	1310	N1433	W231.5	N11125.6	E6662.9	15.4	None
OH-11	Up	1308	N1433	W364.5	N11125.6	E6529.6	19.7	None
OH-13	Down	1298	N1433	W231.5	N11125.6	E6662.9	9.5	None
OH-14	Down	1296	N1433	W364.5	N11125.6	E6529.6	9.7	None

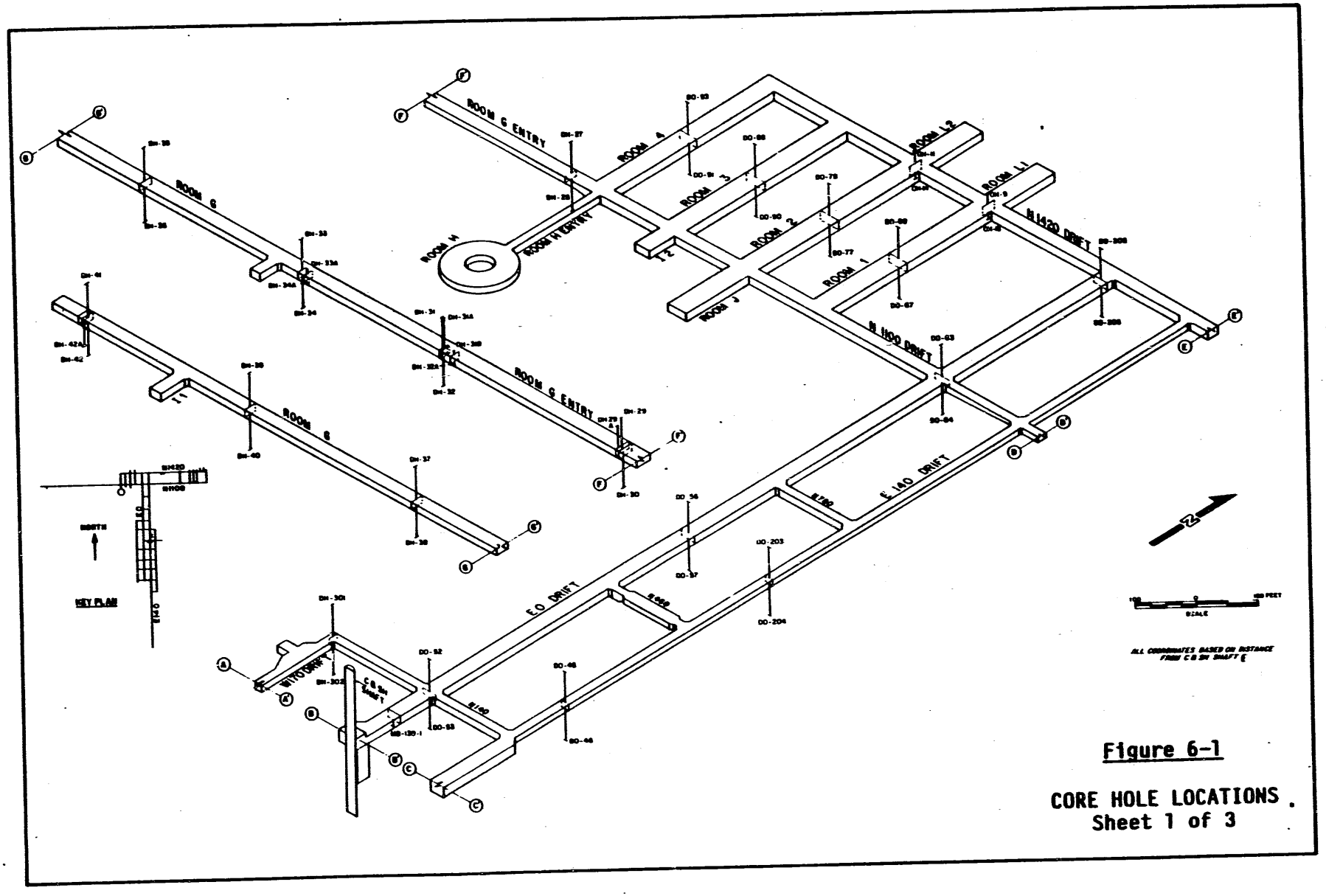


Figure 6-1

CORE HOLE LOCATIONS.
Sheet 1 of 3

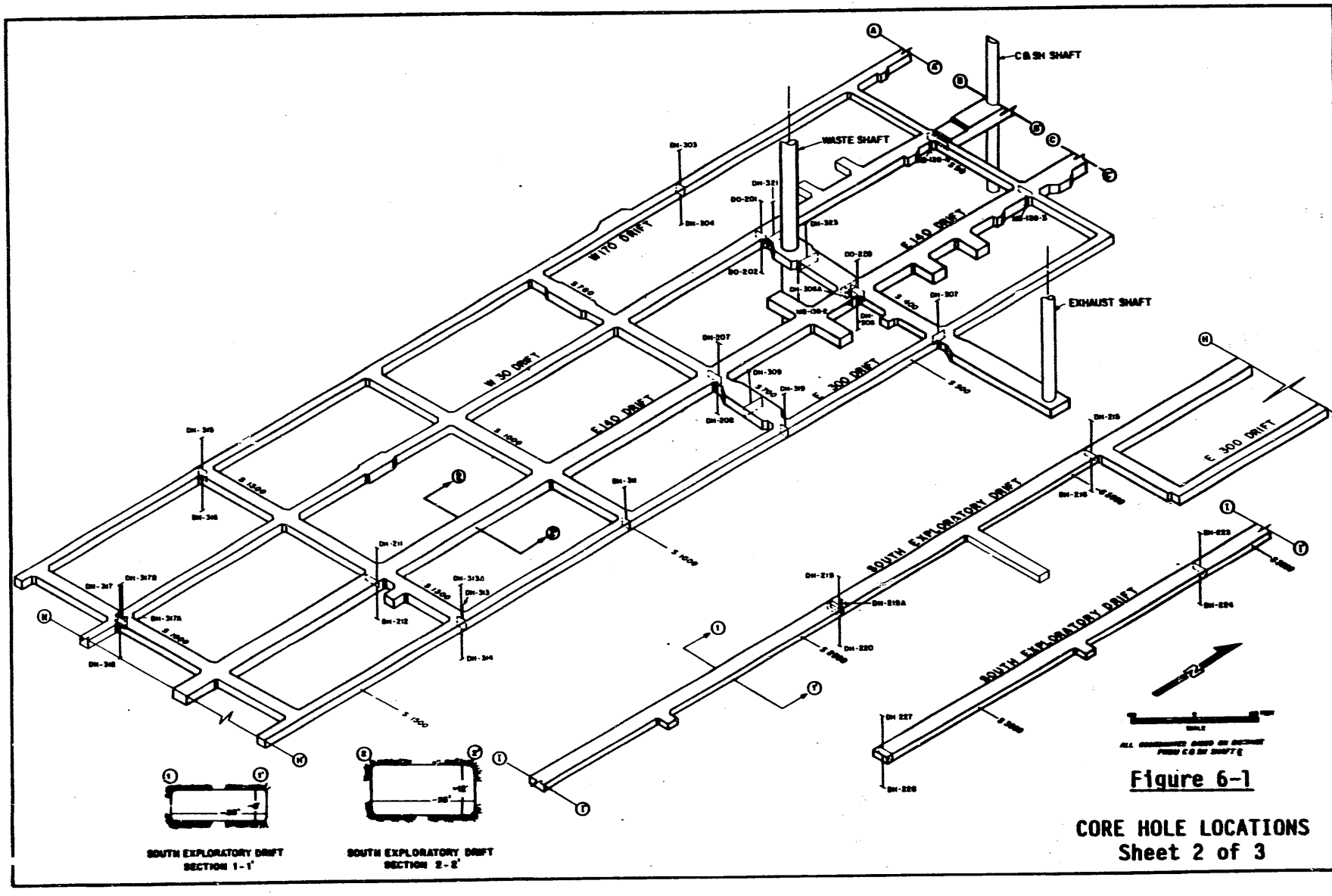


Figure 6-1

CORE HOLE LOCATIONS
Sheet 2 of 3

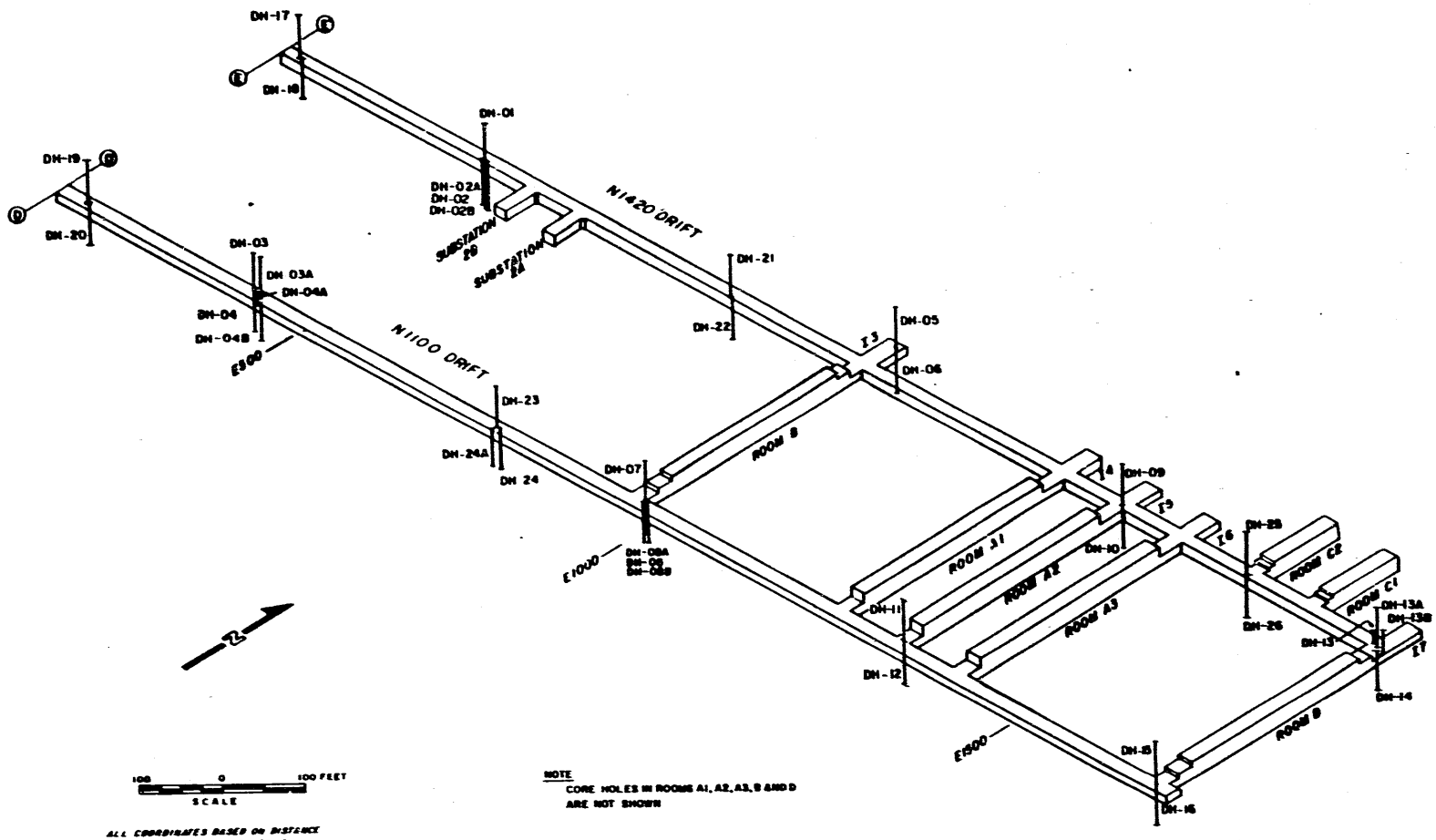


Figure 6-1

CORE HOLE LOCATIONS
Sheet 3 of 3

(7) other pertinent information related to core conditions and observations made during drilling.

Included on the logs of many of the core holes is a core sample reference number for each distinguishable stratigraphic unit (except anhydrite). This number (in some cases several numbers) is shown in brackets at the end of the unit description. The number identifies a specific core sample that has undergone a laboratory analysis to determine its percentage of insolubles (clay/polyhalite). A listing of the reference core samples and their laboratory test results for insoluble residues are presented in Table 6-2. The reference sample system was used to provide uniformity in the logging of the core and to facilitate the comparison of unit descriptions with samples having a known insoluble content. The sample number or numbers which appear on the log are those which are visually most similar to the overall unit. The crystal size in the reference samples may not be the same as in the units with which they are correlated.

Each box of core was photographed and then stored in the WIPP core library. After data from several of the core holes was collected, correlations between the holes were developed.

6.2.2.3 Summary of Results

The underground core drilling program has demonstrated the lateral continuity of stratigraphy throughout the underground facility horizon. Three anhydrite units were identified in the upholes and two anhydrite units were identified in the downholes. These units are consistently underlain by clay seams. In addition, a clay seam designated clay I was found in most of the upholes and a clay seam designated clay D was found in many of the downholes. Anhydrite is commonly associated with these two seams. The remaining units consist of halite with varying amounts of argillaceous material and polyhalite. Individual units vary slightly from hole to hole in thickness, crystal size, and the percentage of accessory constituents such as argillaceous material and polyhalite. The stratigraphy

Table 6-2

INSOLUBLE RESIDUES OF REFERENCE CORE SAMPLES
SANDIA NATIONAL LABORATORIES

Reference Sample Number	Hole Number	Depth Interval (feet)	Water-Insoluble			EDTA-Insoluble (1)		
			Sample Weight (grams)	Residue Weight (grams)	Percent Weight	Sample Weight (grams)	Residue Weight (grams)	Percent Weight
1	DO-52	9.0 - 9.7	451.09	0.03	0.01			
2	DO-52	39.4 - 40.0	336.10	0.11	0.03			
3	DO-52	14.3 - 15.0	415.57	2.15	0.52	1.61	0.72	44.72
4	DO-53	14.1 - 14.5	251.72	0.40	0.16	0.36	0.14	38.89(2)
5	DO-53	4.0 - 4.3	206.53	1.28	0.62	0.80	0.28	35.00(2)
6	DO-53	23.7 - 24.1	155.36	1.26	0.81	0.96	0.59	61.46
7(3)	DH-48	18.0 - 18.35			0.22			
8	DO-52	2.0 - 2.75	436.67	2.16	0.49	1.32	0.91	68.94
9(3)	DH-12	28.15- 28.6			0.75			57.1
10(3)	DH-11	46.5 - 46.9			3.85			39.2
11(3)	DH-12	50.05- 50.4						
12(3)	DH-11	32.8 - 33.35			2.36			50.0
13	DO-53	36.1 - 36.7	364.13	1.89	0.52	1.47	1.17	79.59
14	DO-52	42.6 - 43.5	543.62	17.97	3.31	5.13	4.58	89.28
15	DO-52	33.8 - 34.7	538.73	20.28	3.76	5.05	3.98	78.81
16	DO-52	48.7 - 49.2	315.06	16.59	5.27	5.31	4.33	81.54
17(3)	DH-10	43.3 - 43.6			0.52			49.2

Notes:

(1) For description of sample preparation see Results of Site Validation Experiments, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico, Section 6.4 (ref. 2-6).

(2) Small sample volume may have produced inaccurate result.

(3) Reference sample used for visual comparison is identical to the sample tested in the laboratory, but is from different interval within the same unit.

encountered in the core holes was used to prepare the reference stratigraphic column discussed in subsection 6.3.1.3.

The presence of any gas or brine detected during drilling is recorded on the drill logs. Usually within 2 weeks of completing an air-drilled uphole, brine weeps or moisture halos appear at the collar of the hole. Brine has also collected in some downholes which were dry during drilling. Observations of gas and brine occurrences are discussed in the following subsection.

6.2.3 Fluid Measurements

6.2.3.1 General Description

Ground-water inflow measurements were taken in both the SPDV exploratory and ventilation shafts as part of the geologic field activities for the SPDV Program. In addition, measurements in the waste shaft and exhaust shaft were taken as part of design validation. Gas and brine have been encountered in boreholes and at excavation faces in the facility level drifts and rooms. Studies are being performed by other WIPP project participants to further investigate and evaluate these occurrences.

6.2.3.2 C & SH Shaft

Measurements of fluid inflow were taken during the SPDV exploratory shaft drilling operation when the drill tools were out of the hole for a bit change. The measurements were taken by monitoring changes in the drilling fluid level over a period of several hours. These data were then used to estimate approximate ground-water flow rates into the shaft.

6.2.3.3 Waste Shaft

Ground-water inflow measurements were taken in the 6-foot diameter SPDV ventilation shaft during shaft outfitting. These measurements were taken in the shaft sump and at the base of the Rustler formation. The measurements in the shaft sump were used to determine total flow into

the shaft from all ground-water sources penetrated. Periodic measurements to determine water level rise with respect to a known point at the top of the sump were obtained during test intervals ranging from about 1.5 to 90 hours. The data obtained from these measurements were used to calculate approximate ground-water flow rates into the shaft ranging from 0.3 to 0.9 gallons per minute (gpm). The average flow rate was determined to be about 0.6 gpm.

An attempt to measure ground-water inflow from the rock strata above the Salado formation was only partially successful. A collection system to retain ground-water inflow was constructed at the base of the Rustler formation by placing plastic sheeting across the shaft and attaching it to the wall. The quantity of water collected in the sheeting and drained into a graduated container was calculated to accumulate at a rate of approximately 0.3 to 0.4 gpm from all sources above the Salado formation.

No direct inflow from the Magenta or Culebra dolomite members or at the Rustler/Salado formation contact was measured. The Magenta dolomite did not exhibit measurable flow. Ground water from this member resulted in the wetting of the wall below the dolomite for a distance of about 20 feet. Below this distance the shaft wall was essentially dry. Therefore, it was concluded that the Magenta was making no contribution to the collection system at the base of the Rustler formation. Visual inspection of the Rustler/Salado formation contact, and shaft wall conditions immediately above and below this contact, suggested that the zone was making little, if any, contribution to the water accumulating in the sump. Based on these results, it was concluded that the Culebra dolomite member was contributing the majority of ground water reaching the SPDV ventilation shaft sump.

The 6-foot diameter SPDV ventilation shaft was later enlarged to become the waste shaft for the WIPP facility. Of the three formations observed during geologic mapping activities in the enlarged shaft, only the Magenta and Culebra dolomite members of the Rustler formation were

obvious fluid-bearing zones. The Magenta exhibited only a few weeps and generally produced very little water. The entire Culebra section, however, was wet, but no obvious local concentrations of water inflow were observed. Wherever a ledge was present, a steady dripping of water occurred. The Rustler/Salado formation contact, often considered a fluid-producing zone, did not contain any observable fluid except for some dampness around rock bolts.

After the waste shaft liner was constructed, ground water was observed seeping through cracks and construction joints in it. These observations are discussed in Chapter 8, subsection 8.3.1.1.

6.2.3.4 Exhaust Shaft

A water inflow measurement of approximately 0.4 gpm into the 7 7/8-inch diameter pilot hole for the exhaust shaft was taken on December 1, 1983. On December 21, 1983, a water inflow of 0.47 gpm was measured after the pilot hole was enlarged to 11 inches in diameter.

After the shaft was excavated to its finished dimensions, water inflow through cracks and construction joints in the liner was measured. Measurement was made from the 2-inch drainpipe that connects the three water collection rings in the shaft. The measured flow was 0.35 gpm in January 1985. A grouting program, conducted in June and July 1985 within the lined section of the shaft, reduced this inflow to a non-measurable quantity.

6.2.3.5 Drifts and Test Rooms

Small amounts of gas under pressure have been encountered by some underground boreholes and at the working face of underground horizontal excavations. Brine is observed to weep locally from walls and into some boreholes. The brine occurrences are visible during or immediately after excavation or drilling and remain moist or produce fluid for a period of from several weeks to more than 3 years. The formation of salt blisters on walls and salt straws and precipitate at

hole collars are common. Salt incrustations forming on the roof are being monitored at three locations: W30/S1600, E140/S2190 and E140/S2740.

The gas occurrences encounterd by boreholes are indicated on the geologic drill logs. Pressure transient testing and gas sampling were performed in several holes in the roof and floor of the facility as reported in reference 4-11. Only two occurrences of gas at the working face were documented prior to the end of December 1985. In both cases, degassing could be heard at the face for short periods of time.

The locations of major weeps occurring on walls that were geologically mapped are indicated on the maps and a discussion of their occurrence and structure is presented in reference 4-10. Sampling of brine from weeps for chemical analysis is currently being conducted. A preliminary inventory of brine occurrences at accessible locations is presented in reference 4-15.

The flow of gas from monitored holes has been low and erratic. It appears to be associated with clay seams or a result of fracture permeability in anhydrite beds. The spatial distribution of brine occurrences is also undefined. Although very few weeps have been observed on the roof surface, boreholes in the roof sometimes weep brine. The amount and duration of flow from boreholes and wall areas varies considerably. Based on observations made during preliminary gas testing, the brine appears to be associated primarily with anhydrite beds and their underlying clay seams. However, brine can also weep directly from halitic units, as observed on the walls and roof of drifts and in the drum durability test pit in Room J.

Two program plans have been developed to investigate gas and brine occurrences in the WIPP underground facility. The programs will investigate the origin, migration, volume and composition of the occurrences. Work on the Brine Testing Program (BTP) is presently

being conducted and will continue through 1987. The Gas Testing Program (GTP) is also currently in progress.

As part of the BTP, 36 accessible boreholes containing brine have been monitored. These holes include the shallow holes for the Material Interface-Interactions Test (MIIT) in Room J, inclinometer holes in Test Rooms 1 and 2 (51X-IG-00201 and 51X-IG-00202), an abandoned stressmeter hole (51X-NG-00252) in Test Room 2, hole L1-X00 in Room L1, nine stratigraphic core holes in Room G (DH-35 through DH-42A), and eight stratigraphic core holes in experimental Rooms A1, A2, A3 and B (A1X01, A1X02, A2X01, A2X02, A3X01, A3X02, BX01 and BX02). The static level of any brine in the holes is measured and recorded on a regular basis. The brine is then evacuated from the hole and its volume measured.

The BTP monitoring of brine occurrences in the MIIT holes in Room J was suspended at the end of April 1985 due to interference with experimental activities in the room. Monitoring of the remainder of the boreholes listed above continues. As new monitoring locations for the BTP are identified, they will be added to the program.

An inventory of all boreholes drilled in the underground facility has been assembled. Data contained in the inventory include hole location, diameter, depth, present status, drilling fluid used, and any observations on the occurrence of gas or brine. Over 1400 holes are presently listed, most of which contain geomechanical instruments or are otherwise inaccessible. The list will be used to locate accessible boreholes that may be suitable for use in the gas and brine testing programs.

6.3 DESCRIPTION OF FACILITY GEOLOGY

6.3.1 Stratigraphy

The stratigraphy within the WIPP underground facility horizon has been determined through vertical core hole drilling and geologic mapping of

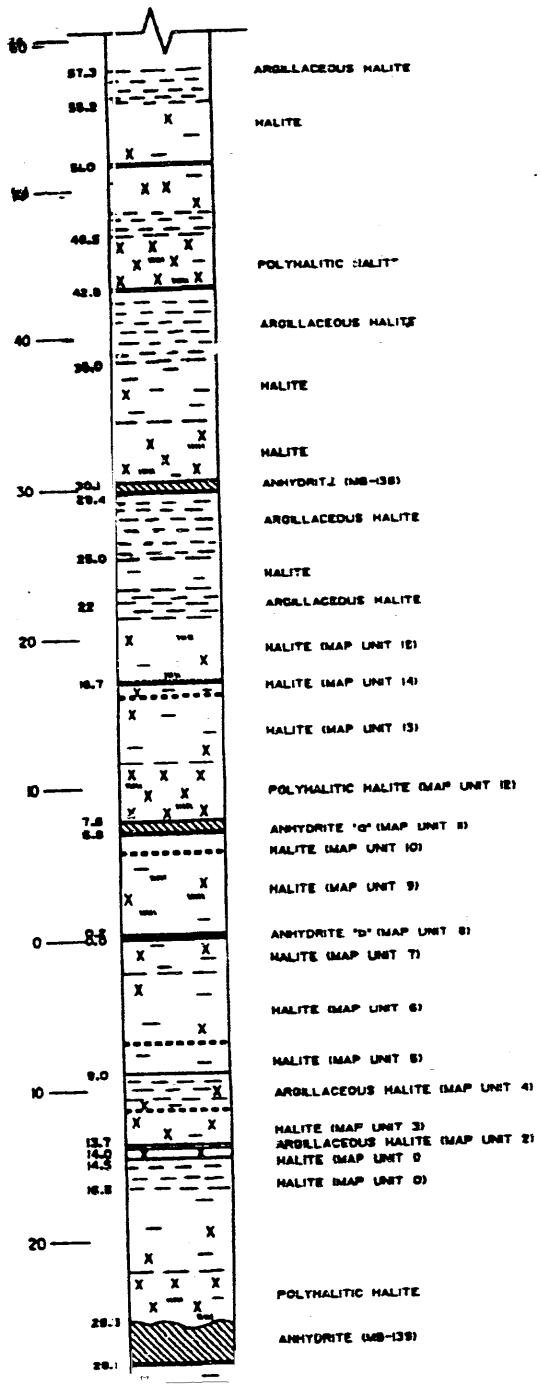
the excavation walls. A description of the generalized stratigraphy and evidence for stratigraphic continuity is presented in the following subsections. Figures showing the stratigraphy within the WIPP underground facility horizon are presented in Appendix B.

6.3.1.1 Generalized Stratigraphy

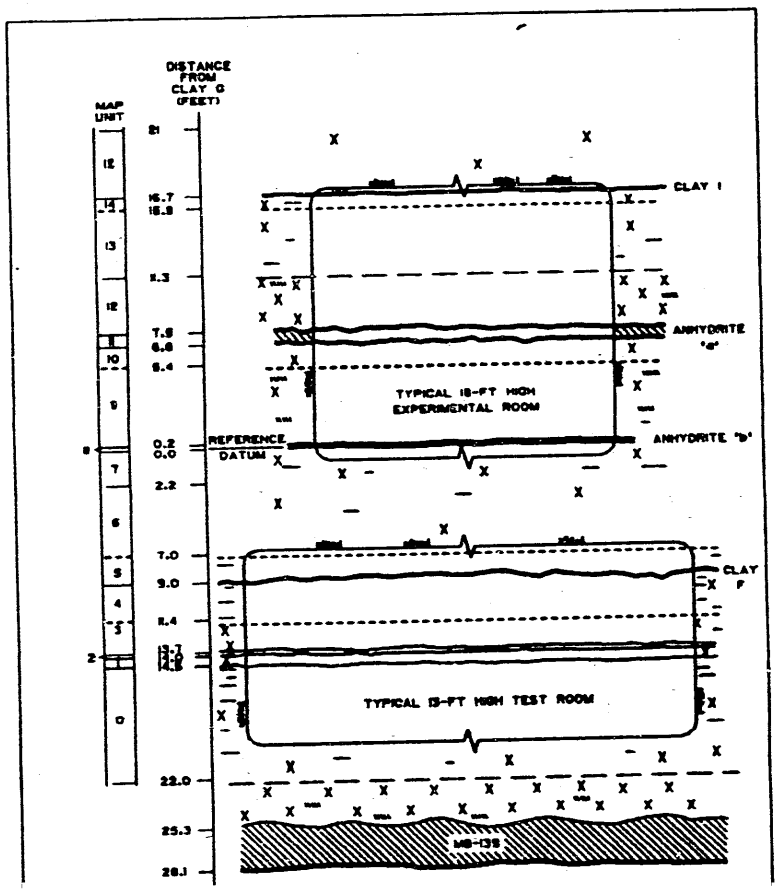
The WIPP underground facility horizon consists primarily of halite containing varying amounts of polyhalite and clay. This halite is interrupted by 5 anhydrite beds, 12 clay seams and 6 argillaceous layers. Figure 6-2 contains a generalized stratigraphic column showing the relationship of these materials. Detailed descriptions of the individual units (except clay seams) are presented in Table 6-3. Figure 6-3 shows the individual clay seams and their descriptions.

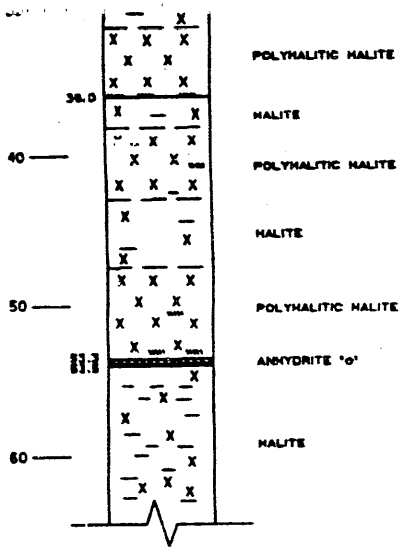
Because of the difference in the behavior of halite and anhydrite, the five anhydrite beds represent significant boundaries above and below the horizontal underground openings. Three of the beds, abouth 1 1/2 to 12 inches thick, occur approximately 7, 14 and 35 feet above the roof of the storage level drifts and rooms. The remaining two beds occur beneath the floor of the drifts and rooms. The most significant of these two beds is MB-139 which occurs approximately 3 1/2 to 4 1/2 feet below the floor of the storage level and varies from 2.5 to 4 feet in thickness. The remaining bed occurs about 32 feet below the storage level and is approximately 4 inches thick. Thin clay seams underlie all of the anhydrite beds.

Fifteen lithologic units have been identified during geologic mapping within the facility level drifts, rooms and waste experimental area. The majority of these units are halite containing varying amounts of polyhalite and argillaceous material, usually less than 2 percent. The remaining units consist of 2 anhydrite beds, 2 argillaceious halite units and 1 polyhalitic halite unit. Each of the 15 mapped units has been assigned a numerical designation as shown on Figure 6-2 and contained in Table 6-3.



(SEE TABLE 6-3 FOR DETAILED DESCRIPTIONS OF UNITS)





NOTES:

1. DISTANCES ARE MEASURED FROM THE BASE OF ANHYDRITE 'b' (CLAY G) AND ARE AVERAGED FROM REPRESENTATIVE CORE HOLE LOGS, SHAFT AND TEST ROOM MAPPING. ACTUAL DISTANCES AND UNIT THICKNESSES MAY VARY LOCALLY FROM THOSE SHOWN.

2. DESCRIPTIONS OF UNITS ARE BASED ON CORE HOLE DATA, SHAFT MAPPING AND VISUAL INSPECTION OF EXPOSURES IN UNDERGROUND DRIFTS AND ROOMS.

3. DETAILED DESCRIPTIONS OF CLAY SEAMS ARE PRESENTED ON FIGURE 6-4.

4. PERCENTAGES OF ARGILLACEOUS MATERIAL AND POLYHALITE ARE BASED ON VISUAL ESTIMATES FROM EXAMINATION OF DRILL CORE AND EXPOSURES IN THE UNDERGROUND EXCAVATIONS. SANDIA NATIONAL LABORATORIES' MEASUREMENTS OF INSOLUBLES FROM SELECTED CORE WERE USED AS A POINT OF REFERENCE.

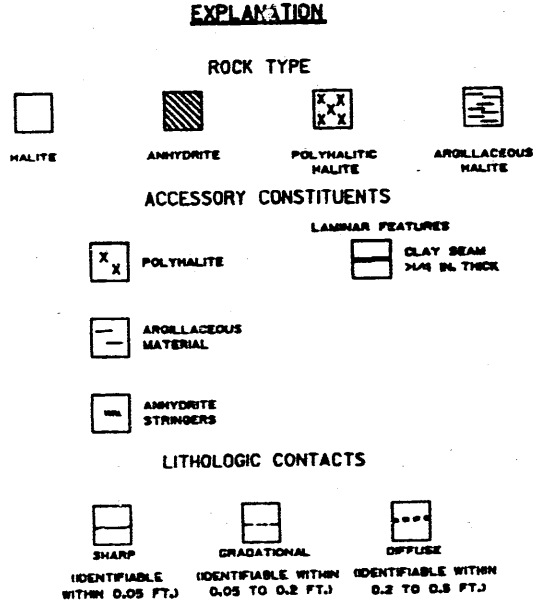


Figure 6-2

WIPP GENERALIZED STRATIGRAPHIC COLUMN

Table 6-3

DESCRIPTION OF GENERALIZED STRATIGRAPHY

Approximate Distance From Clay G (Ft)	Stratigraphic Unit	Description*
55.2 to 57.3	Argillaceous halite	Clear to moderate brown, medium to coarsely crystalline. <1 to 3% brown clay. Intercrystalline and discontinuous breaks. In one core hole, consists of a 1 in. thick clay seam. Unit can vary up to 4 ft thickness. Contact with lower unit is gradational.
46.5 to 55.2	Halite	Clear to moderate reddish orange and moderate brown, coarsely crystalline, some medium. ≤1% brown clay, locally argillaceous (clays M-1 and M-2). Scattered anhydrite stringers locally.
42.8 to 46.5	Polyhalitic halite	Clear to moderate reddish orange, some moderate brown, coarsely crystalline. <1 to 3% polyhalite. None to 1% brown and some gray clay. Scattered anhydrite locally. Contact with unit below is fairly sharp.
38.0 to 42.8	Argillaceous halite	Clear to moderate brown, medium to coarsely crystalline, some fine. <1 to 5% brown clay. Locally contains 10% clay. Intercrystalline and scattered breaks. Locally contains partings and seams. Contact with lower unit is gradational based on increased clay content. Average range of unit is 38.0 to 42.8 ft above clay G but does vary from 33.8 to 46 ft.
34.0 to 38.0	Halite	Clear to moderate brown, some moderate reddish brown, coarsely crystalline, some fine and medium. ≤1% brown clay, trace gray clay locally. Scattered breaks. Locally argillaceous. <1% polyhalite. Contact with unit below is gradational based on clay and polyhalite content.
30.1 to 34.0	Halite	Clear to moderate reddish orange, coarsely crystalline. <1 to 3% polyhalite. Commonly polyhalitic. Scattered anhydrite stringers with anhydrite layers up to 1/2 in. thick locally. Scattered brown clay locally. Contact with MB-138 below is sharp.
29.4 to 30.1	Anhydrite (MB-138)	Light to medium gray, microcrystalline. Partly laminated. Scattered halite growths. Clays seam K found at base of unit.
25.0 to 29.4	Argillaceous halite	Clear to moderate brown, some light moderate reddish orange. Medium to coarsely crystalline. <1 to 3% brown clay, some gray. Locally up to 5% clay. Clay is intercrystalline with scattered breaks and partings present. < 1/2% dispersed polyhalite. Contact with lower unit is gradational based on clay content. Upper contact is sharp with clay K.
23.0 to 25.0	Halite	Clear, some light moderate brown, coarsely crystalline. <1/2% brown clay. Contact with clay J below varies from sharp to gradational depending if clay J is a distinct seam or merely an argillaceous zone.
21.0 to 23.0	Argillaceous halite	Usually consists of scattered breaks or argillaceous zone containing <1 to 3% brown clay. In C & SH shaft, it is a 1/2 in. thick brown clay seam.
16.7 to 21.0	Halite (Map Unit 15)	Clear, coarsely crystalline, scattered medium. None to <1% dispersed polyhalite and brown clay. Scattered anhydrite. Lower contact is sharp with clay I.
15.8 to 16.7	Halite (Map Unit 14)	Clear to grayish orange-pink, coarsely crystalline, some medium. <1/2% dispersed polyhalite. Scattered discontinuous gray clay stringers. Clay I is along upper contact. Contact with lower unit is diffuse.
11.5 to 15.8	Halite (Map Unit 13)	Clear to moderate reddish orange and moderate brown, medium to coarsely crystalline, some fine. ≤1% brown clay, locally up to 3%. Trace of gray clay. Scattered discontinuous breaks. <1% dispersed polyhalite and polyhalite blebs. Contact with unit below is gradational based on clay and polyhalite content.

Table 6-3 (continued)

DESCRIPTION OF GENERALIZED STRATIGRAPHY

Approximate Distance From Clay G (Ft)	Stratigraphic Unit	Description*
7.5 to 11.5	Polyhalitic halite (Map Unit 12)	Clear to moderate reddish orange, coarsely crystalline. <1 to 3% dispersed polyhalite and polyhalite blebs. Scattered anhydrite stringers. Contact is sharp with unit below.
6.8 to 7.5	Anhydrite "a" (Map Unit 11)	Light to medium gray, light brownish gray and sometimes light moderate reddish orange. Microcrystalline. Halite growths within. Partly laminated. Clear, coarsely crystalline halite layer, up to 2 in. wide, found within exposures in waste experimental area. Thin gray clay seam H at base of unit.
5.5 to 6.8	Halite (Map Unit 10)	Clear to moderate reddish orange/brown, fine to coarsely crystalline. <1% brown and/or gray clay and dispersed polyhalite. Discontinuous clay stringers locally. Contact with lower unit is diffuse based on crystal size and varying amounts of clay and polyhalite.
0.2 to 5.5	Halite (Map Unit 9)	Clear to light moderately reddish orange, coarsely crystalline, some medium. None to <1% polyhalite. Trace of gray clay locally. Scattered anhydrite stringers. Contact with unit below is sharp.
0.0 to 0.2	Anhydrite "b" (Map Unit 8)	Light to medium gray, microcrystalline anhydrite. Scattered halite growths. Thin gray clay seam G at base of unit.
0.0 to -2.2	Halite (Map Unit 7)	Clean to light/medium gray, some moderate reddish orange/brown. Coarsely crystalline, some fine and medium. <1 brown and gray clay. Locally up to 2% clay. <1% dispersed polyhalite. Upper contact is sharp with clay G. Contact with lower unit is gradational.
-2.2 to -7.0	Halite (Map Unit 6)	Clear, some moderate reddish orange, coarsely crystalline, some fine to medium locally. <1/2% gray clay and polyhalite. Contact with lower unit gradational and/or diffuse.
-7.0 to -9.0	Halite (Map Unit 5)	Clear coarsely crystalline. <1/2% gray clay. Contact with lower unit is usually sharp with clay F.
-9.0 to -11 4	Argillaceous halite (Map Unit 4)	Clear to moderate brown and moderate reddish brown, coarsely crystalline. <1% polyhalite. <1 to 5% argillaceous material; predominantly brown, some gray, locally. Intercrystalline and discontinuous breaks and partings common in upper part of unit. Decreasing argillaceous content downward. Contact with lower unit is gradational.
-11.4 to -13.7	Halite (Map Unit 3)	Clear to moderate reddish orange, coarsely crystalline. <1% dispersed polyhalite and polyhalite blebs. Locally polyhalitic. Scattered gray clay locally. Contact with lower unit is sharp.
-13.7 to -14.0	Argillaceous halite (Map Unit 2)	Moderate reddish brown to medium gray, medium to coarsely crystalline. <1 to 3% argillaceous material. Contact with lower unit is usually sharp.
-14.0 to -14.5	Halite (Map Unit 1)	Light reddish orange to moderate reddish orange, medium to coarsely crystalline. <1% dispersed polyhalite. Contact with lower unit is sharp.
-14.5 to -22.0	Halite (Map Unit 0)	Clear to moderate reddish orange/brown, moderate brown and grayish brown. Medium to coarsely crystalline. <1 to 5% argillaceous material. Predominantly brown, some gray, intercrystalline argillaceous material and discontinuous breaks and partings. Upper two feet of unit is argillaceous halite decreasing in argillaceous material content downward. None to <1% polyhalite. Contact with lower unit is gradational based on polyhalite content.

Table 6-3 (continued)

DESCRIPTION OF GENERALIZED STRATIGRAPHY

Approximate Distance From Clay G (Ft)	Stratigraphic Unit	Description*
-22.0 to -25.3	Polyhalitic halite	Clear to moderate reddish orange. Coarsely crystalline, some medium locally. <1 to 3% polyhalite. Scattered anhydrite. Scattered gray clay locally. Contact with lower unit (MB-139) is sharp, but commonly irregular and undulating. Trace of gray locally present along this contact.
-25.3 to -28.1	Anhydrite (MB-139)	Moderate reddish orange/brown to light and medium gray, microcrystalline anhydrite. "Swallowtail" pattern, consisting of halite growths within anhydrite, common in upper part of unit. Locally, hairline, clay-filled, low-angle fractures found in lower part of unit. Thin halite layer common close to lower contact. Clay seam E found at base of unit. Upper contact is irregular, undulating and sometimes contains<1/16 in. gray clay.
-28.1 to -31.2	Halite	Clear to moderate reddish orange, and light gray. Coarsely crystalline, some fine and medium. ≤1% polyhalite and intercrystalline gray clay. Contact with lower unit is gradational based on increased polyhalite content.
-31.2 to -36.0	Polyhalitic halite	Clear to moderate reddish orange, coarsely crystalline. <1 to 3% polyhalite. Contact with lower unit is usually sharp along clay D.
-36.0 to -37.8	Halite	Clear to moderate reddish orange, some light gray. Medium to coarsely crystalline. ≤1% polyhalite and gray clay. Contact with lower unit is gradational based on increased polyhalite content.
-37.8 to -42.7	Polyhalitic halite	Clear to moderate reddish orange/brown, coarsely crystalline. <1 to 3% polyhalite. Trace of clay locally. Scattered anhydrite locally. Contact with lower unit is gradational, based on decreased polyhalite content.
-42.7 to -47.3	Halite	Clear to moderate reddish orange, medium to coarsely crystalline. <1% dispersed polyhalite. <1% brown and/or gray clay. Contact with lower init is gradational and/or diffuse.
-47.3 to -53.3	Polyhalitic halite	Clear to moderate reddish orange. Coarsely crystalline with some medium sometimes present close to lower contact. <1 to 3% polyhalite. Scattered anhydrite especially common close to anhydrite "c". Lower contact is sharp with anhydrite "c".
-53.3 to -53.5	Anhydrite "c"	Light to medium gray, microcrystalline anhydrite. Scattered halite growths. Faintly laminated locally. Clay seam B found at base of unit.
-53.5 to -65.7	Halite	Clear to medium gray and moderate brown. Medium to coarsely crystalline, some fine locally. <1% polyhalite, locally polyhalitic. <1 to 3% clay, both brown and gray. Intercrystalline clay with discontinuous breaks and partings. Zones of argillaceous halite found within unit. Seams of clay mixed with halite crystals present locally. Upper contact of this unit is sharp with clay B.

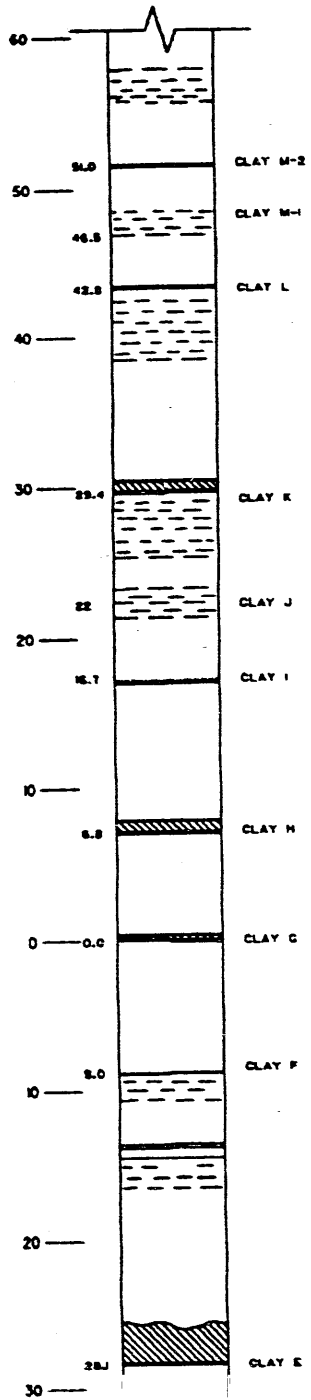
* Descriptions are based on examination of drill core and exposures of units in shafts and other underground openings.

Map units 1 through 6 occur within the storage level drifts and rooms. Unit 1 is a distinct, relatively thin, orange-colored unit commonly referred to as the "orange marker bed". This unit is continuous throughout the facility level excavations. During excavation, it was used as a marker to help keep the underground openings within the proper stratigraphy. The descriptions for map units 7 through 15 represent the lithology most frequently encountered in the drifts and rooms in the waste experimental area. Minor variations in these lithologies occur at various locations but they are not of sufficient difference to justify their inclusion in the generalized descriptions.

6.3.1.2 Stratigraphic Continuity

The results of geologic mapping and core hole drilling in the underground facility have confirmed the lateral extent and stratigraphic continuity of the geologic units within the underground facility horizon. Strata exposed in the drifts have been traced continuously for 4,500 feet in an east-west direction and more than 5,000 feet in a north-south direction. North-south and east-west correlations between the vertical core holes have also demonstrated the continuity of the stratigraphic units above and below the facility level. Figures B-4 through B-9 in Appendix B show the correlations of stratigraphic horizons that have been made based on core hole data. These figures also demonstrate the slight southern dip of the units. Figure B-5 shows a slight thinning of units to the south by about 5 percent. Figures B-1 and B-2 show a larger correlation of stratigraphic horizons between boreholes WIPP-12 to the north and DOE-1 to the south. The five anhydrite beds shown on Figure 6-2 are laterally continuous across the WIPP site.

Although the general character of each stratigraphic unit remains constant throughout the underground facility horizon, minor variations occur. Some thin clay seams are discontinuous and some halite units thin locally or pinch out. The disruptions of some of these units are localized phenomena thought to result from syndepositional processes. Both lateral and vertical variations in the argillaceous and polyhalite



VARIES FROM AN ARGILLACEOUS HALITE ZONE CONTAINING <1 TO 3% BROWN CLAY TO A CLAY/HALITE SEAM UP TO 3 1/2 INCHES THICK.

COMMONLY FOUND AS AN ARGILLACEOUS HALITE ZONE CONTAINING <1 TO 3% BROWN CLAY OR MERELY A BROWN, SOMETIMES GRAY, CLAY PARTING. LOCALLY FOUND AS A SEAM UP TO 1/2-INCH THICK.

IN C & SH SHAFT, IT IS A 2-INCH THICK BROWN CLAY SEAM. MOST COMMONLY IT IS FOUND AS THE UPPER CONTACT OF THE ARGILLACEOUS ZONE BELOW.

USUALLY BROWN CLAY BUT SOMETIMES GRAY TO GRAY-BROWN. IN CORE, MOST COMMONLY FOUND AS 3/4 TO 1 1/4-INCH HARD, BROWN CLAY SEAM. IN THE C & SH SHAFT, IT IS UP TO 1 1/2 INCHES THICK. USUALLY IT IS A LOW ANGLE CONTACT.

IN C & SH SHAFT, CONSISTS OF A REDDISH BROWN CLAY SEAM UP TO 1/2-INCH THICK. IN CORE HOLES, FOUND AS SCATTERED BREAKS OR ARGILLACEOUS HALITE CONTAINING <1 TO 3% CLAY.

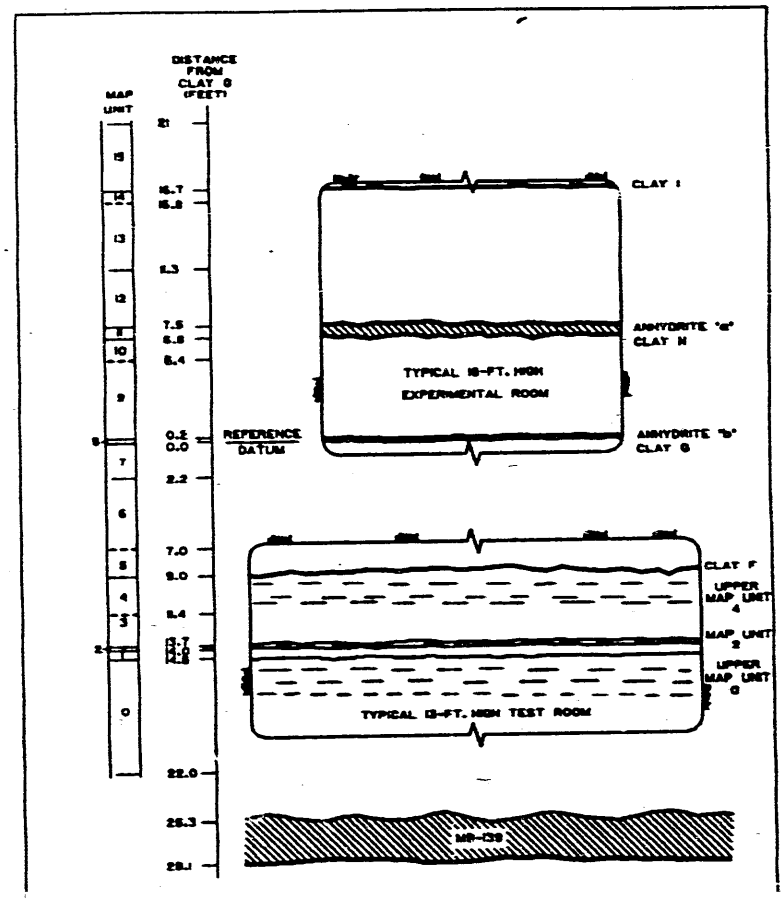
<1/4 TO 5/8-INCH THICK CLAY. COMMONLY BROWN OR BROWNISH GRAY IN CORE BUT GRAY WHERE EXPOSED IN EXPERIMENTAL TEST ROOMS. COMMONLY ASSOCIATED WITH THIN ANHYDRITE ABOVE. EXPOSURES IN EXPERIMENTAL TEST ROOMS SHOW IT TO BE FAIRLY REGULAR WITH UNDULATIONS USUALLY LESS THAN 1 INCH AMPLITUDE. SOME SCATTERED HALITE GROWTHS LOCALLY WITHIN CLAY.

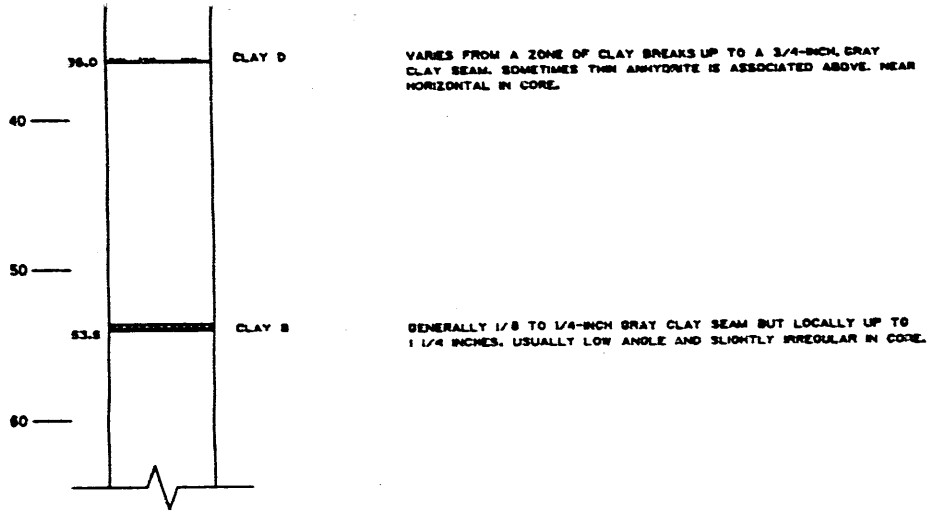
AVERAGES <1/4-INCH THICK CLAY BUT VARIES FROM TRACE UP TO 1/2 INCH. USUALLY GRAY COLOR BUT BROWN IN SEVERAL CORE HOLES. CLAY H IS EXPOSED IN THE WASTE EXPERIMENTAL AREA. HERE IT IS A GRAY, IRREGULAR SEAM WITH UNDULATIONS OF 1 TO 3 INCHES AMPLITUDE.

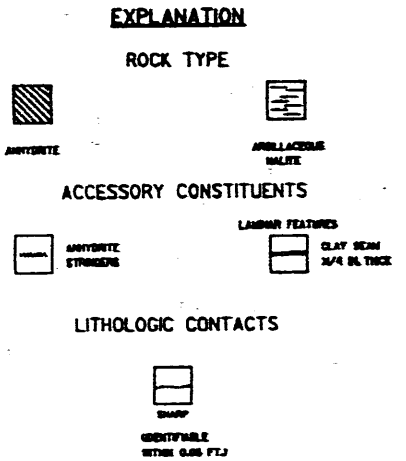
TRACE UP TO 3/8-INCH THICK GRAY CLAY. USUALLY A LOW ANGLE CONTACT IN CORE. EXPOSED IN WASTE EXPERIMENTAL AREA WHERE IT IS A GRAY, FAIRLY REGULAR SEAM WITH UNDULATIONS AVERAGING <2 INCHES AMPLITUDE. LOCALLY, MOISTURE IS NOTED ALONG THIS SEAM. EXPOSED ALONG THE WALLS OF MANY OF THE FACILITY LEVEL DRIFTS AND ROOMS ALONG THE UPPER CONTACT OF MAPPING UNIT 4, VERY IRREGULAR.

GRAY TO BROWN SEAM <1/8 TO 1/2-INCH THICK. HALITE IS COMMONLY MIXED WITH CLAY AND SILT. SOMETIMES BIFURCATES INTO TWO SEAMS. LOCALLY DISCONTINUOUS. UNDULATIONS OF 2 TO 8 INCHES AMPLITUDE.

1/4 TO 1 1/2-INCH GRAY CLAY SEAM. MOISTURE PRESENT IN SOME LOCATIONS. LOCALLY IRREGULAR WITH UNDULATIONS UP TO 4 INCHES AMPLITUDE.







NOTES:

1. DISTANCES ARE MEASURED FROM CLAY G AND ARE AVERAGED FROM REPRESENTATIVE CORE HOLE LOGS AND SHAFT MAPPING.
2. DESCRIPTIONS OF CLAY SEAMS ARE BASED ON CORE HOLE DATA, SHAFT MAPPING AND VISUAL INSPECTION OF EXPOSURES IN UNDERGROUND DRIFTS AND ROOMS.
3. ONLY CLAY SEAMS ARE SHOWN ON THIS FIGURE. ALL OTHER UNITS ARE SHOWN ON FIGURE 6-2 AND DESCRIBED IN TABLE 6-3.

Figure 6-3

CLAY SEAMS

content of the halite units are common. The size of halite crystals varies from fine to coarse both laterally and vertically within inidvidual units. Although the anhydrite is microcrystalline, the beds vary laterally in color, thickness and polyhalite or halite content. The upper surface of MB-139 is undulatory with amplitudes of up to 12 inches.

The halite around the underground openings exhibits slightly varied behavior in response to excavation at different locations. This may be due to minor variations in crystal size or clay content. The clear halite in the roof of the E140 drift south of the waste shaft exhibits more spalling than is apparent in similar halite in other areas of the underground openings. Spalling along the upper portion of map unit 4 occurs in many of the facility level drifts and rooms. In the locations where this unit contains abundant argillaceous material, the spalling appears to be more pronounced. This behavior is discussed in Chapters 10 and 11.

6.3.1.3 Reference Stratigraphy

A meeting was held on November 15, 1979, to determine a reference stratigraphy for the WIPP site. This was titled the "November '79 Reference Stratigraphy" and was based on data obtained from exploratory boreholes. The purpose of the reference stratigraphy was to provide input data for thermal/structural analyses of shafts, drifts and rooms at the WIPP that could be referenced by all structural analysts and updated as more data became available.

The "November '79 Reference Stratigraphy" was revised in July 1981 and again in September 1983 as more data were collected from construction activities and underground core holes. The 1983 revision was titled "September '83 Reference Stratigraphy". This revision was based on the evaluation of 39 core hole logs and the geologic mapping performed in the SPDV exploratory and ventilation shafts.

The evaluation determined that the strata are fairly horizontal but dip slightly to the south. Based on a statistical analysis, the entire stratigraphic section was found to vary in elevation in a regular manner, but individual unit thicknesses and the relative separation between units were found to have no statistically significant variation between the northern and southern limits of the underground facility horizon (ref. 5-3).

Figure 6-4 shows the reference stratigraphy developed by this statistical analysis. This stratigraphy consists of 1 polyhalite bed, 2 argillaceous halite units, 7 anhydrite beds, 12 clay seams, and halite as the remaining constituent. This reference stratigraphy extends approximately 165 feet above and below the facility level. The location and thickness of the various units were adjusted by averaging values determined from the core holes. Geologic maps of the SPDV exploratory and ventilation shafts and the log of borehole ERDA-9 were used for units outside the WIPP underground facility horizon. The uniformity of the rock in the core holes and shafts, the lack of a statistically significant variation in unit thicknesses and elevation, and the expected small influence of any differences on structural behavior resulted in a decision to use the same reference stratigraphy throughout the site.

Subsequent to the development of the September 1983 reference stratigraphy, additional core holes were drilled and logged, the ventilation shaft was enlarged to the waste shaft, the exhaust shaft was completed, and both of these shafts were geologically mapped. Based on additional data from these activities, a generalized stratigraphic column of the underground facility horizon was developed (Figure 6-2 and Table 6-3). This stratigraphic column does not vary significantly from the earlier 1983 reference stratigraphy. Therefore, the 1983 reference stratigraphy continued to be used for model calculations.

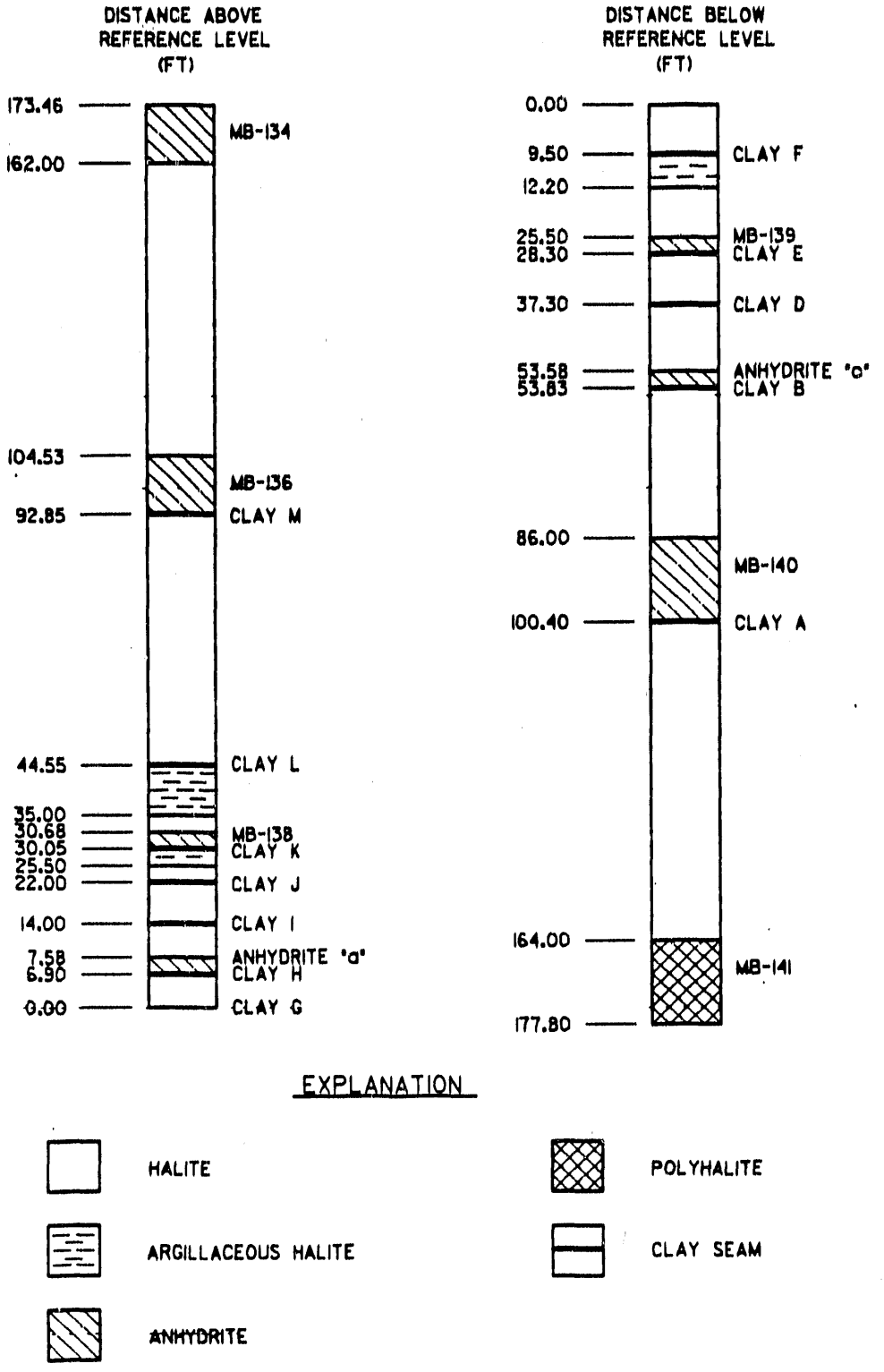


Figure 6-4

REFERENCE STRATIGRAPHY

6.3.2 Lithology

The Salado formation is predominantly halite, but other evaporite minerals and argillaceous materials are present that may locally compose up to 50 percent of the salt. Anhydrite, an early-precipitated evaporite mineral, is found in beds (usually less than 5 feet thick) which are typically underlain by a clay seam (1/16 to 3/4 inch thick). Polyhalite, a late-forming evaporite mineral, is commonly found as an accessory mineral in the Salado formation. Clay and silt may be found disseminated through the halite or in thin seams, partings, or breaks. Following is a description of the major lithologies occurring within the underground facility horizon.

Clear Halite. These units consist of halite with only trace amounts of impurities. The halite is predominantly medium to coarsely crystalline and clear to very light gray or moderate reddish orange. Less commonly, it occurs as finely crystalline, opaque, very light gray halite with a sucrose texture. Trace impurities of clay and/or polyhalite are generally dispersed in the halite. Scattered very light gray to white anhydrite or magnesite stringers may be present.

Polyhalitic Halite. These units are composed mainly of medium to coarsely crystalline halite with accessory amounts of polyhalite. As the polyhalite content increases, the color of the rock changes from transparent light orange-pink to translucent moderately reddish orange/brown or dark reddish brown. The polyhalite occurs primarily as interstitial blebs or patches and, less commonly, in stringers about 1/4 to 3/4 inch thick.

Argillaceous Halite. Six argillaceous halite units, three above and three below clay G, occur within the underground facility horizon. Generally, these units consist of medium to coarsely crystalline and some finely crystalline halite with from less than 1 to as much as 5 percent silty clay. The clay is predominantly brown in color with some gray. It is commonly intercrystalline or forms scattered breaks or partings. Discontinuous clay seams are present locally. The percent

of clay is a visual estimate; laboratory measurements of insolubles (ref. 6-5) were used as a reference.

The contacts between these units and the surrounding materials vary from gradational to distinct. Clays F, K and L occur at the upper contact of three of these argillaceous units. The three units below clay G are exposed in the underground drifts and rooms. These are geologic map units 2 and 4 and the upper portion of map unit O (Figure 6-2). They are exposed continuously throughout the openings except in the waste experimental area which is stratigraphically higher. Map unit 2 is very thin and absent in places.

No significant moisture is associated with these argillaceous halite layers. Commonly, they are slightly moist immediately after excavation and locally develop brine blisters on the walls of the underground openings.

Anhydrite. These beds range in thickness from a few inches to a few feet. Because they are readily identified, the anhydrite beds in the vicinity of the facility level have served as reference units.

Three anhydrite beds, 0.15 to 1.05 feet thick, are present above and two beds, 0.3 and 2.5 to 4 feet thick, are present below the facility level (Figure 6-2). All of the beds are laterally continuous and each is underlain by a thin clay seam. Locally, very thin anhydrite seams are associated with identified clay seams and scattered anhydrite stringers are common in several of the halite units. The anhydrite is microcrystalline and commonly ranges from a very light gray to medium gray-green color, although it is sometimes a moderate reddish to pinkish color. Halite growths are common, especially within MB-139. Anhydrite "a" commonly contains a clear halite seam up to 1 1/2 inches thick.

MB-139 is the thickest anhydrite unit within the underground facility horizon and is the most variable in color and composition. It is

described here in detail because of its importance in the deformational behavior of the underground openings, particularly the test rooms (Chapter 11).

MB-139 ranges from 2.5 to 4 feet thick. For mapping purposes, it has been divided into two subunits (Appendix G, Figures G-10 through G-34). Subunit A corresponds to Zones I, II and III described in reference 6-6. This subunit consists predominantly of reddish polyhalitic anhydrite and anhydrite mixed with light to medium gray anhydrite. Pods, lenses and seams of light to very light gray anhydrite are commonly scattered throughout the subunit. Irregular halite growths, ranging from less than 1/16 to more than 25 square inches, are common, especially in the upper half of subunit A. Commonly, a 1- to 2-inch thick seam of moderately reddish-orange to gray polyhalitic anhydrite with scattered halite and polyhalitic halite growths occurs along the upper contact. This corresponds to Zone I described in reference 6-6. Swallowtail growth patterns and hopper crystals are occasionally present in the upper 12 inches of subunit A, commonly within an upward undulation of the marker bed. Halite-filled fractures are found in places within the undulations. Scattered within the reddish polyhalitic anhydrite is an irregular and sometimes discontinuous layering of light gray anhydrite, which varies from less than 1/8 inch to 1/2 inch thick. Pods and lenses of gray anhydrite are often faintly aligned, although discontinuously, with the general trend of the layering. These pods and lenses are most prevalent in the lower half of subunit A.

Subunit B corresponds to Zones IV and V in reference 6-6. Its contact with subunit A is diffuse and based mainly on a change in color. Subunit B consists of light to medium gray anhydrite. Some core samples exhibit layering which faintly follows the general trend of the layering in subunit A. Halite growths are present, but to a much lesser degree than in subunit A. Usually the lower 4 to 8 inches of the subunit is faintly laminated and contains a few halite growths. A subhorizontal halite layer, usually less than 1/8 inch thick, is occassionally present close to the lower contact.

The upper contact of MB-139 is undulatory. The lower contact is underlain by clay E. This clay ranges from 1/4 inch to 1 1/2 inches thick. It is often slightly moist and sometimes wet.

Clay Seams. Characteristics of the clay seams within the underground facility horizon are shown on Figure 6-3 and summarized in Table 6-4. These include qualitative and/or quantitative characterizations and descriptions of the clay seams in terms of the following:

(1) color;
(2) thickness;
(3) moisture;
(4) grain size;
(5) consistency/plasticity;
(6) planar trend; and
(7) continuity/uniformity.

This information has been gathered through a review of core hole logs, geologic mapping and inspection of existing exposures.

The clay seams underlying anhydrite beds usually vary from less than 1/8 inch to 3/4 inch in thickness but may range up to 1 1/2 inches thick, as is common for clay E. The other, less continuous seams are usually less than 3/4 inch thick but may be as much as 2 inches thick, as is clay L in the C & SH shaft. Clay M-1 was as much as 3 1/2 inches thick in one hole but it consisted of a mixture of clay and halite crystals at this location.

Generally, the seams consist of clay with some silt. The clay varies from gray to brown in color. Only field classifications of the clay in core and underground exposures have been performed. These classifications indicate that the seams generally consist of soft to hard, medium plastic material. Locally, fine to coarse halite crystals are present in some of the seams. Clays F and M-1 commonly contain

Table 6-4

CLAY SEAM CHARACTERISTICS

Seam	Rating (1)	Color	Thickness	Moisture	Grain Size	Consistency/ Plasticity	Planar Trend	Continuity/ Uniformity	Occurrence
B	1	Gray	<1/8 to 1/4 in. average; locally up to 1 1/4 in.	Dry to slightly moist.	Passes #200 sieve.	Generally hard.	Slightly irregular; generally low angle in core but locally up to 35°.	Continuous.	Present in core holes and C & SH and waste shaft mapping.
D	2	Gray	≤3/4 in.	Dry except hole DO-57 where clay is moist; hole drilled with fluid.	Passes #200 sieve.	Hard to medium soft; medium to highly plastic.	Near horizontal in core.	Varies from zone of breaks to seam with associated anhydrite.	Present in many core holes and in C & SH shaft mapping
E	1	Gray	1/4 to 1 1/2 in.	Locally moist to wet.	Passes #200 sieve.	Soft to hard; medium plastic	---	Continuous.	Present in many core holes and in C & SH and waste shaft mapping.
F	2	Gray, sometimes brown.	<1/8 to 1/2 in.	Slight.	Passes #200 sieve. Commonly mixed with halite crystals.	Slightly plastic.	Very irregular; undulations of 2-in. to 8-in. amplitude.	This is at the upper contact of map unit 4; locally discontinuous; sometimes bifurcates into two seams.	Exposed along walls of many of the facility level drifts and rooms.
G	1	Gray	Trace up to 3/8 in.	Slightly to moderately moist; weeps along exposures in underground excavations.	Passes #200 sieve.	Soft to hard; medium plastic.	Fairly regular; undulations average <2-in. amplitude.	Continuous.	Found in most core holes, shaft mapping and underground waste experimental area excavation.
H	1	Gray; brown in several core holes.	Average ≤1/4 in. but ranges from trace up to 1/2 in.	Slightly to moderately moist.	Passes #200 sieve.	Medium plastic.	Fairly irregular; undulations of 1-in. to 3-in. amplitude.	Continuous.	Found in most core holes, shaft mapping and underground waste experimental area excavation.

Table 6-4 (continued)

CLAY SEAM CHARACTERISTICS

Seam	Rating[1]	Color	Thickness	Moisture	Grain Size	Consistency/ Plasticity	Planar Trend	Continuity/ Uniformity	Occurrence
I	1	Brown-brownish gray in core; gray where exposed in waste experimental rooms.	<1/4 to 5/8 in.	Slightly moist.	Passes #200 sieve; some scattered halite crystals locally.	Hard in some core holes; medium plastic.	Regular; undulations generally <1-in. amplitude.	Fairly continuous.	Commonly found in core holes, C & SH and exhaust shafts; also exposed in waste experimental room excavation.
J	3	Reddish-brown	1/2 in. in C & SH Shaft only.	---	Passes #200 sieve; trace silt, trace to some halite crystals.	---	---	Generally found as scattered breaks or localized argillaceous zone.	Found in C & SH shaft as 1/2 in. seam; not found in other shafts; in core holes, found as scattered breaks or localized argillaceous zone; absent in many core holes.
K	1	Brown, sometimes gray to gray-brown.	3/4 to 1 1/2 in.	Dry to moist; locally wet.	Passes #200 sieve; claystone in exhaust shaft.	Hard to medium hard; medium plastic.	Generally low angle contact in core; fairly regular.	Continuous.	Present in many core holes and shafts.
L	3	Brown	Up to 2 in. in C & SH shaft; usually found only as top of argillaceous unit.	---	Passes #200 sieve; some halite crystals.	---	---	Not a continuous seam; it is found generally as the top of argillaceous zone throughout core holes and shafts.	Exposed in C & SH shaft as seam; otherwise only noted as top of argillaceous unit.

Table 6-4 (continued)

CLAY SEAM CHARACTERISTICS

Seam	Rating[1]	Color	Thickness	Moisture	Grain Size	Consistency/ Plasticity	Planar Trend	Continuity/ Uniformity	Occurrence
M-1	4	Brown	<1/16 to 1/2 in.	Dry	Passes #200 sieve.	---	---	Unknown.	These two layers found in core holes in waste experimental area; not noted in shaft mapping.
M-2	4	Brown	Up to 3 1/2 in.	Dry	Clay mixed with halite crystals.	---	---	Unknown.	

Notes:

(1) Key to "Rating": 1 - continuous throughout facility level;
2 - generally continuous, but varies in character and regularity;
3 - discontinuous and not always well developed;
4 - continuity unknown.

(2) Clays B, E, G, H and K are sometimes noted as only a trace or not at all on core logs. This is usually because core grinding or washing during drilling removed evidence of clay.

(3) Some core logs note clay layers are moist. In holes drilled with brine, this may be due to drilling fluid. Many layers are dry in holes drilled with air. These may actually be slightly moist in the in situ state, but dried out by the drilling process.

(4) Clays B, E, G, H and K always underly continuous anhydrite layers. Clays I and D are commonly associated with thin anhydrite layers.

(5) Plasticity and consistency based on evaluation of in situ condition.

more halite mixed with the clay/silt fraction. Clay F also appears to be more silty and less plastic than the other seams.

Generally, the clay seams are slightly moist in their in situ state. However, some of the seams are wet and exhibit some brine weeping in places. This was observed for clays E, G, H and K in some core holes. The clay seams in some of the holes where brine was used as a drilling fluid were observed to be moist. This was probably due in part to the drilling fluid. In contrast, clay seams were observed to be dry in many of the core holes drilled using air circulation. It is expected that, in the in situ state, these seams contain a slight amount of moisture which was evaporated as a result of the drilling method. Some moisture can be seen along exposures of clay H and clay G in the waste experimental area. More moisture is evident along clay G and some salt blisters have accumulated locally along this seam. The clay seams exposed in the underground openings are generally slightly moist during and immediately after excavation. Some seams have continued to expel moisture long after excavation. Often, however, they dry out at the surface within a few days after their exposure.

Clays G, H and I, exposed in the waste experimental area, commonly contain white specks which may be salt resulting from the air drying of the clay. The clay usually has a slightly salty taste. These white specks are soft, can be easily crushed between the fingers, and have a slightly bitter taste.

The consistency of the clay encountered in the core holes and excavations is related to its moisture content. When wet or moist, the clay is generally soft to medium stiff and can be picked out with the fingers and molded into a ball in the hand. When the clay is only slightly moist or dry, it is stiff to hard and is difficult to work in the hand.

6.3.3 Structure

Geologic mapping of the underground openings has not identified any faults, joints, significant folds, or other structural disruptions that could affect the suitability of the WIPP facility for storing radioactive waste. Very small scale (approximately 1 foot), localized disruptions of the bedding have been encountered. These are attributed to penecontemporaneous processes.

Detailed correlations between vertical core holes, combined with the results of geologic mapping in the drifts and test rooms, indicate that the strata within the underground facility horizon are deformed slightly into a sinusoidal shape. Figure B-4 in Appendix B depicts this shape, but greatly exaggerates the amplitude of the deformation. The amplitude of the fold is approximately 10 to 15 feet and its wavelength is approximately 2,000 to 3,000 feet. The fold is superimposed on a gentle southward dip.

The deformation of the strata is post-depositional in origin. While undulations of depositional surfaces are common, all of the strata in the interval from 50 feet above to 50 feet below the facility level exhibit parallel undulations. This consistency in folding over a relatively large interval containing numerous depositional sequences suggests that the beds were deformed after deposition. The folding is a minor feature which does not adversely affect the suitability of the facility for waste storage.

6.4 PROPERTIES OF HOST ROCKS

As discussed in subsection 6.3.2, the underground facility horizon is composed of halite containing beds of argillaceous halite, anhydrite, polyhalite and thin clay seams. Laboratory tests were performed to determine the constitutive equations and material property constants for these host rocks (ref. 5-3). Subsections 6.4.1 and 6.4.2 present the properties of the host rocks based on laboratory and in situ data. In situ closure measurments were also used to "back calculate" the creep parameters for halite.

6.4.1 Laboratory Tests

Laboratory tests were performed on core samples from surface boreholes at the WIPP site prior to the initiation of underground excavation (ref. 5-3). Material property constants determined from the laboratory tests are presented in Tables 6-5 through 6-7. Table 6-5 shows the elastic constants for halite, argillaceous halite, anhydrite and polyhalite.

The failure criteria for both anhydrite and polyhalite were defined based on the results of the laboratory tests. One such criterion is Mohr-Coulomb, which defines failure in terms of friction and cohesion. Failure means that the material is unable to hold a deviatoric stress beyond a certain value. Once this value is reached, the material starts yielding. However, the Mohr-Coulomb criterion ignores the effect of intermediate principal stress on failure. In terms of principal stresses at failure,

$$(\sigma_3 - \sigma_1) = 2\Theta_o \cos\beta - (\sigma_3 + \sigma_1) \sin\beta \qquad (6\text{-}1)$$

where: Θ_o and β are Mohr-Coulomb parameters; and

σ_1 and σ_3 are principal stresses that are positive in tension.

Because the process of yield must be independent of the choice of axes, the failure criterion must be independent of the choice of axes and should be expressed in terms of stress invariants. The Drucker-Prager yield criterion is expressed as follows:

$$\sqrt{J_2'} = c - aJ_1 \qquad (6\text{-}2)$$

where: $\sqrt{J_2'}$ is the second stress invariant and is equal to $\bar{\sigma}/\sqrt{3}$; and

J_1 is the first stress invariant:

$$J_1 = \sigma_1 + \sigma_2 + \sigma_3 \qquad (6\text{-}3)$$

$$\bar{\sigma} = \frac{1}{\sqrt{2}} [(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]^{1/2} \qquad (6\text{-}4)$$

Table 6-5

ELASTIC CONSTANTS DETERMINED FROM LABORATORY TESTS

MATERIAL	E (ksf)	ν
Halite	647,450.	0.25
Argillaceous halite	647,450.	0.25
Anhydrite	1,568,500.	0.35
Polyhalite	1,155,000.	0.36

Note:

E = elastic modulus

ν = Poisson's ratio

Table 6-6

FAILURE CONSTANTS DETERMINED FROM LABORATORY TESTS

	ULTIMATE				YIELD			
MATERIAL	Θ_o (ksf)	β (^{o})	a	c (ksf)	Θ_o (ksf)	β (^{o})	a	c (ksf)
Anhydrite	627.	37.0	0.279	752.	564.	29.0	0.226	689.
Polyhalite	395.	51.0	0.395	414.	359.	46.5	0.361	403.

Table 6-7

CREEP CONSTANTS DETERMINED FROM LABORATORY TESTS

MATERIAL	PRIMARY CONSTANTS A	B	$\dot{\varepsilon}^*$ (sec^{-1})	SECONDARY CONSTANTS D ($ksf^{-4.9}$ sec^{-1})	n	Q (kcal/mole)
Halite	4.56	127	5.39×10^{-8}	4.96×10^{-13}	4.9	12.0
Standard Error				1.05×10^{-13}	0.27	0.65
Argillaceous Halite	4.56	127	5.39×10^{-8}	1.49×10^{-12}	4.9	12.0

For anhydrite, however, the ultimate strength decreases somewhat with the change in strain rate. That is, a 10 percent decrease occurs as the strain rate is decreased from 10^{-4} sec^{-1} to 10^{-6} sec^{-1}. For polyhalite, the ultimate strength is assumed to be independent of the strain rate. Table 6-6 shows the failure constants for anhydrite and polyhalite.

Table 6-7 shows the creep constants for halite and argillaceous halite. Although the data for most individual creep tests are internally consistent, steady-state creep rates obtained from different specimens tested under the nominally same conditions may scatter by an order of magnitude. Nevertheless, statistical analysis has resulted in a "best fit" to the data. Table 6-7 also shows the deviation of the secondary creep constants for halite. It was concluded that when such large deviations or uncertainty exist, calculations using mean values are apt to be meaningless and the design process requires considerable judgement (ref. 6-7).

Based on laboratory tests, the failure criterion of halite can be described using a failure function ϕ, such that when ϕ becomes positive, halite no longer supports any deviatoric stress. The function ϕ is assumed to be:

$$\phi = \bar{\varepsilon} - 0.023 - f(p) \qquad (6\text{-}5)$$

where: $\bar{\varepsilon}$ is the effective creep strain (see Appendix C) and the function f(p) is expressed as:

$$f(p) = \begin{cases} 0.132 & \text{for } p \geq 125.26 \text{ ksf} \\ p(a - bp) & \text{for } p \leq 125.26 \text{ ksf} \end{cases} \qquad (6\text{-}6)$$

where: p, the pressure in ksf, is expressed as

$$p = - \frac{\sigma_1 + \sigma_2 + \sigma_3}{3} \qquad (6\text{-}7)$$

and is positive in compression; and

a and b are equal to 2.122×10^{-3} ksf^{-1} and 8.487×10^{-6} ksf^{-2}, respectively (ref. 5-3).

Equation 6-5 indicates that if $\bar{\epsilon} \geq 0.023 + f(p)$ at any point in the halite, yielding will be initiated at that point. For p greater than 120 ksf, the failure effective strain is about 0.16.

Laboratory test results have also shown that a clay seam will be active for a frictional coefficient of 0.4, and that clay seam separation is unlikely unless the seam is very near the opening.

The average unit weight of the salt within the reference stratigraphy interval was determined to be 143.6 pounds per cubic foot (pcf) (ref. 5-3).

6.4.2 In Situ Data

In situ data was gathered from geomechanical instruments at various underground locations. The creep law shown by equation C.4-1 in Appendix C was used to fit the in situ data and to determine the creep parameters. The MARC General Purpose Finite Element Program (ref. 6-8) was used for the numerical computation based on the theory discussed in Appendix C. Table 6-8 shows the primary and secondary creep parameters determined from test room in situ data. Chapter 11 presents a more detailed discussion of the procedures used for computing these parameters.

Secondary creep parameters were also computed using in situ data from the C & SH shaft. The secondary creep parameters computed from horizontal deformations in the C & SH shaft and in the test rooms are reasonably close. The parameter based on test room wall-to-wall

Table 6-8

CREEP PARAMETERS DETERMINED FROM IN SITU DATA

	PRIMARY PARAMETERS		SECONDARY PARAMETER
MATERIAL	A	z (sec^{-1})	C ($ksf^{-4.9}$ sec^{-1})
Halite			
Roof-to-Floor	1.774	5.573×10^{-8}	2.588×10^{-21}
Wall-to-Wall	1.618	4.757×10^{-8}	1.361×10^{-21}

closure is 1.36×10^{-21} $ksf^{-4.9}$ sec^{-1} while the parameter based on extensometer measurements in the C & SH shaft is 1.30×10^{-21} $ksf^{-4.9}$ sec^{-1}.

6.5 SURFACE SUBSIDENCE MONITORING

The design criteria state that subsidence due to underground excavation shall not exceed 1 inch within a 500-foot radius of the waste shaft. The layout of the underground excavation and the extraction ratio requirements were established to comply with this criteria. Subsidence monuments have been installed on the ground surface above the shaft pillar area (Chapter 2, Figure 2-2). Additional subsidence monuments are scheduled to be installed above the storage area in mid-1986. These monuments will be used to determine surface subsidence during the 25-year facility operating life.

Because the storage area has not yet been excavated, actual subsidence cannot be measured. This subsidence will occur over the next 25 years. The calculations used for the reference design indicate that subsidence is not likely to exceed the criteria limit. Therefore, the reference design subsidence criteria is considered validated on a computational basis rather than on actual measurement data. A review of this conclusion may be required later when a history of actual subsidence is available.

CHAPTER 7
C & SH SHAFT

7.1 INTRODUCTION

This chapter presents the results of the design validation program for the C & SH shaft. Included are discussions of the design criteria, design bases and design configurations pertaining to the C & SH shaft. This is followed by information and data from the design validation process including the data collected, its analysis and evaluation, and predictions regarding future behavior of the shaft liner and key and the rock strata surrounding the shaft. Conclusions and recommendations are presented based on a comparison of the results of the design validation process with the reference design.

7.2 DESIGN

This section presents the design criteria and design bases used to develop the reference design for the C & SH shaft. The configuration of the shaft is discussed in Chapter 3, subsection 3.3.1.

7.2.1 Design Criteria

The Design Criteria document (ref. 2-8) contains the general concepts that were used as a guide for design of the WIPP underground openings. Table 2-1 summarizes those design criteria elements that are to be evaluated by the design validation process. The following discussion provides a summary of the elements that pertain to validation of the C & SH shaft reference design.

The design criteria specify that all shafts shall be designed for structural stability over an operating life of 25 years. The design shall also consider the requirements for shaft decommissioning and sealing. Shaft design shall prevent wall deformations which would interfere with shaft functions or affect the safety of operations within the shafts. Rock support shall be used as required to limit rock deformations and to prevent loosening and fallout of wall rock.

The time-dependent diametric closure of the shafts due to creep shall be considered in their design. The shafts shall be designed so that the minimum dimensions required for shaft functions are maintained throughout the operating life of the facility. Provisions for instruments to measure closure shall be included in the design.

Ground-water flow into the shafts shall be controlled so that no uncontrolled ground water reaches the facility level via the shafts. Ground-water pressures and inflows shall be measured throughout the construction period and operating life of the shaft.

Shaft design shall consider the requirements of decommissioning and backfilling upon termination of operations. The design shall accommodate the need to ultimately seal potential pathways between the storage facility and the biosphere.

The shaft liner shall be designed to help ensure that the shaft dimensions remain within the limits required for shaft functions, prevent ground-water flow into the shaft, protect wall rock from deterioration, and preclude the risk of rockfall from the shaft walls.

The shaft stations shall be designed to provide structurally stable excavations and pillars. Deformations of excavations and pillars shall remain within the limits required for structural functions, ventilation and safety. The excavation design shall maintain the minimum dimensions required for the operating life of the opening by accommodating closure. Closure rates used for design shall be confirmed or modified by instrument observations in the excavations. Rock bolts shall be used where necessary to provide support of the roof and walls.

7.2.2 Design Bases

The Design Basis, Exploratory Shaft (ref. 2-10) and the Design Basis, Exploratory Shaft Geomechanical Instrumentation (ref. 2-12) were the primary documents used as a basis for design of the C & SH shaft. These documents, described in Chapter 2, provided the detailed design

requirements for the C & SH shaft. Table 7-1 summarizes those design basis elements which are to be evaluated by the design validation process. The following discussion provides a summary of the major design bases for the C & SH shaft. Not all of these bases require evaluation as seen by comparing the discussion with Table 7-1.

The design bases specify that the C & SH shaft shall be designed to provide access for personnel and equipment to excavate and operate the underground facility and to provide a means by which the excavated salt can be transported to the surface. It shall also serve as the ventilation intake shaft.

The shaft liner shall be made of structural steel and have an inside diameter of 10 feet. The remainder of the shaft shall be unlined and have an approximate diameter of 11 feet 8 inches. The steel liner shall extend from 1 foot above the ground surface to the top of the salt formation at a depth of approximately 850 feet. The primary materials used to line the shaft shall be cement grout, steel casing, corrugated metal pipe, structural steel and reinforced concrete.

The liner shall protect against sloughing, fallout and deterioration of the rock formations and shall prevent water seepage into the shaft. It shall have a smooth inner surface to reduce air friction. The liner shall be designed for temporary installation loads and permanent loads. The permanent load shall consist of a hydrostatic lateral pressure starting 250 feet below the ground surface and extending to approximately 837 feet below the surface. Rock pressure shall not be used as a factor in the design analysis. Installation loads to be considered shall be the compressive and tensile forces resulting from lateral pressure due to unequal heights of drilling fluid during the various stages of installation.

During shaft drilling, ground-water flow into the shaft shall be determined. If the amount of ground water entering the shaft is determined to be unacceptable by the DOE Contracting Officer, approved

Table 7-1

VALIDATION ELEMENTS OF C & SH SHAFT DESIGN BASES

(1)	Shaft Liner
	a. Hydrostatic pressure is considered to start 250 feet below the ground surface and extend to the top of the key.
	b. Water shall be prevented from flowing down the unlined shaft from behind the liner.
(2)	Shaft Key
	a. Key shall be designed to resist the lateral pressure from the salt. (Assumed to be 75 percent of the overburden pressure.)
	b. Key shall be designed to resist the hydrostatic pressure from above the salt.
(3)	Unlined Section
	Provide 11-foot 8-inch diameter to allow for future salt creep deformation.

corrective action shall be taken to control the water inflow. The basis for determining if the amount of ground water flowing into the shaft is unacceptable shall be if the inflow exceeds an amount which can be tolerated without appreciably altering the drilling fluid characteristics as approved by the DOE Contracting Officer.

The shaft key shall be constructed using reinforced concrete and will serve as the transition element between the lined and the unlined sections of the shaft. It shall retain the rock formation and shall be provided with chemical water seals and a water collection ring with drains to prevent water from flowing from behind the liner down the unlined shaft. The key shall be designed to resist lateral pressure generated by salt creep, rock and soil overburden, and by hydrostatic pressure from above the salt. The design lateral pressure was selected as 75 percent of the overburden pressure based on the configuration of mine shafts in the vicinity of the WIPP. These shafts generally have a concrete liner that is thinner and that extends to a greater depth than the shaft key at the WIPP. Most of these shafts are at least 25 years old and show no significant deterioration or structural instability.

No liner or wire mesh is planned for the section of the shaft in the Salado formation. However, if field conditions require, rock bolts and wire mesh may be installed in zones of fractured salt.

The shaft station excavation shall be the minimum required to meet the operational and safety requirements in the shaft pillar area of the waste storage level. Supports of underground workings shall comply with Federal and New Mexico codes. The use of rock bolts and wire mesh in specific areas shall be determined by excavation conditions and code requirements. The roof, walls and floor shall be checked periodically for loose salt in accordance with applicable codes.

The bottom of the shaft shall extend below the facility level to accommodate the salt handling equipment and a sump to collect water that might enter the shaft. Should the stratigraphy of the facility

level be unsuitable for waste storage, the shaft bottom may be lowered to reach a more suitable stratigraphy.

Geomechanical instruments shall be provided to measure radial convergence (closure) of the shaft, water pressure behind the liner, salt creep, forces on the concrete key, and the variation of load on rock bolts. The type of instruments installed shall be strain gauges, pressure cells, piezometers, stressmeters, extensometers, load cells and radial convergence points.

The shaft liner, key, unlined section and furnishings shall be inspected at approximately 1 month intervals, or lesser intervals as required, to detect cracking, corrosion, deterioration and water intrusion.

7.3 DESIGN VALIDATION PROCESS

The design validation process for the C & SH shaft consists of data collection, analysis and evaluation, and predictions of future behavior. The following discussions of each of these activities have been divided into four sections: the lined section of the shaft; the shaft key; the unlined section; and the shaft station. This division is based on the different in situ and design conditions in each of these areas.

7.3.1 Data Collection

Data collection in the C & SH shaft has consisted of geologic mapping, visual inspections and geomechanical instrument measurements. The results of shaft mapping have been discussed in Chapter 6. Field observations and the geomechanical instrumentation program are discussed in the following subsections.

7.3.1.1 Lined Section

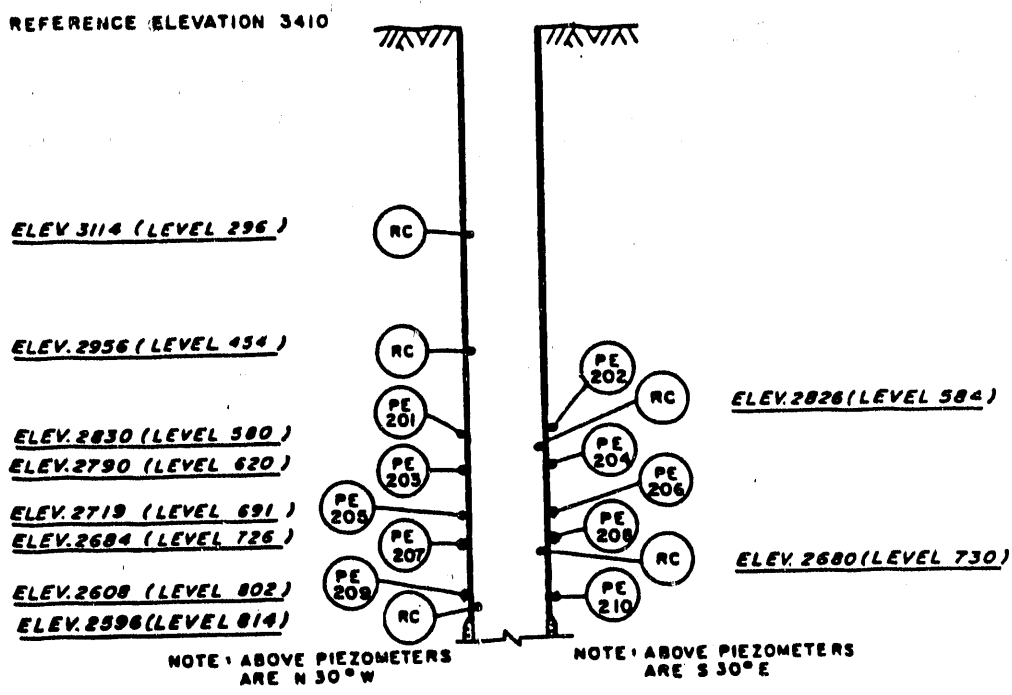
Field Observations. The C & SH shaft has been inspected on a regular basis since its construction. During the facility level construction

phase, the mining contractors conducted weekly shaft inspections for safety and shaft maintenance. These weekly inspections are being continued by the facility operator.

Site geologists inspect the shaft at approximately 6-month intervals. These inspections provide geotechnical evaluations of the condition of the shaft, and of instrument conditions and their performance. Shaft inspections were performed on the following dates: August 29, October 1, October 5, October 22, November 19 and December 3, 1983; June 2, June 21, October 13 and November 12, 1984; and April 9 and December 9, 1985. The results of these inspections are presented in the GFDRs.

Geomechanical Instrumentation. Nine sets of radial convergence points were installed in the C & SH shaft between July 7 and 17, 1982. Two additional sets were installed on October 8, 1982. Five of these 11 sets were installed in the lined section of the shaft (Figure 7-1). Plots of the convergence point data from the lined section are presented in Appendix J, Figures J-205 through J-209.

Ten piezometers were installed in the lined section of the C & SH shaft above the shaft key between July 10 and 17, 1982 (Figure 7-1). Two piezometers each are at elevations of 2830, 2790, 2719, 2684 and 2608 feet. All of these piezometers are in the Rustler formation. The piezometers at elevations of 2790 and 2684 feet are in the water-bearing dolomite members, the Magenta and Culebra, respectively. Graphic plots of piezometer data are presented in Appendix J, Figures J-34 through J-44. The piezometers are dual-component instruments containing a vibrating-wire gauge and a pneumatic gauge. The vibrating-wire gauge is the principal instrument used to measure water pressure. The pneumatic gauge is used for initial calibration and periodic performance checks on the vibrating-wire units. The vibrating-wire piezometers were connected to the datalogger on October 30, 1982. The pneumatic units can only be read manually at the instrument location; however, most of the pneumatic units are no longer functioning.



LEGEND

PE PIEZOMETER

RC RADIAL CONVERGENCE POINTS

GE EXTENSOMETER

NOT TO SCALE

NOTES

1. RC'S AT EACH LEVEL CONSIST OF FOUR POINTS.
2. THE TERM "LEVEL" IS AN APPROXIMATE DEPTH IN FEET FROM THE TOP OF THE SHAFT BUNTON AT ELEVATION OF 3410.0 FT MSL. ELEVATIONS ARE FROM CEMENTATION WEST, INC., 1983, WIPP SHAFT AND STATION SURVEY.

Figure 7-1

C & SH SHAFT LINER INSTRUMENTATION

The shaft instrumentation has had a history of damage. Convergence points and especially piezometers are susceptible to damage from falling objects and construction activities. Damage in the lined section of the shaft has generally consisted of sheared data cables, sheared or bent convergence points, broken junction boxes and water damage.

Water intrusion has been a major problem with most of the shaft instruments and control systems. One water source has been the holes drilled into the steel liner for piezometer installation. The bushing in the liner through which the piezometer was installed did not have tapered threads, making it difficult to seal the hole in the liner. Leakage through these holes has generally occurred at some time in their history. It was especially difficult to effect a seal when a piezometer was reinstalled after being repaired due to other damage.

Water trickling down the liner from around these bushings has sometimes entered damaged fiberglass junction boxes and terminal boxes through cracks. Water has also seeped into the conduit connecting piezometers with the nearest junction box. This water has corroded terminal blocks and seeped down cables connecting lower terminal boxes.

A second water source has been rainfall. During periods of heavy rain, water runs down the shaft along the surface of the liner. This water can enter terminal boxes broken by impact or construction activities. Once in the boxes, it causes corrosion and cable damage.

A great deal of effort has been exerted correcting these problems. Shields were placed over boxes, cables were replaced and rerouted, and piezometers were repaired and sealed as well as possible. These measures improved performance somewhat, but problems still exist. The data acquired from the instruments is considered valid, but must be interpreted in light of the various interruptions in data monitoring. The specific details of instrument damage are updated in every GFDR, particularly in the tables of operating histories.

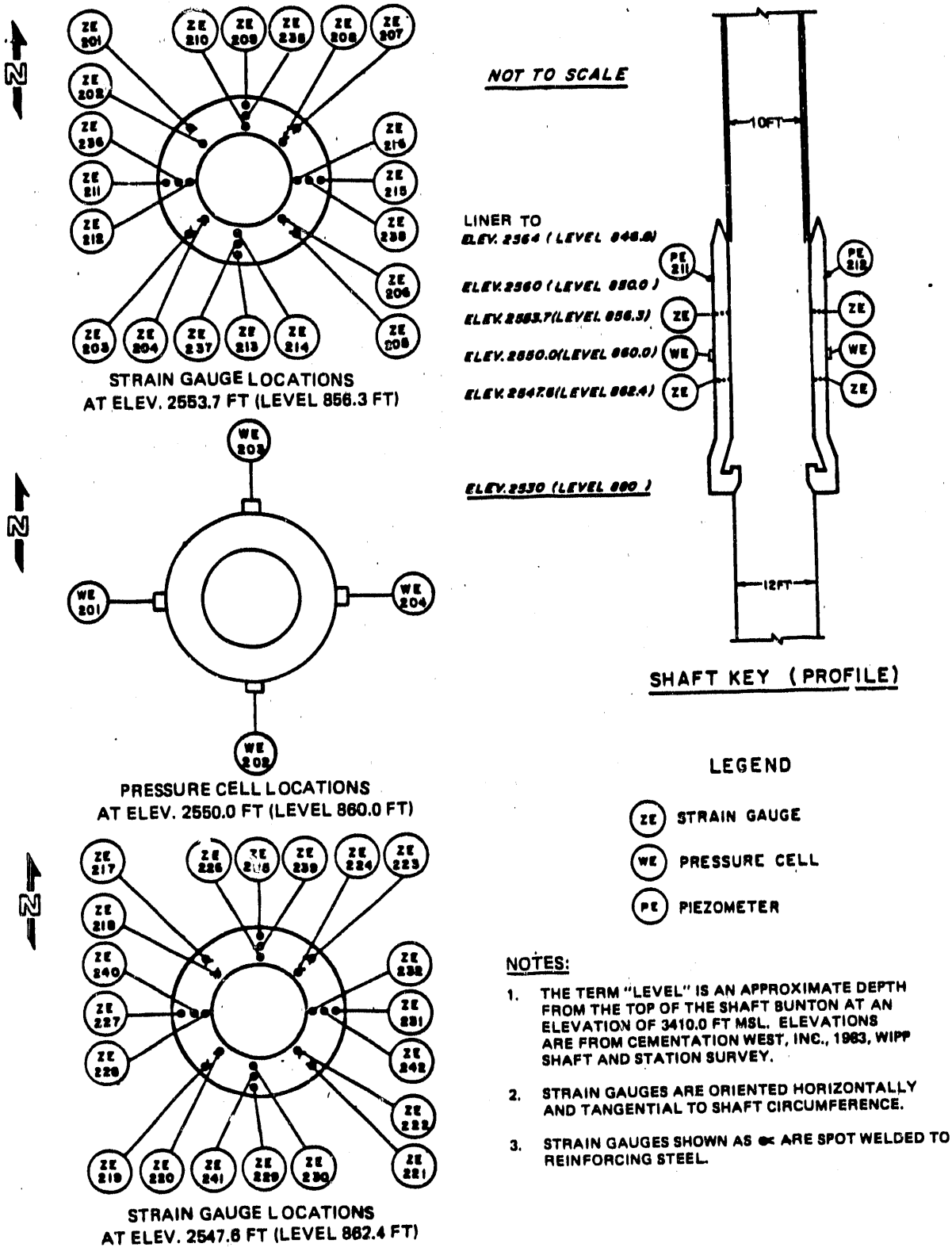
7.3.1.2 Shaft Key

Field Observations. The shaft inspections conducted on October 1 and November 19, 1983, June 2 and October 13, 1984, and April 3 and December 9, 1985, paid particular attention to the shaft key. The design of the key provides a means to determine if any water from the water-bearing zones in the Rustler formation is flowing behind the key. This situation, if it existed, could cause dissolution of the salt around the key resulting in eventual structural instability.

During inspection of the shaft key, the condition of four telltale drains that connect to a French drain behind the key is observed. Any moisture in the drains is noted. Similarly, other capped pipes (those for possible future injection of grout and those originally used for chemical seal injection) are checked for accumulated water. The interface between the salt and the bottom of the key receives particular attention.

The latest geotechnical inspection of the shaft key was made on December 9, 1985. The four telltale drains at the key were inspected and cleaned. Only the hole on the northwest side of the shaft was weeping, resulting in salt accumulation on the terminal box below. After chipping off this salt, a small amount of liquified chemical seal material began oozing out of the telltale. Inspection of the bottom of the key showed no evidence of seepage below the concrete.

Geomechanical Instrumentation. Twenty-four embedment strain gauges, 16 spot-welded strain gauges, and 4 pressure cells were installed in the C & SH shaft key from April 11 to 17, 1982. Two piezometers were installed in the shaft key on July 10, 1982. The locations of these instruments are shown on Figure 7-2. All instruments were read manually until they were connected to the datalogger system on October 30, 1982. Appendix J contains plots of the data from these instruments. Piezometer data are presented on Figures J-44 and J-45. Figures J-54 through J-57 present pressure cell data. The strain gauge data are presented on Figures J-58 through J-97.



NOTES:

1. THE TERM "LEVEL" IS AN APPROXIMATE DEPTH FROM THE TOP OF THE SHAFT BUNTON AT AN ELEVATION OF 3410.0 FT MSL. ELEVATIONS ARE FROM CEMENTATION WEST, INC., 1983, WIPP SHAFT AND STATION SURVEY.
2. STRAIN GAUGES ARE ORIENTED HORIZONTALLY AND TANGENTIAL TO SHAFT CIRCUMFERENCE.
3. STRAIN GAUGES SHOWN AS ⊲ ARE SPOT WELDED TO REINFORCING STEEL.

Figure 7-2

C & SH SHAFT KEY
INSTRUMENTATION

The instruments for monitoring the shaft key, and especially their electrical boxes and cables, have had the same performance problems as the piezometers and convergence points in the lined section above. The two key piezometers have been damaged and repaired repeatedly.

The major problem in the key has been water damage inside the various electrical boxes. The worst damage was in termination cabinet LTC-1. Water seeping down inside cables connected to water-damaged boxes in the lined section of the shaft corroded the terminals in the LTC. LTC-1 links the piezometers, strain gauges and pressure cells to the surface datalogger. Several attempts were made to repair the LTC components. The components were permanently removed in October 1984 in order to avoid further damage. The shaft instrumentation system is scheduled for an overhaul during a future construction contract. Meanwhile, all LTC-1-controlled instruments are read manually during shaft inspections.

The terminal boxes for the pressure cells and strain gauges have also been damaged. Initial damage was to the fiberglass boxes and data cables as they were struck by falling objects and construction materials traveling on the shaft conveyance. Subsequent damage was by water seeping into the boxes. The boxes and cables have been repaired numerous times.

Detailed accounts of instrument damage are presented in the GFDRs, particularly in the tables of operating histories. The GFDRs also discuss data collection, data plots and interpretative problems with the C & SH shaft key instruments.

7.3.1.3 Unlined Section

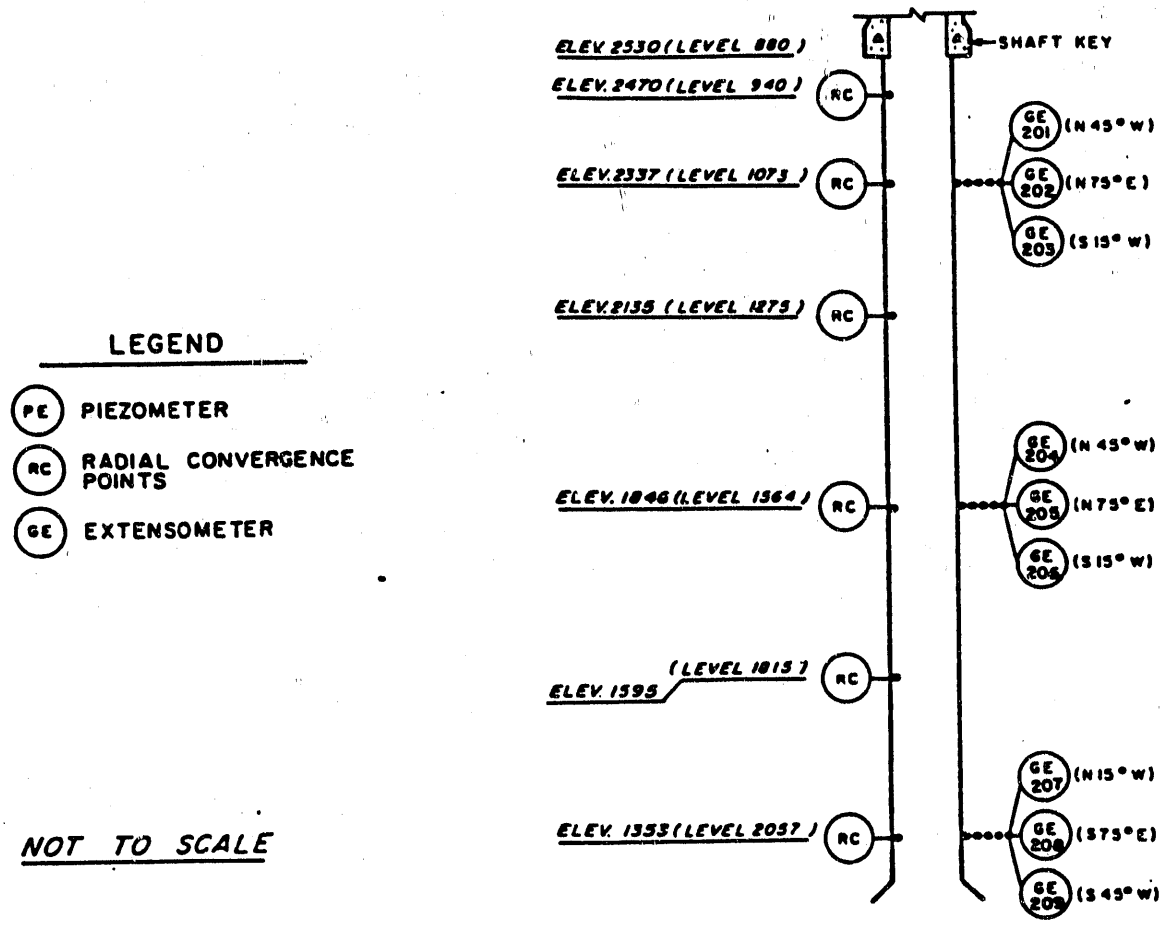
Field Observations. Shaft inspections include observations of the unlined section of the C & SH shaft. This section of the shaft consists of exposed salt forming a smooth wall. The inspections consist primarily of determining if any spalling or fracturing of the salt is occurring.

The unlined section was inspected to a depth of 2,057 feet (elev. 1353 feet) on December 9, 1985. One near-vertical fracture was observed on the west side of the shaft between a depth of 1,021 feet and 1,043 feet (elev. 2389 feet and 2367 feet). It ranged from closed to less than 1/4-inch wide at the wall surface and extended about 10 feet in length. It did not appear on the east side of the shaft. Previous shaft mapping showed the presence of halite-filled vertical fractures in anhydrite from a depth of approximately 1,023 feet to 1,038 feet (elev. 2387 feet to 2372 feet). The fracture observed appears to be one of those previously mapped. Salt blisters and precipitate were noted in various areas commonly associated with clay layers. The most notable area was a 4-foot zone around the entire shaft circumference from a depth of approximately 1,038 feet to 1,042 feet (elev. 2372 feet to 2368 feet).

Geomechanical Instrumentation. Nine borehole extensometers were installed in the unlined section of the C & SH shaft between July 6 and 8, 1982. These extensometers are arranged in three-instrument arrays at elevations of 2337 feet, 1846 feet and 1353 feet (Figure 7-3). Readings were taken manually until the extensometers were connected to the datalogger system in October 1982.

The extensometers are the multiple-point, sonic-probe type consisting of four anchors. The anchors for each extensometer were set at depths of 4, 9, 18 and 36 feet. The collar of the extensometers was recessed 1 foot into the salt. Data plots for the extensometers are presented in Appendix J, Figures J-116 through J-124.

The extensometers have not been damaged as much as the other instruments in the shaft. Their operating histories rarely show any interruption in the data. This lack of damage is a result of several factors. The diameter of the unlined shaft is 2 feet greater than that of the key or lined section. The instruments are recessed and therefore not susceptible to damage from falling objects. The extensometers are connected to LTC-2 and LTC-3, which are not directly



NOTES

1. RC'S AT EACH LEVEL CONSIST OF FOUR POINTS.
2. THE TERM "LEVEL" IS AN APPROXIMATE DEPTH IN FEET FROM THE TOP OF THE SHAFT BUNTON AT ELEVATION OF 3410.0 FT MSL. ELEVATIONS ARE FROM CEMENTATION WEST, INC., 1983, WIPP SHAFT AND STATION SURVEY.

Figure 7-3

C & SH SHAFT UNLINED SECTION INSTRUMENTATION

linked to LTC-1 and the piezometers. Thus, water damage has not been a problem.

Six sets of radial convergence points are located in the unlined section of the shaft. These points have a history of damage and replacement similar to that of the other convergence points. This history is discussed in the GFDRs. Plots of the convergence point data from the unlined section are presented in Appendix J, Figures J-210 through J-214. Only five plots are presented since damage to the set of points at elevation 1595 feet prevented the obtaining of reliable readings.

7.3.1.4 Shaft Station

Field Observations. Site geologists monitor the deformational behavior of the C & SH shaft station on a regular basis. Particular attention is given to four aspects of movement or failure: roof and wall spalling; fracturing at pillar corners; roof displacements and separations; and floor displacements, separations and fracturing. The observations are recorded at least every 3 months and have been published in each GFDR since the February 1984 issue.

A description of the C & SH shaft station excavation and roof support methods were presented in Chapter 3. The failure of resin-anchored rock bolts installed initially in the shaft station roof has been attributed to a combination of the following factors:

(1) the resin firmly held the bolt shank in place and salt creep caused failure at the first weak point;

(2) improper bolt installation resulted in damage to the threaded section of the bolt (improper torque and lack of beveled or spherical washers); and

(3) contributing factors such as corrosion and hydrogen embrittlement.

Rock bolts installed to replace the failed bolts, and subsequent bolt installations, used mechanical anchors. As the load on these bolts increases due to salt creep, the anchor yields by slipping in the hole. Although this slipping is not desirable for the roof support of underground openings in hard rock, it provides more control than rigid anchors that do not yield but instead produce sudden bolt failure as a result of the stress created by creeping salt. The slipping reduces the load on the bolt, thus reducing the potential for bolt failure, but allows continued roof support and prevents sudden roof falls. Each mechanical-anchor rock bolt supports a load that is less than its capacity, but the aggregate support provided by all of the rock bolts in a pattern is more than adequate for positive ground control. The experience at WIPP shows that the mechanical-anchor rock bolts perform well in creeping salt if periodically inspected and maintained.

The station roof and walls have exhibited continual slabbing and spalling which has required periodic scaling. Wire mesh has been installed over the entire station roof to contain any small, loose salt fragments.

Vertical fractures have developed in the pillar corners at the S90 crosscut. The condition of these fractures has been monitored and the results reported on a regular basis in the GFDRs. A discussion of fracturing at pillar corners is presented in Chapters 10 and 11.

Displacements, separations and fractures have been detected in boreholes drilled into the station roof and minor separations have been detected in some holes drilled into the station floor. Separations and fracturing at clay G and in the underlying halite were detected shortly after the initial station excavation. Horizontal displacements have been observed in various boreholes during the past 2 years.

In May and June 1986, 20 boreholes were drilled in four arrays in the shaft station to further investigate the extent of separations and fracturing in the roof and floor. This drilling was conducted as part

of a program to characterize excavation effects in the salt surrounding the openings and particularly in MB-139. This program is discussed more fully in Chapters 10 and 11.

The new boreholes were inspected for the existence of separations and fractures. Existing holes were inspected for horizontal displacements. The probe used for this inspection consisted of an aluminum rod with a 1/16-inch thick nail attached perpendicular to one end. When applying moderate pressure, the nail snags on the borehole wall if a separation, fracture, or clay seam is encountered. The separation is considered to be less than 1/16 inch wide if the nail catches on, but does not penetrate the hole wall. If the separation at the wall surface is at least the nail width (approximately 1/16 inch) there will be a slight penetration. If the separation is larger, the nail penetrates its entire 1/2-inch length into the wall. When the probe catches on the hole wall, the feature is probed on all sides of the hole. This ensures that it is a continuous feature and not a clay pocket or an imperfection caused by the drilling.

Fracture zones, anhydrite beds, or clay seams were sometimes identified by picking out pieces of the material with the probe nail. An estimate of their vertical dimension was made by moving the probe rod up and down within the limits of the feature. Occassionally a slight penetration occurred at the clay seams due to a very small separation or penetration into the softer clay.

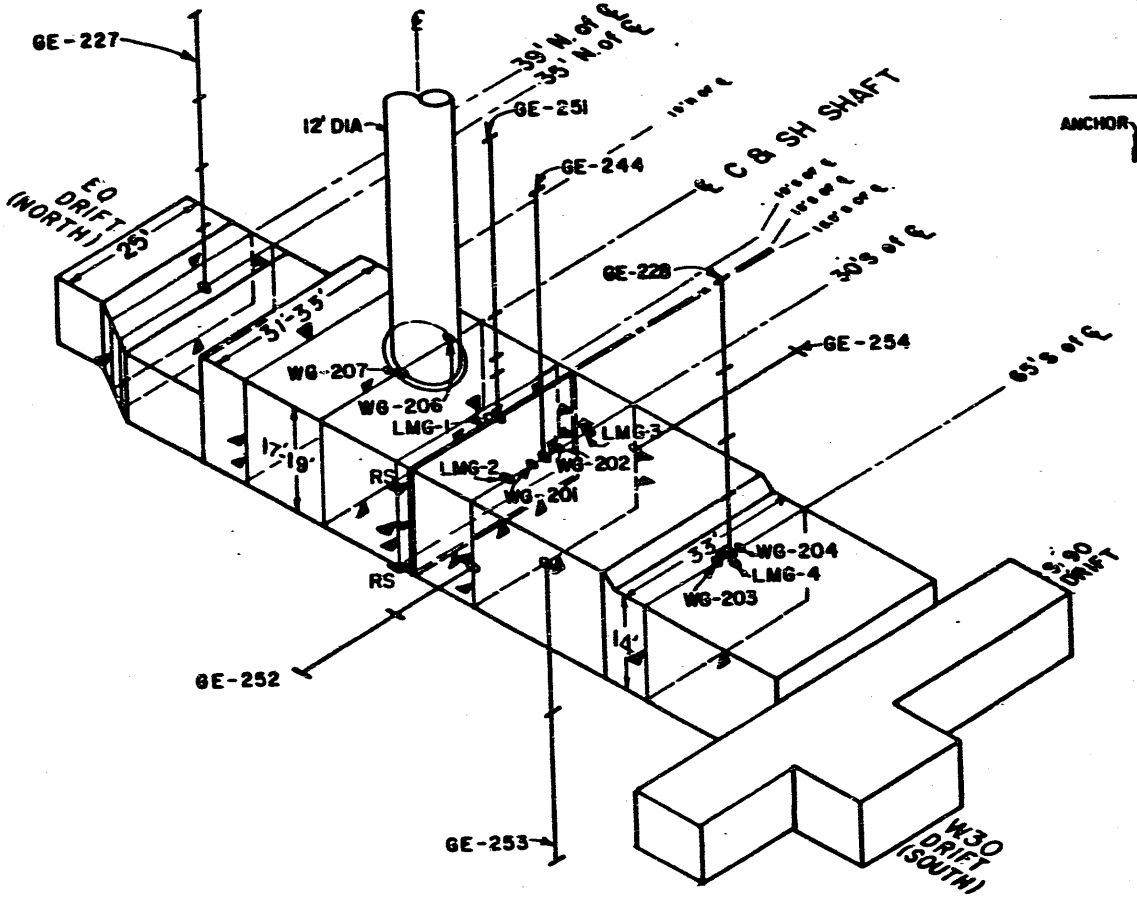
In the array of holes drilled north of the shaft, no separations or fractures were detected in the roof. In the two arrays drilled south of the shaft, multiple separations and fractures, ranging from approximately 1/16 inch to 4 inches wide, were found in most of the roof holes within the halite below clay G. Many of the fractures occur within 3 feet of the roof. Some separation and fracturing appears to be associated with clay G based on data from other holes in the station area and from the central roof holes in the two arrays, but no significant occurrence appears to have developed in the holes closest

to the station walls. A separation, less than 1/16 inch wide was detected in only one roof hole beyond a depth of 4 feet.

Only a few separations or fractures, less than 1/8 inch wide, were detected in the central floor hole of the hole array drilled north of the shaft. Some separations and fractures, less than 1/16 inch to 1 inch wide, were detected in the two floor hole arrays drilled south of the shaft. These occurrences were in MB-139 and the overlying halite. Essentially no separation was encountered at clay E at the base of MB-139. Holes drilled around the edge of the electrical substation concrete base slab foundation to investigate a potential source of its tilting encountered only small scattered separations. The total accumulated vertical separation is estimated to be less than 1/2 inch.

Geomechanical Instrumentation. As in other areas of the underground facility, a suite of geomechanical instruments was installed in the C & SH shaft station (Figure 7-4). The original instrumentation design consisted of 6 rock bolt load cells, 3 borehole extensometers, and 2 sets of convergence points. These instruments were installed between June 30 and November 16, 1982. Subsequently, 4 extensometers, 4 lateral movement gauges, 3 convergence point sets, and 1 set of wall shortening points were installed between January 8 and February 3, 1983. The purpose of this second suite of instruments was primarily to monitor any vertical or lateral movement of the immediate roof in the C & SH shaft station. The immediate station roof consists of a "beam" of salt resulting from separation along the thin clay seam beneath anhydrite "a". South of the shaft this beam is about 3 to 4 1/2 feet thick, while north of the shaft it is about 7 feet thick. Chapter 3, Section 3.2, presents a brief discussion of the underground facility horizon selection and the resulting location of the station with respect to overlying and underlying clay seams and anhydrite layers.

The data plots for the C & SH shaft station are presented in Appendix J. Figures J-146, J-147, J-163, and J-170 through J-173 show



LEGEND

ANCHOR COLLAR

- GE EXTENSOMETER
- RC CONVERGENCE POINT
- RS WALL SHORTENING POINT
- WG ROCKBOLT LOAD CELL
- LMG LATERAL MOVEMENT GAUGE

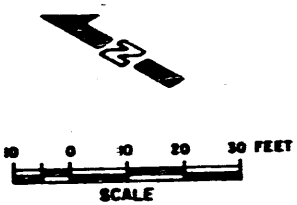


Figure 7-4

C & SH SHAFT STATION INSTRUMENTATION

the extensometer data. Convergence point data are presented on Figures J-188 through J-194 and rock bolt load cell data are shown on Figures J-192 through J-197.

Four lateral movement gauges were installed in the roof of the station. These were intended to measure lateral displacement of the salt above anhydrite "b". However, the lateral movement measurements were distorted by the vertical movement of the roof and a meaningful trend or pattern in the relative direction of horizontal movement did not develop. Therefore, reading of the lateral movement gauges was discontinued and the data are not presented in this report.

7.3.2 Analysis and Evaluation

The data collected from the C & SH shaft have been reviewed and subjected to statistical analysis, closed form solution and model simulation techniques for evaluation against the reference design parameters. The following subsections present discussions of these analyses and evaluations for the four sections of the shaft.

7.3.2.1 Lined Section

Observed Conditions. Observations of the steel liner during shaft inspections have detected no signs of deterioration. There is no indication of any liner instability due to shaft deformation. Water seepage has occurred only through the previously discussed piezometer bushings.

Structural Analysis. As a result of increasing hydrostatic pressure with depth, the thickness of the C & SH shaft steel liner and the size and spacing of its stiffener rings vary accordingly. The stiffener rings are 3-inch thick steel rings welded to the outer face of the liner. The thickness of the liner and the width and spacing of the stiffener rings for various depths are:

Depth (feet)	Plate Thickness (inches)	Stiffener Width (inches)	Stiffener Spacing (feet)
0.00 to 182.45	5/8	7-1/2	10
182.45 to 362.45	1	12	10
362.45 to 542.45	1	11	5
542.45 to 642.45	1-1/4	10-1/2	5
642.45 to 742.45	1-3/8	9	4
742.45 to 842.45	1-1/2	10-1/2	4

A structural analysis was performed for the shaft liner based on these depths and dimensions. The liner and stiffeners were made of A-441 steel fabricated into 20-foot sections by full penetration bevel welds between the liner sections and by fillet welds between the liner and the stiffeners. Radiographic acceptance examinations were performed on all welds in accordance with the American Welding Society (AWS) (ref. 7-1) and the ASME Boiler and Pressure Vessel Code, Sections VIII and IX (ref. 7-2).

A computer program was used to design the steel liner against elastic buckling between the stiffeners, elastic buckling of the combined liner and stiffener, and the yielding of the liner. This program was developed jointly by Fenix & Scisson and Southwest Research Institute and was based on Theory of Plates and Shells by S. P. Timoshenko and S. Woinowsky-Krieger (ref. 7-3).

The computational results of the analysis of the liner, based on the depths and dimensions presented above, show that the external pressure capacities and corresponding closure limits (maximum diametric changes) at the midpoint of a stiffener and at the midpoint between stiffeners are:

Depth (feet)	Pressure Capacity (psi)	Closure Limit at Stiffener (inches)	Closure Limit Between Stiffeners (inches)
0.00 to 182.45	139	0.007	0.054
182.45 to 362.45	281	0.010	0.069
362.45 to 542.45	434	0.019	0.108
542.45 to 642.45	518	0.030	0.104
642.45 to 742.45	595	0.043	0.112
742.45 to 842.45	684	0.043	0.118

In situ hydrostatic pressures determined from piezometer readings at elevations of 2830, 2790, 2719, 2684 and 2608 feet (Figure 7-1) were compared with design pressures and the pressure capacity of the liner as discussed below.

Measured Water Pressure. Piezometers are used to monitor the hydrostatic pressure exerted on the steel liner by water from the two water-bearing zones in the Rustler formation. Selected water pressure measurements are presented in Table 7-2. Because of the piezometer history of damage and leakage, the data must be used with caution. However, as expected, the data show a general trend of increasing pressure (Figure 7-5). The exceptions, 37X-PE-00211 and 37X-PE-00212, are discussed in the next subsection.

As indicated in Table 7-1, the design basis hydrostatic pressure is assumed to begin at a depth of 250 feet below ground level. This corresponds to the potentiometric surface of the water-bearing members in the Rustler formation. The hydrostatic design pressure gradient of the liner in the Rustler formation is shown on Figure 7-5. Piezometer reading data from June 1986 indicate pressures significantly less than the design hydrostatic pressure. This can be explained by a combination of the following conditions:

(1) drawdown of the potentiometric surface in the vicinity of the shafts;

Table 7-2

C & SH SHAFT LINER AND KEY
SUMMARY OF MEASURED WATER PRESSURES (psi)

Date of Reading	PIEZOMETER NO. 37X-PE-00											
	201	202	203	204	205	206	207	208	209	210	211	212
	Elev. 2830		Elev. 2790		Elev. 2719		Elev. 2684		Elev. 2608		Elev. 2560	
Pressure capacity of liner	518		518		595		595		684			
Jun. 20,'83	112	111	108	108	86	86	110	104	140	142	6	12
Dec. 3,'83	96	96	100	101	84	84	98	100	137	139	13	9
Jun. 5,'84	90	93	-	-	79	-	90	96	127	129	5	1
Dec. 27,'84	93	95	119	119	102	100	105	116	-	152	3	0
Feb. 8,'85	98	100	131	130	109	105	107	117	-	157	10	7
May 21,'85	90	93	84	81	61	44*	105	-**	146*	137*	5	6
Jun. 29,'85	89	92	91	-**	97	-**	104	-**	-**	-**	4	7
Dec. 9,'85	90	91	108	104	100	-**	108	-**	-**	-**	-1	-1
Mar. 24, '86	101	102	-	134	107	-**	104	-**	-**	-**	-2	-4
Jun. 02, '86	89	91	104	-	100	-**	108	-**	-**	-**	-	-2

NOTE: All piezometers have leaked or suffered damage at one time or another.

* Piezometer leaking.

** Piezometer removed for repair.

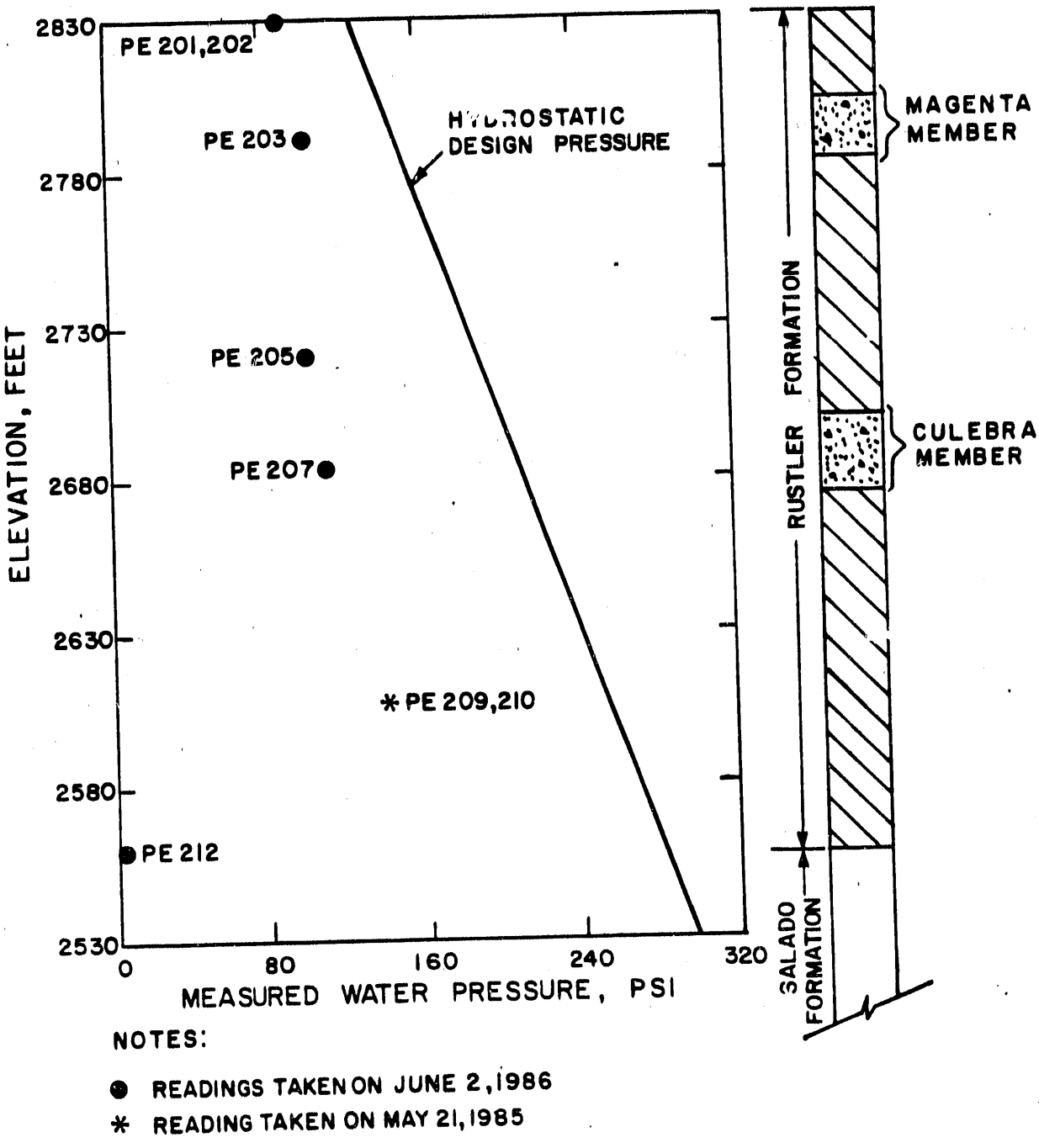


Figure 7-5

C & SH SHAFT LINER AND KEY
WATER PRESSURE DISTRIBUTION

(2) incomplete hydraulic continuity behind the liner;

(3) water leakage through the piezometer bushings and telltales; and

(4) partial plugging of the piezometer filters.

Lowering of the potentiometric surface is primarily the result of water flowing into the unlined SPDV ventilation shaft and later through cracks in both the waste and exhaust shaft liners. Hydrologic testing at the site by SNL has also contributed to lowering the potentiometric surface.

The annular space between the steel liner and the rock was filled with grout during liner installation (Chapter 3). In addition to supporting the liner, the grout was intended to help prevent water in the water-bearing zones from contacting the salt in the key area. The variations in water pressure at the different piezometer elevations, and especially the lack of a linear increase with depth, suggests that this objective has been at least partially achieved. The absence of hydraulic continuity along the rock/liner interface could prevent the water at individual piezometer elevations from achieving the anticipated pressures.

Most of the piezometers have developed leaks at some time in their history. This leakage would result in a drop in water pressure at the affected piezometer. The piezometer would then measure a water pressure that is lower than anticipated. The influence of the leaks on piezometer readings is considered to be minor because, as individual piezometers are repaired or bushings are sealed, the data plots do not show a significant change from the normal variation within the data.

The fourth cause of variation in the pressure readings could be a result of partially-plugged filters. Each piezometer contains a stainless steel, porous stone filter. It has been noted during their

repair that some filters are partially covered with salt deposits and corrosion. It is not clear how much of an effect this may have on the piezometer readings. It is possible that there is no effect if the corrosion and salt deposition occurred after the filter was exposed to the atmosphere during piezometer removal.

Closure. Closure data show the in situ diametric changes in the liner based on radial convergence point measurements at elevations of 3114, 2956, 2826 and 2680 feet (Figure 7-1). These data are considered a lower bound because the in situ readings represent only relative closures since the first readings were taken 329 days after excavation. In addition to the effect of hydrostatic pressure, the closure data are also affected by variables such as temperature and lithostatic pressure.

Radial convergence point measurements in the lined section of the shaft indicate that the maximum diametric closure is less than 0.10 inch. Since the shaft is used for ventilation purposes and is open to the atmosphere, changes in ambient temperature from around 0°F in the winter to over 100°F in the summer may affect the diametric closure by approximately 0.075 inch. Consequently, only closure data recorded at approximately the same temperature should be used for analysis.

7.3.2.2 Shaft Key

Observed Conditions. Shaft key inspections indicate that the key is stable. Certain observations, however, dictate that continuous monitoring of the key will be required. The telltale drains, connected to a French drain behind the key, drip intermittently. Several other capped pipes typically produce small amounts of water when opened after being closed for several weeks.

No water has been observed bypassing the lower chemical water seal. During the June 2, 1984, inspection, liquified chemical seal material was observed in two chemical seal injection pipes. It is likely that chemical seal material is migrating behind the key since small amounts

were observed dripping from the northwest telltale drain and from piezometer 37X-PE-00211. These fluid observations do not present any immediate cause for concern. However, the key should be monitored on a regular basis and appropriate actions taken if required to mitigate any significant increase in fluid discharge.

Inspection of the bottom of the key has revealed no evidence of seepage below the concrete. Some salt stalactites have been observed hanging from the concrete but these originate from brine dripping from the leaking piezometers or telltale drains above.

Model Simulation. The long-term impact of C & SH shaft salt creep on the concrete key was evaluated by a nonlinear computational analysis using the finite element method (ref. 7-4). The objective of the analysis was to determine the structural adequacy of the shaft key based on the appropriate ACI Codes (ref. 7-5). Site stratigraphy was considered in the analysis. The creep behavior of the salt was incorporated into the material properties used in the finite element model. The shrinkage of the concrete during initial curing was also simulated in the computation (ref. 7-6).

From the shaft geologic mapping, it was determined that the stratigraphy in the shaft key area consists of horizontal layers of halite, argillaceous halite, anhydrite and siltstone, with clay seams between some of these layers (Figure 7-6). This stratigraphy was used as the basis in modeling.

The properties for the host rock are based on laboratory test results (refs. 5-3 and 7-7) as described in Appendix C. Because the analysis was performed early in design validation, before the methods of computing primary creep and using in situ material properties were developed (ref. 5-1), the analysis included only the secondary creep of salt based on laboratory test data.

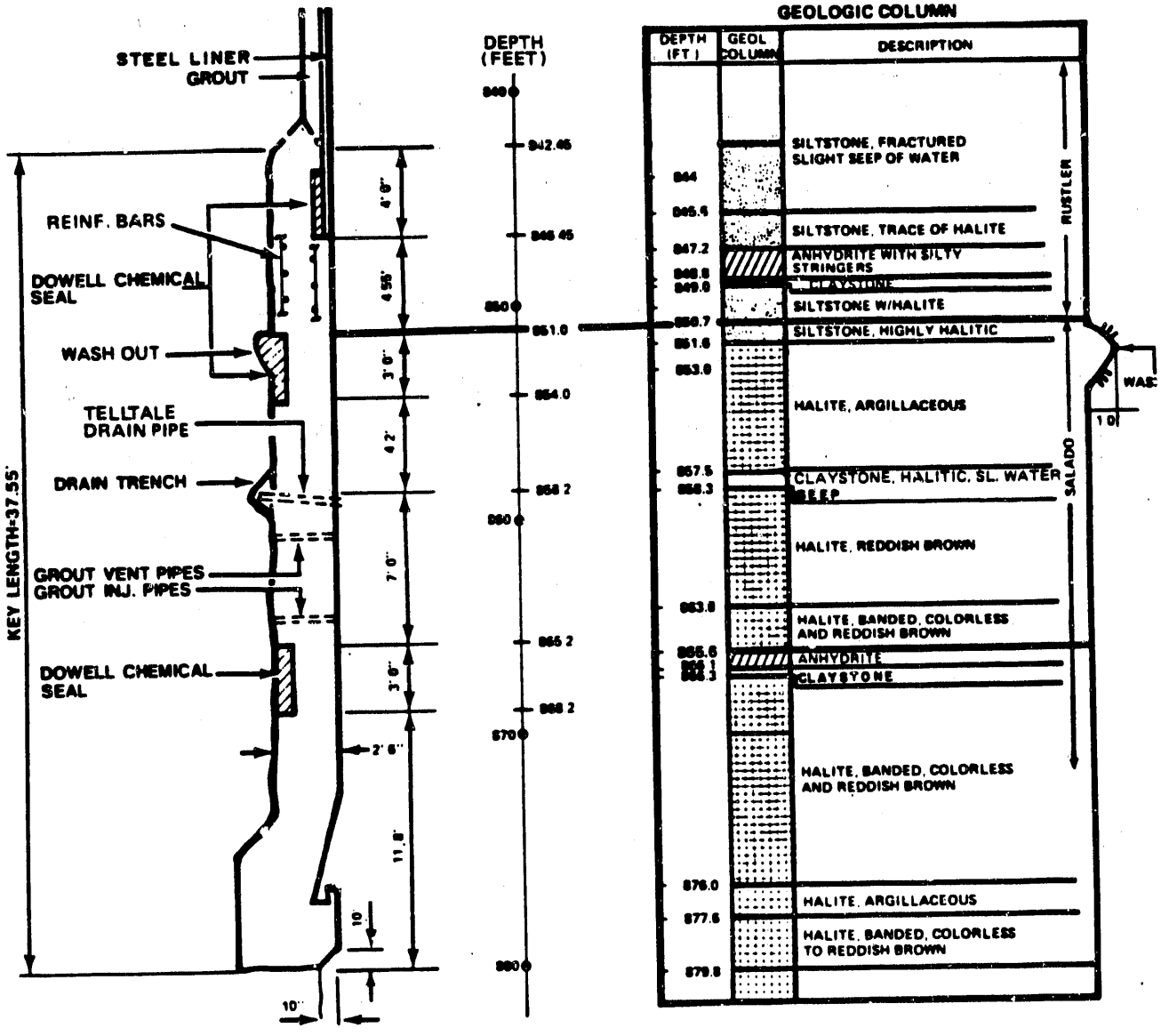


Figure 7-6

C & SH SHAFT KEY
STRATIGRAPHY

The relationship for concrete shrinkage (ref. 7-8) can be expressed as:

$$\varepsilon_{sh} = \frac{t}{35 + t} \varepsilon_{shu} C_{the} C_h C_s C_{cem} C_{fa} \qquad (7\text{-}1)$$

for t in days, or:

$$\varepsilon_{sh} = \frac{t}{3{,}024{,}000 + t} \varepsilon_{shu} C_{the} C_h C_s C_{cem} C_{fa} \qquad (7\text{-}2)$$

where: t is the shrinkage time in seconds;

ε_{shu} is the ultimate shrinkage strain, taken to be 0.0008;

C_{the} is the correction factor for thickness (1.17 - 0.029T);

C_h is the correction factor for humidity (1.40 - 0.010H);

C_s is the correction factor for slump (0.89 + 0.041S);

C_{cem} is the correction factor for cement content (0.75 + 0.034B); and

C_{fa} is the correction factor for percent fines and air content, taken to be 1.0.

The thickness T of the key wall is 30 inches; the humidity H is very low in the region of the key and is assumed to be 50 percent; the slump S of 4 inches is taken as the average value for 5,000 psi concrete; and B is the number of sacks of cement per cubic yard of concrete, considered to be equal to seven. The values of the correction factors C_{the}, C_h, C_s and C_{cem}, as calculated from the equations above, are 0.3, 0.90, 1.05 and 0.99, respectively.

Figure 7-7 shows the finite element model for the creep analysis. Since the structure is symmetrical about the centerline of the shaft, the shaft key and the area around it were modeled using 196 quadrilateral ring finite elements representing 18 distinct geologic layers. The MARC General Purpose Finite Element Analysis Program (ref. 6-8) was used for the analysis. To reduce the computation time, the stress and strain were computed at the centroid of each element. Four clay seams, at depths of 848.9, 857.9, 866.2 and 900.9 feet, were considered as active slip planes, represented by 25 friction and gap link elements with a coefficient of friction equal to 0.4. The outside

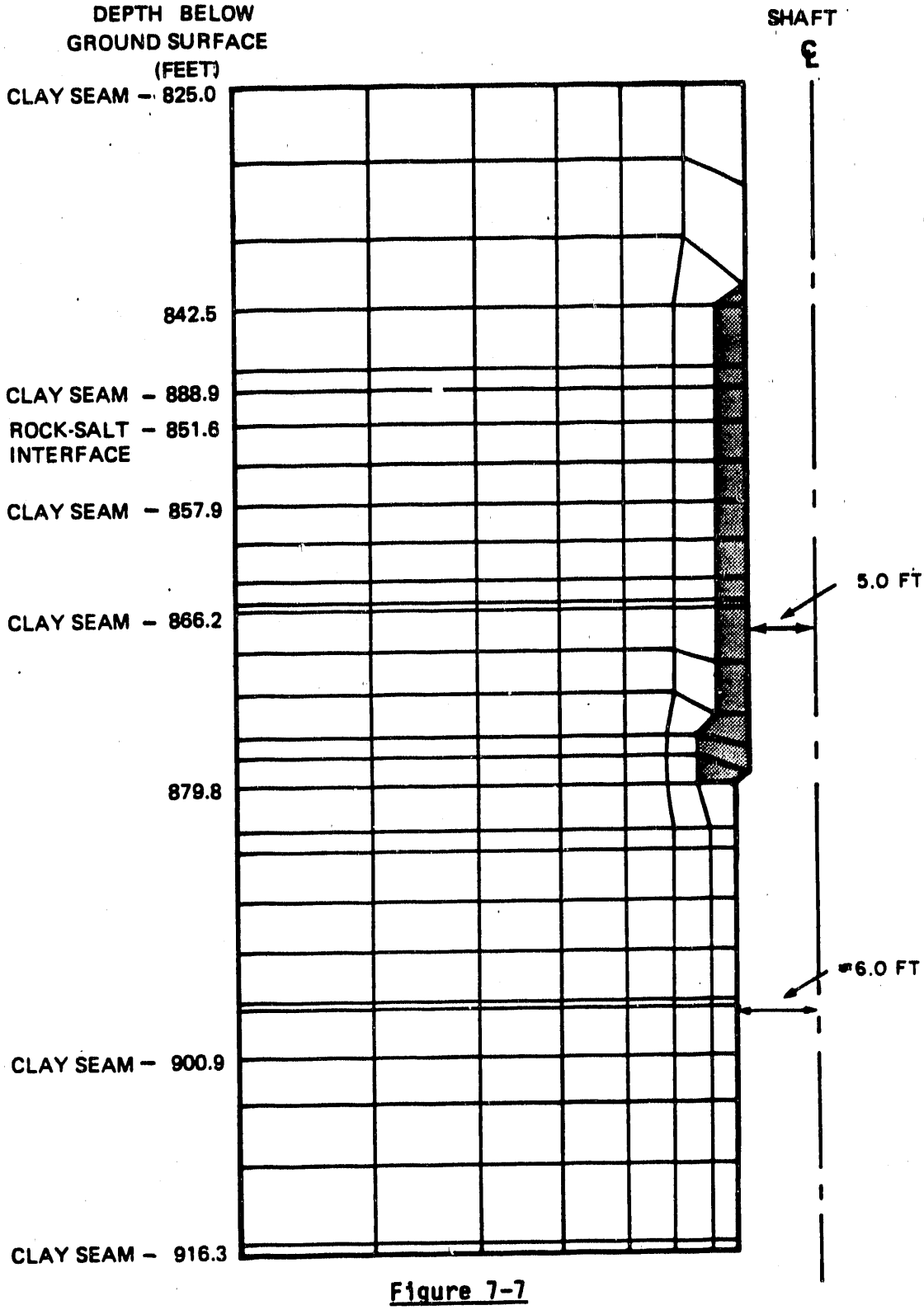


Figure 7-7

C & SH SHAFT KEY
FINITE ELEMENT MODEL

vertical boundary had zero horizontal displacement and the bottom boundary had zero vertical displacement. The boundary conditions at the top of the model were uniform calculated pressures based on the mass density of the geologic formation from the ground surface to the elevation of the boundaries. The lithostatic stress state was defined as described in Chapter 5, equation 5-1.

Creep analysis was performed on the mathematical model by using the procedures described in Chapter 5. The analysis was carried out for a 5-year interval without the key and a comparison was made of the corresponding radial deformations to determine the time when creeping salt would come into contact with the shrinking concrete key. The times computed for various layers behind the key were between 1.6 and 3.9 years with an average value of 2.7 years after excavation of the shaft (or 2 years after construction of the shaft key). To simulate contact of the shaft wall with the concrete key, the elements of the key were tied to the proper locations on the shaft wall and the analysis was continued for a total of 27 years (refs. 7-4 and 7-6).

Deformation. Readings from the strain gauges embedded in the concrete key show a range of strains from approximately 0.00014 in compression to 0.00021 in tension with an average compressive strain of 0.00004 through December 9, 1985. The readings from the strain gauges welded to the reinforcing steel show a range of approximately 0.00031 in compression to 0.00054 in tension with an average tensile strain of 0.00006.

Table 7-3 summarizes the changes in readings of the embedment and welded gauges at a depth of 856 feet (elev. 2554 feet) since April 22, 1982, immediately after concrete was placed for the shaft key. The trend of the change in strain readings indicates that the salt had not made contact with the key by June 1985.

Water Pressure. Figure 7-5 shows water pressure readings from piezometers 37X-PE-00211 and 37X-PE-00212. These piezometers have

Table 7-3

C & SH SHAFT KEY
SUMMARY OF STRAIN GAUGE READINGS AT ELEVATION 2554 FEET

Strain Gauge No.	Change in strain x 10^{-6} since April 22, 1982 Jun. 5, 1984	Feb. 8, 1985	Jun. 29, 1985	Dec. 9, 1985	Remarks
37X-ZE-209	-63	-59	-81	-9.5	Embedment
211	-23	-16	-34	-51	strain gauges
213	-133	-104	-139	-144	14.5 inches
215	-82	-67	-99	-111	from inner surface
235	-12	16	-23	-47	Embedment
236	56	88	37	16	strain gauges
237	-18	35	-23	-8	9 inches from
238	-63	-23	-81	-99	inner surface
210	-110	-71	-123	-154	Embedment
212	178	272	201	215	strain gauges
214	58	128	65	79	3.5 inches
216	-53*	-7	-61	-76	from inner surface
201	-93	-100	-102	-138	Strain gauges
203	-	-	444*	-	welded to the
205	-235	-286	-352	-371	outer rein-
207	-102	-127	-142	-95	forcing bar
202	-43	-	-61	-58	Strain gauges
204	443	2066	1056	541	welded to the
206	-193	-147	-230	-246	inner rein-
208	-	-	-1659**	-	forcing bar

NOTE: Negative strain change indicates compression.

* Reading taken on May 3, 1984.
** Reading taken on Dec 30, 1982.

shown a range of readings from a maximum of 30 psi in 1982 to a current reading of 2 psi. As shown on the figure and in Table 7-2, the readings of these two piezometers are consistently lower than the readings from the upper piezometers. These lower piezometers are at a depth of 850 feet (elev. of 2560 feet), just above the chemical water seal at a depth of 851 feet (elev. 2559 feet). It appears that this seal may be breached and that water is able to bypass it and exit through the French drain and telltales. Piezometers 37X-PE-00211 and 37X-PE-00212 may also be isolated from the upper piezometers by the grout that was injected behind the steel liner at a depth of 843 feet (elev. 2567 feet).

The assumption that the chemical water seal just below the piezometers may be breached is based on observations of piezometer behavior during the October 1983 inspection. As discussed in subsection 7.3.1.2, several capped pipes in the key were found to contain small amounts of water during this inspection and were drained. Prior to this, piezometers 37X-PE-00211 and 37X-PE-00212 indicated pressures of around 6 to 8 psi. After draining the pipes, both piezometers showed a drop to 2 psi within 2 days. This indicates a hydraulic connection across the water seal.

It is unlikely that water in the key originates from higher in the shaft. Detailed mapping in the shaft key noted weeps from claystone and siltstone beds at depths of 842. 846 and 858 feet. This is probably the source of the water seen in the French drain telltales and other pipes in the key. The fact that the key piezometers have had consistently lower readings than the upper piezometers indicates that there is probably no hydraulic connection with the water-bearing members higher in the shaft. The draining of water from the grout pipes influenced only those piezometers in the key; none of the upper piezometers showed any pressure drop. The existence of a source of water in the key area provides a better explanation of the dripping from the telltales and the performance of the key piezometers than does the migration of water from the water-bearing members higher in the shaft.

Salt Pressure. The four earth pressure cells installed between the concrete of the shaft key and the salt have a combined average reading of less than 10 psi in compression. These four cells, located 90 degrees apart at elevation 2550 feet (Figure 7-2), are intended to register changes in lateral pressures on the shaft key exerted by the creeping salt. Table 7-4 shows that the pressure cells have not registered any significant change in readings for a period of over 3 years since construction of the concrete key.

If we assume that the pressure cells are functioning properly, then the halite between a depth of 858 feet and 863 feet (elev. 2552 feet and 2547 feet) had not made contact with the pressure cell diaphragms as of December 9, 1985. According to the results of computational analyses, the contact between the salt and concrete will be reestablished at different elevations at different times between 1984 and 1986.

7.3.2.3 Unlined Section

Observed Conditions. The unlined section of the shaft appears to be stable with no evidence of rock spalling, wall deterioration, or dissolution by water.

Closure. Figure 7-8 compares average diametric closure readings at six elevations on December 9, 1985. The readings reflect only relative closure since the initial readings were taken nearly 1 year after completion of shaft excavation. Thus, the maximum diametric closure at a depth of 2,057 feet (elev. 1353 feet), near the bottom of the shaft, will be more than 1.0 inch. At higher elevations in the shaft, the actual diametric closure over the same period will, likewise, be higher than those shown on the figure.

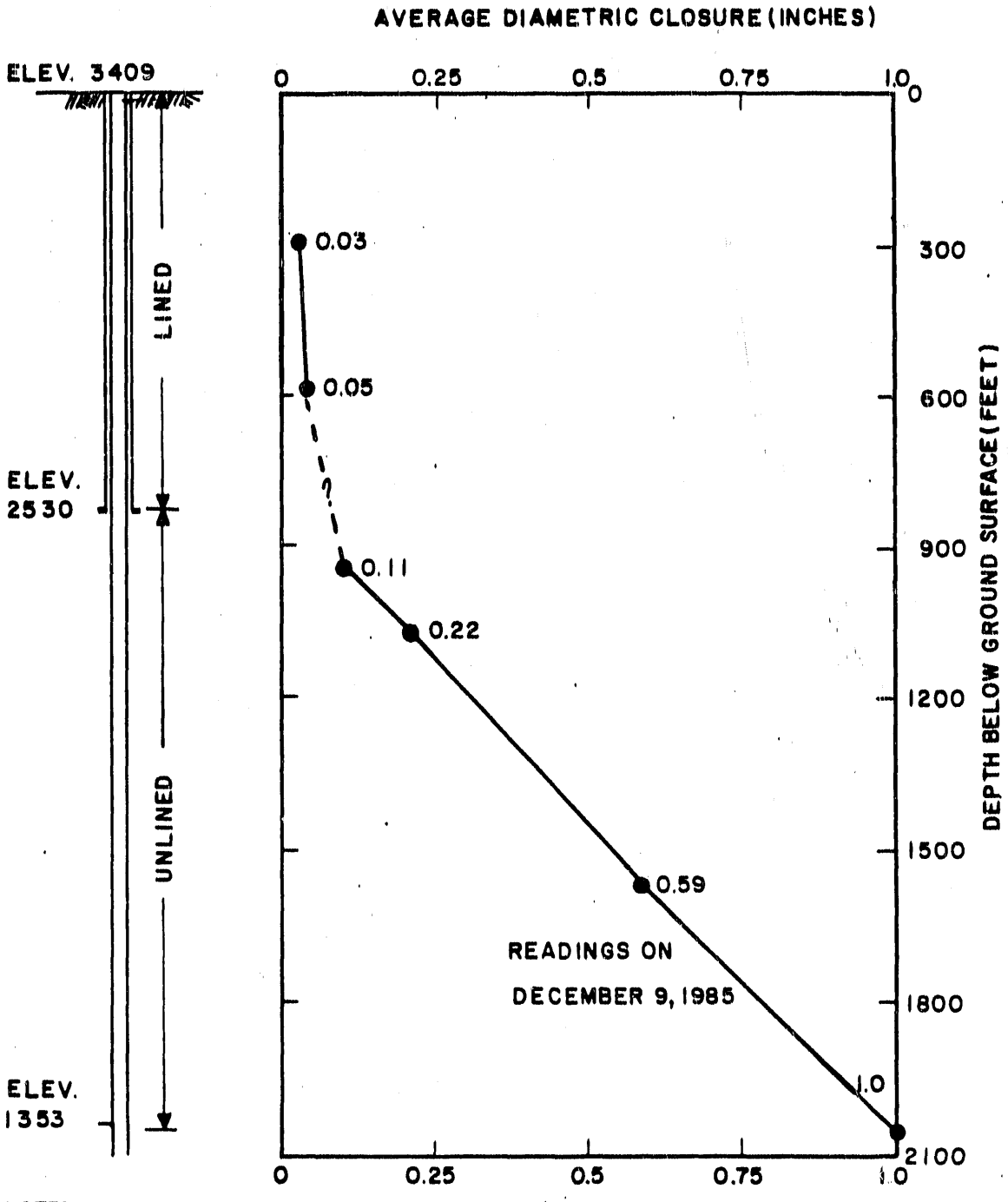
Deformation. The radial deformation of salt behind an opening can be determined from the measurements of movements of borehole extensometers with multiple anchor points.

Table 7-4

C & SH SHAFT KEY
PERFORMANCE HISTORY OF PRESSURE CELLS

Description	Pressure Cell Reading (psi) WE-201	WE-202	WE-203	WE-204	Date of Reading
Initial Irad Gage Co calibration	+1	+2	+6	+13	Feb. 3,'82
Initial SRI calibration	+8	+7	+8	+8	Feb. 16,'82
Site received, inspection	-1	+1	0	-2	Mar. 30,'82
Pre-installation, surface	-1	+1	-5	-2	Apr. 4,'82
Pre-installation, in shaft	0	-1	-2	-2	Apr. 15,'82
After plaster of paris	-2	-2	0	-2	Apr. 15,'82
After concrete placement	0	0	0	0	Apr. 15,'82
Initial installed reading	0	0	0	0	Apr. 16,'82
Time after installation:					
7 days	+2	-1	+2	+17	Apr. 22,'82
107 days	-1	-3	-2	0	Jul. 31,'82
529 days	-2	-5	-31	+1	Sep. 26,'83
530 days	+1	-3	0	-2	Sep. 27,'83
544 days	-4	-8	-32	-3	Oct. 11,'83
597 days	-4	-7	-	0	Dec. 3,'83
797 days	-1	-7	-38	0	Jun. 20,'84
938 days	-12	-11	-27	0	Nov. 8,'84
1030 days	-12	-30	-	-2	Feb. 8,'85
1140 days	-6	-10	-25	+3	May 21,'85
1179 days	-6	-11	-25	+5	Jun. 29,'85
1342 days	-14	-10	-25	-2	Dec. 9,'85

NOTE: Negative sign indicates tension.



NOTES:

1. SHAFT WAS EXCAVATED FROM JULY THROUGH OCTOBER 1981
2. CONVERGENCE POINTS WERE INSTALLED FROM JULY THROUGH OCTOBER 1982.

Figure 7-8

C & SH SHAFT UNLINED SECTION
AVERAGE DIAMETRIC CLOSURE

According to extensometer readings on September 16, 1985, the total average collar displacements at elevations 1846 feet and 1353 feet (Figure 7-3) were 0.19 inches and 0.235 inches, respectively. However, the extensometers were installed nearly 7 1/2 months after the completion of shaft excavation.

Figure 7-9 shows the collar movement time histories for multiple-point borehole extensometers 37X-GE-00202, 37X-GE-00205 and 37X-GE-00208 relative to their deepest anchor. The undulating shape of the curves appears to reflect the influence of seasonal temperature changes on the extensometers. The effect of temperature changes is more pronounced on the instrument behavior than on the salt surrounding the instrument. Figure 7-10 shows the change in calculated rates of collar movement with time for the extensometer time histories on Figure 7-9. The maximum rates coincide with the hottest months while during mid-winter the rates are close to, or slightly less than, zero. Because the time interval chosen for calculating the rate of collar movement is much less than the total observation period of 2 years, these rates are probably very close to the actual rates.

Comparison of the extensometer collar movements with convergence point readings suggests that the salt in the vicinity of the deepest anchor may also be moving. Thus collar movement does not reflect the true radial closure of the shaft. The amount of movement of the deepest anchor for any extensometer of given length can be estimated so that the collar displacement provides absolute radial closure. The diametric closure can be computed by model simulation as described below, by curve fitting as described in reference 4-19, or by closed form solution, also described in reference 4-19. Based on this analysis, the absolute movements of the collar and intermediate anchors for the 36-foot long shaft extensometers will deviate from the measured values by only 0.03 inch.

Model Simulation. The structural behavior of the unlined section of the C & SH shaft was analyzed by a nonlinear creep analysis using the

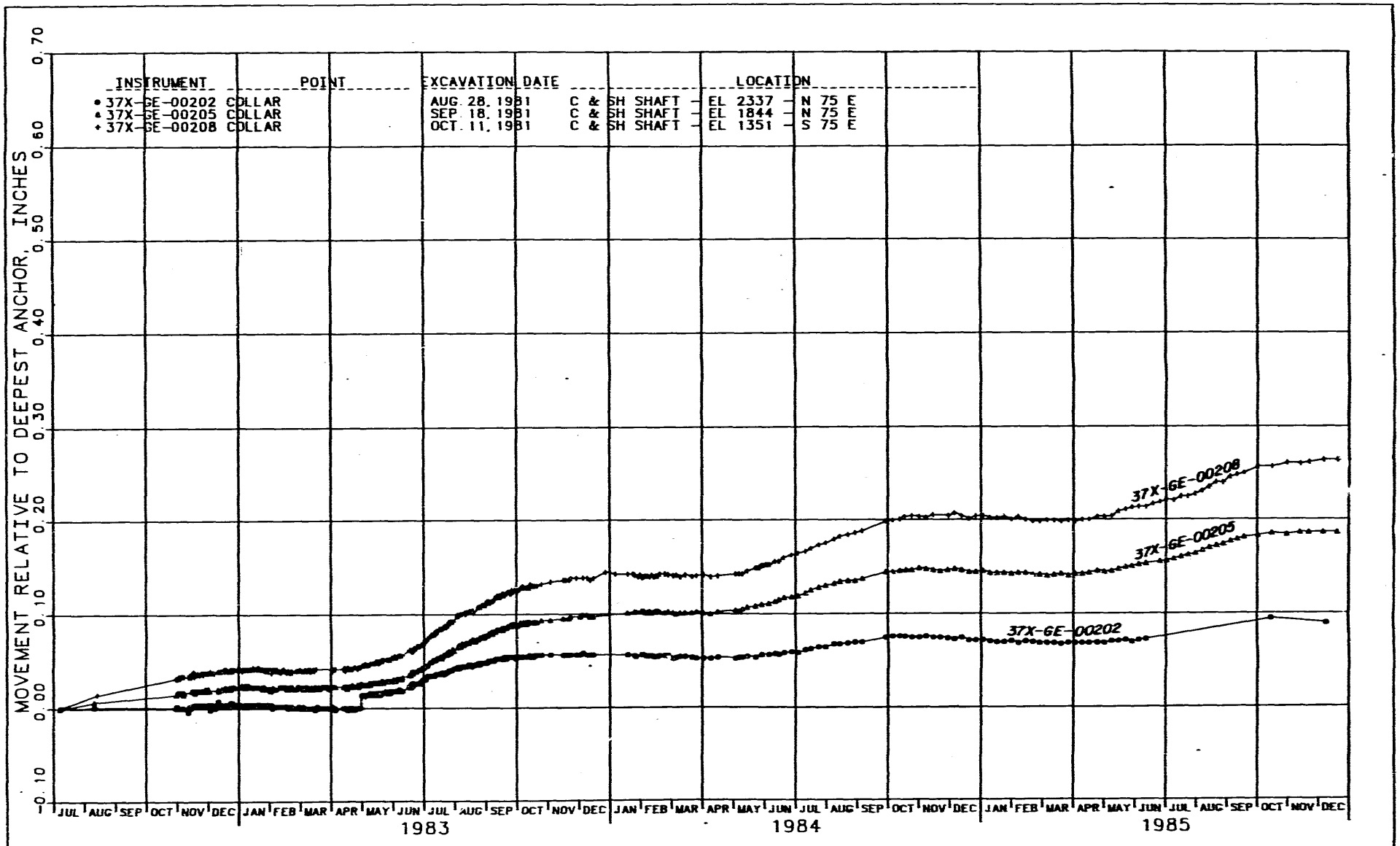
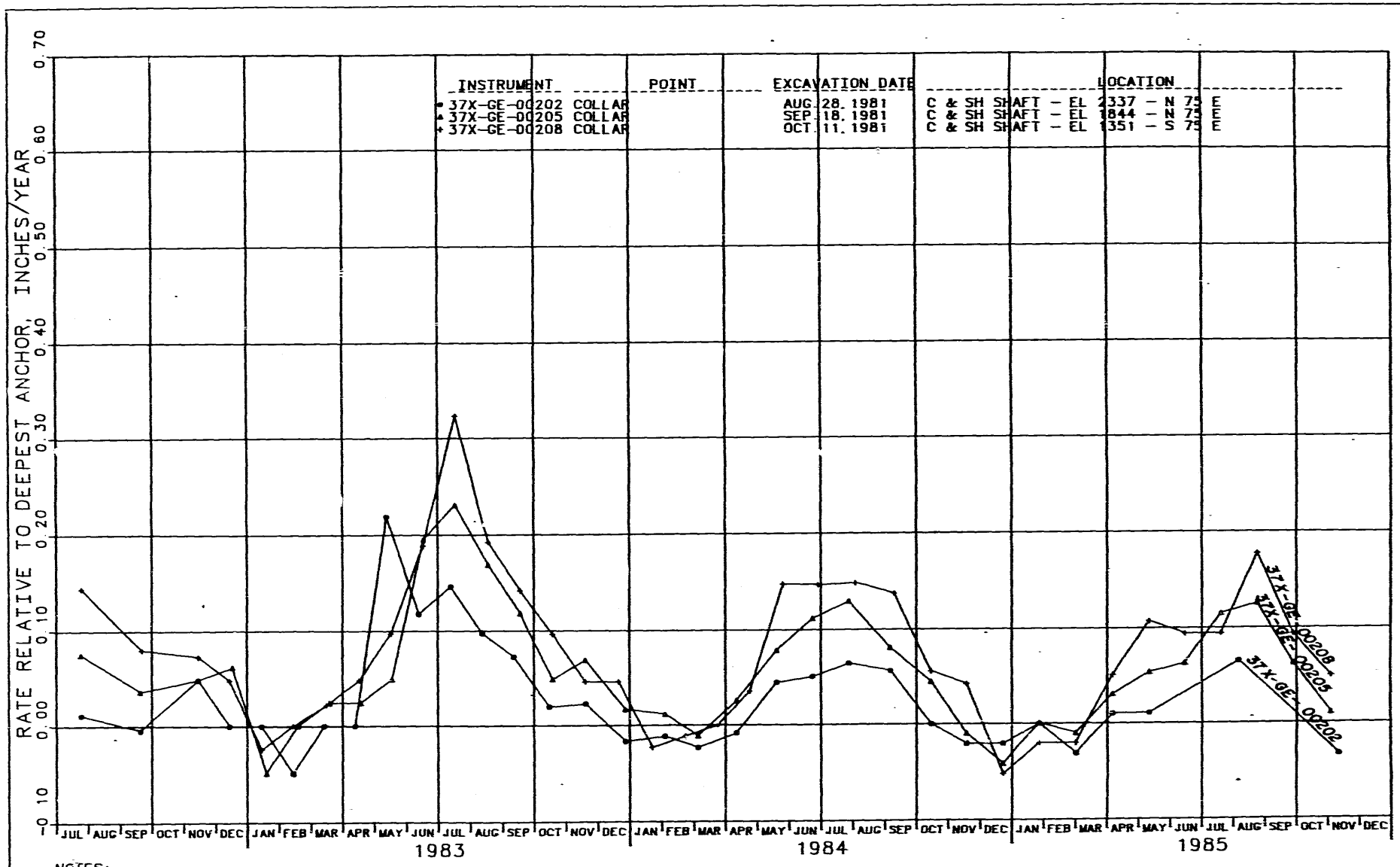


Figure 7-9

C & SH SHAFT UNLINED SECTION
COLLAR MOVEMENT TIME HISTORY



NOTES:

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.

Figure 7-10

C & SH SHAFT UNLINED SECTION
RATE OF COLLAR MOVEMENT VERSUS TIME

MARC General Purpose Finite Element Program (ref. 6-8). The objective of the analysis was to compute actual structural behavior by utilizing available in situ data, thereby verifying the design adequacy of the unlined section of the shaft.

The finite element model used for the analysis utilizes a single horizontal plane of quadrilateral ring elements with the upper and lower horizontal boundaries restrained against vertical displacement. This model is shown on Figure 7-11. The outside vertical boundary was given a constant uniform pressure based upon the lithostatic stress state defined in Chapter 5, equation 5-1. The inside boundary was also given a uniform pressure based upon the same lithostatic stress assumption; however, the pressure was removed in a step-wise fashion over a period of approximately 1 day. This was done to simulate the excavation of the drilled shaft, which results in a gradual relief of overburden pressure on the shaft interior and affects structural behavior in the early stage of excavation.

The secondary creep parameter C in Chapter 6, Table 6-8, was determined based on extensometer data at a depth of 2,057 feet (elev. 1353 feet). The value of C can be computed for each extensometer location using the analytical results and in situ data from the extensometer. Because C, determined from each extensometer, may vary, predicted diametric closures along each extensometer will vary accordingly. Using the diametric closures predicted at different directions on the horizontal plane, the principal directions of the strain on the horizontal plane can be determined. Consequently, closure along two horizontal principal directions can be predicted. Based on the predicted diametric closures at a depth of 2,057 feet in the N15°W, S75°E and S45°W directions, the major axis was found to be N17°40'W and the minor axis N72°20'E.

Closure predictions were made for two principal directions on the horizontal plane. Because the stress and strain distributions are not sensitive to the value of the secondary creep parameter, except during

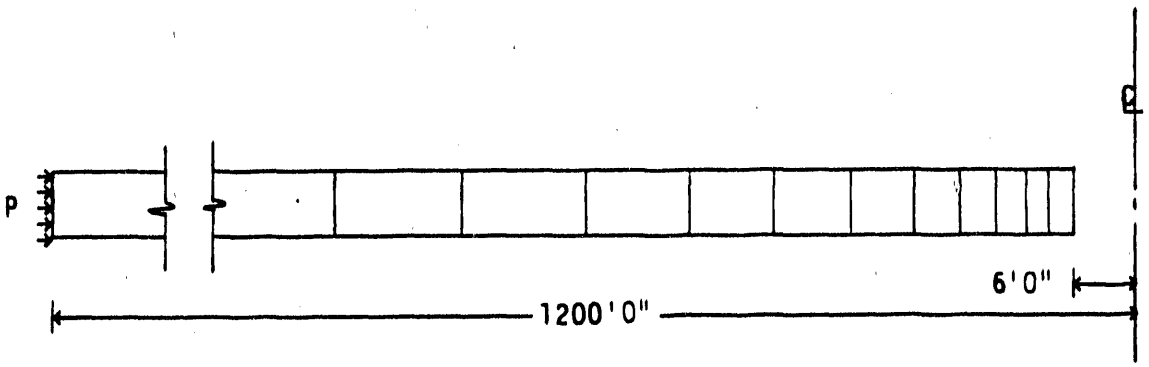


Figure 7-11

C & SH SHAFT UNLINED SECTION
FINITE ELEMENT MODEL

the initial stages of creep, the stress and strain distributions were computed based on the average values of the creep parameter C determined from three different directions.

7.3.2.4 Shaft Station

Observed Conditions. The C & SH shaft station exhibits spalling from both the roof and wall surfaces that requires continual routine maintenance. Displacements, separations and fracturing occuring above the roof at clay G and in the underlying halite were expected.

Data from the Excavation Effects Program indicate that the halite from 4 to 10 feet above the roof contains essentially no separations or fracturing. Floor heave is evident at the electrical substation where the concrete base slab has tilted several degrees, but holes drilled into the station floor encountered only minor separations and fracturing. Extensometer 51X-GE-00253, in the station floor, does not show any significant increase in collar movement that would be expected if floor heave and fracturing is occurring. Although the C & SH shaft station is the oldest and largest horizontal opening, the extent of separations and fracturing beneath the floor is very small relative to the fracturing found in the floor beneath Test Room 3 (Chapter 11).

The observed behavior in the station is apparently due in large part to its initial excavation by blasting. No other underground area has exhibited the degree of spalling that has occurred in the station. The blasting is thought to have accelerated separations at clay G and in the underlying halite in the main station area south of the shaft. However, the extensive rock bolting in the roof appears to have effectively controlled these separations.

Fracturing in the pillar corners at the S90 crosscut has continued to evolve as the salt responds to stresses produced by the station excavation. Changes in the fracturing are exhibited primarily by the appearance of new vertical fractures and by the elongation and widening of existing fractures. Minor spalling has also occurred, particularly

at the roof and wall intersection in the upper portion of geologic map unit 4.

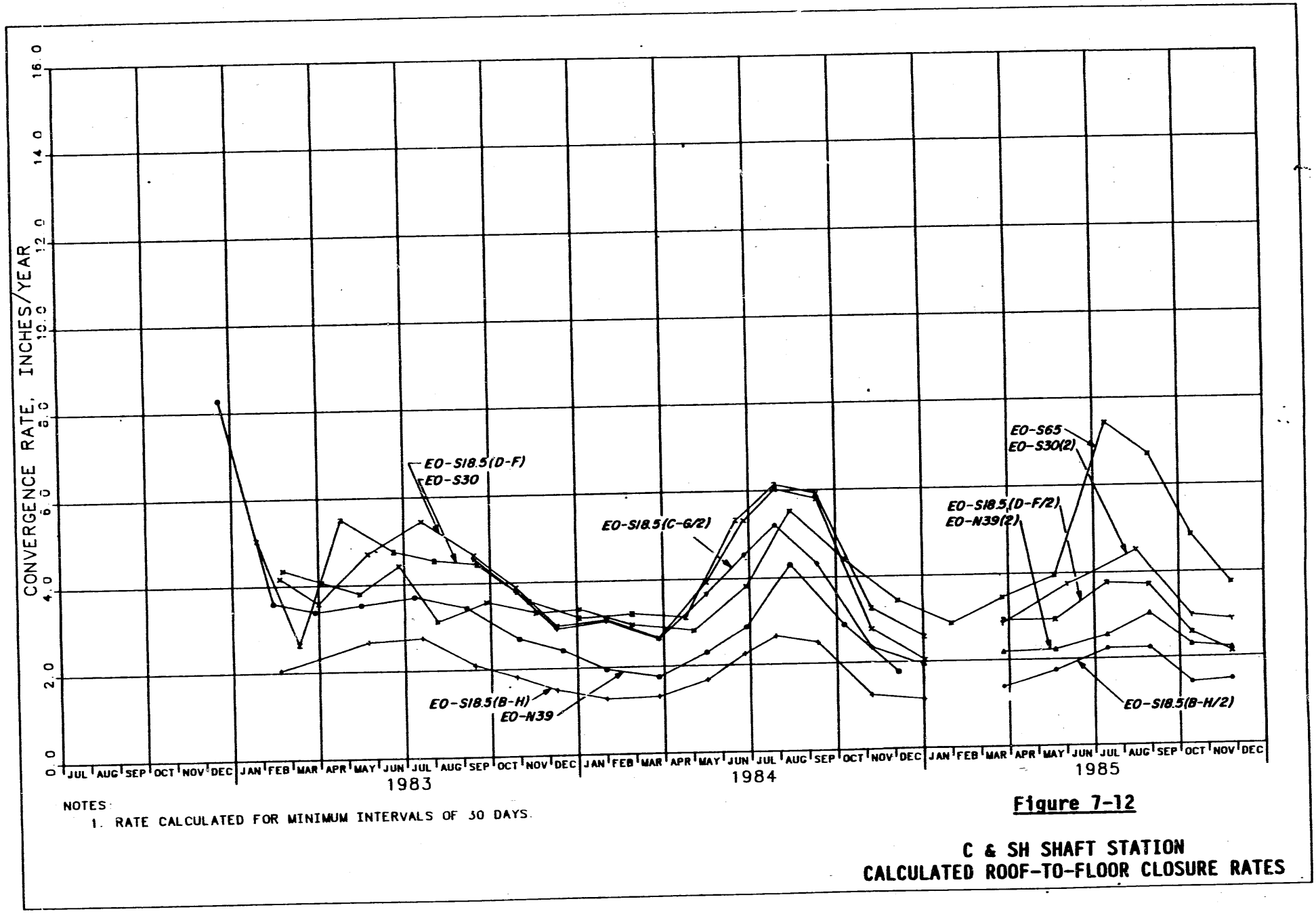
Closure. Figure 7-12 shows closure rates calculated from the readings of roof-to-floor convergence points. The maximum rate appears to have occurred during the early part of August 1984.

The closure rates shown on Figure 7-12 cannot be directly compared without considering the differences in dimensions at the locations shown, as well as differences in the thickness of the roof beam below clay G, and the number of rock bolts in the vicinity of the respective convergence measurement stations.

Figure 7-13 compares the central vertical closure readings at stations S18.5 and N39. Although the closure measurements are very close at both stations, actual total closure at the S18.5 station will be greater since the initial reading at this station was taken nearly 261 days after the completion of excavation, compared to only 35 days at the N39 station. In addition, the larger opening dimensions at the S18.5 station will also result in more rapid closure. Even though the density of rock bolts is greater south of the C & SH shaft than north of it, the roof-to-floor closure is greater to the south. This is probably because the roof beam below clay G is thinner and longer to the south.

Figure 7-14 shows the collar movements of multiple-point borehole extensometers 51X-GE-00227 and 51X-GE-00228 in the station roof, 35 feet north and 65 feet south of the C & SH shaft, respectively. The average collar movement rate of 51X-GE-00228 is higher than that of 51X-GE-00227, as determined from Figure 7-14. The roof closure rate south of the shaft is currently more than the rate north of the shaft.

A double-point borehole extensometer (51X-GE-00253) was installed in the floor of the C & SH shaft station. The initial reading from this extensometer was taken nearly 238 days after the completion of



NOTES:
1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.

Figure 7-12

C & SH SHAFT STATION
CALCULATED ROOF-TO-FLOOR CLOSURE RATES

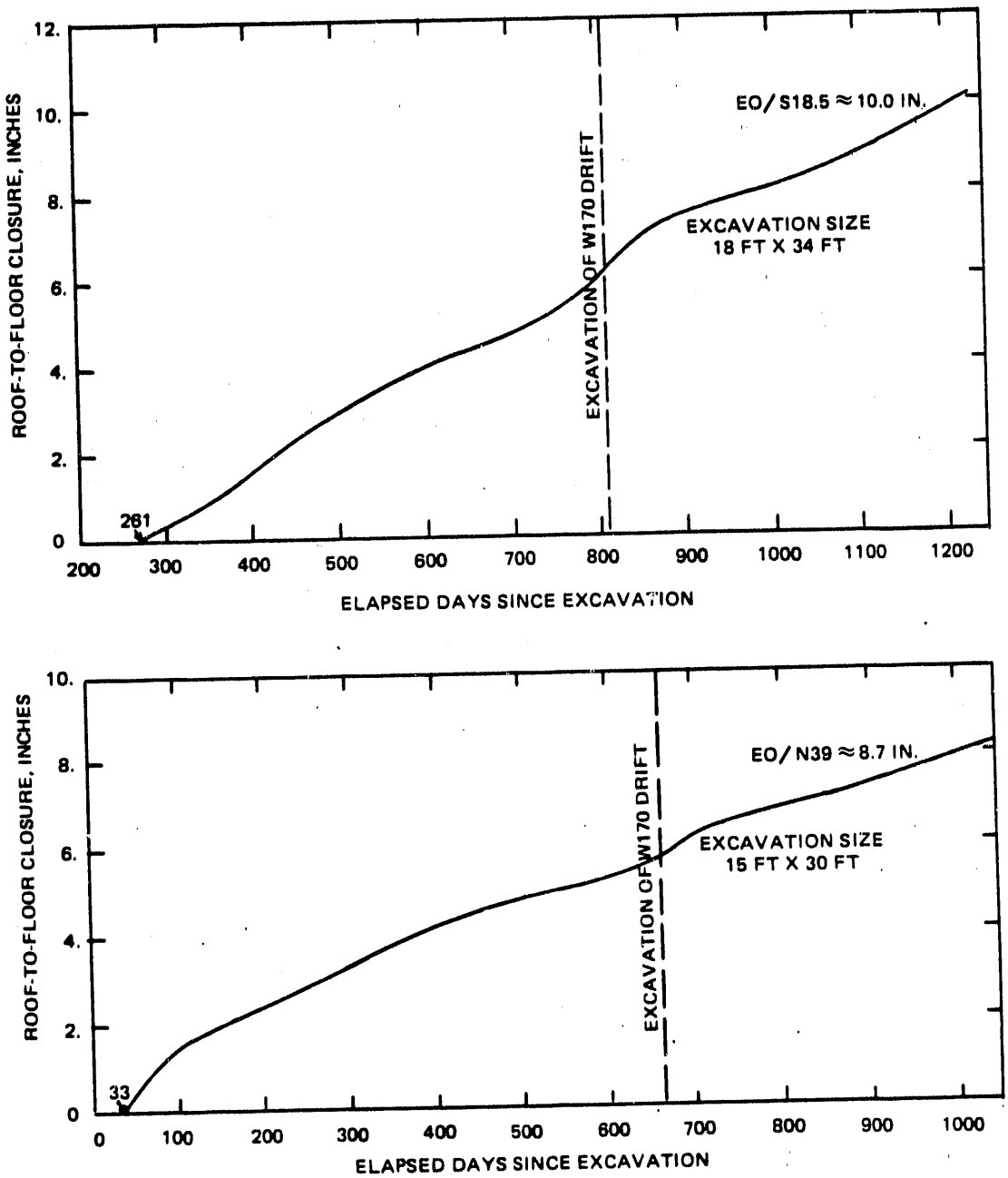


Figure 7-13

C & SH SHAFT STATION
TYPICAL ROOF-TO-FLOOR CLOSURE HISTORY

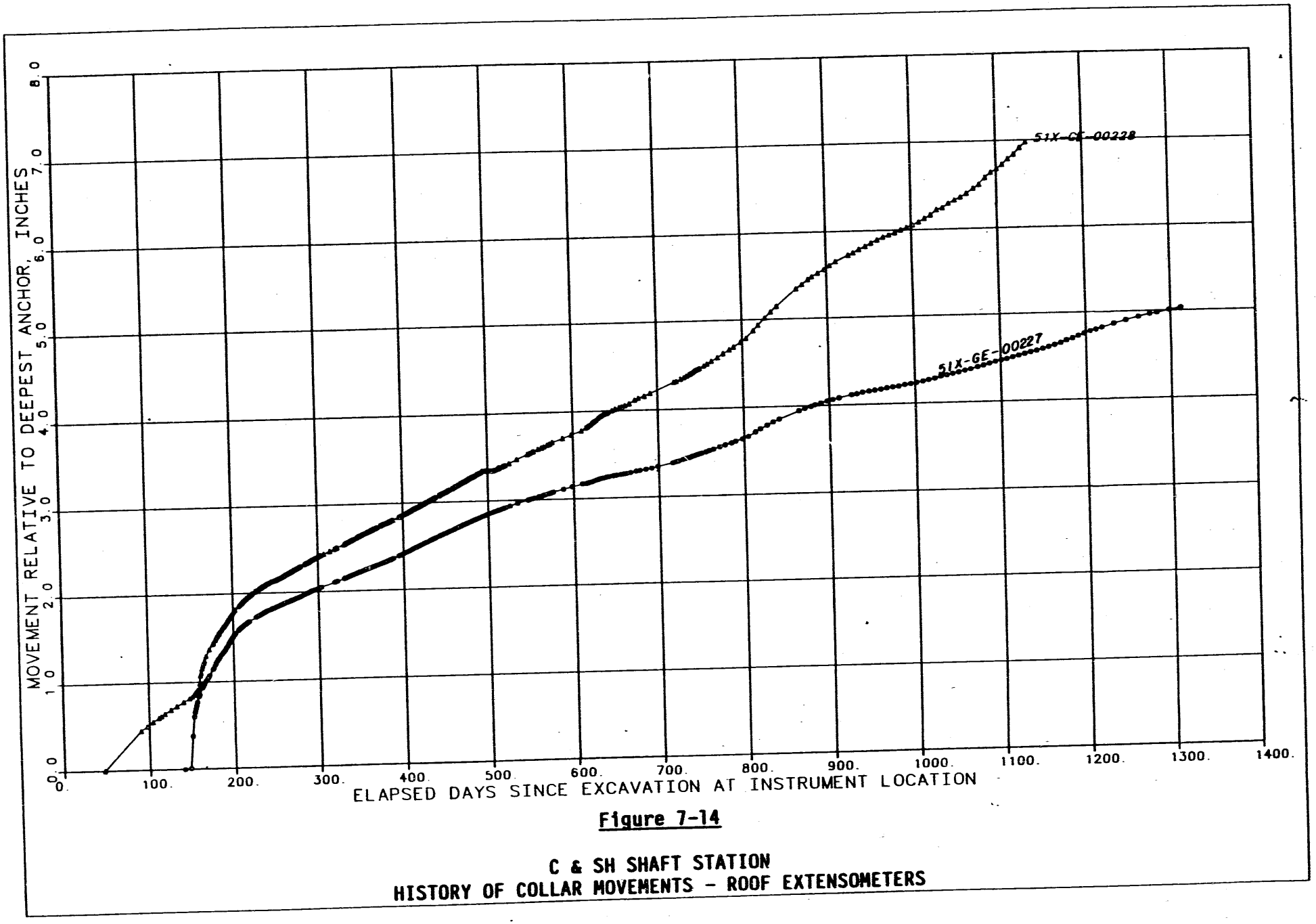


Figure 7-14

C & SH SHAFT STATION
HISTORY OF COLLAR MOVEMENTS - ROOF EXTENSOMETERS

excavation at the instrument location (Appendix J, Figure J-172). The measured collar movement relative to the deepest anchor was 3.26 inches on December 20, 1985. Actual floor heave will be higher as a result of the time-lag between the end of excavation and the initial reading date. There was a slight increase in the collar movement rate due to excavation of the nearby W170 drift, but the rate has since become steady.

Roof Stability. Figure 7-15 shows the distribution of measured movements along roof extensometer 51X-GE-00251, 18 1/2 feet south of the C & SH shaft, for the readings taken on September 18, 1985. The magnitudes shown are cumulative between the initial reading date of January 11, 1983, and September 18, 1985. The movements are also expressed as percentages of the collar reading. Sixty-one percent of the relative movement has taken place between the collar and anchor A. This has remained practically constant since December 1983 and is an indirect indication that there is no accelerating trend in the rate of opening at clay G in the vicinity of this extensometer. For comparison, the distribution of measured movement along roof extensometer 51X-GE-00227, 35 feet north of the C & SH shaft, is shown on Figure 7-16. The relative movement between the collar and anchor A has remained constant at 52 percent through December 1985. Based on these measurements, there is no indication that clay G is parting at an accelerating rate either north or south of the shaft.

7.3.3 Prediction of Future Behavior

This subsection presents the results of the analysis and evaluation of the finite element modeling and the data collected in the C & SH shaft. These results are presented in the form of predictions for future behavior of the constructed shaft elements (liner and key) and of the salt surrounding the unlined section of the shaft and the shaft station.

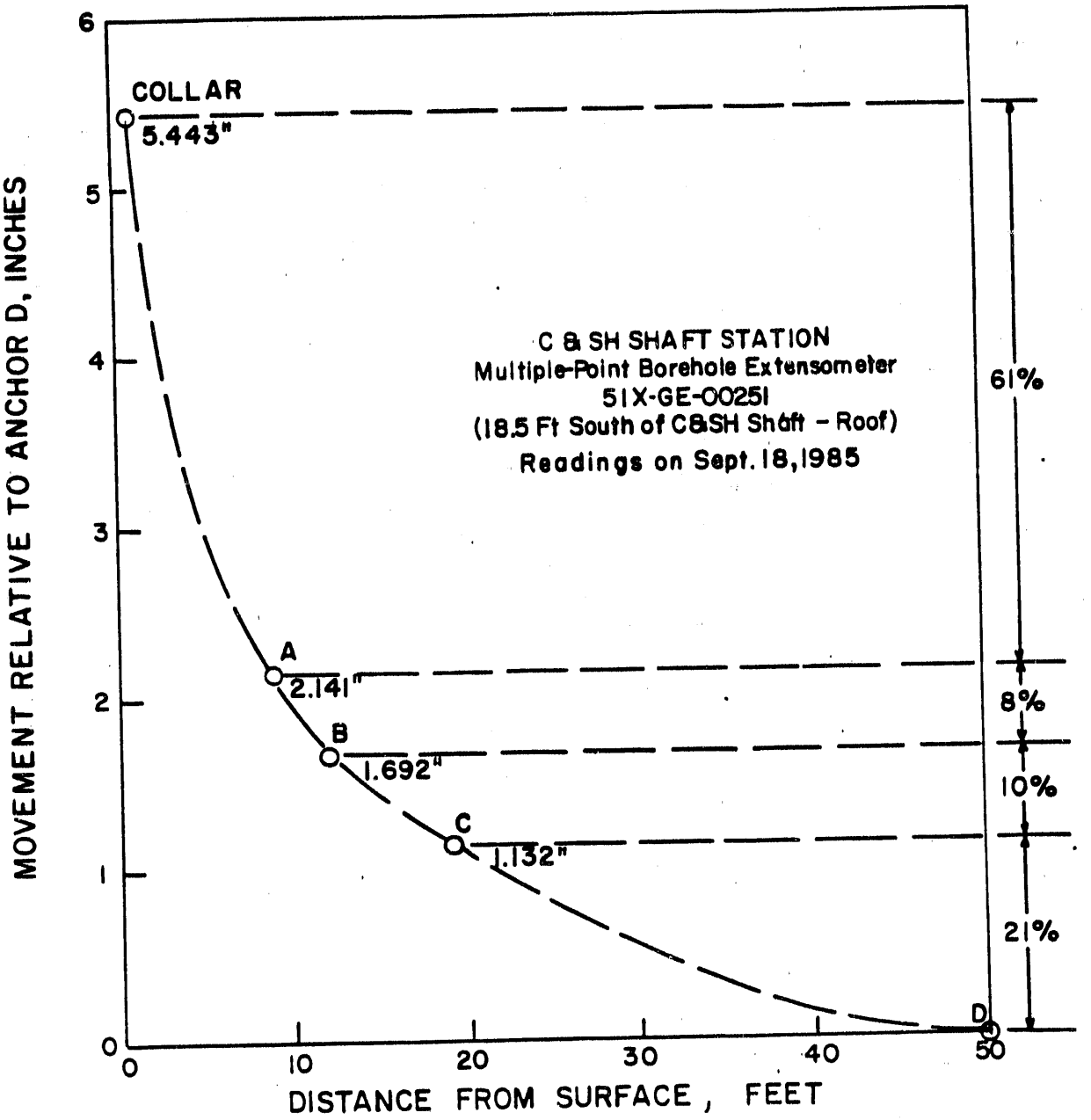


Figure 7-15

C & SH SHAFT STATION
MOVEMENT DISTRIBUTION ALONG ROOF EXTENSOMETER 51X-GE-00251

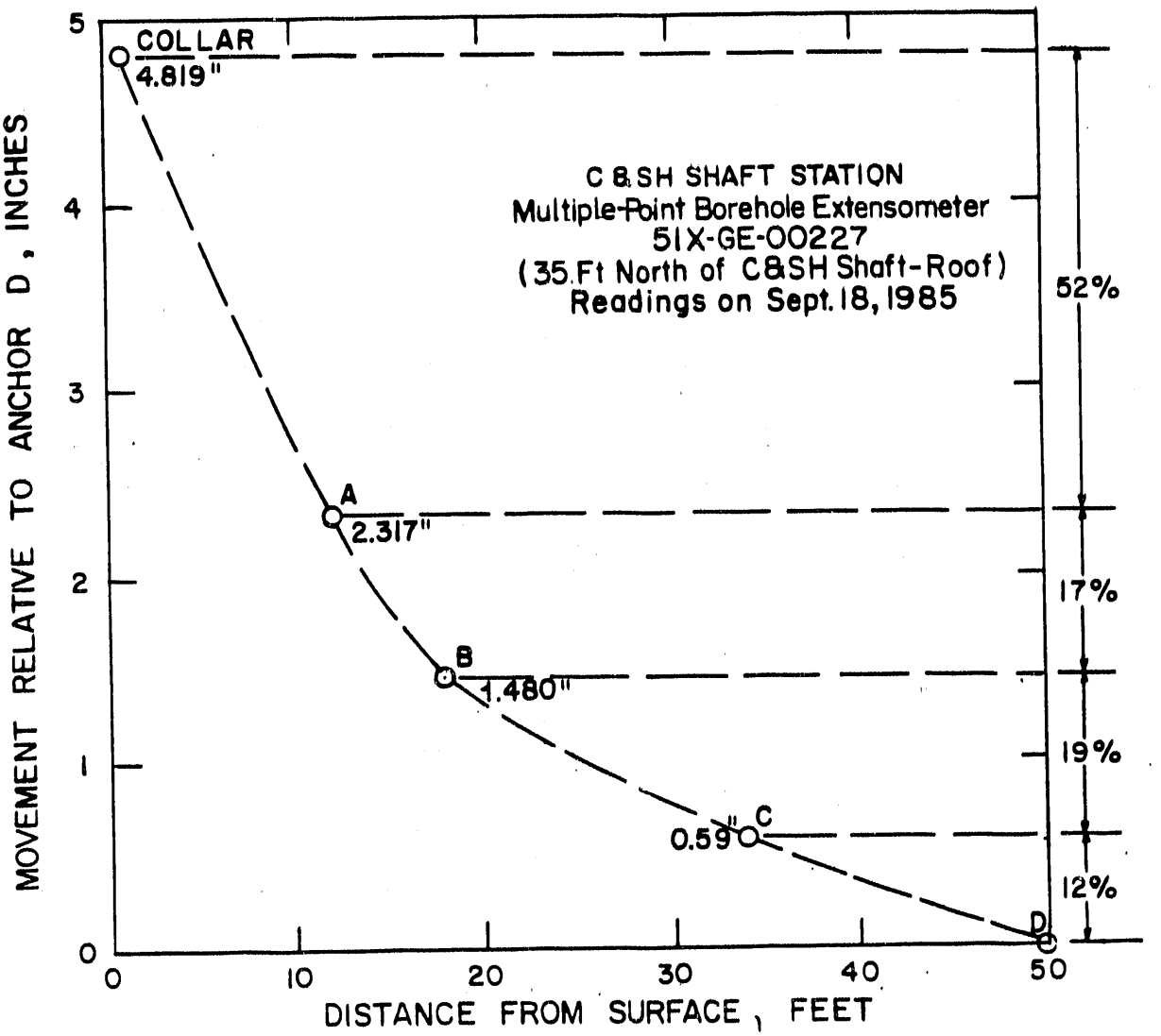


Figure 7-16

C & SH SHAFT STATION
MOVEMENT DISTRIBUTION ALONG ROOF EXTENSOMETER 51X-GE-00227

7.3.3.1 Lined Section

The water pressure on the shaft liner to date has been less than the hydrostatic design pressure. The prediction of future water pressures behind the liner is difficult due to the reasons discussed in subsection 7.3.2.1. The lower potentiometric surface and lack of hydraulic continuity along the rock/liner interface may prevent the ground water from reaching the design hydrostatic head. In addition, leaks around the piezometers and possibly obstructed filters may cause the measurements to be somewhat less than the actual pressure conditions.

Figure 7-17 shows that if the water pressure does reach the design hydrostatic pressure, the liner will remain stable based on its design factor of safety. The figure shows that the pressure capacity of the liner far exceeds the design hydrostatic pressure. This pressure was determined based on water level data obtained at the site during preliminary design activities. The data indicated that the highest potentiometric surface in the Rustler formation beneath the site occurred at a depth of approximately 250 feet below the ground surface. This data was later confirmed by investigations conducted in the site vicinity by the U.S. Geological Survey (USGS) (ref. 7-9). It is not expected that this potentiometric surface will be exceeded during the 25-year operating life of the facility. If any external water were to infiltrate along the rock/liner interface to form a column of water that would exceed the hydrostatic head contained in the design bases, the stability and safety of the steel liner would still not be compromised based on the design factor of safety.

7.3.3.2 Shaft Key

The results of the shaft key analysis indicate that after concrete is placed against the shaft wall it shrinks away from the wall at a rate greater than the rate of salt creep, resulting in a separation between the concrete and the salt. The rate of concrete shrinkage decreases with time and continuous salt creep eventually results in the salt

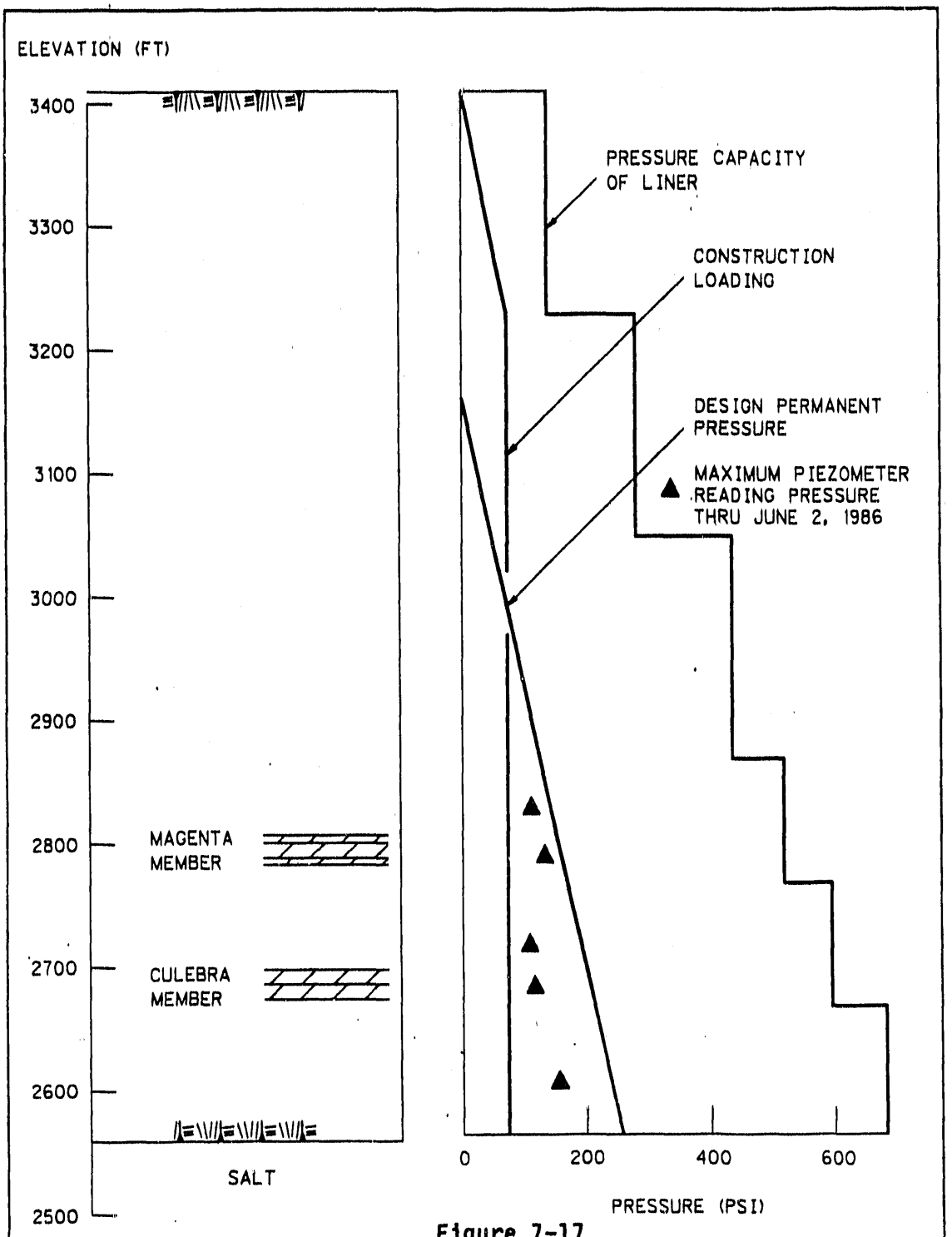


Figure 7-17

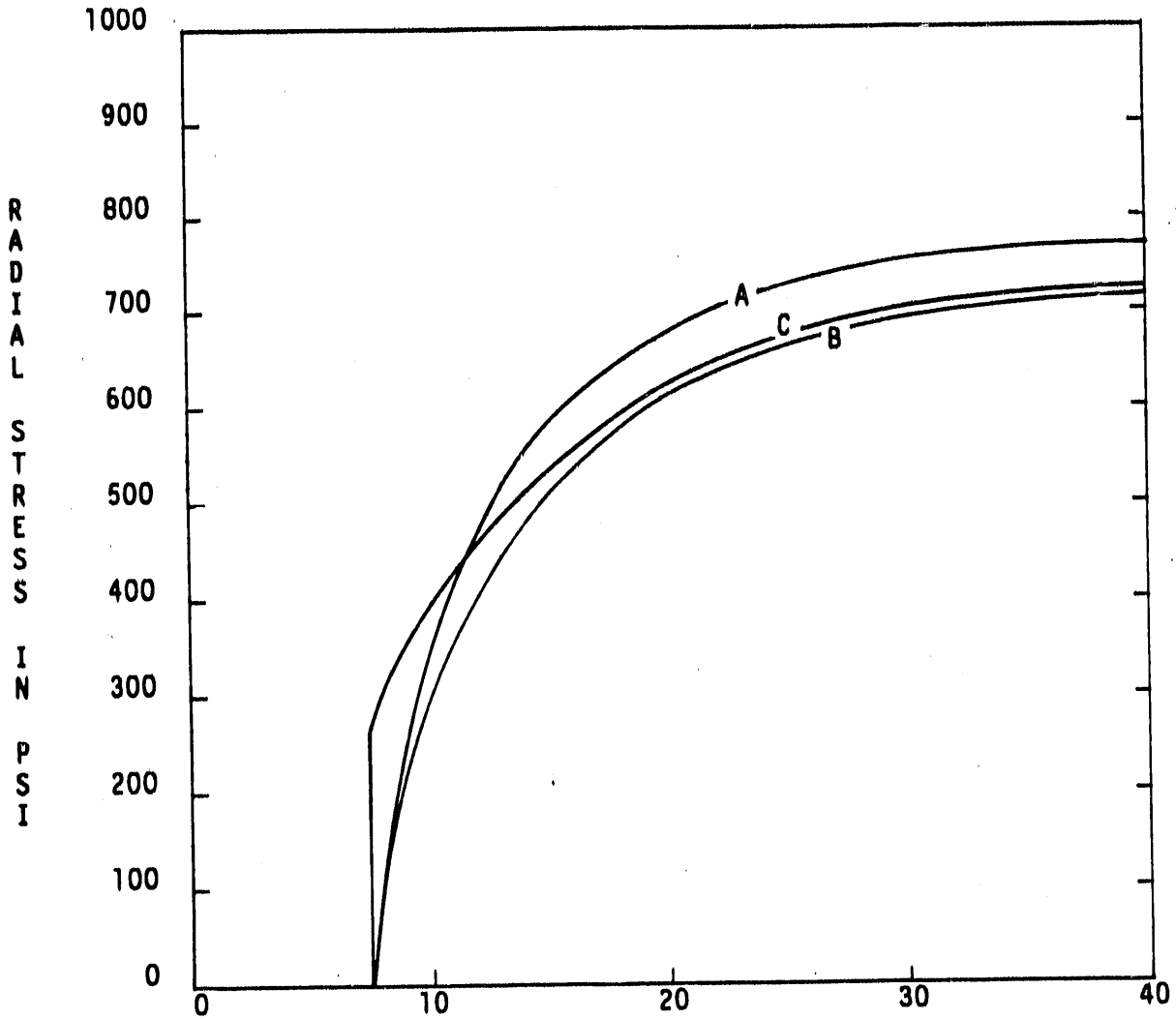
C & SH SHAFT LINER
LATERAL PRESSURE COMPARISON

contacting the concrete again. The interactive pressure between the concrete and the salt will then gradually increase due to continuous salt creep.

In the key area, the shaft wall radial and tangential stresses (Figures 7-18 and 7-19, respectively) were plotted as a function of distance from the centerline of the shaft for a typical section immediately after excavation of the shaft and for 1 year and 25 years after concrete placement. As expected, the radial stresses in the salt are initially relieved near the opening but begin increasing after the salt comes in contact with the concrete. Further away from the opening, the stresses trend toward the overburden pressure.

The tangential stresses in the salt 3 days after excavation show an elastic response which gives very high values near the opening. The stresses are relieved near the opening from the time the salt starts to creep until it contacts the concrete. After contact is made, and for the remainder of the 25 year analysis period, the stresses in the salt and concrete key increase. There exists a discontinuity of stress at the concrete/salt interface which is primarily due to differences in their material properties. Like the radial stresses, the tangential stresses approach the overburden pressure with increasing distance from the opening.

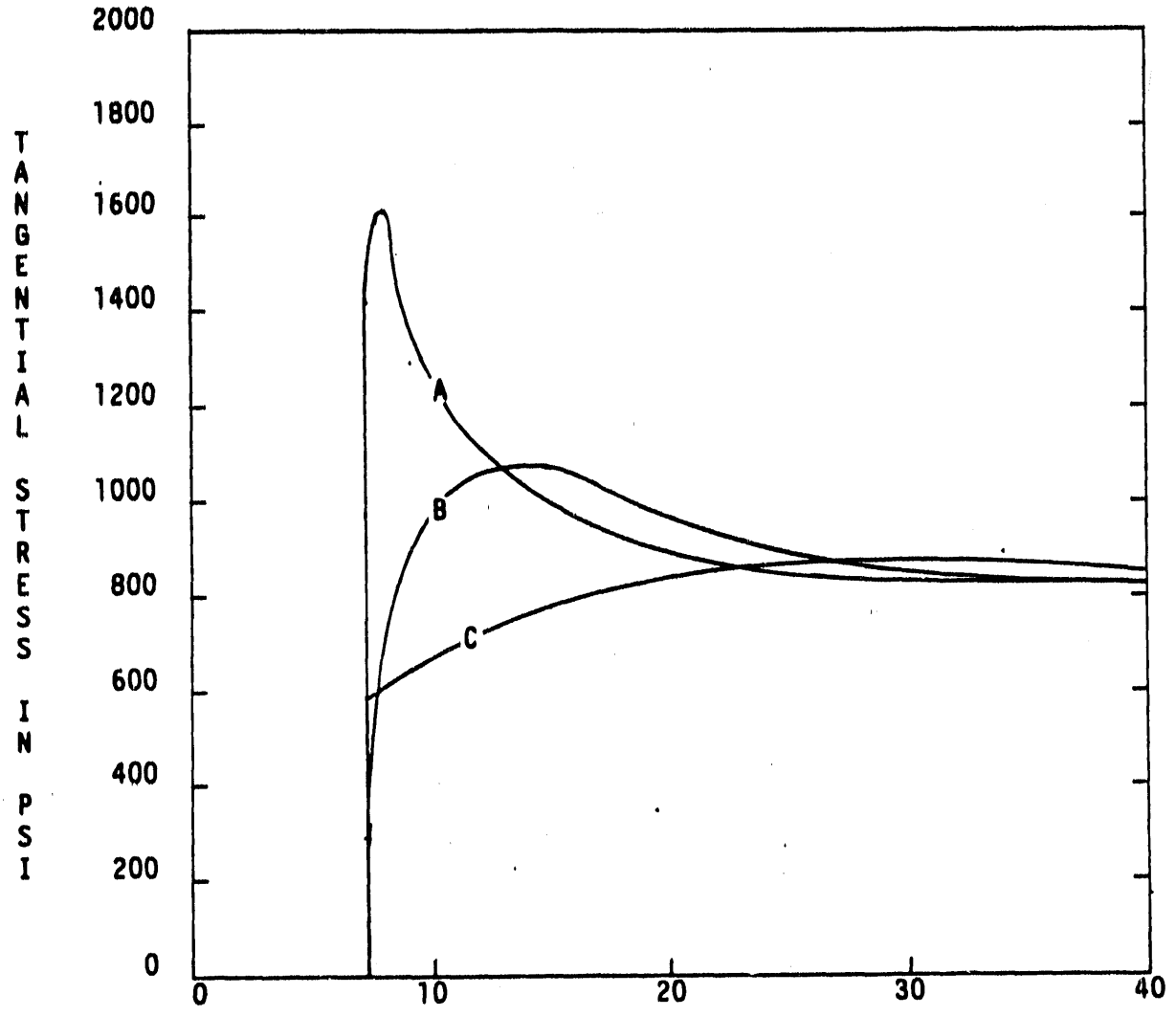
At 25 years, the radial stresses, which are equal to the lateral pressures on the salt face of the key, will increase to an average value of 275 psi. At the same time, the maximum hoop stress at the inside face of the concrete key has an approximate value of 1,000 psi, with an average value across the key of about 825 psi. Figures 7-20 and 7-21 show the predictions for average lateral pressures and average hoop stresses, respectively. A lateral pressure capacity in the key of 833 psi, based on an allowable hoop stress controlled by a concrete compression of 3,000 psi, results in a factor of safety of approximately three.



A – IMMEDIATELY AFTER EXCAVATION
B – ONE YEAR AFTER CONCRETE PLACEMENT
C – 25 YEARS AFTER CONCRETE PLACEMENT

Figure 7-18

C & SH SHAFT KEY
RADIAL STRESS DISTRIBUTION



A – IMMEDIATELY AFTER EXCAVATION
B – ONE YEAR AFTER CONCRETE PLACEMENT
C – 25 YEARS AFTER CONCRETE PLACEMENT

Figure 7-19

C & SH SHAFT KEY
TANGENTIAL STRESS DISTRIBUTION

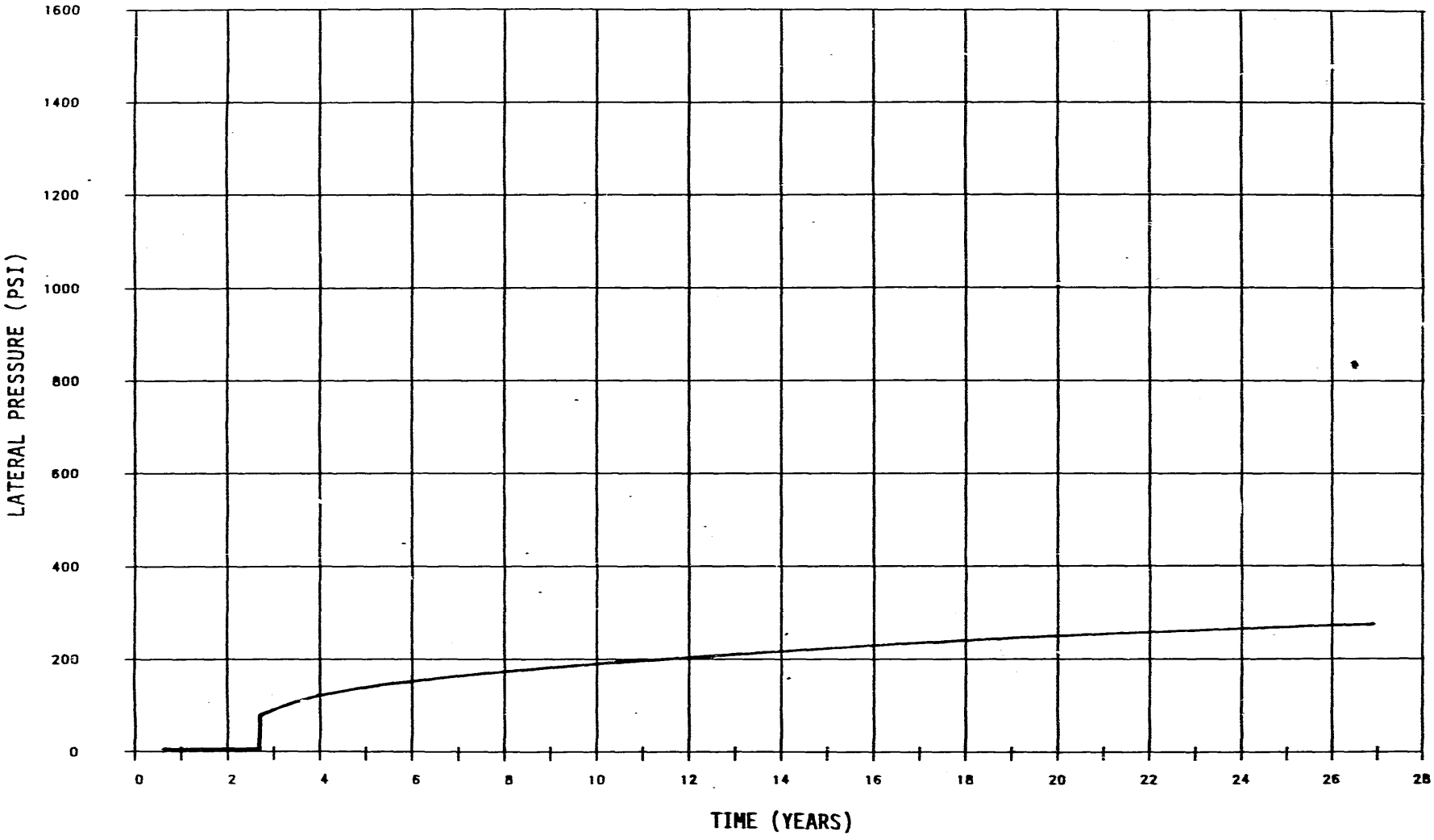


Figure 7-20

C & SH SHAFT KEY
LATERAL PRESSURE PREDICTION

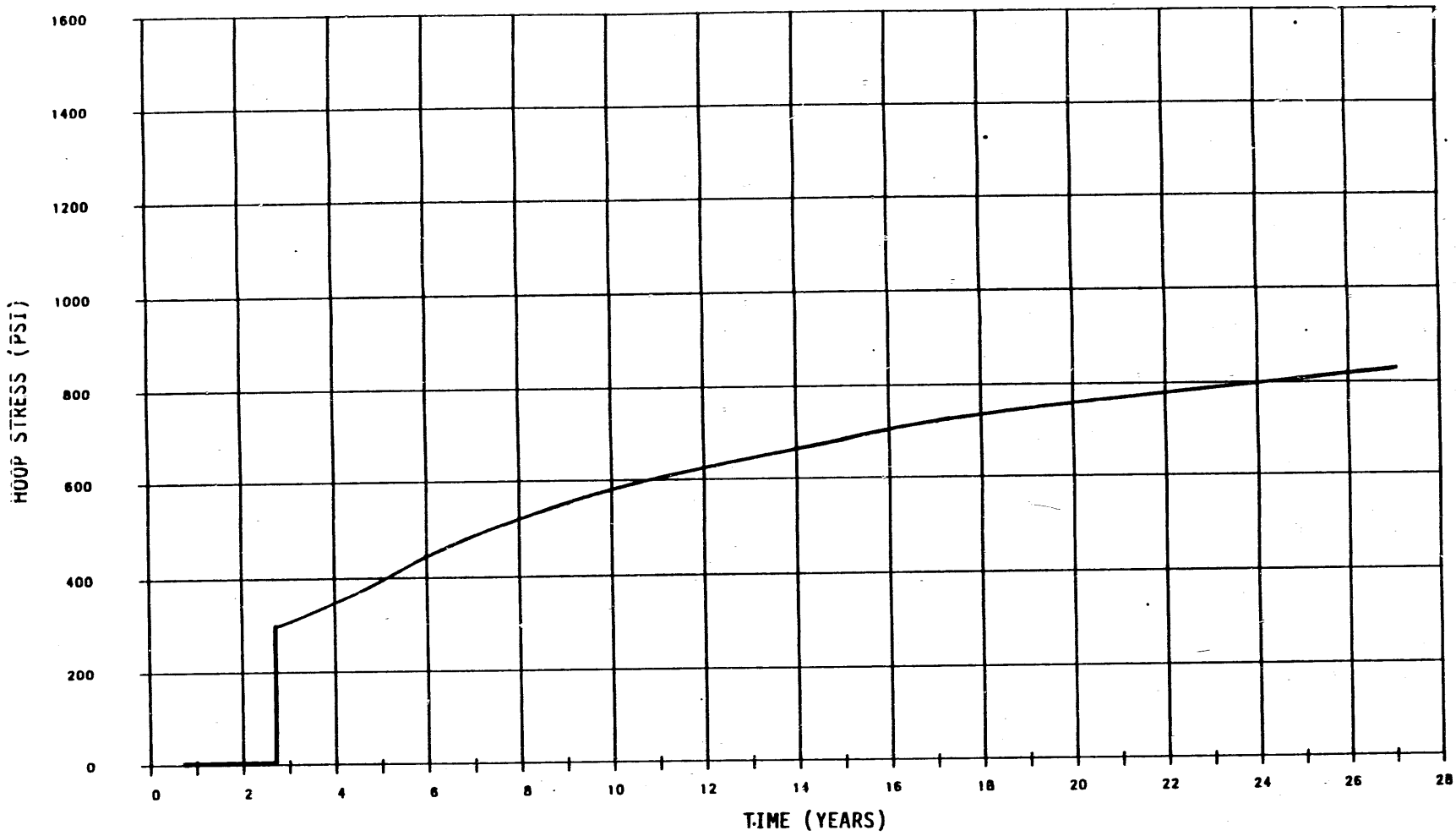


Figure 7-21

C & SH SHAFT KEY
HOOP STRESS PREDICTION

The average diametric closure of the key at 27 years is expected to be about 0.1 inch with a maximum value of 0.175 inch, or about half the predicted value for the salt in the unlined section immediately below the key (Figure 7-22). The average diametric closure of the unlined section immediately below the key at 27 years varies from 0.03 inch for the anhydrite bed to 0.38 inch for the argillaceous halite layer. Figure 7-23 shows the diametric closure predictions for both the concrete key and the salt in the adjacent shaft wall.

7.3.3.3 Unlined Section

Extrapolation of In Situ Responses. Convergence point measurements are too few to be used for the extrapolation of future in situ responses in the unlined section of the shaft. Thus, the readings of collar movements of multiple-point borehole extensometers must be used for this extrapolation. Because the extensometer collars are recessed 1 foot into the wall, and the readings are referenced to the deepest anchor which is also moving, extrapolation of collar movement will not produce an exact estimate of the movement of the shaft surface.

The maximum collar movement occurs at multiple-point borehole extensometer 37X-GE-00208 at a depth of 2,057 feet (elev. 1353 feet) (Figure 7-3). As discussed earlier, and as shown on Figure 7-9, the collar movement is affected by seasonal temperature fluctuations. However, if we consider only the later portion of the curve, its slope is approximately 0.125 inch/year between June 1984 and June 1985. Assuming this rate to be constant for another 22 years, the additional radial movement of the collar will be nearly 3 inches. Thus, the effective diameter of the unlined shaft will be reduced by nearly 6 inches.

Replication of In Situ Responses. Figures 7-24 and 7-25 show the radial and tangential stress distributions relative to the overburden stress at different times. Figure 7-24 indicates that the zone where radial stresses are affected increases in size with time while Figure 7-25 indicates that tangential stresses are only affected within an approximately constant radius of 60 feet.

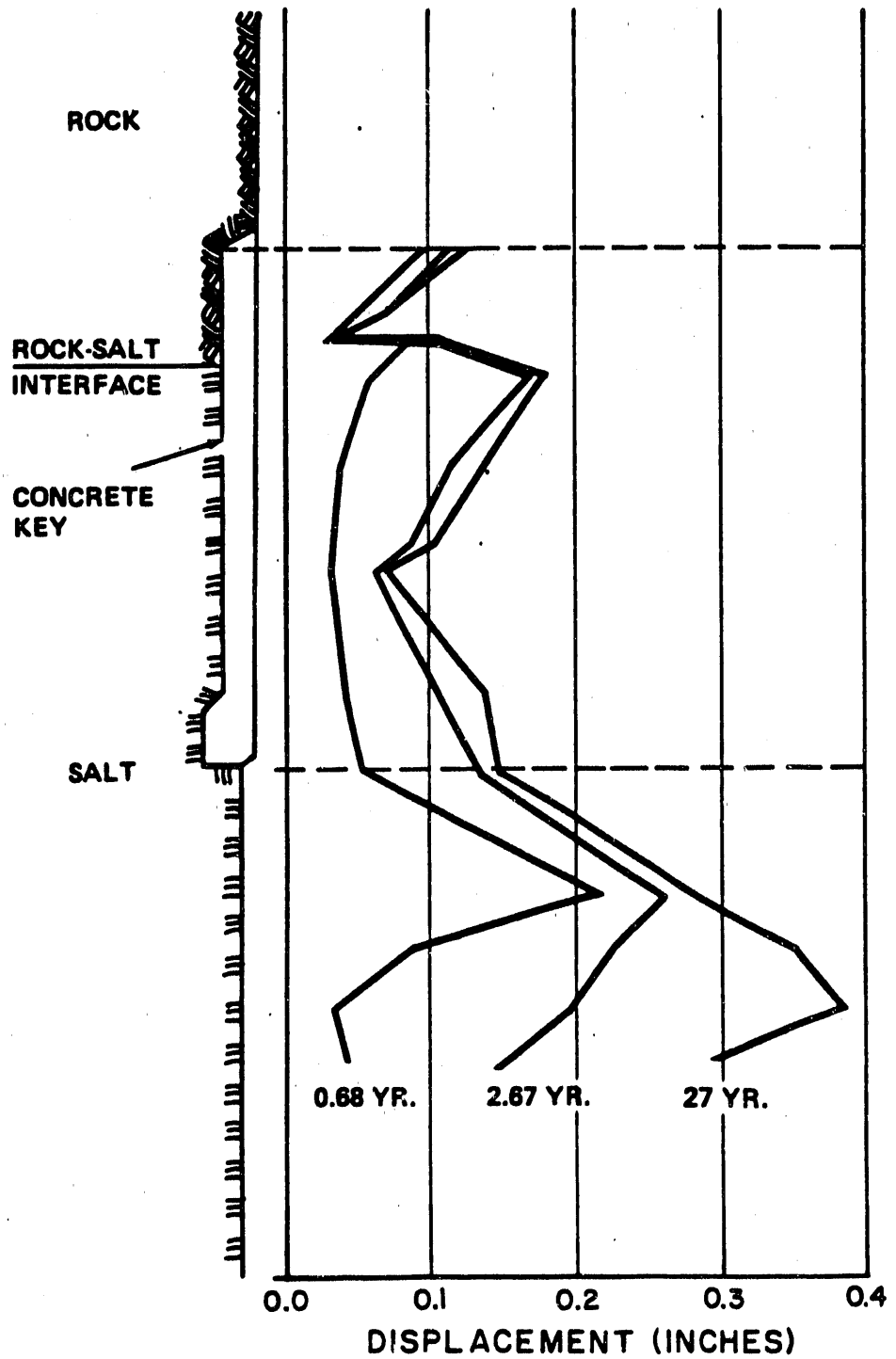


Figure 7-22

C & SH SHAFT KEY
DIAMETRIC CLOSURE

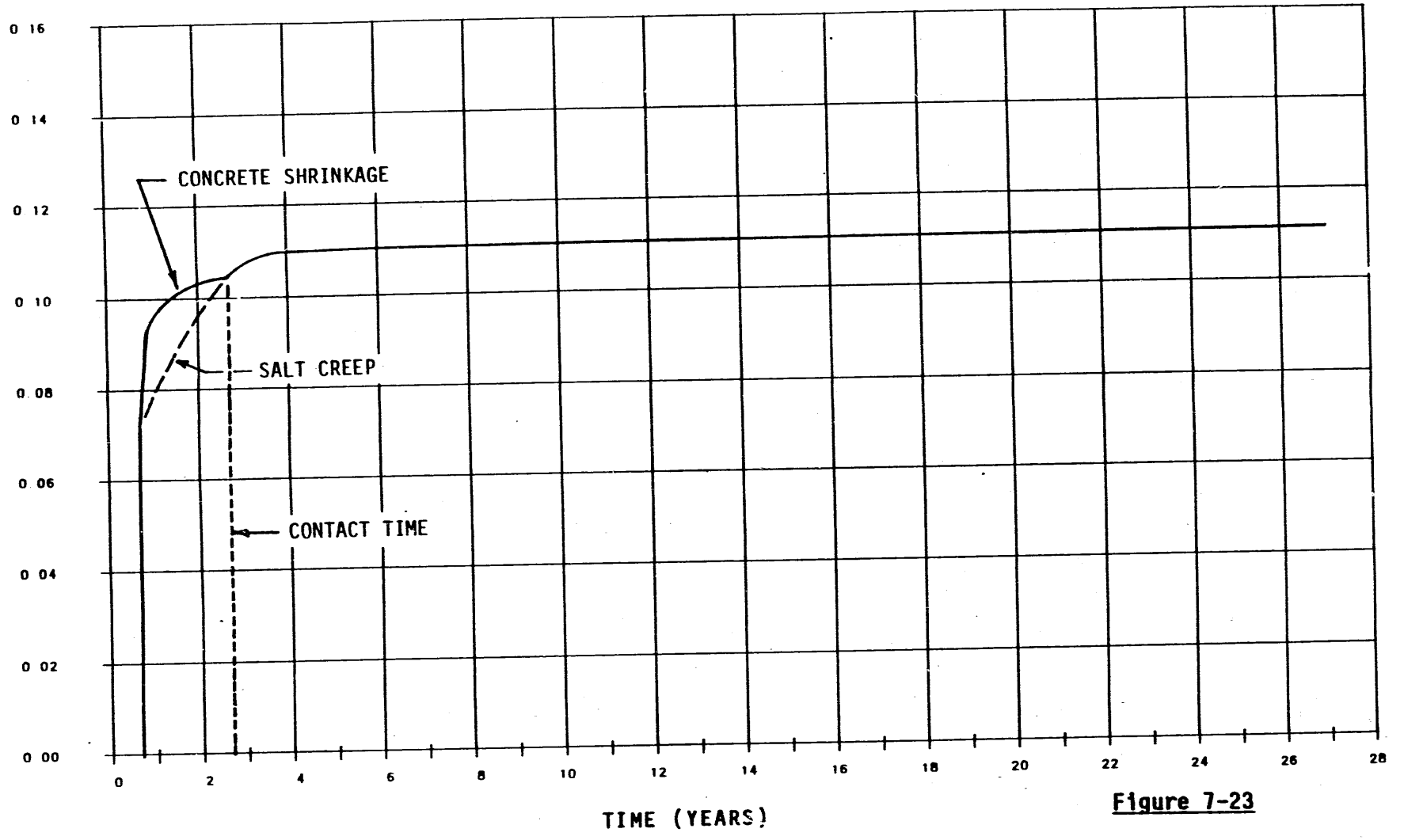
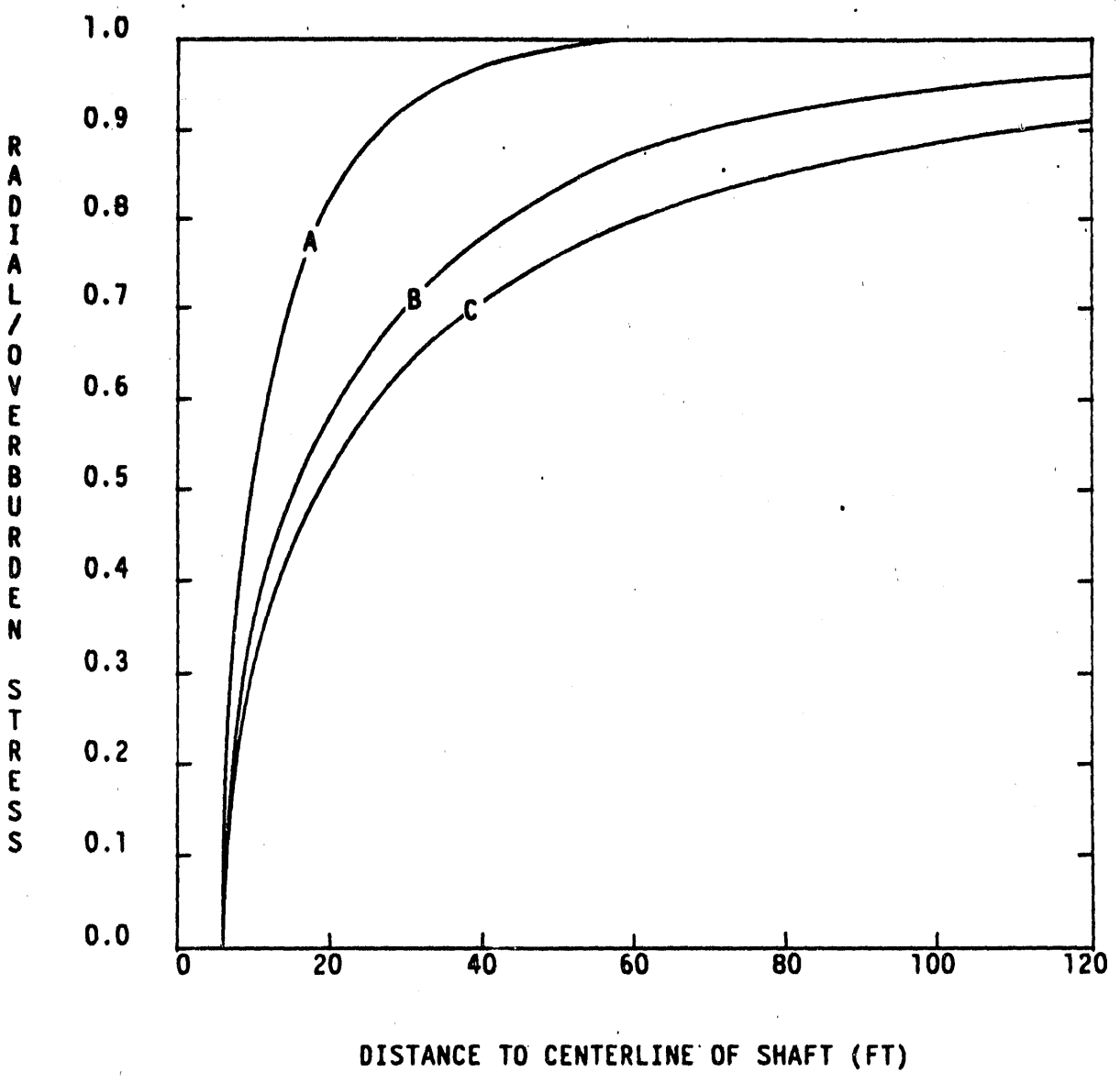


Figure 7-23

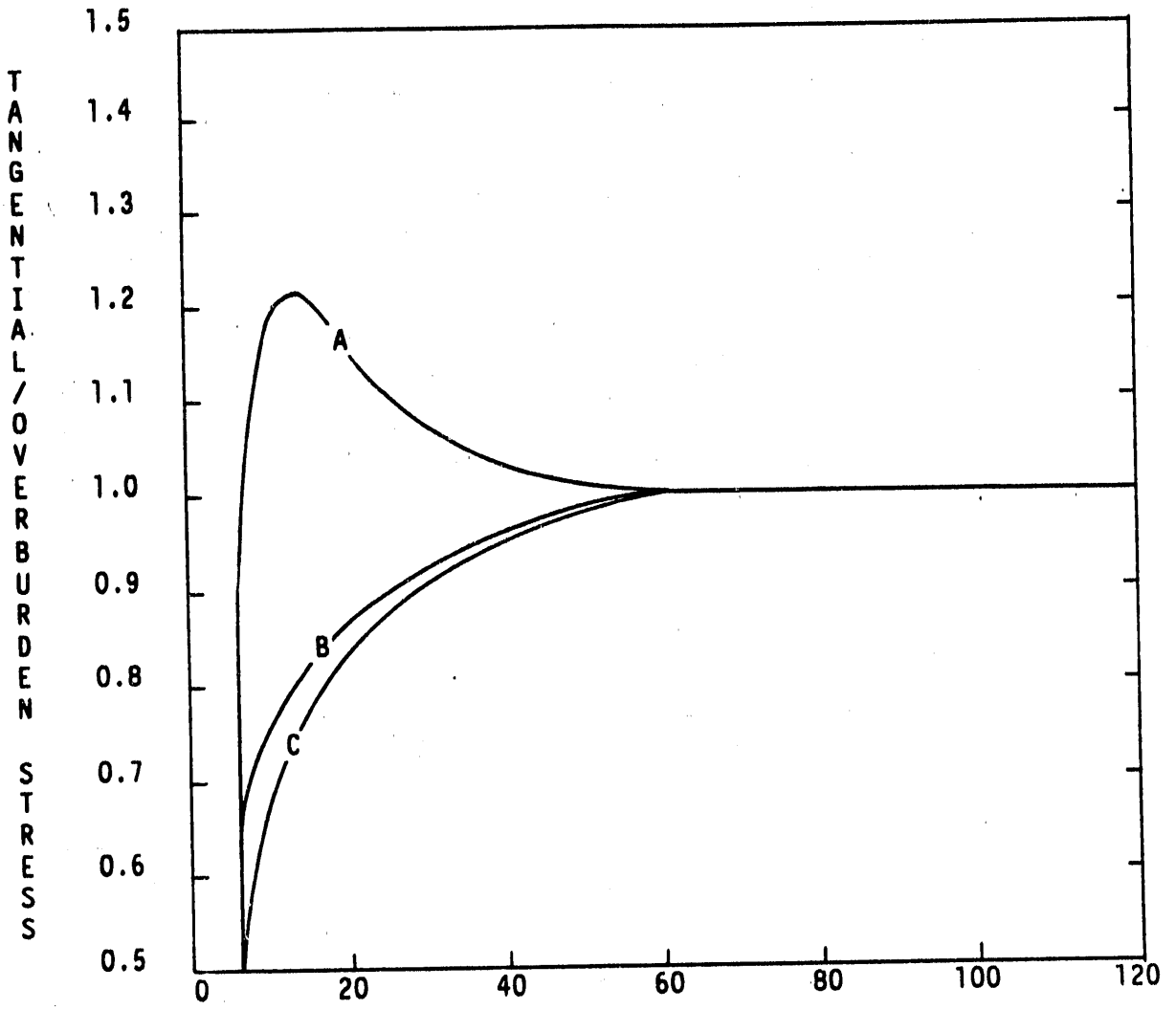
C & SH SHAFT KEY
DIAMETRIC CLOSURE PREDICTION



A – IMMEDIATELY AFTER EXCAVATION
B – ONE YEAR AFTER EXCAVATION
C – 15 YEARS AFTER EXCAVATION

Figure 7-24

C & SH SHAFT UNLINED SECTION
RADIAL STRESS DISTRIBUTION AT ELEVATION 1353



A – IMMEDIATELY AFTER EXCAVATION
B – ONE YEAR AFTER EXCAVATION
C – 15 YEARS AFTER EXCAVATION

Figure 7-25

C & SH SHAFT UNLINED SECTION
TANGENTIAL STRESS DISTRIBUTION AT ELEVATION 1353

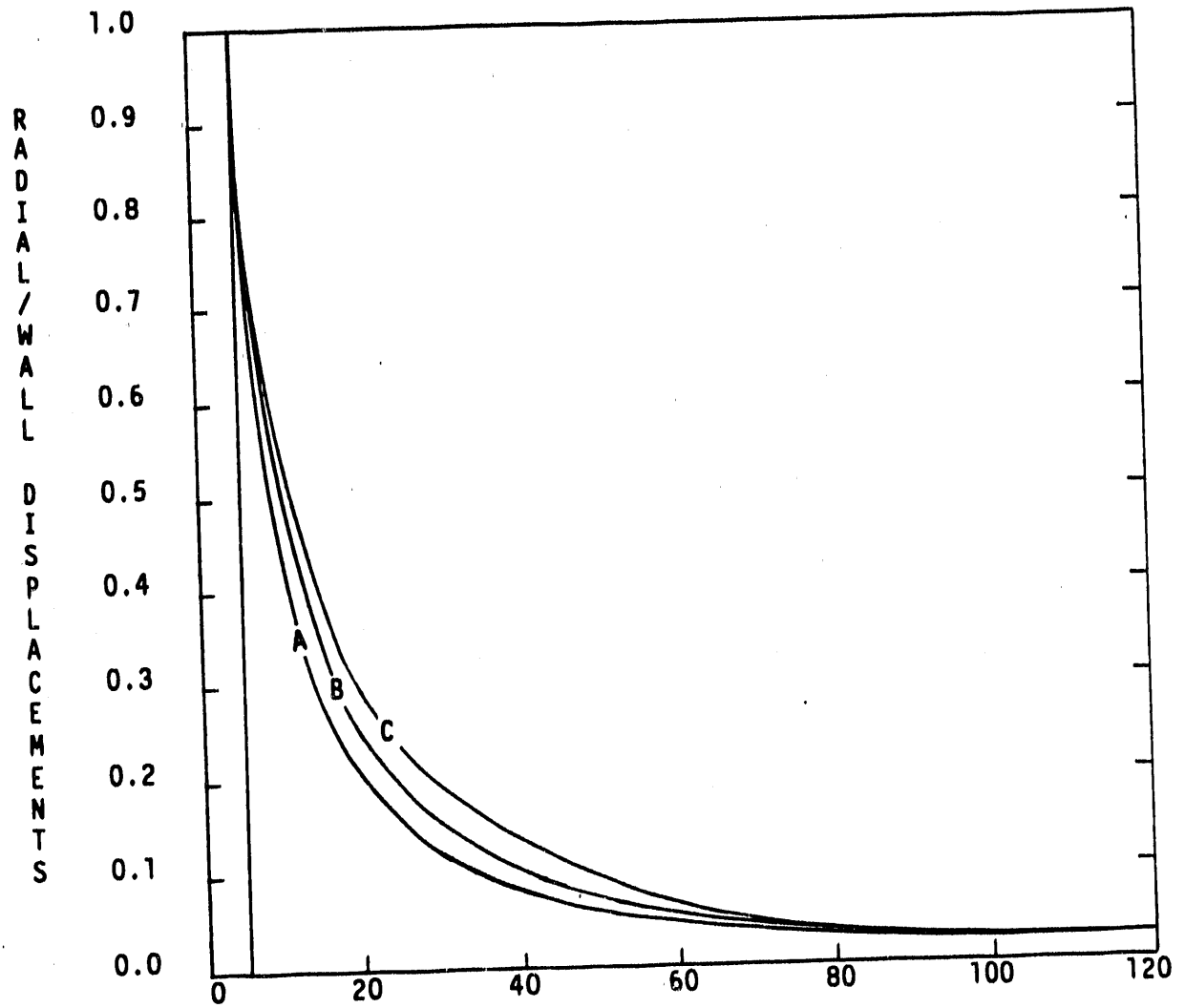
Figure 7-26 shows the ratio of radial displacements at various distances from the shaft centerline relative to the radial displacement of the shaft wall at different times. Based on this figure, the ratio of the displacements between each extensometer anchor point and the shaft wall can be determined. This figure indicates that the extensometer collar readings relative to the deepest anchor will reach about 84 percent of the actual radial displacement of the shaft wall 15 years after excavation.

Figure 7-27 illustrates the effective creep strain distribution in the shaft at a depth of 2,057 feet (elev. 1353 feet) at selected times after excavation. The magnitude of effective strain at the shaft wall at 15 years approaches a value of approximately 0.03.

Figure 7-28 shows diametric closure versus depth at different times. The response curves are drawn relative to the time the initial instrument readings were made. The response indicated by the curve to the left of the vertical axis corresponds to the computed response which took place between excavation and the initial instrument reading. The relative response between October 1982 and June 1984 is correct regardless of the time offset. Varying the time offset in effect shifts the position of all other response curves relative to the vertical axis. The diametric closure prediction at a depth of 2,057 feet is shown on Figure 7-29.

7.3.3.4 Shaft Station

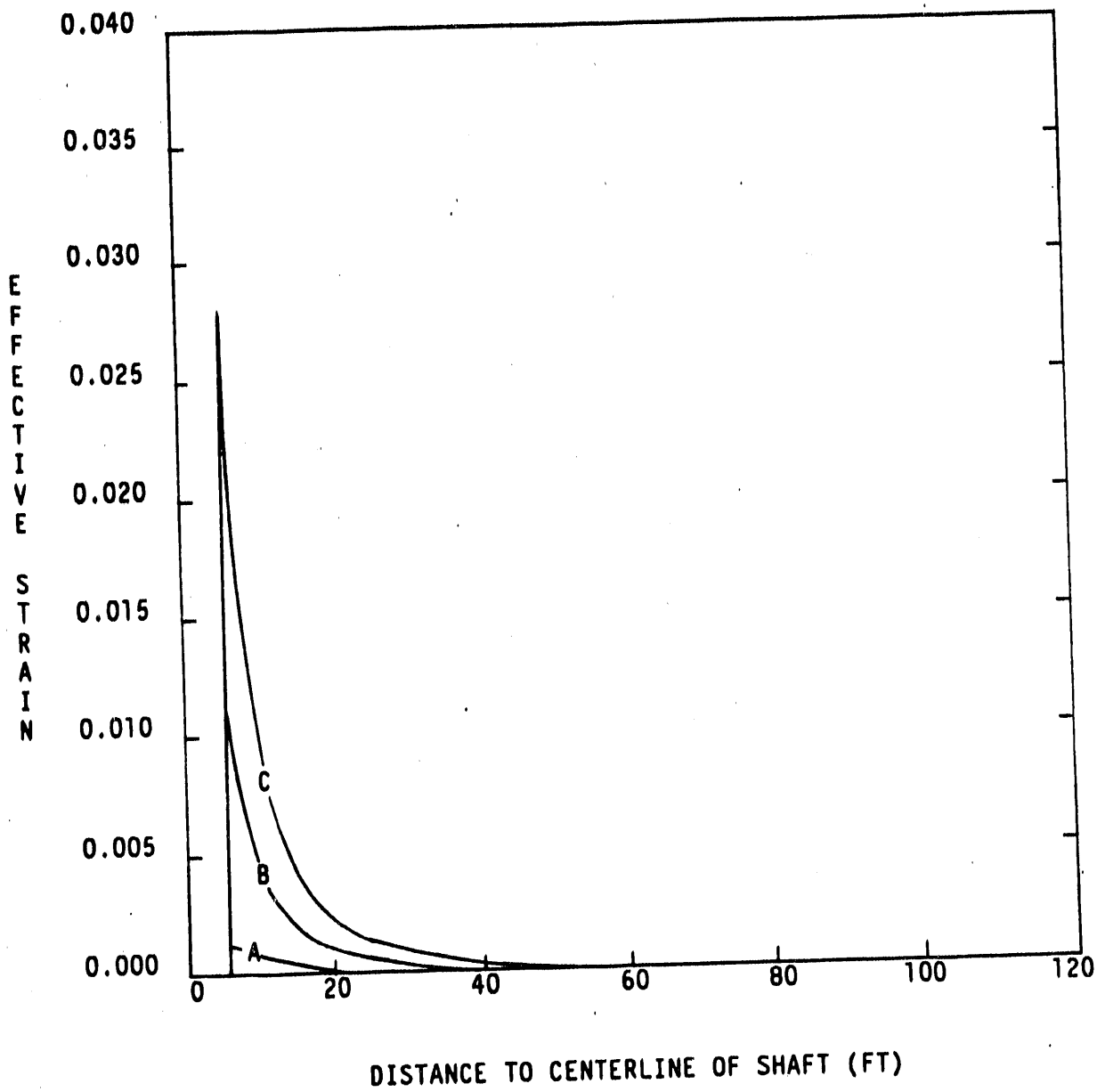
Figure 7-15 shows that, for roof extensometer 51X-GE-00251 in the C & SH shaft station, the relative movement between the collar and anchor A, expressed as a percentage of the collar reading, has remained practically constant for the last 2 years. Thus, provided that no failure of the mechanical-anchor rock bolts occurs, the closure rate of the roof is expected to stabilize. It is assumed that no new excavation will occur close to the station. If additional excavation is performed, the rate of closure between the roof and floor and between the walls may be accelerated.



A – IMMEDIATELY AFTER EXCAVATION
B – ONE YEAR AFTER EXCAVATION
C – 15 YEARS AFTER EXCAVATION

Figure 7-26

C & SH SHAFT UNLINED SECTION
RADIAL DISPLACEMENT DISTRIBUTION AT ELEVATION 1353



A – IMMEDIATELY AFTER EXCAVATION
B – ONE YEAR AFTER EXCAVATION
C – 15 YEARS AFTER EXCAVATION

Figure 7-27

C & SH SHAFT UNLINED SECTION
EFFECTIVE CREEP STRAIN DISTRIBUTION AT ELEVATION 1353

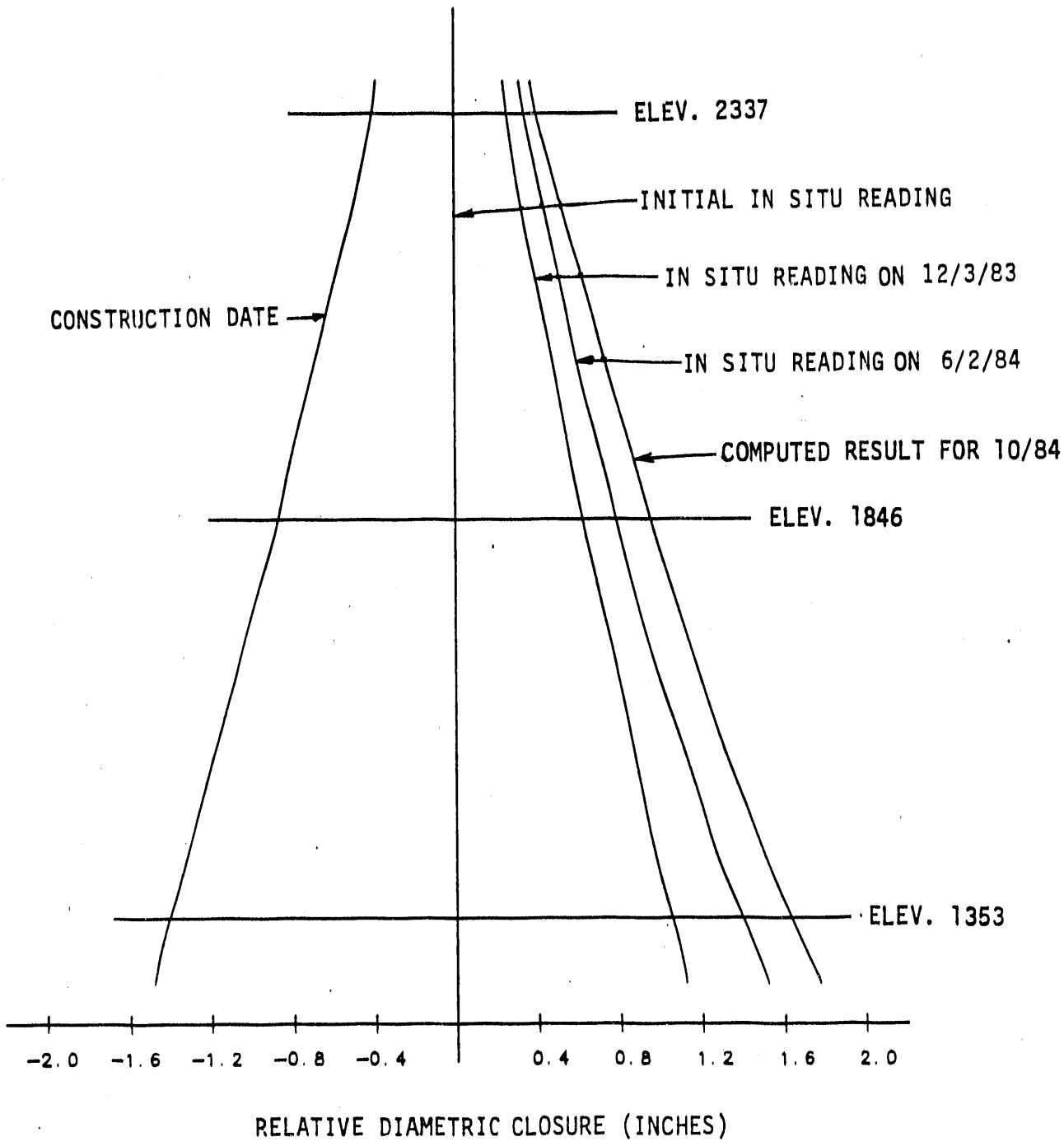
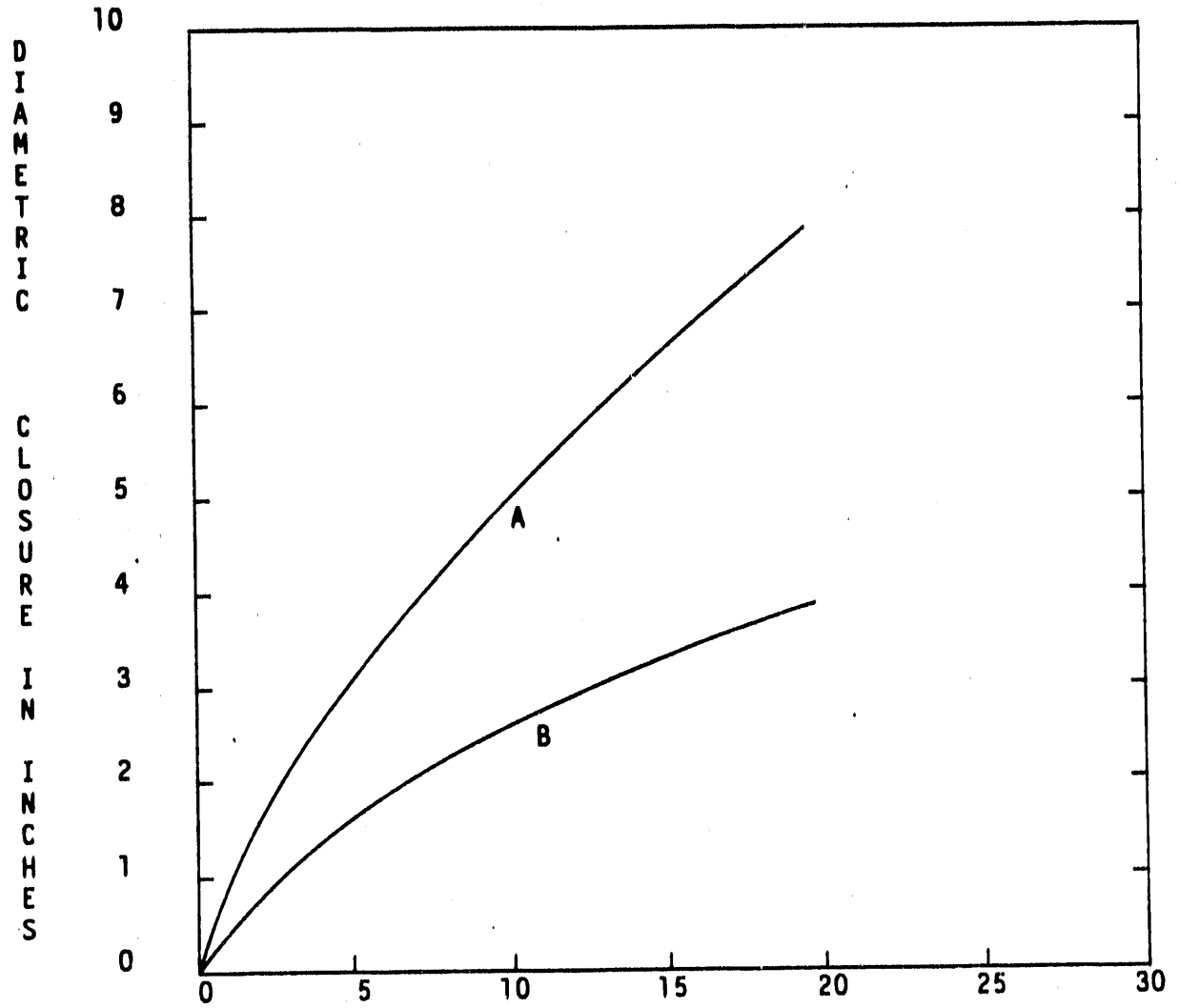


Figure 7-28

C & SH SHAFT UNLINED SECTION
RELATIVE DIAMETRIC CLOSURE



A – NORTH 17°40' WEST- MAJOR AXIS
B – NORTH 72°20' EAST- MINOR AXIS

Figure 7-29

C & SH SHAFT UNLINED SECTION
CLOSURE PREDICTION AT ELEVATION 1353

The rock bolts and wire mesh in the station roof will control spalling and stabilize the roof to provide a safe working environment but will not control salt creep. Although separations and fracturing have developed in the salt surrounding the shaft station, they exist on a much smaller scale than those observed in Test Room 3. They are expected to continue to develop throughout the operating life of the facility.

The total measured roof-to-floor closure in the C & SH shaft station was approximately 10 inches on September 16, 1985, nearly 3 1/4 years after the completion of excavation. The measured wall-to-wall closure over the same period was about 6 inches. Actual closure values are higher because the initial readings were taken nearly 260 days after the station was excavated. The average rate of roof-to-floor closure over the measurement period is approximately 3.89 inches/year. Assuming this rate will be constant throughout the operating life of 25 years, an additional roof-to-floor closure of about 8 feet is expected. Since the wall-to-wall closure is approximately 60 percent of the roof-to-floor closure, the additional wall-to-wall closure is expected to be nearly 5 feet.

7.4 CONCLUSIONS AND RECOMMENDATIONS

Design validation requires a determination of the compatibility of the design criteria, design bases and design configurations used in the reference design. Therefore, the following conclusions and recommendations address those criteria identified as applicable to the C & SH shaft in Chapter 2, Table 2-1, and the design basis elements presented in this chapter, Table 7-1. Other conclusions and recommendations that are a product of the design validation process are also presented.

7.4.1 Conclusions

Validation of the C & SH shaft reference design is based on a comparison of the applicable elements contained in the Design Criteria

and Design Bases documents with in situ conditions. These documents contain the requirements that the C & SH shaft must meet in terms of shaft stability, deformation, water pressure, water control, and shaft station stability and deformation.

Observations made during shaft inspections have not detected any signs of deterioration or instability. Due to its design pressure capacity, the liner is expected to remain stable even if the water pressure exceeds the design hydrostatic pressure.

The design basis assumption that the hydrostatic pressure begins 250 feet below the ground surface is suitable. Piezometer measurements indicate that the hydrostatic pressure is currently much less than the design basis pressure. These measurements are of sufficient accuracy to indicate that an anomalously high hydrostatic condition does not exist.

The design basis requirement that the key be designed to resist lateral pressure from the salt equal to 75 percent of the overburden pressure, approximately 640 psi, is suitable. The shaft key analysis indicates that the lateral pressure on the key at the end of 25 years will be approximately 275 psi. The lateral pressure capacity of the key is 833 psi. This provides for a factor of safety of about three. The analysis further shows that the maximum diametric closure expected for the key at the end of the operating period is only 0.175 inch. If the plastic flow or creep properties of the concrete were included in the analysis, the results would indicate that the design pressure would not be reached until after the 25-year operating life of the facility.

Based on the computed vertical, horizontal and effective stresses in the unlined section, the magnitude of stresses immediately adjacent to the opening decreases with time as the stress arch around the opening migrates away. The maximum stress occurs immediately after excavation and is followed by relaxation due to creep behavior. The stresses will, therefore, not cause a future stability problem in the unlined section of the C & SH shaft.

The analyses show the locations of effective creep strain concentrations in the unlined section of the shaft at different times. It is predicted that the maximum effective creep strain will not exceed 0.05 at the end of the operating life of the shaft. Based on the effective creep strain limit discussed in Chapter 6, the structural stability of the C & SH shaft will remain within required safety limits during its operating life.

The analyses also predict that the diametric closure near the bottom of the shaft at the end of its operating life will be approximately 10 inches along the major axis of principal strain, approximately 18 degrees from the longitudinal direction of the shaft tubular steel supports (buntons). Based on the predicted deformations and closures, the unlined section of the shaft will meet the requirements stated in the design criteria. The diameter of approximately 12 feet in the unlined section will allow for salt creep over the operating life, as required by the design bases. However, based on the design configuration of the C & SH shaft, the connections at both ends of some buntons do not provide sufficient allowance for longitudinal adjustment.

The C & SH shaft reference design complies with the criteria that require control of ground-water flow. This conclusion is made despite the fact that considerable instrumentation damage has been caused by water flow. This water has seeped into the shaft through holes cut in the liner for piezometer installation or is a result of direct rainfall. The piezometer leakage problem has been addressed and will receive additional corrective attention during a future shaft renovation. The rainwater does not reach the facility level in any significant or measureable quantity.

The chemical water seal just below the key piezometers is probably breached. The lowest water seal in the key is functioning properly. The water draining from the telltale drains has a local source. Therefore, it is concluded that there is no solutioning of the salt behind the key.

The C & SH shaft station exhibits the highest degree of deterioration in the underground facility. This is considered to be the result of the effects of blasting for initial excavation of the station. The station roof has been stabilized by rock bolting and no further significant deterioration is expected. However, removal of the 3-foot thick salt beam between the roof and clay G may be required for safety reasons in the future. Closure will continue at a rate of 3.89 inches/year vertically and 2.33 inches/year horizontally. Total closure after 25 years will be on the order of 8 feet vertically and 5 feet horizontally. This closure will require that the station roof or floor, and walls be trimmed periodically to maintain the design dimensions.

Separation and fracturing in the salt is expected to continue in the station roof and beneath the floor. Both closure and fracturing in the station will necessitate periodic maintenance during its operating life in order to maintain safety as well as the required clearances for equipment and operations.

The reference design for the C & SH shaft is validated based on the preceding discussions. The reference design complies with the design criteria and design bases. Except for instrument repair and maintenance, no modifications are required to the shaft reference design. The C & SH shaft will perform its functions as required during the operating life of the facility.

7.4.2 Recommendations

Based on the results of design validation, the following recommendations are made with respect to the C & SH shaft:

(1) Water behind the shaft key is undesirable and should be monitored carefully. If the volume of water behind the key increases, or if water starts flowing from beneath the key, past the lower water seal, it may become necessary to inject grout above the top water seal in the key. Grout should not

be placed behind the key (below the top seal) unless absolutely necessary. If this cannot be avoided, the grout must be a chemical gel (or other non-rigid grout) and must be compatible with both the existing water seal material and with the Plugging and Sealing Program requirements.

(2) Based on the results of design validation of the C & SH shaft, it is recommended that, during inspection of the shaft furnishings, the bunton connections should be inspected for closure allowance. If the allowance is insufficient, corrective action should be taken to provide for additional closure.

(3) The observation holes drilled in the roof of the shaft station to monitor displacements and separations, and in the floor to monitor fracturing, should be maintained. Continued observations of conditions in these holes will be valuable in assessing the safety and stability of the station.

CHAPTER 8
WASTE SHAFT

8.1 INTRODUCTION

The waste shaft provides the connection between the surface waste handling facilities and the underground storage level. A discussion of shaft construction was presented in Chapter 3 and geologic characterization of the shaft stratigraphy was presented in Chapter 6. This chapter presents discussions of the design criteria and design bases pertaining to the waste shaft. It documents the collection of waste shaft geotechnical data, its analysis and evaluation, and presents predictions of future shaft behavior. Conclusions and recommendations are presented based on a comparison of the results of the design validation process with the shaft reference design.

8.2 DESIGN

This section presents the design criteria and design bases used to develop the reference design for the waste shaft. The design configuration of the shaft is discussed in Chapter 3, subsection 3.3.2.

8.2.1 Design Criteria

The design criteria for the waste shaft are the same as those for the C & SH shaft. The criteria requiring validation are indicated in the listing of abridged criteria presented in Chapter 2, Table 2-1, and are discussed in Chapter 7.

The design criteria requiring evaluation for design validation of the waste shaft are:

(1) shaft shall be designed to be structurally stable;

(2) shaft shall be designed to accommodate salt creep;

(3) ground-water flow into the shaft shall be controlled;

(4) underground openings (i.e. waste shaft station) shall be designed to accommodate deformation; and

(5) underground openings shall be stable.

8.2.2 Design Bases

The Design Basis, Waste Shaft (ref. 2-15) was the primary document used as a guide for waste shaft design. The major elements of this basis are summarized in this subsection. Only a few of these elements must be evaluated or have a direct impact on design validation. These particular elements are presented in Table 8-1.

The design bases specify that the waste shaft shall be designed to transport personnel, materials and radioactive waste. It shall also serve as an intake shaft for a small volume of air during normal operations and as an escape route during emergency operations.

The shaft shall be lined with unreinforced concrete from the bottom of its collar in the waste handling building to the top of the shaft key at the rock/salt interface. The liner shall be permanent and shall protect against spalling, fallout and deterioration of the rock in the shaft wall. It shall also prevent water seepage into the shaft.

The shaft liner shall be designed in compliance with applicable ACI Codes. A load factor of 1.4 shall be used for designing the concrete liner. The specified concrete compressive strength shall be 5,000 psi. No lateral rock pressure shall be assumed for design of the shaft liner. Hydrostatic pressure shall be considered to start at 250 feet below the ground surface and extend to the rock/salt interface at the top of the key. The water pressure shall be considered to increase 0.437 pounds per square inch (psi) for each foot of depth.

At water-bearing zones, the shaft shall be enlarged and liner plate installed to provide pressure relief and drainage space behind the liner during concrete placement and curing. Drainage pipes and

Table 8-1

VALIDATION ELEMENTS OF WASTE SHAFT DESIGN BASES

(1)	Shaft liner Hydrostatic pressure is considered to start at 250 feet below the ground surface and extend to the top of the key.
(2)	Shaft key Design lateral pressure shall be 50 percent of the vertical pressure due to soil, rock and salt overburden.
(3)	Unlined section Provide 20-foot diameter to allow for future salt creep deformation.

temporary hoses shall be installed to control water inflow prior to placement of the concrete liner. When the concrete liner has attained adequate strength, the area behind the liner plate shall be grouted to preclude deterioration of the dolomite and mudstone in the water-bearing zones.

The shaft key at the bottom of the concrete liner shall be constructed of reinforced concrete keyed into the rock and salt strata. A chemical water seal shall be placed behind the top and bottom of the key to prevent the migration of water. After the completion of shaft excavation and construction of the concrete liner and key, permanent piping from water collection rings to the shaft station shall be installed. Water from the collection rings shall be piped to a tank in the shaft station and then transported to the surface. The piping shall include inspection and clean-out fittings. Inspection and cleaning of the water collection rings and drainage piping shall be performed as necessary.

A load factor of 1.7 shall be applied to the design loading used for the concrete in the shaft key. The key shall be designed to resist lateral pressure generated by salt creep. The design lateral pressure shall be 50 percent of the total vertical pressure due to the soil, rock and salt overburden.

Below the key, the shaft shall be excavated 20 feet in diameter to allow for future salt creep deformation. Rock bolts and wire mesh shall be installed in this unlined section of the shaft in order to provide a structurally stable salt surface.

A shaft station shall be excavated at the storage level. The shaft shall extend below the storage level to such a depth as required by the hoisting equipment and sump. The use of rock bolts and wire mesh shall be dictated by the condition of excavated surfaces as well as code requirements. The roof, walls and floor shall be checked periodically for loose salt in accordance with applicable codes. The tolerance for

excavation of roof, floor and wall surfaces shall be no greater than plus 6 inches. In no case shall the finished cross section dimensions be less than the design dimensions.

Geomechanical instruments shall be installed to measure water pressure behind the shaft liner, salt creep pressure behind the key, and radial convergence in the unlined section of the shaft. The types of instruments installed shall be piezometers, pressure cells, radial convergence points and extensometers.

The shaft, including the liner, key, unlined section, station and furnishings, shall be inspected at 1 month intervals, or as required by applicable codes, to detect cracking, corrosion, deterioration and water intrusion.

8.3 DESIGN VALIDATION PROCESS

The design validation process for the waste shaft consists of analytical calculations, finite element modeling, and the analysis of data collected from geomechanical instruments installed in the C & SH and waste shafts. The in situ material parameters of salt determined from C & SH shaft instrumentation data were used to analyze the closure behavior of the waste shaft. For the shaft station, the in situ measurement data obtained from the C & SH shaft station were used to predict future closure behavior. The following subsections present information pertaining to validation of the waste shaft reference design.

8.3.1 Data Collection

Data collection in the waste shaft has consisted of geologic mapping, visual observations and geomechanical instrumentation measurements. Data obtained from the geologic mapping were presented in Chapter 6. The following subsections discuss the field observations and the geomechanical instrumentation in the shaft.

8.3.1.1 Field Observations

Waste shaft inspections have been concerned primarily with water seepage through the concrete liner, salt incrustation on the surface of the liner, dissolution in the shaft sump and the results of the liner grouting program.

Water seepage through the waste shaft liner has occurred since construction. As discussed in Chapter 3, subsection 3.4.2, grouting during construction behind the steel liner plate at both the Magenta and Culebra members did not completely prevent water from entering the shaft. It was estimated that the total water seepage through the liner was approximately 0.5 gallons per minute (gpm). A remedial grouting program (ref. 3-3), conducted from August 11 through August 25, 1984, reduced the seepage to about 0.015 gpm as measured in October 1984. Subsequent inspections in February and June 1985 determined that fresh water had begun seeping through cracks and construction joints in the liner from zones within and above the grouted area. The highest level of water seepage was occurring at a depth of only 60 feet below the shaft collar. Because this is higher than the potentiometric surface of ground water in the Magenta and Culebra members, the source of the seepage was probably rainwater and construction water contained in the backfill around the shaft collar and in the underlying Gatuna sandstone. This is based on the fact that heavy rains in the late summer of 1984 left substantial quantities of water ponded in the waste-handling building excavations and in the remnant of the SPDV ventilation shaft drilling fluid reserve pit.

The initial rate of this renewed seepage could not be measured because the PVC drainpipe had been broken in several places. Subsequent repair of the drainpipe has permitted the rate of water inflow to be measured on a regular basis. The measurements are obtained by timing the flow of water from the drainpipe into a calibrated bucket. These measurements do not consider the small amount of uncontrolled "fly water" that falls down the inside of the shaft. The initial measurement, in January 1986, was 0.47 gpm. The measurements, are

plotted on Figure 8-1 and show a generally decreasing trend in the flow rate. This trend may be influenced by three factors. First, the water contained in the backfill and sandstone has slowly drained into the shaft. Second, the rate of evaporation increases as the outside air temperature increases, thus reducing the amount of water reaching the drains. Both of these conditions are temporary. A series of rainstorms could recharge the backfill and sandstone, and evaporation will decrease with cooler winter temperatures. Heavy rains in June 1986 may have been responsible for the increased flow detected by the late June reading. The third factor influencing the flow trend is the possibility that the water collection rings and the drainpipe may be partially blocked by debris. This would result in reduced water flow through the drainpipe and an increase in the amount of unmeasureable fly water.

Although there has been limited access to the waste shaft since August 1984, several inspections of the shaft and sump have been made. One inspection was made on February 21, 1985, at which time some instrumentation damage was observed. In addition, the PVC drainpipe was observed to have been broken in several locations. Appreciable salt incrustation was noted on the surface of the concrete liner and on many of the instrumentation boxes and cables. This incrustation was primarily attributed to salt dust from the underground excavation adhering to the damp shaft walls during the period since September 1984 when the waste shaft was used as an exhaust shaft. A small percentage of this salt incrustation was also attributed to water seepage through the liner.

On June 16, 1985, another inspection of the waste shaft was made to within 60 feet of the shaft station. The shaft ventilation had been changed from upcast to downcast after the February inspection. Very little salt incrustation was present on the concrete liner and only a small amount was present in places on the wire mesh. Fresh water entering the shaft through the liner, from approximately 60 feet below the collar, was running down the liner. Although much of the liner was

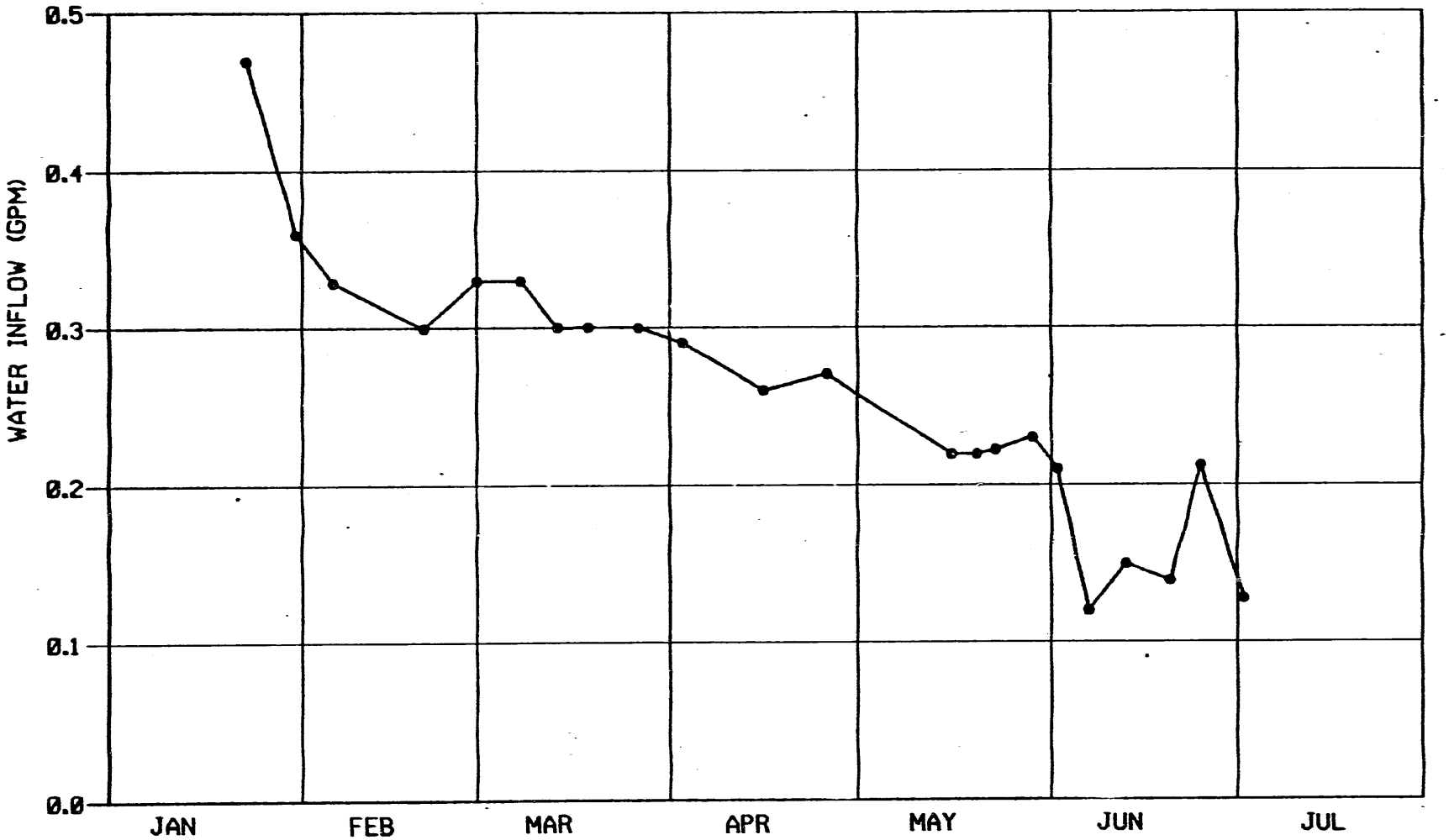


Figure 8-1

WASTE SHAFT
WATER INFLOW MEASUREMENTS

observed to be wet, the water rings were not full. This water appeared to have dissolved the salt incrustation observed in the February 1985 inspection. Cracks were common in the liner to within 60 feet of the collar. The PVC drainpipe damage had not been repaired. No water was seen draining from below the concrete key. The shaft sump contained water to within 60 feet of the shaft station floor. This water was a combination of rainwater, construction water and ground water. It was pumped out in September 1985.

On December 1, 1985, another inspection of the waste shaft was made. The PVC drainpipe was still broken or disconnected at several levels. The water rings were plugged and overflowing. There appeared to be an increase in water flow into the shaft, most noticeably at the Culebra member. An approximately 1/8- to 1/4-inch thickness of salt had been deposited on the liner below the Culebra.

On December 11, 1985, an inspection of the waste shaft sump was made. During this inspection, and a subsequent inspection on December 12, 1985, MB-139 was observed closely. The clay along the lower contact was distinct and no separations were noted. Although the upper contact could not be distinguished behind a covering of wire mesh, MB-139 could be seen quite well and appeared to be intact and undisturbed. One small fracture, approximately 2 feet long and 1/2 inch wide was observed on the west side of the shaft approximately 1 foot above the lower contact.

An anhydrite bed 61 to 66 feet below the station floor was also observed during this inspection. A zone of dissolution was present along the upper contact of this layer in the northwest to southeast half of the shaft. The dissolution occurred partially within the anhydrite bed. The maximum void width of approximately 0.7 foot occurred on the south-southwest side of the shaft and extended approximately 18 feet south into the salt. The zone of dissolution pinched out going around the shaft in either direction away from the area of maximum opening. There did not appear to be any disturbance of

the strata overlying or underlying this zone anywhere around the shaft and no voids or disturbance of the anhydrite existed on the opposite side of the shaft. The upper contact of the anhydrite with the overlying halite did not exhibit any irregularities. From the physical evidence available, it appeared that this feature was the result of localized dissolution. No dissolution of the anhydrite was observed. The dissolved material was probably a soluble evaporite mineral representing a facies change within the Salado formation. The dissolution appeared to have resulted from the previously discussed water which had been standing in the sump. The level of this water was measured at 60 feet from the shaft station floor prior to its being pumped out in September 1985. The shaft wall below the water line exhibited no significant deterioration due to the standing water. However, some sloughing of an anhydrite layer 71 to 75 feet below the shaft station floor and widening of the shaft near the bottom of the sump was evident. The shaft wall exhibited a glazed surface which probably resulted from minor dissolution of the salt surface.

A shaft inspection was conducted on July 24, 1986. The inspection team mapped the location of cracks in the concrete liner and any associated seepage. They also mapped the location of leaking construction joints. This mapping indicates that additional cracks have developed in the liner since mapping was conducted prior to the August 1984 grouting program. The shaft was found to be considerably drier than during the 1984 mapping program. Many of the new cracks mapped may have existed in 1984 but were masked by the water on the shaft walls. Also, salt precipitates now enhance the outline of the cracks. The inspection also revealed that recent construction work inside the shaft has resulted in some instrument cable and junction box damage and in breakage of the previously repaired PVC drainpipe.

The waste shaft station has shown little deterioration since it was enlarged from the SPDV ventilation shaft station dimensions. Visual surveys are performed approximately every 3 months by site geologists. The results of these inspections are documented in the GFDRs. Only

minor spalling along the station walls has occurred. Vertical fractures similar to those found in the drifts and test rooms have developed at intersection corners. The roof, although showing no visible evidence of deterioration, has been covered by wire mesh and rock bolts for safety purposes. During the July 1986 shaft inspection, some separation at clay G was observed on the east and west sides of the shaft. The separation was a maximum of 3/4 inch wide at the shaft surface and decreased away from the shaft. No separation was observed at clay H.

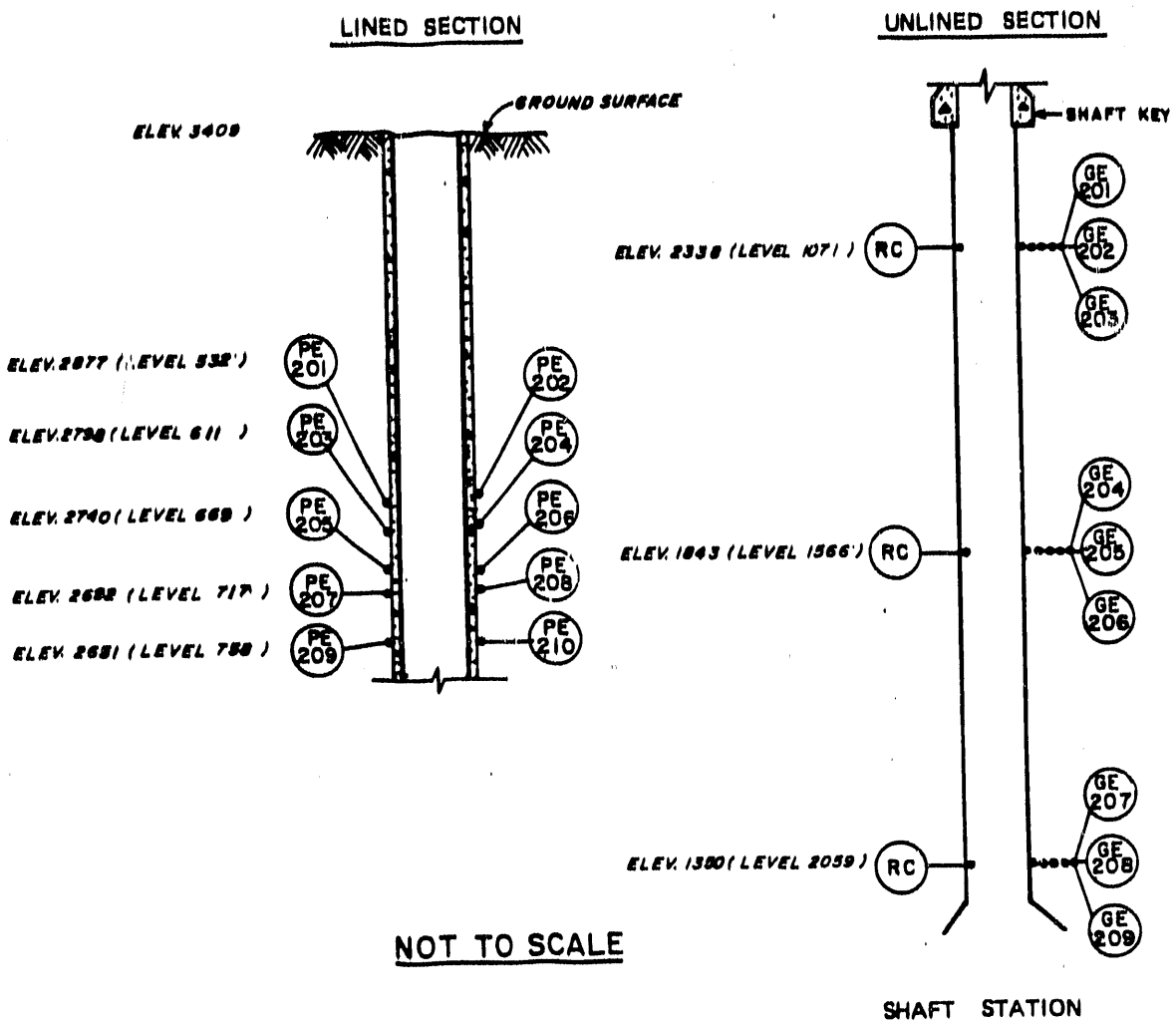
Minor separations and fracturing in MB-139 and in the overlying halite have been observed in the station floor. A dish-like fracture zone similar to that found in Test Room 2 is present, but has developed on a much smaller scale. Inspection of MB-139 in the shaft sump, and evidence from boreholes drilled in the station floor, show that the marker bed and the overlying halite are, for the most part, intact.

8.3.1.2 Geomechanical Instrumentation

The waste shaft geomechanical instrumentation is similar in design to that of the C & SH shaft. The shaft contains 12 vibrating-wire piezometers, 4 pressure cells, 9 multiple-point borehole extensometers, and 3 sets of radial convergence points. Figure 8-2 shows the instrument locations in the waste shaft and Figure 8-3 shows details of the key instrumentation.

As in the C & SH shaft, all of the geomechanical instruments, except the convergence points, are monitored remotely. The instruments are connected to the surface datalogger that polls all of the remotely-read underground instruments on a scheduled basis.

The 12 piezometers were installed on September 7 and 8, 1984, after the 6-foot diameter SPDV ventilation shaft had been enlarged to become the 20-foot to 23-foot diameter waste shaft. The water that could exert pressure on the liner is expected to come from the two water-bearing members in the Rustler formation. The Magenta dolomite member occurs



LEGEND

(PE) PIEZOMETER

(RC) CONVERGENCE POINTS

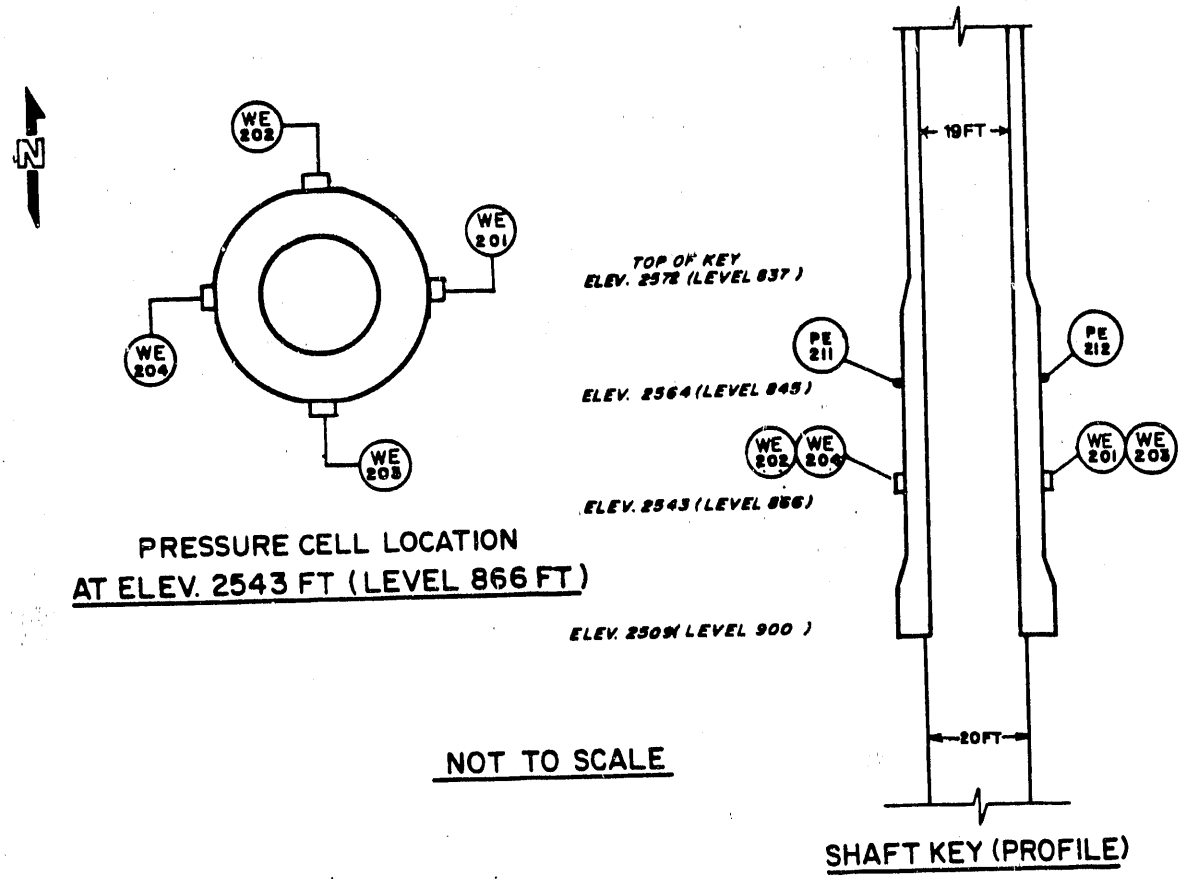
(GE) EXTENSOMETER

NOTES:

1. PC'S AT EACH LEVEL CONSIST OF FOUR POINTS.
2. THE TERM "LEVEL" IS AN APPROXIMATE DEPTH IN FEET FROM THE SHAFT COLLAR AT ELEVATION 3409 FT MSL
3. SEE FIGURE 8-2 FOR DETAILS OF SHAFT KEY INSTRUMENTATION.

Figure 8-2

WASTE SHAFT
INSTRUMENTATION



LEGEND

(WE)-PRESSURE CELL

(PE)-PIEZOMETER

NOTES:

1. THE TERM "LEVEL" IS AN APPROXIMATE DEPTH IN FEET FROM THE SHAFT COLLAR AT ELEVATION 3409 FT MSL
2. PRESSURE CELLS LOCATED AT CONCRETE-ROCK INTERFACE.

Figure 8-3

WASTE SHAFT KEY
INSTRUMENTATION

from a depth of 596 feet to 621 feet (elev. 2813 to 2788 feet) and the Culebra dolomite member from a depth of 706.5 feet to 728.5 feet (elev. 2702.5 to 2680.5 feet). Two piezometers are at each of the following elevations: 2877, 2798, 2740, 2692, 2651 and 2564 feet (Figures 8-2 and 8-3). The piezometers are located on opposite sides of the shaft, one at N60°E and the other at S60°W. Piezometer readings are shown on the data plots in Appendix J.

The four pressure cells are located in the waste shaft key between the salt of the shaft wall and the concrete comprising the key. The pressure cells were installed at a depth of 866 feet (elev. 2543 feet). The four cells are spaced 90 degrees apart around the shaft at the north, east, south, and west positions (Figure 8-3). Initial pressure cell readings were taken on April 6, 1984. The waste shaft key concrete was placed between March 23 and April 3, 1984. Pressure cell data plots are also presented in Appendix J.

The extensometers and convergence points were installed only in the unlined section of the shaft below the key. These instruments, whose locations are shown on Figure 8-2, were installed after enlargement of the shaft to its final dimensions.

The nine multiple-point borehole extensometers were installed between August 31 and September 5, 1984, 3 to 5 months after the completion of shaft enlargement. Three extensometers each are located at three elevations in the unlined section of the shaft: 2338, 1843 and 1350 feet (Figure 8-2). The extensometers are spaced 120 degrees apart around the shaft. Plots of the readings are presented in Appendix J.

A set of radial convergence points, consisting of four points each, is located at each of the same elevations as the extensometers. The convergence points were installed immediately after enlargement of the shaft. Due to interference by shaft furnishings, it was not possible to set the convergence points at 90 degrees from each other. The set of convergence points at a depth of 1,071 feet consists of two points

on each side of the shaft conveyance furnishings. The two points were set 44 degrees apart. At the other two depths the two points on each side of the shaft are set 53 degrees apart. Convergence point readings were obtained from April through June 1984 and are plotted in Appendix J. However, their performance is considered poor and erratic. The readings have been affected by salt incrustation on the convergence point eyebolts and extensions. Convergence point readings were discontinued when the temporary waste shaft hoist was decommissioned on September 12, 1984. The convergence points will be inaccessible until approximately December 1986, when the permanent waste shaft hoist is installed.

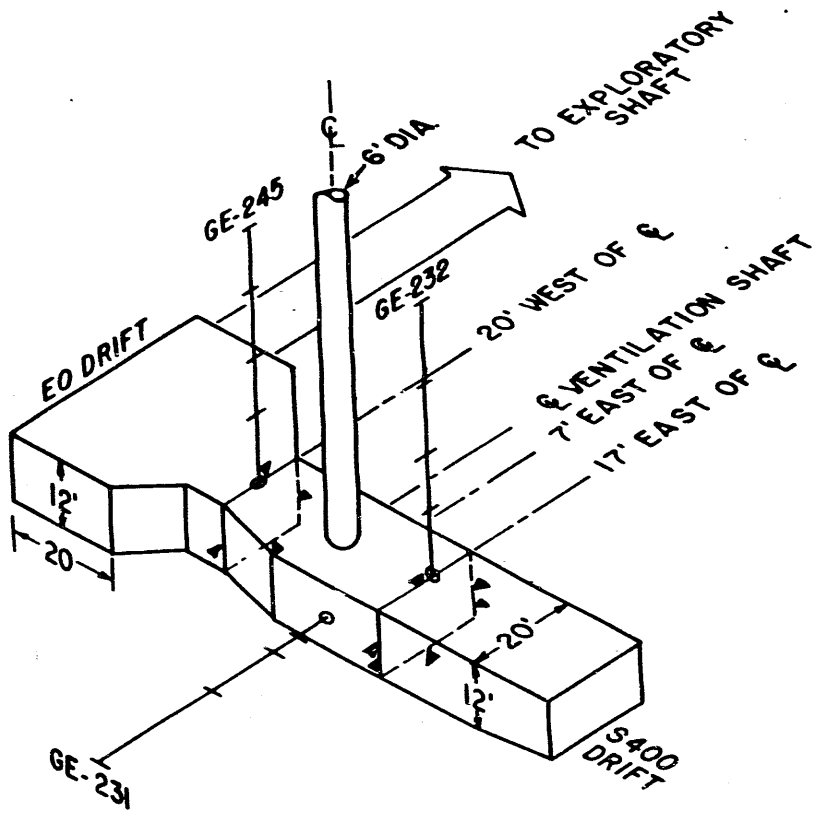
Geomechanical instruments were installed in the SPDV ventilation shaft station in late 1982. The instrumentation consisted of three multiple-point borehole extensometers and two sets of convergence points as shown on Figure 8-4. When the shaft was enlarged to become the waste shaft, the station was also enlarged and the original instruments were destroyed. Two extensometers were then installed in the enlarged shaft station. Both of these extensometers are in the roof, one on either side of the waste shaft (Figure 8-5).

8.3.2 Analysis and Evaluation

Analysis of the waste shaft data and its evaluation against reference design parameters has been divided into four elements: the concrete-lined section of the shaft; the shaft key; the unlined section; and the shaft station. This division is based on the different in situ and design conditions in each of these areas.

8.3.2.1 Lined Section

Engineering mechanics principles were used to design the concrete liner against elastic buckling. Both axial and flexural stresses were considered in the design. Permissible stress values were those used for structural plain concrete (ref. 8-1) utilizing the ultimate strength design method. Since there are no significant salt strata in



EXPLANATION

ANCHOR — COLLAR — GE EXTENSOMETER

RC RADIAL CONVERGENCE POINT

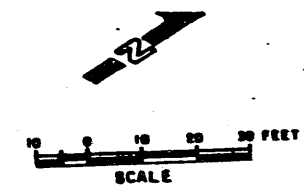
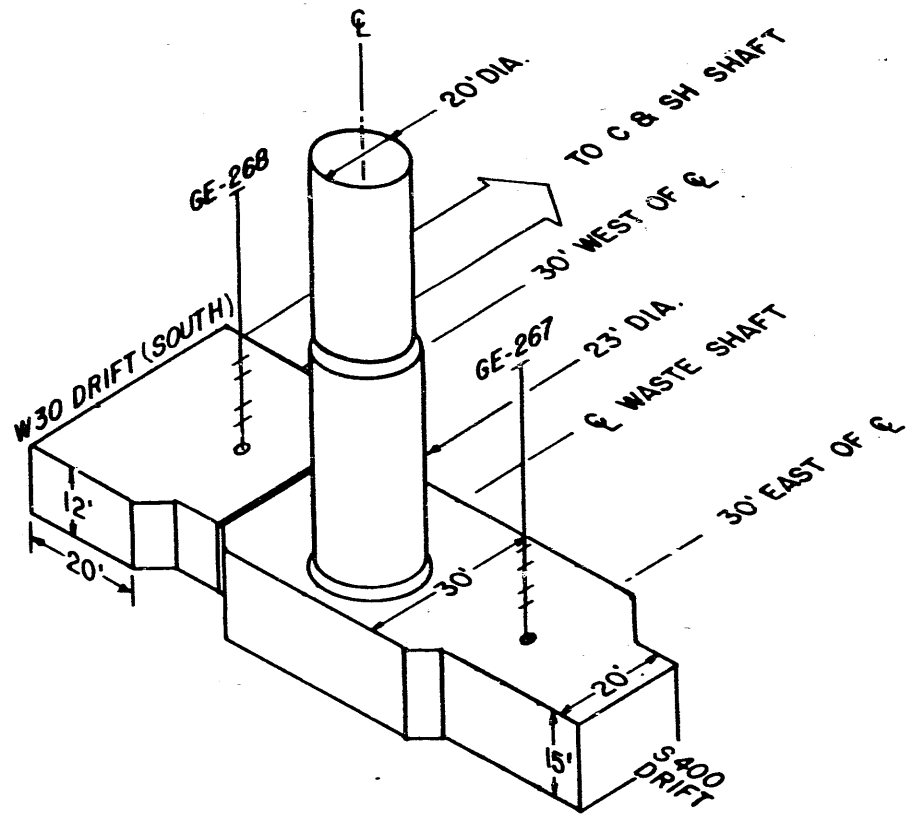


Figure 8-4

SPDV VENTILATION SHAFT STATION INSTRUMENTATION



NOTES:

1. PREVIOUSLY IDENTIFIED AS THE SPDV VENTILATION SHAFT STATION.
2. INITIAL INSTRUMENTATION WAS DESTROYED IN JUNE 1984. EXTENSOMETERS GE-267 AND GE-268 WERE INSTALLED AFTER STATION ENLARGEMENT.

EXPLANATION

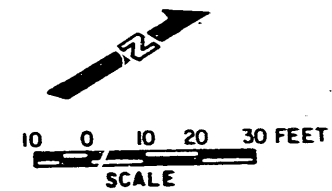


Figure 8-5

WASTE SHAFT STATION INSTRUMENTATION

the rock surrounding the liner, rock creep and the resulting rock pressure against the liner were assumed to be negligible. Hydrostatic pressure acting from a depth of 250 to 844 feet was used in the design based on the applicable design basis element (Table 8-1).

Additional stresses in the liner due to initial imperfections in roundness and grouting pressures were also considered. For stress calculations, an initial imperfection of 1 inch was assumed in the roundness of the liner. In place of the local water pressures, grouting pressures 1.3 times the ground-water pressure were assumed to act over one-sixth of the circumference of the liner. Due to localized effects, a 20 percent increase in the allowable concrete stress was assumed due to the short-term loading of the grouting pressure.

The external pressure capacities and corresponding closure limits (maximum diametric changes) for different thicknesses of the liner are:

Depth (feet)	Liner Thickness (inches)	Pressure Capacity (psi)	Closure Limit (inches)
27 to 462	10	216	0.165
462 to 580	14	370	0.215
580 to 762	18	523	0.251
762 to 837	20	598	0.266

The intent of the shaft piezometers is to monitor the pressure exerted on the liner by water from the Rustler formation. These data would indicate if the design hydrostatic pressure from the design basis was suitable.

Table 8-2 summarizes the variation in measured water pressures behind the liner at different times. Figure 8-6 shows the average reading on September 18, 1985, for each piezometer pair plotted against shaft depth. For comparison, the hydrostatic design pressure for the liner through this interval is also shown.

The measured pressures at this time are lower than the design pressure for two apparent reasons. First, water seepage through cracks and

Table 8-2

WASTE SHAFT LINER AND KEY
SUMMARY OF MEASURED WATER PRESSURES (psi)

PIEZOMETER NO. 31X-PE-00

Date of Reading	201	202	203	204	205	206	207	208	209	210	211	212
	Elev. 2879		Elev. 2798		Elev. 2740		Elev. 2692		Elev. 2651		Elev. 2564	
Dec. 26, 1984	-1	0	16	20	-7	-8	77	93	65	76	13	11
May 16, 1985	-2	0	11	16	12	-15	79	95	58	84	8	10
June 27, 1985	*	0	13	19	*	-16	78	95	*	91	11	12
Sep. 18, 1985	*	1	17	26	*	-14	99	115	*	107	19	22
Dec. 18, 1985	*	-3	-3	-2	*	-3	47	51	*	27	4	8
Mar. 16, 1986	*	-3	2	6	*	-13	*	63	*	47	5	12
June 13, 1986	*	0	10	15	*	-20	*	85	*	74	18	19

* Piezometer not functioning.

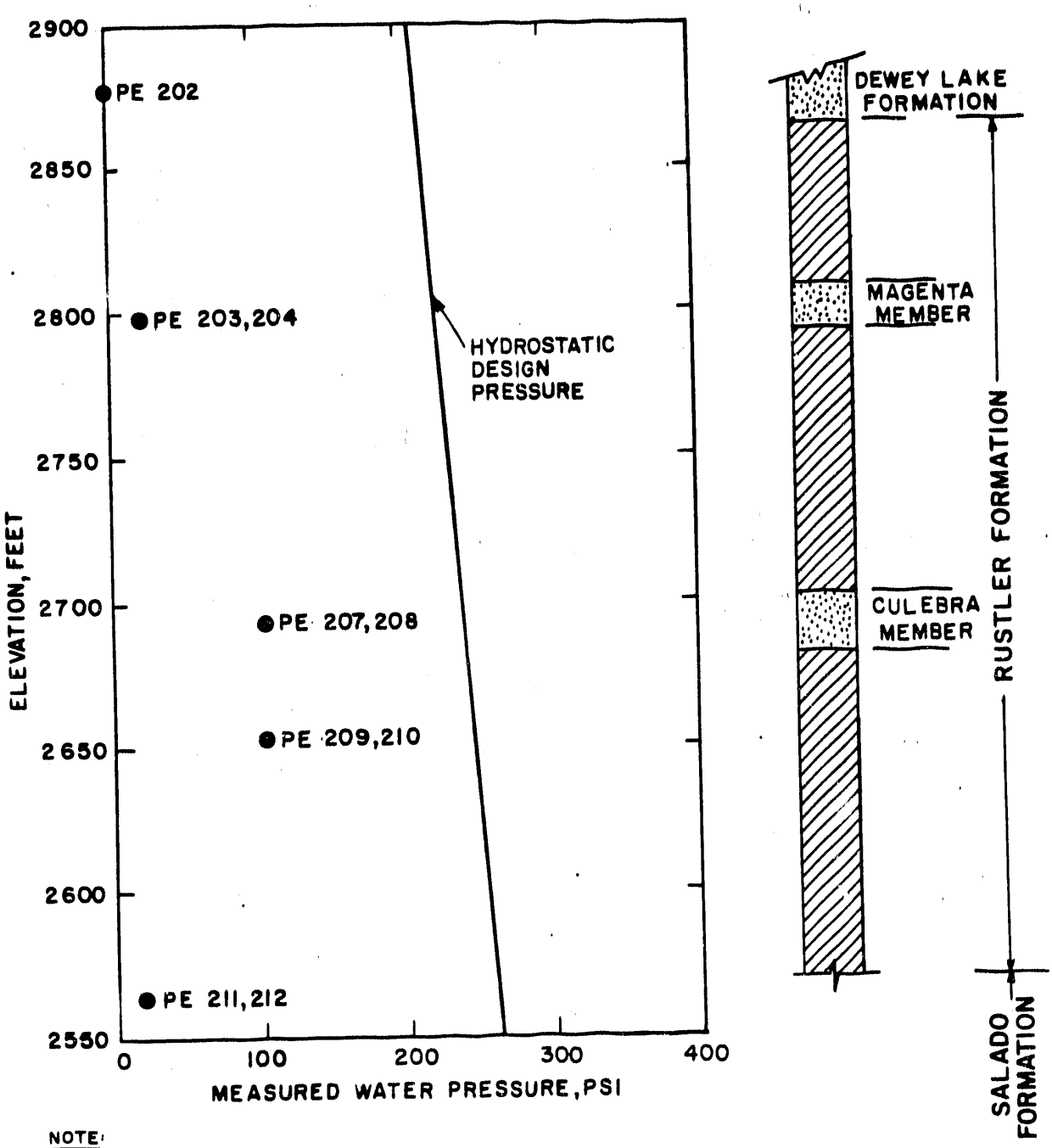


Figure 8-6

WASTE SHAFT LINER
WATER PRESSURE MEASUREMENTS

construction joints in the liner has not allowed the water to build up to its full hydrostatic head. This means that the piezometers are not measuring the full pressure that might be expected against the liner if the leaks were sealed. Second, the low pressure readings, and especially the variation in readings, suggest that hydraulic continuity is incomplete along the rock/liner interface. It is possible that water from the Culebra has been isolated, or at least restricted, in its vertical extent. This is suggested by the distribution of pressures shown on Figure 8-6.

The pressure distribution of the piezometers is also shown on Figure 8-7. These readings, however, are the maximum pressure values measured for each piezometer elevation. The figure also shows the design hydrostatic pressure distribution for the entire liner and its pressure capacity. The pressure capacity provides a significant factor of safety over the design hydrostatic pressure.

8.3.2.2 Shaft Key

Due to lithostatic pressure, the salt formation behind the shaft key tends to creep over time. The result is a buildup of inward pressure against the concrete key. The concrete key was designed to withstand a lateral pressure equal to 50 percent of the vertical overburden pressure (approximately 60 ksf) for at least 25 years after its construction. This reduction in lateral pressure from 75 percent of the overburden pressure for the C & SH shaft to 50 percent for the waste shaft was based on the results of the analysis of data obtained from the C & SH shaft (Chapter 7).

A nonlinear finite element analysis was utilized to simulate the long-term creep interaction of the salt and the concrete key. The analysis was performed using the MARC Finite Element Program discussed in Chapter 6. The material properties of the finite element model simulated the creep behavior of the salt via a power law (equation C.4-6 in Appendix C) provided in the analysis.

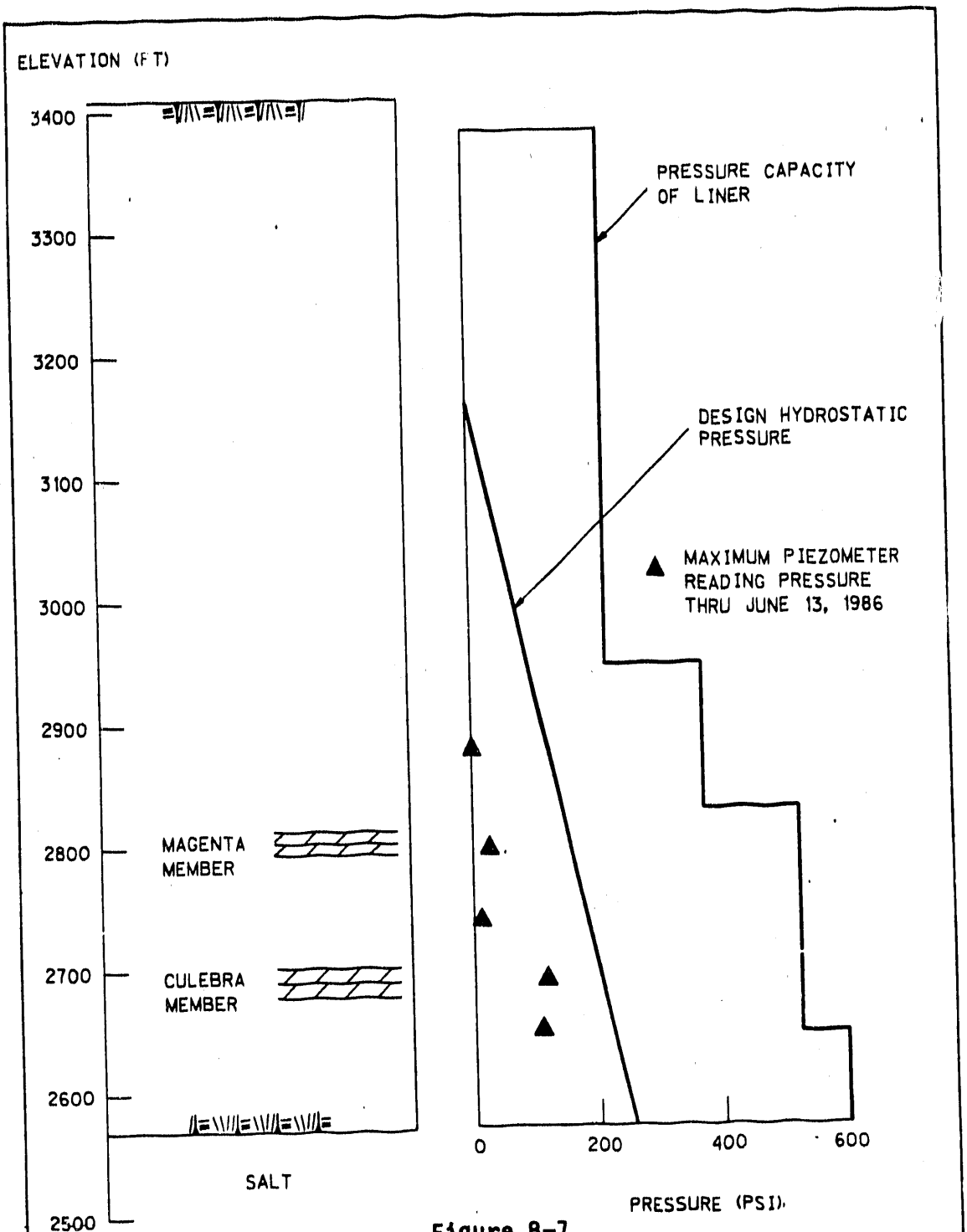
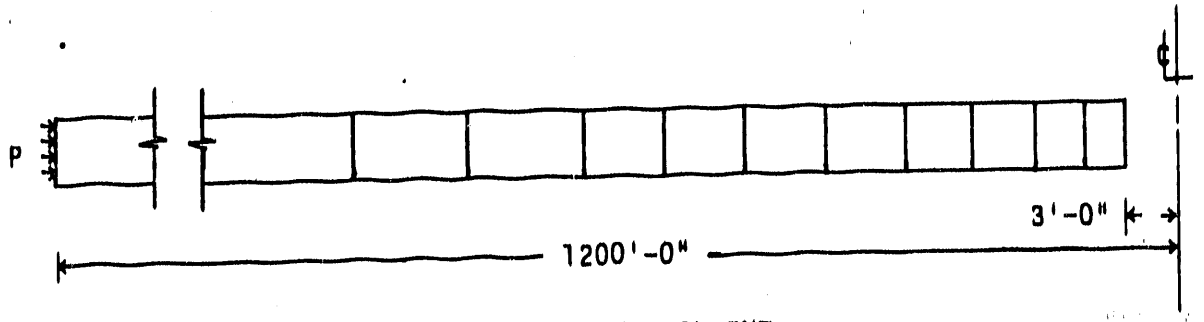
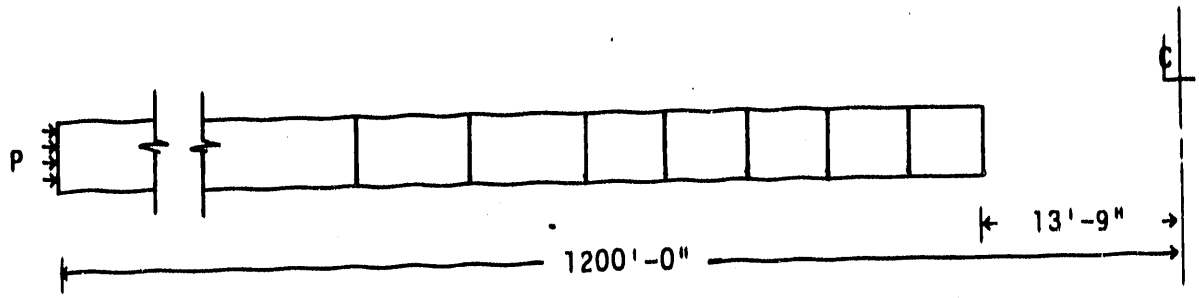


Figure 8-7

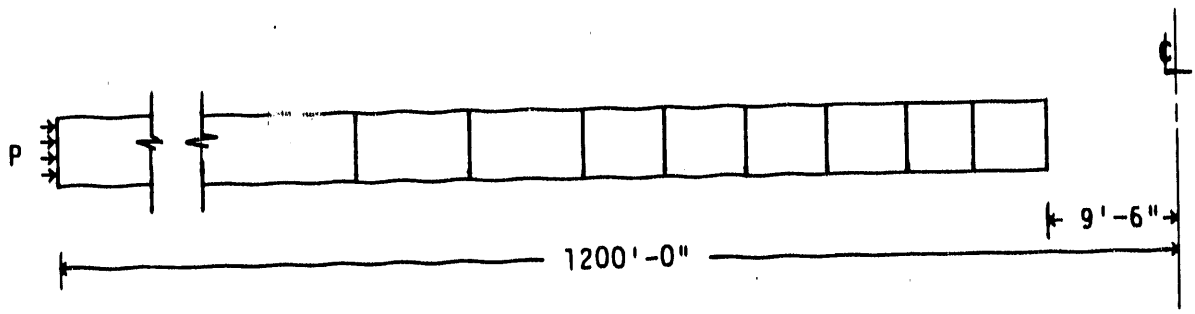
WASTE SHAFT LINER
LATERAL PRESSURE COMPARISON



(A) BEFORE ENLARGEMENT



(B) AFTER ENLARGEMENT



(C) AFTER CONCRETE CONSTRUCTION

Figure 8-8

WASTE SHAFT KEY
FINITE ELEMENT MODEL

Model Simulation. Unlike the more sophisticated analysis of the C & SH shaft key (which employed a multi-layered, axisymmetric finite element model), the finite element model for the waste shaft key and surrounding salt consists of a single layer of quadrilateral, axisymmetric ring elements as shown on Figure 8-8. Because only the lateral flexural stiffness of the shaft key was considered in the finite element model, and not its longitudinal flexural stiffness, the analysis provides conservative results. Also for conservatism, the shrinkage effect of the concrete was not taken into account in this analysis.

An inner element of the model, shown on Figure 8-8, represents a segment of the concrete key. In order to simulate the time interval between shaft excavation and concrete placement for the key, this element was not tied to the surrounding salt deposits. All depth-dependent input values, such as overburden stresses, were computed for a depth of 892 feet, low in the key, where such values are at a maximum. Because halite is the most dominant material in the rock around the shaft key, its properties were used for the model elements. Halite is also the material at the base of the shaft key where lateral pressure is at a maximum.

The following analytical procedure was used to perform a creep analysis of the waste shaft key:

(1) Initially, lateral forces were applied outwardly against the inside surface of the shaft. This simulates the condition prior to excavation of the original 6-foot diameter shaft.

(2) Lateral forces were applied inwardly against the outer vertical boundary of the model. The magnitude of these forces were based on the lateral earth pressure, equal to 892 feet of overburden, computed for the key elevation of 2517 feet.

(3) Internal stresses were applied in each element to represent the initial lithostatic stress state.

(4) All nodes of the model were restrained against vertical displacement.

(5) Subsequently, outward lateral forces against the inside surface of the shaft were removed to simulate excavation of the original 6-foot diameter shaft.

(6) A creep analysis was performed on the salt deposits surrounding the 6-foot diameter shaft until that time when the shaft diameter was enlarged and the concrete for the key was placed (795 days).

(7) The three innermost ring elements were detached (tie constraints removed) from the model to represent the enlargement of the shaft. A concrete ring element (tie constraints added to the model) then replaced the three salt elements just removed to model the concrete key.

(8) A second creep analysis was performed using this new model and a creep time representing 28 years after placement of the concrete key.

The stratigraphy in the upper section of the waste shaft is similar to that in the C & SH shaft. The creep parameters determined from in situ salt behavior in the C & SH shaft were, therefore, assumed to be valid for correlating analytical results of the waste shaft from normalized time to real time. The secondary creep parameter C was found to equal 5.70×10^{-21} $ksf^{-4.9}$ sec^{-1}. Because early in situ measurements were not available for the C & SH shaft, the primary creep parameters A and z were determined from in situ data from the horizontal drifts and were found to be 3.2 and 1.1×10^{-7} sec^{-1}, respectively.

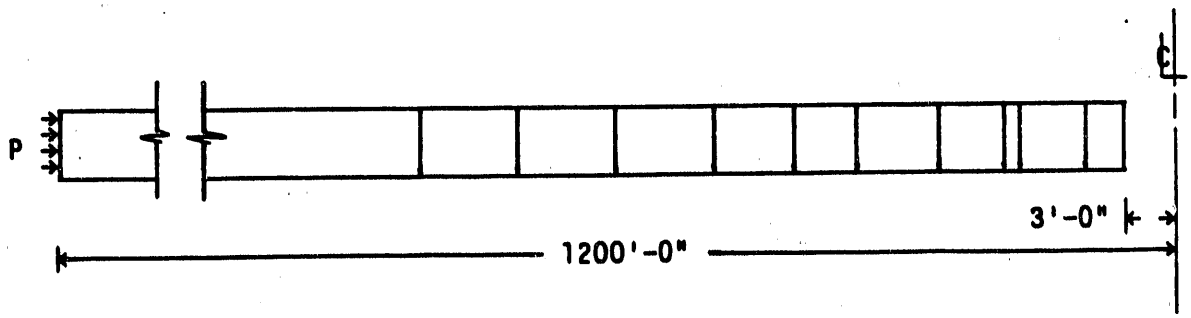
Seepage Evaluation. The structural integrity of the shaft key is not totally dependent upon salt creep. The stability of the key, and consequently the shaft liner, can be compromised by water dissolving the salt surrounding the key. Water is prevented from seeping from the upper water-bearing zones down into the salt around the key primarily by two chemical water seals. The key configuration, including the seals, is described in Chapter 3.

The number of piezometers in the key are not sufficient to conclusively support an evaluation of seepage. However, the distribution of water pressure behind the liner and key provides an indication that there is probably no hydraulic continuity along the rock/liner interface. This is especially evident at the lowermost water-bearing zone at a depth of 717 feet (elev. 2692 feet). Here, water pressures are over 100 psi. The next lower level of piezometers, at a depth of 758 feet (elev. 2651 feet), also indicate pressures of about 100 psi. However, the lowest level of piezometers, in the shaft key, reflect pressures of less than 25 psi.

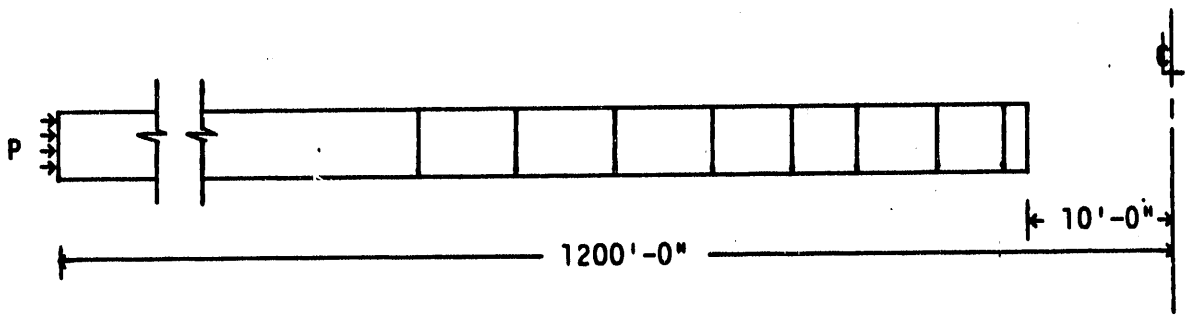
The telltale drains in the waste shaft key could not be located during the July 1986 inspection. Assuming they were constructed as designed, they may be covered by a thin veneer of concrete formed during concrete placement. A seep was noted on one side of the shaft at the approximate design level of the telltales. Inspection of the base of the key determined that no water was seeping from behind the key. This indicates that ground water is not bypassing the lower water seal between the key and the surrounding halite.

8.3.2.3 Unlined Section

The structural behavior of the unlined section of the waste shaft was also computed by a nonlinear creep analysis using the MARC Finite Element Program (ref. 6-8). The objective of the analysis was to compute the actual structural behavior by utilizing applicable in situ data from the C & SH shaft and the horizontal drifts, and to verify the design adequacy of the unlined section of the shaft.



(A) BEFORE ENLARGEMENT



(B) AFTER ENLARGEMENT

Figure 8-9

WASTE SHAFT UNLINED SECTION
FINITE ELEMENT MODEL

Model Simulation. The finite element model used for the unlined section of the waste shaft utilizes a single horizontal row of 70 quadrilateral axisymmetric ring elements. The model, shown on Figure 8-9, has its upper and lower horizontal boundaries restrained against vertical movement and a constant uniform lithostatic pressure, equal to 2,059 feet of overburden, applied to its outside vertical boundary. The same lithostatic pressure was initially applied to the inside vertical boundary as well; however, that pressure was later removed from the inside boundary to simulate the drilling of the original 6-foot diameter shaft.

The analysis simulates the salt creep until that time when the 6-foot diameter shaft was enlarged to its present 20-foot diameter. The shaft enlargement was simulated in the model by removing those ring elements that were located within the 20-foot diameter shaft opening. With the enlarged shaft configuration, simulated salt creep for another 28 years was analyzed.

Determination of Creep Parameters. Because the stratigraphy beneath the WIPP site is fairly uniform, the values of the creep parameters for the unlined section of the waste shaft were assumed to be identical to those values calculated at the corresponding elevations of the C & SH shaft. In addition, the C & SH shaft was drilled at a much earlier date than was the waste shaft; therefore, more in situ geomechanical instrument measurements were available for the C & SH shaft. The values of the creep parameters for the C & SH shaft were determined by correlating analytical results with extensometer readings obtained from a depth of 2,057 feet (elev. 1353 feet) in the shaft. The creep parameters C, A and z for the C & SH shaft were found to be 1.30×10^{-21} $ksf^{-4.9}$ sec^{-1}, 3.2 and 1.1×10^{-7} sec^{-1}, respectively. Chapter 7 presents specific details on how the creep parameters were evaluated for the C & SH shaft.

8.3.2.4 Shaft Station

The analysis of closure and stability of the waste shaft station is based upon closure measurements in the C & SH shaft station. This is due to the limited amount of geomechanical instrumentation data available from the waste shaft station for the reasons discussed in subsection 8.3.1. The following discussion presents a brief comparison of the two shaft stations.

The waste shaft station cross-section dimensions are 15 feet high and 30 feet wide. These dimensions are comparable to those of the C & SH shaft station. However, the C & SH shaft station was excavated by drilling and blasting while the waste shaft station was excavated using a mining machine. The density of rock bolts in the roof of the C & SH shaft station is much greater than that in the waste shaft station. Also, the roof of the C & SH shaft station close to the shaft is approximately 3 feet below clay G, while clay G at the waste shaft station is nearly 8 feet above the roof. Thus, closure analysis of the waste shaft station using measurement data from the C & SH shaft station will be conservative.

The dimensions of the waste shaft station are also comparable to those of the test rooms and storage rooms. Computational analysis of the storage rooms (Chapter 12) predicts that failure will occur in MB-139, below the floor, due to gradual stress buildup. Similar behavior is expected to occur in MB-139 beneath the waste shaft station.

8.3.3 Prediction of Future Behavior

This subsection presents predictions of future behavior for the various elements of the waste shaft including the lined section, the shaft key, the unlined section and the shaft station.

8.3.3.1 Lined Section

The cracks in the concrete-lined section of the shaft are primarily the result of normal tension cracking occurring during the restrained

shrinkage of plain concrete. The cracks are not detrimental to the liner's structural integrity but sealing by grouting will be required to meet the design criteria regarding ground-water control.

Although the rate of water flowing into the waste shaft has been minor, the total volume of flow has resulted in the lowering of the potentiometric surface around the shaft. Other activities have also affected the potentiometric level in the vicinity of the shafts. Most notably, SNL pumping tests in borehole H-3 in late 1985 lowered the potentiometric surface approximately 40 feet (A.R. Lappin, SNL, personal communication). Due to the unknown effect of current and future hydrologic studies at the WIPP, it is difficult to predict the magnitude of future water pressure on the liner. However, two statements can be made concerning this water pressure:

(1) The piezometer data present a valid indication of water pressures behind the liner. Although this data cannot be used for predicting future pressures, continuous monitoring of these instruments will reflect current pressures and indicate short-term trends. This information can be compared with the design basis pressure distribution (Figures 8-6 and 8-7) to evaluate liner stability.

(2) Following the next grouting program in the waste shaft, if all water seepage through the liner has been stopped, it is possible that the potentiometric surface could return to its highest level determined during preliminary design activities. Assuming complete hydraulic continuity behind the liner, this condition would result in a pressure distribution equal to that of the hydrostatic pressure used for liner design. This condition would be within the design limits.

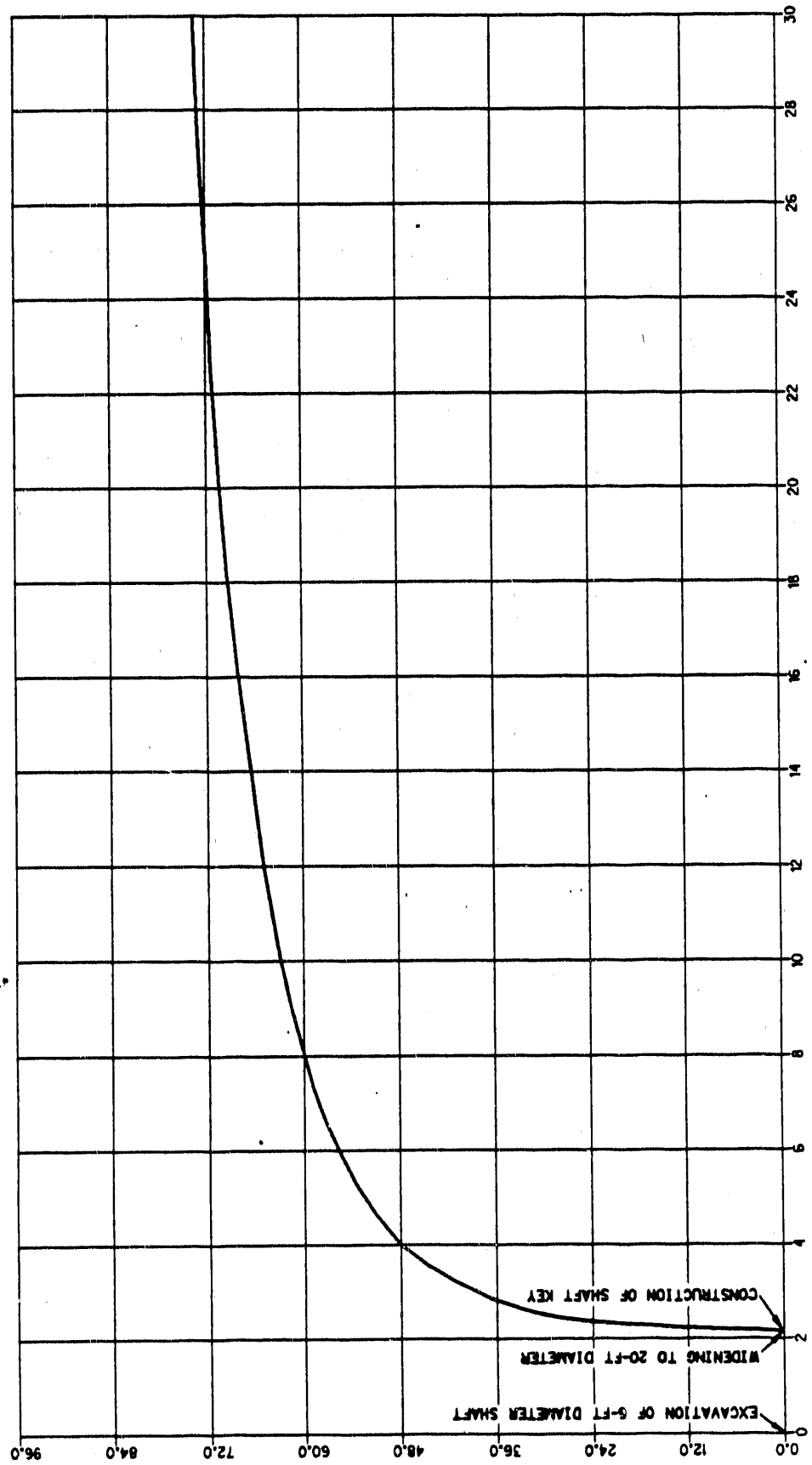

WASTE SHAFT KEY
LATERAL PRESSURE PREDICTION
LATERAL PRESSURE, KSF
0.0
12.0
24.0
36.0
48.0
60.0
72.0
84.0
96.0
ELAPSED YEARS SINCE EXCAVATION
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
EXCAVATION OF 6-FT DIAMETER SHAFT
WIDENING TO 20-FT DIAMETER
CONSTRUCTION OF SHAFT KEY

Figure 8-10

8.3.3.2 Shaft Key

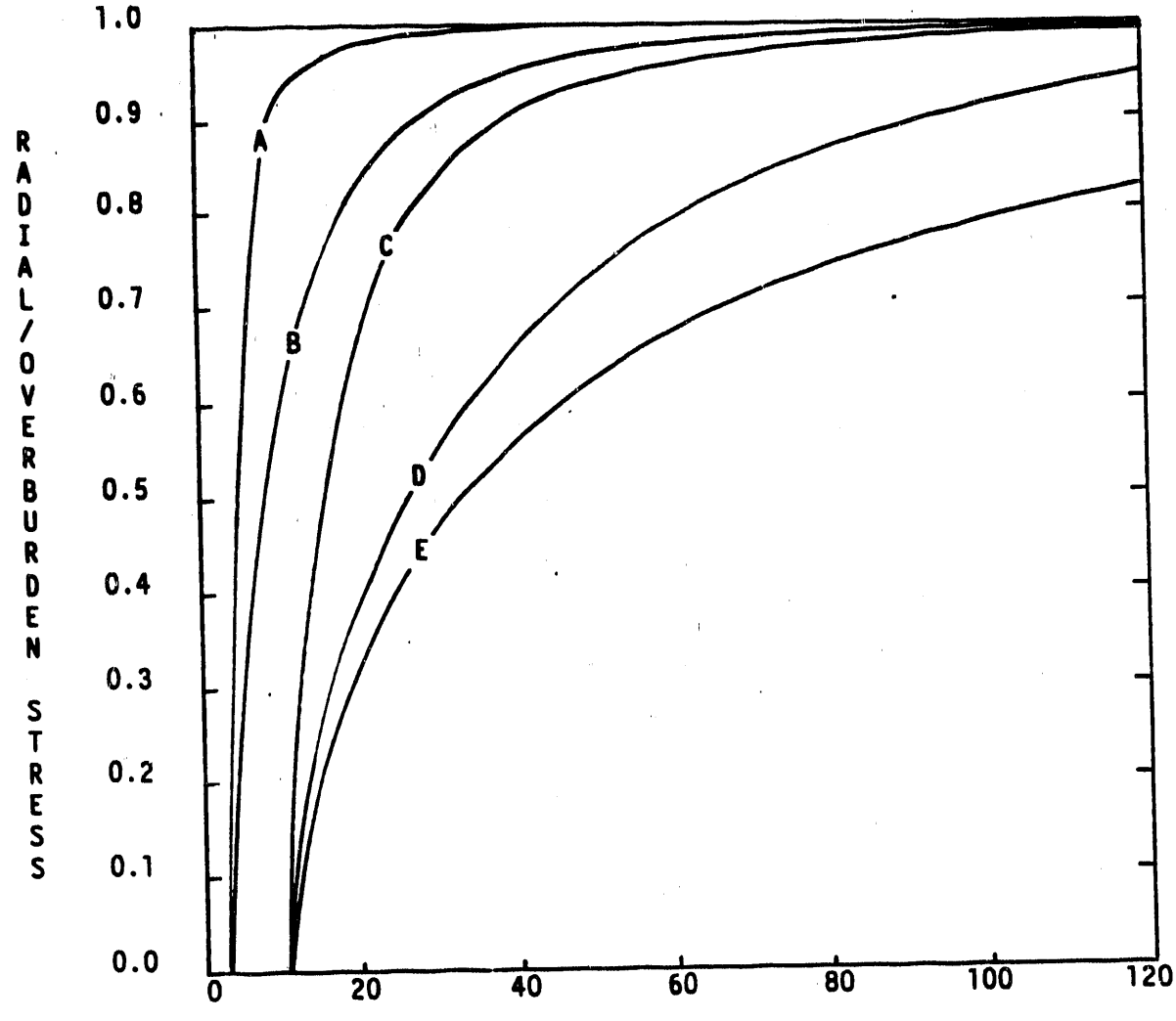
Figure 8-10 shows the predicted lateral pressure curve for the concrete key based on the finite element analysis. The key was designed as a compression cylinder in accordance with the strength design method for reinforced concrete (ref. 7-5) using an ultimate hoop stress of 4.25 ksi ($0.85\ f'_c$). Using the design basis load factor of 1.7 for lateral loads, the maximum allowable hoop stress in the concrete key is 2.50 ksi, which results in an allowable lateral rock pressure of 148 ksf based on the diameter of the key. The design basis lateral pressure design requirement is approximately 60 ksf. Figure 8-10 shows a lateral pressure on the shaft key of approximately 72 ksf at the end of the 25-year shaft operating life. If the shrinkage and creep properties of the concrete were taken into account in the finite element analysis, the lateral pressure would actually be less than 72 ksf at 25 years.

The reinforced concrete of the shaft key is expected to exhibit cracks due to shrinkage. These are tensile cracks due to the reinforcement restraining the concrete from shrinking. The cracks are not considered significant because they are common to most reinforced concrete structures.

8.3.3.3 Unlined Section

Figures 8-11 and 8-12 show the radial and tangential (hoop) stress distributions relative to the overburden stress for different times in the unlined section of the waste shaft. Figure 8-11 shows the zone around the shaft opening where radial stresses are affected and indicates a decrease in magnitude over time. The computational results depicted on Figure 8-12 indicate that tangential stresses are only affected within a radius of approximately 120 feet.

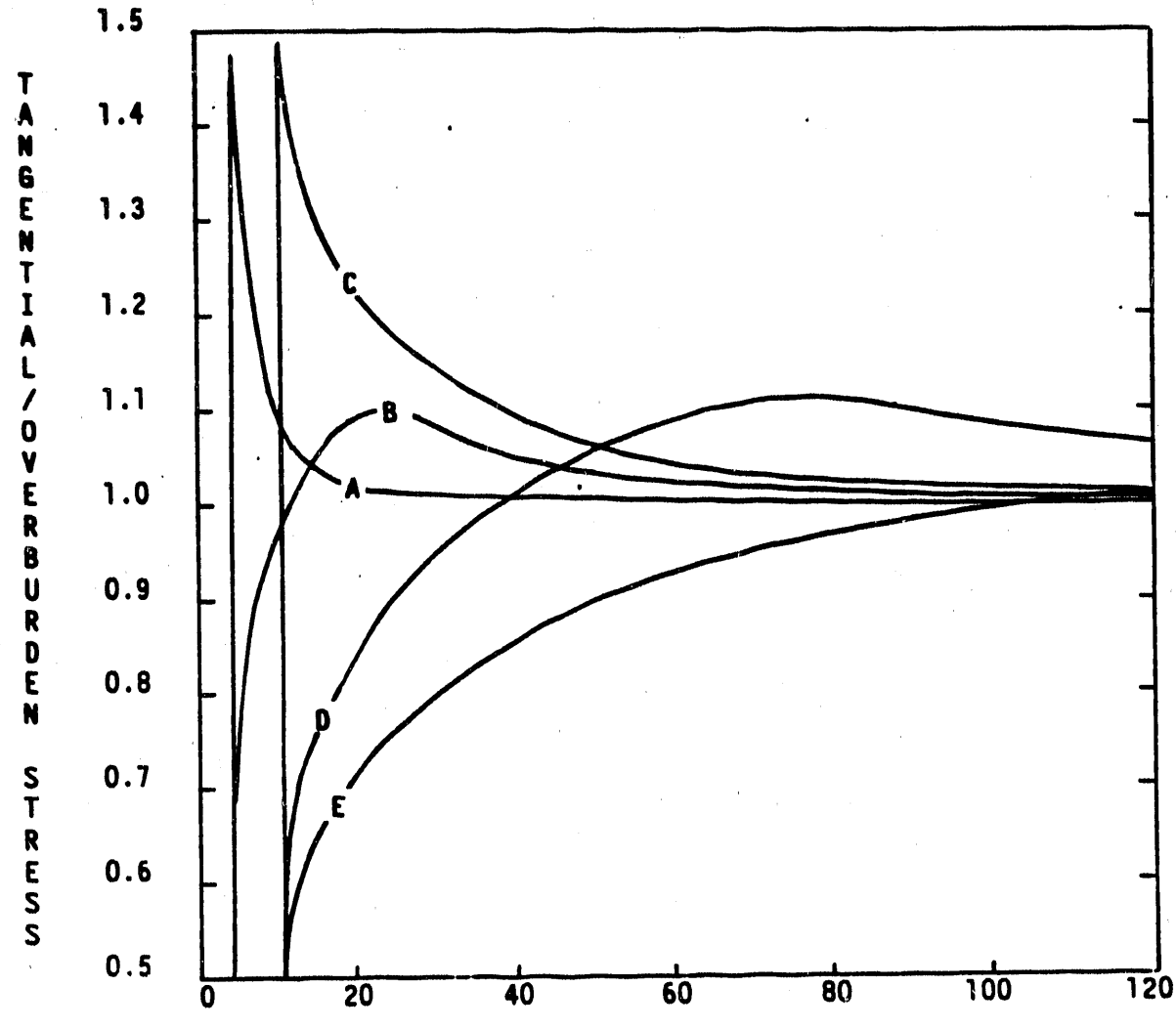
Figures 8-13 and 8-14 show the effective stress and effective creep strain distributions in the unlined section of the waste shaft. The effective stress in the shaft wall at 25 years is approximately 140 ksf



A - IMMEDIATELY AFTER EXCAVATION OF 6-FT DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 20-FT DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 20-FT DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

Figure 8-11

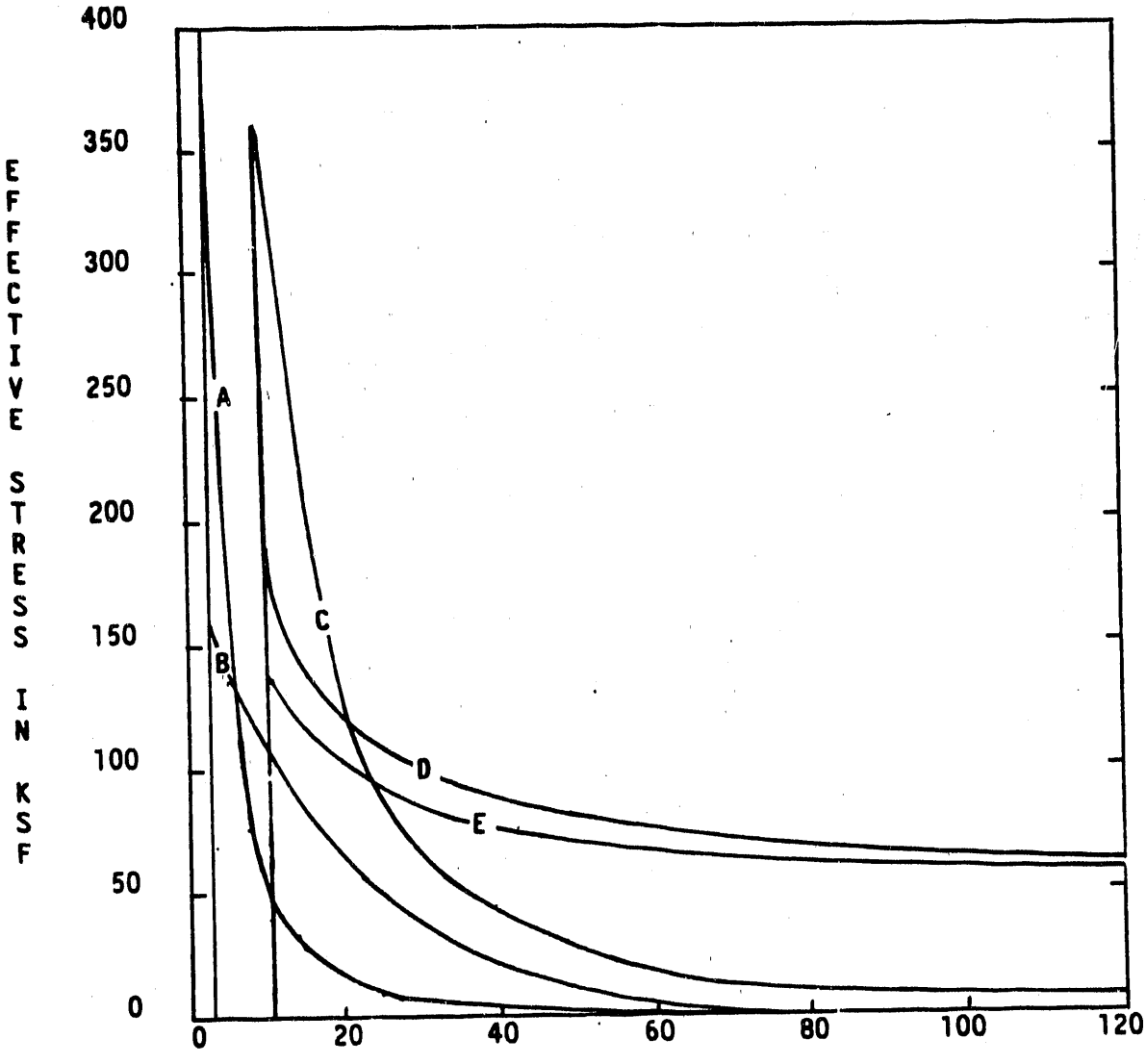
WASTE SHAFT UNLINED SECTION
RADIAL STRESS DISTRIBUTION AT ELEVATION 1350 FEET



A - IMMEDIATELY AFTER EXCAVATION OF 5 FT-DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 20 FT-DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 20 FT-DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

Figure 8-12

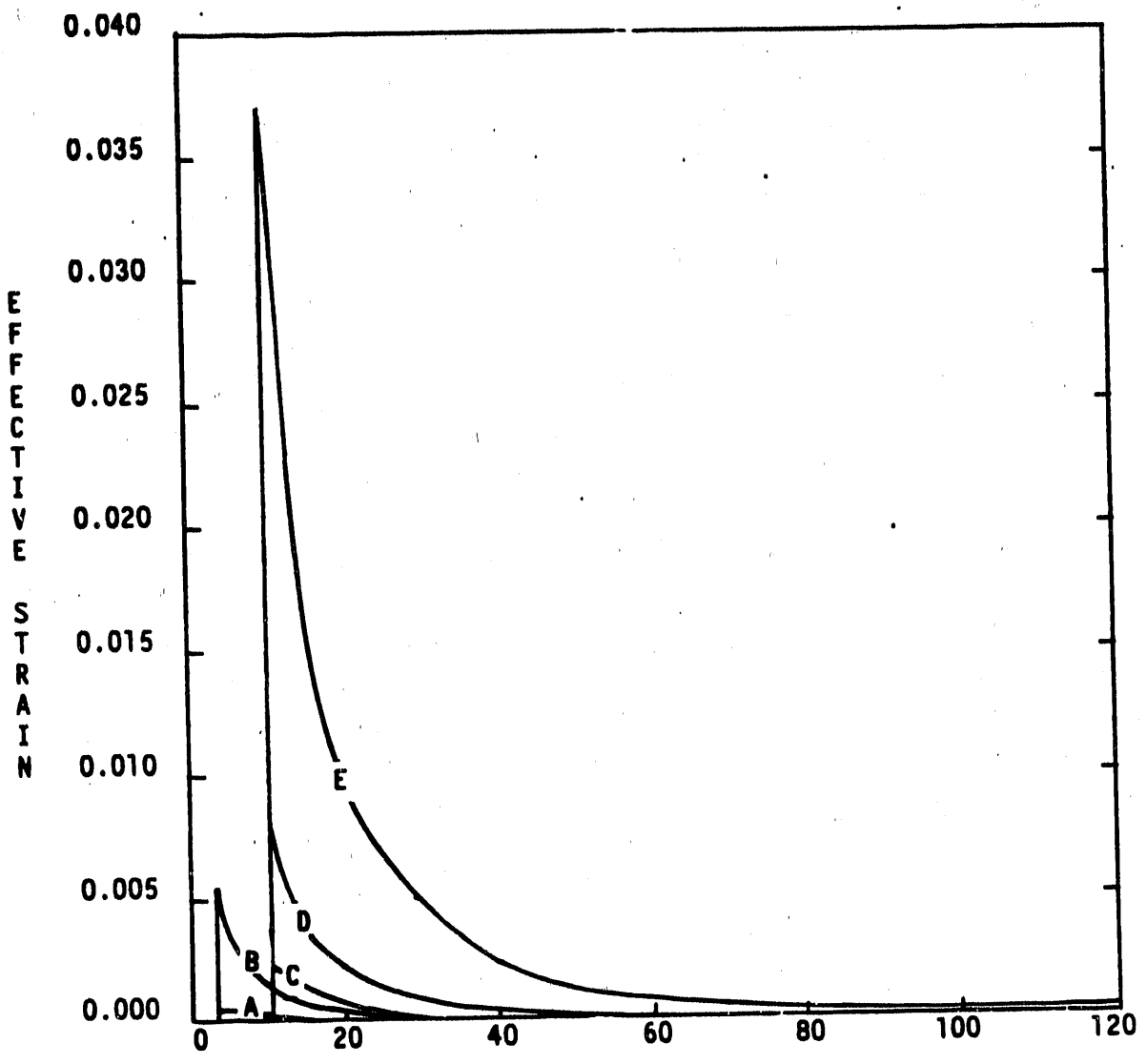
WASTE SHAFT UNLINED SECTION
TANGENTIAL STRESS DISTRIBUTION AT ELEVATION 1350 FEET



A - IMMEDIATELY AFTER EXCAVATION OF 6-FT DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 20-FT DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 20-FT DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

Figure 8-13

WASTE SHAFT UNLINED SECTION
EFFECTIVE STRESS DISTRIBUTION AT ELEVATION 1350 FEET



A - IMMEDIATELY AFTER EXCAVATION OF 6-FT DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 20-FT DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 20-FT DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

Figure 8-14

WASTE SHAFT UNLINED SECTION
EFFECTIVE CREEP STRAIN DISTRIBUTION AT ELEVATION 1350 FEET

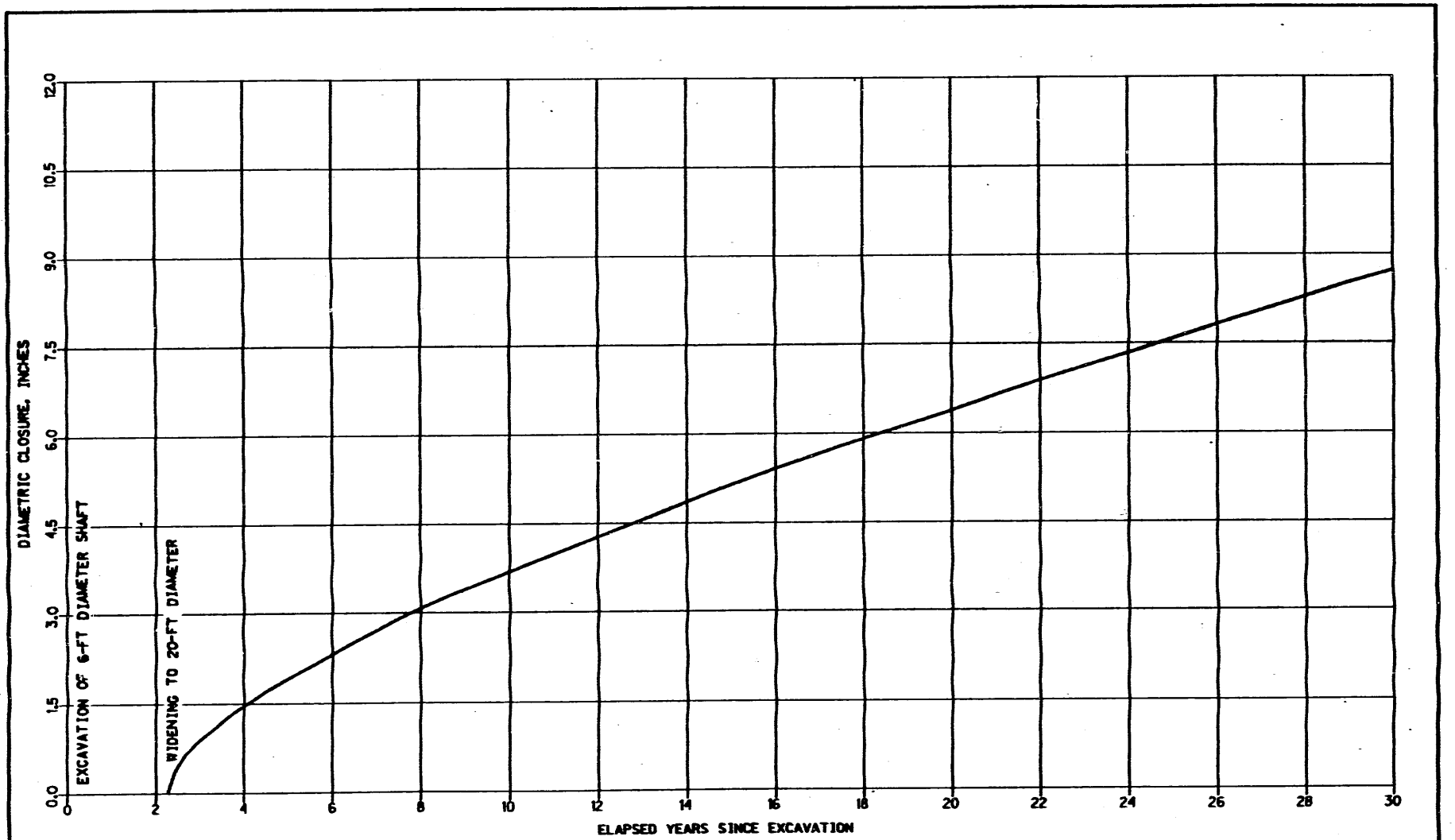


Figure 8-15

WASTE SHAFT UNLINED SECTION
CLOSURE PREDICTION AT ELEVATION 1350 FEET

while the effective creep strain in the shaft wall at 25 years reaches a value of approximately 0.037.

Figure 8-15 contains the prediction of diametric closure for the unlined section of the waste shaft at a depth of 2,059 feet (elev. 1350 feet). This figure shows a diametric closure of approximately 7 1/2 inches over the 25-year operating life of the shaft.

8.3.3.4 Shaft Station

Closure in the waste shaft station is predicted using measurement data from the C & SH shaft station. The measured roof-to-floor closure in the C & SH shaft station was approximately 10 inches on September 16, 1985, over 3 years after the completion of excavation. The measured wall-to-wall closure is greater than 6 inches over the same time period. However, the initial readings were taken nearly 260 days after the station was excavated; therefore, the actual closure magnitudes will be higher. The average rate of roof-to-floor closure over the measurement period was approximately 3.89 inches/year. Using this value as a constant closure rate over the plant operating life of 25 years, an additional roof-to-floor closure of about 8 feet is expected to occur. The wall-to-wall closure over the same period is expected to be approximately 60 percent of the roof-to-floor closure, or about 5 feet. Actual closure may be lower as discussed in subsection 8.3.2.4.

8.4 CONCLUSIONS AND RECOMMENDATIONS

Design validation requires an assessment of the compatibility of the design criteria, design bases and design configurations used for the reference design. The following conclusions and recommendations address those design elements identified in Section 8.2. Other conclusions and recommendations resulting from the design validation process are also presented.

8.4.1 Conclusions

The design criteria require that all of the shafts are to be stable. Shaft stability has been evaluated using analytical calculations,

finite element modeling and in situ data analysis. The shaft liner is considered stable because the water pressure exerted on it has remained significantly below the design hydrostatic pressure. If the water pressure increases to the design hydrostatic pressure, as may be expected if the leaks are sealed by additional grouting, liner stability will not be compromised. The pressure capacity of the liner sufficiently exceeds the design hydrostatic pressure.

Based on existing evidence, the cracks in the liner and key do not present a structural problem. The unreinforced concrete liner is expected to function as intended, provided that the existing cracks and construction joints are grouted and contact grouting is performed at the rock/liner interface. Consolidation grouting of the surrounding rock may also be necessary to achieve a dry shaft.

The shaft key was designed to withstand a design basis lateral pressure equal to 50 percent of the overburden pressure (approximately 60 ksf). The finite element analysis determined that the lateral pressure on the key at the end of the facility operating life will be approximately 72 ksf. Although this value is higher than the design lateral pressure, the key is expected to remain stable throughout its operating life because the allowable lateral rock pressure is 148 ksf. This is twice the lateral pressure predicted and provides a sufficient margin of safety. Furthermore, if the shrinkage and creep properties of the concrete were taken into account in the analysis, the lateral pressure would be less than 72 ksf.

The analytical results for the waste shaft, presented in Section 8.3, show the calculated redistribution of stresses around the shaft due to the effects of creep. Based on the computed vertical, horizontal and effective stresses in the unlined section, the magnitude of stresses immediately adjacent to the opening decreases with time as the stress arch around the opening migrates away. The maximum stress occurs immediately after excavation and is followed by relaxation due to creep behavior. Therefore, the stresses will not cause a future stability

problem in the waste shaft except in the anhydrite bed (MB-139) below the floor of the shaft station. Gradual buildup of stress in this bed may result in floor heave and fracturing.

The analysis shows the locations of effective creep strain concentrations for selected times in the unlined section. Based on these predicted values of effective creep strain and the strain limit discussed in Chapter 6, the waste shaft will remain structurally stable over its planned 25-year operating life.

The analysis predicts that diametric closure in the unlined section of the waste shaft will be approximately 7 1/2 inches over its 25-year operating life. Based on the predicted deformations and closures, the waste shaft will meet the requirements stated in the design criteria and the 20-foot diameter unlined section will provide sufficient operating clearance to allow for salt creep.

The design criteria requires that no uncontrolled ground water reach the facility level via the shafts. The majority of water seeping through cracks and construction joints in the liner is collected in three water-collection rings and directed to the underground facility where it is disposed. Only minor amounts of uncontrolled fly water reach the facility level. This water has a negligible impact and does not affect validation of the criterion regarding ground water reaching the facility level.

Shaft inspections have determined that only one minor seep occurs in the key and that no water seepage occurrs from the base of the key. This supports the conclusion that the water seals are functioning, that no water is seeping along the concrete/salt interface, and that no salt dissolution is occurring behind the concrete key. The installation technique for the waste shaft water seals was improved over that used for the C & SH shaft water seals (Chapter 3).

The zone of dissolution observed in the shaft sump wall is not considered to be detrimental to the operation of the facility. The

material was dissolved differentially by standing water in the sump resulting from construction activities. It is not the result of any geologic discontinuity or process. This zone will not produce any structural problems in construction of the waste shaft facilities.

The waste shaft station is expected to undergo roof-to-floor closure at a rate of 3.89 inches/year. However, this rate has been obtained by using the C & SH shaft station instrument data. The actual closure rate may be lower. Additional heave and fracturing in the salt beneath the floor, as well as in MB-139, is expected to occur. Some remedial work will be required to maintain the required roof-to-floor clearance for operational equipment and activities.

The reference design for the waste shaft is considered to be validated in accordance with the objectives of the design validation program based on the analyses, evaluations and predictions of future behavior presented in this chapter. With one exception, the waste shaft reference design complies with the design criteria and the design bases. The criterion that stipulates that shaft liner design shall prevent ground-water flow into the shaft has not been met. The rate of water currently seeping into the waste shaft is not considered to be detrimental to the stability of the shaft or to its functional purpose. However, the criteria will be satisfied when additional remedial grouting has been performed. No modifications to the shaft reference design will be required.

8.4.2 Recommendations

Based on the results of design validation, the following recommendations with respect to the waste shaft are made:

(1) Due to the limited in situ data base, validation of the waste shaft key and unlined section relies on numerical modeling utilizing creep parameters derived from the C & SH shaft in situ data. It is recommended that the modeling be repeated, prior to the first receipt of waste, using the latest in situ

data from the waste shaft. This analysis should be repeated periodically for comparison and verification of in situ data against design parameters.

(2) Grouting should be performed to completely seal the waste shaft liner. This should include contact grouting behind the liner and grouting of shrinkage cracks and construction joints. Consolidation grouting may also be required. Qualified personnel should inspect the shaft at regularly scheduled intervals. The liner should be checked for leaks after grouting has been completed. The key should be checked for water seeping from behind the key at its base. If any seepage is detected it may become necessary to grout the area above the upper water seal. If possible, grout should not be placed behind the key below the upper seal. However, should grouting behind the key become necessary, the grout must be a chemical gel (or other non-rigid grout) and must be compatible with both the existing water seal material and with the requirements of the Plugging and Sealing Program.

(3) The dissolution zone in the waste shaft sump should be filled with a salt-compatible cement mortar.

(4) Because waste shaft station closure is based on C & SH shaft station data, and because of the importance of the waste shaft station in general, vertical convergence points or meters should be installed at selected locations and measurements taken periodically. These data should then be analyzed to obtain better estimates of station closure.

CHAPTER 9
EXHAUST SHAFT

9.1 INTRODUCTION

This chapter presents information on design validation of the exhaust shaft. Included are discussions of its design, the design validation process, and conclusions and recommendations pertaining to validation of the reference design.

9.2 DESIGN

This section presents the design criteria and design bases used to develop the reference design for the exhaust shaft. The design configuration of the shaft is discussed in Chapter 3, subsection 3.3.3.

9.2.1 Design Criteria

The design criteria for the exhaust shaft are identical to those for the other two shafts. The criteria requiring validation are indicated in the listing of abridged criteria presented in Chapter 2, Table 2-1, and are discussed in Chapter 7.

The design criteria requiring evaluation for design validation of the exhaust shaft are:

(1) shaft shall be designed to be structurally stable;

(2) shaft shall be designed to accommodate salt creep; and

(3) ground-water flow into the shaft shall be controlled.

9.2.2 Design Bases

The design bases are the detailed design requirements developed from the design criteria. The primary design basis document for the exhaust shaft is the Design Basis, Exhaust Shaft (ref. 2-16). The major elements of the design bases are the same as those for the waste shaft,

except for the items discussed in the next paragraph. The elements that require evaluation or that have a direct impact on design validation are presented in Table 9-1.

In addition to adhering to the design basis elements discussed previously for the waste shaft, the exhaust shaft shall be designed to connect the facility level with the exhaust filter building at the ground surface. The exhaust shaft shall be used to remove air from the underground development level during construction and storage operations. The entire shaft shall be inspected utilizing a closed-circuit television camera that shall be lowered from the top of the shaft. Unlike the design bases for the other two shafts, the exhaust shaft design basis does not require the installation of geomechanical instrumentation.

9.3 DESIGN VALIDATION PROCESS

As discussed in Chapter 5, design validation of the exhaust shaft has been achieved by data collection, its analysis and evaluation, and the prediction of future behavior. Data collection activities have included geologic mapping and visual observations of the exhaust shaft wall. Although geomechanical instruments have been installed in the shaft, no data was available for design validation due to the late date of installation.

Computational analyses for the exhaust shaft were performed in the same manner as those for the waste shaft. The finite element analyses of the shaft key and unlined section used the material parameters for salt obtained from the C & SH shaft and horizontal drift analyses. The results of the analyses were then used to predict future behavior.

9.3.1 Data Collection

Data collection in the exhaust shaft was on a much smaller scale than in the other two shafts. Geologic mapping was conducted in the shaft to verify the stratigraphy. This mapping is discussed in detail in Chapter 6. Visual inspections and observations in the shaft were

Table 9-1

VALIDATION ELEMENTS OF EXHAUST SHAFT DESIGN BASES

(1)	Shaft liner Hydrostatic pressure should be considered to start at 250 feet below the ground surface and extend to the top of the key.
(2)	Shaft key Design lateral pressure shall be 50 percent of the vertical pressure due to soil, rock and salt overburden.
(3)	Unlined section Provide 15-foot diameter to allow for future salt creep deformation.

sporadic due to limited access. The following discussion presents those observations which affect design validation.

9.3.1.1 Field Observations

Exhaust shaft construction was completed on January 15, 1985. Initial of the lined section of the shaft was performed on January 30, 1985. At that time water seepage through cracks and construction joints in the liner was observed. Seepage into the shaft was measured at 0.35 gallons per minute (gpm).

Subsequent inspections of the exhaust shaft liner were made in February and May 1985 to observe its condition and to evaluate the need for grouting to reduce water seepage. The first occurrence of moisture on the liner was observed 25 feet below the shaft collar. The majority of water seepage was occurring between approximate depths of 569 feet and 759 feet (elev. 2840 feet and 2650 feet). Below a depth of 759 feet the entire shaft liner was wet, making it difficult to determine the exact source of seepage. Some salt accumulation was observed on the liner below the Culebra water-bearing member. The May 1985 inspection generally revealed a 1/4- to 3/8-inch thickness of salt incrustation in this area with some local accumulation up to 4 inches in thickness.

Salt accumulation at two telltale drain holes, at a depth of 857 feet (elev. 2552 feet) on the northeast and east sides of the shaft key, had resulted in the almost complete plugging of these holes. The six other drain holes had minor salt accumulation. The bottom of the key had salt stalactites hanging from the concrete but no flow of water under the concrete was observed. There was no evidence of any dissolution of salt at the concrete/salt contact.

A cement/chemical grouting program was conducted in the exhaust shaft from June 1 through July 31, 1985. An inspection of the exhaust shaft liner was made on July 30, 1985. The liner was appreciably drier than it had been prior to grouting, especially below the Culebra member. One collar pipe, for future piezometer installation at a depth of 616

feet (elev. 2793 feet), was weeping and one pipe, at a depth of 722 feet (elev. 2687 feet), was dripping. This water constituted the majority of the total seepage into the shaft. Weeping from random cracks above a depth of 617 feet appeared to be of the same magnitude as before grouting. The water ring at the base of the shaft key was relatively dry. New telltale drain holes at a depth of 870 feet (elev. 2539 feet) were all dry. Several of the original drain holes, at 857 feet, and several new holes, at a depth of 855 feet (elev. 2554 feet), were weeping slightly. No evidence of seepage at the concrete key/salt contact was observed. The grouting program reduced water seepage into the exhaust shaft to an essentially non-measurable quantity.

Cursory inspections of the exhaust shaft made during the installation of geomechanical instruments in November and December 1985 indicated no appreciable change in the condition of the shaft liner since the July 1985 inspection.

A second grouting program was conducted in the exhaust shaft during August, September and October, 1986. The program was performed at this time to reduce the possible need for grouting in the future when shaft access will be limited. The grouting was conducted on a smaller scale than in the earlier program. It consisted of injecting grout through existing sleeves from the top of the salt in the key are to the top of the Magenta member. Grouting was also performed, as required, above the Magenta through sleeves in the liner. The results of the grouting were not available at the time of publication of this report.

9.3.1.2 Geomechanical Instrumentation

The original exhaust shaft design contained no provision for the installation of geomechanical instrumentation based on the assumption that rock behavior would be similar to that in the waste shaft. However, it was subsequently decided that geomechanical instrumentation should be installed to obtain shaft-specific behavior information for later use in the shaft sealing program.

Instrument locations in the exhaust shaft were based on waste shaft instrument locations. Twenty-one piezometers, 4 pressure cells and 9 extensometers have been installed in the exhaust shaft. The instrument installation was completed on December 27, 1985, 385 days after the completion of shaft excavation. All exhaust shaft instruments are monitored remotely by the datalogger.

9.3.2 Analysis and Evaluation

The analysis and evaluation of the constructed exhaust shaft has been performed using direct observation data and geomechanical instrumentation readings from the C & SH and waste shafts. This analysis and its evaluation against reference design parameters was performed for the three major sections of the shaft: the lined section; the shaft key; and the unlined section.

The adequacy of the exhaust shaft reference design was evaluated based on a complete spectrum of geomechanical behavior including stress, strain and deformation over the planned operating life of 25 years. The analyses used creep parameters computed from the C & SH shaft and the 8 x 25-foot drifts as well as hydrostatic pressures from the waste shaft.

9.3.2.1 Lined Section

Analyses were performed for the unreinforced concrete liner in the exhaust shaft. However, because no instrumentation data from this shaft were available, the analyses were based on data obtained from the C & SH and waste shafts.

The structural analysis and design of the exhaust shaft were performed using engineering mechanics principles and design bases similar to those used for the waste shaft as described in Chapter 8. For example, both axial and flexural stresses were considered in the design of the concrete liner, with permissible stress values taken as those used for structural unreinforced concrete (ref. 8-1) utilizing the ultimate

strength design method. Loads considered in the design of the concrete liner included a hydrostatic pressure assumed to act from a depth of 250 to 844 feet; a grouting pressure equal to 1.3 times the ground-water pressure acting over one-sixth of the circumference of the liner; and stresses due to an initial imperfection of 1 inch in the roundness of the liner. Since there is no major salt strata surrounding the liner, no significant creep will occur and rock pressures against the liner were assumed to be negligible.

Based on its finished dimensions, the computational results show that the external pressure capacities and corresponding closure limits (maximum diametric changes) for different thicknesses of the exhaust shaft liner are:

Depth (feet)	Liner Thickness (inches)	Pressure Capacity (psi)	Closure Limit (inches)
15 to 500	10	320	0.140
500 to 740	14	513	0.175
740 to 844	16	611	0.190

Since no measurements of the finished liner diameter were taken during construction, the actual closure is not available for comparison.

Figure 9-1 shows the relationship between the hydrostatic design pressure and the pressure capacity of the liner. The hydrostatic pressure is identical to that used for design of the waste shaft. Because the exhaust shaft liner also has water seeping through cracks and construction joints, the hydrostatic pressure is expected to behave in the same manner as discussed for the waste shaft in Chapter 8. That is, the design hydrostatic pressure is not expected to be reached until the shaft liner is completely sealed. When the design hydrostatic pressure is reached, the liner will have a factor of safety greater than two, based on the liner pressure capacity.

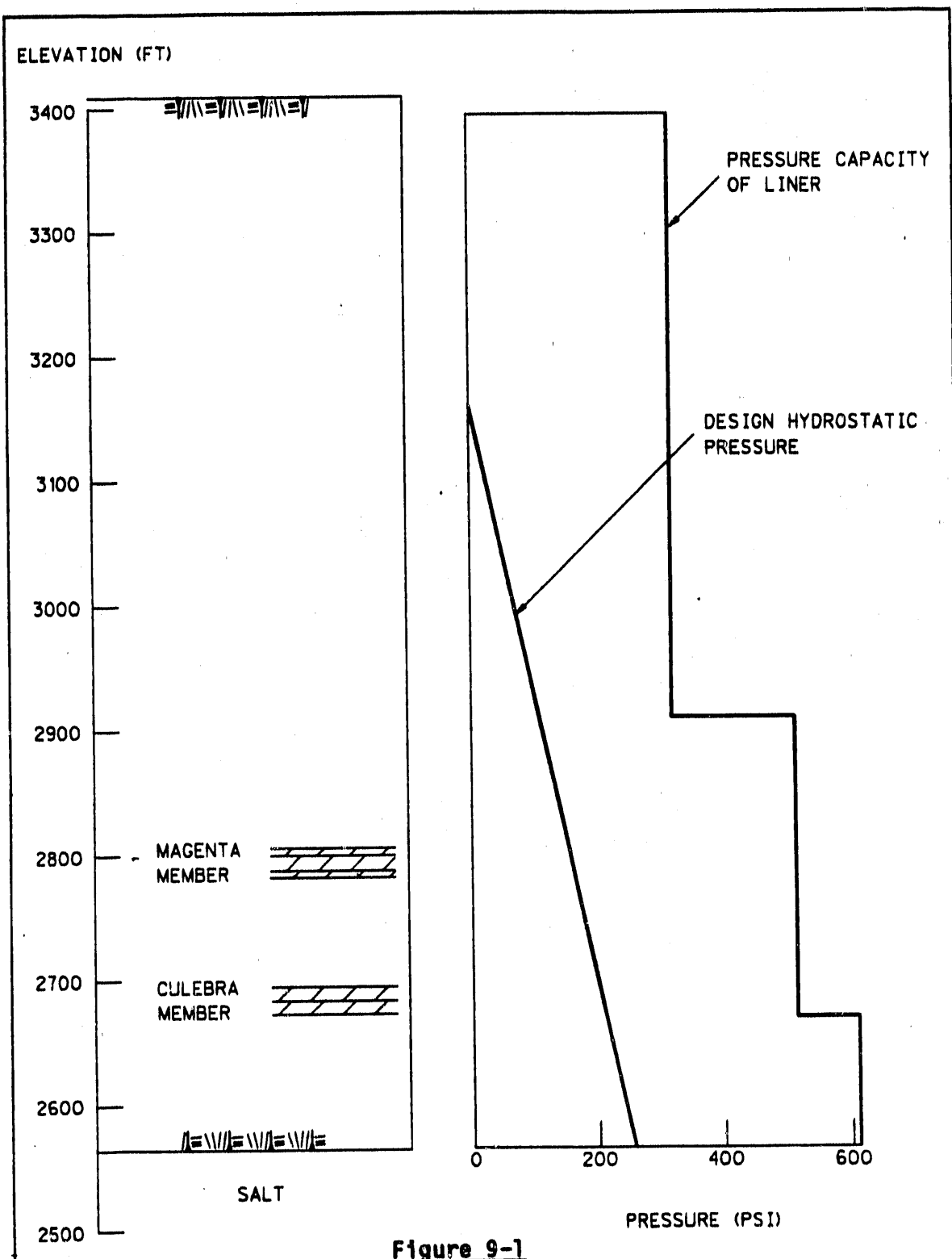


Figure 9-1

EXHAUST SHAFT LINER
LATERAL PRESSURE COMPARISON

9.3.2.2 Shaft Key

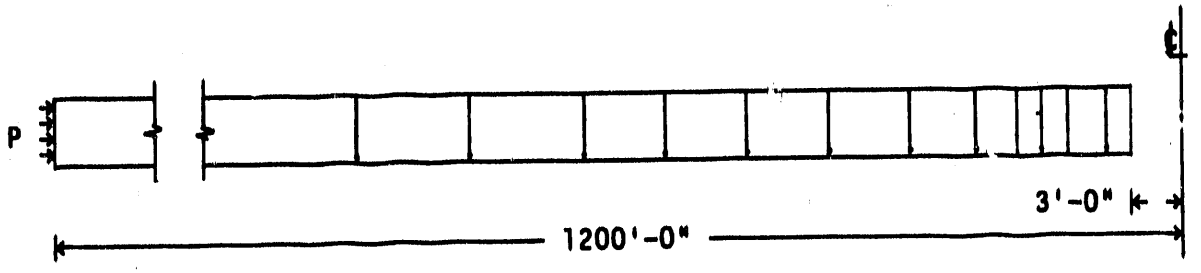
The exhaust shaft key was designed to withstand a lateral pressure equal to 50 percent of the vertical overburden pressure or about 60 ksf. A nonlinear finite element analysis, similar to that performed for the waste shaft key described in Chapter 8, was used to simulate the long-term creep interaction of the salt and the concrete key. The creep behavior of the salt was simulated using a power law (equation C.4-6 in Appendix C). For conservatism, the shrinkage effects and creep of the concrete were not taken into account in the analysis.

Model Simulation. The finite element model for the exhaust shaft key and surrounding salt consists of a single layer of quadrilateral axisymmetric ring elements as shown on Figure 9-2. An inner element of the model represents a segment of the concrete key; however, this element is not tied to the surrounding salt deposits until that time when the concrete for the shaft key is actually placed. All depth dependent input values, such as overburden stresses, initial lithostatic state, etc., were computed based on a depth of 891.5 feet, low in the key, where such values are at a maximum. Halite is the prevalent material present at the base of the shaft key and its properties were used for the parameters modeling the salt deposits surrounding the key.

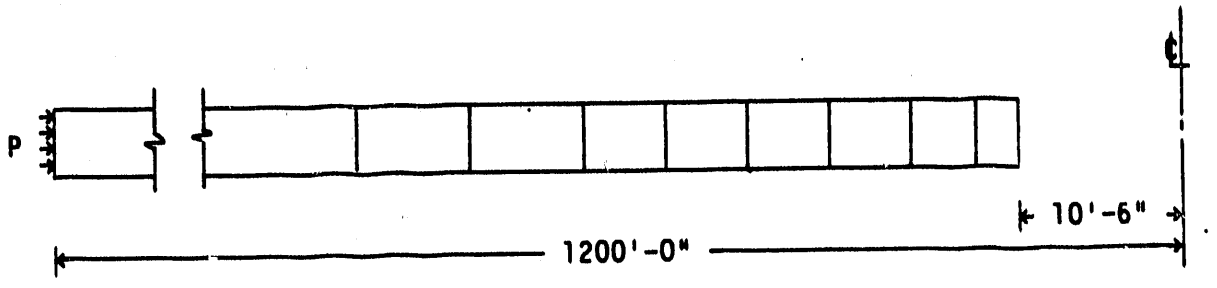
The analytical procedure used to perform the creep analysis for the exhaust shaft key was similar to that used for the waste shaft key analysis described in Chapter 8. However, in the finite element model for the exhaust shaft, the key diameter was enlarged to 21 feet with a finished inside diameter of 14 feet.

9.3.2.3 Unlined Section

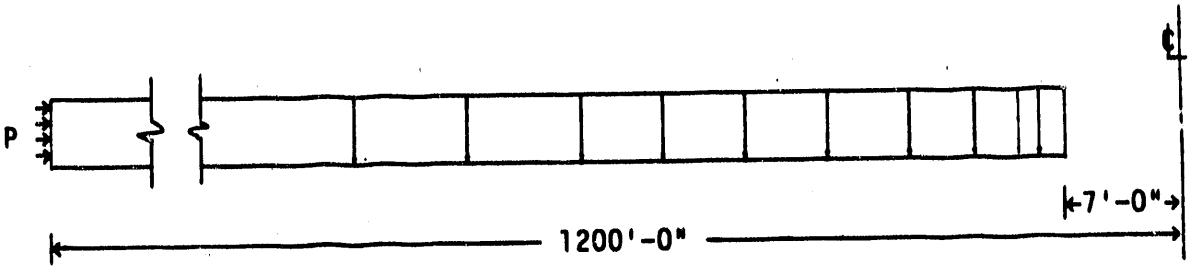
The structural behavior of the unlined section of the exhaust shaft was also computed using the MARC Finite Element Program discussed in Chapter 6. The analysis computed the actual structural behavior by utilizing applicable in situ data from the C & SH shaft and the horizontal drifts.



(A) BEFORE ENLARGEMENT



(B) AFTER ENLARGEMENT



(C) AFTER KEY PLACEMENT

Figure 9-2

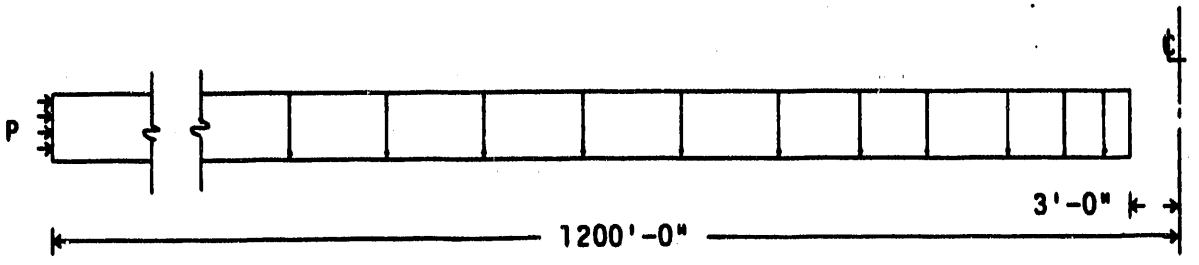
EXHAUST SHAFT KEY
FINITE ELEMENT MODEL

Model Simulation. The finite element model used for the unlined section of the exhaust shaft utilizes a single horizontal row of 70 quadrilateral axisymmetric ring elements. The model, shown on Figure 9-3, has its upper and lower horizontal boundaries restrained against vertical movement and has a constant lithostatic uniform pressure, equal to 2,066 feet of overburden, applied to its outside vertical boundary. The same lithostatic pressure was initially applied to the inside vertical boundary; however, that pressure was later removed from the inside boundary to simulate the drilling of the 6-foot diameter pilot bore.

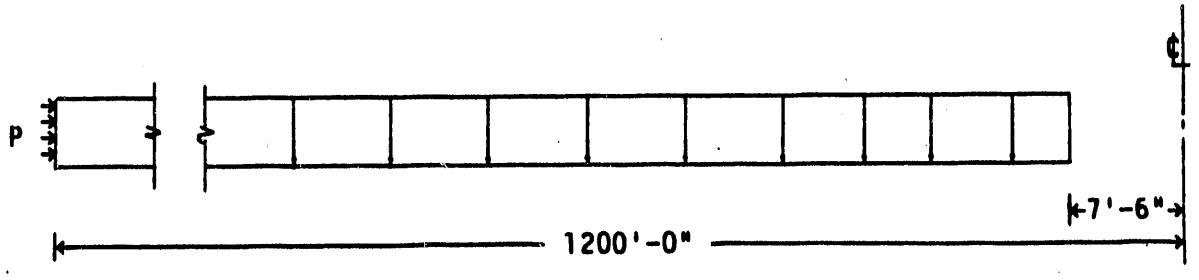
The analysis simulates the salt creep until that time when the 6-foot diameter hole was enlarged to its present 15-foot diameter. The shaft enlargement is simulated in the model by removing those ring elements which are located within the newly-excavated 15-foot diameter. With the enlarged shaft configuration, simulated salt creep for another 25 years was analyzed.

Determination of Creep Parameters. Since the stratigraphy surrounding the C & SH shaft is similar to that surrounding the exhaust shaft, the creep parameters determined from the in situ salt behavior in the C & SH shaft were assumed to be valid for correlating analytical results for the exhaust shaft from normalized time to real time. The secondary creep parameter C for the C & SH shaft was found to equal 5.70×10^{-21} $ksf^{-4.9}$ sec^{-1}. Since early in situ measurements were not available for the C & SH shaft, the primary creep parameters A and z were determined from in situ data from the horizontal drifts and were found to be 3.2 and 1.1×10^{-7} sec^{-1}, respectively.

Chapter 7 presents specific details on the computation of the secondary creep parameter C from the C & SH shaft. Chapter 10 presents the computation of the primary creep parameters A and z from the drifts.



(A) BEFORE ENLARGEMENT



(B) AFTER ENLARGEMENT

Figure 9-3

EXHAUST SHAFT UNLINED SECTION
FINITE ELEMENT MODEL

9.3.3 Prediction of Future Behavior

This subsection presents the results of the analysis and evaluation of the exhaust shaft. Predictions of future behavior for the lined section, key and unlined section are discussed.

9.3.3.1 Lined Section

The cracks in the concrete liner of the exhaust shaft are primarily tension cracks formed during restrained shrinkage we described in Chapter 8 with respect to the waste shift liner. These are neither unusual nor unexpected. Grouting of the cracks, as well as the leaking construction joints, will be required to meet the design criteria regarding ground-water control.

As discussed in Chapter 7, subsection 7.3.3.1, there is no reason to expect that the potentiometric surface at the WIPP site will exceed the design basis depth of 250 feet below the ground surface over the operating life of the facility. In the future, the recently installed piezometers will permit monitoring of the actual water pressure on the liner. Even if the water pressure rises to the design pressure, the pressure capacity of the liner will provide a sufficient margin of safety.

9.3.3.2 Shaft Key

The elapsed time from the drilling of the 6-foot diameter pilot bore to its widening to 21 feet in the key area and construction of the concrete key was approximately 316 days. Figure 9-4 shows the predicted lateral pressure curve for the concrete key based on the finite element analysis. The key was designed as a compression cylinder in accordance with the strength design method for reinforced concrete (ref. 7-5) using an ultimate hoop stress of 4.25 ksi. Using a load factor of 1.7 for lateral loads, the maximum allowable hoop stress in the key is 2.50 ksi. This hoop stress results in an allowable lateral rock pressure of 154 ksf based on the diameter of the key. Figure 9-4 shows a lateral pressure on the key of approximately 72 ksf

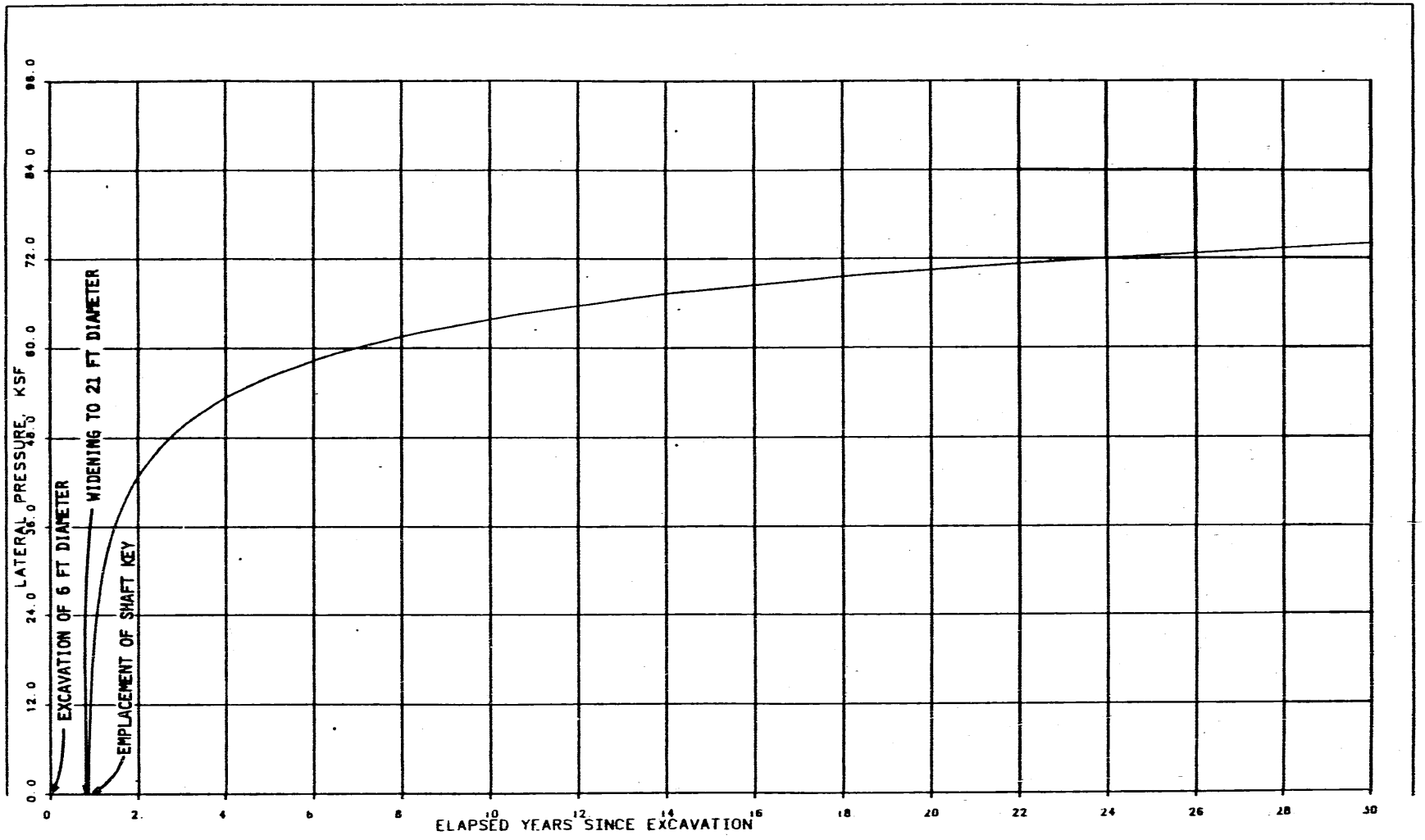


Figure 9-4

EXHAUST SHAFT KEY
LATERAL PRESSURE PREDICTION

at 25 years. Although higher than the design basis lateral pressure of 60 ksf, this value is about 50 percent of the allowable lateral pressure. In addition, the lateral pressure would actually be less than 72 ksf if concrete shrinkage and creep were taken into account in the finite element analysis.

Although no shrinkage cracks have been found in the reinforced concrete in the key, their presence would not be unexpected. They are common to most reinforced concrete structures and should not be of major concern.

9.3.3.3 Unlined Section

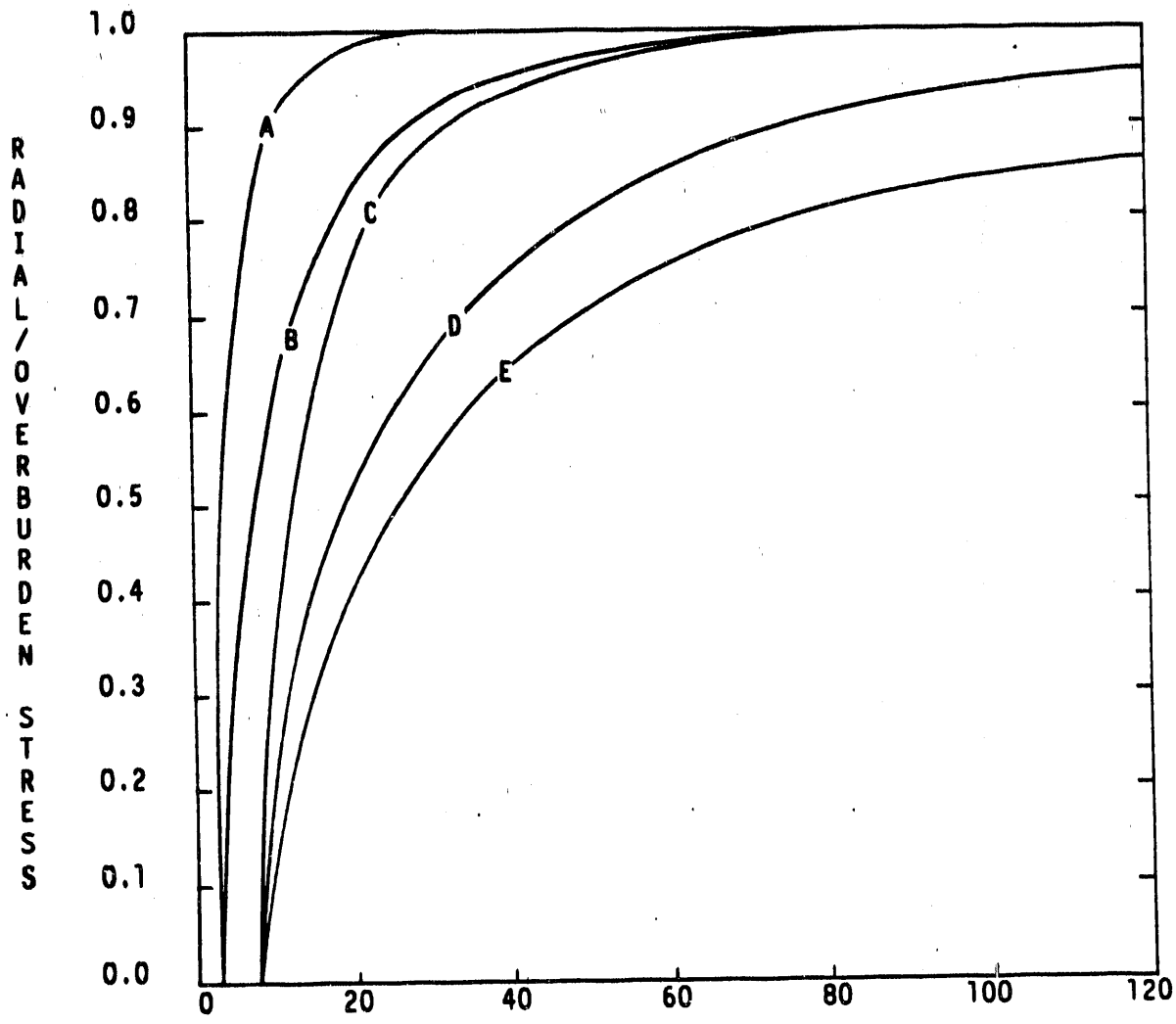
Figures 9-5 and 9-6 show predictions for radial and tangential (hoop) stress distributions relative to the overburden stress at different times for the unlined section of the exhaust shaft. Figure 9-5 shows the zone around the shaft opening where radial stresses are affected and their decrease in magnitude over time. The computational results indicate that tangential stresses are affected only within a radius of approximately 120 feet.

Figures 9-7 and 9-8 show predictions of the effective stress and effective creep strain distributions in the unlined section of the exhaust shaft. The magnitude of the effective stress in the shaft wall at 25 years approaches 140 ksf while the effective creep strain reaches a value of approximately 0.037.

Figure 9-9 shows approximately 6 inches of diametric closure in the unlined section of the exhaust shaft at a depth of 2,066 feet (elev. 1343 feet) over the 25-year operating life of the shaft.

9.4 CONCLUSIONS AND RECOMMENDATIONS

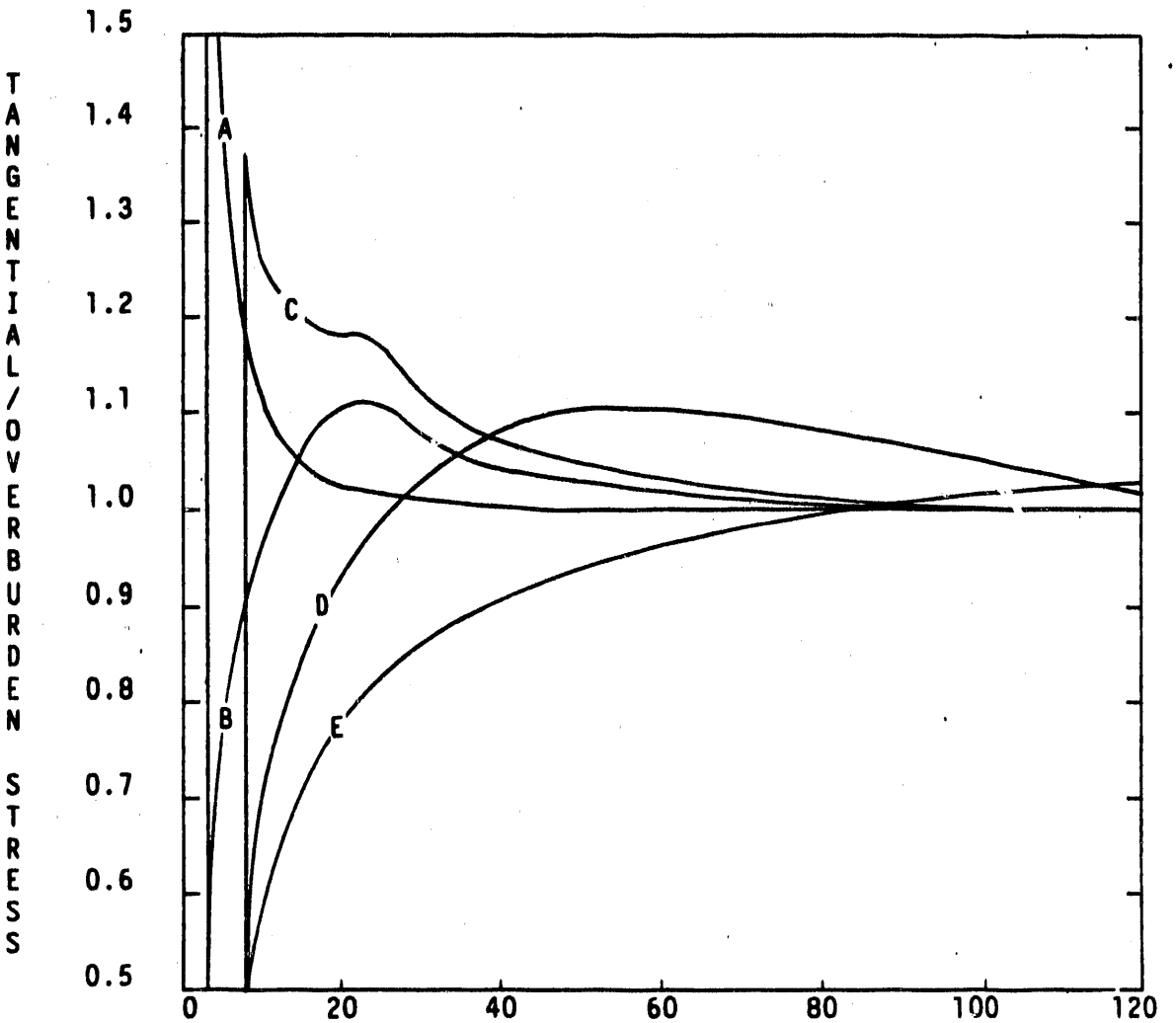
Design validation of the exhaust shaft requires an assessment of the compatibility of the design criteria, design bases and design configurations used for the reference design. The following discussion presents conclusions and recommendations regarding validation of the



A - IMMEDIATELY AFTER EXCAVATION OF 6-FT DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 15-FT DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 15-FT DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

Figure 9-5

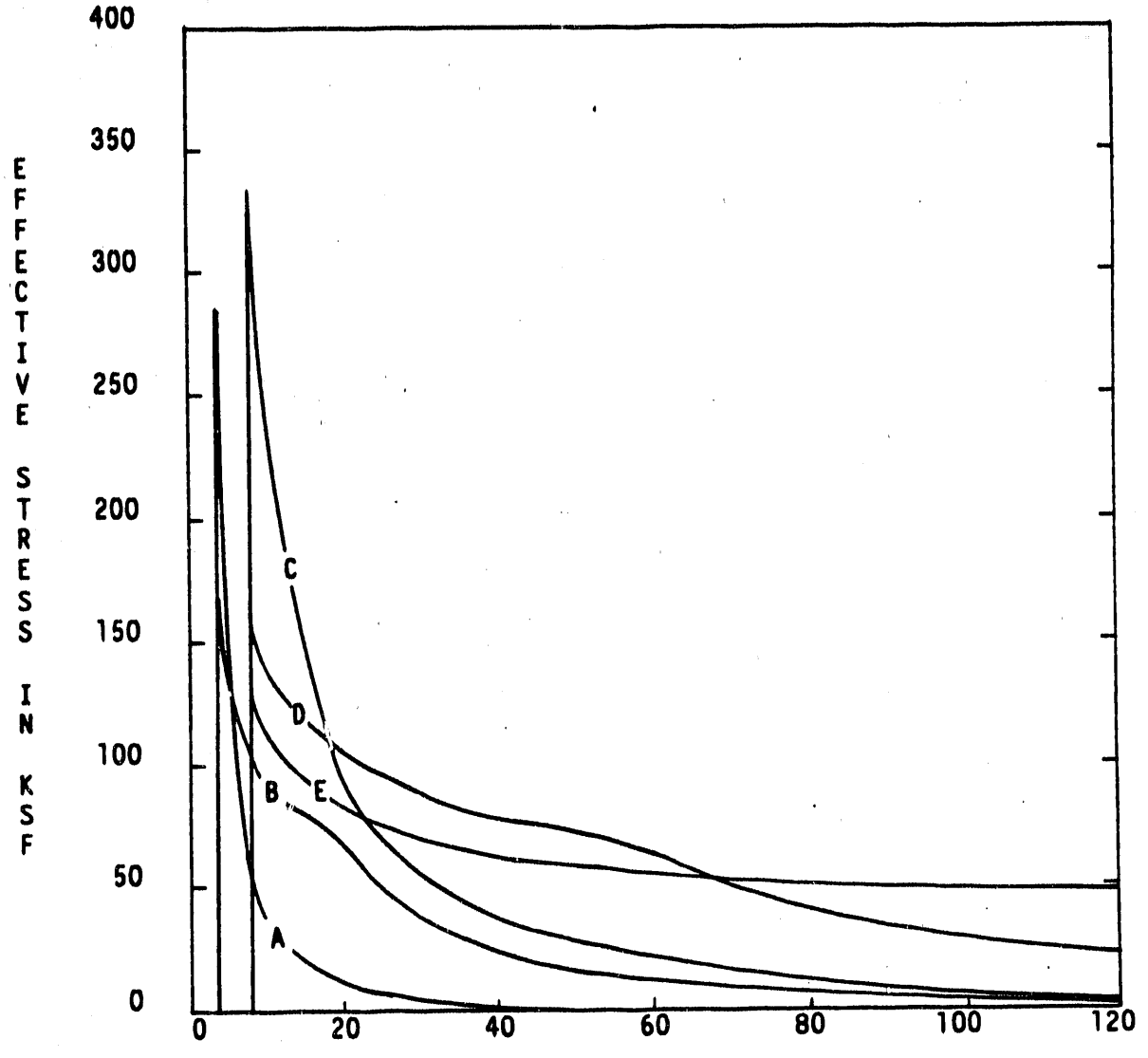
EXHAUST SHAFT UNLINED SECTION
RADIAL STRESS DISTRIBUTION AT ELEVATION 1343 FEET



A - IMMEDIATELY AFTER EXCAVATION OF 6-FT DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 15-FT DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 15-FT DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

Figure 9-6

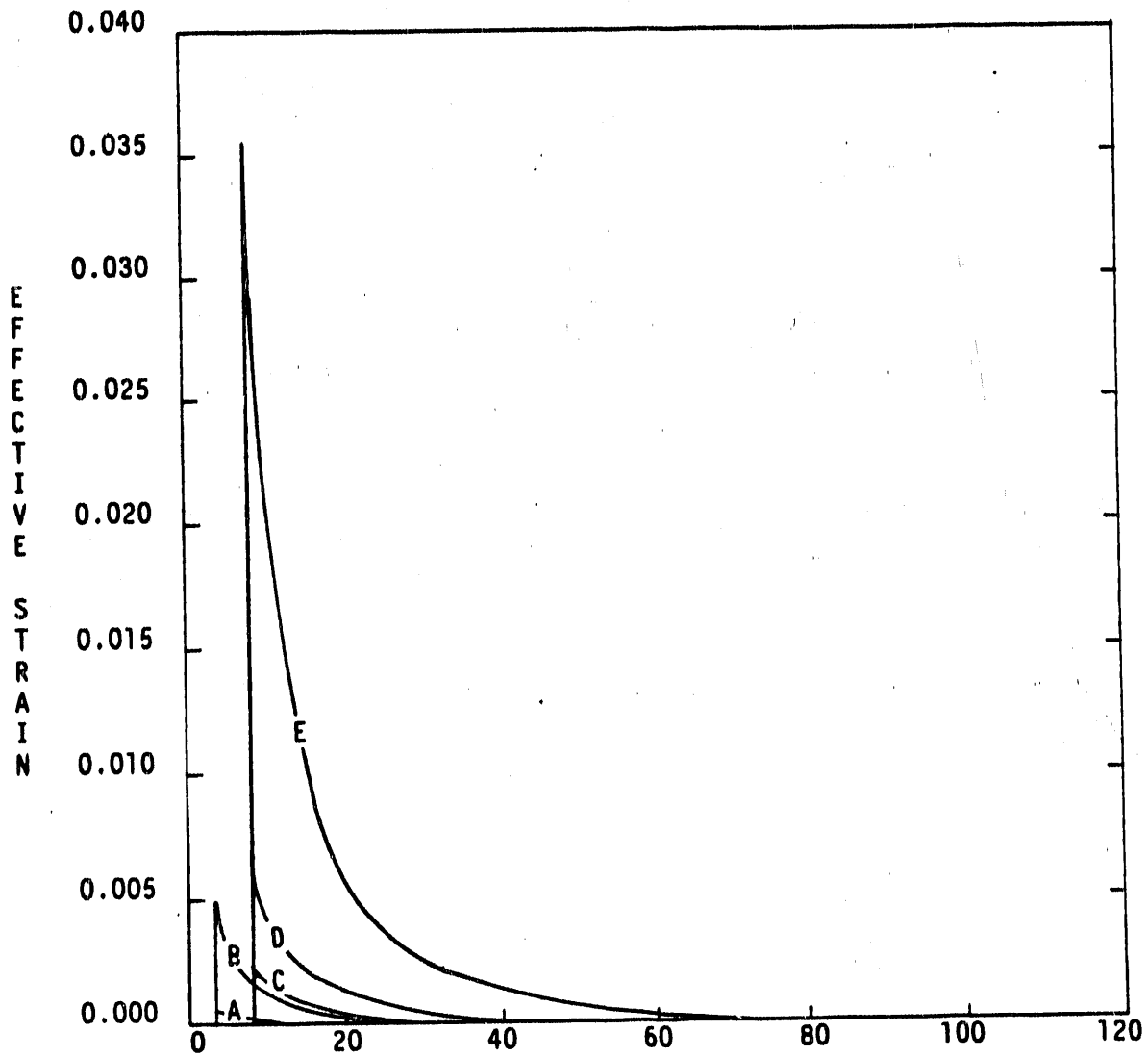
EXHAUST SHAFT UNLINED SECTION
TANGENTIAL STRESS DISTRIBUTION AT ELEVATION 1343 FEET



A - IMMEDIATELY AFTER EXCAVATION OF 6-FT DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 15-FT DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 15-FT DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

Figure 9-7

EXHAUST SHAFT UNLINED SECTION
EFFECTIVE STRESS DISTRIBUTION AT ELEVATION 1343 FEET



A - IMMEDIATELY AFTER EXCAVATION OF 6-FT DIAMETER SHAFT
B - IMMEDIATELY BEFORE WIDENING TO 15-FT DIAMETER
C - IMMEDIATELY AFTER WIDENING TO 15-FT DIAMETER
D - ONE YEAR AFTER WIDENING OF SHAFT
E - 25 YEARS AFTER WIDENING OF SHAFT

Figure 9-8

EXHAUST SHAFT UNLINED SECTION
EFFECTIVE CREEP STRAIN DISTRIBUTION AT ELEVATION 1343 FEET

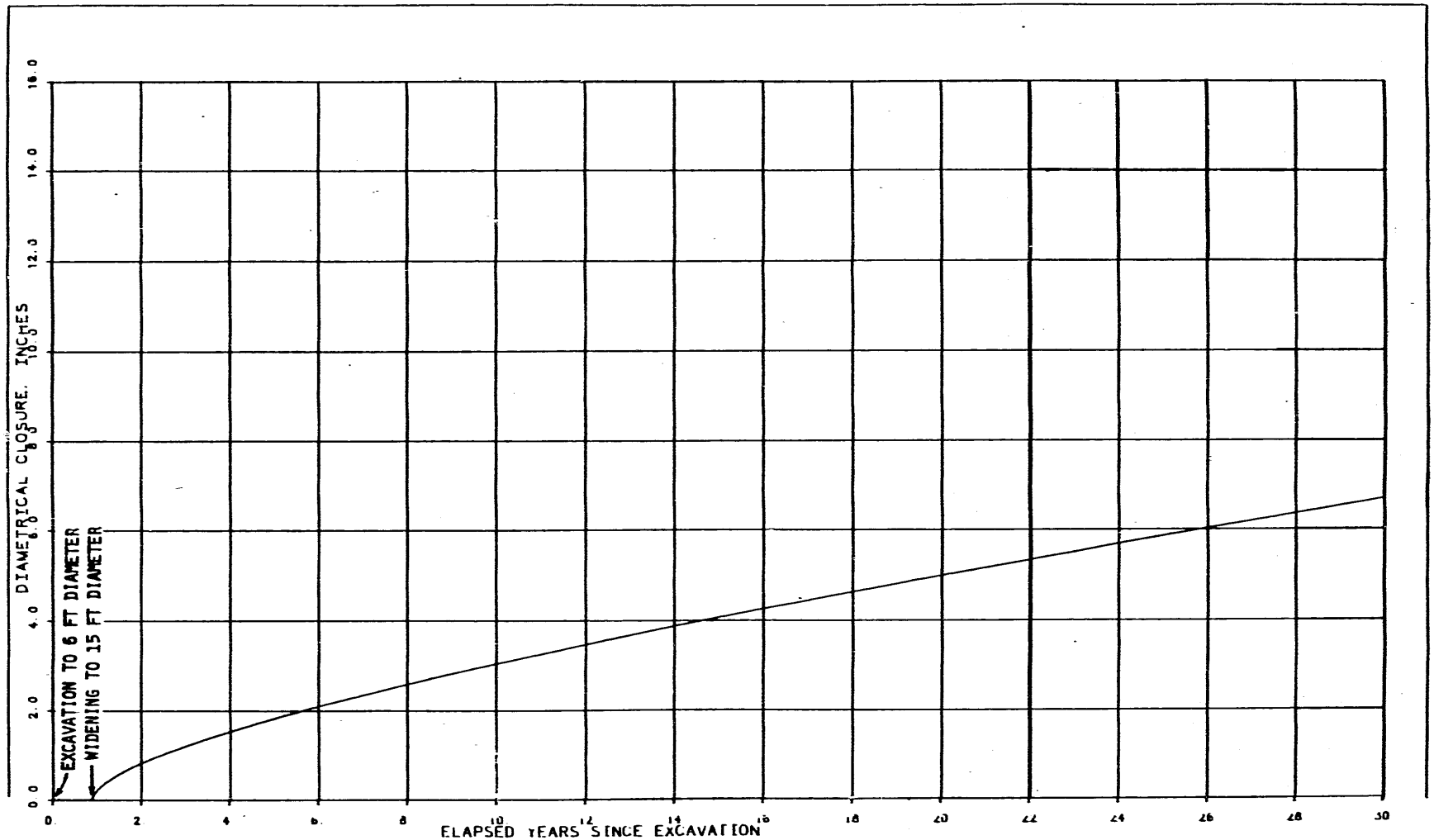


Figure 9-9

EXHAUST SHAFT UNLINED SECTION
CLOSURE PREDICTION AT ELEVATION 1343 FEET

exhaust shaft design as they pertain to the design elements identified in Section 9.2. These design elements stipulate the requirements that the exhaust shaft must meet in terms of shaft stability, deformation, water pressure and water control. Other conclusions and recommendations that are a product of the design validation process are also presented.

9.4.1 Conclusions

The stability of the exhaust shaft has been evaluated using analytical calculations, finite element modeling and analysis of data from the C & SH and waste shafts. The conclusions regarding shaft stability are the same as those for the waste shaft. The water pressure exerted on the shaft liner is currently less than the design hydrostatic pressure. If the hydrostatic pressure increases to its design limit, the liner will remain stable because its pressure capacity exceeds the design hydrostatic pressure by a factor greater than two. The cracks in the liner are not expected to result in any structural instability.

Analytical results show that the lateral pressure on the shaft key at the end of the 25-year operating life will be approximately 72 ksf. Although this pressure exceeds the design basis lateral pressure of 60 ksf, the allowable lateral pressure on the key is 154 ksf, or more than twice the predicted lateral pressure at 25 years. This provides a sufficient margin of safety against failure. If concrete shrinkage and creep were taken into account in the analysis, the margin of safety would be even greater.

The analytical results also show the redistribution of stresses around the unlined section of the shaft due to the effects of salt creep. Based on the computed vertical, horizontal and effective stresses in the unlined section, the magnitude of stresses immediately adjacent to the opening decreases and the stress arch around the opening migrates away with time. The maximum stress occurs immediately after excavation and is followed by relaxation due to creep behavior. Therefore, the stresses will not cause a future stability problem in the unlined

section of the shaft. The analysis shows the locations of effective creep strain concentrations at different times around the opening in the unlined section. Based on the predicted values of effective creep strain and the strain limit discussed in Chapter 6, the exhaust shaft will remain structurally stable within the limits required for safety during its operating life.

The analysis also predicts that the maximum diametric closure in the unlined section at the end of the operating period will be approximately 6 inches. Based on the predicted deformations and closures, the exhaust shaft will meet the requirements stated in the design criteria. The design basis requirement that the 15-foot diameter unlined section allow for salt creep over its operating life will be met.

As in the waste shaft, water is entering the exhaust shaft through cracks and construction joints in the concrete liner. The amount of water seepage was greatly reduced by grouting conducted after construction. The small amount of water still reaching the open shaft quickly evaporates in the upcast flow of exhaust air. While the exhaust fans are operating, no water reaches the underground facility level. The water seals behind the shaft concrete key appear to be functioning as intended at the bottom of the key. No water is seeping from the concrete/salt interface. There is no evidence of salt dissolution behind the key.

The reference design for the exhaust shaft has been validated in accordance with the objectives of the design validation program, based on the analyses, evaluations and predictions of future behavior presented in this chapter. With one exception, the exhaust shaft reference design complies with the design criteria and the design bases. The criterion that the liner shall prevent ground-water flow into the shaft has not been met. However, the water currently seeping into the shaft is not considered to be detrimental to shaft stability or function. No modifications to the exhaust shaft reference design are required.

9.4.2 Recommendations

Based on the results of design validation, recommendations similar to those for the waste shaft are made for the exhaust shaft:

(1) Validation of the exhaust shaft key and unlined section relied on analysis and modeling using in situ data from the C & SH and waste shafts. It is recommended that the numerical modeling be repeated, prior to the first receipt of waste, using in situ data from the exhaust shaft instruments. This analysis should be repeated periodically for the comparison of in situ data against design parameters.

(2) The exhaust shaft should be inspected by qualified personnel at regularly scheduled intervals. The liner should be inspected for renewed seepage and grouting performed if an amount of water considered sufficient to affect the liner's stability or functional purpose is observed. The key should be inspected for water seeping from behind the key at its base. If any is detected, grout should be injected above the top water seal. Grout should not be placed behind the key below the top seal. If this cannot be avoided, the grout must be a chemical gel (or other non-rigid grout) and must be compatible with both the existing water seal material and with the requirements of the Plugging and Sealing Program.

CHAPTER 10
DRIFTS

10.1 INTRODUCTION

This chapter presents the results of validation of the reference design for the underground drifts. Discussions are presented on the reference design, data collected from the openings, its analysis and evaluation, and predictions of future behavior. Conclusions and recommendations pertaining to the reference design are presented based on the results of the validation process.

The term drifts includes all horizontal underground openings except the shaft stations, test rooms, and storage area rooms and their associated drifts. Discussions of the shaft stations are presented in Chapters 7 and 8. Discussions of the test rooms, storage rooms and storage area drifts are presented in Chapters 11 and 12.

The largest drifts planned for the underground facility were initially excavated 8 feet high and 25 feet wide. These drifts have been or will be enlarged to 12 feet high. The present 12-foot high, 25-foot wide drifts were excavated earlier than most of the smaller drifts and, therefore, have the longest history of in situ data collection. Because these 12 x 25-foot drifts are the largest to be excavated, they also have the most critical dimensions. Consequently, the analyses, evaluations and predictions are based primarily on these larger drifts. The smaller drifts and rooms are, therefore, considered to be validated as a result of the validation of the larger 12 x 25-foot drift reference design.

10.2 DESIGN

This section presents the design criteria and design bases used to develop the reference design of the drifts.

10.2.1 Design Criteria

The design criteria established for the design of the WIPP underground facility are discussed in Chapter 2 and summarized in Table 2-1. Table 2-1 presents the major criteria affecting underground design, including such items as waste receipt rate, type of waste, backfill requirement, etc. Those criteria requiring evaluation of their suitability for design validation are indicated in Table 2-1. The remaining criteria contained in the Design Criteria document (ref. 2-7) do not require evaluation.

Three of the indicated criteria pertain directly to the drift reference design. The first criterion states that the underground openings shall be designed to provide structurally stable excavations and pillars. "Stable" is defined in the criteria document to mean that deformations of excavations and pillars are to remain within the limits required for structural function, ventilation and safety. The second criterion states that the underground opening reference design shall provide maximum stability for the excavated rooms and drifts. The third criterion stipulates that the underground excavation shall be designed to accommodate creep closure and maintain the minimum dimensions required for the operating life of the opening. Not only are these criteria to be evaluated for their suitability, but the reference design configurations based on them must also be evaluated. These reference design configurations were discussed in Chapter 3.

10.2.2 Design Bases

The design bases comprise the second level of the design documents. They outline specific design requirements that were followed in designing the final drift configurations. Only those design bases that apply directly to the underground drift configurations are discussed in this subsection. The Design Basis, Underground Excavations (refs. 2-9 and 2-18), Design Basis, Underground Shops and Facilities (ref. 2-20), and Design Basis, Geomechanical Instrumentation (ref. 2-17) should be referred to for details of the appropriate design bases used for the underground drifts. None of these design bases contained elements

pertaining specifically to the drifts that required evaluation during the validation program. Those bases that required evaluation for validation pertain only to the storage area drifts and are discussed in Chapter 12.

The design bases specify that excavation within the shaft pillar area shall be the minimum required to meet the operational and safety requirements of the waste storage level. The area extraction ratio was, therefore, kept below 15 percent in this area.

The maximum tolerance for excavation of the roof, floor and walls shall be plus six inches. In no case shall the finished dimensions be less than those specified by the design. The minimum vertical dimension for equipment clearances used to meet this basis was 11 feet.

Supports for underground workings shall comply with Federal and New Mexico codes. The use of rock bolts and wire mesh in specific areas shall be determined by mine conditions and code requirements. Entry roofs, walls and floors shall be checked periodically for loose salt in accordance with applicable codes. Methods of locating gas or brine accumulations shall be implemented, such as drilling holes ahead of the excavation and testing for the presence of gas.

A geomechanical instrumentation system shall be installed to provide in situ measurement data for design verification or modification and for subsequent operational planning. In addition, the instrumentation system shall monitor stress change, closure and creep to provide a record of the structural stability of the drifts and to provide early warning of abnormal conditions for operational safety.

Deformation measurements in the drifts shall be measured as a function of horizontal and vertical closure. Salt creep and stress distributions around the drifts and at intersections shall also be measured.

The instrumentation shall provide the primary detection of changes in structural behavior. Visual observations shall follow any detected abnormal strain, pressure or deformation for evaluation of the safety of the underground working places. In addition, a program shall be provided for periodic visual inspection of all underground working places.

10.3 DESIGN VALIDATION PROCESS

Validation of the reference design of the underground drifts includes the collection of data and the presentation of results based on its analysis and evaluation. The results of the design validation process are used to present conclusions regarding the compatibility of the design criteria, design bases and design configurations, and recommendations for modifications, if any. This section presents the data collected and predictions of future drift behavior based on analysis and evaluation of the data.

10.3.1 Data Collection

Data pertaining to the underground drifts was collected from various sources. Geologic data was acquired from geologic mapping and core drilling. These data verified the stratigraphic continuity at the facility level and are discussed in detail in Chapter 6. Data were also acquired from periodic visual inspections and from geomechanical instrumentation. Collection of these data are described in the following subsections.

10.3.1.1 Field Observations

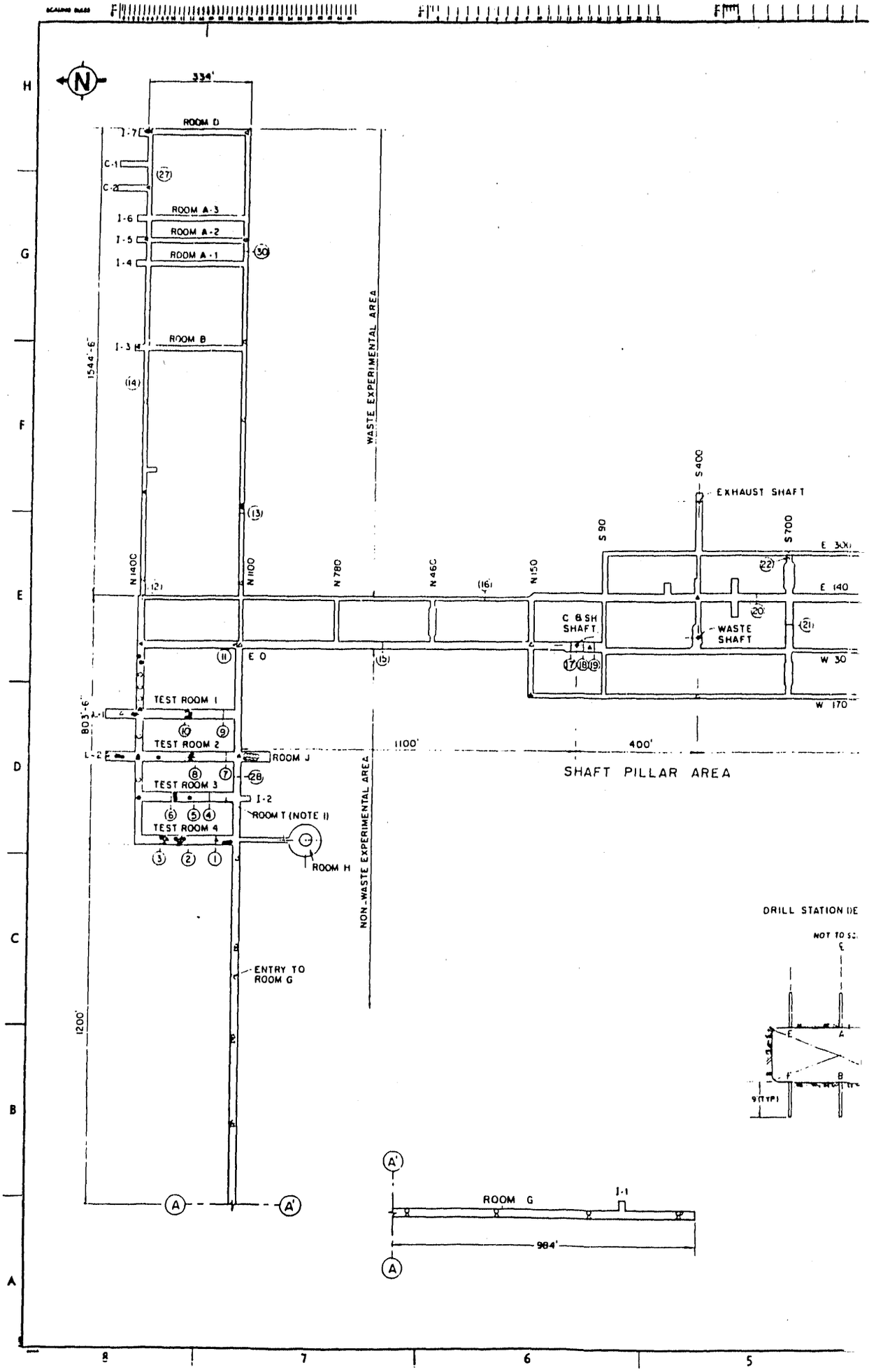
Various aspects of underground behavior are evaluated by qualitative observations and documentation. Visual inspections of the drifts include observations of their general surface conditions in response to stress redistribution and creep. These conditions include shallow spalls from the roof and walls, especially at their intersection; and vertical fracturing in the pillars, both at corners and parallel to the walls. In addition to visual inspections, other techniques are used. Boreholes are surveyed using video cameras and displacements,

separations and fracturing of geologic strata surrounding the boreholes are detected using a simple probe. Surveys of underground conditions have been performed at least once every 3 months. Each survey is documented in a GFDR beginning with the February 1984 edition (refs. 4-12 through 4-19).

Recently, a special program was conducted to determine the effect of excavation induced deformation on the salt strata surrounding the facility level. An array of boreholes was drilled into the roof and floor at 30 locations in the drifts and test rooms during May through July 1986. These arrays are shown on Figure 10-1. These boreholes were used to locate separations and fractures in the halite and anhydrite near the horizontal underground openings. This Excavation Effects Program was instigated after the discovery of significant fracturing beneath the southern half of Test Room 3 (Room T). The objectives of this excavation effects study were to determine if fracturing of this magnitude has occurred anywhere else and to investigate existing conditions at selected localities throughout the facility.

The documented field observations can be separated into four categories: roof and wall spalling; pillar fracturing; roof displacements and separations; and floor displacements, separations and fracturing.

Roof and Wall Spalling. During and immediately after excavation, a sounding survey of the roofs of all drifts was performed. Each survey identified areas of potential instability, such as drummy or slabby salt. Remedial work was accomplished immediately and included scaling, additional excavation, or rock bolting. Comprehensive sounding surveys were also performed in every underground opening in July 1983 and November 1984. The behavior of the roof and walls is documented in the table entitled "Condition of Roof and Walls" in each GFDR.


N
334'
ROOM D
C-1
C-2
(27)
ROOM A-3
ROOM A-2
ROOM A-1
(30)
I-6
I-5
I-4
ROOM B
I-3
(14)
1544'-6"
WASTE EXPERIMENTAL AREA
(13)
N 1400
(12)
N 1100
N 780
N 460
(16)
N 150
S 90
S 400
EXHAUST SHAFT
S 700
E 300
E 140
(22)
(20)
(21)
C & SH SHAFT
WASTE SHAFT
(11)
E 0
(15)
(17)(18)(19)
W 30
W 170
TEST ROOM 1
TEST ROOM 2
TEST ROOM 3
TEST ROOM 4
803'-6"
L-2
ROOM J
(28)
I-2
ROOM T (NOTE 11)
ROOM H
1100'
400'
SHAFT PILLAR AREA
NON-WASTE EXPERIMENTAL AREA
ENTRY TO ROOM G
1200'
A
A'
ROOM G
I-1
984'
DRILL STATION DE
NOT TO SC
H
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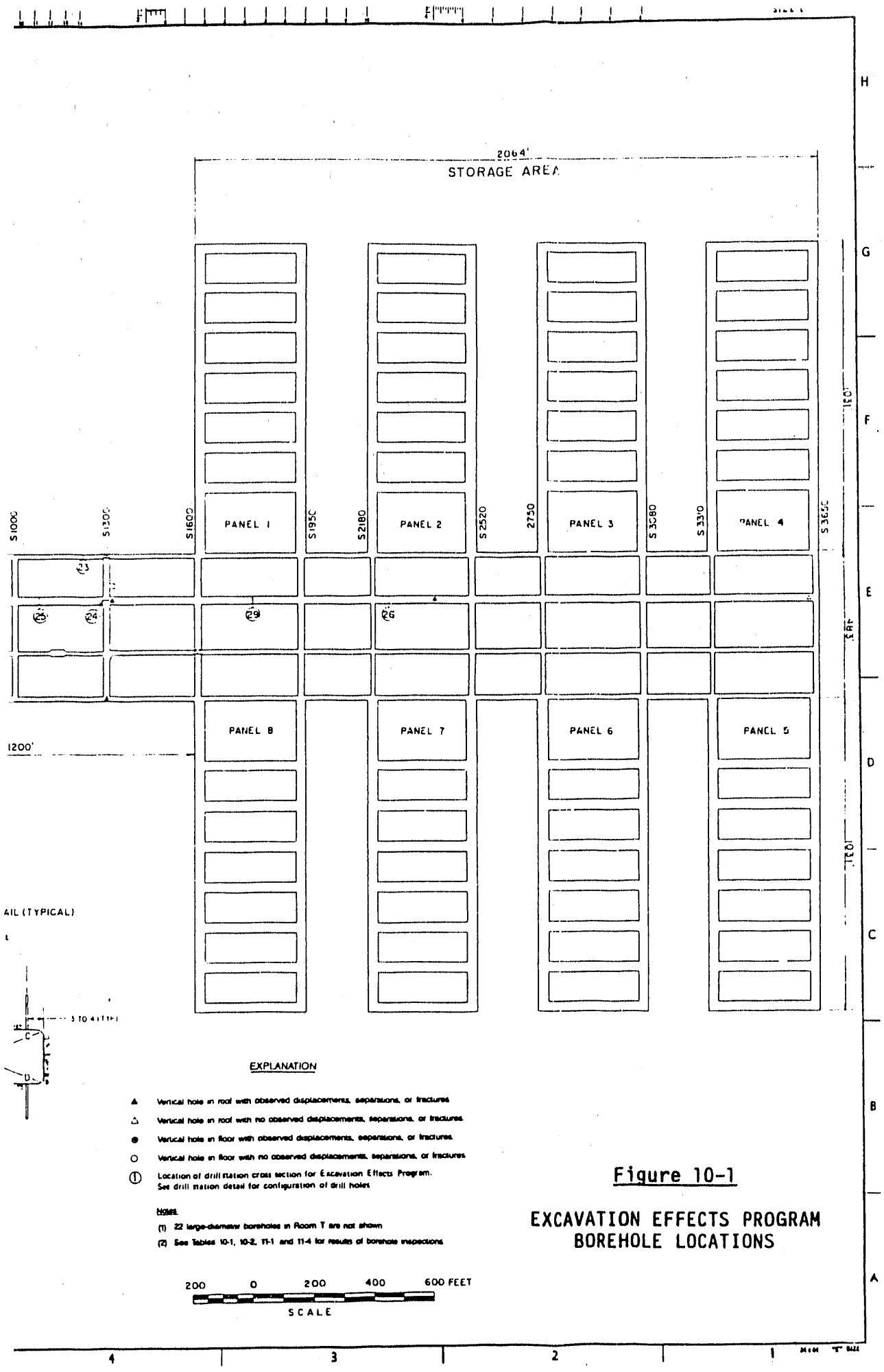


Figure 10-1

EXCAVATION EFFECTS PROGRAM BOREHOLE LOCATIONS

Pillar Fracturing. Vertical fractures have developed in the corners formed by drift intersections. These fractures began appearing about 3 to 6 months after excavation. Site geologists have monitored the growth of these fractures and have included their observations in the GFDRs.

Vertical fractures parallel to the drift walls have been detected in several horizontal boreholes. These fractures were not present at the time of drilling. They were first observed in May 1986 and occur within 1 to 2 feet of the wall surface.

Roof Displacements and Separations. Horizontal displacements and vertical separations have been detected in some open boreholes in the drifts during the past 2 years. Periodic inspections of all accessible boreholes in the drifts have been made since September 1985. The results of these inspections in the roof holes are presented in Table 10-1.

Visual inspections were conducted directly or remotely using a video camera and/or probe. The probe used was described in Chapter 7, subsection 7.3.1.4. Depths to displacements and separations were measured with a tape measure. Relative horizontal displacements were measured where possible or estimated.

The recently conducted Excavation Effects Program consisted of drilling numerous arrays of 1 7/8-inch and 3-inch diameter holes at selected locations along the drifts (Figure 10-1). The holes were drilled approximately 9 feet into the roof and floor and inspected using a probe. The results of the inspection of these holes are presented in Table 10-2.

The N1100 and N1420 drifts were excavated eastward to E1680 in early 1984. These drifts incline upward to the experimental area. The roofs of both drifts intersect anhydrite beds "a" and "b". Slabby rock at the intersection was removed by the mining machine and rock bolts

Table 10-1

DRIFTS
RESULTS OF INSPECTION OF VERTICAL BOREHOLES IN ROOFS

Hole	Date Completed	Hole Size (in.)	Depth (ft)	Approximate Location	Observed Condition*
DH-01	2-10-84	3	50.8	N1424/E439.5	None
DH-03	2-7-84	3	48.8	N1112/E444	D
DH-03A	3-12-84	3	49.9	N1112/E450.5	D
DH-05	3-9-84	3	51.0	N1463/E972	D
DH-07	2-22-84	3	49.8	N1112/E976.5	None
DH-09	3-14-84	3	51.1	N1432/E1332.5	None
DH-11	3-6-84	3	50.9	N1112/E1332.5	None
DH-13	3-28-84	3	13.8	N1424/E1690	D, S
DH-13A	3-29-84	3	49.0	N1425/E1691	D, S
DH-13B	4-5-84	3	21.0	N1425/E1695	D, S
DH-15	3-21-84	3	51.0	N1104/E1688.5	None
DH-17	1-19-84	3	52.0	N1104/E1688	None
DH-19	1-21-84	3	51.6	N1107/E206.5	None
DH-21	2-27-84	3	50.4	N1421/E786	None
DH-23	2-15-84	3	51.0	N1112/E781	None
DH-25	3-30-84	3	51.8	N1422/E1510	D, S
DH-27	7-27-84	3.5	50.5	N1107/W682	None
DH-29	7-25-84	3.5	50.4	N1099/W982	None
DH-29A	9-12-84	3.5	35.0	N1099/W987	None
DH-31	7-19-84	3.5	50.5	N1099/W1282	None

* D = displacement; S = separation; F = fracturing

Table 10-1 (continued)

DRIFTS
RESULTS OF INSPECTION OF VERTICAL BOREHOLES IN ROOFS

Hole	Date Completed	Hole Size (in.)	Depth (ft)	Approximate Location	Observed Condition*
DH-31A	7-24-84	3.5	49.2	N1099/W1280	None
DH-31B	9-12-84	3.5	4.9	N1099/W1261	None
DH-33	7-18-84	3.5	50.5	N1099/W1582	None
DH-33A	9-13-84	3.5	4.1	N1099/W1570	None
DH-35	1-27-85	3.5	52.0	N1102/W1882	None
DH-37	1-26-85	3.5	51.5	N1101/W2182	None
DH-39	1-24-85	3.5	50.7	N1101/W2482	None
DH-41	1-24-85	3.5	49.9	N1101/W2782	None
DH-205	2-18-83	3	50.7	N1410/E0	None
DH-211	12-19-82	3	50.0	S1320/E163	None
DH-219	1-14-83	3	51.0	S2422/E162	None
DH-227	1-28-83	3	51.7	S3656/E147	None
DH-301	8-30-84	3.5	50.8	N150/W170	D
DH-303	9-4-84	3.5	51.4	S400/W170	None
DH-313	7-10-84	3	19.6	S1300/E300	None
DH-313A	7-12-84	3	50.2	S1300/E299	None
DH-315	9-6-84	3.5	50.3	S1300/W170	D
DH-317	7-6-84	3	50.1	S1600/W33	None
DH-317A	7-6-84	3	5.0	S1600/W30	None
DH-317B	9-7-84	3.5	51.0	S1597/W30	None
DH-319	9-10-85	3.5	51.1	S700/E300	None

Table 10-1 (continued)

DRIFTS
RESULTS OF INSPECTION OF VERTICAL BOREHOLES IN ROOFS

Hole	Date Completed	Hole Size (in.)	Depth (ft)	Approximate Location	Observed Condition*
OH-2	8-83	4	20	S410/E147	None
OH-3	8-83	4	20	Room 2 centerline	S, F
OH-4	8-83	4	20	N1110/W365	S
OH-6	8-83	4	20	N1110/W5	None
OH-7	8-83	4	20	S70/E0	D, S, F
OH-8	8-83	4	20	N140/E0	None
OH-9	2-84	4	15.4	N1433/W232	S, F
OH-10	2-84	4	21.0	N1420/W218	D
OH-11	2-84	4	19.7	N1433/W365	None
-	-	5	10	Room L1 centerline	None
L2PU-02	-	5	9.2	Room L2 centerline	None

Table 10-2

EXCAVATION EFFECTS PROGRAM
BOREHOLE INSPECTION SUMMARY

SECTION	OPENING DIMENSIONS (HxW-FT)	EXCAVATION DATE	LOCATION	DATE DRILLED	DATE INSPECTED	OBSERVED CONDITIONS					
						ROOF HOLES			FLOOR HOLES		
						E	A	C	F	B	D
11	12x25	2/83 (FLOOR LOWERED 4 FT 12/83)	N110, W02	5/30/86	6/02/86	C	NONE	C (POSSIBLY CLAY G)	C	S, C	C
12	12x14	2/83	N1430, E140	6/05/86	6/10/86	S, C	C	C	S, C	S	S(?), C
13	8x14	1/84	N110, E439	6/20/86	6/30/86	D *	NONE	NONE	NONE	NONE	NONE
14	12x14	2/84	N1430, E875	6/05/86	6/10/86	S	S(?)	S	S(?)	C	S(?)
15	12x25	2/83 (FLOOR LOWERED 4 FT 12/83)	N626, W02	6/20/86	6/30/86	NONE	C	S, C	C	S, C	C
16	8x14	2/83	N305, E147	7/15/86	7/18/86	NO ROOF HOLES			NONE	C	C
17	12x32	10/82	C&SH SHAFT STATION - N028	5/30/86	6/02/86	C	NONE	F	NONE	S, F	NONE
18	17x35	6/82	C&SH SHAFT STATION - S024	6/04/86	6/04/86	C	S, F	F	S	NONE	S
19	15x35	6/82	C&SH SHAFT STATION - S056	6/03/86	6/04/86	F, C	F	F	F, C	C	C
20	14x25	12/82 (FLOOR LOWERED 5/84)	S592, E155	7/10/86	7/11/86	NONE	NONE	NONE	S, C	NONE	NONE
—	15x35	6/82	C&SH SHAFT STATION - ELECTRICAL SUBSTATION	6/05/86	6/06/86					X	Y
										S, C	S, C
21	12x20	7/85	S700, E66	7/08/86	7/09/86	NONE	NONE	NONE	NONE	S	C (POSSIBLY CLAY E)
22	12x14	5/84; 7/84	S700, E300	7/08/86	7/09/86	NONE	NONE	NONE	C	NONE	NONE
23	12x14	7/84	S890, E229	7/09/86	7/10/86	NONE	NONE	C	NONE	C	C
24	12x20	12/82; 8/85; 6/84	S1300, E55	7/09/86	7/10/86	NONE	NONE	NONE	NONE	NONE	NONE

Table 10-2 (continued)

EXCAVATION EFFECTS PROGRAM

BOREHOLE INSPECTION SUMMARY

SECTION	OPENING DIMENSIONS (BxH-FT)	EXCAVATION DATE	LOCATION	DATE DRILLED	DATE INSPECTED	OBSERVED CONDITIONS					
						ROOF HOLES			FLOOR HOLES		
						E	A	C	F	B	D
25	12x25	12/82 @FLOOR LOWERED 5/84	S829, E55	7/9/86	7/10/86	NONE	NONE	NONE	C	C	C
26	8x25	1/83	** S2205, E154	7/16/86	7/18/86	NO ROOF HOLES			NONE	NONE	C
27	12x14	3/84	** N430, E555	7/11/86	7/18/86	NO ROOF HOLES			NONE	NONE	C
28	12x20	3/83 @FLOOR LOWERED 4/83	** N80, W432	7/16/86	7/18/86	NONE	NO HOLE	NONE	NONE	NO HOLE	C
29	12x25	12/82 @FLOOR LOWERED 8/85	** S1700, E55	7/10/86	7/11/86	C	NONE	NONE	NO FLOOR HOLES		
30	8x14	2/84	** N80, E303	7/11/86	7/18/86	C	NO HOLE	NONE	C	NO HOLE	NONE

* EXISTING HOLE.
** LOCATION APPROXIMATE. NOT SURVEYED.

EXPLANATION

D = HORIZONTAL DISPLACEMENT. FOUND ONLY IN PREVIOUSLY DRILLED HOLES. DISPLACEMENT APPEARS TO DEVELOP WITH TIME FOLLOWING HOLE DRILLING.

S = VERTICAL SEPARATION. PROBE NAIL PENETRATES HOLE WALL SURFACE. VERTICAL SEPARATIONS RANGE FROM APPROXIMATELY 1/16 INCH TO 6 INCHES.

F = FRACTURE ZONE. PIECES OF HALITE COMMONLY PICKED OUT OF ZONE BY PROBE NAIL.

C = PROBE NAIL CATCHES ON HOLE WALL SURFACE BUT DOES NOT PENETRATE. INDICATES POSSIBLE SEPARATION OF LESS THAN 1/16 INCH. OCCURENCES AT KNOWN CLAY LAYERS ARE NOT INDICATIVE OF SEPARATION AND ARE NOT INCLUDED IN THIS TABLE.

NOTES:

1. SECTION LOCATIONS AND HOLE CONFIGURATIONS ARE SHOWN ON FIGURE 10-1.
2. HOLES WERE DRILLED VERTICALLY USING A JACK-LEG DRILL.
3. NOMINAL HOLE DEPTH IS 9 FEET BUT SOME HOLES ARE SHORTER DUE TO LOW DRIFT ROOF OR DRILLING DIFFICULTIES.
4. ONE ROOF AND ONE FLOOR HOLE OF EACH ARRAY WERE GENERALLY DRILLED 3 INCHES IN DIAMETER TO ACCOMODATE USE OF BOREHOLE CAMERA IF DESIRED. OTHER HOLES WERE DRILLED 1-7/8 INCHES IN DIAMETER. EXISTING HOLES WERE USED WHERE POSSIBLE.
5. OBSERVATIONS WERE MADE USING A PROBE CONSISTING OF A NAIL ATTACHED PERPENDICULAR TO THE END OF A ROD.
6. HOLES AT SECTION 13 WERE DRILLED TO ONLY 6- OR 6.5-FT DEPTH DUE TO LOW DRIFT ROOF. NO ROOF HOLES WERE DRILLED AT SECTIONS 16 OR 26 DUE TO LOW DRIFT ROOF.
7. POSSIBLE SEPARATIONS IN FLOOR HOLES AT SECTION 25 ARE PROBABLY AT CLAY E.

and wire mesh were installed. Several fractures in the roof brow at these anhydrites have been observed.

A portion of the N140 crosscut between W170 and E140 has been excavated above clay G. An inspection of this area in June 1986 showed some minor vertical separation, on the order of 1/8 inch, as well as some squeezing out of clay G. No fractures in the underlying halite were observed.

Floor Displacements, Separations and Fracturing. Fracturing has developed beneath the floor in some locations. These fractures occur in the halite above MB-139 and sometimes extend into MB-139. The most prominent fracturing at present is beneath Test Room 3, as discussed in Chapter 11.

As with the roof boreholes, observations were accomplished using both video equipment and a probe. The results of floor hole inspections conducted through July 1986 in accessible boreholes are presented in Table 10-3. Results of the Excavation Effects Program are included in Table 10-2.

10.3.1.2 Geomechanical Instrumentation

An extensive system of geomechanical instruments has been installed in the underground drifts (Figure 10-2) to provide in situ data on the deformational behavior of these openings. The majority of the instruments were installed during the SPDV Program and therefore have been monitored for over three years. Additional instrumentation was installed after the SPDV program was completed.

Instrumentation in the drifts consists of radial convergence points and multiple-point borehole extensometers. The convergence points consist of pairs of eyebolts anchored in the salt of the roof, floor and walls of the drifts as well as at corners of intersections. The closure of the opening is measured between a pair of convergence points using a tape extensometer. The borehole extensometers are the sonic-probe type

Table 10-3

DRIFTS
RESULTS OF INSPECTION OF VERTICAL BOREHOLES IN FLOORS

Hole	Date Completed	Hole Size (in.)	Depth (ft)	Approximate Location	Observed Condition*
DH-36	1-26-85	3.5	51.5	N1102/W1882	None
DH-38	1-26-85	3.5	47.5	N1101/W2182	None
DH-40	1-25-85	3.5	51.0	N1101/W2482	None
DH-42	1-23-85	3.5	51.2	N1101/W2782	None
DH-42A	1-25-85	3.5	40.5	N1101/W2789	None
DH-228	1-28-83	3	50.4	S3656/E147	None
OH-13	2-84	4	9.5	N1433/W232	S, F
OH-14	2-84	4	9.7	N1433/W365	D, S, F
JV-01	9-85	36	8	Room J	None
JV-02	9-85	36	8	Room J	None
JV-03	9-85	36	8	Room J	None
JV-04	9-85	36	8	Room J	None
JV-05	9-85	36	8	Room J	None
JV-06	9-85	36	8	Room J	None
JV-07	9-85	36	8	Room J	None
JV-08	9-85	36	8	Room J	F
JV-09	9-85	36	8	Room J	None
L2X-01	1-85	30	12	Room L2	None
L2PD-01	-	5	13.0	Room L2 centerline	D, S, F
-	-	5	11.3	Room L2 centerline	S, F

* D = displacement; S = separation; F = fracturing

Table 10-3 (continued)

DRIFTS
RESULTS OF INSPECTION OF VERTICAL BOREHOLES IN FLOORS

Hole	Date Completed	Hole Size (in.)	Depth (ft)	Approximate Location	Observed Condition*
-	-	16	10.3	Room L2 centerline	D, S
NPD-03	1-86	5	9.3	N1420, east of Test Room 1	None
NPD-04	1-86	5	9.5	N1420, east of Test Room 1	None
NPD-05	1-86	5	9.6	N1420/Room L1	None
NPD-06	1-86	5	9.5	N1420/Room L1	None
NPD-07	1-86	5	9.0	N1420/Room L2	S, F
NPD-08	1-86	5	12.0	N1420, east of Test Room 1	S
NPD-11	1-86	5	8.9	N1420, between Test Rooms 2 and 3	None
NPD-12	1-86	5	9.0	N1420, between Rooms L1 and L2	None

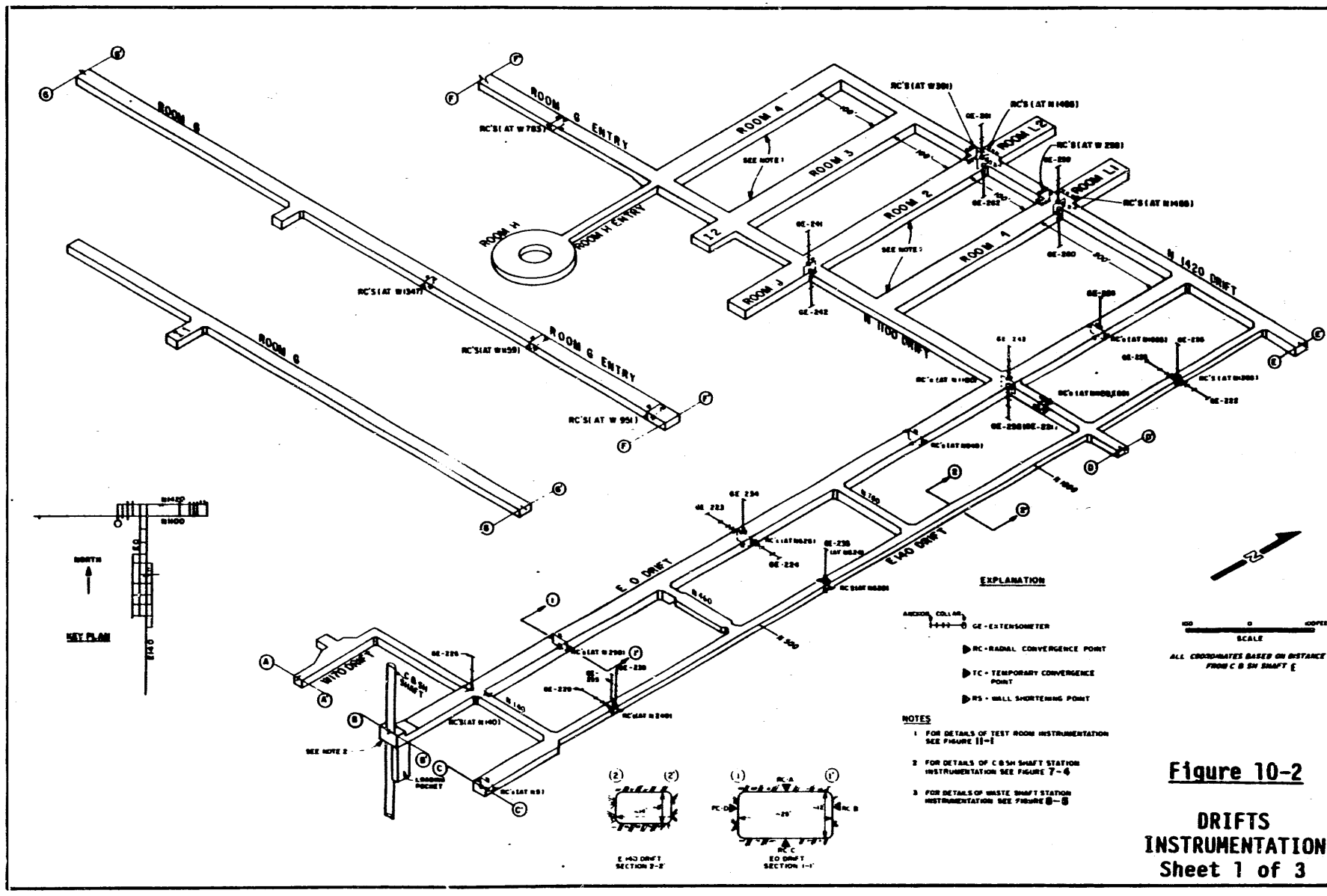


Figure 10-2

DRIFTS INSTRUMENTATION
Sheet 1 of 3

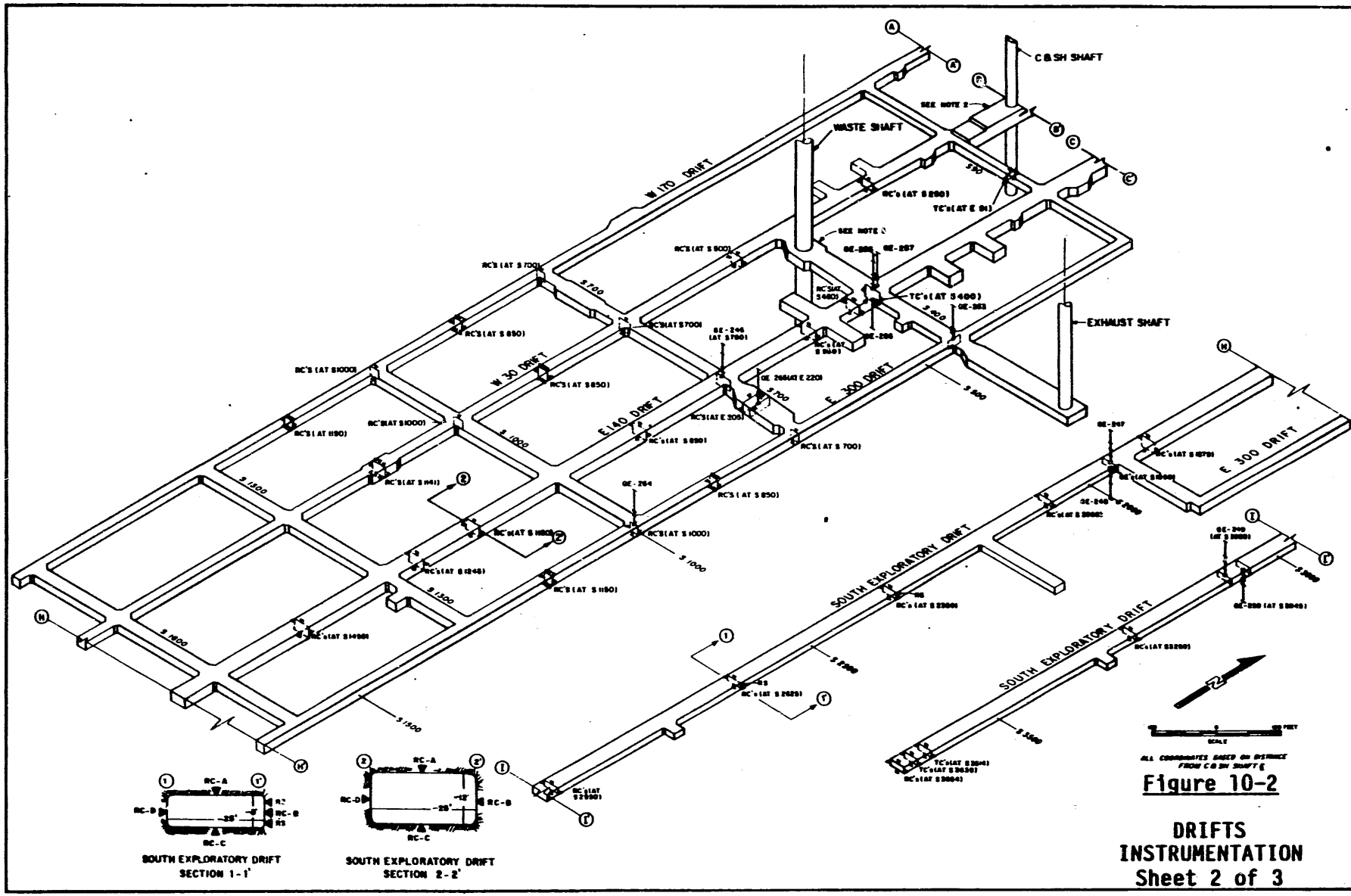


Figure 10-2

DRIFTS INSTRUMENTATION
Sheet 2 of 3

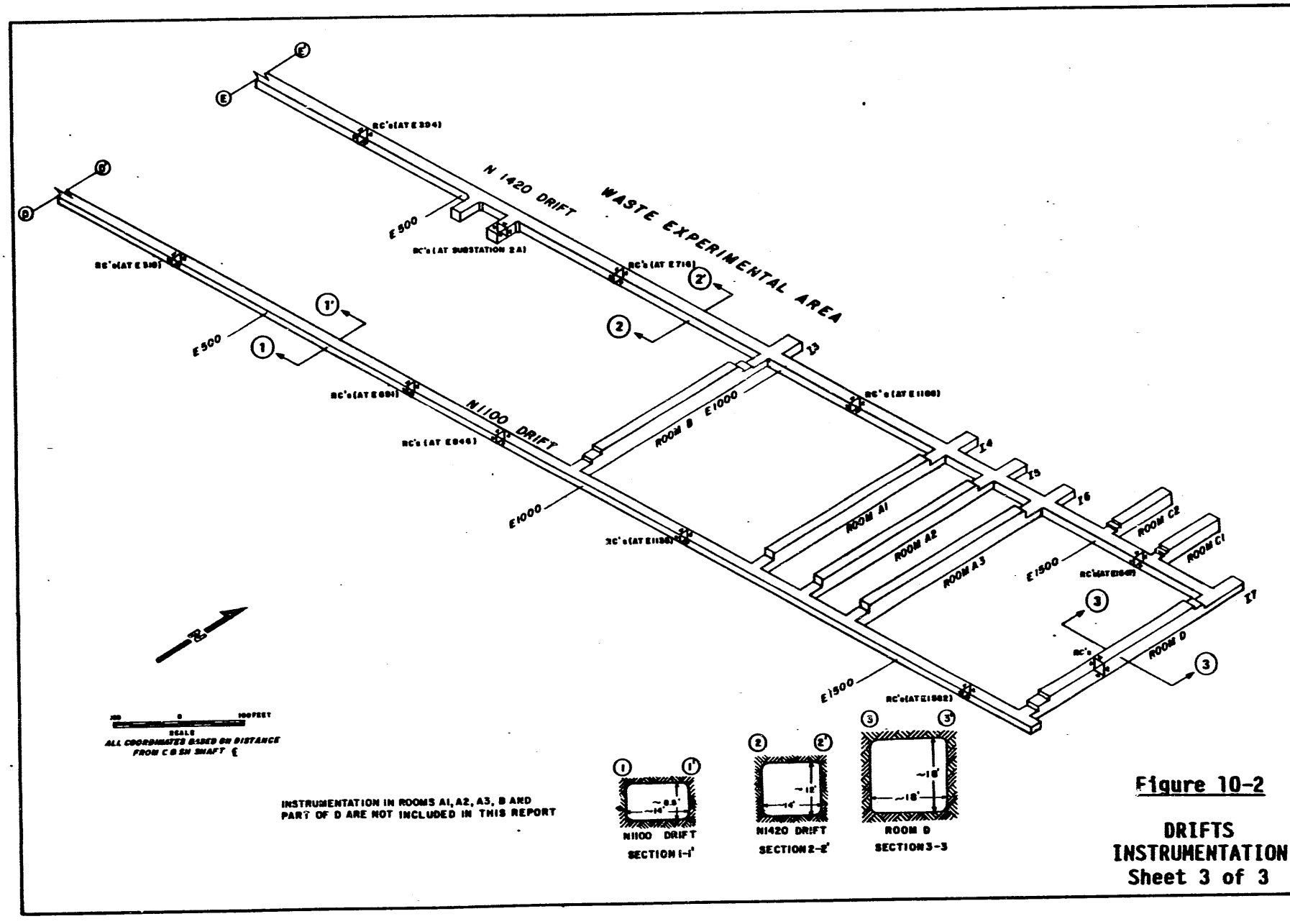


Figure 10-2

DRIFTS INSTRUMENTATION
Sheet 3 of 3

with stainless steel anchor rods and expansion-ring anchors. Two-anchor, four-anchor and five-anchor extensometers have been installed. Anchor depths vary with locality and site-specific stratigraphy. Recent data plots for the drift instruments are presented in Appendix J.

No stressmeters were installed in either the halite or anhydrite surrounding the drift openings. A program to develop reliable stressmeters for use in halite was begun but abandoned when other WIPP participants initiated similar programs. The results of their programs indicate that measurements using modified stressmeters are not yet sufficiently reliable to be considered for design validation. Therefore, numerical modeling was relied upon to analyze stress changes with time in the halite and anhydrite around the openings. The reliability of the readings from the two stressmeters installed in MB-139 beneath Test Room 2 is discussed in Chapter 11.

The underground instrumentation system has had a complex history. All extensometers have been reset at least once because salt creep moved the anchor-rod magnets beyond the initial 2-inch measurement limit. Convergence points were frequently damaged by construction activities and were regularly replaced. Extensometers were also damaged during construction; some were replaced and others were abandoned. The operational history of the instruments is presented in each issue of the GFDRs.

10.3.2 Analysis and Evaluation

The in situ data collected and observations made during the design validation process were analyzed and evaluated to determine the effects of salt behavior on the drift excavations. Closure data were analyzed and a model simulation was performed for a typical 8 x 25-foot wide drift. An option for lowering the floor 5 feet was incorporated into the model for subsequent analysis of the drifts in the storage area. The results of the analysis of the larger drifts are presented in Chapter 12.

10.3.2.1 Observed Conditions

Evaluation of observed conditions is a qualitative process. It represents the assessment of qualified geologists and engineers and is an important component of the analysis and evaluation of measured responses and structural calculations.

Roof and Wall Spalling. Changes in roof and wall conditions occur slowly. Drummy areas detected during the original soundings have not enlarged significantly. These drummy areas occur in clear halite and are not associated with any noticeable clay deposits. Separations occur along planes of weakness, probably created by the orientation of crystal faces. Few new slabby areas have developed. For an unknown reason, more slabby areas developed in the roof of the E140 drift south of the waste shaft during excavation than in any other underground area. These areas have shown little, if any, growth.

Wall spalling is even more subdued. The most noticeable spalling occurs in the argillaceous halite unit and associated clay seam (geologic map unit 4 and clay F) near the intersection of the wall and roof. This area has exhibited slowly deteriorating conditions and requires occasional scaling. This spalling of map unit 4 and the squeezing out of associated clay F is most noticeable in the N1420 drift north of the test rooms and along the E140 drift south of the waste shaft. Spalling results from room closure and is related to the percentage of argillaceous material in the halite and to the proximity of the roof intersection. Similar behavior associated with anhydrite "b", anhydrite "a" and clay I has been observed in the walls of the drifts and test rooms in the waste experimental area. Some minor squeezing of clay G, clay H and clay I has occurred where these clays are exposed along drift walls. Relative motion along these clays similar to clay F is exhibited by the lower section of the wall moving into the excavation relative to the upper section. Some spalling of map unit O has also been noted along the E140 drift south of approximately S2500.

Pillar Fracturing. The vertical fractures that have developed in the pillar corners occur throughout the underground facility. They are particularly prominent in corners that were not beveled during excavation. The fractures range in width from closed to about 2 inches and extend into the salt essentially perpendicular to the surface.

The fractures grow steadily with time as the halite responds to deformation around the opening. Pillar corner fractures are the most obvious manifestation of pillar shortening in the drifts and rooms. These fractures will continue to grow and the corners will continue to deteriorate, with increasing spalling as a result. This behavior is expected and poses no stability problems, but it will require monitoring and maintenance throughout the operating life of the facility.

Vertical fractures have developed in the walls of the drifts parallel to the longitudinal drift axis. The fracture openings range from closed to 1/16 inch in width. The fractures have been detected in some boreholes where they occur within 2 feet of the wall surface. This type of fracturing is typical of underground excavations and probably represents tension fractures developed due to stress relief.

Roof Displacements and Separations. Clay G and clay H, above the roof of the facility level drifts, and clay I, above the roof of the drifts in the experimental area, have exhibited displacements and separations. Table 10-1 presents the results of observations made through July 1986 in 58 open boreholes. Twenty of these holes exhibited positive evidence of the occurrence of displacements and/or separations. Sixteen of these holes are at intersections. The vertical separations range from closed to 1/4 inch in width, and the horizontal displacements are up to 1 inch wide.

An additional 32 holes in 11 arrays were drilled in the roof at various facility level drift locations during the Excavation Effects Program (Figure 10-1). Of these, four arrays were drilled at intersections. Three additional arrays were drilled in the roof of drifts in the waste experimental area.

Inspection of the recently drilled holes using a probe indicate that minimal separation has occurred at the intersections and along the drifts. The size of the opening as well as the elapsed time since its excavation do not appear to have a significant effect on this phenomenon. Although the E140 drift south of the waste shaft was excavated early in construction and has the largest opening dimensions (12 x 25 feet), only minimal separations, less than 1/16 inch wide, were detected.

No separations were detected at clay G in the drift hole arrays, and the separations in the halite were usually less than 1/16 inch. There appears to be about 1/8 inch of separation at clay I in the array at E875 in the N1420 drift. This is consistent with observations made in previously drilled holes in the waste experimental area.

The observed displacements and separations immediately above the facility drifts appear to be normal deformational behavior. As the deviatoric stress around the underground openings increases following excavation, the surrounding salt will deform. The clay seams are zones of weakness that provide slip planes for salt movement during lateral loading. Movement is generally represented by the halite section below the clay seams moving into the excavation relative to the section above.

Floor Displacements, Separations and Fracturing. Minor displacements, separations and fracturing have occurred beneath the floor of the drifts. Table 10-3 presents the results of observations made in 34 open boreholes through July 1986. Ten of these holes exhibited displacements, separations or fracturing. Displacements up to 3/4 inch wide and separations up to 1/2 inch wide have been observed in boreholes at the intersection of Test Room 1 and Room L1, as well as at the intersection of Test Room 2 and Room L2. These are large, four-way intersections with 20 x 33-foot dimensions. Some displacements, separations and fracturing were also detected in three open boreholes in Room L2. Only two holes in the N1420 drift east of Test Room 1 exhibited separations, less than 1/8 inch wide. No other separations

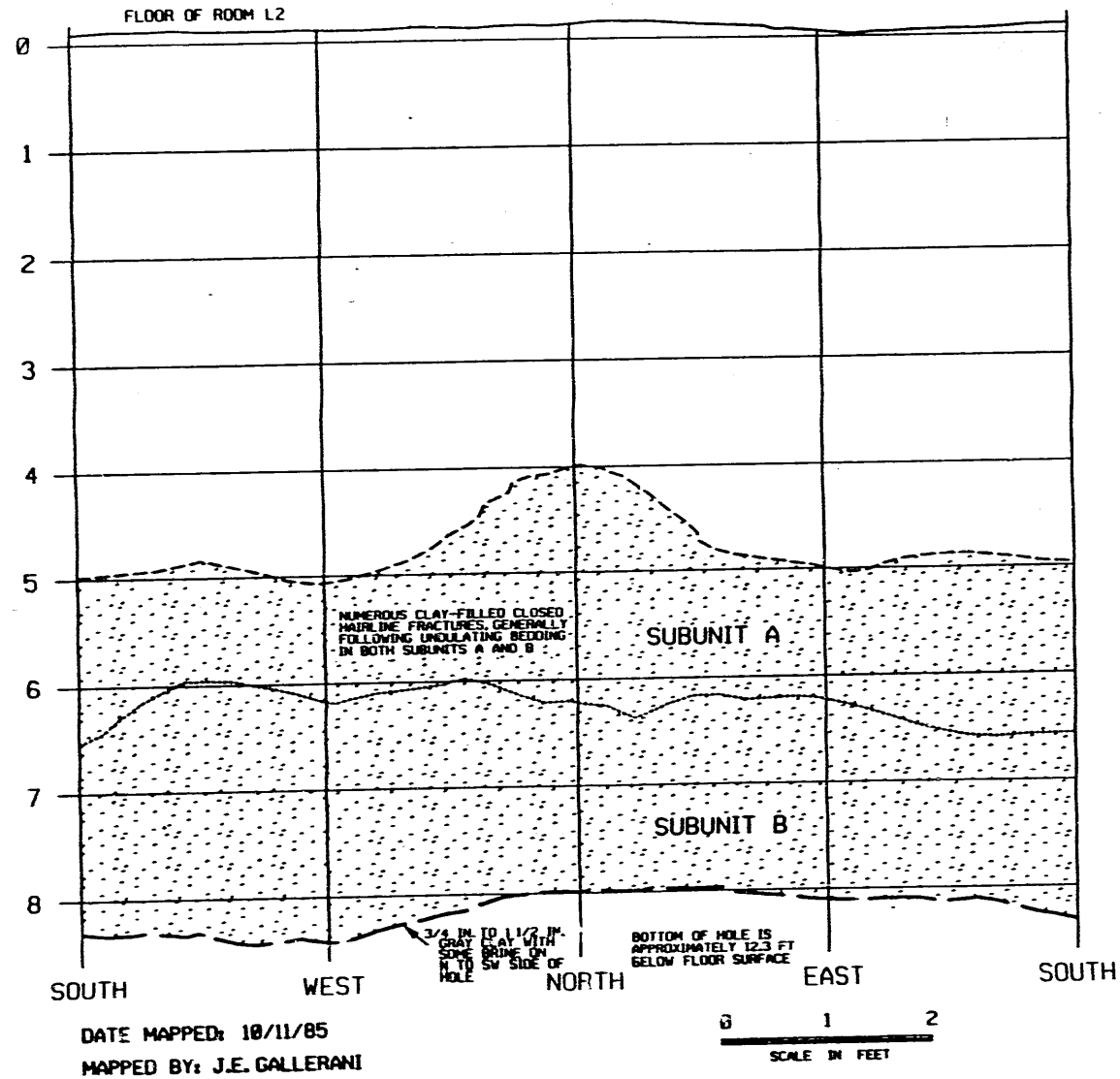
have been detected in any other open boreholes in the N1420 drift or Room G. Only closed fractures were observed in the 30-inch diameter hole (L2X-01) in Room L2 (Figure 10-3). These fractures, many coated with clay, appeared to have originated prior to room excavation.

Nine small-diameter holes were drilled in the floor of the 35-foot wide S700 crosscut and inspected using a probe. These holes were drilled to determine the depth to MB-139 as well as to determine if any fractures were present. Fracture zones up to 1 inch wide were encountered in two locations in the halite above MB-139. Only one borehole contained a hairline fracture within MB-139.

During September 1985, nine 36-inch diameter holes were drilled in the floor of Room J, a 33-foot wide room, to accommodate structural steel columns. Only one near-horizontal fracture, less than 1/32 inch wide, was encountered in the halite above MB-139 in hole JV-8. No fractures were found in the other holes in Room J.

One fracture has been detected in the floor of the E140 drift south of the waste shaft. This fracture was observed while the drift was being enlarged from 8 feet to 12 feet high from April through June 1984. The fracture was about 18 inches below the original floor in halite and extended from approximately S1859 to S1871. Separation ranged from 1/16 inch to 1/2 inch and was associated with some clay. It curved upwards toward the floor at its northern and southern limits.

The results of the Excavation Effects Program indicate that minimal separations occur beneath the floor of the drifts and intersections. As determined from the roof holes, the size of the opening and elapsed time since excavation do not appear to have any effect on the occurrence of separations in the salt beneath the floor. No fracture zones were detected in any of the holes and separations where encountered, ranged from less than 1/16 inch to 1/8 inch wide. As with the older open boreholes, the Excavation Effects Program holes show evidence of separations within MB-139, at clay E and in the overlying halite.



DATE MAPPED: 10/11/85

MAPPED BY: J.E. GALLERANI

EXPLANATION

- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT B
- CLAY E (LOWER CONTACT OF MB-139)
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE BOREHOLE WALL.
- FRACTURE ZONE
  ZONE OF FRACTURED SALT BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE WIDTH OF SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE OPENING, 12 INCHES FROM BOREHOLE WALL.

NOTES:

1. BOREHOLE IS 30 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM AN UNSURVEYED REFERENCE LINE.
3. MAPPING WAS PERFORMED AT A SCALE OF 1 INCH EQUALS 1 FOOT.

Figure 10-3

DRIFTS
GEOLOGIC LOG OF HOLE L2X-01

The floor hole array in the N1420 drift at E875 encountered a slight separation of approximately 1/16 inch, coincident with a clay seam at a depth of about 8 1/2 feet. MB-139 at this location is about 22 feet below the floor.

Brine was encountered during the drilling of the central hole in the array at S700/E66 and continued to flow from the hole for several days after the completion of drilling. The hole encountered several separations up to 1/16 inch wide between a depth of 7.4 and 7.7 feet. No separations were detected in the other holes of this array. Brine has been encountered at several other hole array locations but no significant separations were detected in the holes.

The observations made to date indicate that fracturing in the drift floors is minimal. This includes observations of the E140 drift, which was one of the earliest excavations made during the SPDV Program. No fractures of the magnitude found in Test Room 3 (Chapter 11) have been detected in any of the drifts. Displacements, separations and fracturing beneath the floor is expected to continue in the future.

10.3.2.2 Closure Behavior at Selected Stations

Analyses were performed at selected stations to study roof-to-floor and wall-to-wall closure. Analysis was also performed to study the effect of floor lowering on closure.

Roof-to-Floor Closure. Until May 1984, the E140 drift south of the waste shaft was unique in that there were neither crosscuts nor nearby parallel drifts. However, in May and June 1984 the floor of the drift was lowered by 4 feet and new drifts and crosscuts were added between stations N140 and S1620. These two operations have resulted in an increase in closure rates for this portion of the drift. Since both operations occurred concurrently, it is difficult to isolate their effects on closure. However, it has generally been observed that any far field disturbance has only a short-term effect on the closure, and

that the closure rate, after a momentary increase, decays to its pre-perturbation rate pattern.

If we assume that the closure at station E140/S1879 is not measurably affected by the additional excavations performed north of station S1620, this station can then represent the closure of an infinitely long opening in a geologically uniform formation. However, because the convergence points were installed nearly 4 days after the completion of excavation, the roof-to-floor closure versus elapsed time curve was extrapolated backwards by fitting an equation in the form of

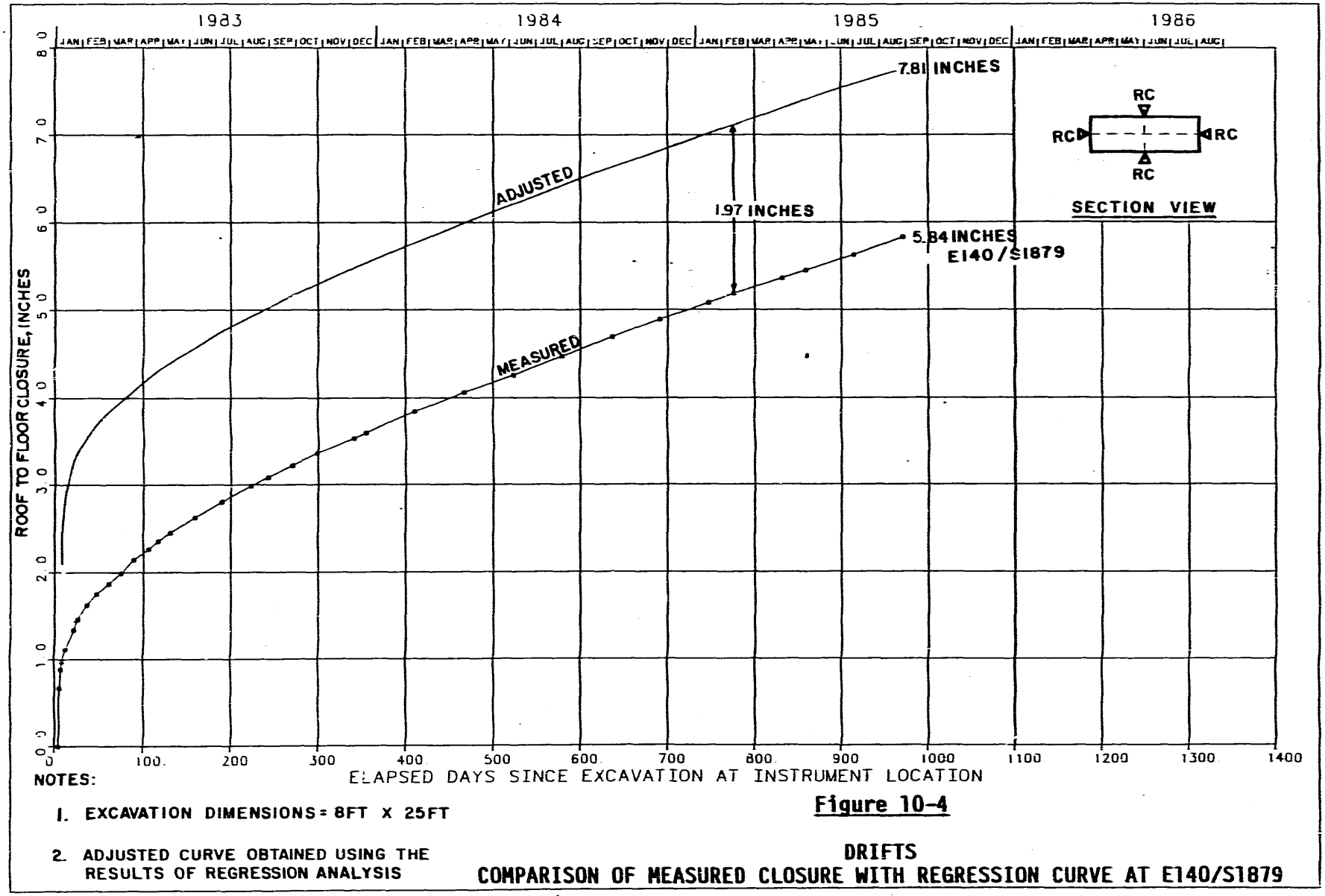
$$t = t_1 \, (1 + R(t)/R_1)^3 \qquad (10\text{-}1)$$

where: $R(t)$ is the instrument reading at elapsed time t since the end of excavation; and
R_1 is the regression parameter, equal to total closure at elapsed time t_1 since the end of excavation.

This equation indicates that at t equal to 0, the slope of the closure curve is infinite. This is not true because the slope at t equal to 0 is finite but large.

Based on the results of the regression analysis, the value of R_1 was determined to be 1.97 inches. However, the curve-fitting was not very good, probably because excavation at the instrument location was done in two stages making it difficult to assign the value for t_1. Because the shape of the early part of the closure versus time curve is not smooth, the estimated value of t_1 is approximate.

Figure 10-4 compares the measured closure with the adjusted curve at station E140/S1879 using the results of the regression analysis. The reading of roof-to-floor closure on August 26, 1985, was 5.84 inches and the adjusted value is 7.81 inches. Note that this station is nearly 230 feet from the boundary location north of which the floor was lowered 4 feet. It is likely that the excavation had some effect on



NOTES:

1. EXCAVATION DIMENSIONS = 8FT X 25FT
2. ADJUSTED CURVE OBTAINED USING THE RESULTS OF REGRESSION ANALYSIS

Figure 10-4

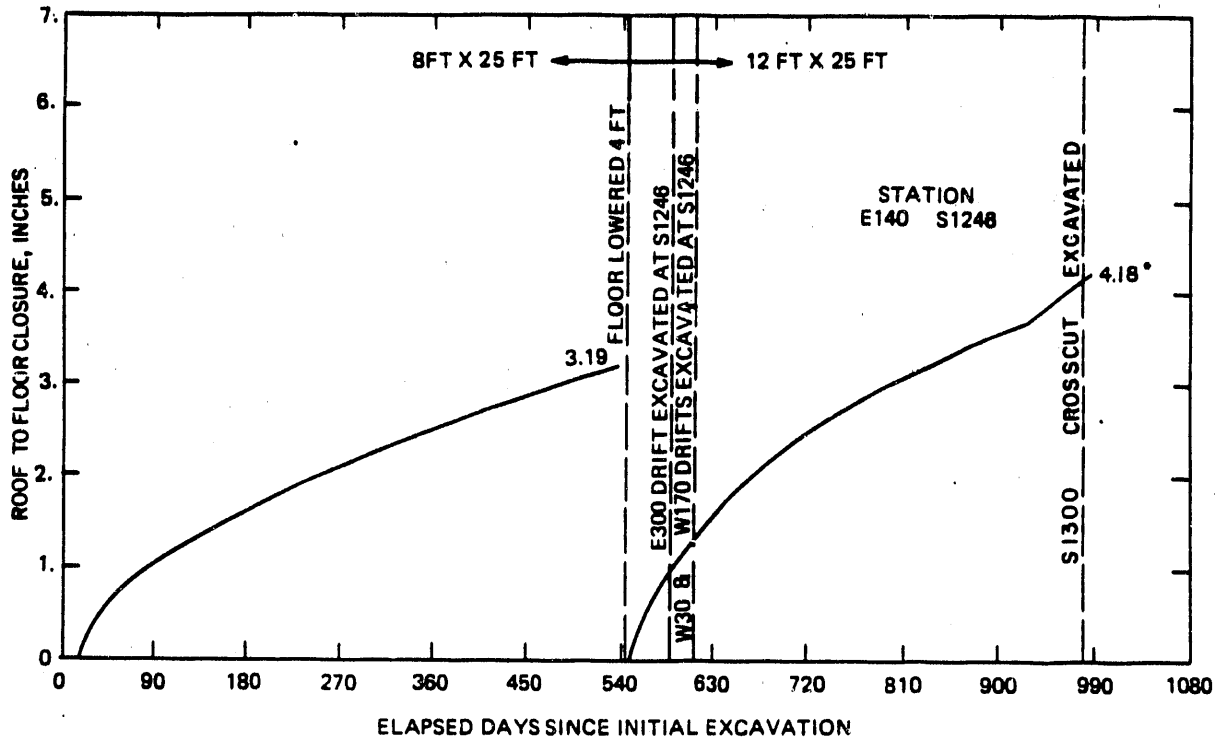
DRIFTS
COMPARISON OF MEASURED CLOSURE WITH REGRESSION CURVE AT E140/S1879

the closure at this station, although Figure 10-4 does not clearly show such an effect. The convergence points at this location have since been destroyed.

Figure 10-5 shows the central roof-to-floor closure at E140/S1246. The roof-to-floor convergence points were installed nearly 14 days after excavation at this location. This figure shows the effect that lowering the floor 4 feet has on the closure. In addition, the E300 drift excavation passed this location on August 21 and 22, 1984. The effect of lowering the floor, though, masks the effects of the adjacent excavation. As of August 26, 1985, the roof-to-floor closure of the 12 x 25-foot drift was 4.18 inches. The initial reading was taken on July 11, 1985, 1 day after the floor was lowered. Because the closure rate is very high at the early stages, actual roof-to-floor closure is greater than 4.18 inches.

Relationship Between Roof-to-Floor Closure and Drift Dimensions. Convergence points have been installed at various stations in underground drifts having different cross section dimensions. Some of the drifts, especially the E140 drift south of S1600, are isolated, while most of the other drifts have nearby parallel drifts and crosscuts. The closure behavior of these drifts is affected not only by the opening dimensions but also by the presence of adjacent openings. Differences in creep properties of the salt may also be responsible for differences in creep behavior. In addition, the closure behavior is affected by the 4- to 5-foot lowering of the drift floor.

Figure 10-6 shows measured roof-to-floor closure at selected stations in drifts with different cross section dimensions. Because measurements were not made immediately after the opening was excavated, the closure values were normalized to the values at approximately 10 days after the completion of excavation at the respective instrument station. As shown on this figure, the maximum closure and closure rate occur in drifts with opening dimensions of 12 x 25-feet. Because the



* MEASUREMENT ON AUGUST 26, 1985.

Figure 10-5

DRIFTS
EFFECT OF FLOOR LOWERING AND ADJACENT EXCAVATIONS
ON CLOSURE AT E140/S1246

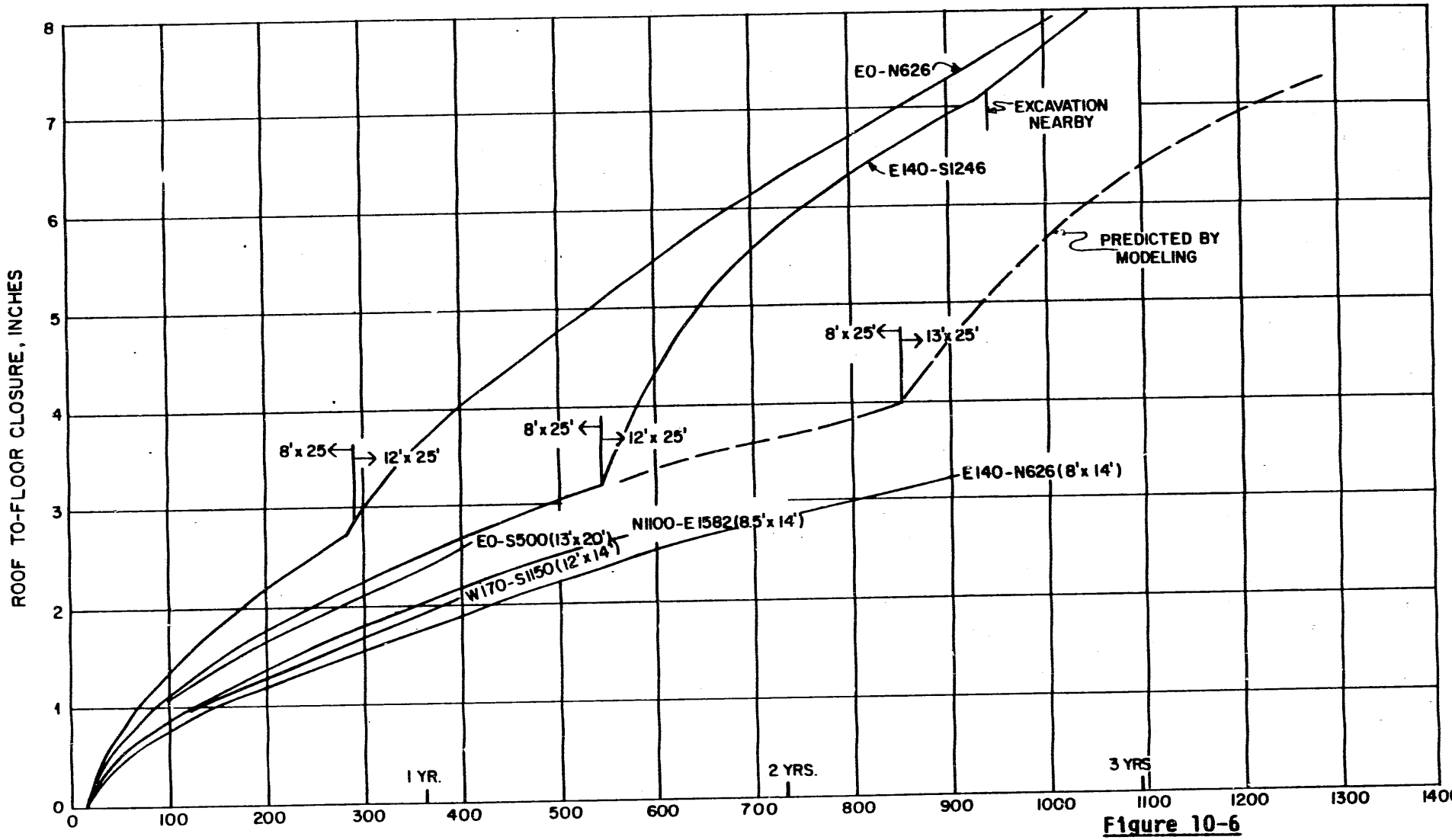


Figure 10-6

DRIFTS

COMPARISON OF ROOF-TO-FLOOR CLOSURE IN DRIFTS WITH DIFFERENT DIMENSIONS

drifts in the storage area will have cross section dimensions of 13 x 25 feet, the modeling analysis discussed in this chapter and in Chapter 12 focuses on predicting the behavior of the 13 x 25-foot drift opening for the operating life of 25 years.

The effect of lowering the floor 4 feet at instrument stations E0/N626 and E140/S1246 is to increase the closure rate permanently. Although the floor lowering was performed at different times at these stations, the steady state rate after excavation appears to be nearly the same. However, if the floor lowering is performed at a much later date following the initial excavation, it is likely that the total closure may be somewhat decreased. The closure behavior at these two stations is influenced by the presence of nearby parallel drifts and crosscuts, as well as likely differences in the creep properties of the salt.

Figure 10-6 also shows the predicted roof-to-floor closure of an infinitely long, single drift with cross section dimensions of 13 x 25 feet. This closure was obtained by modeling and is discussed in Chapter 12. The approximate steady state closure rate at E0/N626 and E140/S1246 is 2.00 inches/year. The steady state closure rate predicted for the infinitely long, single drift is 1.60 inches/year. The nearly 25 percent difference in these rates is probably due to the presence of adjacent drifts and crosscuts. This value compares well with the value of 30 percent obtained from modeling as discussed in subsection 10.3.3.3.

Figure 10-7 presents a comparison of the predicted closure of a 13 x 25-foot drift with the observed behavior of a 12 x 25-foot drift at E0/N626. The closure for the 13 x 25-foot drift was obtained by increasing the closure rate obtained from modeling the infinitely long, single drift by 30 percent. The roof-to-floor closure at E0/N626 does not include the values before the floor was lowered by 4 feet. This comparison indicates that it is reasonable to increase the closure rate of a single, infinitely long, 13 x 25-foot drift by 30 percent to account for the presence of adjacent parallel drifts and crosscuts.

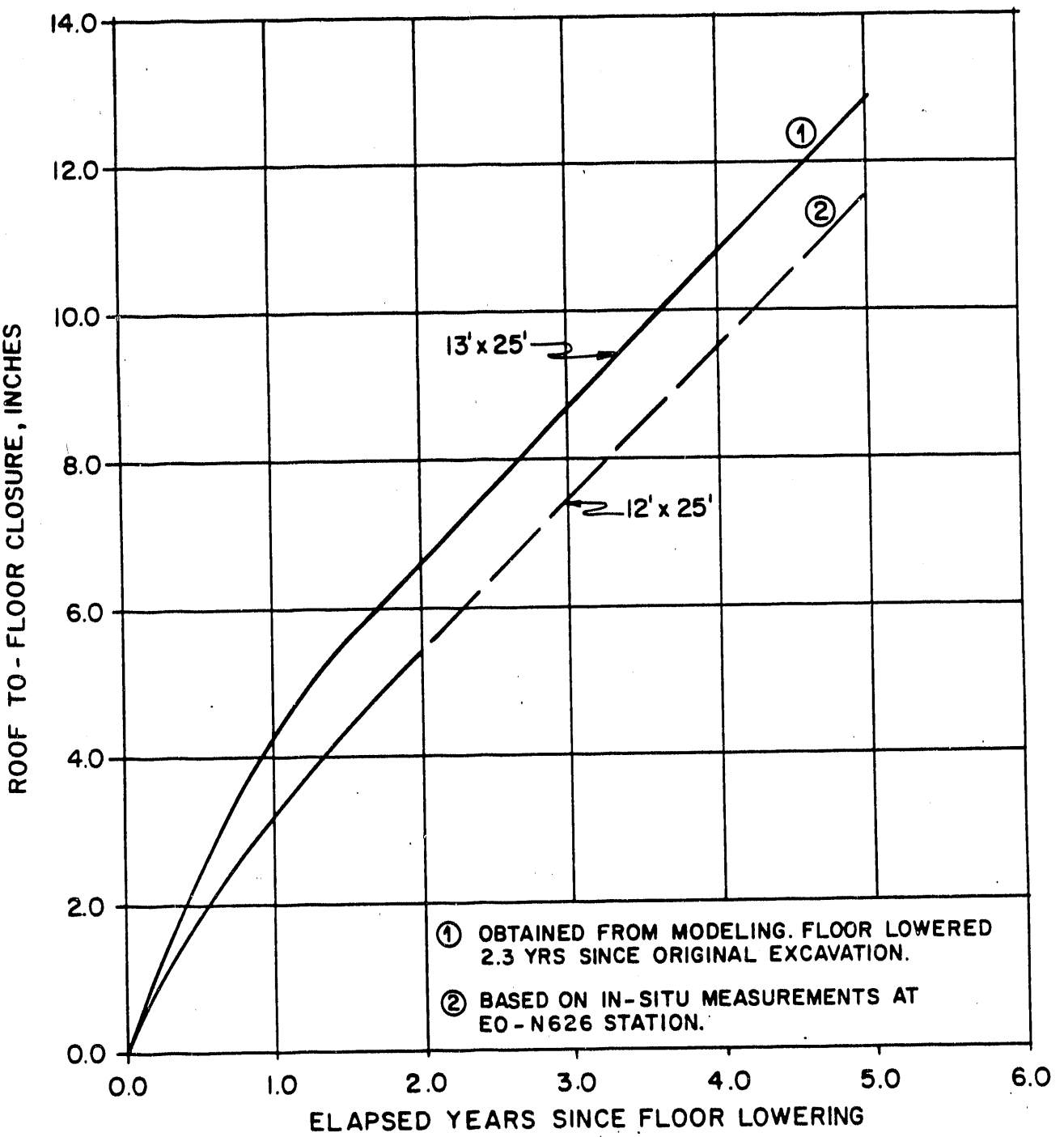


Figure 10-7

DRIFTS
COMPARISON OF PREDICTED AND OBSERVED
ROOF-TO-FLOOR CLOSURE

Wall-to-Wall Closure. The wall-to-wall convergence points at the S1246 station were installed immediately after the original excavation at this location was completed. When the cross section dimensions were 8 x 25 feet, the measurements were close to the true wall-to-wall closure at midheight of the instrument location. On June 30, 1984, the wall-to-wall closure was 5 inches for an elapsed time period of 564 days. After the floor was lowered, a new set of wall-to-wall convergence points was installed. The additional wall-to-wall closure was 3.31 inches through August 26, 1985.

Comparison of Roof-to-Floor to Wall-to-Wall Closures. Table 10-4 summarizes the closure of the E140 drift for locations south of S1620. Until August 1985, these locations were unique in that there were no crosscuts and no nearby parallel drifts at the time of the analysis. The cross section dimension was 8 x 25 feet. The maximum measured roof-to-floor closure of 5.19 inches was at station S1879. Stations S3614, S3639 and S3664 are influenced by the end constraints of the drift which terminates at about S3664.

Effect of Adjacent Drifts. Table 10-5 compares closure in the drifts at S1150. Because the initial readings were not taken immediately after the station location was excavated, the comparison is approximate. Note that, for the E140/S1150 station, the original cross section dimensions were 8 x 25 feet until June 8, 1984, and that no convergence points existed at this location prior to lowering the floor. The closure values at E140/S1150 are the maximum, not only because the opening dimensions are the largest, but also because the opening had already existed for nearly 550 days before the floor was lowered 4 feet. It is also likely that there is mutual influence between the openings.

Effect of Floor Lowering. The E0 drift between N140 and N1420 was increased in height from 8 feet to 12 feet (by lowering the floor) from November 9, 1983, through January 9, 1984. The closure readings increased rapidly as excavation approached the measurement stations but

Table 10-4

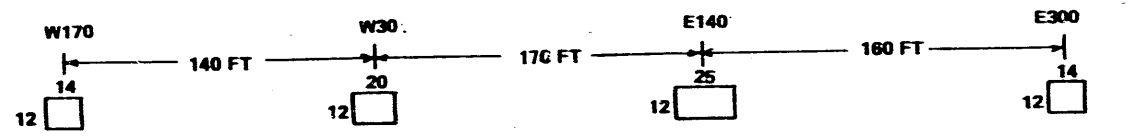
E140 DRIFT SOUTH OF S1620
SUMMARY OF MEASURED CLOSURE
(CROSS SECTION DIMENSIONS = 8 x 25 feet)

Instrument Location	Time-lag between end of excavation and initial reading (days)		Convergence point reading (inches) Feb. 12, 1985	
	R-T-F*	W-T-W*	R-T-F*	W-T-W*
E140/S3664	14	0	1.70	1.48
E140/S3639	0	0	4.07	3.24
E140/S3614	0	0	4.49	3.72
E140/S3250	11	11	4.13	2.97
E140/S2950	10	10	4.19	3.18
E140/S2625	6	6	4.43	3.59
E140/S2350	9	9	4.33	3.44
E140/S2066	8	8	4.32	3.40
E140/S1879	4	2	5,46	4.00

* R-T-F = roof-to-floor
W-T-W = wall-to-wall

Table 10-5

COMPARISONS OF CLOSURE IN DRIFTS AT S1150



	W170/S1150	W30/S1141	E140/S1150	E300/S1150
INSTRUMENT LOCATION				
DATE OF EXCAVATION	AUGUST 21, 1984	AUGUST 21, 1984	JUNE 8, 1984*	JULY 23, 1984
DATE OF INITIAL READING				
CENTRAL ROOF-TO-FLOOR	AUGUST 23, 1984	AUGUST 22, 1984	JUNE 14, 1984	JULY 26, 1984
CENTRAL WALL-TO-WALL	AUGUST 23, 1984	AUGUST 22, 1984	JUNE 14, 1984	JULY 26, 1984
DATE OF LATEST READING FOR BOTH ROOF-TO-FLOOR AND WALL-TO-WALL CONVERGENCE POINTS	SEP. 16,1985	SEP. 16, 1985	AUG. 26, 1985	SEP. 30, 1985
CLOSURE (IN.)				
CENTRAL ROOF-TO-FLOOR	2.46	3.10	3.61	2.18
CENTRAL WALL-TO-WALL	2.62	2.76	3.03	2.35

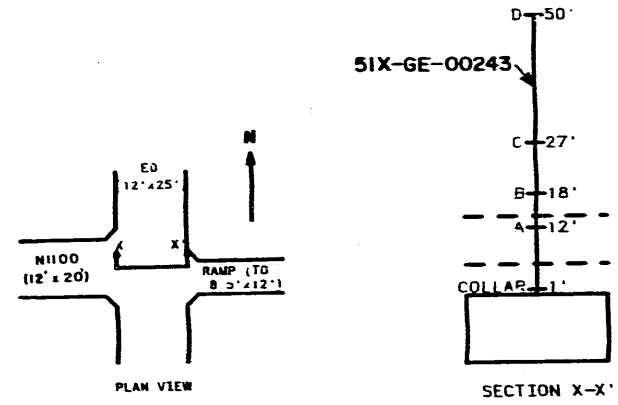
* FLOOR LOWERED BY 4 FT ON JUNE 8, 1984. DIMENSIONS WERE 8 FT X 25 FT BEFORE JUNE 8, 1984. CROSS DRIFTS S1100 AND S1300 EXCAVATED IN AUGUST, 1985.

dropped rapidly to, or slightly above, the pre-excavation rate. The floor lowering has affected the salt material above the roof of the openings to distances of at least 30 feet.

Figure 10-8 shows the relationship of the movement rates for the collar and two intermediate anchors of roof extensometer 51X-GE-00243 at the E0/N1100 intersection. The figure shows that the movement rate of the collar and these anchors increased due to floor lowering but then began decreasing until March 1984 (about 400 days after the initial excavation). The rate then began increasing again from March until August 1984 (about 550 days after the initial excavation). Because excavation activities were performed in the area of this instrument at this time, it is possible that parting at the clay seams above the roof was occurring at an increasing rate.

Figure 10-9 shows the movement rates of the collar and anchors of roof and wall extensometers at E0/N626. The collar movement rate of the east wall extensometer appears to be somewhat less than that of the west wall extensometer. It was also observed that floor lowering has affected the closure behavior of pillars as far as 25 feet from the opening. Similarly, roof behavior has been affected, probably up to at least 30 feet above the roof.

The height of the E140 drift remained at 8 feet during floor lowering in the E0 drift between N140 and N1420. However, excavation performed in the E0 drift appears to have affected the closure behavior of the E140 drift. Figure 10-10 shows the movement rates of the collar and anchor A for roof extensometer 51X-GE-00235 at E140/N624. The collar movement rate was decreasing monotonically until late December 1983. However, it appears to have increased around January 1984. Assuming the instrument was functioning properly and there was no anomalous behavior of clay seams in the roof of the E140 drift, excavation in the E0 drift may have influenced salt behavior as much as 150 feet from the E0 drift.



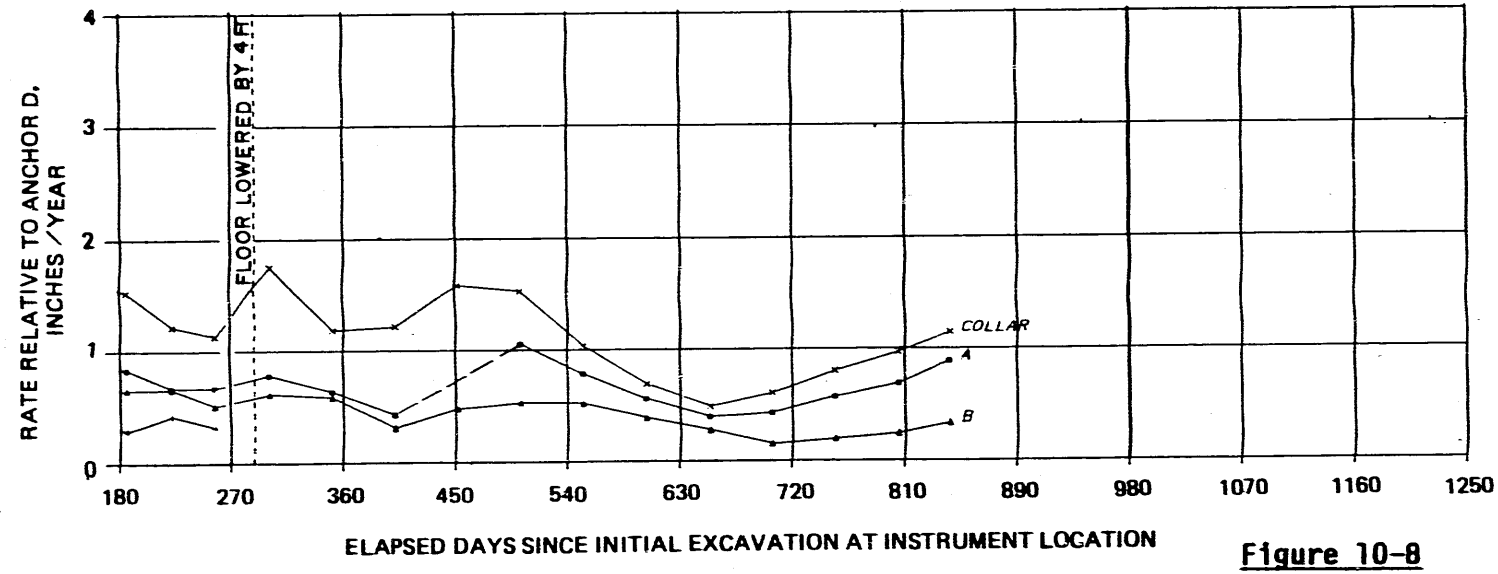
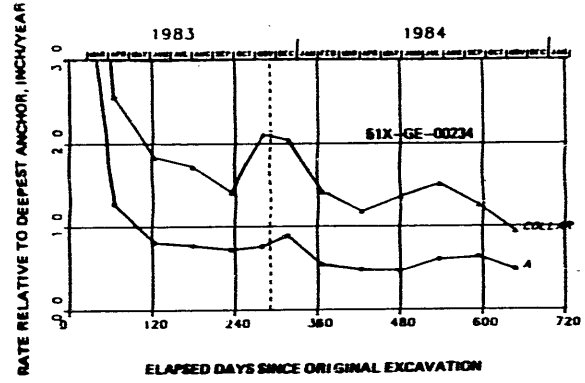
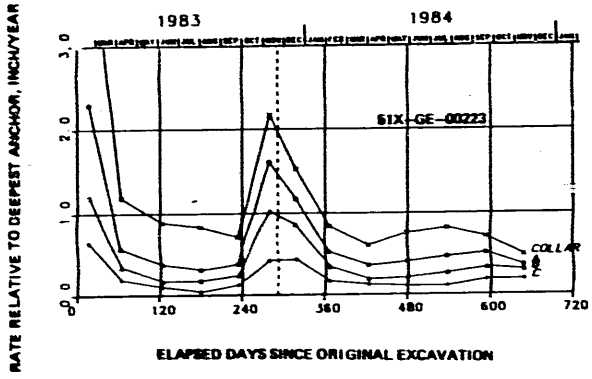


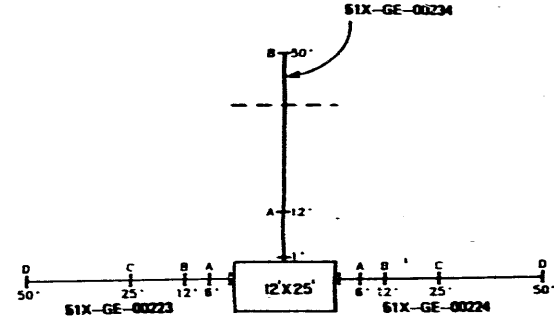
Figure 10-8

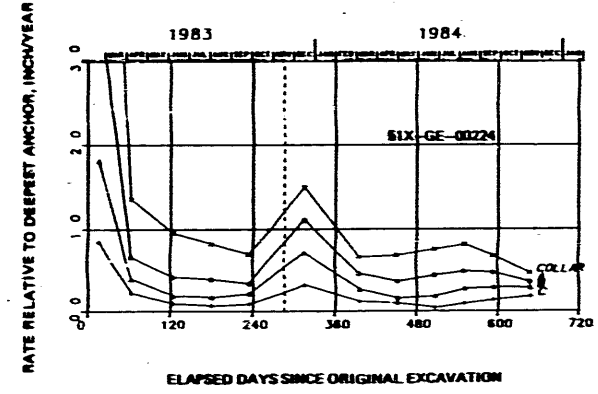
DRIFTS
EFFECT OF FLOOR LOWERING ON ROOF BEHAVIOR AT E0/N1100 INTERSECTION

NOTE: RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.







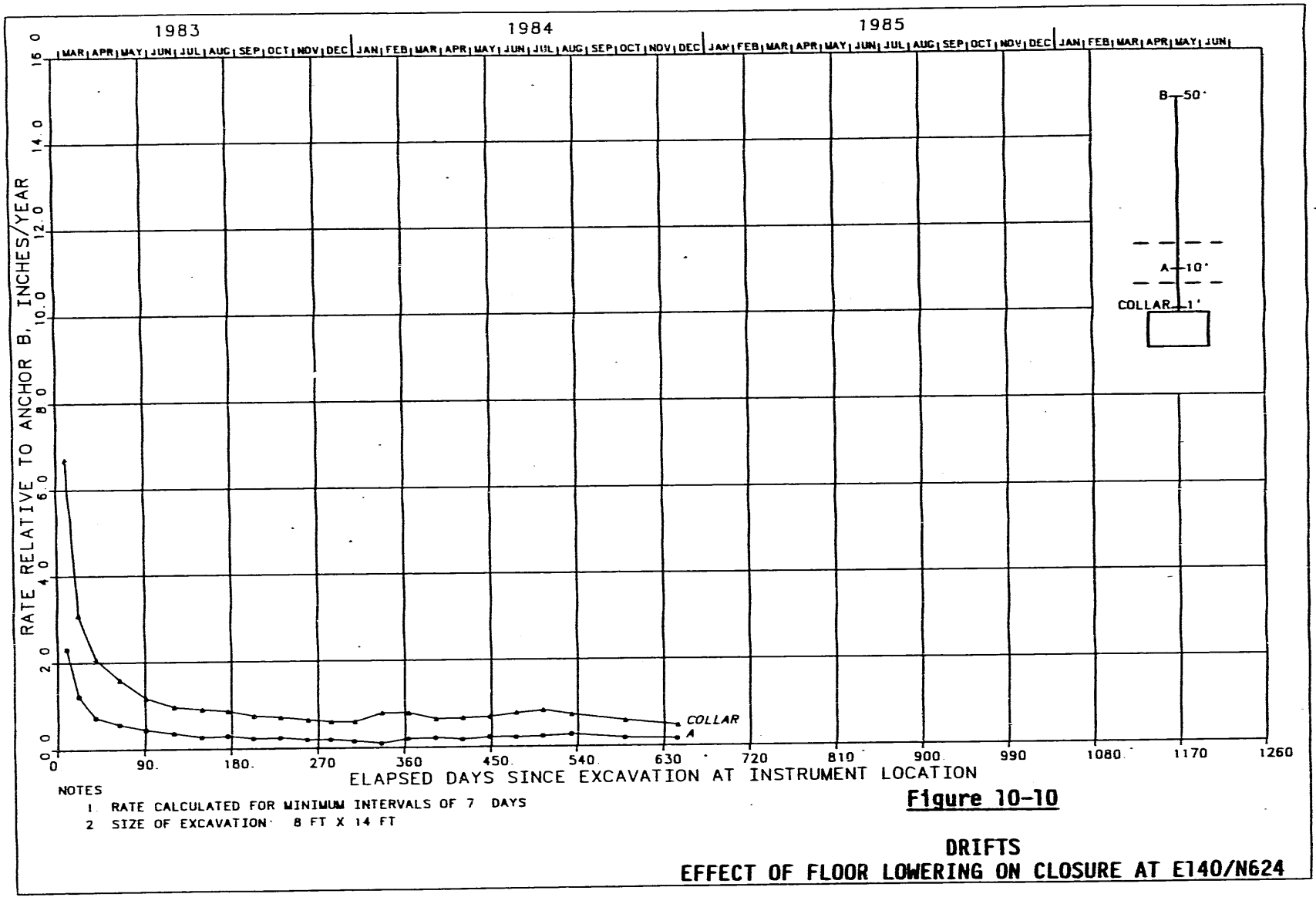


NOTE:

VERTICAL DASHED LINE INDICATES TIME WHEN THE FLOOR WAS EXCAVATED FOUR FEET.

Figure 10-9

DRIFTS
EFFECT OF FLOOR LOWERING ON CLOSURE AT EO/N626



NOTES
1. RATE CALCULATED FOR MINIMUM INTERVALS OF 7 DAYS
2. SIZE OF EXCAVATION 8 FT X 14 FT

Figure 10-10

DRIFTS
EFFECT OF FLOOR LOWERING ON CLOSURE AT E140/N624

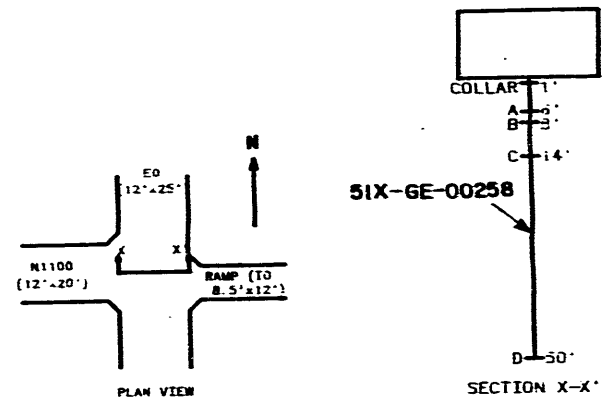
Observations of the effect of floor lowering on closure behavior are summarized below:

(1) The closure reading at an instrument station increases rapidly as floor excavation approaches the station and decreases rapidly to, or slightly above, the pre-excavation closure rate as excavation passes the instrument station.

(2) Floor lowering affects creep behavior of the salt above the roof of the openings to depths of at least 30 feet. This effect is short-lived, however, extending over a period of only a few months.

(3) Although the floor of the E140 drift north of the C & SH shaft was not lowered for most of its length, excavation performed in the E0 drift appears to have affected the E140 drift closure.

The movement rates of the anchors of extensometer 51X-GE-00243 at the E0/N1100 intersection increased and then decreased between March and August 1984. Because no excavation activity took place at this time in the vicinity of the instrument station, it was assumed that the clay seams above the roof may have been parting at an increasing rate. Figure 10-8 shows the variation in closure rates for the collar and anchor points with time. The rates of the collar and anchor movements have subsided and are probably returning to their pre-perturbation values. For comparison, the rates of collar and anchor movements of floor extensometer 51X-GE-00258 are shown on Figure 10-11. The rates of movements of the collar and intermediate anchors have a similar trend as the roof extensometer over the same time period. However, this extensometer was damaged due to mining operations on February 8, 1985. Since then, the readings have remained anomalous.



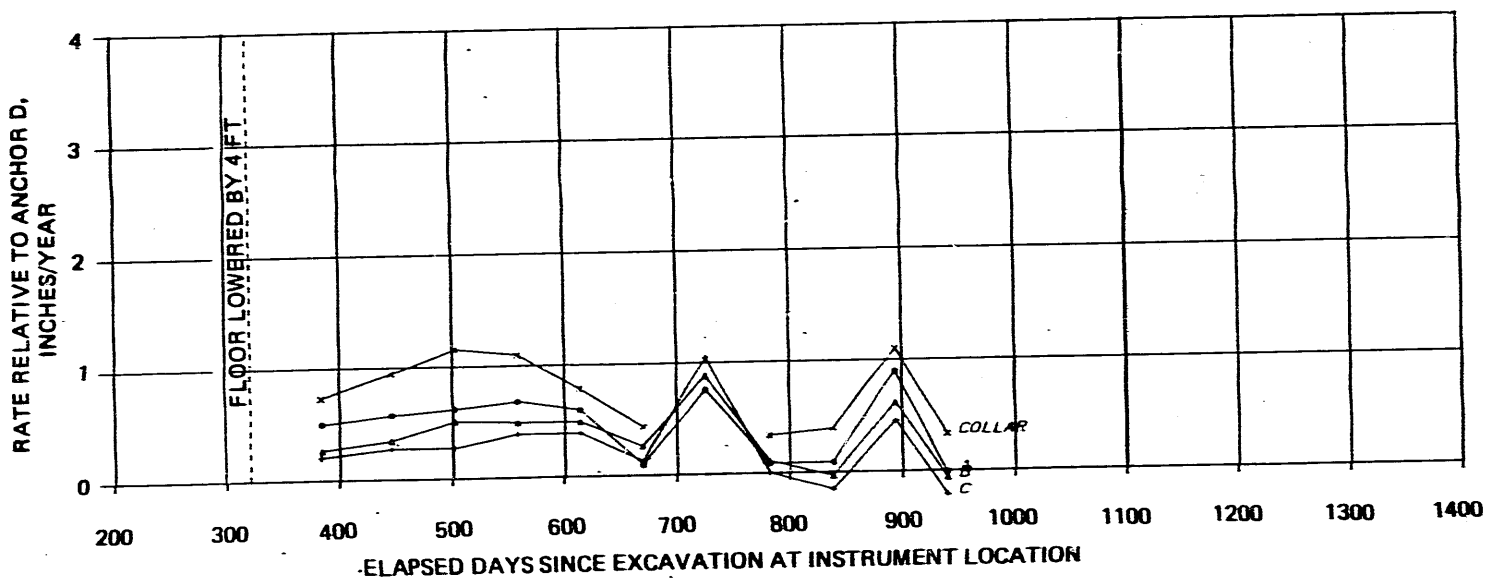


Figure 10-11

DRIFTS
RATE OF FLOOR HEAVE AT EO/N1100

NOTE: RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.

10.3.2.3 Model Simulation

A finite element model utilizing an engineering approach was used to simulate the behavior of an 8 x 25-foot drift. The method described in Appendix C was used to mathematically simulate the in situ behavior of the drifts by determining the creep parameters C, A, and z. The following discussion describes the numerical modeling and the utilization of in situ data for the drifts. Also discussed are simulations of the effect of adjacent parallel and perpendicular drifts.

Utilization of Reference Stratigraphy. The reference stratigraphy described in Chapter 6 was used in the analysis. The reference level representing the elevation of clay G is 2,129.40 feet below the ground surface, based on the core hole log at station E140/S1960. Because the finite element method lends itself well to multiple layer analysis in which distinct material properties can be accounted for, the MARC General Purpose Finite Element Program (ref. 6-8) was used.

Structural Characterization. Figure 10-12 shows the finite element model used to predict closures, stresses and deformed shapes as a function of time for an 8 x 25-foot opening. The model consists of 122 plane strain elements with 21 gap/friction link elements modeling the clay seams and an option for lowering the floor 5 feet. The top and bottom boundaries of the model are at depths of 2,045.00 feet and 2,245.00 feet, respectively, below the ground surface. The drift roof, drift floor before lowering, and drift floor after lowering are at depths of 2,128.70, 2,136.70, and 2,141.70 feet, respectively, below the ground surface. The roof beam is 8.10 feet thick and the final floor level is 4.39 feet above MB-139.

Only anhydrite layers with thicknesses greater than 1 foot were included in the model. Calculations showed that most anhydrite layers less than 1 foot thick failed at vertical stresses less than 1 percent of the overburden pressure. Therefore, because their contribution to the stiffness of the model would be insignificant, they were not included.

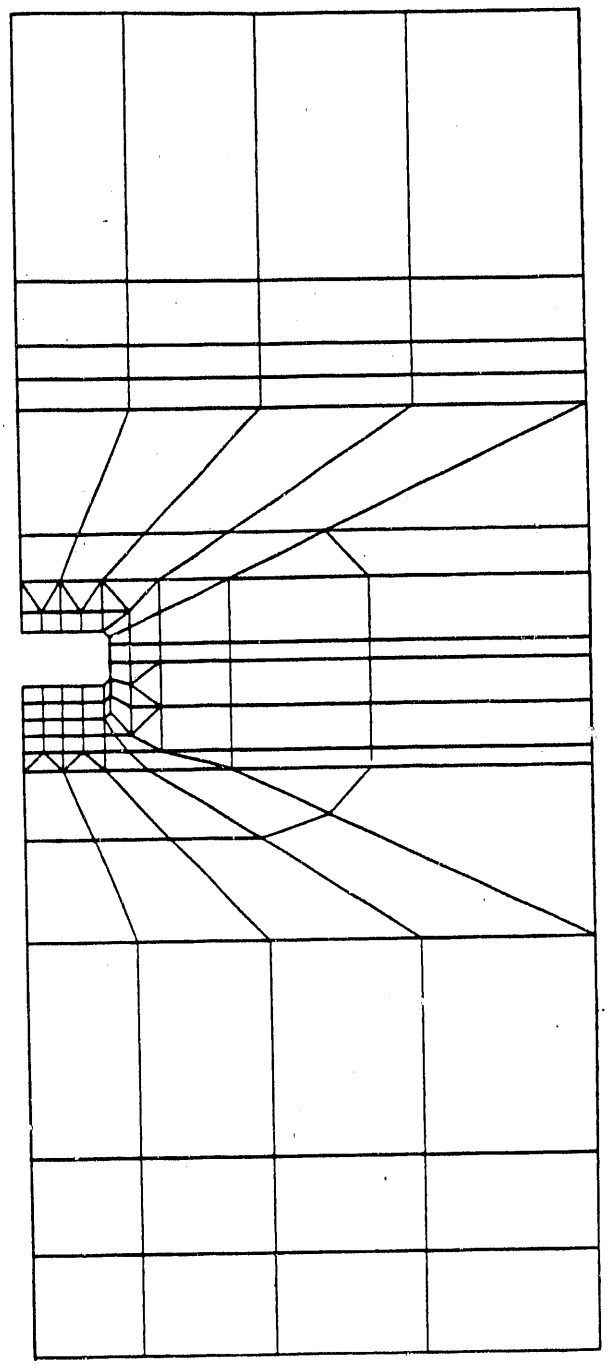


Figure 10-12

DRIFTS
FINITE ELEMENT MODEL - BEFORE FLOOR LOWERING

Clay seams in the model were limited to two above and two below the drift opening. The justification for this is twofold: first, reference 5-4 states that "90 percent of the drift closure measured with ten active slidelines could be captured with four slidelines, two directly above and two directly below the drift"; second, previous analyses have shown that, at locations representative of the more distant clay seams, the shear force is considerably less than the normal force; therefore, any slippage along these clay seams would be negligible compared to that along seams closer to the opening and they need not be included in the model. To simplify the analysis of this model, a coefficient of friction equal to 0.0 was assumed for the gap/friction elements modeling the clay seams.

The lateral boundaries of the model are 82 feet apart. and were established based upon vertical axes of symmetry with regard to adjacent drifts. The upper and lower boundaries of the model were based upon experience from previous analyses and were extended far enough in both directions so that the difference between vertical and horizontal stresses at each point of the boundaries would be within 10 percent of the vertical stresses. Horizontal restraints were assumed for the lateral boundaries while vertical restraints were assumed for the lower boundary of the model. Stress boundary conditions were utilized for the upper boundary.

Element sizes were established to make them proportional in size to the estimated stress gradient across each element. In addition, the orientations of the elements were established in order to have the radiating mesh coincide with the assumed principal stress axes. These aspects of the model were designed to enhance the overall efficiency of the analysis.

Consideration of Drift Opening. The drift openings were originally excavated to 8 x 25 feet. Further development trimmed an additional 4 feet from the floor to provide a 12 x 25-foot opening in the shaft pillar area. To provide continuous response histories from initial

excavation through the floor lowering period, special considerations were provided for modeling the opening.

Determination of Creep Parameters. Data from ten different locations along the E140 drift from S550 to S3250 were reviewed and one representative location was selected to calculate creep parameters for the drifts and for use in predicting closures and stress distributions.

Figure 10-13 shows the correlated roof-to-floor and wall-to-wall in situ data curves from the selected location, as well as the predicted closure based on the calculated creep parameters.

Transformation of Time Domains. Having determined the values of C, A and z to be 1.40×10^{-21} $ksf^{-4.9}$ sec^{-1}, 3.2 and 1.1×10^{-7} sec^{-1}, respectively, the normalized time at which the floor lowering was scheduled to take place was determined by transforming 7.25×10^{7} sec (or 2.3 years) to normalized time using equation C.4-17 in Appendix C.

The normalized time which corresponds to the scheduled real time for drift floor lowering was determined to be 1.4205×10^{-13} $ksf^{-4.9}$ or 418 time increments from the start of the program. Accordingly, the drift height was changed at the end of increment 418, and the analysis continued until a total real time of approximately 5 years was reached.

Effect of Parallel Drifts. The extraction ratio at a particular location is dependent upon the arrangement of the drifts and pillars. Therefore, the effect that the extraction ratio has on structural responses can be determined by considering the effect of adjacent drifts. Two different cases were considered in the analysis. One case assumes the adjacent drifts are parallel to the drift being analyzed while the other case assumes adjacent drifts are perpendicular to the drift being analyzed.

To simplify and minimize the computational effort, a multiple drift model was used for the analysis of the 8 x 25-foot drift. For this

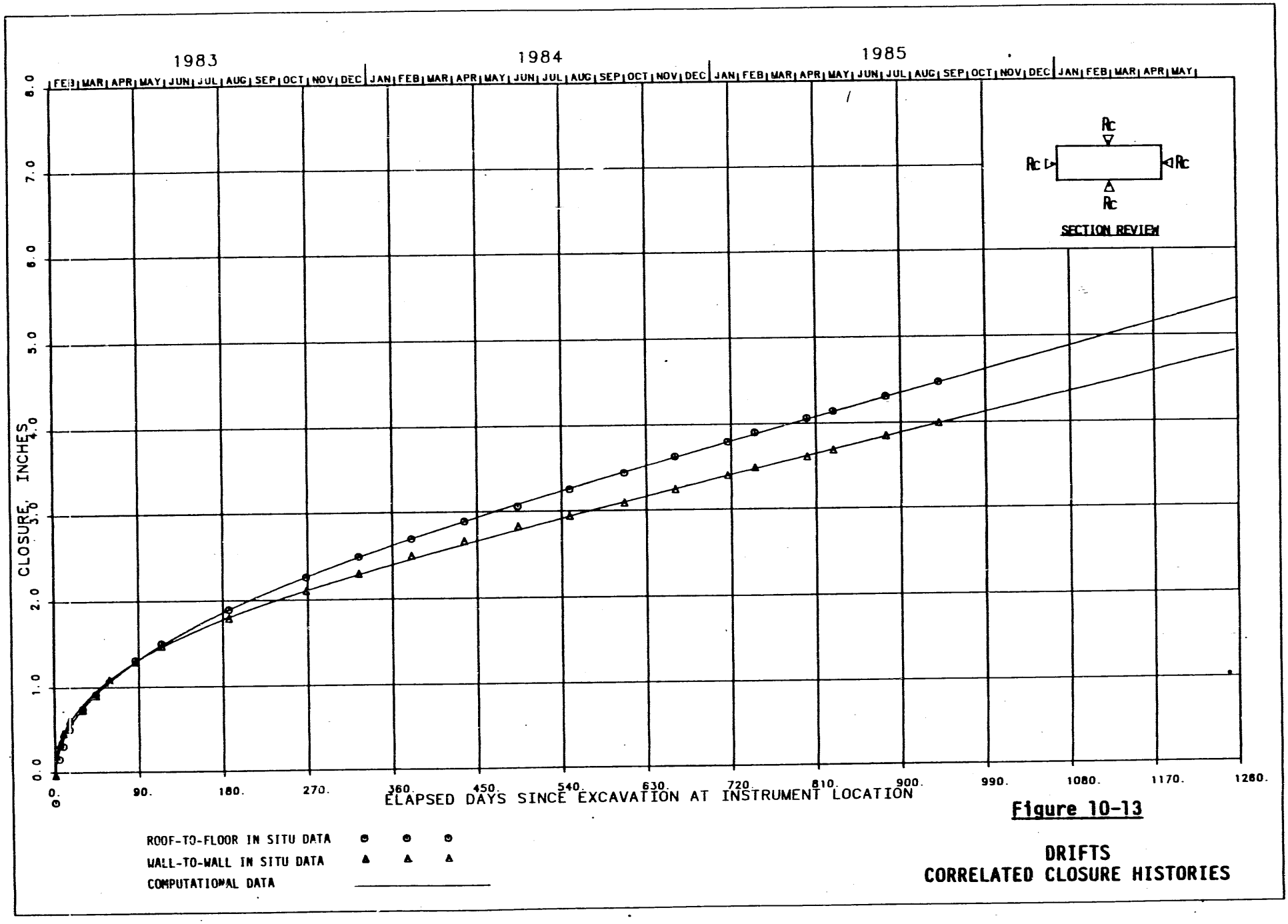


Figure 10-13

DRIFTS
CORRELATED CLOSURE HISTORIES

model, the drift was assumed to be located between an infinite number of parallel drifts, with each having identical cross sections and pillar widths. Two-dimensional analyses using this model were performed assuming a state of plane strain. The boundary displacement conditions at the centerline of the pillar were assumed to be restrained in the horizontal direction but free in the vertical direction. Under these assumptions, this mathematical model can more accurately simulate the geologic conditions in the future when adjacent drifts will exist rather than at the present time when only a single drift exists. Computational results for the parallel drifts are presented in subsection 10.3.3. Parallel drifts with different dimensions and spacings can be incorporated into the present mathematical model and corresponding structural responses can be computed.

Effect of Perpendicular Drifts. Ideally, a three-dimensional analysis is required for the case when the drifts are not parallel to each other. However, the structural responses can be approximated based on the two-dimensional analysis described in this section.

Additional drifts which intersect perpendicular to the drift in question increase the average overburden pressure in the pillar. The two-dimensional analysis of parallel drifts has indicated that the vertical stresses initially increase sharply in the pillar area adjacent to the opening. Over time, salt creep reduces this stress peak as the stresses are redistributed over the width of the pillar. Eventually, the vertical stress level becomes nearly uniform over most of the pillar width.

The total overburden load in the pillar is equal to the average vertical stress multiplied by the pillar support area. Because this total overburden load remains constant before and after the excavation of perpendicular drifts, the average vertical pressure is inversely

proportional to the support area. This increased average vertical stress can, therefore, be expressed as:

$$\bar{\sigma}_r = \bar{\sigma}_i \, W_t/W_2 \qquad (10\text{-}2)$$

where: $\bar{\sigma}_r$ is the average vertical stress of a rectangular pillar, i.e., pillar within a gridwork of intersecting drifts;
$\bar{\sigma}_i$ is the average vertical stress of an infinitely long pillar, i.e., pillar without the perpendicular drifts;
W_t is the distance between the center lines of the perpendicular drifts; and
W_2 is the pillar width in the perpendicular direction, i.e., W_t minus the width of the perpendicular drift.

After the excavation of additional drifts in the perpendicular direction, the restraints at the new wall boundaries are released. Consequently, the distribution of effective stress in the pillar changes. Actual distribution of the effective stresses can be obtained through a three-dimensional computational analysis. However, a two-dimensional analysis can be used to estimate the stress distribution.

A two-dimensional analysis can neither model the restraint conditions nor predict out-of-plane displacements that occur at the boundary of the perpendicular drifts. As a result, the vertical stress distribution from the two-dimensional analysis is assumed to represent a plane some distance from the perpendicular drifts where the actual behavior more closely represents the plane strain condition. The accuracy of this assumption depends upon the distance between the plane being analyzed and the perpendicular drift. In all cases, the results of a two-dimensional analysis represent a lower bound on the effects of perpendicular drifts.

The pillar dimensions are identified as W_1 for the width of the pillar between parallel drifts and W_2 for the width of the pillar

between perpendicular drifts. For an infinitely long pillar, which can be considered as a rectangular pillar with W_1/W_2 equal to zero, the vertical stress distribution of the drift to the center of the pillar can be determined from a two-dimensional analysis. The distribution of the vertical stress $\sigma_i(y)$, shown at the top of Figure 10-14, is symmetrical with respect to the centerline of the pillar and stabilizes within several months after excavation.

For a square pillar, which can be considered as a special case of the rectangular pillar with W_1/W_2 equal to one, the vertical stress distribution should be symmetrical with respect to the two centerlines and two diagonals of the pillar. This is shown graphically in the middle of Figure 10-14, where the x-axis is assumed to be along the drift axis. Assuming the vertical stress distribution $\sigma_s(x,y)$ from the center of the pillar to any of the four walls is the same as the stress distribution $\sigma_i(y)$ across the width of the infinite pillar, the ratio of the average vertical stresses between the square and the infinite pillars can then be estimated from equation 10-3:

$$\frac{\bar{\sigma}_s}{\bar{\sigma}_i} = \frac{\int_0^{W/2} \int_{-x}^{+x} \sigma_s(x,y)\, dydx}{\int_0^{W/2} \int_0^{W/2} \sigma_i(y)\, dydx} \qquad (10\text{-}3)$$

where: $\bar{\sigma}_i$ is the average vertical stress for the infinitely long pillar;

$\bar{\sigma}_s$ is the average vertical stress for the square pillar;

$\sigma_i(y)$ is the vertical stress distribution for the infinitely long pillar; and

$\sigma_s(x,y)$ is the vertical stress distribution for the square pillar.

Based on the computational results from the previous analyses, the average vertical stress of a square pillar is estimated to be 15 percent higher than that for the infinitely long pillar. At the WIPP

facility level, most of the pillars have a rectangular shape. As shown at the bottom of Figure 10-14, a rectangular pillar can be separated into regions which are assumed to act either as an infinite or square pillar. By using a weighted area method, the following equation expresses the effect of varying the pillar's aspect ratio on the average vertical stress:

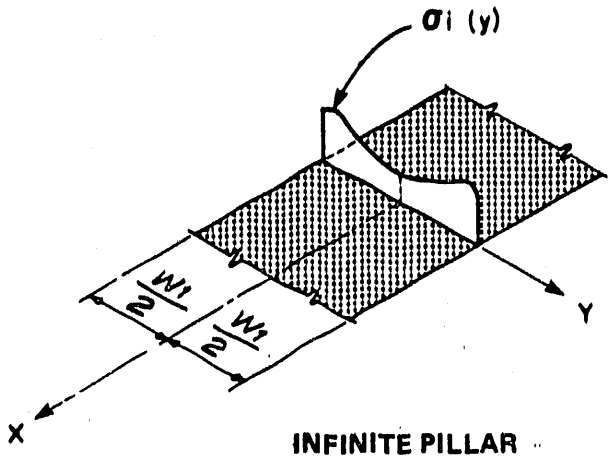
$$\bar{\sigma}_r = (1 + 0.15 \frac{W_1}{W_2}) \bar{\sigma}_i \qquad (10\text{-}4)$$

where: $\bar{\sigma}_r$ is the average vertical stress for the rectangular pillar.

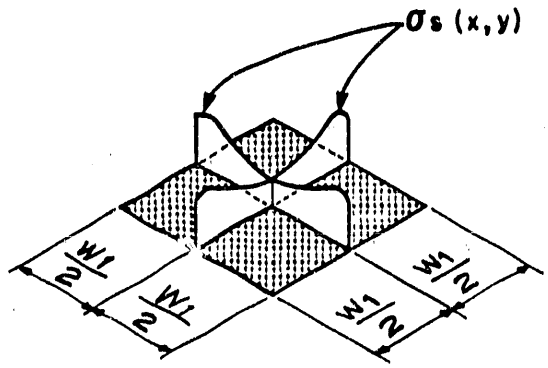
The corresponding change in pillar shortening is proportional to the ratio of $\bar{\sigma}_r$ to $\bar{\sigma}_i$, raised to some power, with an exponent not exceeding n, where n is the exponent in the power law expression for the creep behavior. Subsection 10.3.3.3 presents the results using equation 10-4.

10.3.2.4 Bay Strains

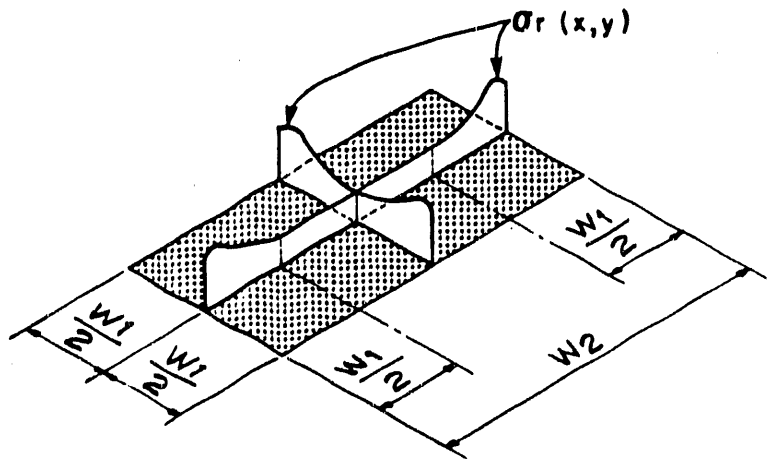
Strains around an opening in salt vary with space and time. Although, it is difficult to measure these strains directly, they can be inferred from the measurements of anchor displacements of multiple-point borehole extensometers. Relative movements between anchors will provide an approximate distribution of strain along the axis of the extensometer. If these relative displacements are normalized over the spacing between the anchors, then these normalized relative displacements are termed "bay strains". The bay strain will be closer to the true strain provided that the spacing between anchors is small and that the deformation varies linearly with spacing between anchors. Bay strains are useful in detecting any anomalous behavior in salt around an opening such as that influenced by discontinuities, clay seams, or the effect of local stress concentrations.



INFINITE PILLAR



SQUARE PILLAR



RECTANGULAR PILLAR

Figure 10-14

DRIFTS
VERTICAL STRESS DISTRIBUTIONS IN VARIOUS PILLARS

Figure 10-15 shows the variation of bay strains with elapsed time since completion of excavation for floor extensometer 51X-GE-00242. This extensometer is located at the intersection of Test Room 2 and the N1100 drift. The sudden increase in the bay strains may not be related to salt behavior and is apparently related to system measurement. Thus, it is likely that the maximum average bay strain in the first 6 feet of salt in the floor is no more than 1 percent. The analysis of bay strains in the floor of the drifts in other locations indicates that the maximum average bay strain generally occurs in the first 6 feet (collar to anchor A) in either the roof or the floor. Figures K-36 to K-45 in Appendix K show the variation of bay strains with elapsed time since excavation.

Figure 10-16 shows the rate of bay strains for extensometer 51X-GE-00242. The overall trend is that the rates decrease with time and are currently less than 0.5 percent/year. Figures K-46 to K-55 in Appendix K summarize the variation of strain rates with time.

The decreasing trend in the rates of bay strain with time is an indication that the salt in the roof and floor of the drifts is currently stable.

10.3.3 Prediction of Future Behavior

The results of the analysis of the 8 x 25-foot drift have been categorized as follows:

(1) Effective stresses and effective creep strains immediately after initial excavation; immediately before and after floor lowering; and 5 years after initial excavation.

(2) Principal stresses immediately after initial excavation; immediately before and after floor lowering; and 5 years after initial excavations.

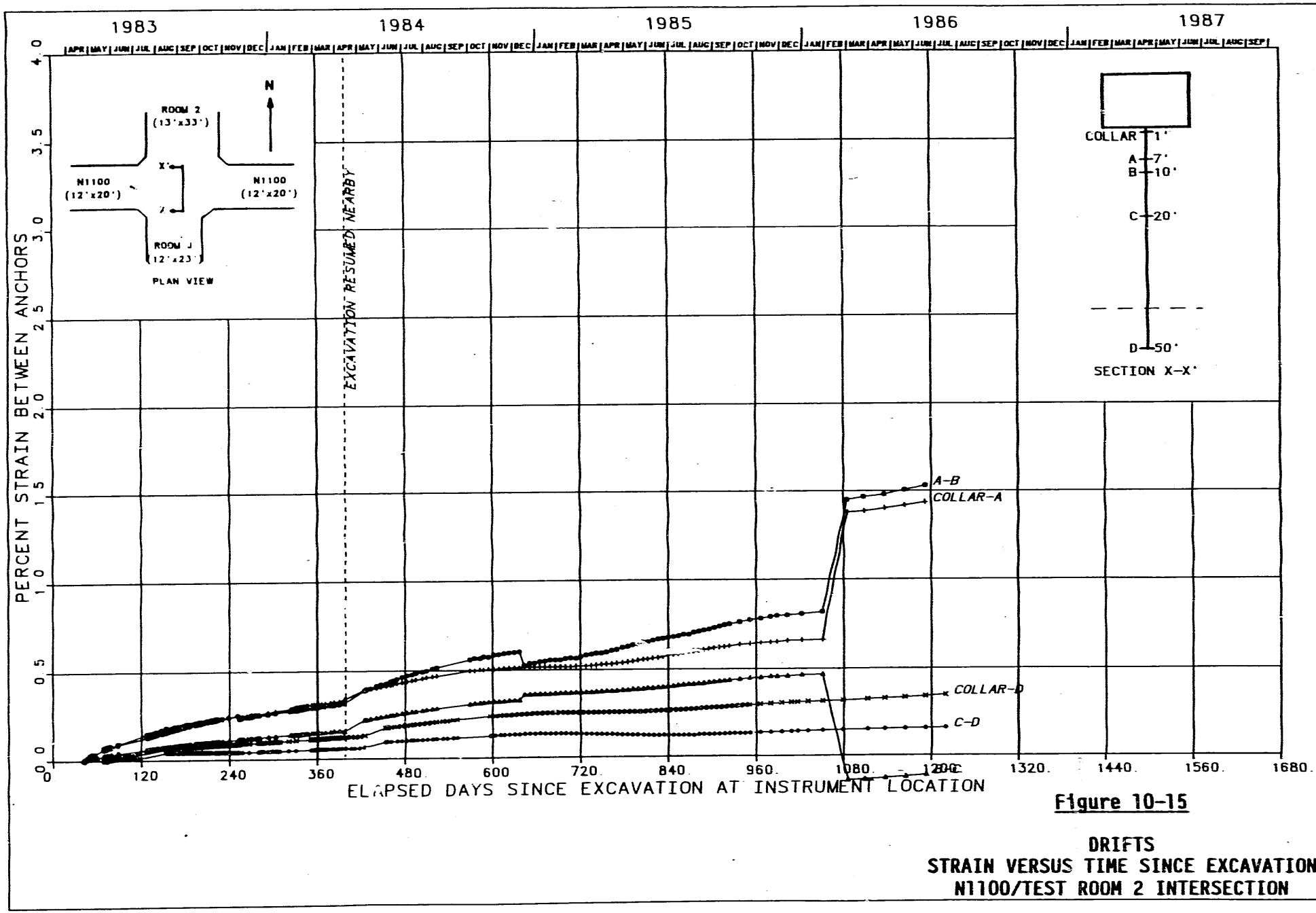
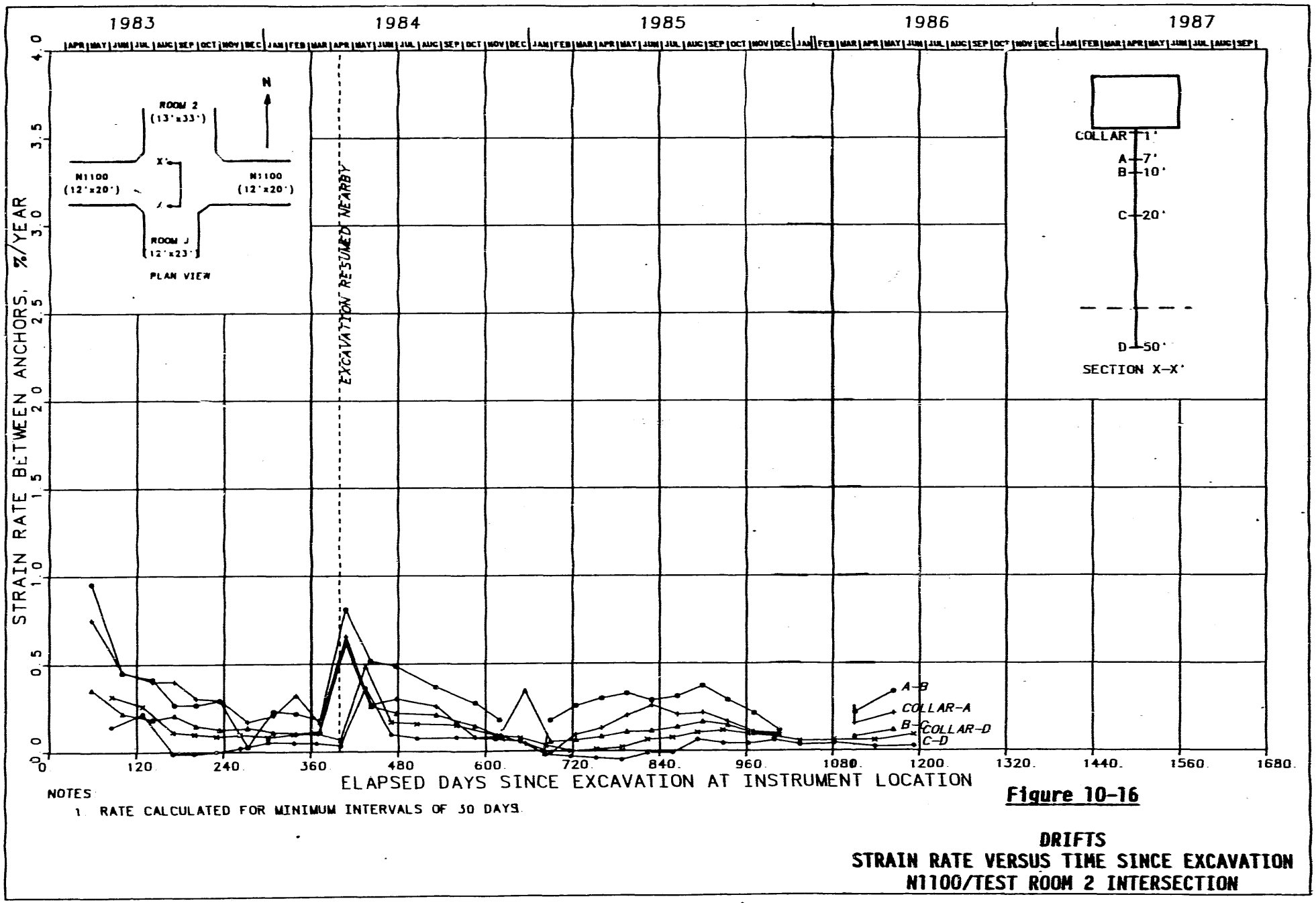


Figure 10-15

DRIFTS
STRAIN VERSUS TIME SINCE EXCAVATION
N1100/TEST ROOM 2 INTERSECTION



NOTES

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.

Figure 10-16

DRIFTS
STRAIN RATE VERSUS TIME SINCE EXCAVATION
N1100/TEST ROOM 2 INTERSECTION

(3) Deformed drift shapes immediately before floor lowering and 5 years after initial excavation.

10.3.3.1 Effective Stresses

Figures 10-17 and 10-18 show the distribution of effective stresses in each of the elements of the mesh located near the midheight of the finite element model. The contours are numbered with integers from 1 to 10 with each contour interval representing an effective stress increment of 100 ksf. As time passes, the plots show the effective stresses becoming more concentrated in the anhydrite layer. That is, more energy in the form of strain energy is transferred from the creeping halite and argillaceous halite layers to the anhydrite.

10.3.3.2 Principal Stresses

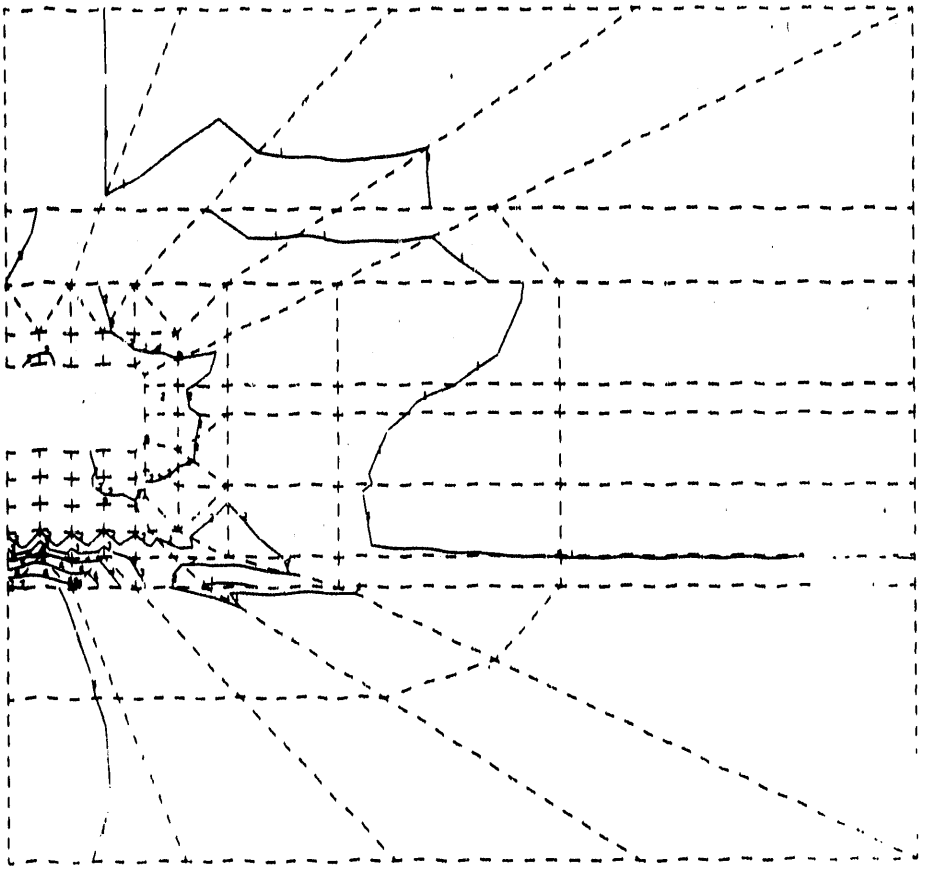
The principal stress plots (Figures 10-19 and 10-20) show that, immediately after excavation, the magnitudes of the predicted principal stresses are relatively large in the corners of the drift and in the anhydrite layer. As the salt creeps, the principal stresses concentrate in the anhydrite layer near the centerline of the drift.

10.3.3.3 Deformation and Closure

A mesh showing the deformed drift shape is presented on Figure 10-21. This mesh shows the outline of the original, undeformed drift in dashed lines while the deformed shape at the corresponding creep time is shown in solid lines.

The deformed shape immediately before floor lowering shows significant vertical deflection (downward) in the roof area of the drift. The drift floor has heaved upward only slightly and the walls have begun to creep inward.

Effects Due to Extraction Ratio. An analysis was performed to simulate the effect on the response of the drift due to a change in the extraction ratio. A change in the extraction ratio is caused by



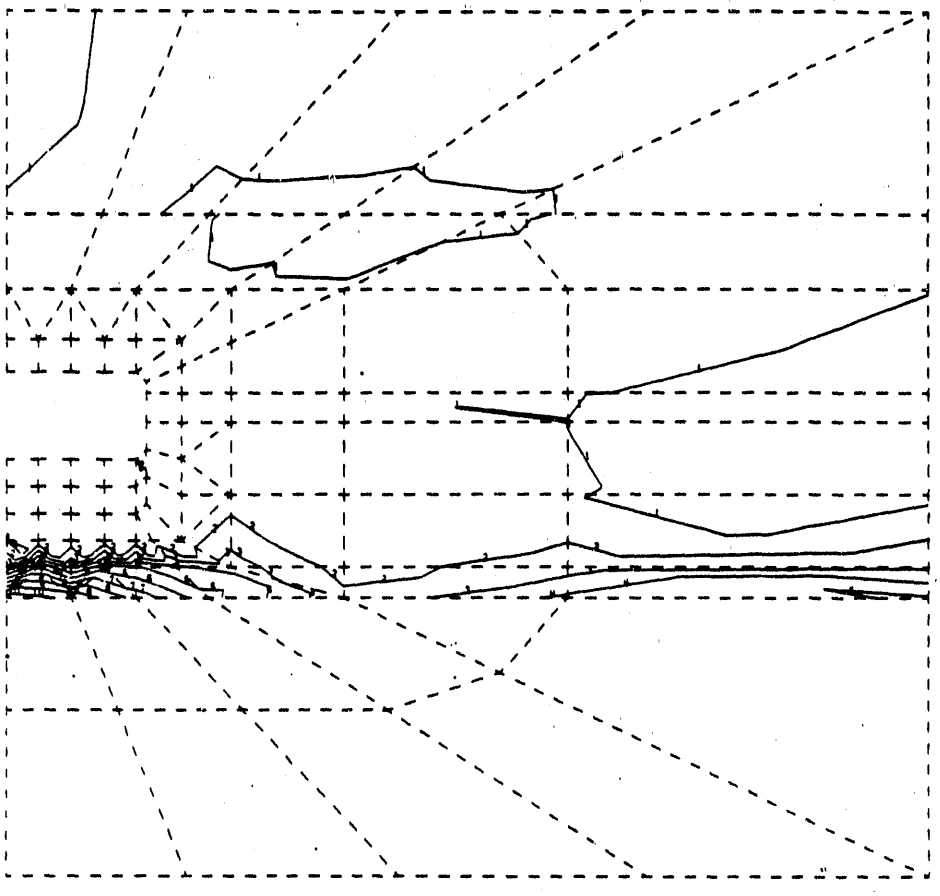
EXPLANATION OF CONTOUR LINES

1 = 100 KSF
2 = 200 KSF
3 = 300 KSF
4 = 400 KSF
5 = 500 KSF
6 = 600 KSF
7 = 700 KSF
8 = 800 KSF
9 = 900 KSF
10 = 1000 KSF

NOTE:
KSF = Kips per square foot.

Figure 10-17

DRIFTS
EFFECTIVE STRESS DISTRIBUTION IMMEDIATELY AFTER EXCAVATION



EXPLANATION OF CONTOUR LINES

1 = 100 KSF
2 = 200 KSF
3 = 300 KSF
4 = 400 KSF
5 = 500 KSF
6 = 600 KSF
7 = 700 KSF
8 = 800 KSF
9 = 900 KSF
10 = 1000 KSF

NOTE:
KSF = Kips per square foot.

Figure 10-18

DRIFTS
EFFECTIVE STRESS DISTRIBUTION IMMEDIATELY BEFORE FLOOR LOWERING

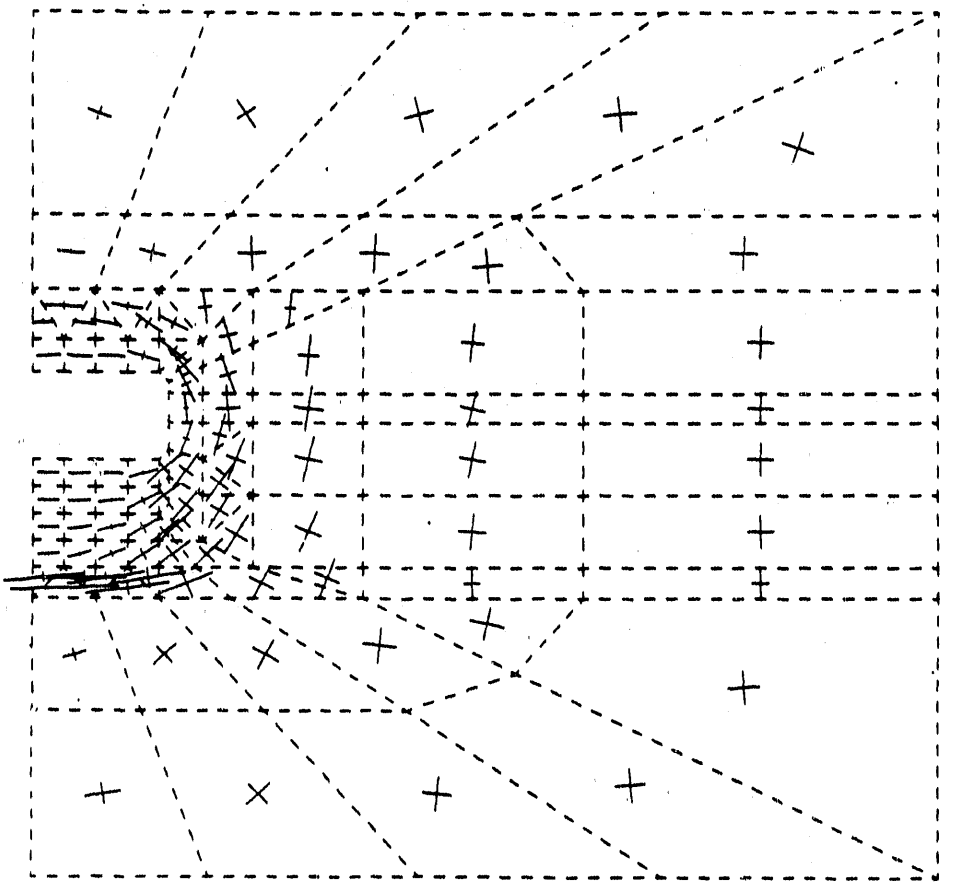


Figure 10-19

DRIFTS
PRINCIPAL STRESSES IMMEDIATELY AFTER EXCAVATION

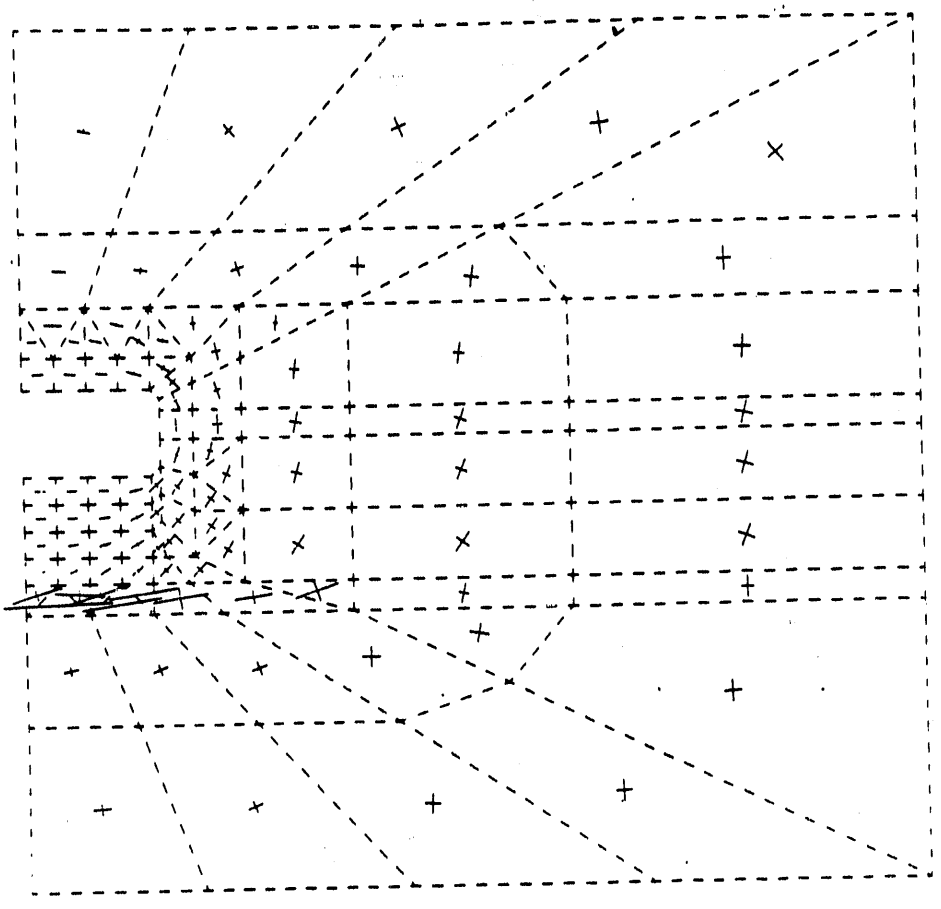


Figure 10-20

DRIFTS
PRINCIPAL STRESSES IMMEDIATELY BEFORE FLOOR LOWERING

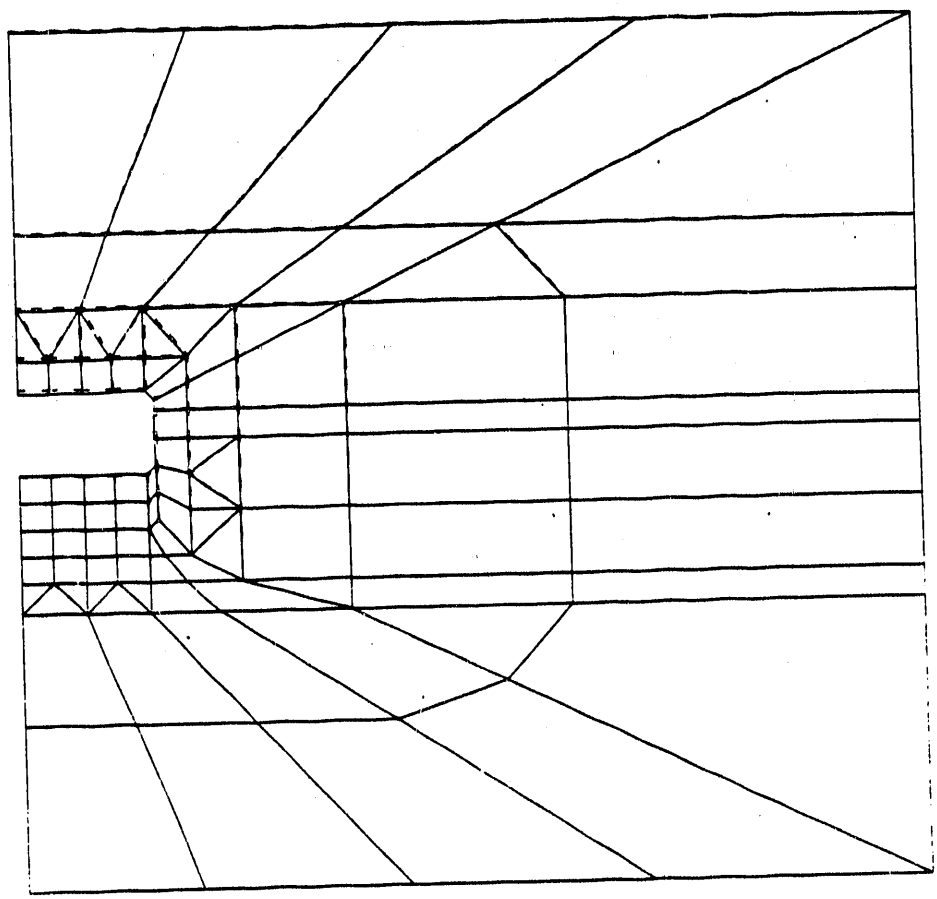


Figure 10-21

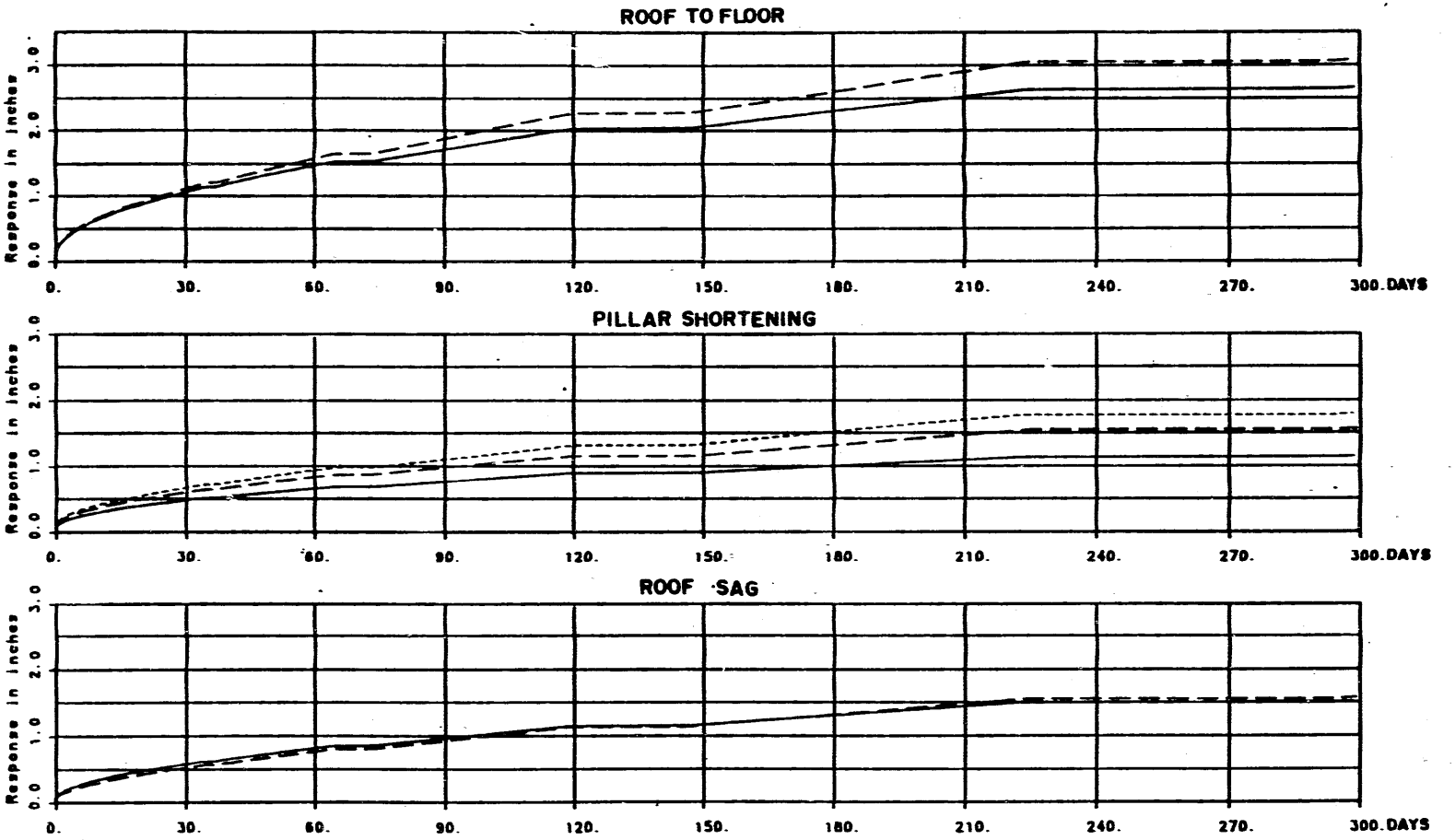
DRIFTS
DEFORMED SHAPE IMMEDIATELY BEFORE FLOOR LOWERING

excavation in adjacent or remote areas. The effect due to excavation in adjacent areas was simulated by modifying the finite element model used in the analysis. The difference is essentially a comparison of a single drift to a set of intersecting multiple drifts. Developing a single drift model which accurately represents the behavior of the infinite pillar requires assuming a width for the model. Therefore, to examine the effect of pillar width on analytical results, a 139-foot wide model similar to the one shown on Figure 10-12 was used as a base case and was later widened to 278 feet. Each model consists of an 8 x 25-foot drift.

Figures 10-22 and 10-23 show comparisons of the closure behavior for the two different pillar widths. Because the width of the model is expected to affect the vertical stresses, both the pillar shortening and roof sag components of closure are included. The top graph in both figures indicates that by halving the pillar width to that of the northern area spacing the roof-to-floor closure increases by about 15 percent.

The effects on pillar shortening due to increased overburden stress from the perpendicular drifts can be seen on the middle graph in Figure 10-22. Comparison of the infinite pillar with and without perpendicular drifts indicates a 15 percent increase in pillar shortening due to the presence of the intersecting drifts. Comparing the curves for the narrow pillar in the top two graphs indicates that pillar shortening contributes approximately half of the total closure response. The 15 percent increase in the pillar shortening then corresponds to a 7 1/2 percent contribution in total closure. This is also true for the total closure rate. The combined effects of single versus multiple drifts and multiple parallel drifts versus an intersecting gridwork account for about a 24 percent difference in the total closure rate.

The effects of releasing the boundary constraints at the perpendicular drift wall can be estimated by the use of equation 10-4. For the



Wide Pillar ————————————

Narrow Pillar — — — — — — — — — — — —

Narrow Pillar with Perpendicular Drift ----------

Figure 10-22

DRIFTS
COMPARISON OF CLOSURE COMPONENT RESPONSES

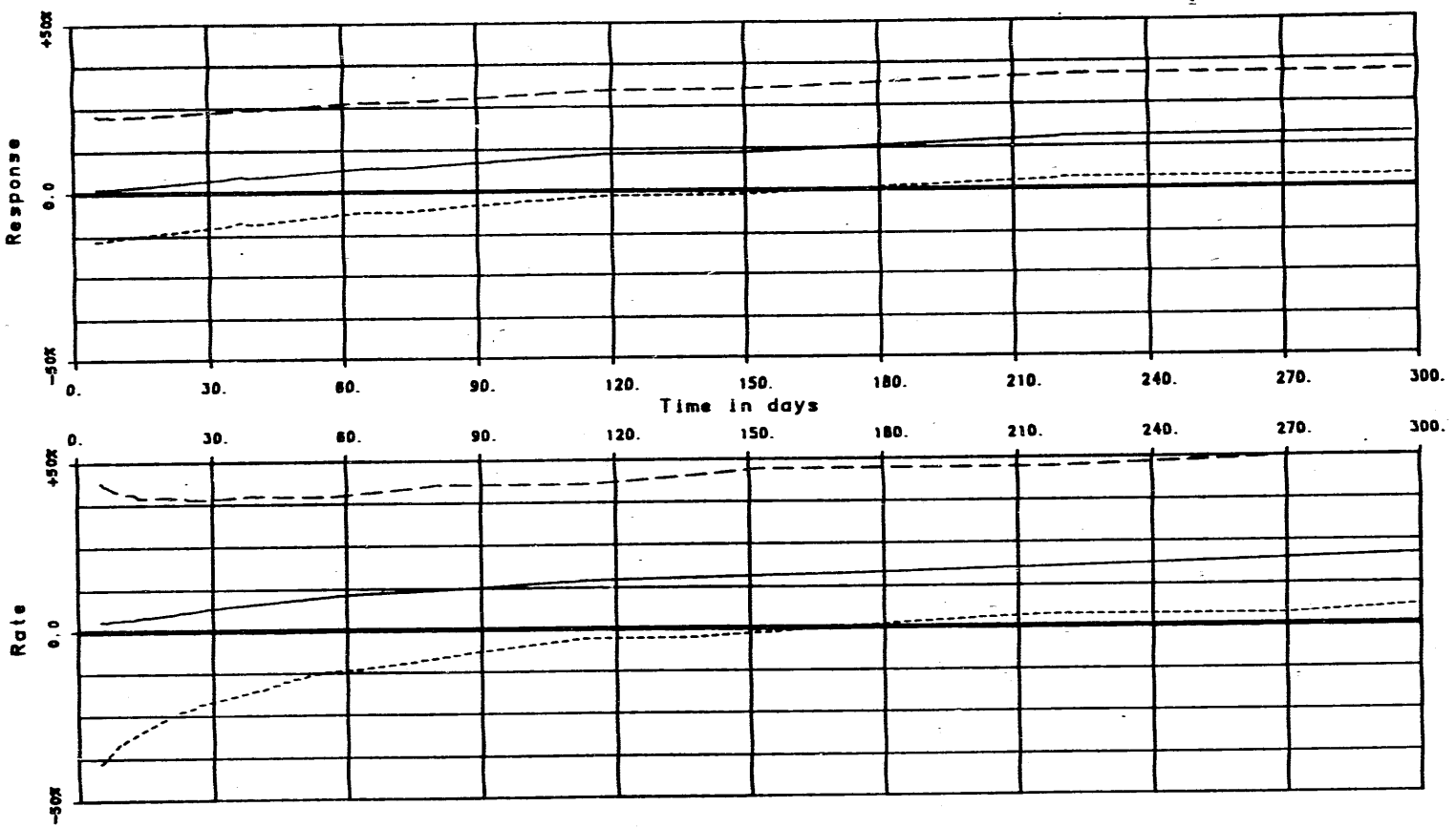


Figure 10-23

DRIFTS
CLOSURE EFFECTS DUE TO PILLAR WIDTH

northern area where the W_1/W_2 ratio is approximately 0.4, the average effective stress is increased by about 6 percent. If the pillar shortening rate is proportional to the square of the increase in average effective stress in the pillar, the boundary release accounts for a 12 percent increase in pillar shortening. As described in the previous paragraph, this 12 percent increase in pillar shortening rate corresponds to about a 6 percent increase in the total closure rate. This factor, combined with the previously described effects, yields about a 30 percent difference in the total closure rate. This compares well with the value presented in subsection 10.3.2.2.

The roof sag component of closure is shown in the bottom graph of Figure 10-23. Figure 10-22 shows the comparison of the closure components of the narrow model relative to the wide model which is equivalent to comparing multiple parallel drifts to a single drift. As this figure indicates, the behavior differences appear to stabilize after about 200 days.

10.3.3.4 Effectiveness of Numerical Modeling

The creep parameters C, A and z were determined using roof-to-floor and wall-to-wall closure data. The effectiveness of the numerical modeling which uses one set of measured data to predict with reasonable accuracy other variables such as stress and strain needs to be verified to infuse confidence in the numerical modeling procedure. Besides, such a comparison will enable testing the adequacy of the basic creep level as well as assumptions regarding the statigraphy assumed for the model.

The 8 x 25-foot drift south of S2180 was isolated until July 1986 and different sets of creep parameters were determined by numerical modeling using roof-to-floor closure data from various convergence point measurements. In situ roof-to-floor closure data for stations south of S2180 indicate that the drift behaves essentially like an infinitely long isolated opening except at the very end of the E140 drift. This affords an opportunity to compare the measured relative displacements in the roof as well as in the floor at one instrument

location with the values obtained from numerical modeling which used roof-to-floor closure data from measurements at some other instrument location to "back calculate" the creep parameters.

Figure 10-24 compares the measured relative displacement between the collar and anchor D of extensometer 51X-GE-00247, in the roof at E140/S1950, with the values obtained from the numerical modeling. The calculated value is the relative vertical displacement of two nodes comparable to the positions of the collar and anchor D of the extensometer. The parameters C, A and z were obtained using roof-to-floor closure data from the instrument location at E140/S1879. The agreement is reasonable because the slopes of both the measured and calculated relative displacements are nearly identical. Figure 10-25 similarly compares the measured relative displacement in floor extensometer 51X-GE-00248 at E140/S1950 with the calculated values from the same numerical modeling. The slope of the in situ curve is 28 percent steeper than the calculated value. This is probably because the numerical model assumes that the anhydrite layer in the floor of the drift as linearly elastic with infinite strength. This may not be true if the anhydrite has pre-existing fractures, and thus may not be able to absorb the heave from the salt below.

Figure 10-26 compares the measured wall-to-wall closure at E140/S1879 with the calculated wall-to-wall closure from the results of the same numerical modeling. The average slope of the curve from numerical modeling is nearly 43 percent steeper than the slope of the curve from measurement data.

10.4 CONCLUSIONS AND RECOMMENDATIONS

The following subsections present conclusions pertaining to validation of the drift reference design and recommendations for design modifications. These are based on a comparison of the design criteria, design bases and reference design configurations with the results of the analysis and evaluation of data collected during the design validation process.

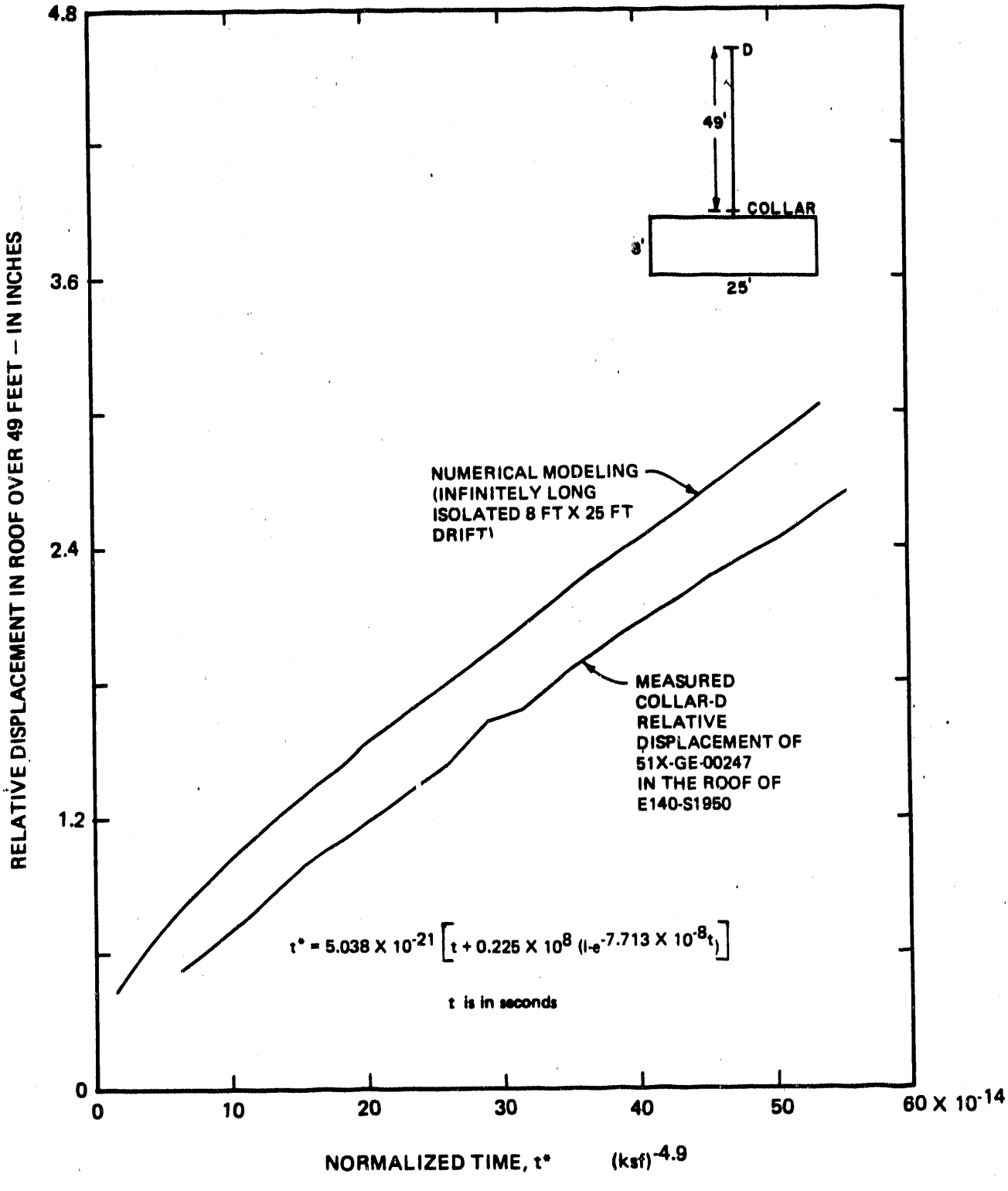


Figure 10-24

DRIFTS
NUMERICAL MODELING VERSUS IN SITU MEASUREMENT
DATA FROM ROOF EXTENSOMETER

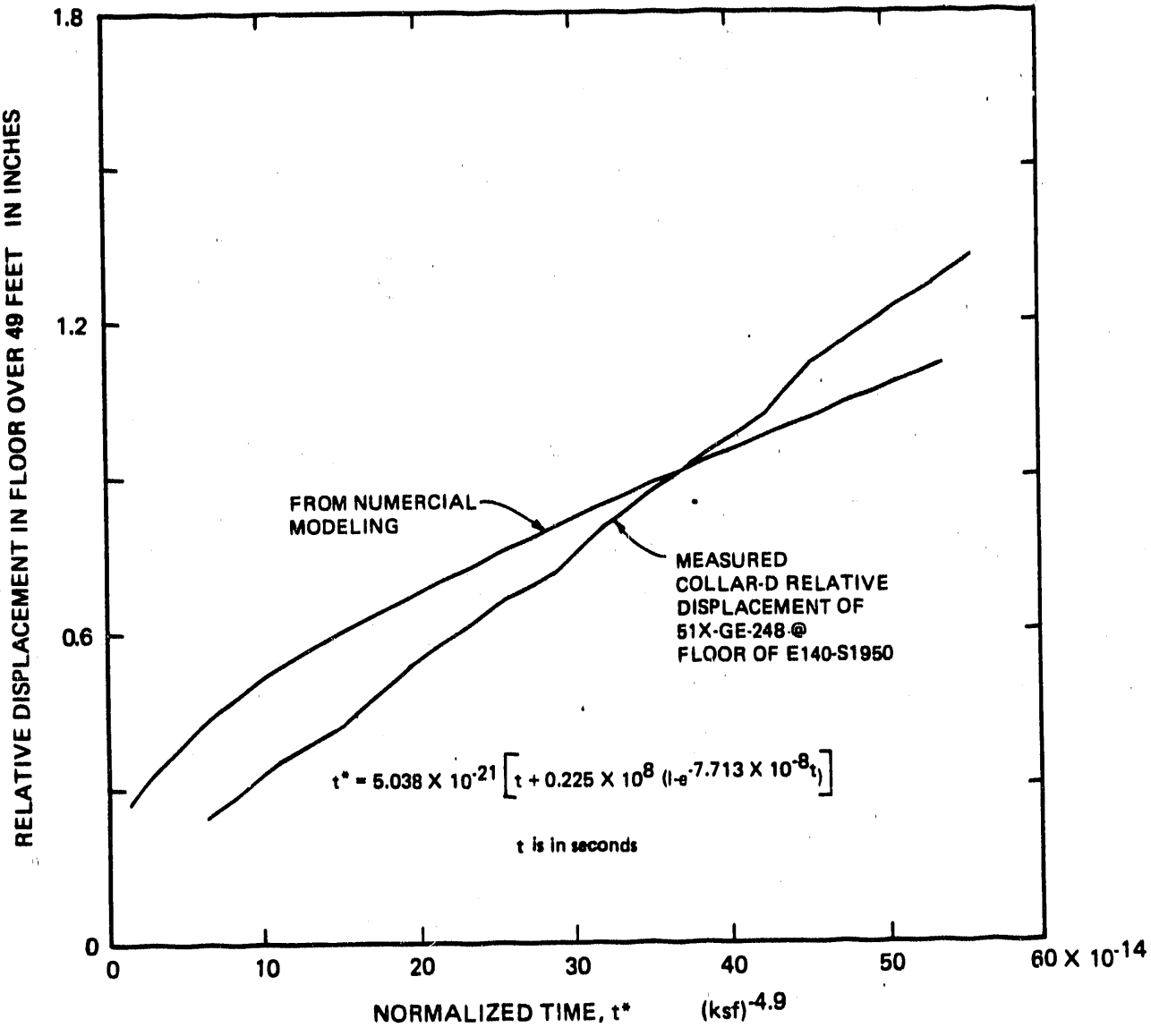


Figure 10-25

DRIFTS
NUMERICAL MODELING VERSUS IN SITU MEASUREMENT
DATA FROM FLOOR EXTENSOMETER

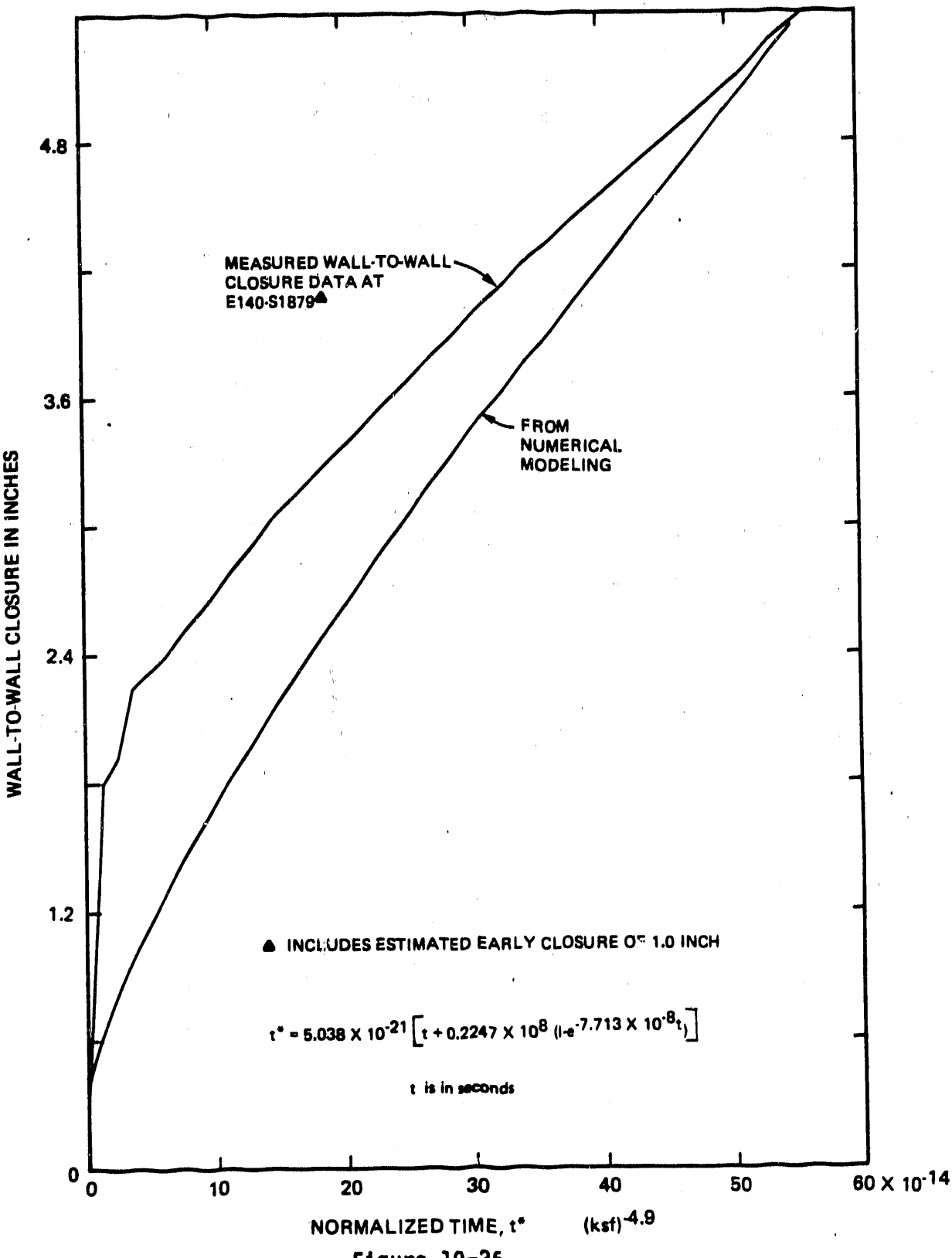


Figure 10-26

DRIFTS
NUMERICAL MODELING VERSUS MEASURED WALL-TO-WALL CLOSURE
AT E140/S1879

10.4.1 Conclusions

The evaluation of field observations and analytical results shows that the design criteria were appropriate for design of the horizontal openings. The three criteria identified as requiring specific evaluation, that the drifts remain within the required structural limits, provide maximum stability, and maintain the minimum required dimensions, were determined to be suitable. The reference design for the horizontal openings is therefore validated.

Spalling from the roof and walls of the drifts and fracturing and spalling at pillar corners will continue. Displacements and separations at clay seams above the roof may slowly increase. This deformational behavior is expected and can be controlled by scaling and rock bolting as necessary.

The average bay strains determined from the relative displacements of extensometer anchors 3 years after drift excavation are within 1 percent. The strain rates as well as the closure rates decrease with time indicating that the drifts are stable. Based on the projections of closure rates, the drifts will continue to be stable.

Fracturing beneath the floor of the drifts is minor and has nowhere developed to near the degree as that beneath the floor of Test Room 3. If additional fracturing develops in the future beneath the drifts, it is also expected to be minor. Based on experience in local potash mines, this type of fracturing is not expected to cause stability or operational problems.

The comparison of measured closure behavior in drifts with different dimensions indicates that the maximum closure and closure rate will occur in 12 x 25-foot drifts. The closure rates are affected by the presence of nearby parallel drifts and crosscuts as well as differences in salt properties. Based on available measurement data and the results of modeling analyses, the closure rate in the 13 x 25-foot

storage area drifts may be 30 percent greater than that of a single, infinitely long drift with the same dimensions (Chapter 12).

Analyses of salt behavior around the 25-foot wide drifts has determined the redistribution of stresses due to the effect of creep. Based on the computed vertical, horizontal and effective stresses, the stress which develops immediately after excavation is followed by relaxation due to creep behavior. According to the analyses, stress should not cause future stability problems in the drifts.

The analyses have also determined the locations of effective creep strain concentrations around the drifts at different times. Based on the predicted values of effective creep strain and the strain limit discussed in Chapter 6, the drifts will remain within the structural stability limits required, with respect to catastrophic failure, during the facility operating life. Minor spalls from the roof and wall surfaces are expected to occur. Analysis of observations in mines and discussion with mine personnel indicates that the surfaces of the drifts may start to deteriorate more rapidly after about 15 years. Increased maintenance will then be required.

10.4.2 Recommendations

Based on the results of design validation of the drifts, it is recommended that all drifts be inspected frequently for operational clearance and safety. If the clearance is insufficient, the drifts must be trimmed to the required dimensions. Trimming the floor to increase drift height is preferred over trimming the roof. Over the 25 year operating life, the roof should not be trimmed more than 12 inches for drifts 25 feet wide or less. Trimming the roof more than 12 inches would make the beam of salt too thin and increase the possiblity of a roof fall. Further trimming must be accomplished from the floor even though this will decrease the thickness of the salt above MB-139. Scaling and rock bolting should be performed where

necessary for safety purposes. Periodic inspection of accessible open boreholes should be performed to monitor the occurrence and behavior of displacements, separations and fracturing in the salt above the roof and beneath the floor of the drifts.

CHAPTER 11
TEST ROOMS

11.1 INTRODUCTION

The four test rooms comprise a panel with a configuration similar to that designed for the waste storage area. The test rooms were instrumented, observed and analyzed in order to evaluate the potential behavior of the storage rooms. This chapter presents the results of data collection activities in the test rooms and the analysis and evaluation of the data with respect to the behavior of the excavated rooms. The information presented here will be used in Chapter 12 to predict the future behavior of the storage rooms and to validate their reference design.

11.2 DESIGN

The test rooms represent a portion of the storage room reference design configuration. The purpose of the test rooms is to provide geotechnical information that can be used to predict the potential behavior of the storage rooms. Because they were excavated to permit validation of the storage room reference design, and will not be used for permanent storage, the test rooms were not specifically addressed in the Design Criteria document. The design criteria apply to the configuration of the storage rooms and, therefore, only indirectly to the configuration of the four-room test panel.

No Design Basis documents were developed specifically for the test rooms. Only two Design Basis documents (refs. 2-9 and 2-18) contain elements pertaining to the test rooms. These elements specify that test rooms shall be provided to verify underground conditions as required by the SPDV Program and that their dimensions shall be 33 feet wide, 13 feet high and 300 feet long. All other design bases that require evaluation are applicable to the storage rooms rather than to the test rooms.

11.3 DESIGN VALIDATION PROCESS

The test room panel is the experimental model for the storage rooms. Validation of the test panel reference design configuration is not required. The test room data and analyses presented in this chapter are the bases for validation of the storage rooms. Predictions of the future behavior of the storage rooms based on these data analyses are presented in Chapter 12.

11.3.1 Data Collection

Data collection in the test rooms consisted of the accumulation of geotechnical data from geologic mapping, core drilling, observations of deformational behavior and geomechanical instrument measurements. Geologic mapping and core drilling were performed in the four test rooms. The stratigraphy defined by the mapping and core logging is discussed in Chapter 6. Observations of in situ behavior and data from the geomechanical instrumentation program are presented in the following subsections.

11.3.1.1 Field Observations

Some aspects of test room behavior can only be evaluated by visual observation. Visual inspections of the rooms include observations of their general surface conditions in response to stress redistribution and salt creep. These conditions include small spalls from the roof and walls, especially at their intersection, and vertical fracturing at pillar corners and along the walls in response to pillar shortening.

Field observations include other qualitative and quantitative techniques in addition to visual inspections of excavation surfaces. Boreholes are surveyed using video cameras. Horizontal displacements and vertical separations of the geologic strata surrounding boreholes are determined using a probe, as described in Chapter 7, subsection 7.3.1.4. Wall surfaces of large diameter holes are mapped by a geologist.

A qualitative determination of the conditions of the test rooms is made

by site geologists during an inspection of the rooms at least once every 3 months. These inspections have been documented in each GFDR starting with the February 1984 edition (refs. 4-12 through 4-19). Detailed descriptions of observed test room behavior are contained in each of these reports.

As discussed in Chapter 10, an Excavation Effects Program was conducted throughout the underground facility during May through July 1986. This program was conducted to further characterize near-field deformation above and below the facility level. Ten arrays of boreholes were drilled in the roof and floor of the test rooms. The locations of the arrays are shown on Figure 10-1 in Chapter 10.

The results of some of these observations are used in conjunction with the results of numerical analysis and in situ measurement data to quantify the structural behavior of the test rooms. The documented field observations can be separated into four categories: roof and wall spalling; pillar fracturing; roof displacements and separations; and floor displacements, separations and fracturing.

Roof and Wall Spalling. A sounding survey of the roof of each test room was conducted during and immediately after excavation. Only a few areas of drummy rock were discovered and these were either removed or rock bolted.

The rooms have exhibited only minimal spalling over a period of 3 years since their excavation. The drummy areas originally found in the roofs have not grown noticeably, but some additional areas have been discovered by subsequent roof soundings. Additional scaling and rock bolting have been performed in most of these areas. The most noticeable spalling is associated with the argillaceous halite unit (geologic map unit 4, Appendix G, Figures G-1 through G-4) high on the test room walls. This spalling is generally continuous but shallow. Some spalling from the roof close to the walls has also been observed within the past year that has required support by rock bolts in selected areas.

Pillar Fracturing. Vertical fracturing has occurred in the corners formed by the intersection of drifts with the test rooms. The fractures have separations that range from essentially closed to about 2 inches wide. They generally extend into the rock perpendicular to the rock surface for an unknown distance. All corners of the test rooms show fracturing and consequent spalling. The fractures first appeared in the pillar corners about 3 to 6 months after excavation. They started as thin, hairline fractures and have steadily grown in length, width and presumably depth. Each of the GFDRs document this gradual development of the fractures. Scaling of these corners has been performed periodically.

Vertical fracturing has developed in the pillars parallel to the room walls. This fracturing is relatively minor and, to date, has been observed only in Test Rooms 3 and 4. The fracturing has been detected in horizontal boreholes drilled into the walls and occurs within approximately 2 feet of the wall surface. The fractures range from closed to about 1/32 inch wide.

Roof Displacements and Separations. Inspections of open boreholes in the test room roofs were conducted using a video camera and/or probe. The video camera produces high-resolution, color videotapes that are useful in identifying horizontal displacements and vertical separations. The probe is used in conjunction with a tape measure to determine the location and amount of movement in the boreholes. As in other areas of the underground facility, expected horizontal and vertical movements of the geologic strata surrounding the boreholes have been observed or measured in the test rooms. These observations are summarized in Table 11-1.

Ten arrays of boreholes were drilled in the test rooms in May 1986 as part of the Excavation Effects Program. These holes were used for additional investigation of test room roof displacements and separations. Each hole was inspected using a probe. Table 11-2 presents a summary of the results of this study.

Table 11-1

TEST ROOMS 1 THROUGH 4
RESULTS OF INSPECTION OF VERTICAL BOREHOLES IN ROOFS

Hole	Date Completed	Hole Size (in.)	Depth (ft)	Approximate Location	Observed Condition*
IG-205	4-17-83	3	56	Room 1; 1 ft from west wall	D
IG-206	4-15-83	3	52	Room 1; 1 ft from east wall	D
IG-203	3-26-83	3	52	Room 2; 1 ft from west wall	D
IG-204	3-83	3	52	Room 2; 1 ft from east wall	D
OH-3	8-83	4	20	Room 2 centerline	S, F
P4X-26	10-83	5	52.1	Room 4; N1360/W630	None
P4X-30	12-83	4	50.9	Room 4; N1360/W630	S
-	-	6	8	Room 4; N1360/W639	D, F
-	-	5	9±	Room 4 center; N1176	S(?)

* D = Displacement; S = Separation; F = Fracturing

Table II-2

EXCAVATION EFFECTS PROGRAM

BOREHOLE INSPECTION SUMMARY

SECTION	OPENING DIMENSIONS (HxW-FT)	EXCAVATION DATE	LOCATION	DATE DRILLED	DATE INSPECTED	OBSERVED CONDITIONS					
						ROOF HOLES			FLOOR HOLES		
						E	A	C	F	B	D
1	13x33	4/83	ROOM 4, NIT5	5/15/86	5/15/86	C	S(?) *	C(?)	D, S *	C	S, C
2	13x33	4/83	ROOM 4, NI264	5/16/86	5/16/86	C(?)	NONE	C	NONE	C	S
3	13x33	4/83	ROOM 4, NI36I	5/16/86	5/16/86	NONE	D *	NONE	NONE	D, S, F *	S
4	13x33	4/83	ROOM 3, NI98	5/15/86	5/15/86	NONE	NONE	S	NONE	S	S
5	13x33	4/83	ROOM 3, NI243	5/15/86	5/15/86	NONE	NONE	NONE	S, F (USED ROOM 3 LARGE DIAMETER HOLES)		
6	13x33	4/83	ROOM 3, NI312	5/15/86	5/15/86	S	C	NONE	D, S, F (USED PREVIOUSLY DRILLED HOLES M8-FI-01 THROUGH 03)		
7	13x33	3/83	ROOM 2, NI147	5/21/86	5/22/86	NONE	NONE	C	C	F, C	NONE
8	13x33	3/83	ROOM 2, NI23I	5/21/86	5/22/86	F	F	NONE	S	S, F, C	F
9	13x33	4/83	ROOM 1, NII59	5/21/86	5/22/86	C	F	NONE	C	S, C	NONE
10	13x33	4/83	ROOM 1, NI275	5/21/86	5/22/86	F	S, F, C	NONE	C	S	S, C

* EXISTING HOLE.

EXPLANATION

D = HORIZONTAL DISPLACEMENT. FOUND ONLY IN PREVIOUSLY DRILLED HOLES. DISPLACEMENT APPEARS TO DEVELOP WITH TIME FOLLOWING HOLE DRILLING.

S = VERTICAL SEPARATION. PROBE NAIL PENETRATES HOLE WALL SURFACE. VERTICAL SEPARATIONS RANGE FROM APPROXIMATELY 1/16 INCH TO 6 INCHES.

F = FRACTURE ZONE. PIECES OF HALITE COMMONLY PICKED OUT OF ZONE BY PROBE NAIL.

C = PROBE NAIL CATCHES ON HOLE WALL SURFACE BUT DOES NOT PENETRATE. INDICATES POSSIBLE SEPARATION OF LESS THAN 1/16 INCH. OCCURENCES AT KNOWN CLAY LAYERS ARE NOT INDICATIVE OF SEPARATION AND ARE NOT INCLUDED IN THIS TABLE.

NOTES:

1. SECTION LOCATIONS AND HOLE CONFIGURATIONS ARE SHOWN IN CHAPTER 10, FIGURE 10-1.
2. HOLES WERE DRILLED VERTICALLY USING A JACK-LEG DRILL.
3. NOMINAL HOLE DEPTH IS 9 FEET BUT SOME HOLES ARE SHORTER DUE TO LOW DRIFT ROOF OR DRILLING DIFFICULTIES.
4. ONE ROOF AND ONE FLOOR HOLE OF EACH ARRAY WERE GENERALLY DRILLED 3 INCHES IN DIAMETER TO ACCOMODATE USE OF BOREHOLE CAMERA IF DESIRED. OTHER HOLES WERE DRILLED 1-7/8 INCHES IN DIAMETER. EXISTING HOLES WERE USED WHERE POSSIBLE.
5. OBSERVATIONS WERE MADE USING A PROBE CONSISTING OF A NAIL ATTACHED PERPENDICULAR TO THE END OF A ROD.

Floor Displacements, Separations and Fracturing. Horizontal displacements, vertical separations and fracturing have been observed beneath the floor of the test rooms in boreholes. They have been observed to occur in MB-139 and in the overlying halite. Geologic maps of Test Room 3 (Room T) boreholes are presented in Appendix G, Figures G-10 through G-31. A summary of the results of the inspection of all small-diameter boreholes drilled in the floor of the test rooms is presented in Table 11-3. The inspections were accomplished using video equipment and/or a probe.

The only prominent exposure of floor fracturing is in the 36-inch diameter boreholes drilled in the floor of the south half of Test Room 3 (Room T). A total of 22 holes were drilled in this area during September and November 1985 for the erection of structural steel columns. A drilling summary is presented in Table 11-4. The holes are approximately 7.2 feet deep. The bottom of many of the holes coincides with the occurence of clay E at the base of MB-139. The remaining holes were terminated above the base of the marker bed.

The holes were logged on a 360 degree foldout at a scale of 1 inch to 1 foot. All features were measured from a level reference line which was later surveyed to determine elevations. Fracture traces, fracture zones and hairline fractures, in addition to lithologic contacts, were logged. A fracture trace is a distinct fracture surface exposed on the wall of the borehole. Fracture traces shown on the logs, unless otherwise noted, are closed within a few inches of the wall surface. A fracture zone is an area on the wall bounded by distinct fractures. Rock within the zone is broken by numerous smaller fractures spaced less than 1 inch apart. The fractured rock is commonly broken out very close to the wall surface of the borehole due to drilling, but becomes closed within 1/2 to 2 inches of the wall surface. Locally, the zone is open or partially filled with drill cuttings. At a distance of 12 inches from the borehole, the cumulative vertical separation measured over the length of the hole varies from less than 1/4 inch to 6 inches. The hairline fractures are closed fractures usually found

Table 11-3

TEST ROOMS 1 THROUGH 4
RESULTS OF INSPECTION OF VERTICAL BOREHOLES IN FLOOR

Hole	Date Completed	Hole Size (in.)	Depth (ft)	Approximate Location	Observed Condition*
IG-202	4-18-83	3	52	Room 1; 1 ft from west wall	D
GE-269	1-86	3	55	Room 1 centerline	S, F
IG-201	3-26-83	3	52	Room 2; 1 ft from west wall	D
NG-254	3-84	6	7	Room 2 centerline	None
GE-270	1-86	3	55	Room 2 centerline	S, F
2NPD-01	2-86	5	8.9	Room 2; N1370	S, F
MB-FI-01	12-85	4	12.0	Room 3; N1309	D, S, F
MB-FI-02	12-85	4	12.0	Room 3; N1309	D, S, F
MB-FI-03	12-85	4	12.0	Room 3; N1309	D, S, F
GE-271	1-86	3	55	Room 3 centerline	S, F
P4X-06	1983	5	9.0	Room 4; N1369/W625	D, S, F
P4X-25	10-83	5	50.2	Room 4; N1360/W630	D, S, F
P4X-27	10-83	5	51.1	Room 4; N1360/W630	D, S, F
P4X-29	10-83	5	49.5	Room 4; N1360/W630	D, S, F
P4X-31	11-83	5	50.4	Room 4; N1360/W630	D, S, F
P4X-81	11-83	16	-	Room 4	D, S, F
P4X-83	12-83	16	6.1	Room 4	S, F
P4X-84	1-84	36	9.5	Room 4	D, S, F

* D = Displacement; S = Separation; F = Fracturing

Table 11-4

TEST ROOM 3 (ROOM T)
SUMMARY OF DRILLING

Hole	Date Completed	Drilling Fluid	Communication During Drilling*
TV-01	10-25-85	Brine**	---
TV-02	10-28-85	Air	---
TV-03	11-05-85	Air	TV-07, TV-14 through 75° dipping fracture. TV-15 through fractures in halite close to surface on east side. Surface fracture close to east wall 25 feet south of TV-03. No communication to TV-13. TV-17, TV-12.
TV-04	11-08-85	Air	---
TV-05	11-20-85	Air	---
TV-06	11-13-85	Air	---
TV-07	10-29-85	Air	TV-12
TV-08	11-19-85	Air	---
TV-09	11-21-85	Air	---
TV-10	11-14-85	Air	TV-13, TV-14, TV-17, TV-15, TV-06, TV-11
TV-11	11-11-85	Air	---
TV-12	9-17-85	Air	---
TV-13	10-09-85	Air	TV-12, TV-15
TV-14	10-11-85	Air	TV-15
TV-15	9-23-85	Air	TV-19
TV-16	9-30-85	Air	TV-19, TV-20

Table 11-4 (continued)

TEST ROOM 3 (ROOM T)
SUMMARY OF DRILLING

Hole	Date Completed	Drilling Fluid	Communication During Drilling*
TV-17	10-15-85	Air	---
TV-18	10-02-85	Air	---
TV-19	9-20-85	Air	---
TV-20	9-25-85	Air	TV-19 along main fracture zone on north-northeast side.
TV-21	10-18-85	Air	---
TV-22	10-19-85	Air	TV-19 along main fracture zone on north-northeast side. TV-20 along main fracture zone on west side.

* Communication is indicated by drilling dust emanating from connected holes and detected by driller or geologist.

** Source of brine encountered in TV-01 is clay E at base of MB-139. Driller noted that this clay and about 4 inches of the overlying anhydrite were moist in many holes.

within fracture zones less than 1 inch wide. Some of these appear to be pre-excavation features within MB-139.

Additional small-diameter boreholes were drilled into the test room floors as part of the Excavation Effects Program. The 10 arrays summarized in Table 11-2 include three floor holes at each array. These holes were drilled primarily to determine if the fracturing observed in the 22 large-diameter holes in Test Room 3 extends to other areas beneath the test rooms.

11.3.1.2 Geomechanical Instrumentation

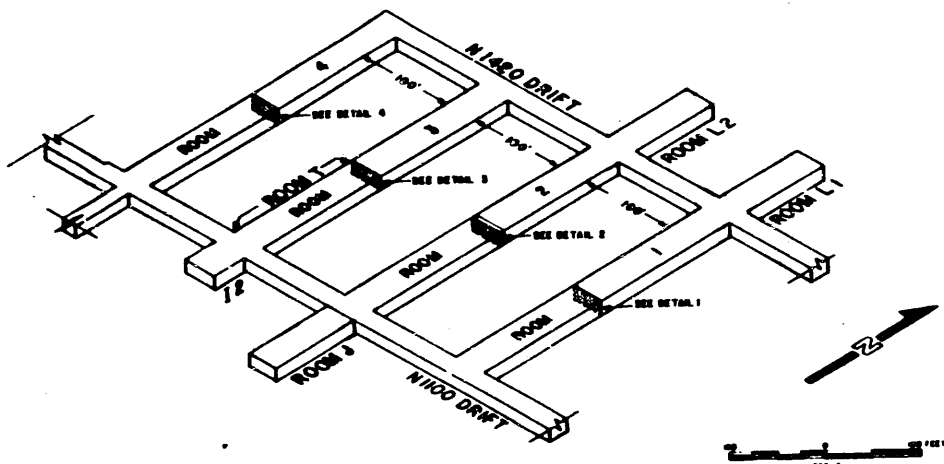
Geomechanical instrumentation in Test Rooms 1 through 4 initially consisted of 19 borehole extensometers, 16 horizontal inclinometers, 6 vertical inclinometers, 4 sets of convergence points, 2 convergence meters, and 2 rigid-inclusion vibrating-wire stressmeters (Figure 11-1). These instruments, with the exception of the inclinometers and convergence points, were connected to the datalogger system on May 13, 1983.

Due to failure for various reasons, some instruments in the test rooms had to be replaced. Those instruments replaced include both stressmeters in Test Room 2 and the extensometers in the floor of Test Rooms 1, 2 and 3. The history of instrument performance and maintenance is discussed in the GFDRs.

Figure 11-2 shows the instruments in each test room and the excavation dates at the instrument locations. Because the excavation of each test room required about 10 days to complete, it was difficult to assign a single date of excavation for some instrument locations. Table 11-5 presents the dates of excavation used for plotting and analysis of the test room data.

11.3.2 Analysis and Evaluation

This section discusses the analysis and evaluation of the results of



ALL COORDINATES BASED ON DISTANCE FROM C.B Sh SHAFT ℄

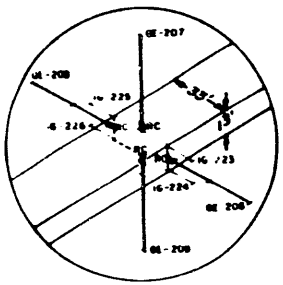
(FOR DETAILS 1,2,3,4)

EXPLANATION

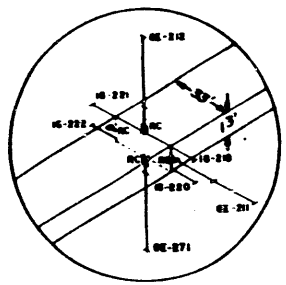
- IG INCLINOMETER
- CE CONVERGENCE METER
- COLLAR
- GE EXTENSOMETER
- RC RADIAL CONVERGENCE POINT
- SG STRESSMETER (HOOD INCLUSION)

NOTE:

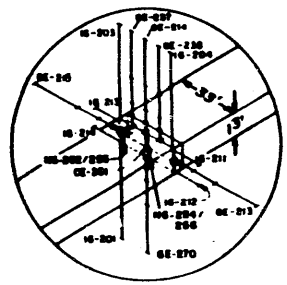
1. EXTENSOMETERS GE-269, GE-270 AND GE 271 REPLACED GE-220, GE-218 AND GE-219, RESPECTIVELY.



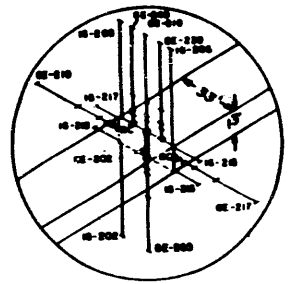
ROOM 4
INSTRUMENTATION LOCATION
DETAIL 4



ROOM 3
INSTRUMENTATION LOCATION
DETAIL 3



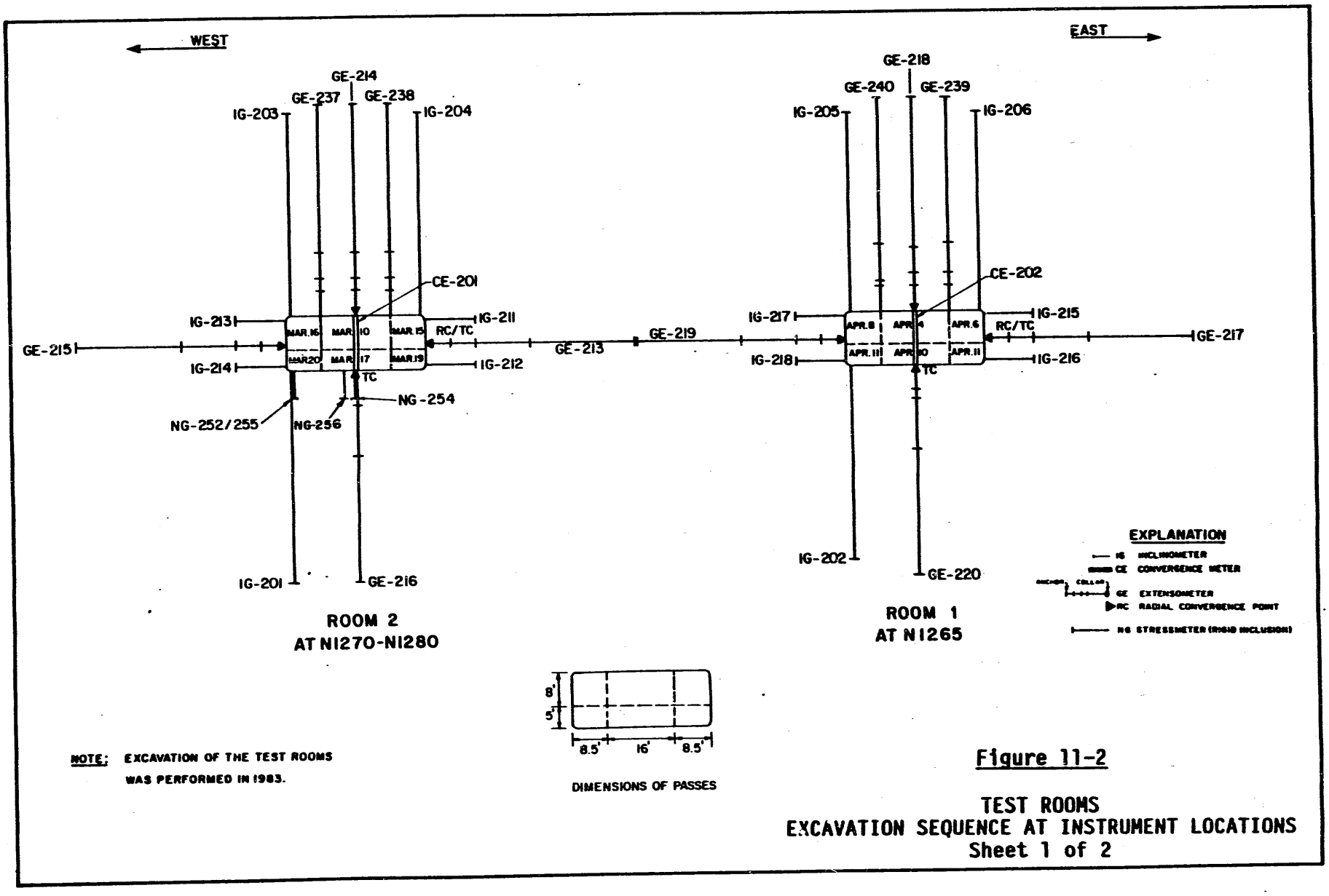
ROOM 2
INSTRUMENTATION LOCATION
DETAIL 2



ROOM 1
INSTRUMENTATION LOCATION
DETAIL 1

Figure 11-1

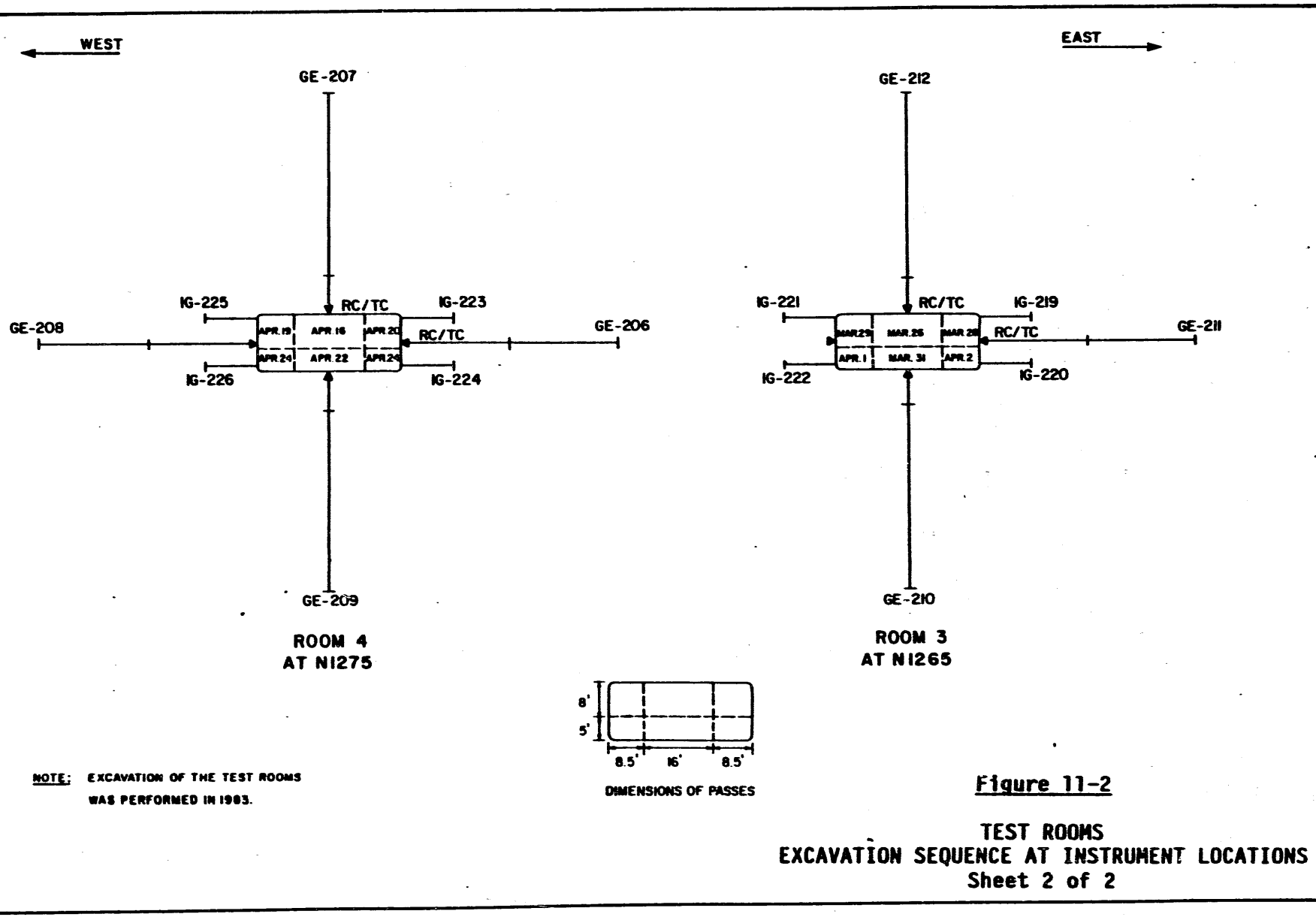
TEST ROOMS INSTRUMENTATION



NOTE: EXCAVATION OF THE TEST ROOMS WAS PERFORMED IN 1983.

Figure 11-2

TEST ROOMS
EXCAVATION SEQUENCE AT INSTRUMENT LOCATIONS
Sheet 1 of 2



NOTE: EXCAVATION OF THE TEST ROOMS WAS PERFORMED IN 1983.

Figure 11-2

TEST ROOMS
EXCAVATION SEQUENCE AT INSTRUMENT LOCATIONS
Sheet 2 of 2

Table 11-5

TEST ROOMS
ASSUMED EXCAVATION DATES FOR DATA ANALYSIS

Type of Instrument/Location	Instrument Designation	Assumed Date of Excavation Room 1	Room 2	Room 3	Room 4	Basis for Selection
Convergence meters	51X-CE-00202 51X-CE-00201	Apr. 7, 1983	Mar. 13, 1983			Average of dates for upper and lower center passes.
Roof extensometers - center	51X-GE-00218 51X-GE-00214 51X-GE-00212 51X-GE-00207	Apr. 4, 1983	Mar. 10, 1983	Mar. 26, 1983	Apr. 16, 1983	Date for upper center pass.
Floor extensometers - center	51X-GE-00220 51X-GE-00216 51X-GE-00210 51X-GE-00209	Apr. 10, 1983	Mar. 17, 1983	Mar. 31, 1983	Apr. 22, 1983	Date for lower center pass.
Roof extensometers - east side	51X-GE-00239 51X-GE-00238	Apr. 5, 1983	Mar. 13, 1983			Average of dates for upper center and upper east passes.
Roof extensometers - west side	51X-GE-00240 51X-GE-00237	Apr. 6, 1983	Mar. 13, 1983			Average of dates for upper center and upper west passes.
Wall extensometers - east side	51X-GE-00217 51X-GE-00213 51X-GE-00211 51X-GE-00206	Apr. 6, 1983	Mar. 15, 1983	Mar. 28, 1983	Apr. 20, 1983	Date for upper east pass.
Wall extensometers - west side	51X-GE-00219 51X-GE-00215 51X-GE-00208	Apr. 8, 1983	Mar. 16, 1983		Apr. 19, 1983	Date for upper west pass.

Table 11-5 (continued)

TEST ROOMS
ASSUMED EXCAVATION DATES FOR DATA ANALYSIS

Type of Instrument/Location	Instrument Designation	Assumed Date of Excavation Room 1	Room 2	Room 3	Room 4	Basis for Selection
Wall shortening points - east side	IG 215-216 RS IG 211-212 RS IG 219-220 RS IG 223-224 RS	Apr. 8, 1983	Mar. 17, 1983	Mar. 30, 1983	Apr. 22, 1983	Average of dates for upper and lower east passes.
Wall shortening points - west side	IG 217-218 RS IG 213-214 RS IG 221-222 RS IG 225-226 RS	Apr. 9, 1983	Mar. 18, 1983	Mar. 30, 1983	Apr. 21, 1983	Average of dates for upper and lower west passes.
Wall-to-Wall convergence points - near roof	IG 211-213 TC IG 219-221 TC		Mar. 15, 1983	Mar. 28, 1983		Average of dates for upper east and west passes.
Wall-to-Wall convergence points - near floor	IG 212-214 TC IG 220-222 TC		Mar. 19, 1983	Apr. 1, 1983.		Average of dates for lower east and west passes.
Wall-to-Wall permanent convergence points - center	Room 1 RC Room 2 RC Room 3 RC Room 4 RC	Apr. 7, 1983	Mar. 15, 1983	Mar. 29, 1983	Apr. 19, 1983	Average of dates for upper east and west passes.
Roof-to-Floor permanent convergence points - center	Room 3 RC Room 4 RC			Mar. 28,1983	Apr. 19, 1983	Average of dates for upper and lower center passes.

Table 11-5 (continued)

TEST ROOMS
ASSUMED EXCAVATION DATES FOR DATA ANALYSIS

Type of Instrument/Location	Instrument Designation	Assumed Date of Excavation				Basis for Selection
		Room 1	Room 2	Room 3	Room 4	
Wall-to-Wall temporary convergence points - center	Room 1 TC Room 2 TC Room 3 TC Room 4 TC	Apr. 7, 1983	Mar. 15 1983	Mar. 29, 1983	Apr. 19, 1983	Average of dates for upper east and west passes.
Roof-to-Floor temporary convergence points - center	Room 1 TC Room 2 TC Room 3 TC Room 4 TC	Apr. 7, 1983	Mar. 13, 1983	Mar. 28, 1983	Apr. 19, 1983	Average of dates for upper and lower center passes.
Floor stressmeters - west corner	51X-NG-00252 51X-NG-00255		Mar. 20, 1983 Mar. 20, 1983			Date for lower west pass. Date for lower west pass.
Floor stressmeters - center	51X-NG-00254 51X-NG-00256		Mar. 17, 1983 Mar. 17, 1983			Date for lower center pass. Date for lower center pass.

Notes:

(1) The "Elapsed Days Since Excavation" shown on the data plots in Appendix J were calculated using this "Assumed Date of Excavation".

(2) See Figure 11-2 for the excavation sequence at the center of the test rooms.

(3) The dates of excavation for individual inclinometers were not used for plotting.

field observations and in situ measurement data. The results of numerical modeling of the test rooms using in situ measurement data are also presented. In addition, regression analyses of the closure rate obtained from the closure measurements were also performed. The fitted equations were used to supplement the prediction of closure behavior in the storage rooms and are discussed in Chapter 12.

11.3.2.1 Observed Conditions

Roof and Wall Spalling. Minor spalling from the roof in the test rooms, resulting in shallow drummy areas, has occurred as expected. Drummy areas usually occur within 3 to 6 inches of the roof in areas of clear halite not associated with any noticeable clay. Separations occur along local planes of weakness in the halite, probably created by the orientation of crystal surfaces. This same phenomenon occurs in the drifts. Drummy areas have been identified immediately after excavation and additional areas have developed since that time. These later-occurring drummy areas appear to develop primarily along the roof within several feet of the walls.

Spalling along the walls of the test rooms is a result of local stress concentrations and the low tensile properties of salt. It is also related to the percentage of argillaceous material in the halite and to the proximity of floor and roof intersections. The squeezing of clay F at the upper contact of geologic map unit 4 is associated with the spalling phenomenon. Minor spalling is also associated with map unit O, near the floor.

Pillar Fracturing. Vertical fracturing in the pillars is the expected result of room deformation and stress concentrations. The fractures that have developed in the walls of the test rooms, parallel to the rooms, are considered to be tension fractures resulting from stress relief. Fractures detected in boreholes drilled in the upper portion of geologic map unit 4 are related to the spalling occurring in this unit.

Horizontal inclinometers in the test room walls show both upward and downward vertical movement toward the center of the wall (Appendix J, Figures J-320 through J-335). Although no displacements have been observed, the inclinometer data indicate that the salt has moved toward the central horizontal axis of the room. This movement, due to vertical compressive stress and salt creep, is discussed further in subsection 11.3.2.2. Tensile stresses resulting from this salt creep and pillar shortening have caused fractures to lengthen and widen and new fractures to develop. Fracturing is more prominent at pillar corners that were not beveled to the 4 x 4-foot design.

Fracturing parallel to the room walls will continue to occur. Spalling and local failure will also continue at pillar corners and will require periodic maintenance.

Roof Displacements and Separations. The displacements observed in various open boreholes in the test room roofs are the result of deformation around the openings. The halite at the storage horizon is interrupted by anhydrite beds and thin clay layers. These layers, particularly anhydrite "b" and the underlying clay G, are directly associated with the displacements observed in the test room roofs.

Lateral displacement in the salt above the test rooms is similar to that detected above the drifts. The halite bounded by the roof and clay G moves toward the room center relative to the upper layers of salt. The movement is, however, not exactly symmetrical about the room centerline. This is confirmed by inclinometer readings in the roof of Test Rooms 1 and 2 which show that the lateral movement of the salt close to the roof is greater to the west than to the east (Appendix J, Figures J-316 through J-319). However, this trend is reversed at about 32 feet above the roof of the test rooms. The halite comprising the lower roof beam is subjected to horizontal compressive stresses resulting in shear along clay G and possible vertical separation as the beam moves downward. Some casing deformations have also been observed within 1 foot of the hole collar of the roof inclinometers. The

relative movement here is opposite to that observed above and is probably due to the near surface halite resisting the shear movement along clay G.

Movement within the halite below clay G, opposite to that found elsewhere, has been observed in one borehole in Test Room 4. This may be the result of movement along existing planes of weakness in the halite or of the resistance of the halite to shear movement along clay G.

The current results of the Excavation Effects Program indicate that minimal separation or fracturing has occurred at clay G or in the underlying halite above the test room roofs. In Test Rooms 3 and 4, separations less than 1/16 inch wide have been observed. No separation has been observed at clay G. In the array of holes comprising Section 5 in Table 11-2, above the 36-inch diameter holes in the floor of Test Room 3 (Room T), no separations or fracturing were detected. In hole C of Section 4 in Test Room 3, two 1/4-inch vertical separations were found within 1 foot of the roof. These fractures resulted from roof spalling.

Similar small separations were observed in the roof of Test Rooms 1 and 2. Also, fracture zones (in one case 2.4 inches wide) were detected in the halite below clay G in the center hole of three of the four arrays.

Floor Displacements, Separations and Fracturing. The only prominant display of fracturing observed throughout the entire WIPP underground facility during design validation has been in the area of the 36-inch diameter holes drilled in the floor in the south half of Test Room 3 (Room T). Cross sections of the room floor through these holes are presented in Appendix G, Figures G-33 and G-34. Two distinct fracture zones are evident. The first is a dish-shaped zone that angles 10 to 20 degrees downward from near the room walls, intersects MB-139, and flattens near the room center. This zone is most pronounced along the series of holes shown on Figure G-34. In the

northern cross section (Figure G-33), this fracture zone is evident in the holes west of the room centerline but is not present in the holes east of the centerline. In both sections, this upper fracture zone "daylights" at the floor surface or pinches out before reaching the room pillars.

A second fracture zone, dipping approximately 50 to 60 degrees from horizontal and exposed in the holes closest to the room walls, occurs below the upper fracture zone. This lower zone is more regular and planar than the upper zone. With the exception of one hole, this lower zone occurs entirely within MB-139 and is more developed on the west side of the room.

In addition to the two major fracture zones, some subhorizontal fracturing is present just above clay E at the base of MB-139. This fracturing is most evident in the holes closest to the room centerline. No separations along clay E were observed in any of the holes.

Communication between holes during drilling was observed and is described in Table 11-3. During the drilling of hole TV-03, drilling dust was observed coming up through a surface fracture close to the east wall, 25 feet south of the hole location.

A series of measuring pins were installed in two open holes, TV-03 and TV-19, in late January 1986 to monitor movements within the holes. The pins were installed in MB-139 and in the overlying halite and straddle the fracture zones. Measurements taken until the holes became inaccessible in June 1986 indicated that some small-scale dilation was occurring in both of the holes.

The fractures observed beneath the floor of Test Room 3 are directly related to the excavation geometry and the stratigraphy. Some fractures within MB-139 may have been pre-existing but have opened since room excavation.

Three 4-inch diameter holes were drilled in the north half of Test Room 3 to determine if fracturing is occuring there. These holes were drilled to a nominal depth of 12 feet below the floor. A thin fracture zone was detected within 1 1/2 feet of the floor in two of the holes and minor fracturing was detected in MB-139 in all of the holes. This fracturing is significantly less developed than that observed in the south half of Test Room 3.

The 22 large-diameter holes in Test Room 3 were drilled late in 1985. They are, therefore, too recent to document any lateral displacements along the observed fractures. However, other older floor boreholes do indicate relative displacement. In Test Room 4, boreholes P4X-06, P4X-25, P4X-27, P4X-29 and P4X-31 all show multiple displacements and vertical separations (Table 11-2). These are primarily within MB-139 and exhibit up to 2 inches of lateral displacement and up to 1/2 inch of vertical separation. These five holes are near the room centerline. The relative movement of the multiple displacements observed is complicated and does not follow the simpler interpretation of the roof displacements. The most significant displacements in all of the holes have taken place closest to the floor surface and, in all cases, the salt above the fracture has moved east relative to the underlying salt. Inclinometers IG-202 and IG-201, in Test Rooms 1 and 2, also exhibit similar relative displacement. Both of these inclinometers are on the west side of their respective test rooms. The marker bed and the overlying salt have moved east towards the room centerline relative to the underlying salt. Movement is apparently along clay E and is approximately 3/4 inch.

Although no detailed investigation of the salt beneath the test room pillars has been performed, the Test Room 3 fracture mapping indicates that it is unlikely that fractures extend beneath them to any significant extent. Neither of the two fracture zones identified can be traced into the pillars. The upper fracture zone pinches out prior to reaching the walls or daylights at the floor surface. The lower fracture zone cannot be traced beyond the hole walls, but it is not

suspected of continuing beneath the pillars. One small diameter hole was drilled at an angle into each of the walls of Test Room 3 in May 1986. Except for a localized clay break at a depth of 3.2 feet, there was no evidence of separation.

Fractures and separations have been observed in four large-diameter holes drilled in the floor in the south end of Test Room 4. Fractures were observed in these holes during drilling in November 1983 and January 1984. The fracturing was minor, however, with no separations observed. One hole became inaccessible soon thereafter. Fractures in the other holes have been observed to increase in number and to exhibit separation (Table 11-2). Fractures occur in the marker bed and in the overlying halite. Because two of the holes have restricted access, monitoring of the fractures is difficult. Borehole P4X-84, in the southwest corner of Test Room 4, was mapped in February 1986 and the results are shown in Appendix G, Figure G-32. The separations and displacements in P4X-84 over the 2 year period since excavation are small in comparison to those in the floor holes in the south half of Test Room 3.

A low-angle fracture in the floor of Test Room 2 was observed in August 1985. An inspection in June 1986 showed that it extended from approximately N1242 to N1208. This fracture daylights at the floor surface, 1.5 feet to 6 feet from the west wall, and extends 2 feet below the floor surface toward the east. Approximately 8 to 10 inches of separation is present along this fracture, and approximately 25 square feet of floor in the vicinity of this fracture sounds drummy.

As part of the Excavation Effects Program, a series of holes were drilled in each of the test rooms to determine the extent of floor fracturing and for future monitoring of this phenomenon. Existing boreholes, such as those in Test Rooms 3 and 4, were utilized where possible. The locations of the holes are shown on Figure 10-1 in Chapter 10. These holes were inspected using a probe and the results are summarized in Table 11-2. The holes exhibited some fractures and

separations. The dish-shaped fracture profile observed in the holes in Test Room 3 was also found in some of the hole arrays, although on a much smaller scale. It was most pronounced in several of the holes close to the room walls where separations were estimated to be a maximum of 6 inches. In other locations, the separation ranged from 1/8 inch to 3 inches. Within MB-139, fractures and separations found in the central holes of the Test Room 1 array ranged from approximately 1/8 inch to 3 inches. For other hole arrays, the maximum separations were 1/2 inch and, again, these were found in the central holes.

Horizontal displacements and vertical separations have been observed in various small-diameter boreholes in the test room floors. Horizontal displacements up to 2 1/2 inches and vertical separations estimated to be up to 1/2 inch wide were present in some of these holes. Multiple displacements in single boreholes were also present. The horizontal displacements and vertical separations found in many of the holes are within MB-139 or coincide with the lower contact of this unit. These displacements and separations have developed since room excavation, although some of them may have developed along pre-existing planes of weakness in the marker bed.

In addition to observations made in open boreholes, ground-penetrating radar and gas permeability testing have been conducted in some of the test rooms. A radar survey was conducted in Test Rooms 2 and 3. The radar method has some limitations. It appears to be effective in locating the first reflector such as a fracture or clay seam beneath the floor, but the structure below this is not easily distinguished. MB-139 is readily defined on the records but fractures within it cannot be discerned.

Zones of relatively high permeability have been found to develop immediately beneath the floor of the test rooms and beneath the intersections of Test Rooms 1 and 2 with the N1420 drift. There also appears to be a slight increase in permeability, relative to background values, within MB-139 and immediately beneath the floor of the N1420

drift between Test Rooms 1 and 2. Some increase in permeability also appears to occur in MB-139 near the center of the pillar between Test Rooms 2 and 3. This data is only preliminary, however, because only one hole intersecting MB-139 beneath the pillar has been drilled and tested for permeability.

Gas tracer measurements performed along the centerline in the north half of Test Room 2 and across the N1420 drift to Room L2 indicate the existence of fracturing beneath the floor. A video survey of the boreholes used for the tracer tests shows the presence of fracture zones and separations mainly within MB-139. Holes tested along the N1420 drift, except at intersections, show little increase in background permeability. A video survey of these holes did not show any separations or fracturing.

In summary, subhorizontal fracturing has developed beneath the test room floors. The majority of this fracturing occurs as single fractures or thin fracture zones within MB-139 and the overlying halite. Horizontal displacements ranging up to 2 inches and separations generally ranging up to 1/2 inch have been measured in small diameter boreholes. Separations up to 6 inches have been observed locally. Only the south half of Test Room 3 (Room T) in the WIPP underground facility has exhibited extensive fracturing beneath the floor.

The Excavation Effects Program was designed in part to determine if fracturing similar to that occurring beneath the floor of Test Room 3 has developed in other areas of the facility. The results of this program show that, although small-scale fracturing is occurring beneath all of the test rooms, no other areas of fracturing have developed on the same order of magnitude as that in Test Room 3. The fracturing occurring beneath the floor of Test Room 3 appears to have existed prior to drilling. The stress changes induced by the size and number of holes drilled in this area probably exacerbated the existing fractures.

11.3.2.2 Closure

Roof-to-Floor Closure. Figure 11-3 shows the relationship between measured roof-to-floor closure and the elapsed time since excavation of the four test rooms, as determined from convergence meter and convergence point data. Because of differences in time-lag between the end of excavation and the time of the initial readings, the relative positions of these curves are deceptive. For analysis purposes, the roof-to-floor closure that occurred before installation of the convergence instruments was determined using equation 10-1 in Chapter 10.

In addition, part of the measurement data from the temporary convergence points were added to the permanent convergence instrument data to obtain approximate values of the actual roof-to-floor closure. Table 11-6 shows roof-to-floor convergence point readings and adjusted closure magnitudes for the test rooms. Item 7 in this table shows the approximate roof-to-floor closure obtained by adding suitable portions of the temporary convergence point readings to the readings of the permanent convergence instruments.

It is apparent that the fracturing observed in the floor of the test rooms, and vertical separations in the roof, have contributed to the total roof-to-floor closure. However, based on measured cumulative vertical separations in September 1985, the contribution of floor fracturing to the total roof-to-floor closure is not more than 1 inch.

The total estimated closure (item 9 in Table 11-6) includes the values of early closure estimated by using equation 10-1 in Chapter 10. Based on the indicated additive values, the maximum roof-to-floor closure of approximately 16 1/2 inches through June 1986 occurs in Test Rooms 2 and 3. Test Room 4 has undergone the least roof-to-floor closure. Figure 11-4 shows the adjusted roof-to-floor closure values as a function of time.

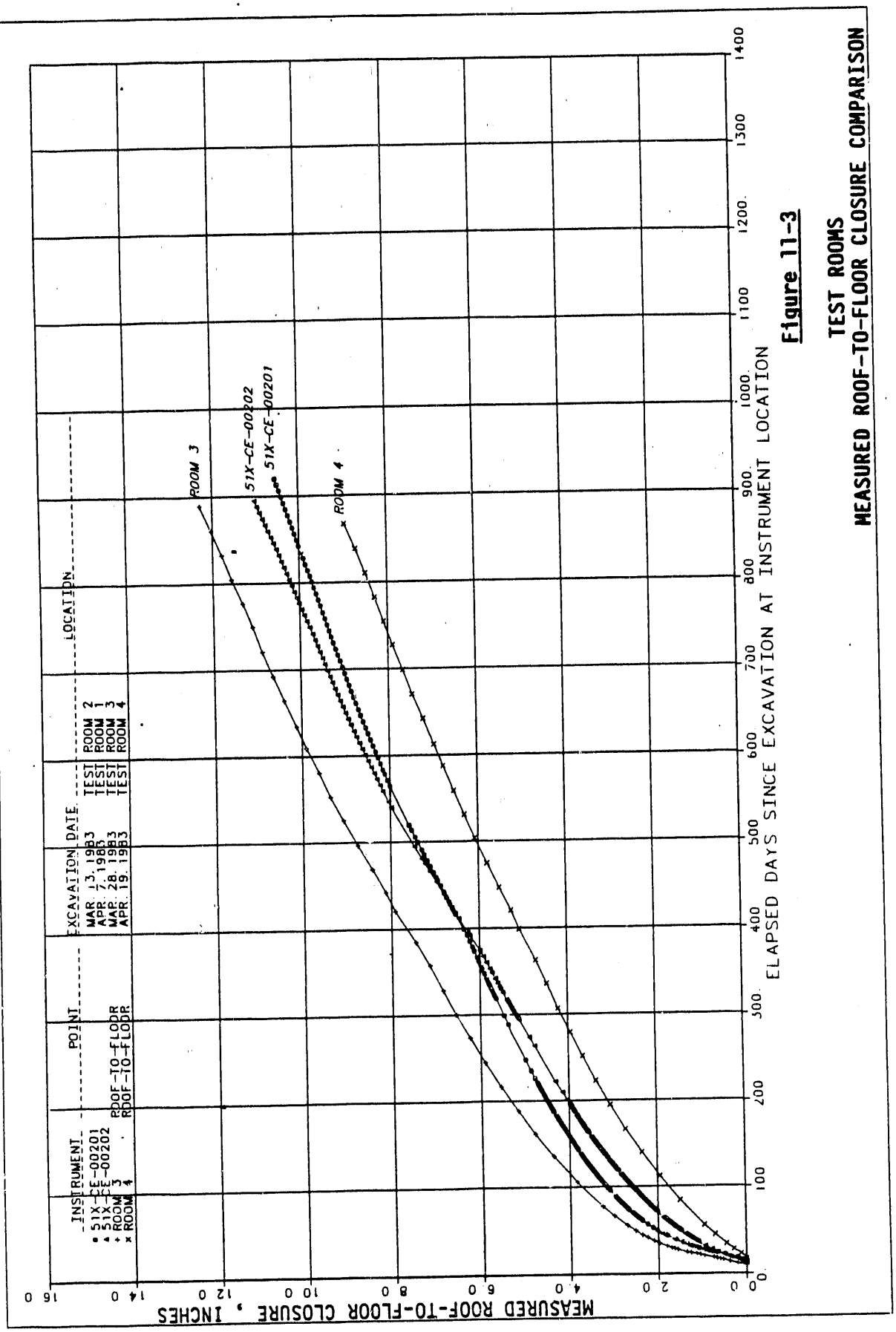

TEST ROOMS
MEASURED ROOF-TO-FLOOR CLOSURE COMPARISON
MEASURED ROOF-TO-FLOOR CLOSURE , INCHES
ELAPSED DAYS SINCE EXCAVATION AT INSTRUMENT LOCATION
INSTRUMENT
51X-CE-00201
51X-CE-00202
ROOM 3
ROOM 4
POINT
ROOF-TO-FLOOR
ROOF-TO-FLOOR
EXCAVATION DATE
MAR. 13, 1983
APR. 7, 1983
MAR. 28, 1983
APR. 19, 1983
LOCATION
TEST ROOM 2
TEST ROOM 1
TEST ROOM 3
TEST ROOM 4
ROOM 3
51X-CE-00202
51X-CE-00201
ROOM 4

Figure 11-3

Table 11-6

TEST ROOMS
ROOF-TO-FLOOR CLOSURE COMPARISONS

Description	Test Room 1	2	3	4
(1) Excavation period	April 3-13 1983	March 9-20 1983	March 24-April 3 1983	April 15-25 1983
(2) Date of first reading of temporary convergence (TC) points	April 12, 1983	March 21, 1983	April 4, 1983	April 26, 1983
(3) Date of first reading of permanent convergence (RC and CE) instruments	April 20, 1983	March 29, 1983	April 7, 1983	May 6, 1983
(4) Reading of TC points (inches) on date indicated	0.84 April 20, 1983	0.88 March 28, 1983	0.40 April 7, 1983	0.45 May 5, 1983
(5) Reading of RC and CE instruments (inches) on date indicated	13.11 June 13, 1986	12.20 June 13, 1986	13.83 April 28, 1986	10.62 April 28, 1985
(6) Total elapsed days of combined TC and RC measurements [Date for (5) - Date for (2)]	1157	1179	1120	1098
(7) Total measured closure (inches) [(4) + (5)]	13.95	13.08	14.23	11.07
(8) Estimated closure (inches) by regression analysis for the period of (2) - (1)	2.39	3.72	2.17	1.32
(9) Total estimated closure (inches) [(7) + (8)]	16.34	16.80	16.40	12.39

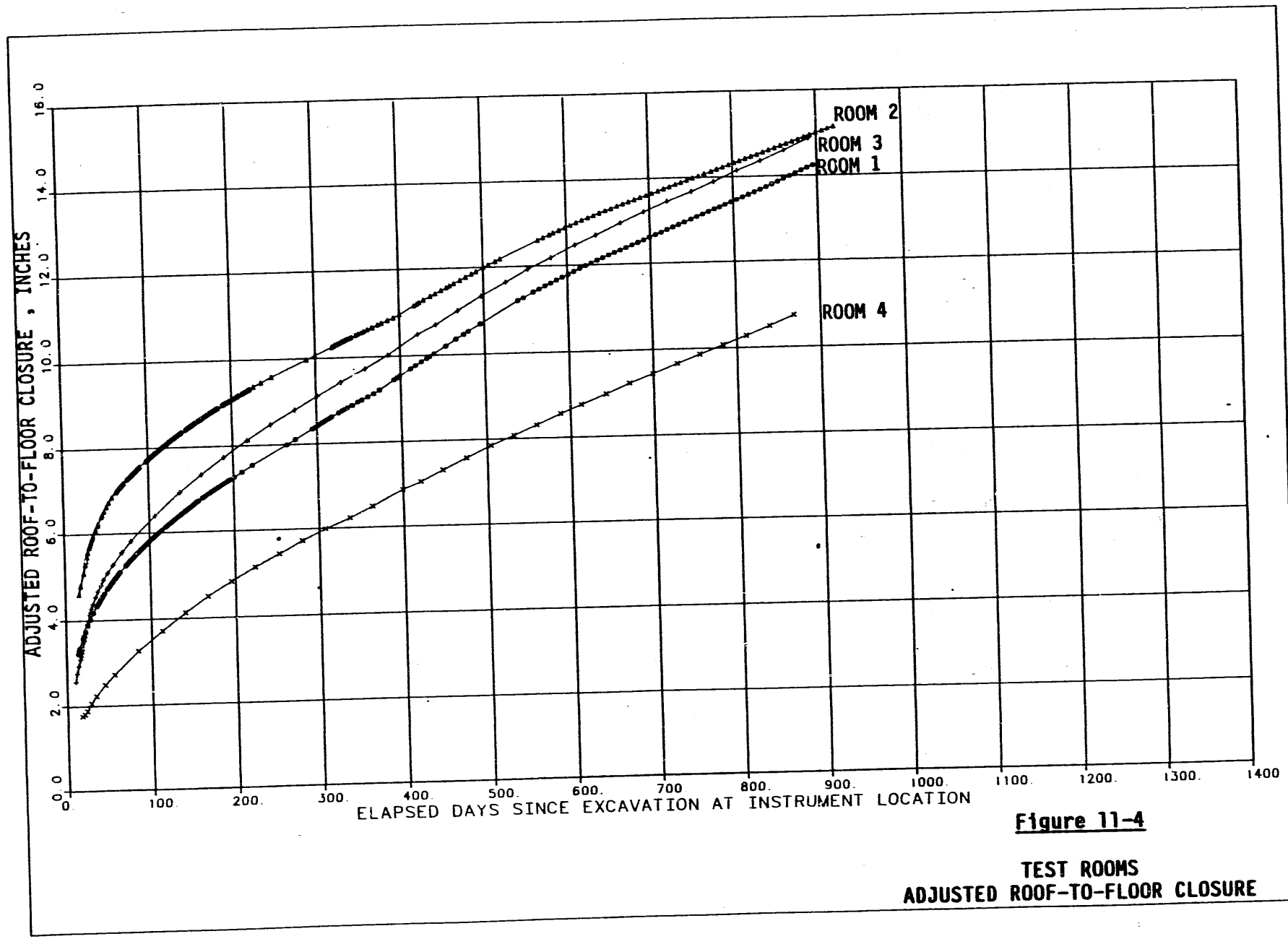


Figure 11-4

TEST ROOMS
ADJUSTED ROOF-TO-FLOOR CLOSURE

Figure 11-4 shows that the closure rate generally decreases with time, except for occasional increases due to disturbances from nearby excavations. Provided there are no additional perturbations in and around the test rooms, it is likely that the rate of closure will reach a steady state value. It is possible to get an estimate of the rate of closure using either a phenomenological rheological model or an empirical model that is essentially a curve-fitting procedure. Both methods have been attempted. Numerical methods using the phenomenological approach are discussed in Chapter 5.

Closure rates rather than measured closure are used in the empirical approach because measured closure is not absolute. Early closure measurements are not available because the instruments could not be installed immediately after excavation. However, the calculation of closure rates is not affected by the lack of early measurements. The closure rates are calculated by assuming a linear relationship between closure and elapsed time over a short interval. This time interval has been arbitrarily chosen as a minimum of 7 days.

Because it is expected that the closure rate will initially be relatively high and then decrease to a steady rate, the following equation was used:

$$C(t) = \frac{A}{t^n} + C_c(1 - e^{-at}) \qquad (11\text{-}1)$$

where: $C(t)$ is the closure rate at elapsed time t after excavation;
A, a and n are constants which depend upon the deformation characteristics of the salt, initial stress regime and dimensions of the opening; and
C_c is the steady state closure rate.

The value of C(t) is obtained by arbitrarily choosing a time interval of not less than 7 days. If R_i is the closure reading at calendar time t_i and R_{i+1} is the closure reading at t_{i+1}, then

$$C(t) = \frac{R_{i+1} - R_i}{\Delta t} \qquad (11\text{-}2)$$

where: $\Delta t = (t_{i+1} - t_i) \quad \geq 7$ days (11-3)

The value of t is defined as:

$$t = \frac{t_i + t_{i+1}}{2} \qquad (11\text{-}4)$$

A regression analysis, which is the fitting of an equation like 11-1 to the set of [C(t),t] data points, was performed using NLIN, a commercially available statistical software package (ref. 11-1). The general method used to estimate the constants, herein called the regression parameters, was to minimize the sum of the squares of the differences between the actual measured values and the values predicted by the proposed equation.

Equation 11-1, a nonlinear equation, cannot be converted into linear form. The statistical software NLIN employs iterative methods that attempt to find least-square estimates for nonlinear models. The methods commonly employed are the Gauss-Newton technique and the Marquardt compromise technique (ref. 11-2). However, the requisite partial derivatives of the equation with respect to the parameters must be specified. In many cases, the Marquardt compromise, which is considered to work well in many circumstances, gives a better estimate and provides quicker convergence of the values of the regression parameters. However, nonlinear regression analyses may not always result in good estimates of the regression parameters. In addition, the analysis tacitly assumes that the regressor variables are measured without error. Thus, the observations, which in this case are the values of C(t), were not weighted.

Figure 11-5 compares the roof-to-floor closure rates for Test Room 1 calculated by equation 11-1 to the values calculated using the fitted equation 11-2. The data used was obtained during the first year following the completion of excavation. The regression analysis showed that, for all practical purposes, equation 11-1 could be simplified as

$$C(t) = \frac{A}{t^n} + C_c \qquad (11\text{-}5)$$

because the value of 'a' obtained from the regression analysis was large enough to make the term e^{-at} comparatively negligible. The fitted equation for the roof-to-floor closure data in Test Room 1 has the form

$$C(t) = \frac{206.58}{t^{0.84}} + 2.24(1-e^{-5.27t}) \text{ inches/year} \qquad (11\text{-}6)$$

where: t is the elapsed time in days since excavation.

However, as shown by equation 11-5, equation 11-6 can be approximated as

$$C(t) = \frac{206.58}{t^{0.84}} + 2.24 \text{ inches/year} \qquad (11\text{-}7)$$

The method used was the Marquardt compromise technique. The coefficient of determination is 0.99.

The analysis was repeated later using roof-to-floor closure data at 980 days (2.68 years) after the completion of excavation. The regression equation was

$$C(t) = \frac{211.16}{t^{0.85}} + 2.44 \text{ inches/year} \qquad (11\text{-}8)$$

The steady state closure rate determined using the first year of data only is 9 percent less than the rate determined by using 2.68 years of

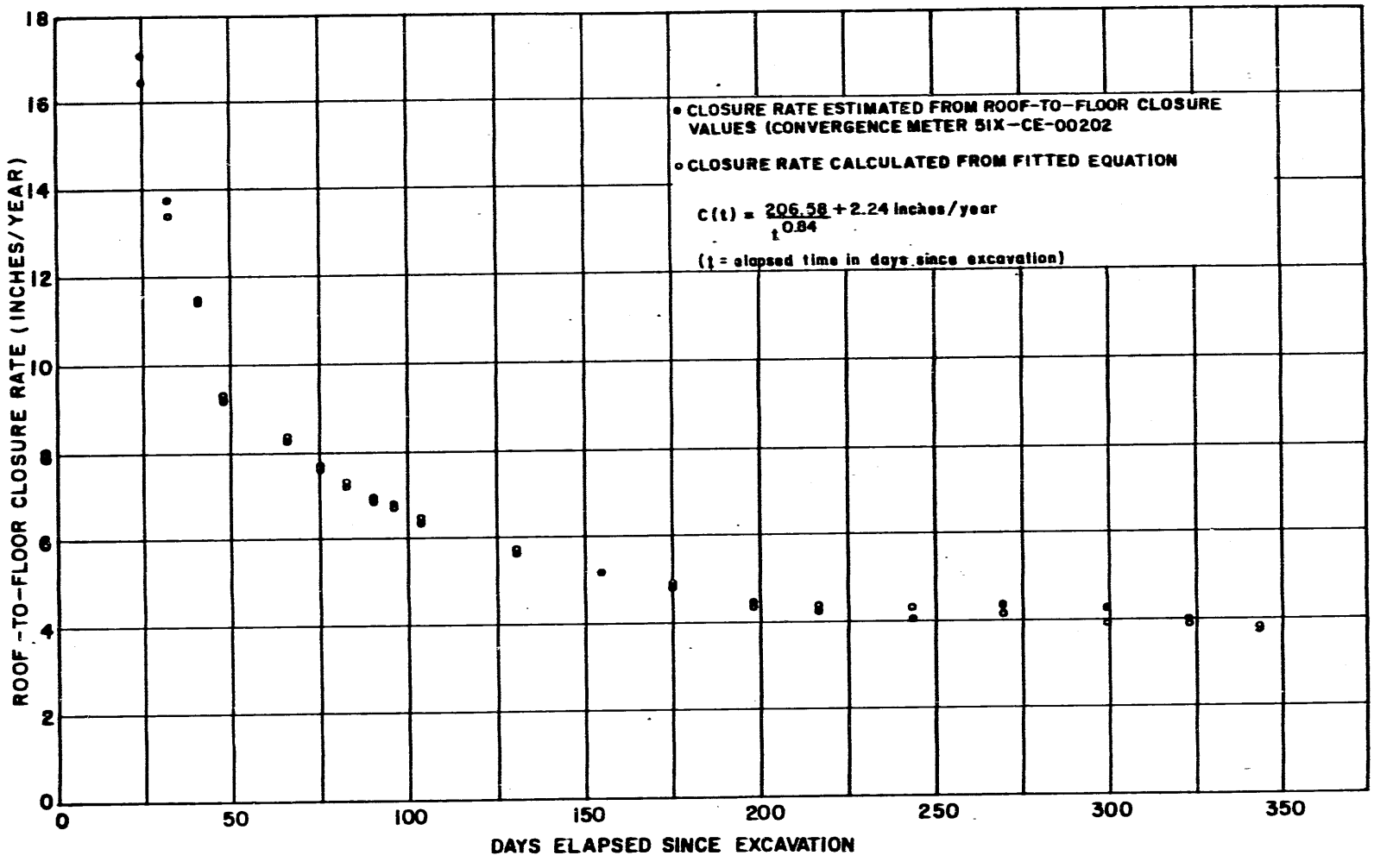


Figure 11-5

TEST ROOM 1
REGRESSION ANALYSIS OF ROOF-TO-FLOOR CLOSURE

data. A third analysis, using 3 years of measurement data, up to June 1986, gave

$$C(t) = \frac{208}{t^{0.85}} + 2.40 \text{ inches/year} \qquad (11\text{-}9)$$

Equations 11-7, 11-8 and 11-9 show the consistency of the regression parameters for different input data sets.

Figure 11-6 shows the predicted roof-to-floor closure rate for Test Room 1 as a function of elapsed time in years using equation 11-9. Based on equation 11-7, the roof-to-floor closure rate at the end of 25 years is expected to be approximately 2.34 inches/year. Using equation 11-8, it will be 2.53 inches/year or 2.49 inches/year using equation 11-9.

Figures 11-7 through 11-10 show the fitted curves based on roof-to-floor closure rates calculated from equation 11-2, using data up to June 1986. To get an approximate idea of the roof-to-floor closure for periods of time greater than 1 year since the completion of excavation, equation 11-7 was integrated with respect to time between the limits of 1 year and time t_2 (in years) to yield

$$R(t) = 0.78(t_2^{0.147} - 1) + 0.20(t_2 - 1) \qquad (11\text{-}10)$$

Figure 11-11 shows the predicted roof-to-floor closure in feet for Test Room 1 (excluding that which has occurred in the first year after excavation) as a function of time in years. According to this prediction, 25 years after excavation this value will be 5.34 feet. A similar analysis using equation 11-9 gave a value of 5.3 feet.

Table 11-7 is a summary of the results of the nonlinear regression analyses for the roof-to-floor closure rates in the test rooms using 3 years of measurement data. The parameters contained in this table are applicable for an elapsed time expressed in years. For Test Room 4, the regression analysis using only the permanent convergence point data did not produce satisfactory results. The analysis was

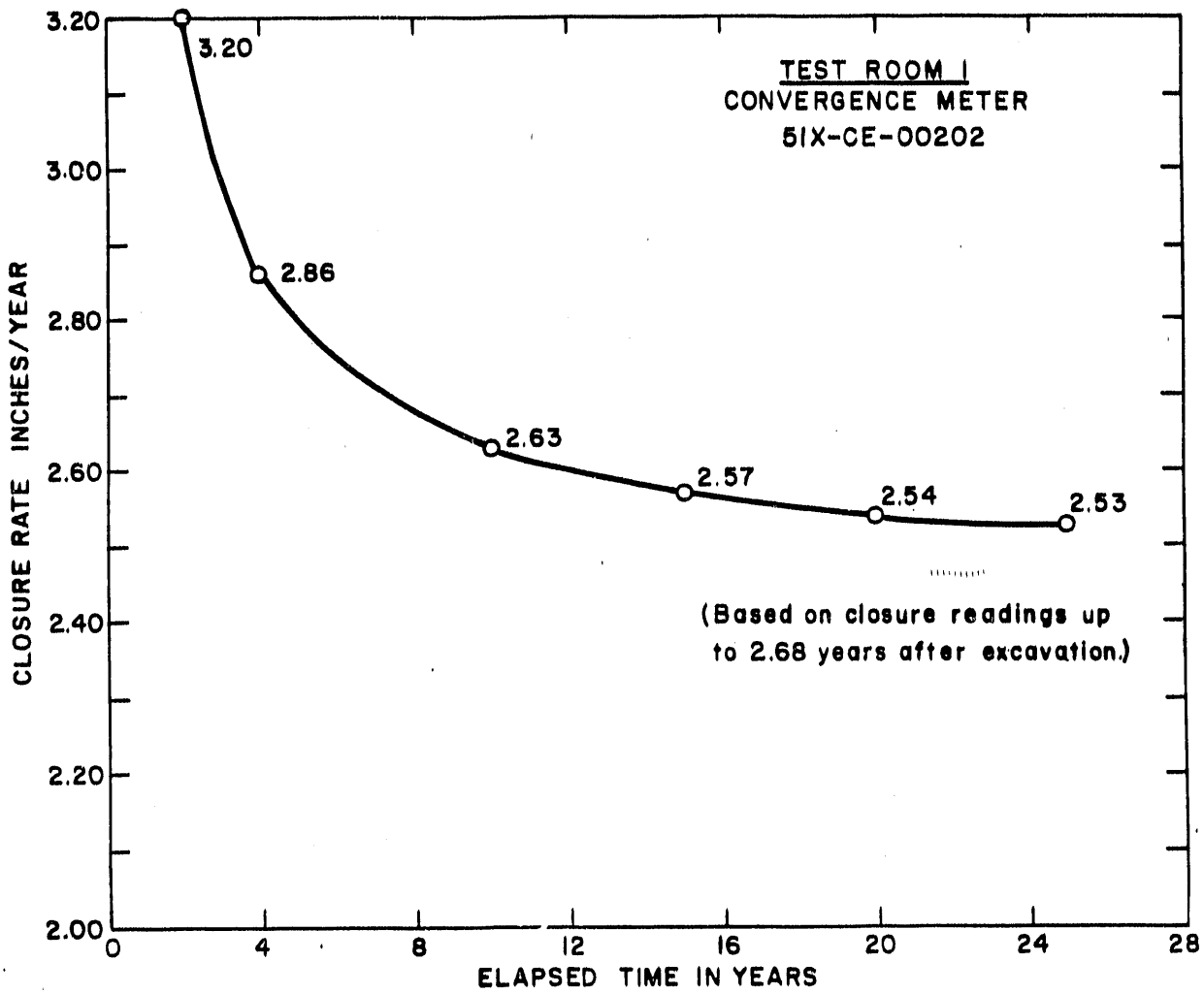
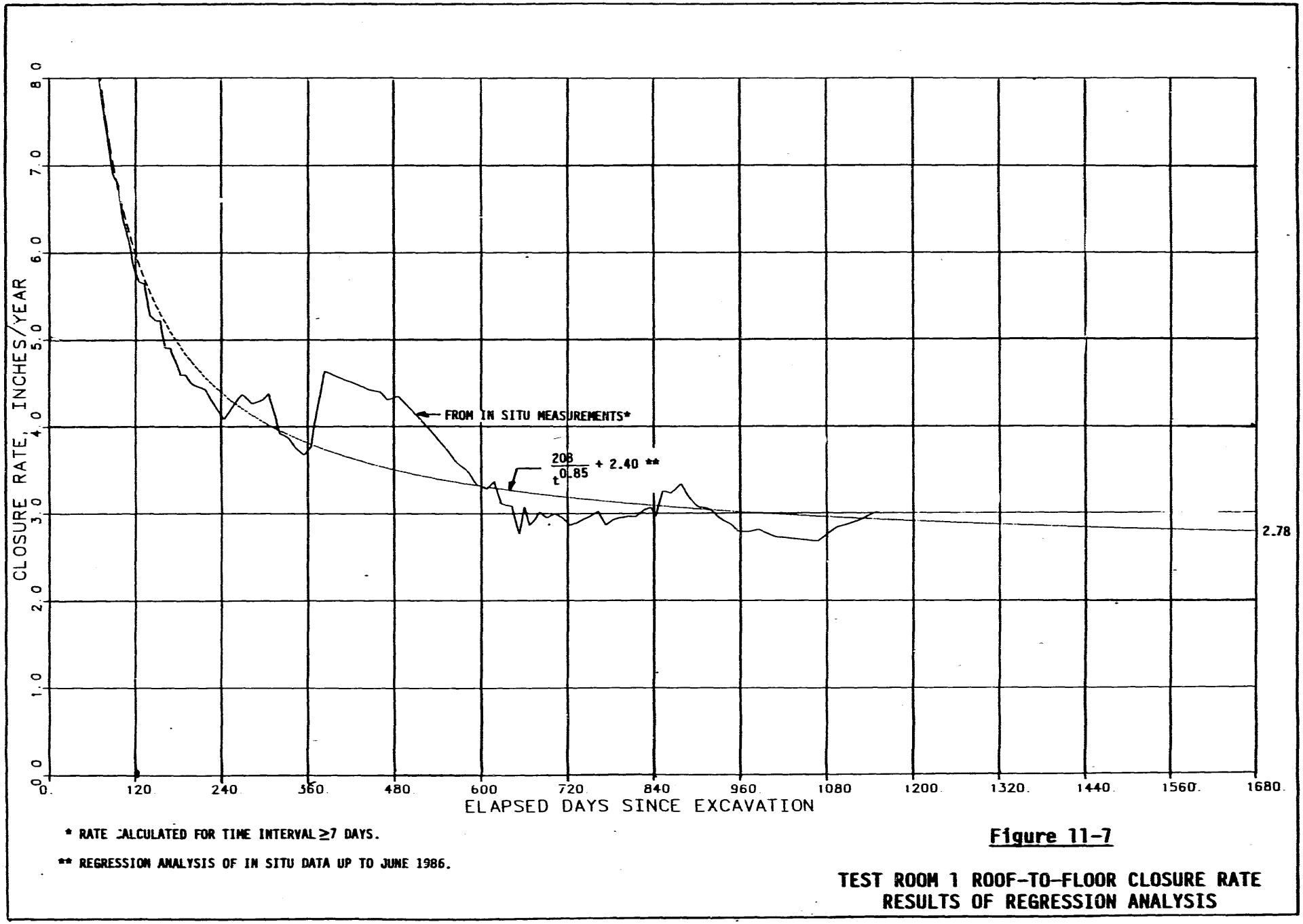


Figure 11-6

TEST ROOM 1
PREDICTED ROOF-TO-FLOOR CLOSURE RATE

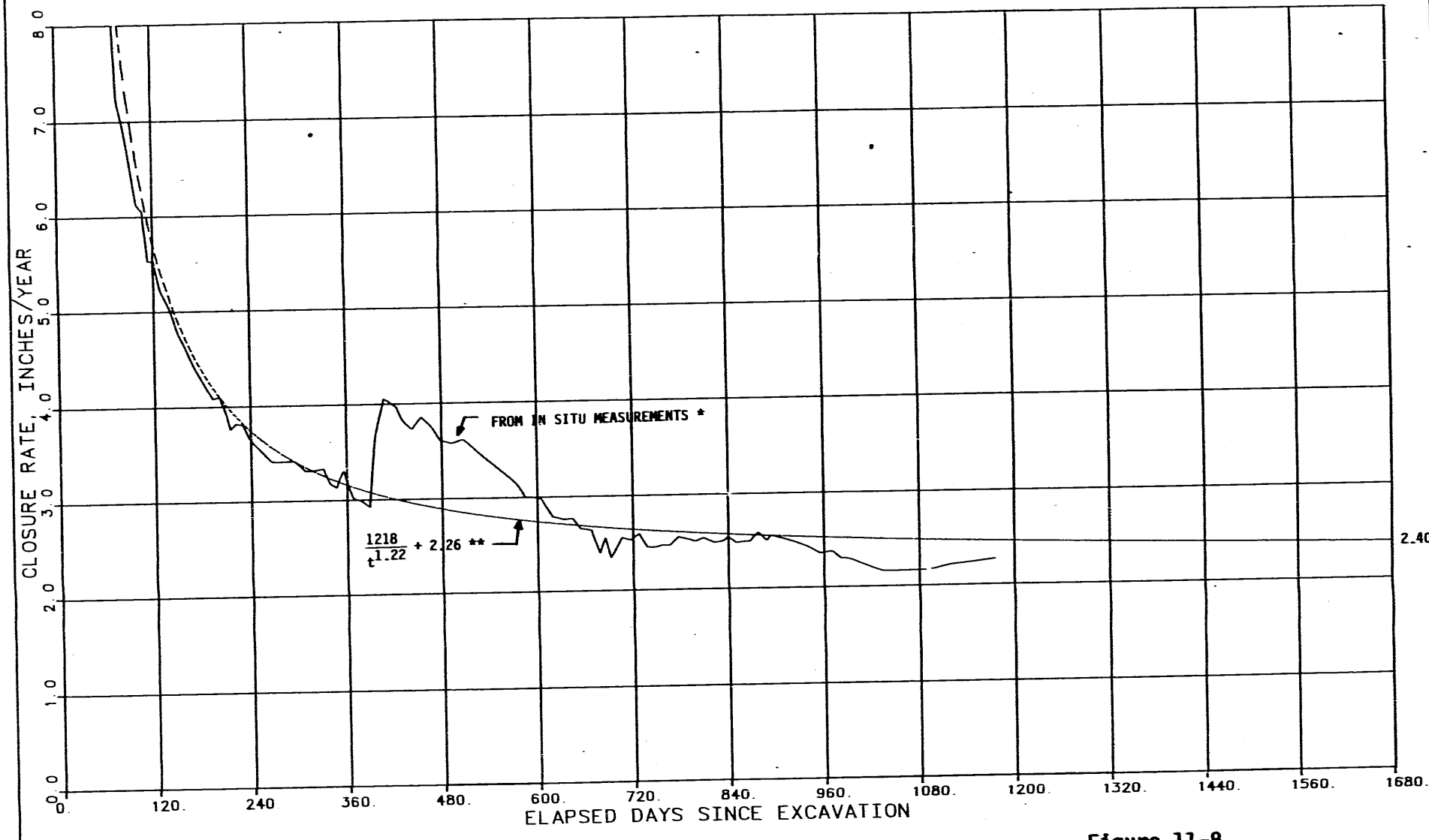


* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-7

TEST ROOM 1 ROOF-TO-FLOOR CLOSURE RATE RESULTS OF REGRESSION ANALYSIS

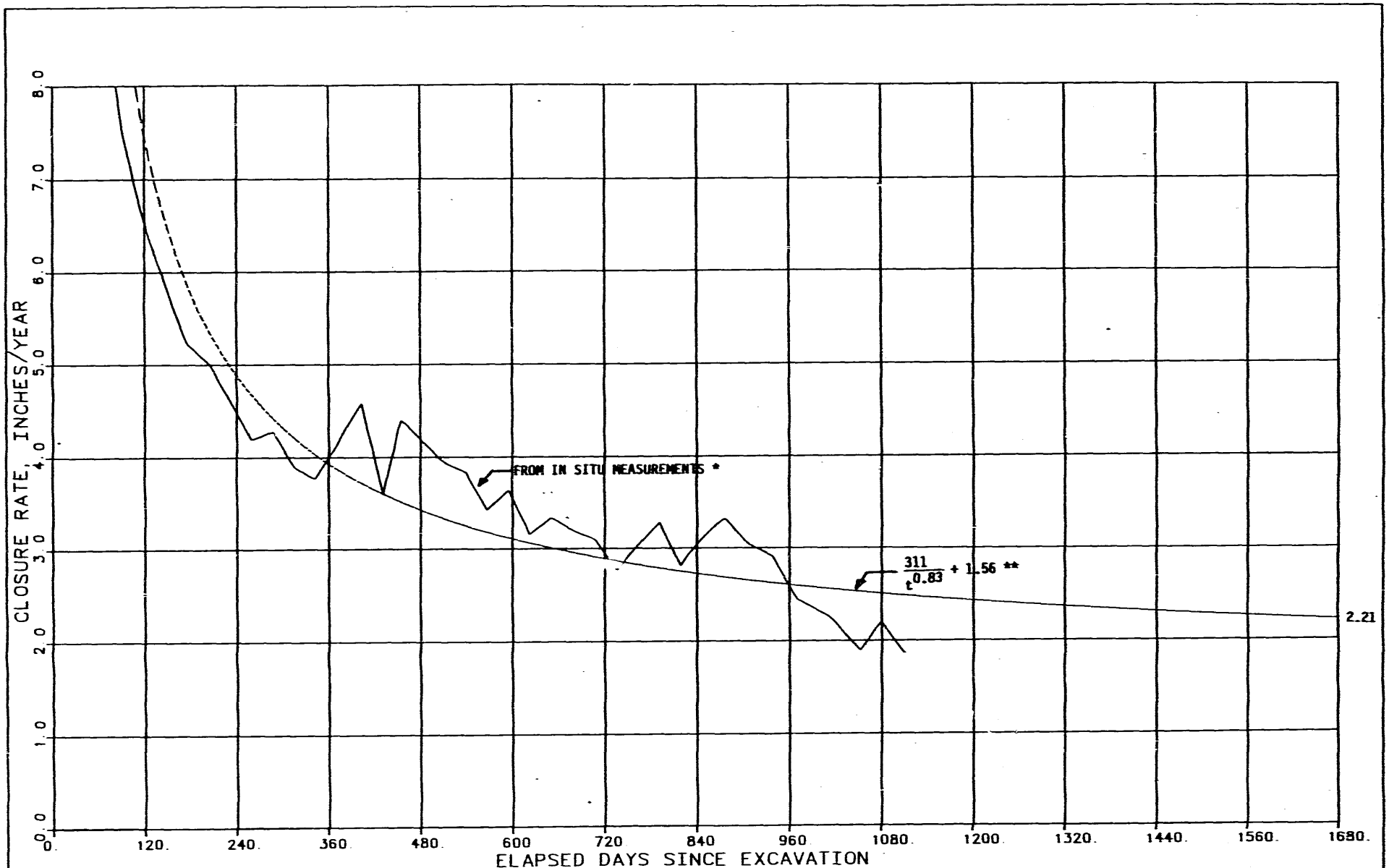


* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-8

TEST ROOM 2 ROOF-TO-FLOOR CLOSURE RATE RESULTS OF REGRESSION ANALYSIS

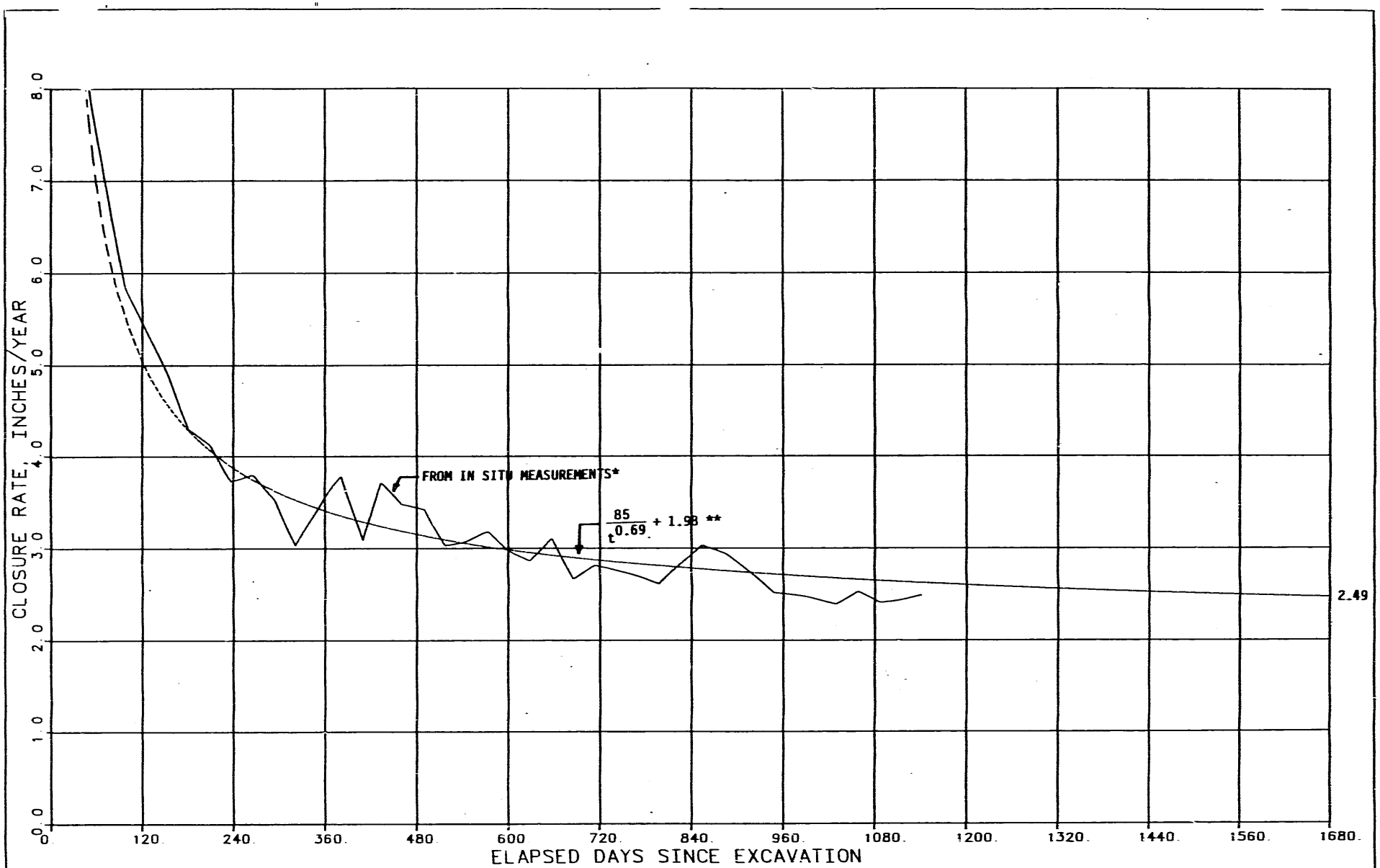


* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-9

TEST ROOM 3 ROOF-TO-FLOOR CLOSURE RATE RESULTS OF REGRESSION ANALYSIS



* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-10

TEST ROOM 4 ROOF-TO-FLOOR CLOSURE RATE
RESULTS OF REGRESSION ANALYSIS

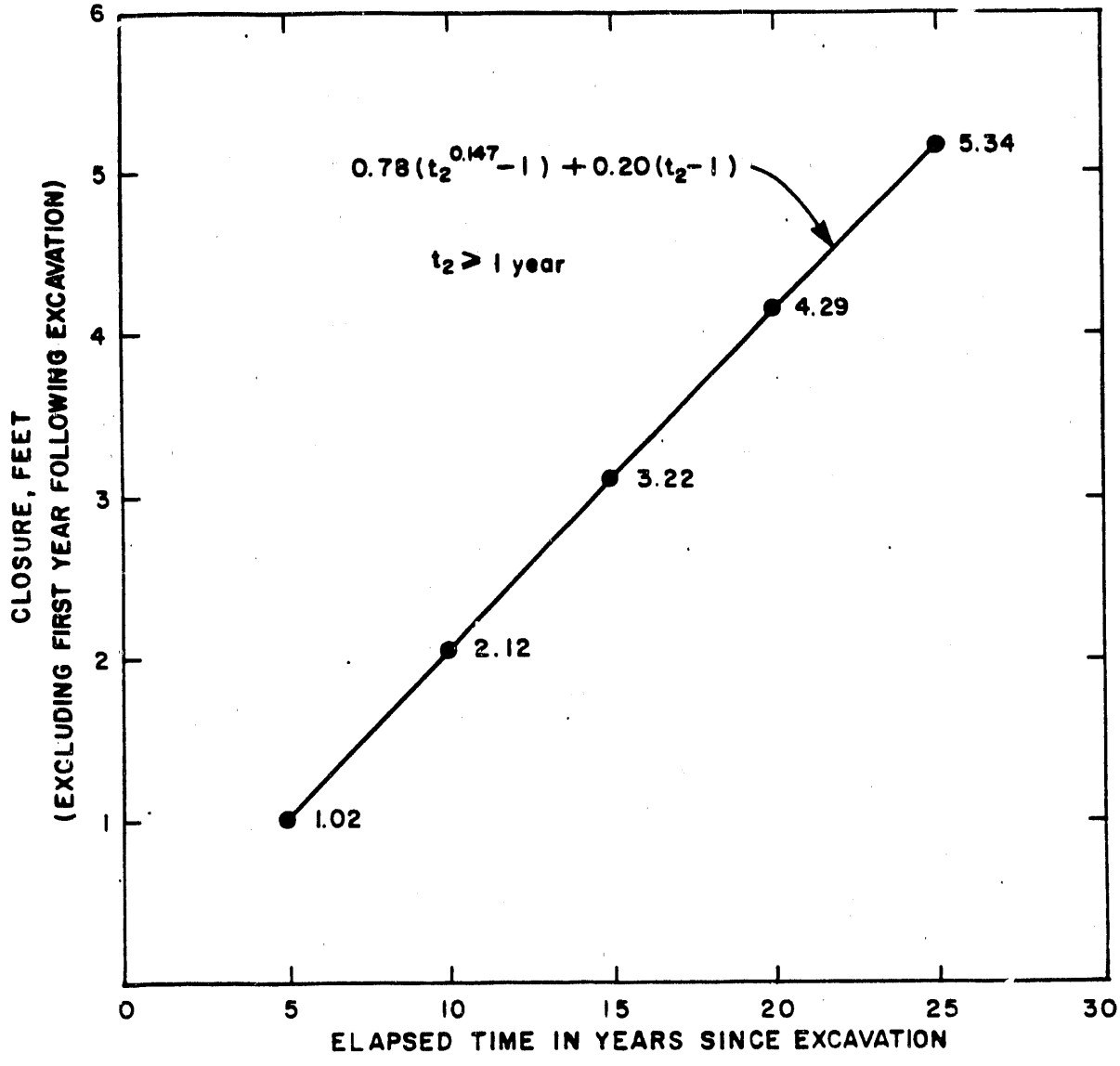


Figure 11-11

TEST ROOM 1
PREDICTED ADDITIONAL ROOF-TO-FLOOR CLOSURE

Table 11-7

TEST ROOMS
SUMMARY OF RESULTS OF REGRESSION ANALYSES
FOR ROOF-TO-FLOOR CLOSURE RATES

Description	Test Room 1	2	3	4*
Regression Parameters**				
A	208	1218	311	85
n	0.85	1.22	0.83	0.69
C_c	2.40	2.26	1.56	1.98
r^2	0.99	0.98	0.94	0.97

Note: Analyses based on data obtained through June 1986.

* Data used for regression analysis includes data from temporary convergence points.

** Equation is: $C(t) = \frac{A}{t^n} + C_c$

where: C(t) is closure rate in inches/year;
A and n are constants;
t is elapsed time in days; and
C_c is steady state closure rate.

r^2 is the coefficient of determination.

repeated with the inclusion of temporary convergence point data, and produced good results. The results of the regression analysis of roof-to-floor closure rates discussed in this subsection are used in Chapter 12 to define the bounds on the roof-to-floor closure rates for the storage rooms.

Wall-to-Wall Closure. Figure 11-12 summarizes the measured wall-to-wall closure magnitudes for the test rooms. Because of the lack of early measurements, the relative positions of the individual curves are not absolute. Table 11-8 presents an estimate of the actual wall-to-wall closure for the four test rooms. The approach is similar to the one used for estimating the actual roof-to-floor closure values. The maximum wall-to-wall closure occurs in Test Room 3 and is about 13 inches. The minimum wall-to-wall closure is about 9 inches in Test Room 4.

The regression analysis of wall-to-wall closure rates for Test Room 1, using measurement data up to June 1986, shows that the equation has the form

$$C(t) = \frac{202}{t^{0.94}} + 1.75 \text{ inches/year} \qquad (11\text{-}11)$$

where: t = elapsed time in days since excavation.

Comparing equation 11-11 with equation 11-9, the long-term wall-to-wall closure rate will be 73 percent of the roof-to-floor closure rate.

Table 11-9 is a summary of the results of the regression analyses for the wall-to-wall closure rates in Test Rooms 1 through 4. The closure rate values determined from temporary convergence point readings were included in the analysis of Test Room 2. The fitted curves for Test Rooms 2 and 3 are relatively poor. Figures 11-13 through 11-16 show the fitted equations for the wall-to-wall closure rate versus elapsed time curves for Test Rooms 1 through 4.

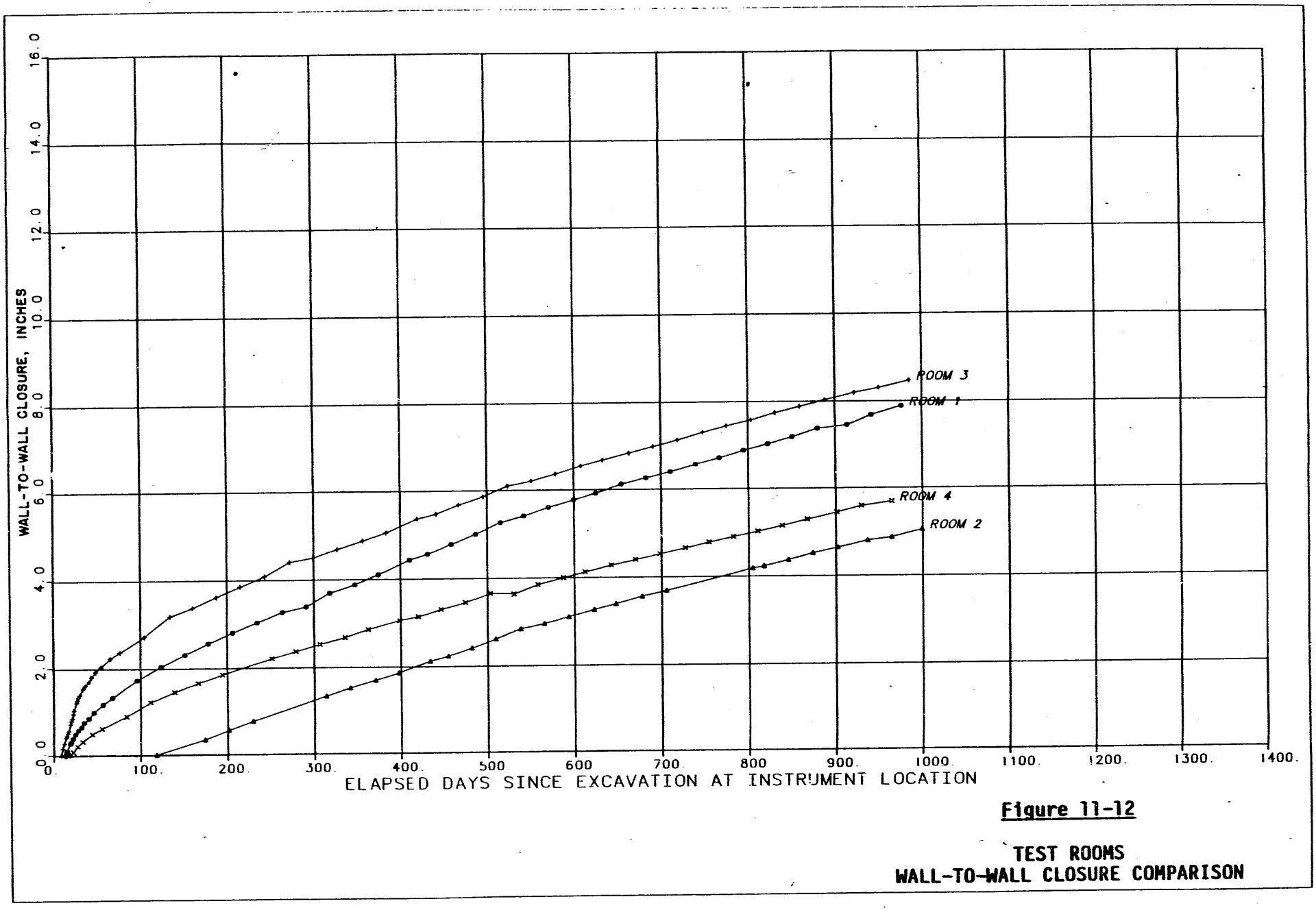


Figure 11-12

TEST ROOMS
WALL-TO-WALL CLOSURE COMPARISON

Table 11-8

TEST ROOMS
WALL-TO-WALL CLOSURE COMPARISONS

Description	Test Room 1	2	3	4
(1) Excavation period	April 3-13 1983	March 9-20 1983	March 24-April 3 1983	April 15-25 1983
(2) Date of first reading of temporary convergence (TC) points	April 9, 1983	March 21, 1983	March 31, 1983	April 21, 1983
(3) Date of first reading of permanent convergence (RC) points	April 20, 1983	July 12, 1983	April 7, 1983	May 6, 1983
(4) Reading of TC points (inches) on date indicated	1.58 April 20, 1983	3.36 July 12, 1983	1.42 April 7, 1983	1.48 May 5, 1983
(5) Reading of RC points (inches) on date indicated	8.82 June 16, 1986	5.82 June 16, 1986	9.24 June 16, 1986	6.39 June 16, 1986
(6) Total elapsed days of combined TC and RC measurements [Date for (5) - Date for (2)]	1166	1151	1176	1151
(7) Total measured closure (inches) [(4) + (5)]	10.40	9.18	10.66	7.87
(8) Estimated closure (inches) by regression analysis for the period of (2) - (1)	1.79	2.51	2.16	1.42
(9) Total estimated closure (inches) [(7) + (8)]	12.19	11.69	12.82	9.29

Table 11-9

TEST ROOMS
SUMMARY OF RESULTS OF REGRESSION ANALYSES
FOR WALL-TO-WALL CLOSURE RATES

Description	Test Room 1	2*	3	4
Regression Constants**				
A	202	222	231	1766
n	0.94	0.79	0.83	1.81
C_c	1.75	0.30	0.74	1.88
r^2	0.96	0.95	0.92	0.99

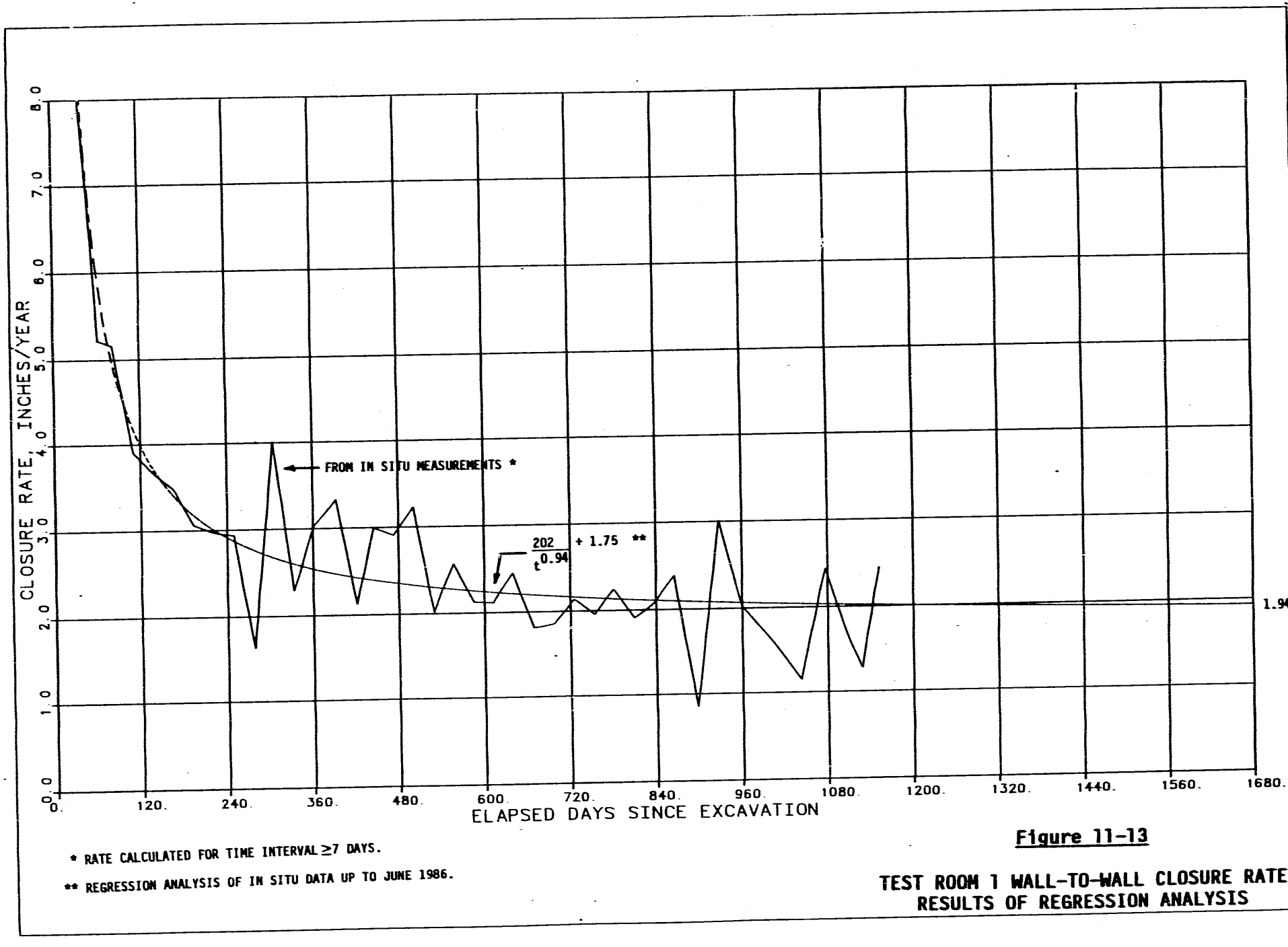
Note: Analyses based on data obtained through June 1986.

* Data used for regression analysis includes data from temporary convergence points.

** Equation is: $C(t) = \frac{A}{t^n} + C_c$

where: C(t) is closure rate in inches/year;
A and n are constants;
t is elapsed time in days; and
C_c is steady state closure rate.

r^2 is the coefficient of determination.

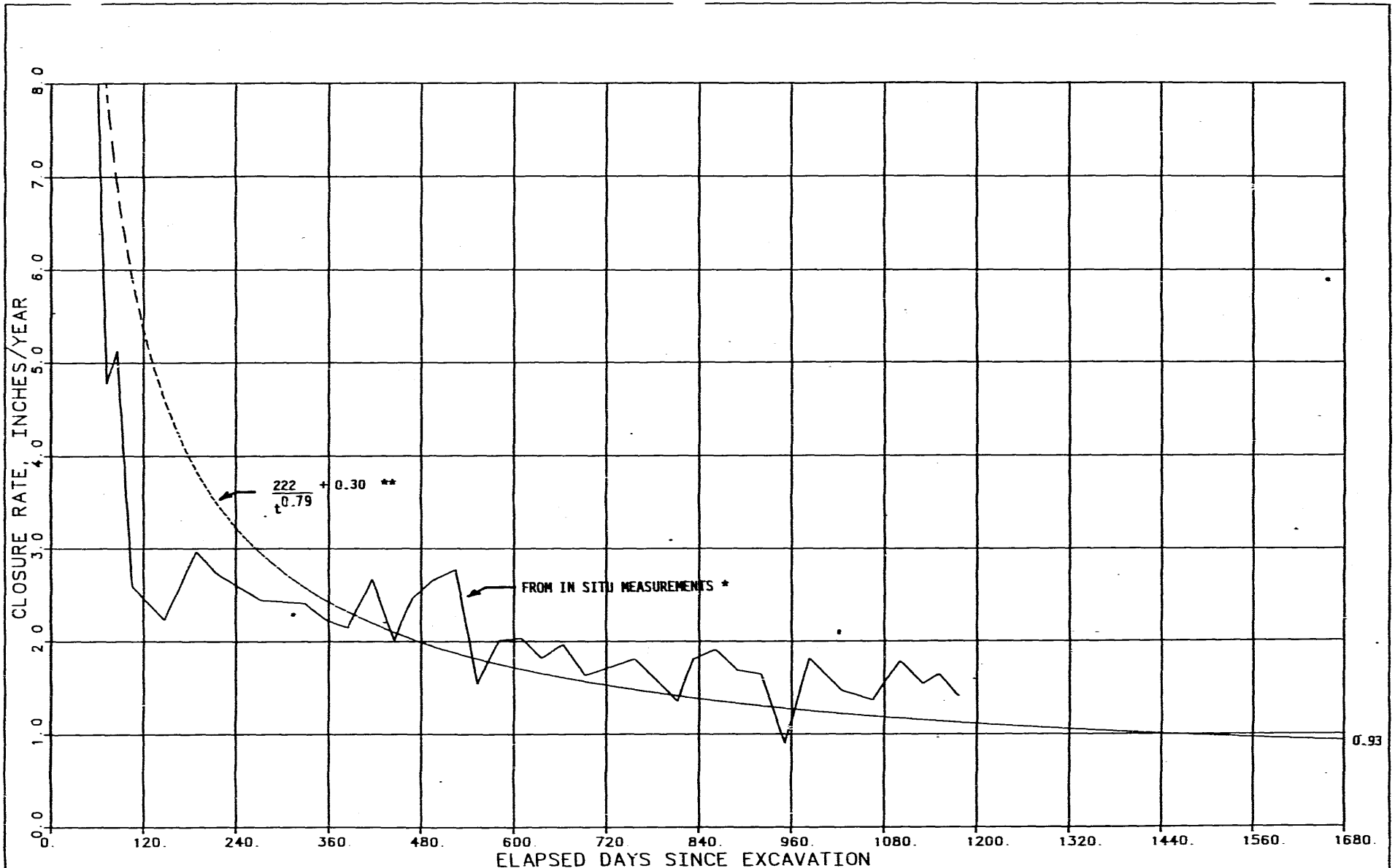


* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-13

TEST ROOM 1 WALL-TO-WALL CLOSURE RATE RESULTS OF REGRESSION ANALYSIS

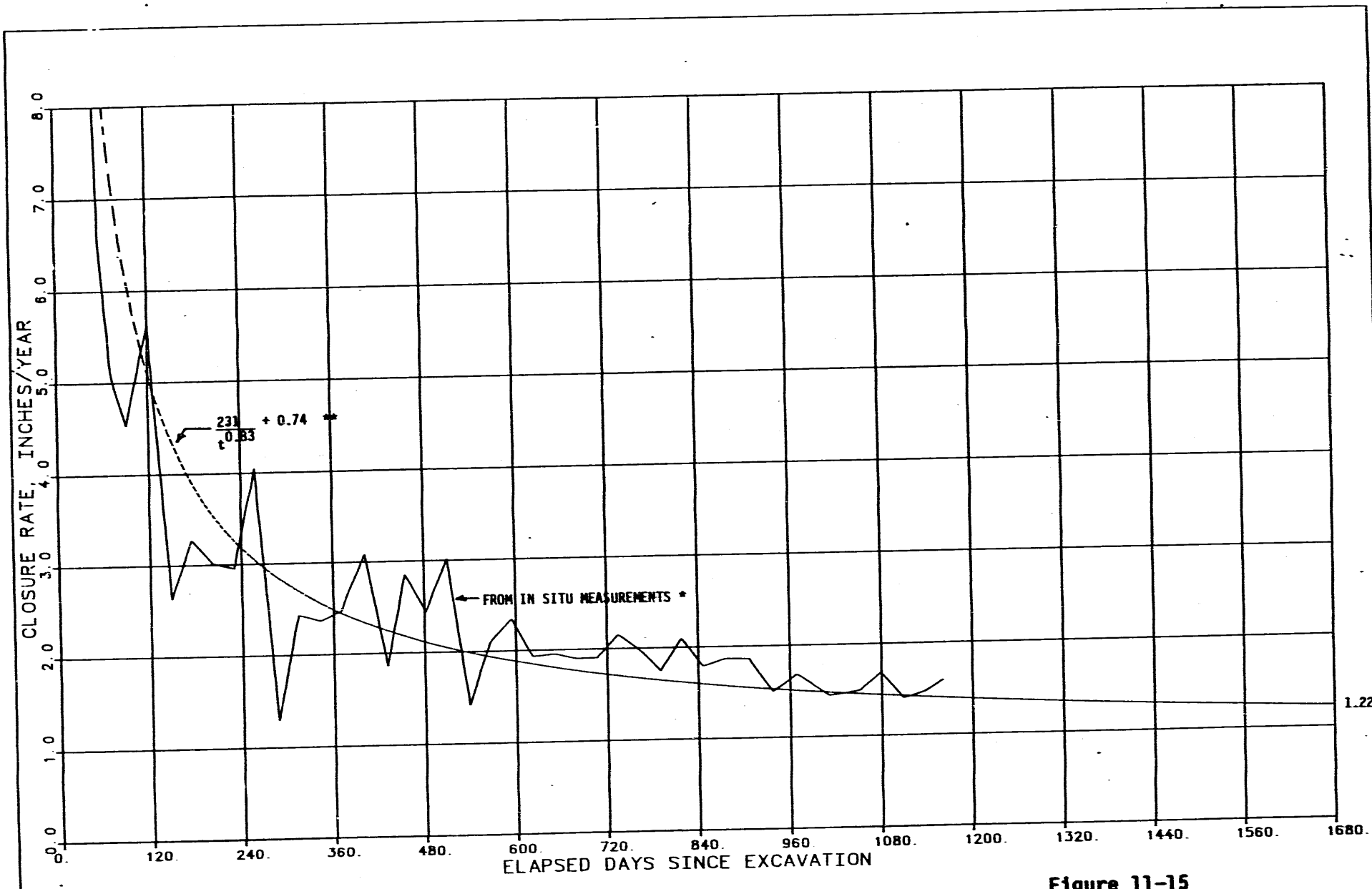


* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-14

TEST ROOM 2 WALL-TO-WALL CLOSURE RATE RESULTS OF REGRESSION ANALYSIS

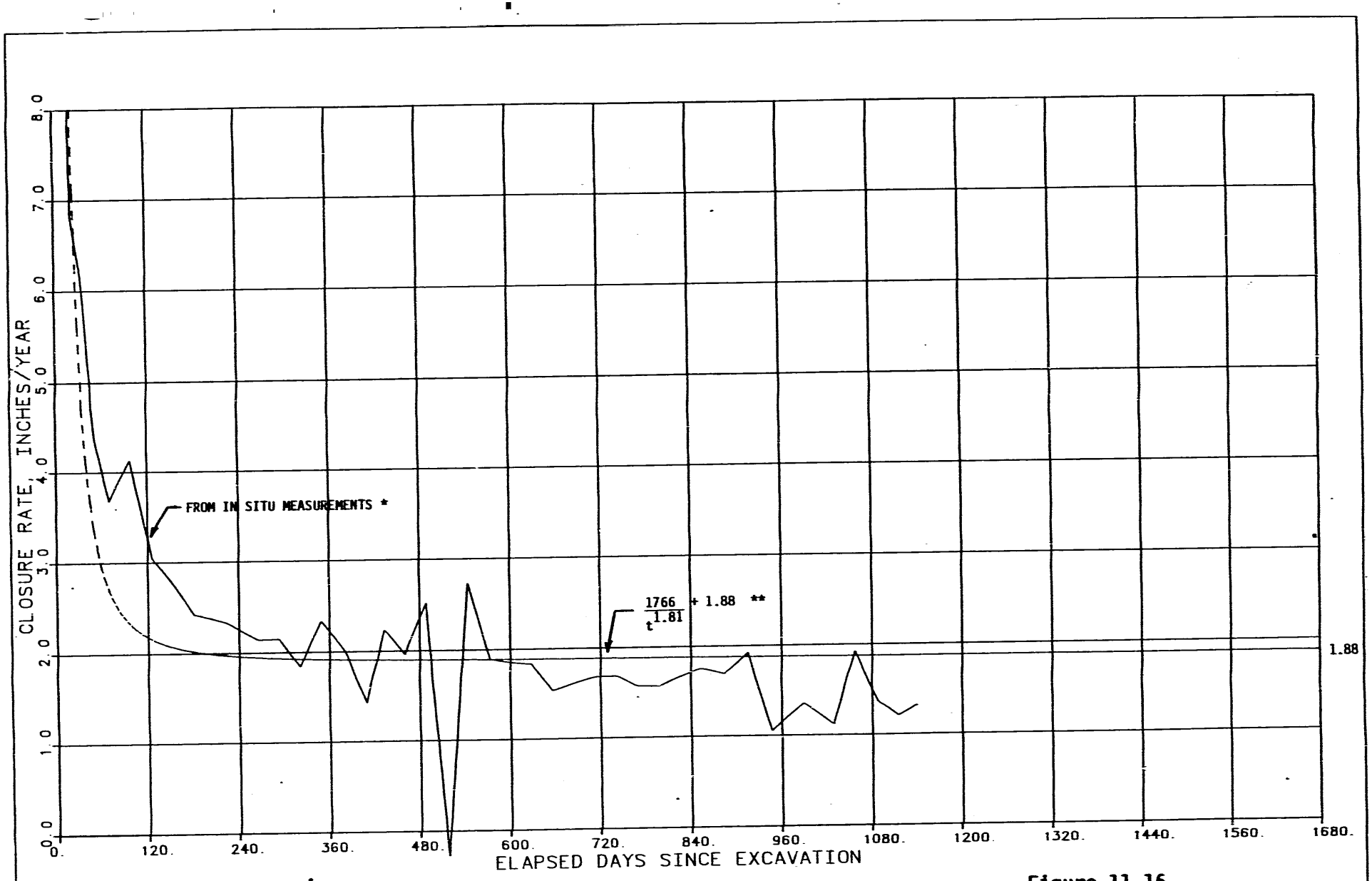


* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-15

TEST ROOM 3 WALL-TO-WALL CLOSURE RATE RESULTS OF REGRESSION ANALYSIS



* RATE CALCULATED FOR TIME INTERVAL ≥7 DAYS.

** REGRESSION ANALYSIS OF IN SITU DATA UP TO JUNE 1986.

Figure 11-16

TEST ROOM 4 WALL-TO-WALL CLOSURE RATE RESULTS OF REGRESSION ANALYSIS

Table 11-10 is a summary of the collar readings from the wall multiple-point borehole extensometers in the test rooms. Because the extensometers could not be installed as soon as the excavation was completed, the collar readings do not reflect absolute closure. The table also shows the sum of the collar movements from both the east and west walls in each of the rooms except Test Room 3, which has no extensometer in the west wall. The last two columns of this table permit a comparison of the sum of the collar movements with wall-to-wall convergence point readings. Ideally, providing the salt is homogeneous, the central vertical lines of the pillars between Test Rooms 1 and 2 and Test Rooms 2 and 3 should be lines of symmetry with zero lateral strain. The deepest anchor at 50 feet for extensometers 51X-GE-00213 and 51X-GE-00215 should be expected to undergo negligible displacement. Therefore, the sum of the collar movements for Test Rooms 2 and 3 should be approximately the same as the wall-to-wall convergence point readings. As shown in Table 11-10, this is the case for Test Room 2. Exact equivalence is difficult to obtain because the collars of the extensometers are recessed into the wall by variable amounts and the time-lag between the end of excavation and the date of initial reading is not the same for the extensometers and the convergence points.

Comparison of Roof-to-Floor to Wall-to-Wall Closure Rates. Table 11-11 presents recent roof-to-floor and wall-to-wall closure rates for the test rooms. The rates were calculated using convergence point readings with a time interval of approximately 1 month. Based on these readings, the average wall-to-wall closure rate is approximately 68 percent of the roof-to-floor closure rate.

11.3.2.3 Deformation

An indication of the deformation of the salt around the test rooms may be obtained by comparing inclinometer measurements around a room. Figure 11-17 shows the cumulative measurements from the four wall inclinometers located around Test Room 3 through March 6, 1985. The inclinations are measured along the plane of the cross section.

Table 11-10

TEST ROOMS
WALL EXTENSOMETER COLLAR MOVEMENTS VERSUS CONVERGENCE POINT READINGS

Test Room	Extensometer	Location	Readings on June 13, 1986 (inches)	Sum of East & West Readings (inches)	Wall-to-Wall Convergence Point Readings on June 16, 1986 (inches)
1	51X-GE-00217	East wall	3.16	7.36	8.82*
	51X-GE-00219	West wall	4.20		
2	51X-GE-00213	East wall	4.95	9.52	9.18**
	51X-GE-00215	West wall	4.57		
3	51X-GE-00211	East wall	4.17	-	9.24*
	-	West wall	-		
4	51X-GE-00206	East wall	3.26	5.95	6.39*
	51X-GE-00208	West wall	2.69		

* From (5) in Table 11-8.
** From (7) in Table 11-8.

Table 11-11

TEST ROOMS
CLOSURE RATE COMPARISONS

Description of Closure Location	Test Room 1	2	3	4
Roof-to-Floor				
Reading/Date	12.88/May 16, 1986	12.03/May 16, 1986	13.65/Mar. 24, 1986	10.39/Mar. 24, 1986
Reading/Date	13.11/June 13, 1986	12.20/June 13, 1986	13.83/Apr. 28, 1986	10.62/Apr. 28, 1986
Difference in readings	0.23 inch	0.17 inch	0.18 inch	0.23 inch
Time interval	28 days	28 days	27 days	27 days
Rate ($\dot{V}$)	3.00 inch/yr	2.22 inch/yr	2.43 inch/yr	3.10 inch/yr
Wall-to-Wall				
Reading/Date	8.63/May 19, 1986	5.72/May 19, 1986	8.90/Mar. 24, 1986	6.09/Mar. 24, 1986
Reading/Date	8.82/June 16, 1986	5.82/June 16, 1986	9.03/Apr. 28, 1986	6.22/Apr. 28, 1986
Difference in	0.19 inch	0.10 inch	0.13 inch	0.13 inch

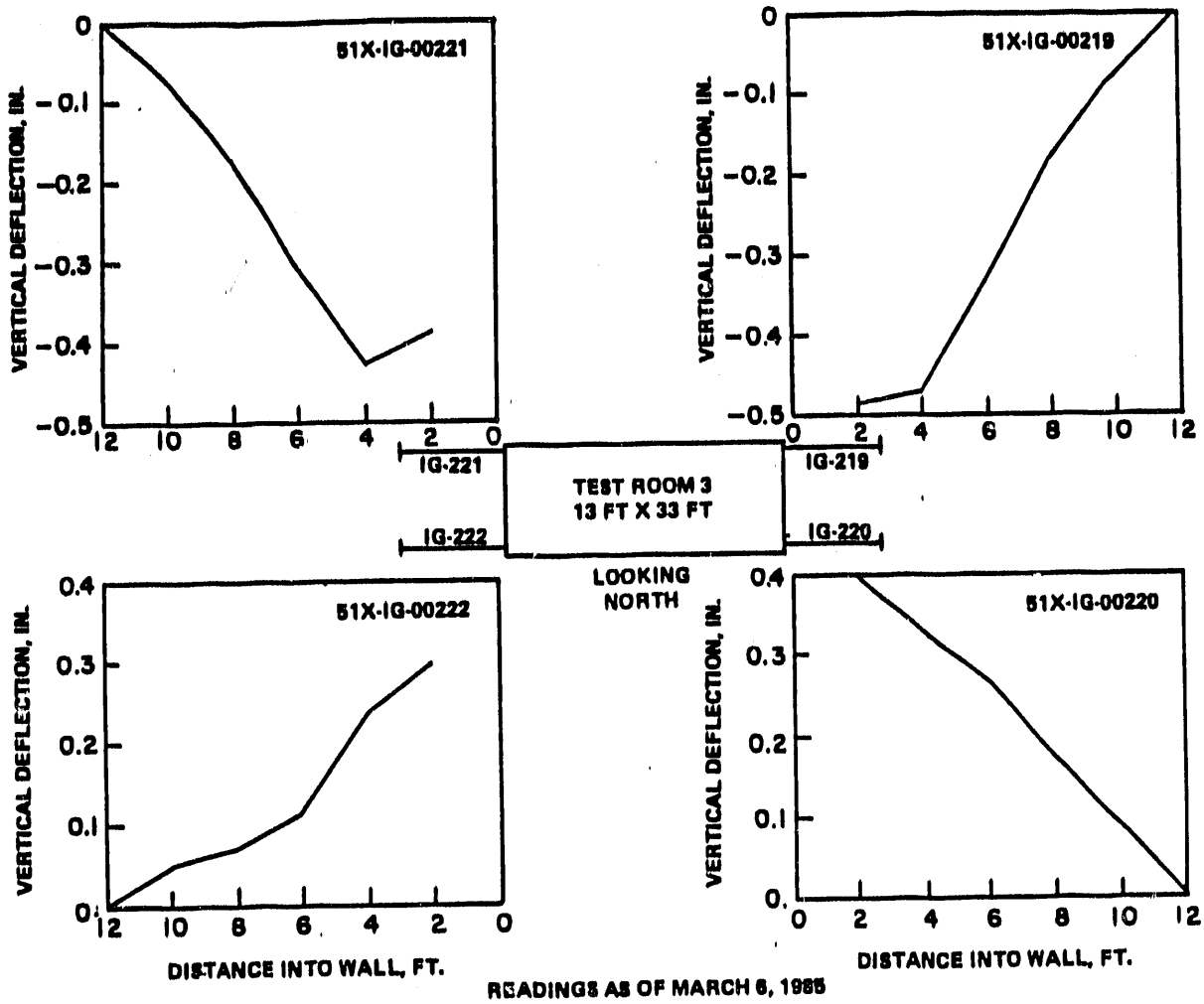


Figure 11-17

TEST ROOM 3
WALL INCLINOMETER BEHAVIOR

Figure 11-18 shows the inclinometer behavior around Test Room 4 through March 6, 1985. The initial readings from these inclinometers were taken 9 to 15 days after the completion of excavation in the test room. The current readings indicate that the maximum relative vertical deflection is on the order of 1 inch over a length of 12 feet.

The inclinometers near the roof show vertical downward deflection while those near the floor indicate upward deflection. This indicates that the central multiple-point borehole extensometers located in the walls of the test rooms probably undergo negligible vertical deflection.

11.3.2.4 Bay Strains

Relative movements between anchors of the multiple-point borehole extensometers will provide an approximate distribution of salt deformation around the excavated openings. The relative displacements are normalized over the spacing between anchors and are termed "bay strains". The bay strain is approximately the average axial strain between any two anchor points and will be closer to the true strain provided that the spacing between the anchors is small and that the deformation varies linearly with the spacing between the anchors. Bay strains are useful in detecting any anomalous behavior in the salt around an opening, such as that influenced by discontinuities, clay seams, or the effect of local stress concentrations.

Figure 11-19 shows the strain between the collar and anchor A for the roof extensometers in Test Room 1. The distance between the collar and anchor A is 5 feet. The maximum strain occurs at the east and west sides of the roof of the test room and is equal to approximately 4 percent through June 1986. Although the roof sag, as depicted by collar movement, is higher at the center of the rooms than at the sides, the bay strain is higher at the sides than at the center. As discussed in subsection 11.3.2.5, the numerical modeling also indicates higher strain at the roof and wall intersections. Figure 11-20 shows the vertical strain rates for these same extensometers. The rates are

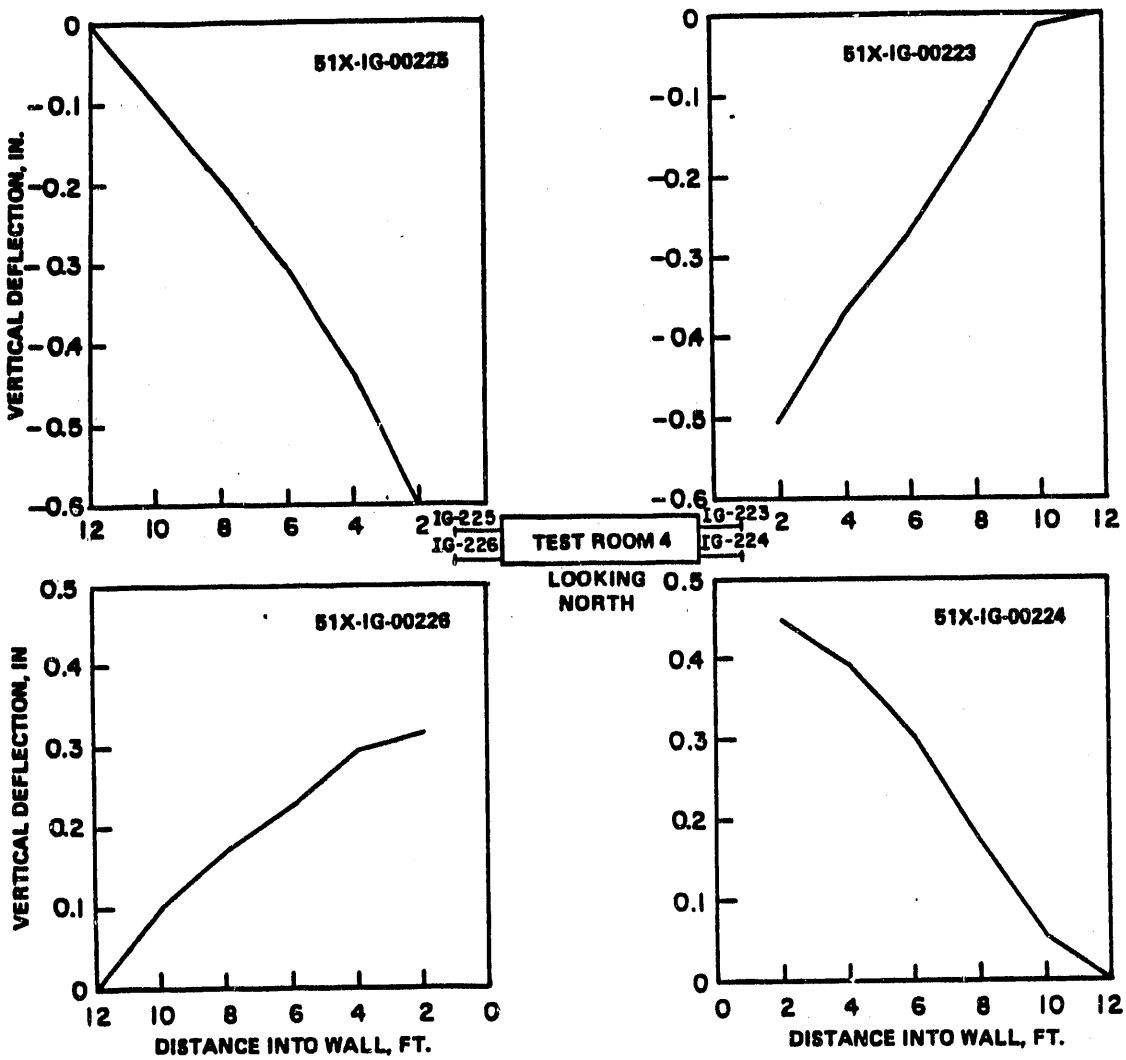


Figure 11-18

TEST ROOM 4
WALL INCLINOMETER BEHAVIOR

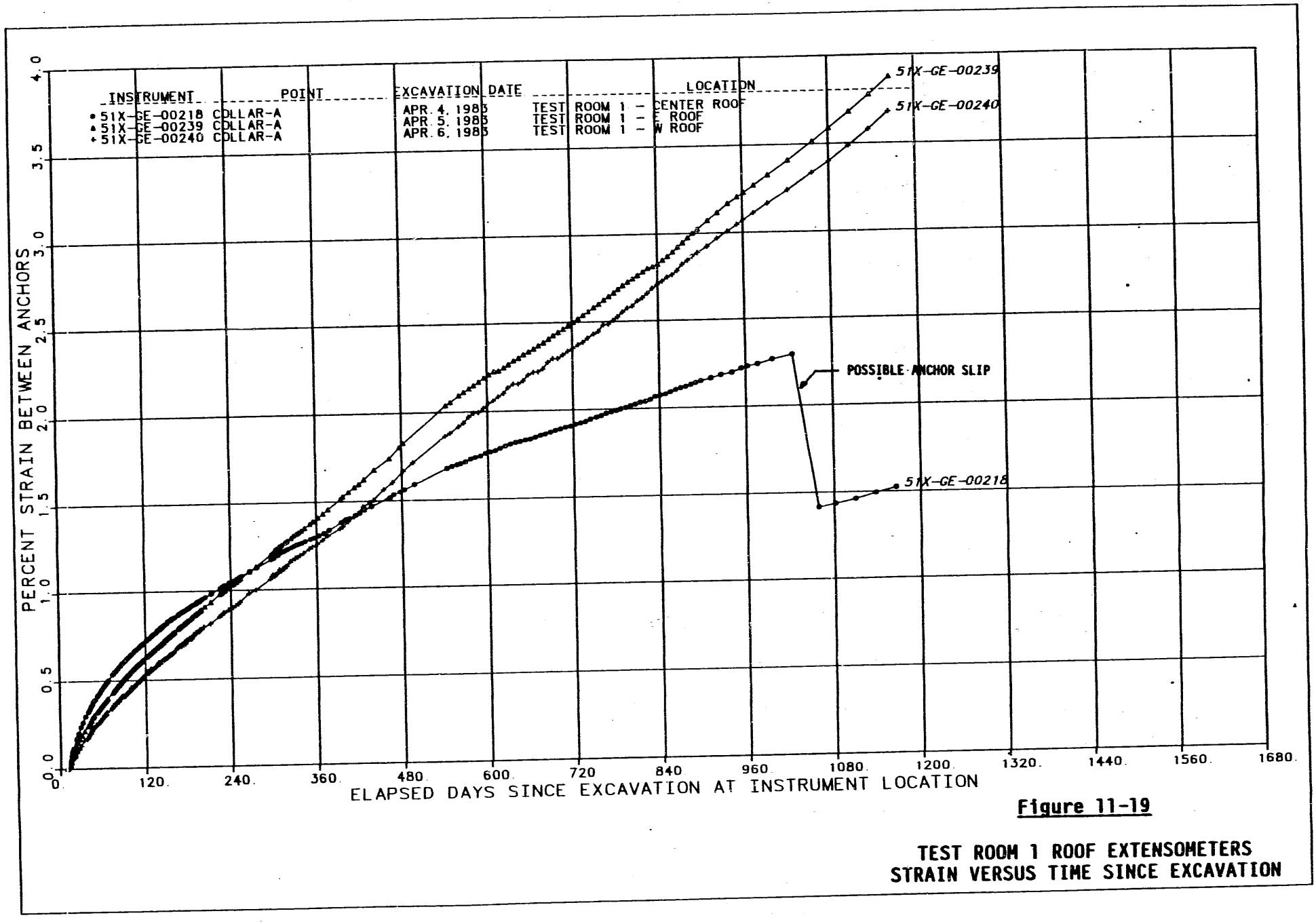
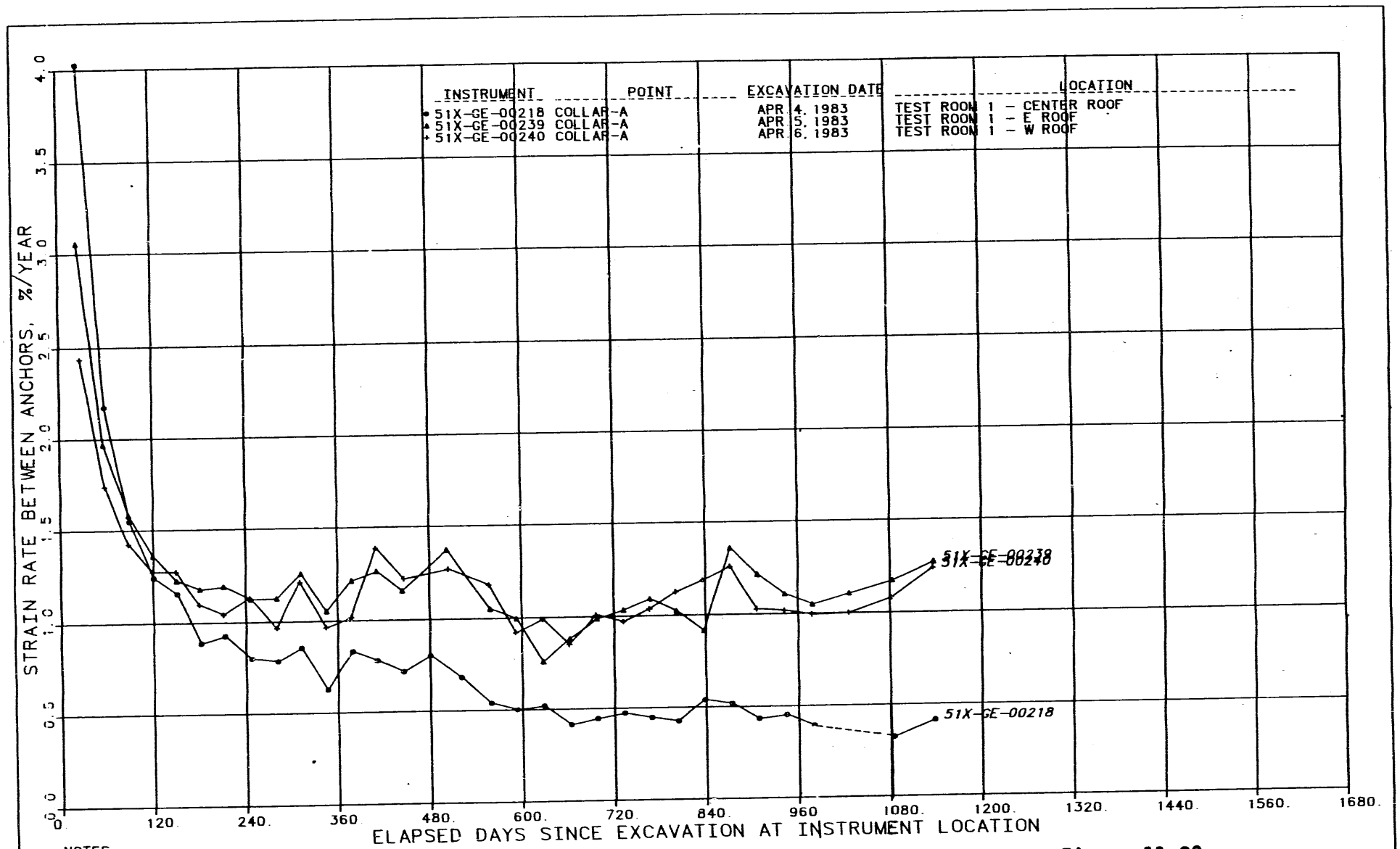


Figure 11-19

TEST ROOM 1 ROOF EXTENSOMETERS
STRAIN VERSUS TIME SINCE EXCAVATION



NOTES:
1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.

Figure 11-20

TEST ROOM 1 ROOF EXTENSOMETERS
STRAIN RATE VERSUS TIME SINCE EXCAVATION

generally decreasing with time. As with the strains, the strain rates are higher close to the pillars.

Figures K-37 through K-46 in Appendix K show the bay strains in percent as a function of elapsed time since excavation for all of the test rooms. To monitor more closely the separation across the clay seam at the base of anhydrite "b", the spacing between anchors A and B in Test Rooms 1 and 2 is 1 foot. Currently, the maximum strain occurs between anchors A and B on the west side and central part of the roof in Test Room 1, and is on the order of 5 percent. Because the anchors are not equally spaced, and the deformation varies nonlinearly with the distance along the anchor, a comparison of bay strain between successive anchors may be misleading.

Figures K-47 through K-56 in Appendix K show the strain rate plots for all of the roof and floor extensometers. In general, the strain rate is decreasing with time, except for floor extensometer 51X-GE-00210 in Test Room 3 where, for anchor A, the strain rate increased with time until the extensometer failed (Figure K-42). The decreasing trend in the strain rates is an indication that the salt above the roof and below the floor is currenty stable and will remain stable based on the projected decreasing rate.

11.3.2.5 Model Simulation

As discussed in Chapter 5, Section 5.3, numerical analyses using creep constants obtained from laboratory tests did not provide a good correlation with in situ measured closure. Therefore, an engineering approach using curve fitting methods was employed. The finite element method was used to simulate the behavior of the test rooms and to determine stress distributions. The effects of material properties and the proximity to other rooms were considered for incorporation into the model. The reference stratigraphy used in the model and the material properties of the geologic layers are described in Chapter 6. The constitutive equations used in the analyses, particularly the governing creep equations, are presented in Appendix C. Using the procedures

described in Chapter 5, Section 5.4, in situ roof-to-floor closure data through June 30, 1985, were correlated with the finite element responses to determine the values of creep parameters C, A and z for each test room. In order to eliminate the effect of excavation sequence on computation of the creep parameters, only in situ data taken after the completion of all test room excavation activities were utilized. The average values of these parameters for the four test rooms were then used to predict the responses of the future storage rooms as described in Chapter 12.

Figure 11-21 shows the finite element model for the test room panel based on the reference stratigraphy. The model has 363 nodes and consists of 270 plane strain elements, with gap/friction link elements modeling a clay seam at a depth of 2,104.87 feet. A friction coefficient of 0.4 was used for a member property of the gap/friction link elements. MB-139 was modeled as an elastic layer from a depth of 2,130.36 to 2,133.18 feet. The top and bottom boundaries of the model are at depths of 1,978.5 feet and 2,250.0 feet, respectively. The roof and floor of the room are at depths of 2,112.56 feet and 2,125.56 feet, respectively.

Two openings were incorporated in the finite element model to simulate differences resulting from the proximity of inner and outer rooms. These openings were modeled using height and width dimensions of 13 feet and 33 feet respectively. The boundary on one side of the model was taken as the vertical axis of symmetry for the center pillar and consists of horizontal restraints. The boundary on the other side of the model also utilized horizontal restraints. These boundaries were established based on experience from previous analyses and were extended far enough so that the effects of the boundaries on the structural responses were minimal. Stress boundary conditions were used at the top and bottom of the finite element model. A single vertical restraint at the lower left corner of the model was used to eliminate any rigid body modes in the model.

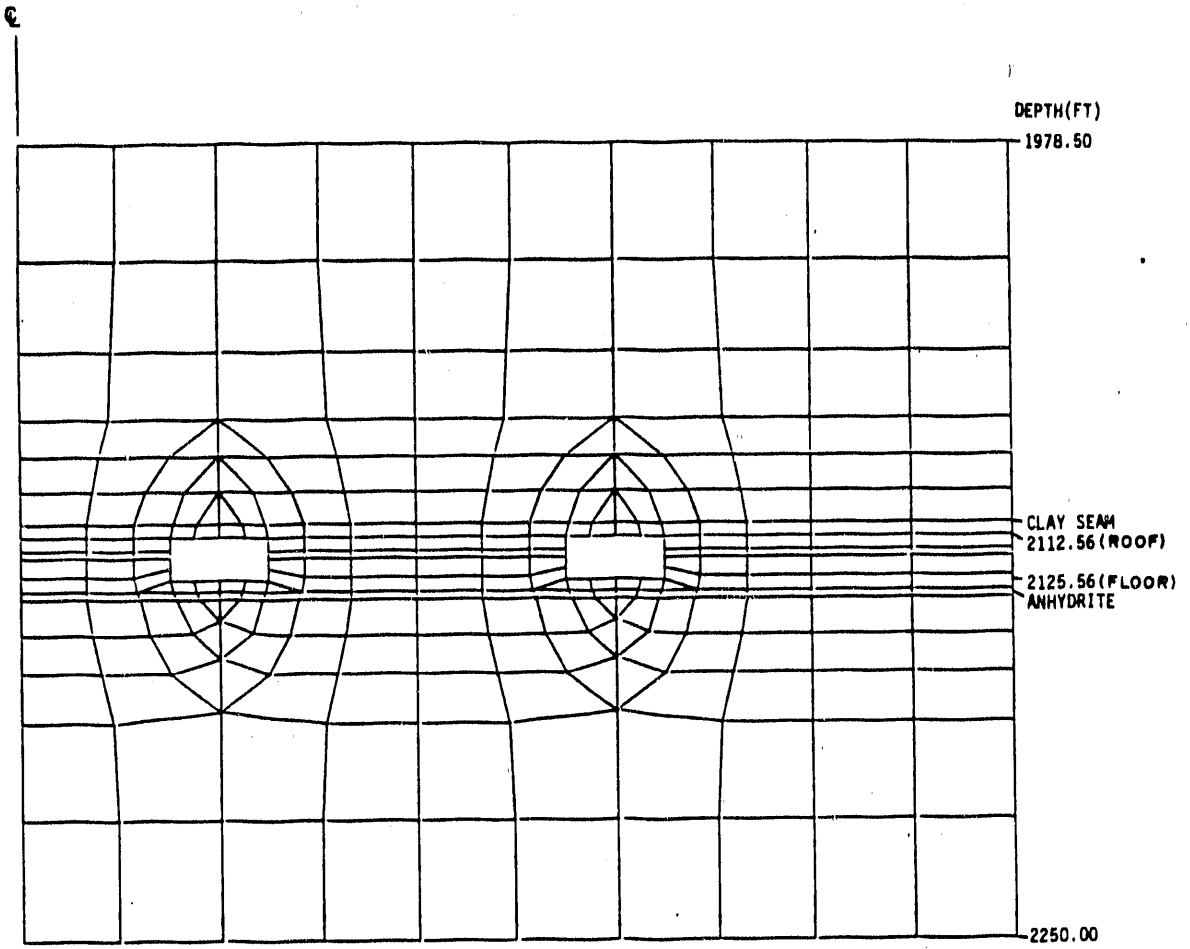


Figure 11-21

TEST ROOMS
FINITE ELEMENT MODEL

Element sizes were proportioned to minimize the stress gradients across each element. In addition, elements were oriented to have the mesh radiating from the opening of the model to be commensurate with estimated orientations of the principal stress axes. These aspects of the model were designed to increase the overall efficiency of the analyses.

Computation of In Situ Responses and Creep Parameters. The test room analyses were performed using the procedures described in Chapter 6 and the MARC General Purpose Finite Element Program (ref. 6-8). Time steps used in the analyses were within the specified tolerances recommended by the MARC Program. The analysis was performed in several stages with each stage containing between 50 and 100 integration steps. After completing each stage, the corresponding real time was computed to determine the required number of integration steps for the subsequent runs.

Figures 11-22 through 11-25 show the correlations of in situ and analytical roof-to-floor closures for Test Rooms 1 through 4. The in situ roof-to-floor closure data for Test Rooms 1 and 2 are from convergence meter readings while the measurements for Test Rooms 3 and 4 are from convergence points. Table 11-12 shows the individual creep parameters C, A and z for all four test rooms determined by numerically correlating the in situ roof-to-floor closure data. The table also shows the mean values of the creep parameters for three test room combinations.

Similarly, Figures 11-26 through 11-29 show the correlations of in situ and finite element wall-to-wall closures for Test Rooms 1 through 4. The in situ wall-to-wall closure data for Test Rooms 1, 3 and 4 are from permanent convergence points while the data from Test Room 2 consists of both temporary and permanent convergence point measurements. Table 11-13 shows the individual creep parameters C, A and z for all four test rooms determined by numerically correlating the in situ wall-to-wall closure data. The table also shows the mean values of the creep parameters for three test room combinations.

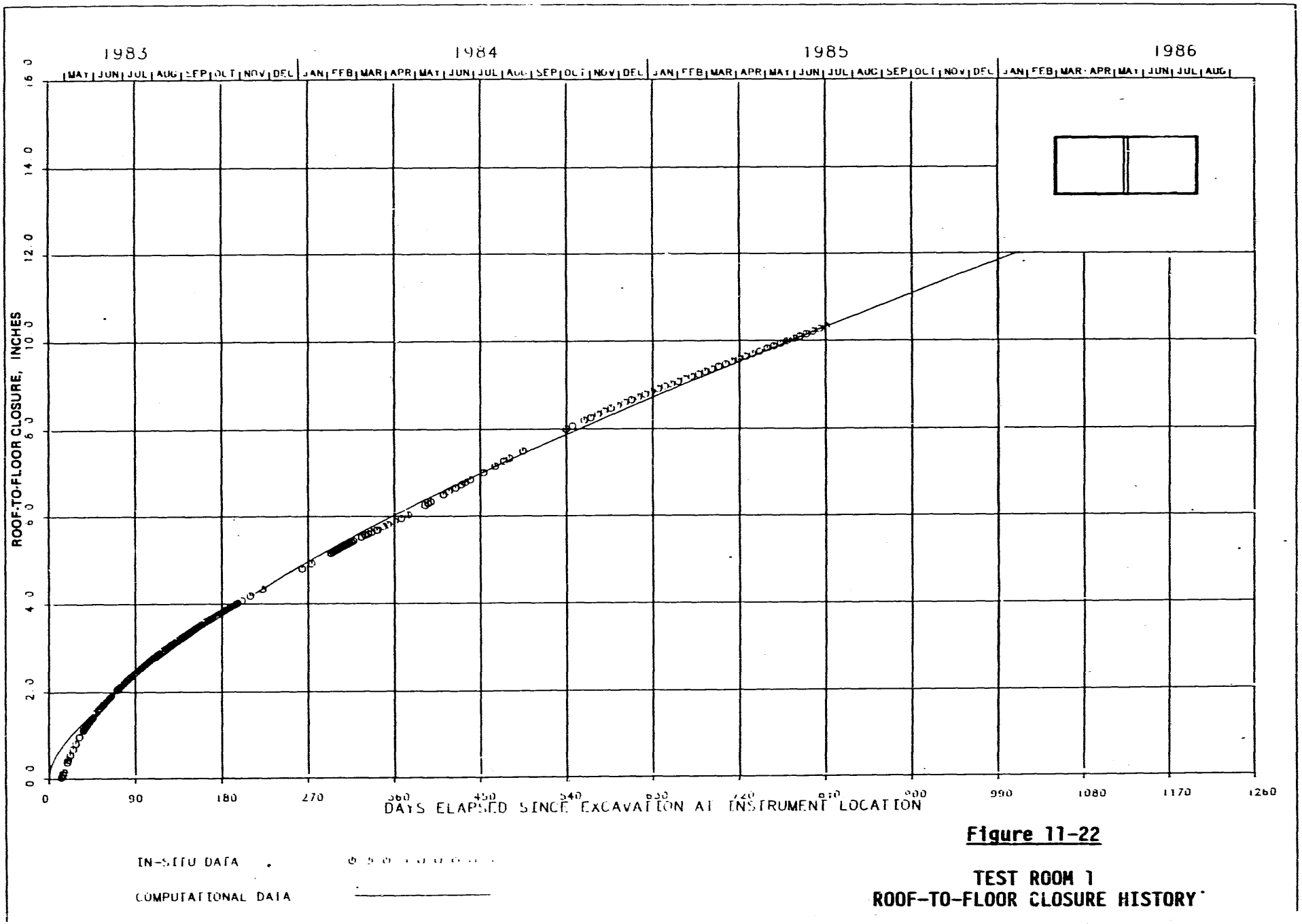


Figure 11-22

TEST ROOM 1
ROOF-TO-FLOOR CLOSURE HISTORY

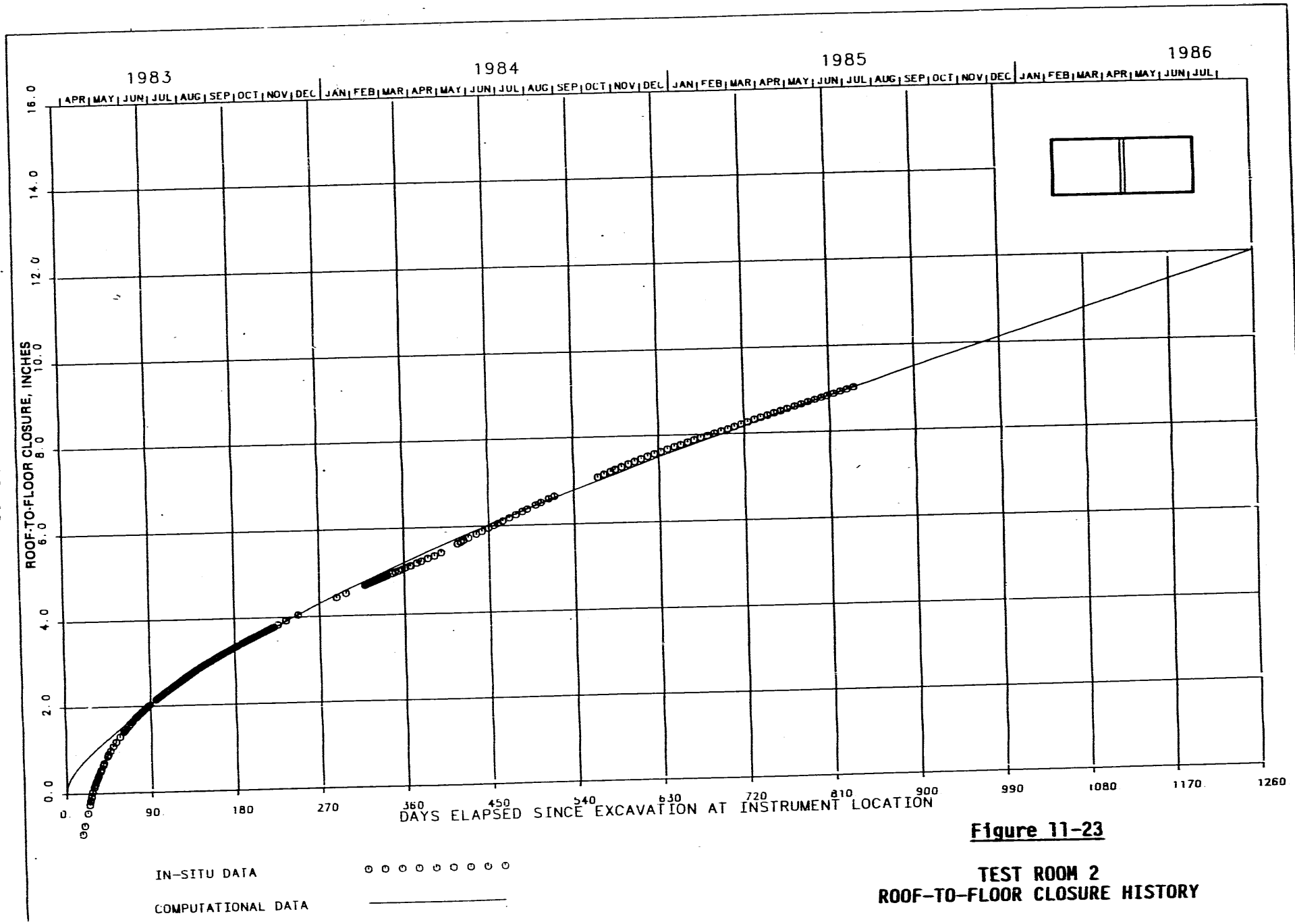


Figure 11-23

TEST ROOM 2
ROOF-TO-FLOOR CLOSURE HISTORY

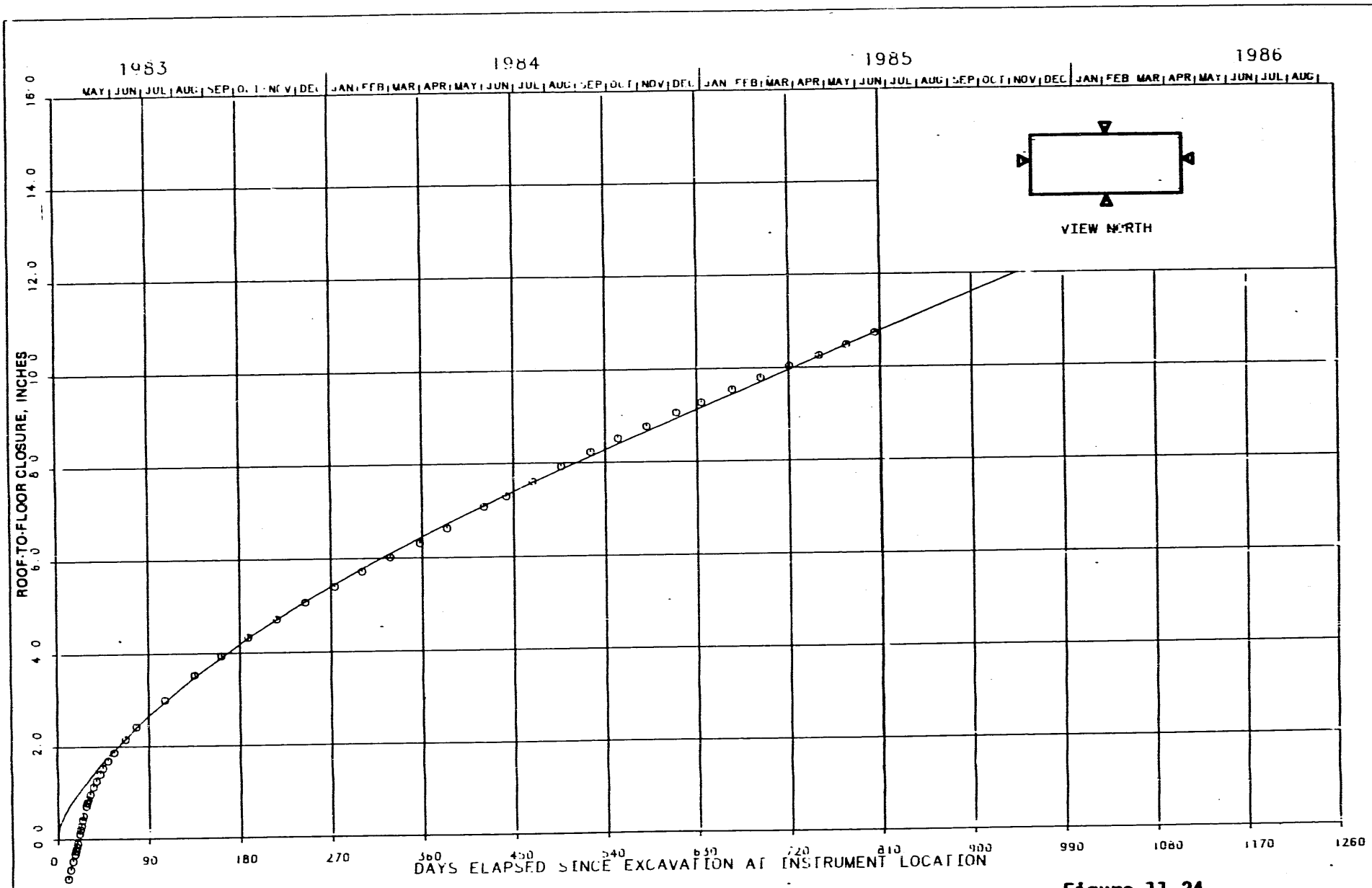


Figure 11-24

TEST ROOM 3
ROOF-TO-FLOOR CLOSURE HISTORY

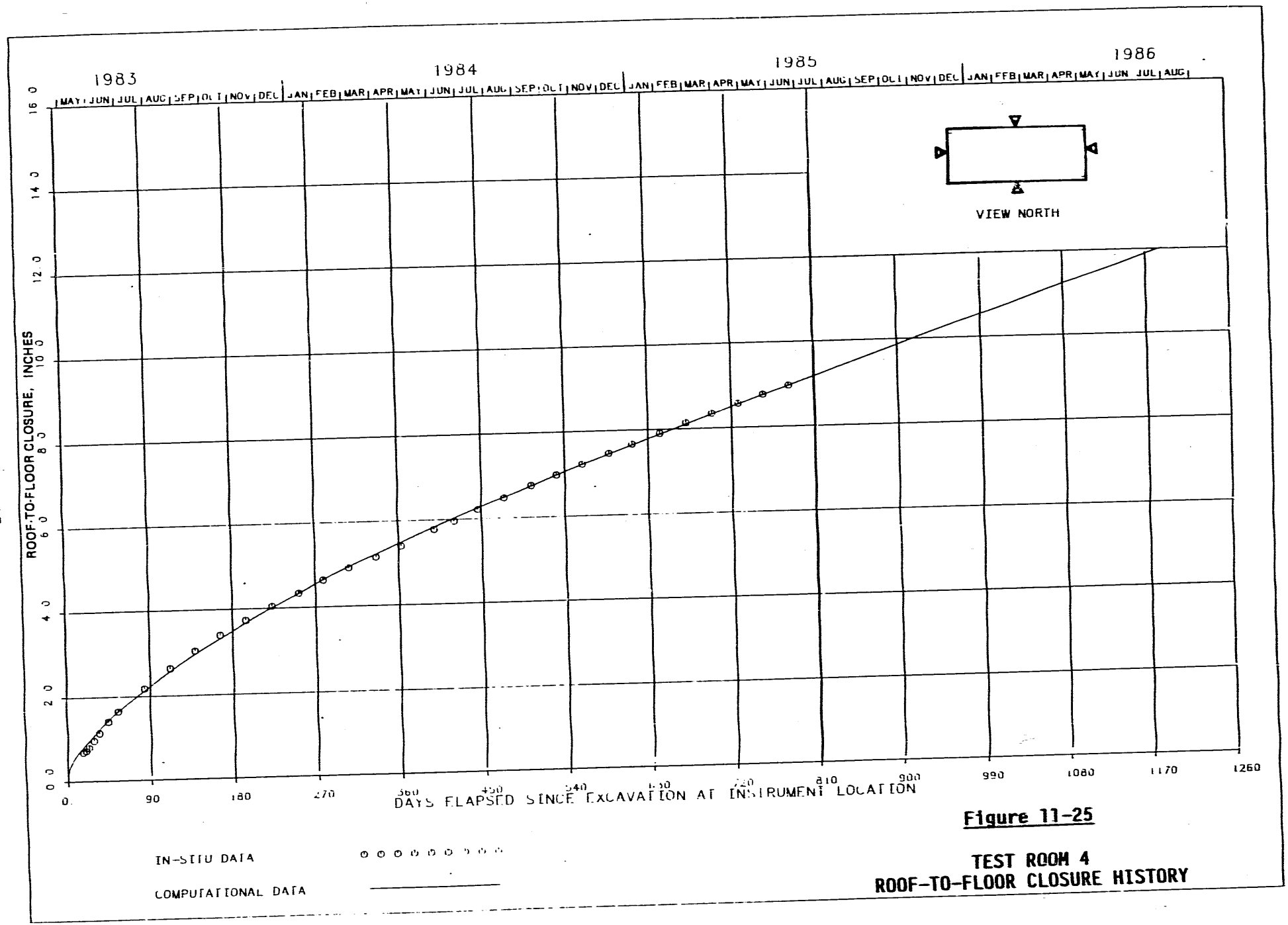


Figure 11-25

TEST ROOM 4
ROOF-TO-FLOOR CLOSURE HISTORY

Table 11-12

TEST ROOM CREEP PARAMETERS
DETERMINED FROM ROOF-TO-FLOOR CLOSURES

Test Room	C ($ksf^{-4.0}sec^{-1}$)	A	z (sec^{-1})
1	3.103×10^{-21}	1.593	4.670×10^{-8}
2	1.919×10^{-21}	1.712	4.782×10^{-8}
3	2.516×10^{-21}	2.077	7.268×10^{-8}
4	2.813×10^{-21}	1.712	5.572×10^{-8}
Mean $\bar{X}$ (Rooms 1 thru 4)	2.588×10^{-21}	1.774	5.573×10^{-8}
Mean $\bar{X}$ (Rooms 1 & 4)	2.958×10^{-21}	1.653	5.121×10^{-8}
Mean $\bar{X}$ (Rooms 2 & 3)	2.218×10^{-21}	1.895	6.025×10^{-8}

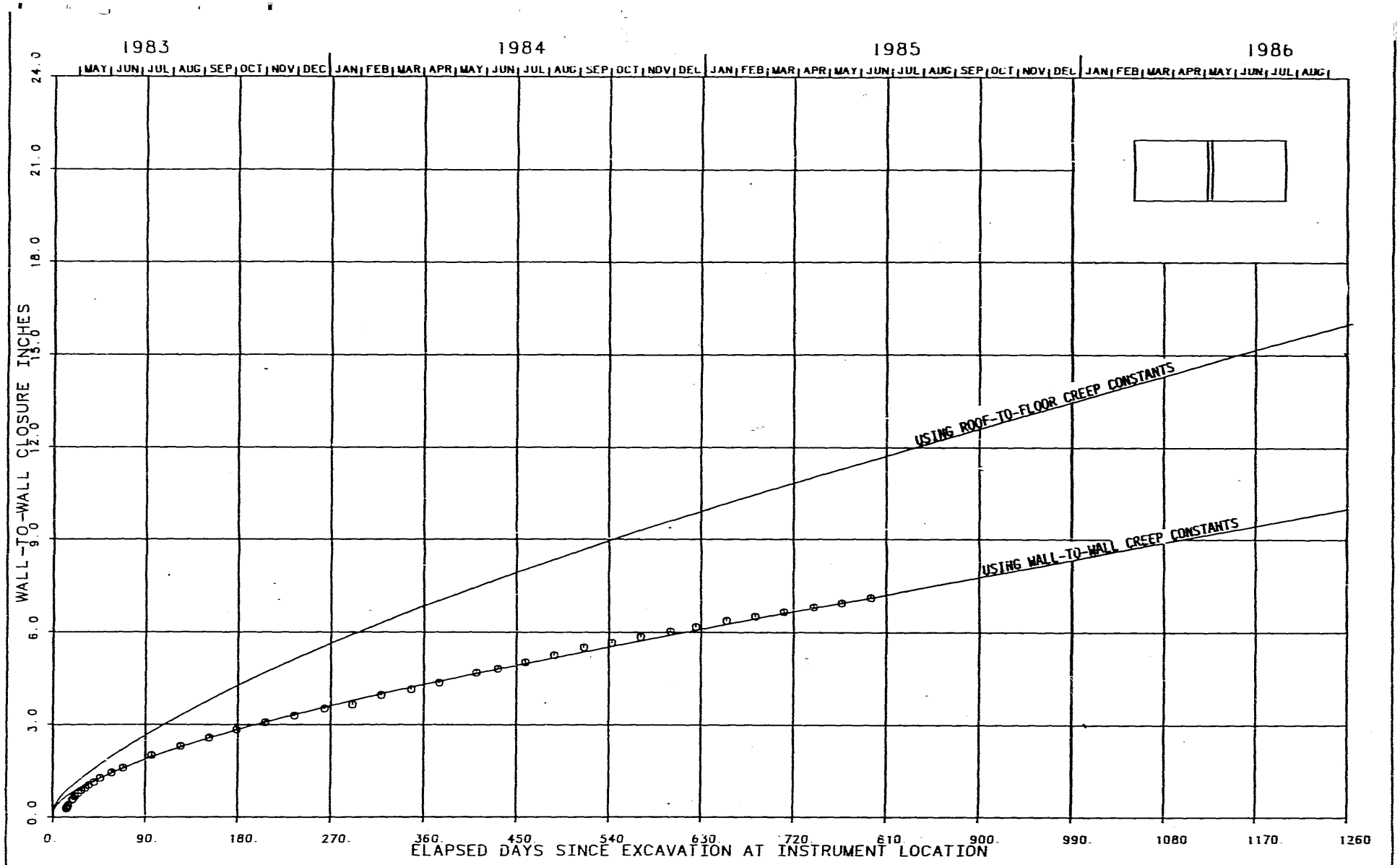


Figure 11-26

TEST ROOM 1
WALL-TO-WALL CLOSURE HISTORY

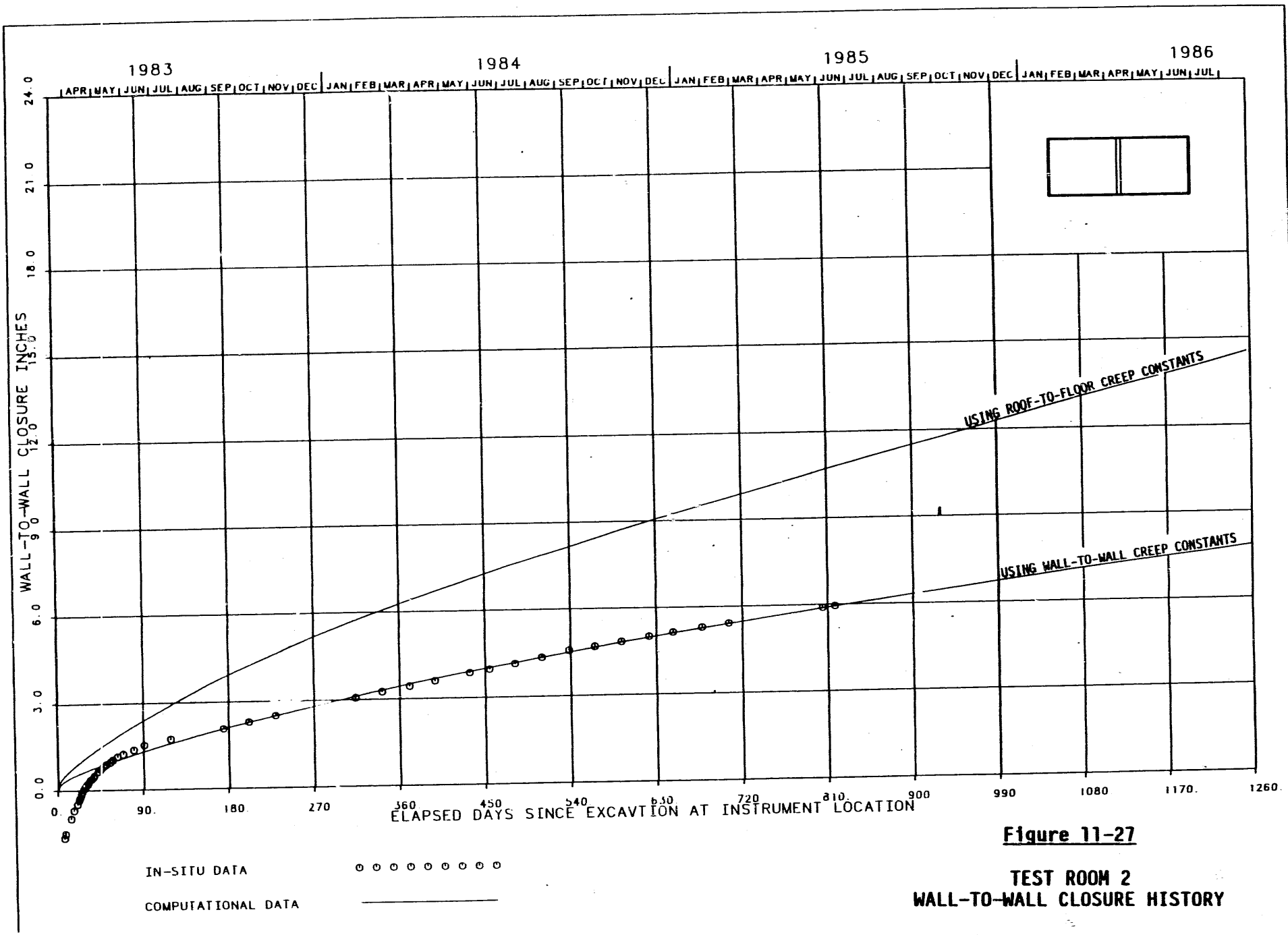


Figure 11-27

TEST ROOM 2
WALL-TO-WALL CLOSURE HISTORY

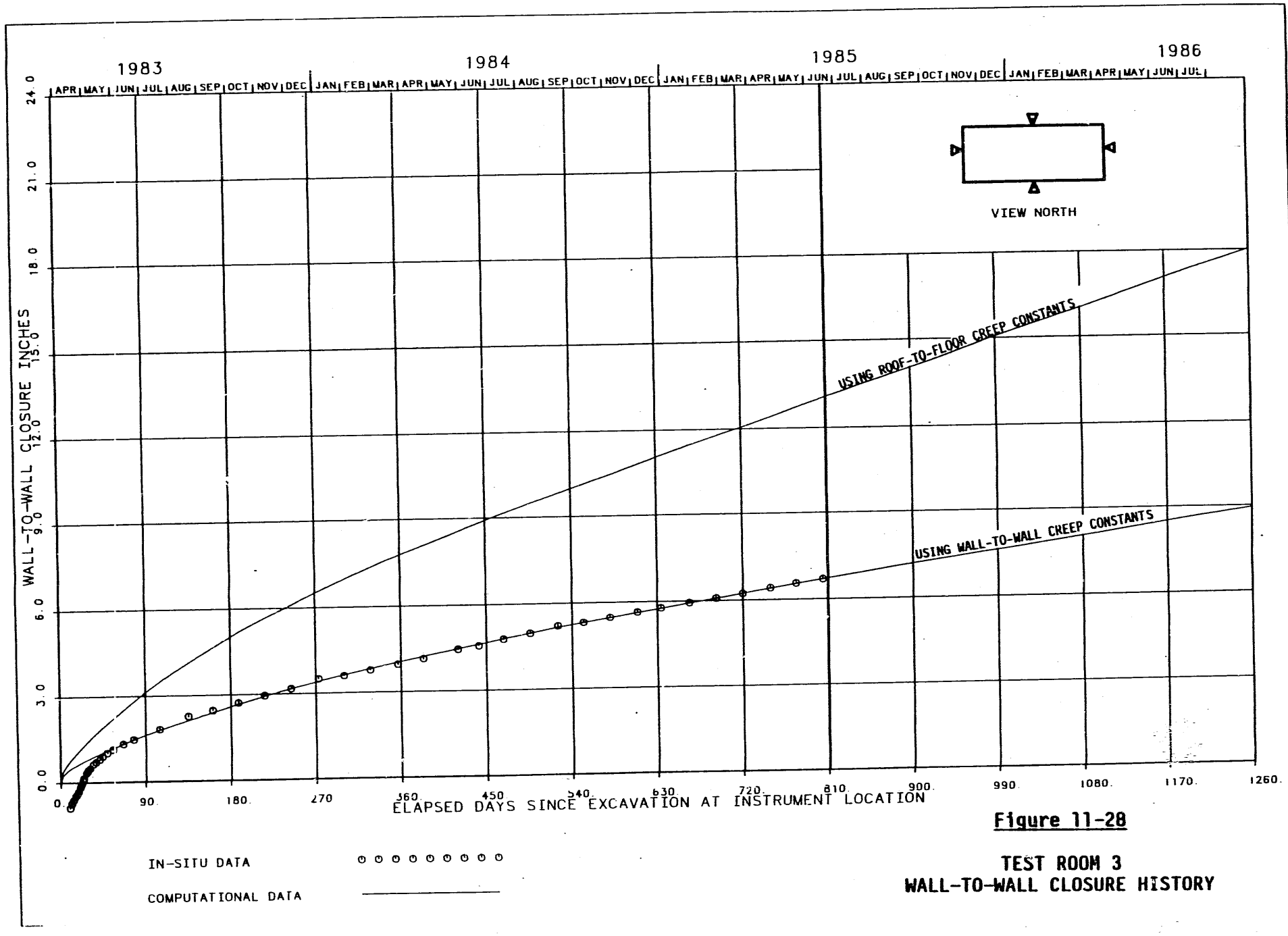


Figure 11-28

TEST ROOM 3
WALL-TO-WALL CLOSURE HISTORY

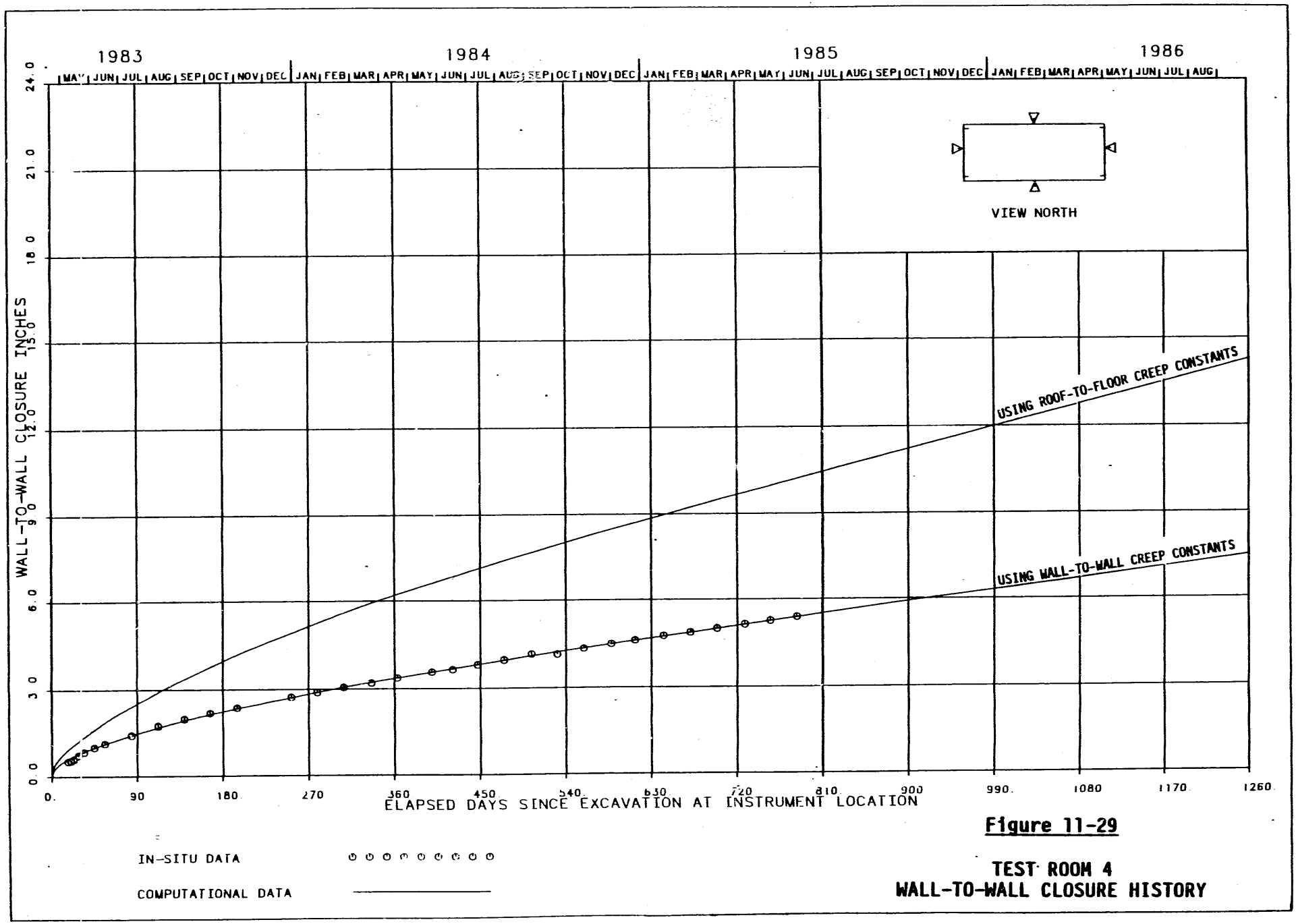


Figure 11-29

TEST ROOM 4
WALL-TO-WALL CLOSURE HISTORY

Table 11-13

TEST ROOM CREEP PARAMETERS
DETERMINED FROM WALL-TO-WALL CLOSURES

Test Room	C ($ksf^{-4.9}sec^{-1}$)	A	z (sec^{-1})
1	2.054×10^{-21}	1.502	6.810×10^{-8}
2	0.850×10^{-21}	1.630	2.476×10^{-8}
3	1.095×10^{-21}	1.920	4.464×10^{-8}
4	1.444×10^{-21}	1.419	5.276×10^{-8}
Mean $\bar{X}$ (Rooms 1 thru 4)	1.361×10^{-21}	1.618	4.757×10^{-8}
Mean $\bar{X}$ (Rooms 1 & 4)	1.749×10^{-21}	1.461	6.043×10^{-8}
Mean $\bar{X}$ (Rooms 2 & 3)	0.973×10^{-21}	1.775	3.470×10^{-8}

As shown in Tables 11-12 and 11-13, the creep parameters obtained for the test rooms using roof-to-floor closure values vary significantly from the values obtained using wall-to-wall closure values. To illustrate these variations, the upper curves on Figures 11-26 through 11-29 show the wall-to-wall finite element responses using creep parameters determined from roof-to-floor numerical correlations. The discrepancy may be partly due to material anisotropy of the salt which is not taken into account in the constitutive relationship for the salt. However, the most important contributor to the discrepancy may be the behavior of the clay seams and anhydrite beds. The model also does not include the complete effects of anisotropic creep behavior due to the combination of different layers in the actual stratigraphy. This behavior, due to anisotropic geometry, can be shown using a simple one-dimensional model similar to the one used by Branstetter et. al. (ref. 11-3). Consider a block of halite containing N horizontal layers with equal thickness. The creep law for each of the layers is assumed to be

$$\dot{\epsilon}_c = f_i(t)\sigma^{-n} \qquad i = 1, 2, \ldots\ldots N \qquad (11\text{-}12)$$

The equivalent vertical creep function computed by considering only the creep relation in the vertical direction can be expressed as

$$f_v(t) = \frac{\sum_{i=1}^{N} f_i(t)}{N} \qquad (11\text{-}13)$$

However, the equivalent horizontal creep function computed by considering only the horizontal direction becomes

$$f_h(t) = \left[\sum_{i=1}^{N} f_i(t)^{-\frac{1}{n}} \right]^{-n} N^n \qquad (11\text{-}14)$$

It was found that, for any problem in which $f_i(t)$ varies, the value of the equivalent creep function in the horizontal direction, based on

equation 11-14, is lower than the value in the vertical direction, based on equation 11-13.

Replication of in situ creep behavior by the finite element model would require extensive research into the existing constitutive equations and perhaps modification of the MARC Finite Element Program. It is believed that the present methodology can adequately predict the roof-to-floor and wall-to-wall closures within acceptable engineering accuracy and that further work into anisotropic creep behavior is not justified for design validation.

One method of determining the structural adequacy of the salt is by using the effective strain. Model simulation of Test Room 2 behavior showed that the effective strain reached a maximum value at the intersections of the walls with the roof and floor. As discussed in subsection 11.3.2.4, bay strains in the vertical direction, determined from roof and floor extensometer data, are on the order of 5 percent through June 1986. Field observations of the test room walls have not found any structural failure at these strain values. Occasional minor, shallow spalls are a continuing occurrence, especially along the upper portion of geologic map unit 4.

Based on the results of the model simulation of Test Room 2, the maximum effective strain at the roof and wall intersection will be 6 percent about 15 years after excavation. The corresponding average vertical strain over a 2-foot thickness of salt will be 15 percent. However, effective strain is not directly measurable. At best, only vertical or horizontal strains can be determined from multiple-point borehole extensometer measurements. A comparison of the predicted vertical strain with the vertical strain determined from the relative displacement between the collar and anchor A of the roof extensometers has been made. Because the collar and anchor A are 5 feet apart, the strain calculated from the relative displacements will be an average value. Similarly, the strain from three elements spanning the collar to anchor A interval were summed and averaged for comparison.

Figure 11-30 shows the comparison for the average vertical strain at the roof and wall intersection. Although the relation is expressed in terms of t*, the relationship between t* and the real time t is approximately linear. The strain determined from the collar to anchor A readings indicates that the rate is currently decreasing with time.

Figure 11-31 shows the relationship for the center of the roof. This rate is also decreasing with time, even though the numerical analysis shows a constant rate.

11.3.2.6 Effectiveness of Model Simulation

The procedure discussed in the previous subsection and in Chapter 5 used roof-to-floor closure data for the test rooms to calculate the creep parameters C, A and z. Extrapolation of creep behavior was then accomplished using these derived creep parameters.

The numerical analysis gives the displacements of nodal points and stresses within the elements. The effectiveness of the model used can be checked by comparing measurement data other than roof-to-floor closure with the magnitude predicated by the model. For example, relative displacements between anchor points in multiple-point borehole extensometers may be compared with predicted relative displacements between appropriate nodes of the model. Such a comparison will be helpful to assess the effectiveness of model simulation.

Because a symmetrical two-room model representing four rooms was used for model simulation, the relative displacement between the collar and the deepest anchor of the central roof extensometers in Test Rooms 1 and 4 were calculated for an interval of 60 days, and the average value determined. The real time t was converted to the normalized time t* using equation C.4-17 in Appendix C. This is because the numerical analysis was performed in terms of the normalized time. The vertical displacements of appropriate nodes in the finite element model, which approximately duplicate the collar and the deepest anchor of the roof extensometers, were compiled. If the nodes did not exactly match the

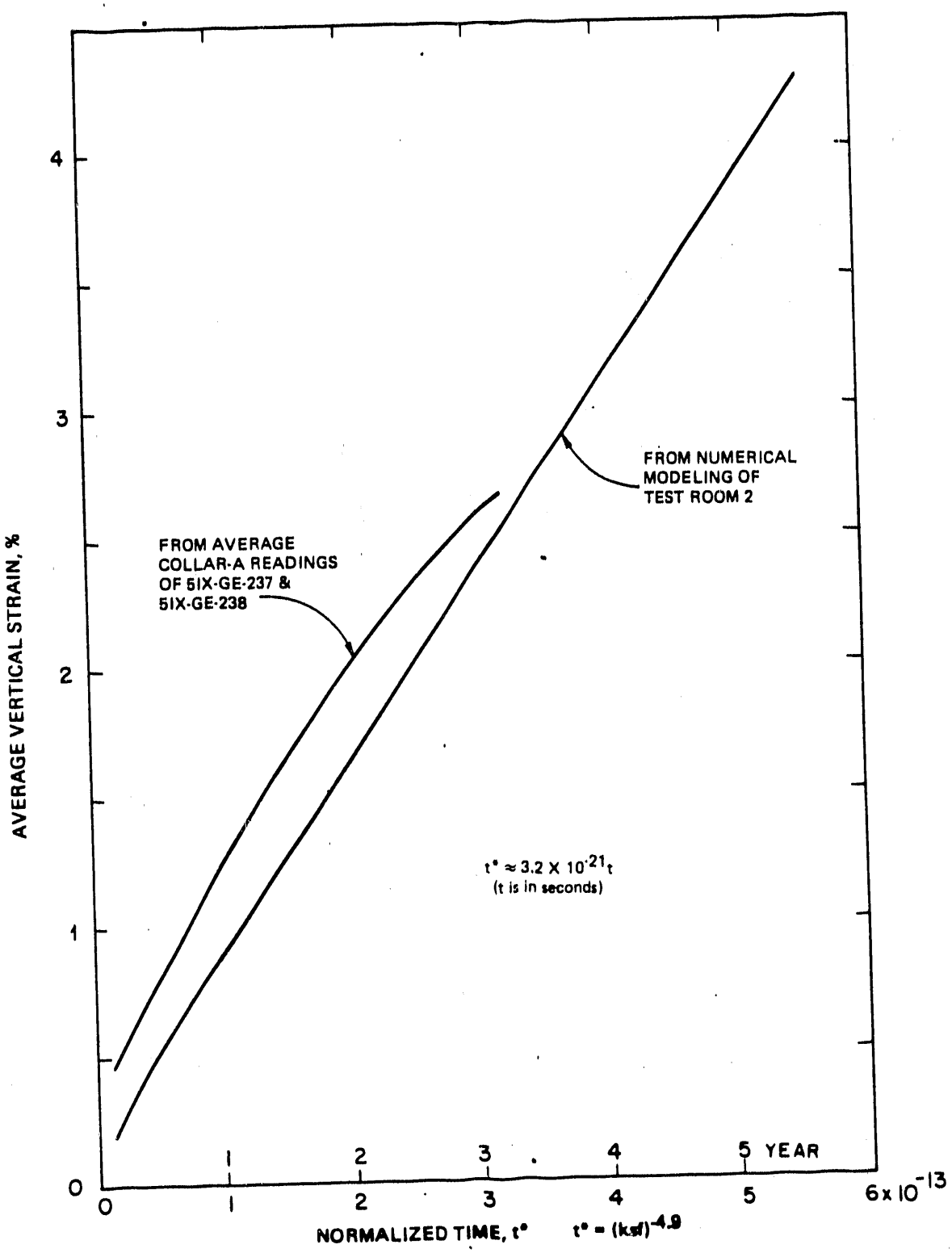


Figure 11-30

TEST ROOM 2
VERTICAL STRAIN AT ROOF AND PILLAR CORNER

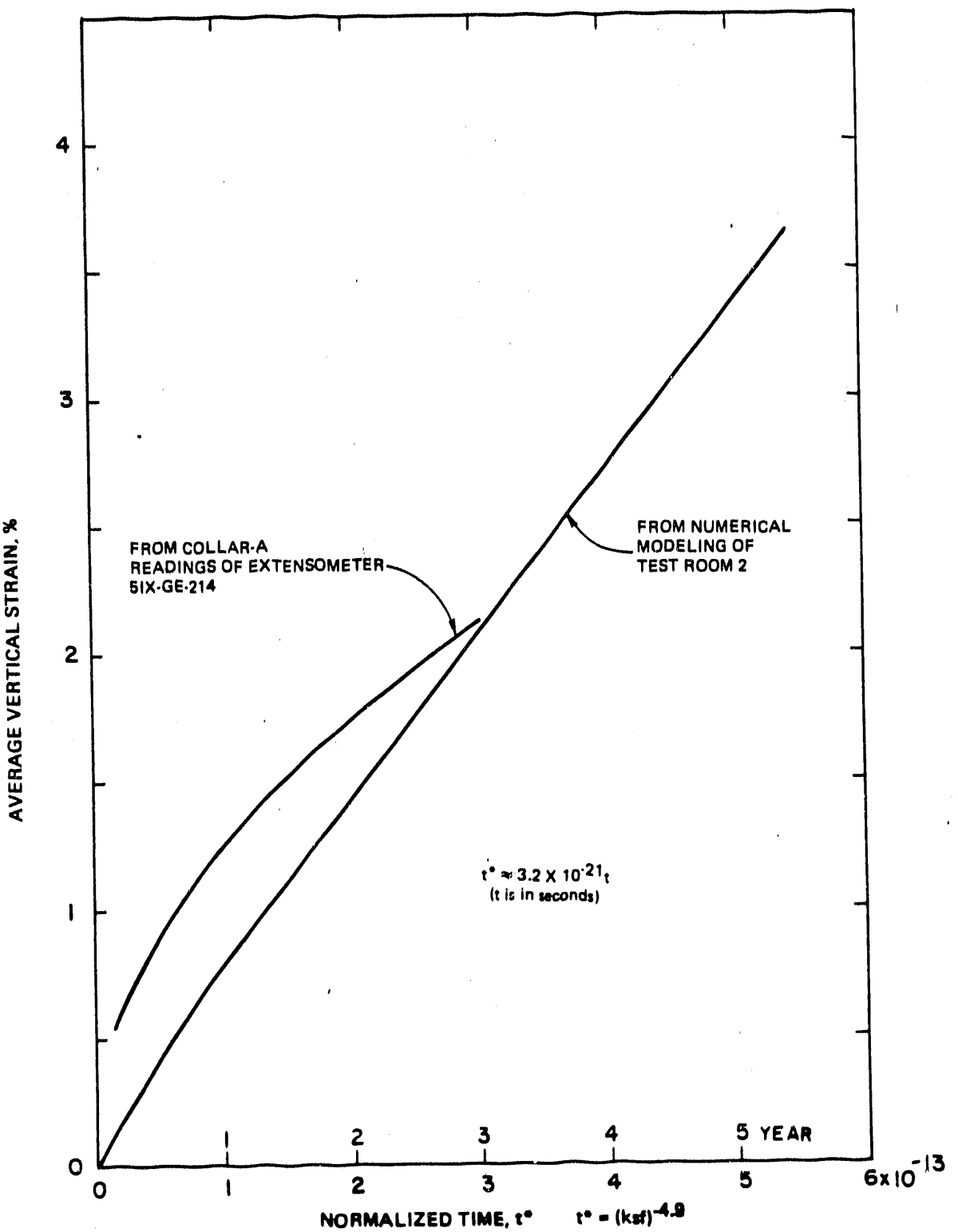


Figure 11-31

TEST ROOM 2
VERTICAL STRAIN AT ROOF CENTER

location of the deepest anchor, then linear interpolation was used to determine the displacement of salt at the required location.

Figure 11-32 compares the average relative displacement between the collar and the deepest anchor for the central roof extensometers 51X-GE-00207 and 51X-GE-00218, with the relative displacement between appropriate nodal points computed from the numerical model. A normalized time t* of 37.07×10^{-14} is equivalent to an elapsed time of nearly 3 years since the completion of excavation at the instrument location. The discrepancy between the measured and calculated relative movements is nearly 2 inches in 3 years.

For large values of t, the normalized time is approximately proportional to the real time, since the exponential term in equation C.4-17 in Appendix C approaches unity. For large values of t* (and t), the calculated relative displacement rate will be approximately 44 percent higher than the measured relative displacement rate if the current rate is maintained. A similar analysis was made for Test Rooms 2 and 3. Figure 11-33 compares the measured values with the values obtained from numerical modeling. The discrepancy in this case is 27 percent with respect to the measured value at nearly 3 years of elapsed time.

A comparison of salt heave measurement data from a floor extensometer in Test Room 4 was made with the values computed from numerical modeling. Figure 11-34 shows the results of this comparison. The numerical model underestimates the salt heave in the floor by approximately 70 percent of the measured value. This discrepancy is probably due to the assumption in the model that MB-139, 4.8 feet below the floor, is elastic and has infinite strength. Measurements from the floor extensometer and observations of fracturing indicate that MB-139 cannot be strictly considered as elastic. As discussed in subsection 11.3.2.1, borehole P4X-84 indicates the presence of lateral displacements and vertical separations in MB-139 beneath the floor of Test Room 4. This indicates that stresses in parts of the anhydrite bed may have reached the failure state.

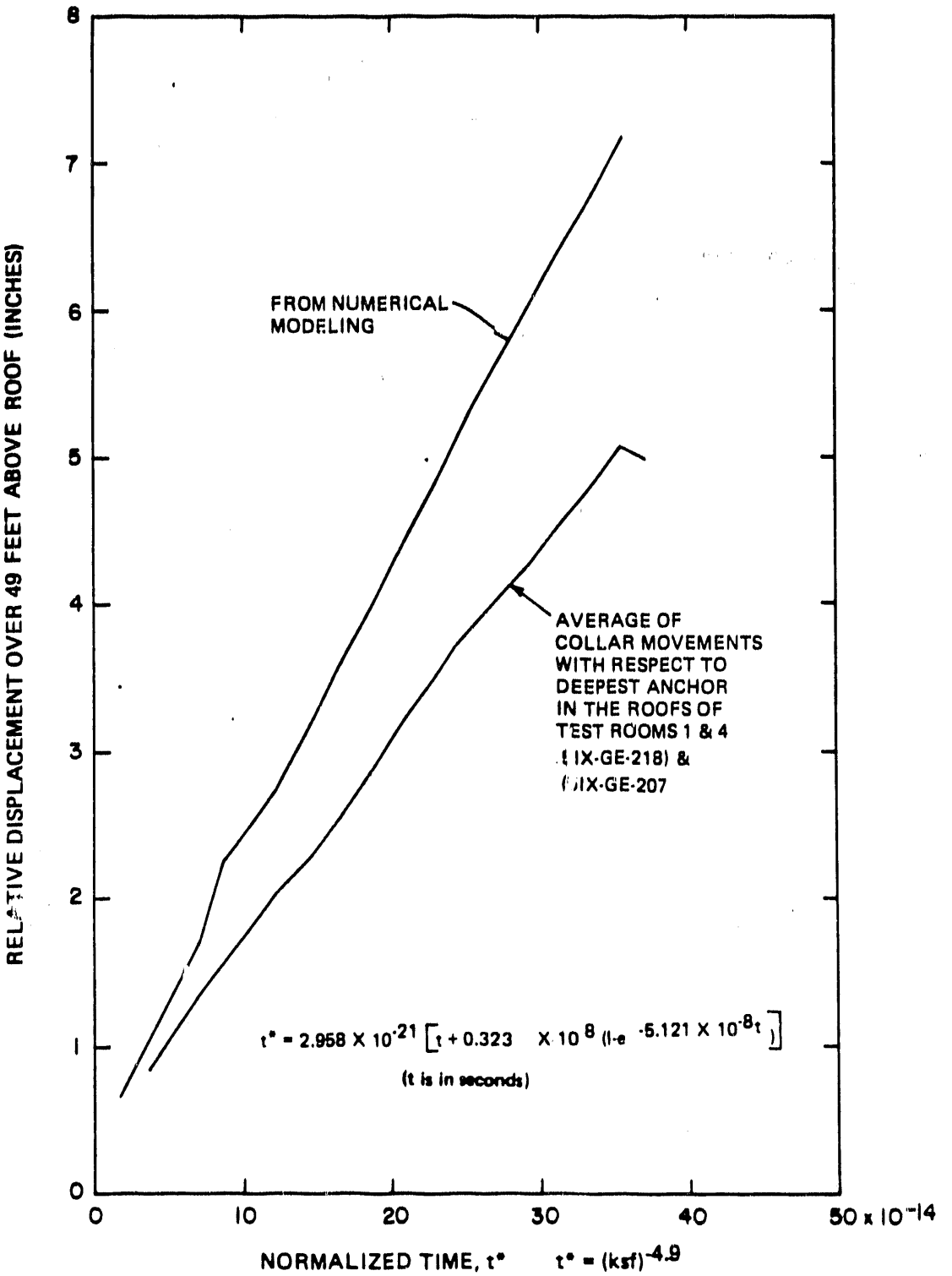


Figure 11-32

TEST ROOMS 1 AND 4 ROOF EXTENSOMETERS
NUMERICAL MODELING VERSUS IN SITU MEASUREMENT DATA

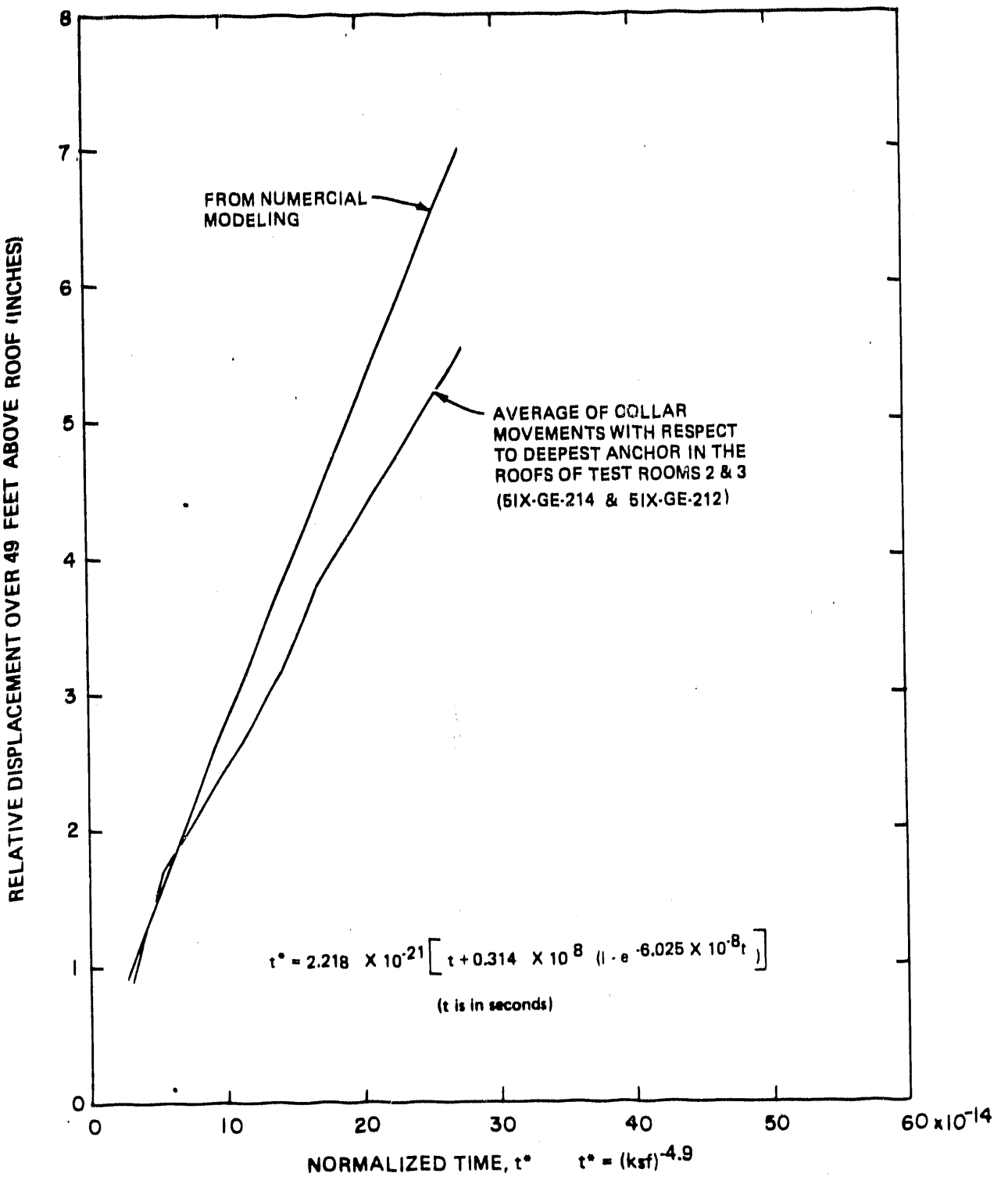


Figure 11-33

TEST ROOMS 2 AND 3 ROOF EXTENSOMETERS
NUMERICAL MODELING VERSUS IN SITU MEASUREMENT DATA

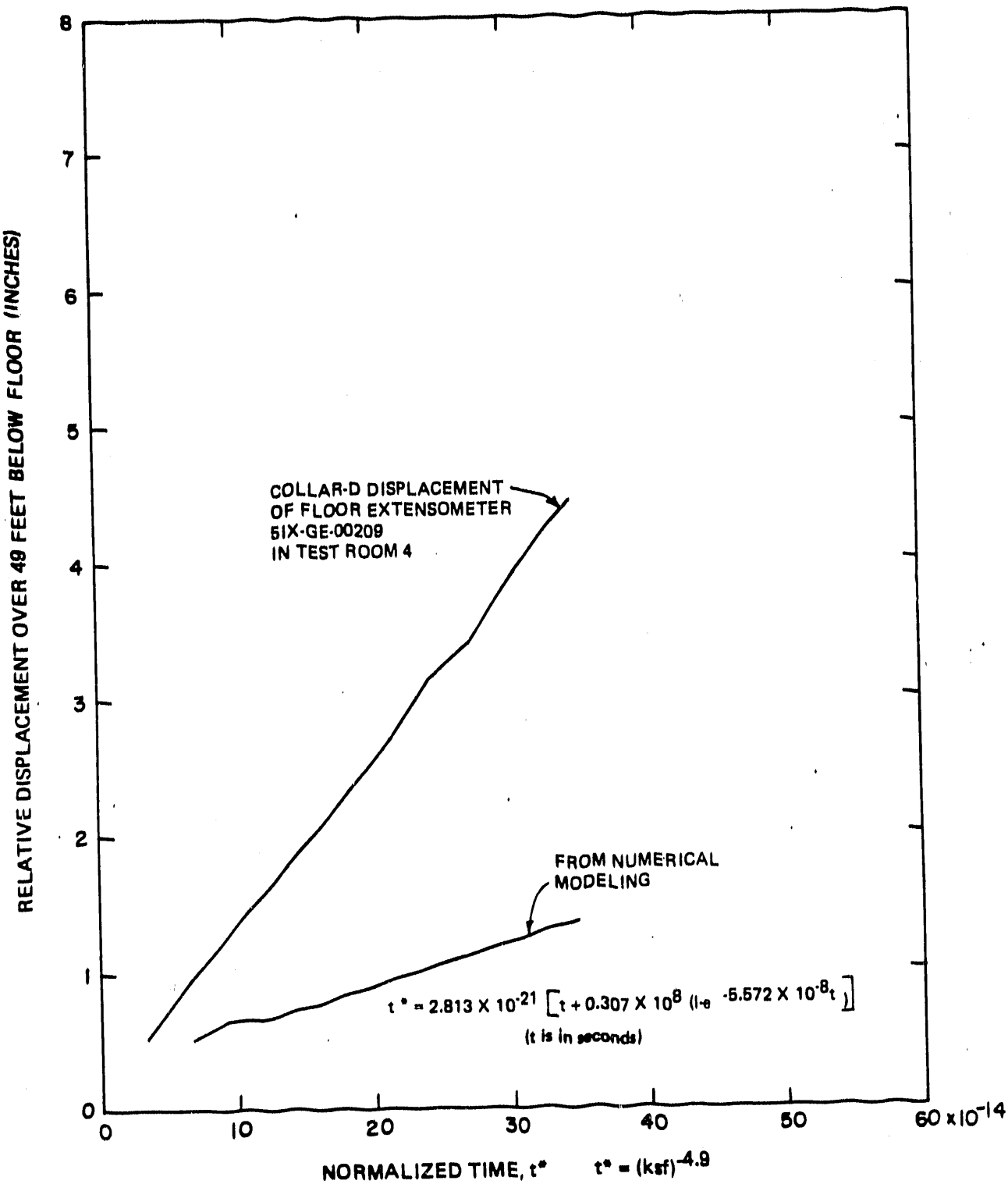


Figure 11-34

TEST ROOM 4 FLOOR EXTENSOMETER
NUMERICAL MODELING VERSUS IN SITU MEASUREMENT DATA

Another possibility is that the fractures might have developed prior to excavation of the test rooms (ref. 6-6). In either case, assumptions of linear elasticity for the anhydrite bed become untenable. Modifications to the material characterization of this anhydrite material will be required to better represent its deformational behavior.

The basic philosophy of the model simulation developed in this report is that in situ measurement data are utilized to back calculate the creep parameters of the salt mass with the attendant discontinuities such as clay seams and anhydrite beds. For the model simulation technique, the in situ roof-to-floor closure data have been used to extract the creep parameters and predict future behavior using these creep parameters. This is because the roof-to-floor closure is deemed critical to evaluate the adequacy of the room dimensions for the effective storage and retrieval of waste. The discussions in the previous paragraphs indicate that there are discrepancies between measured and predicted quantities for variables other than roof-to-floor closure, such as deformations within the salt mass. Such discrepancies are not due exclusively to any inadequacy of the numerical modeling procedure but are also due to differences in the actual and assumed stratigraphy, variations in creep parameters with space and time, and inadequate representation of the stress-strain behavior of the anhydrite bed. However, it has been demonstrated that the model can predict, with sufficient accuracy for engineering purposes, the roof-to-floor closure behavior of the test rooms. A similar model simulation analysis was made for wall-to-wall closure and independent creep parameters were developed. Extrapolation of wall-to-wall closure with time was achieved using these creep parameters. This model simulation technique using in situ data was employed because the more detailed approach using material properties derived from laboratory tests may not produce more accurate results, as discussed in Chapter 5, subsection 5.4.3.

11.3.2.7 Computational Analysis Using Laboratory Test Creep Data

The reference design was based on computations for a single room rather than for multiple rooms. It was assumed that, with a low extraction ratio, the rooms with 100-foot pillars would not have as much early interaction as that which has developed in the four-room test panel. In Figure 11-35 the two lower curves show the computational results of roof-to-floor closure predictions for a 13 x 33-foot room using creep constants obtained from laboratory tests. The bottom curve represents the computational results from reference 11-4, dated August 1982, while the middle curve represents the updated result from reference 11-5, dated March 1985, which used revised creep parameters and an updated reference stratigraphy. In situ closure data for all four test rooms, including adjustments for their early closure, are plotted on the same figure for comparison. Interaction effects may be partly responsible for the discrepancy.

11.4 CONCLUSIONS AND RECOMMENDATIONS

11.4.1 Conclusions

The determination of the closure behavior of the WIPP underground openings using creep constants derived from laboratory experiments underestimated the actual closure. The measured roof-to-floor closure in the test rooms has exceeded 12 inches in the 3 years since the end of their excavation. This does not comply with the design criteria vertical closure allowance of 12 inches in 5 years.

Average vertical strains at roof and wall intersections, as determined from extensometer readings, were close to 3 percent in June 1986 and the strain rate was decreasing. Maximum vertical strain by numerical modeling occurs at roof and wall intersections and compares well with the value determined from in situ measurements.

Spalling from the roofs and walls, and fractures in the pillars and at pillar corners have been observed. Displacements and minor separations have been observed at clay seams and in the underlying halite in

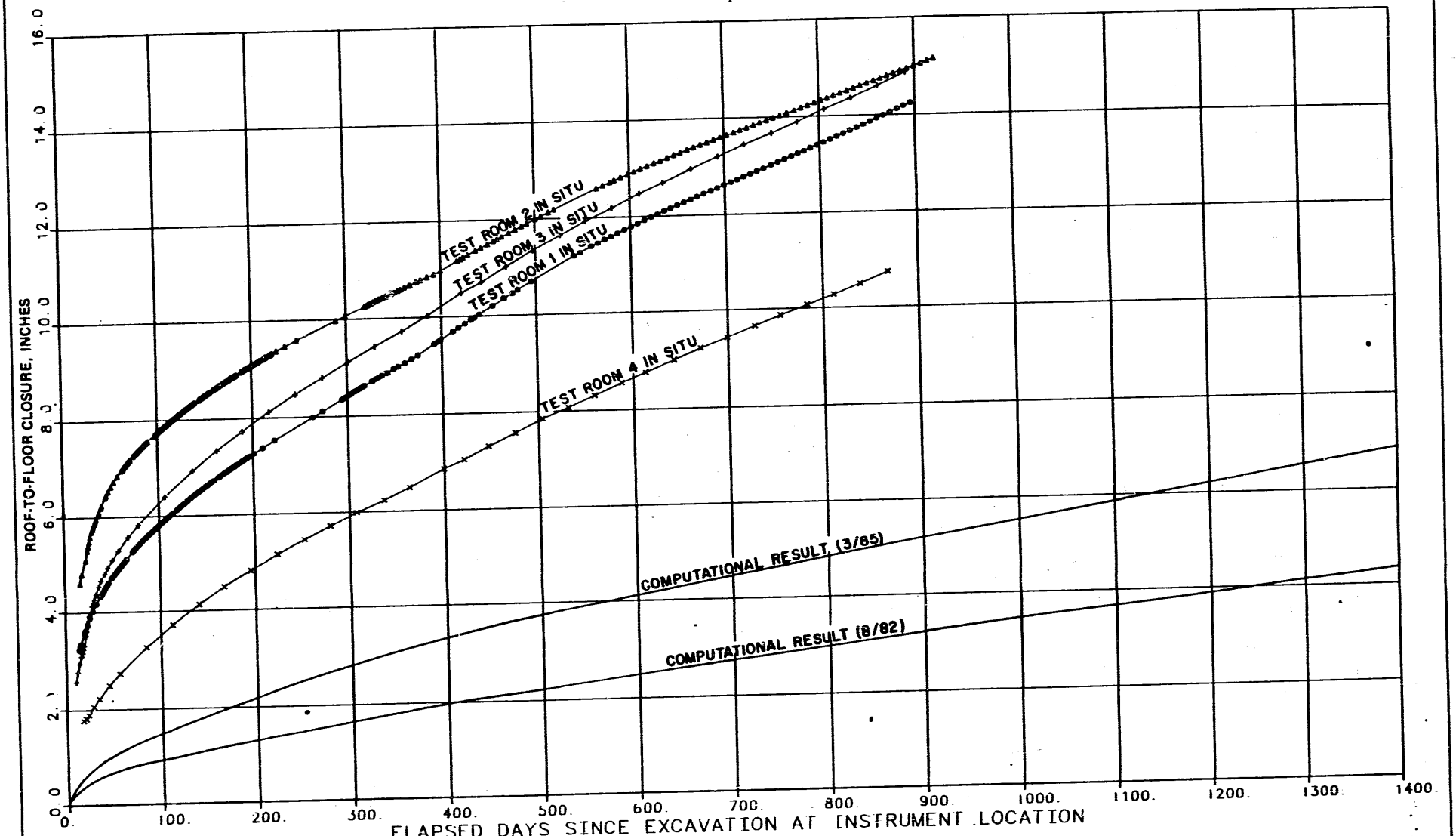


Figure 11-35

TEST ROOMS
COMPARISON OF LABORATORY VERSUS IN SITU DATA

boreholes that penetrate the roofs. These occurrences are expected to continue. Periodic maintenance of the roof and wall surfaces will be required.

Floor fracturing is well developed in the south half of Test Room 3 (Room T). Floor fracturing also occurs to a minor degree in the other test rooms and in a few areas in the drifts. Because the prominent floor fracturing occurring in Test Room 3 has not been found in any other rooms or drifts, it is considered to be anomalous to the underground facility. It is possible that the number and size of the 22 large-diameter holes in Test Room 3 exacerbated the pre-existing fractures. If floor fracturing occurs in the storage rooms, it is not expected to cause any operational or storage problems. As discussed in Chapter 3, Section 3.2, the WIPP project participants agreed, in a meeting on February 13, 1986, that the underground conditions do not require moving the facility level (ref. 3-2).

11.4.2 Recommendations

Observations and geomechanical instrumentation measurements should continue in the test rooms. Because they are the models for the determination of storage room behavior, trimming, rock bolting and other maintenance in the test rooms should be kept to the minimum required for safety, and the rooms allowed to deform.

It is recommended that Test Room 2, in particular, be preserved. It is the only test room that has not been physically altered. This room will then serve as a model for the storage rooms as they will exist prior to waste emplacement. Test Room 2 should not be trimmed or supported except as anticipated for the storage rooms. Additional instrumentation may be installed and small-diameter holes should be drilled in the roof and floor to observe the development of displacements, separations and fracturing. Large-diameter drilling should be prohibited and the room should be closed to all other activities. Continued observations of Test Room 2 behavior will

provide valuable data on anticipated storage room performance for the period between room excavation and the emplacement of waste.

A program of drilling, testing and geologic mapping should be continued to determine the development and extent of fracturing beneath the test room floors. When this has been determined, several monitoring stations should be established to document the behavior of the fractures. This program should also include monitoring roof displacements and separations. Arrays of small-diameter holes should be drilled in a few locations in each test room as soon as possible to document movement above the roof. However, drilling in Test Room 2 should be kept to a minimum.

Additional efforts are needed to refine constitutive laws for the creep behavior of salt as well as the representation of stratigraphy. The stress-strain-time behavior of anhydrite beds should be more accurately represented.

CHAPTER 12
STORAGE AREA

12.1 INTRODUCTION

The storage area encompasses all rooms, drifts and crosscuts that will be used for the permanent storage of CH and RH TRU wastes. The storage area is located south of the waste shaft station, from S1600 to S3664 (see Chapter 1, Figure 1-2, and this chapter, Figure 12-1, for location and layout). The storage area is arranged to provide a system in which CH and RH TRU wastes can be efficiently and safely handled and stored. A panel of four full-scale test rooms was excavated to determine the adequacy of the opening configuration and dimensions (Chapter 11). Evaluation of in situ data from these test rooms were utilized to predict the closures of, and stresses and strains around, the future storage area rooms and drifts.

This chapter presents information on the reference design of the storage area rooms and drifts, the design validation process, conclusions regarding the suitability of the reference design based on the findings of the validation process, and recommendations for modifications to the storage area design configurations that will, if implemented, result in a validated reference design.

12.2 DESIGN

This section presents the design criteria, design bases and reference design configurations that were used for the WIPP storage area rooms and drifts.

12.2.1 Design Criteria

The Design Criteria, RMC-IIA, for the storage area (ref. 2-8) is summarized in Chapter 2, Table 2-1. This table presents the major criteria that governed the WIPP underground opening reference design, including those criteria that require evaluation as part of the design validation process. The following discussion presents a description of

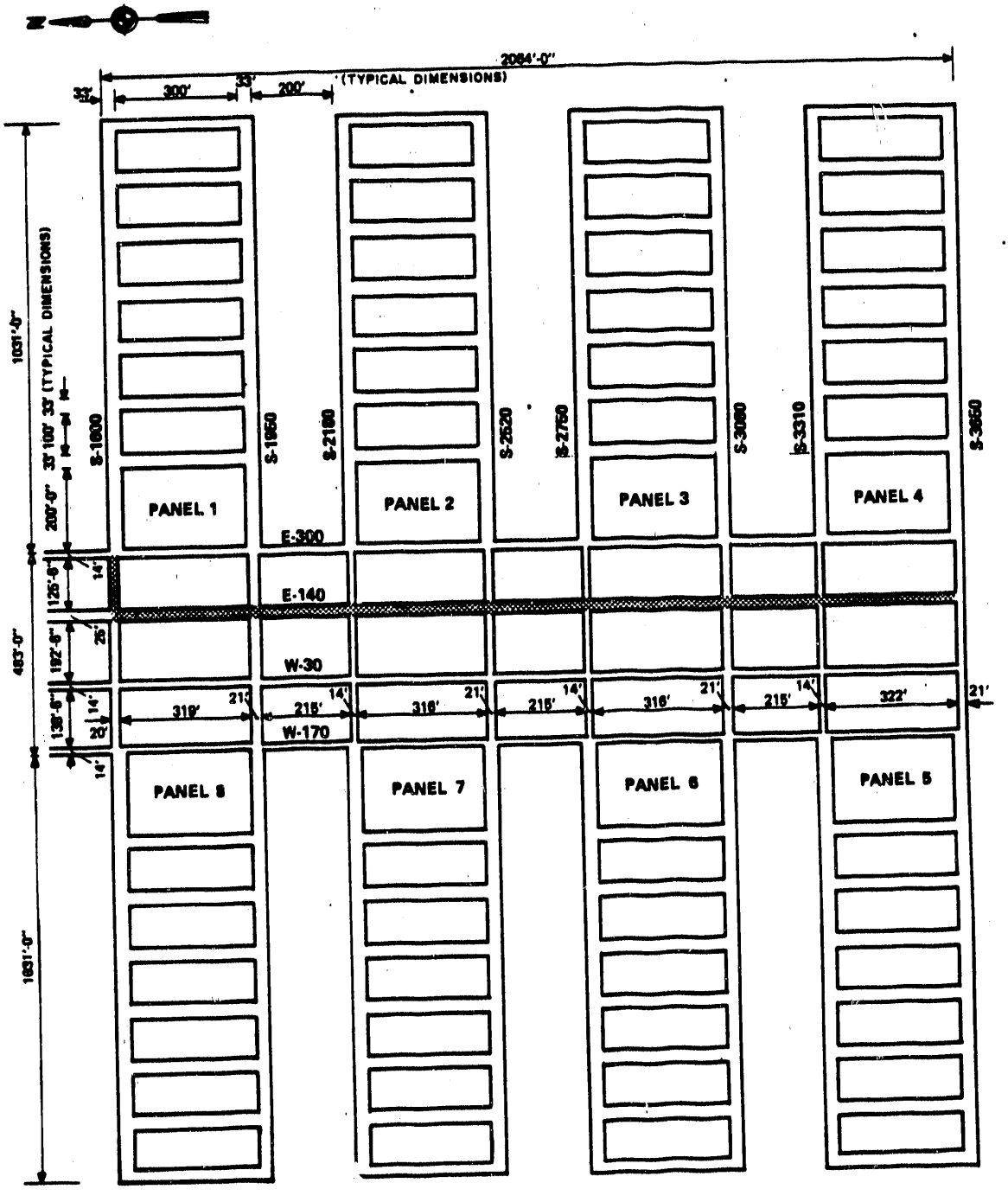


Figure 12-1

STORAGE AREA
REFERENCE DESIGN PLAN

the three design criteria pertaining to the storage area that require evaluation for validation of the reference design.

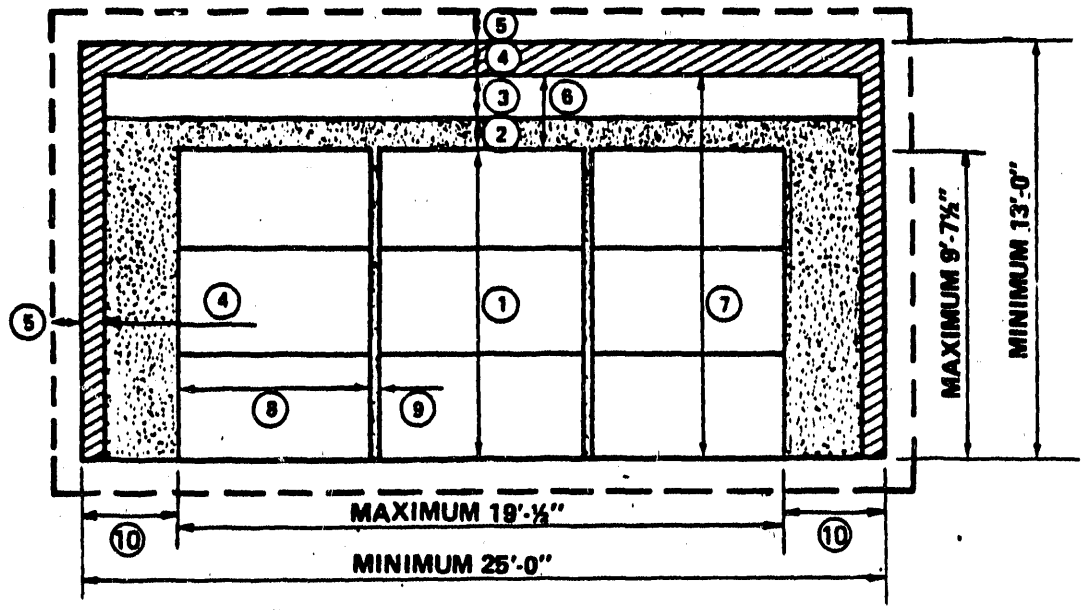
The first criterion requires that the excavation dimensions of the storage area rooms and drifts include an allowance for creep closure sufficient to prevent container breaching by creep-induced stresses during the retrievability period. The second criterion states that each storage room shall allow for salt creep and shall be sized to minimize breaching of the CH waste containers for a period of 10 years. The third criterion states that the underground storage rooms and access drifts shall be designed to be compatible with the waste transport vehicle, with the waste container sizes, shapes, weights, and stacking configurations, and with the waste handling and backfilling equipment requirements.

Other criteria that apply to the storage area reference design also apply to the drifts and were discussed in Chapter 10.

12.2.2 Design Bases

The design bases describe the specific dimensional requirements used to develop the reference design for the storage area drift and room configurations (Figures 12-2 and 12-3). The Design Basis, Underground Excavations (ref. 2-18) contains the bases used for the storage area reference design. The major elements from this Design Basis document are summarized in the following discussion. Although other design bases were also used, they did not have a direct impact on design validation. The specific design bases requiring evaluation during the validation process are presented in Table 12-1.

The design bases specify that the reference design shall provide an underground storage area in which CH and RH TRU wastes can be efficiently handled and stored. The reference design of the waste storage area shall permit simultaneous storage of CH and RH TRU wastes. To the extent possible, the configuration of the storage area shall minimize haulage distances for excavated salt and waste storage.



EXPLANATION

(1) HEIGHT OF WASTE PACKAGES STACKED THREE HIGH: 9'-7 1/2" FOR BOXES; 9'-0" FOR SIX PACKS.

(2) SALT COVER: 1' TO 2'; LEVEL OF SALT IS MAINTAINED AT 10'-8" ABOVE THE FLOOR.

(3) VENTILATION SPACE: 1'-4" MINIMUM UNTIL ROOM OR PANEL IS FILLED AND PLUGGED.

(4) SALT CREEP ALLOWANCE: 1'-0" ROOF; 4 1/2" EACH WALL (ASSUMED TO BE ADEQUATE FOR 5 YEARS).

(5) CONSTRUCTION TOLERANCE: +6". THE CONTRACTOR MUST MAINTAIN THE MINIMUM ROOM DIMENSIONS.

(6) BACKFILLING CONVEYOR CLEARANCE: 2'-4" ABOVE WASTE PACKAGES.

(7) HEADROOM: 12'-0" FOR CH BOXES AND RH TRANSPORTER.

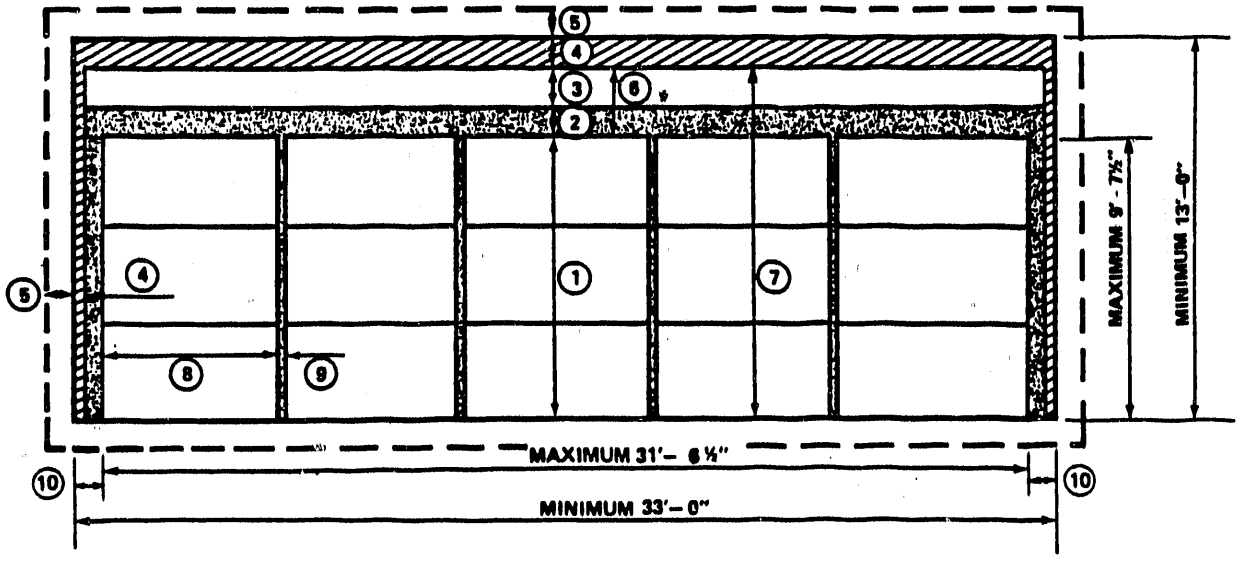
(8) WASTE PACKAGE WIDTH: 6'-2 1/2" FOR BOXES; 6'-1 1/2" FOR SIX PACKS.

(9) STACKING TOLERANCE: 2 1/2" BETWEEN WASTE PACKAGES.

(10) SALT BACKFILL: 3'-0" BETWEEN WASTE PACKAGES AND WALL.

Figure 12-2

STORAGE AREA
DRIFT REFERENCE DESIGN DIMENSIONS



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(9) STACKING TOLERANCE: 2 1/2" BETWEEN WASTE PACKAGES.

(10) SALT BACKFILL: 8 3/4" BETWEEN WASTE PACKAGES AND WALL.

Figure 12-3

STORAGE AREA
ROOM REFERENCE DESIGN DIMENSIONS

Table 12-1

VALIDATION ELEMENTS OF STORAGE AREA DESIGN BASES

(1) Operational requirements

a. The storage area rooms, drifts and crosscuts shall be designed to allow for retrieval of all CH and RH waste stored for a period of up to 5 years after the initial emplacement of each waste species.

b. Excavation dimensions in the waste storage area shall be to a uniform height of 13 feet.

(2) Essential features

Provide 1 foot vertical and 9 inches horizontal allowance for creep closure to maintain the minimum design dimensions up to 5 years after initial emplacement.

(3) Safety design requirements

A minimum opening of 16 inches shall be left at the top of the rooms and drifts for air passage above the waste and backfill.

Construction and storage operations shall be physically separated and performed during different shifts.

Each storage room is to be filled with waste containers consisting of six-packs of CH TRU waste storage drums and/or boxes of CH TRU waste. The containers shall be stacked three high and five wide, stored with their longest dimension across the opening. A 2 1/2-inch stacking tolerance shall be allowed between waste packages. All rooms, drifts and crosscuts in the storage area may be used to store CH waste containers stacked three high. For this reason, excavation shall be to a uniform height of 13 feet throughout the waste storage area.

The underground storage area shall provide for the horizontal emplacement of 1,000 RH canisters. The RH canisters, nominally 10 feet long and 26 inches in diameter, shall be stored in the salt pillars. Emplacement holes shall be perpendicular to the walls, approximately midway between the floor and ceiling and evenly spaced laterally. Canister spacing shall be based on the assumption that the average heat output per canister will be 60 watts or less. Thermal loading in the RH waste storage area shall not exceed 10 kilowatts (kw) per acre. Allowing 12 inches for salt creep, RH waste emplacement machinery shall be designed to operate in an effective room height of 12 feet, including all required clearances.

The storage area floor shall be approximately 2,150 feet below the ground surface. The final level of the excavations shall be as determined by the DOE Contracting Officer.

Four parallel entries shall be provided from the shafts to the waste storage area. These entries shall provide separate channels for air intake and exhaust, salt removal, and waste storage.

Excavation dimensions shall include an allowance for salt creep of 1 foot in the vertical direction and 9 inches in the horizontal direction for all rooms for up to 5 years. The tolerance for excavation of roof,

floor and wall surfaces shall be no greater than plus 6 inches. In no case shall the finished cross section dimensions be less than the design dimensions.

Provision shall be made for the expansion of the storage area within the boundaries of Zone II (Chapter 1, Figure 1-1) if required in the future. The area extraction ratio in the storage area shall not exceed 25 percent.

The stored CH TRU waste packages shall be covered with a layer of salt backfill (3/8 inch or less in grain size) for fire protection. The volume of stored CH TRU waste in any one compartment without a vertical fire barrier shall be limited to a maximum of 500,000 cubic feet. For ventilation above the backfilled waste, a minimum opening of 16 inches shall be provided.

No personnel may work in air that has passed over the stored CH TRU waste. However, personnel may work in air that has passed through an opening where RH TRU waste has been emplaced provided that canister holes have been sealed with plugs. Personnel may not work in air that has passed through openings where RH TRU waste is being emplaced.

12.2.3 Design Configuration

The reference design of the storage area was developed in accordance with the design criteria and the design bases. The design configuration is based on the stratigraphy determined from borehole ERDA-9 and on salt creep performance determined from laboratory tests on core extracted from ERDA-9. The ERDA-9 exploratory hole was the only hole within the underground development area which was permitted to penetrate the Salado formation to the underground facility horizon.

The storage area reference design configuration (Figures 12-1, 12-2 and 12-3) consists of eight panels with seven rooms each. The rooms are 13 feet high, 33 feet wide and 300 feet long. The panel entries are also 13 feet high and 33 feet wide. The rooms are separated in each panel

by 100-foot wide pillars and the panels are separated by 200-foot wide pillars. The test rooms discussed in Chapter 11 were designed to be the same size as the storage rooms. The test rooms were constructed to monitor salt performance, permit observations of opening stability, and to permit validation of the storage room reference design.

The reference design provides for the storage of CH waste in one room while RH waste is stored in another room. Emplacement of RH waste canisters into horizontal holes is depicted on Figure 12-4. After the RH waste canisters are emplaced in the walls of the storage room a shield plug is placed in the wall sleeve. When the emplacement of RH waste canisters is completed in the storage room, CH waste can be stored in the same room. During the 5-year demonstration period, the RH waste canisters are stored in steel sleeves in the first room of Panel 1. During permanent storage, they are emplaced in pillars throughout the storage area as dictated by the receival rate of the waste.

The RH waste canisters (with a heat output of 60 watts or less) are placed in horizontal holes spaced so that the local storage area thermal loading does not exceed the design basis limit of 10 kw/acre. For the reference design, and for this report, the thermal effects on storage room behavior were not considered significant. The reference design for RH waste is subject to the results of the ongoing WIPP experimental program.

The reference design configuration also defines stacking configurations and tolerances for ventilation, backfill and salt creep. These tolerances are shown on Figures 12-2 and 12-3 for the storage area drifts and rooms, respectively. In order to meet these requirements, the reference design configuration incorporates a reference operating procedure. This procedure is based on the waste receipt rates, emplacement rates, and retrieval rates stipulated by the design criteria. This operating procedure is part of the storage room reference design and is incorporated in construction package EP-01X.

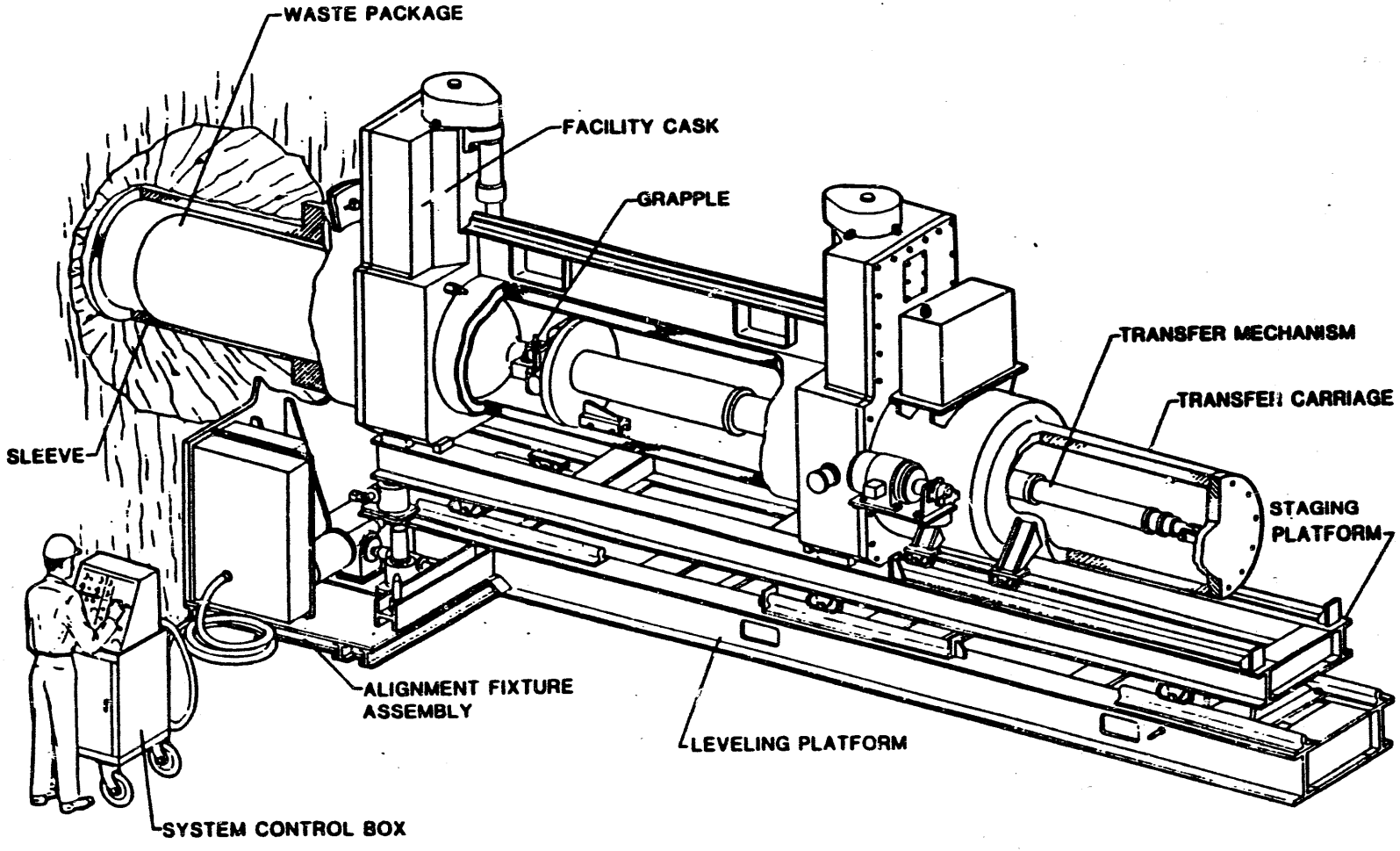


Figure 12-4

STORAGE AREA
HORIZONTAL EMPLACEMENT OF RH WASTE

This package contains the design documents that will be used to operate the WIPP.

12.3 DESIGN VALIDATION PROCESS

The design validation process for the storage area consists of the evaluation of numerical modeling and data analysis from the drifts and test rooms (Chapters 10 and 11) and its application to the reference design of the storage area drifts and rooms. The predicted future performance of the storage area openings was compared to the performance of existing openings having comparable dimensions. This was then used as the upper bound for validating the reference design.

12.3.1 Data Collection

Geomechanical instrumentation data collected from the test rooms were used to compute the creep parameters of the surrounding salt. Geologic mapping and drill cores from the underground facility were used to confirm the stratigraphy of the storage area. Test room instrumentation data and the computation of creep parameters are presented in Chapter 11. Chapter 6 presents information on the geologic mapping, drill cores and development of the reference stratigraphy.

The geomechanical instruments in the test rooms have provided deformation measurements and response data on the excavated openings. Periodic visual inspections of the rooms have provided observational data with which to further evaluate the response of the surrounding salt. Geologic mapping and core drilling in the E140 drift south of the waste shaft have provided information on the stratigraphy in the storage area.

12.3.2 Analysis and Evaluation

12.3.2.1 Storage Rooms

Analysis and evaluation of the storage room reference design have been performed using data collected from the test rooms. The adequacy of

the reference design was evaluated by analysis of the geomechanical behavior, including stress, strain and deformation, which could be expected to occur over the operating life of each room. The operating life is defined as the period of time from initial excavation of the room until retrieval operations are completed, if the decision to retrieve is made, or until the storage operation for each panel is completed.

Evaluation of the geologic mapping and drill cores from the E140 drift south of the waste shaft has confirmed the continuity of the stratigraphy 50 feet above and below the storage area (refs. 4-1 and 4-2).

Based on an engineering approach (Chapter 5), numerical analyses were performed based on creep parameters determined from test room data and the stratigraphy surrounding the facility level. Because the extrapolation of the in situ closure data for the drifts and test rooms indicates that more than four rooms in a storage panel could influence the total closure and overall creep rate, a mathematical model was developed to estimate the upper bound responses. This requires assuming an infinite array of equally spaced storage rooms such that the centerline of a typical room and the centerline of any one of its pillars form axes of symmetry. In addition, the rooms were assumed to be infinitely long.

Figure 12-5 shows the finite element model that was used to determine the responses for an infinite array of infinitely long storage rooms. The model has 94 nodes and consists of 59 plane strain elements, with gap/friction link elements having a friction coefficient of 0.4 to model a clay seam. Because test room creep parameters are used in predicting the responses of the storage rooms, this model uses the same comparative element sizes and external loads as those used in the test room model described in Chapter 11, Section 11.3. The boundaries on both sides of the model were taken as vertical axes of symmetry to represent the pillar centerlines and consist of horizontal restraints.

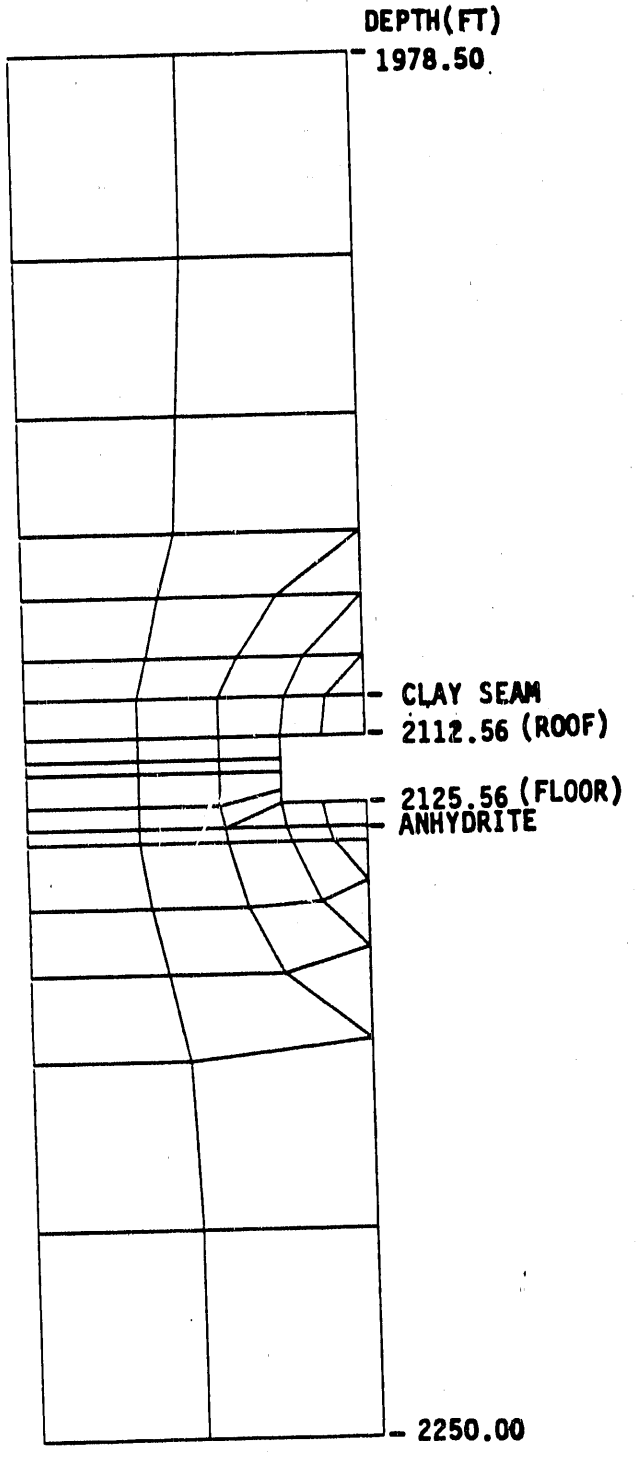


Figure 12-5

STORAGE AREA
ROOM FINITE ELEMENT MODEL

Elevations at the top and bottom of the model, the clay seam, the anhydrite bed, and the roof and floor of the room are based on the reference stratigraphy and are identical to those used in the test room finite element model.

The analyses were performed using the MARC General Purpose Finite Element Program discussed in Chapter 6. The average values of the creep parameters were derived from test room roof-to-floor and wall-to-wall in situ closure data. Using these computed creep parameters, previously presented in Chapter 11, Tables 11-10 and 11-11, the predicted future responses of the storage rooms were computed. The results of the analyses are presented below.

12.3.2.2 Storage Area Drifts

Analysis and evaluation of the 13 x 25-foot drift design for the storage area have been performed using data collected from the existing 8 x 25-foot drifts. The same finite element model used for the 8 x 25-foot drifts (Chapter 10) was used for the larger drifts. A removable floor section extending 5 feet vertically downward from the original floor level was integrated into the model so that this group of elements could be removed at the appropriate stage in the analysis to simulate floor excavation. A coefficient of friction of 0.0 was assumed for the gap/friction elements to model a clay seam. The time between initial excavation and the subsequent floor excavation was assumed to be 2 years. Therefore, all results presented in the following subsection are directly affected by these assumptions. Figure 12-6 shows the model after removal of the floor elements.

12.3.3 Prediction of Future Behavior

12.3.3.1 Storage Rooms

Because the room size and panel configuration of the four test rooms is similar to the design of the proposed storage rooms, the behavior of the storage rooms was computed using the measured data from the test rooms, as presented in Chapter 11. The results of the storage room

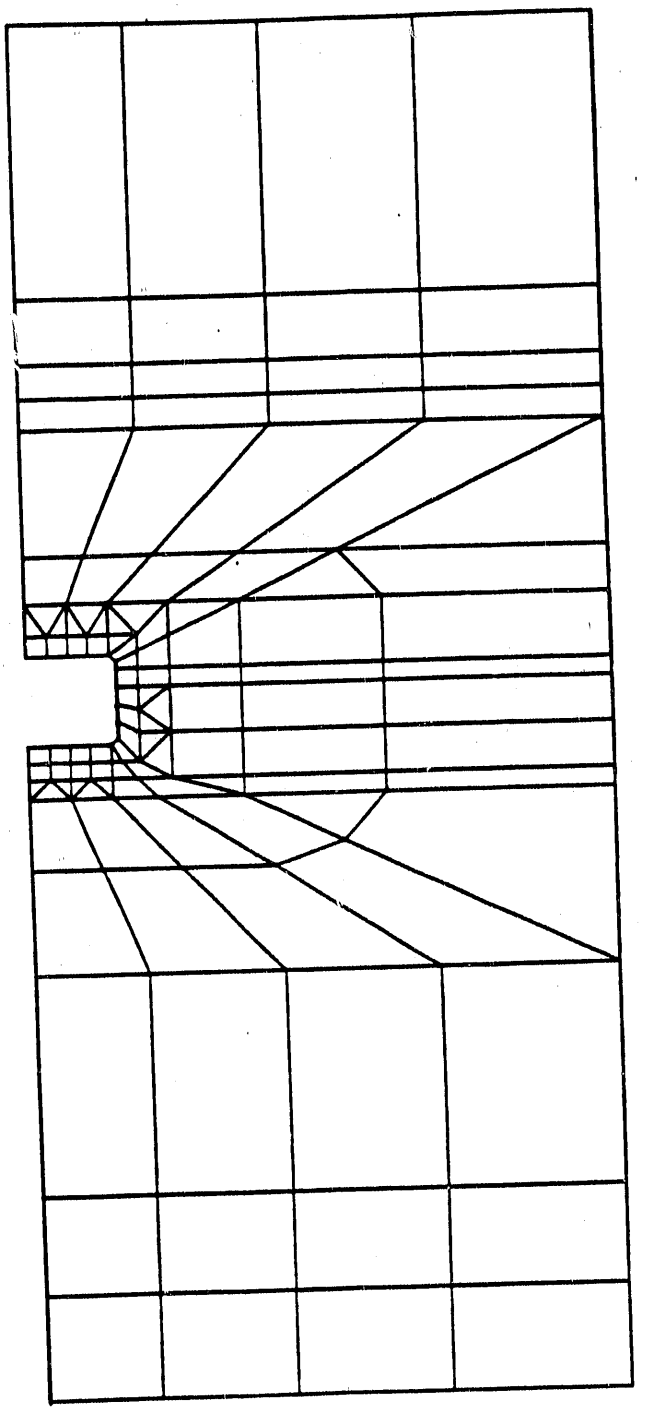


Figure 12-6

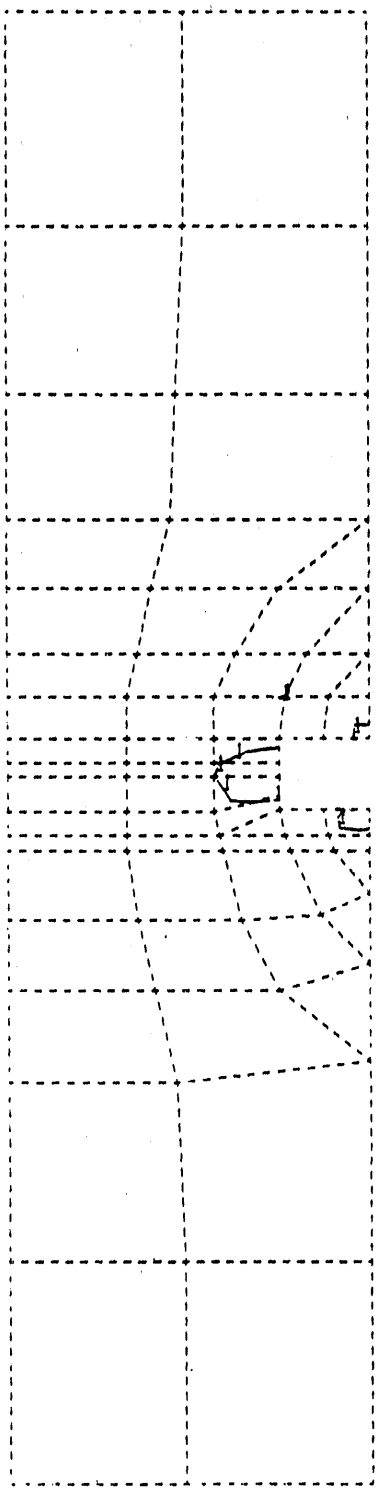
STORAGE AREA
DRIFT FINITE ELEMENT MODEL - AFTER FLOOR LOWERING

analyses were plotted at various integration time steps. These integration steps correspond to real times immediately after excavation, 1 year and 10 years after excavation. The horizontal and vertical stresses, effective stresses, effective creep strains, principal stresses and the deformed shapes were plotted at these times based on the mean value of the averaged wall-to-wall and roof-to-floor creep parameters presented in Tables 11-12 and 11-13 in Chapter 11. A closure calculation considering the effects at a room intersection was performed utilizing the values from these tables. Roof-to-floor and wall-to-wall closure predictions for the storage room were then plotted.

Horizontal and Vertical Stresses. The computed horizontal stress distributions in the storage rooms are plotted on selected elements of the finite element mesh immediately after excavation and at times of 1 year and 10 years after excavation (Figures 12-7 through 12-9). A contour interval of 250 ksf was chosen and 10 contour increments were used to span a stress range from 0 to 2,500 ksf compression.

Horizontal stresses immediately after excavation are totally compressive throughout the selected elements of the model. Most of the changes in horizontal stresses in the salt around the opening occur within the first year after excavation and remain practically constant even 10 years after excavation. The walls and the underlying anhydrite bed (MB-139), near the center of the room, have the largest compressive stresses, with values between 250 and 500 ksf compression. As the opening slowly deforms, horizontal stresses tend to become more compressive in the anhydrite bed near the room's vertical centerline. In the anhydrite bed far from the room centerline, the horizontal stresses are relatively low.

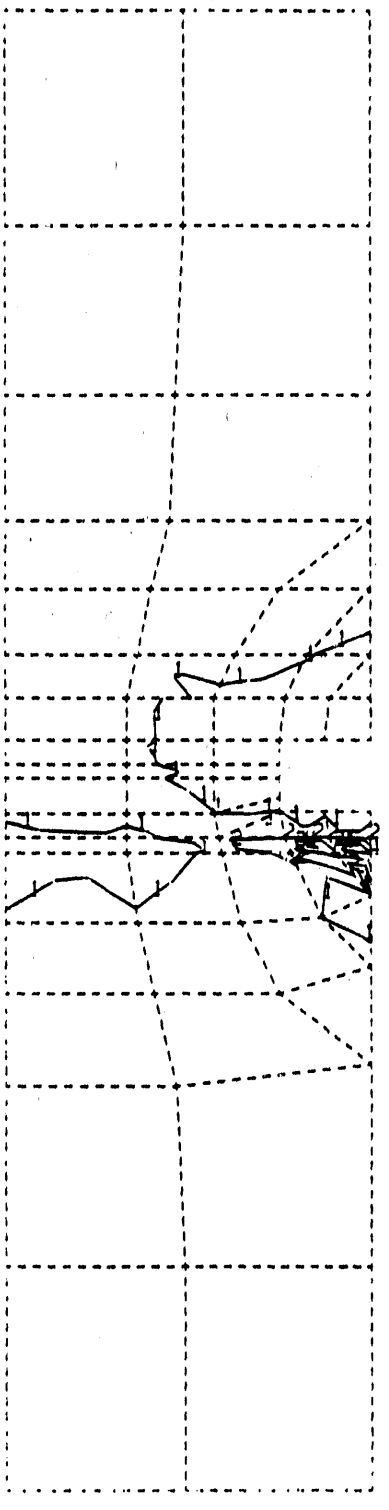
The vertical stress distribution was also plotted for time periods immediately after excavation and at times of 1 year and 10 years after excavation (Figures 12-10 through 12-12). The contour interval and stress range are the same as those used for the horizontal stress plots.



CONTOUR	σ_h(ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-7

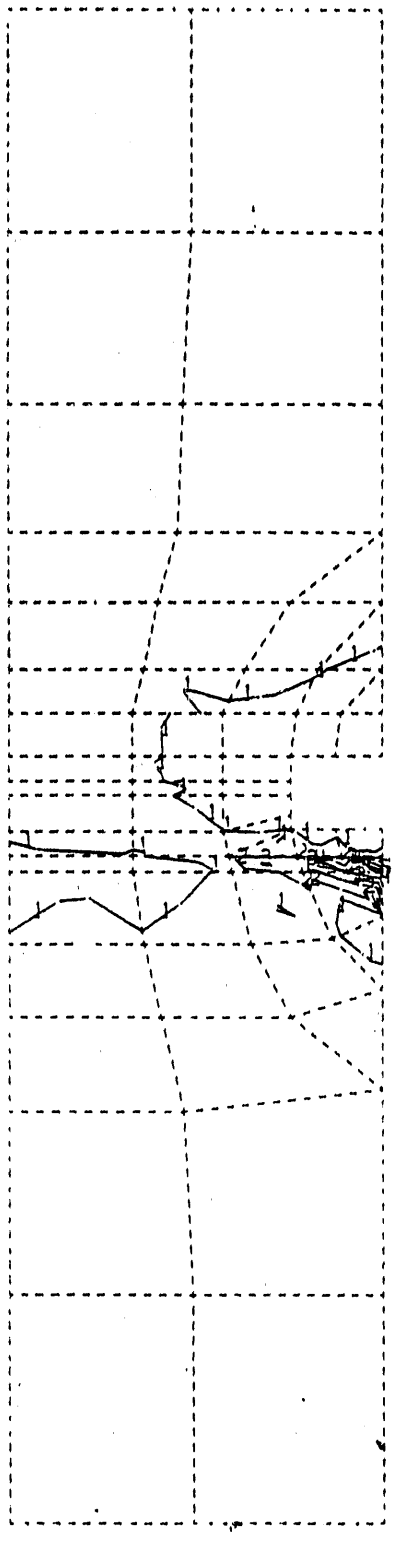
STORAGE ROOMS
HORIZONTAL STRESS DISTRIBUTION IMMEDIATELY AFTER EXCAVATION



CONTOUR	σ_h (ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-8

STORAGE ROOMS
HORIZONTAL STRESS DISTRIBUTION 1 YEAR AFTER EXCAVATION



CONTOUR	σ_h(ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-9

STORAGE ROOMS
HORIZONTAL STRESS DISTRIBUTION 10 YEARS AFTER EXCAVATION

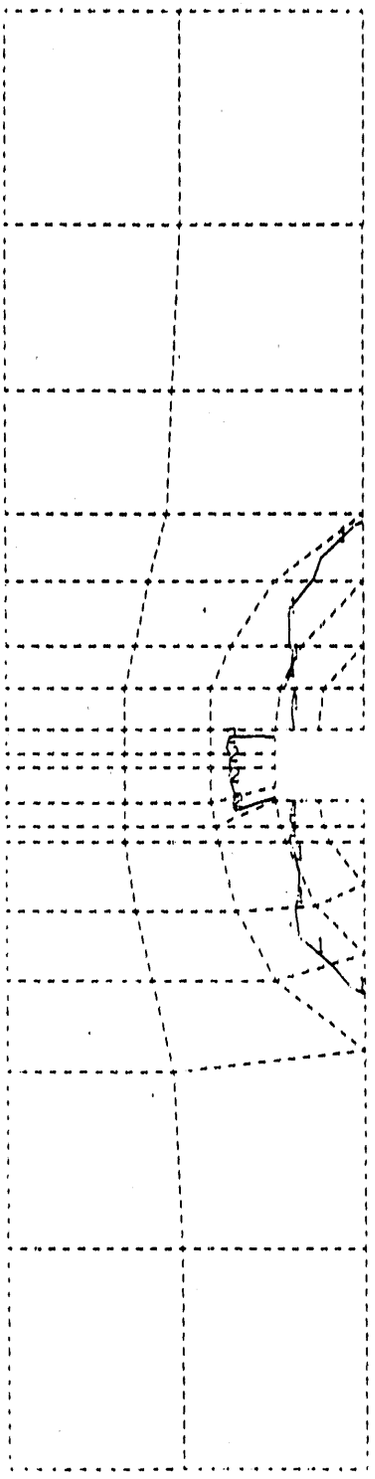
Figure 12-10 shows a vertical stress in the wall near the room opening immediately after excavation of between 500 and 750 ksf compression. This stress is approximately twice the original lithostatic stress before excavation and clearly shows the expected stress concentrations around the opening immediately after excavation. As the opening deforms, the vertical stress is redistributed around the opening and reduced to between 250 and 500 ksf compression.

Figures 12-11 and 12-12 show very small differences from 1 year through 10 years after excavation. That is, the vertical stress is relatively constant throughout that period with most of the halite roof beam having low stress in the vertical direction. Likewise, the uppermost level of elements in the room's floor has relatively low stress in the vertical direction due to its lack of vertical confinement.

The anhydrite bed (MB-139) below the storage room is, in general, subjected to low vertical stresses; however, some compressive vertical stress is indicated under the pillars.

Effective Stresses and Effective Creep Strains. Figures 12-13 through 12-15 show the computed effective stress distribution in those elements of the finite element model near the room opening. Ten contour increments, each having an interval of 250 ksf, were chosen to span a stress range from 0 to 2,500 ksf. The effective stress plot immediately after excavation shows a relatively low stress concentration in the anhydrite bed below the floor and no stresses greater than 500 ksf in the halite beds.

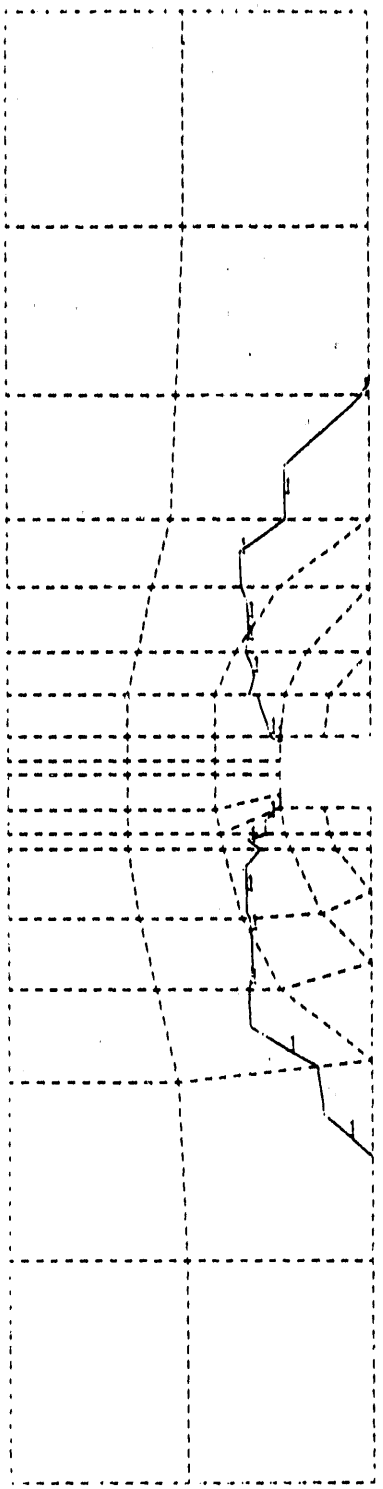
At 1 year and 6.5 years after excavation, the computed effective stresses have increased and concentrated in the anhydrite bed and overlying halite. Because the anhydrite was modeled as being elastic until failure and stiffer than halite, it supports more stress, which results in a large effective stress gradient in the anhydrite. The maximum computed effective stress is 2,600 ksf, concentrated in the anhydrite bed near the room centerline.



CONTOUR	σ_v (ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-10

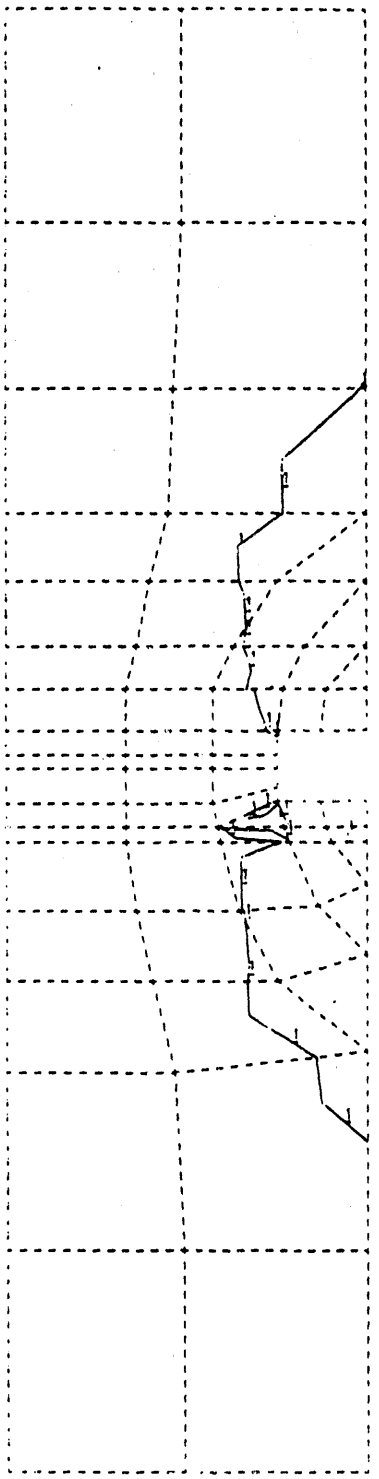
STORAGE ROOMS
VERTICAL STRESS DISTRIBUTION IMMEDIATELY AFTER EXCAVATION



CONTOUR	σ_v (ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-11

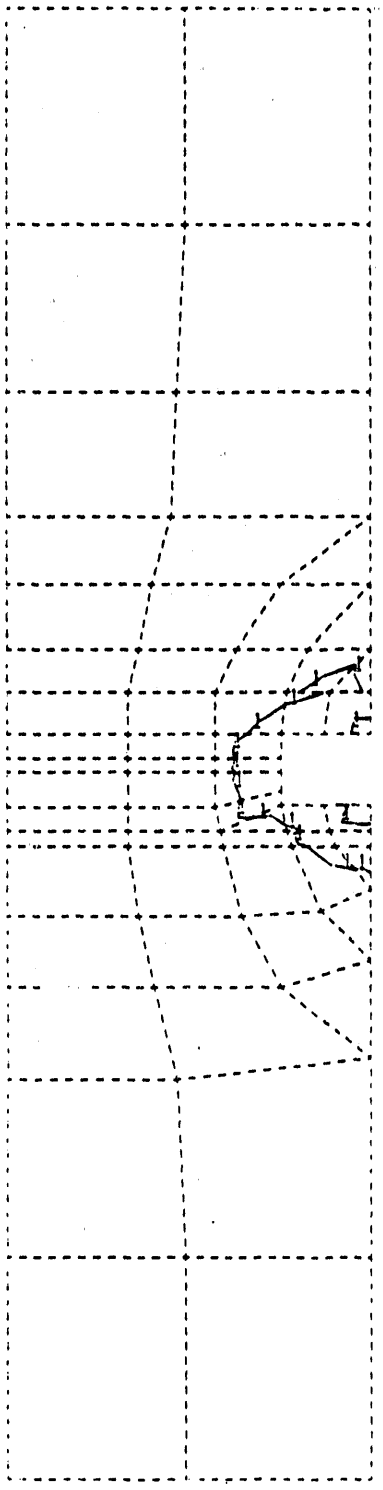
STORAGE ROOMS
VERTICAL STRESS DISTRIBUTION 1 YEAR AFTER EXCAVATION



CONTOUR	σ_v(ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-12

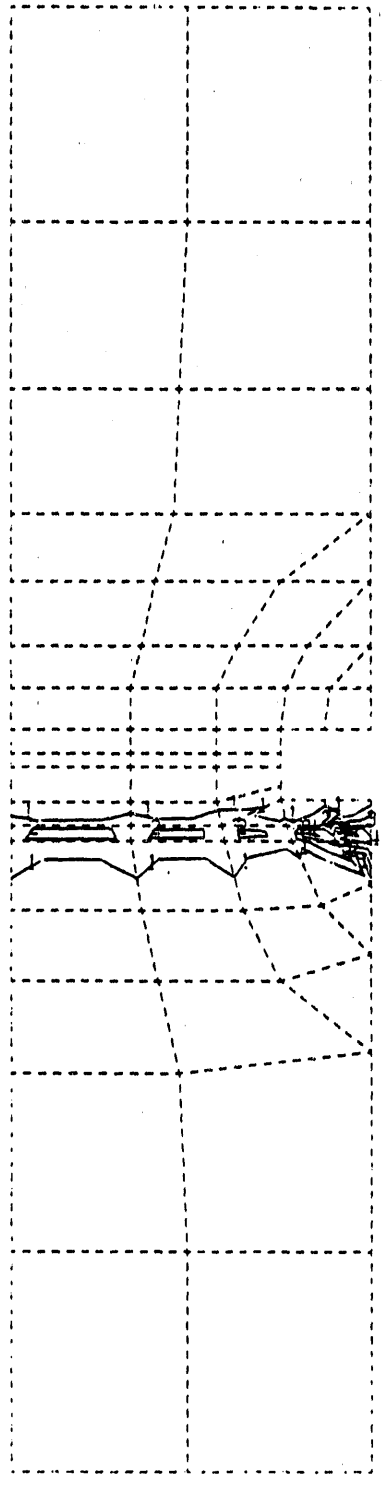
STORAGE ROOMS
VERTICAL STRESS DISTRIBUTION 10 YEARS AFTER EXCAVATION



CONTOUR	$\bar{\sigma}$ (ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-13

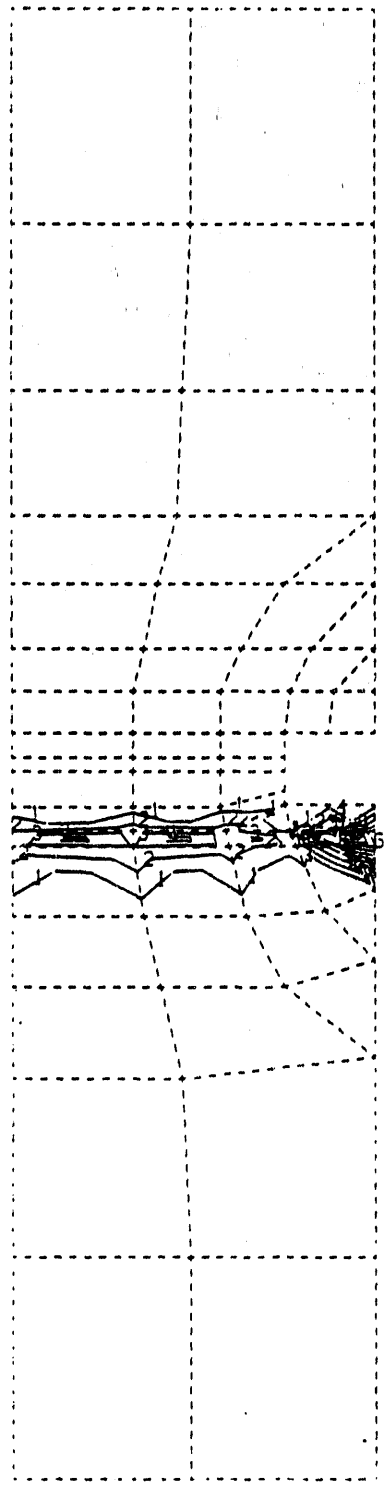
STORAGE ROOMS
EFFECTIVE STRESS DISTRIBUTION IMMEDIATELY AFTER EXCAVATION



CONTOUR	$\bar{\sigma}$(ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-14

STORAGE ROOMS
EFFECTIVE STRESS DISTRIBUTION 1 YEAR AFTER EXCAVATION



CONTOUR	$\bar{\sigma}$ (ksf)
1	250
2	500
3	750
4	1000
5	1250
6	1500
7	1750
8	2000
9	2250
10	2500

Figure 12-15

STORAGE ROOMS
EFFECTIVE STRESS DISTRIBUTION 10 YEARS AFTER EXCAVATION

Because the model does not include failure criteria for the anhydrite bed, an analysis for potential failure in this bed was performed separately. In Chapter 6, the failure criterion

$$\sqrt{J_2'} = 752 - 0.279J_1 \quad \text{(stress in ksf)} \tag{12-1}$$

was defined for the anhydrite bed based on laboratory tests. Rewriting this equation in terms of the effective stress at failure $\bar{\sigma}_f$ and the first stress invarient at failure $(J_1)_f$:

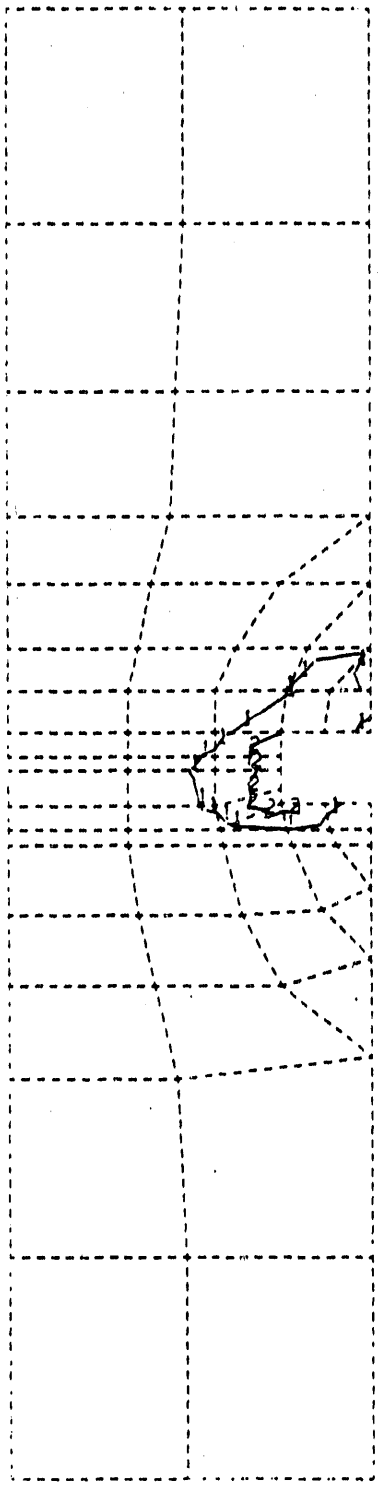
$$\bar{\sigma}_f(\text{ksf}) = 1302.5 - 0.483\ (J_1)_f \tag{12-2}$$

From the results of the numerical modeling, the average effective stress stress at a point close to the center of the room exceeds $\bar{\sigma}_f$ at about 8.5 years since excavation. This does not mean catastrophic failure will occur. Instead, there will be a redistribution of stress in the anhydrite bed which the model cannot consider.

Computed effective creep strain distributions were plotted on selected elements of the deformed mesh at 1 year and 6.5 years after excavation (Figures 12-16 and 12-17). Ten strain increments with an interval of 0.01 were used to span a strain range from 0 to 0.100.

At 1 year after excavation, effective creep strains have concentrated in the region around the room opening. At 6.5 years after excavation, the effective creep strains have further intensified around the room opening and in the region above the anhydrite bed near the room centerline.

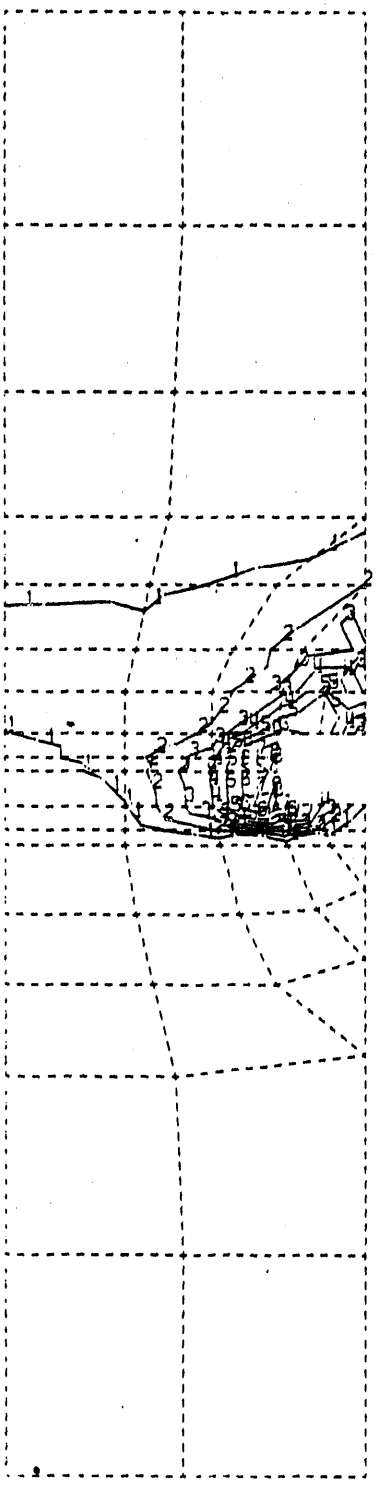
Based on laboratory creep tests on samples of halite, a failure criterion has been proposed (equation 6-5 in Chapter 6). Based on this criterion, the failure effective strain for halite is a function of the mean normal stress intensity and reaches a maximum magnitude of nearly 16 percent at a mean stress intensity of 125 ksf.



CONTOUR	$\bar{\epsilon}$
1	0.01
2	0.02
3	0.03
4	0.04
5	0.05
6	0.06
7	0.07
8	0.08
9	0.09
10	0.10

Figure 12-16

STORAGE ROOMS
EFFECTIVE CREEP STRAIN DISTRIBUTION 1 YEAR AFTER EXCAVATION



CONTOUR	$\bar{\epsilon}$
1	0.01
2	0.02
3	0.03
4	0.04
5	0.05
6	0.06
7	0.07
8	0.08
9	0.09
10	0.10

Figure 12-17

STORAGE ROOMS
EFFECTIVE CREEP STRAIN DISTRIBUTION 10 YEARS AFTER EXCAVATION

Based on the computed values of effective creep strain up to 6.5 years since excavation, and by linear extrapolation beyond 6.5 years, failure will be initiated in the halite about 12 years after the completion of excavation. The failure will be initiated at floor and wall intersections.

However, the numerical modeling also shows that effective strain decreases rapidly with distance away from the opening. Thus, the failure is expected to be confined very close to the opening. This will require periodic scaling and trimming.

Principal Stresses. The computed principal stresses on the plane of a section across the storage rooms are presented in a qualitative manner on Figures 12-18 through 12-20. The magnitudes of the two principal stresses are proportional to the lengths of the corresponding lines which are plotted, perpendicular to each other, at the centroid of each of the elements.

Immediately after excavation, the magnitudes of the principal stresses are relatively large in the corners of the room and in the anhydrite bed. As the room opening deforms, the principal stresses concentrate in the anhydrite bed near the room centerline.

The plots of the principal stresses also show the stress arch which forms around the room due to the transfer of loads around the room opening. The stress arch tends to become enlarged with time and migrates away from the room.

Deformation and Closure. Figures 12-18 through 12-20 also show the predicted deformed shapes of a typical storage room at different times. The dashed lines represent the outline of the deformed shape of the storage room.

Immediately after excavation, deformation starts around the opening. After 1 year of creep, the halite roof beam deforms noticeably at its

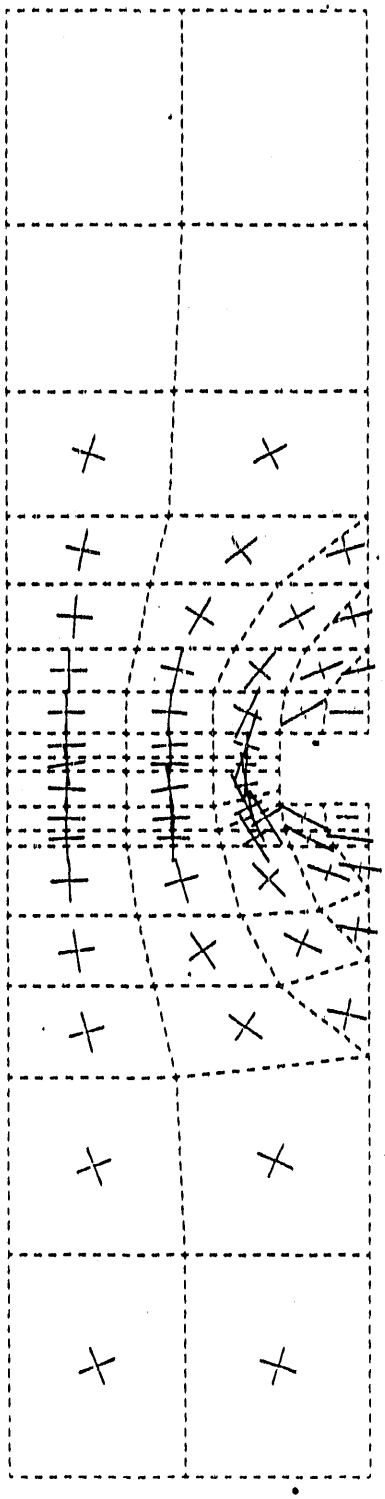


Figure 12-18

STORAGE ROOMS
PRINCIPAL STRESSES AND DEFORMED SHAPE
IMMEDIATELY AFTER EXCAVATION

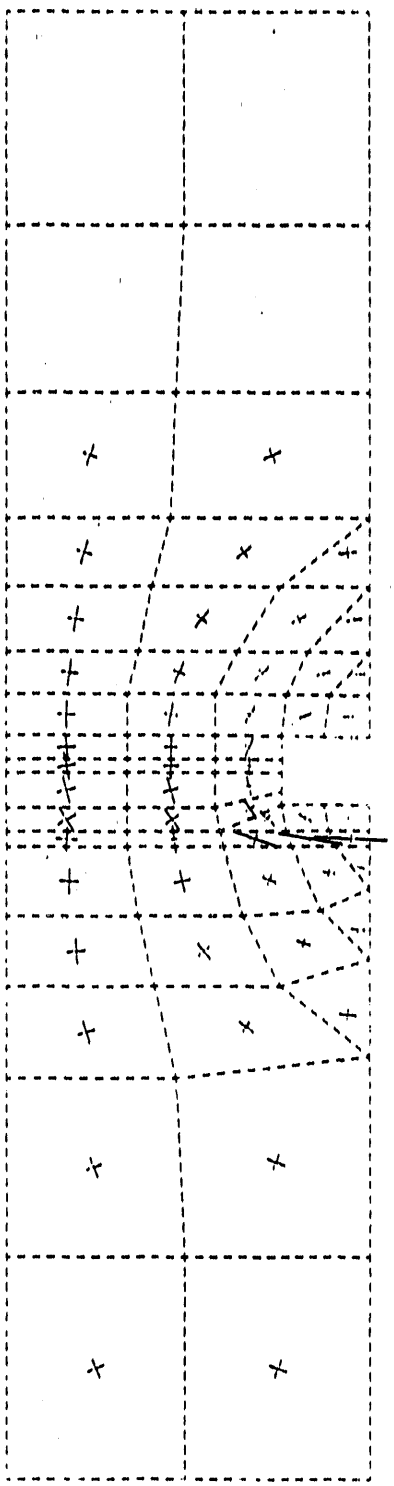


Figure 12-19

STORAGE ROOMS
PRINCIPAL STRESSES AND DEFORMED SHAPE
1 YEAR AFTER EXCAVATION

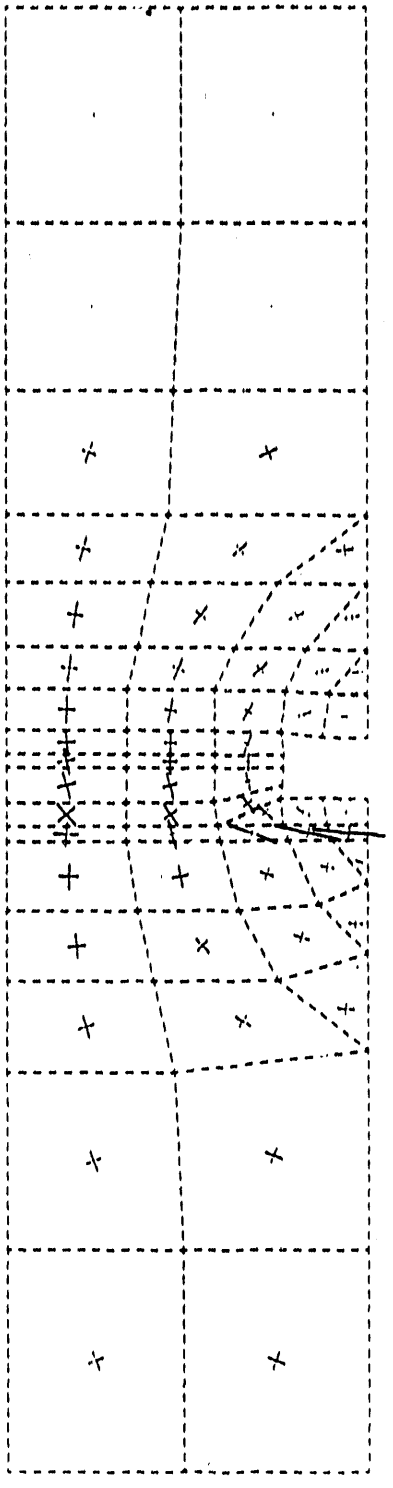


Figure 12-20

STORAGE ROOMS
PRINCIPAL STRESSES AND DEFORMED SHAPE
10 YEARS AFTER EXCAVATION

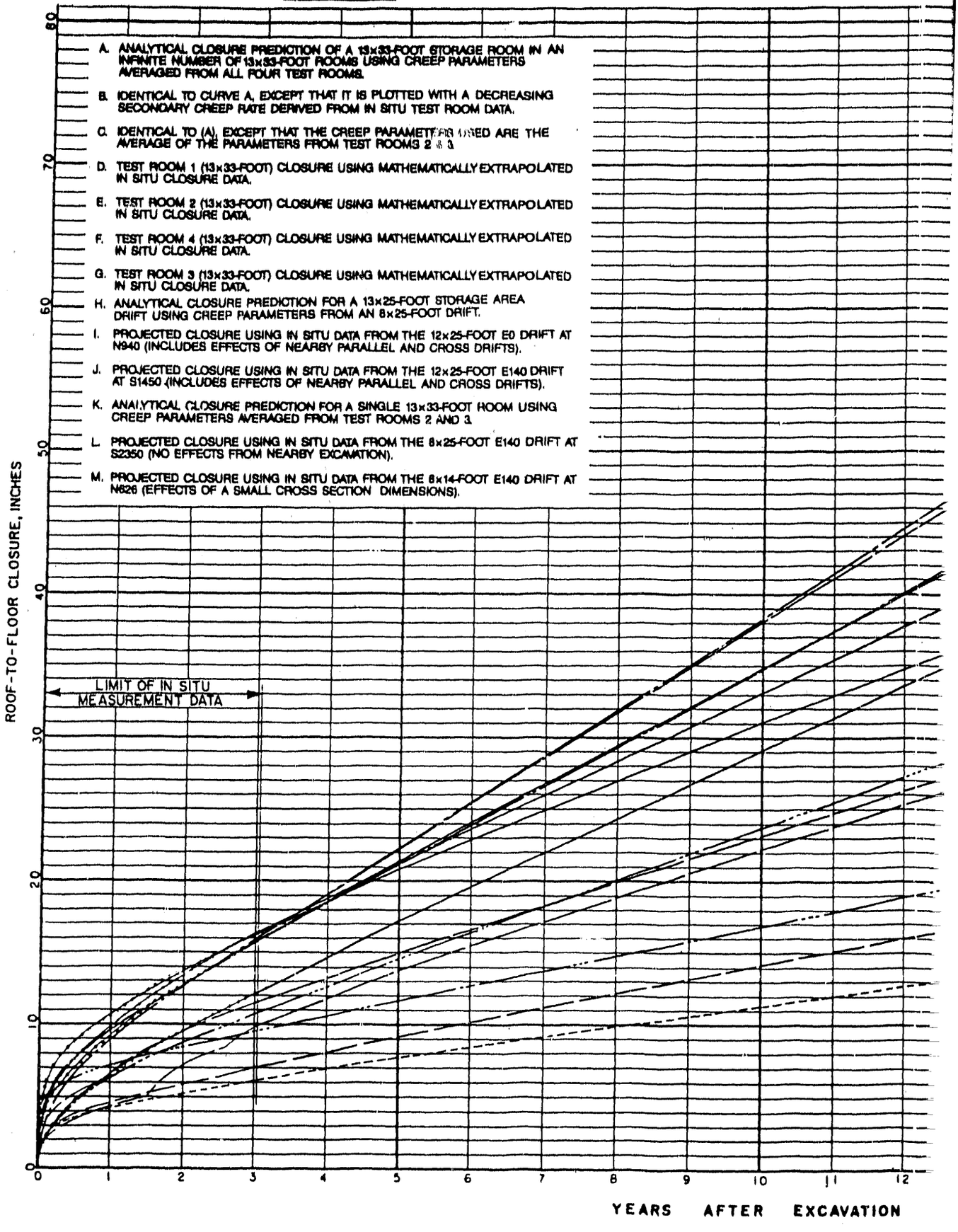
centerline and the predicted wall deformation is nearly as large. However, the floor heave is still very small. Also, some slippage has occurred along the clay seams. This is graphically depicted as a slight horizontal disjointing of the lines that form the element boundaries along a clay seam.

At 6.5 years after excavation, the predicted deformed shape of the storage room shows much downward deformation in the roof beam at its centerline. The floor has heaved slightly upward, with the upward displacement being somewhat more noticeable in the center of the room. The analysis shows very little deformation in the anhydrite bed even after 10 years. Based on the small amount of floor heave, it appears that the stiff anhydrite bed diminishes the amount of floor creep by supporting a large amount of lateral pressure. However, because there is a potential for the anhydrite bed to fail locally at about 8.5 years after excavation, it may not be able to support this large amount of lateral pressure. This may result in a higher creep rate in the floor than predicted by the model.

As discussed in Chapter 11, laboratory derived creep constants underpredicted actual closure in the test rooms. Thus, back calculation of average creep parameters was made using either measured roof-to-floor or wall-to-wall closure data. The effectiveness of the model simulation techniques used to derive the creep parameters and extrapolate closure behavior were discussed in detail in Chapter 11, subsection 11.3.2.5. Because MB-139 was assumed to be linearly elastic with infinite strength, the numerical modeling underpredicted floor heave but overpredicted roof sag. However, the overall roof-to-floor closure is reasonably well predicted by the model.

In order to show the effect of geometry and extraction on the closure rate, extrapolations of the in situ closure histories for the test rooms and various size drifts, as well as the calculated roof-to-floor and wall-to-wall closures for the storage rooms were plotted for comparison (Figures 12-21 and 12-22). Similar calculations were made using the

EXPLANATION



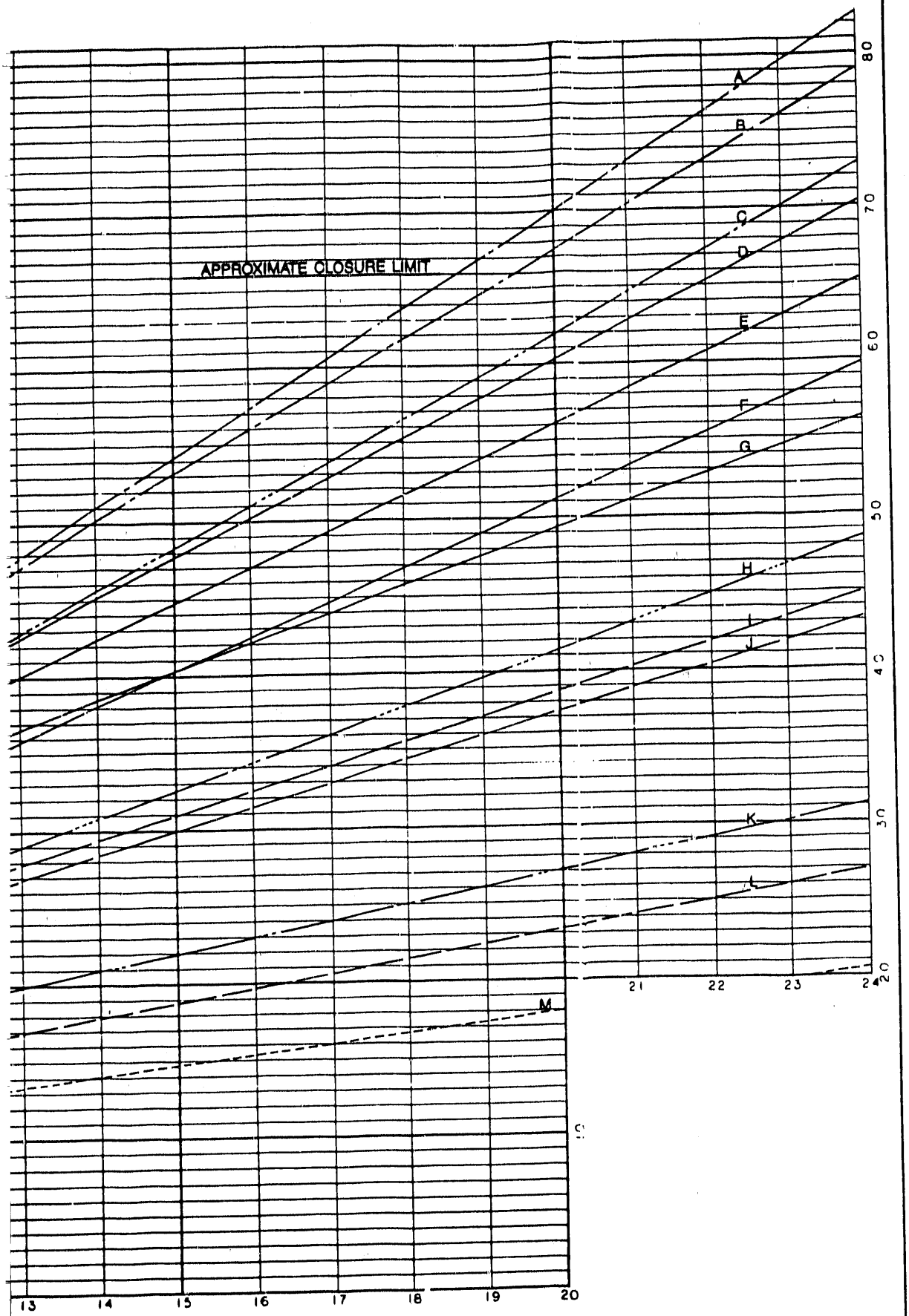
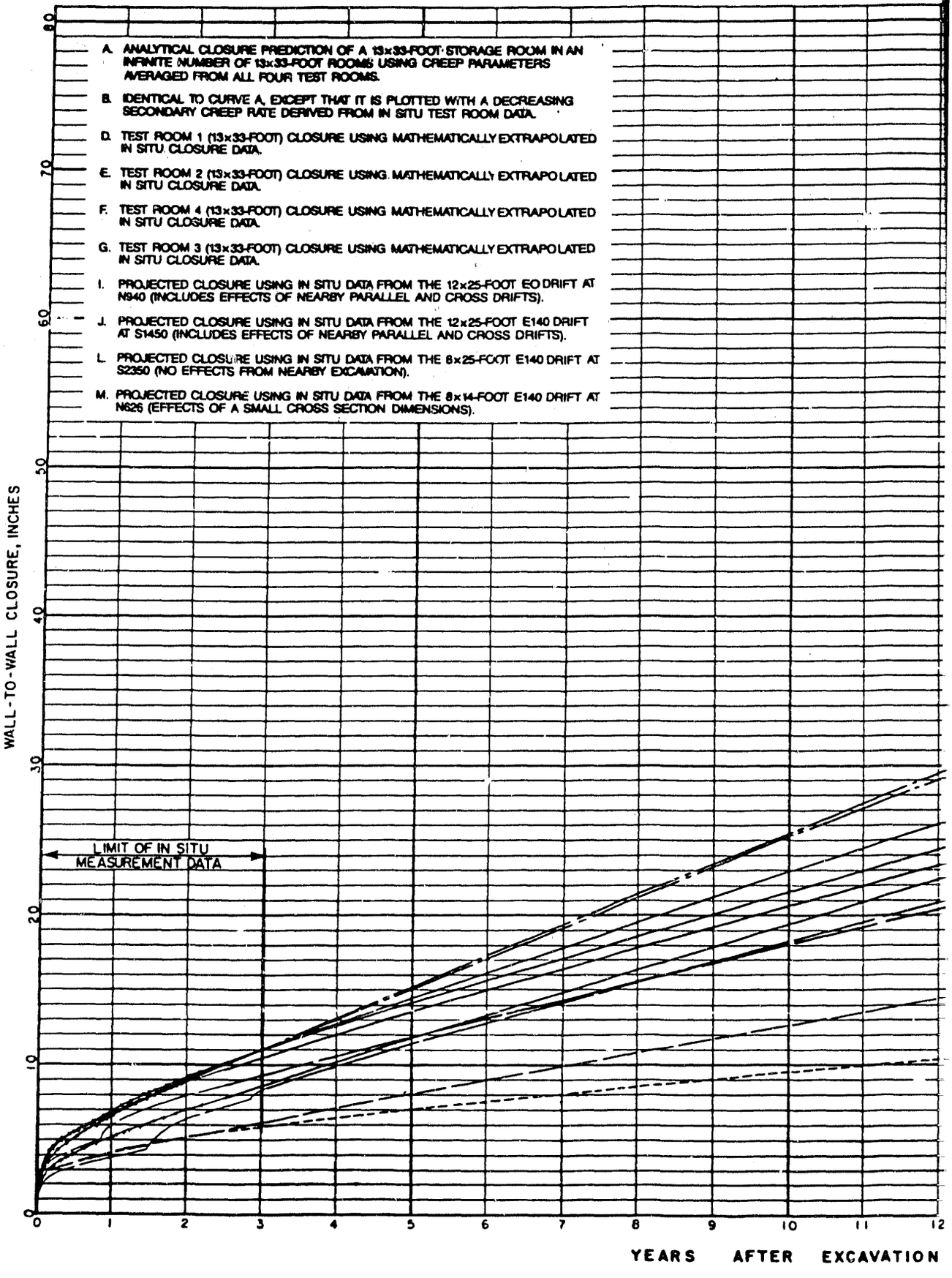


Figure 12-21

ROOF-TO-FLOOR CLOSURE
GEOMETRY AND EXCAVATION EFFECTS

EXPLANATION



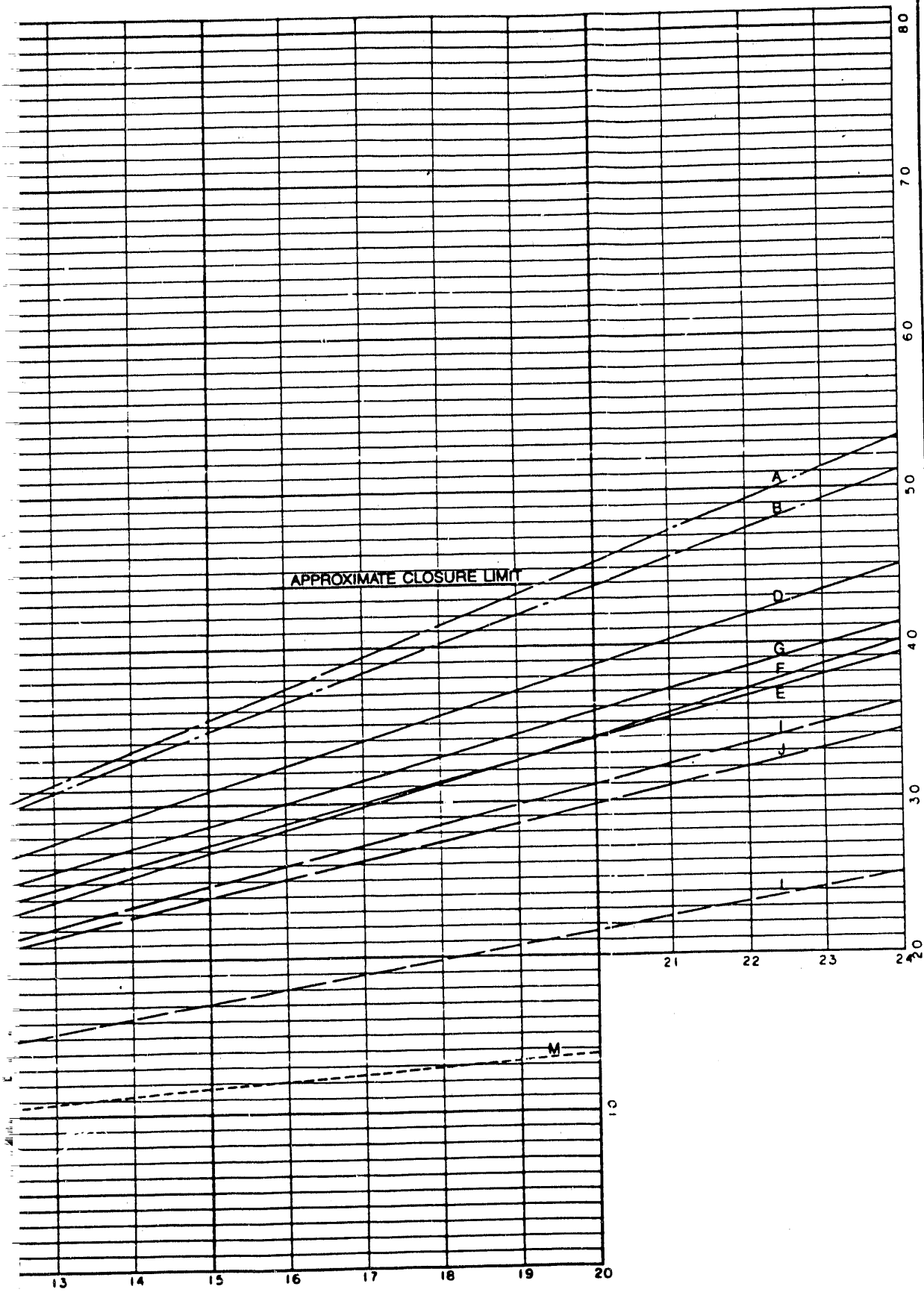


Figure 12-22

WALL-TO-WALL CLOSURE
GEOMETRY AND EXCAVATION EFFECTS

average creep parameters for the two interior 13 x 33-foot test rooms and using an infinite array of rooms to indicate the sensitivity of the value of the parameters. The same parameters were also used in the calculations of a single 13 x 33-foot room model to determine the effects of extraction on the number of rooms in an array. The descriptions of the closure curves plotted on Figures 12-21 and 12-22 are as follows:

(A) Analytical closure prediction of a 13 x 33-foot storage room in an infinite number of 13 x 33-foot rooms using creep parameters averaged from all four test rooms.

(B) Identical to curve A, except that it is plotted with a decreasing secondary creep rate derived from in situ test room data.

(C) Identical to curve A, except that the creep parameters used are the average of the constants from Test Rooms 2 and 3.

(D) Test Room 1 closure using mathematically extrapolated in situ closure data.

(E) Test Room 2 closure using mathematically extrapolated in situ closure data.

(F) Test Room 4 closure using mathematically extrapolated in situ closure data.

(G) Test Room 3 closure using mathematically extrapolated in situ closure data.

(H) Analytical closure predicted for a 13 x 25-foot storage area drift using creep parameters from an 8 x 25-foot drift.

(I) Projected closure using in situ data from the 12 x 25-foot E0 drift at N940 (includes effects of nearby parallel and cross drifts).

(J) Projected closure using in situ data from the 12 x 25-foot E140 drift at S1450 (includes effects of nearby parallel and cross drifts).

(K) Analytical closure prediction for a single 13 x 33-foot room using creep parameters averaged from Test Rooms 2 and 3.

(L) Projected closure using in situ data from the 8 x 25-foot E140 drift at S2350 (no effects from nearby excavation).

(M) Projected closure using in situ data from the 8 x 14-foot E140 drift at N626 (effects of small cross section dimensions).

As expected, the two interior test rooms (Test Rooms 2 and 3) had more closure and higher closure rates during the first year than the outer rooms (Test Rooms 1 and 4). This is due to the fact that Test Rooms 2 and 3 were excavated before Test Rooms 1 and 4. However, Test Rooms 1 and 4 exhibit higher closure rates during the secondary creep stage. This is consistent with the stress arch principle.

An evaluation of these 13 closure curves indicates that geometry and extraction ratio strongly impact the total closure in a seven-room panel within an eight-panel storage area and that the rate of closure will be faster than the extrapolated curves for a test room within the four-room test panel. For conservatism, Curve A (Figures 12-21 and 12-22) is used for storage room analysis, prediction and validation.

Curve A on Figure 12-21 represents the roof-to-floor closure prediction using the average creep parameter values for Test Rooms 1 through 4. These values were previously presented in Chapter 11, Table 11-12. In

the first year following excavation, the roof-to-floor closure curve is non-linear. The primary creep closure rate is very fast, as shown by the steeply sloped region in the first 3 months. Two and one half inches were added to the measured closure values to compensate for the lack of early closure data (Chapter 11). During secondary creep, the curve flattens and becomes approximately linear with a closure rate of approximately 3 inches per year. This closure prediction shows a closure of approximately 22 inches at 5 years after excavation and 54 inches at 15 years after excavation.

Curve A on Figure 12-22 represents the wall-to-wall closure prediction using the average creep parameter values for Test Rooms 1 through 4. These values were previously presented in Chapter 11, Table 11-13. As with the roof-to-floor closure, the wall-to-wall closure is non-linear in the first year following excavation. Again, the closure rate due to primary creep is initially very fast in the first 3 months as shown by the steep slope of the curve. Two inches were added to the measured closure values, as discussed in Chapter 11, to compensate for the lack of early closure data. The curve eventually flattens during the secondary creep phase and becomes approximately linear with a closure rate of about 2 inches per year. The wall-to-wall closure prediction shows a closure of approximately 15 inches at 5 years after excavation and 36 inches at 15 years after excavation.

When the storage rooms are fully occupied by waste and backfill material, the closure of the room will be limited by the ability of the contents to be compacted. Assuming that the volume of the waste container can be compacted by 40 percent and the volume of the backfill material by 15 percent, the roof-to-floor closure is predicted to have a maximum value of 66 inches and the wall-to-wall closure a maximum value of 44 inches. This maximum closure would occur after about 18 years for vertical closure and 19 years for horizontal closure (Figures 12-21 and 12-22). A reduction in the closure rate after the wall and roof surfaces begin compacting the backfill material and exerting pressure on the waste containers has not been considered.

Curve A on Figures 12-21 and 12-22 represents the most conservative estimates of storage room closure. Therefore, values from these curves were used in evaluating the reference design against the design criteria and design bases requirements. The design bases allow up to 12 inches of closure in the first 5 years after excavation in order to maintain a 16-inch space for ventilation and backfill equipment and to maintain a 12-foot minimum clearance for storage equipment. The estimated vertical closure in 5 years using curve A is about 22 inches. This 10 inch increase over the design basis limit could be accommodated by increasing the reference design room height from 13 feet to 13 feet 10 inches. This would be satisfactory for permanent storage. Another way to accommodate the increased closure and still maintain the 16-inch ventilation space (Figure 12-3) is to eliminate the backfill or reduce its thickness covering the CH containers to 6 inches or less. Deleting the salt backfill would require a change in the design criteria.

The solution to the increased vertical closure is not so simple for permanent storage, however. If at the end of the 5-year demonstration period, a decision is made requiring the stored waste to be retrieved, the design criteria assume that it will take twice as long to retrieve waste as it took to store it. This would result in a room being an additional 10 years old before retrieval is completed. Under these circumstances, a 15-year old room would have a closure of 54 inches, based on Curve A. Assuming that a storage room was excavated to the maximum allowable height of 14 feet, the closure would be 14 inches more than could be accommodated (24 inches for closure allowance, including 12 inches allowed by the design basis and 12 inches for the increase in room height from 13 feet to 14 feet, and 16 inches for ventilation space). This would result in the backfill being compressed and in the possible crushing and breaching of the waste containers. Because this scenario does not comply with the design criteria requirements, other alternatives must be considered.

These alternatives, including modification of the design criteria, are presented in subsection 12.6.2. Two considerations must be addressed here, however, to support the recommendations. First, the 10 year maximum retrieval period assumed by the design criteria is very conservative. Should retrieval be conducted on a three shifts per day basis, rather than the assumed one shift per day, no room would be older than 7 years by the time its waste was retrieved. Based on Curve A, a 7 year old room, from the time of initial excavation, would have a closure of about 28 inches. Assuming a room was excavated to the 14-foot high maximum and allowing 24 inches for closure, the waste containers will not be crushed or breached. However, the ventilation space will be reduced to 12 inches. This could be tolerated because the maximum 28-inch closure will be at the room centerline; additional ventilation space will be gained closer to the room walls. Alternatively, the thickness of the salt backfill over the containers could be reduced or eliminated to maintain the ventilation.

The second consideration supporting the recommendations is that a reduction in room closure can be gained by modifying the excavation technique. A panel of rooms could be excavated to the reference design dimension of 13 to 14 feet high. After a year of closure, these openings will be closing at the rate determined by secondary creep. At this time the rooms could be trimmed to 14 feet high. Trimming will remove the salt that has moved into the room during the year and provide a full dimensioned room that will close at the rate determined by secondary creep. Based on an average secondary creep closure rate of 3 inches per year, the rooms would have the following predicted closures after trimming:

5 years	15 inches
7 years	21 inches
10 years	30 inches
15 years	45 inches

Should the retrieval be effected within 7 years after trimming, a

trimmed 14-foot high room with 21 inches of closure would meet all of the retrieval requirements without further modification.

In order to gain the reduced closure benefits of secondary creep, the amount of trimming must be kept to a minimum. The rooms should initially be excavated as close to the 14-foot high maximum dimension as possible. The trimming operation a year later should remove no more salt from the floor than necessary to enlarge the room height to 14 feet. This small amount of trimming will minimize the increase in closure that typically follows major re-excavation, as has already been experienced at the WIPP during floor lowering in some drifts (Chapter 10, Figure 10-6, and this chapter, Figure 12-21, Curve J). This is discussed in detail in the next subsection.

The width of the storage rooms presents similar problems. The reference design specifies a minimum room width of 33 feet and a maximum width of 34 feet. Again, Curve A on Figure 12-22 represents the most conservative estimate of horizontal closure. The design basis allows 9 inches of horizontal closure in the first 5 years (4 1/2 inches for each wall). The space between the wall and the waste containers (Item 10, Figure 12-3), for the storage area reference design, will be backfilled with loose salt.

The predicted wall-to-wall closure in 5 years, using Curve A, is about 15 inches. This closure will result in compaction of the salt backfill and possibly in the crushing and breaching of some containers. This condition is suitable for permanent storage. Should retrieval be required, the predicted closure for a 15-year old room would be 36 inches. If it is assumed that the room is excavated to its maximum dimensions, as discussed earlier, the room would be 34 feet wide with the waste containers 15 inches from each wall. This 30 inches of horizontal clearance is not adequate to meet the design criteria requirements for the crushing and breaching of containers, even if backfill were not required. In order to meet the intent of the design criteria, the reference design must be modified. The five alternatives presented in subsection 12.6.2 include modifications to accommodate this horizontal closure.

As is the case with vertical closure in the storage rooms, timing of retrieval operations and two-stage excavation can be used to reduce the wall-to-wall closure. Should three shifts per day be used during retrieval and if the rooms are a maximum of 7 years old, then wall-to-wall closure would be about 20 inches. If the storage operation is conducted on a first emplaced/first retrieved basis and retrieval is effected before a room exceeds an age of 6 years, horizontal closure would be further reduced to 18 inches. Both of these operational changes would decrease the possiblity of crushing or breaching the waste containers.

Two-stage excavation gains additional closure benefits. If a room is initially excavated to the maximum design width of 34 feet and after a year of closure trimmed to 34 feet, closure would be controlled by secondary creep. Based on a wall-to-wall secondary creep closure rate of 2 inches per year, the rooms would have the following predicted closures after trimming:

5 years	10 inches
7 years	14 inches
10 years	20 inches
15 years	30 inches

This will further minimize crushing or breaching of the waste containers.

It is expected that increasing the distance between the waste canisters and the wall by increasing the room to the maximum design width of 34 feet, thereby increasing the amount of loose salt backfill in this space, will increase the time it takes for horizontal closure to consolidate the backfill and transfer sufficient load to crush the waste canisters. This, coupled with the faster retrieval schedules discussed previously and the fact that the backfill will not be completely confined, will minimize crushing and breaching of the canisters as required by the criteria. How much it will be minimized

cannot be determined until the results from in situ experiments dealing with backfill consoldiation and container stability become available.

12.3.3.2 Storage Area Drifts

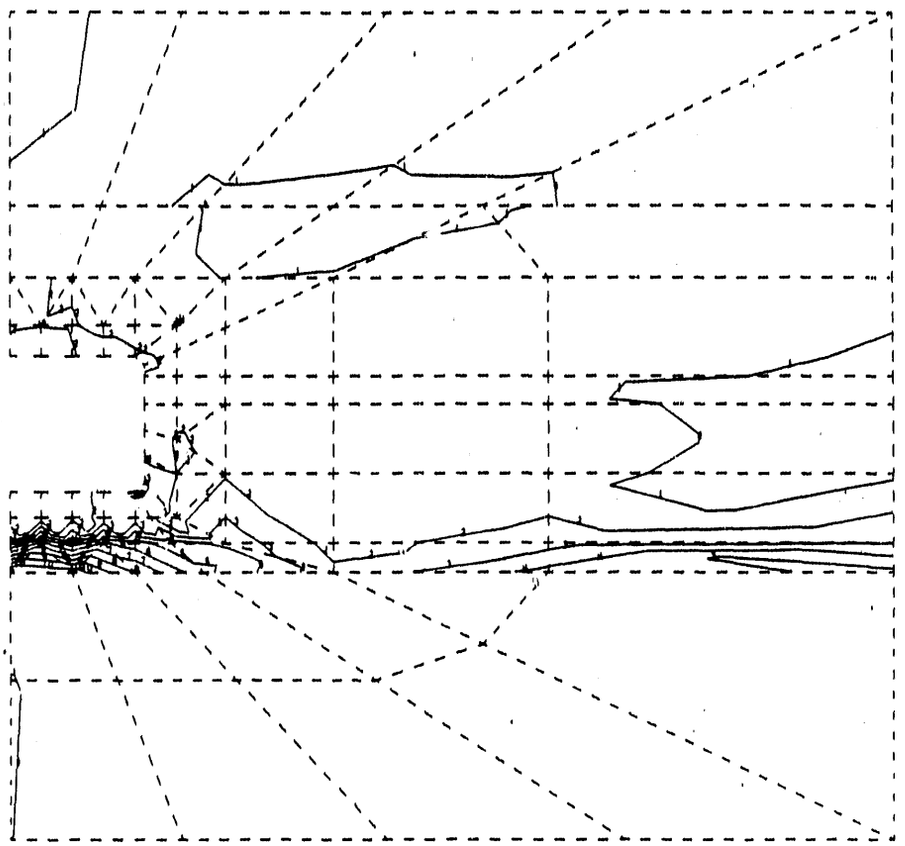
The results of the analysis of the storage area drifts with dimensions of 8 x 25 feet were plotted at various integration time steps. These integration steps correspond to real times immediately after floor lowering and 5 years after initial excavation. The effective stress and effective creep strain, principal stresses, and deformed shape were plotted at these times based on the roof-to-floor creep parameters for a representative station (Chapter 10).

Effective Stresses and Effective Creep Strains. Figures 12-23 and 12-24 show the calculation for effective stress distribution in those elements of the finite element model near the drift opening. As with similar plots for the 8 x 25-foot drifts discussed in Chapter 10, each contour increment represents an effective stress interval of 100 ksf.

The plot of effective stress immediately after floor lowering shows the impact on the stress distribution as a result of the drift height modification. This change in effective stress precipitates a concomitant increase in the creep rate. This appears as a sharp but short increase in slope on the roof-to-floor closure versus time curve (Chapter 10, Figure 10-6, and this chapter, Figure 12-21, Curve J).

At the end of 5 years, the anhydrite bed shows a very large effective stress gradient from top to bottom in the vicinity of the drift floor due to the stiffness of the bed. Maximum effective stresses are in excess of 1,000 ksf.

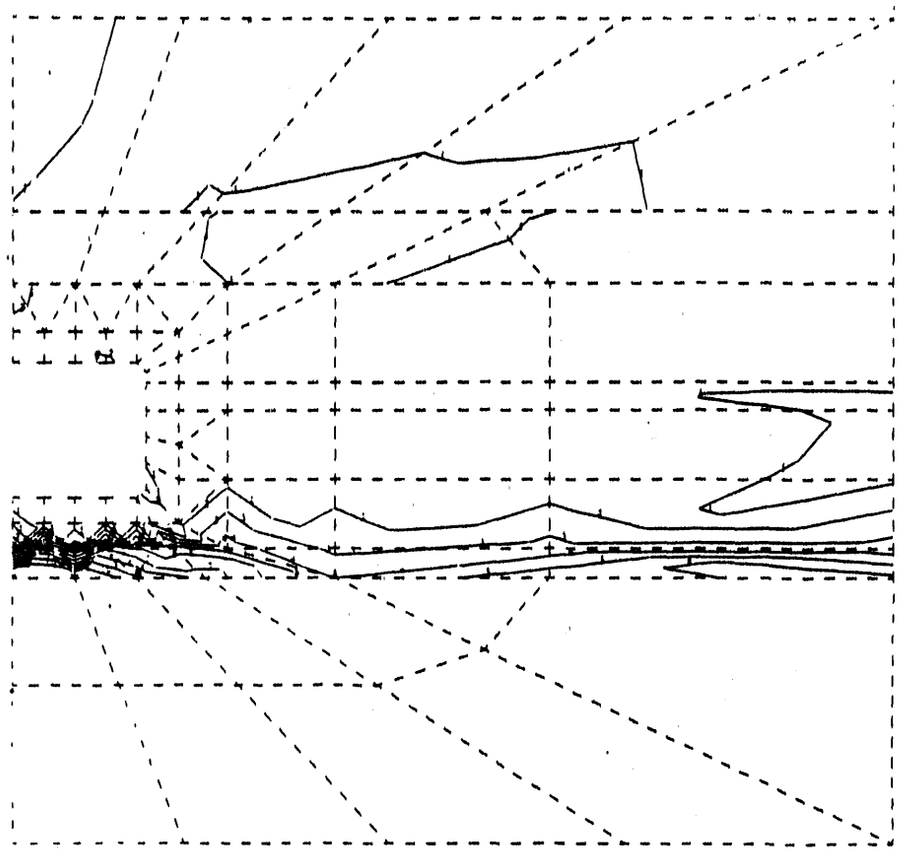
The effective creep strains have concentrated in the region around the drift opening and intensify with time. A rough linear extrapolation of effective creep strain beyond 5 years indicates that the maximum



CONTOUR	$\bar{\sigma}$(ksf)
1	100
2	200
3	300
4	400
5	500
6	600
7	700
8	800
9	900
10	1000

Figure 12-23

STORAGE AREA DRIFTS
EFFECTIVE STRESS DISTRIBUTION IMMEDIATELY AFTER FLOOR LOWERING



CONTOUR	$\bar{\sigma}$(ksf)
1	100
2	200
3	300
4	400
5	500
6	600
7	700
8	800
9	900
10	1000

Figure 12-24

STORAGE AREA DRIFTS
EFFECTIVE STRESS DISTRIBUTION 5 YEARS AFTER EXCAVATION

average effective creep strain may reach 16 percent at about 20 years after excavation. Based on failure criteria for halite obtained from laboratory test data (Chapter 6), failure in halite may start at about 15 percent. However, the numerical modeling indicates that the effective creep strain drops off sharply away from the opening. It is therefore expected that high effective strain would not result in a large scale failure in halite.

Principal Stresses. The plots of principal stresses (Figures 12-25 and 12-26) consistently show the "arch" pattern which develops around the drift in order to transfer loads past the drift opening. The arch is shown to migrate away from the opening with time. As expected, the magnitude of major principal stress is greater in the corners of the drift and in the underlying anhydrite bed. The anhydrite in particular is subjected to large stresses because it is the only material that has been assumed in the model to not creep; it therefore "stores" a large amount of energy in the form of elastic strain.

Deformation and Closure. Figure 12-27 shows the deformed shape 5 years after drift excavation, or approximately 3 years after floor lowering. It should be noted that, while both the roof and walls are creeping inward, the upward floor heave is small by comparison. This phenomenon is due to the stiffening effect of the underlying anhydrite bed.

The stress redistribution that occurs as a result of modifying the drift height is the driving force behind the large roof and wall deflections that are the most prominent features of the plot at 5 years. A close examination of the 5-year deformed plot shows that clay seam slippage has occurred. The most noticeable slippage has occurred in the clay seam located about 8 feet above the existing roof. Here, the maximum horizontal relative displacement across the seam is approximately 3 1/2 inches. Actual relative displacement will be lower because the clay seams have a finite friction coefficient.

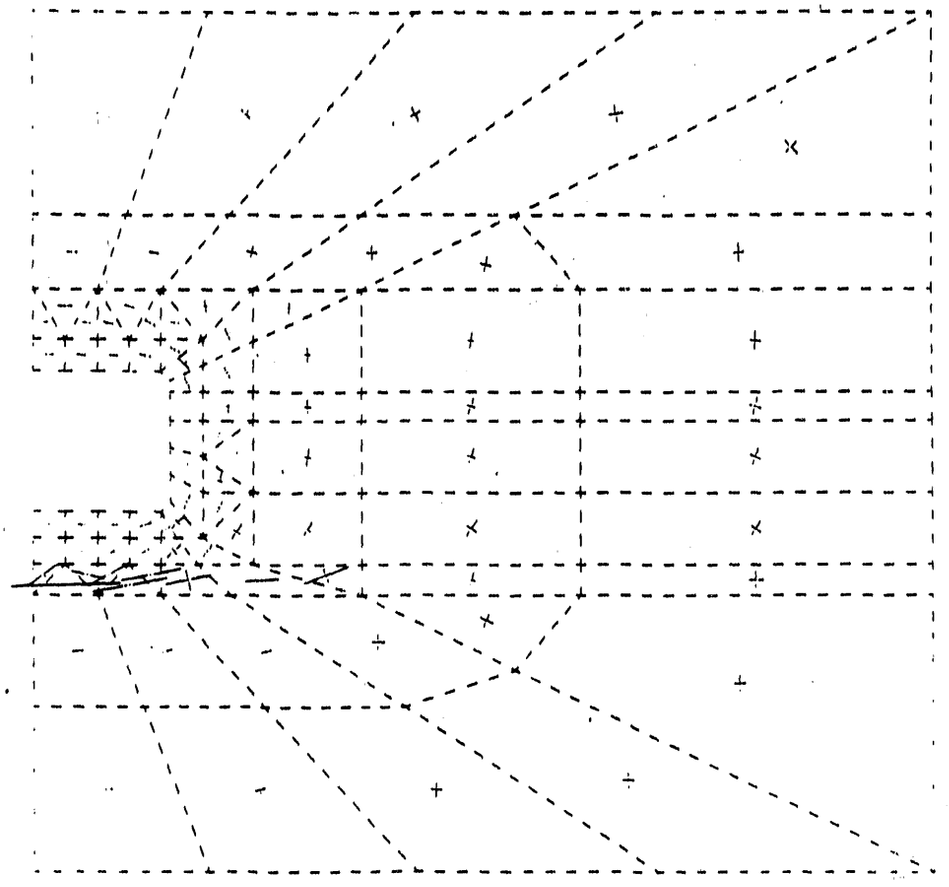


Figure 12-25

STORAGE AREA DRIFTS
PRINCIPAL STRESSES IMMEDIATELY AFTER EXCAVATION

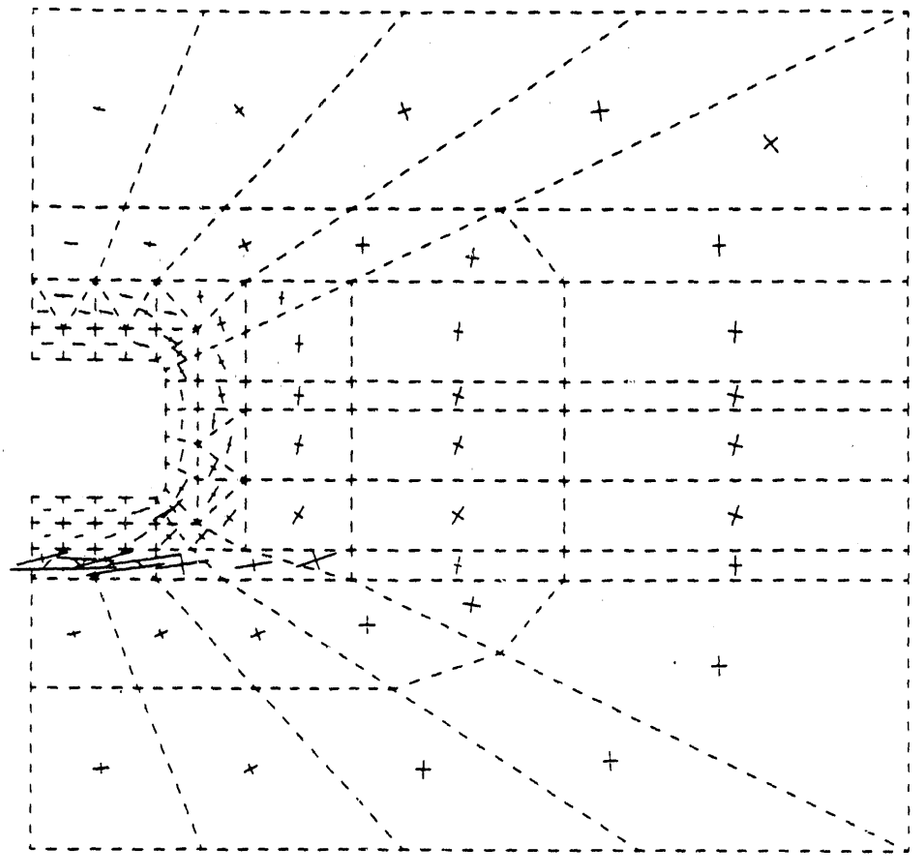


Figure 12-26

STORAGE AREA DRIFTS
PRINCIPAL STRESSES 5 YEARS AFTER EXCAVATION

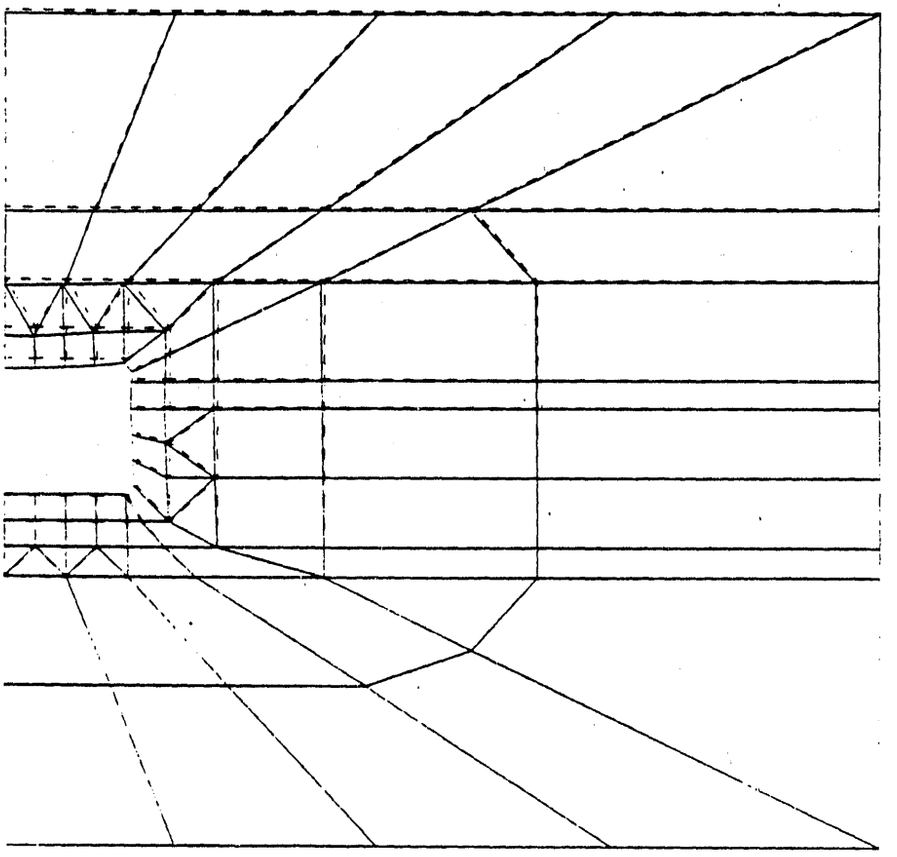


Figure 12-27

STORAGE AREA DRIFTS
DEFORMED SHAPE 5 YEARS AFTER EXCAVATION

Figure 12-28 demonstrates the effect of increasing the vertical dimension of a storage area drift at some point after initial excavation. The finite element model is calibrated with in situ data. It models an 8 x 25-foot drift that has its height increased to 13 feet by excavating an additional 5 feet from the floor. The 8 x 25-foot drift exhibits typical closure; that is, the curve shows high rate of closure during primary creep and a nearly constant closure rate during secondary creep. When the floor is lowered (in this case 2.3 years after excavation), primary creep is temporarily reinitiated. The secondary creep phase is eventually re-established, but with some difference. The slope of the curve during secondary creep after floor lowering is slightly steeper than the secondary creep prior to floor lowering. The rate of closure does not return to the initial rate, but rather reflects the new, larger dimension of the drift. In this model, the modified drift has 11 inches of vertical closure 5 years after initial excavation.

The same computation included wall-to-wall closure. The effects of floor lowering were the same as for roof-to-floor closure. After floor lowering, primary creep was reinitiated and followed by a new secondary creep phase with a slightly higher closure rate. Five years after initial excavation, the predicted horizontal closure is about 8 inches.

A rough extrapolation of the predicted roof-to-floor and wall-to-wall closures based on model simulation and resulting secondary creep closure indicates the following:

Time (Years)	Roof-to-Floor Closure at 2.0 inches/year (inches)	Wall-to-Wall Closure at 1.6 inches/year (inches)
10	20	16
15	30	24
20	40	32
25	50	40

The maximum effective strain around the drift opening reaches 6 percent about 8 years after excavation. Based on in situ observations and the

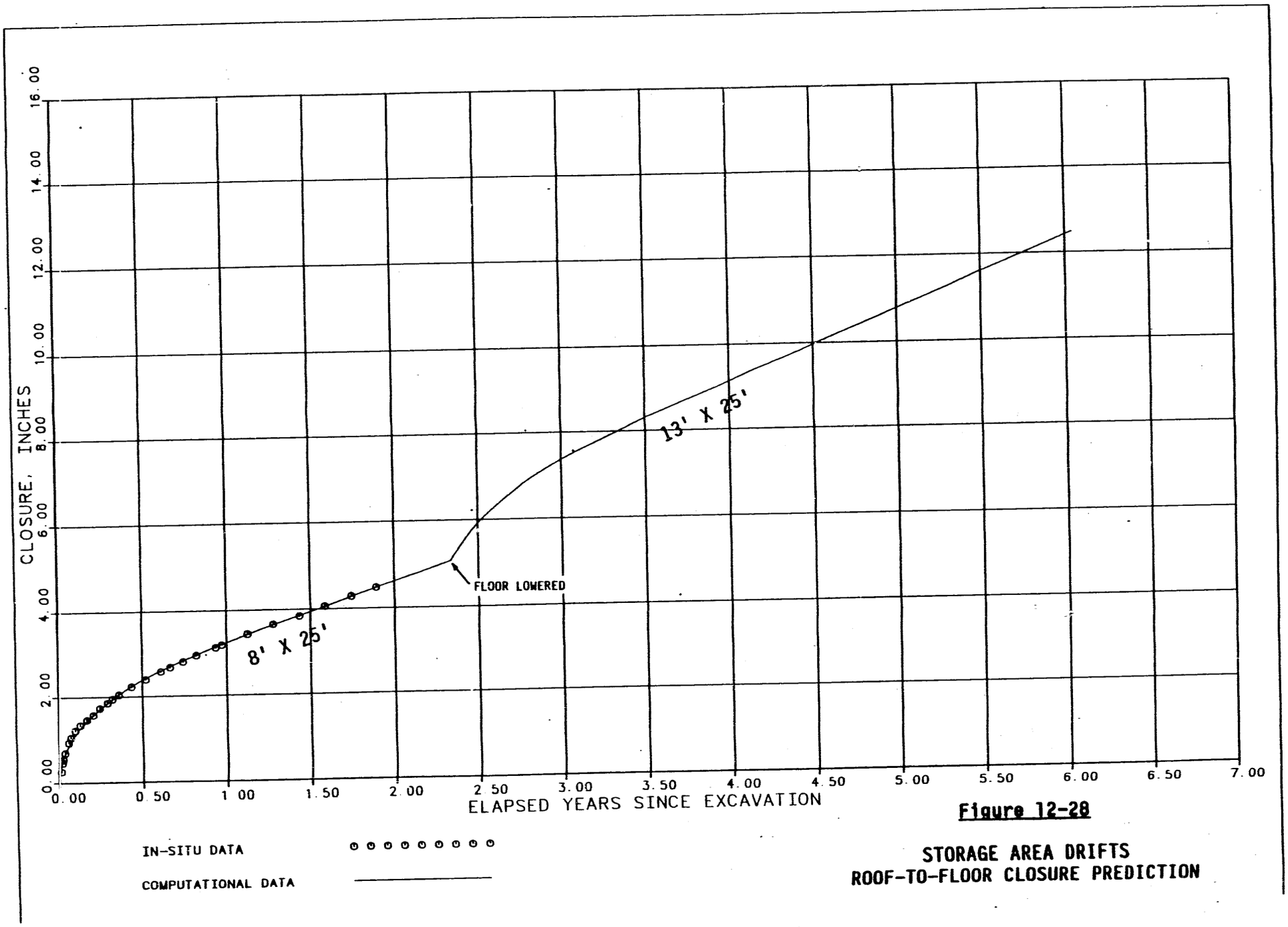


Figure 12-28

STORAGE AREA DRIFTS
ROOF-TO-FLOOR CLOSURE PREDICTION

results of modeling the test rooms, this effective strain of 6 percent may not result in instability of the drifts. However, in 15 years the effective strain at the excavation surface will exceed 10 percent locally and the roof-to-floor closure will be nearly 30 inches. According to the failure criterion, based on laboratory tests on samples of halite (Chapter 6), the halite is supposed to fail at about 16 percent effective strain. Therefore, minor surface deterioration can be expected and some trimming will be required to permit operation of the waste storage equipment. Because the effective strain decreases rapidly within the salt, trimming on the order of only a few feet may be needed after 20 years.

The storage drifts, as with the storage rooms, must accommodate greater than predicted closure. The reference design provides for waste storage in the storage area drifts only after all of the main storage rooms are filled. Since this would occur toward the end of the operating phase, waste in these drifts would not be subject to retrieval under the provisions governing the 5-year demonstration period. Waste stored in the drifts would be on a permanent basis.

Increased closure does impact waste emplacement and emplacement machinery. In the reference design, the greatest age a drift would reach before waste was emplaced would be about 15 years. At this age, based on the calculated closure for a 13 x 25-foot drift, the predicted roof-to-floor closure would be about 25 inches and the predicted wall-to-wall closure would be about 20 inches. The storage drifts would have to be trimmed to permit proper storage and equipment clearance. Similarly, the storage drifts and crosscuts less than 25 feet wide would also require trimming.

12.3.3.3 Intersections

The modeling of intersections is an expensive, three-dimensional analysis. However, to estimate closures at a storage room intersection, a simplified method can be utilized in place of a

three-dimensional analysis. The following discussion develops the mathematical relationship for computing the roof-to-floor closure at the intersections.

When normalized time is sufficiently large, analytical results have consistently shown that room closure in the normalized time domain can be estimated by the following equation:

$$u = u^*_o + \dot{u}^*_f \, t^* \qquad \text{when: } t^* > 1\text{x}10^{-11} \text{ ksf}^{-4.9} \tag{12-3}$$

where: $t^* = C[t + \frac{A}{z}(1 - e^{-zt})]$ is the normalized time;

u^*_o is a constant; and

$$\dot{u}^*_f = \lim_{\Delta t \to 0} \frac{\Delta u}{\Delta t^*}$$

Closure for the storage room intersections, in normalized time, was calculated using the creep parameters discussed in Chapter 11 and in situ data collected near the intersections of the N1420 drifts with Rooms L1 and L2. As expected, the closure history follows equation 12-3 when the normalized time is greater than $8.0\text{x}10^{-12}$ ksf$^{-4.9}$. The average values of u^*_o and $\dot{u}^*_f$ for Rooms L1 and L2 were calculated to be 0.0450 feet and $1.967\text{x}10^{12}$ ksf$^{-4.9}$, respectively.

After determining the values of u^*_o and $\dot{u}^*_f$, equation 12-3 can be utilized for computing the closure at a storage room intersection. Figure 12-29 shows the roof-to-floor closure prediction at a storage room intersection.

12.4 STORAGE AREA PLUGS

The design criteria require that the storage area reference design contain provisions for the isolation of the waste storage panels from each other. The reference design contains recommended locations for plugs which would provide this isolation. It does not, however,

provide a specific design for the plugs. The design of the plugs is currently under investigation by SNL (ref. 12-8).

The recommended locations for the plugs are shown on Figure 12-30. The plugs will be constructed in the entry drifts to each panel. The four main access drifts to the storage area will also contain plugs. The section of the entry drifts leading from the access drifts to the first storage room is 200 feet long. The reference design contains provisions for the construction of approximately 100-foot long plugs centered in this 200-foot section of each entry drift.

Originally, the reference design contained entry drift cross section dimensions of 13 feet high and 33 feet wide. These dimensions are the same as those for the storage room reference design and were chosen based on waste container stacking considerations. This design was modified as the result of a meeting between the DOE and all project participants (ref. 3-2). The reference design modification was based on the necessity to minimize the cross section area of the plugs while maintaining sufficient room for the excavation and waste storage equipment.

The reference design modification for the entry drifts is shown on Figure 12-31. The 100-foot long section containing the plug has been reduced in cross section to 13 feet high and 14 feet wide for the exhaust drift and 20 feet wide for the intake drift. However, the operating contractor may further modify these dimensions to accommodate equipment. The four main access drifts will retain their original cross section dimensions in the areas of the planned plugs.

The plug shown on Figure 12-31 would consist of multiple components as described in reference 12-8. These components include a central core of bentonite or bentonite-based mix, salt-brick bulkheads, and cement-based bulkheads. Prior to constructing the multiple-component plug in an entry drift, the operating contractor must investigate the disturbed zone surrounding the drift. In particular, the occurrence of any fractures within and above MB-139, beneath the floor, and any

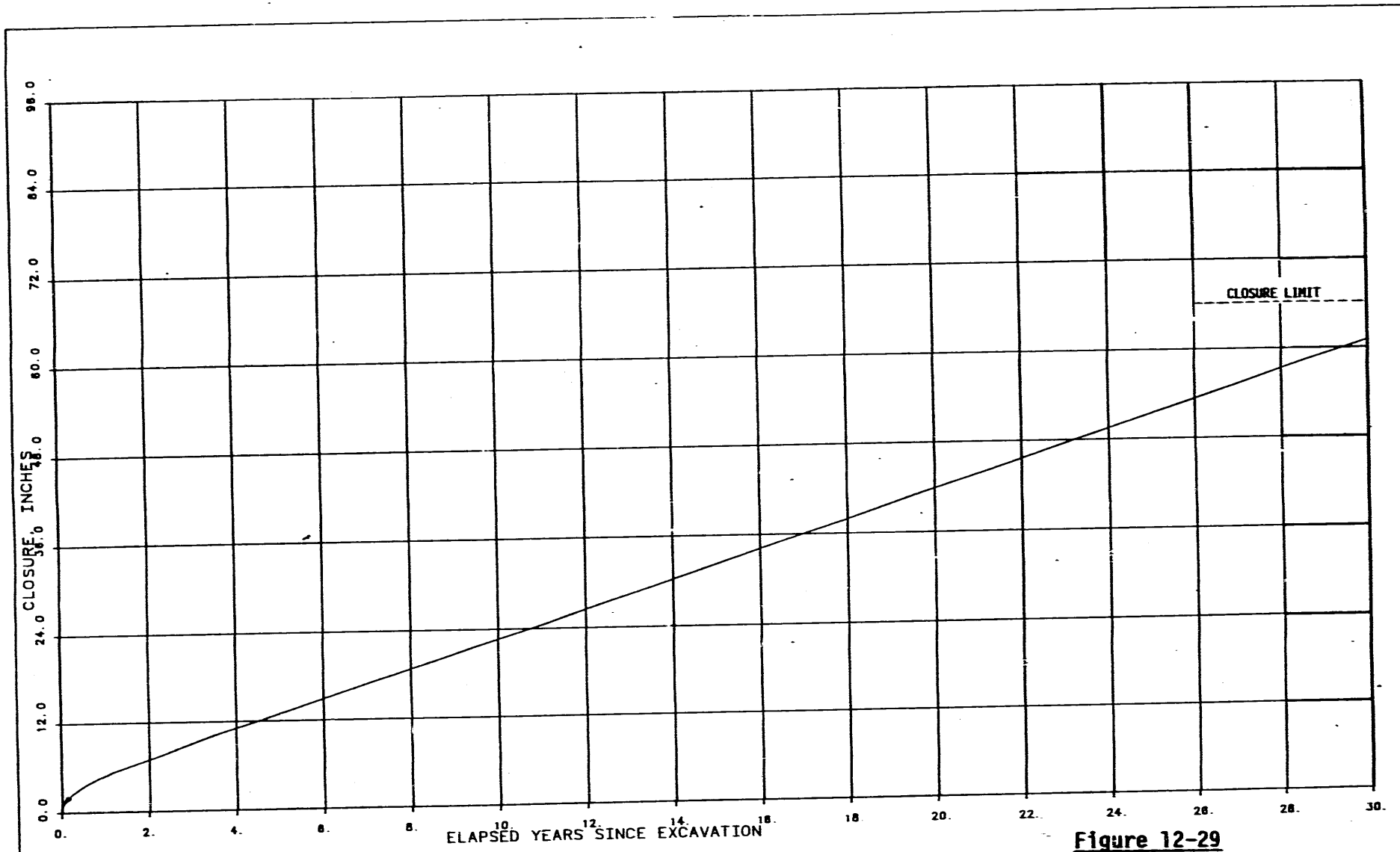


Figure 12-29

STORAGE ROOM INTERSECTION
ROOF-TO-FLOOR CLOSURE PREDICTION

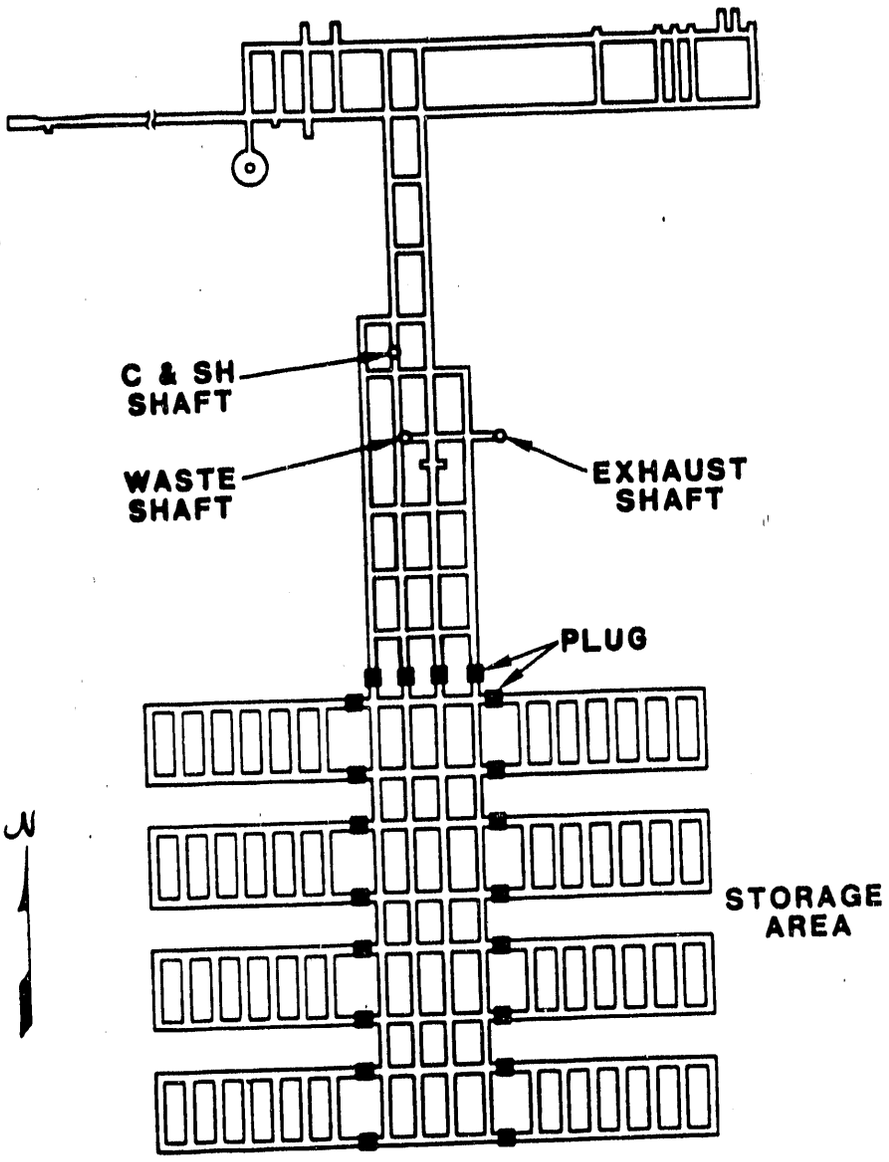


Figure 12-30

STORAGE AREA
PLUG LOCATIONS

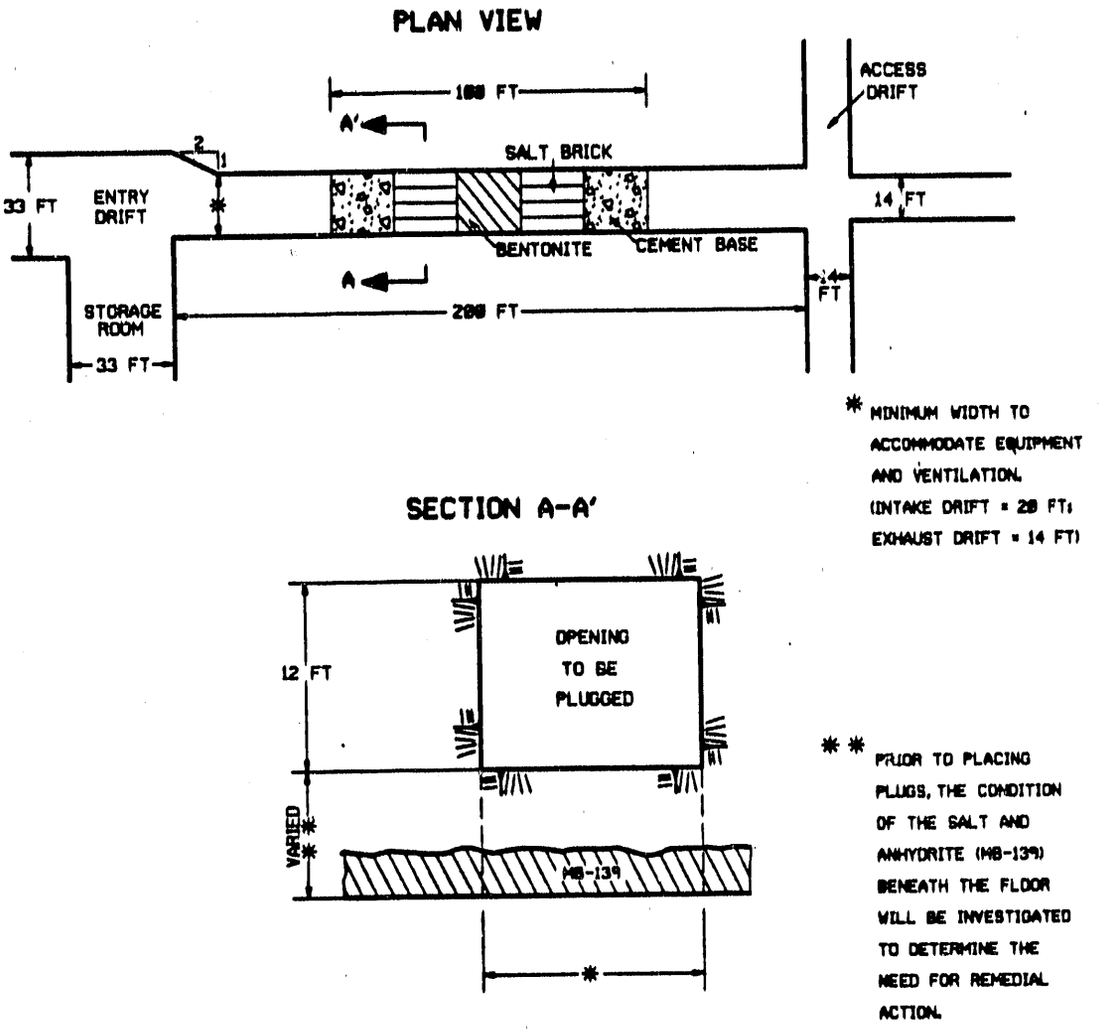


Figure 12-31

STORAGE AREA
PROPOSED PANEL PLUG REFERENCE DESIGN

separations at clay seams above the roof will need to be evaluated. If zones of unacceptable permeability are detected in the floor, the plug area should be lowered to remove the fractured zone and MB-139. Similarly, should any separations be found at clay seams above the entry drift, the roof should be excavated up through the highest seam exhibiting separation.

If the disturbed zone effects are not substantial, low-pressure grouting may be considered as an alternative remedial action. This would permit retention of the minimum cross section for the plug area. In addition, pressure grouting could be used in conjunction with excavation to treat deeper fractures, if present.

12.5 STORAGE ROOM BACKFILL

In accordance with the design criteria, the storage room reference design includes backfilling the rooms with crushed salt after waste emplacement. The storage area drift and room dimensional requirements are shown on Figures 12-2 and 12-3. The thickness of the salt backfill covering the waste packages shown on these figures is 1 to 2 feet. This is to be the thickness of the salt after placement and does not take into account backfill consolidation during room closure.

The only purpose for backfilling presented in the criteria is to provide fire protection in the storage rooms based on an accident scenario in which spontaneous ignition of the contents of a CH TRU waste container results in fire propagation to adjacent containers. Recent studies concerning the potential for spontaneous ignition in CH TRU waste containers have indicated that this is not a credible scenario. Although backfill is a design criteria requirement and therefore must be incorporated into the reference design, the results of these studies indicate that backfill will not be necessary for fire protection.

12.6 CONCLUSIONS AND RECOMMENDATIONS

The following subsections present conclusions pertaining to validation of the WIPP storage area reference design and recommendations for design modifications to achieve validation of the reference design. These are based on a comparison of the design criteria, design bases and reference design configurations with the results of the analysis and evaluation of data collected during the design validation process.

12.6.1 Conclusions

The most significant finding of the design validation program is the difference between closure predicted from laboratory test data and the closure actually occurring in the underground facility. The storage area reference design configurations were designed before long-term in situ data were available. Closure rates were estimated using creep constants derived from the laboratory analyses of salt cores from borehole ERDA-9. These estimates resulted in the establishment of a closure limit of 12 inches in the first 5 years following excavation. Evaluation of the in situ data demonstrates that this closure limit is insufficient. The predicted closure based on laboratory analyses underestimates the actual closure at 3 years by about a factor of three (Figure 11-35). Establishing the causes for this underprediction of closure requires additional study and research and is beyond the scope of this report.

Vertical and horizontal closure demonstrated by the in situ data will not allow the reference design to meet the design criteria requirements. The waste containers will most likely be crushed and breached. Furthermore, because of the in situ closure the waste container stacking configurations and transport vehicle would not be compatible with the reference design room and drift configurations. In order for the reference design to comply with the design criteria, the storage area design configurations or the design criteria will have to be modified. Five alternative modifications are presented in the next subsection.

The analytical results for the storage area show the redistribution of stresses around the openings due to the effects of creep. Based on the computed vertical, horizontal and effective stresses, the magnitude of stresses immediately adjacent to the openings decreases and the stress arch around the openings migrates away with time. The maximum stress occurs immediately after excavation and is followed by relaxation due to creep behavior. Therefore, the stresses will not cause a future stability problem in the storage area except in MB-139, where a gradual buildup of stress may cause local failure of the anhydrite. This failure is expected to be in the form of floor slabbing and should not affect the structural performance of the openings nor hinder the waste storage operations. Investigations of the test room floors indicate that major fracturing has occurred only in the south half of Test Room 3 (Room T). All other floor fracturing has been minor.

The analysis shows the locations of effective creep strain concentrations at different times around the openings. Based on the predicted values of effective creep strain and the strain limit discussed in Chapter 6, effective creep strain may locally exceed the critical strain which is based on laboratory test data. However, this is not expected to disturb the overall structural stability within the limits required for safety during the 5-year demonstration period and permanent storage. Minor spalls and failures on the wall surfaces, similar to the ones discussed in Chapter 11, are expected to occur and can be easily identified and monitored. Scaling of these minor failures, when necessary, is considered a normal maintenance operation.

The facility stratigraphy is continuous and uniform. No anomalous conditions have been encountered that would jeopardize facility operations or waste storage integrity. The fracturing that is occurring beneath the test room floors may develop to some degree beneath the storage rooms. These fractures are not considered to be deleterious to storage room performance. There have been no occurrences of gas or brine in quantities that would adversely affect waste storage operations.

The storage area has been designed to accommodate panel plugs as required by the criteria. The reference design for the panel entry drifts contains a reduced cross section in the plug area. The minimum dimensions for the plug area will be dictated by operating requirements. The dimensions may also require alteration if disturbed zone effects are present that necessitate additional excavation.

An independent study has concluded that spontaneous combustion in the waste containers is not a credible event. In this case, crushed salt backfill will not be required for fire protection. Because it has been determined that the storage rooms will close at a rate faster than originally anticipated, deletion of the backfill requirement will provide additional allowance for vertical closure. This has favorable implications in terms of recommended modifications discussed in the next subsection.

12.6.2 Recommendations

The reference design will be validated when any of the following alternative modifications or combinations thereof are incorporated:

(1) Maintain the reference design room dimensions (13 to 14 feet high and 33 to 34 feet wide), retain the salt backfill but reduce the volume of waste to be stored and modify the waste stacking configuration in each room and entry drift (Figure 12-32). These changes would be required only during the 5-year demonstration period. Revise the criteria to require that retrieval operations be accomplished within 7 years of excavating each room. This will assure that the waste containers will not be crushed or breached. However, it will require a significant number of additional rooms during and after the demonstration period.

(2) Maintain the reference design room dimensions and the waste storage volume. Revise the criteria to delete the requirement for salt backfill and to require that if the

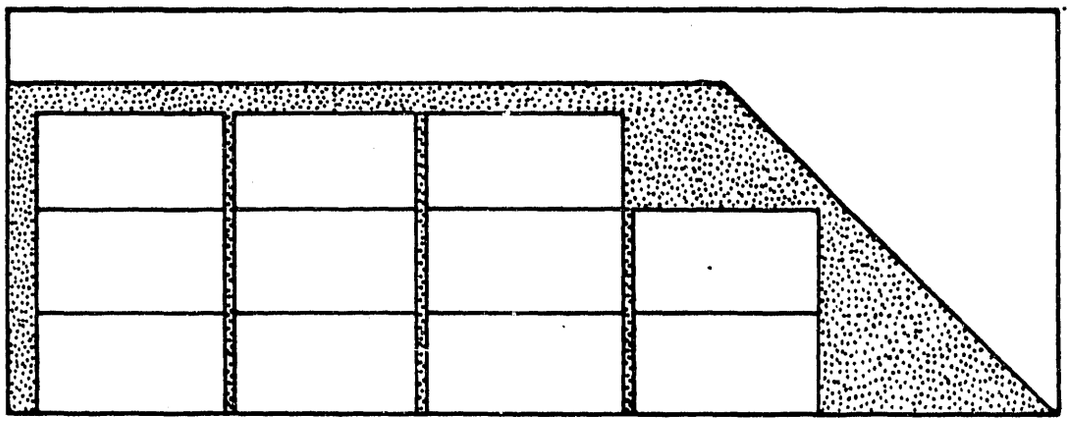


Figure 12-32

STORAGE AREA
MODIFIED WASTE STACKING CONFIGURATION

waste is to be retrieved it shall be done before the age of any room in which waste is being retrieved reaches 7 years. This will preclude the possibility of crushing and/or breaching any waste containers and will make retrieval easier and more rapid. No additional rooms will be required.

(3) Maintain the reference design room dimensions, the waste storage volume, and the salt backfill. Revise the storage operations during the 5-year demonstration period so that the waste stored first can be retrieved first. Excavate the rooms to 14 x 34 feet initially and then trim them to 14 x 34 feet a year later. Rooms having waste retrieved will not be older than 6 years and the wall-to-wall closure will be approximately 12 inches. This would minimize the crushing and breaching of the waste containers. The criteria are to be revised as stated under (5) of these recommendations. However, due to the first-in/first-out recommendation, more rooms will be required during the 5-year demonstration period to accommodate the expected volume of waste. Trimming to the final dimensions will also increase operating costs. The total number of rooms required will be the same as provided by the reference design.

(4) For the 5-year demonstration period, reduce the storage room width from 33 feet to 28 feet, maintain the 13 to 14-foot height, and reduce the pillar width to 84 feet. Maintain the first room for RH emplacement at 33 feet to 34 feet wide and 13 feet to 14 feet high as provided in the reference design. Reduce the volume of waste to be stored in each room and maintain the salt backfill. Excavate the rooms to 14 x 28 feet then, after approximately 1 year, trim them to 14 x 28 feet again. Provide for first-in/first-out emplacement and retrieval during the 5-year demonstration period. This will reduce the rate of creep to approximately

the rate for the 13 x 25-foot drifts. The potential for crushing and breaching of the waste containers will be minimized and the stability should be better than that for a 33-foot wide room. The total volume of excavation will be approximately the same. If this alternative is selected, additional engineering evaluation will be required.

(5) Maintain all of the features of the reference design. That is, maintain the storage room configuration of 13 feet high and 33 feet wide, maintain the salt backfill, maintain the planned volume of waste to be stored in each room and drift, and maintain the same optimized excavation plan for the 5-year demonstration period and permanent storage. Revise the design criteria to allow crushing and breaching of the CH waste containers during the 5-year demonstration period as well as during permanent storage. Also, revise the criteria requiring a demonstration of waste package handling to include a demonstration of the retrieval of crushed and breached containers prior to receiving waste. This alternative will not only demonstrate the safe retrieval of waste if required during the 5-year demonstration period but also at any time during permanent storage.

In addition to these recommended alternative modifications, the following modifications are recommended:

(6) The drifts used for storage will have to be maintained and trimmed to provide the required equipment and storage clearances. The closure rates are not critical for storage because these drifts will be used only for permanent storage near the end of the permanent storage period.

(7) Add additional rooms to compensate for the space occupied by the plugs in the entry drifts.

(8) Install instrumentation in the storage rooms to obtain in situ data to monitor storage room behavior.

GLOSSARY

G.1 TERMINOLOGY

Back - The roof of underground horizontal openings.

Bunton - Horizontal, tubular steel section installed in the C & SH shaft to support the wood guide rails which center the shaft conveyance as they travel in the shaft.

CH TRU waste - Contact-handled transuranic waste that is packaged so that the dose rate at the surface of the waste package is not greater than 200 millirem/h.

Closure - The gradual decrease in distance between two opposing points in an underground opening as a result of rock or salt movement.

Convergence - See "closure".

Datalogger - Computer system that collects and records the output of geomechanical instrumentation.

Design bases - Detailed requirements established from the design criteria to provide additional direction in development of the engineering design of the WIPP underground facilities.

Design configuration - Engineered design dimensions of underground facility openings based on requirements of design criteria and design bases.

Design criteria - General requirements established to govern the engineering design of the WIPP underground facilities.

Design validation - The process of confirming the WIPP underground opening reference design by determining the compatibility of the design criteria, design bases and reference design configurations using site specific information. Validation is achieved through an assessment of the condition and behavior of the underground openings, and on predictions of their future behavior, based on in situ observations and measurements.

Drummy - Term used to describe rock that sounds hollow or loose when tapped with a solid object; used especially in relation to a mine roof.

Facility level - The underground horizontal portion of the WIPP facility developed for waste storage purposes.

Floor/roof beam - The rock thickness between the floor or roof of an excavated opening and the first underlying or overlying clay seam.

Galloway - A multi-decked steel platform suspended in a shaft and raised or lowered by means of a cable hoist. It is used to transport material and personnel in the shaft, particularly during shaft outfitting.

Guide - Vertical shaft member of steel or wood which is used to center the conveyance equipment as it travels in the shaft.

Long-term monitoring - The extended acquisition and evaluation of data to determine the geomechanical response of the rock/salt to excavation. These data will supplement the R & D program.

Muck - The broken rock and other material that is removed during shaft or horizontal opening excavation.

Penecontemporaneous - Term used to indicate a geologic process that occurs concurrent with or after sediment deposition but before lithification.

Potash - Any potassium-rich rock mined and refined to produce products used in agriculture or industry.

Preliminary design validation - The process of achieving a preliminary evaluation of the underground design criteria, design bases and design configurations early in construction, primarily by visual observations of the underground openings and geomechanical instrumentation measurements.

R & D Program - The WIPP mission designed to provide a technical understanding of systems design, safety and environmental assessments for the disposal of radioactive waste from U.S. defense programs. The program includes technology development through laboratory testing of theoretical analysis and in situ testing to evaluate the techniques used to monitor the responses of materials and facility systems.

RH TRU waste - Remote-handled transuranic waste that is packaged so that the dose rate at the surface of the package is greater than 200 millirem/h but less than 100 rem/h.

Rib - The vertical wall of underground horizontal openings.

Scaling - The removal of loose rock from underground opening surfaces.

Shaft outfitting - The process of installing shaft furnishings (utilities, buntons, guides, conveyance equipment, etc.), as well as stabilizing the wall by means of rock bolts, wire mesh or lining.

Short-term monitoring - The acquisition and evaluation of data to determine the initial geomechanical response of the rock/salt to excavation.

Site and Preliminary Design Validation (SPDV) - A WIPP program consisting of two integrated subprograms, Site Validation and Preliminary Design Validation, that are defined in their individual listings.

Site characterization - The process of obtaining geotechnical data and conducting experiments to determine the suitability of the WIPP site for a research and development facility to demonstrate the safe disposal of defense-related nuclear waste.

Site validation - The process of achieving the highest practicable level of confidence in the site's suitability and overall qualification through subsurface investigations.

Slabbing - The weakening of rock fragments or segments along fractures parallel to the excavation surface.

Spud - To begin drilling a well, hole or shaft.

Spalling - The breaking loose of chips, thin slabs, or fragments from the outer surface of a rock mass.

Telltale pipe - A pipe used to monitor the effectiveness of the chemical water seals in the shaft keys. The pipe provides a pathway for water to flow through the concrete beneath the seals from the salt/concrete interface to the inside face of the concrete key.

Transuranic (TRU) waste - Radioactive waste containing transuranic elements created by the absorption of neutrons into uranium atoms.

Underground development level - See "facility level".

Underground facility horizon - The stratigraphic interval within the Salado formation, from a depth of approximately 2,100 to 2,170 feet (elev. 1240 to 1310 feet), which was selected for testing and storage of low-level nuclear waste.

G.2 ACRONYMS

ACI	American Concrete Institute
AEC	Atomic Energy Commission
BNI	Bechtel National, Incorporated
BTP	Brine Testing Program
C & SH	Construction and salt handling
CH TRU	Contact-handled transuranic
DOE	U.S. Department of Energy
FEIS	Final Environmental Impact Statement
GFDR	Geotechnical Field Data Report
GSA	Geological Society of America
GTP	Gas Testing Program
LTC	Local termination cabinet
MIIT	Material Interface-Interactions Test
MOC	Management and Operating Contractor
MSHA	Mine Safety and Health Administration
NAS	National Academy of Sciences
R & D	Research and development
RH TRU	Remotely-handled transuranic
RMC-IIA	Revised Mission Concept IIA
SAR	Safety Analysis Report
SME	Society of Mining Engineering
SNL	Sandia National Laboratories
SPDV	Site and Preliminary Design Validation
TRU	Transuranic
TSC	Technical Support Contractor
USGS	United States Geological Survey
WIPP	Waste Isolation Pilot Plant

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WASTE ISOLATION PILOT PLANT

DESIGN VALIDATION
FINAL REPORT

APPENDICES

JOB 12484

OCTOBER 1986

BECHTEL NATIONAL, INC.
SAN FRANCISCO, CALIFORNIA

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APPENDIX A

STIPULATED AGREEMENT (PARTIAL)

The Department of Energy (DOE) and the State of New Mexico on July 1, 1981, entered into a Stipulated Agreement to perform certain work to validate the design of the WIPP underground facilities. Proposals for performing this work were identified in two parts: 1) tasks necessary to detail plans and rationale for the proposed design validation assessment, and 2) tasks necessary to prepare a report providing data, analysis and interpretation of the results of design validation assessment. The scope of work associated with these two DOE proposals included in the Stipulated Agreement are given below:

DOE Proposal to Prepare the Plan for Design Validation

1. Assumptions

The following assumption was made to define the tasks necessary to fulfill the requirements of this request.

a) The plan will primarily focus on the development of test panels for observing rock mechanics behavior.

2. Proposed Work

The tasks to be completed to provide the required plan include:

a) Review of the current test plans.

b) Establishment of objectives and needs of the test plan, based on past analysis, material property data, uncertainty in design assumptions, the behavior, time period for test, etc.

c) Establishment of the rational behind the test plan.

d) Establishment of priorities for various components of the test.

e) Preparation of the steps in design, analysis, monitoring and review of the test program.

f) Review of the consistency of the proposed plan with the objectives and rationale for the test.

g) DOE will provide an individual to coordinate communications on test planning and experiment progress with the state.

3. Expected Results

The anticipated results include a more detailed test plan with appropriate technical rationale, and justification to perform to construct a test panel within the non-waste experimental area. The test panel may consist of four rooms separated by pillars. The dimensions of each will be similar to those to be used in the WIPP waste storage area. The results from the test should validate key assumptions for design regarding rock mass behavior. The test results will be of particular interest for predicting long term behavior of room closures.

4. Merits of the Proposed Plan

The proposed plan will provide a defensible, rational plan for the design test panel. The actual tests should significantly enhance the level of confidence and credibility in the resulting design.

5. Schedule

The draft of the proposed plan will be submitted to the State of New Mexico by the end of November 1981. [Revised to the end of October 1982 at a joint meeting on September 21, 1982, between DOE, EEG, et al]

DOE Proposal for the Proposed Report

1. Assumptions

The following assumption was made with regard to the proposal to provide the subject report:

a) The impact of SPDV Design Validation Experiment results on basic design assumptions will be the focus of this report, and validity of the actual designs in all its aspects will not be emphasized.

b) If all the tests can not be completed within the present schedule, an interim report summarizing the status of experiments may be provided.

2. Proposed Work

The following tasks will be undertaken as a part of the proposed work.

a) The experimental data will be obtained and deciphered.

b) A basic data package will be prepared.

c) Anaylsis of data for the rock mechanics parameters will be made.

d) The results will be evaluated against the basic design assumptions.

e) An overall evaluation of the impact of any differences between the assumed and observed design parameters will be made.

f) A report summarizing the above steps will be prepared.

3. Work Not Proposed

The proposed work will not include validation/verification of the designs, since the verification/validation would require further steps being carried out separately such as checking of the design calculations and drawings.

4. Expected Results

Results of the experiments will likely demonstrate the validity of the basic design assumptions regarding rock mechanics parameters. It could also possibly suggest a review of these assumptions and their overall impact on the design development.

5. Schedule

A draft of the proposed topical report will be provided by the end of March 1983*. If significant experimental results are not available prior to that time, an interim status report will be provided, and a draft of the entire report will follow as soon as reasonably possible.

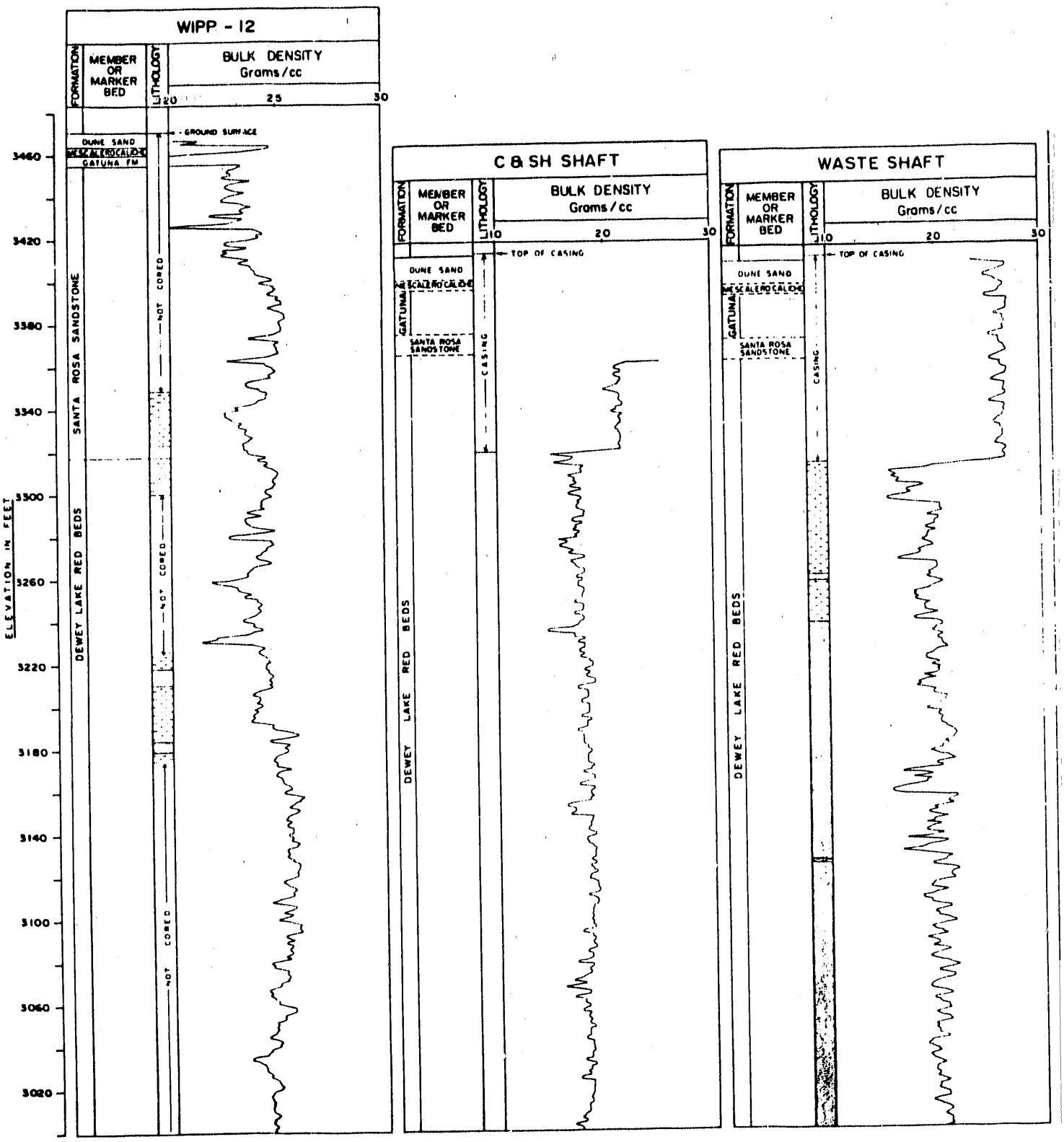
*Revised to the end of March 1983 at a joint meeting on September 21, 1982, between DOE, EEG, et al.

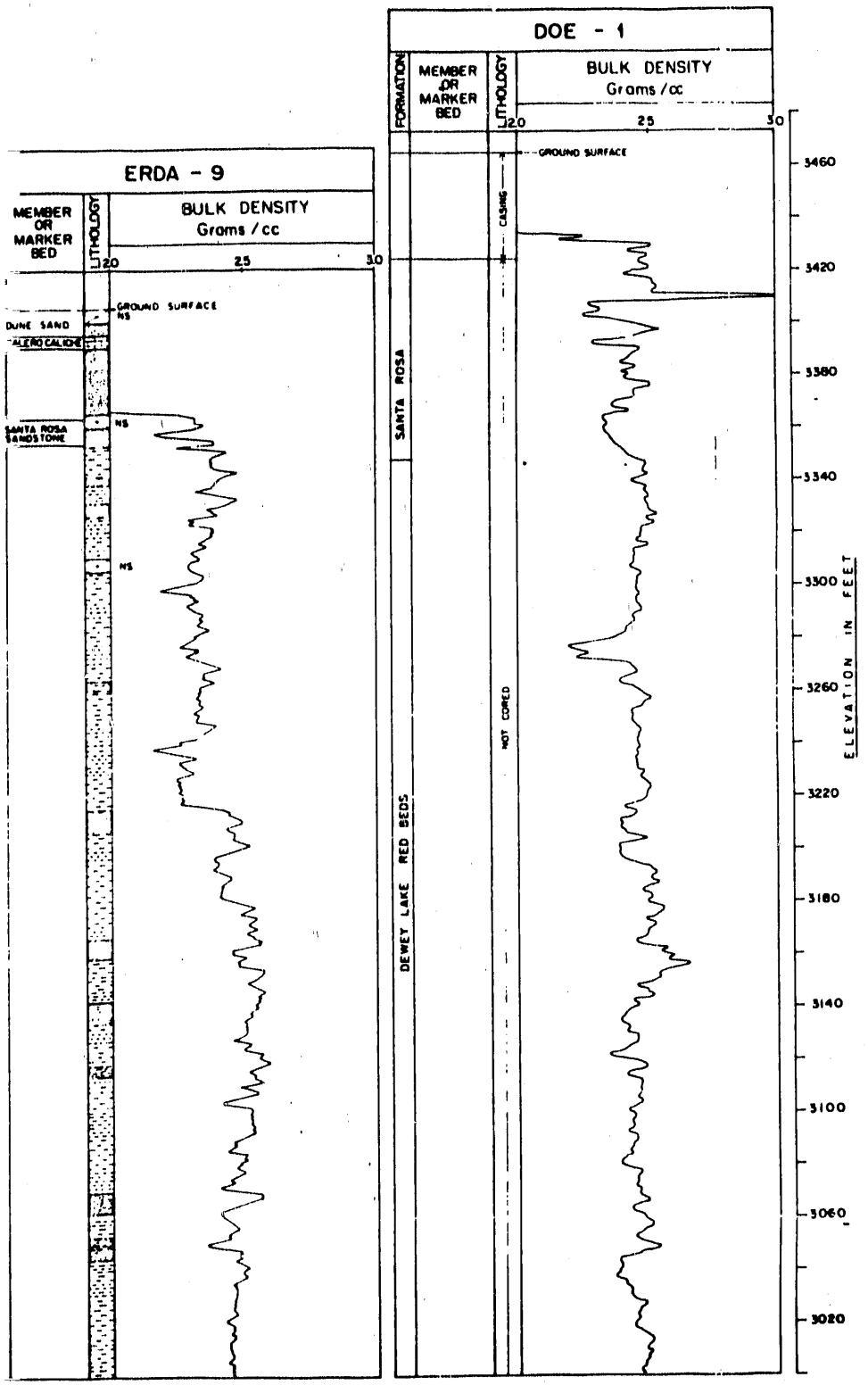
APPENDIX B

GEOLOGIC CORRELATIONS

CONTENTS

Figure No.	Title/Description
B-1	Geologic Correlation WIPP-12 to DOE-1 (5 Sheets)
B-2	Geologic Correlation WIPP-12 to DOE-1 Facility Horizon Area
B-3	Geologic Correlation C & SH Shaft to ERDA-9 Facility Level Area
B-4	Geologic Correlation North-South Section, E140 Drift Station N254 to S3656
B-5	Geologic Correlation North-South Section, E0 Drift Station N146 to N1410
B-6	Geologic Correlation East-West Section, N1100 Drift Station E206 to E1698
B-7	Geologic Correlation East-West Section, N1420 Drift Station E178 to E1698
B-8	Geologic Correlation East-West Section, N1270± Station E0 to W630
B-9	Geologic Correlation East-West Section, N1100 Drift Station W682 to W2782 (2 Sheets)

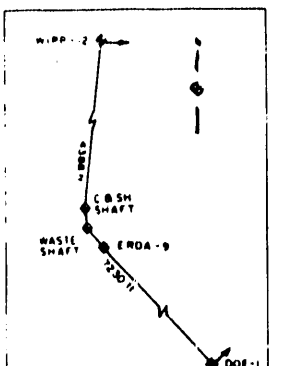

WIPP - 12
FORMATION
MEMBER OR MARKER BED
LITHOLOGY
BULK DENSITY Grams/cc
20
25
30
GROUND SURFACE
DUNE SAND
CALEROCALDO
GATUNA FM
SANTA ROSA SANDSTONE
DEWEY LAKE RED BEDS
NOT CORED
NOT CORED
NOT CORED
ELEVATION IN FEET
3460
3420
3380
3340
3300
3260
3220
3180
3140
3100
3060
3020
C & SH SHAFT
FORMATION
MEMBER OR MARKER BED
LITHOLOGY
BULK DENSITY Grams/cc
10
20
30
TOP OF CASING
DUNE SAND
CALEROCALDO
GATUNA
SANTA ROSA SANDSTONE
CASING
DEWEY LAKE RED BEDS
WASTE SHAFT
FORMATION
MEMBER OR MARKER BED
LITHOLOGY
BULK DENSITY Grams/cc
10
20
30
TOP OF CASING
DUNE SAND
CALEROCALDO
GATUNA
SANTA ROSA SANDSTONE
CASING
DEWEY LAKE RED BEDS



EXPLANATION

- Sandstone
- Caliche
- Siltstone
- Mudstone
- Anhydrite
- Gypsum
- Dolomite
- Halite
- Argillaceous Halite
- Polyhalite

NC = Not Cored
NR = No Recovery
NS = No Sample
MB = Marker Bed

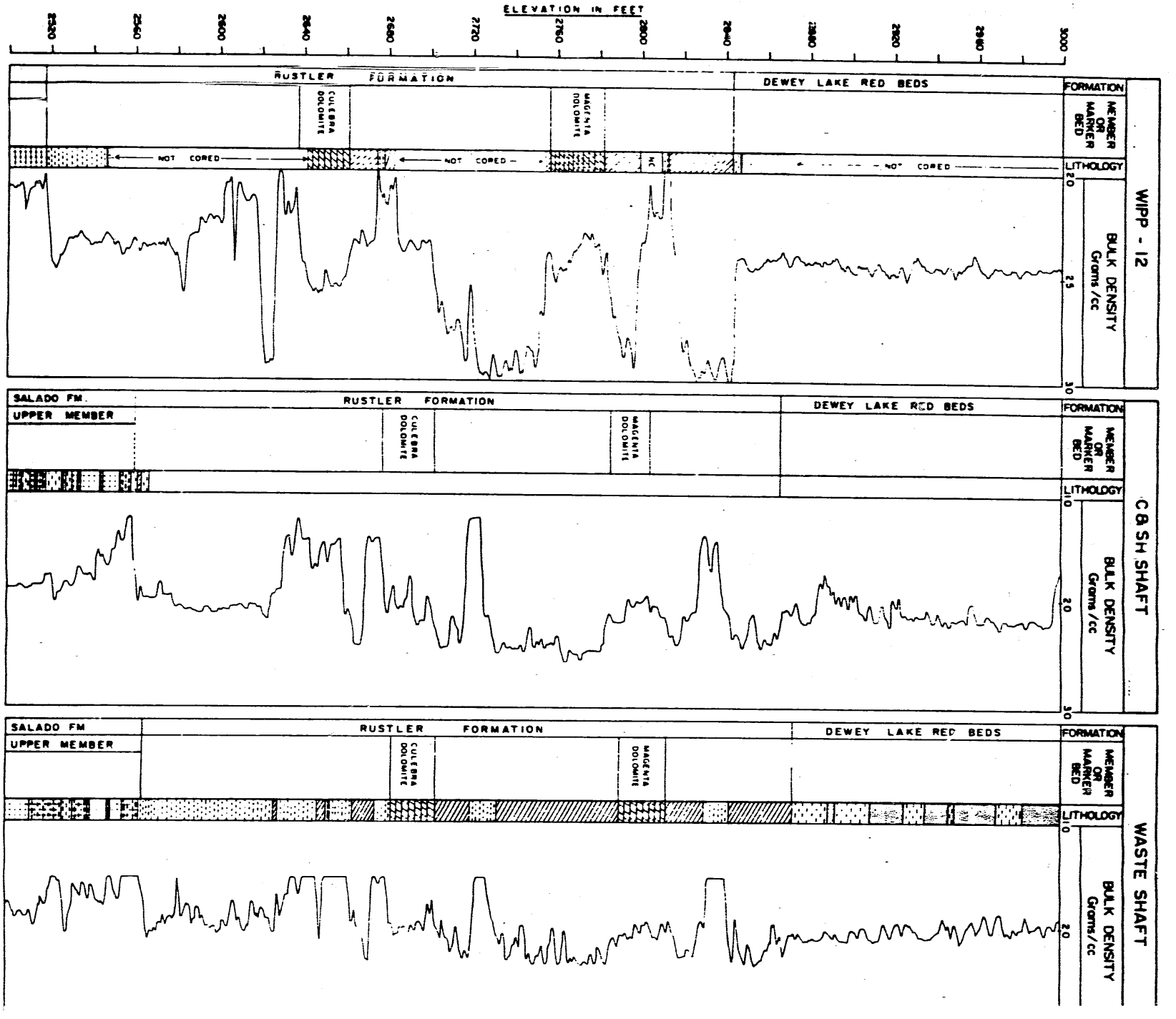


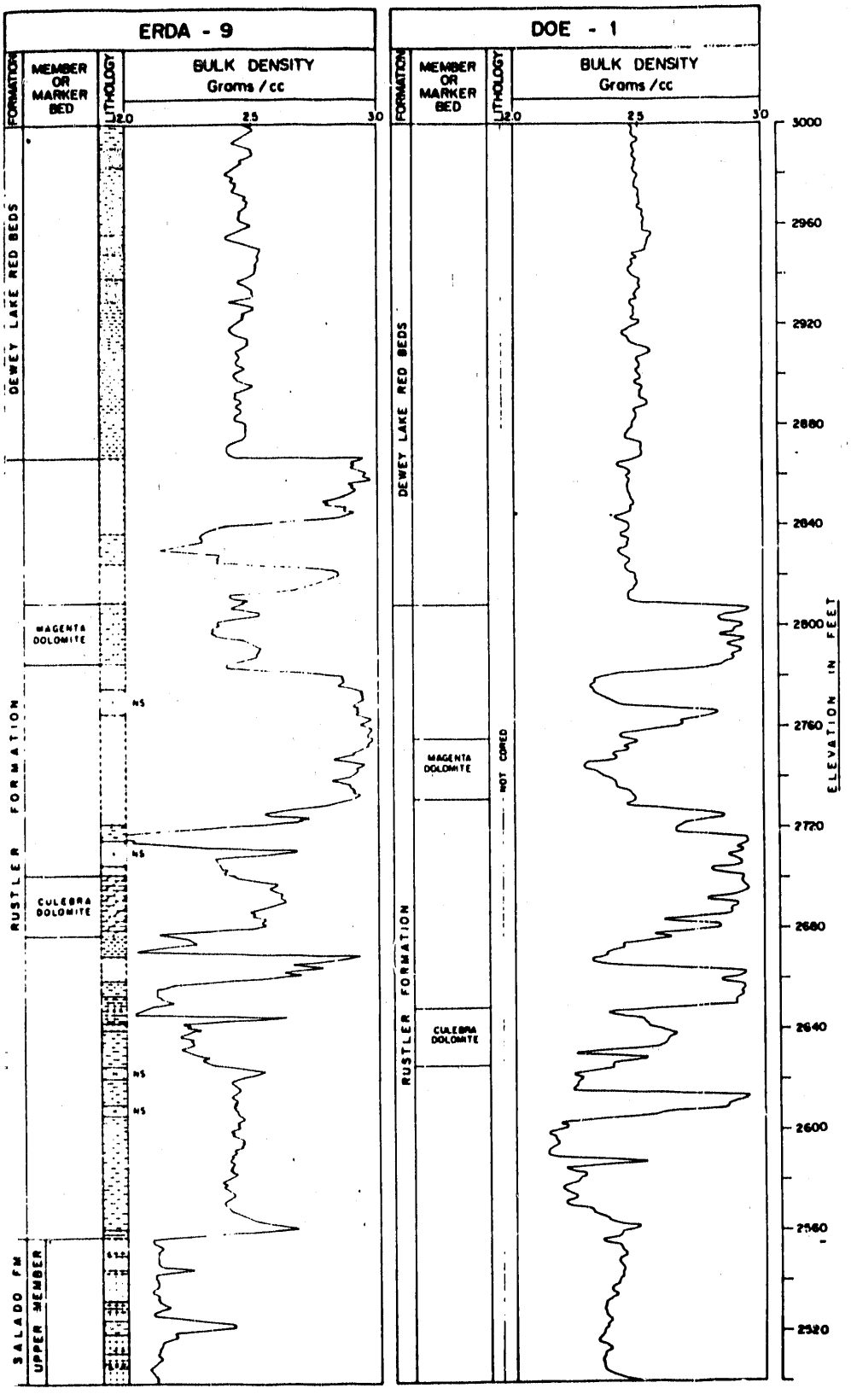
KEY PLAN

FIGURE B-1

GEOLOGIC CORRELATION
WIPP-12 TO DOE - 1

SHEET 1 OF 5


ELEVATION IN FEET
2520
2560
2600
2640
2680
2720
2760
2800
2840
2880
2920
2960
3000
RUSTLER FORMATION
DEWEY LAKE RED BEDS
CULEBRA DOLOMITE
MAGENTA DOLOMITE
NOT CORED
NC
FORMATION
MEMBER OR MARKER BED
LITHOLOGY
BULK DENSITY Grams/cc
2.0
2.5
3.0
WIPP - 12
SALADO FM.
UPPER MEMBER
C-B-SH SHAFT
WASTE SHAFT



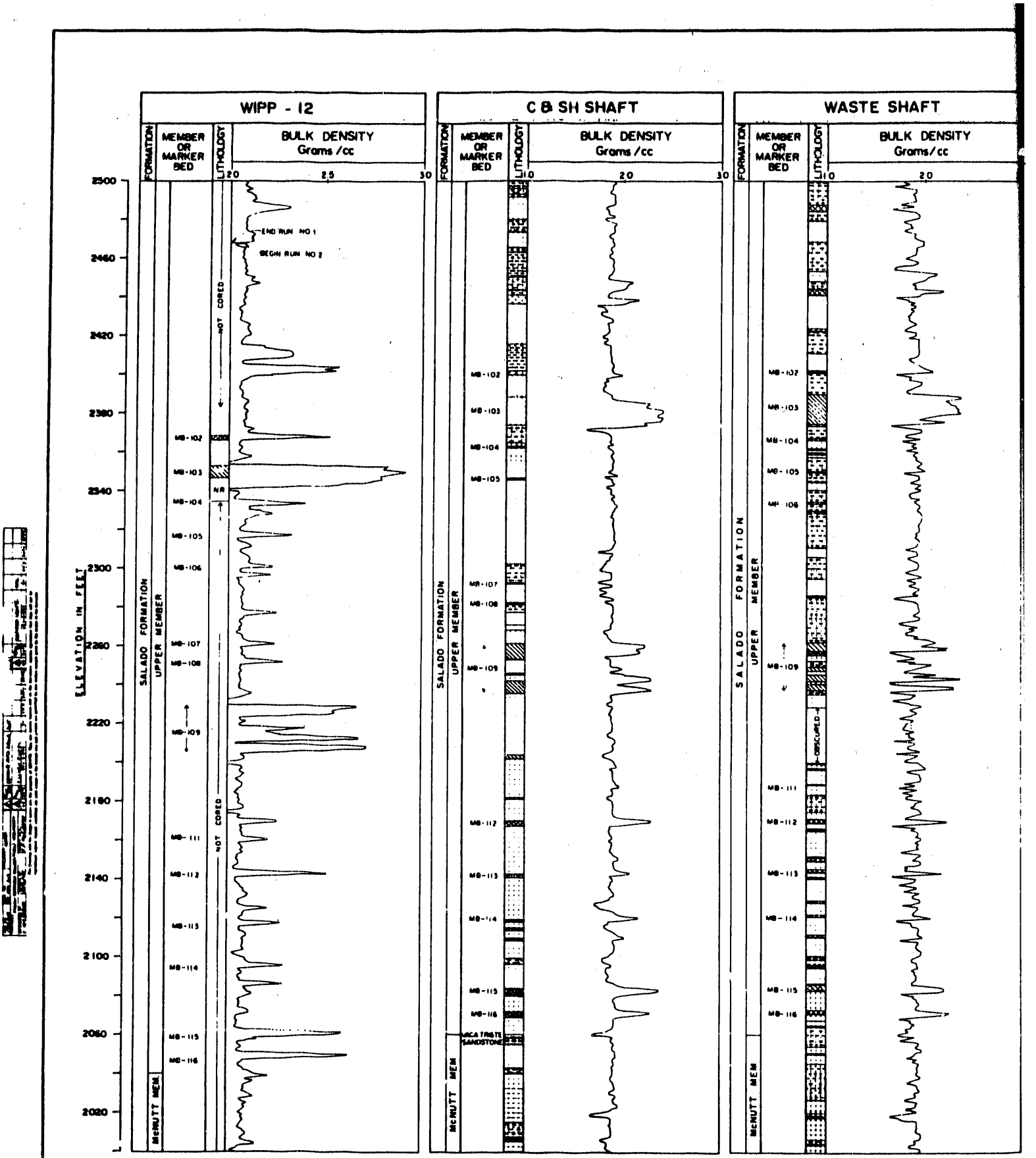
NOTE

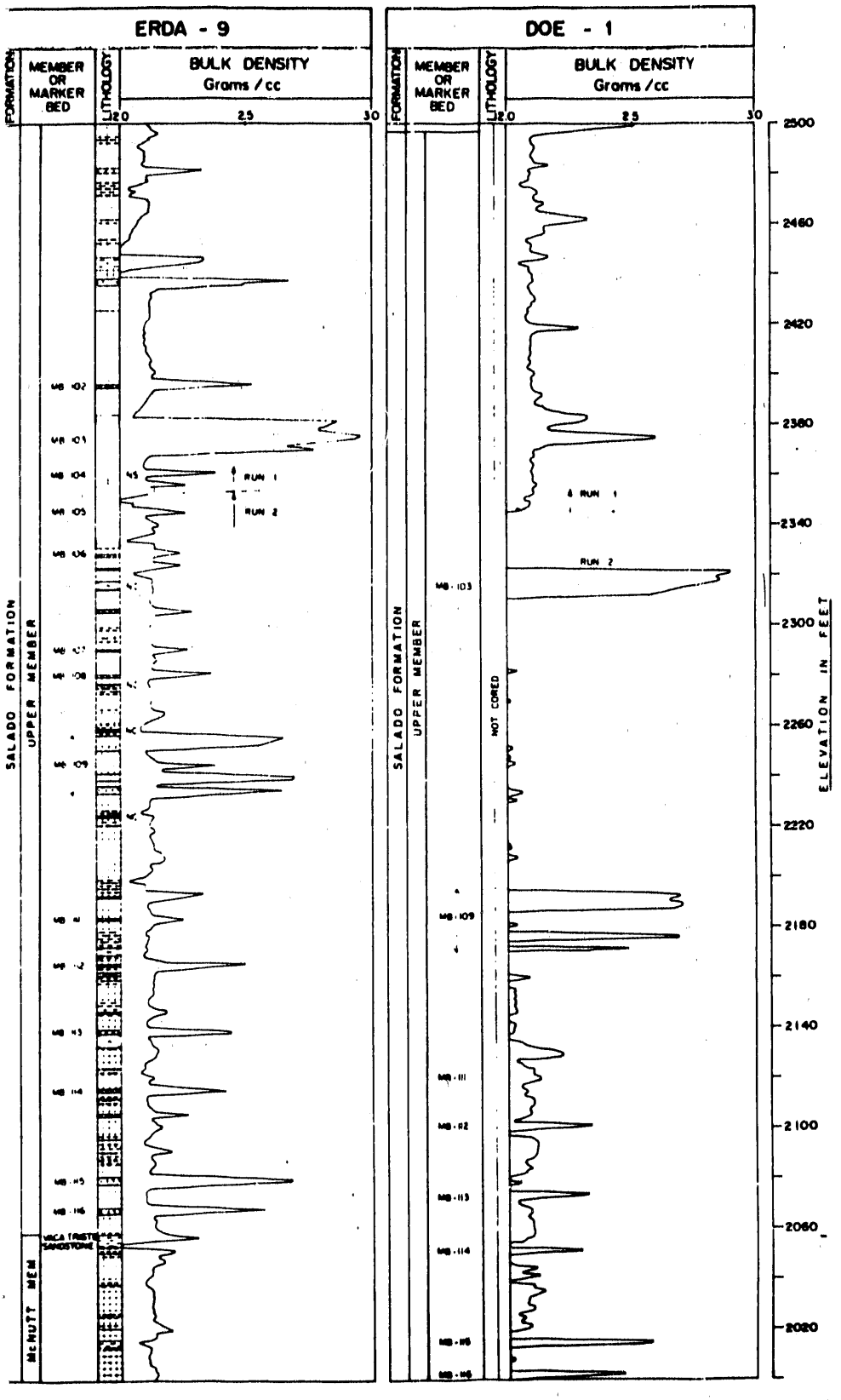
See sheet 1 for explanation and key plan

FIGURE B-1

GEOLOGIC CORRELATION
WIPP-12 TO DOE-1

SHEET 2 OF 5


WIPP - 12
C & SH SHAFT
WASTE SHAFT
FORMATION
MEMBER OR MARKER BED
LITHOLOGY
BULK DENSITY Grams /cc
2.0
2.5
3.0
END RUN NO 1
BEGIN RUN NO 2
NOT CORED
NR
SALADO FORMATION
UPPER MEMBER
McNUTT MEM
MB-102
MB-103
MB-104
MB-105
MB-106
MR-107
MB-108
MB-109
MB-111
MB-112
MB-113
MB-114
MB-115
MB-116
ELEVATION IN FEET
2500
2460
2420
2380
2340
2300
2260
2220
2180
2140
2100
2060
2020



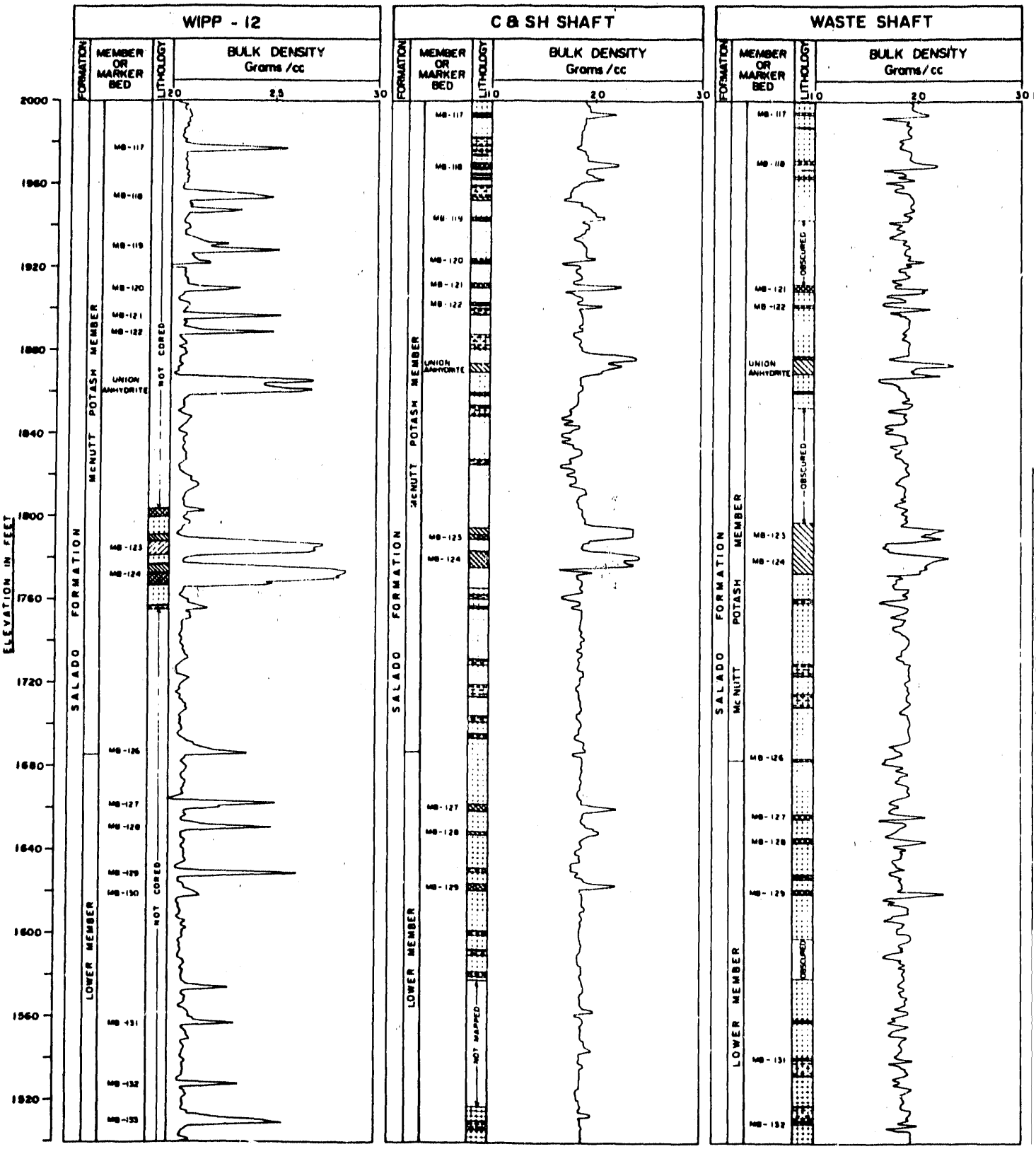
NOTE

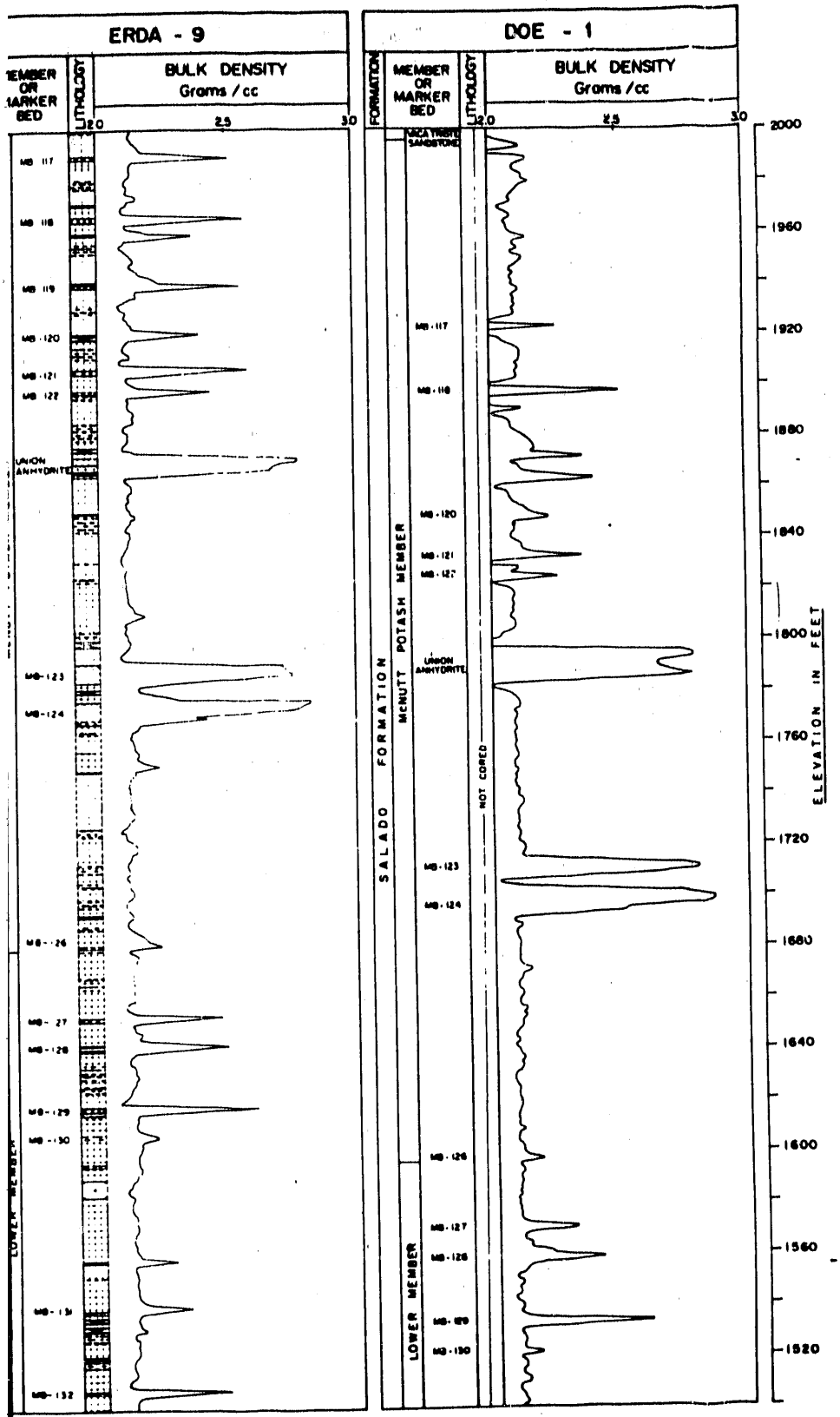
See sheet 1 for explanation and key plan

FIGURE B-1

GEOLOGIC CORRELATION
WIPP-12 TO DOE-1

SHEET 3 OF 5


WIPP - 12
C & SH SHAFT
WASTE SHAFT
FORMATION
MEMBER OR MARKER BED
LITHOLOGY
BULK DENSITY Grams / cc
2.0
2.5
3.0
1.0
ELEVATION IN FEET
2000
1960
1920
1880
1840
1800
1760
1720
1680
1640
1600
1560
1520
SALADO FORMATION
McNUTT POTASH MEMBER
LOWER MEMBER
MB-117
MB-118
MB-119
MB-120
MB-121
MB-122
UNION ANHYDRITE
MB-123
MB-124
MB-126
MB-127
MB-128
MB-129
MB-130
MB-131
MB-132
MB-133
NOT CORED
NOT MAPPED
OBSCURED



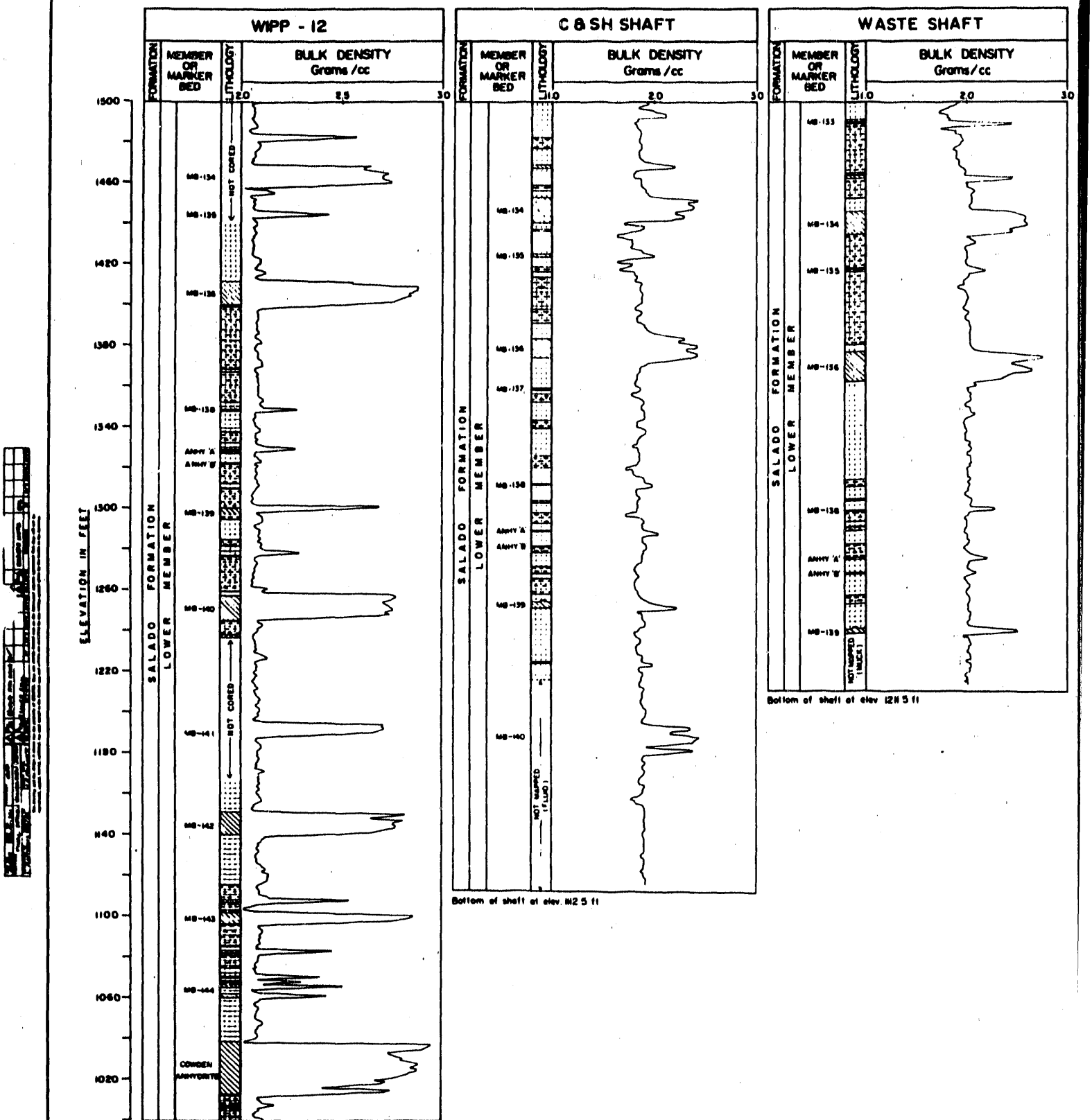
NOTE

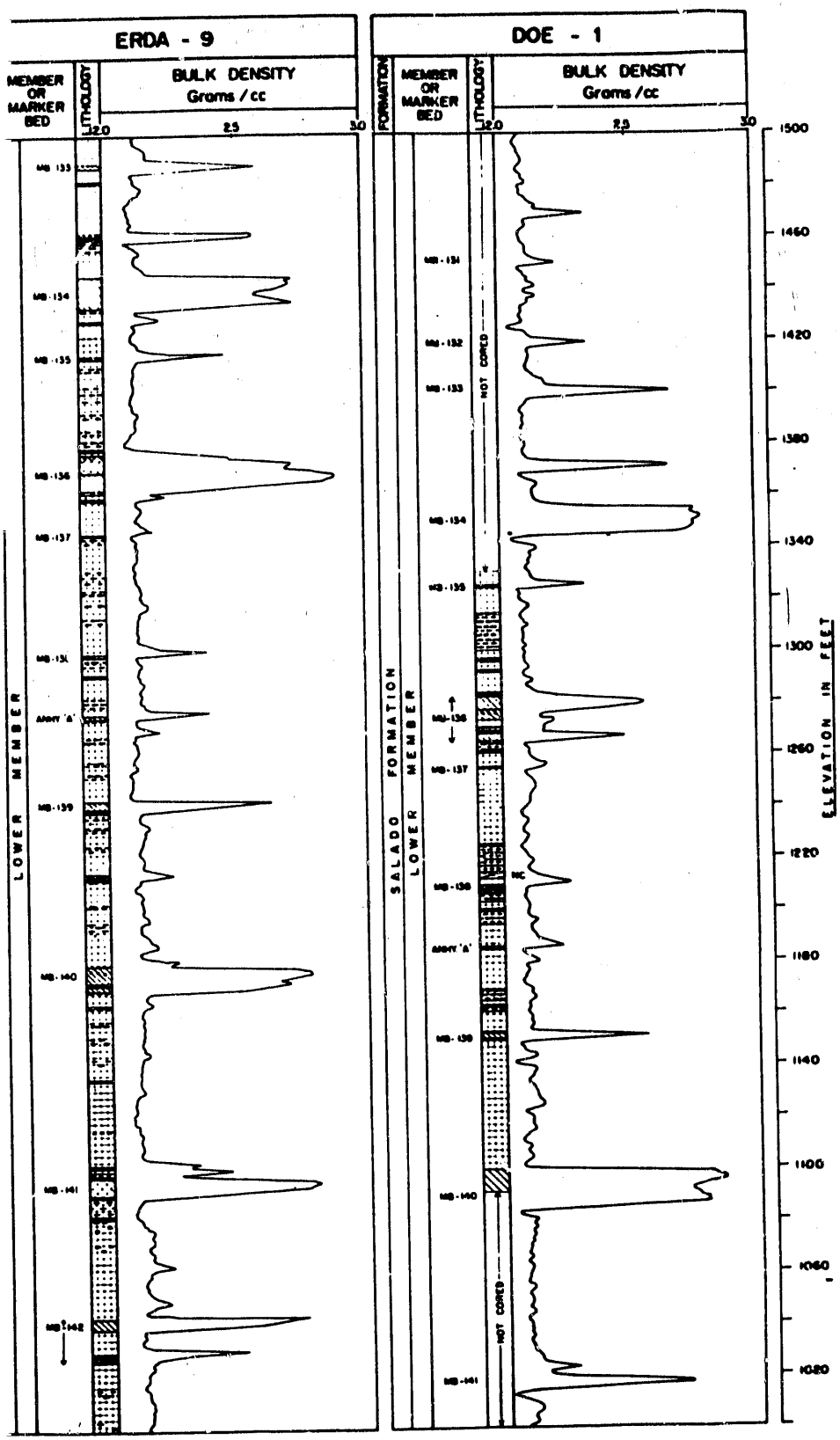
See sheet 1 for explanation and key plan

FIGURE B-1

GEOLOGIC CORRELATION
WIPP-12 TO DOE-1

SHEET 4 OF 5


WIPP - 12
C & SH SHAFT
WASTE SHAFT
FORMATION
MEMBER OR MARKER BED
LITHOLOGY
BULK DENSITY
Grams /cc
2.0
2.5
3.0
1.0
ELEVATION IN FEET
1500
1460
1420
1380
1340
1300
1260
1220
1180
1140
1100
1060
1020
SALADO FORMATION
LOWER MEMBER
MB-134
MB-135
MB-136
MB-138
ANHY 'A'
ANHY 'B'
MB-139
MB-140
MB-141
MB-142
MB-143
MB-144
COWDEN ANHYDRITE
NOT CORED
NOT MAPPED (FLUID)
MB-137
MB-133
Bottom of shaft at elev. 1125 ft
Bottom of shaft at elev 1215 ft



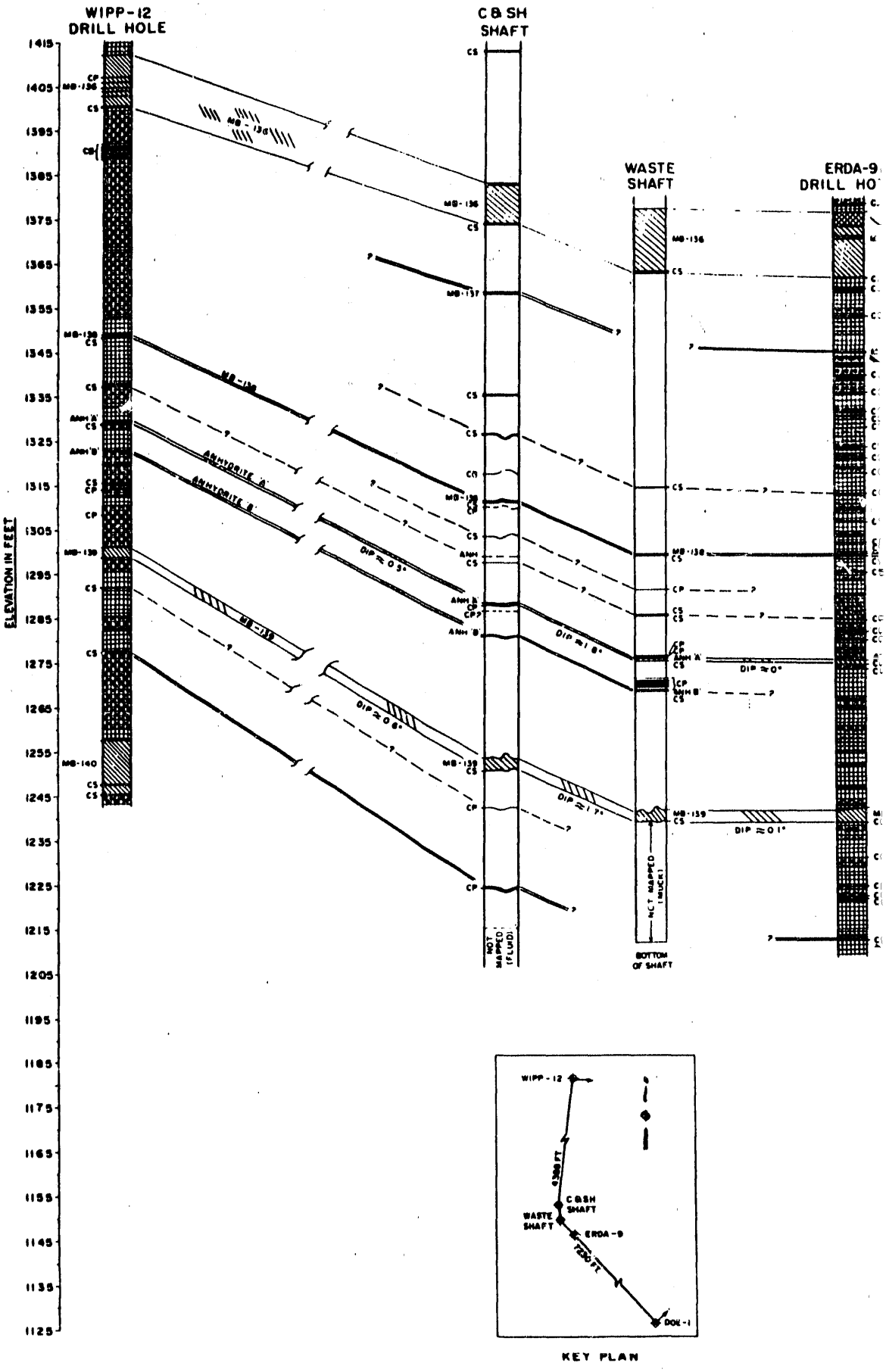
NOTE

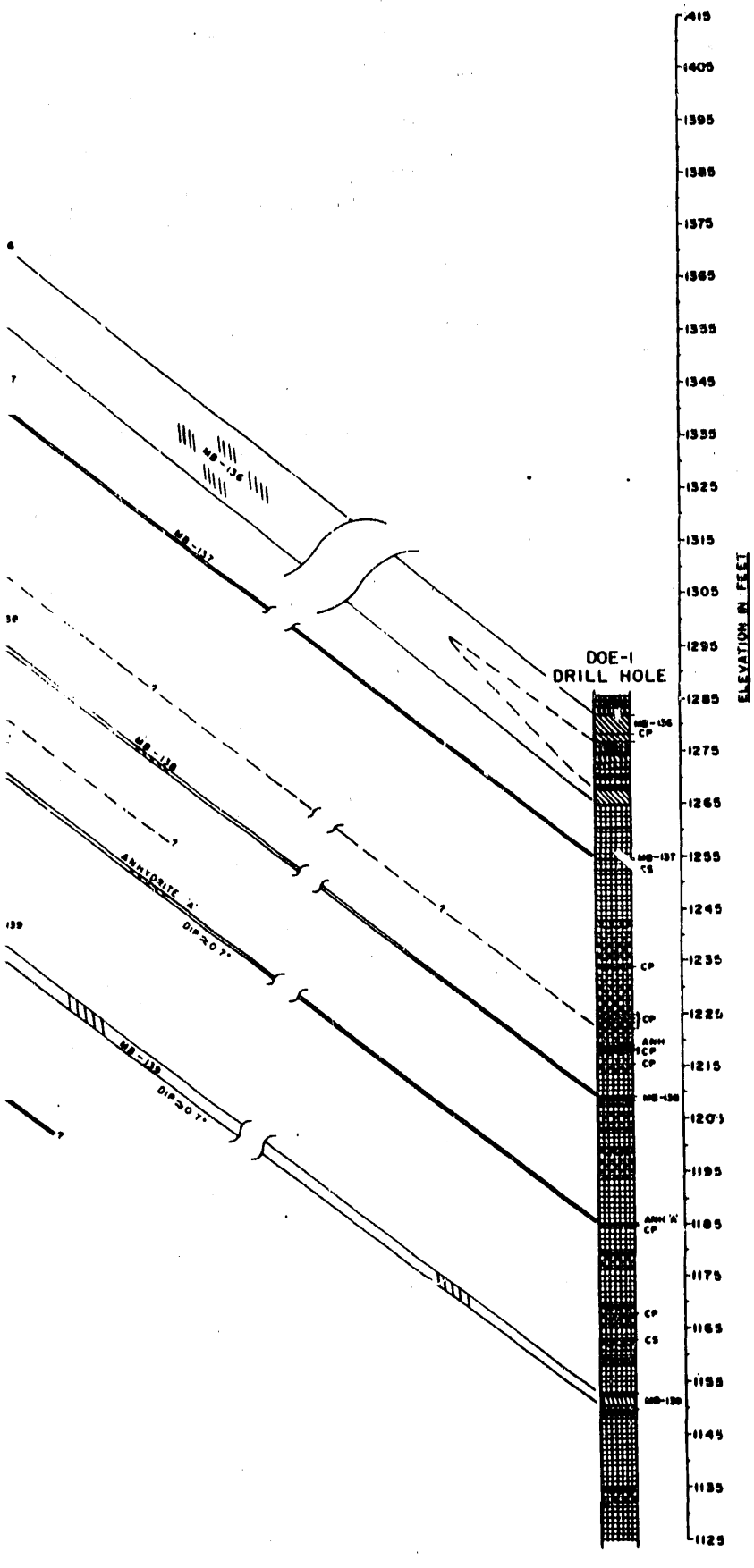
See sheet 6 for explanation and key plan

FIGURE B-1

GEOLOGIC CORRELATION
WIPP-12 TO DOE-1

SHEET 5 OF 5


WIPP-12 DRILL HOLE
C & SH SHAFT
WASTE SHAFT
ERDA-9 DRILL HO
ELEVATION IN FEET
1415
1405
1395
1385
1375
1365
1355
1345
1335
1325
1315
1305
1295
1285
1275
1265
1255
1245
1235
1225
1215
1205
1195
1185
1175
1165
1155
1145
1135
1125
MB-136
MB-137
MB-138
MB-139
MB-140
ANHYDRITE 'A'
ANHYDRITE 'B'
DIP ≈ 0°
DIP ≈ 1.6°
DIP ≈ 2.0°
DIP ≈ 1.7°
DIP ≈ 0.1°
NOT MAPPED (FLUID)
NOT MAPPED (MUCK)
BOTTOM OF SHAFT
WIPP-12
1398 FT
C&SH SHAFT
WASTE SHAFT
ERDA-9
7230 FT
DOE-1
KEY PLAN
8
7
6
5



EXPLANATION

- Halite
- Argillaceous Halite
- Anhydrite
- Polyhalite
- Anhydritic Halite
- Clay Seam (CS)

CP = Clay Parting

CB = Clay Break

MB = Marker Bed

ANH. = Anhydrite

NOTES:

1. Stratigraphic and lithologic descriptions for WIPP-12, ERDA-9, and DOE-1 based on geologic logging of rock core. Descriptions for C & SH and waste shafts based on geologic mapping of shaft walls.
2. See Figure B-3 for detailed lithology of C & SH and waste shafts.
3. Polyhalite content of halite not shown.
4. Dips shown are apparent and not true dips

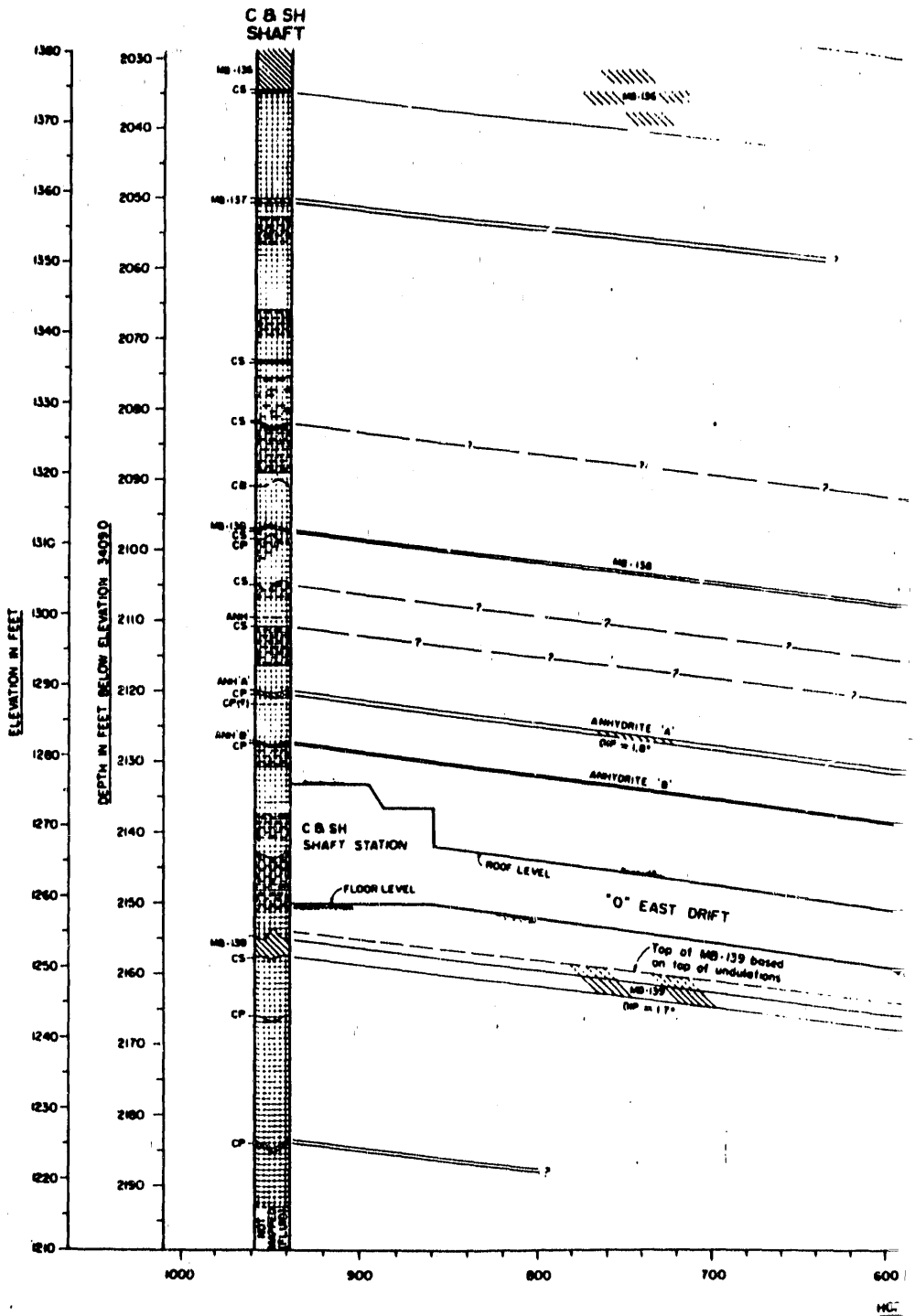
REFERENCES:

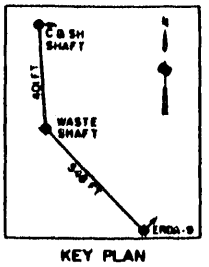
1. Jones, C. L., Geologic Data for Borehole ERDA-9, 1981

2. U.S. Dept. of Energy, Basic Data Report for Borehole DOE-1, 1982.

FIGURE B-2

GEOLOGIC CORRELATION WIPP-12 TO DOE-1 FACILITY HORIZON AREA





NOTES

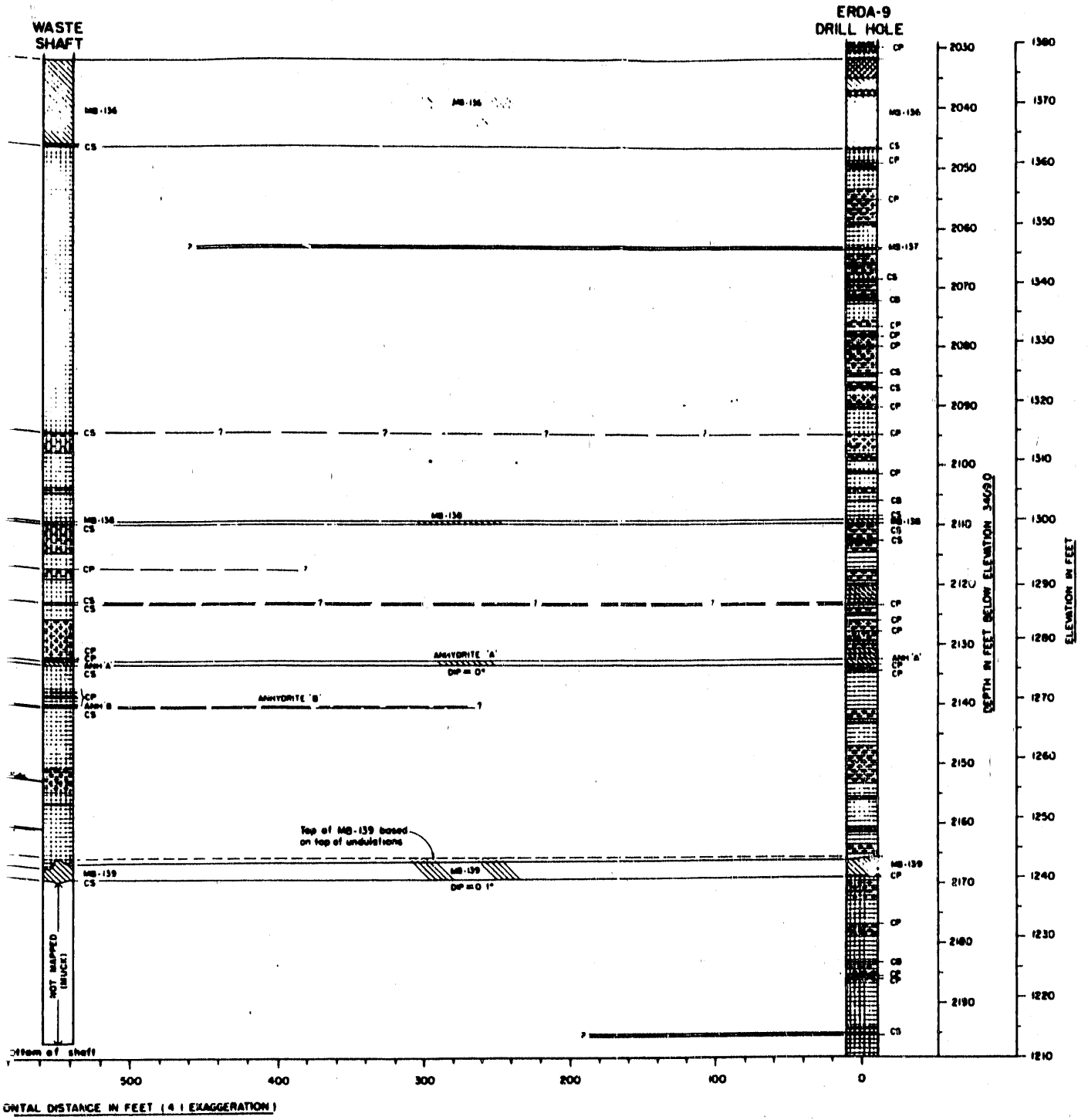
1 Stratigraphic
ERDA-9 ba
Descriptions
on geologic

2 See Figure

3 Polyhalite

4 Dips shown

8 7 6



lithologic descriptions for
on geologic logging of rock core
C&SH and waste shafts based
ping of shaft walls.

-2 for explanation of symbols and references

of halite not shown

apparent and not true dips.

FIGURE B-3

GEOLOGIC CORRELATION
C&SH SHAFT TO ERDA-9
FACILITY LEVEL AREA

The following descriptions pertain to the geologic map units shown in the drifts on Figures B-4, B-5 and B-8:

UNIT DESCRIPTIONS

UNIT 6[1] Halite: colorless with grayish orange-pink (1 OR 8/2)[2] tint; transparent to translucent; coarsely crystalline; trace of dispersed polyhalite; unit extends into the roof; lower contact with Unit 5 is gradational and/or diffuse.

UNIT 5 Halite: colorless; transparent to translucent; coarsely crystalline; trace of bluish-white (5B 9/1) to light bluish-gray (5B 7/1) argillaceous material occurring as pods (1/2-inch diameter) and discontinuous laminations or filling interstices; lower contact with Unit 4 is generally sharp and based on prominent color change in argillaceous material (gray to red-brown) from Unit 5 to Unit 4.

UNIT 4 Argillaceous halite: colorless to moderate reddish-brown (1 OR 4/6), less frequently light bluish-gray (5B 7/1); transparent; coarsely crystalline; trace of dispersed polyhalite; trace to abundant argillaceous material (decreasing downward) consisting of clay containing a trace of silt and fine crystals of halite, occurring as discontinuous laminations in upper half of unit and interstitially in lower half; lower contact with Unit 3 is gradational and based on absence of argillaceous material in Unit 3.

UNIT 3 Halite: colorless to moderate reddish-orange (1 OR 6/6); transparent to translucent; coarsely crystalline; trace of dispersed polyhalite; polyhalite content commonly increases downward; lower contact with Unit 2 is sharp.

UNIT 2 Argillaceous halite: moderate reddish-brown (1 OR 5/5), less frequently light bluish-gray (5B 7/1); medium to coarsely crystalline; argillaceous material primarily occurs interstitially or as discontinuous laminations; lower contact with Unit 1 is generally sharp, less frequently gradational.

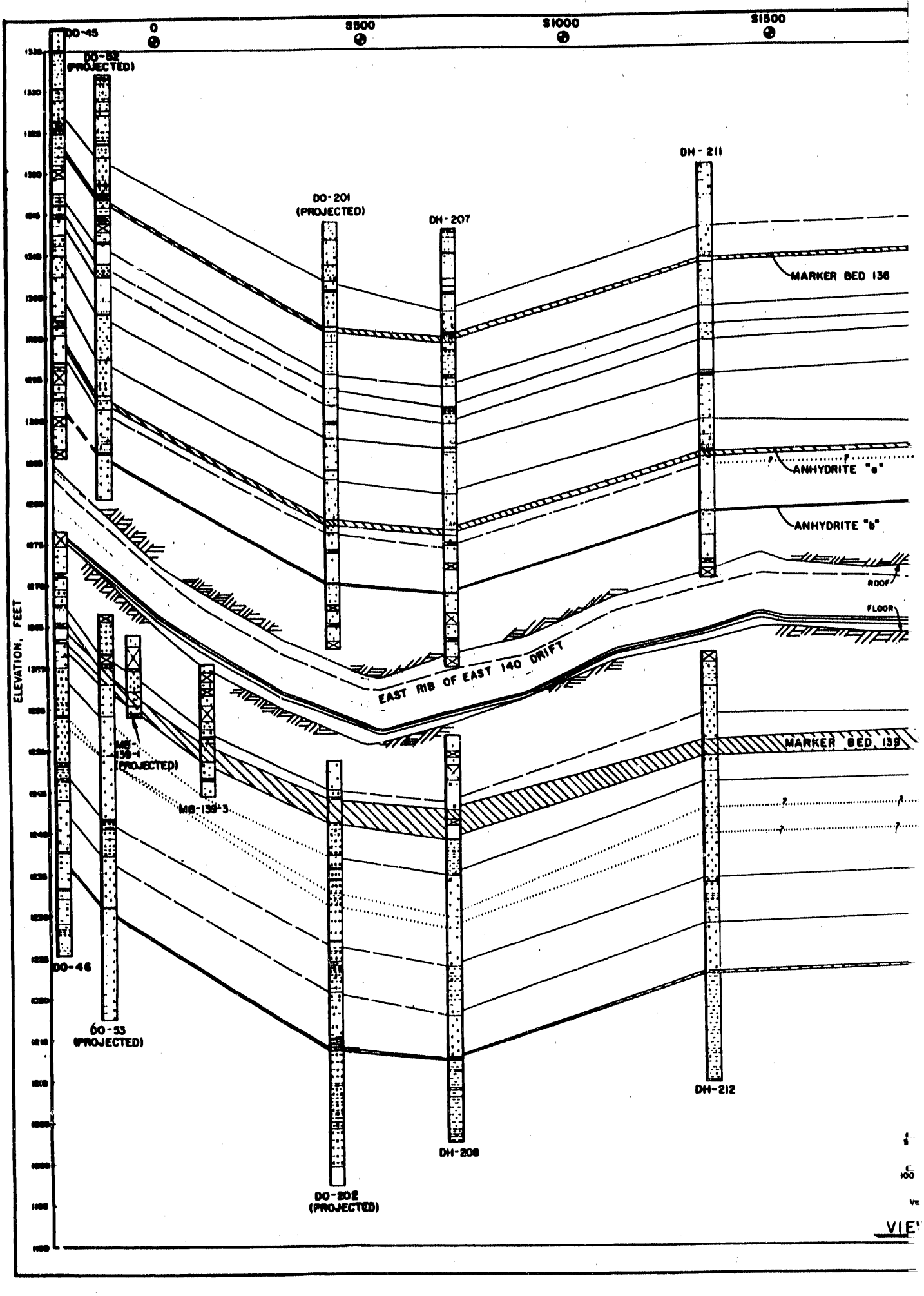
UNIT 1 Halite: light reddish-orange (1 OR 8/6) to moderate reddish-orange (1 OR 6/6), less frequently colorless; translucent to transparent; medium to coarsely crystalline; trace of dispersed polyhalite; lower contact with Unit 0 is sharp.

UNIT 0 Argillaceous halite: colorless to moderate reddish-orange (1 OR 6/6) and moderate reddish-brown (1 OR 4/6); medium to coarsely crystalline; trace of dispersed polyhalite; some argillaceous material occurs as discontinuous laminations and blebs or fills interstices (decreasing downward); contains finely crystalline halite; unit extends into the floor.

NOTES:

(1) Units listed in descending order from roof to floor.

(2) Alpha-numeric color designations are based on Geological Society of America Rock Color Chart.


0
$500
$1000
$1500
DO-45
DO-32
(PROJECTED)
DO-201
(PROJECTED)
DH-207
DH-211
MARKER BED 136
ANHYDRITE "a"
ANHYDRITE "b"
ROOF
FLOOR
EAST RIB OF EAST 140 DRIFT
MARKER BED 139
MB-139-1
(PROJECTED)
MB-139-3
DO-46
DO-33
(PROJECTED)
DH-208
DH-212
DO-202
(PROJECTED)
ELEVATION, FEET

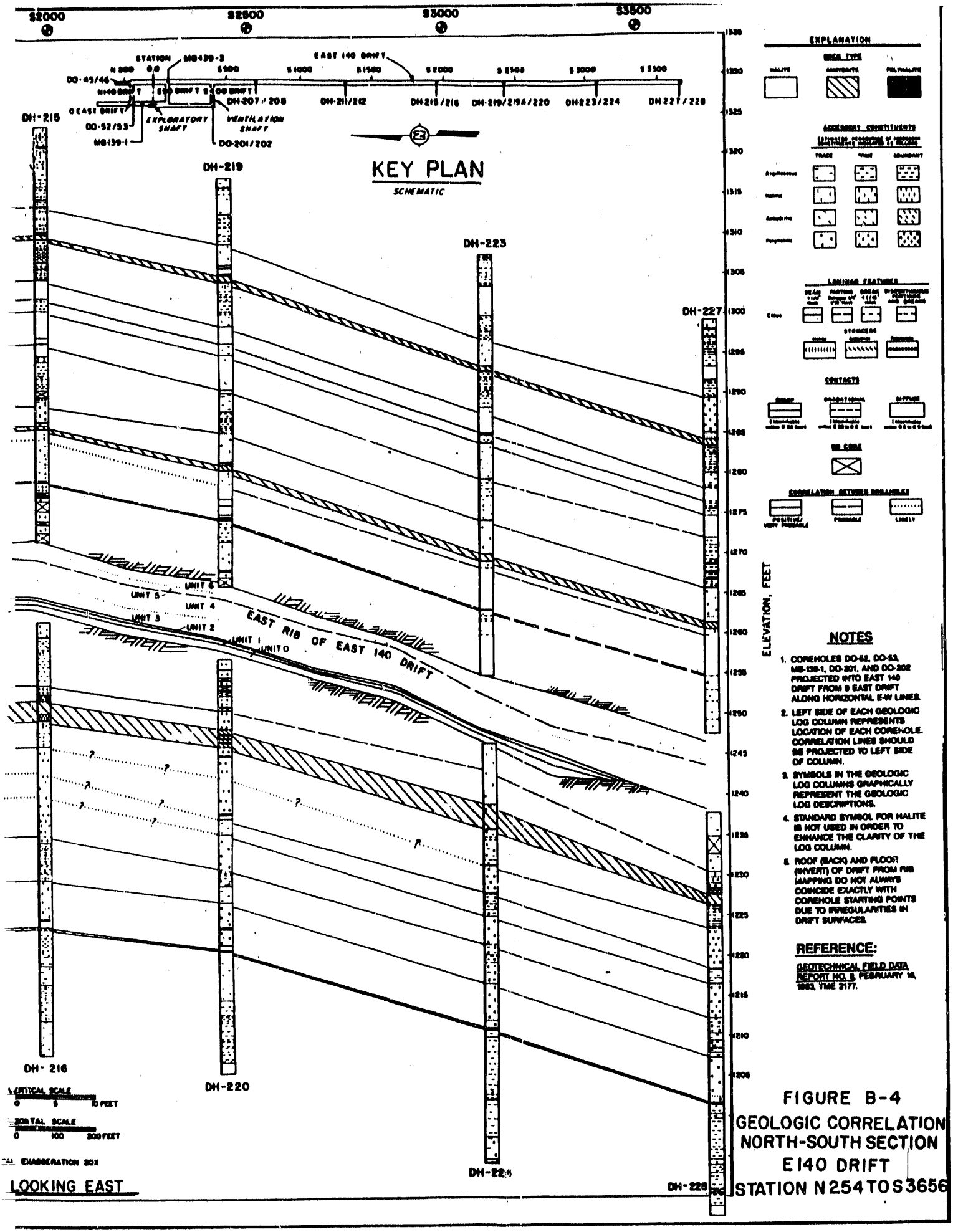
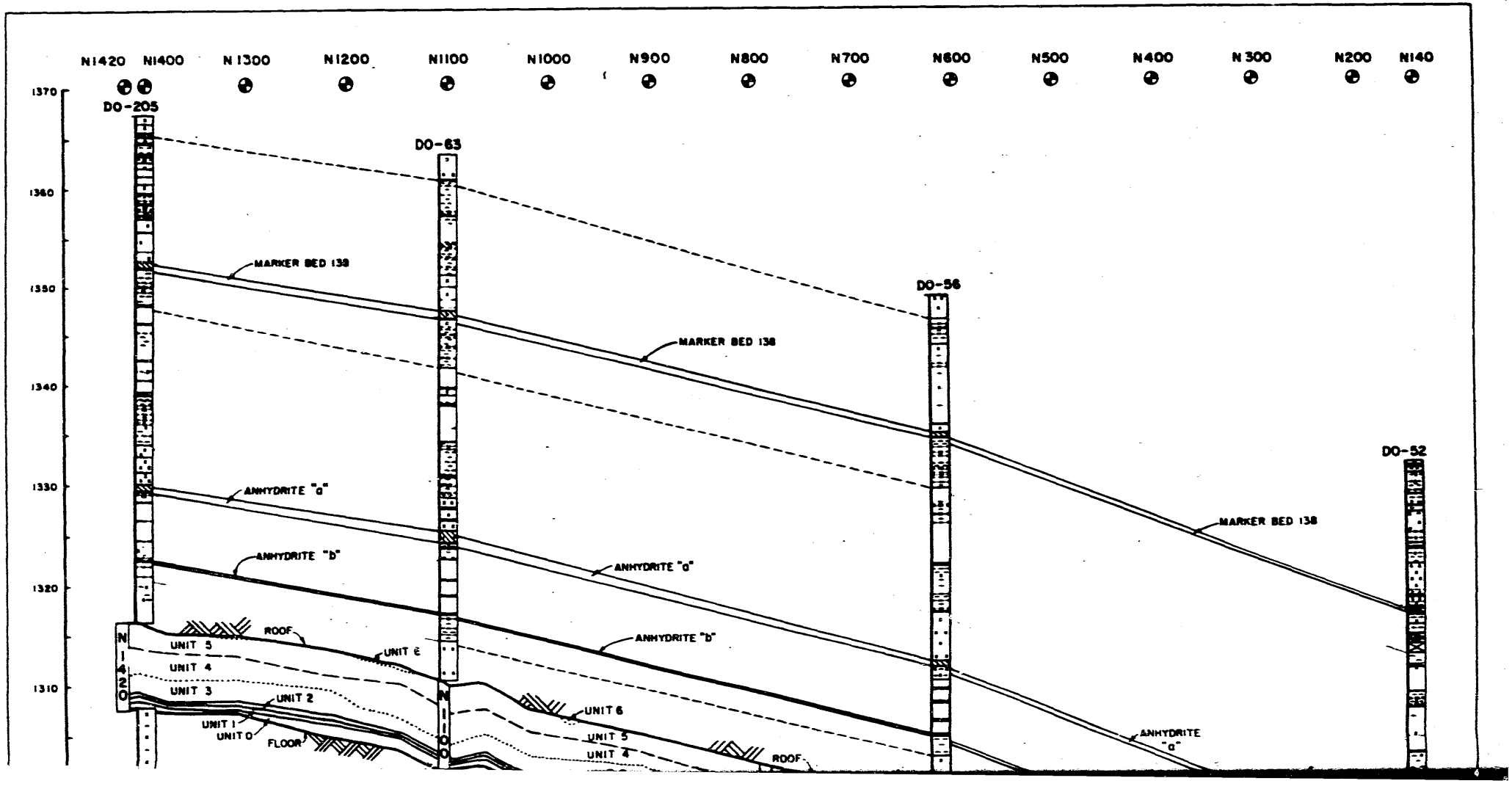
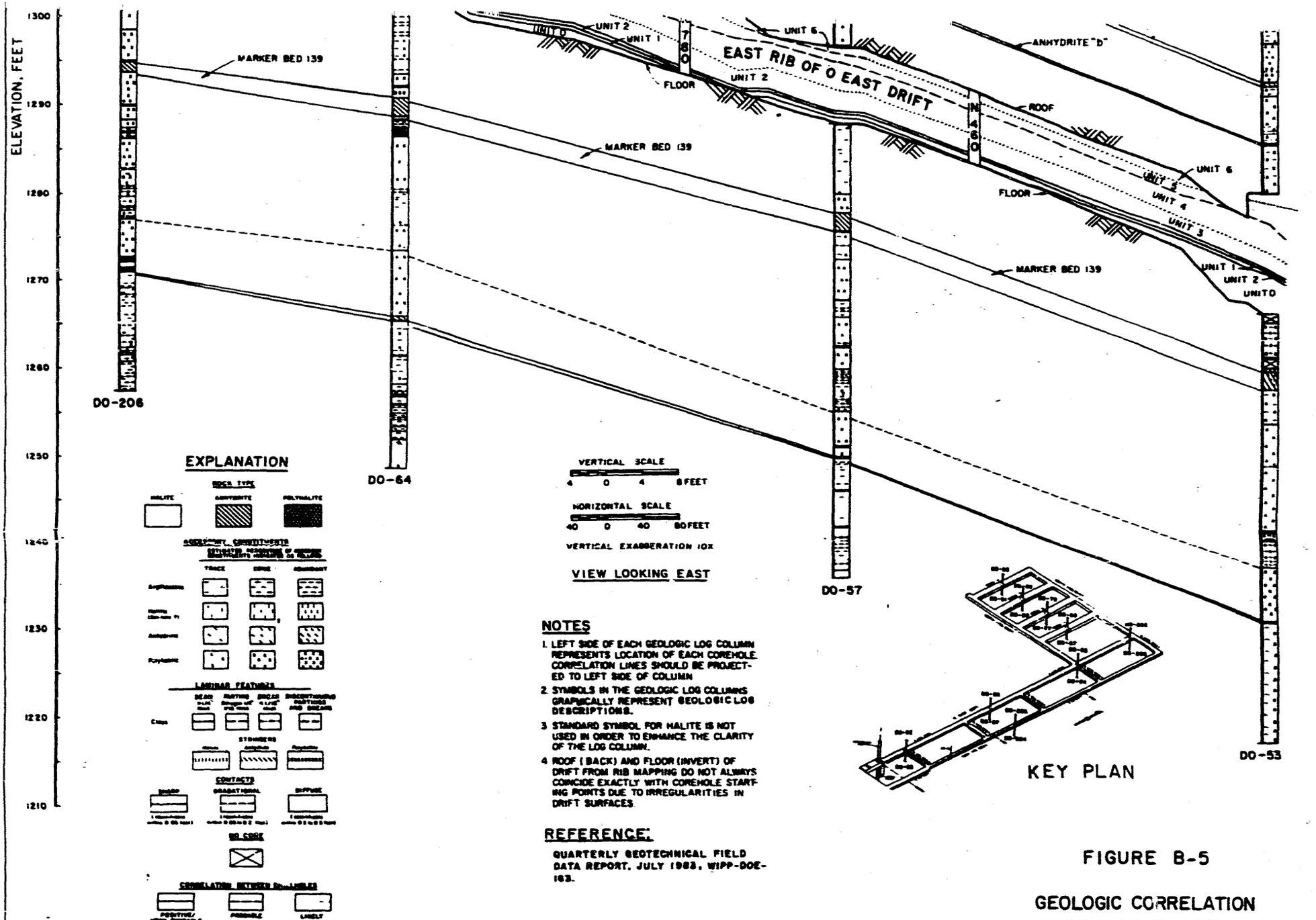


FIGURE B-4
GEOLOGIC CORRELATION
NORTH-SOUTH SECTION
E140 DRIFT
STATION N254 TO S3656


N1420
N1400
N1300
N1200
N1100
N1000
N900
N800
N700
N600
N500
N400
N300
N200
N140
1370
1360
1350
1340
1330
1320
1310
DO-205
DO-63
DO-56
DO-52
MARKER BED 138
MARKER BED 138
MARKER BED 138
ANHYDRITE "a"
ANHYDRITE "b"
ANHYDRITE "a"
ANHYDRITE "b"
ANHYDRITE "a"
ROOF
UNIT 5
UNIT 4
UNIT 3
UNIT 2
UNIT 1
UNIT 0
FLOOR
UNIT 6
UNIT 5
UNIT 4
ROOF



NOTES

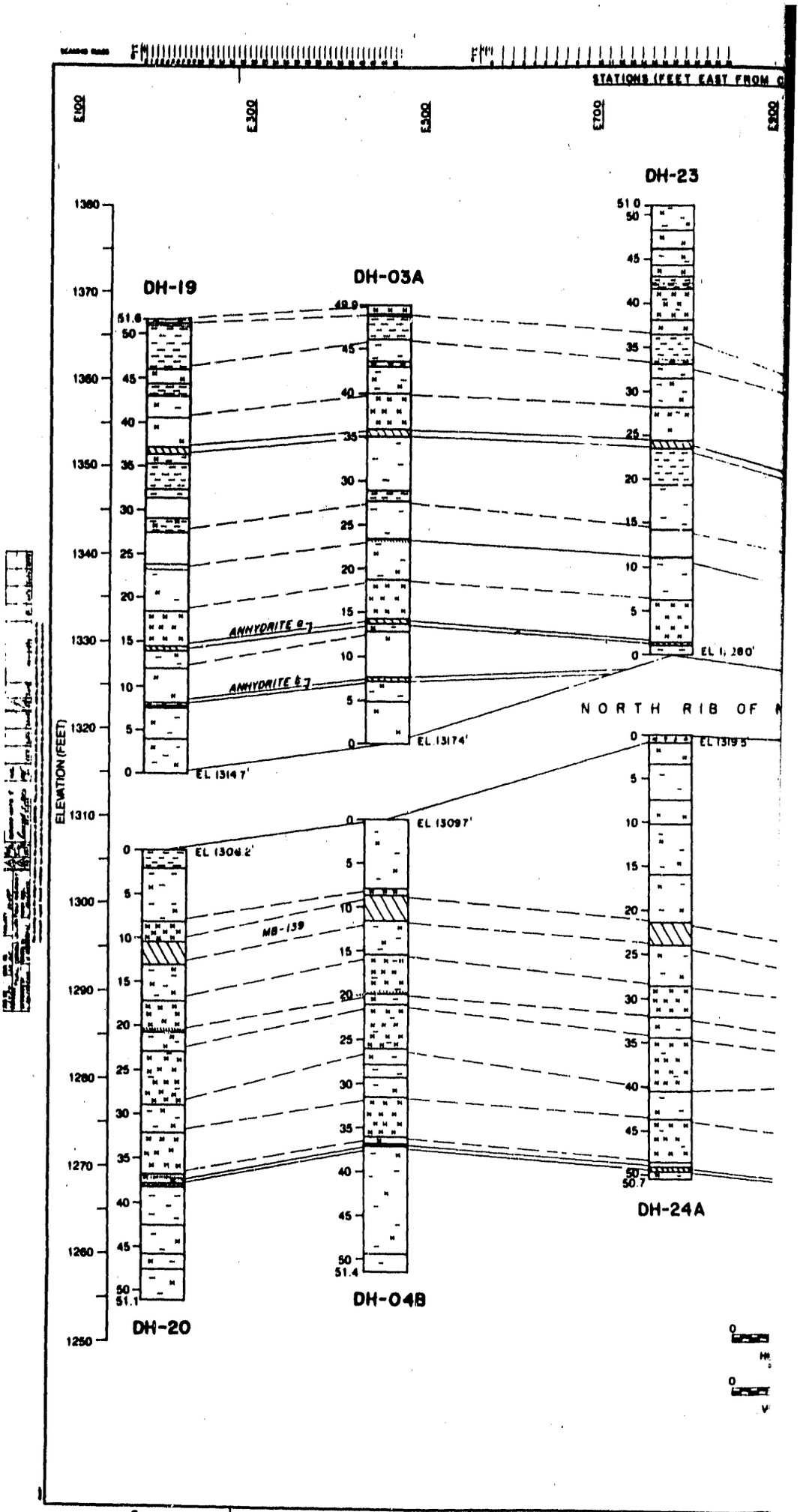
1. LEFT SIDE OF EACH GEOLOGIC LOG COLUMN REPRESENTS LOCATION OF EACH COREHOLE CORRELATION LINES SHOULD BE PROJECTED TO LEFT SIDE OF COLUMN
2. SYMBOLS IN THE GEOLOGIC LOG COLUMNS GRAPHICALLY REPRESENT GEOLOGIC LOG DESCRIPTIONS.
3. STANDARD SYMBOL FOR HALITE IS NOT USED IN ORDER TO ENHANCE THE CLARITY OF THE LOG COLUMN.
4. ROOF (BACK) AND FLOOR (INVERT) OF DRIFT FROM RIB MAPPING DO NOT ALWAYS COINCIDE EXACTLY WITH COREHOLE STARTING POINTS DUE TO IRREGULARITIES IN DRIFT SURFACES

REFERENCE:

QUARTERLY GEOTECHNICAL FIELD DATA REPORT, JULY 1983, WIPP-DOE-163.

FIGURE B-5

GEOLOGIC CORRELATION
NORTH-SOUTH SECTION
EO DRIFT
STATION N146 TO N1410


STATIONS (FEET EAST FROM
E100
E300
E500
E700
E900
DH-19
DH-03A
DH-23
DH-20
DH-04B
DH-24A
ELEVATION (FEET)
1380
1370
1360
1350
1340
1330
1320
1310
1300
1290
1280
1270
1260
1250
ANHYDRITE B
ANHYDRITE A
MB-139
EL 1314.7'
EL 1317.4'
EL 1280'
EL 1308.2'
EL 1309.7'
EL 1319.5'
NORTH RIB OF
8
7
6

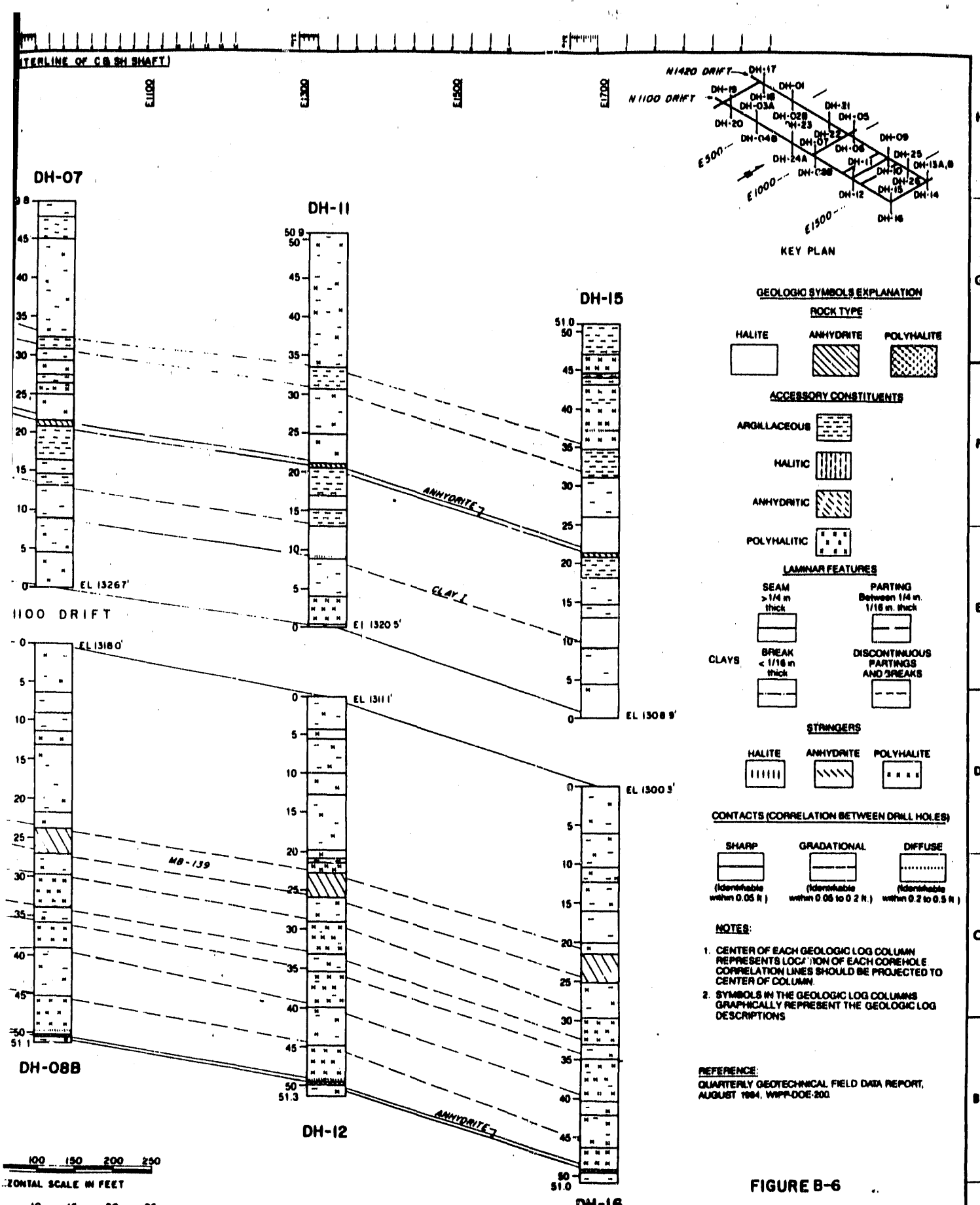
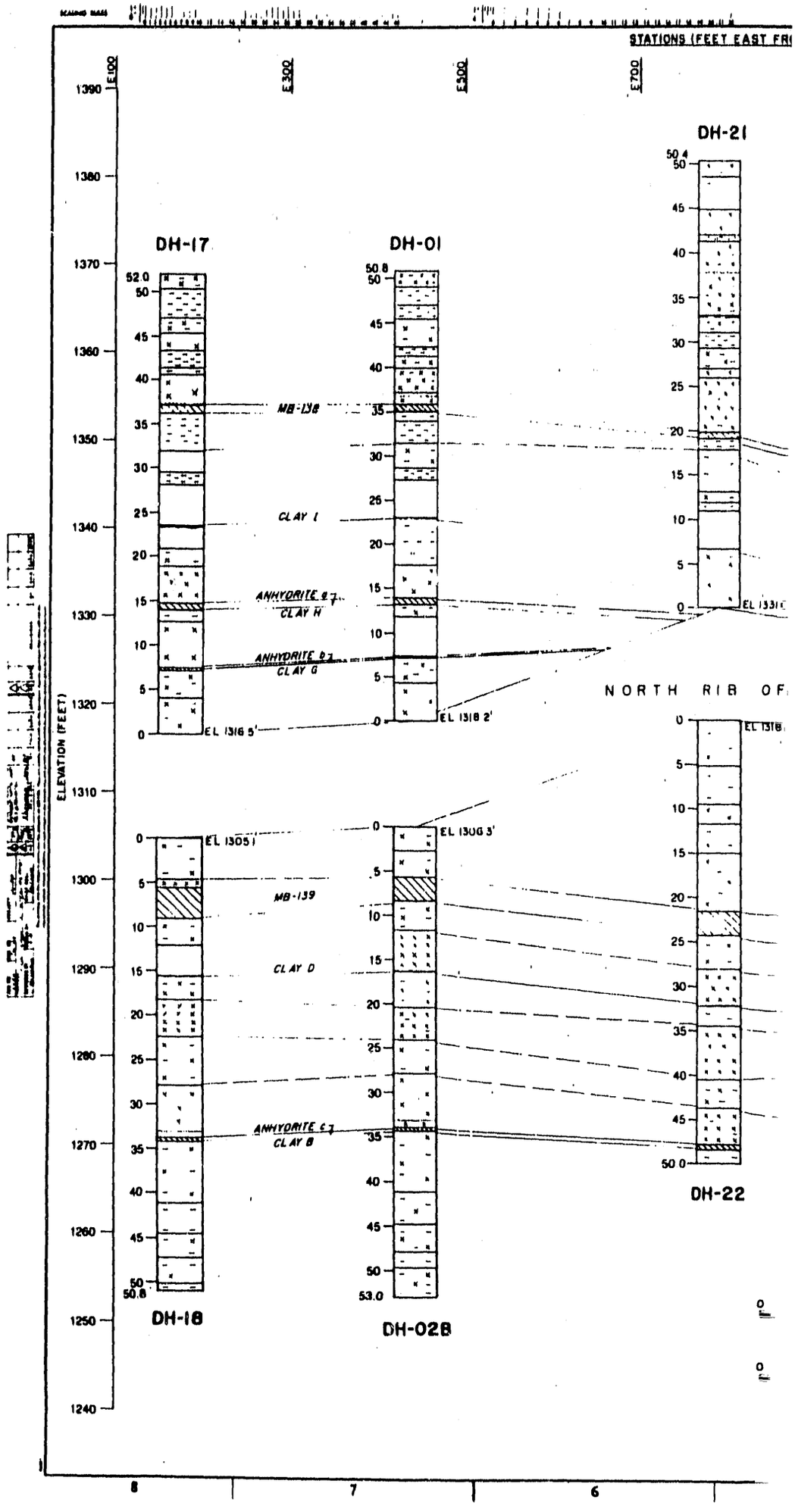
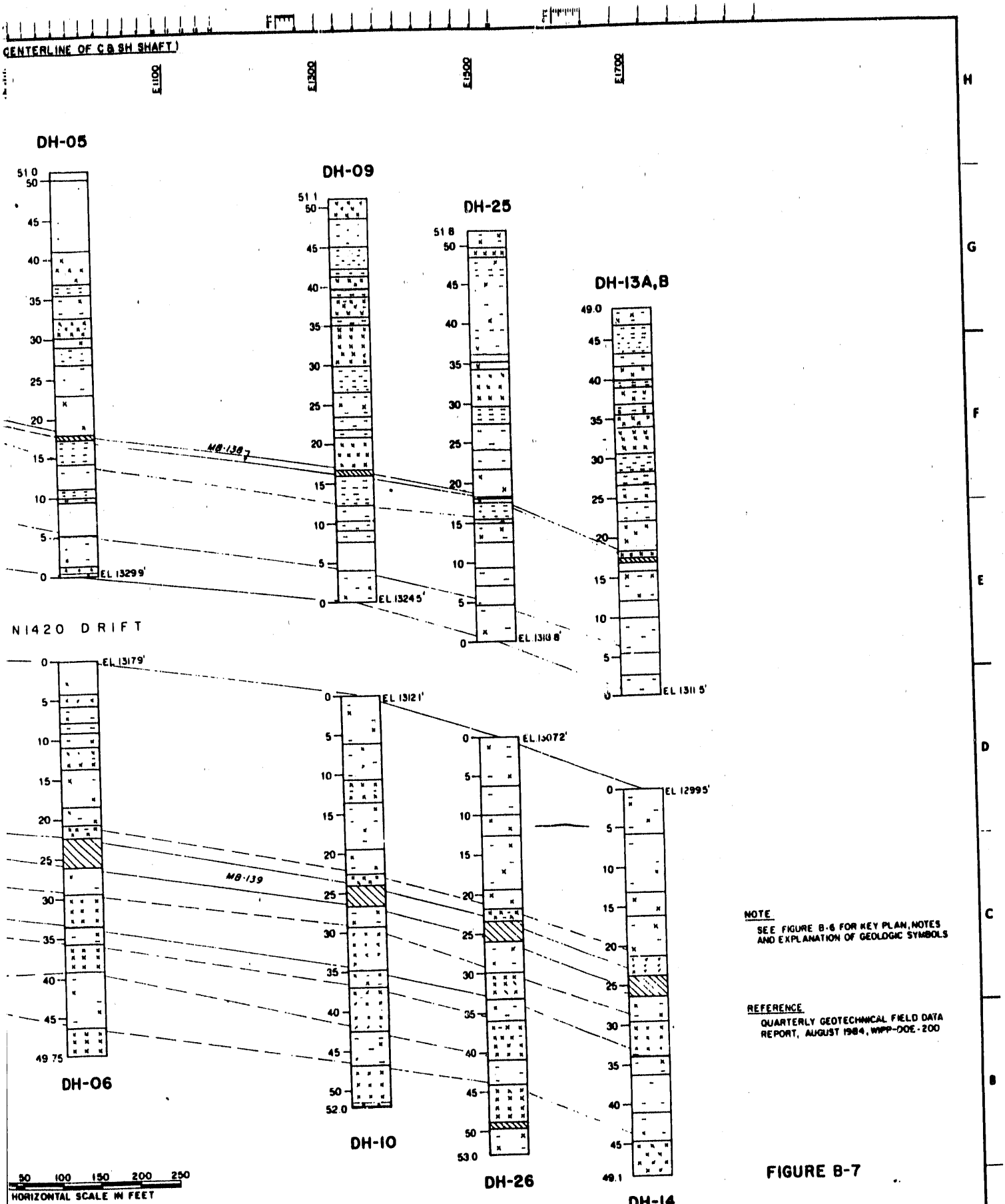


FIGURE B-6

GEOLOGIC CORRELATION
EAST-WEST SECTION, N1100 DRIFT
STATION E206 TO E1698


STATIONS (FEET EAST FR
E100
E300
E500
E700
ELEVATION (FEET)
1390
1380
1370
1360
1350
1340
1330
1320
1310
1300
1290
1280
1270
1260
1250
1240
DH-17
DH-01
DH-21
DH-18
DH-02B
DH-22
MB-138
CLAY I
ANHYDRITE & CLAY H
ANHYDRITE D & CLAY G
MB-139
CLAY D
ANHYDRITE C & CLAY B
EL 1316 5'
EL 1318 2'
EL 1305 1'
EL 1306 3'
NORTH RIB OF
8
7
6



NOTE

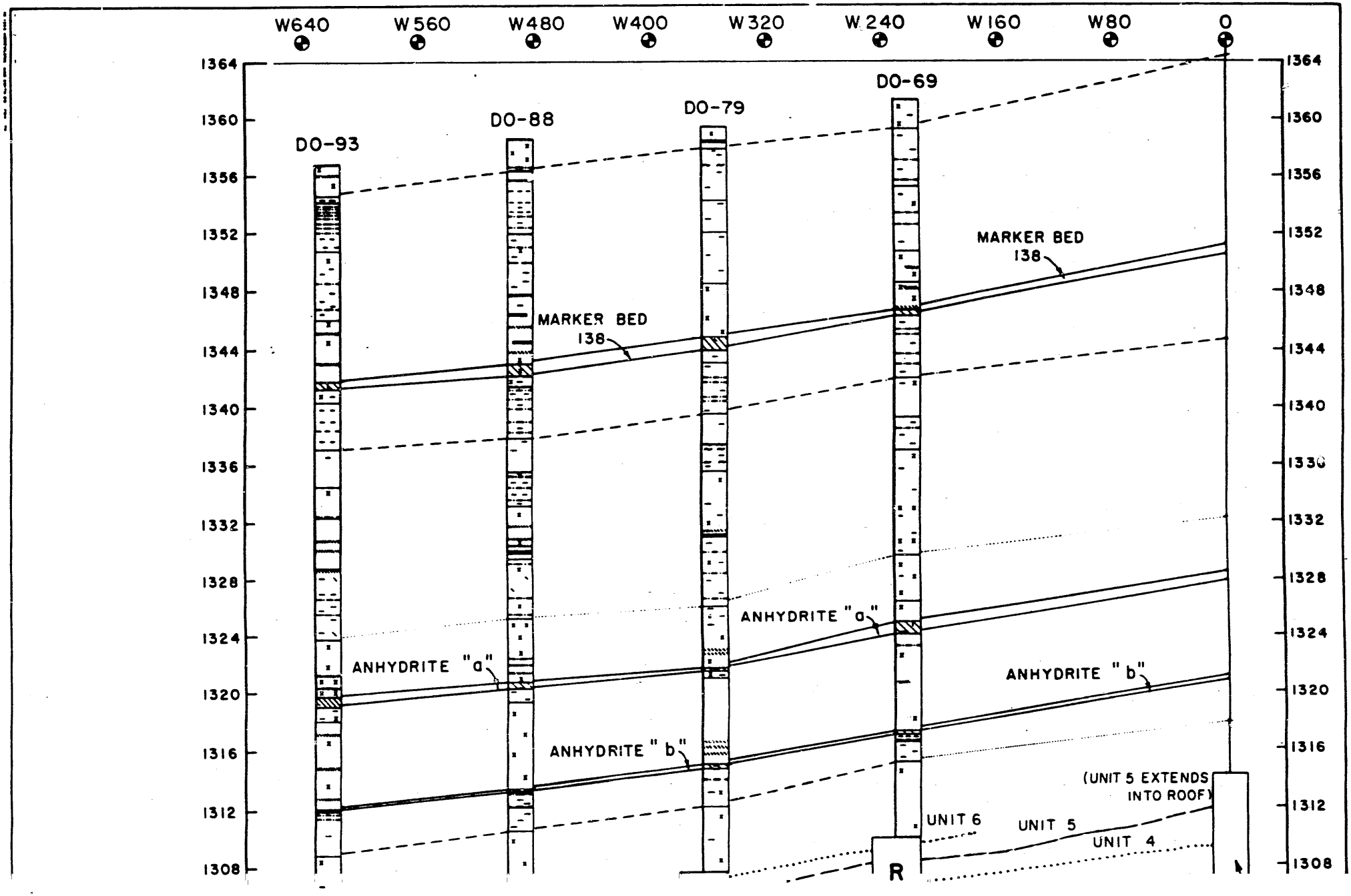
SEE FIGURE B-6 FOR KEY PLAN, NOTES AND EXPLANATION OF GEOLOGIC SYMBOLS

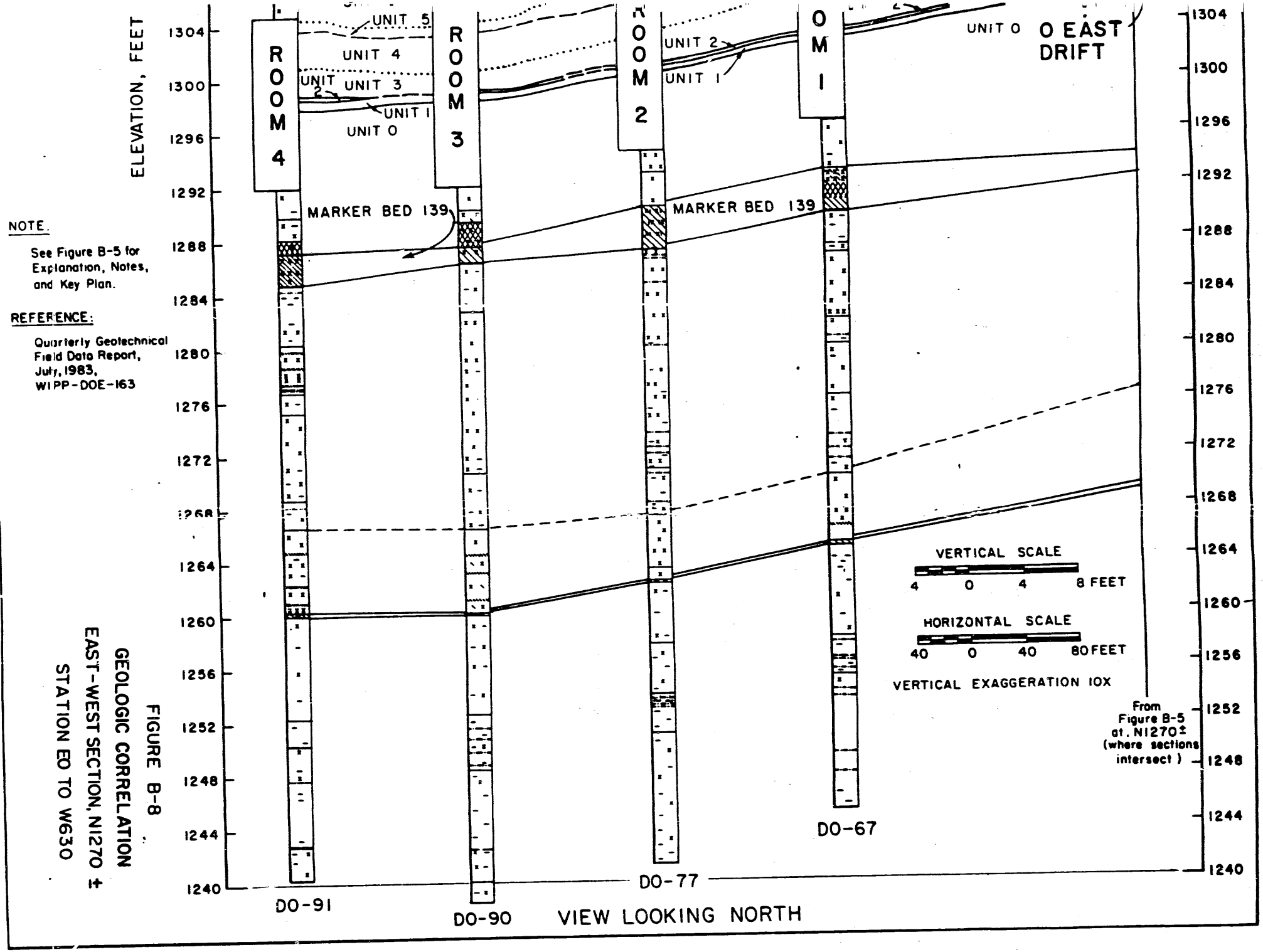
REFERENCE

QUARTERLY GEOTECHNICAL FIELD DATA REPORT, AUGUST 1984, WIPP-DOE-200

FIGURE B-7

GEOLOGIC CORRELATION
EAST-WEST SECTION, N1420 DRIFT
STATION E206 TO E1698


W640
W560
W480
W400
W320
W240
W160
W80
0
1364
1360
1356
1352
1348
1344
1340
1336
1332
1328
1324
1320
1316
1312
1308
DO-93
DO-88
DO-79
DO-69
MARKER BED 138
MARKER BED 138
ANHYDRITE "a"
ANHYDRITE "a"
ANHYDRITE "b"
ANHYDRITE "b"
(UNIT 5 EXTENDS INTO ROOF)
UNIT 6
UNIT 5
UNIT 4
R



NOTE.

See Figure B-5 for Explanation, Notes, and Key Plan.

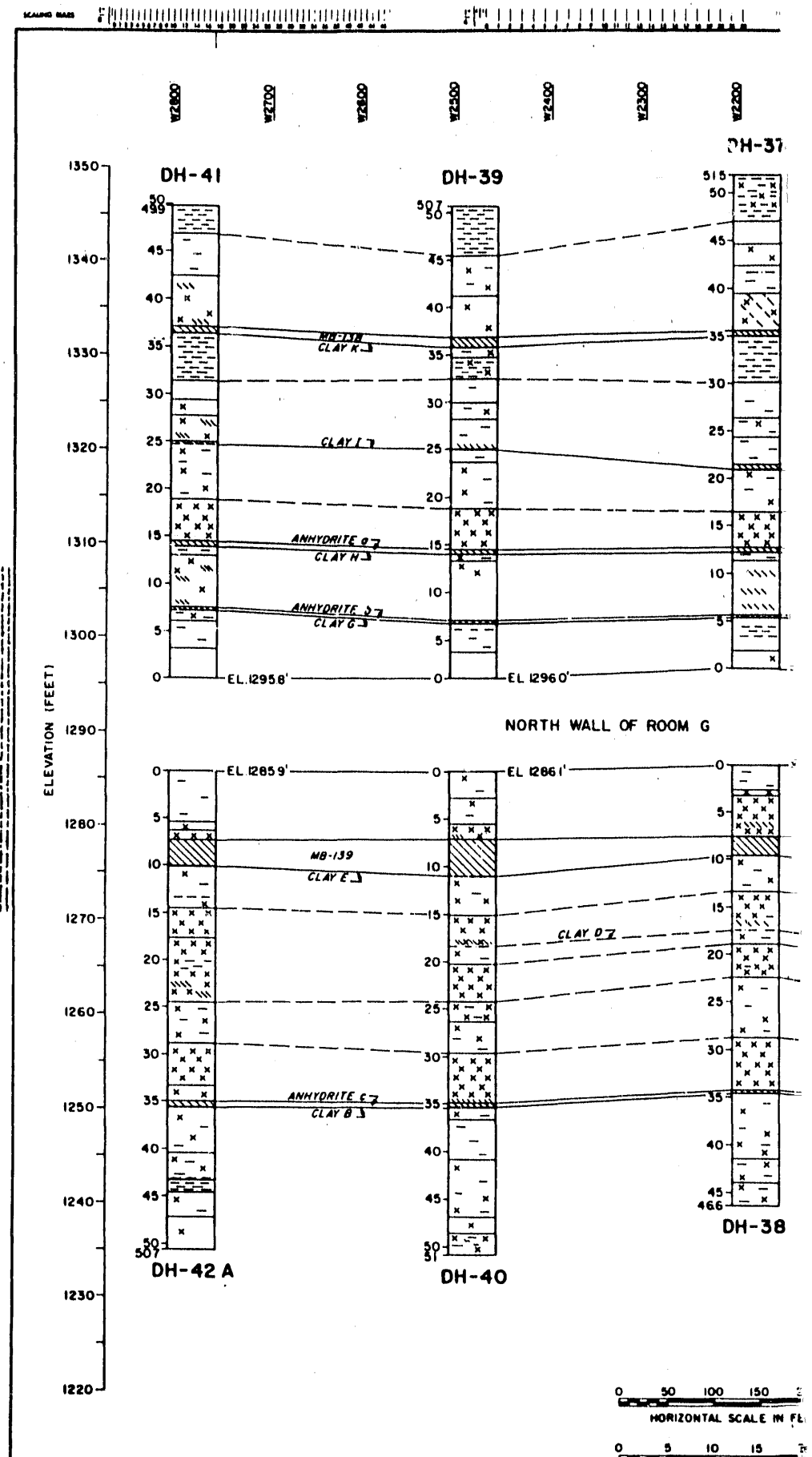
REFERENCE:

Quarterly Geotechnical Field Data Report, July, 1983, WIPP-DOE-163

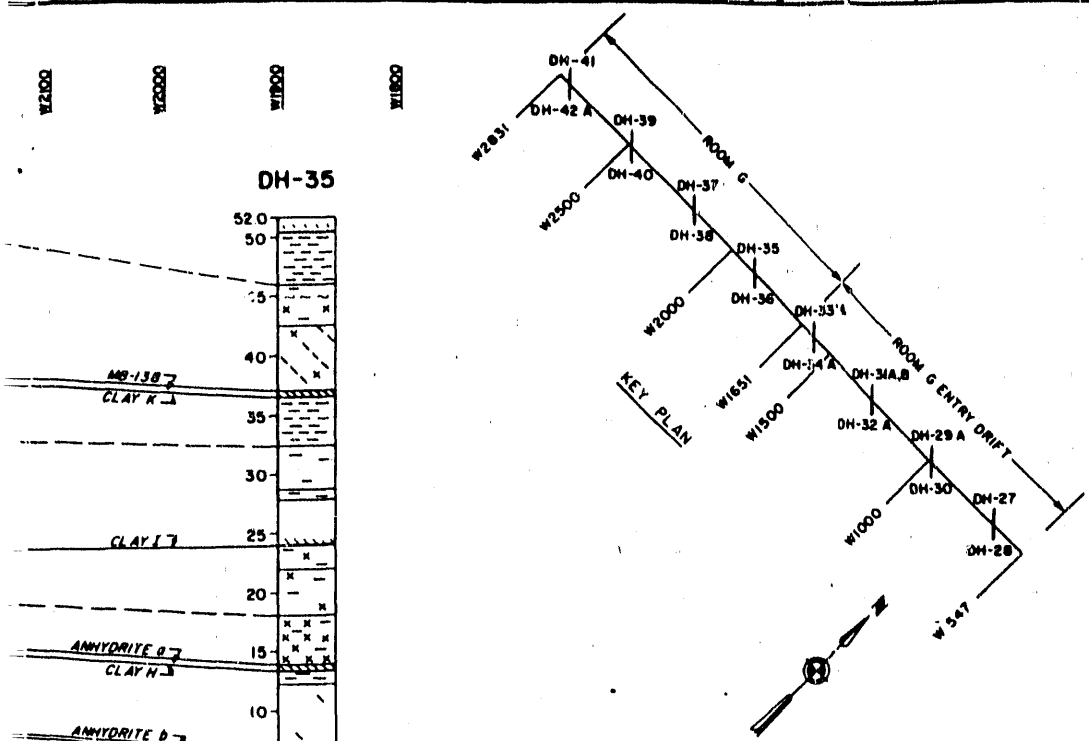
FIGURE B-8

GEOLOGIC CORRELATION

EAST-WEST SECTION, N1270 ± STATION E0 TO W630


W2800
W2700
W2600
W2500
W2400
W2300
W2200
DH-37
DH-41
DH-39
ELEVATION (FEET)
1350
1340
1330
1320
1310
1300
1290
1280
1270
1260
1250
1240
1230
1220
MB-139
CLAY K
CLAY I
ANHYDRITE D
CLAY H
ANHYDRITE B
CLAY G
EL. 1295.8'
EL. 1296.0'
NORTH WALL OF ROOM G
EL. 1285.9'
EL. 1286.1'
MB-139
CLAY E
CLAY D
ANHYDRITE C
CLAY B
DH-42 A
DH-40
DH-38
0 50 100 150
HORIZONTAL SCALE IN FE
0 5 10 15
VERTICAL SCALE IN FE
VIEW LOOKING NORTH

8 7 6



GEOLOGIC SYMBOLS EXPLANATION

ROCK TYPE

HALITE ANHYDRITE

ACCESSORY CONSTITUENTS

ARGILLACEOUS

ANHYDRITIC

POLYHALITIC

LAMINAR FEATURES

DISCONTINUOUS PARTINGS AND BREAKS

STRINGERS

ANHYDRITE

CONTACTS (CORRELATION BETWEEN DRILL HOLES)

SHARP (identifiable within 0.05 ft)

GRADATIONAL (identifiable within 0.05 to 0.2 ft)

DIFFUSE (identifiable within 0.2 to 0.5 ft)

NOTES:

1 CENTER OF EACH GEOLOGIC LOG COLUMN REPRESENTS LOCATION OF EACH COREHOLE CORRELATION LINES SHOULD BE PROJECTED TO CENTER OF COLUMN

2 SYMBOLS IN THE GEOLOGIC LOG COLUMNS GRAPHICALLY REPRESENT THE GEOLOGIC LOG DESCRIPTIONS

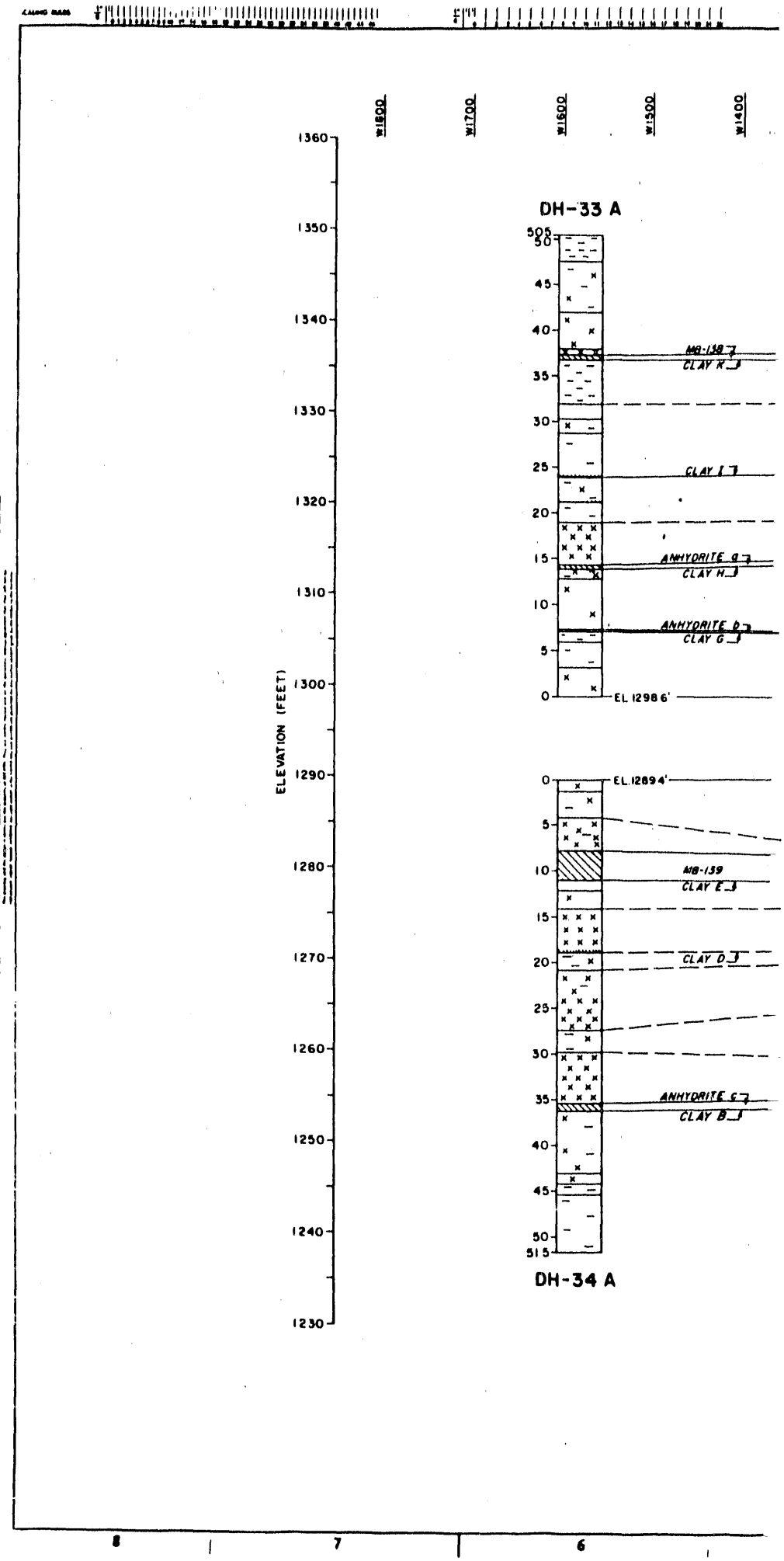
REFERENCE:

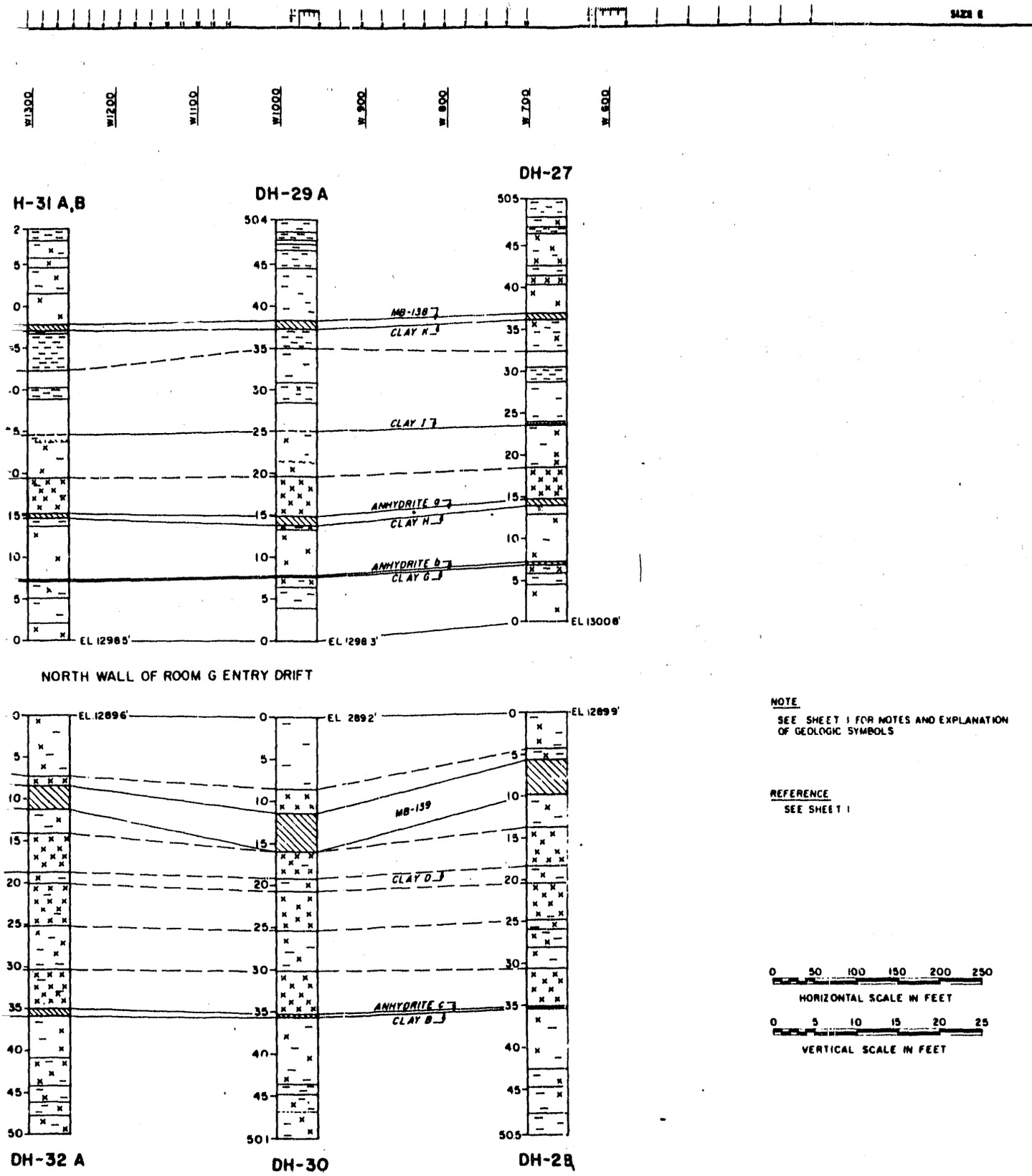
QUARTERLY GEOTECHNICAL FIELD DATA REPORT, JUNE 1985, WIPP-DOE-213.

FIGURE B-9

GEOLOGIC CORRELATION
EAST-WEST SECTION, N 1100 DRIFT
STATION W682 TO W2782

SHEET 1 OF 2


W1800
W1700
W1600
W1500
W1400
ELEVATION (FEET)
1360
1350
1340
1330
1320
1310
1300
1290
1280
1270
1260
1250
1240
1230
DH-33 A
MB-138
CLAY K
CLAY I
ANHYDRITE G
CLAY H
ANHYDRITE D
CLAY G
EL 12986'
EL.12894'
MB-139
CLAY E
CLAY D
ANHYDRITE C
CLAY B
DH-34 A
8
7
6



NOTE

SEE SHEET 1 FOR NOTES AND EXPLANATION OF GEOLOGIC SYMBOLS

REFERENCE

SEE SHEET 1

0 50 100 150 200 250

HORIZONTAL SCALE IN FEET

0 5 10 15 20 25

VERTICAL SCALE IN FEET

FIGURE B-9

GEOLOGIC CORRELATION
EAST-WEST SECTION, N1100 DRIFT
STATION W682 TO W2782

SHEET 2 OF 2

APPENDIX C

MATHEMATICAL SIMULATION OF UNDERGROUND IN SITU BEHAVIOR

CONTENTS

Section	Title
C.1	INTRODUCTION
C.2	MATERIAL BEHAVIOR OF HOST ROCKS
C.3	FORMULATION OF GOVERNING EQUATIONS
C.4	NORMALIZATION OF GOVERNING EQUATIONS
C.5	DETERMINATION OF CREEP CONSTANTS
C.6	PREDICTION OF STRUCTURAL BEHAVIOR
C.7	CONCLUSIONS

Figure No.	Title/Description
C-1	Time Response Relationship of the Normalized Creep Analysis Method
C-2	Graphical Representation of Creep Constants Relating Time Domains
C-3	Comparison of Analytical Results and In Situ Responses for Various Data Point Sets
C-4	Comparison of Analytical Results and In Situ Response for Various Instrument Offset Values

APPENDIX C

MATHEMATICAL SIMULATION OF UNDERGROUND IN SITU BEHAVIOR

C.1 INTRODUCTION

The methodology described in the following sections presents analytical techniques for simulating underground behavior in salt formations. Consideration is given to time-dependent non-linear material behavior and incorporation of in situ measurements to predict structural responses. The theoretical background and procedures presented by this methodology are explained.

C.2 MATERIAL BEHAVIOR OF HOST ROCKS

The most significant physical property of halite is that it creeps. Its creep behavior is dependent upon the variations of stress and temperature with respect to time. The creep phenomenon is also affected by the physical properties of the geologic strata adjacent to the halite and by discontinuities in the geologic layers. Therefore, non-halitic interbeds and clay seams should also be considered when modeling and simulating the structural behavior of salt formations. The following subsections summarize the material behavior of various host rocks (ref. C-1).

C.2.1 Halitic Materials

The constitutive equation for halitic materials can be expressed as:

$$\dot{\varepsilon}_{ij} = -\frac{\nu}{E}\,\dot{\sigma}_{kk}\,\delta_{ij} + \frac{1+\nu}{E}\,\dot{\sigma}_{ij} + \dot{\varepsilon}^{C}_{ij} \qquad \text{(C.2-1)}$$

where: $\dot{\varepsilon}_{ij}$ are the components of the strain tensor;

ν is Poisson's ratio;

E is Young's modulus;

δ_{ij} is the Kronecker delta;

$\dot{\sigma}_{ij}$ are the components of the stress tensor; and

the creep strain rate, $\dot{\varepsilon}^c_{ij}$, is given by:

$$\dot{\varepsilon}^c_{ij} = |\dot{\varepsilon}^c_{kl}| \frac{\sigma'_{ij}}{|\sigma'_{mn}|} \qquad \text{(C.2-2)}$$

where: σ'_{ij} are the components of the deviatoric stress tensor.

The magnitude of the creep strain rate can be expressed in terms of the effective creep strain rate, $\dot{\varepsilon}$, or the effective stress, σ. Thus,

$$|\dot{\varepsilon}^c_{ij}| = \sqrt{1.5}\ \bar{\dot{\varepsilon}} \qquad \text{(C.2-3)}$$

where the effective strain rate $\bar{\dot{\varepsilon}}$ is defined as:

$$\bar{\dot{\varepsilon}} = \left(\frac{2}{3} \dot{\varepsilon}^c_{ij}\ \dot{\varepsilon}^c_{ij} \right)^{1/2} \qquad \text{(C.2-4)}$$

which is the sum of the primary and secondary creep strain rates, namely

$$\bar{\dot{\varepsilon}} = \dot{\varepsilon}_p + \dot{\varepsilon}_s \qquad \text{(C.2-5)}$$

where the primary creep strain rate is defined as:

$$\dot{\varepsilon}_p = (A - B\ \varepsilon_p)\ \dot{\varepsilon}_s \qquad \text{for } \dot{\varepsilon}_s \geq \dot{\varepsilon}^*$$

and (C.2-6)

$$\dot{\varepsilon}_p = \left(A - B\ \frac{\dot{\varepsilon}^*}{\dot{\varepsilon}_s} \varepsilon_p\right)\ \dot{\varepsilon}_s \qquad \text{for } \dot{\varepsilon}_s < \dot{\varepsilon}^*$$

where $\dot{\varepsilon}_s$ can be defined by an exponential law

$$\dot{\varepsilon}_s = D\ \sigma^{-n}\ e^{-Q/R\Theta} \qquad \text{(C.2-7)}$$

and $\bar{\sigma} = \left(\frac{3}{2} \sigma'_{ij}\ \sigma'_{ij} \right)^{1/2}$ is the effective stress;

$\dot{\varepsilon}^*$, A and B are primary creep constants;

D and n are secondary creep constants;

Θ is temperature in Kelvin;

Q is the effective activation energy in cal/mole; and

R is the universal gas constant, 1.987 cal/mole-K.

C.2.2 Non-halitic Materials

In the underground facility horizon at the WIPP site, certain portions of the rock are non-halitic. The stress-strain relationship for non-halitic materials is assumed to follow the Prandtl-Reuss constitutive equation:

$$\dot{\varepsilon}_{ij} = -\frac{\nu}{E}\dot{\sigma}_{kk}\delta_{ij} + \frac{1+\nu}{E}\dot{\sigma}_{ij} + \dot{\varepsilon}^{P}_{ij} \qquad \text{(C.2-8)}$$

The plastic behavior is defined by the two-dimensional Mohr-Coulomb criterion:

$$\sigma_3 - \sigma_1 = 2\Theta_0\cos\beta - (\sigma_3 + \sigma_1)\sin\beta \qquad \text{(C.2-9)}$$

and the Drucker-Prager criterion, which is the generalized form of the Mohr-Coulomb criterion:

$$\sqrt{J_2'} = c - aJ_1 \qquad \text{(C.2-10)}$$

where: σ_3 and σ_1 are the two principal stresses, which are positive in tension;

Θ_0, β, c and a are the plastic constants;

$\sqrt{J_2'}$ is the second deviatoric stress invariant; and

J_1 is the first stress invariant.

The numerical modeling does not include failure criterion for the non-halitic materials. Anhydrite is assumed to be linearly elastic.

C.2.3 Clay Seams

Thin seams of clay are present between some of the rock layers. These clay seams can allow relative slippage and separation of the layers across the clay seams. The slippage of the clay seams follows a dry friction law:

$$\sigma_{12} = \mu |\sigma_{11}| \qquad \text{(C.2-11)}$$

where: μ is the frictional coefficient; direction 1 of the stress is normal to the plan of the seam; and direction 2 of the stress is in the direction of motion or incipient motion.

C.3 FORMULATION OF GOVERNING EQUATIONS

The underground behavior of salt can be determined by solving the following governing equations:

(1) Equation of equilibrium:

$$\sigma_{ij,j} + X_i = 0 \qquad \text{(C.3-1)}$$

where: σ_{ij} is the stress tensor; and

X_i is the body force vector.

(2) Strain-rate velocity relation:

$$2\dot{\varepsilon}_{ij} = \dot{u}_{i,j} + \dot{u}_{j,i} \qquad \text{(C.3-2)}$$

where: $\dot{\varepsilon}_{ij}$ is the strain rate tensor;

$\dot{u}_i$ is the velocity vector; and

($\dot{}$) represents the derivative of ( ) with respect to time t.

(3) Stress strain relations:

<u>halitic materials</u>

$$\dot{\varepsilon}_{ij} = -\frac{\upsilon}{E}\,\dot{\sigma}_{kk}\delta_{ij} + \frac{1+\upsilon}{E}\,\dot{\sigma}_{ij} + \dot{\varepsilon}^{c}_{ij} \qquad \text{(C.3-3)}$$

where: $\dot{\varepsilon}^{c}$ is defined in subsection C.2.1.

<u>non-halitic materials</u>

$$\dot{\varepsilon}_{ij} = -\frac{\upsilon}{E}\,\dot{\sigma}_{kk}\,\delta_{ij} + \frac{1+\upsilon}{E}\,\dot{\sigma}_{ij} + \dot{\varepsilon}^{p}_{ij} \qquad \text{(C.3-4)}$$

(4) Boundary conditions:

$$\dot{u}_i = \dot{U}_i \qquad \text{over } S_u \qquad \text{(C.3-5)}$$

$$\sigma_{ij} n_j = T_i \qquad \text{over } S_\sigma \qquad \text{(C.3-6)}$$

where: S_u is the surface on which $\dot{u}_i$ is specified as U_i and S_σ is the surface on which the traction vector $\sigma_{ij} n_j$ is specified as T_i where n_j is the component of the outward-pointing unit normal vector.

C.4 NORMALIZATION OF GOVERNING EQUATIONS

In order to determine the creep properties of halite, the governing equations in Section C.3 need to be solved before knowing the values of the creep constants. This can be achieved by normalizing the governing equations to the creep function and solving the normalized equations. The creep constants can then be determined by correlating the analytical results with in situ data.

Consider the creep behavior of halitic material follows a power law:

$$\dot{\varepsilon} = F\,\sigma^{-n} \qquad \text{(C.4-1)}$$

where: F is a creep function.

The governing equations in Section C.2 can be normalized to F by transforming to a normalized time domain in terms of time t* such that:

$$dt^* = F\,dt \qquad \text{(C.4-2)}$$

By substituting equation (C.4-2) into equations (C.3-1) through (C.3-6), a system of normalized equations can be formed:

(1) Equation of equilibrium:

$$\sigma_{ij,j} + X_i = 0 \qquad \text{(C.4-3)}$$

(2) Strain-rate velocity relation:

$$2\dot{\varepsilon}^*_{ij} = \dot{u}^*_{i,j} + \dot{u}^*_{j,i} \qquad \text{(C.4-4)}$$

where: $(\dot{}^*)$ represents the derivative of ( ) with respect to the normalized time t*.

(3) Stress strain relations:

halitic materials

$$\dot{\varepsilon}^*_{ij} = -\frac{\upsilon}{E}\dot{\sigma}^*_{kk}\,\delta_{ij} + \frac{1+\upsilon}{E}\dot{\sigma}^*_{ij} + \dot{\varepsilon}^{*c}_{ij} \qquad \text{(C.4-5)}$$

where: $\dot{\varepsilon}^*_s = \sigma^{-n}$ (C.4-6)

non-halitic materials

$$\dot{\varepsilon}^*_{ij} = -\frac{\upsilon}{E}\dot{\sigma}^*_{kk}\,\delta_{ij} + \frac{1+\upsilon}{E}\dot{\sigma}^*_{ij} + \dot{\varepsilon}^{*p}_{ij} \qquad \text{(C.4-7)}$$

(4) Boundary conditions:

$$\dot{u}^*_i = \dot{U}^*_i \qquad \text{over } S_u \qquad \text{(C.4-8)}$$

where: $\dot{U}^*_i$ is computed as $\dot{U}^*_i = U_i/F$

$$\sigma_{ij}n_j = T_i \qquad \text{over } S_\sigma \qquad \text{(C.4-9)}$$

The above normalized governing equations are similar to the governing equations before normalization, except that the time derivatives in the normalized equations are taken with respect to normalized time t*, and the creep function F has been eliminated. Since the normalized governing equations have the same form as the governing equations before normalization, a conventional method such as the finite element technique can be used to solve the normalized governing equations for the analytical results in terms of normalized time t*, without knowing the creep function F.

After obtaining the normalized analytical result, the creep function F can be determined for establishing the relationship between the real and the normalized time domains. From Equations (C.2-5) through (C.2-7), the function F can be expressed as:

$$F = [f(\varepsilon_p, \dot{\varepsilon}_s) + 1]C \qquad \text{(C.4-10)}$$

where: $C = D\, e^{-Q/R\Theta}$; A is defined in equation (C.2-6); D, Q, R and Θ are defined in equation (C.2-7); and $f(\varepsilon_p, \varepsilon_s)$ represents the portion inside the parentheses of equation (C.2-6), which is expressed as:

$$f(\varepsilon_p, \dot{\varepsilon}_s) = A - B\,\varepsilon_p \qquad \text{for } \dot{\varepsilon}_s \geq \dot{\varepsilon}^*$$

and (C.4-11)

$$f(\varepsilon_p, \dot{\varepsilon}_s) = A - B\,\frac{\dot{\varepsilon}^*}{\dot{\varepsilon}_s}\varepsilon_p \qquad \text{for } \dot{\varepsilon}_s < \dot{\varepsilon}^*$$

From equation (C.4-11), it can be found that at time $t = 0$, $\varepsilon_p = 0$, which provides an initial condition:

$$f(\varepsilon_p, \dot{\varepsilon}_s) = A \qquad \text{for } t = 0 \qquad \text{(C.4-12)}$$

When the time t approaches the steady state stage t_s, primary creep is no longer active. Therefore:

$$f(\varepsilon_p, \dot{\varepsilon}_s) \to 0 \qquad \text{for } t \to t_s \qquad \text{(C.4-13)}$$

since the primary creep decreases exponentially with time (ref. C-1). Based on the auxiliary conditions (C.4-12) and (C.4-13), the function f can be expressed as an exponential function:

$$f = A\, e^{-zt} \qquad \text{(C.4-14)}$$

By substituting equation (C.4-14) into equation (C.4-1), function F can be written as:

$$F = [A\, e^{-zt} + 1]C \qquad \text{(C.4-15)}$$

where: the constants C, A and z can be determined from in situ data.

The relationship between the real time domain and the normalized time domain can then be obtained by integrating equation (C.4-2):

$$t^* = \int_0^t F\, dt \qquad \text{(C.4-16)}$$

Substituting equation (C.4-15) into equation (C.4-16) and using the initial condition $t^* = 0$, when $t = 0$, equation (C.4-16) becomes:

$$t^* = C\,[t + A/z\,(1 - e^{-zt})] \qquad \text{(C.4-17)}$$

After determining the creep constants, the analytical results can then be mapped from the normalized time domain to the real time domain using equation (C.4-17).

C.5 DETERMINATION OF CREEP CONSTANTS

The computational method can also be considered as a two-phased process which allows structural responses to be determined for any time in question. The first phase is a transformation from the real to the normalized time domain by use of parametric equations containing creep constants. The second phase is relating a structural response to that the normalized time by performing a structural analysis. The fundamental relationship can be represented graphically as shown on Figure C-1. The upper curve indicates the expression relating the two time domains which depends on the creep constants C, A and z. The double vertical axes represent the relationship between the normalized time t* and response as indicated by the results of the structural analysis.

The terms A and z represent primary creep constants that can be viewed in a number of ways. By themselves, 'A' relates the ratio of initial to steady-state creep rates and 'z' corresponds to the primary creep decay constant. A simplified relationship can be used utilizing only the ratio of A to z when the term inside the parentheses in equation (C.4-15) approaches unity in the steady-state period. As Figure C-2 indicates, the value of A/z (also identified as t_o) represents a real time offset such that the following equation can be used:

$$t^* = C\,(t + A/z) \qquad \text{(C.5-1)}$$

A Salt Creep Constant Evaluation computer program (SCCE, Bechtel computer program CE 465) was developed for the purpose of evaluating the creep constants from in situ data.

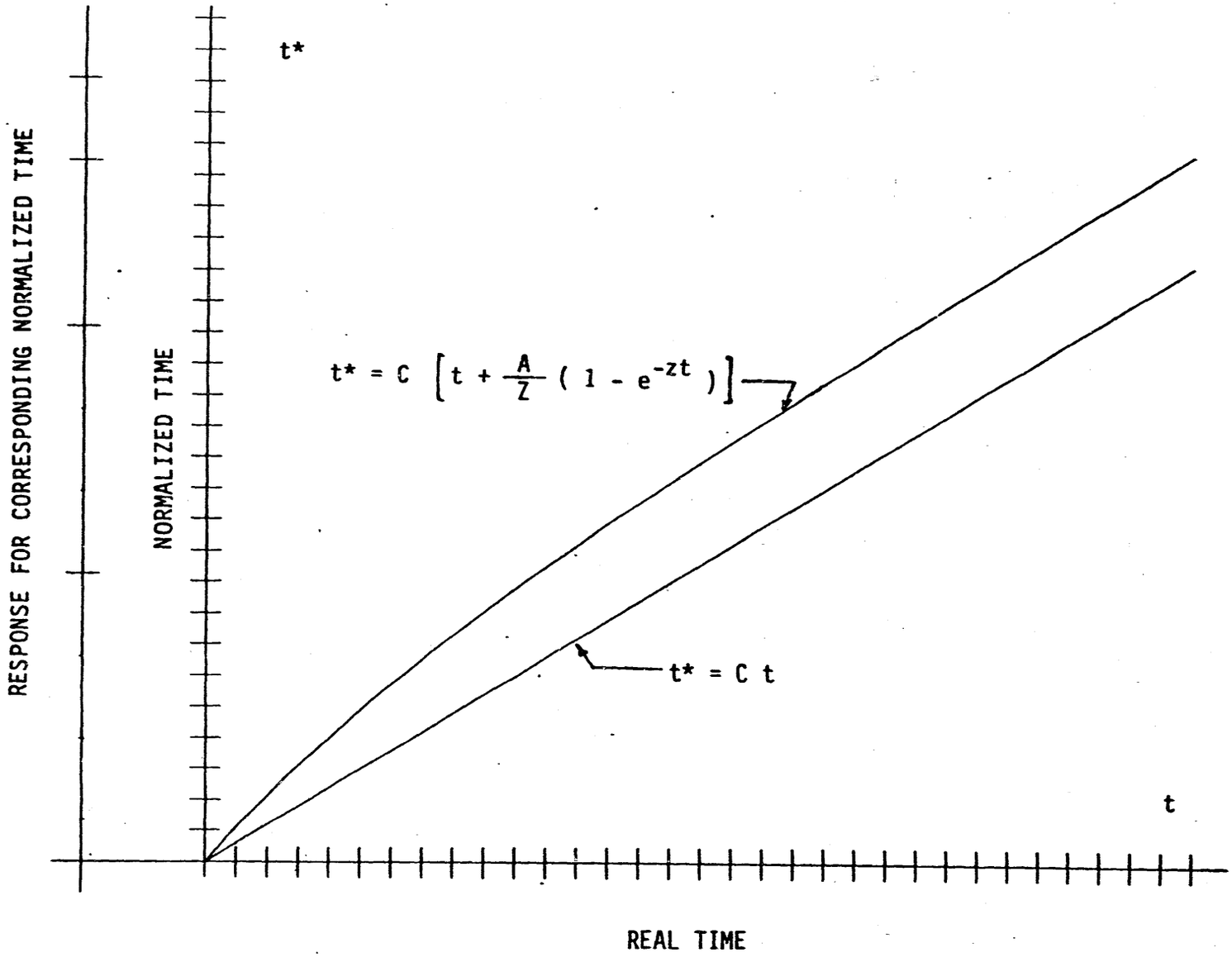


FIGURE C-1

TIME RESPONSE RELATIONSHIP OF THE NORMALIZED CREEP ANALYSIS METHOD

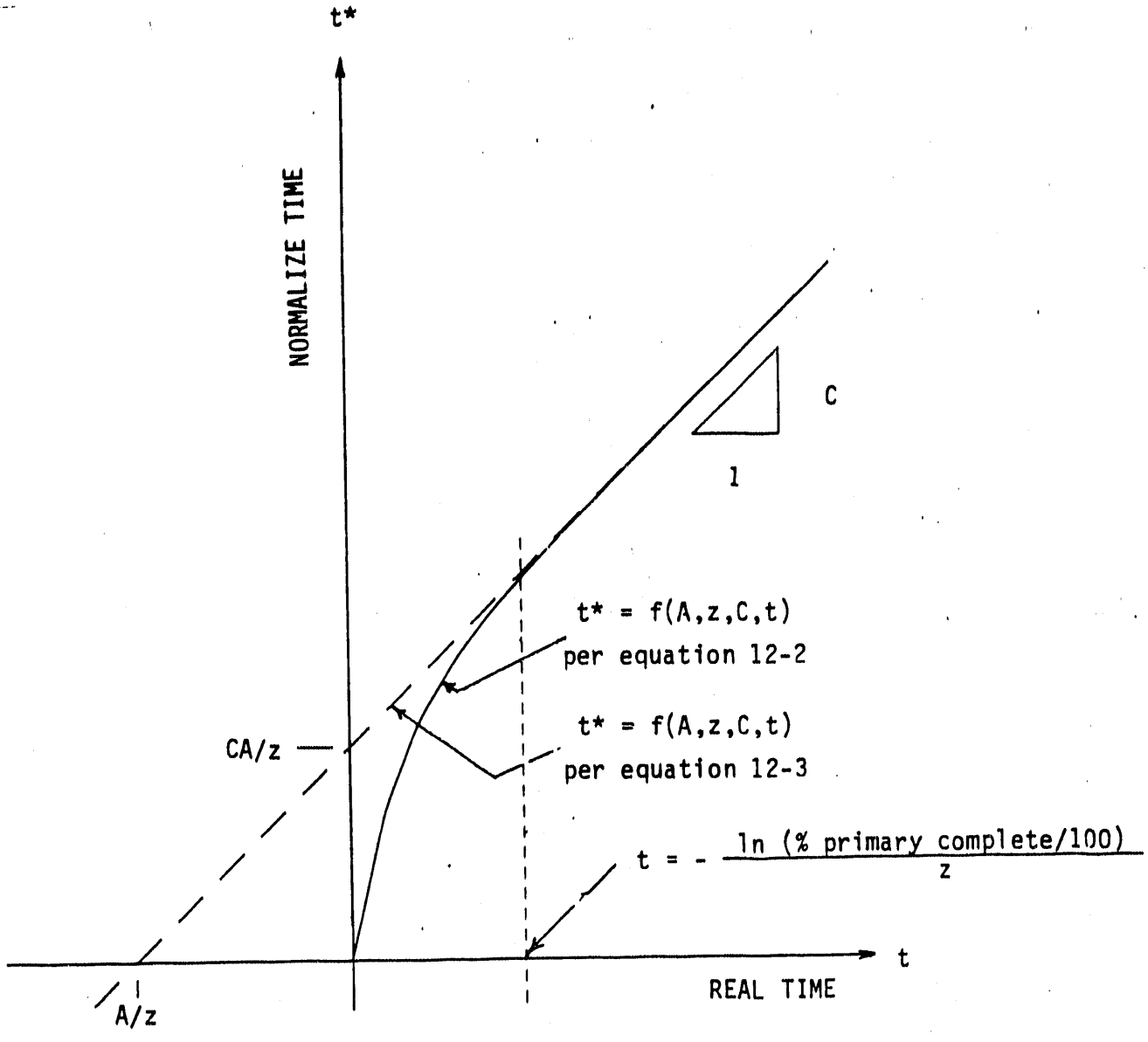


FIGURE C-2

GRAPHICAL REPRESENTATION OF

CREEP CONSTANTS RELATING TIME DOMAINS

The link between real time and response is completed by relating the normalized time to the response determined from the structural analysis. In brief, if the creep constants are known, the normalized time associated with any real time can be determined from equation (C.4-17) and the response corresponding to this time is found from the analysis results. Conversely, if in situ data which relates real time to response is available, this two-phased process can be worked backwards to evaluate the creep constants.

Because the response in both the in situ measurements and the structural analysis must be consistent, the displacements caused by creep are related.

In the analysis, the total response is an accumulation of elastic and creep responses,

$$R_t(t^*) = R_c(t^*) + R_e(t^*) \qquad \text{(C.5-2)}$$

where: R_t is the total response;
R_c is the creep response; and
R_e is the elastic response.

In as much as the total response at time $t^* = 0$ consists of elastic response only, and the elastic response $R_e(t^*)$ is always approximately equal to $R_t(0)$, the following equation can be used in lieu of equation (C.5-2):

$$R_c(t^*) = R_t(t^*) - R_t(0) \qquad \text{(C.5-3)}$$

The in situ readings represent the response relative to the time when the instrument was installed. In order for an actual creep response to be determined, the creep response which takes place between the time the excavation was made and the time when the instrument was installed must be found. Theoretically, if an instrument had been installed very shortly after excavation, this difference between measured and actual creep responses would be negligible. In reality, the excavation of all material contributing to the support of a specific location in an opening cannot be completed within a few days. As a result, the measured response from an instrument installed immediately after excavation would be a combination of initial creep and elastic responses. The term "instrument offset" is introduced to identify the difference between the actual creep response and the measured response starting at time t_1 when nearby excavations no longer introduce initial creep and elastic responses. This relationship is shown below:

$$R_I(t) = R_M(t) + R_I(t_1) \qquad \text{(C.5-4)}$$

where: R_I is the actual in situ response;
R_M is the measured response; and
$R_I(t_1)$ is the instrument offset.

Determination of the constant C, which represents the steady state creep rate, requires that the in situ readings are well into the steady state range. If this is the case, the relationship

$$dt^* = F\, dt \qquad \text{(C.5-5)}$$

can be used to determine the value of C since C equals F at very large values of t. The expression for C is:

$$C = (t^*_n - t^*_m) / (t_n - t_m) \qquad \text{(C.5-6)}$$

If t_m and t_n represent the times at which instrument readings are taken and $R_I(t_m)$ and $R_I(t_n)$ are the actual creep responses at these times, then the values of t^*_m and t^*_n can be found by relating these actual in situ creep responses with the analytical creep responses.

Assuming for the moment that the true value of instrument offset is known, equation (C.4-15) can be written for two time-response situations to produce two simultaneous equations which contain only the two remaining creep constants, A and z. By cancelling out the A term, the solution of the following equation provides the value of z.

$$\frac{1 - e^{-zt_n}}{1 - e^{-zt_m}} - \frac{t^*_n/C - t_n}{t^*_m/C - t_m} = 0 \qquad \text{(C.5-7)}$$

Once the value of z is found to satisfy the expression, A can be found from the following equation:

$$A = z\,(t_m^*/C - t_m) \,/\, (1 - e^{-zt}) \qquad \text{(C.5-8)}$$

Graphically this method determines constants which force the analytical curve to match the in situ data at the two time-response situations used in calculating the constants. Each different set of data points yields different values of A and z. Figure C-3 compares analytical and in situ responses for a few different sets of data points. Whereas creep behavior is history dependent, matching the last available data point is advantageous in predicting future responses. The determination of best values of A and z is done by minimizing the area between in situ and analytic response histories. The least area yields the best values. The SCCE program can be set up to search for this optimal condition.

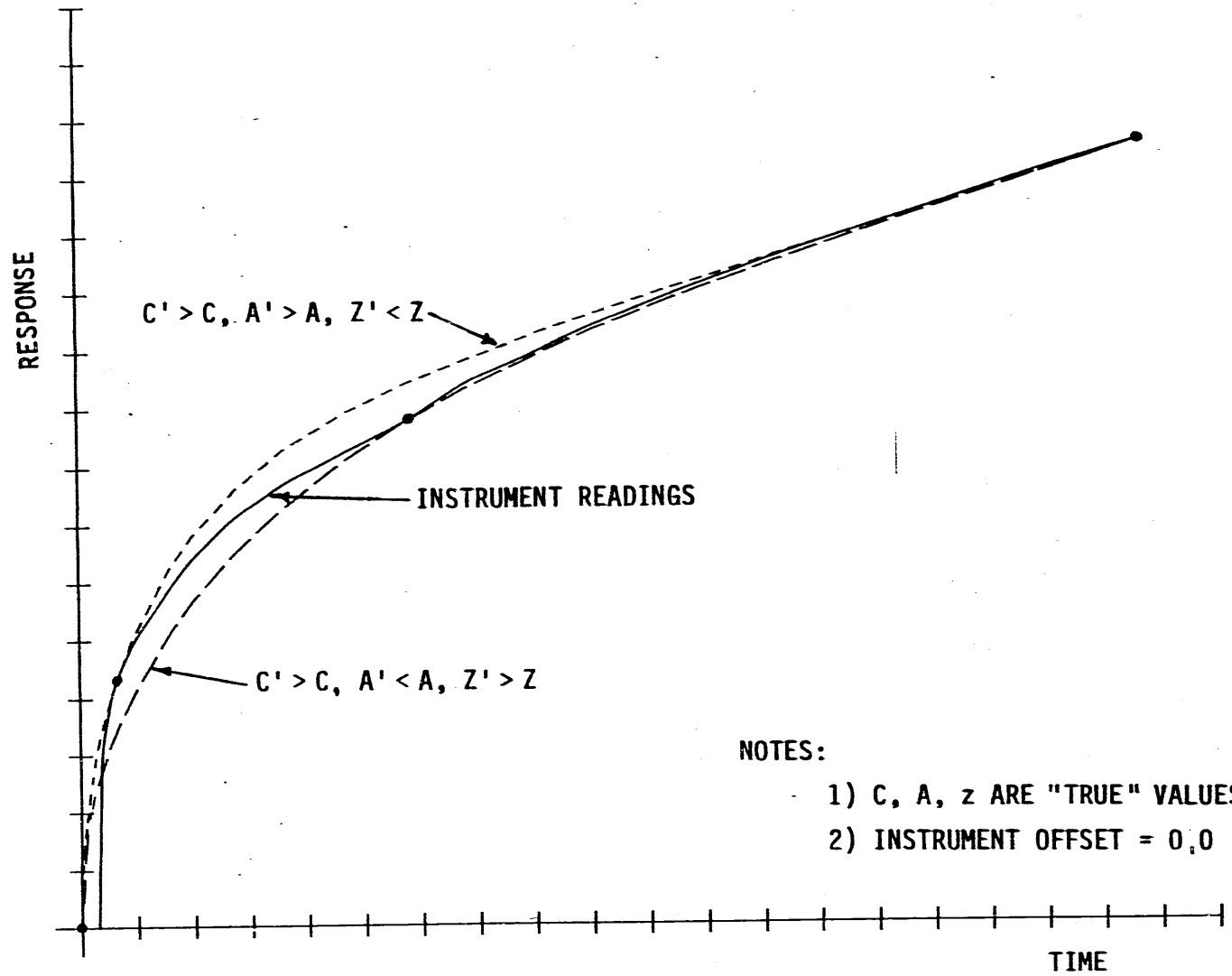


FIGURE C-3

COMPARISON OF ANALYTICAL RESULTS AND IN-SITU RESPONSES FOR VARIOUS DATA POINT SETS

The point which must be kept in perspective is that the determination of the constants A and z are dependent on both the instrument offset and the steady-state creep constant C. The effects of uncertainty in C can be minimized by assuring that no extraneous data are used in the solution of equation (C.5-6). The appropriate value of the instrument offset can only be found from minimizing the response deviation as was described in the previous paragraph. Figure C-4 shows how analytical and in situ responses compare for a few different values of the instrument offset. The curves in Figures C-3 and C-4 were generated through use of the SCCE program.

The SCCE computer program provides an effective means of determining salt creep properties by being able to process the large volume of in situ data and analytical results for design validation.

C.6 PREDICTION OF STRUCTURAL BEHAVIOR

After the creep constants C, A and z are determined, the structural response history can then be mapped from the normalized time domain into the real time domain using equation (C.4-15). Utilizing the in situ creep constants, additional mathematical models can also be used to predict the future structural responses for various facilities.

C.7 CONCLUSIONS

By normalizing the time in the governing equations to the creep function, the structural responses can be computed as functions of normalized time. This computation is performed without knowing the creep constants. After correlating the response history obtained from the analysis to the corresponding one measured from the site, the creep constants can be determined. Consequently, the relationship between the normalized and real time can be established, and the analytical responses can be mapped from the normalized time domain to the real time domain. Predicted results can therefore be provided for validating the adequacy of the underground behavior in the salt formation.

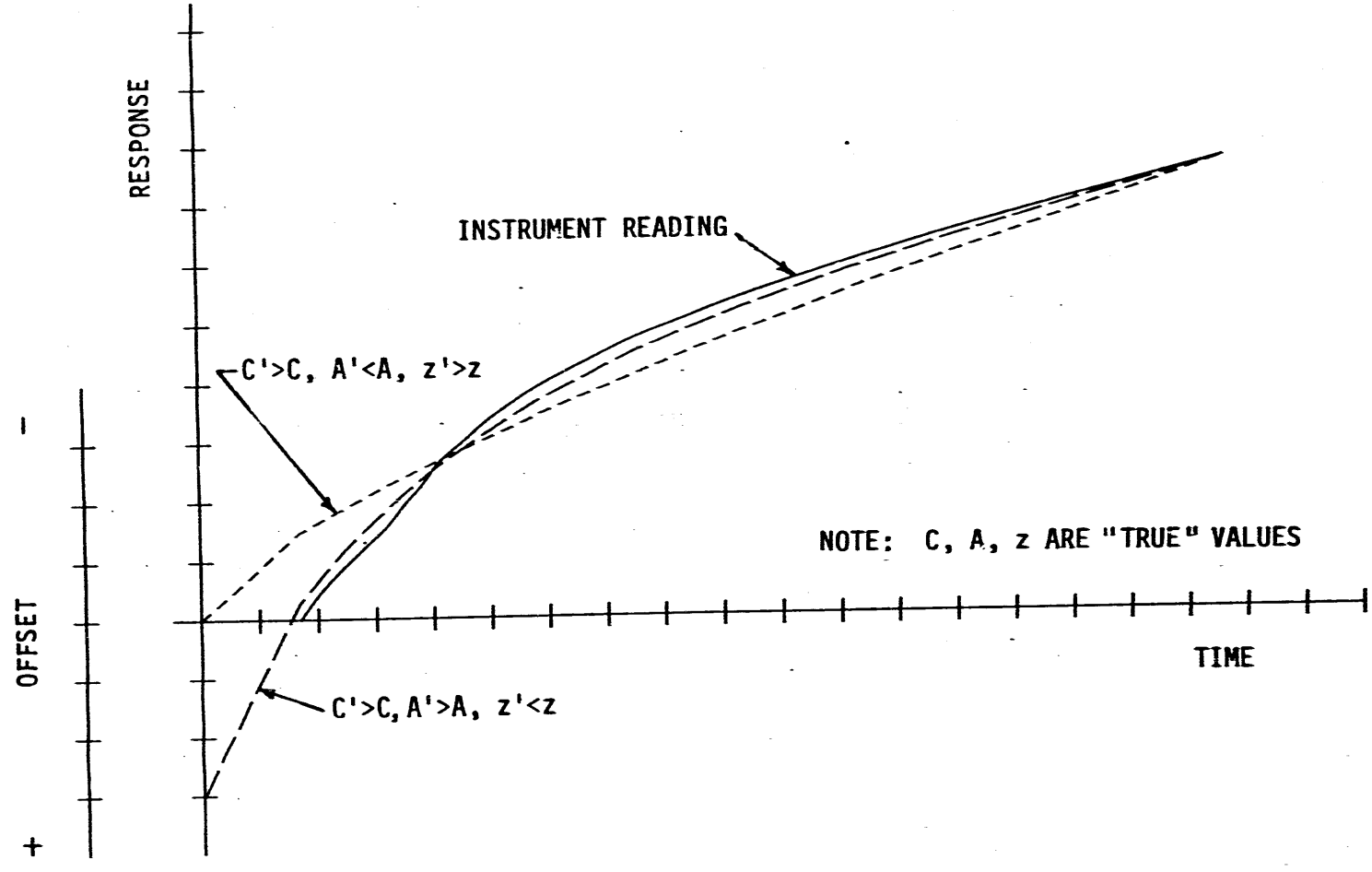


FIGURE C-4

COMPARISON OF ANALYTICAL RESULTS AND IN-SITU RESPONSE
FOR VARIOUS INSTRUMENT OFFSET VALUES

REFERENCES

C-1 Krieg, R. D., January 1984, Reference Stratigraphy and Properties for the Waste Isolation Pilot Plant Project, SAND83-1908, Sandia National Laboratories, Albuquerque, New Mexico.

APPENDIX D

C & SH SHAFT
GEOLOGIC LOGS AND MAPS

CONTENTS

Figure No.	Title/Description
D-1	Geologic Drill Log 0 to 850 feet (11 Sheets)
D-2	Key Area Geology Bottom of casing to 920 feet
D-3	Lithologic Log Showing Sample and Instrument Locations Bottom of casing to 2200 feet (3 Sheets)
D-4	Facility Level Area Geology 2080 to 2192 feet

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
WIPP	12484	1 OF 11	EXPLORATORY SHAFT (SPDV)

SITE	COORDINATES (PLANT GRID)	ANGLE FROM HORIZ.	BEARING
WIPP EDDY CO., NEW MEXICO	N 9687.23 E 6894.89	90°	N. A.

BEGUN	COMPLETED	DRILLER	DRILL MAKE AND MODEL	HOLE SIZE	OVERBURDEN (FT.)	ROCK (FT.)	TOTAL DEPTH
7-4-81	10-24-81	CHALLENGER DRILLING CO.	NATIONAL 125	142 IN.	16	2282	(FROM G.S.) 2298 FT.

CORE RECOVERY (FT./%)	CORE BOXES	SAMPLES	EL. TOP OF CASING	GROUND EL.	DEPTH/EL. GROUND WATER	DEPTH/EL. TOP OF ROCK
N. A.	N. A.	172	N.A.	3410.5	NOT DETERMINED	(FROM GROUND SURFACE) 16 FT./3394.5

SAMPLE HAMMER WEIGHT/FALL	CASING LEFT IN HOLE: DIA./LENGTH	LOGGED BY:
N. A.	180 IN./11FT. 144 IN./93.4 FT. 120 IN./843FT.	R.M. BEATHARD, R.C. KISER, J.L. MATTHEWS

SAMPLER TYPE AND DIAMETER	SAMPLER ADVANCE / LENGTH CORE RUN	SAMPLE RECOVERY / CORE RECOVERY	SAMPLE BLOWS "N" / PERCENT CORE RECOVERY	WATER PRESSURE TESTS: LOSS IN G.P.M.	WATER PRESSURE TESTS: PRESSURE P.S.I.	WATER PRESSURE TESTS: TIME IN MINUTES	ELEVATION	DEPTH (FT.) BELOW K. B.	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
							3417.5	0				Rig depths measured from kelly bushing approx. 7 ft. above ground surface.
							3410.5				GROUND SURFACE	
BACKHOE 168 IN. DIA. AUGER FROM 11 TO 97.5 FT		NO SAMPLES TAKEN FROM GROUND SURFACE TO 103 FT.					3399.5	10			0-11' DUNE SAND, Reddish brown 11-16' CALICHE, White	NOTES: 1. Stratigraphic description from 0 to 103 ft. based on geologic log of boring B-25. 2. 168 in. dia. pilot hole augered from 0-97.5 ft. by Meredith Drilling Co. prior to setting and cementing 144 in. dia. surface casing. 3. All depths given are from ground surface except for those shown in depth column.
							3394.5	20			16-36.5' GATUNA FORMATION, Sandstone, reddish brown, fine to medium grained	
								30				
								40				
							3374.0				36.5-46.5' SANTA ROSA FORMATION, Sandstone, gray and reddish brown, fine grained	CASING: 0-11 ft. = 180 in. dia CMP 0-93.4 ft. = 144 in. dia. surface casing 0-843 ft. = 120 in. dia. steel liner (installed after completion of shaft drilling)
								50				
							3364.0				46.5-538' DEWEY LAKE FORMATION, Siltstone and sandstone, reddish brown, whitish veins of gypsum interspersed throughout	
								60				
							3347.5	70				

SS = SPLIT SPOON; ST = SHELBY TUBE; D = DENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M.

HOLE NO.: EXPLORATORY SHAFT

H&CF 19-1

BECHTEL

GEOLOGIC DRILL LOG

PROJECT: WIPP | JOB NO.: 12484 | SHEET NO.: 2 OF 11 | HOLE NO.: EXPLORATORY SHAFT (SPDV)

SAMPLER TYPE AND DIAMETER	SAMPLER ADVANCE / LENGTH CORE RUN	SAMPLE RECOVERY / CORE RECOVERY	SAMPLE BLOWS "N" / PERCENT CORE RECOVERY	WATER PRESSURE TESTS: LOSS IN G.P.M.	WATER PRESSURE TESTS: PRESSURE P.S.I.	WATER PRESSURE TESTS: TIME IN MINUTES	ELEVATION	DEPTH (FT.) BELOW K.B.	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
168 IN. DIA. AUGER		NO SAMPLES TAKEN					3347.5	70			DEWEY LAKE FORMATION, Siltstone and sandstone, reddish brown, whitish veins of gypsum interspersed throughout	
								80				
								90				
								100				← Horizontal displacement at 99 ft. was 0.01 ft. S27°06'W
								110		1	Siltstone, dark reddish brown, moderately weak, thinly bedded	Cuttings samples collected from discharge end of blooie-line unless otherwise indicated. Sample depths shown are approximate
142 IN. DIA. ROTARY CUTTER BIT FROM 97.5 TO 2298 FT.		CUTTINGS SAMPLES TAKEN FROM 103 TO 2298 FT.						120		2	Sandstone, dark reddish brown, fine grained, well sorted, sub-rounded grains, weakly cemented	
								130		3	Sandstone, silty, very fine grained, grading into siltstone in places	Drilling rate from 122 to 148 ft. was 1.4 ft/hr
								140		4	As above	
							3267.5	150		5	Siltstone, sandy, dark reddish brown	

SS = SPLIT SPOON; ST = SHELBY TUBE; B = BENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M.

HOLE NO.: EXPLORATORY SHAFT

M&CF 19-2

BECHTEL

GEOLOGIC DRILL LOG

PROJECT: WIPP | JOB NO.: 12484 | SHEET NO.: 3 of 11 | HOLE NO.: EXPLORATORY SHAFT (SPDV)

SAMPLER TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY CORE RECOVERY	SAMPLE BLOWS "N" PERCENT CORE RECOVERY	WATER PRESSURE TESTS: LOSS IN G.P.M.	WATER PRESSURE TESTS: PRESSURE P.S.I.	WATER PRESSURE TESTS: TIME IN MINUTES	ELEVATION	DEPTH (FT.) BELOW G.L.	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
							3267.5	150			Siltstone, sandy, dark reddish brown, moderately weak, thin bedded, grading into sandstone in places	Horizontal displacement at 143 ft. was 0.02 ft. S 04°07'W
								160		6	Clay, dark reddish brown, some siltstone (dark reddish brown and greenish gray, moderately weak), clay probably occurs as claystone interbedded with siltstone	Drilling rate from 148 to 158 ft. was 3.3ft./hr.
								170		7	Siltstone, sandy, dark reddish brown, moderately weak, little clay	Drilling rate from 158 to 194 ft. was 12 ft./hr.
								180		8	As above	
								190		9	Clay and Siltstone, dark reddish brown	Horizontal displacement at 183 ft. was 0.01 ft. S17°47'W
								200		10	Sandstone, dark reddish brown, moderately weak, very fine grained, subrounded, well sorted	Drilling rate from 194 to 203 ft. was 1.3 ft./hr.
								210		11	Siltstone, dark reddish brown, moderately weak, gypsum fragments	Drilling rate from 203 to 217 ft. was 1.2 ft./hr.
								220		12	Sandstone, silty, dark reddish brown, moderately weak, very fine grained, subrounded, well sorted	Drilling rate from 217 to 245 ft. was 1.4 ft./hr.
142 IN. DIA. ROTARY CUTTER BIT			CUTTINGS SAMPLES				3187.5	230		13	Siltstone, dark reddish brown	

SS = SPLIT SPOON; ST = SHELBY TUBE; B = BENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M.

HOLE NO.: EXPLORATORY SHAFT

H&CF 19-2

BECHTEL

GEOLOGIC DRILL LOG

PROJECT: WIPP | JOB NO.: 12484 | SHEET NO.: 4 OF 11 | HOLE NO.: EXPLORATORY SHAFT (SFDV)

SAMPLER TYPE AND DIAMETER	SAMPLER ADVANCE — LENGTH CORE RUN	SAMPLE RECOVERY — CORE RECOVERY	SAMPLE BLOWS "N" — PERCENT CORE RECOVERY	WATER PRESSURE TESTS: LOSS IN G.P.M.	WATER PRESSURE TESTS: PRESSURE P.S.I.	WATER PRESSURE TESTS: TIME IN MINUTES	ELEVATION	DEPTH (FT.) BELOW K.B.	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
							3187.5	230			Siltstone, dark reddish brown, moderately weak, gypsum fragments, little clay	← Horizontal displacement at 229 ft. was 0.02 ft. S43° 30'W
								240		14	Sandstone, silty, dark reddish brown, moderately weak, very fine grained, subrounded, well sorted, some siltstone, abundant gypsum fragments	
								250		15	As above, much less gypsum	S#16 taken from drill bit - no formal description
										16		
								260		17	As above (sample No. 14)	Drilling rate from 245 to 262 ft. was 1.0 ft./hr.
								270		18	As above, abundant gypsum and greenish sandstone fragments	Drilling rate from 262 to 276 ft. was 0.6 ft./hr.
								280		19	As above	← Horizontal displacement at 271 ft. was 0.03 ft. S19° 29'W
								290		20	As above	Drilling rate from 276 to 299 ft. was 1.2 ft./hr.
								300		21	Sandstone, silty, dark reddish brown, moderately weak, very fine grained, well sorted, and Siltstone, dark reddish brown, moderately weak, some gypsum fragments	Drilling rate from 299 to 309 ft. was 1.3 ft./hr.
142 IN. DIA. ROTARY CUTTER BIT			CUTTINGS SAMPLES				3107.5	310		22	Sandstone, as above, some lt. green color	

SS = SPLIT SPOON; ST = SHELBY TUBE; D = DENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M.

HOLE NO.: EXPLORATORY SHAFT

H&CF 19-2

BECHTEL

GEOLOGIC DRILL LOG

PROJECT: WIPP | JOB NO.: 12484 | SHEET NO.: 5 OF 11 | HOLE NO.: EXPLORATORY SHAFT (SPDV)

SAMPLER TYPE AND DIAMETER	SAMPLER ADVANCE/ LENGTH CORE RUN	SAMPLE RECOVERY/ CORE RECOVERY	SAMPLE BLOWS "N" / PERCENT CORE RECOVERY	WATER PRESSURE TESTS: LOSS IN G.P.M.	WATER PRESSURE TESTS: PRESSURE P.S.I.	WATER PRESSURE TESTS: TIME IN MINUTES	ELEVATION	DEPTH (FT.) BELOW K.B.	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
							3107.5	310		23		S# 23 taken from drill bit - no formal description
								320		24	Sandstone, silty, dark reddish brown, moderately weak, very fine grained, well sorted, and Siltstone, dark reddish brown, moderately weak	← Horizontal displacement at 313 ft. was 0.04 ft. S 0° 03'E
												Drilling rate from 309 to 322 ft. was 1.9 ft./hr.
								330		25	Sandstone, silty, dark reddish brown, moderately weak, very fine grained, subrounded, well sorted, some gypsum fragments	Drilling rate from 322 to 336 ft. was 1.6 ft./hr.
								340		26	Siltstone, clayey, dark reddish brown, moderately weak, and Sandstone, dark reddish brown, moderately weak, very fine grained, trace of clay	Drilling rate from 336 to 375 ft. was 2.1 ft./hr.
								350		27	Siltstone, sandy, dark reddish brown and greenish gray, moderately weak	
								360		28	Siltstone, sandy, dark reddish brown, moderately weak, grades into Sandstone, dark reddish brown, moderately weak, very fine grained	← Horizontal displacement at 357 ft. was 0.06 ft. S 01° 10'E
								370		29	Sandstone, silty, dark reddish brown, moderately weak, very fine grained, subrounded, well sorted	
								380		30	As above, with gypsum fragments	Drilling rate from 375 to 433 ft. was 2.0 ft./hr.
							3027.5	390		31	Sandstone, as above, and Siltstone	

142 IN. DIA. ROTARY CUTTER BIT

CUTTINGS SAMPLES

SS = SPLIT SPOON; ST = SHELBY TUBE; D = DENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M.

HOLE NO.: EXPLORATORY SHAFT

H&CF 19-2

GEOLOGIC DRILL LOG

PROJECT: WIPP | JOB NO.: 12486 | SHEET NO.: 6 of 11 | HOLE NO.: EXPLORATORY SHAFT (SPDV)

SAMPLER TYPE AND DIAMETER	SAMPLER ADVANCE / LENGTH CORE RUN	SAMPLE RECOVERY / CORE RECOVERY	SAMPLE BLOWS "N" / PERCENT CORE RECOVERY	WATER PRESSURE TESTS: LOSS IN G.P.M.	WATER PRESSURE TESTS: PRESSURE P.S.I.	WATER PRESSURE TESTS: TIME IN MINUTES	ELEVATION	DEPTH (FT.) BELOW K.B.	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
142 IN. DIA. ROTARY CUTTER BIT		CUTTINGS SAMPLES					3027.5	390			Sandstone, as above, and Siltstone, sandy. dark reddish brown, some greenish gray frags., moderately weak, abundant gypsum fragments	
								400		32	As above	
								410		33	Sandstone, as sample No. 29, abundant gypsum fragments	← Horizontal displacement at 401 ft. was 0.08 ft. S08° 13'W
								420		34	As above	
								430		35	As above	
								440		36	As above, some gray green color	Drilling rate from 433 to 464 ft. was 1.6 ft./hr.
								450		37	Sandstone and Siltstone, as sample No. 32	← Horizontal displacement at 445 ft. was 0.10 ft. S18° 50'W
								460		38	As above	
							2947.5	470		39	Sandstone, as sample No. 29	

SS = SPLIT SPOON; ST = SHELBY TUBE; D = DENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M. | HOLE NO.: EXPLORATORY SHAFT

H&CF 19-2

BECHTEL

GEOLOGIC DRILL LOG

PROJECT: WIPP | JOB NO.: 12484 | SHEET NO.: 7 OF 11 | HOLE NO.: EXPLORATORY SHAFT (SPDV)

SAMPLER TYPE AND DIAMETER	SAMPLER ADVANCE/LENGTH CORE RUN	SAMPLE RECOVERY/CORE RECOVERY	SAMPLE BLOWS "N"/PERCENT CORE RECOVERY	WATER PRESSURE TESTS: LOSS IN G.P.M.	WATER PRESSURE TESTS: PRESSURE P.S.I.	WATER PRESSURE TESTS: TIME IN MINUTES	ELEVATION	DEPTH (FT.) BELOW K.B.	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
							2947.5	470				Drilling rates: 464-490 ft. = 1.5 ft./hr. 490 - 502 ft. = 0.8 ft./hr. 502 - 506 ft. = 0.7 ft./hr.
								480		40	Siltstone, dark reddish brown, moderately weak, gypsum fragments, trace of sandstone	
								490		41	Sandstone, silty, dark reddish brown, moderately strong to moderately weak, very fine grained, abundant greenish gray reduction spots	
												← Horizontal displacement at 489 ft. was 0.14 ft. S28°17'W
								500		42	As above	
								510		43	As above, subrounded, well sorted, gypsum fragments	Drilling rates: 506 - 510 ft. = 1.3 ft./hr. 510 - 513 ft. = 0.5 ft./hr. 513 - 527 ft. = 0.6 ft./hr. 527 - 538 ft. = 0.5 ft./hr. 538 - 548 ft. = 0.4 ft./hr.
								520		44	As above	
								530		45	As above, moderately weak, some greenish gray reduction spots	
								540		46	As above	← Horizontal displacement at 533 ft. was 0.18 ft. S35° 10'W
										47	As above	
										48	As above	
							2872.5				538 - 850' RUSTLER FORMATION, primarily anhydrite, dolomite, and mudstone	
							2867.5	550		49	Anhydrite, white to light brownish gray	

142 IN. DIA. ROTARY CUTTER BIT

CUTTINGS SAMPLES

SS = SPLIT SPOON; ST = SHELBY TUBE; D = DENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M.

HOLE NO.: EXPLORATORY SHAFT

H&CF 19-2

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
WIPP	12484	8 of 11	EXPLORATORY SHAFT (SPDV)

Column headings: SAMPLER TYPE AND DIAMETER | SAMPLER ADVANCE | LENGTH CORE RUN | SAMPLE RECOVERY | CORE RECOVERY | SAMPLE BLOWS "N" | PERCENT CORE RECOVERY | WATER PRESSURE TESTS: LOSS IN G.P.M. / PRESSURE P.S.I. / TIME IN MINUTES | ELEVATION | DEPTH (FT.) BELOW K.B. | GRAPHIC LOG | SAMPLE | DESCRIPTION AND CLASSIFICATION | NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.

Sampler type and diameter: 142 IN. DIA. ROTARY CUTTER BIT

Sample: CUTTINGS SAMPLES

Elevation	Depth (ft.)	Sample	Description and Classification	Notes
2867.5	550		Anhydrite, white to light brownish gray, hard, finely crystalline, some gypsum fragments	Drilling rates: 548-554 ft. = 0.5 ft./hr. 554-561 ft. = 0.7 ft./hr.
	560	50	As above	
	570	51	As above, light gray to light brownish gray	
	580	52	Clay, dark brown, high plasticity, some silt	Horizontal displacement at 577 ft. was 0.24 ft. S40° 12'W
	590	53	Siltstone, medium gray, moderately weak, some very fine sand and minor clay	
2817.5	600	54	Anhydrite, very lt. gray to med. dk. gray, moderately hard	
			593 - 628' MAGENTA DOLOMITE MEMBER	
	610	55	Siltstone, calcareous, med. olive gray to olive gray, strong, mod. hard, mod. to well cemented, sparse gypsum crystals	
	620	56	As above	
2795.5			?— — — — — — — — — — — —?	
2787.5	630	57	Dolomite, olive gray	

SS = SPLIT SPOON; ST = SHELBY TUBE; D = DENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M.

HOLE NO. EXPLORATORY SHAFT

H&CF 19-2

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
WIPP	12484	9 of 11	EXPLORATORY SHAFT (SPDV)

SAMPLER TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY / CORE RECOVERY	SAMPLE BLOWS "N" / PERCENT CORE RECOVERY	WATER PRESSURE TESTS: LOSS IN G.P.M.	WATER PRESSURE TESTS: PRESSURE P.S.I.	WATER PRESSURE TESTS: TIME IN MINUTES	ELEVATION	DEPTH (FT.) BELOW K.B.	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
							2787.5	630				
							2782.5				Dolomite, olive gray, mod. strong, mod. hard, sugary texture w/small silver blebs (mica?), evidence of lamella, powdered sample reacts slightly w/HCl acid	
								640		58	Anhydrite, very light gray to brownish gray, mod. strong, mod. hard, well cemented, possibly gypsiferous	
								650		59	As above	
								660		60	As above	
								670		61	As above, contains minor amt. of small black grains w/resinous luster, pulverized grains have earthy to sandy appearance & small reaction w/HCl acid	
								680		62	As above (sample No. 58), lighter in overall color and larger fragments	
142 IN. DIA. ROTARY CUTTER BIT		CUTTINGS SAMPLES						690		63	As above, lighter in overall color, smaller fragments than above	
								700		64	Anhydrite, mot. pale yellow brn. overall, some pale reddish brn. frags. (polyhalite), stronger and harder than previous samples, trace translucent to white, fibrous satinspar gypsum, trace gray clay frags.	
							2707.5	710		65	Anhydrite, slightly mot. med. to lt. gray	

SS = SPLIT SPOON; ST = SHELBY TUBE; D = DENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M.

HOLE NO.: EXPLORATORY SHAFT

H&CF 19-2

BECHTEL

GEOLOGIC DRILL LOG

PROJECT: WIPP | JOB NO.: 1240[illegible] | SHEET NO.: 10 OF 11 | HOLE NO.: EXPLORATORY SHAFT (SPDV)

SAMPLER TYPE AND DIAMETER	SAMPLER ADVANCE LENGTH CORE RUN	SAMPLE RECOVERY CORE RECOVERY	SAMPLE BLOWS "N" PERCENT CORE RECOVERY	WATER PRESSURE TESTS: LOSS IN G.P.M.	WATER PRESSURE TESTS: PRESSURE P.S.I.	WATER PRESSURE TESTS: TIME IN MINUTES	ELEVATION	DEPTH (FT. BELOW K.B.)	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
142 IN. DIA. ROTARY CUTTER BIT			CUTTINGS SAMPLES				2707.5	710			Anhydrite, slightly mot. med. to lt. gray overall, trace gypsum	
							2699.5	720		66	711-740' CULEBRA DOLOMITE MEMBER Dolomite, crystalline, lt. olive gray, mod. strong, well cemented, sugary texture, powdered sample reacts slightly w/HCl acid, trace transparent gypsum crystals	
								730		67		
								740		68	As above	
							2670.5	750		69	Anhydrite, crystalline, variegated color (primarily grayish pink, pale red, and light gray), strong, hard, sugary texture, blebs of grayish red (polyhalite?)	
							2658.5	760		70	Halite, pale reddish brn., strong, hard, dissolves slowly in hot water, few transparent frags. exhibiting cleavage faces, trace argillaceous material	← Horizontal displacement at 753 ft. was 0.49 ft. 85° 15'W
								770		71	As above, more abundant crystals, some mudstone (clay to fine sand particles, grayish red, poor to mod. cementation, crumbles easily)	
								780		72	As above, trace anhydrite (yellow gray, strong, mod. hard)	
							2627.5	790		73	Mudstone, moderate brown	

SS = SPLIT SPOON; ST = SHELBY TUBE; B = BENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M.

HOLE NO.: EXPLORATORY SHAFT

H&CF 19-2

BECHTEL

GEOLOGIC DRILL LOG

PROJECT	JOB NO.	SHEET NO.	HOLE NO.
WIPP	12484	11 of 11	EXPLORATORY SHAFT (SFDV)

SAMPLER TYPE AND DIAMETER	SAMPLER ADVANCE / LENGTH CORE RUN	SAMPLE RECOVERY / CORE RECOVERY	SAMPLE BLOWS "N" / PERCENT CORE RECOVERY	WATER PRESSURE TESTS: LOSS IN G.P.M.	WATER PRESSURE TESTS: PRESSURE P.S.I.	WATER PRESSURE TESTS: TIME IN MINUTES	ELEVATION	DEPTH (FT.) BELOW L.S.	GRAPHIC LOG	SAMPLE	DESCRIPTION AND CLASSIFICATION	NOTES ON: WATER LEVELS, WATER RETURN, CHARACTER OF DRILLING, ETC.
142 IN. DIA. ROTARY CUTTER BIT		CUTTINGS SAMPLES					2627.5	790			Mudstone, primarily silt w/clay and fine sand particles, mod. brn., strong, hard, well cemented, trace transparent halite crystals	
										74	As above, less halite, trace anhydrite	
								800				
										75	Mudstone, primarily silt w/fine sand & minor clay particles, olive gray, strong, hard, mod. cemented, mica flakes present	
								810				
										76	As above (sample No. 73), trace gypsum crystals and olive gray mudstone	
								820				
										77	As above (sample No. 75), trace brn. mudstone	
								830				
										78	As above	
								840				
										79	As above, larger frags.	← Horizontal displacement at 841 ft. was 0.59 ft. S54°18'W
								850				
										80	As above, brown and olive gray, trace anhydrite	
							2560.5				850-2298' SALADO FORMATION	
								860		81	Note: For description of Salado Formation stratigraphy and lithology see geologic map of shaft	
							2547.5	870		82		

SS = SPLIT SPOON; ST = SHELBY TUBE; B = DENNISON; P = PITCHER; O = OTHER

SITE: WIPP - EDDY CO., N. M.

HOLE NO.: EXPLORATORY SHAFT

H&CF 19-2

NOTES:

1) ELEVATIONS REFER TO BOTTOM OF CONCRETE AT ELEVATION OF 2530.36 WHICH WAS TIED TO CWI BENCHMARK NO. CW-1 (BRASS CAP OUTSIDE THE C & SH S(AFT) AT ELEVATION 3410.060 ON DECEMBER 2, 1982.

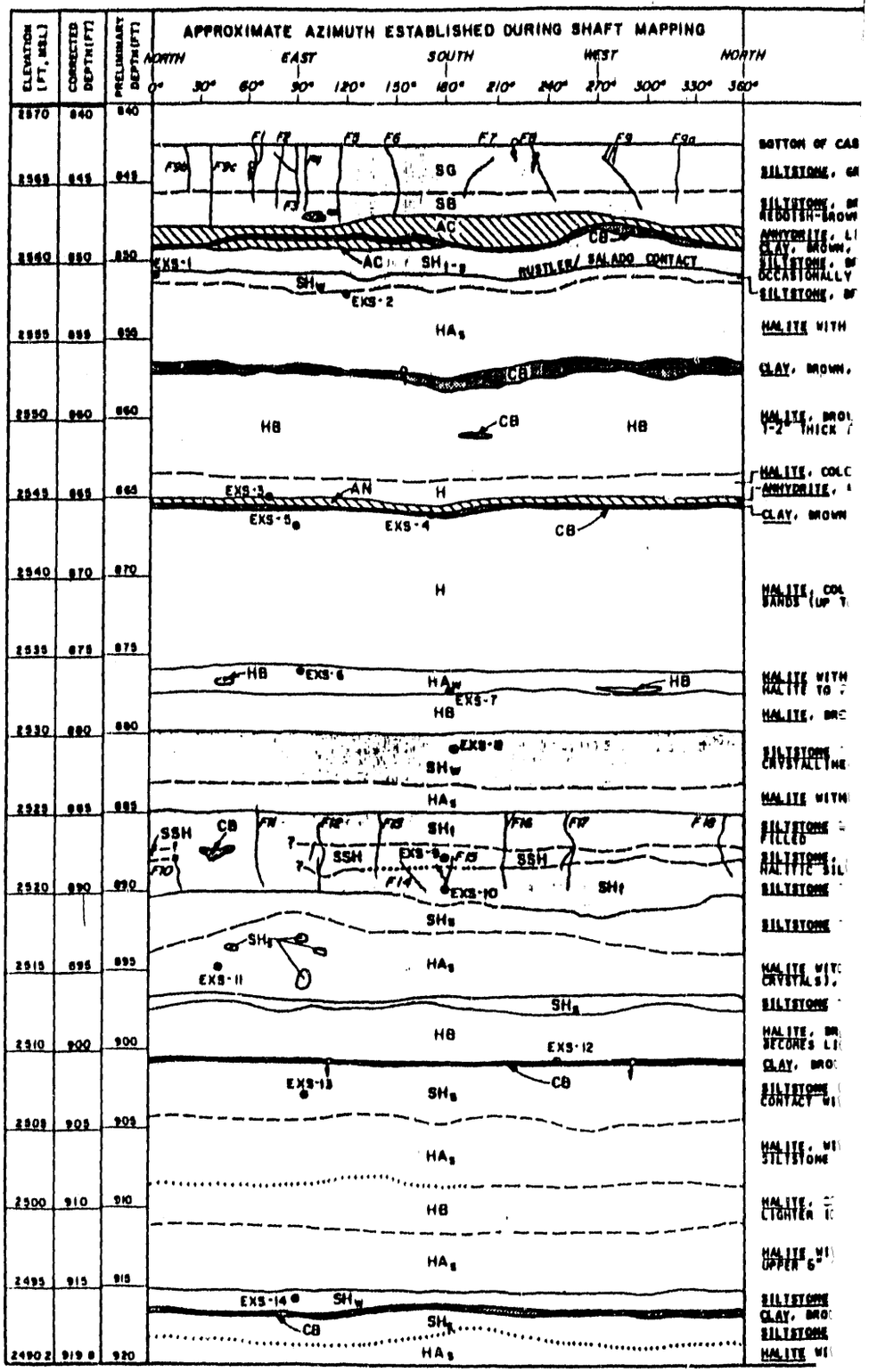
2) DEPTHS ARE RELATED TO THE TOP OF FIRST SUNTON AT ELEVATION 3416.6 FT. MSL.

3) PRELIMINARY DEPTHS WERE CORRECTED BY THE ADDITION OF A -0.2 FT. CORRECTION FACTOR.

4) STANDARD GEOLOGIC SYMBOL FOR HALITE IS NOT USED IN ORDER TO ENHANCE THE CLARITY OF THE LOG COLUMN.

REFERENCE:

GEOTECHNICAL ACTIVITIES IN THE EXPLORATORY SHAFT-SELECTION OF THE FACILITY INTERVAL, MARCH 1983, TME 3178.



SCALE

5 0 5 10 FT

FRACTURE NOTE

FRACTURES DESIGNATED F1 TO F9C REFER TO THOSE IN A TO 847 FEET. FRACTURES F10 TO F18 ARE IN A SILTST

F1 OPEN TO 1/4-INCH WIDE ABOVE CONTACT, CLOSED BELOW CONTACT; VERY MINOR SEEPAGE.

F2 FILLED WITH WHITE PRECIPITATE (SALT?); 1/8-INCH WIDE IN UPPER EXTENT, CLOSED IN LOWER EXTENT.

F3 BIFURCATION FORMS POTENTIAL SPALL AREA.

F4 VERY MINOR SEEPAGE; OPEN.

F5 OXIDIZED MATERIAL IN FRACTURE BELOW CONTACT; 1/8-INCH MAXIMUM WIDTH.

F6 TRENDS N20°E; 1/4-INCH WIDE; OPEN.

F8 OPEN 1/16- TO 1/2-INCH WIDE ABOVE CONTACT; BELOW CONTACT; PARTIALLY FILLED WITH SILT SEEPAGE.

F9 1/8- TO 1/4-INCH WIDE.

F9a ESTIMATED STRIKE N60°W.

F9b OPEN 1/4-INCH WIDE.

F9c CLOSED TO OPEN 1/4-INCH WIDE.

F10 HALITE FILLED, STRIKE E-W.

F11 VERTICAL FRACTURE WITH MAXIMUM WIDTH OF 1 HALITE FILLED; MODERATE REDDISH-BROWN COL

REMARKS

, NUMEROUS FRACTURES, SOME FRACTURES SEEPING

., NO HALITE, SEVERAL SPALLED AREAS; SPALLS SHALLOW (0.1' DEEP), WITH
BLACK OXIDIZED FRACTURE SURFACE
GRAY TO WHITE, UNDULATORY LOWER CONTACT
2" TO 1 1/2" THICK, SOFT, VERY MOIST
., TRACE TO SOME HALITE, LOCALLY MOTTLED WITH LIGHT OLIVE-GRAY,
ALLED, SEVERAL SEEPS
., WITH ABUNDANT HALITE, WASHED OUT APPROXIMATELY 1' INTO SHAFT WALL

: ARGILLACEOUS MATERIAL, VERY COARSELY CRYSTALLINE, MASSIVE

TH TRACE HALITE, MINOR SEEPS ALONG LOWER CONTACT

WITH SOME POLYHALITE, VERY COARSELY CRYSTALLINE, CONTAINS BROWN CLAY LENS
1 1/2' LONG

SS, VERY COARSELY CRYSTALLINE
T GRAY TO WHITE, FINE-GRAINED, POROUS, MASSIVE AT TOP, UPPER CONTACT
OVERLAIN BY THIN (<1") SEAM OF SOFT, SATURATED CLAY
SEAM SATURATED, VERY SOFT

ESS, CONTAINS BANDS (2 1/2"-7" THICK) OF COLORLESS HALITE ALTERNATING WITH
1/2" THICK) OF DARK REDDISH-BROWN HALITE; BANDS ARE SLIGHTLY UNDULATORY.

UNDANT ARGILLACEOUS MATERIAL, HALITE CONTENT VARIES FROM BLEBS OF PURE
INANTLY SILTSTONE, LOCALLY 50% DARK REDDISH-BROWN CLAYEY SILT.

OCCASIONAL IRREGULAR BLEBS AND LAYERS OF ANHYDRITE

: ABUNDANT HALITE, SILTY, CLAYEY, DARK RED, COMPETENT; HALITE MEDIUM
IN BOREHOLE B-25 THIS BED IS AN ARGILLACEOUS HALITE)

E ARGILLACEOUS MATERIAL AS SILTY CLAY

: TRACE HALITE, LIGHT PINKISH-GRAY, NUMEROUS FRACTURES, MOST FRACTURES HALITE

Y, MEDIUM REDDISH-ORANGE, VERY FINE-GRAINED, GRADES ABOVE AND BELOW TO
ONE, NUMEROUS FRACTURES CONTINUING FROM ABOVE UNIT
: TRACE HALITE, NUMEROUS FRACTURES CONTINUING FROM ABOVE UNIT

H SOME HALITE, HALITE IN LARGE (1/2"-1") CUBES AND BLEBS

ME ARGILLACEOUS MATERIAL, HALITE IS VERY COARSELY CRYSTALLINE (1" TO 2"
TAINS IRREGULAR FRAGMENTS OF SILTSTONE UP TO 1.5' LONG
H SOME HALITE, HALITE FINELY TO MEDIUM CRYSTALLINE

:, CONTAINS 1/8" THICK DISCONTINUOUS LAYERS OF CLAYEY SILTSTONE, COLOR OF BED
ER TOWARD BASE
1" TO 3" SEAM, SILTY, CONTAINS THIN LAMINAE OF CRYSTALLINE HALITE, MINOR SEEPS
H SOME HALITE, SOME CLAY, HALITE CONTENT INCREASES DOWNWARD TO TRANSITIONAL
UNDERLYING HALITE

SOME ARGILLACEOUS MATERIAL, IRREGULAR BLEBS (1" TO 2" DIAMETER) OF CLAYEY

., CONTAINS LESS ARGILLACEOUS MATERIAL THAN ABOVE HALITE, MORE MASSIVE AND
EOR THAN ABOVE

SOME ARGILLACEOUS MATERIAL SIMILAR TO ARGILLACEOUS HALITE AT 904' TO 908.5',
TAINS ARGILLACEOUS MATERIAL IN THIN DISCONTINUOUS BANDS

TH ABUNDANT HALITE
3"-6" SEAM, SOFT
TH SOME HALITE, CONTAINS COARSELY CRYSTALLINE HALITE (U TO 1 1/2" CRYSTALS)
SOME ARGILLACEOUS MATERIAL, VERY COARSELY CRYSTALLINE

TSTONE BED AT DEPTHS 842.5
D AT DEPTHS 875 TO 880 FEET.

OSED
NOR

F12 FRACTURE PARTIALLY FILLED WITH HALITE; STRIKE N88°E; MATCHES WITH F17.

F13 NO SPECIFIC DATA.

F14 ESTIMATED STRIKE N60°W, DIPPING 40°SW.

F15 POSSIBLY MATCHES F117; STRIKE N30°E.

F16 VERTICAL FRACTURE 3/4-INCH WIDE; HALITE FILLED; PROBABLY MATCHES F18; STRIKE N11°E.

F17 VERTICAL FRACTURE 1/2-INCH WIDE; HALITE FILLED; MATCHES F12; STRIKE N88°E.

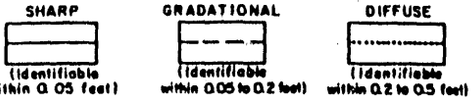
CH:

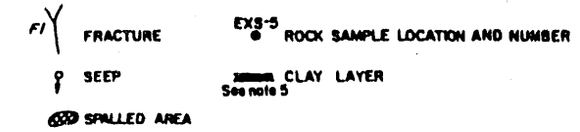
F18 ESTIMATED STRIKE N10 TO 20°E; FRACTURE F18 MATCHES
[illegible] FILLED

EXPLANATION

ROCK TYPE

CONTACTS





GEOLOGIC UNIT SYMBOLS AND DESCRIPTIONS *

A ARGILLACEOUS MATERIAL, GENERALLY FOUND AS AN INTERGRANULAR ACCESSORY CONSTITUENT, LIGHT GRAY (N7) TO MODERATE REDDISH-BROWN (10R 4/6), SLIGHTLY MOIST TO MOIST, TRACE TO SOME SILT.

AN ANHYDRITE, LIGHT GRAY (N7) TO WHITE (N9), MODERATE ORANGE-PINK (10R 7/4) TO PALE REDDISH-BROWN (10R 5/4), FINELY CRYSTALLINE.

AC ANHYDRITE, LIGHT GRAY (N7) TO GRAYISH-ORANGE (10YR 7/4) TO WHITE (N9), WITH SEVERAL SOFT 1/2- TO 1 1/2-INCH CLAY STRINGERS WITH TRACE OF SILT.

CB CLAY, DARK REDDISH-BROWN (10R 3/4) TO MODERATE REDDISH-BROWN (10R 4/6) WITH TRACE TO SOME SILT, TRACE TO SOME HALITE.

HA** HALITE, DARK REDDISH-BROWN (10R 3/4) TO MODERATE REDDISH-BROWN (10R 4/6) TO MODERATE REDDISH-ORANGE (10R 6/6), LOCALLY MEDIUM LIGHT GRAY (N7), MEDIUM TO COARSELY CRYSTALLINE, ARGILLACEOUS.

HB HALITE, DARK REDDISH-BROWN (10R 3/4) TO MODERATE REDDISH-BROWN (10R 4/6), SLIGHTLY TRANSLUCENT, MEDIUM TO COARSELY CRYSTALLINE.

H HALITE, COLORLESS (TRANSPARENT TO TRANSLUCENT) TO GRAYISH-ORANGE-PINK (5YR 7/2), MEDIUM TO COARSELY CRYSTALLINE, MAY BE BANDED.

SB SILTSTONE, DARK REDDISH-BROWN (10R 3/4), TRACE TO NO HALITE, TRACE FINE-GRAINED SAND.

SG SILTSTONE, LIGHT OLIVE-GRAY (5Y 6/1), TRACE FINE-GRAINED SAND, TRACE TO NO HALITE.

SH** SILTSTONE, DARK REDDISH-BROWN (10R 3/4) TO MODERATE REDDISH-BROWN (10R 4/6), HALITIC, TRACE TO SOME CLAY, LOCALLY CONTAINS VERY FINE TO FINE-GRAINED SAND.

SSH SILTSTONE, MODERATE REDDISH-ORANGE (10R 6/6), WITH VERY FINE-GRAINED SAND, TRACE HALITE; LOCALLY GRADES TO A VERY FINE TO FINE-GRAINED SANDSTONE, MODERATE REDDISH-BROWN (10R 4/6) TO MEDIUM LIGHT GRAY (N7), TRACE TO SOME SILT.

* SLIGHT VARIATIONS FROM THESE GENERAL DESCRIPTIONS MAY EXIST. THE EXCEPTIONS ARE NOTED IN THE REMARKS COLUMN.

** ESTIMATED CONTENT OF ACCESSORY CONSTITUENTS IS INDICATED BY A MODIFIER: T = TRACE
S = SOME
W = WITH OR ABUNDANT

FIGURE D-2
C & SH SHAFT
KEY AREA GEOLOGY
BOTTOM CASING TO 920 FEET

NOTES:

1) ELEVATIONS REFER TO BOTTOM OF CONCRETE AT ELEVATION OF 2530.38 WHICH WAS TIED TO CWI BENCHMARK NO. CW-1 (BRASS CAP OUTSIDE THE C & SH SHAFT) AT ELEVATION 3410.080 ON DECEMBER 2, 1982.

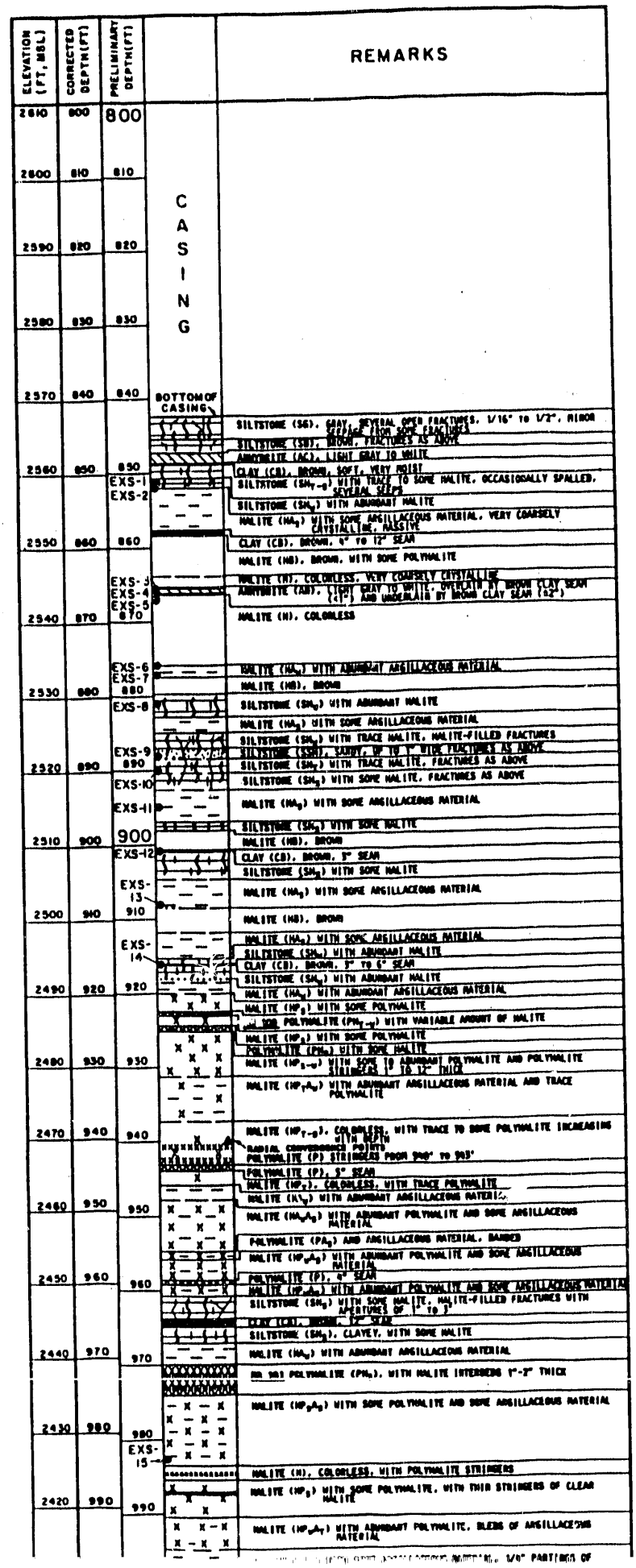
2) DEPTHS ARE RELATED TO THE TOP OF FIRST BUNTON AT ELEVATION 3410.8 FT. MSL.

3) PRELIMINARY DEPTHS WERE CORRECTED BY THE ADDITION OF A CORRECTION FACTOR.

4) STANDARD GEOLOGIC SYMBOL FOR HALITE IS NOT USED IN ORDER TO ENHANCE THE CLARITY OF THE LOG COLUMN.

REFERENCE:

GEOTECHNICAL ACTIVITIES IN THE EXPLORATORY SHAFT-SELECTION OF THE FACILITY INTERVAL, MARCH 1983, TME 3178.



GEOLOGIC UNIT SYMBOLS AND DESCRIPTIONS*

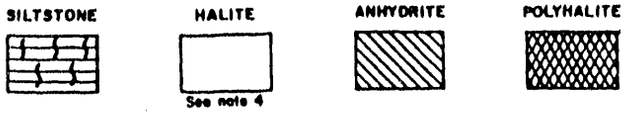
A	ARGILLACEOUS MATERIAL, GENERALLY FOUND AS AN INTERGRANULAR ACCESSORY CONSTITUENT, LIGHT GRAY (N7) TO MODERATE REDDISH-BROWN (10R 4/6), SLIGHTLY MOIST TO MOIST, TRACE TO SOME SILT.
AC	ANHYDRITE, LIGHT GRAY (N7) TO WHITE (N9) TO GRAYISH-ORANGE (10YR 7/4), FINELY CRYSTALLINE TO MICROCRYSTALLINE, SEVERAL SOFT 1/2- TO 1 1/2-INCH CLAY STRINGERS WITH TRACE SILT.
AH	ANHYDRITE, MEDIUM DARK GRAY (N4) TO LIGHT GRAY (N7) TO WHITE (N9), MODERATE ORANGE-PINK (10R 7/4) TO PALE REDDISH-BROWN (10R 5/4), FINELY CRYSTALLINE TO MICROCRYSTALLINE.
CB	CLAY, DARK REDDISH-BROWN (10R 3/4), TRACE TO SOME SILT, TRACE TO SOME HALITE.
CG	CLAY, MEDIUM LIGHT GRAY (N6) TO MEDIUM DARK GRAY (N4) TO LIGHT OLIVE-GRAY (5Y 6/1), TRACE TO SOME SILT, TRACE TO SOME HALITE.
H	HALITE, COLORLESS (TRANSPARENT TO TRANSLUCENT) TO GRAYISH-ORANGE-PINK (5YR 7/2), MEDIUM TO COARSELY CRYSTALLINE, MAY BE BANDED.
HA**	HALITE, DARK REDDISH-BROWN (10R 3/4) TO MODERATE REDDISH-BROWN (10R 4/6), MEDIUM TO COARSELY CRYSTALLINE, ARGILLACEOUS.
HB	HALITE, DARK REDDISH-BROWN (10R 3/4) TO MODERATE REDDISH-BROWN (10R 4/6), SLIGHTLY TRANSLUCENT.
HP**	HALITE, TRANSLUCENT TO MODERATE REDDISH-ORANGE (10R 6/6) TO MODERATE REDDISH-BROWN (10R 4/6), POLYHALITIC.
HPA**	HALITE, MODERATE REDISH-ORANGE (10R 6/6) TO MODERATE REDDISH-BROWN (10R 4/6), POLYHALITIC AND ARGILLACEOUS.
P	POLYHALITE, MODERATE REDDISH-BROWN (10R 4/6) TO MODERATE REDDISH-ORANGE (10R 6/6), FINELY CRYSTALLINE TO MICROCRYSTALLINE.
PA**	POLYHALITE, MODERATE REDDISH-BROWN (10R 4/6), FINELY CRYSTALLINE TO MICROCRYSTALLINE, ARGILLACEOUS.
PH**	POLYHALITE, MODERATE REDDISH-BROWN (10R 4/6) TO MODERATE REDDISH-ORANGE (10R 6/6), FINELY CRYSTALLINE TO MICROCRYSTALLINE, HALITIC.
SB	SILTSTONE, DARK REDDISH-BROWN (10R 3/4), TRACE HALITE, TRACE FINE SAND.
SG	SILTSTONE, LIGHT OLIVE-GRAY (5Y 6/1), TRACE HALITE, TRACE FINE-GRAINED SAND.
SH**	SILTSTONE, DARK REDDISH-BROWN (10R 3/4) TO MODERATE REDDISH-BROWN (10R 4/6), HALITIC, TRACE TO SOME CLAY, LOCALLY CONTAINS VERY FINE-GRAINED SAND.
SSH	SILTSTONE, MODERATE REDDISH-ORANGE (10R 6/6), WITH VERY FINE-GRAINED SAND, TRACE HALITE; LOCALLY GRADES TO VERY FINE TO FINE-GRAINED SANDSTONE, MODERATE REDDISH-BROWN (10R 4/6) TO MEDIUM LIGHT GRAY (N6) TRACE TO SOME SILT.

* SLIGHT VARIATIONS FROM THESE GENERAL DESCRIPTIONS MAY EXIST. THE EXCEPTIONS ARE NOTED IN THE REMARKS COLUMN.

**ESTIMATED CONTENT OF ACCESSORY CONSTITUENTS IS INDICATED BY A MODIFER:
T = TRACE
S = SOME
W = WITH OR ABUNDANT

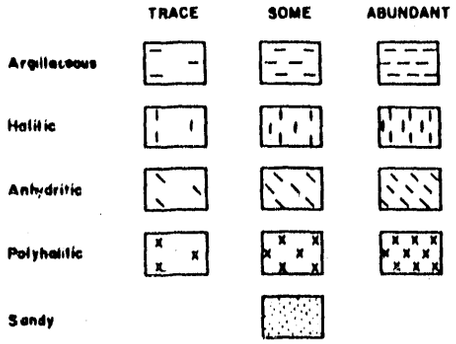
EXPLANATION

ROCK TYPE

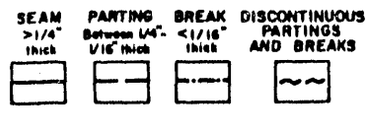


ACCESSORY CONSTITUENTS

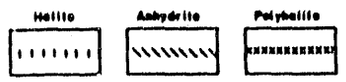
ESTIMATED PERCENTAGE OF ACCESSORY CONSTITUENTS INDICATED AS FOLLOWS:



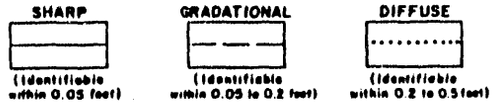
LAMINAR FEATURES



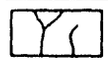
STRINGERS



CONTACTS



FRACTURES



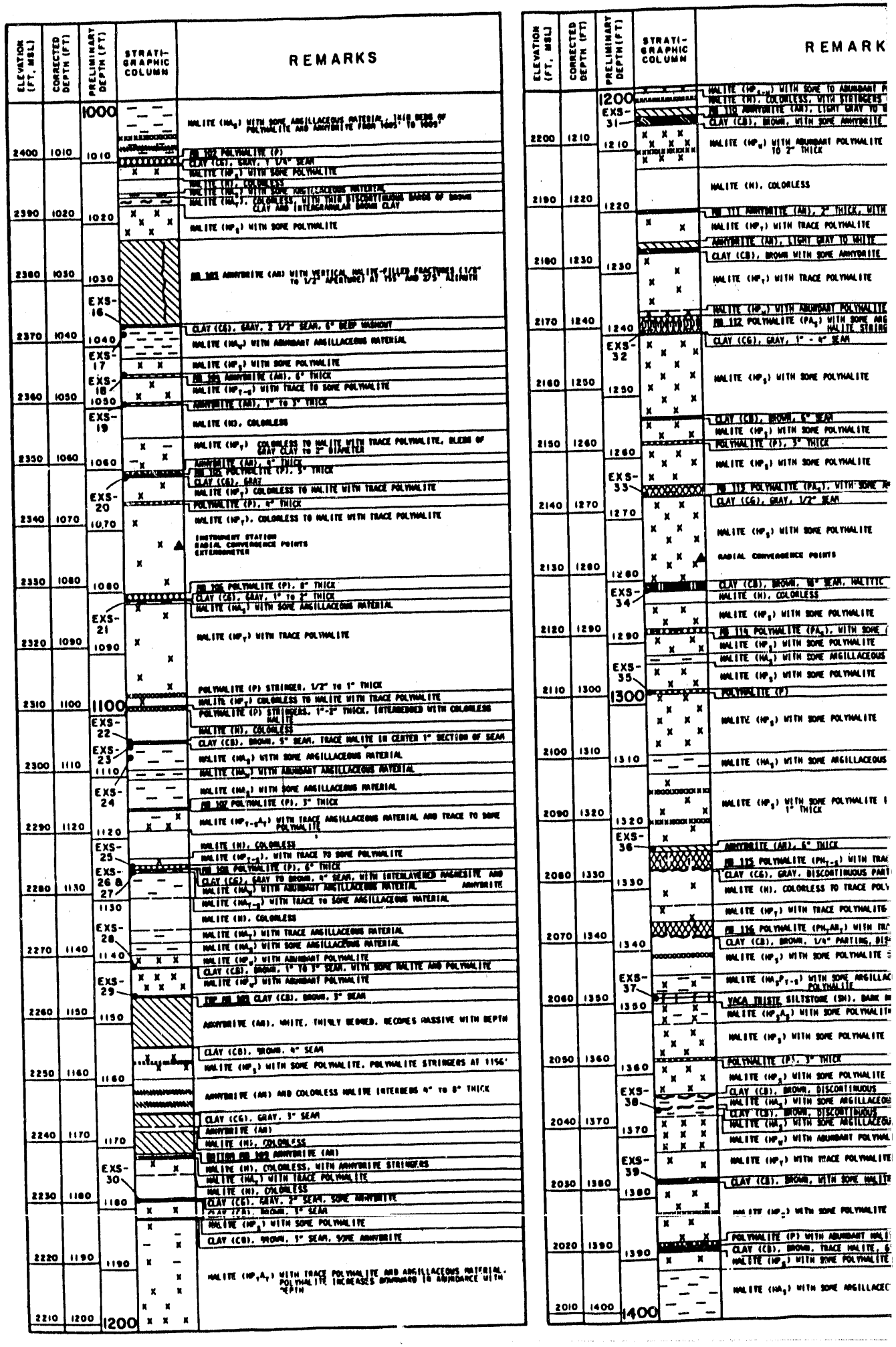
EXS-6
● ROCK SAMPLE LOCATION AND NUMBER

▲ INSTRUMENT LOCATION

FIGURE D-3

C & SH SHAFT
LITHOLOGIC LOG SHOWING
SAMPLE AND INSTRUMENT LOCATIONS
BOTTOM OF CASING TO 2200 FEET

SHEET 1 OF 3


ELEVATION (FT, MSL)
CORRECTED DEPTH (FT)
PRELIMINARY DEPTH (FT)
STRATIGRAPHIC COLUMN
REMARKS
REMARK
2400
1010
1000
2390
1020
2380
1030
2370
1040
2360
1050
2350
1060
2340
1070
2330
1080
2320
1090
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1100
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1190
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1200
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1400
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EXS-32
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1380
1390
1400
HALITE (HA$_0$) WITH SOME ARGILLACEOUS MATERIAL, THIN BEDS OF POLYHALITE AND ANHYDRITE FROM 1005' TO 1009'
HALITE (HP$_0$) WITH SOME POLYHALITE
CLAY (CB), GRAY, 1 1/4" SEAM
HALITE (HP$_1$) WITH SOME POLYHALITE
HALITE (H), COLORLESS
HALITE (HA$_1$), COLORLESS, WITH THIN DISCONTINUOUS BANDS OF BROWN CLAY AND INTERGRANULAR BROWN CLAY
HALITE (HP$_0$) WITH SOME POLYHALITE
HALITE (HA$_0$) WITH SOME ARGILLACEOUS MATERIAL
CLAY (CB), GRAY, 2 1/2" SEAM, 6" DEEP WASHOUT
HALITE (HA$_0$) WITH ABUNDANT ARGILLACEOUS MATERIAL
HALITE (HP$_0$) WITH SOME POLYHALITE
HALITE (HP$_{1-0}$) WITH TRACE TO SOME POLYHALITE
ANHYDRITE (AH), 1" TO 3" THICK
HALITE (H), COLORLESS
HALITE (HP$_1$) COLORLESS TO HALITE WITH TRACE POLYHALITE, BLEBS OF GRAY CLAY TO 2" DIAMETER
ANHYDRITE (AH), 4" THICK
CLAY (CG), GRAY
HALITE (HP$_1$) COLORLESS TO HALITE WITH TRACE POLYHALITE
POLYHALITE (P), 4" THICK
HALITE (HP$_1$), COLORLESS TO HALITE WITH TRACE POLYHALITE
INSTRUMENT STATION
RADIAL CONVERGENCE POINTS
EXTENSOMETER
CLAY (CG), GRAY, 1" TO 2" THICK
HALITE (HA$_0$) WITH SOME ARGILLACEOUS MATERIAL
HALITE (HP$_1$) WITH TRACE POLYHALITE
POLYHALITE (P) STRINGER, 1/2" TO 1" THICK
HALITE (HP$_0$) COLORLESS TO HALITE WITH TRACE POLYHALITE
POLYHALITE (P) STRINGERS, 1"-2" THICK, INTERBEDDED WITH COLORLESS HALITE
HALITE (H), COLORLESS
CLAY (CB), BROWN, 5" SEAM, TRACE HALITE IN CENTER 1" SECTION OF SEAM
HALITE (HA$_0$) WITH SOME ARGILLACEOUS MATERIAL
HALITE (HA$_0$) WITH ABUNDANT ARGILLACEOUS MATERIAL
HALITE (HA$_0$) WITH SOME ARGILLACEOUS MATERIAL
HALITE (HP$_{1-0}$A$_1$) WITH TRACE ARGILLACEOUS MATERIAL AND TRACE TO SOME POLYHALITE
HALITE (H), COLORLESS
HALITE (HP$_{1-0}$), WITH TRACE TO SOME POLYHALITE
CLAY (CG), GRAY TO BROWN, 4" SEAM, WITH INTERLAMINED ANGHYDRITE AND HALITE (HA$_0$) WITH ABUNDANT ARGILLACEOUS MATERIAL
HALITE (HA$_{1-0}$) WITH TRACE TO SOME ARGILLACEOUS MATERIAL
HALITE (H), COLORLESS
HALITE (HA$_1$) WITH TRACE ARGILLACEOUS MATERIAL
HALITE (HA$_0$) WITH SOME ARGILLACEOUS MATERIAL
HALITE (HP$_0$) WITH ABUNDANT POLYHALITE
CLAY (CB), BROWN, 1" TO 3" SEAM, WITH SOME HALITE AND POLYHALITE
HALITE (HP$_0$) WITH ABUNDANT POLYHALITE
TOP OF MB 138 CLAY (CB), BROWN, 3" SEAM
ANHYDRITE (AH), WHITE, THINLY BEDDED, BECOMES MASSIVE WITH DEPTH
CLAY (CB), BROWN, 4" SEAM
HALITE (HP$_0$) WITH SOME POLYHALITE, POLYHALITE STRINGERS AT 1156'
ANHYDRITE (AH) AND COLORLESS HALITE INTERBEDS 4" TO 8" THICK
CLAY (CG), GRAY, 3" SEAM
ANHYDRITE (AH)
HALITE (H), COLORLESS
BOTTOM MB 142 ANHYDRITE (AH)
HALITE (H), COLORLESS, WITH ANHYDRITE STRINGERS
HALITE (HA$_1$) WITH TRACE POLYHALITE
HALITE (H), COLORLESS
CLAY (CG), GRAY, 3" SEAM, SOME ANHYDRITE
CLAY (CB), BROWN, 3" SEAM
HALITE (HP$_0$) WITH SOME POLYHALITE
CLAY (CB), BROWN, 1" SEAM, SOME ANHYDRITE
HALITE (HP$_1$A$_1$) WITH TRACE POLYHALITE AND ARGILLACEOUS MATERIAL. POLYHALITE INCREASES DOWNWARD TO ABUNDANCE WITH DEPTH
MB 107 POLYHALITE (P)
MB 108 POLYHALITE (P), 5" THICK
MB 109 POLYHALITE (P), 8" THICK
MB 110 POLYHALITE (P), 3" THICK
MB 111 POLYHALITE (P), 6" THICK
MB 112 POLYHALITE (PA$_0$) WITH SOME ARG
MB 113 POLYHALITE (PA$_0$), WITH SOME A
MB 114 POLYHALITE (PA$_0$), WITH SOME
MB 115 POLYHALITE (PH$_{1-0}$) WITH TRA
MB 116 POLYHALITE (PH$_1$A$_1$) WITH TR
MB 117 ANHYDRITE (AH), LIGHT GRAY TO T
ANHYDRITE (AH), 2" THICK, WITH
ANHYDRITE (AH), LIGHT GRAY TO WHITE
HALITE (H), COLORLESS
HALITE (HP$_0$) WITH ABUNDANT POLYHALITE TO 2" THICK
HALITE (HP$_1$) WITH TRACE POLYHALITE
CLAY (CB), BROWN WITH SOME ANHYDRITE
HALITE (HP$_1$) WITH TRACE POLYHALITE
HALITE (HP$_{1-0}$) WITH ABUNDANT POLYHALITE
CLAY (CG), GRAY, 1" - 4" SEAM
HALITE (HP$_0$) WITH SOME POLYHALITE
CLAY (CB), BROWN, 6" SEAM
HALITE (HP$_1$) WITH SOME POLYHALITE
POLYHALITE (P), 3" THICK
HALITE (HP$_0$) WITH SOME POLYHALITE
CLAY (CG), GRAY, 1/2" SEAM
HALITE (HP$_0$) WITH SOME POLYHALITE
RADIAL CONVERGENCE POINTS
CLAY (CB), BROWN, 18" SEAM, HALITIC
HALITE (H), COLORLESS
HALITE (HP$_0$) WITH SOME POLYHALITE
HALITE (HP$_0$) WITH SOME POLYHALITE
HALITE (HA$_0$) WITH SOME ARGILLACEOUS
HALITE (HP$_0$) WITH SOME POLYHALITE
POLYHALITE (P)
HALITE (HP$_0$) WITH SOME POLYHALITE
HALITE (HA$_0$) WITH SOME ARGILLACEOUS
HALITE (HP$_0$) WITH SOME POLYHALITE 1" THICK
ANHYDRITE (AH), 6" THICK
CLAY (CG), GRAY, DISCONTINUOUS PART
HALITE (H), COLORLESS TO TRACE POLY
HALITE (HP$_1$) WITH TRACE POLYHALITE
CLAY (CB), BROWN, 1/4" PARTING, DI
HALITE (HP$_0$) WITH SOME POLYHALITE
HALITE (HA$_0$P$_{1-0}$) WITH SOME ARGILLA POLYHALITE
HALITE (HP$_0$A$_0$) WITH SOME POLYHALITE
HALITE (HP$_0$) WITH SOME POLYHALITE
POLYHALITE (P), 3" THICK
HALITE (HP$_0$) WITH SOME POLYHALITE
CLAY (CB), BROWN, DISCONTINUOUS
HALITE (HA$_0$) WITH SOME ARGILLACEOUS
CLAY (CB), BROWN, DISCONTINUOUS
HALITE (HA$_0$) WITH SOME ARGILLACEOUS
HALITE (HP$_0$) WITH ABUNDANT POLYHALITE
HALITE (HP$_1$) WITH TRACE POLYHALITE
CLAY (CB), BROWN, WITH SOME HALITE
HALITE (HP$_0$) WITH SOME POLYHALITE
POLYHALITE (P) WITH ABUNDANT HALI
CLAY (CB), BROWN, TRACE HALITE, 6
HALITE (HP$_0$) WITH SOME POLYHALITE
HALITE (HA$_0$) WITH SOME ARGILLACEO

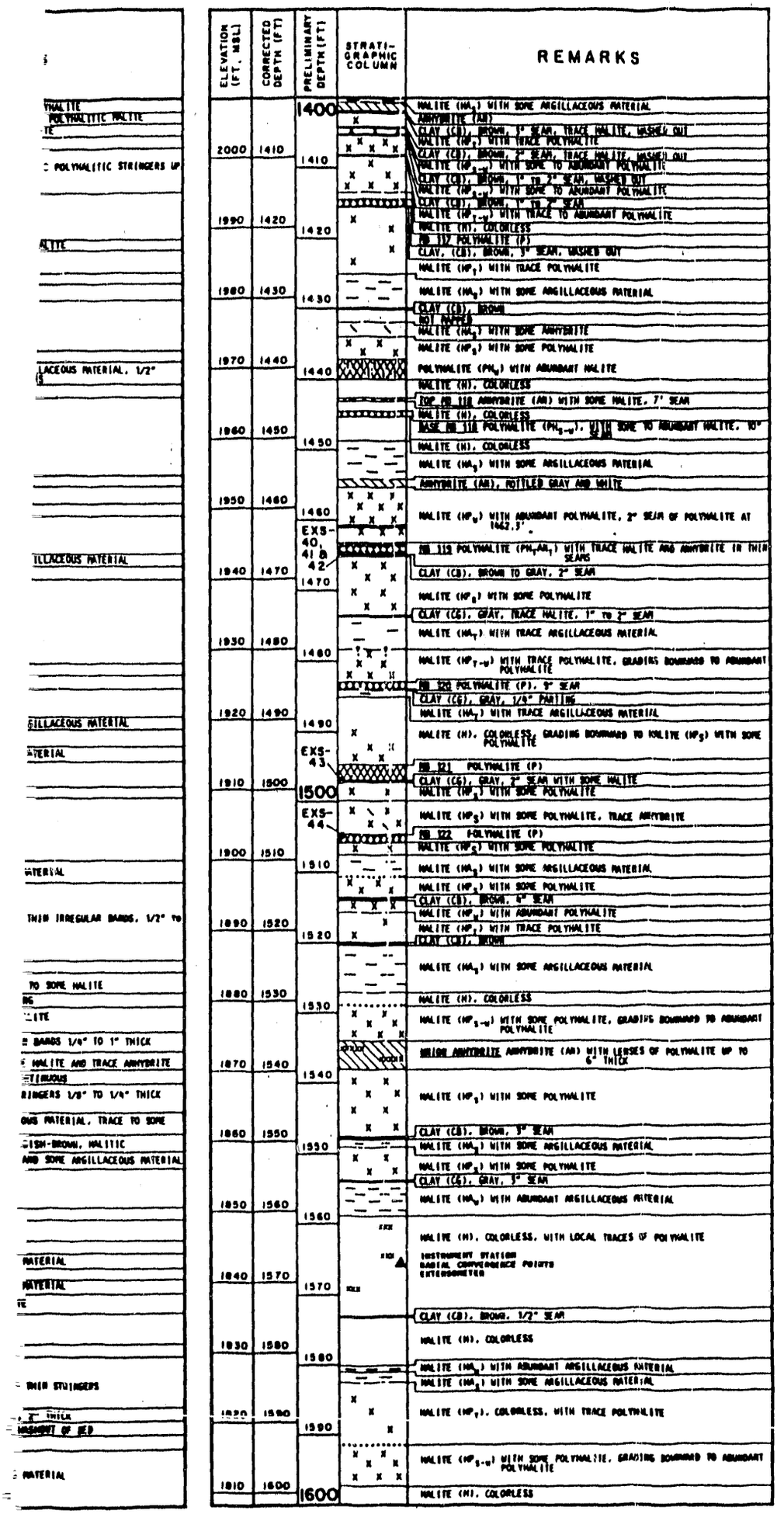


FIGURE D-3
C & SH SHAFT
LITHOLOGIC LOG SHOWING
SAMPLE AND INSTRUMENT LOCATIONS
BOTTOM OF CASING TO 2200 FEET

SHEET 2 OF 3

ELEVATION (FT. MSL)
CORRECTED DEPTH (FT)
PRELIMINARY DEPTH (FT)
STRATIGRAPHIC COLUMN
REMARKS
HALITE (H), COLORLESS
HALITE (HA1) WITH TRACE ARGILLACEOUS MATERIAL
HALITE (H), COLORLESS, WITH TRACE POLYHALITE IN UPPER 2'
HALITE (HP3) WITH SOME POLYHALITE
MB 123 ANHYDRITE (AH)
BASE MB 123 POLYHALITE (P), WITH SOME MAGNESITE
HALITE (HP1), COLORLESS, WITH TRACE POLYHALITE
MB 123 POLYHALITE (P)
CLAY (CG), GRAY, WASHED OUT 1' INTO WALL
POLYHALITE (PA4) WITH ABUNDANT GRAY ARGILLACEOUS MATERIAL
HALITE (HP1-3) WITH TRACE TO SOME POLYHALITE
EXS-45
HALITE (H), COLORLESS
HALITE (HA1) WITH SOME ARGILLACEOUS MATERIAL
HALITE (HP3A1) WITH SOME POLYHALITE, SLIGHTLY ARGILLACEOUS
HALITE (HA1) WITH SOME ARGILLACEOUS MATERIAL
HALITE (HP1) WITH SOME POLYHALITE
CLAY (CG), GRAY, DISCONTINUOUS BREAK
HALITE (HP1) WITH SOME POLYHALITE
CLAY (CG), GRAY, DISCONTINUOUS BREAK
HALITE (HP1) WITH SOME POLYHALITE
CLAY (CG), GRAY, DISCONTINUOUS BREAK
HALITE (HP3A1) WITH SOME POLYHALITE, SLIGHTLY ARGILLACEOUS
HALITE (HA4) WITH ABUNDANT ARGILLACEOUS MATERIAL
HALITE (HP1), COLORLESS, WITH TRACE POLYHALITE
MB 125 HALITE (HP1-3A1) WITH TRACE TO SOME POLYHALITE, TRACE ARGILLACEOUS MATERIAL
CLAY (CG), GRAY, 2" TO 3" SEAM
HALITE (HP1-2) TRACE TO SOME POLYHALITE, TRACE ARGILLACEOUS MATERIAL
HALITE (HA1) WITH ABUNDANT ARGILLACEOUS MATERIAL
HALITE (HP1A3) WITH TRACE POLYHALITE AND SOME ARGILLACEOUS MATERIAL
HALITE (HP3) WITH SOME POLYHALITE
EXS-46
HALITE (HA1) WITH SOME ARGILLACEOUS MATERIAL
HALITE (HP3) WITH SOME POLYHALITE
HALITE (HA4) WITH ABUNDANT ARGILLACEOUS MATERIAL
HALITE (HP3) WITH SOME POLYHALITE
MB 126 CLAY (CG), GRAY
HALITE (HP1A1) WITH TRACE POLYHALITE AND TRACE ARGILLACEOUS MATERIAL
CLAY (CB), BROWN
HALITE (HP1A1) WITH TRACE POLYHALITE AND TRACE ARGILLACEOUS MATERIAL
HALITE (HP3) WITH ABUNDANT POLYHALITE
MB 127 POLYHALITE (P) WITH STRINGERS OF HALITE
CLAY (CG), GRAY, 1" SEAM
HALITE (HP1) WITH TRACE POLYHALITE
POLYHALITE (P) STRINGERS, 1" AND 2" THICK
MB 128 POLYHALITE (PH3) WITH SOME HALITE
BASE MB 128 CLAY (CG), GRAY, 1/2" SEAM
HALITE (HB), BROWN, WITH SOME POLYHALITE BANDS
HALITE (HP3) WITH SOME POLYHALITE
HALITE (HA4) WITH ABUNDANT ARGILLACEOUS MATERIAL
CLAY (CB), BROWN, 1/8" PARTING
EXS-47
HALITE (HP3-1) WITH SOME POLYHALITE DECREASING DOWNWARDS TO TRACE POLYHALITE
MB 129 POLYHALITE (P)
CLAY (CB), BROWN
HALITE (HP3) WITH ABUNDANT POLYHALITE, POLYHALITE SEAM IN LOWER 2"
CLAY (CG), GRAY, 1/4" SEAM
HALITE (HP1) WITH SOME POLYHALITE, GRADING DOWNWARD TO SOME POLYHALITE WITH TRACE ARGILLACEOUS MATERIAL
EXS-48
CLAY (CG), GRAY, 1" TO 2" SEAM
HALITE (HA1) WITH SOME ARGILLACEOUS MATERIAL
EXS-49
HALITE (H), COLORLESS
RADIAL CONVERGENCE POINTS
HALITE (HA1) WITH SOME ARGILLACEOUS MATERIAL
HALITE (H), COLORLESS
HALITE (HP3A1) WITH ABUNDANT POLYHALITE AND MATERIAL
HALITE (H), COLORLESS
NOT MAPPED
POLYHALITE (P) STRINGER, DEPTH AND THICKNESS
NOT MAPPED
MB 131 POLYHALITE (P), THICKNESS ESTIMATED
NOT MAPPED
HALITE (HA1) WITH TRACE ARGILLACEOUS MATERIAL
MB 132 CLAY (CB), BROWN, 6" SEAM
HALITE (HP3A1) WITH SOME POLYHALITE AND SOME
HALITE (H), COLORLESS
HALITE (HP3-HA3) WITH SOME POLYHALITE AND ANHYDRITE
CLAY (CB), BROWN
NOT MAPPED
CLAY (CB)
HALITE (HP3) WITH SOME POLYHALITE
HALITE (HP1) WITH TRACE POLYHALITE
HALITE (HA3-H) WITH SOME ARGILLACEOUS MATERIAL CONTAINING DISCONTINUOUS GRAY AND INTERSTITIAL FILLING AT
HALITE (H), COLORLESS
HALITE (HP3) WITH SOME POLYHALITE
POLYHALITE (P), 6" THICK
ANHYDRITE (AH), WITH 3" THICK HALITE SEAM
CLAY (CG), GRAY, 6" SEAM, WASHED OUT
HALITE (HA1) WITH TRACE ARGILLACEOUS MATERIAL
CLAY (CG), GRAY, 6" SEAM
HALITE (HA1) WITH TRACE ARGILLACEOUS MATERIAL
CLAY (CG), GRAY, 6" SEAM
HALITE (HA1) WITH TRACE ARGILLACEOUS MATERIAL
CLAY (CG), GRAY, 6" SEAM
HALITE (HA1) WITH TRACE ARGILLACEOUS MATERIAL
HALITE (HA4) WITH ABUNDANT ARGILLACEOUS MATERIAL
HALITE (HA1) WITH TRACE ARGILLACEOUS MATERIAL
MB 134 ANHYDRITE (AC), LIGHT GRAY TO WHITE
EXS-50
CLAY (CG), GRAY, 5" TO 6" SEAM
HALITE (HA1-2) WITH TRACE TO SOME ARGILLACEOUS
ANHYDRITE (AC), LIGHT GRAY TO WHITE, 2" SEAM
CLAY (CG), 1/4" PARTING
HALITE (H), COLORLESS
HALITE (HA1) WITH TRACE ARGILLACEOUS MATERIAL
HALITE (H), COLORLESS
EXS-51
CLAY (CG), GRAY, 5" SEAM
MB 135 ANHYDRITE (AC), LIGHT GRAY TO WHITE
HALITE (H), COLORLESS
HALITE (HP3A1) WITH SOME POLYHALITE AND MATERIAL
CLAY (CG), GRAY, 6" SEAM, WITH SOME HALITE
HALITE (HP3A1) WITH TRACE POLYHALITE AND
HALITE (H), COLORLESS
HALITE (HA1) WITH SOME ARGILLACEOUS MATERIAL
CLAY (CB), BROWN, 6" SEAM
HALITE (HP1A1) WITH TRACE POLYHALITE AND ABUNDANT ARGILLACEOUS MATERIAL
HALITE (H), COLORLESS

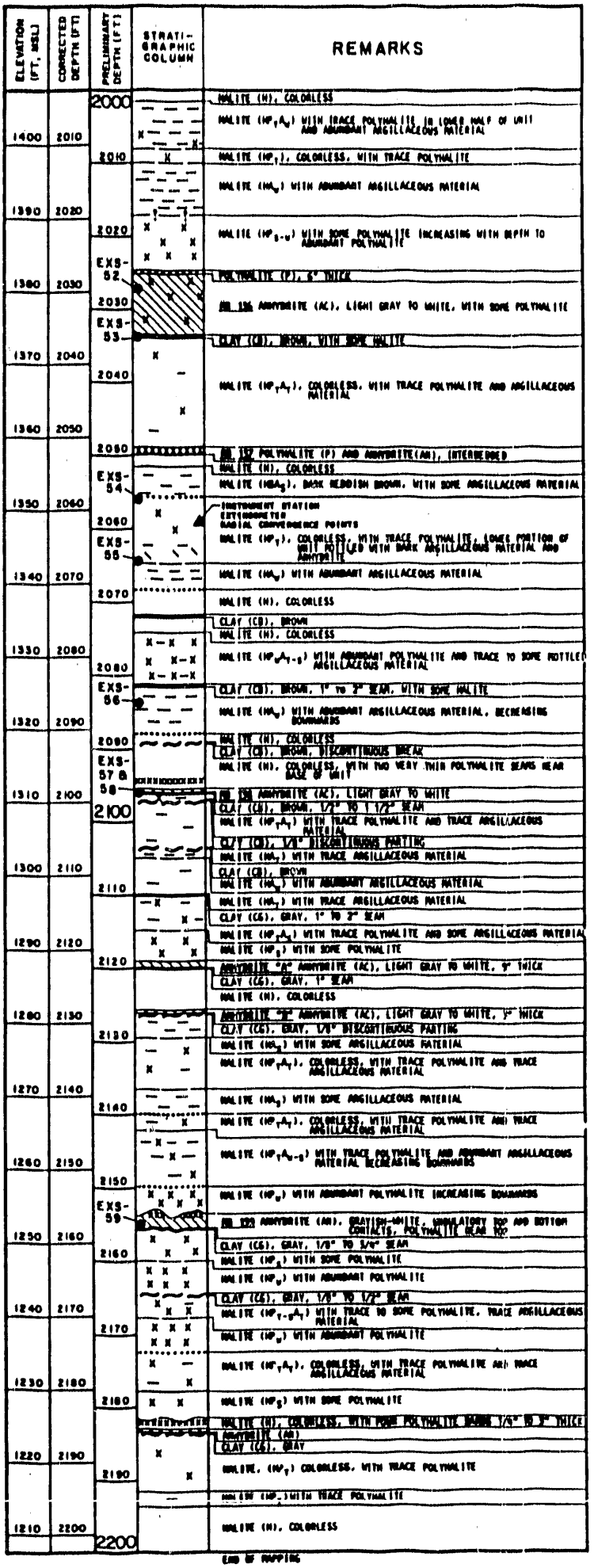
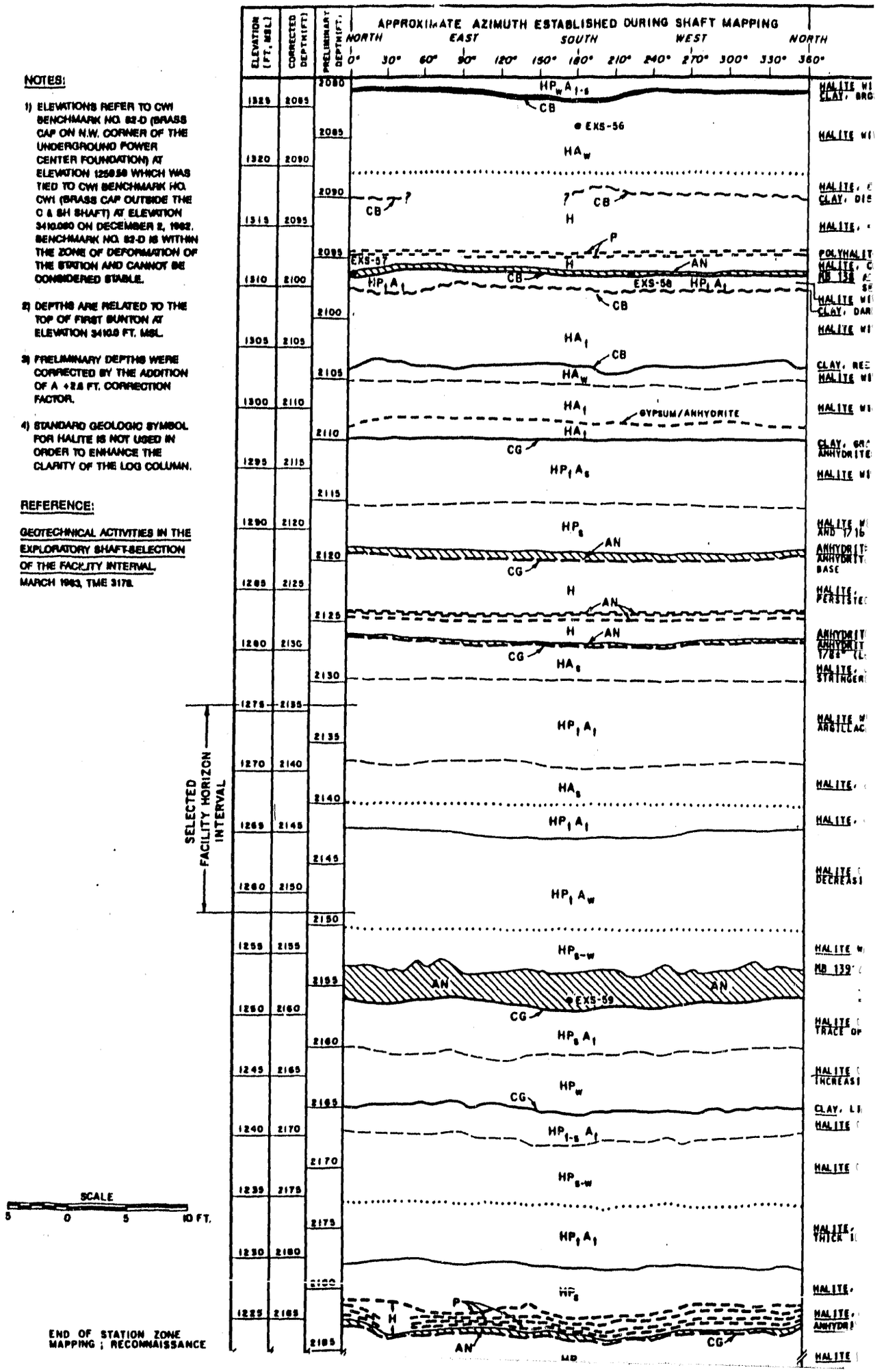


FIGURE D-3

C & SH SHAFT.
LITHOLOGIC LOG SHOWING
SAMPLE AND INSTRUMENT LOCATIONS
BOTTOM OF CASING TO 2200 FEET

SHEET 3 OF 3



NOTES:

1) ELEVATIONS REFER TO CWI BENCHMARK NO. 82-D (BRASS CAP ON N.W. CORNER OF THE UNDERGROUND POWER CENTER FOUNDATION) AT ELEVATION 1258.58 WHICH WAS TIED TO CWI BENCHMARK NO. CW1 (BRASS CAP OUTSIDE THE C & SH SHAFT) AT ELEVATION 3410.080 ON DECEMBER 2, 1982. BENCHMARK NO. 82-D IS WITHIN THE ZONE OF DEFORMATION OF THE STATION AND CANNOT BE CONSIDERED STABLE.

2) DEPTHS ARE RELATED TO THE TOP OF FIRST BUNTON AT ELEVATION 3410.0 FT. MSL.

3) PRELIMINARY DEPTHS WERE CORRECTED BY THE ADDITION OF A +2.5 FT. CORRECTION FACTOR.

4) STANDARD GEOLOGIC SYMBOL FOR HALITE IS NOT USED IN ORDER TO ENHANCE THE CLARITY OF THE LOG COLUMN.

REFERENCE:

GEOTECHNICAL ACTIVITIES IN THE EXPLORATORY SHAFT-SELECTION OF THE FACILITY INTERVAL. MARCH 1983, TME 3178.

REMARKS

ABUNDANT POLYHALITE, TRACE TO SOME ARGILLACEOUS MATERIAL
1" TO 2" SEAM, WITH SOME HALITE

ABUNDANT ARGILLACEOUS MATERIAL, CLAY CONTENT DECREASING TOWARDS BASE

=LESS
.TINUOUS BREAK

=LESS

YWO THIN SEAMS APPROXIMATELY 6" APART
=LESS
=RITE, MEDIUM DARK GRAY, MICROCRYSTALLINE, FAINTLY BANDED, WITH 1/8 TO 1/4" THICK
S OF CRYSTALLINE HALITE) BROWN CLAY SEAM, 1/2 TO 1 1/2" THICK, AT BASE
YRACE POLYHALITE AND ARGILLACEOUS MATERIAL
/DDISH-BROWN, DISCONTINUOUS PARTING, 1/8" THICK
TRACE ARGILLACEOUS MATERIAL; LOCALLY ABUNDANT IN DISCONTINUOUS PARTINGS

=H-BROWN, 1/8"TO 1/2" THICK
ABUNDANT ARGILLACEOUS MATERIAL IN NUMEROUS GRAY CLAY BLEBS

TRACE ARGILLACEOUS MATERIAL AND A THIN DISCONTINUOUS GYPSUM/ANHYDRITE SEAM,

=TO GRAYISH-RED TO LIGHT BROWN, 1"TO 2 1/2" THICK, WITH IRREGULAR LENSES OF
=D HALITE ALONG UPPER SURFACE
TRACE POLYHALITE, SOME ARGILLACEOUS MATERIAL

; SOME INTERGRANULAR POLYHALITE IN IRREGULAR ELONGATED BLEBS, 1/4"TO 1 1/2" LONG
; 1/8" THICK

A"
=HITE TO VERY LIGHT GRAY, 9±" THICK; WITH 1/8±" THICK SOFT GRAY CLAY PARTING AT

=ORLESS, MOTTLED WITH 1/8±" THICK, GENERALLY DISCONTINUOUS ANHYDRITE PARTINGS;
=ARTINGS SHOWN

"B"
=HITE TO VERY LIGHT GRAY, 3±" THICK, CONTAINS IRREGULAR BLEBS OF HALITE; WITH
=ALLY THICKENS TO 1") SOFT TO MEDIUM GRAY CLAY PARTING AT BASE
=TTLED WITH SOME ARGILLACEOUS MATERIAL, OCCASIONALLY WITH REDDISH-BROWN CLAY

=H TRACE POLYHALITE, TRACE ARGILLACEOUS MATERIAL AS REDDISH-BROWN CLAY;
=NS CONTENT (BLEBS) INCREASES IN LOWER TWO FEET

=IGHTLY BANDED, WITH SOME ARGILLACEOUS MATERIAL

=LORLESS, TRACE POLYHALITE AND TRACE ARGILLACEOUS MATERIAL

=H TRACE POLYHALITE, ABUNDANT ARGILLACEOUS MATERIAL AS GRAY CLAY BLEBS,
= ARGILLACEOUS MATERIAL TOWARDS BASE

=H SOME POLYHALITE, POLYHALITE CONTENT INCREASING TOWARDS BASE

=HYDRITE, LIGHT GRAY, MICROCRYSTALLINE; WITH DISCONTINUOUS 1/4 TO 1/2" THICK POLYHALITE
=AM AT TOP; ANHYDRITE CONTAINS FLOW STRUCTURES WITH HALITE PSEUDOMORPH CRYSTALS AND BLEBS
POLYHALITE NEAR TOP, LOCALLY MASSIVE TO LAYERED POLYHALITE BELOW FLOW STRUCTURES;
=NTINUOUS 1/8±" (LOCALLY THICKENS TO 1/2" AND 3/4") SOFT GRAY CLAY SEAM AT BASE

=TH SOME POLYHALITE IN DISCONTINUOUS 1/4"TO 1" THICK BANDS AND IN IRREGULAR BLEBS;
=RAY CLAY IN THIN IRREGULAR PARTING

=TH ABUNDANT POLYHALITE; 3"TO 6" THICK LAYER OF CLEAR HALITE AT THE TOP;
=E POLYHALITE CONTENT WITH DEPTH

=HT GRAY, 1/8"TO 1/2" THICK SEAM, SOFT
=YH TRACE TO SOME POLYHALITE, TRACE ARGILLACEOUS MATERIAL

=YH SOME TO ABUNDANT INTERGRANULAR POLYHALITE

=OLORLESS, WITH TRACE POLYHALITE; TRACE OF ARGILLACEOUS MATERIAL IN 1/8"TO 1/2"
=EGULAR DISCONTINUOUS PARTINGS

=OARSELY CRYSTALLINE, WITH POLYHALITE STRINGERS DISPERSED THROUGHOUT

=OLORLESS, WITH FOUR POLYHALITE BANDS 1/4"TO 3" THICK SPACED AT 2"TO 3" INTERVALS
=, LIGHT GRAY, FINELY CRYSTALLINE, WITH GRAY CLAY PARTING AT BASE

=ITH TRACE POLYHALITE

EXPLANATION

ROCK TYPE

HALITE — See note 4

ANHYDRITE

LAMINAR FEATURES

MISCELLANEOUS (AS LABELED)

CLAY: SEAM >1/4" thick; PARTING Between 1/4" 1/16" thick; BREAK <1/16" thick; DISCONTINUOUS PARTINGS AND BREAKS

CONTACTS

SHARP (Identifiable within 0.05 feet)

GRADATIONAL (Identifiable within 0.05 to 0.2 feet)

DIFFUSE (Identifiable within 0.2 to 0.5 feet)

EXS-56 ROCK SAMPLE LOCATION AND NUMBER

CLAY LAYER

GEOLOGIC UNIT SYMBOLS AND DESCRIPTIONS *

A** ARGILLACEOUS MATERIAL, GENERALLY FOUND AS AN INTERGRANULAR ACCESSORY CONSTITUENT, LIGHT GRAY (N7) TO MODERATE REDDISH-BROWN (10R 4/6), SLIGHTLY MOIST TO MOIST, TRACE TO SOME SILT.

AH ANHYDRITE, MEDIUM DARK GRAY (N4) TO LIGHT GRAY (N7) TO WHITE (N9), MODERATE ORANGE-PINK (10R 7/4) TO PALE REDDISH-BROWN (10R 5/4), FINELY CRYSTALLINE TO MICROCRYSTALLINE.

CB CLAY, DARK REDDISH-BROWN (10R 3/4), TRACE TO SOME SILT, TRACE TO SOME HALITE.

CG CLAY, MEDIUM LIGHT GRAY (N6) TO MEDIUM DARK GRAY (N4) TO LIGHT OLIVE-GRAY (5Y 6/1), TRACE TO SOME SILT, TRACE TO SOME HALITE.

HA** HALITE, DARK REDDISH-BROWN (10R 3/4) TO MODERATE REDDISH-BROWN (10R 4/6), MEDIUM TO COARSELY CRYSTALLINE, ARGILLACEOUS.

H HALITE, COLORLESS (TRANSPARENT TO TRANSLUCENT) TO GRAYISH-ORANGE-PINK (5YR 7/2), MEDIUM TO COARSELY CRYSTALLINE, MAY BE BANDED.

HP** HALITE, TRANSLUCENT TO MODERATE REDDISH-ORANGE (10R 6/6) TO MODERATE REDDISH-BROWN (10R 4/6), POLYHALITIC.

HPA** HALITE, MODERATE REDDISH-ORANGE (10R 6/6) TO MODERATE REDDISH-BROWN (10R 4/6), POLYHALITIC AND ARGILLACEOUS.

P POLYHALITE, MODERATE REDDISH-BROWN (10R 4/6) TO MODERATE REDDISH-ORANGE (10R 6/6), FINELY CRYSTALLINE TO MICROCRYSTALLINE.

* SLIGHT VARIATIONS FROM THESE GENERAL DESCRIPTIONS MAY EXIST. THE EXCEPTIONS ARE NOTED IN THE REMARKS COLUMN.

** ESTIMATED CONTENT OF ACCESSORY CONSTITUENTS IS INDICATED BY A MODIFIER: T = TRACE; S = SOME; W = WITH OR ABUNDANT

FIGURE D-4

C & SH SHAFT
FACILITY LEVEL AREA GEOLOGY
2080 TO 2192 FEET

APPENDIX E

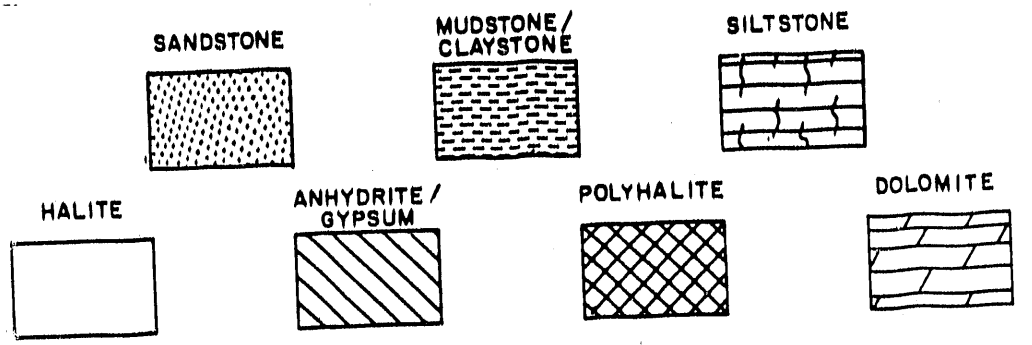
WASTE SHAFT
GEOLOGIC LOGS AND MAPS

CONTENTS

Figure No.	Title/Description
E-1	Lithologic Log 97 to 2286 feet (26 Sheets)
E-2	Magenta Dolomite 597 to 620 feet
E-3	Culebra Dolomite 705 to 727 feet
E-4	Rustler Formation Fracture Zone 779 to 843 feet
E-5	Rustler/Salado Formation Contact 840 to 930 feet (2 Sheets)
E-6	Facility Level Area 2100 to 2170 feet (2 Sheets)

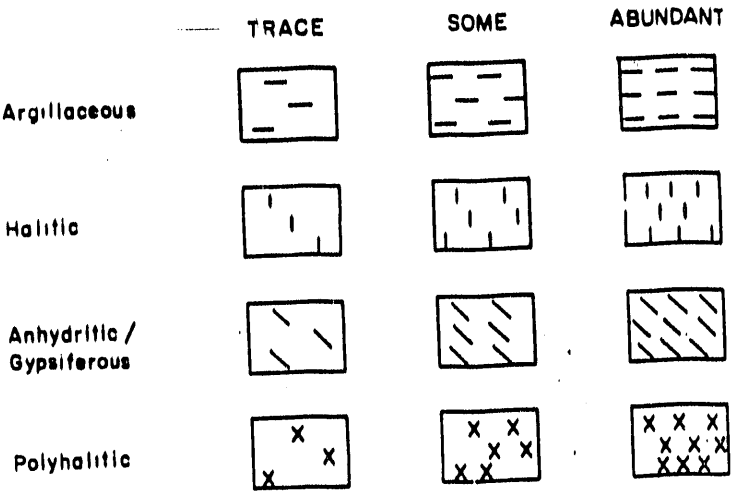
EXPLANATION

ROCK TYPE

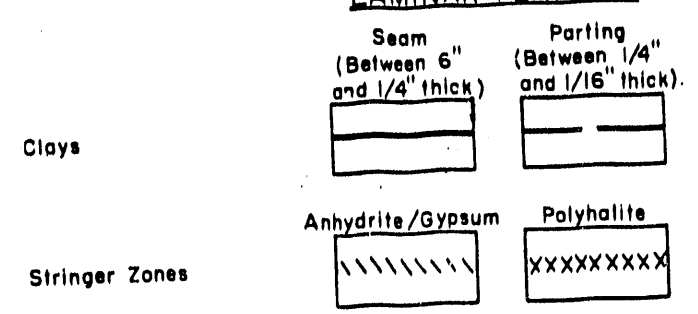


ACCESSORY CONSTITUENTS

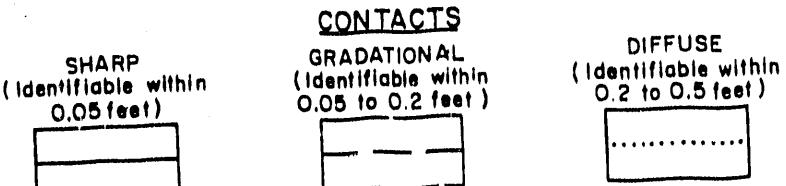
ESTIMATED PERCENTAGE OF ACCESSORY CONSTITUENTS INDICATED AS FOLLOWS



LAMINAR FEATURES



CONTACTS



Queries on inferred or uncertain contacts.
"Obscured" where lithologic and stratigraphic details are uncertain in the interval between contacts shown.
See "remarks" for complete description of units.

REFERENCE:

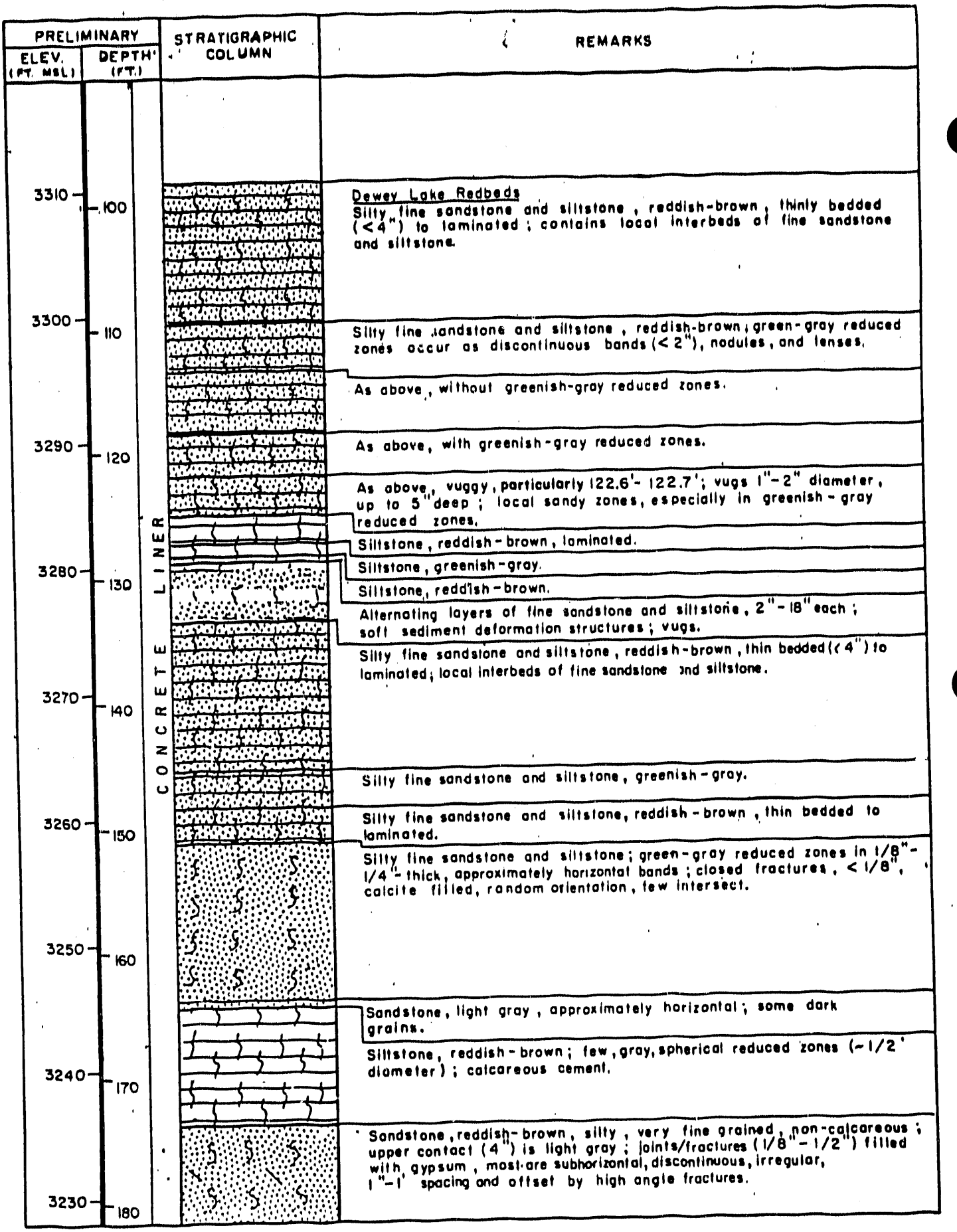
Geotechnical Activities in the Waste Handling Shaft, October 1984, WSTD-TME-038.

PREPARED BY RMH DATE 6/21/84

CHECKED BY _____ DATE _____

FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 1 OF 26



PREPARED BY RMM DATE 6/21/84
CHECKED BY ____ DATE ____

FIGURE E-1

WASTE HANDLING SHAFT LITHOLOGIC LOG SHEET 2 OF 26

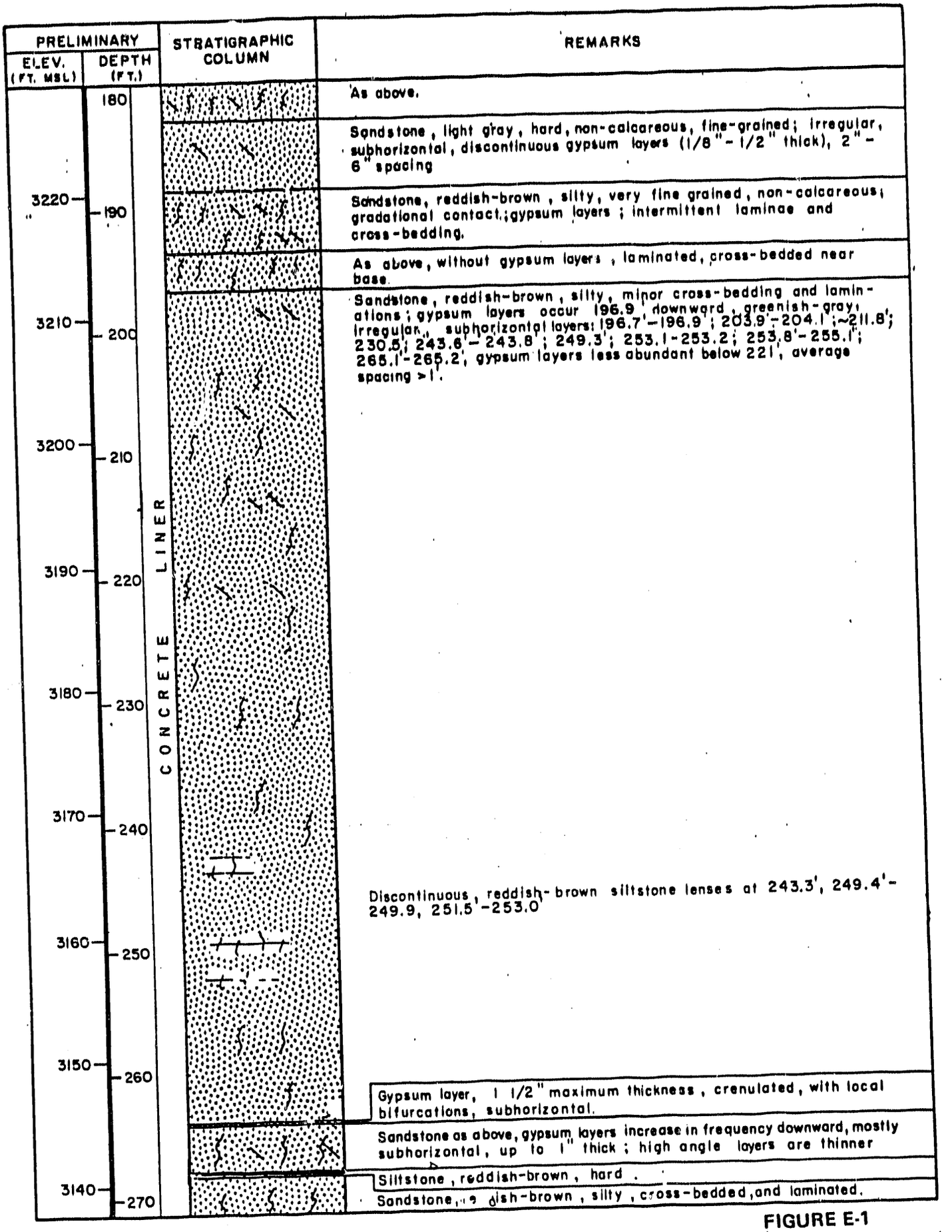


FIGURE E-1

PREPARED BY RMH DATE 6/21/84
CHECKED BY _____ DATE _____

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 3 OF 26

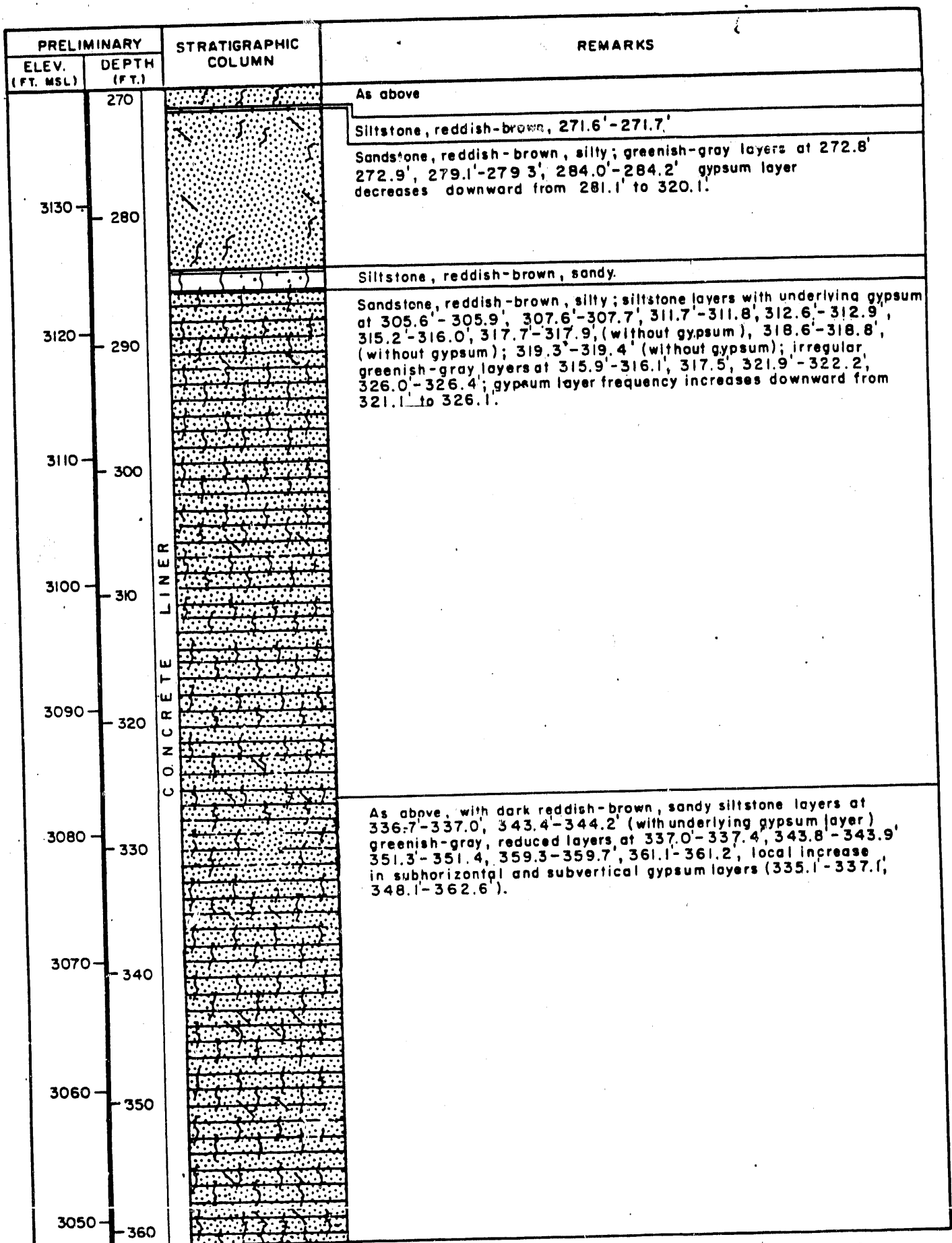


FIGURE E-1

PREPARED BY RMN DATE 6/21/84
CHECKED BY ____ DATE ____

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 4 OF 26

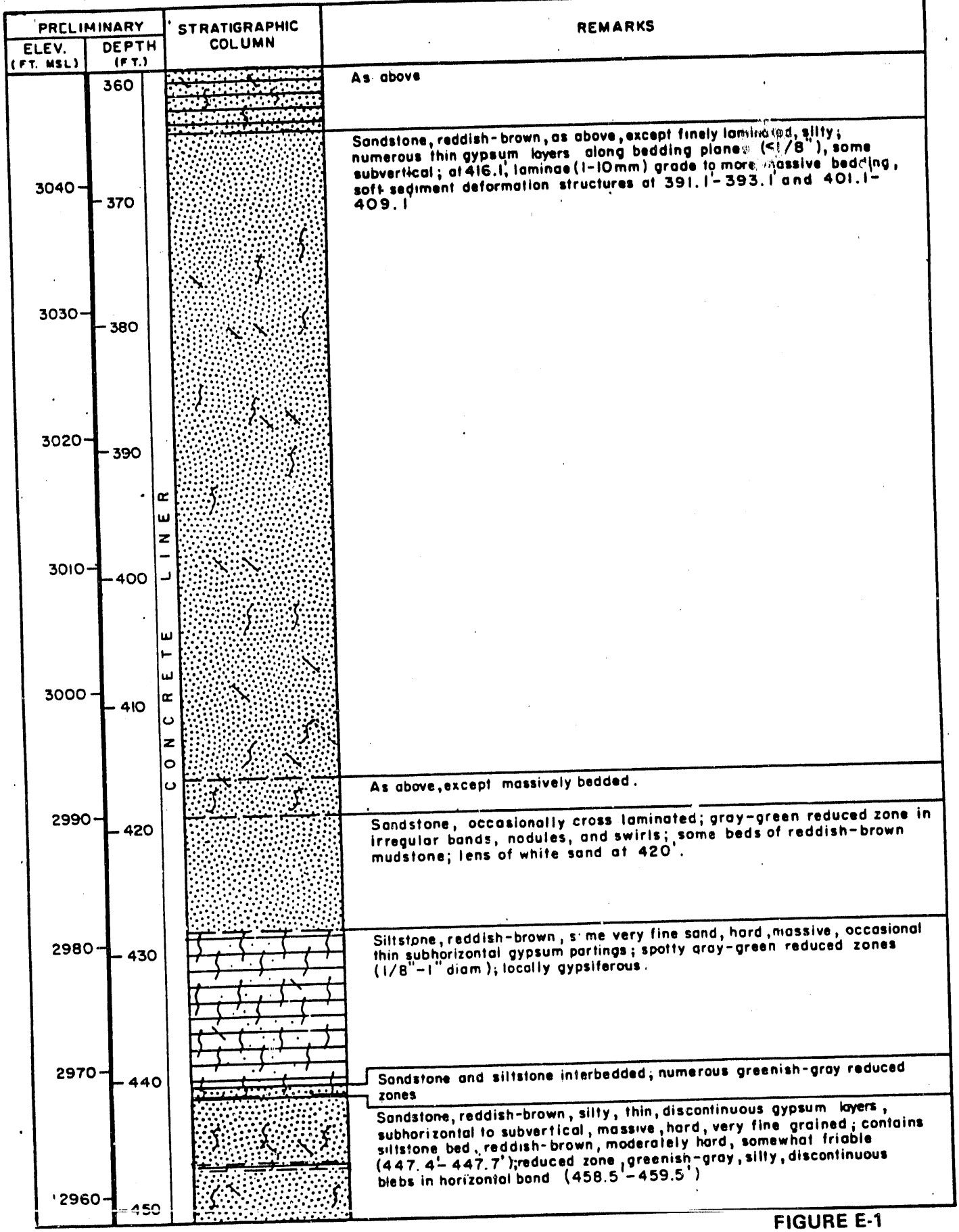


FIGURE E-1

PREPARED BY RMH DATE 6/21/84

CHECKED BY _____ DATE _____

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 5 OF 26

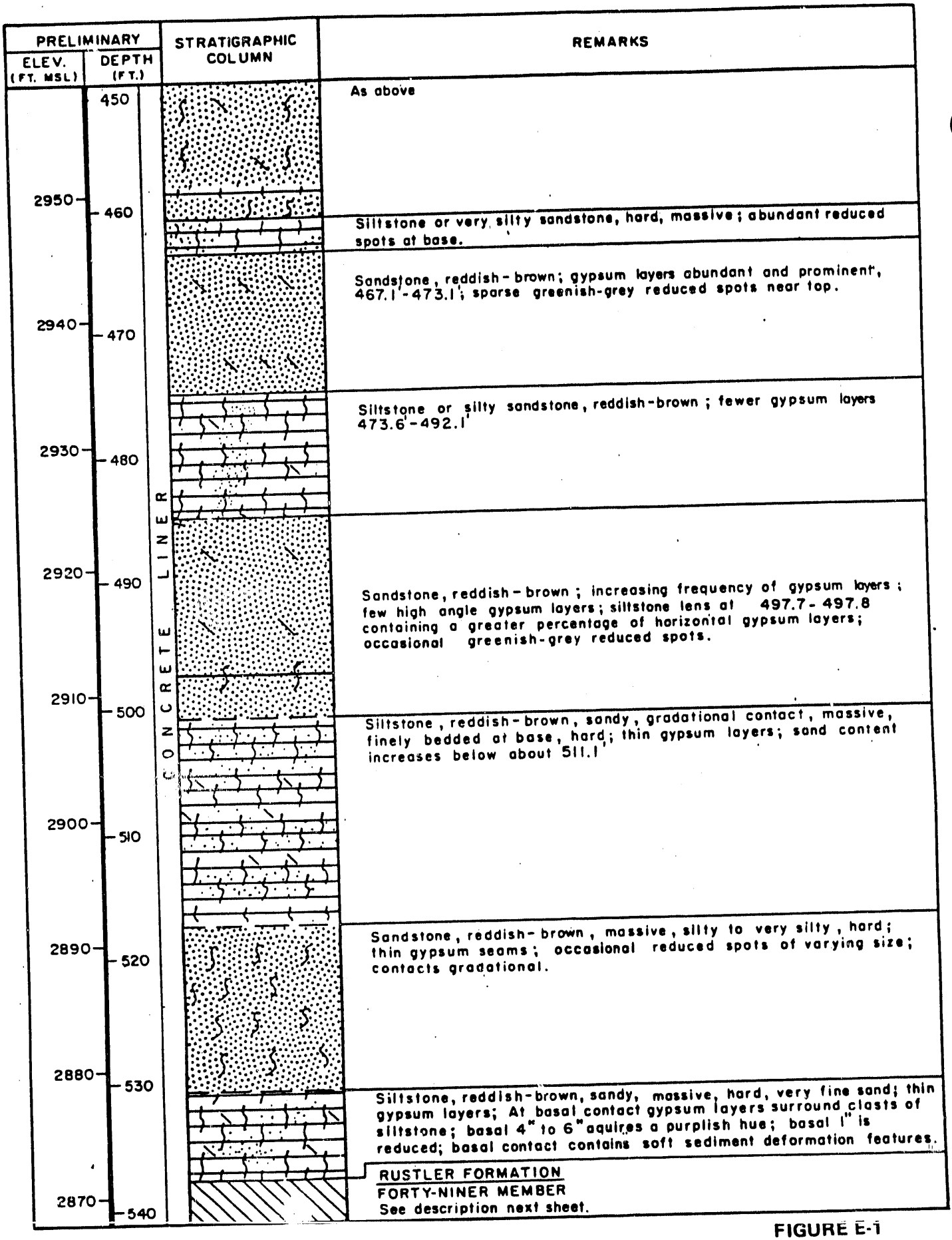


FIGURE E-1

PREPARED BY RMH DATE 6/21/84
CHECKED BY _____ DATE _____

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 6 OF 26

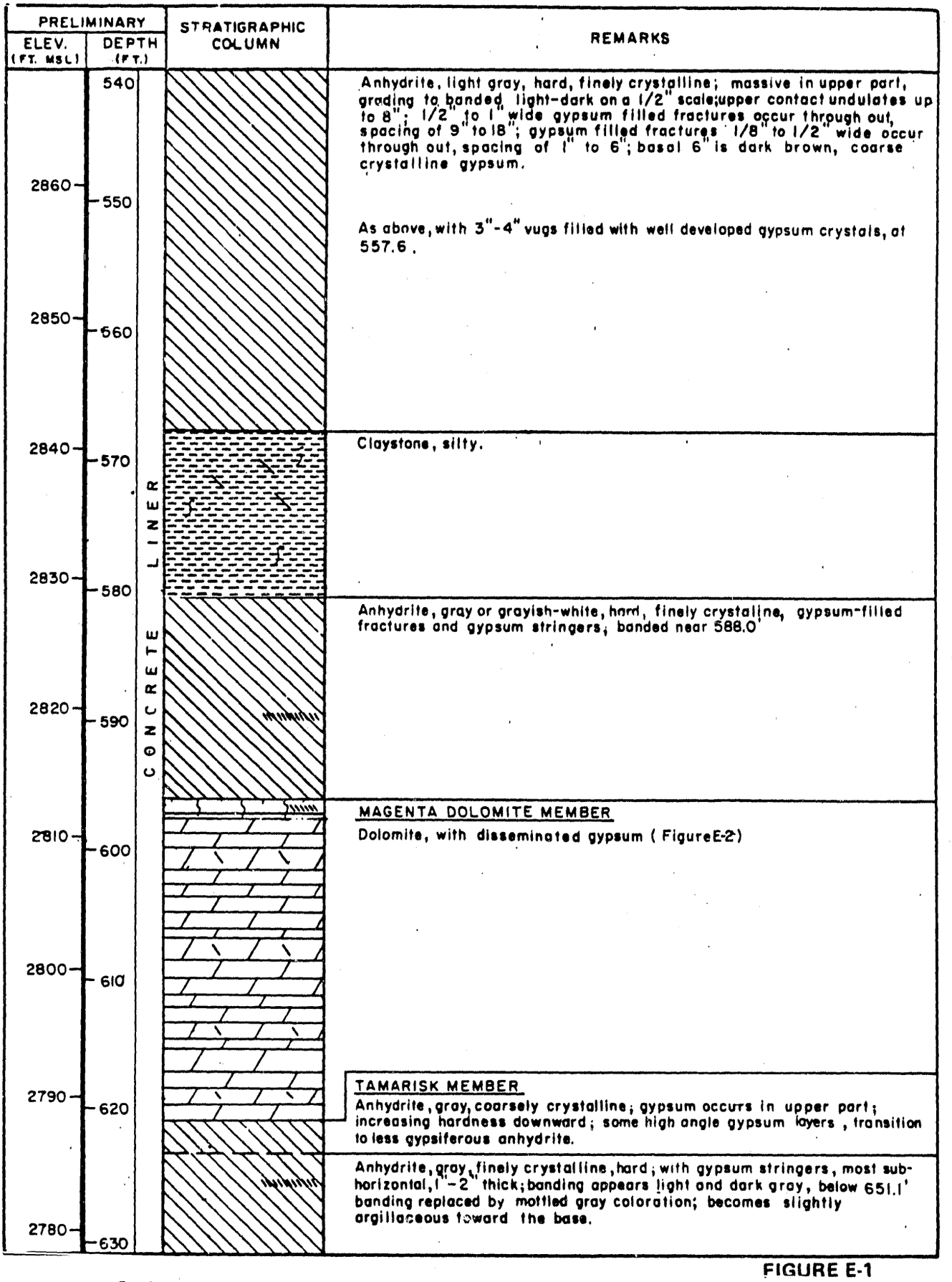


FIGURE E-1

PREPARED BY RMH DATE 6/21/84

CHECKED BY _____ DATE _____

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 7 OF 26

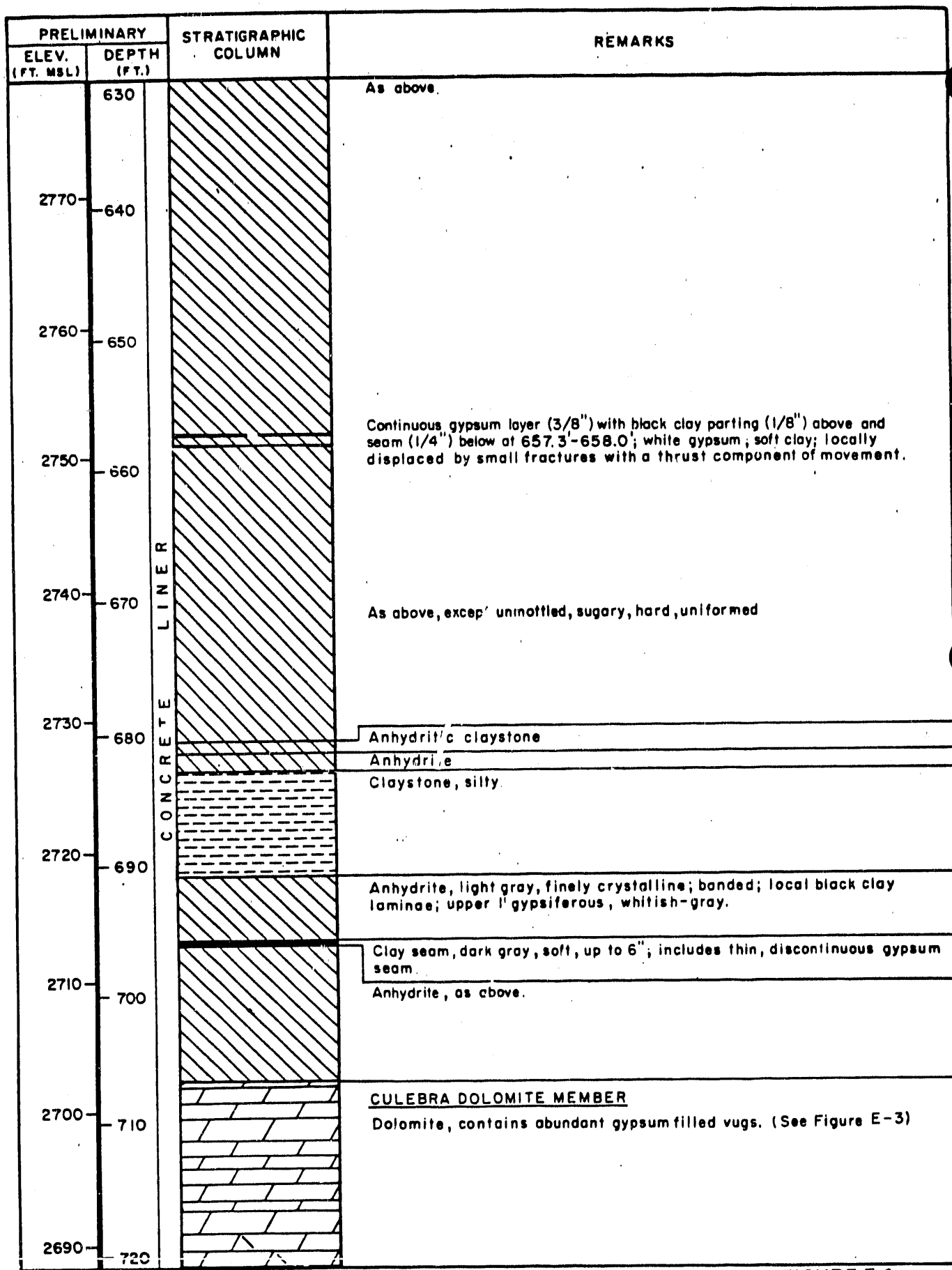
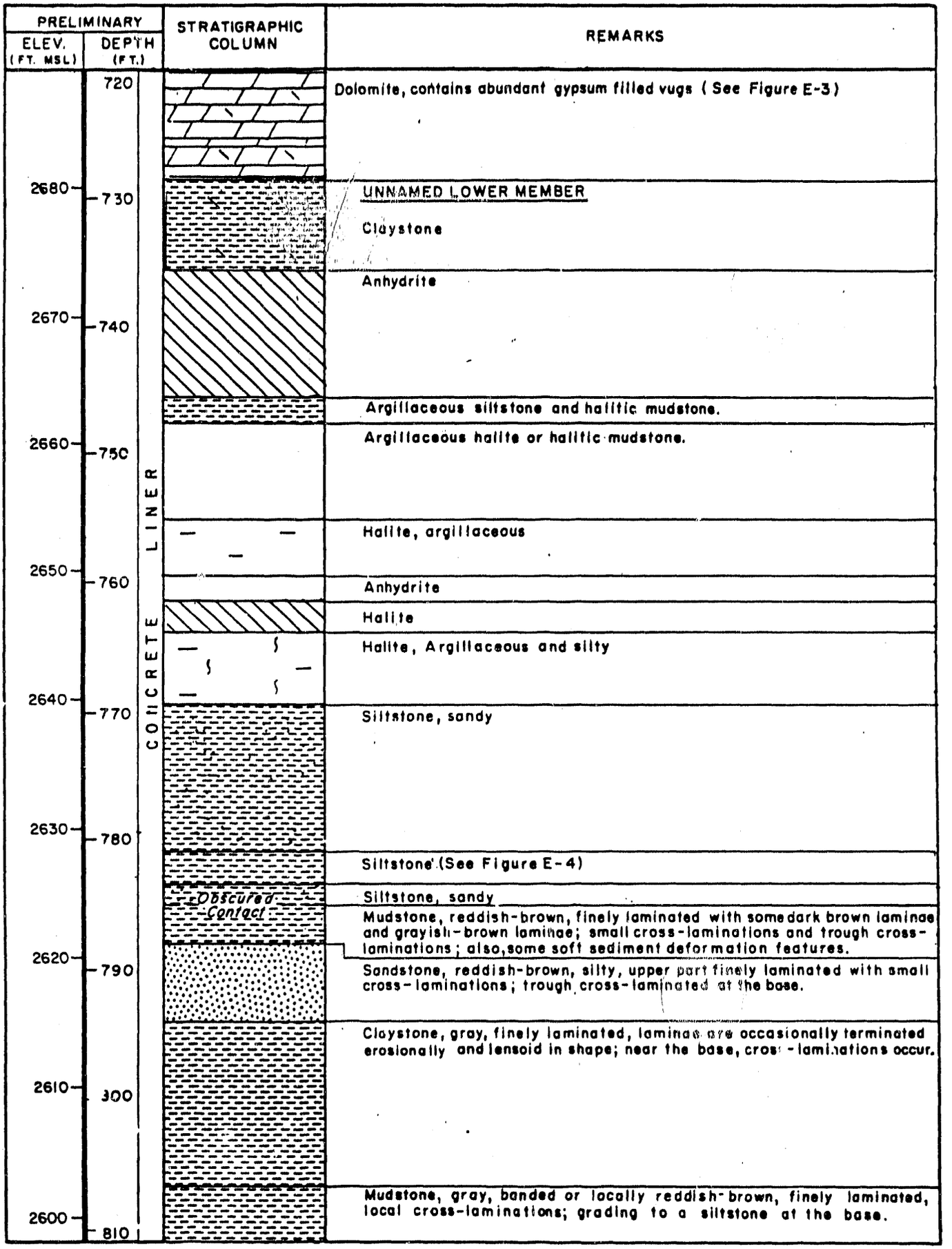


FIGURE E-1

PREPARED BY RMH DATE 6/21/84
CHECKED BY _____ DATE _____

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 8 OF 26



PREPARED BY [illegible] DATE 6/21/88

CHECKED BY _____ DATE _____

FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 9 OF 26

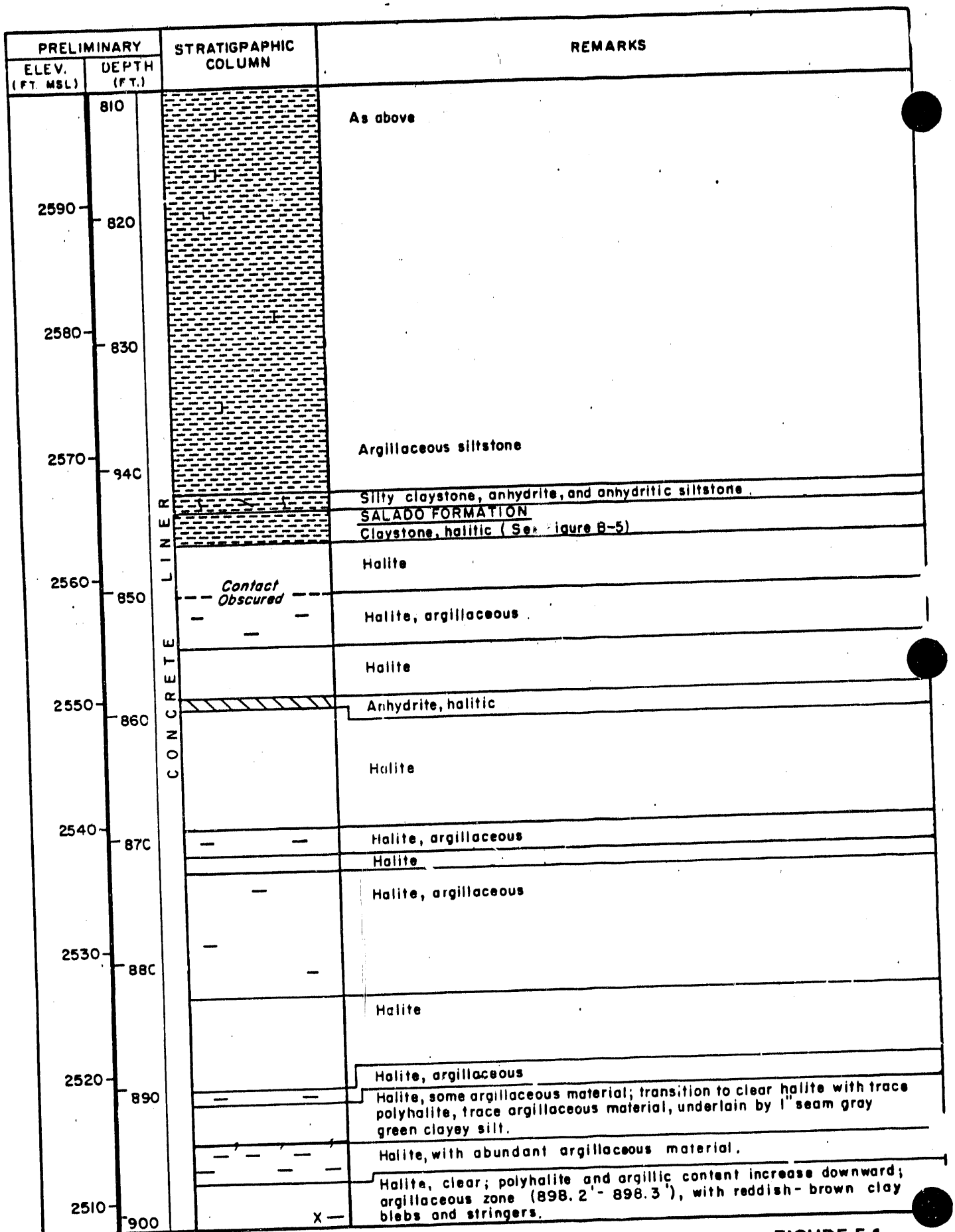
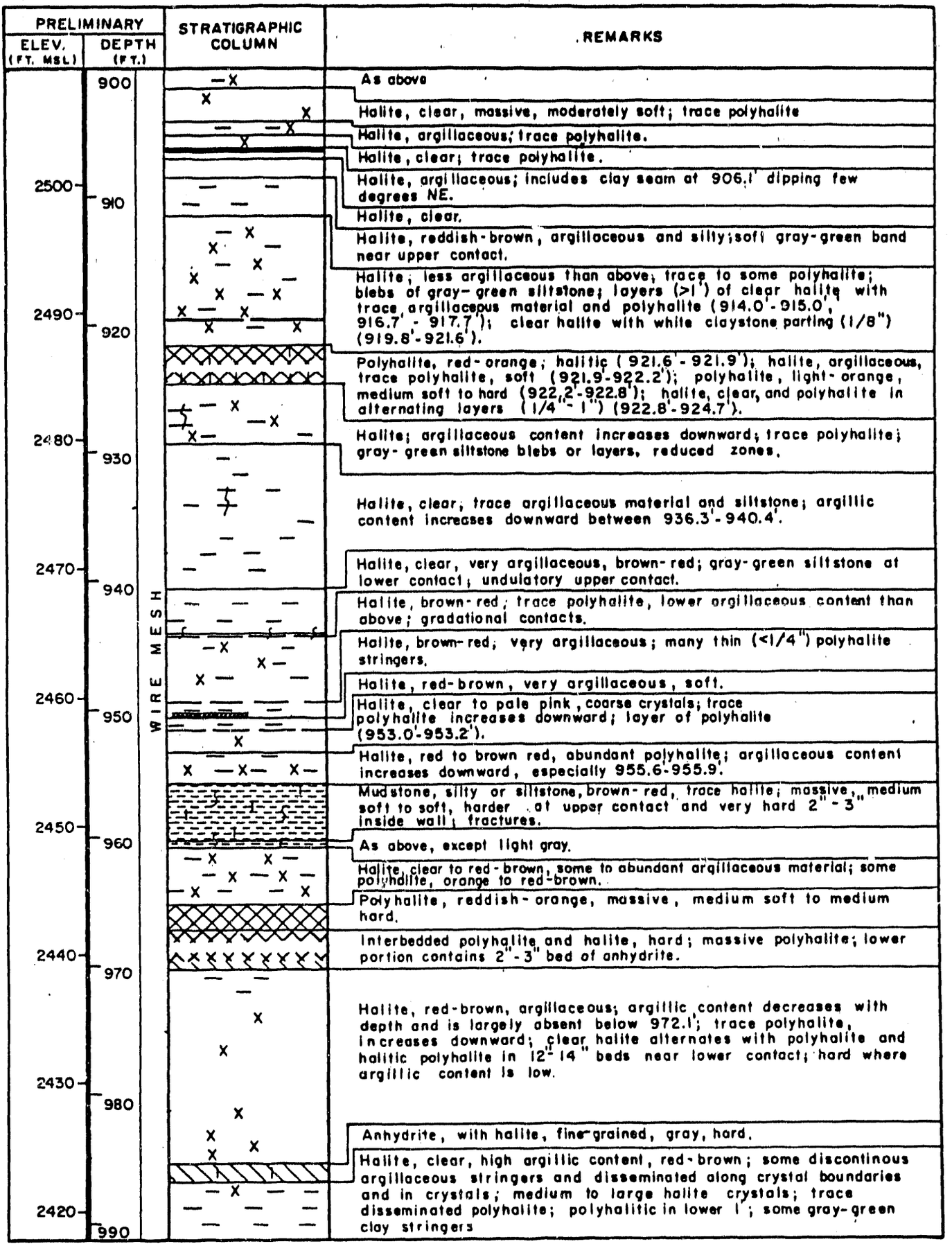


FIGURE E-1

PREPARED BY [illegible] DATE 6/21/84

CHECKED BY _____ DATE _____

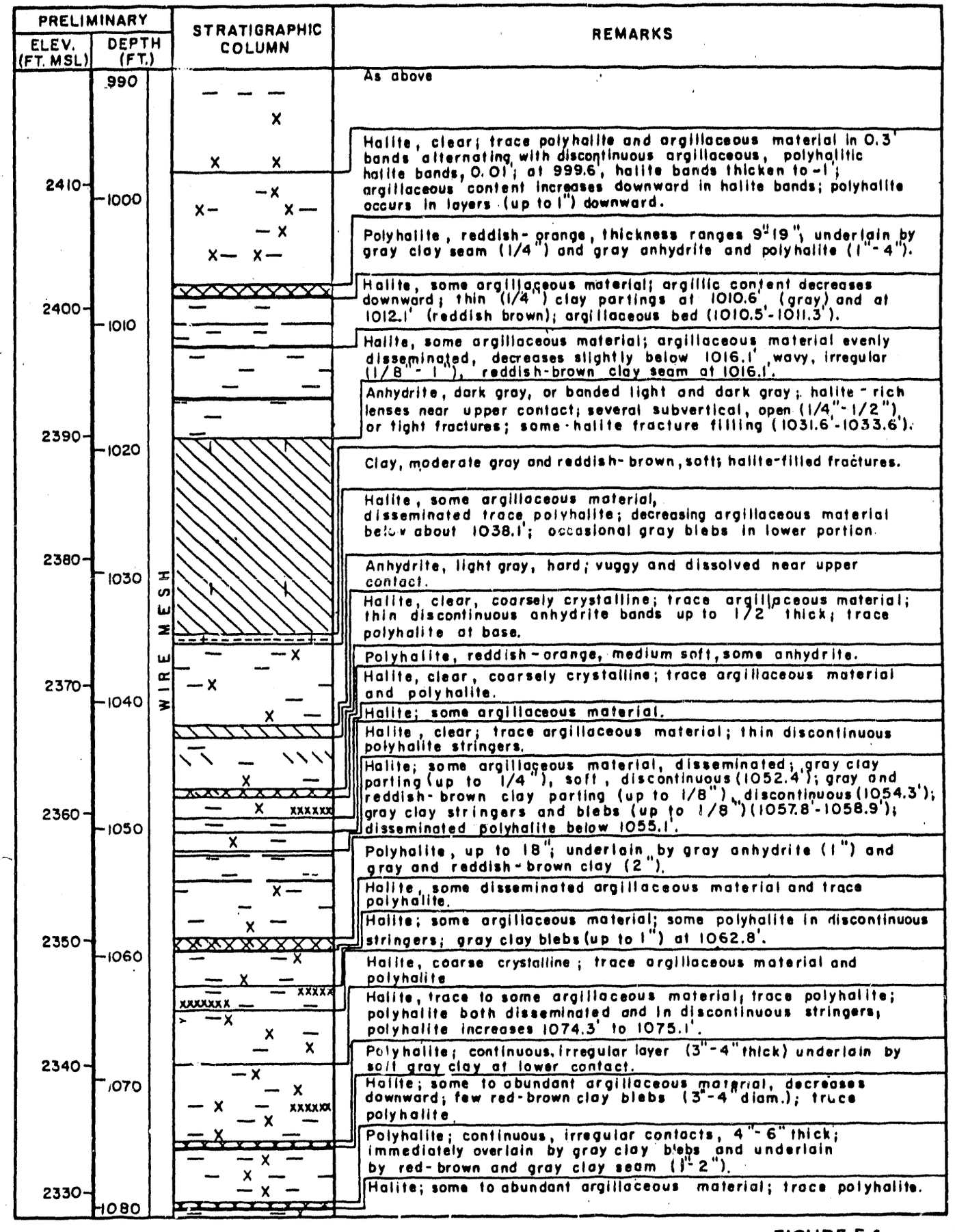
WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 10 OF 26



PREPARED BY RMH DATE 6/21/84
CHECKED BY _____ DATE _____

FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 11 OF 26



PREPARED BY RMH DATE 6/21/84
CHECKED BY _____ DATE _____

FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 12 OF 26

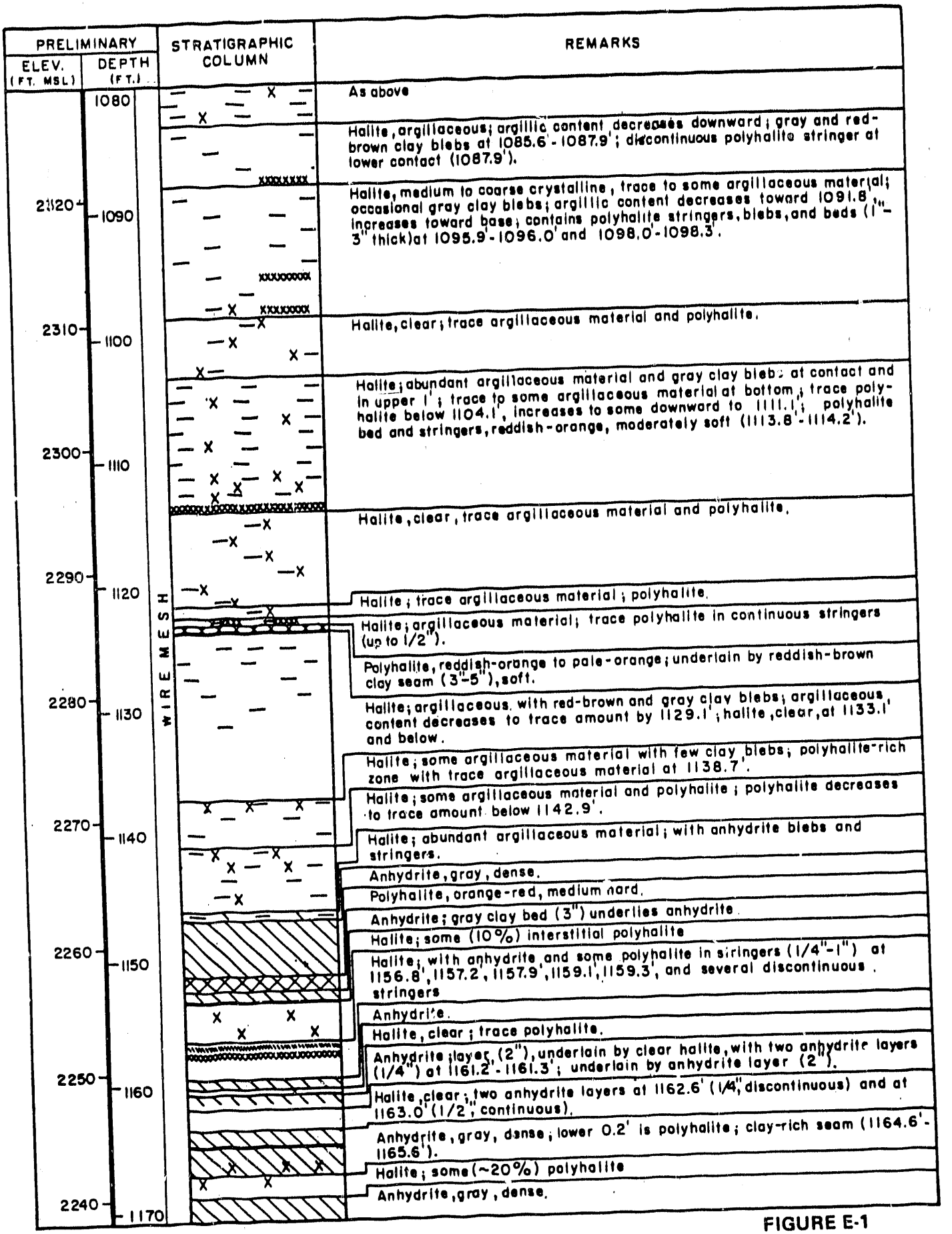


FIGURE E-1

PREPARED BY RMH DATE 6/21/84
CHECKED BY ____ DATE ____

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 13 OF 26

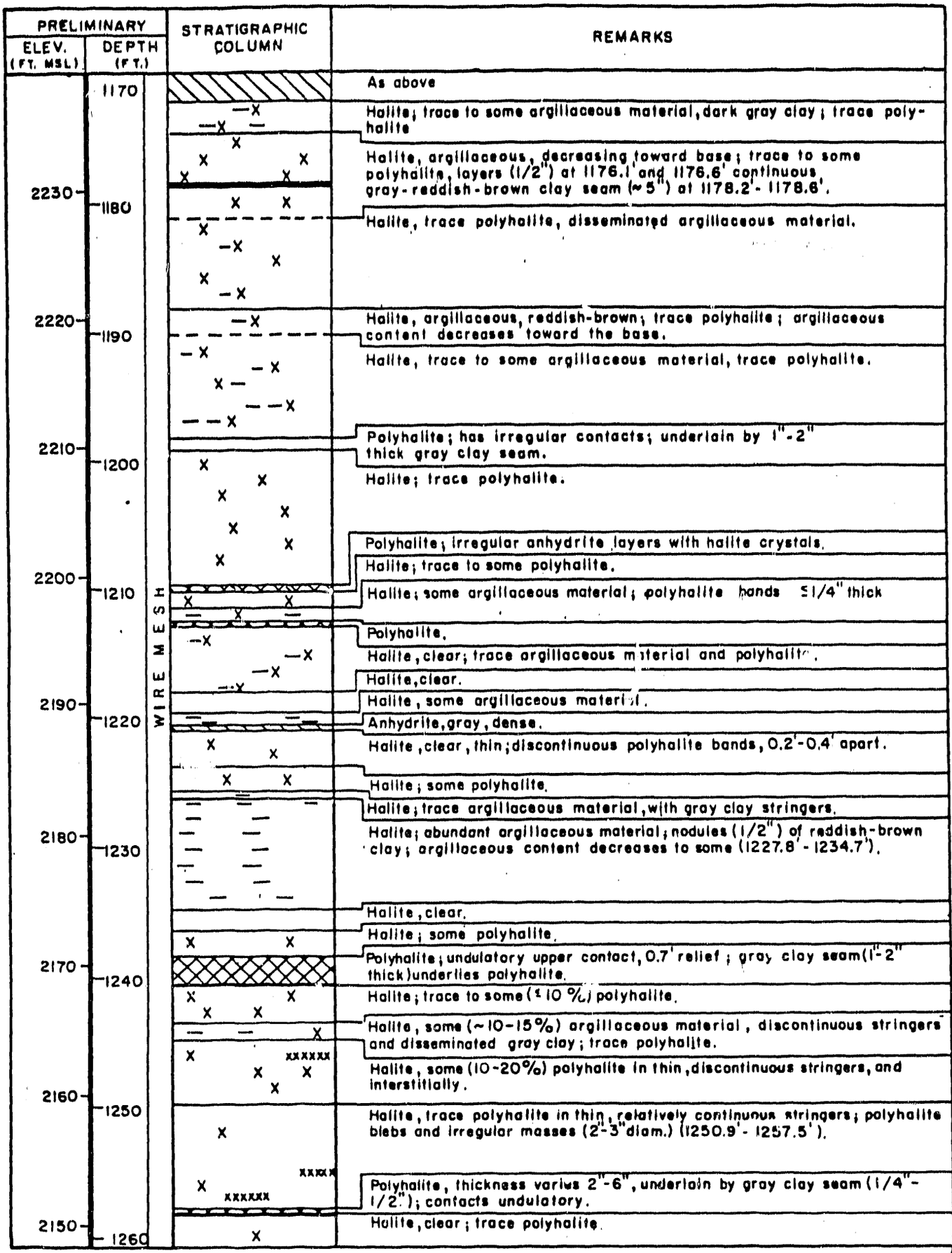


FIGURE E-1

PREPARED BY RMH DATE 6/21/84
CHECKED BY _____ DATE _____

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 14 OF 26

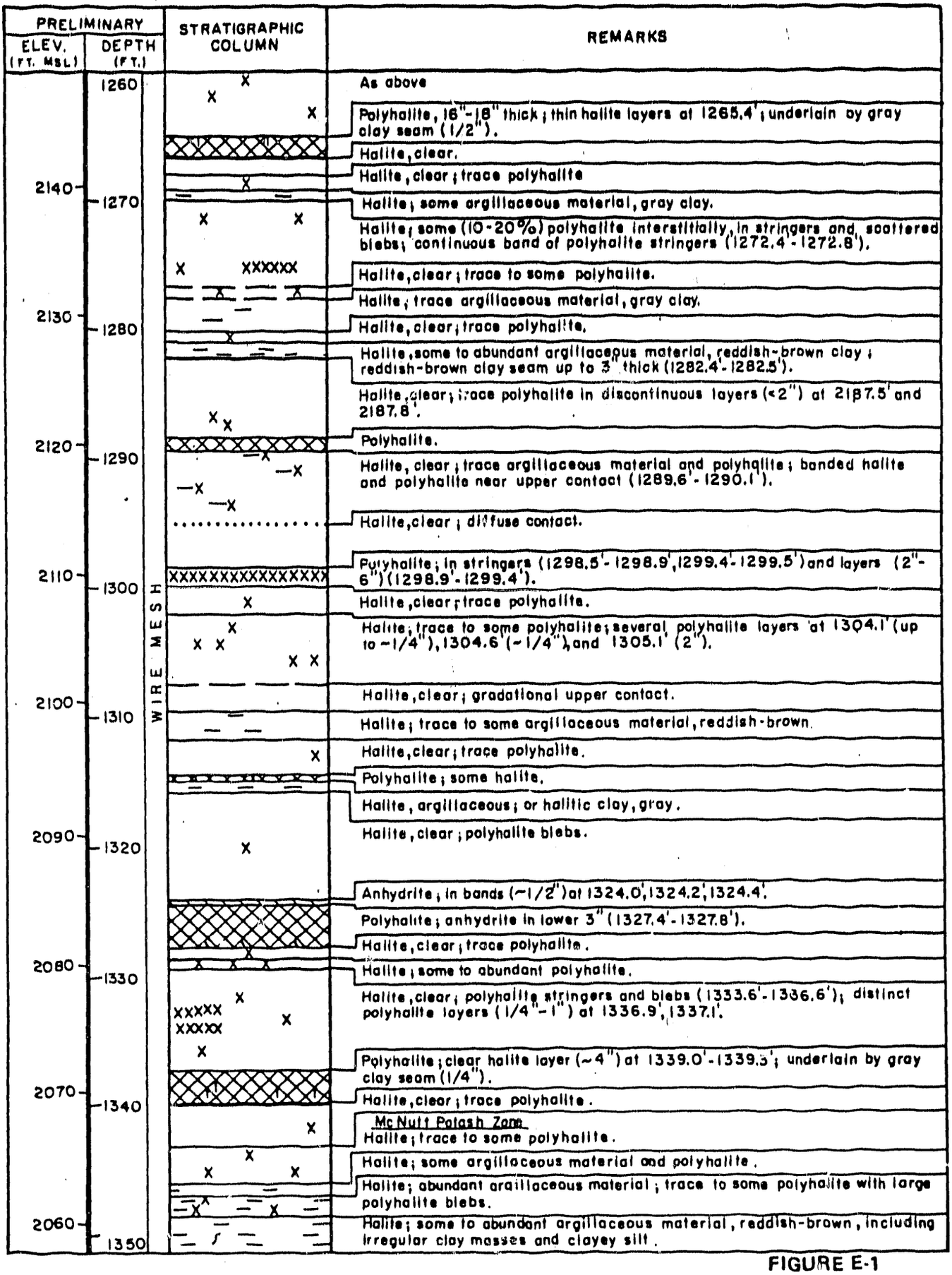
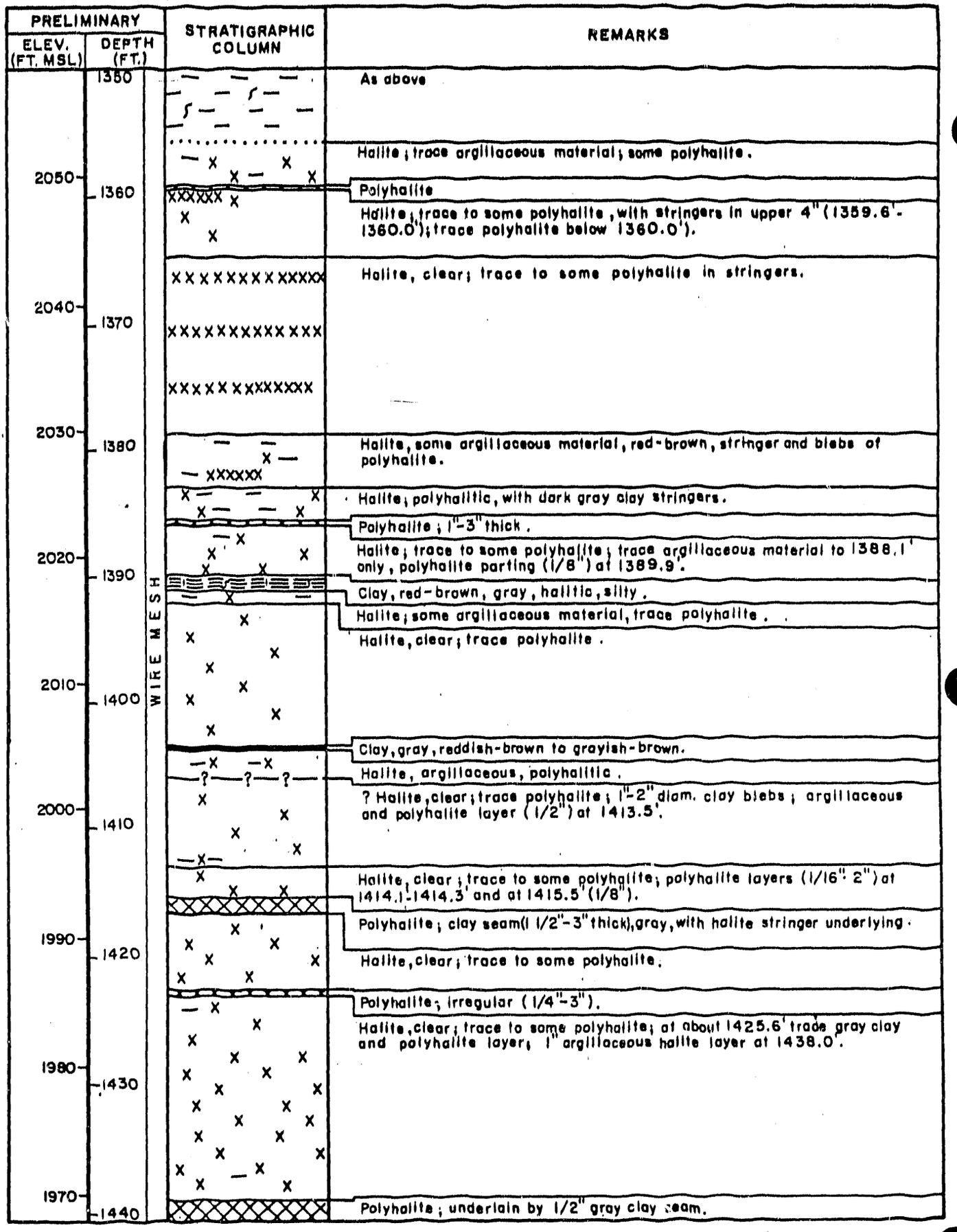


FIGURE E-1

PREPARED BY R Matt DATE 6/21/84
CHECKED BY ____ DATE ____

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 15 OF 26



PREPARED BY RBH DATE 6/21/84
CHECKED BY ____ DATE ____

FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 16 OF 26

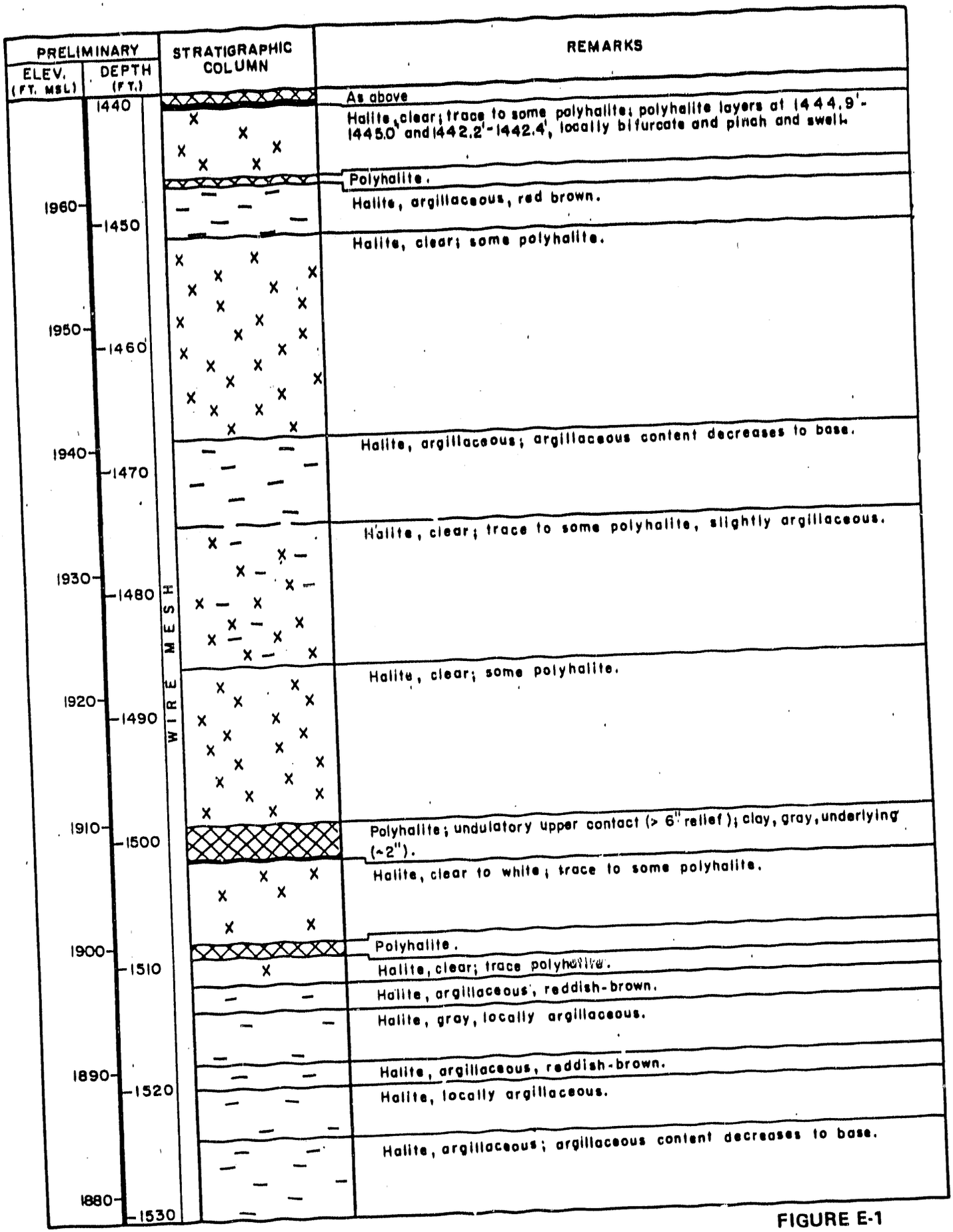


FIGURE E-1

PREPARED BY RMH DATE 6/21/84
CHECKED BY ____ DATE ____

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 17 OF 26

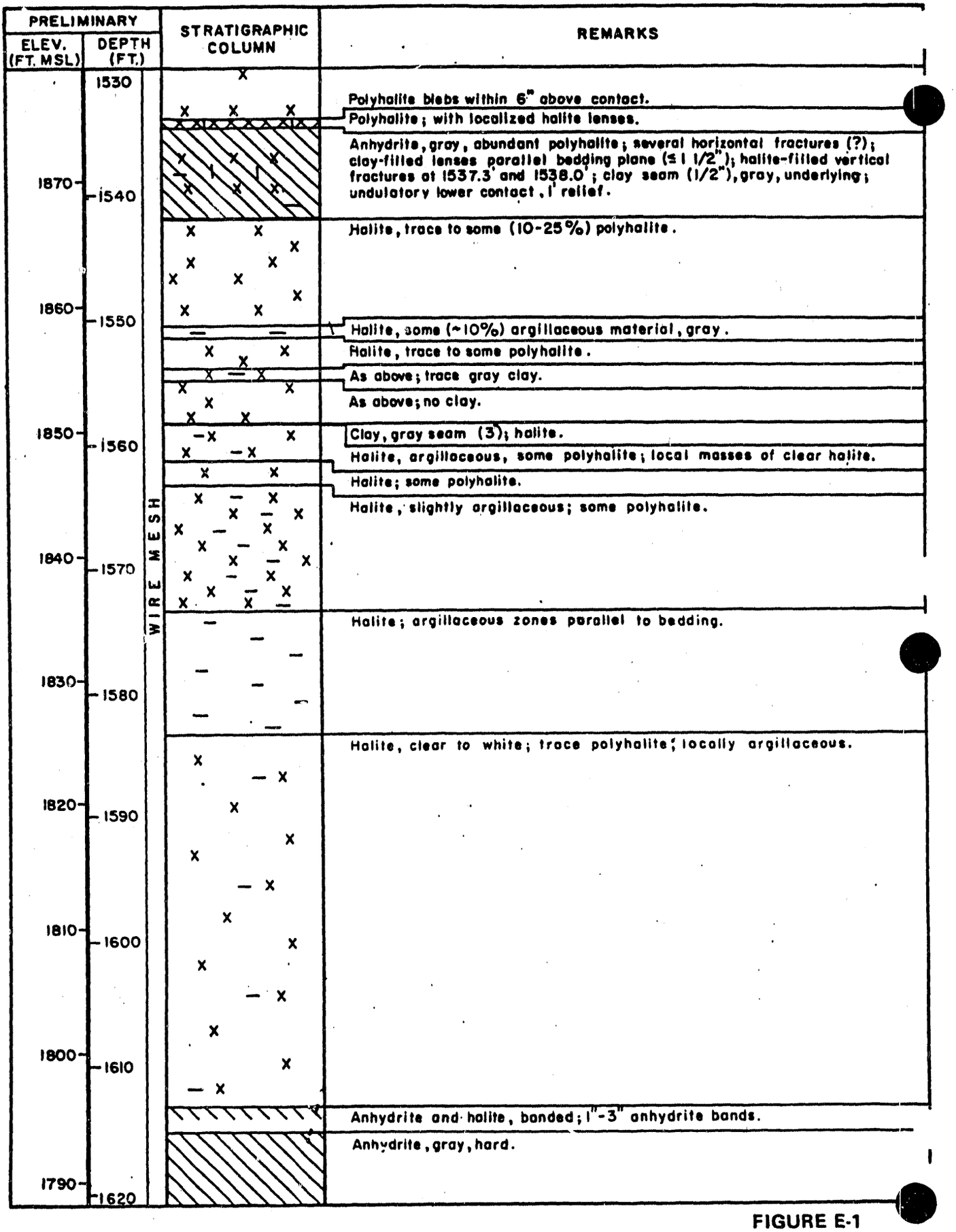
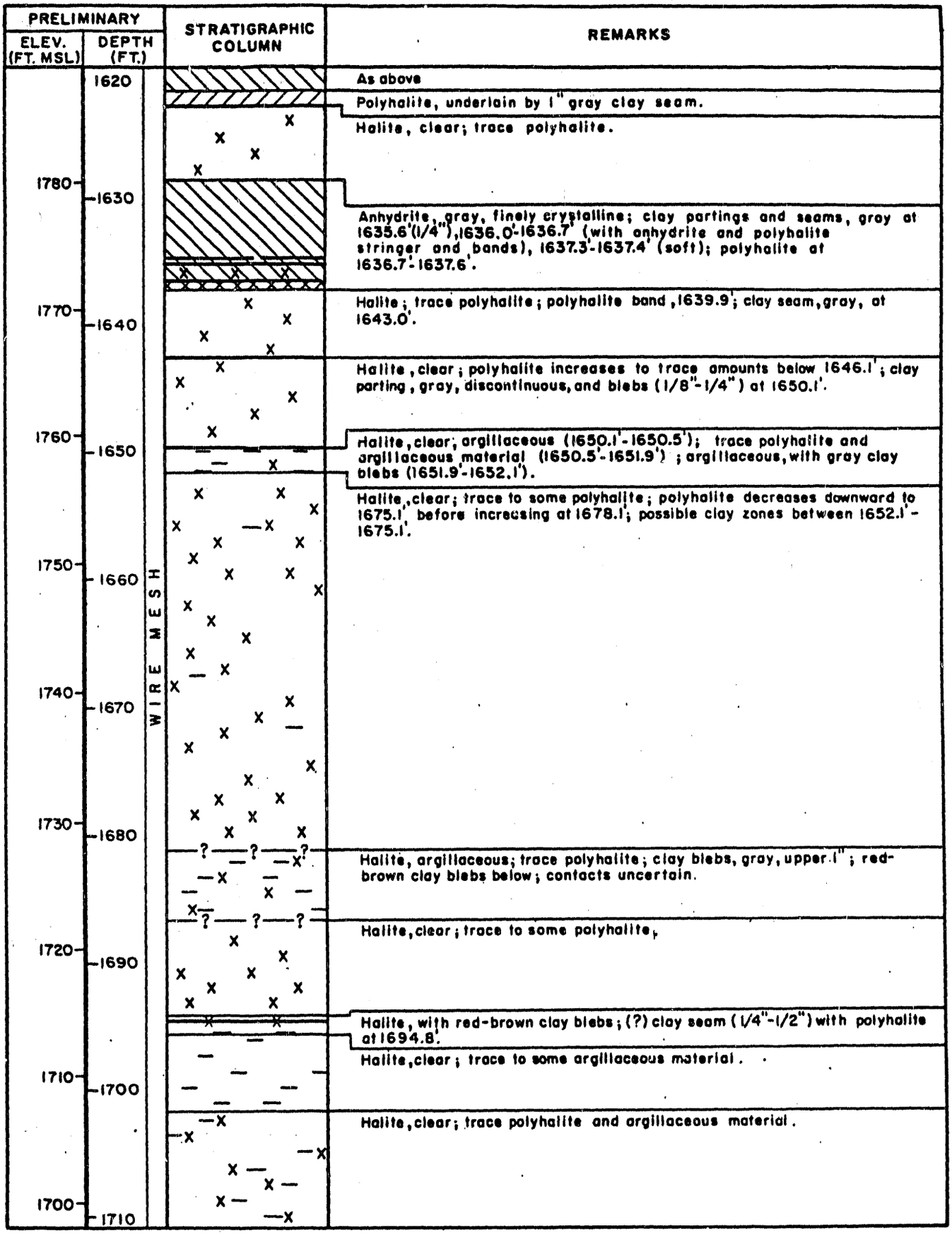


FIGURE E-1

PREPARED BY RMH DATE 6/21/84
CHECKED BY ____ DATE ____

WASTE HANDLING SHAFT LITHOLOGIC LOG SHEET 18 OF 26

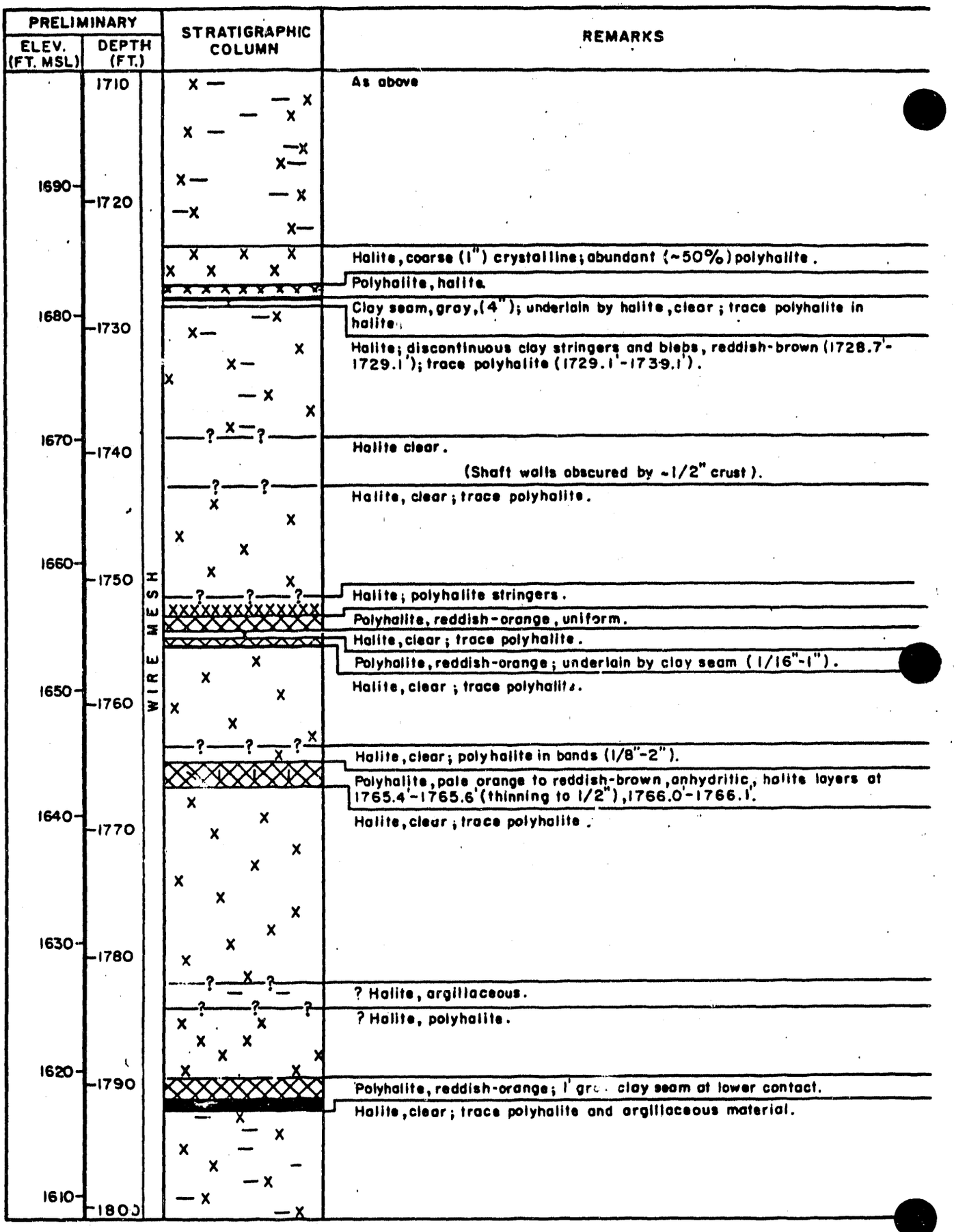


PREPARED BY RDH DATE 6/21/84

CHECKED BY _____ DATE _____

FIGURE E-1

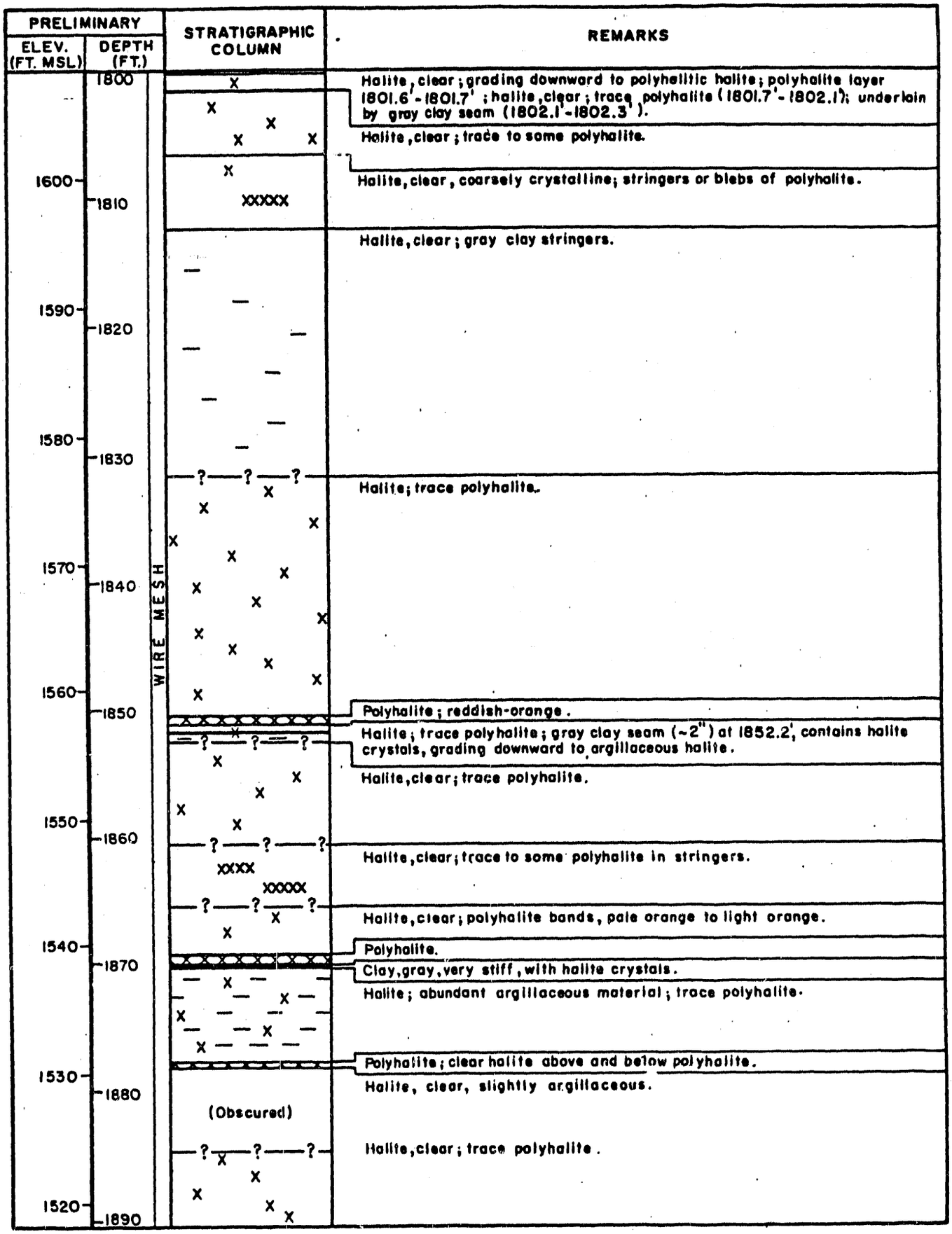
WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 19 OF 26



PREPARED BY R.M.H. DATE 6/21/84
CHECKED BY _____ DATE _____

FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 20 OF 26



PREPARED BY RMH DATE 6/21/84
CHECKED BY ____ DATE ____

FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 21 OF 26

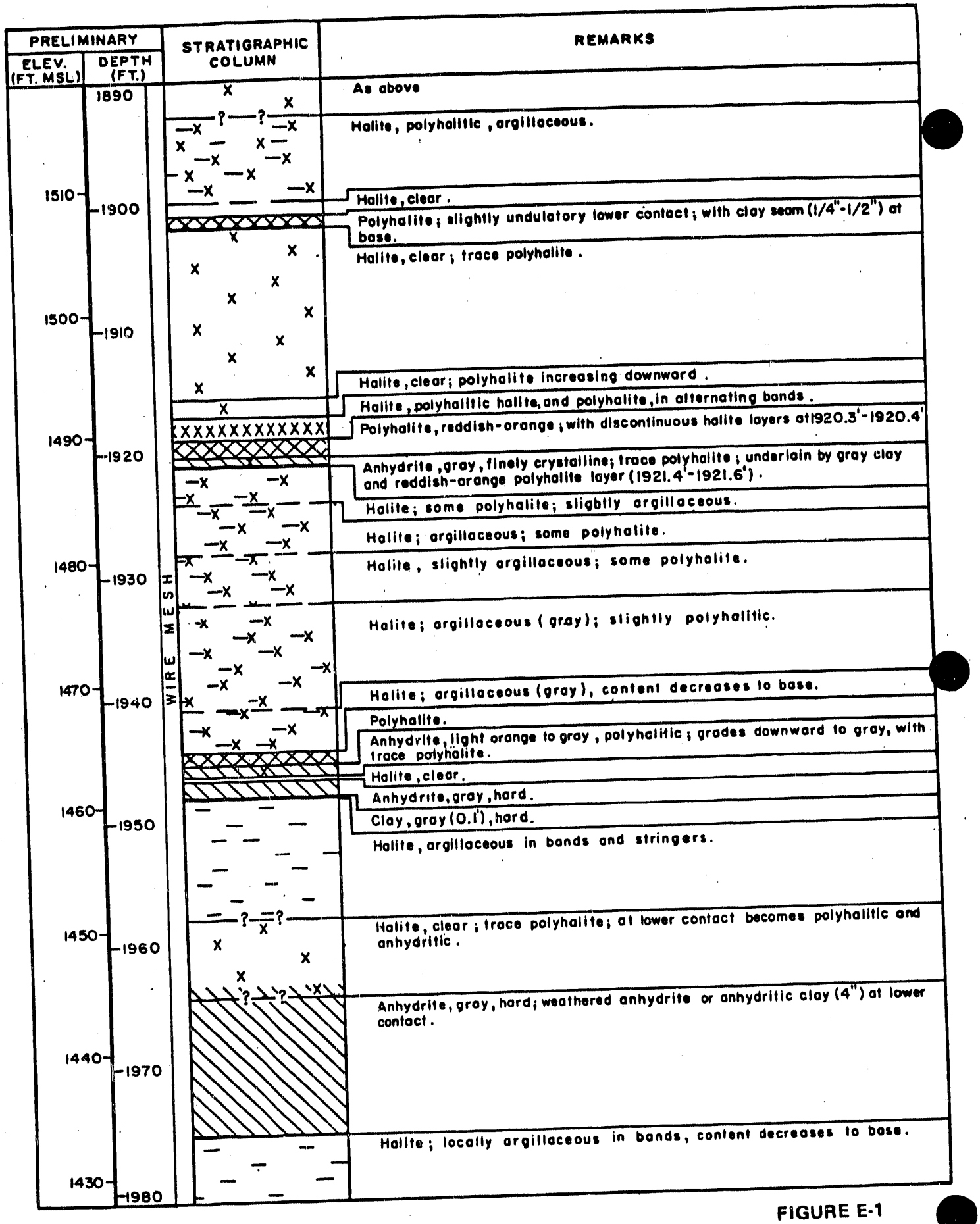
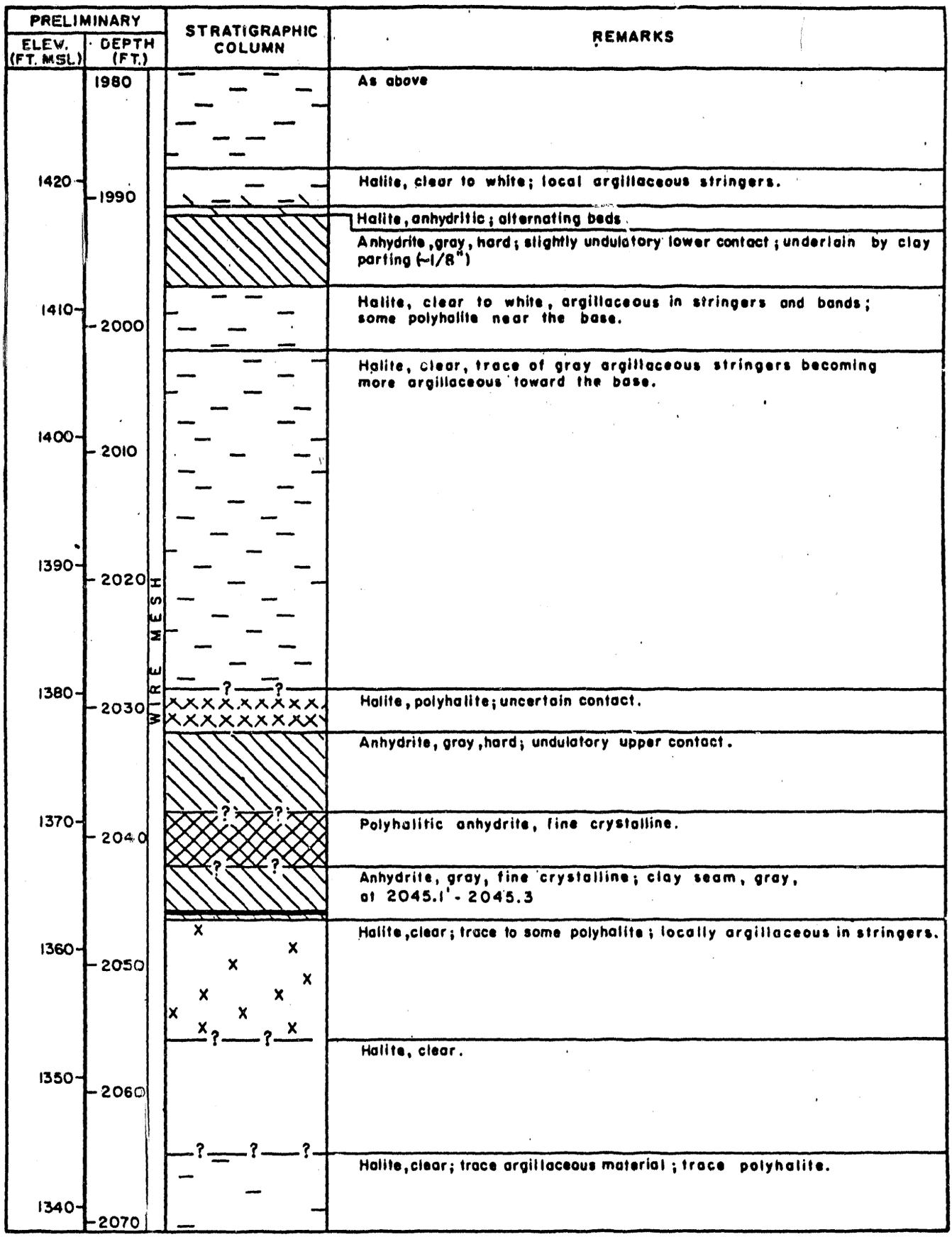


FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 22 OF 26

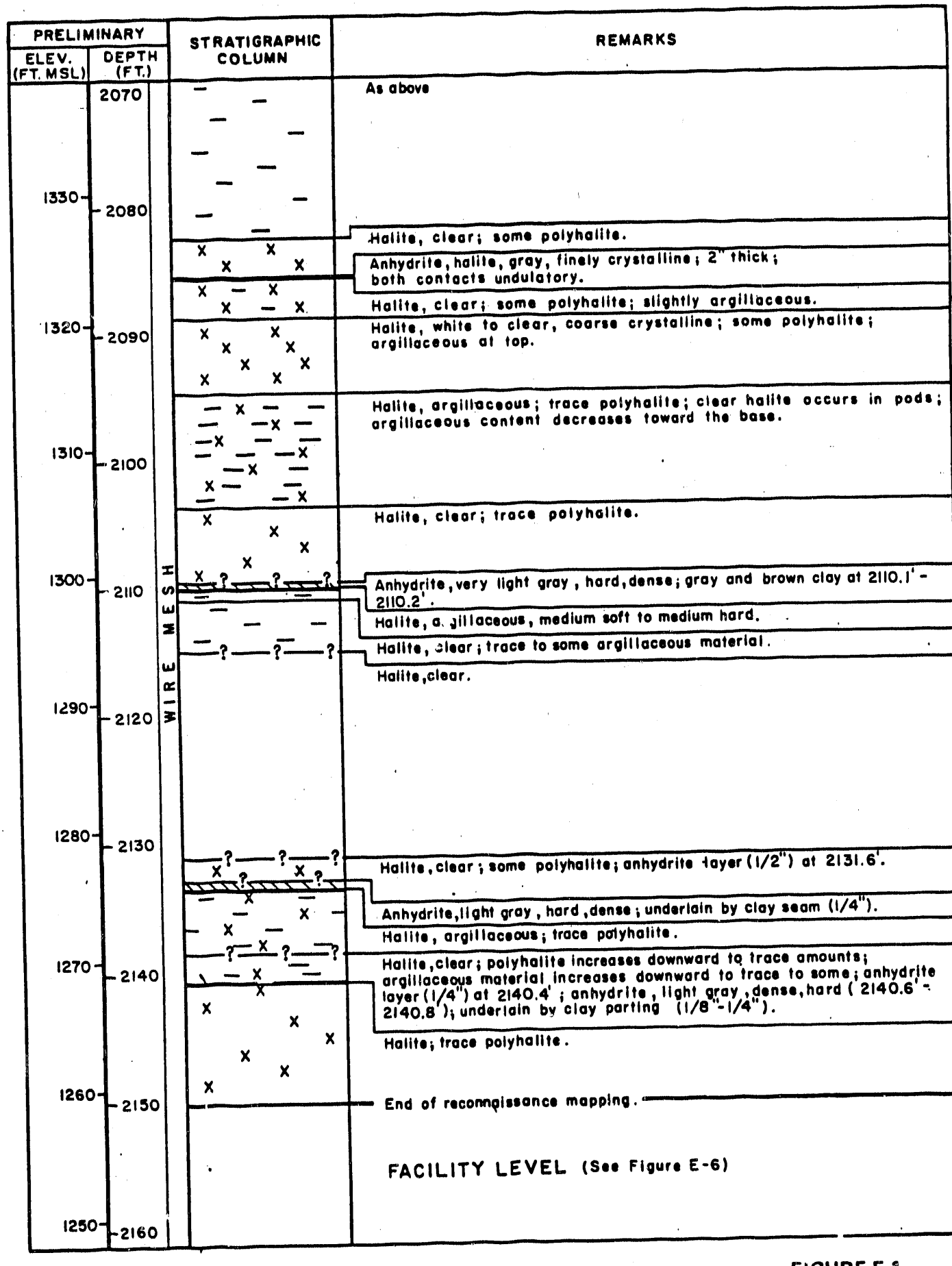
PREPARED BY RMH DATE 6/21/84
CHECKED BY _____ DATE _____



PREPARED BY RMH DATE 6/21/84
CHECKED BY _____ DATE _____

FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 23 OF 26



PREPARED BY RMH DATE 6/21/84
CHECKED BY ____ DATE ____

FIGURE E-1

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 24 OF 26

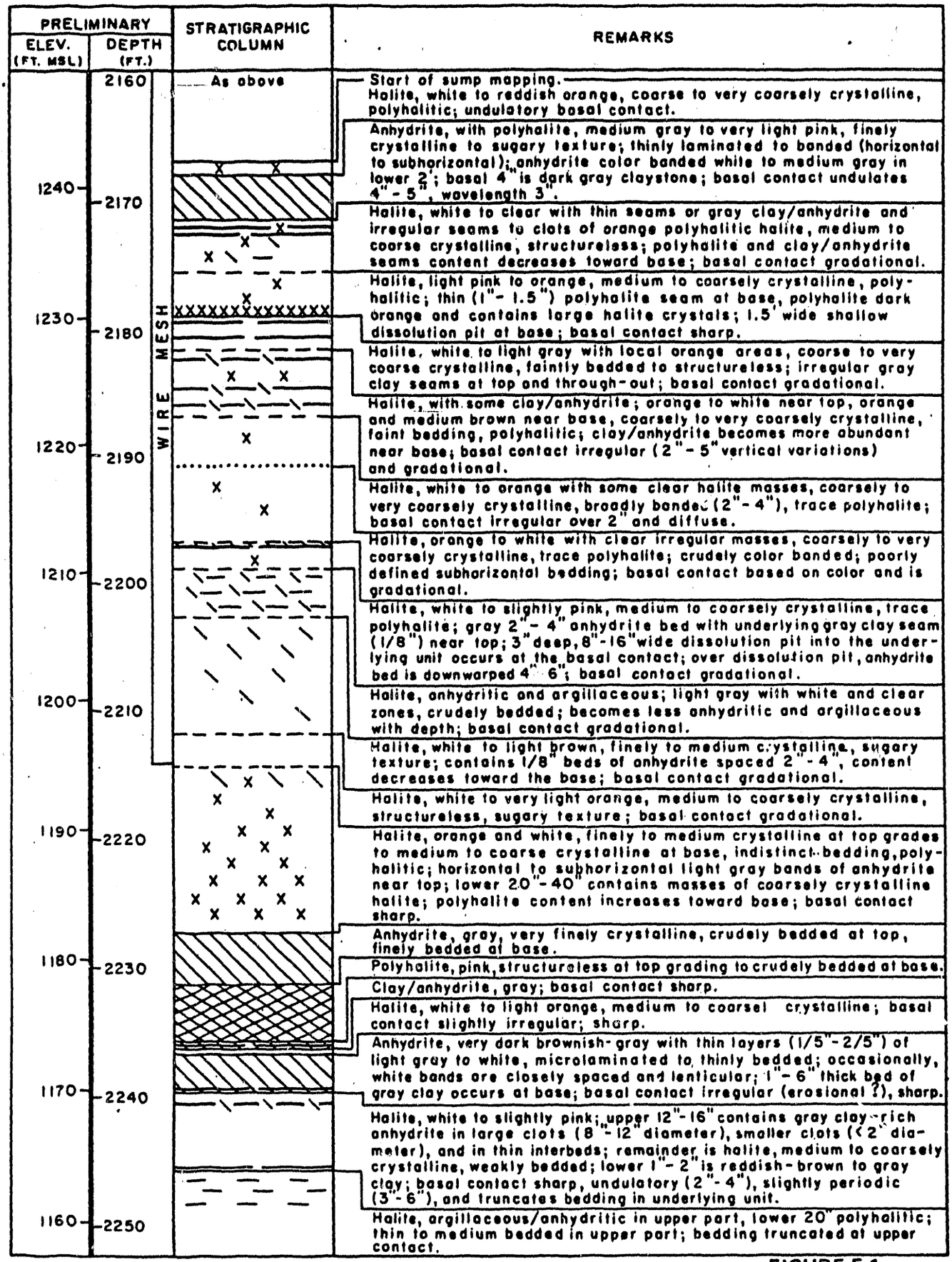


FIGURE E-1

PREPARED BY RMH DATE 9/13/88
CHECKED BY _____ DATE _____

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 25 OF 26

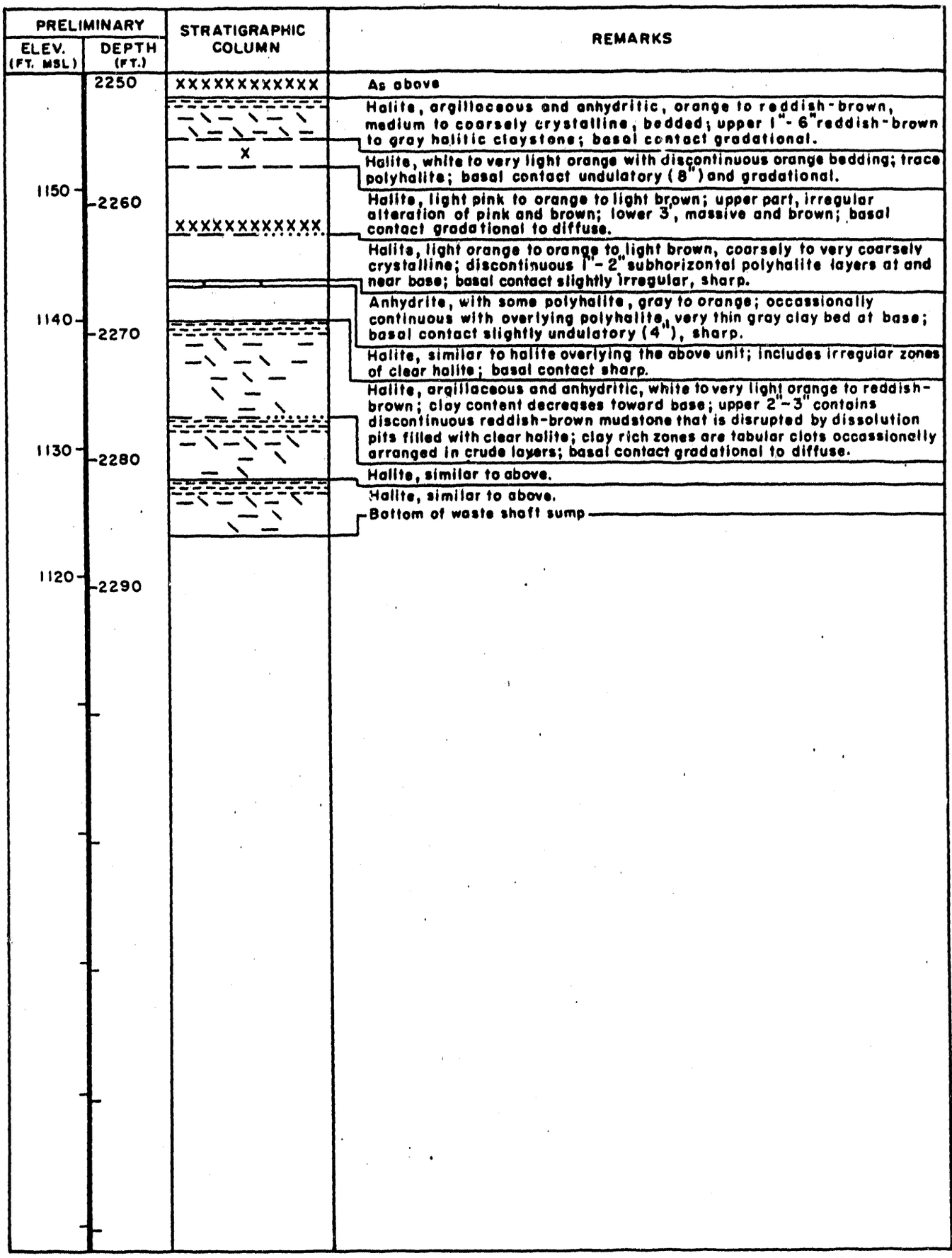
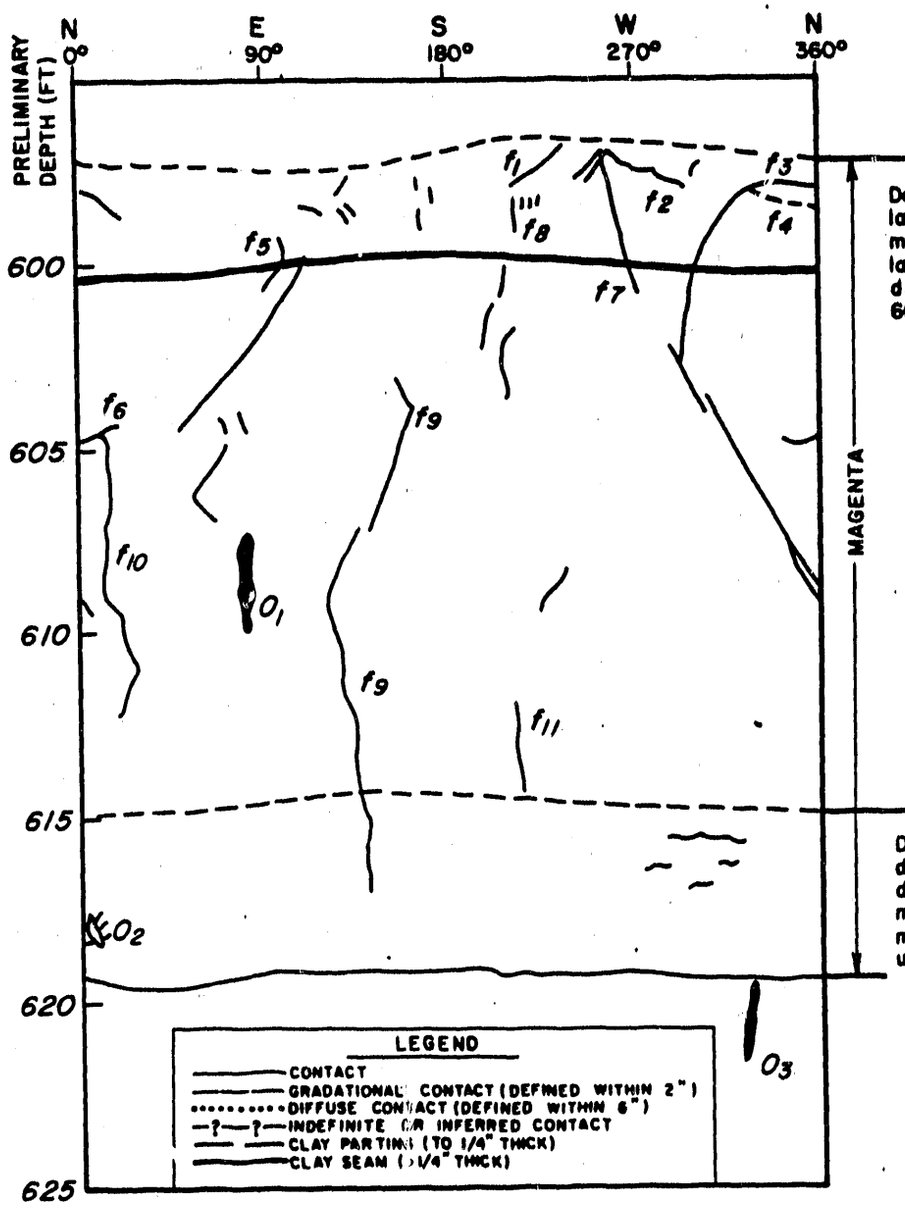


FIGURE E-1

PREPARED BY Rath DATE 9/13/84
CHECKED BY _____ DATE _____

WASTE HANDLING SHAFT
LITHOLOGIC LOG
SHEET 26 OF 26



FRACTURE NOTES

- f_1 Open.
- f_2 Open.
- f_3 Gypsum filled near the north extent, open (1/2") or accompanied by gypsum dissolution on west wall.
- f_4 Open (1/32").
- f_5 Open (1/32"); gypsum filled at depth; appears to offset laminae in dolomite.
- f_6 Open (1/32") near upper terminus; filled near 604'; open (1/16"-1/2") toward lower terminus; composed of several small fractures.
- f_7 Open (1/16").
- f_8 Fracture connects vuggy or leached zone to the west.
- f_9 Open (up to 1/4"), some gypsum fill has been leached.
- f_{10} As f_9
- f_{11} Open (1/16"); small amount of gypsum fill.

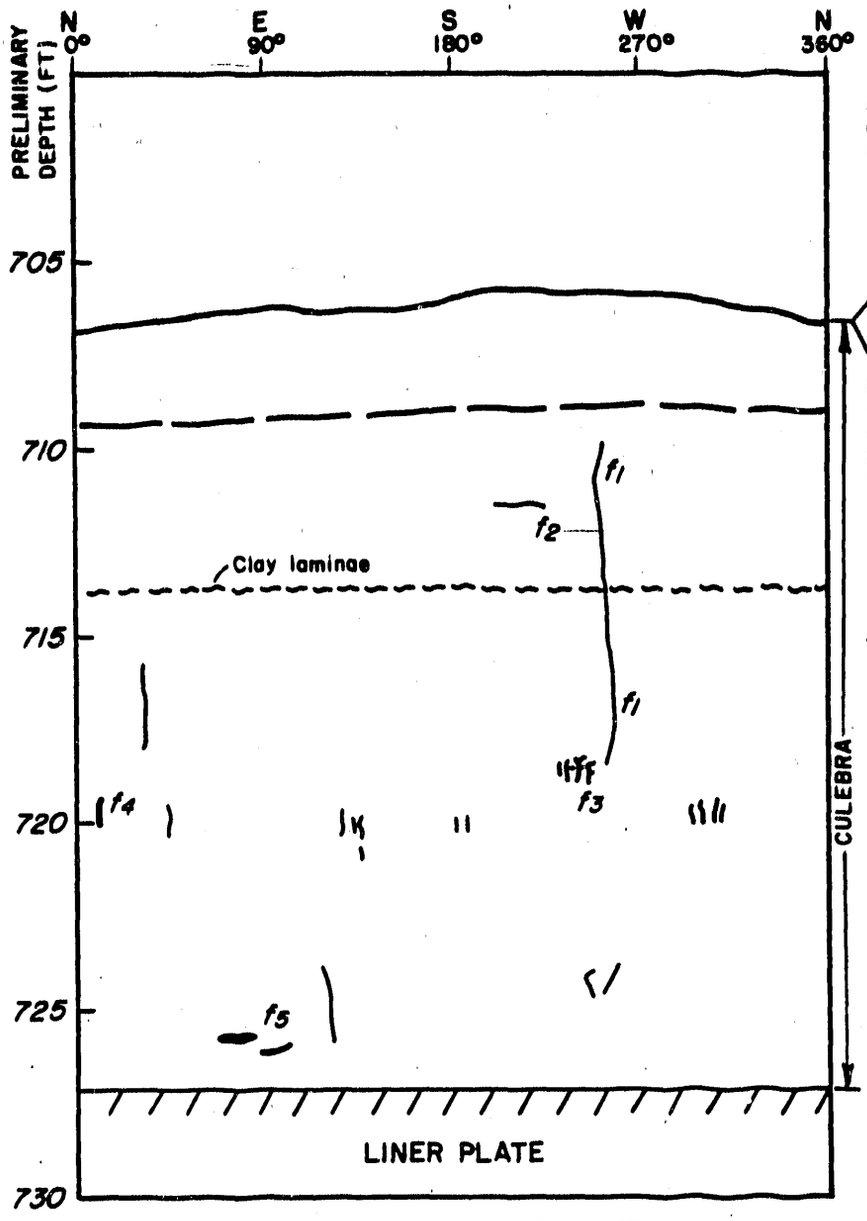
OTHER NOTES

- O_1 Iron oxide (red) stain.
- O_2 Large dolomite clast embedded in laminated dolomite; laminae distorted downward around clast.
- O_3 Solution feature in underlying Rustler Formation (anhydrite)

REFERENCE:

Geotechnical Field Data Report No. 4, 1983, Geologic Mapping & Water Inflow Testing in SPDV Ventilation Shaft.

Figure E-2
WASTE SHAFT
MAGENTA DOLOMITE
597 TO 620 FEET



Anhydrite, gray, banded, sandy or silty, calcareous, laminated, with laminae finer downward; near lower contact, laminae are distorted.

Clay, black seam (1"), soft where exposed, stiff to hard, dry inside shaft wall

Dolomite, light gray, hard, fine-grained, vuggy; clay, black-gray parting (1/16") at 709.0', dipping slightly north; large vugs (1"-2" deep) in 1'-2' zone at 712.0'; series of clay laminae, black, dip slightly to north at ~ 714.5'-714.8'.

REFERENCE:
Geotechnical Field Data Report No. 4, 1983, Geologic Mapping and Water Inflow Testing in SPDV Ventilation Shaft.

FRACTURE NOTES

f1 Closed, tight, clay fill.

f2 Closed, tight.

f3 Series of short, hairline fractures; at 718.0' hairline fracture density increases.

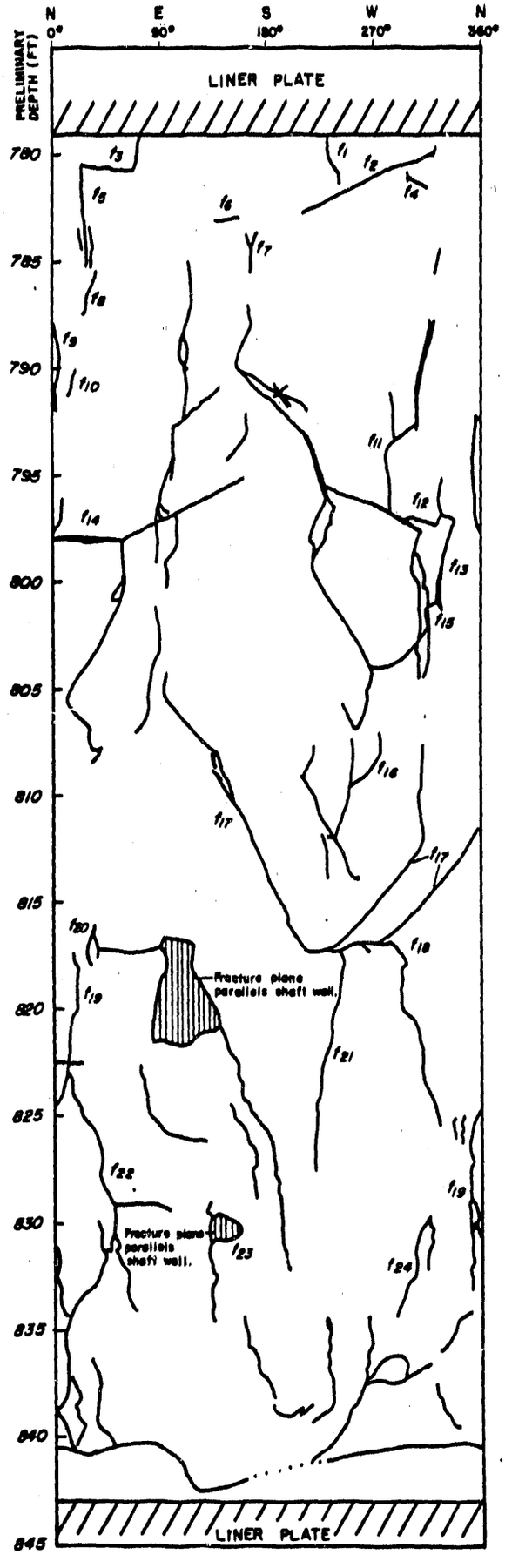
f4 Open, up to 1/8", filled with soft erodable material (clay?).

f5 Sparry calcite or dolomite, may be fracture fill.

LEGEND

- CONTACT
- GRADATIONAL CONTACT (DEFINED WITHIN 2")
- DIFFUSE CONTACT (DEFINED WITHIN 6")
- INDEFINITE OR INFERRED CONTACT
- CLAY PARTING (TO 1/4" THICK)
- CLAY SEAM (>1/4" THICK)

Figure E-3
WASTE SHAFT
CULEBRA DOLOMITE
705 TO 727 FEET



Host rock is dark reddish-brown mudstone.

FRACTURE NOTES

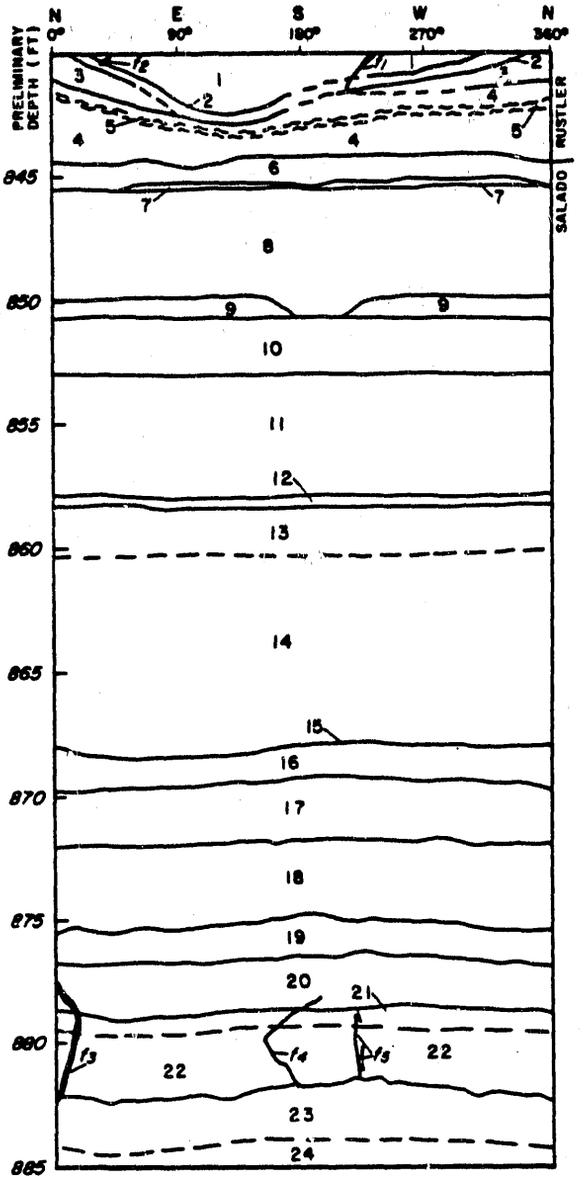
f_1	Open (1/4"-1").
f_2	Open (1/4"-1/2").
f_3	Open (1/4"-1").
f_4	Open.
f_5	Open (1/4").
f_6	Open (1"), 1 1/2" deep into shaft wall.
f_7	Open (1/4").
f_8	Open (1/2")
f_9	Open (1/8"-1"), polyhalitic halite fill.
f_{10}	Open (1/8").
f_{11}	Open (1/16") to closed.
f_{12}	Open (2"); polyhalite and halite fill actively dissolving.
f_{13}	Open (3/4"); polyhalite and halite fill.
f_{14}	Open (1/8"- 2 1/2"), up to 1' deep in shaft wall
f_{15}	Open (1"); polyhalite fill.
f_{16}	Open (1/16").
f_{17}	Open (1/4"-3/4"); halite fill remnants.
f_{18}	Open (1/4") to closed.
f_{19}	Open (1/4") to closed.
f_{20}	Open (1/4"-1"); halite fill remnants; curved fracture strikes S5E to S25E.
f_{21}	Open (1/4") to closed.
f_{22}	Closed; below 830', open (1/8"-1/4"); probable halite fill.
f_{23}	Fracture plane roughly parallels wall, strike N80E.
f_{24}	Closed.

REFERENCE:

GEOTECHNICAL FIELD DATA REPORT NO. 4, 1983, GEOLOGIC MAPPING AND WATER INFLOW TESTING IN SPDV VENTILATION SHAFT.

FIGURE E-4

WASTE SHAFT
RUSTLER FORMATION FRACTURE ZONE
779 TO 843 FEET



LEGEND

- CONTACT
- GRADATIONAL CONTACT (DEFINED WITHIN 2")
- DIFFUSE CONTACT (DEFINED WITHIN 6")
- INDEFINITE OR INFERRED CONTACT
- CLAY PARTING (TO 1/4" THICK)
- CLAY SEAM (>1/4" THICK)

EXPLANATION

1 Mudstone, light gray to reddish-brown, silty.

2 Mudstone, dark reddish-brown, silty (clay siltstone), 3"-6" thick; finer grained than 1; minor deformations due perhaps to dissolution below.

3 Mudstone or siltstone, banded dark and light grey, silty, fine sand.

4 Mudstone or siltstone, reddish-brown, fine-grained, and softer than 3.

5 Anhydrite, light grey; bands (1/8"-1/2") in an ~2" thick zone in unit 4.

6 Dissolution residue, granular, soft, loose material, dark reddish-brown

7 Polyhalite, moderate reddish-orange; pinch and swell (0--5"); locally underlain by dissolution residue.

8 Halite, light reddish-brown to reddish-orange; polyhalite disseminated in upper 1', locally rich polyhalite pockets, trace disseminated elsewhere, polyhalite-rich at lower 1'; argillaceous material as surface residue (clay).

9 Clayey mudstone or silty claystone, dark reddish-brown, 0-12" thick.

10 Halite, dark reddish-brown; some argillaceous material.

11 Halite, light reddish-brown to clear; trace polyhalite; argillaceous in upper 1'-1 1/4'

12 Anhydrite and polyhalite, light gray to light reddish-orange, fine granular, 6" thick; underlain by seam (1"-2") of clay, dark reddish-brown, soft.

13 Halite, dark to moderate reddish-brown; some polyhalite and argillaceous material.

14 Halite, clear to light reddish-brown, banded; trace polyhalite, in stringers and bands (3"-6").

15 Siltstone or mudstone, gray-green, sandy; anhydrite blebs; variable thickness (1/8"-1").

16 Halite, reddish-brown, argillaceous; clayey residue on shaft wall.

17 Halite, polyhalitic; indistinct banding; polyhalite veinlets along crystal boundaries; polyhalite content increases downward.

18 Halite, argillaceous material, reddish-brown; clayey residuum on shaft surface.

19 Halite; trace polyhalite; trace argillaceous material; irregular upper contact

20 Mudstone, reddish-brown, gray-green mottling with higher silt content, soft where weathered.

21 Mudstone, gray-green, sandy to silty, hard.

22 Mudstone, reddish-brown, hard.

23 Halite, reddish-brown, argillaceous; clay residuum on shaft surface.

24 As above; transition to lower argillaceous content.

FRACTURE NOTES

f1 Open (up to 1/4") to closed; ends with depth.

f2 Open (up to 1/16") to closed; nearby vertical fractures are general closed and discontinuous.

f3 Strike ~N 45°E; halite fill; 1/2" wide, increases downward to 1-1/2" to 2"

f4 Strike ~ N 30°E

f5 Strike N 60° E; uncertain upward extent.

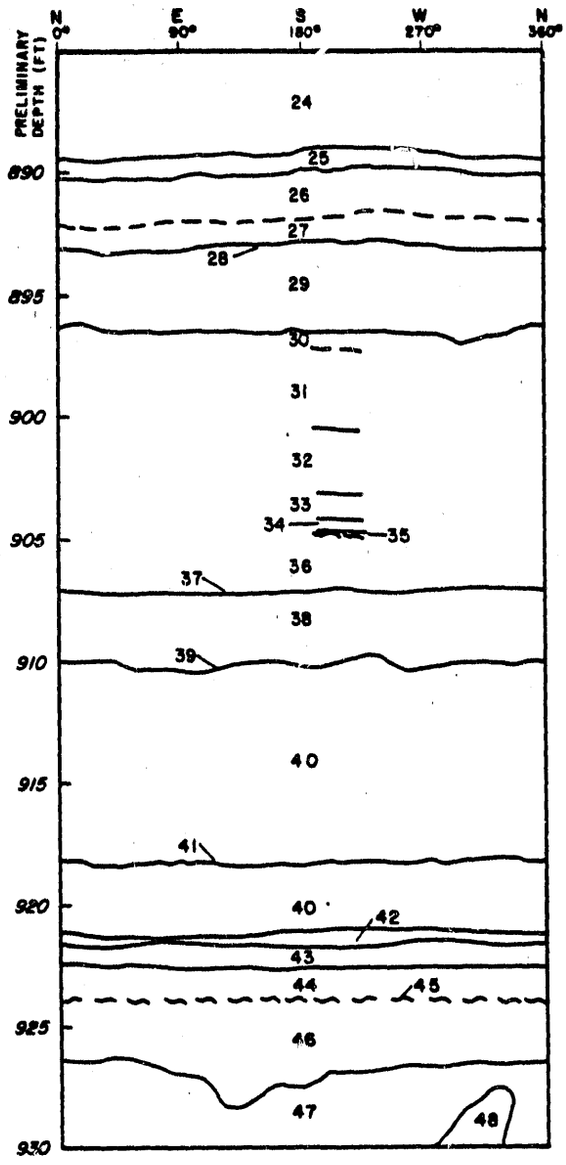
REFERENCE:

GEOTECHNICAL FIELD DATA REPORT NO. 4, 1983, GEOLOGIC MAPPING AND WATER INFLOW TESTING IN SPDV VENTILATION SHAFT.

FIGURE E-5

WASTE SHAFT
RUSTLER/SALADO FORMATION CONTACT
840 TO 930 FEET

SHEET 1 OF 2



EXPLANATION

25 [illegible]; argillaceous content higher than 24.

26 Halite; some argillaceous material.

27 Halite, clear; trace polyhalite and argillaceous material; transition from 26.

28 Silt, gray-green, clayey, ~1".

29 Halite; some to abundant argillaceous material; clayey residuum on shaft surface.

30 Halite, clear.

31 Halite, polyhalitic.

32 Halite, clear.

33 Halite, polyhalitic, argillaceous.

34 Halite, clear.

35 Clay, gray thin seam (~ 1/8")

36 Halite, polyhalitic, argillaceous.

37 Clay, gray and reddish-brown seam (0.1'-0.3')

38 Mudstone, halite and/or very argillaceous halite; stiff clay; halite crystals up to 1".

39 Clay, gray and reddish-brown seam (0.1'-0.3')

40 Halite; some argillaceous material.

41 Clay, gray and reddish-brown; and polyhalite, reddish-orange seam (1/4"-1/2"), soft.

42 Polyhalite, pale orange; underlain by anhydrite, gray, dense, 1/4."

43 Halite, polyhalite; thinly interbedded.

44 Halite, clear; trace polyhalite.

45 Clay parting, gray.

46 Halite; abundant argillaceous material, reddish-brown with gray blebs; grades to halitic mudstone; halite crystals up to 1/2".

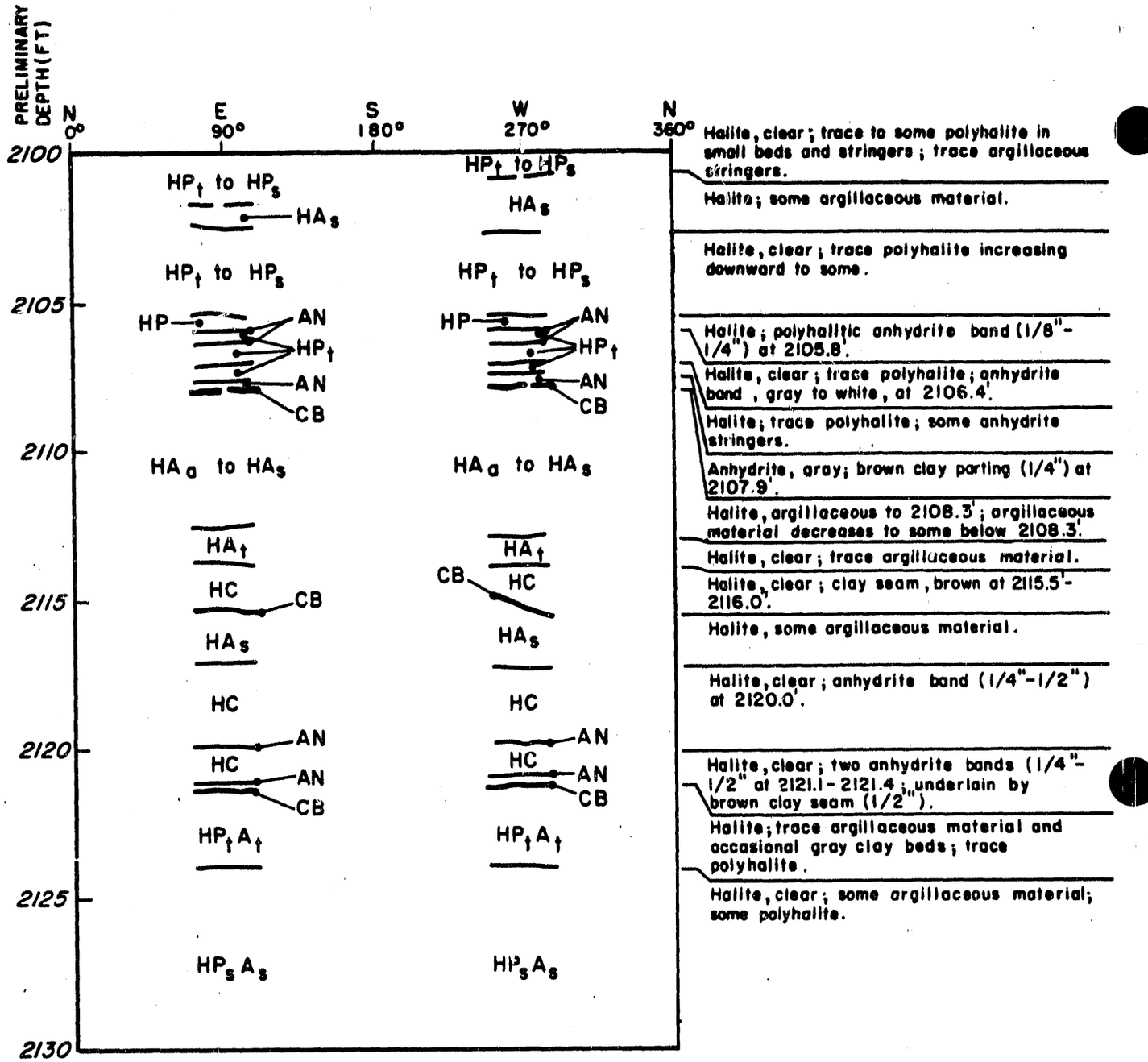
47 Halite; some to abundant argillaceous material.

48 Clay, reddish-brown, few gray blebs; inclusion in 47; disseminated halite.

LEGEND

——— CONTACT
——— GRADATIONAL CONTACT (DEFINED WITHIN 2")
••••••••• DIFFUSE CONTACT (DEFINED WITHIN 6")
—?—?— INDEFINITE OR INFERRED CONTACT
— — — CLAY PARTING (TO 1/4" THICK)
——— CLAY SEAM (>1/4" THICK)

FIGURE E-5
WASTE SHAFT
RUSTLER/SALADO FORMATION CONTACT
840 TO 930 FEET
SHEET 2 OF 2



LEGEND

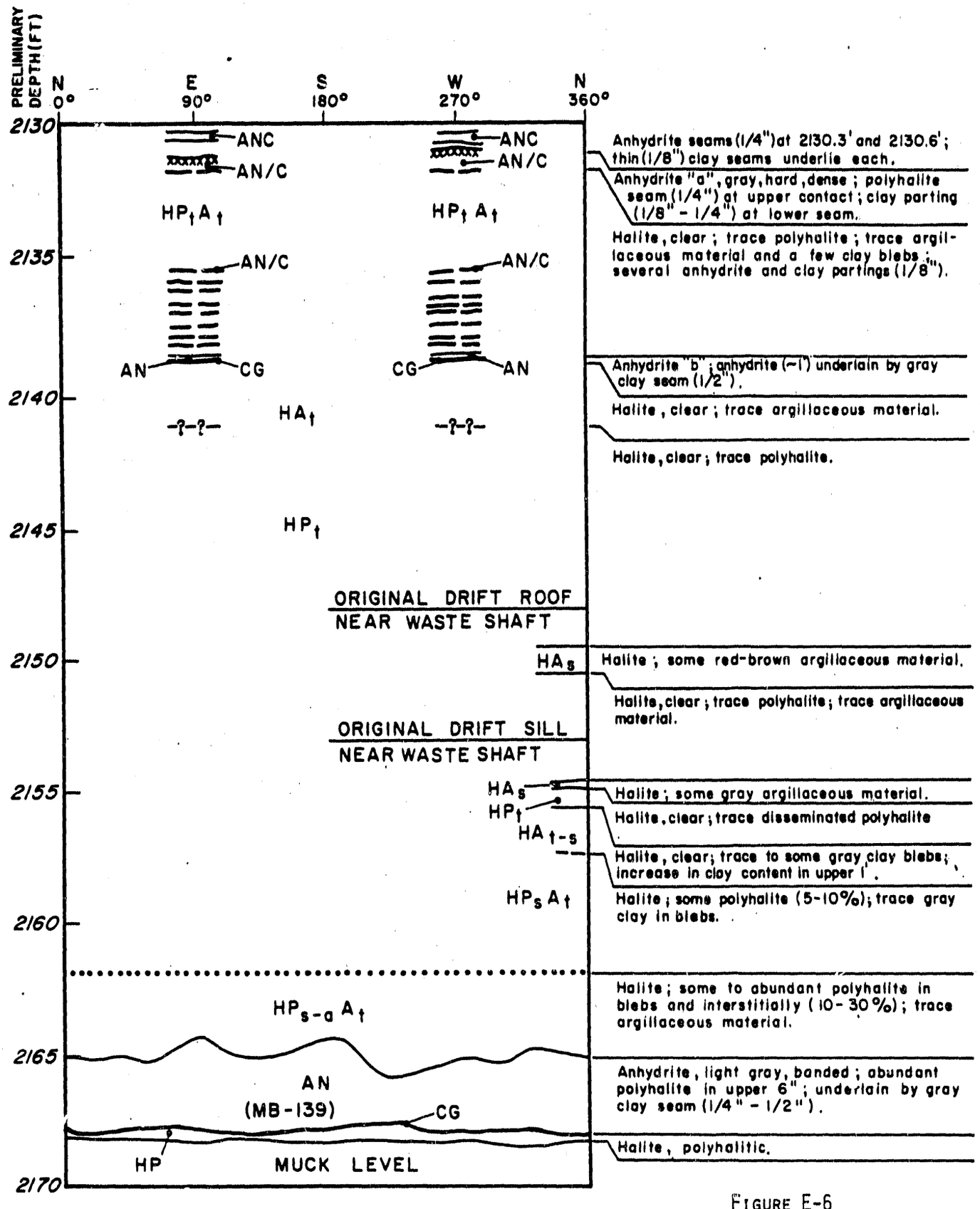
- ——— CONTACT
- ——— GRADATIONAL CONTACT (DEFINED WITHIN 2")
- ••••••••• DIFFUSE CONTACT (DEFINED WITHIN 6")
- —?—?— INDEFINITE OR INFERRED CONTACT
- ——— CLAY PARTING (1/4" TO 1-1/16" THICK)

REFERENCE:

GEOTECHNICAL FIELD DATA REPORT NO. 4, 1983, GEOLOGIC MAPPING AND WATER INFLOW TESTING IN SPDV VENTILATION SHAFT.

FIGURE E-6
WASTE SHAFT
FACILITY LEVEL AREA
2100 TO 2170 FEET

SHEET 1 OF 2



LEGEND

- CONTACT
- GRADATIONAL CONTACT (DEFINED WITHIN 2")
- DIFFUSE CONTACT (DEFINED WITHIN 6")
- —?—?— INDEFINITE OR INFERRED CONTACT
- CLAY PARTING (TO 1/4" THICK)
- CLAY SEAM (>1/4" THICK)

FIGURE E-6

WASTE SHAFT
FACILITY LEVEL AREA
2100 TO 2170 FEET

SHEET 2 OF 2

APPENDIX F

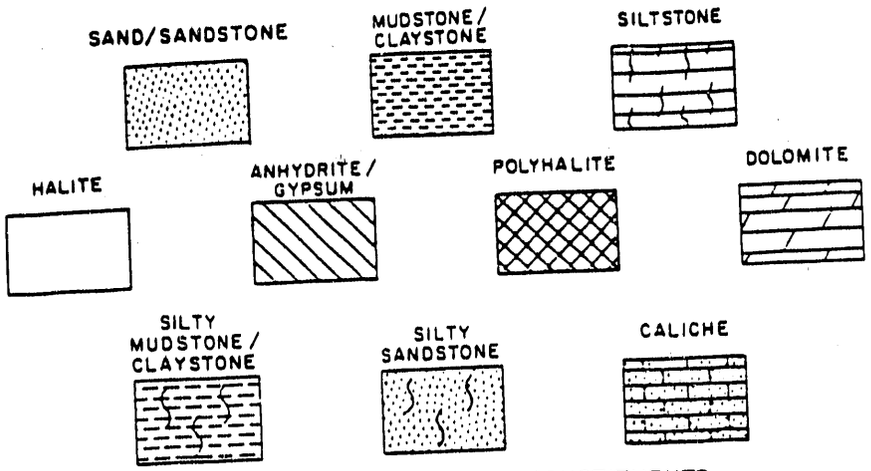
EXHAUST SHAFT
GEOLOGIC LOG

CONTENTS

Figure No.	Title/Description
F-1	Exhaust Shaft Geologic Log (49 Sheets)

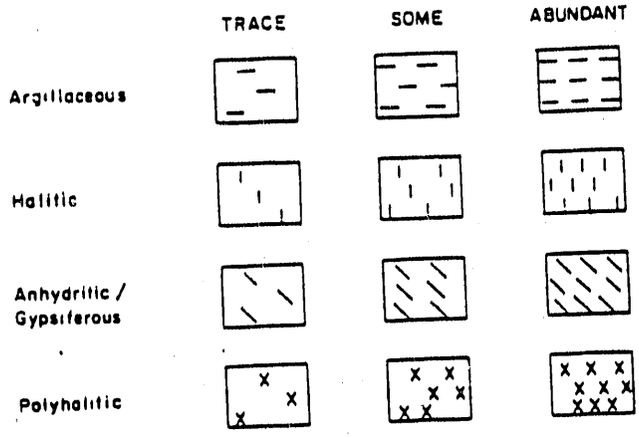
EXPLANATION

ROCK TYPE

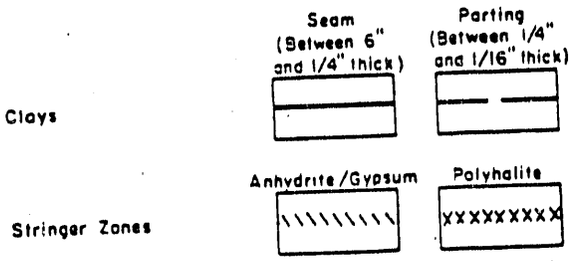


ACCESSORY CONSTITUENTS

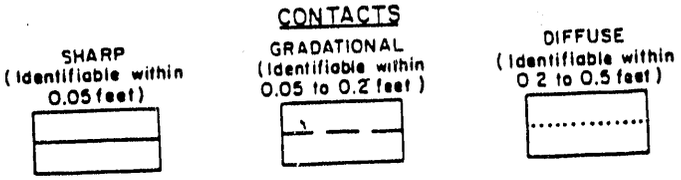
ESTIMATED PERCENTAGE OF ACCESSORY CONSTITUENTS INDICATED AS FOLLOWS



LAMINAR FEATURES



CONTACTS



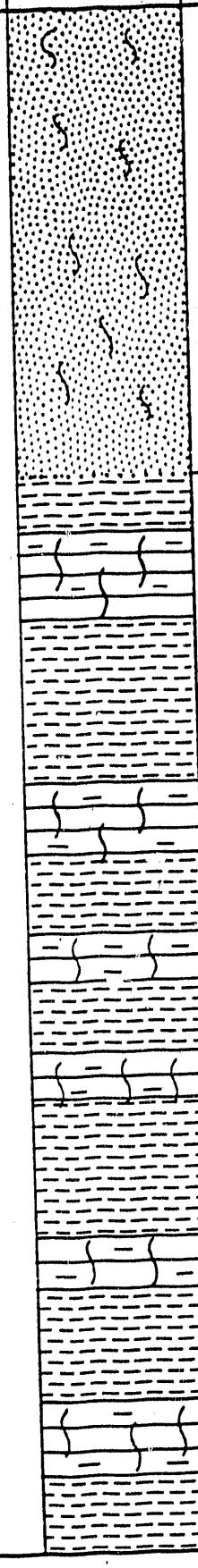
SALADO MARKER BEDS ARE IDENTIFIED BY NUMBER IN THE STRATIGRAPHIC COLUMN

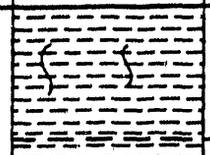
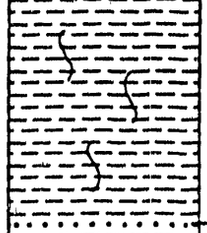
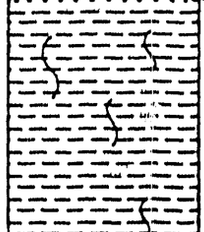
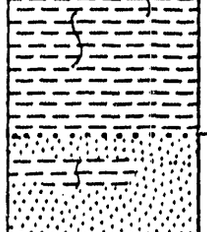
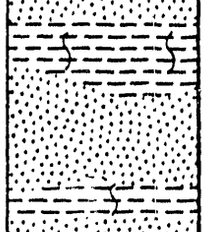
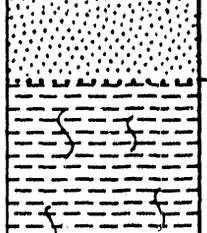
EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
3411.5			
			COLLAR PAD
3410			
3409	0		QUATERNARY DUNE SAND. SAND, SILTY, REDDISH-BROWN, POORLY SORTED, SUBANGULAR GRAINS, A FEW MAFIC GRAINS (LESS THAN 10%); WEAKLY CONSOLIDATED.
3404	5		
			MESCALERO CALICHE. CALICHE, WHITE TO TAN, NODULAR, SIZE AND QUANTITY OF NODULES INCREASING WITH DEPTH; CARBONATE CONTENT HIGHEST IN LIGHT COLORED SUBHORIZONTAL STRINGERS; UPPER 1.0' HARD, HARDNESS DECREASING TOWARD BASE; MOIST; CONTAINS LOCAL CONCENTRATIONS OF SILTSTONE AND SANDSTONE; COLOR BECOMES REDDISH-BROWN TOWARD BASE; IRREGULARLY-SHAPED DISCONTINUOUS BEDS OF SILTSTONE, CHERT AND SANDSTONE PEBBLE CONGLOMERATE MIGRATE VERTICALLY AND LATERALLY; THICK DISCONTINUOUS BEDS OF ORANGISH-BROWN SAND OCCUR NEAR BASE; BASAL CONTACT DIFFUSE.
3399	10		
3394	15		
			GATUNA FORMATION. SANDSTONE, FINE TO VERY FINE GRAINED, REDDISH-BROWN, POORLY SORTED, CALCAREOUS, FRIABLE, DRY; BASAL 1.5' IS SANDSTONE, COARSE TO FINE GRAINED, POORLY SORTED, ROUNDED, CONTAINING ANGULAR DEBRIS FROM UNDERLYING REDBEDS; BASAL CONTACT SHARP, EROSIONAL, SLIGHTLY UNDULATORY.
3389	20		
3384	25		
3379	30		
			SANTA ROSA FORMATION. SILTSTONE AND VERY FINE GRAINED SANDSTONE, SILT TO VERY FINE SAND-SIZED GRAINS, REDDISH-BROWN, CALCAREOUS, POORLY SORTED, CONTAINS PEBBLES OF CHERT AND MAFIC GRAINS; UPPER 1.0' CONTAINS CALICHE IN SUBHORIZONTAL STRINGERS; BASAL CONTACT DIFFUSE.
3374	35		
3369	40		

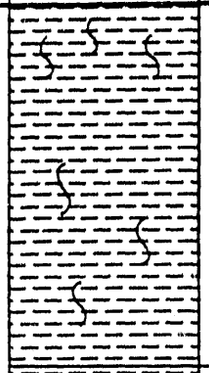
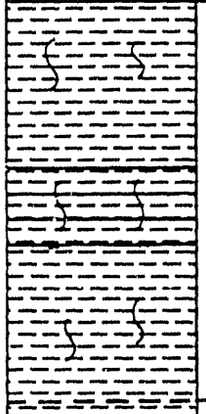
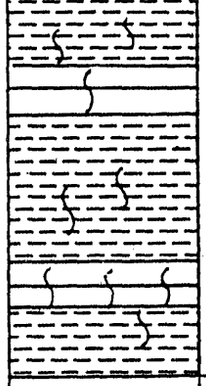
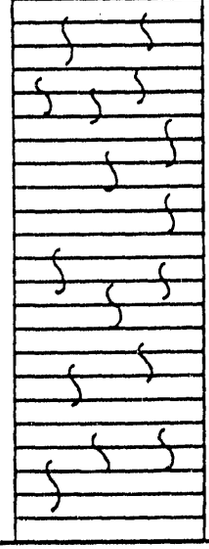
EXHAUST SHAFT

LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
3369	40		AS ABOVE
3364	45		
3359	50		
3354	55		DEWEY LAKE REDBEDS MUDSTONE INTERBEDDED WITH ARGILLACEOUS SILTSTONE, REDDISH-BROWN, THINLY LAMINATED TO THINLY BEDDED (1/8" TO 1"), BEDDING SLIGHTLY UNDULATORY, HARD; SEDIMENTARY STRUCTURES INCLUDE: SMALL TABULAR RIP-UP CLASTS (<1/4") ALIGNED IN THIN BEDS, CROSS LAMINATIONS, LOAD STRUCTURES, FILLED DESICCATION CRACKS; OCCASIONAL 1-1/2" INTERBEDS OF GRAY SILTSTONE; RARE GREENISH-GRAY REDUCTION SPOTS (<1/16" DIAMETER); BASAL CONTACT GRADATIONAL.
3349	60		
3344	65		
3339	70		
3334	75		
3329	80		
3324	85		

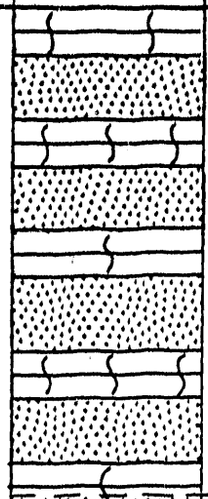
PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
3324	85		AS ABOVE
3319	90		MUDSTONE, REDDISH-BROWN, THINLY LAMINATED TO THINLY BEDDED, HARD; CONTAINS THIN BEDS (1/2" TO 1") OF GRAY SILTY MUDSTONE; FRACTURES PARALLEL TO BEDDING, SPACED 3"; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS (1/4" TO 1/2" DIAMETER); CONTAINS OCCASIONAL LOAD STRUCTURES; BASAL CONTACT DIFFUSE.
3314	95		SILTY MUDSTONE INTERBEDDED WITH ARGILLACEOUS SILTSTONE, REDDISH-BROWN, THINLY LAMINATED TO THINLY BEDDED (<1/32" TO 2-1/2"); OCCASIONAL GREENISH-GRAY SILTSTONE INTERBEDS; OCCASIONAL LOAD STRUCTURES; SMALL OPEN FRACTURES PARALLEL TO BEDDING, SPACED 1" TO 2-1/2"; FEW SUBVERTICAL FRACTURES, SPACED 1' TO 2.5'; BASAL CONTACT DIFFUSE.
3309	100		
3304	105		SANDSTONE, VERY FINE GRAINED, REDDISH-BROWN, THINLY LAMINATED TO CROSS-LAMINATED, HARD TO SOFT, RARE INTERBEDS OF SILTY MUDSTONE (1/2" TO 1" THICK); THIN (<1/32") SUBHORIZONTAL FRACTURES PARALLEL TO BEDDING, SPACED 3" TO 9"; TWO 1/2" THICK PARALLEL HORIZONTAL FRACTURES FILLED WITH CARBONATE OCCUR AT 108.0' AND 108.5'; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS; BASAL CONTACT DIFFUSE.
3299	110		
3294	115		SILTY MUDSTONE INTERBEDDED WITH MUDSTONE, REDDISH-BROWN, THINLY LAMINATED TO CROSS-LAMINATED, HARD; RARE GREENISH-GRAY REDUCTION SPOTS (1/16" TO 1/2" DIAMETER); OCCASIONAL 1/4" TO 2" THICK GREENISH-GRAY INTERBEDS; OCCASIONAL SOFT SEDIMENT DEFORMATION FEATURES; HORIZONTAL FRACTURES PARALLEL TO BEDDING, SPACED 1" TO 4"; BASAL CONTACT SHARP.
3289	120		SILTSTONE, REDDISH-BROWN, THINLY LAMINATED TO CROSS-LAMINATED; OCCASIONAL INTERBEDS OF SILTY MUDSTONE; LOAD STRUCTURES, MUDSTONE RIP-UP CLASTS; MODERATELY ABUNDANT GREENISH-GRAY REDUCTION SPOTS (1/16" TO 1/4" DIAMETER); OCCASIONAL GREENISH-GRAY BEDS (1/2" TO 2" THICK); THIN HORIZONTAL FRACTURES (<1/32") WITH GYPSUM FILLING BELOW 121.5', SPACED 2" TO 1.5'; BASAL CONTACT SHARP.
3284	125		
3279	130		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
3279	130		SILTY MUDSTONE, REDDISH-BROWN, THINLY LAMINATED (<1/32"), LOCALLY INTERBEDDED WITH SILTSTONE; CONTAINS CROSS-LAMINATIONS, FILLED DESICCATION CRACKS; SUBVERTICAL CLAY-FILLED FRACTURES OCCUR NEAR TOP, SPACED 3" TO 4"; LOCALLY, BEDDING MAY BE GREENISH-GRAY IN COLOR; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS (1/16" TO 1" DIAMETER); SUBHORIZONTAL GYPSUM-FILLED FRACTURES, SPACED 3" TO 6"; SUBVERTICAL FRACTURES SPACED 3" TO 12"; IN LOWER 3', 1/8" TO 3" THICK HORIZONTAL GREENISH-GRAY REDUCTION ZONES OCCUR IN GROUPS, INDIVIDUAL ZONES SPACED 1/2", GROUPS SPACED 0.8' TO 1.5'; BASAL CONTACT SHARP, MARKED BY 2" BED OF WHITISH-GRAY SILTSTONE WITH A GREENISH-GRAY REDUCTION ZONE ABOVE AND BELOW.
3274	135		
3269	140		MUDSTONE, DARK REDDISH-BROWN, INTERBEDDED WITH SILTY MUDSTONE, LIGHT REDDISH-BROWN, THINLY LAMINATED TO BEDDED (<1/32" TO 1/2"), LOCALLY FISSILE, OCCASIONALLY CROSS-LAMINATED, BEDDING MAY TERMINATE EROSIONALLY, STRUCTURES BECOMES LESS FINE BELOW 148.0'; RARE SUBVERTICAL TO HIGH ANGLE FRACTURES WITH GRANULAR GYPSUM FILLING (<1/8" THICK); FROM 132.5' TO 147.5', ABUNDANT SUBHORIZONTAL FRACTURES, SPACED 1'; ABUNDANT GREENISH-GRAY REDUCTION SPOTS (1/32" TO 2" DIAMETER); BASAL CONTACT GRADATIONAL.
3264	145		
3259	150		SILTY MUDSTONE, DARK REDDISH-BROWN, INTERBEDDED WITH SILTSTONE, REDDISH-BROWN, THINLY LAMINATED TO BEDDED (1/32" TO 1-1/2"), SOFT; OCCASIONALLY CROSS-LAMINATED, CONTAINS LOAD STRUCTURES, OVERALL SEDIMENTARY STRUCTURES ARE LESS FINE THAN OVERLYING UNIT, GRAIN SIZE COARSENS DOWNWARD; 1" TO 2" THICK HORIZONTAL GREENISH-GRAY REDUCED ZONES, SPACED 3" TO 5"; FRACTURES OCCUR BELOW 154.5', 1/8" THICK, FILLED WITH GYPSUM; SUBVERTICAL FRACTURES SPACED 2' TO 3', SUBHORIZONTAL FRACTURES SPACED 0.5' TO 1.5'; BASAL 2' CONTAINS GREENISH-GRAY AND REDDISH-BROWN INTERBEDDED MUDSTONE; ABUNDANT GREENISH-GRAY REDUCTION SPOTS (1/32" TO 1" DIAMETER); BASAL CONTACT SHARP.
3254	155		
3249	160		
3244	165		SILTSTONE, REDDISH-BROWN, THINLY LAMINATED TO STRUCTURELESS; BEDDING THICKENS AND THINS (1/2" TO 2"); OCCASIONAL GREENISH-GRAY BEDS 1/8" TO 1/2" THICK, SPACED 3.0'; ONLY A FEW HIGH ANGLE FRACTURES 1/8" THICK, GYPSUM-FILLED, STRIKING N60°W; AT 167.5' CHANNEL LAG CONGLOMERATE OCCURS CONTAINING SILTSTONE PEBBLES; THINLY LAMINATED SILTY MUDSTONE FROM 170.5' TO 171.3' WITH GREENISH-GRAY REDUCTION ZONES 1" TO 3" THICK, SPACED 4"; NEAR 171.3' BECOMES POORLY SORTED; THINLY LAMINATED WITH CROSS-LAMINATIONS AND EROSIONAL TERMINATIONS NEAR BASE; CONTAINS GREENISH-GRAY REDUCTION SPOTS UP TO 2" DIAMETER; BASAL CONTACT GRADATIONAL.
3239	170		
3234	175		

EXHAUST SHAFT
LITHOLOGIC LOG

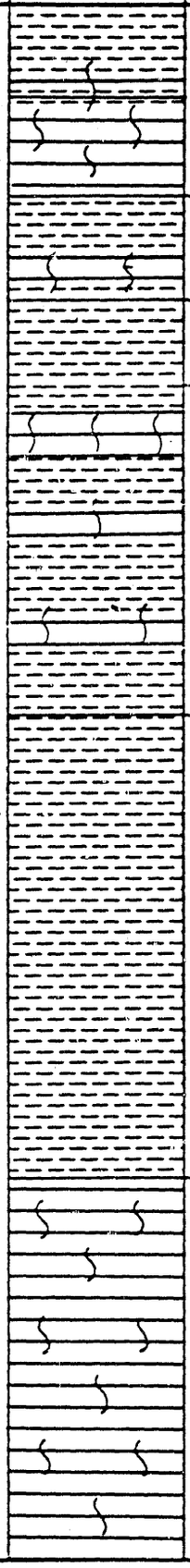
PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
3234	175		AS ABOVE
3229	180		
3224	185		MUDSTONE, REDDISH-BROWN, THINLY LAMINATED TO BEDDED (1/32" TO 1/2" THICK), SOFT; BEDDING INDISTINCT; RARE GREENISH-GRAY REDUCTION SPOTS TO 1" DIAMETER, REDUCTION SPOTS CONCENTRATED AROUND REDUCED, ..NISH-GRAY, 1" WIDE HORIZONTAL BAND AT 191.7', VERY FEW FRACTURES; BASAL 1.5' BECOMES SILTY; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY, OVERLYING BEDS DRAPE OVER CONTACT, EROSIONAL.
3219	190		
3214	195		SANDSTONE, VERY FINE GRAINED, GRAYISH-WHITE, HARD TO SOFT; TROUGH CROSS-BEDDING BECOMES APPARENT NEAR BASE; CONTAINS FIBROUS GYPSUM-FILLED FRACTURES WITH VARIABLE ORIENTATION, 1/4" TO 1" THICK; BASAL CONTACT SHARP.
3209	200		SANDSTONE AT TOP GRADING TO SILTSTONE, REDDISH-MAROON, LAMINATED TO BEDDED, OCCASIONALLY CROSS-LAMINATED, HARD; COLOR BECOMES WHITISH-MAROON TOWARD BASE; LOWER 1.3' IS SANDSTONE, STRUCTURELESS EXCEPT FOR OCCASIONAL INTERBEDS OF REDDISH-BROWN SILTSTONE; ABUNDANT FRACTURES, MOST HORIZONTAL TO SUBHORIZONTAL AND SLIGHTLY UNDULATORY, FILLED WITH FIBROUS GYPSUM, THICKNESS 1/16" TO 2", SPACED 1/8" TO 6"; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY.
3204	205		CLAYSTONE, REDDISH-BROWN, THINLY LAMINATED; CROSS-LAMINATED, SETS 1/2" ACROSS, BEDDING EROSIONALLY TERMINATED, CONTAINS SOFT SEDIMENT DEFORMATION FEATURES; BECOMES SILTY TOWARD BASE; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS TO 1/2" DIAMETER, SPOTS OCCASIONALLY BROKEN BY GYPSUM-FILLED FRACTURES; SEE FIGURE 6 FOR FRACTURE NOTES; BASAL CONTACT GRADATIONAL.
3199	210		MUDSTONE WITH INTERBEDDED SILTSTONE, DARK REDDISH-BROWN, THINLY LAMINATED, ABUNDANT CROSS-LAMINATIONS, BEDDING OFTEN TERMINATED EROSIONALLY; ABUNDANT SUBHORIZONTAL GYPSUM-FILLED FRACTURES, SPACED 6", 1/8" TO 3" THICK; VERTICAL AND SUBVERTICAL FRACTURES RARE; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS; BASAL CONTACT GRADATIONAL.
3194	215		
3189	220		

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
3189	220		SILTSTONE INTERBEDDED WITH VERY FINE SANDSTONE, REDDISH-BROWN, THINLY LAMINATED TO BEDDED, CROSS-LAMINATED, BEDS OFTEN EROSIONALLY TERMINATED, HARD; CROSS-LAMINATIONS INCREASE BELOW 223.0', HORIZONTAL EROSIONAL PLANES OCCUR BELOW 223.0', SPACED 1.0' TO 7.0'; SUBHORIZONTAL GYPSUM-FILLED FRACTURES ABUNDANT, 1/16" TO 1/4" THICK; RARE SUBVERTICAL FRACTURES; BASAL CONTACT GRADATIONAL.
3184	225		
3179	230		
3174	235		SANDSTONE, REDDISH-BROWN, SILTY, THINLY LAMINATED TO BEDDED, OCCASIONALLY CROSS-LAMINATED; ABUNDANT SUBHORIZONTAL GYPSUM-FILLED FRACTURES, 1/16" TO 1" THICK, SPACED 2" TO 1.0', FRACTURES BIFURCATE LOCALLY; RARE SUBVERTICAL GYPSUM-FILLED FRACTURES; BASAL CONTACT SHARP.
3169	240		
3164	245		
3159	250		SANDSTONE, REDDISH-BROWN, SILTY, STRUCTURELESS EXCEPT RARE CROSS-LAMINATIONS AND HORIZONTAL LAMINATIONS; FEWER GYPSUM-FILLED FRACTURES THAN OVERLYING UNIT, FRACTURES TO 2" THICK; BASAL CONTACT GRADATIONAL.
3154	255		
3149	260		SANDSTONE, REDDISH-BROWN, SILTY, LOCALLY LAMINATED AND CROSS-LAMINATED; OCCASIONAL SUBHORIZONTAL GYPSUM-FILLED FRACTURES, 1/4" TO 1/2" THICK, SPACED 2.8' TO 3.4'. FRACTURES BIFURCATE LOCALLY; SUBVERTICAL FRACTURES RARE; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS TO 1" DIAMETER; BASAL 1.0' CONSISTS OF REDDISH-BROWN SILTSTONE; BASAL CONTACT GRADATIONAL.
3144	265		

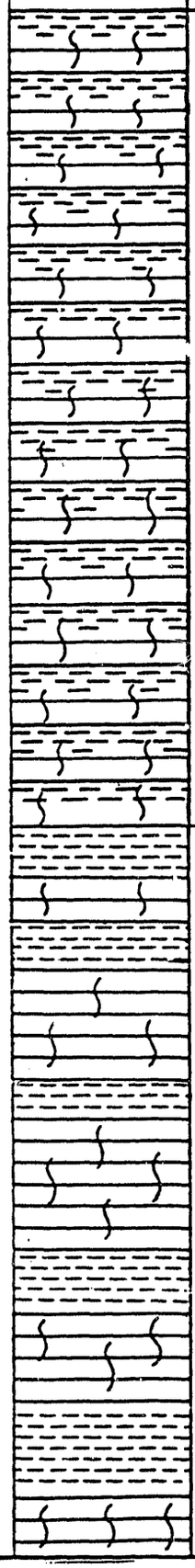
EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
3144	265		AS ABOVE
			SANDSTONE, RETTISH-BROWN, SILTY, MOSTLY MASSIVE WITH SOME LOCAL LAMINATIONS AND CROSS-BEDDING; SUBHORIZONTAL AND SUBVERTICAL GYPSUM-FILLED FRACTURES, SUBHORIZONTAL MORE ABUNDANT, SEE FIGURE 7; BASAL CONTACT GRADATIONAL.
3139	270		
3134	275		
3129	280		ARGILLACEOUS SILTSTONE, REDDISH-BROWN, THINLY LAMINATED TO LAMINATED (1/16" TO 1/4" THICK); ABUNDANT SEDIMENTARY STRUCTURES INCLUDING: TROUGH CROSS-LAMINATIONS, EROSIONAL SURFACES TRACEABLE AROUND CIRCUMFERENCE OF SHAFT, SOFT SEDIMENT DEFORMATION FEATURES; CROSS-LAMINATION SETS ARE 1" TO 4" ACROSS, INCREASING TO 2.0' TO 3.0' ACROSS NEAR BASE; LOWER 1.0' CONTAINS 1/4" THICK BEDS OF CLAYSTONE; HORIZONTAL AND SUBHORIZONTAL GYPSUM-FILLED FRACTURES 1/4" TO 1" THICK, SPACED 0.5' TO 2.0'; VERTICAL AND SUBVERTICAL GYPSUM-FILLED FRACTURES 1/8" TO 1/4" THICK, SPACED 3.0' TO 5.0'; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS TO 1" DIAMETER; BASAL CONTACT SHARP, MARKED BY OCCURRENCE OF A MUDSTONE BED.
3124	285		
3119	290		MUDSTONE INTERBEDDED WITH SILTY CLAYSTONE, REDDISH-BROWN, THINLY LAMINATED TO VERY THINLY BEDDED (<1/16" TO 1/2" THICK); ABUNDANT SETS OF TROUGH CROSS-LAMINATIONS 1" TO 4" ACROSS, CLAY DRAPE OVER RIPPLE CROSS-LAMINATIONS; OCCASIONAL SOFT SEDIMENT DEFORMATION; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS (1/16" TO 1/2" DIAMETER); UNIT BOUNDED BY HORIZONTAL GYPSUM-FILLED FRACTURES, 1" THICK AT TOP GRADING TO 1/2" THICK AT BASE; BASAL CONTACT SHARP.
3114	295		MUDSTONE AT TOP GRADING TO SILTSTONE AT BASE, REDDISH-BROWN, THINLY LAMINATED TO THINLY BEDDED (1/6" TO 1" THICK); ABUNDANT FINE STRUCTURES INCLUDING: FLASER BEDDING, CROSS-LAMINATIONS, TROUGH CROSS-LAMINATIONS, FILLED DESICCATION CRACKS, LOAD STRUCTURES, ABUNDANT EROSIONAL CONTACTS; GYPSUM-FILLED FRACTURES ARE MODERATELY ABUNDANT, 1/16" TO 1-1/2" THICK, HORIZONTAL AND SUBHORIZONTAL FRACTURES SPACED 1.0' TO 4.0', VERTICAL AND SUBVERTICAL FRACTURES SPACED 3.0' TO 5.0'; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS (1/16" TO 1" DIAMETER); RARE 2" THICK, SUBHORIZONTAL, GREENISH-GRAY REDUCED ZONES; BASAL CONTACT SHARP.
3109	300		
3104	305		
			AS BELOW
3099	310		

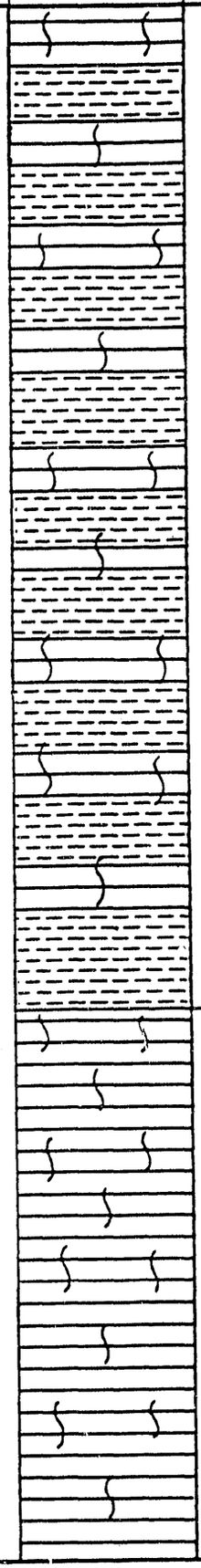
EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
3099	310		MUDSTONE AT TOP, GRADING TO SILTSTONE, DARK REDDISH-BROWN TO REDDISH-BROWN, WITH MINOR INTERBEDDED MUDSTONE, THINLY LAMINATED TO LAMINATED (<1/32" TO 1/8"), HARD; CROSS-LAMINATED, BECOMING MORE ABUNDANT WITH DEPTH; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS (1/16" TO 1/4" DIAMETER); FIBROUS GYPSUM-FILLED FRACTURES BECOME LESS ABUNDANT WITH DEPTH; HORIZONTAL AND SUBHORIZONTAL FRACTURES 1/16" TO 1" THICK, SPACED 2" TO 2.0'; VERTICAL AND SUBVERTICAL FRACTURES 1/16" TO 1/4" THICK, SPACED 2" TO 2.0'; BASAL CONTACT SHARP.
3094	315		
			MUDSTONE AT TOP, GRADING TO SILTSTONE WITH DEPTH, DARK REDDISH-BROWN TO REDDISH-BROWN, UNIT SIMILAR TO ABOVE EXCEPT FOR A 3" THICK BED OF MUDSTONE WHICH OCCURS AT 316.2' AND HAS A SHARP UPPER CONTACT AND GRADES TO SILTSTONE WITH DEPTH, HARD; MUDSTONE: STRUCTURELESS; SILTSTONE: FINELY LAMINATED TO CROSS-LAMINATED; FRACTURES SIMILAR TO OVERLYING UNIT; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS TO 1" DIAMETER; BASAL CONTACT MARKED BY 3" THICK SUBHORIZONTAL GREENISH-GRAY ZONE AND DARK REDDISH-BROWN MUDSTONE, SHARP.
3089	320		
			MUDSTONE, REDDISH-BROWN, STRUCTURELESS; FRACTURES SIMILAR TO OVERLYING UNIT; BASAL CONTACT GRADATIONAL.
			CLAYSTONE, DARK REDDISH-BROWN, INTERBEDDED WITH SILTSTONE, LIGHT REDDISH-BROWN, MICRO-LAMINATED TO VERY THINLY BEDDED (<1/32" TO 1/2"); SILTSTONE: CROSS-LAMINATED; CLAYSTONE: STRUCTURELESS; ABUNDANT GREENISH-GRAY REDUCTION SPOTS; GRADES TO SILTSTONE AT BASE; ALL FRACTURES FILLED WITH FIBROUS GYPSUM; HORIZONTAL AND SUBHORIZONTAL FRACTURES 1/8" TO 1" THICK, SPACED 3" TO 2.0'; VERTICAL AND SUB-VERTICAL FRACTURES 1/16" TO 1/4" THICK, SPACED 2.0' TO 3.0'; BASAL CONTACT SHARP.
3084	325		
3079	330		
			CLAYSTONE, DARK REDDISH-BROWN, MICRO-LAMINATED TO THINLY LAMINATED (<1/32" TO 1/16"), STRUCTURE POORLY DEFINED DUE TO ABUNDANT FRACTURING, OCCASIONAL CROSS-LAMINATIONS, BEDDING OFTEN CONVOLUTED AND EROSIONALLY TERMINATED; ABUNDANT GREENISH-GRAY REDUCTION SPOTS (1/16" TO 1" DIAMETER); ABUNDANT GYPSUM-FILLED FRACTURES, ~90% HORIZONTAL AND SUBHORIZONTAL; TWO SCALES OF SPACING: MINOR - 1/8" TO 2", MAJOR - 2" TO 6". FRACTURE DENSITY INCREASES TOWARD BASE, THICKNESS VARIES FROM 1/16" TO 1.0'; REMAINING ~10% VERTICAL AND SUBVERTICAL FRACTURES, SPACED 2" TO 2.5', THICKNESS 1/16" TO 1/4"; BASAL CONTACT SHARP.
3074	335		
3069	340		
			SILTSTONE, REDDISH-BROWN, LAMINATED TO BEDDED, CROSS-LAMINATED, SOFT SEDIMENT DEFORMATION FEATURES, HARD; ALL FRACTURES FILLED WITH FIBROUS GYPSUM; SUBHORIZONTAL AND HORIZONTAL FRACTURES 1/16" TO 1" THICK, SPACED 1" TO 1.0'; VERTICAL AND SUBVERTICAL FRACTURES 1/8" TO 1/2" THICK, SPACED 6" TO 2.0'; ABUNDANT GREENISH-GRAY REDUCTION SPOTS 1/16" TO 1" DIAMETER; BASAL CONTACT SHARP.
3064	345		
3059	350		
3054	355		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
3054	355		MUDSTONE GRADING TO SILTSTONE IN VERTICAL GRADATIONAL SEQUENCES 1.0' TO 3.0' THICK, REDDISH-BROWN (SILTSTONE) AND DARK REDDISH-BROWN (MUDSTONE), EACH SEQUENCE CONSISTS OF STRUCTURELESS MUDSTONE AT TOP GRADING TO THINLY LAMINATED TO BEDDED SILTSTONE AT BASE; AMOUNT OF SEDIMENTARY STRUCTURES INCREASE TO BASE OF EACH SEQUENCE, THESE STRUCTURES INCLUDE: CROSS-LAMINATIONS, TROUGH CROSS-LAMINATIONS, EROSIONAL SURFACES, OCCASIONAL SOFT SEDIMENT DEFORMATION FEATURES; UPPER CONTACT OF EACH SEQUENCE IS EROSIONAL; OCCASIONAL GREENISH-GRAY REDUCTION SPOTS (1/16" TO 1" DIAMETER); ALL FRACTURES GYPSUM-FILLED; VERTICAL AND HIGH ANGLE FRACTURES APPEAR YOUNGER THAN HORIZONTAL AND SUBHORIZONTAL FRACTURES; SUBHORIZONTAL FRACTURE FILLING OCCASIONALLY SIGMOIDAL AND/OR TILTED; FILLING IN VERTICAL AND HIGH ANGLE FRACTURES HAVE A COMPONENT OF THRUST; THREE TYPES OF HORIZONTAL AND SUBHORIZONTAL FRACTURES; THICK - 1/2" TO 1", SPACED 1.0' TO 2.0'; MODERATELY THIN - 1/8" TO 1/2:, SPACED 1" TO 1.5'; THIN - <1/8", SPACED 1/4" TO 1"; BASAL CONTACT SHARP.
3049	360		
3044	365		
3039	370		
3034	375		
3029	380		SILTSTONE, REDDISH-BROWN, WITH INTERBEDDED CLAYSTONE, DARK REDDISH-BROWN, 1" TO 4" THICK FINING UPWARD SEQUENCES, THINLY LAMINATED TO THINLY BEDDED (1/16" TO 2" THICK), HARD; SEDIMENTARY STRUCTURES INCLUDE: CROSS-LAMINATIONS, SOFT SEDIMENT LOAD STRUCTURES, EROSIONAL CONTACTS AT TOP OF EACH FINING UPWARD SEQUENCE; LOCALLY ABUNDANT GREENISH-GRAY REDUCTION SPOTS (1/16" TO 1" DIAMETER), SOME OCCUR IN ALIGNED ZONES; OVERALL GRAIN SIZE INCREASES TO BASE; ABUNDANT HORIZONTAL, FIBROUS GYPSUM-FILLED FRACTURES OCCUR IN TWO SIZE GROUPS: 0" TO 1/4" THICK, SPACED 1/4" TO 1"; 1/4" TO 1/2" THICK, SPACED 0.5' TO 2.0'; VERTICAL AND HIGH ANGLE FIBROUS GYPSUM-FILLED FRACTURES ARE MODERATELY ABUNDANT, 1/16" TO 1/2" THICK, SPACED 2.5' TO 5'; BASAL CONTACT SHARP, UNDULATORY, POSSIBLY EROSIONAL.
3024	385		
3019	390		
3014	395		
3009	400		

EXHAUST SHAFT
LITHOLOGIC LOG
SHEET 10 OF 49

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
3009	400		SILTSTONE, REDDISH-BROWN, WITH INTERBEDDED CLAYSTONE, DARK REDDISH-BROWN, 1" TO 4" THICK FINING UPWARD SEQUENCES, THINLY LAMINATED TO THINLY BEDDED (1/16" TO 2" THICK), HARD; SEDIMENTARY STRUCTURES INCLUDE: CROSS-LAMINATIONS, SOFT SEDIMENT LOAD STRUCTURES, EROSIONAL CONTACTS AT TOP OF EACH FINING UPWARD SEQUENCE; LOCALLY ABUNDANT GREENISH-GRAY REDUCTION SPOTS (1/16" TO 1" DIAMETER), SOME OCCUR IN ALIGNED ZONES; OVERALL GRAIN SIZE INCREASES TO BASE; ABUNDANT HORIZONTAL, FIBROUS GYPSUM-FILLED FRACTURES OCCUR IN TWO SIZE GROUPS: 0" TO 1/4" THICK, SPACED 1/4" TO 1"; 1/4" TO 1/2" THICK, SPACED 0.5' TO 2.0'; VERTICAL AND HIGH ANGLE FIBROUS GYPSUM-FILLED FRACTURES ARE MODERATELY ABUNDANT, 1/16" TO 1/2" THICK, SPACED 2.5' TO 5'; BASAL CONTACT SHARP, UNDULATORY, POSSIBLY EROSIONAL.
3004	405		
2999	410		
2994	415		
2989	420		
2984	425		
2979	430		SILTSTONE AT TOP, GRADING TO CLAYSTONE AT BASE, REDDISH-BROWN TO DARK REDDISH-BROWN, TRACE OF BEDDING AT TOP GRADING TO STRUCTURELESS AT BASE, HARD; CONTAINS OCCASIONAL CLAYSTONE CLASTS <1/8" DIAMETER; RARE INTERBEDS OF CLAYSTONE, 1/16" THICK; ABUNDANT GREENISH-GRAY REDUCTION SPOTS (1/16" TO 2" DIAMETER) OCCUR IN ZONES; ABUNDANT HORIZONTAL AND SUBHORIZONTAL FIBROUS GYPSUM-FILLED FRACTURES, MAJORITY 1/16" THICK, SPACED 1" TO 2"; MODERATELY ABUNDANT VERTICAL AND SUBVERTICAL FIBROUS GYPSUM-FILLED FRACTURES UP TO 1/4" THICK, SPACED 1.0' TO 3.0'; BASAL CONTACT OBSCURED.
2974	435		
2969	440		
2964	445		

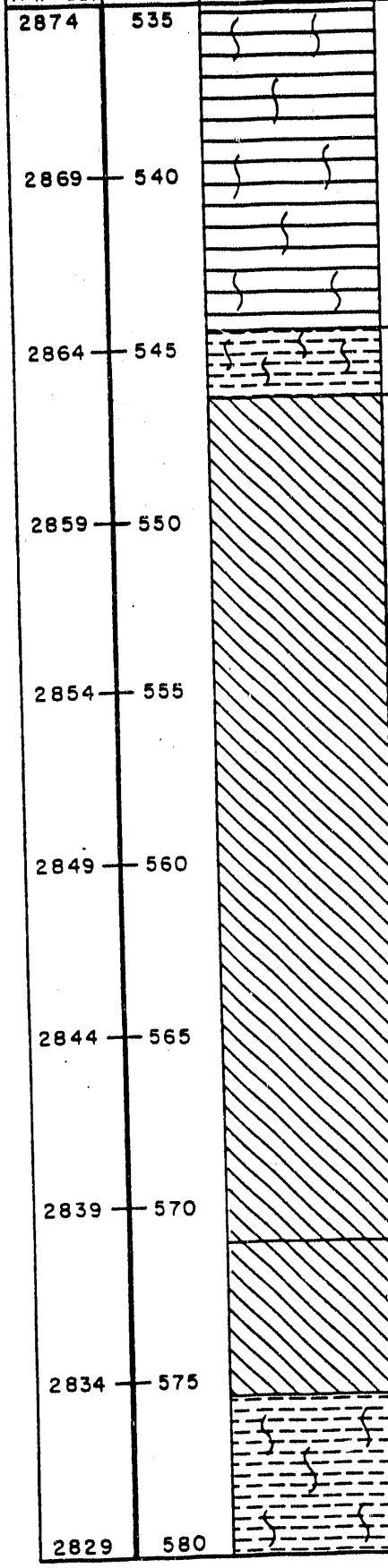
EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2964	445		AS ABOVE
2959	450		
2954	455		
		OBSCURED	SLIGHTLY SANDY SILTSTONE, REDDISH-BROWN, INTERBEDDED WITH SILTY-MUDSTONE, DARK REDDISH-BROWN, 1" THICK FINING UPWARDS SEQUENCES, THINLY BEDDED (1"); MINOR EROSIONAL CONTACTS AT TOP OF EACH FINING UPWARD SEQUENCE; HORIZONTAL AND SUBHORIZONTAL FIBROUS GYPSUM-FILLED FRACTURES <1/8" THICK, SPACED 0" TO 6"; SUBVERTICAL AND VERTICAL FIBROUS GYPSUM-FILLED FRACTURES ARE LESS ABUNDANT AND CROSS-CUT HORIZONTAL AND SUBHORIZONTAL FRACTURES; BASAL CONTACT SHARP.
2949	460		
2944	465		SILTSTONE AT TOP GRADING TO CLAYSTONE AT BASE, REDDISH-BROWN TO DARK REDDISH-BROWN, TRACE OF BEDDING AT TOP GRADING TO STRUCTURELESS AT BASE, HARD; ABUNDANT GREENISH-GRAY REDUCTION SPOTS (1/16" TO 2" DIAMETER); HORIZONTAL AND SUBHORIZONTAL FIBROUS GYPSUM-FILLED FRACTURES <1/8" THICK; SUBVERTICAL AND VERTICAL GYPSUM-FILLED FRACTURES ARE LESS ABUNDANT AND CROSS-CUT HORIZONTAL AND SUBHORIZONTAL FRACTURES; BASAL CONTACT SHARP.
2939	470		
2934	475		
2929	480		
			MUDSTONE, SILTY, DARK REDDISH-BROWN, STRUCTURELESS; NO HORIZONTAL OR SUBHORIZONTAL GYPSUM-FILLED FRACTURES; RARE SUBVERTICAL AND VERTICAL FRACTURES PRESENT, 0" TO 1/2" THICK; BASAL CONTACT GRADATIONAL.
2924	485		
2919	490		

EXHAUST SHAFT
LITHOLOGIC LOG
SHEET 12 OF 49

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2919	490		AS ABOVE
2914	495		
2909	500		CLAYSTONE GRADING TO SILTSTONE WITH DEPTH, REDDISH-BROWN TO DARK REDDISH-BROWN, THIN 1" TO 3" THICK FINING UPWARDS SEQUENCES, THINLY BEDDED; CONTAINS MINOR EROSIONAL CONTACTS AT TOP OF EACH FINING UPWARDS SEQUENCE; ABUNDANT HORIZONTAL AND SUBHORIZONTAL FIBROUS GYPSUM-FILLED FRACTURES 0" TO 1/8" THICK, SPACED 0" TO 6"; MODERATELY ABUNDANT VERTICAL AND SUBVERTICAL FIBROUS GYPSUM-FILLED FRACTURES 1/8" TO 1/2" THICK; BASAL CONTACT SHARP.
2904	505		
2899	510		
2894	515		
2889	520		
2884	525		SILTSTONE, (FIGURE 9).
2879	530		
2874	535		

EXHAUST SHAFT
LITHOLOGIC LOG



REMARKS

SILTSTONE

RUSTLER FORMATION

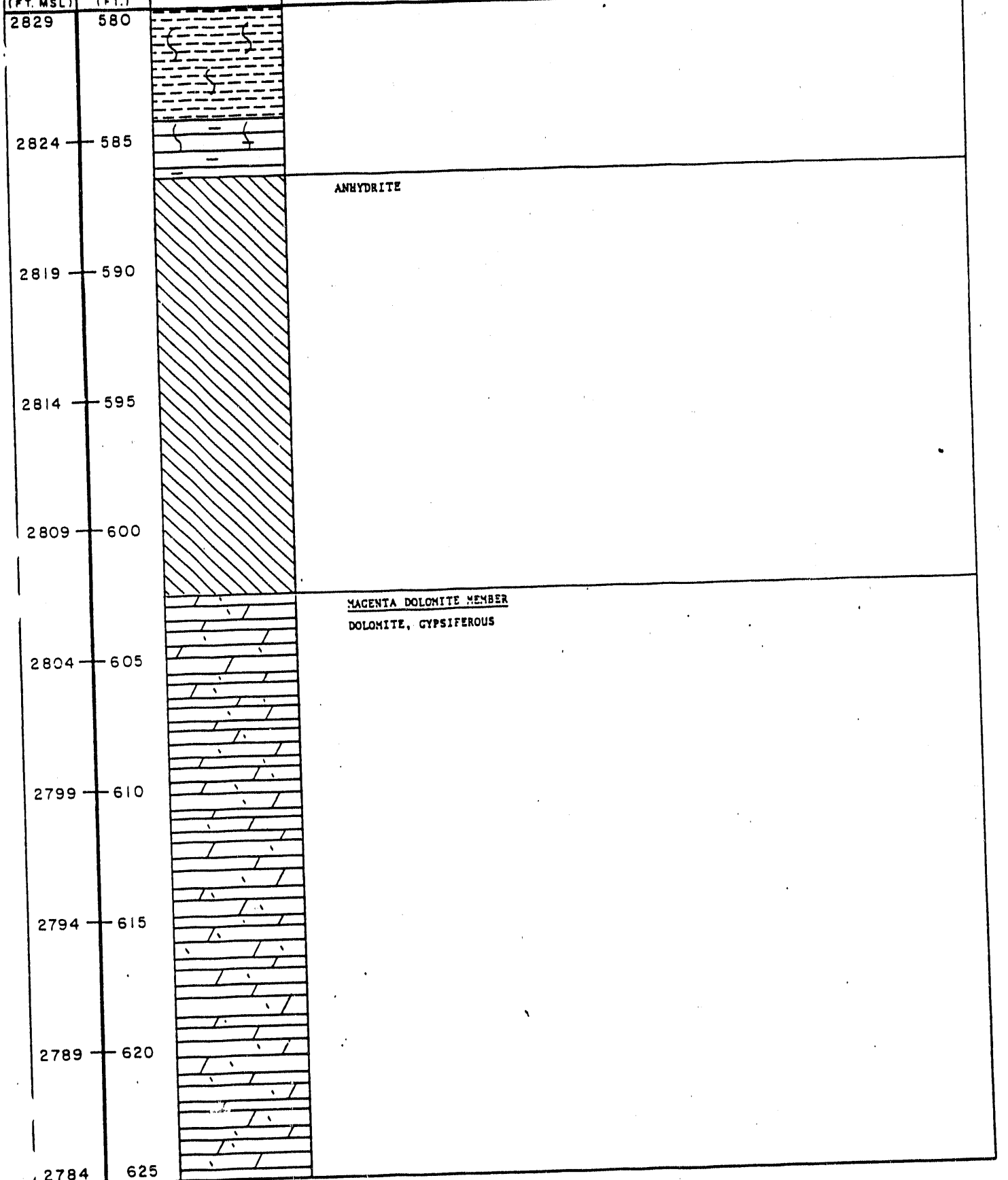
FORTY-NINER MEMBER

ANHYDRITE, FINELY CRYSTALLINE, GRAY TO GRAYISH-BROWN, WHITE AT UPPER CONTACT, BANDED TO OCCASIONALLY LAMINATED, SPACED 1/16" TO 1"; BANDS AND LAMINAE UNDULATORY UP TO 1/4" AND OCCASIONALLY TERMINATE ABRUPTLY, GRAY BANDS USUALLY THICKEST, BECOME STRUCTURELESS WITH DEPTH, LOCALLY NODULAR; UPPER 3.0' CONTAINS INTERBEDDED CLAY LAMINAE, CONTENT DECREASING WITH DEPTH; LOCALLY GYPSIFEROUS IN UPPER 6"; NEAR TOP, HORIZONTAL AND SUBHORIZONTAL GYPSUM-FILLED FRACTURES ARE ABUNDANT, 1/8" TO 1/2" THICK, SPACED 1" TO 3"; BEDDING TERMINATED EROSIONALLY AT UPPER CONTACT; HORIZONTAL AND SUBHORIZONTAL GYPSUM-FILLED FRACTURES SPACED 1" TO 2.0', 1/16" TO 1/4" THICK; RARE VERTICAL AND SUBVERTICAL GYPSUM-FILLED FRACTURES, 1/8" TO 1/4" THICK, SPACED 2.0' TO 6.0'; BASAL CONTACT SHARP.

ANHYDRITE

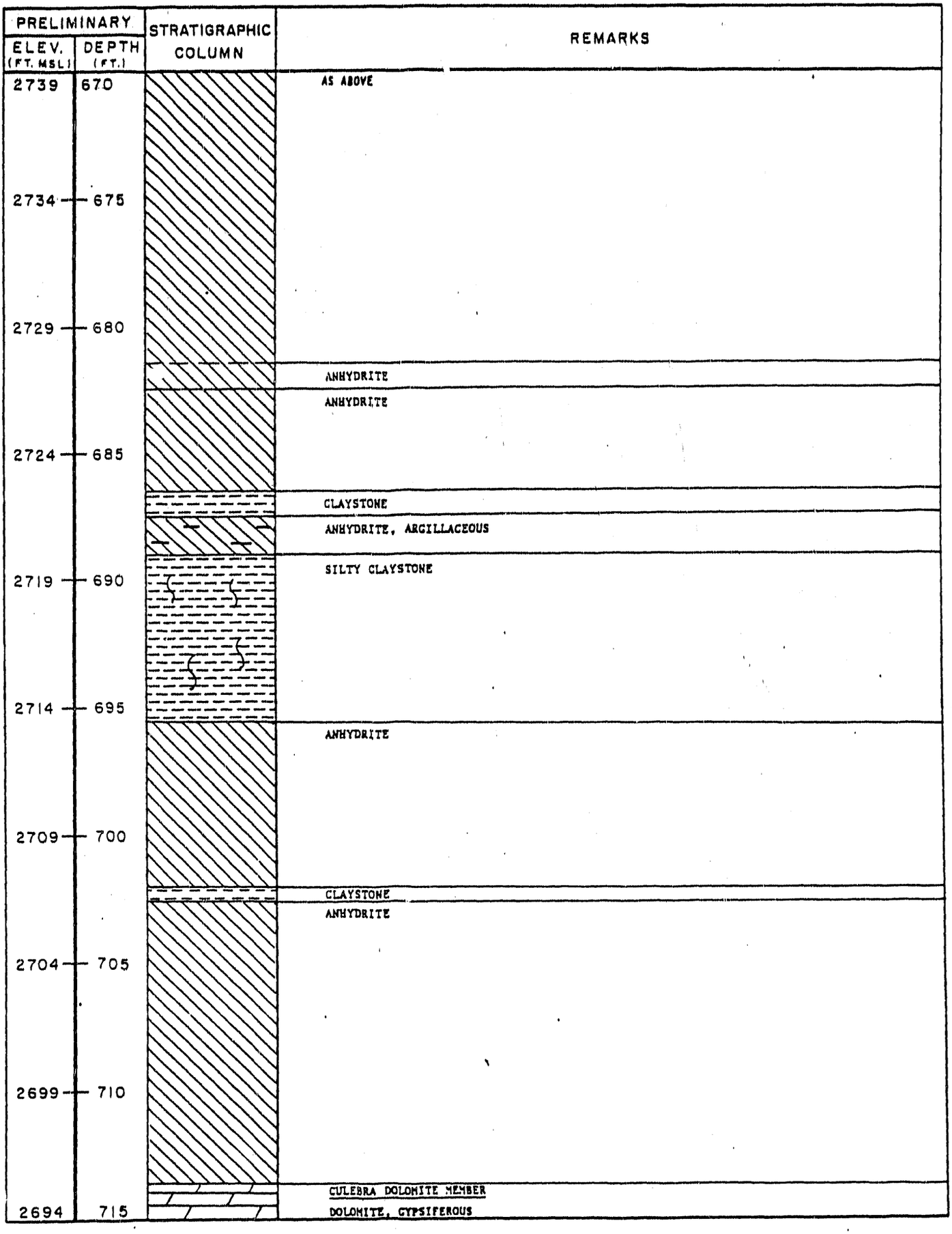
SILTY CLAYSTONE

EXHAUST SHAFT
LITHOLOGIC LOG

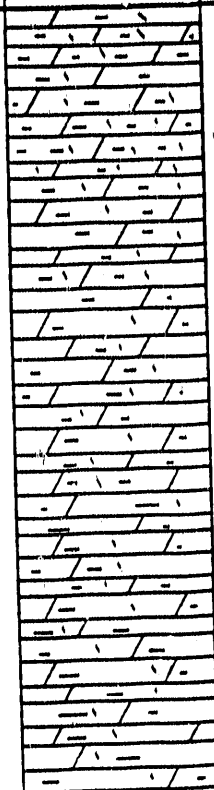


EXHAUST SHAFT
LITHOLOGIC LOG
SHEET 15 OF 49

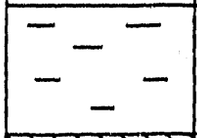
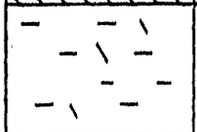
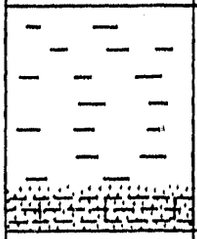
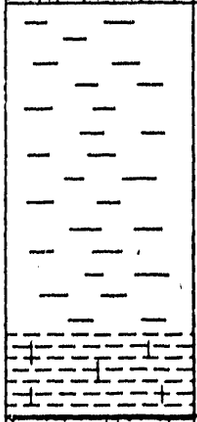
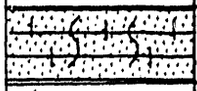
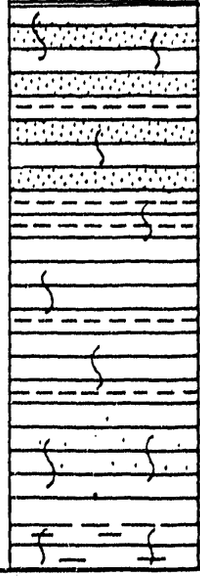
PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2784	625		
2779	630		TAMARISK MEMBER ANHYDRITE, FINELY CRYSTALLINE, GRAY TO LIGHT BROWNISH-GRAY TO TAN WITH DEPTH, LAMINATED TO NODULAR, HARD; LOCALLY GYPSIFEROUS AT UPPER CONTACT; CONTAINS INTERBEDS OF LAMINATED CARBONATE LOCALLY AND NEAR BASE; LAMINAE MAY LOCALLY BE TERMINATED EROSIONALLY; 1" TO 2" THICK ORGANIC (?) BLACK CLAYSTONE AT 665.9', CONTAINS FIBROUS GYPSUM-FILLED FRACTURES, FIBERS ORIENTED VERTICALLY, 1/32" TO 1" THICK, DISCONTINUOUS, LOCALLY BIFURCATING; HORIZONTAL FIBROUS GYPSUM-FILLED FRACTURES THROUGHOUT WITH SPACING 0.5' TO 1.5', 1/32" TO 1/16" THICK; RARE SUBVERTICAL FRACTURES; BASAL CONTACT GRADATIONAL.
2774	635		
2769	640		
2764	645		
2759	650		
2754	655		
2749	660		
2744	665		
2739	670		



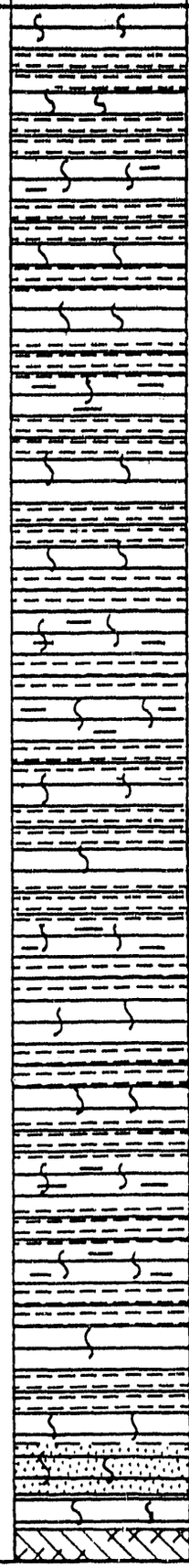
EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2694	715		AS ABOVE
2689	720		
2684	725		
2679	730		
2674	735		
			UNNAMED LOWER MEMBER SILTY CLAYSTONE
2669	740		
2664	745		ANHYDRITE
2659	750		
2654	755		SANDY MUDSTONE
			HALITIC MUDSTONE OR ARGILLACEOUS HALITE
2649	760		

EXHAUST SHAFT
LITHOLOGIC LOG
SHEET 18 OF 49

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2649	760		AS ABOVE
2644	765		HALITE
			ANHYDRITE
2639	770		HALITE, ARGILLACEOUS HALITE
2634	775		ARGILLACEOUS HALITE AND HALITIC MUDSTONE
2629	780		ARGILLACEOUS HALITE AND HALITIC MUDSTONE
2624	785		
2619	790		SANDY HALITIC SILTSTONE
2614	795		SILTSTONE AND SANDY SILTSTONE, LIGHT BROWN TO REDDISH-BROWN WITH THIN LAYERS OF MEDIUM GRAY CLAYSTONE AND MUDSTONE, THINLY BEDDED TO LAMINATED, DIVISIBLE INTO UNITS 8" TO 20" THICK; BEDDING AND LAMINATIONS GENERALLY HORIZONTAL TO SUBHORIZONTAL, SOME WAVY BEDDING, SOME MICRO CROSS-LAMINATIONS; FROM 792.0' TO 795.0' LARGER CROSS-CUTTING RELATIONSHIPS WITH SOME UNITS PARTIALLY TO WHOLLY EROSIONALLY REMOVED, UNITS GENERALLY DOWN-CUT TO EAST AND SOUTHEAST; SMALL-SCALE CROSS-BEDDING HAS VARIABLE CURRENT DIRECTIONS WITH DEPTH, MOST SOUTH; AT 794.0' SYMMETRICAL RIPPLES WITH CLAY DRAPE; RIPPLE SETS 1/4" TO 1/2" THICK; MINOR SOFT SEDIMENT DEFORMATION, LOCAL FINING UPWARDS SEQUENCES; BASAL CONTACT GRADATIONAL.
2609	800		
2604	805		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2604	805		SILTSTONE AND ARGILLACEOUS SILTSTONE INTERBEDDED WITH CLAYSTONE, GRAY AND DARK GRAY, THINLY LAMINATED (1/32" TO 1/8"); ABUNDANT FINE STRUCTURES INCLUDING HORIZONTAL LAMINATIONS, LOW-ANGLE CROSS-LAMINATION SETS OF VARYING SIZE (2" TO 3.0'); CURRENT DIRECTIONS IN SMALLER SETS VARY, CURRENT DIRECTIONS IN LARGER SETS MOSTLY NORTHEAST; RARE LOAD STRUCTURES, EROSIONAL SCOUR AND FILL; RARE HIGH-ANGLE HALITE-FILLED FRACTURES; FRACTURE OCCURRENCE INCREASES WITH DEPTH, NEAR BASE RARE HORIZONTAL AND SUBVERTICAL HALITE-FILLED FRACTURES 1/8" TO 3" THICK, SPACED 3.0' TO 8.0'; SOME LARGER SUBHORIZONTAL FRACTURES EXHIBIT AN EAST (TOP) WEST (BOTTOM) SHEAR; CONTAINS DARK GRAY SPOTS AND BLEBS (BIOTURBATION), CONTENT INCREASING WITH DEPTH; BECOMES ARGILLACEOUS SILTSTONE WITH DEPTH; GRAY WITH LOCAL REDDISH-BROWN AREAS, THINLY LAMINATED AND CONTAINS BROWNISH CLASTS OF ANHYDRITE (1/8" TO 1-1/2" DIAMETER) ROUNDED AND OCCASIONALLY FLATTENED PARALLEL TO BEDDING; CLASTS RANDOMLY SCATTERED THROUGHOUT; RARE LOW-ANGLE CROSS-LAMINATION SETS; BASAL CONTACT GRADATIONAL OVER 1/2", IRREGULAR, MAPPED AS DIFFUSE DUE TO EXTREME CONTACT UNDULATIONS.
2599	810		
2594	815		
2589	820		
2584	825		
2579	830		
2574	835		
2569	840		
2564	845		
			SANDY SILTSTONE
			SILTSTONE
2559	850		POLYHALITE, ANHYDRITE, AND ARGILLACEOUS ANHYDRITE

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2559	850		SALADO FORMATION HALITIC MUDSTONE
2554	855		HALITE
2549	860		HALITE
2544	865		HALITIC CLAYSTONE
			HALITE
2539	870		
2534	875		HALITIC CLAYSTONE
			HALITE
2529	880		HALITIC CLAYSTONE
			ARGILLACEOUS HALITE
2524	885		CLAYSTONE, SLIGHTLY HALITIC
2519	890		HALITE, ARGILLACEOUS
2514	895		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2514	895		
			ARGILLACEOUS HALITE
			HALITE
2509	900		
			ARGILLACEOUS HALITE
2504	905		HALITE, SLIGHTLY ARGILLACEOUS
2499	910		
			HALITE, COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE, THINLY BEDDED WITH THIN SUBHORIZONTAL STRINGERS OF ANHYDRITE AND POLYHALITE; SLIGHTLY ARGILLACEOUS IN UPPER 0.5'; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY.
2494	915		SILTY CLAYSTONE, BROWNISH-RED, VERY SOFT; HALITIC, HALITE OCCURS AS 1/4" TO 1" DISPLACIVE CRYSTALS; CONTAINS LOCALLY REDUCED CLAYSTONE; BASAL CONTACT DIFFUSE, GENETICALLY GRADATIONAL.
2489	920		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; CONTAINS INTERSTITIAL RED CLAY IN UPPER 3.0', CONTENT DECREASES WITH DEPTH; TRACE RANDOMLY ORIENTED STRINGERS OF POLYHALITE IN REMAINDER OF UNIT; BASAL CONTACT DIFFUSE.
2484	925		HALITE MIXED WITH POLYHALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR; POLYHALITE CONTENT DECREASES WITH DEPTH, CONTENT GREATEST IN UPPER 0.5', OCCURS AS GROUPS OF SUBHORIZONTAL STRINGERS, BECOMING LESS ABUNDANT WITH DEPTH; SUBHORIZONTAL STRINGERS OF ANHYDRITE OCCUR WITH DEPTH, STRINGERS OF POLYHALITE AND ANHYDRITE BECOME RANDOMLY ORIENTED WITH DEPTH; BASAL CONTACT GRADATIONAL.
2479	930		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO ORANGE TO CLEAR; ABUNDANT POLYHALITE IN UPPER 3" TINTS HALITE ORANGE; SUBHORIZONTAL STRINGERS OF POLYHALITE AND ANHYDRITE SPACED 1" TO 3"; BED OF VERY POLYHALITIC HALITE OCCURS BETWEEN 729.4' AND 730.0', UNIDENTIFIED GAS ORIGINATES FROM THIS AREA ALONG FRACTURES; BASAL CONTACT DIFFUSE.
2474	935		ARGILLACEOUS HALITE, ARGILLACEOUS MATERIAL REDDISH-BROWN, HALITE WHITISH-GRAY TO CLEAR; HALITE OCCURS AS DISPLACIVE CRYSTALS AND AGGREGATES OF CRYSTALS; UNIT CONTAINS LOCAL GREENISH-GRAY REDUCTION ZONES; CLAY CONTENT DECREASES WITH DEPTH, DECREASES ABRUPTLY BELOW 937.0'; ROCK BELOW 937.0' CLASSIFIED AS: HALITE, WHITE, MEDIUM TO COARSELY CRYSTALLINE, SLIGHTLY ARGILLACEOUS, CLAY CONTENT DECREASING WITH DEPTH, TRACE POLYHALITE AND ANHYDRITE STRINGERS CONTENT INCREASING WITH DEPTH, STRINGERS RANDOMLY ORIENTED AT TOP, BECOMING SUBHORIZONTAL WITH DEPTH, SPACED 1" TO 3"; BASAL CONTACT GRADATIONAL, MARKED BY 1" THICK ZONE OF GRAYISH-WHITE HALITE.
2469	940		

EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2469	940		AS ABOVE
2464	945		
2459	950		ARGILLACEOUS HALITE, FINELY TO COARSELY CRYSTALLINE, WHITISH-GRAY TO CLEAR, MASSIVE; HALITE OCCURS AS CRYSTAL AGGREGATES IN ZONES OR PODS; CLAY CONTENT DECREASES ABRUPTLY BELOW 949.0'; TRACE DISSEMINATED POLYHALITE BLEBS, CONTENT INCREASES WITH DEPTH; BECOMES BEDDED IN LOWER 2.0' WITH ALTERNATING POLYHALITIC HALITE AND CLEAR HALITE BEDS 2" TO 3" THICK; BASAL CONTACT SHARP, DISCONFORMABLE.
2454	955		
2449	960		ARGILLACEOUS HALITE IN UPPER 2.0', REDDISH-BROWN, CLAY CONTENT DECREASES WITH DEPTH, GRADES INTO POLYHALITIC HALITE; HALITE IS WHITE TO TINTED ORANGE TO CLEAR, MEDIUM TO COARSELY CRYSTALLINE; POLYHALITE OCCURS AS BLEBS AND STRINGERS, POLYHALITE BED AT 961.5'; CONTAINS LOCAL GREENISH-GRAY REDUCTION SPOTS IN ARGILLACEOUS MATERIAL NEAR THE BASE; BASAL CONTACT SHARP, MARKED BY 3" THICK HORIZONTAL FIBROUS HALITE-FILLED FRACTURE.
2444	965		SILTSTONE, REDDISH-BROWN, TRACE OF BEDDING; CONTAINS SMALL 1/4" IMBAYED DISPLACIVE HALITE CRYSTALS NEAR TOP; CONTAINS RARE SUBVERTICAL HALITE-FILLED FRACTURES; BECOMES ANHYDRITIC (GRAY) IN LOWER 2.0'; CONTAINS DISPLACIVE HALITE CRYSTALS <1/8"; BASAL CONTACT SHARP.
2439	970		ARGILLACEOUS HALITE, ARGILLACEOUS MATERIAL REDDISH-BROWN, HALITE CLEAR; BELOW 969.0' CLAY CONTENT DECREASES ABRUPTLY, UNIT BECOMES SLIGHTLY ARGILLACEOUS AND POLYHALITIC, CLAY AND POLYHALITE OCCUR AS RANDOMLY ORIENTED STRINGERS; OVERALL CLAY CONTENT DECREASES WITH DEPTH; POLYHALITE CONTENT INCREASES WITH DEPTH; BASAL CONTACT GRADATIONAL.
2434	975	MB 101	POLYHALITE, ANHYDRITIC, FINELY CRYSTALLINE, ORANGE, HARD; HALITIC, HALITE WHITE; ANHYDRITE GRAY; DISCONTINUOUS BEDS OF WHITE FINELY CRYSTALLINE HALITE NEAR TOP; AT 975.0', 1" THICK BED OF THINLY LAMINATED ANHYDRITE OCCURS; UNIT CONTAINS CLEAR DISPLACIVE HALITE CRYSTALS NEAR BASE; BASAL CONTACT SHARP.
			HALITE, POLYHALITIC, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE, THIN TO MEDIUM BEDDED BY SUBHORIZONTAL STRINGERS OF POLYHALITE; BASAL CONTACT SHARP, MARKED BY A 2" THICK BED OF POLYHALITE.
2429	980		ARGILLACEOUS HALITE, REDDISH-BROWN, SLIGHTLY ANHYDRITIC, CLAY CONTENT DECREASES WITH DEPTH; NEAR TOP, HALITE OCCURS AS DISPLACIVE CRYSTALS; BECOMES THE DOMINANT MINERAL TYPE WITH DEPTH, BECOMES MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR, THINLY BEDDED IN LOWER 2.0' WITH STRINGERS OF POLYHALITE SEPARATING BEDS; ARGILLACEOUS MATERIAL OCCURS AS MATRIX IN UPPER PART, STRINGERS IN LOWER PART; SOME GREENISH-GRAY REDUCTION SPOTS OCCUR NEAR TOP; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH; BASAL CONTACT SHARP, DISCONFORMABLE.
2424	985		

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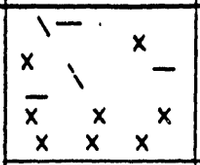
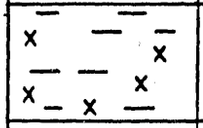
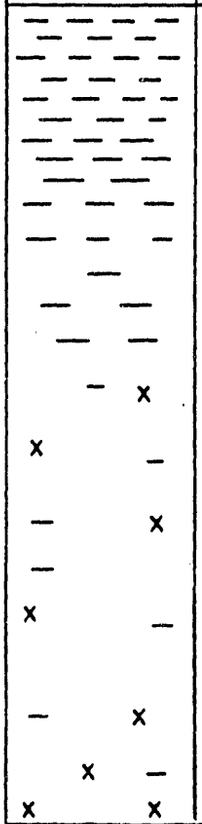
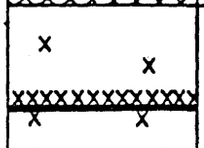
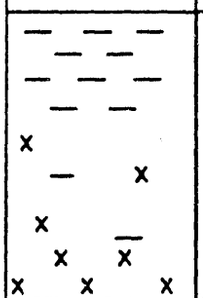
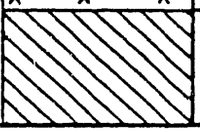
PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2424	985		AS ABOVE
2419	990		ARGILLACEOUS HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE; REDDISH-BROWN CLAY MATRIX IN UPPER 4"; POLYHALITIC; CLAY AND POLYHALITE OCCUR AS SUBHORIZONTAL STRINGERS SPACED 1" TO 4"; BASAL CONTACT SHARP.
2414	995		ARGILLACEOUS HALITE GRADING TO HALITE WITH DEPTH; CLAY OCCURS AS REDDISH-BROWN MATRIX AT TOP, HALITE OCCURS AS DISPLACIVE CRYSTALS AND CRYSTAL AGGREGATES ALIGNED IN ZONES, CLAY IN UPPER 1" GREENISH GRAY; CLAY CONTENT DECREASES WITH DEPTH, OCCURS AS SUBHORIZONTAL STRINGERS; HALITE BECOMES DOMINANT ROCK TYPE WITH DEPTH, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; TRACE POLYHALITE BLEBS AND RANDOMLY ORIENTED TO SUBHORIZONTAL STRINGERS; RARE ANHYDRITE STRINGERS; LOWER 3.0' TINTED ORANGE; BASAL CONTACT SHARP.
2409	1000		
2404	1005		
2399	1010		
2394	1015		POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE; 1" THICK GRAY CLAYSTONE BEDS 3" ABOVE AND AT BASAL CONTACT; BASAL CONTACT SHARP.
			HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR TO ORANGE; TRACE POLYHALITE STRINGERS AND DISSEMINATED BLEBS; AT 1017.8', 1" THICK BED OF POLYHALITE OCCURS UNDERLAIN BY A 1/4" THICK BED OF GRAY CLAYSTONE; BASAL CONTACT SHARP, MARKED BY DISSOLUTION TROUGHS.
2389	1020		ARGILLACEOUS HALITE, WHITE TO CLEAR, MEDIUM TO COARSELY CRYSTALLINE; CLAY OCCURS AS BROWN SUBHORIZONTAL STRINGERS, SPACED 1" TO 2"; STRINGERS ARE TERMINATED EROSIONALLY AT UPPER CONTACT, CLAY CONTENT DECREASES WITH DEPTH; TRACE POLYHALITE STRINGERS AND DISSEMINATED BLEBS, CONTENT INCREASES IN LOWER 3.0'; BASAL CONTACT SHARP, EROSIONAL, UNDULATORY UP TO 1.0'.
2384	1025		
2379	1030		AS BELOW

EXHAUST SHAFT
LITHOLOGIC LOG
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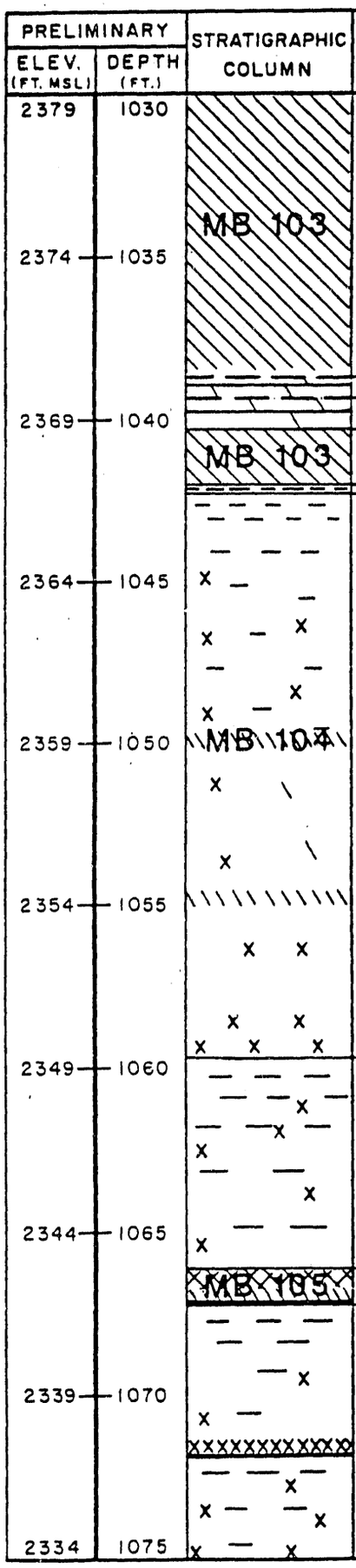


REMARKS

ANHYDRITE, FINELY CRYSTALLINE, ALTERNATING LIGHT AND DARK GRAY, LAMINATED TO VERY THINLY BEDDED; BEDDING UNDULATES SLIGHTLY, BEDS OFTEN CONTAIN ENTROLITHIC STRUCTURES; LOCAL <1/4" CRYSTALS OF HALITE; LIGHT BROWN CARBONATE (?) INTERBEDS; BASAL CONTACT GRADATIONAL.

CARBONATE (DOLOMITE?), FINELY CRYSTALLINE OR GRAINED, LIGHT BROWN WITH GRAYISH-BROWN LAMINAE, THINLY LAMINATED, LAMINAE OCCUR AS CONCAVE DOWNWARD SETS AVERAGING 4" TO 7" ACROSS; PROBABLE ALGAL STROMATOLITES; DARKER LAMINAE ORGANIC (?); BASAL CONTACT MARKED BY SUBHORIZONTAL GRAYISH-BROWN LAMINAE, GRADATIONAL.

DOLOMITE, FINELY CRYSTALLINE, LIGHT BROWN, HINT OF BEDDING; BASAL CONTACT SHARP, EROSIONAL.

ANHYDRITE, CARBONATE-RICH, FINELY CRYSTALLINE, ALTERNATING LIGHT GRAY AND GRAY, THINLY LAMINATED IN UPPER 0.9', REMAINDER STRUCTURELESS; BASAL CONTACT SHARP, EROSIONAL.

SILTY CLAYSTONE, GRAY, LOCALLY THINLY LAMINATED; CONTAINS DISPLACIVE HALITE CRYSTALS; BASAL CONTACT SHARP.

HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO ORANGE; CLAY MATRIX IN UPPER 1.0', HALITE OCCURS AS DISPLACIVE CRYSTALS, CLAY CONTENT DECREASES WITH DEPTH; CLAY MORPHOLOGY CHANGES FROM MATRIX TO SUBHORIZONTAL STRINGERS SPACED 1" TO 2", BELOW 1047.0' ARGILLACEOUS STRINGERS BECOME DISCONTINUOUS AND ORIENTED RANDOMLY; TRACE DISCONTINUOUS SUBHORIZONTAL STRINGERS AND PODS OF POLYHALITE, CONTENT INCREASES WITH DEPTH; AT 1050.0' A 0.3' THICK LAMINATED BED OF ANHYDRITE OCCURS, BELOW THIS BED CLAY CONTENT DECREASES MARKEDLY AND TRACE AMOUNTS OF POLYHALITE AND ANHYDRITE OCCUR IN DISCONTINUOUS STRINGERS; 2" THICK BED OF ANHYDRITE OCCURS AT 1055.0'; LOWER 1.0' IS VERY POLYHALITIC; BASAL CONTACT SHARP.

ARGILLACEOUS HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR, CLAY OCCURS IN RANDOMLY-ORIENTED STRINGERS; STRINGERS AND BLEBS OF POLYHALITE; BASAL CONTACT SHARP, UNDULATORY UP TO 1.0'.

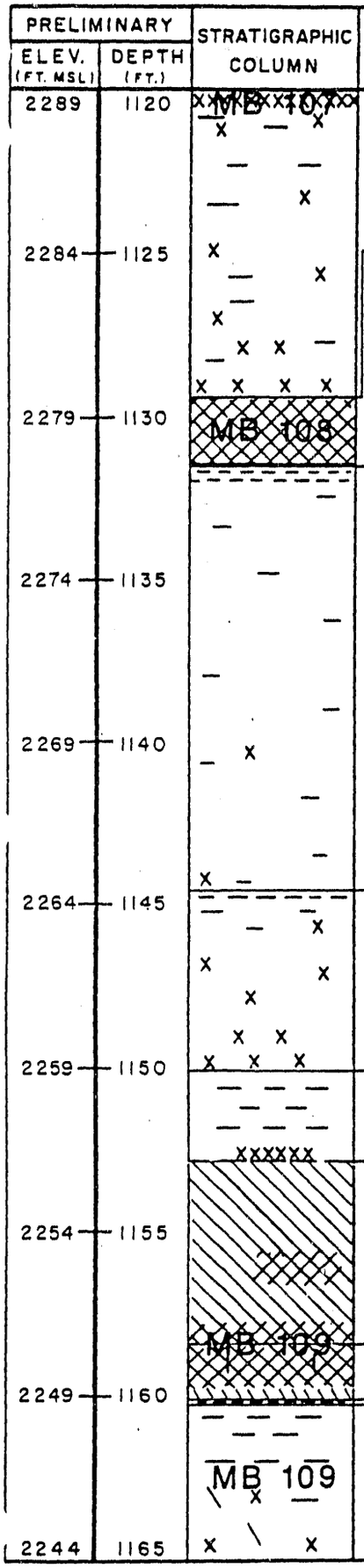
POLYHALITE, FINELY CRYSTALLINE, ORANGE, STRUCTURELESS EXCEPT NEAR BASE; LOCALLY HALITIC; THIN GRAY ANHYDRITE BED OCCURS AT BASE; BASAL CONTACT SHARP, MARKED BY A THIN BED OF GRAY CLAYSTONE.

HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; ARGILLACEOUS AT TOP, REDDISH-BROWN, CONTENT DECREASES WITH DEPTH, CLAY OCCURS IN STRINGERS; TRACE POLYHALITE AS RANDOMLY-ORIENTED STRINGERS WHICH GRADE TO SUBHORIZONTAL WITH DEPTH, CONTENT INCREASES WITH DEPTH; AT 1071.6, 1" THICK BED OF POLYHALITE OCCURS UNDERLAIN BY 1" THICK GRAY CLAYSTONE BED; CLAY CONTENT INCREASES SLIGHTLY BELOW 1071.6', COLOR REDDISH-BROWN TO GRAY; BECOMES VERY POLYHALITIC IN LOWER 1.0'; BASAL CONTACT SHARP.

EXHAUST SHAFT
LITHOLOGIC LOG

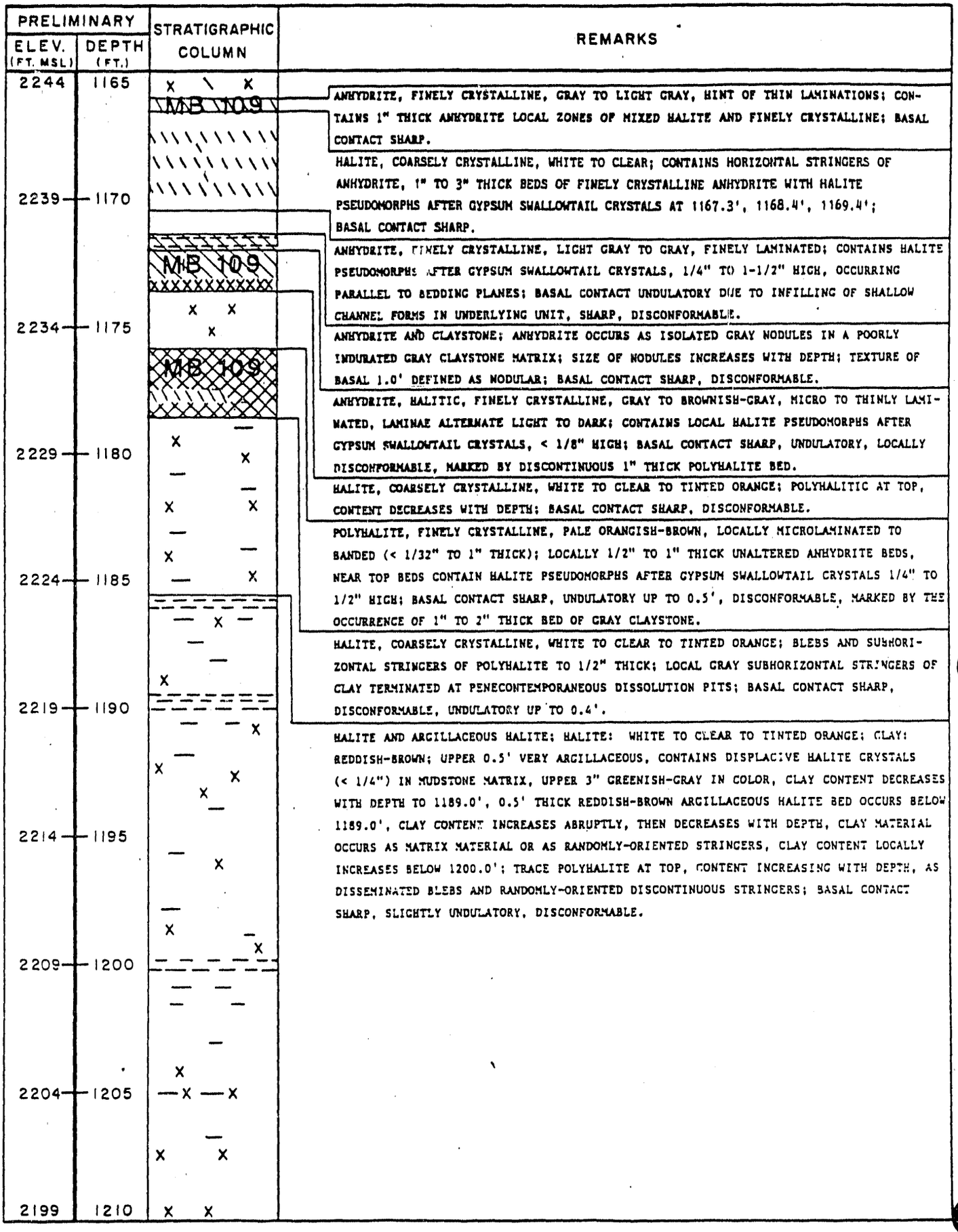
PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2334	1075		AS ABOVE
2329	1080		POLYHALITE, FINELY CRYSTALLINE, ORANGE; UNDERLAIN BY 1/2" THICK GRAY CLAYSTONE BED; BASAL CONTACT SHARP.
			HALITE, MEDIUM TO COARSELY CRYSTALLINE, CLEAR TO WHITE; UPPER 1.0' ARGILLACEOUS STRINGERS, CONTENT DECREASES WITH DEPTH; POLYHALITE STRINGERS, CONTENT INCREASES WITH DEPTH; BASAL CONTACT SHARP.
2324	1085		
		MB 10A	POLYHALITE, FINELY CRYSTALLINE, ORANGE, STRUCTURELESS; UNDERLAIN BY 1" THICK GRAY CLAYSTONE BED; BASAL CONTACT SHARP.
			HALITE, MODERATELY ARGILLACEOUS AND POLYHALITIC, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; LOCAL REDDISH-BROWN CLAY MATRIX, HALITE OCCURS AS DISPLACIVE CRYSTALS, LOCAL GREENISH-GRAY REDUCTION ZONES; ARGILLACEOUS STRINGERS ABUNDANT IN UPPER 3.0', CONTENT DECREASES WITH DEPTH, ABSENT BELOW 1103.0'; POLYHALITE OCCURS AS DISSEMINATED BLEBS AND STRINGERS, CONTENT INCREASING WITH DEPTH, 1" THICK POLYHALITE BED AT 1105.2'; BASAL CONTACT SHARP.
2319	1090		
2314	1095		
2309	1100		
2304	1105		
2299	1110		HALITE, ARGILLACEOUS AND POLYHALITIC, COARSELY CRYSTALLINE, WHITE TO CLEAR; CLAY OCCURS AS STRINGERS; POLYHALITE OCCURS AS DISSEMINATED BLEBS AND STRINGERS, 6" THICK IRREGULAR BED OF POLYHALITE AT 1120.5', LOWER 6" VERY POLYHALITIC; BASAL CONTACT SHARP.
2294	1115		
2289	1120		

EXHAUST SHAFT
LITHOLOGIC LOG
SHEET 26 OF 49



REMARKS
AS ABOVE
POLYHALITE, FINELY CRYSTALLINE, ORANGE, STRUCTURELESS; UNDERLAIN BY 2" THICK GRAY CLAYSTONE BED; BASAL CONTACT SHARP.
HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; UPPER 4" VERY ARGILLACEOUS, CLAY OCCURS AS REDDISH-BROWN DISCONTINUOUS RANDOMLY-ORIENTED STRINGERS; REMAINDER CONTAINS TRACE CLAY STRINGERS, LOCALLY STRINGERS BECOME SUBHORIZONTAL AND DENSITY MAY INCREASE; CONTAINS TRACE POLYHALITE WITH DEPTH; BASAL CONTACT SHARP, DISCONFORMABLE.
HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR TO ORANGE; UPPER 1" VERY ARGILLACEOUS, SLIGHTLY ARGILLACEOUS TO 1146.0'; MODERATELY ABUNDANT RANDOMLY-ORIENTED STRINGERS AND LARGE BLEBS OF POLYHALITE, CONTENT INCREASING WITH DEPTH, LOWER 1.5' VERY POLYHALITIC; BASAL CONTACT SHARP, DISCONFORMABLE.
ARGILLACEOUS HALITE, FINELY TO COARSELY CRYSTALLINE; LOCALLY INTERBEDDED WITH HALITIC MUDSTONE CONTAINING DISPLACIVE HALITE CRYSTALS; REDDISH-BROWN CLAY DISSEMINATED THROUGHOUT AS MATRIX, CONTENT INCREASES WITH DEPTH; IRREGULARLY SHAPED ZONES (1.0' x 2.0') OF PURE HALITE RANDOMLY SCATTERED THROUGHOUT UNIT; LOCAL SMALL ZONES OF REDUCED GREENISH-GRAY CLAY; DISSOLUTION PITS THROUGH UNIT FILLED WITH ARGILLACEOUS HALITE; POLYHALITIC, CONTENT INCREASES WITH DEPTH, DISCONTINUOUS 1" THICK POLYHALITE BED AT BASAL CONTACT; BASAL CONTACT GRADATIONAL, IRREGULAR WITH UP TO 1.0' OF RELIEF, LOCALLY SHARP, EROSIONAL.
ANHYDRITE, FINELY CRYSTALLINE, LIGHT GRAY TO LIGHT TANNISH-GRAY, THINLY LAMINATED TO THINLY BEDDED, BEDS SEPARATED BY DARK GRAY THIN LAMINAE; HALITE PSEUDOMORPHS AFTER GYPSUM SWALLOWTAIL CRYSTALS BECOME ABUNDANT BELOW 1155.0', 1/16" TO 2" HIGH, BECOME MORE ABUNDANT AND LARGER WITH DEPTH, MOST OCCUR ALONG SUBHORIZONTAL BEDDING PLANES, OCCASIONALLY PSEUDOMORPHS LIE PARALLEL TO BEDDING; AT UPPER CONTACT DISSOLUTION PITS INTO ANHYDRITE OCCUR, FILLED WITH GRAY ARGILLACEOUS HALITE AND HALITIC MUDSTONE, 0.5' TO 2.0' DEEP INTO ANHYDRITE, BEDDING TERMINATED EROSIONALLY AT SIDES OF DISSOLUTION PITS; LOCALLY, POLYHALITE IS INCLUDED IN HALITE FILLING OF HALITE PSEUDOMORPHS AFTER GYPSUM SWALLOWTAIL CRYSTALS, POLYHALITE ALSO OCCURS IN IRREGULARLY-SHAPED ZONES (2" x 3") AS REPLACEMENT OF ANHYDRITE; HALITE OCCURS ALONG BEDDING PLANES BELOW 1157.0'; LOWER 1" CONTAINS INTERBEDS OF POLYHALITE; BASAL CONTACT SHARP.
POLYHALITE, SLIGHTLY HALITIC, FINELY CRYSTALLINE, REDDISH-ORANGE, HINT OF BEDDING IN UPPER 4", REMAINDER STRUCTURELESS EXCEPT FOR RARE HALITE PSEUDOMORPHS AFTER SWALLOWTAIL GYPSUM CRYSTALS; CONTAINS ABUNDANT IRREGULARLY-SHAPED CRYSTALS OF HALITE (1/32" TO 1/2"); LOWER 3" IS ANHYDRITIC OR CARBONATE-RICH, COLOR GRADES TO BROWN AT BASE; BASAL CONTACT SHARP, UNDULATORY ON TWO SCALES: MINOR - UP TO 3", MAJOR - UP TO 2.5', EXHIBITS SOFT SEDIMENT DEFORMATION DUE TO LOADING.
CLAYSTONE, LIGHT GRAY AT TOP TO GRAY AT BASE, STRUCTURELESS EXCEPT FOR FLOWAGE STRUCTURES; THICKNESS RANGES FROM 0.2' TO 1.0'; LOCALLY BROKEN BY 0" TO 2" THICK FRACTURES FILLED WITH CLEAR TO ORANGE HALITE; BASAL CONTACT SHARP, UNDULATORY UP TO 2.0', DISCONFORMABLE.
HALITE, COARSELY CRYSTALLINE, CLEAR TO WHITE; CONTAINS GRAY CLAY STRINGERS IN UPPER 2.0', CONTENT DECREASES WITH DEPTH; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS BLEBS, RANDOMLY-ORIENTED STRINGERS, AND AS THICK SUBHORIZONTAL STRINGERS 1/4" THICK; ANHYDRITE OCCURS WITH POLYHALITE STRINGERS, CONTENT INCREASES WITH DEPTH; BASAL CONTACT SHARP, UNDULATORY UP TO 1.0'.

EXHAUST SHAFT
LITHOLOGIC LOG



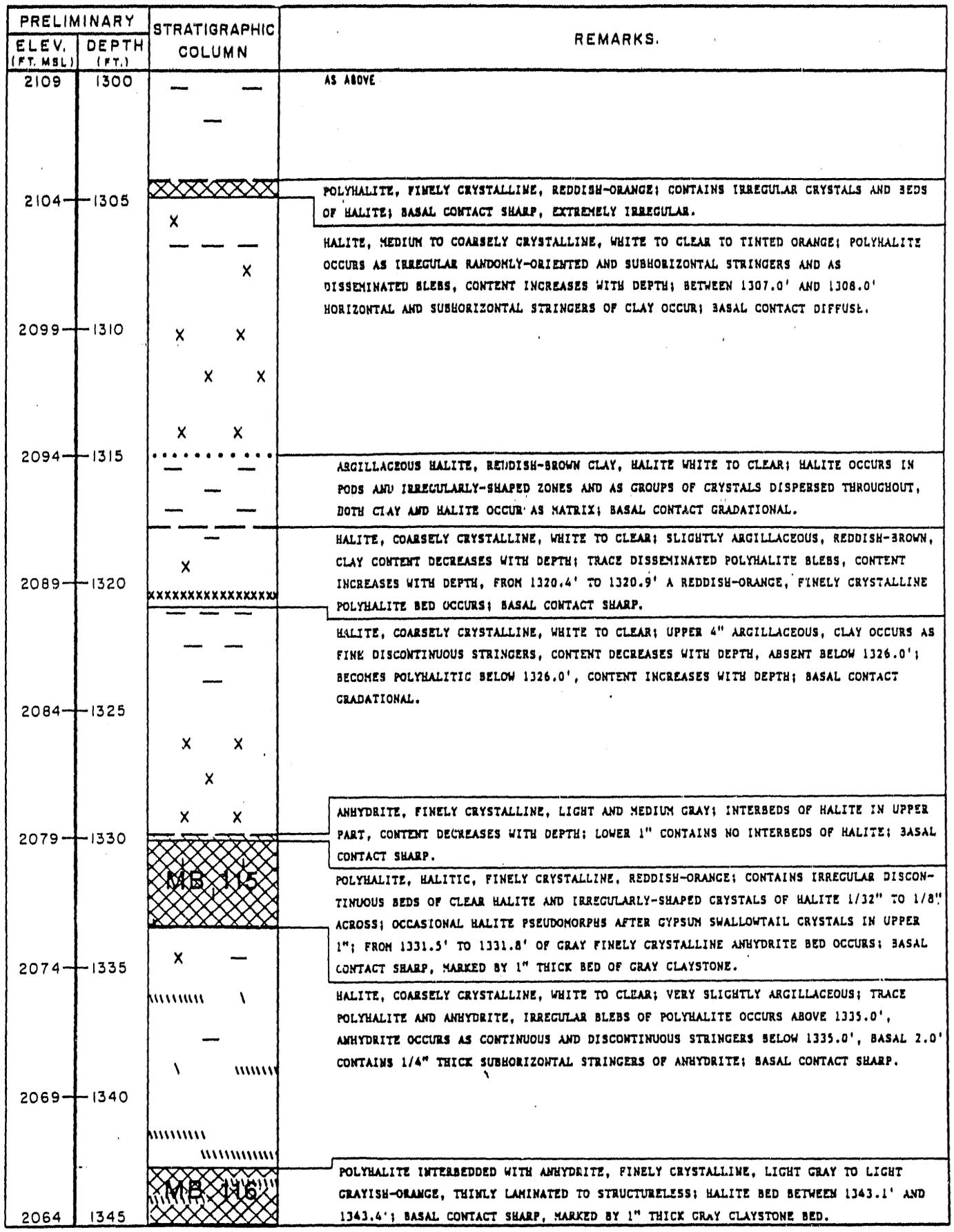
EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2199	1210		
2194	1215	MB 170	HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO ORANGISH-WHITE; UPPER 2.0' REDDISH-BROWN HALITIC MUDTONE CONTAINING DISPLACIVE HALITE CRYSTALS, GRADES INTO SLIGHTLY ARGILLACEOUS HALITE; REMAINDER CONTAINS GRAY CLAY DISSEMINATED THROUGHOUT AS INTER-CRYSTALLINE MATERIAL; POLYHALITE OCCURS AS RANDOMLY-ORIENTED STRINGERS AND DISSEMI-NATED BLEBS, BETWEEN 1217.0' AND 1219.0', 2" THICK POLYHALITE BEDS SPACED 0.5' TO 1.0' OCCUR, 3" THICK DISCONTINUOUS BED OF POLYHALITE UNDERLAIN BY A THIN BED OF GRAY CLAYSTONE OCCURS AT 1219.0', BED OF FINELY CRYSTALLINE ORANGISH-WHITE POLYHALITE OCCURS BETWEEN 1227.1' TO 1227.5'; 1/8" TO 1/4" THICK SUBHORIZONTAL STRINGERS OF POLYHALITE OCCUR IN THE INTERVALS FROM 1225.1' TO 1227.1' AND 1227.5' TO 1229.5'; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY, DISCONFORMABLE.
2189	1220		
2184	1225	MB	
2179	1230		
2174	1235		HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR; CLAY AND POLYHALITE OCCUR AS RANDOMLY-ORIENTED DISCONTINUOUS STRINGERS; UPPER 2.0' ARGILLACEOUS HALITE, HALITE OCCURS IN DISCONTINUOUS ZONES AND PODS OF CRYSTALS IN CLAY AND HALITE MATRIX, CLAY CONTENT DECREASES WITH DEPTH; BASAL CONTACT SHARP, UNDULATORY.
2169	1240		HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR; POLYHALITIC AND ARGILLACEOUS; ARGIL-LACEOUS HALITE OCCURS IN UPPER 0.5', CONTENT DECREASES WITH DEPTH; POLYHALITE OCCURS AS DISCONTINUOUS STRINGERS, BELOW 1243.0' POLYHALITE BECOMES ABUNDANT; BASAL CONTACT SHARP, UNDULATORY UP TO 1.0'.
2164	1245	MB 172	POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE, CONTAINS ZONES OF LIGHT ORANGE; APPEARS TO HAVE MOUND FORMS AT UPPER CONTACT; CONTAINS IRREGULARLY-SHAPED CRYSTALS OF HALITE (1/16" TO 3/4") DISSEMINATED THROUGHOUT; BASAL CONTACT SHARP, MARKED BY 1" TO 2-1/2" THICK GRAY CLAYSTONE CONTAINING HALITE.
2159	1250		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; TRACE GRAY CLAY, CONTENT DECREASES WITH DEPTH, BETWEEN 1255.8' AND 1257.0' SUBHORIZONTAL STRINGERS OF REDDISH-BROWN CLAY ARE CONTINUOUS AROUND THE CIRCUMFERENCE OF THE SHAFT; DISSEMINATED POLYHALITE BLEBS, CONTENT INCREASES WITH DEPTH; BASAL CONTACT SHARP.
2154	1255		

EXHAUST SHAFT
LITHOLOGIC LOG
SHEET 29 OF 49

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2154	1255		AS ABOVE
2149	1260		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; UPPER 0.5' ARGILLACEOUS, CLAY OCCURS WITH HALITE AS MATRIX, BELOW 1260.7' CLAY OCCURS AS STRINGERS, CONTENT DECREASES WITH DEPTH; DISSEMINATED POLYHALITE BLEBS; BASAL CONTACT SHARP.
			POLYHALITE, FINELY CRYSTALLINE, ORANGISH-RED, STRUCTURELESS; UNDERLAIN BY 1" THICK GRAY CLAYSTONE BED; BASAL CONTACT SHARP.
2144	1265		HALITE, WHITE TO CLEAR, COARSELY CRYSTALLINE, SLIGHTLY ARGILLACEOUS; CLAY OCCURS IN STRINGERS, CONTENT DECREASES WITH DEPTH, ABSENT BELOW 1268.0'; TRACE POLYHALITE BLEBS; BASAL CONTACT SHARP.
2139	1270	MB 113	POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE, STRUCTURELESS; UNIT SPLIT BY 4" THICK CLEAR HALITE BED, OCCURS 3" BELOW UPPER CONTACT; BASAL CONTACT SHARP, MARKED BY 2" THICK GRAY CLAYSTONE BED.
2134	1275		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO ORANGE TO CLEAR; TRACE POLYHALITE, OCCURS AS DISCONTINOUS RANDOMLY-ORIENTED STRINGERS AND AS DISSEMINATED BLEBS; SLIGHTLY ARGILLACEOUS, GRAY CLAY STRINGERS TO 1276.0', ABSENT BETWEEN 1276.0' AND 1280.0', CLAY STRINGERS IN 1.0' THICK BAND BELOW 1280.0', BELOW 1284.0' CLAY CONTENT INCREASES AS SUBHORIZONTAL STRINGERS; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY.
2129	1280		
2124	1285		
2119	1290		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; ARGILLACEOUS, UPPER 1.5' TO 2.0' ARGILLACEOUS HALITE WITH CLAY AND HALITE MATRIX, HALITE OCCURS AS ZONES AND PODS OF CRYSTALS AND DISPLACIVE CRYSTALS TO 1/2" ACROSS, CLAY CONTENT DECREASES WITH DEPTH; POLYHALITE OCCURS AS SUBHORIZONTAL STRINGERS AND DISSEMINATED BLEBS, CONTENT INCREASES WITH DEPTH; BASAL CONTACT SHARP, UNDULATORY.
			POLYHALITE, FINELY CRYSTALLINE, ORANGISH-RED, STRUCTURELESS EXCEPT FOR 1" THICK INTERBEDS OF HALITE; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY.
2114	1295	MB 114	HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR; CONTAINS SUBHORIZONTAL CONTINUOUS STRINGERS OF POLYHALITE IN UPPER 0.3', IN THE REMAINDER OF THE UNIT POLYHALITE OCCURS AS RARE DISSEMINATED BLEBS; BASAL CONTACT SHARP.
2109	1300		HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR; ARGILLACEOUS AT TOP, CLAY OCCURS AS RANDOMLY-ORIENTED STRINGERS, CONTENT DECREASES WITH DEPTH; BASAL CONTACT GRADATIONAL.

EXHAUST SHAFT
LITHOLOGIC LOG
SHEET 30 OF 49



EXHAUST SHAFT
LITHOLOGIC LOG

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2064	1345		HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR; POLYHALITE OCCURS AS CONTINUOUS HORIZONTAL AND SUBHORIZONTAL STRINGERS AND AS IRREGULARLY-SHAPED BLEBS, CONTENT INCREASES WITH DEPTH; BASAL CONTACT SHARP.
2059	1350		ARGILLACEOUS HALITE, FINELY TO COARSELY CRYSTALLINE, REDDISH-BROWN HALITIC CLAYSTONE MATRIX, HALITE CLEAR TO WHITE; HALITE OCCURS AS IRREGULARLY-SHAPED AGGREGATES OF CRYSTALS; CONTAINS 1/4" TO 2" THICK SUBHORIZONTAL HALITE-FILLED FRACTURES; BASAL CONTACT UNDULATORY UP TO 2.0', GRADATIONAL TO SHARP, DISCONFORMABLE.
2054	1355		McNUTT POTASH ZONE VACA TRISTA MARKER BED HALITIC SILTSTONE, REDDISH-BROWN, THINLY LAMINATED TO STRUCTURELESS; HALITE OCCURS AS ISOLATED DISPLACIVE CRYSTALS UP TO 1-1/2" ACROSS; LOCAL CHANNEL FILL STRUCTURES PRESENT; CONTAINS BOTH SUBVERTICAL AND SUBHORIZONTAL HALITE-FILLED FRACTURES 1/8" TO 2" THICK; CHANNEL INTO UNDERLYING UNIT 3.0' DEEP (EAST SIDE OF SHAFT); NUMEROUS FILLED CHANNELS THROUGHOUT UNIT; OCCASIONAL CROSS-LAMINATIONS; BASAL CONTACT GRADATIONAL TO LOCALLY SHARP, UNDULATORY UP TO 3.0'.
2049	1360		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; ARGILLACEOUS TO 1363.0', CLAY OCCURS AS REDDISH-BROWN MATRIX, CONTENT DECREASES WITH DEPTH, HALITE OCCURS AS IRREGULARLY-SHAPED CRYSTAL MASSES; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH AS SUBHORIZONTAL CONTINUOUS AND DISCONTINUOUS STRINGERS AND THIN BEDS, ALSO AS DISSEMINATED BLEBS; BELOW 1363.0' ARGILLACEOUS MATERIAL OCCURS AS LOCAL SUBHORIZONTAL STRINGERS; 1" THICK BED OF POLYHALITE OCCURS AT 1365.6'; FROM 1373.4' TO 1373.9' ARGILLACEOUS HALITE OCCURS; BASAL CONTACT SHARP, DISCONFORMABLE.
2044	1365		
2039	1370		
2034	1375		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE, CRUDELY THIN TO MEDIUM BEDDED; POLYHALITE OCCURS AS SUBHORIZONTAL PARALLEL STRINGERS GROUPED IN UPPER 2.0', RANDOMLY-ORIENTED STRINGERS BELOW 1380.4', DISSEMINATED BLEBS, CONTENT DECREASES WITH DEPTH; LOCALLY SLIGHTLY ARGILLACEOUS, COLOR WHITISH-GRAY, SUBHORIZONTAL STRINGERS AND LOCAL IRREGULARLY-SHAPED ZONES OF CLAY, CONTENT DECREASES WITH DEPTH; 1/4" TO 1/2" THICK CLAYSTONE BED AT 1383.8'; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY, DISCONFORMABLE.
2029	1380		HALITIC CLAYSTONE AND ARGILLACEOUS HALITE, CLAY REDDISH-BROWN, HALITE WHITE TO CLEAR AND FINELY CRYSTALLINE; HALITE CONTENT INCREASES WITH DEPTH, OCCURS AS DISPLACIVE CRYSTALS (1/8" TO 1/2" ACROSS) AND PODS OF RELATIVELY PURE HALITE; LOCAL PODS OF POLYHALITE; BASAL CONTACT GRADATIONAL.
2024	1385		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; LOCALLY ARGILLACEOUS, REDDISH-BROWN CLAY OCCURS AS RANDOMLY-ORIENTED STRINGERS IN SUBHORIZONTAL ZONES, CONTENT DECREASES WITH DEPTH, DECREASES ABRUPTLY BELOW 1390.1'; TRACE POLYHALITE AS RARE DISSEMINATED RANDOMLY-ORIENTED STRINGERS AND BLEBS, CONTENT INCREASES WITH DEPTH, POLYHALITE BED OCCURS BETWEEN 1390.9' AND 1391.1', CONTENT INCREASES ABRUPTLY NEAR BASE; LOCAL ZONES AND STRINGERS OF ARGILLACEOUS HALITE CONTAINING GRAY CLAY; BASAL CONTACT SHARP, DISCONFORMABLE.
2019	1390		

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PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
2019	1390		AS ABOVE
2014	1395		HALITIC CLAYSTONE, UPPER 2" GRAY, REMAINDER REDDISH-BROWN, STRUCTURELESS EXCEPT FOR DISPLACIVE CRYSTALS (1/8" TO 1/2"); LOCAL GREENISH-GRAY REDUCTION SPOTS; HINT OF RELICT BEDDING; BASAL CONTACT GRADATIONAL, UNDULATORY.
2009	1400		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; VERY POLYHALITIC TO 1400.0', OCCURRING AS ABUNDANT RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS AND ZONES; BELOW 1400.0' RARE POLYHALITE AND SUBHORIZONTAL GRAY STRINGERS OF CLAY; BASAL CONTACT SHARP, DISCONFORMABLE.
2004	1405		ARGILLACEOUS HALITE; GRAY CLAY IN UPPER 1.0', REMAINDER REDDISH-BROWN; HALITE OCCURS AS WELL-ROUNDED PODS OR COBBLES (?) 1" TO 4" DIAMETER, FINE GRAINED OR CRYSTALLINE COARSENING TOWARD CENTER, WHITE TO CLEAR WITH RARE ORANGE TINT, PODS BREAK IN SPHERICAL PATTERN; LOCALLY HALITE OCCURS AS CLEAR TO WHITE IRREGULARLY SHAPED ZONES, HALITE ALSO OCCURS AS SMALL DISPLACIVE CRYSTALS <1/32" TO 1/8" ACROSS; LOCAL 1/8" TO 1/4" DISCONTINUOUS HALITE-FILLED (FIBROUS) FRACTURES; CONTAINS LOCAL POLYHALITE ZONES; BASAL CONTACT SHARP.
1999	1410		
1994	1415		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; ARGILLACEOUS AT TOP, CONTENT DECREASES WITH DEPTH, LOCAL DISCONTINUOUS IRREGULARLY-SHAPED ZONES OF CLAYSTONE, CLAY ALSO OCCURS AS RANDOMLY-ORIENTED AND SUBHORIZONTAL STRINGERS; MODERATELY ABUNDANT POLYHALITE, OCCURS AS DISSEMINATED BLEBS AND SUBHORIZONTAL DISCONTINUOUS STRINGERS; CLAY ABSENT BELOW 1415.0'; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY UP TO 4".
1989	1420	MB 117	POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE; THIN SUBHORIZONTAL HALITE-FILLED FRACTURES <1/16" THICK; CONTAINS RARE CRYSTALS OF HALITE 1/16" TO 1/4" ACROSS; LOWER 4" CONTAINS BLACK LAMINAE PARALLEL TO LOWER CONTACT; BASAL CONTACT SHARP, UNDULATORY ON TWO SCALES: MAJOR - 0.8', MINOR - 0.1', MARKED BY 1" THICK GREENISH-GRAY CLAYSTONE BED.
1984	1425		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; RARE IRREGULAR DISCONTINUOUS STRINGERS AND BLEBS OF POLYHALITE; LOCAL TRACE AMOUNTS OF GRAY SUBHORIZONTAL STRINGERS OF CLAY; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY, DISCONFORMABLE.
1979	1430		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; MODERATELY ARGILLACEOUS, CLAY REDDISH-BROWN TO GRAY WITH DEPTH, OCCURS AS INTER-CRYSTALLINE MATERIAL AND SUBHORIZONTAL TO RANDOMLY-ORIENTED STRINGERS, CONTENT DECREASES WITH DEPTH; TRACE POLYHALITE BLEBS, CONTENT INCREASES WITH DEPTH, AT 1437.5' A 0.1' THICK BED OF REDDISH-ORANGE POLYHALITE OCCURS; BELOW POLYHALITE BED CLAY CONTENT INCREASES SLIGHTLY THEN DECREASES WITH DEPTH; BASAL CONTACT DIFFUSE, CONFORMABLE.
1974	1435		

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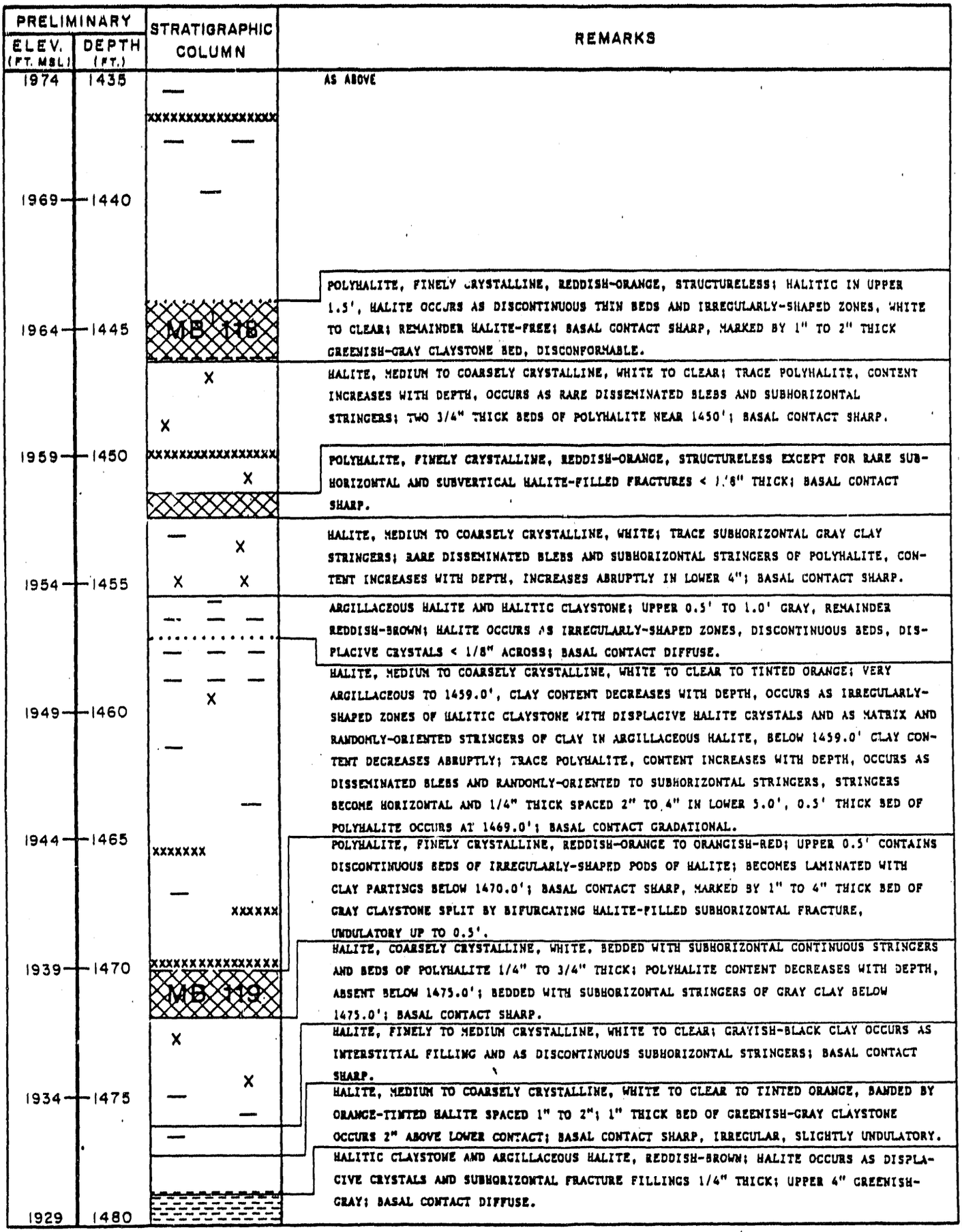

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PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1929	1480		AS ABOVE
			HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; SLIGHTLY ARGILLACEOUS IN UPPER 2.0' AS DISCONTINUOUS RANDOMLY-ORIENTED STRINGERS; TRACE POLYHALITE AT TOP, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND STRINGERS; BASAL CONTACT SHARP.
1924	1485		
			POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE, STRUCTURELESS; BASAL CONTACT SHARP, MARKED BY 1/2" TO 1" THICK GRAY CLAYSTONE BED.
1919	1490	MB 120	
			HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR; CONTAINS SUBHORIZONTAL STRINGERS OF BLACKISH-GRAY CLAY SPACED 2" TO 4"; BASAL CONTACT SHARP.
			HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE, BANDED WHITE AND ORANGE, SPACED 1" TO 2", TRACE POLYHALITE; BASAL CONTACT GRADATIONAL.
1914	1495		
			ARGILLACEOUS HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR; HALITE OCCURS AS PODS AND IRREGULARLY-SHAPED ZONES OF CRYSTALS SURROUNDED BY REDDISH-BROWN CLAY MATRIX; CLAY CONTENT DECREASES WITH DEPTH; UPPER 4" CONTAINS SUBHORIZONTAL STRINGERS OF BLACKISH-GRAY CLAY SPACED 1"; BASAL CONTACT DIFFUSE.
1909	1500		HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR TO ORANGE; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED STRINGERS; BASAL CONTACT SHARP, IRREGULAR, UNDULATORY UP TO 1", DISCONFORMABLE.
			POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE; HALITIC. CONTAINS IRREGULARLY-SHAPED PODS OF HALITE TO 4" ACROSS; CONTAINS LOCAL ZONES RICH IN ANHYDRITE OR LANGBENITE (?); BASAL CONTACT SHARP, UNDULATORY, SLIGHTLY IRREGULAR.
1904	1505	MB 121	
			HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED STRINGERS; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY.
1899	1510		
		MB 122	POLYHALITE, FINELY CRYSTALLINE, BROWN TO TAN, STRUCTURELESS; BASAL CONTACT SHARP.
			HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR; CONTAINS STRINGERS OF POLYHALITE AND GRAY CLAY SPACED 1" TO 2"; BASAL CONTACT SHARP.
1894	1515		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE; UPPER 0.5' ARGILLACEOUS, REDDISH-BROWN, CONTENT DECREASES WITH DEPTH; TWO 3" THICK BEDS OF REDDISH-BROWN ARGILLACEOUS HALITE OCCUR AT 1519.8' AND 1520.2'; BASAL 0.5' CONTAINS SUBHORIZONTAL GRAY CLAY STRINGERS, SPACED 1" TO 3"; TRACE POLYHALITE, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY, DISCONFORMABLE.
1889	1520		
1884	1525		

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PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1884	1525		AS ABOVE
			ARGILLACEOUS HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; CLAY REDDISH-BROWN, UPPER 1.0' TO 3.0' GRAY ARGILLACEOUS HALITE WITH RARE SMALL DISPLACIVE HALITE CRYSTALS < 1/16" ACROSS; HALITE OCCURS AS AGGREGATES OF CRYSTALS IN PODS OR ZONES; CLAY OCCURS AS MATRIX IN UPPER PART, OCCURS AS DISSEMINATED IRREGULARLY-SHAPED ZONES AND RANDOMLY-ORIENTED STRINGERS WITH DEPTH, CONTENT DECREASES WITH DEPTH; BASAL CONTACT SHARP.
1879	1530		
1874	1535		UNION ANHYDRITE ANHYDRITE, ALTERNATES WHITISH-GRAY TO DARK GRAY, FINELY CRYSTALLINE, THINLY LAMINATED TO THINLY BEDDED; HALITIC, CONTAINS RARE 1/16" CRYSTALS OF HALITE; UPPER 2" TO 5" POLYHALITIC, DISCONTINUOUS POLYHALITE LENS OCCURS ON NORTHWEST SIDE OF SHAFT BETWEEN 1539.5' AND 1541.6'; LOWER 1.0' TO 2.0' CONTAINS WHITE LAMINAE INTERBEDDED WITH ANHYDRITE, POSSIBLY CARBONATE; BASAL CONTACT GRADATIONAL, ALTERNATION CONTACT, CONFORMABLE.
1869	1540		POLYHALITE, FINELY CRYSTALLINE, ORANGISH-RED TO REDDISH-ORANGE, THINLY LAMINATED TO THINLY BEDDED, LOCALLY STRUCTURELESS, LAMINAE OFTEN SLIGHTLY CONTORTED; LOCALLY ANHYDRITIC, OCCURS AS UNALTERED LAMINAE AND ZONES; BASAL CONTACT SHARP, MARKED BY LOAD CASTS INTO UNDERLYING UNIT (2" DEEP BY 1" TO 3" ACROSS) AND FLAME STRUCTURES.
1864	1545		ANHYDRITIC CLAYSTONE, FINELY LAMINATED, GRAY TO WHITISH-GRAY; CONTAINS LOCAL, SMALL ENTROLITHIC STRUCTURES; BASAL CONTACT GRADATIONAL TO DIFFUSE.
			HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE, SLIGHTLY BEDDED BY DISCONTINUOUS SUBHORIZONTAL STRINGERS OF POLYHALITE AND BANDS OF POLYHALITIC HALITE; BASAL CONTACT SHARP, DISCONFORMABLE.
1859	1550		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE, STRUCTURELESS; SLIGHTLY ARGILLACEOUS, MODERATELY ABUNDANT IN UPPER 1.0', CONTENT DECREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED STRINGERS; BASAL CONTACT GRADATIONAL.
1854	1555		
1849	1560		HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR; ARGILLACEOUS IN UPPER 1.5', GRAY, AS SUBHORIZONTAL STRINGERS AND BEDS, CONTENT DECREASES WITH DEPTH, 1.0' TO 2.0' THICK BED OF GRAY ARGILLACEOUS HALITE AT 1560.2'; BELOW 1560.2' CLAY CONTENT INCREASES AND BECOMES REDDISH-BROWN, OCCURS AS STRINGERS AND DISCONTINUOUS BEDS OF ARGILLACEOUS HALITE, CONTENT DECREASES WITH DEPTH, LOCALLY GRAY, CONTENT DROPS TO TRACE NEAR BASE; SOME POLYHALITE, CONTENT INCREASES TO 1560.2', BELOW WHICH IT DECREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS; BASAL CONTACT SHARP, DISCONFORMABLE.
18	1565		
1839	1570		

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PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1839	1570		AS ABOVE
1834	1575		
1829	1580		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE, STRUCTURELESS; UPPER 0.5' SLIGHTLY ARGILLACEOUS, REDDISH-BROWN, CONTENT DECREASES WITH DEPTH, ABSENT BELOW 1582.0', OCCURS AS DISCONTINUOUS STRINGERS AND AS INTERCRYSTALLINE MATRIX; TRACE DISSEMINATED POLYHALITE BLEBS; BASAL CONTACT GRADATIONAL, HIGHLY IRREGULAR, MARKED BY THE OCCURRENCE OF ARGILLACEOUS HALITE.
1824	1585		
1819	1590		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; UPPER 0.5' HAS REDDISH-BROWN CLAY MATRIX, CONTENT DECREASES SLIGHTLY WITH DEPTH, CLAY BECOMES BOTH GRAY AND REDDISH-BROWN, OCCURS AS RANDOMLY-ORIENTED STRINGERS; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND AS STRINGERS WITH DEPTH; BASAL CONTACT GRADATIONAL, DISCONFORMABLE.
1814	1595		
1809	1600		
1804	1605		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; SLIGHTLY ARGILLACEOUS, CONTENT DECREASES WITH DEPTH, REDDISH-BROWN, OCCURS AS INTERCRYSTALLINE MATERIAL AND RANDOMLY-ORIENTED STRINGERS, LOCALLY OCCURS IN GREATER CONCENTRATIONS; TRACE POLYHALITE, CONTENT INCREASES SLIGHTLY WITH DEPTH, OCCURS AS DISSEMINATED BLEBS, BLEBS BECOME LARGER WITH DEPTH (UP TO 2" x 1"); BASAL CONTACT SHARP.
1799	1610		
1794	1615		

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PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1794	1615	— X	
		MB 123	ANHYDRITE, FINELY CRYSTALLINE, BROWNISH-GRAY TO ORANGISH-TAN, THINLY LAMINATED; LOCALLY ALTERED TO POLYHALITE; LAMINAE OFTEN CONTORTED AND SLIGHTLY HALITIC, LOCALLY NODULAR, STRUCTURE OFTEN ENTROLITHIC; BASAL CONTACT GRADATIONAL.
1789	1620		
		X XXXXXXXXXXXXXX X	HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE; 3" THICK BED OF ORANGISH-RED POLYHALITE AT 1624.2'; TRACE POLYHALITE, OCCURS AS RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS AND AS DISSEMINATED BLEBS; THIN 1" THICK IRREGULAR BED OF ANHYDRITE AT 1626.3'; BASAL CONTACT SHARP, DISCONFORMABLE (?).
1784	1625		
1779	1630	MB 124	ANHYDRITE, FINELY CRYSTALLINE, BROWNISH-GRAY TO TANNISH-GRAY, ENTROLITHIC TO NODULAR TO 1633.0', BELOW 1633.0', BECOMES LAMINATED TO THINLY BEDDED, LOCALLY CONTAINS ANHYDRITE PSEUDOMORPHS AFTER GYPSUM SWALLOWTAIL CRYSTALS; LOCALLY POLYHALITIC; BASAL CONTACT SHARP, MARKED BY 2.0" TO 4.0" THICK GRAY THINLY LAMINATED CLAYSTONE BED CONTAINING SEVERAL SUBHORIZONTAL FIBROUS HALITE-FILLED FRACTURES 1/8" TO 1/4" THICK, SPACED 1" TO 2"; BASAL CONTACT GRADATIONAL.
1774	1635		
		MB 124	ARGILLACEOUS POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE; POLYHALITE OCCURS AS REPLACEMENT OF ANHYDRITE OR GYPSUM NODULES IN GRAY CLAYSTONE MATRIX; NODULE CONCENTRATION INCREASES WITH DEPTH UNTIL MATRIX IS POLYHALITE; NODULE DIAMETER 1/8" TO 1/2"; UNDERLAIN BY 1" TO 2" GRAY CLAYSTONE BED; BASAL CONTACT SHARP, UNDULATORY, IRREGULAR.
1769	1640	X X X	HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE; POLYHALITIC, OCCURS AS DISSEMINATED BLEBS AND AS RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS; GRAY CLAYSTONE BED OCCURS AT 1644.0'; POLYHALITE CONTENT TRACE BELOW 1644.0'; LOWER 1.5' CONTAINS TRACE AMOUNT OF CLAY STRINGERS; BASAL CONTACT SHARP, IRREGULAR WITH DISSOLUTION PITS 0.3' DEEP, MARKED BY 2" TO 3" THICK GRAY CLAYSTONE BED.
1764	1645	X X X	
1759	1650	—	
1754	1655	X X —	HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO ORANGE; POLYHALITIC, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS; TRACE DISSEMINATED GRAY CLAY; BASAL CONTACT SHARP.
1749	1660	— X	AS BELOW

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PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1749	1660		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; TRACE REDDISH-BROWN AND GRAY CLAY, OCCURRING AS STRINGERS AND AS LOCALLY DISSEMINATED MATRIX, CLAY CONTENT INCREASES ABRUPTLY BELOW 1662.0' AS REDDISH-BROWN STRINGERS, CONTENT DECREASES WITH DEPTH, ARGILLACEOUS HALITE BED OCCURS WITH CLAY AS STRINGERS AND MATRIX BETWEEN 1673.0' AND 1673.8', LOWER 2.5' CONTAINS DISCONTINUOUS HORIZONTAL AND SUBHORIZONTAL STRINGERS OF GRAY CLAY; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS WITH SIZE INCREASING WITH DEPTH (1" DIAMETER); BASAL CONTACT SHARP, IRREGULAR, UNDULATORY TO 0.5'.
1744	1665		
1739	1670		
1734	1675		
1729	1680		
1724	1685		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; ARGILLACEOUS HALITE OCCURS BETWEEN 1681.4' AND 1682.6', GRAY CLAY; REDDISH-BROWN ARGILLACEOUS HALITE OCCURS BETWEEN 1682.6' AND 1684.1', CLAY OCCURS AS RANDOMLY-ORIENTED STRINGERS AND AS MATRIX; CLAY CONTENT DECREASES ABRUPTLY BELOW 1684.1'; TRACE POLYHALITE BELOW 1686.4', CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND AS RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS; BASAL CONTACT SHARP.
1719	1690		
1714	1695		ARGILLACEOUS HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; VERY ARGILLACEOUS IN UPPER 0.5', CLAY REDDISH-BROWN, CONTENT DECREASES WITH DEPTH, OCCURS AS INTERCRYSTALLINE MATRIX AND RARE STRINGERS, CONTENT DECREASES ABRUPTLY BELOW 1704.0'; TRACE POLYHALITE, OCCURS AS DISSEMINATED BLEBS; BASAL CONTACT SHARP, IRREGULAR, DISCONFORMABLE.
1709	1700		
1704	1705		

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PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1704	1705		AS ABOVE
1699	1710		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; UPPER 0.3' TO 0.4' AND LOWER 0.7' PURE HALITE, REMAINDER SLIGHTLY ARGILLACEOUS, CLAY REDDISH-BROWN, BECOMING GRAY WITH DEPTH; BASAL CONTACT SHARP, IRREGULAR, DISCONFORMABLE.
1694	1715		
1689	1720		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; UPPER 1.0' ARGILLACEOUS, CONTENT DECREASES WITH DEPTH; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED STRINGERS, LOWER 1.0' VERY POLYHALITIC; BASAL CONTACT SHARP, IRREGULAR, UNDULATORY.
1684	1725		POLYHALITE, FINELY CRYSTALLINE, ORANGISH-RED, STRUCTURELESS; UNIT VERY UNDULATORY; BASAL 0.4' CONSISTS OF GREENISH-GRAY CLAYSTONE; BASAL CONTACT SHARP, UNDULATORY, DISCONFORMABLE.
1679	1730		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; LOCALLY ARGILLACEOUS, CLAY REDDISH-BROWN, CONTENT DECREASES WITH DEPTH; TRACE POLYHALITE, OCCURS AS DISSEMINATED BLEBS; BASAL CONTACT SHARP, IRREGULAR WITH DISSOLUTION PITS 1.0' DEEP INTO UNDERLYING UNIT.
1674	1735		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; UPPER 2.0' SLIGHTLY ARGILLACEOUS, CLAY REDDISH-BROWN, OCCURS AS RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS AND DISSEMINATED INTERCRYSTALLINE MATERIAL; TRACE POLYHALITE AT TOP, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED STRINGERS; BASAL CONTACT GRADATIONAL.
1669	1740		
1664	1745		
1659	1750		

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PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1659	1750	X	AS ABOVE
		MB 127	POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE, TRACE THIN LAMINATIONS; LOCALLY ANHYDRITIC; BASAL CONTACT SHARP.
		MB 127	HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE OCCASIONALLY TINTED ORANGE; SUBHORIZONTAL POLYHALITE STRINGERS, 1/8" THICK; BASAL CONTACT SHARP, IRREGULAR.
1654	1755	X	POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE; BASAL CONTACT SHARP, MARKED BY 1" THICK GRAY CLAYSTONE BED.
		X	HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; POLYHALITIC, CONTENT DECREASES WITH DEPTH, OCCURS AS STRINGERS AND BLEBS; 0.1' TO 0.4' THICK ANHYDRITE BED OCCURS AT 1761.9'; BASAL CONTACT SHARP.
1649	1760	X	
		MB 128	POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE, THINLY LAMINATED; 0.3' THICK HALITE BED AT 1763.9', LOWER 0.1' TO 0.2' HALITIC GRAY CLAYSTONE; BASAL CONTACT SHARP.
1644	1765	— — —	HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE OCCASIONALLY TINTED ORANGE, HINT OF BEDDING FROM SUBHORIZONTAL STRINGERS OF POLYHALITE SPACED 0.2'; 0.1' THICK BED OF ARGILLACEOUS HALITE OCCURS AT 1767.3'; POLYHALITE CONTENT INCREASES ABRUPTLY NEAR BASE; BASAL CONTACT SHARP, DISCONFORMABLE.
1639	1770	X X	
		— — —	ARGILLACEOUS HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; GRAY CLAY OCCURS AS MATRIX AND INTERCRYSTALLINE MATERIAL, CLAY BECOMES REDDISH-BROWN BELOW 1773.8', CLAY CONTENT DECREASES WITH DEPTH; CLAY-FREE POLYHALITIC HALITE OCCURS BETWEEN 1773.3' AND 1773.8'; POLYHALITE CONTENT INCREASES WITH DEPTH; BASAL CONTACT SHARP, IRREGULAR.
		X X X	
1634	1775	— —	
		—	
1629	1780	—	
		—	HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; ARGILLACEOUS TO 1782.4', CONTENT DECREASES ABRUPTLY BELOW, CLAY OCCURS AS MATRIX; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED STRINGERS; BASAL CONTACT GRADATIONAL.
		—	
1624	1785	X	
			POLYHALITE, FINELY CRYSTALLINE, DARK REDDISH-ORANGE, HINT OF THIN LAMINATIONS; TRACE HALITE; BASAL CONTACT SHARP, MARKED BY 1" THICK GRAY CLAYSTONE BED, SLIGHTLY UNDULATORY, DISCONFORMABLE.
		MB 129	
1619	1790	— —	ARGILLACEOUS HALITE, FINELY TO COARSELY CRYSTALLINE, CLEAR; GRAY CLAY AT TOP, GRADING TO REDDISH-BROWN WITH DEPTH, CONTENT DECREASES WITH DEPTH UNTIL ABSENT AT 1792.3'; CLAY CONTENT INCREASES AS INTERCRYSTALLINE MATERIAL AND STRINGERS BELOW 1792.3', CONTENT DECREASES WITH DEPTH, ABSENT BELOW 1794.0'; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS; BASAL CONTACT SHARP, MARKED BY 0.1' THICK BED OF POLYHALITE UNDERLAIN BY 1/4" THICK GRAY CLAYSTONE BED.
		—	
		X	
1614	1795	—	

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PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1614	1795		AS ABOVE
1609	1800		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; CONTAINS SUBHORIZONTAL GRAY CLAY STRINGERS TO 1804.3', ABSENT BELOW 1804.3'; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND SUBHORIZONTAL STRINGERS; BASAL CONTACT SHARP, MARKED BY 3" ZONE OF GRAYISH HALITE UNDERLAIN BY 1" THICK GRAY CLAYSTONE.
1604	1805		
1599	1810		
1594	1815		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; UPPER 1.8' ARGILLACEOUS, REDDISH-BROWN, CONTENT DECREASES WITH DEPTH; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS, BLEBS ALIGNED IN ZONES AND STRINGERS OCCUR BELOW 1817.6'; CONTAINS GRAY CLAY AS STRINGERS AND DISSEMINATED INTER-CRYSTALLINE MATERIAL BETWEEN 1819.2' AND 1819.9'; BASAL CONTACT SHARP, IRREGULAR, DISCONFORMABLE.
1589	1820		
1584	1825		HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; ARGILLACEOUS, REDDISH-BROWN, CLAY OCCURS AS INTERCRYSTALLINE MATRIX AND STRINGERS, CONTENT DECREASES WITH DEPTH, CONTENT DECREASES ABRUPTLY BELOW 1823.0'; TRACE POLYHALITE, OCCURS AS DISSEMINATED BLEBS; BASAL CONTACT GRADATIONAL.
1579	1830		
1574	1835		HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; SLIGHTLY ARGILLACEOUS IN UPPER 4.0', CONTENT DECREASES WITH DEPTH, CLAY OCCURS AS STRINGERS AND INTERCRYSTALLINE MATRIX, CONTAINS RARE SMALL (<1/16") DISPLACIVE HALITE CRYSTALS; TRACE POLYHALITE, OCCURS AS DISSEMINATED BLEBS; BASAL CONTACT SHARP, MARKED BY DISSOLUTION PITS 6" TO 8" DEEP INTO UNDERLYING UNIT, IRREGULAR, UNDULATORY.
1569	1840		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; ARGILLACEOUS TO 1839.8', OCCURS AS GRAY STRINGERS; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS BLEBS AND RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS; BASAL CONTACT GRADATIONAL, HIGHLY IRREGULAR, SLIGHTLY UNDULATORY.

PRELIMINARY ELEV. (FT. MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1569	1840		AS ABOVE
1564	1845		POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE; HALITIC; BASAL CONTACT GRADATIONAL, VERY IRREGULAR, UNDULATORY.
1559	1850		HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; ARGILLACEOUS, GRAY AT TOP GRADING TO REDDISH-BROWN WITH DEPTH, CONTENT DECREASES WITH DEPTH, CLAY OCCURS AS SUBHORIZONTAL STRINGERS AND AS MATRIX MATERIAL IN IRREGULARLY-SHAPED ZONES OF ARGILLACEOUS HALITE; POLYHALITIC, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND RANDOMLY-ORIENTED DISCONTINUOUS STRINGERS; CONTAINS LARGE IRREGULAR ZONES (SEVERAL SQUARE FOOT AREA) OF PURE WHITE HALITE WHICH ARE CONTINUOUS INTO UNDERLYING UNIT (DISSOLUTION PITS ?); BASAL CONTACT SHARP, IRREGULAR, DISCONFORMABLE.
1554	1855		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; ARGILLACEOUS AT TOP, CONTENT DECREASES WITH DEPTH, OCCURS AS RANDOMLY-ORIENTED STRINGERS; TRACE POLYHALITE, OCCURS AS DISSEMINATED BLEBS; CONTAINS DISSOLUTION PITS 2.0' TO 3.0' DEEP, FILLED WITH WHITE COARSELY CRYSTALLINE HALITE; BASAL CONTACT SHARP TO ABSENT, MARKED BY 1" THICK GRAY CLAYSTONE BED.
1549	1860		HALITE, COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE; POLYHALITIC, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND SUBHORIZONTAL 1/4" THICK STRINGERS; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY.
1544	1865	MB 131	POLYHALITE, FINELY CRYSTALLINE, DARK REDDISH-ORANGE, STRUCTURELESS; HALITIC; UNDERLAIN BY 4" THICK BED OF GRAY HALITIC CLAYSTONE; BASAL CONTACT GRADATIONAL.
1539	1870		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; SLIGHTLY ARGILLACEOUS, CONTENT DECREASES WITH DEPTH, OCCURS AS SUBHORIZONTAL STRINGERS; POLYHALITIC, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND SUBHORIZONTAL STRINGERS, POLYHALITE BED 0.1' THICK AT 1875.7'; BASAL CONTACT SHARP, IRREGULAR, SLIGHTLY UNDULATORY.
1534	1875		ARGILLACEOUS HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR; CLAY REDDISH-BROWN TO GRAY, OCCURS AS IRREGULAR SUBHORIZONTAL STRINGERS; HALITE OCCURS IN PODS OR ZONES OF CRYSTALS; TRACE POLYHALITE; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY.
			HALITE, COARSELY CRYSTALLINE, WHITE; BECOMES SLIGHTLY ARGILLACEOUS WITH DEPTH; POLYHALITIC, OCCURS AS BLEBS AND SUBHORIZONTAL STRINGERS; BASAL CONTACT SHARP, IRREGULAR, SLIGHTLY UNDULATORY.
1529	1880		ARGILLACEOUS HALITE, REDDISH-BROWN WITH TRACE OF GRAY; HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR, OCCURS AS IRREGULARLY-SHAPED BEDS AND PODS, LOCALLY POLYHALITIC AND FREE OF CLAY; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND IRREGULAR RANDOMLY-ORIENTED STRINGERS; 1/4" THICK BED OF POLYHALITE UNDERLAIN BY 1/4" THICK DISCONTINUOUS BED OF GRAY CLAYSTONE OCCURS AT 1898.2'; BASAL CONTACT SHARP, IRREGULAR, SLIGHTLY UNDULATORY.
1524	1885		

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PRELIMINARY ELEV. (FT MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1524	1885		AS ABOVE
1519	1890		
1514	1895		
		MB 132	POLYHALITE, FINELY CRYSTALLINE, DARK REDDISH-ORANGE, STRUCTURELESS; UNDERLAIN BY 1" THICK GREENISH-GRAY CLAYSTONE; BASAL CONTACT SHARP.
1509	1900		HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE; TRACE ARGILLACEOUS MATERIAL BELOW 1901.0', CONTENT DECREASES WITH DEPTH, TOTALLY ABSENT BELOW 1904.8', OCCURS AS RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS BECOMING BLEBS WITH DEPTH; 1/4" THICK SUBHORIZONTAL STRINGERS OF ANHYDRITE OCCUR BELOW 1914.0'; AT 1916.5', A 0.2' THICK PINKISH-RED POLYHALITE BED OCCURS; BASAL CONTACT SHARP, SLIGHTLY IRREGULAR AND UNDULATORY.
1504	1905		
1499	1910		
1494	1915		
		MB 133	POLYHALITE, FINELY CRYSTALLINE, DARK RED, STRUCTURELESS AT TOP GRADING TO LAMINATED AT BASE; HALITIC, BASAL CONTACT SHARP TO GRADATIONAL, MARKED BY 0.1' TO 0.2' THICK GRAY CLAYSTONE BED.
1489	1920		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR, SLIGHTLY ARGILLACEOUS, OCCURS AS RANDOMLY-ORIENTED STRINGERS; ABUNDANT POLYHALITE, OCCURS AS DISSEMINATED BLEBS; CONTAINS LOCAL ZONES OF PURE HALITE; BASAL CONTACT GRADATIONAL, IRREGULAR.
1484	1925		HALITE, MEDIUM TO COARSELY CRYSTALLINE, CLEAR TO WHITE; RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS OF BLACK CLAY OCCUR BETWEEN 1923.5' AND 1926.4'; POLYHALITIC, CONTENT INCREASES ABRUPTLY BELOW 1926.8', THEN DECREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS; BASAL CONTACT DIFFUSE.
1479	1930		

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PRELIMINARY ELEV. (FT MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1479	1930		HALITE, FINELY TO COARSELY CRYSTALLINE, CLEAR TO WHITE; MODERATELY ARGILLACEOUS, CONTENT DECREASES WITH DEPTH, OCCURS AS BLACK BLEBS AND STRINGERS; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH, OCCURS AS DISCONTINUOUS IRREGULAR RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS AND DISSEMINATED BLEBS; CONTAINS LOCAL BEDS AND ZONES OF CLAY-FREE HALITE; POLYHALITE CONTENT INCREASES ABRUPTLY NEAR BASE; BASAL CONTACT SHARP.
1474	1935		
1469	1940		
			ANHYDRITE, FINELY CRYSTALLINE, LIGHT TO DARK GRAY, THINLY LAMINATED TO LAMINATED; UPPER 0 TO 0.5' POLYHALITIC; LOCALLY HALITIC, OCCURS AS DISCONTINUOUS BEDS AND PODS; SOME LAMINAE ORGANIC-RICH (?); LAMINAE UNDULATE SLIGHTLY; UNDERLAIN BY 0.1' TO 0.3' THICK GRAY HALITIC CLAYSTONE; BASAL CONTACT SHARP, IRREGULAR, SLIGHTLY UNDULATORY.
1464	1945		
1459	1950		HALITE, COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE, STRUCTURELESS; SLIGHTLY ARGILLACEOUS IN UPPER 5.0', OCCURS AS GRAY DISCONTINUOUS SUBHORIZONTAL STRINGERS, BELOW 1952.3' CONTENT INCREASES SHARPLY, THEN DECREASES WITH DEPTH, DISCONTINUOUS 1" TO 2" THICK IRREGULAR GRAY CLAYSTONE BED OCCURS AT 1952.3'; TRACE POLYHALITE, OCCURS AS LIGHT ORANGISH-WHITE DISSEMINATED BLEBS; IN BASAL 1.0' POLYHALITE AND ANHYDRITE OCCUR AS DISCONTINUOUS SUBHORIZONTAL STRINGERS; BASAL CONTACT SHARP, IRREGULAR.
1454	1955		
1449	1960		
		MB 134	ANHYDRITE, FINELY CRYSTALLINE, GRAY ALTERNATING WITH DARK GRAY, THINLY LAMINATED; LOCALLY CONTAINS PODS OF HALITE AND HALITE-RICH LAMINAE; BASAL CONTACT SHARP, CONFORMABLE.
1444	1965	MB 134	ANHYDRITE, FINELY CRYSTALLINE, GRAY; HALITIC, OCCURS AS ABUNDANT HALITE PSEUDOMORPHS AFTER GYPSUM SWALLOWTAIL CRYSTALS ALIGNED PARALLEL TO BEDDING, 1/8" TO 2" HIGH, MAJORITY ORIENTED VERTICALLY; LOCALLY, ANHYDRITE IS FREE OF PSEUDOMORPHS AND THINLY LAMINATED, LAMINAE ALTERNATE FROM LIGHT TO DARK GRAY; HALITE PSEUDOMORPHS ABSENT BETWEEN 1966.6' AND 1967.5'; BASAL CONTACT GRADATIONAL TO DIFFUSE.
1439	1970	MB 134	ANHYDRITE, FINELY CRYSTALLINE, ALTERNATING LIGHT AND DARK GRAY, THINLY LAMINATED TO LAMINATED; LAMINAE OFTEN CONTAIN INSIPIENT ENTROLITHIC STRUCTURES AND ANHYDRITE PSEUDOMORPHS AFTER GYPSUM SWALLOWTAIL CRYSTALS; UNDERLAIN BY 0.4' TO 0.5' THICK BED OF MICROLAMINATED TO THINLY LAMINATED GRAY CLAYSTONE CONTAINING SUBHORIZONTAL BIFURCATING 0 TO 1" THICK HALITE-FILLED FRACTURES; BASAL CONTACT SHARP, IRREGULAR, UNDULATORY, DISCONFORMABLE.
1434	1975		

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PRELIMINARY ELEV. (FT MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1434	1975		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR, STRUCTURELESS; MODERATELY ARGILLACEOUS, GRAY, CONTENT DECREASES WITH DEPTH, OCCURS AS DISSEMINATED RANDOMLY-ORIENTED DISCONTINUOUS STRINGERS AND BLEBS; TRACE POLYHALITE BLEBS; CONTAINS INTER-UNIT DISSOLUTION PITS FILLED WITH RELATIVELY PURE HALITE; FREE OF GRAY CLAY FROM 1985.0' TO 1989.0'; THIN (<1/8") SUBHORIZONTAL STRINGERS OF ANHYDRITE OCCUR BELOW 1986.0'; IRREGULAR BED OF HALITIC ANHYDRITE IN LOWER 1" TO 3" OVERLIES HIGHLY UNDULATORY BASAL CONTACT, CONTACT MARKED BY GRAY CLAYSTONE IN CHANNEL TROUGHS, CONTACT EROSIONALLY TERMINATES UNDERLYING UNIT AT THE WEST SIDE OF SHAFT; BASAL CONTACT SHARP.
1429	1980		
1424	1985		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE; CONTAINS DISCONTINUOUS SUBHORIZONTAL STRINGERS OF ANHYDRITE, <1/4" THICK; UNIT THICKNESS VARIES FROM 0 TO 1.5' AS IT IS EROSIONALLY TERMINATED AT UPPER CONTACT; SHAPE LENTICULAR (0 TO 1.5' X 6'); BASAL CONTACT SHARP.
1419	1990	MB 135	ANHYDRITE, FINELY CRYSTALLINE, LIGHT GRAY, LOCALLY THINLY LAMINATED; CONTAINS ABUNDANT HALITE PSEUDOMORPHS AFTER GYPSUM SWALLOWTAIL CRYSTALS; BASAL CONTACT SHARP, MARKED BY 1/4" TO 1/2" THICK GRAY CLAYSTONE BED.
			HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED GRAY, BANDED, SPACED 1/2" TO 4", TRACE GRAY CLAY; CONTAINS CONTINUOUS IRREGULAR SUBHORIZONTAL STRINGERS OF GRAY CLAY; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY UP TO 4".
1414	1995		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED GRAY, BANDED ON 1/2" TO 2" SCALE, SLIGHTLY ARGILLACEOUS, OCCURS AS SUBHORIZONTAL STRINGERS AND LOCAL RANDOMLY-ORIENTED STRINGERS; TRACE POLYHALITE, OCCURS AS DISSEMINATED BLEBS, CONTENT INCREASES WITH DEPTH; BASAL CONTACT SHARP.
1409	2000		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR, STRUCTURELESS; SLIGHTLY ARGILLACEOUS IN UPPER PART, CONTENT DECREASES WITH DEPTH, OCCURS AS REDDISH-BROWN RANDOMLY-ORIENTED STRINGERS; TRACE POLYHALITE, CONTENT INCREASES WITH DEPTH; BASAL CONTACT SHARP, SLIGHTLY IRREGULAR, SLIGHTLY UNDULATORY (3").
1404	2005		ARGILLACEOUS HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE; CLAY REDDISH-BROWN, CONTENT DECREASES WITH DEPTH, OCCURS AS INTERCRYSTALLINE MATRIX, GRADES TO SUBHORIZONTAL STRINGERS WITH DEPTH; HALITE OCCURS AS DISCONTINUOUS BEDS AND ALIGNED PODS; BASAL CONTACT SHARP, IRREGULAR, UNDULATORY.
1399	2010		
1394	2015		
1389	2020		

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PRELIMINARY ELEV. (FT MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1389	2020		AS ABOVE
1384	2025		HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE, OCCURS AS IRREGULAR DISCONTINUOUS BEDS 1/2" TO 2" THICK AT TOP, BECOMES MASSIVE WITH DEPTH; VERY ARGILLACEOUS AT TOP, CONTENT DECREASES WITH DEPTH, OCCURS AS INTERCRYSTALLINE MATRIX; ABUNDANT POLYHALITE AT TOP, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS AND RARE SUBHORIZONTAL STRINGERS; CONTAINS ABUNDANT VERTICALLY-ORIENTED ELONGATE ZONES OF PURE AND POLYHALITIC HALITE WITH IRREGULAR EDGES, 1.0' TO 2.0' ACROSS, UP TO 3.0' DEEP; BASAL CONTACT EXHIBITS CHANNEL FORM, WITH HIGH SIDE OCCURRING ON WEST SIDE OF SHAFT AT 2032.0' AND LOW POINT OCCURRING ON EAST SIDE OF SHAFT AT 2036.3'; CHANNEL FILL CONSISTS OF HALITE AND POLYHALITIC HALITE BELOW 2032.0', A 0.5' THICK BED OF FINELY CRYSTALLINE ANHYDRITE OCCURS AT 2032.3' AND TERMINATES AGAINST UNDERLYING UNIT AT WEST SIDE OF SHAFT, FILL CONTAINS ABUNDANT SUBHORIZONTAL STRINGERS OF ANHYDRITE THAT TERMINATE AGAINST UNDERLYING UNIT AT WEST SIDE OF SHAFT; BASAL CONTACT SHARP.
1379	2030		
1374	2035		
1369	2040	MB 136	POLYHALITE, FINELY CRYSTALLINE, REDDISH-ORANGE, STRUCTURELESS EXCEPT FOR LOCAL ZONES CONTAINING HALITE PSEUDOMORPHS AFTER GYPSUM SWALLOWTAIL CRYSTALS AND LOCAL ZONES WITH NODULAR STRUCTURE, LOCALLY THINLY LAMINATED NEAR BASE; UPPER 2.0' ON WEST SIDE OF SHAFT CONSISTS OF THINLY LAMINATED ANHYDRITE; BASAL CONTACT GRADATIONAL, UNDULATORY.
1364	2045	MB 136	ANHYDRITE, FINELY CRYSTALLINE, ALTERNATING LIGHT AND DARK GRAY, THINLY LAMINATED, LAMINAE UNDULATE SLIGHTLY; 0.3' ABOVE LOWER CONTACT, 0 TO 1" THICK DISCONTINUOUS PURE HALITE BED OCCURS, CONTAINS ONE DISCONTINUOUS STRINGER OF POLYHALITE; BASAL CONTACT SHARP.
1359	2050		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; SLIGHTLY ARGILLACEOUS, CONTENT DECREASES WITH DEPTH, OCCURS AS REDDISH-BROWN TO GRAY RANDOMLY-ORIENTED TO SUBHORIZONTAL STRINGERS WHICH BECOME SUBHORIZONTAL WITH DEPTH; TRACE POLYHALITE, OCCURS AS DISSEMINATED BLEBS AND SUBHORIZONTAL STRINGERS NEAR BASE; 1" TO 2" THICK BED OF ANHYDRITE (NORTHWEST SIDE OF SHAFT) AND POLYHALITE (SOUTHEAST SIDE OF SHAFT) AT 2059.3'; SUBHORIZONTAL STRINGERS OF ANHYDRITE IN LOWER 5.0'; NO CLAY OCCURS BELOW 2059.3'; BASAL CONTACT SHARP, UNDULATORY TO 0.4', DISCONFORMABLE.
1354	2055		
1349	2060	MB 137	HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR TO TINTED ORANGE AND GRAY, THINLY BEDDED TO GRAY ARGILLACEOUS HALITE WITH CLAY-FREE HALITE, BEDDING TERMINATED AT UPPER CONTACT; TRACE POLYHALITE AT TOP, CONTENT INCREASES WITH DEPTH, OCCURS AS DISSEMINATED BLEBS; ARGILLACEOUS, CONTENT DECREASES WITH DEPTH, GRAY AT TOP GRADING TO GRAYISH-BROWN WITH DEPTH, OCCURS AS DISCONTINUOUS RANDOMLY-ORIENTED STRINGERS AND LOCAL ZONES OF INTERCRYSTALLINE MATERIAL, BECOMES REDDISH-BROWN BELOW 2070.2', CONTENT DECREASES ABRUPTLY BELOW 2079.0', BASAL 2.0' SLIGHTLY ARGILLACEOUS; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY, IRREGULAR, MARKED BY DISCONTINUOUS IRREGULAR 2" THICK BED OF HALITIC ANHYDRITE.
1344	2065		

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PRELIMINARY ELEV. (FT MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1344	2065		AS ABOVE
1339	2070		
1334	2075		
1329	2080		
			HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; TRACE POLYHALITE, OCCURS AS DISSEMINATED BLEBS; ARGILLACEOUS IN UPPER 1.2', OCCURS AS REDDISH-BROWN DISCONTINUOUS SUBHORIZONTAL STRINGERS AND MASSES OF HALITIC MUDSTONE, CONTENT DECREASES WITH DEPTH; BASAL CONTACT SHARP.
1324	2085		
			HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; TRACE DISSEMINATED BLEBS AND RANDOMLY-ORIENTED STRINGERS OF POLYHALITE; ARGILLACEOUS IN UPPER 1.0', CONTENT DECREASES WITH DEPTH; LOCAL ANHYDRITE STRINGERS OCCUR NEAR BASAL CONTACT; BASAL CONTACT SHARP, SLIGHTLY IRREGULAR AND UNDULATORY.
1319	2090		
			HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; RARE DISSEMINATED POLYHALITE BLEBS; ARGILLACEOUS AT TOP, CONTENT DECREASES WITH DEPTH EXCEPT FOR LOCAL INCREASES, CONTENT DECREASES ABRUPTLY BELOW 2101.5', OCCURS AS DISCONTINUOUS SUBHORIZONTAL STRINGERS; THIN DISCONTINUOUS STRINGERS OF ANHYDRITE AND POLYHALITE OCCUR IN LOWER 2.0'; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY.
1314	2095		
1309	2100		
1304	2105		ANHYDRITE, FINELY CRYSTALLINE, ALTERNATING LIGHT AND DARK GRAY, THINLY LAMINATED; UNDERLAIN BY 1/2" THICK GRAYISH-BROWN CLAYSTONE BED; BASAL CONTACT SHARP.
			HALITE, FINELY TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE, BEDDED AT TOP WITH REDDISH-BROWN ARGILLACEOUS HALITE, SPACED 1" TO 2"; ARGILLACEOUS, CONTENT DECREASES WITH DEPTH, OCCURS AS INTERCRYSTALLINE MATRIX IN ARGILLACEOUS HALITE BANDS AT TOP AND RANDOMLY-ORIENTED STRINGERS WITH DEPTH, CONTENT DECREASES ABRUPTLY BELOW 2111.3'; RARE DISSEMINATED BLEBS OF POLYHALITE; BASAL CONTACT DIFFUSE.
1299	2110		

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PRELIMINARY ELEV. (FT MSL)	PRELIMINARY DEPTH (FT.)	STRATIGRAPHIC COLUMN	REMARKS
1299	2110		AS ABOVE
1294	2115		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; RARE STRINGERS OF CLAY IN UPPER 1.7'; TRACE SUBHORIZONTAL TO HORIZONTAL CONTINUOUS STRINGERS OF ANHYDRITE BELOW 2117.0'; BASAL CONTACT SHARP.
1289	2120		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO TINTED ORANGE, RARE RANDOMLY-ORIENTED CLAY STRINGERS TO 2125.2'; UPPER CONTACT MARKED BY ANHYDRITIC CLAYSTONE CONTAINING DISPLACIVE HALITE CRYSTALS (<1/4"); TRACE POLYHALITE BLEBS; ANHYDRITE STRINGERS OCCUR BETWEEN 2128.1' AND 2128.5'; BASAL CONTACT SHARP, SLIGHTLY UNDULATORY, IRREGULAR.
1284	2125		
1279	2130		ANHYDRITE (A), FINELY CRYSTALLINE, LIGHT GRAY, THINLY LAMINATED, LAMINAE SLIGHTLY CONTORTED; LOCALLY CONTAINS SMALL HALITE CRYSTALS (<1/16"); BASAL CONTACT SHARP, SLIGHTLY UNDULATORY.
			HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; RARE CLAY STRINGERS TO 2131.5'; SUBHORIZONTAL STRINGERS OF ANHYDRITE SPACED 2" TO 4" OCCUR BELOW 2134.0'; BASAL CONTACT SHARP.
1274	2135		ANHYDRITE (B), FINELY CRYSTALLINE, LIGHT GRAY, HINT OF THIN LAMINATIONS; HALITIC, BASAL CONTACT SHARP, IRREGULAR, SLIGHTLY UNDULATORY.
1269	2140		HALITE, MEDIUM TO COARSELY CRYSTALLINE, WHITE TO CLEAR; RARE SUBHORIZONTAL CLAY STRINGERS AT TOP, CONTENT DECREASES WITH DEPTH; VERY RARE BLEBS OF POLYHALITE; BASAL CONTACT NOT OBSERVED.
1264	2145		
	2146.4	FACILITY LEVEL	

EXHAUST SHAFT

LITHOLOGIC LOG

APPENDIX G

TEST ROOMS
GEOLOGIC MAPS AND SECTIONS

CONTENTS

Figure No.	Title/Description
G-1	Test Room 1 - Instrument Array Geologic Strip Map
G-2	Test Room 2 - Instrument Array Geologic Strip Map
G-3	Test Room 3 - Instrument Array Geologic Strip Map
G-4	Test Room 4 - Instrument Array Geologic Strip Map
G-5	Section Through Test Room 1
G-6	Section Through Test Room 2
G-7	Section Through Test Room 3
G-8	Section Through Test Room 4
G-9	Room T Large Diameter Drill Hole Location Plan
G-10	Geologic Map of Drill Hole TV-01
G-11	Geologic Map of Drill Hole TV-02
G-12	Geologic Map of Drill Hole TV-03
G-13	Geologic Map of Drill Hole TV-04
G-14	Geologic Map of Drill Hole TV-05
G-15	Geologic Map of Drill Hole TV-06
G-16	Geologic Map of Drill Hole TV-07
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G-20	Geologic Map of Drill Hole TV-11
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G-23	Geologic Map of Drill Hole TV-14
G-24	Geologic Map of Drill Hole TV-15
G-25	Geologic Map of Drill Hole TV-16
G-26	Geologic Map of Drill Hole TV-17
G-27	Geologic Map of Drill Hole TV-18
G-28	Geologic Map of Drill Hole TV-19
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G-30	Geologic Map of Drill Hole TV-21
G-31	Geologic Map of Drill Hole TV-22
G-32	Section A Through Room T
G-33	Section B Through Room T
G-34	Geologic Map of Drill Hole P4X-84

The following descriptions pertain to the geologic map units shown on Figures G-1 through G-4:

UNIT DESCRIPTIONS

UNIT 6[1] Halite: colorless with grayish orange-pink (1 OR 8/2)[2] tint; transparent to translucent; coarsely crystalline; trace of dispersed polyhalite; unit extends into the roof; lower contact with Unit 5 is gradational and/or diffuse.

UNIT 5 Halite: colorless; transparent to translucent; coarsely crystalline; trace of bluish-white (5B 9/1) to light bluish-gray (5B 7/1) argillaceous material occurring as pods (1/2-inch diameter) and discontinuous laminations or filling interstices; lower contact with Unit 4 is generally sharp and based on prominent color change in argillaceous material (gray to red-brown) from Unit 5 to Unit 4.

UNIT 4 Argillaceous halite: colorless to moderate reddish-brown (1 OR 4/6), less frequently light bluish-gray (5B 7/1); transparent; coarsely crystalline; trace of dispersed polyhalite; trace to abundant argillaceous material (decreasing downward) consisting of clay containing a trace of silt and fine crystals of halite, occurring as discontinuous laminations in upper half of unit and interstitially in lower half; lower contact with Unit 3 is gradational and based on absence of argillaceous material in Unit 3.

UNIT 3 Halite: colorless to moderate reddish-orange (1 OR 6/6); transparent to translucent; coarsely crystalline; trace of dispersed polyhalite; polyhalite content commonly increases downward; lower contact with Unit 2 is sharp.

UNIT 2 Argillaceous halite: moderate reddish-brown (1 OR 5/5), less frequently light bluish-gray (5B 7/1); medium to coarsely crystalline; argillaceous material primarily occurs interstitially or as discontinuous laminations; lower contact with Unit 1 is generally sharp, less frequently gradational.

UNIT 1 Halite: light reddish-orange (1 OR 8/6) to moderate reddish-orange (1 OR 6/6), less frequently colorless; translucent to transparent; medium to coarsely crystalline; trace of dispersed polyhalite; lower contact with Unit 0 is sharp.

UNIT 0 Argillaceous halite: colorless to moderate reddish-orange (1 OR 6/6) and moderate reddish-brown (1 OR 4/6); medium to coarsely crystalline; trace of dispersed polyhalite; some argillaceous material occurs as discontinuous laminations and blebs or fills interstices (decreasing downward); contains finely crystalline halite; unit extends into the floor.

NOTES:

(1) Units listed in descending order from roof to floor.

(2) Alpha-numeric color designations are based on Geological Society of America Rock Color Chart.

The following legend and notes pertain to the geologic maps shown on Figures G-1 through G-4:

LEGEND:

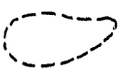
CONTACTS

——————— SHARP (LESS THAN 0.05 FEET)

——— ——— ——— GRADATIONAL (0.05 TO 0.2 FEET)

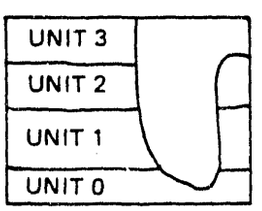
. . . . . DIFFUSE (0.2 TO 0.5 FEET)

WEEP



DAMP AREA WITH 1/4" TO 3/4" DIAMETER KNOBS AND INCRUSTATIONS OF FINELY-CRYSTALLINE HALITE.

BREAKS IN BED CONTINUITY

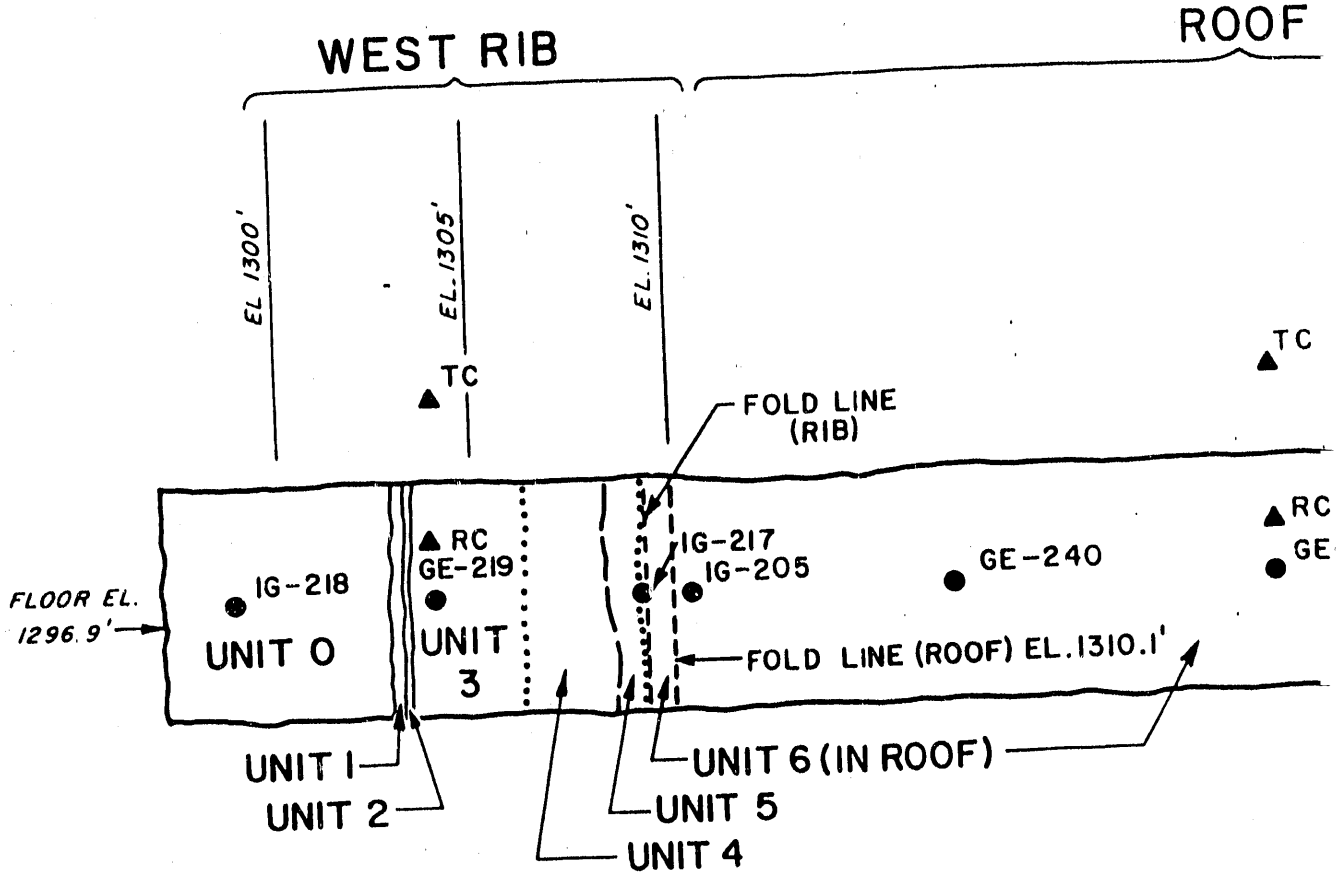


SYN- OR IMMEDIATELY POST-DEPOSITIONAL DISSOLUTION OR SCOUR CHANNELS FILLED WITH SEDIMENT FROM OVERLYING UNIT. (TYPICAL)

NOTES:

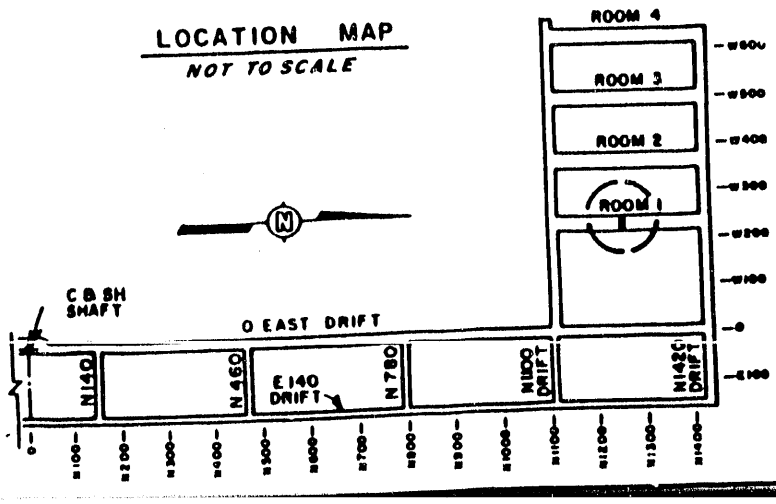
1. VERTICAL CONTROL FOR MAPPING IS MEAN SEA LEVEL (MSL) REFERENCED TO UNDERGROUND SURVEY POINTS ESTABLISHED BY CEMENTATION WEST, INC.
2. HORIZONTAL CONTROL FOR MAPPING REFERENCED TO ZERO POINT AT CENTER-LINE OF C&SH SHAFT.

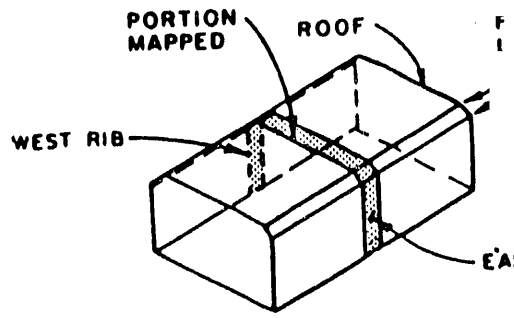
DRAWN BY	CHECKED BY	DRAWING NUMBER
[illegible] 7-28-83	APPROVED BY [illegible] 7-28-83	[illegible] 7-28-83



LOCATION MAP

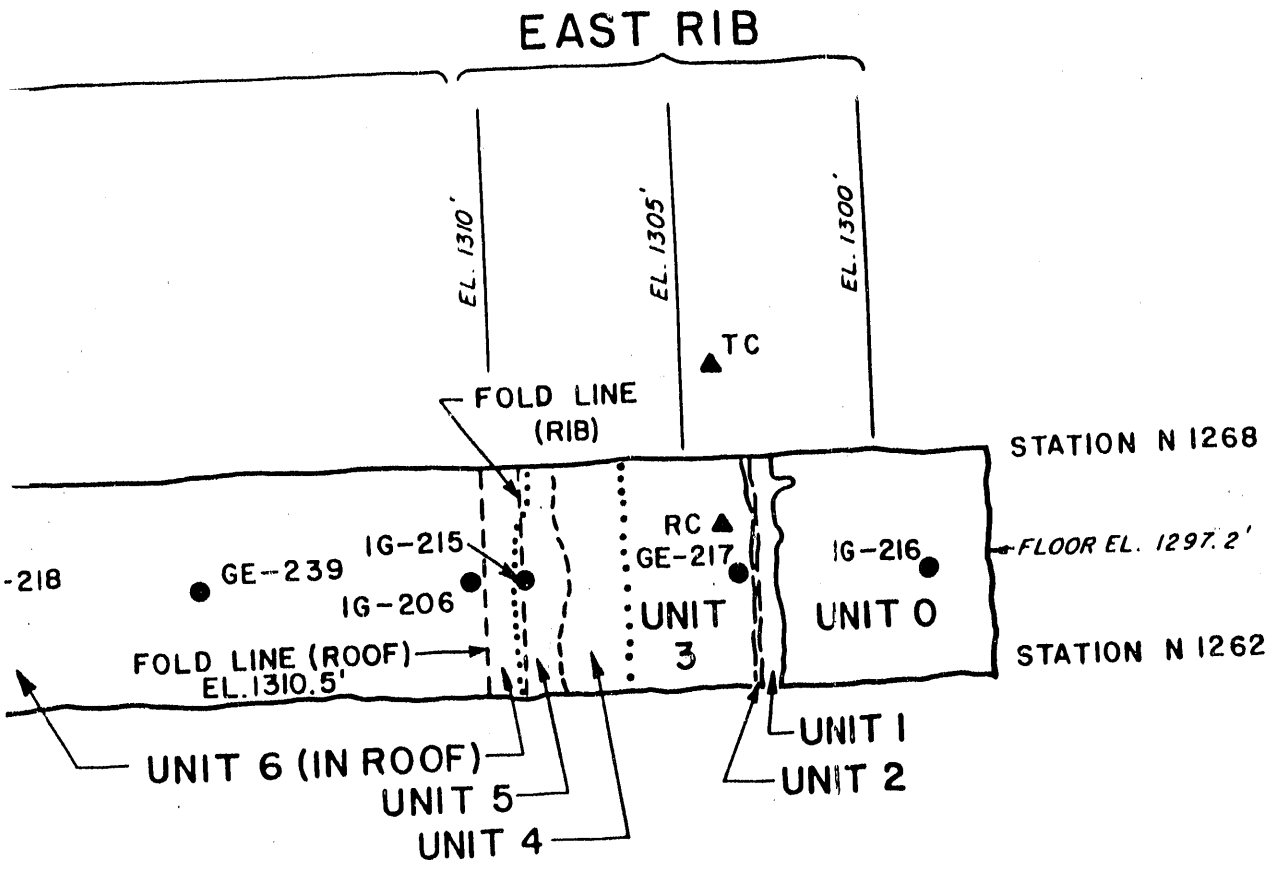
NOT TO SCALE





SCHEMATIC SECTION

NOT TO SCALE



5 0 5 FEET

SCALE

EXPLANATION

FOR UNIT DESCRIPTIONS, LEGEND AND NOTES SEE FRONT OF THIS APPENDIX.

● IG-217 INCLINOMETER

● GE-218 BOREHOLE EXTENSOMETER

▲ RC/TC CONVERGENCE POINTS

REFERENCE:

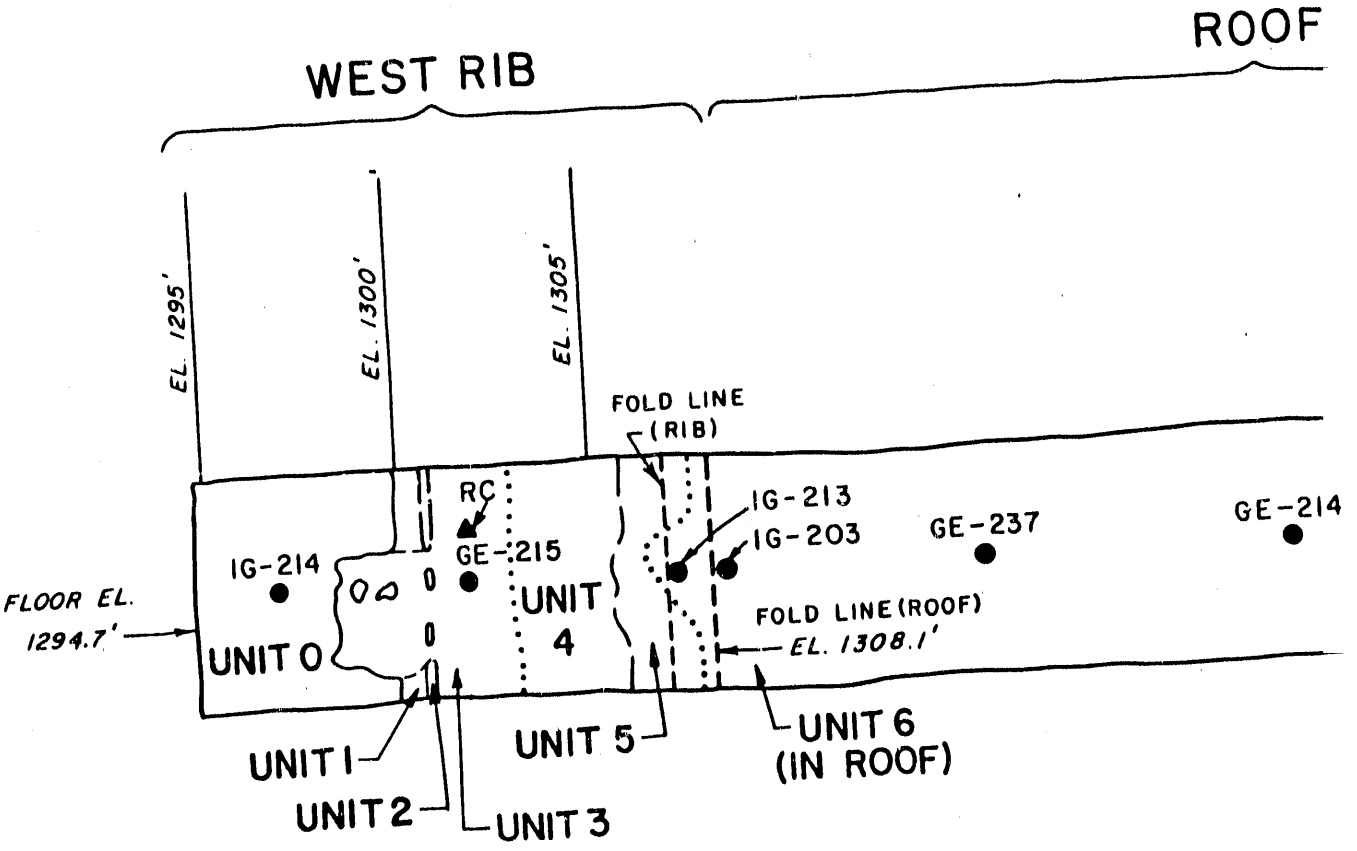
QUARTERLY GEOTECHNICAL FIELD DATA REPORT, JULY 1983, WIPP-DOE-163.

FIGURE G-1

TEST ROOM 1

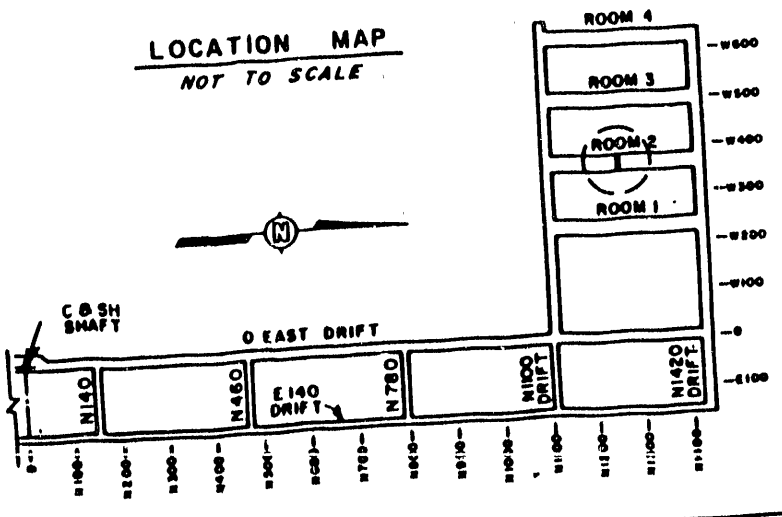
INSTRUMENT ARRAY GEOLOGIC STRIP MAP

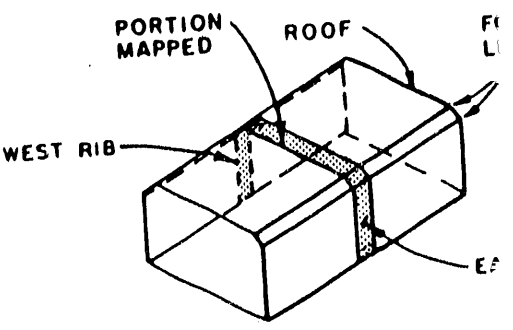
DRAWN BY	CHECKED BY	DRAWING NUMBER
[illegible] 7-28-83	[illegible]	[illegible]
	APPROVED BY	
	[illegible]	



LOCATION MAP

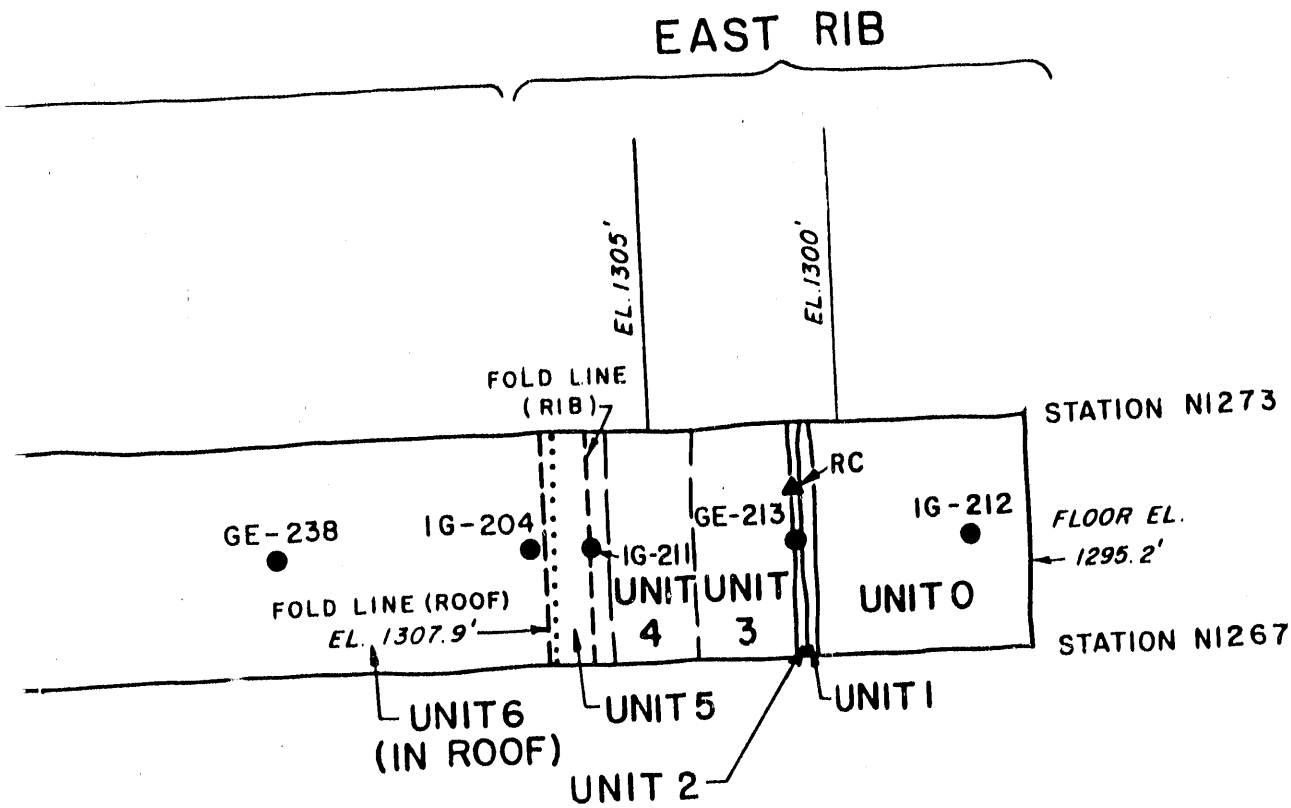
NOT TO SCALE





SCHEMATIC SECTION

NOT TO SCALE



5 0 5 FEET

SCALE

EXPLANATION

FOR UNIT DESCRIPTIONS, LEGEND AND NOTES SEE FRONT OF THIS APPENDIX.

EAST RIB - MAPPING UNIT CONTACTS ARE OBSCURED BY GROUT TO 2' SOUTH AND 4' NORTH OF INSTRUMENT LINE. INDICATED CONTACTS ARE PROJECTED FROM THESE POINTS.

- ● IG-215 INCLINOMETER
- ● GE-214 BOREHOLE EXTENSOMETER
- ▲ RC/TC CONVERGENCE POINTS

REFERENCE:

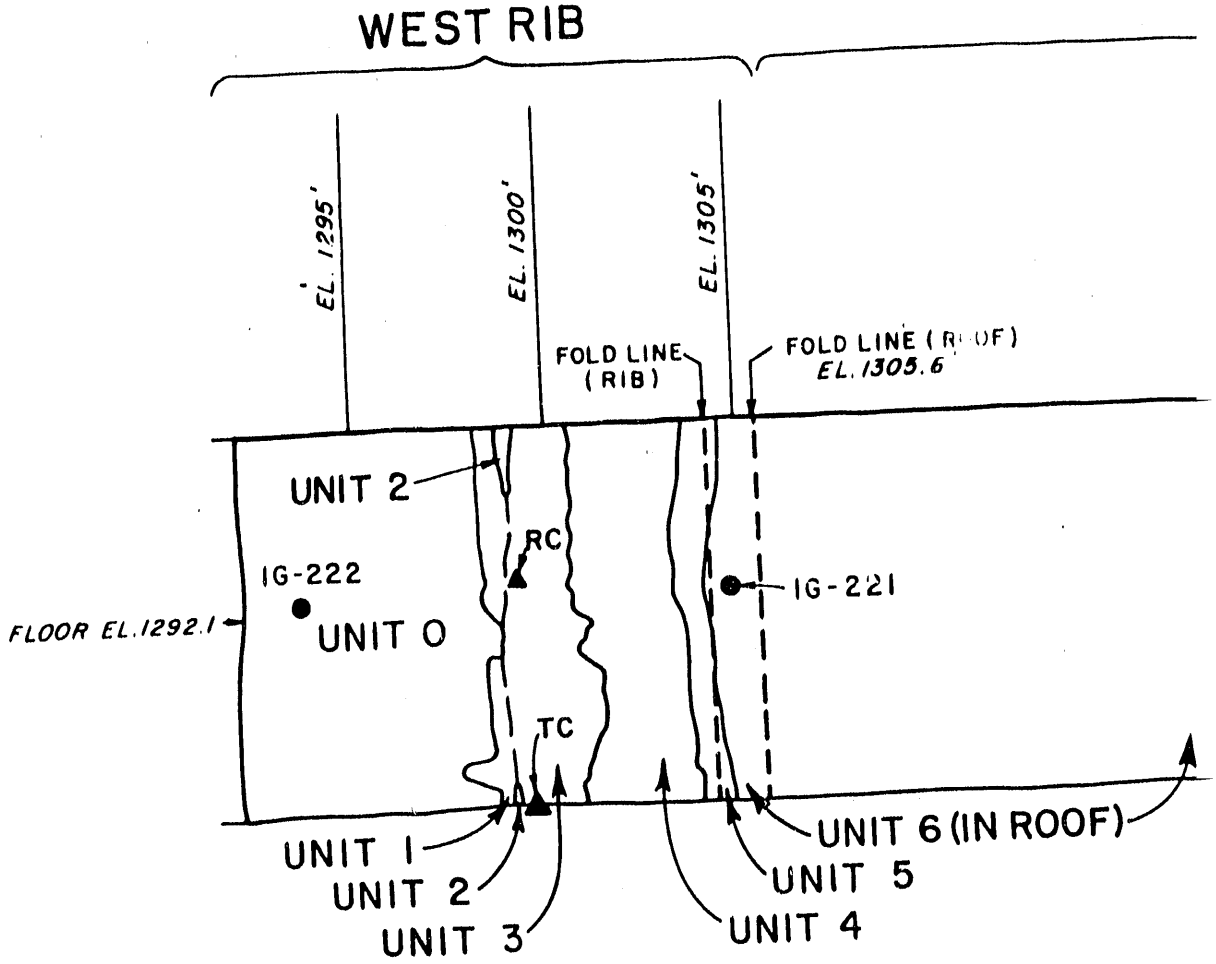
QUARTERLY GEOTECHNICAL FIELD DATA REPORT, JULY 1983, WIPP-DOE-163.

FIGURE G-2

TEST ROOM 2

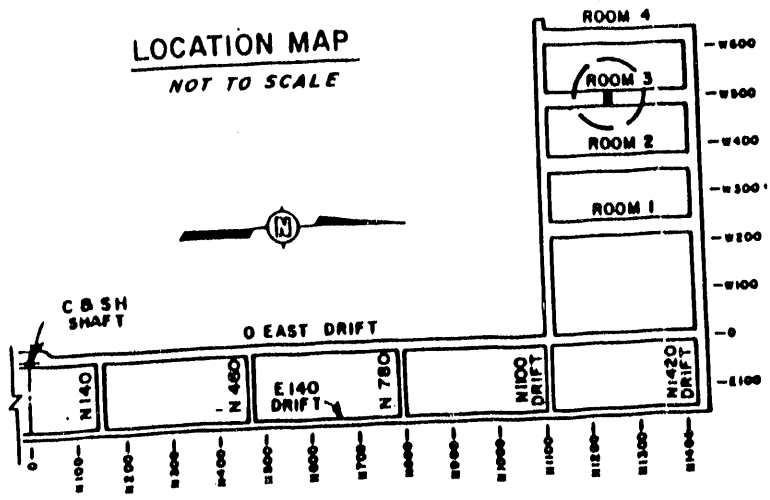
INSTRUMENT ARRAY GEOLOGIC STRIP MAP

DRAWN BY	2-28-83	
CHECKED BY	2-28-83	
APPROVED BY	2-28-83	
DRAWING NUMBER		138-83

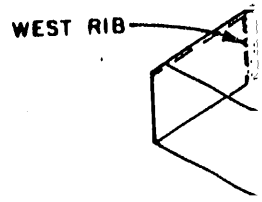


LOCATION MAP

NOT TO SCALE

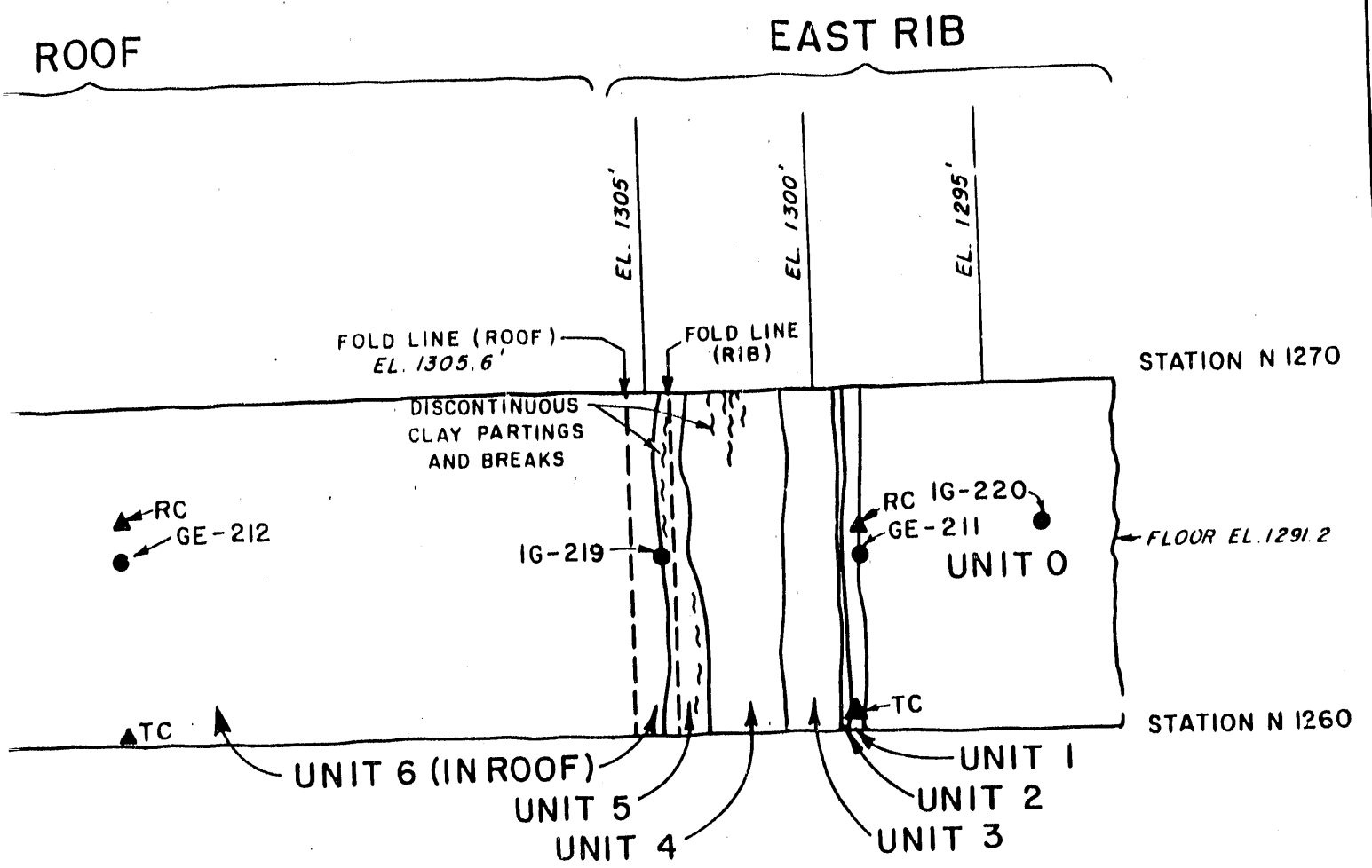


PORTION MAPPED



SCHEMAT

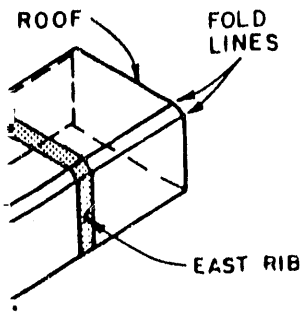
NOT TO



EXPLANATION

FOR UNIT DESCRIPTIONS, LEGEND AND NOTES SEE FRONT OF THIS APPENDIX.

- ● IG-221 INCLINOMETER
- ● GE-211 BOREHOLE EXTENSOMETER
- ▲ RC/TC CONVERGENCE POINTS



C SECTION

SCALE

5 0 5 FEET

SCALE

REFERENCE:

QUARTERLY GEOTECHNICAL FIELD DATA REPORT, JULY 1983, WIPP-DOE-163.

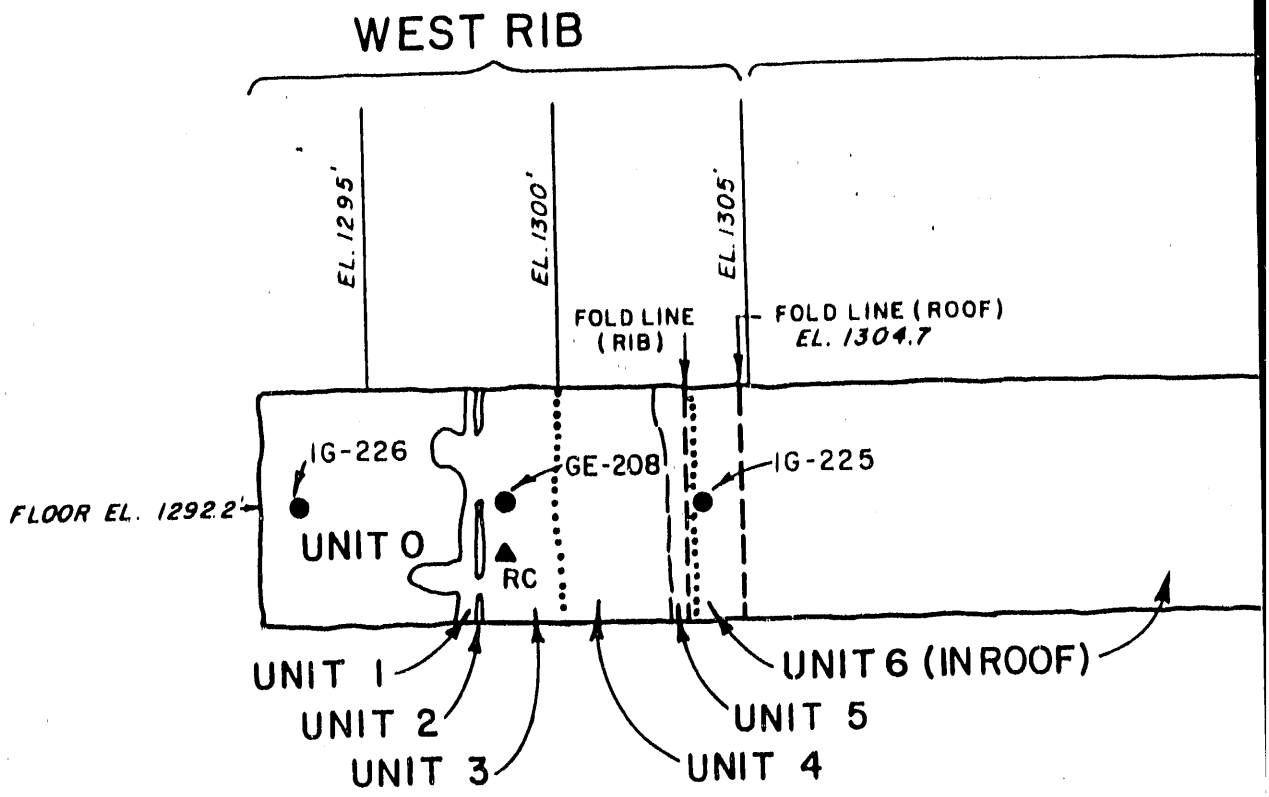
FIGURE G-3

TEST ROOM 3

INSTRUMENT ARRAY GEOLOGIC STRIP MAP

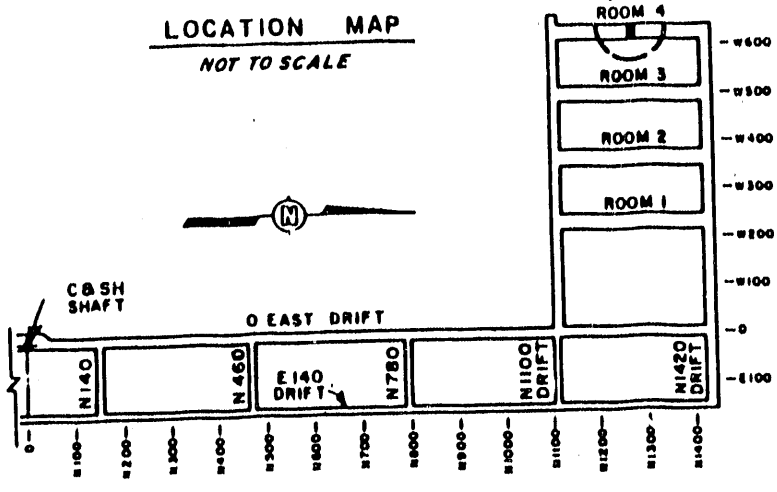
080-B

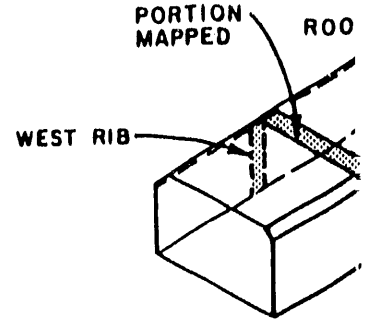
DRAWN BY	CHECKED BY	DRAWING NUMBER
L A 5/19/83	APPROVED BY	NM78-648-B



LOCATION MAP

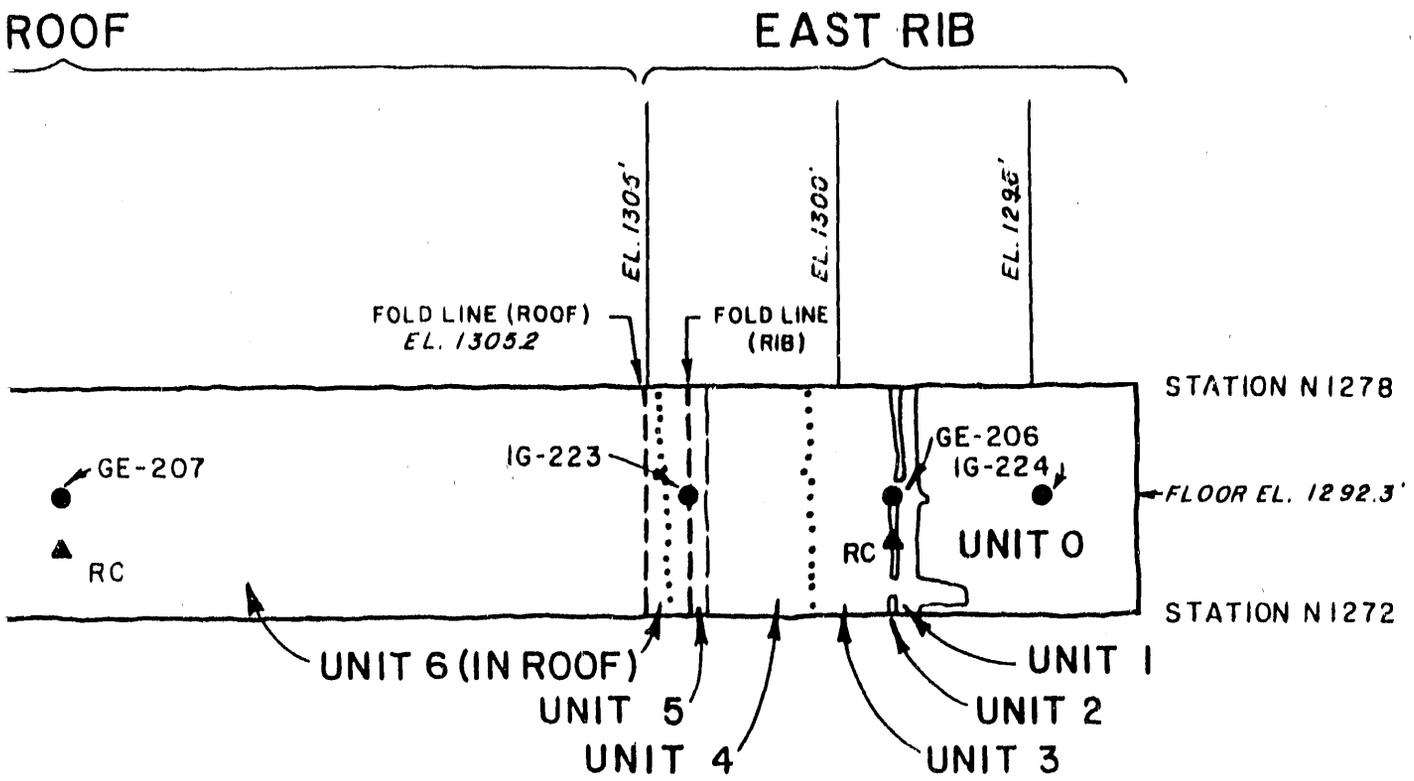
NOT TO SCALE





SCHEMATIC S

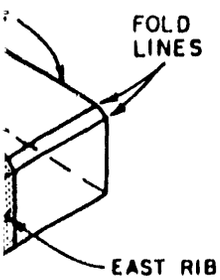
NOT TO SCAL



EXPLANATION

FOR UNIT DESCRIPTIONS, LEGEND AND NOTES SEE FRONT OF THIS APPENDIX.

- ● IG-225 INCLINOMETER
- ● GE-207 BOREHOLE EXTENSOMETER
- ▲ RC/TC CONVERGENCE POINTS



5 0 5 FEET

SCALE

REFERENCE:

QUARTERLY GEOTECHNICAL FIELD DATA REPORT, JULY 1983, WIPP-DOE-163.

FIGURE G-4

TEST ROOM 4

INSTRUMENT ARRAY GEOLOGIC STRIP MAP

ECTION

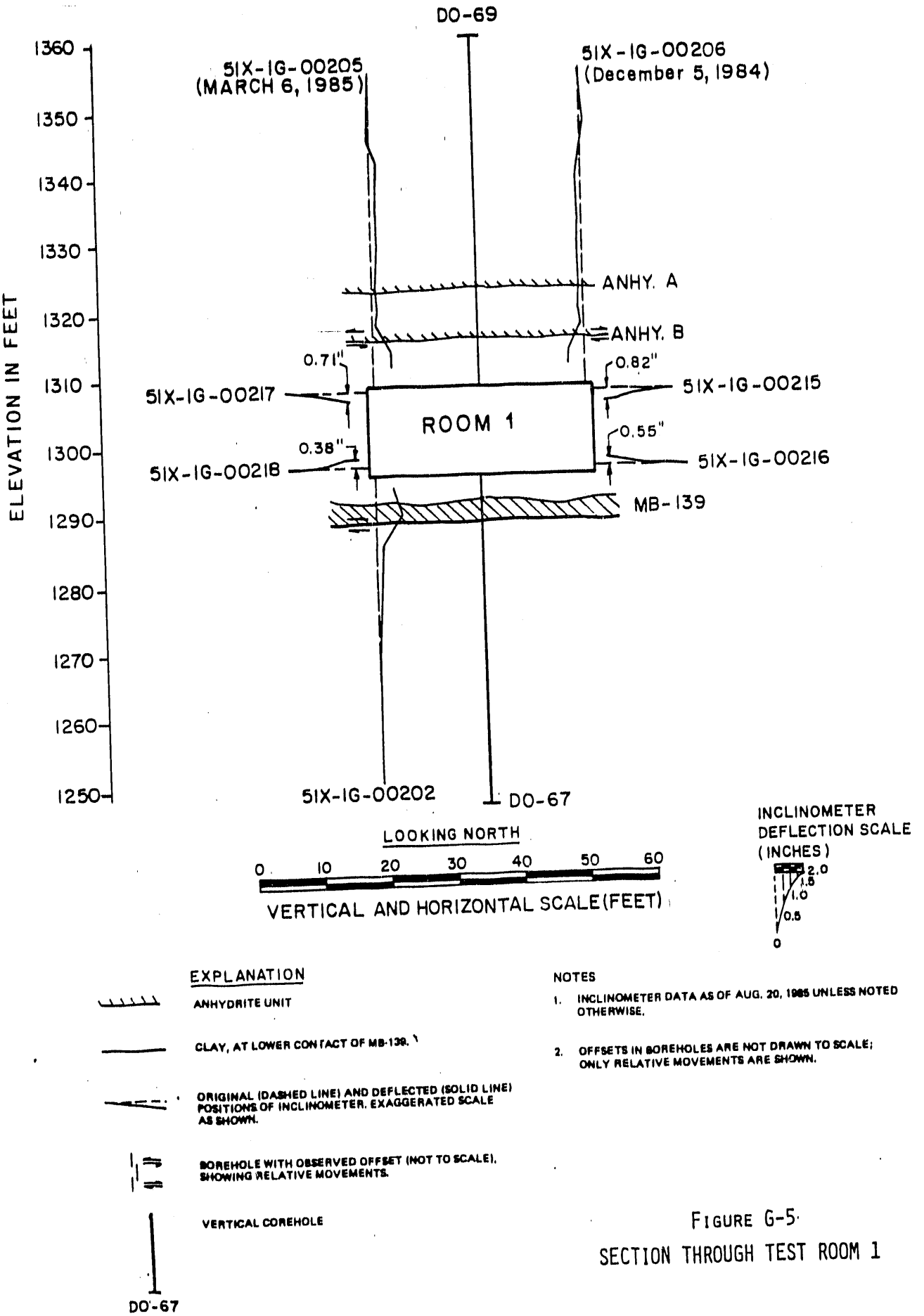
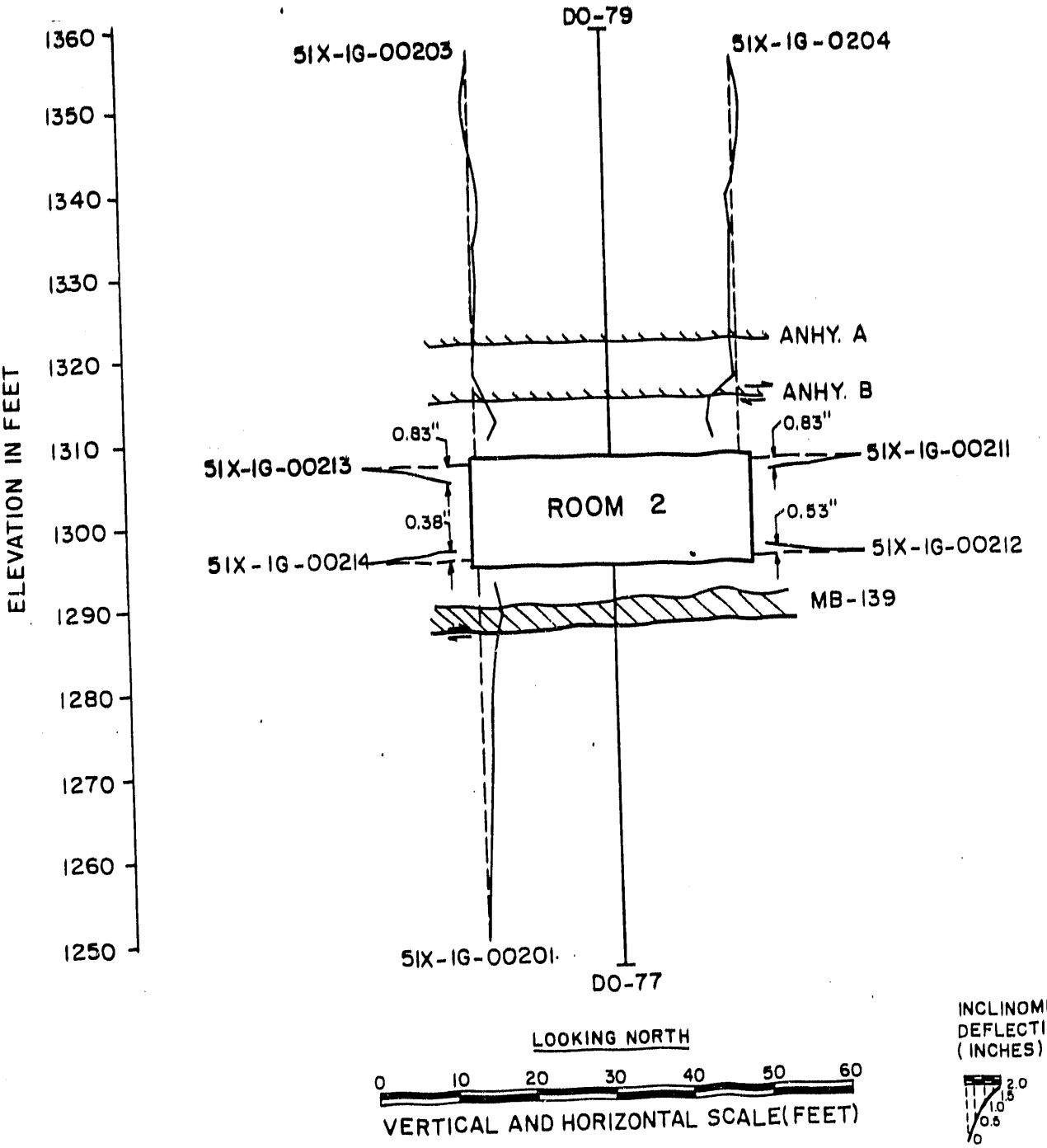


FIGURE G-5.
SECTION THROUGH TEST ROOM 1



EXPLANATION

- ANHYDRITE UNIT
- CLAY, AT LOWER CONTACT OF MB-139.
- ORIGINAL (DASHED LINE) AND DEFLECTED (SOLID LINE) POSITIONS OF INCLINOMETER. EXAGGERATED SCALE AS SHOWN.
- BOREHOLE WITH OBSERVED OFFSET (NOT TO SCALE), SHOWING RELATIVE MOVEMENTS.
- VERTICAL COREHOLE

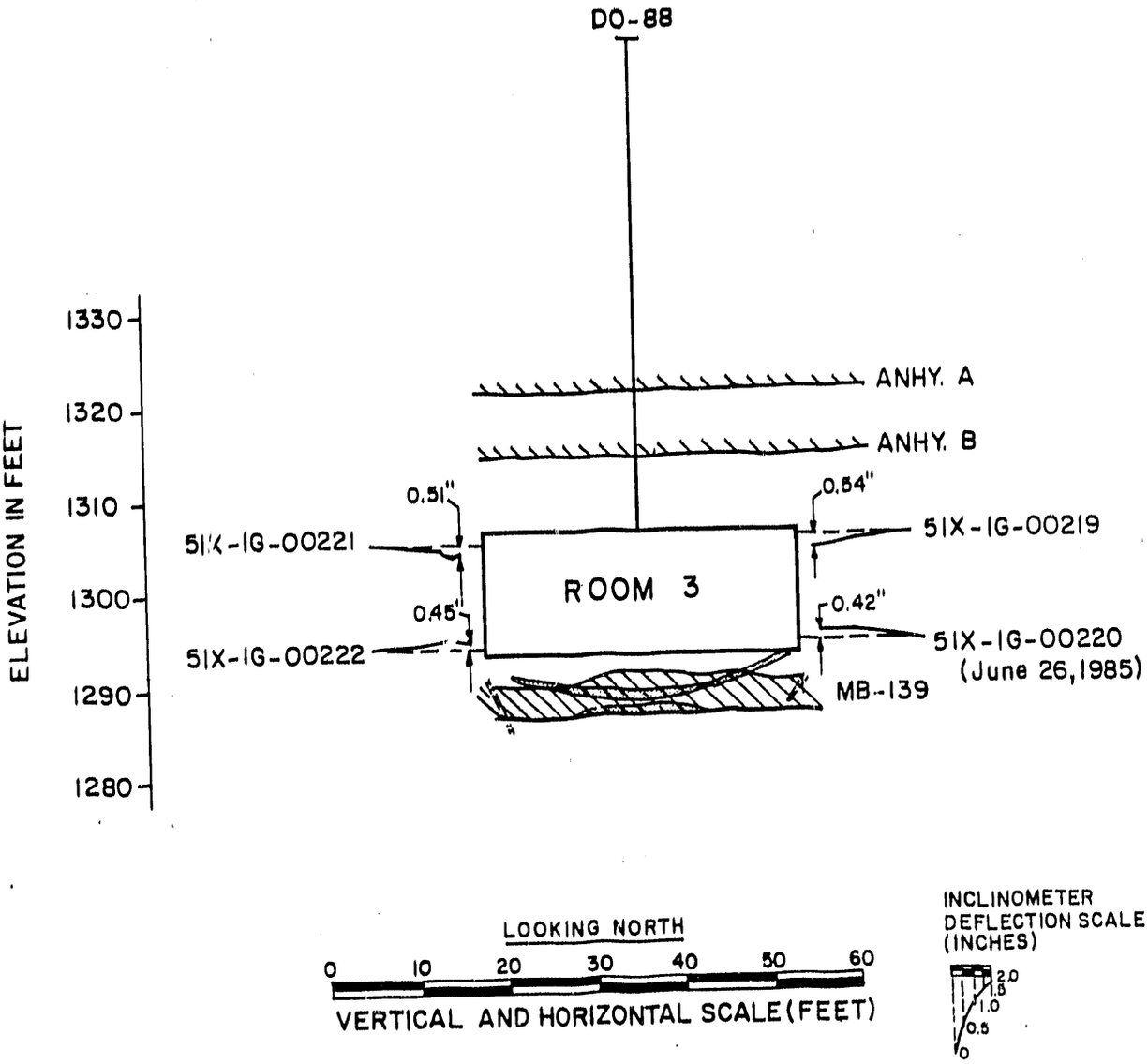
DO-77

NOTES

1. INCLINOMETER DATA AS OF AUG. 20, 1985 UNLESS NOTED OTHERWISE.
2. OFFSETS IN BOREHOLES ARE NOT DRAWN TO SCALE; ONLY RELATIVE MOVEMENTS ARE SHOWN.

FIGURE G-6

SECTION THROUGH TEST ROOM 2



EXPLANATION

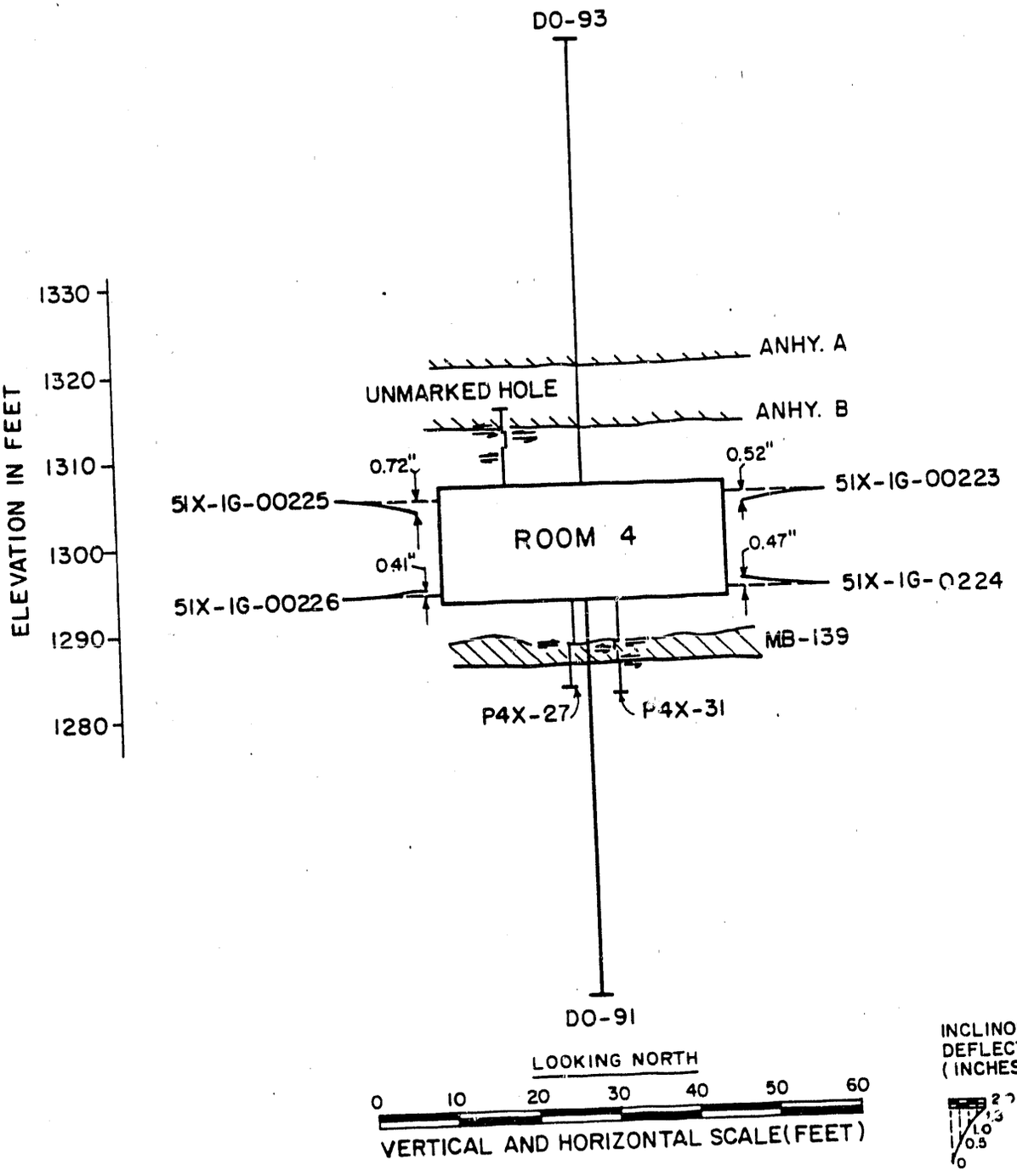
- ANHYDRITE UNIT
- FRACTURE ZONE
- CLAY, AT LOWER CONTACT OF MB-139.
- OPEN FRACTURE
- ORIGINAL (DASHED LINE) AND DEFLECTED (SOLID LINE) POSITIONS OF INCLINOMETER. EXAGGERATED SCALE AS SHOWN.
- BOREHOLE WITH OBSERVED OFFSET (NOT TO SCALE), SHOWING RELATIVE MOVEMENTS.
- DO-88 VERTICAL COREHOLE

NOTES

1. OPEN FRACTURES AND FRACTURE ZONES SHOWN BELOW ROOM 3 ARE GENERALIZED FROM GEOLOGIC MAPPING OF LARGE (36-INCH) DIAMETER BOREHOLES. INFORMATION ON FRACTURES BELOW OTHER ROOMS IS INCOMPLETE.
2. INCLINOMETER DATA AS OF AUG. 20, 1985 UNLESS NOTED OTHERWISE.
3. OFFSETS IN BOREHOLES ARE NOT DRAWN TO SCALE; ONLY RELATIVE MOVEMENTS ARE SHOWN.

FIGURE G-7

SECTION THROUGH TEST ROOM 3



EXPLANATION

ANHYDRITE UNIT

CLAY, AT LOWER CONTACT OF MB-139.

ORIGINAL (DASHED LINE) AND DEFLECTED (SOLID LINE) POSITIONS OF INCLINOMETER. EXAGGERATED SCALE AS SHOWN.

BOREHOLE WITH OBSERVED OFFSET (NOT TO SCALE), SHOWING RELATIVE MOVEMENTS.

VERTICAL COREHOLE

DO-91

NOTES

1. INCLINOMETER DATA AS OF AUG. 20, 1985 UNLESS NOTED OTHERWISE.
2. OFFSETS IN BOREHOLES ARE NOT DRAWN TO SCALE; ONLY RELATIVE MOVEMENTS ARE SHOWN.

FIGURE G-8

SECTION THROUGH TEST ROOM 4

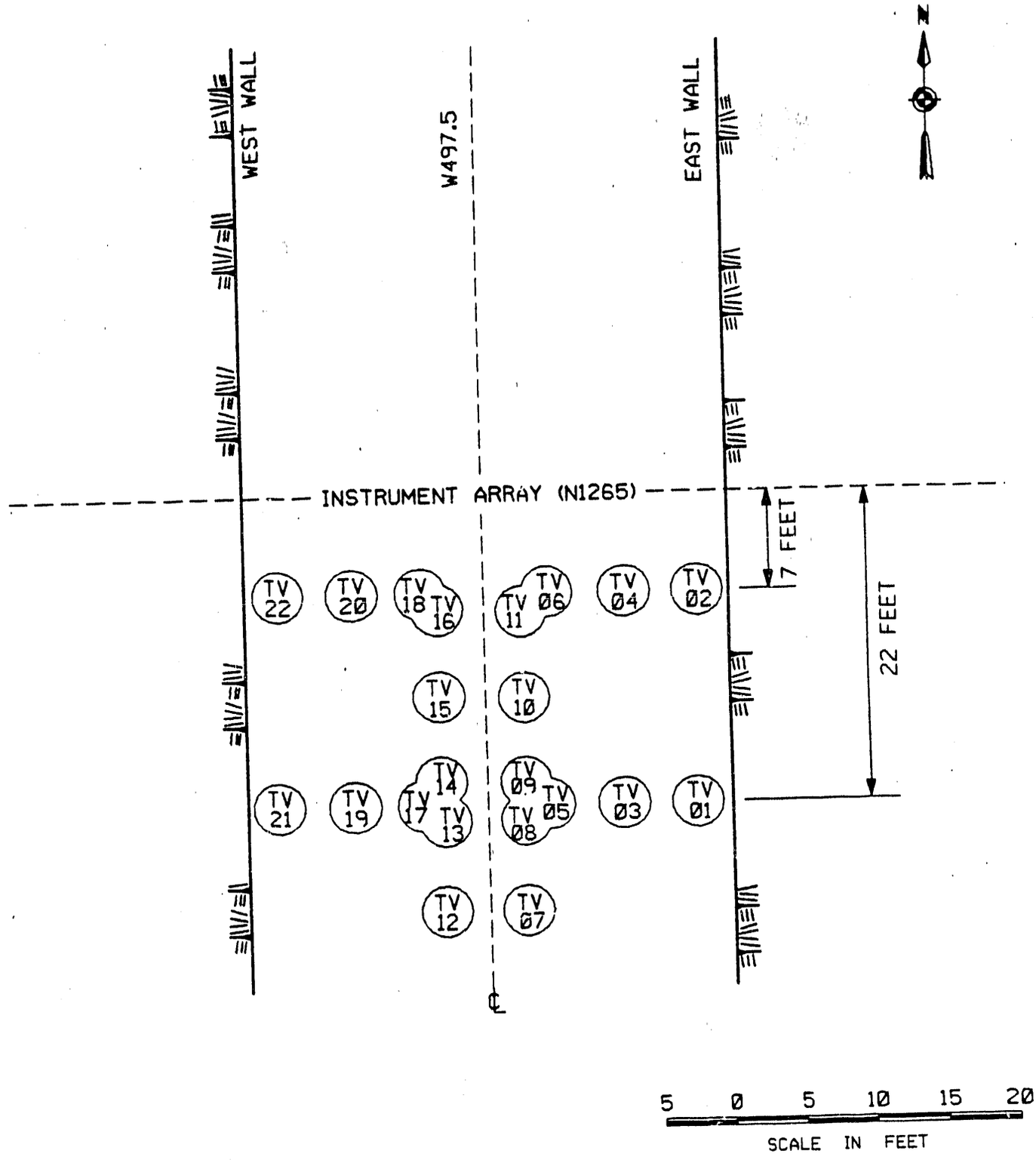
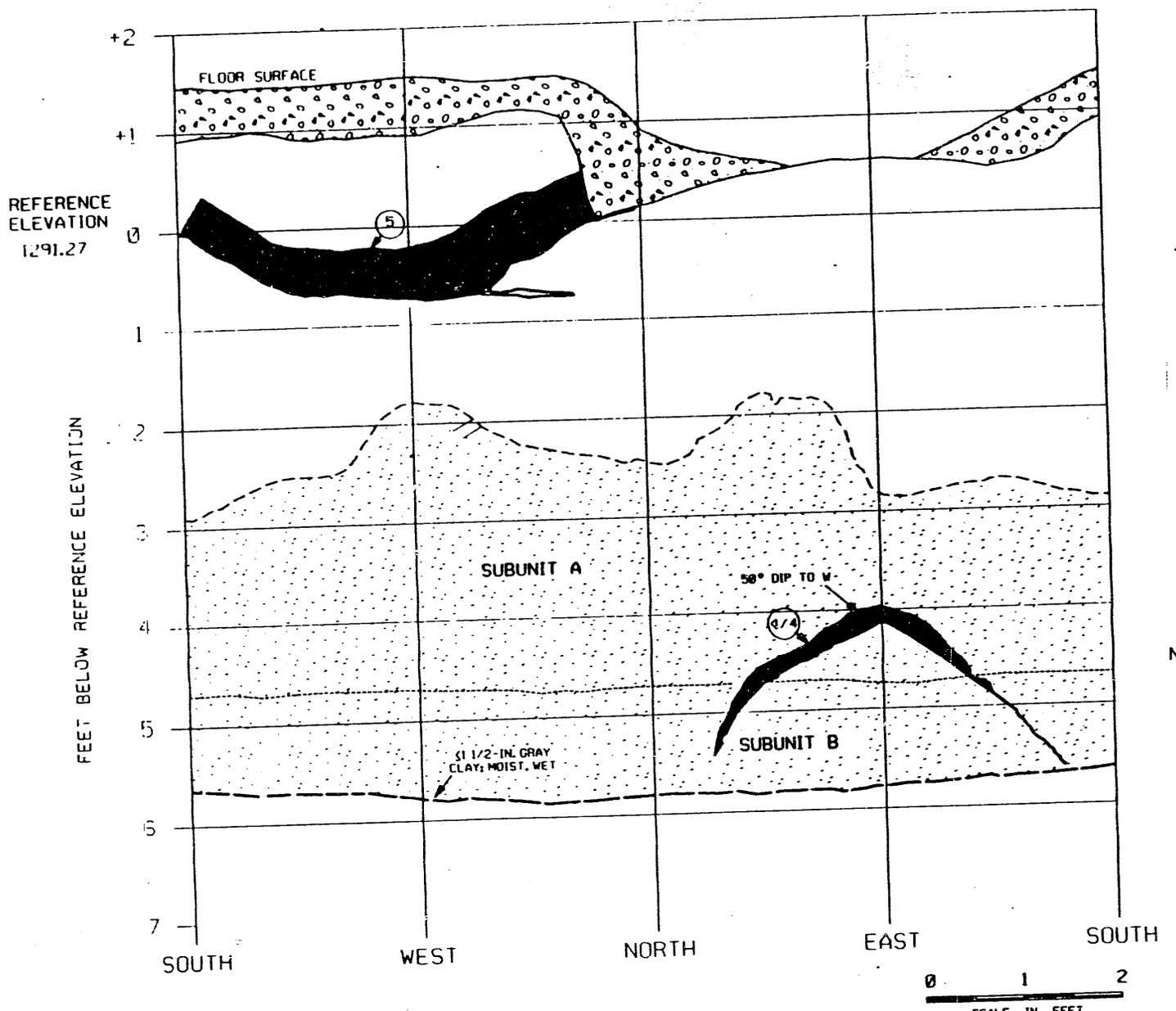


FIGURE G-9

ROOM T
LARGE DIAMETER DRILL HOLES
LOCATION PLAN



DATE MAPPED: 10/30/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

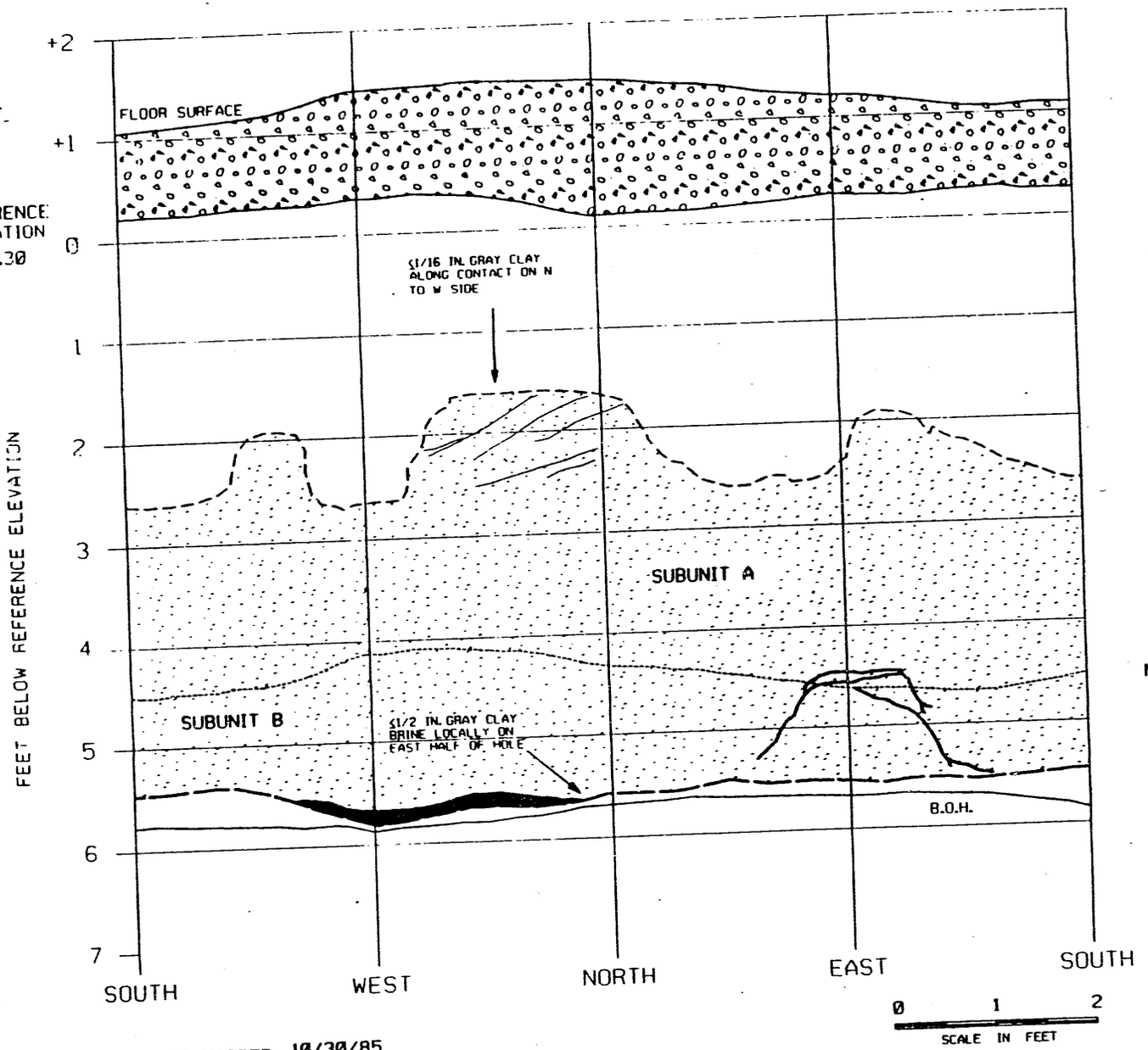
- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT B
- CLAY E (LOWER CONTACT OF MB-139)
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-10

GEOLOGIC MAP OF DRILL HOLE TV-01



DATE MAPPED: 10/30/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

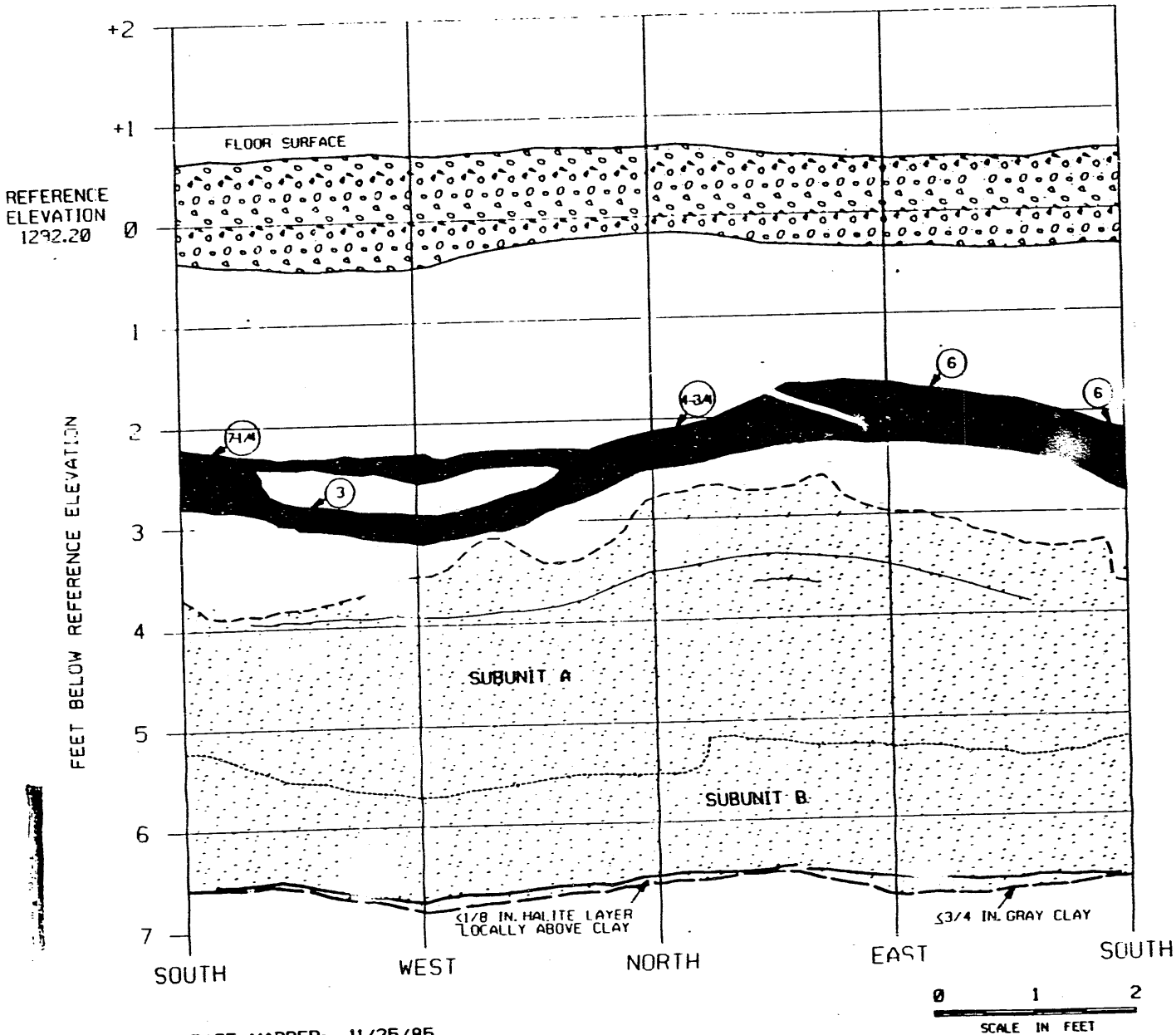
- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT B
- CLAY E (LOWER CONTACT OF MB-139)
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-11

GEOLOGIC MAP OF DRILL HOLE TV-02



DATE MAPPED: 11/25/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

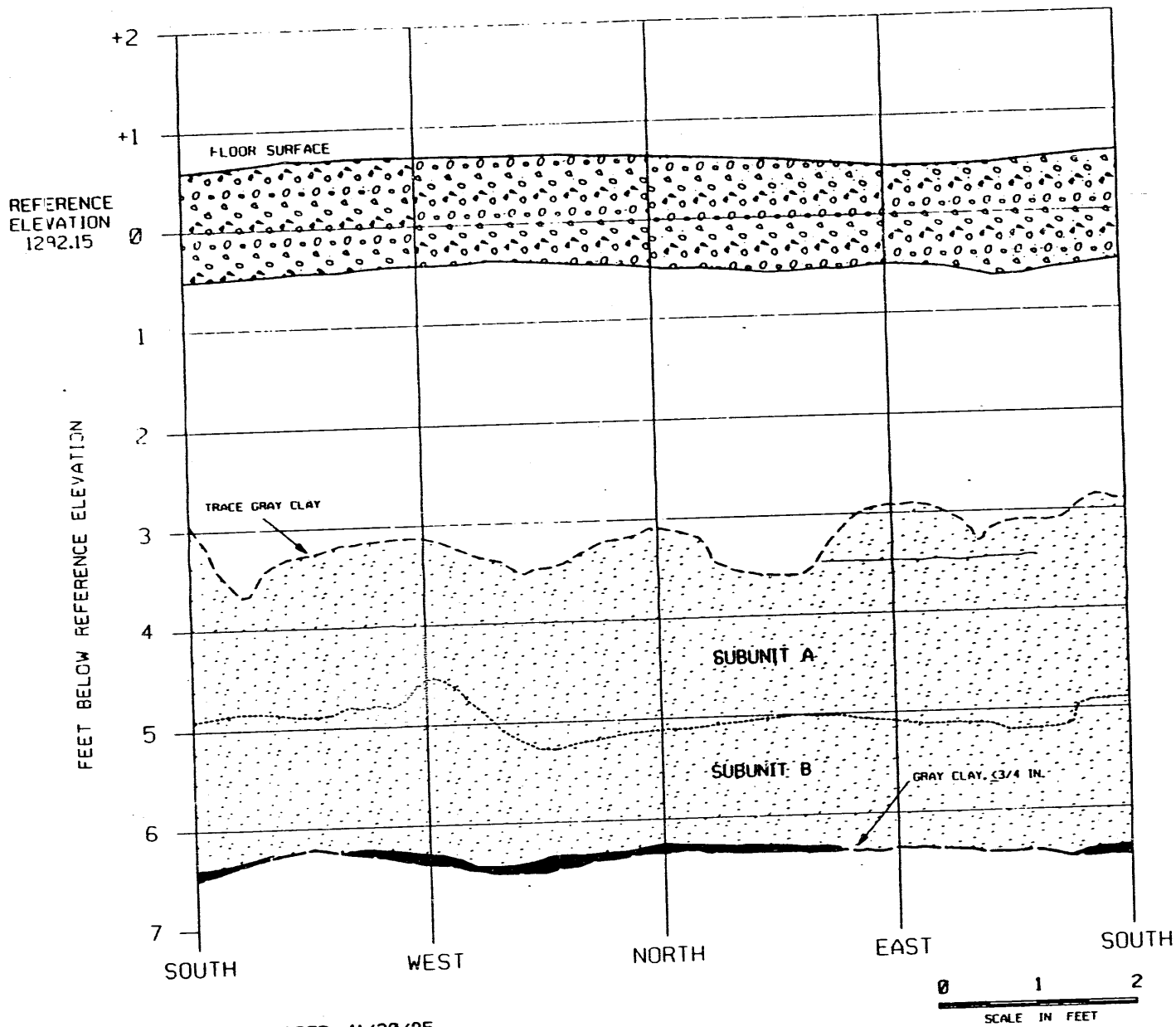
- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT B
- CLAY E (LOWER CONTACT OF MB-139)
- FRACTURE TRACE — DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE — ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE — CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-12

GEOLOGIC MAP OF DRILL HOLE TV-83



DATE MAPPED: 11/20/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

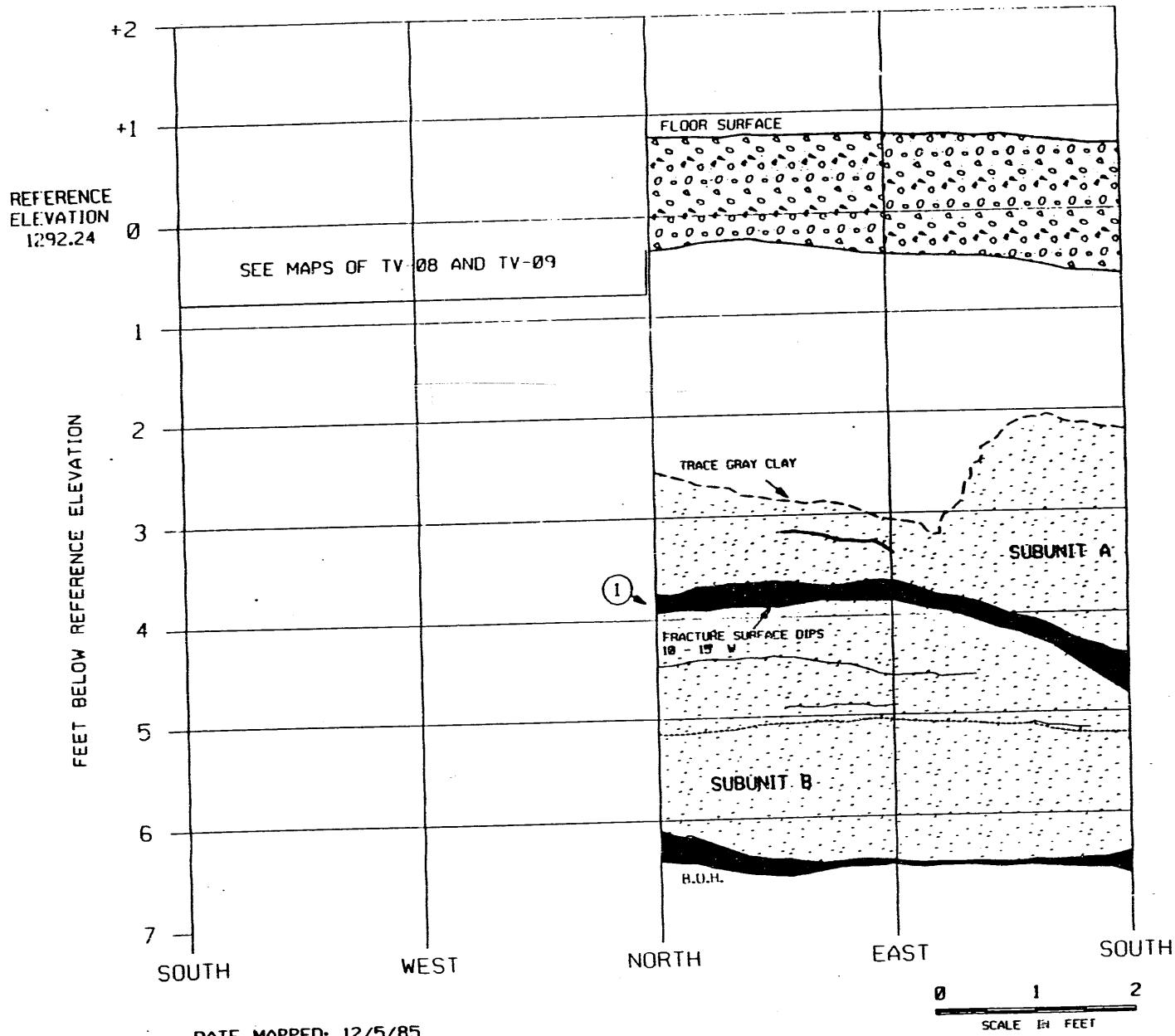
- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT B
- CLAY E (LOWER CONTACT OF MB-139)
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-13

GEOLOGIC MAP OF DRILL HOLE TV-04



DATE MAPPED: 12/5/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

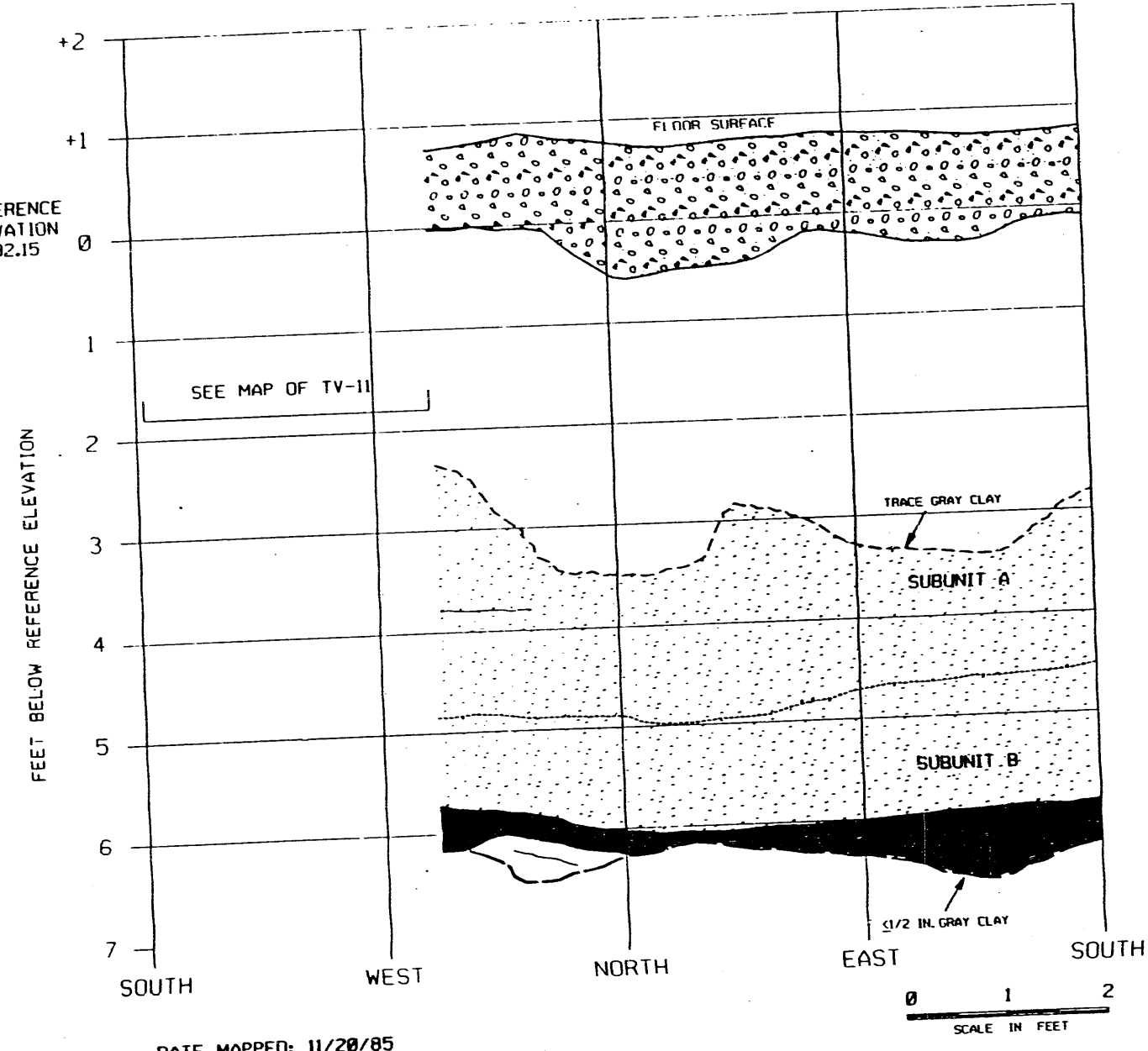
- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT B
- CLAY E (LOWER CONTACT OF MB-139)
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-14

GEOLOGIC MAP OF DRILL HOLE TV-05



DATE MAPPED: 11/20/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

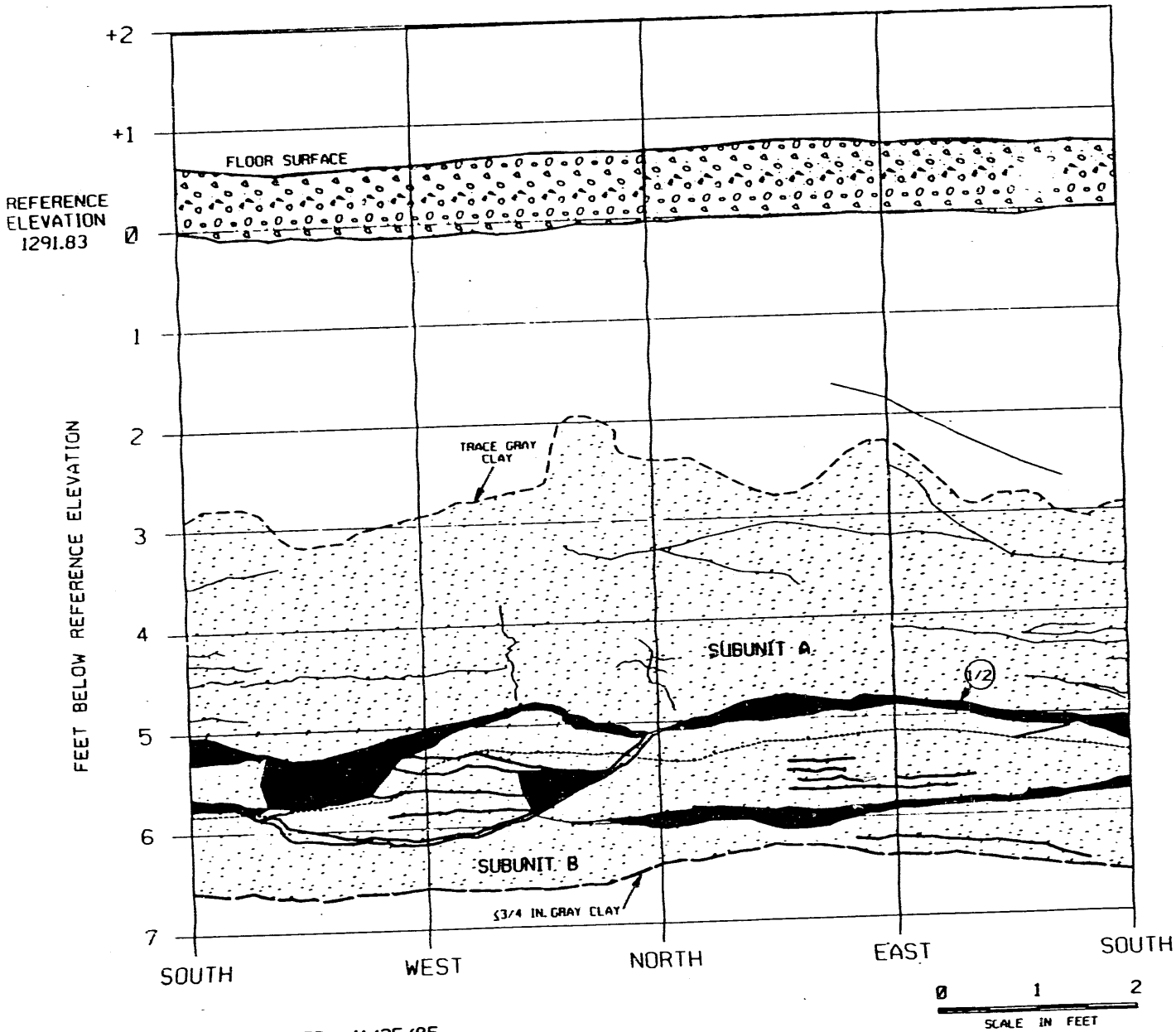
- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
  - UPPER CONTACT OF MB-139
  - UPPER CONTACT OF SUBUNIT B
  - CLAY E (LOWER CONTACT OF MB-139)
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-15

GEOLOGIC MAP OF DRILL HOLE TV-06



DATE MAPPED: 11/25/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

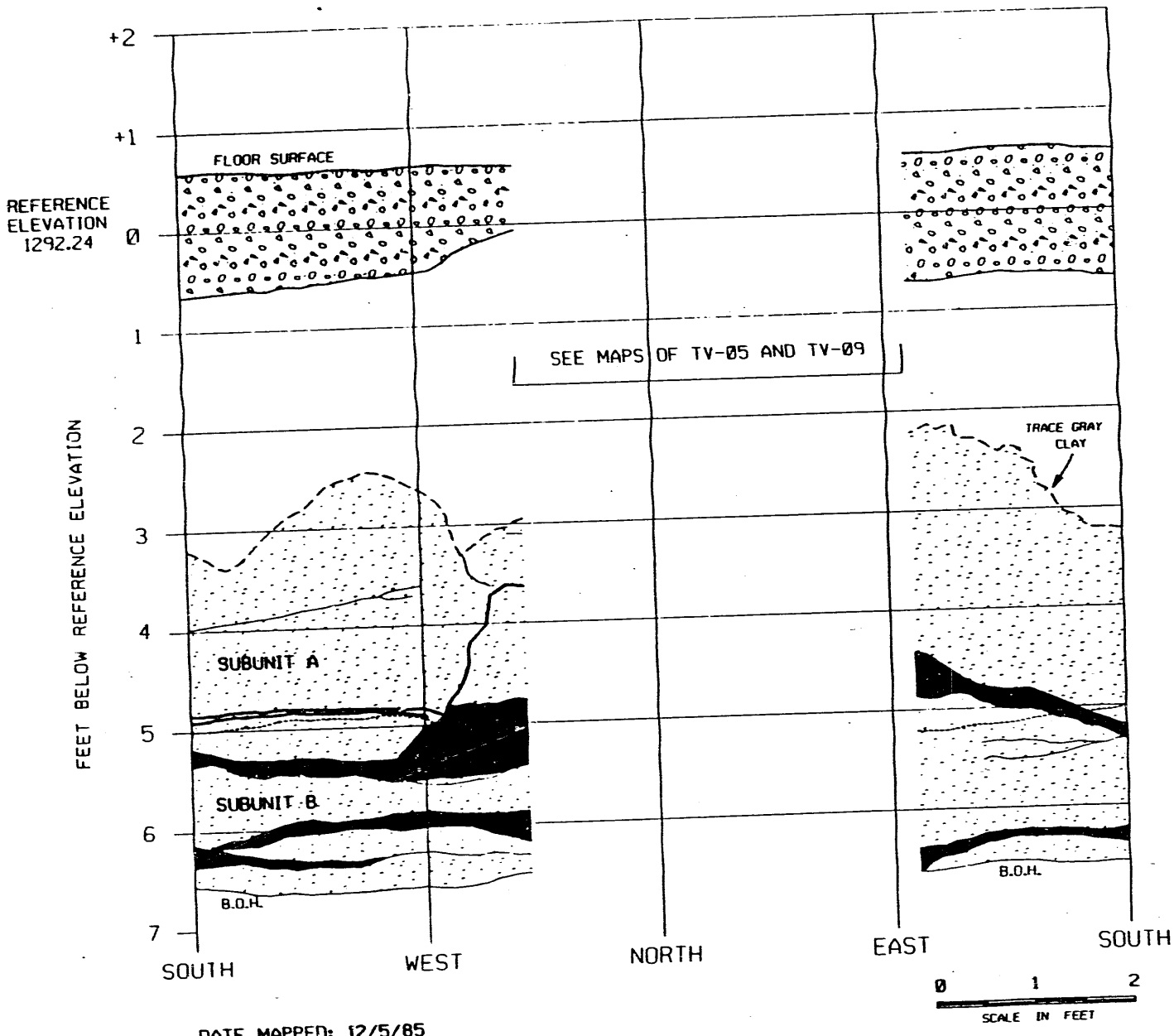
- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT B
- CLAY E (LOWER CONTACT OF MB-139)
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-16

GEOLOGIC MAP OF DRILL HOLE TV-07



DATE MAPPED: 12/5/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

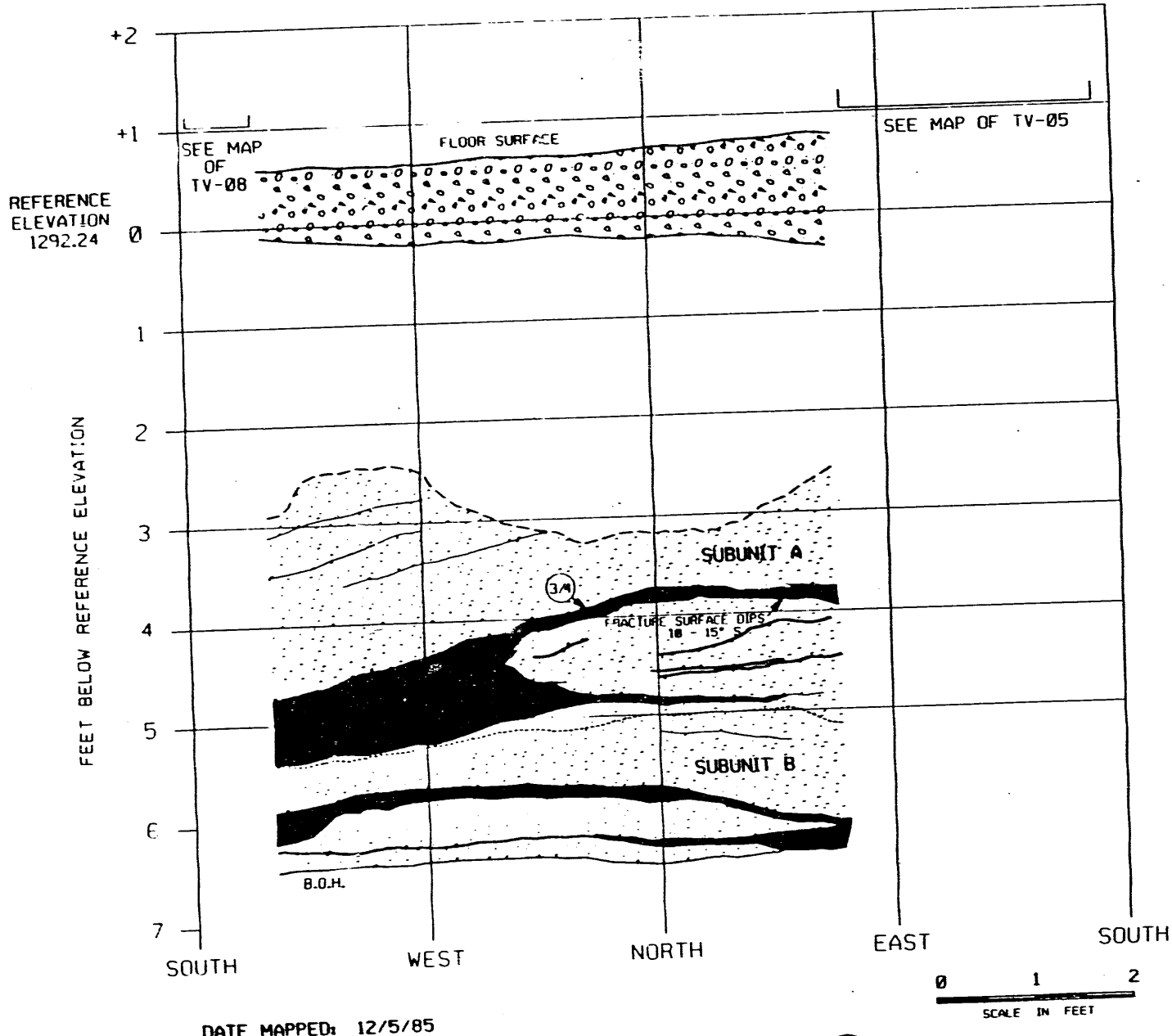
- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT E
- CLAY E (LOWER CONTACT OF MB-139)
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- 1/2 APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-17

GEOLOGIC MAP OF DRILL HOLE TV-08



EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT B
- CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES. USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES. USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

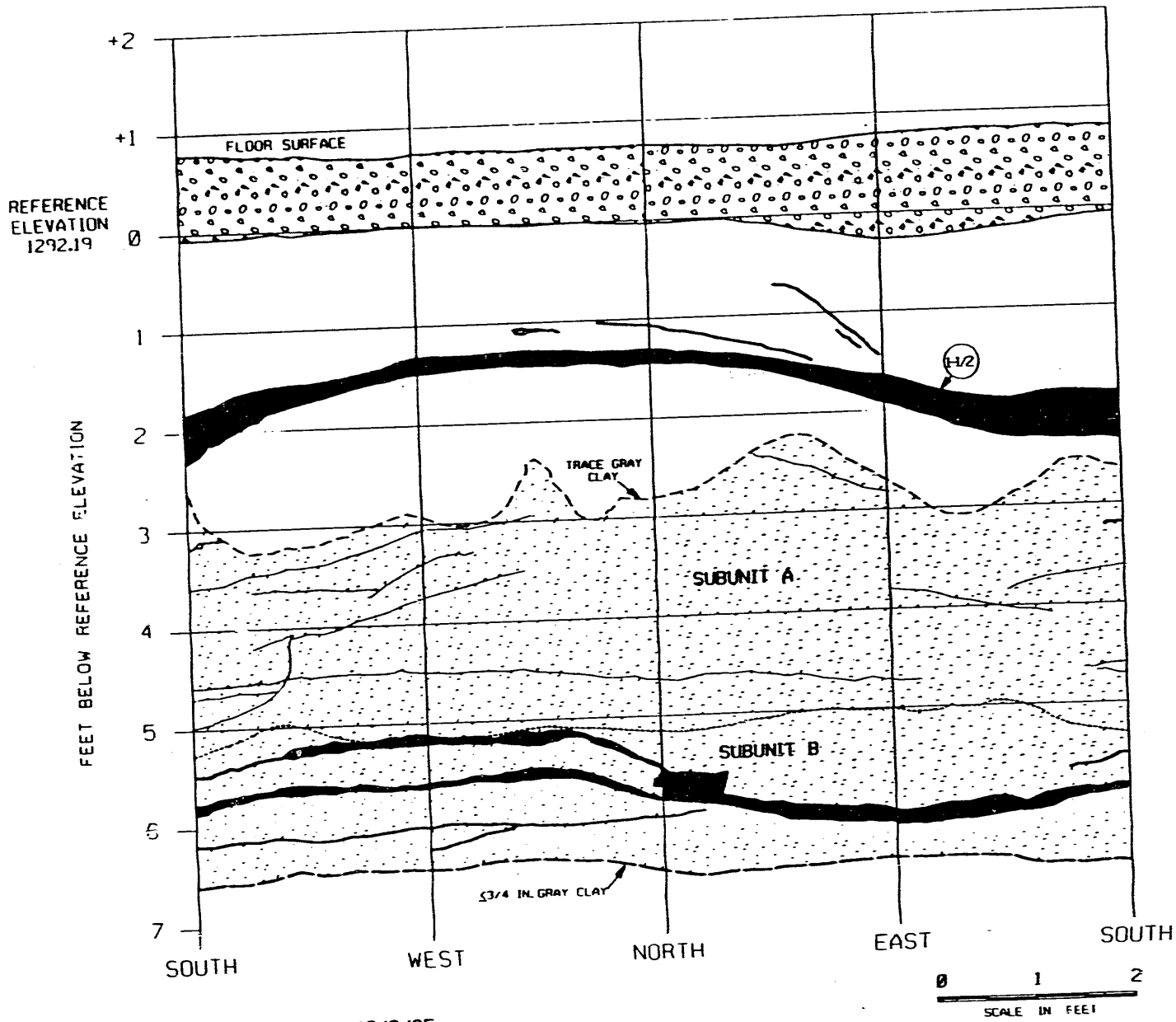
NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

DATE MAPPED: 12/5/85
MAPPED BY: J.E. GALLERANI

FIGURE G-18

GEOLOGIC MAP OF DRILL HOLE TV-09



DATE MAPPED: 12/2/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

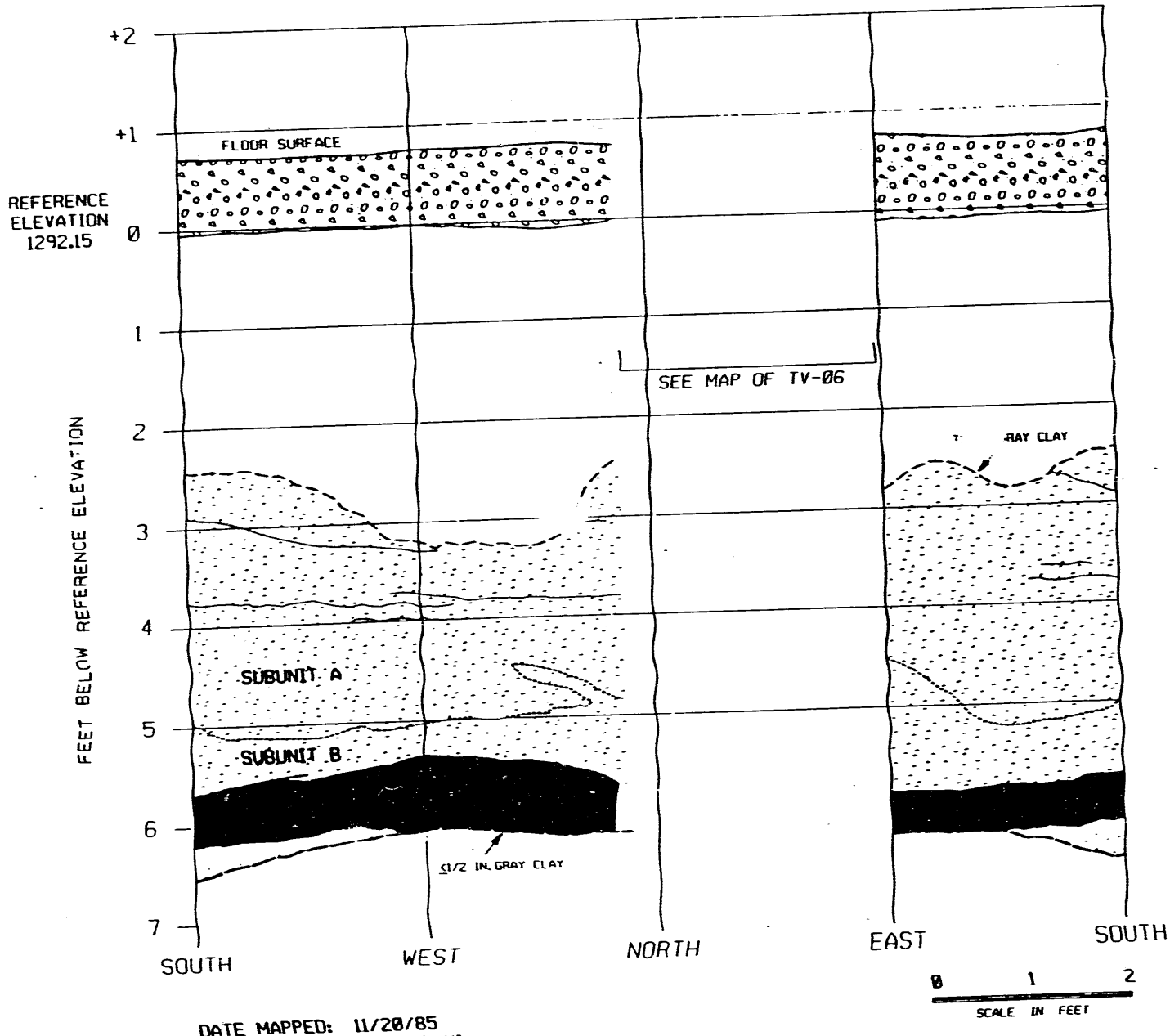
- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT B
- CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES. USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- 1/2 APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-19

GEOLOGIC MAP OF DRILL HOLE TV-10



EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT B
- CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

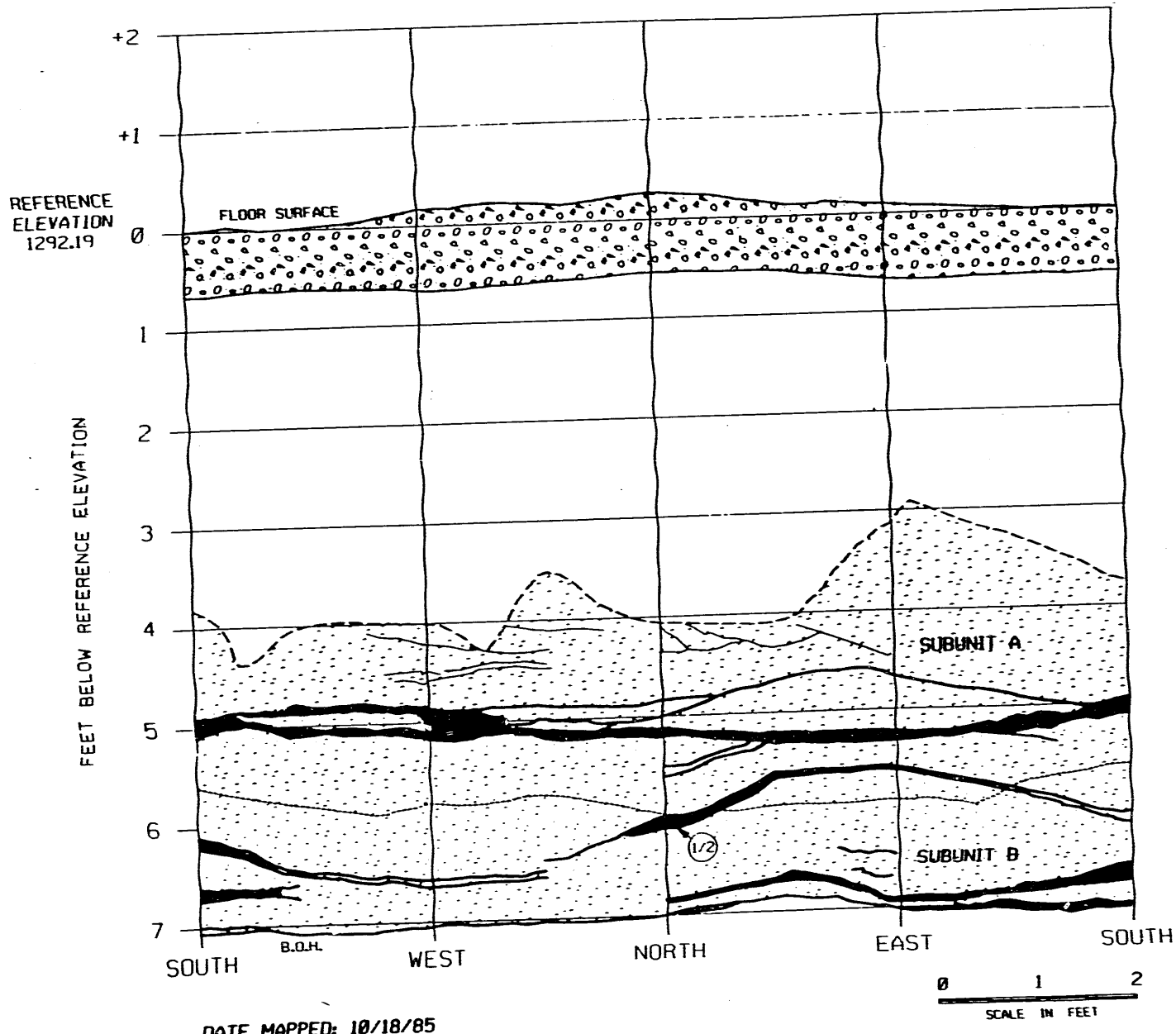
NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

DATE MAPPED: 11/20/85
MAPPED BY: J.E. GALLERANI

FIGURE G-20

GEOLOGIC MAP OF DRILL HOLE TV-11



DATE MAPPED: 10/18/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

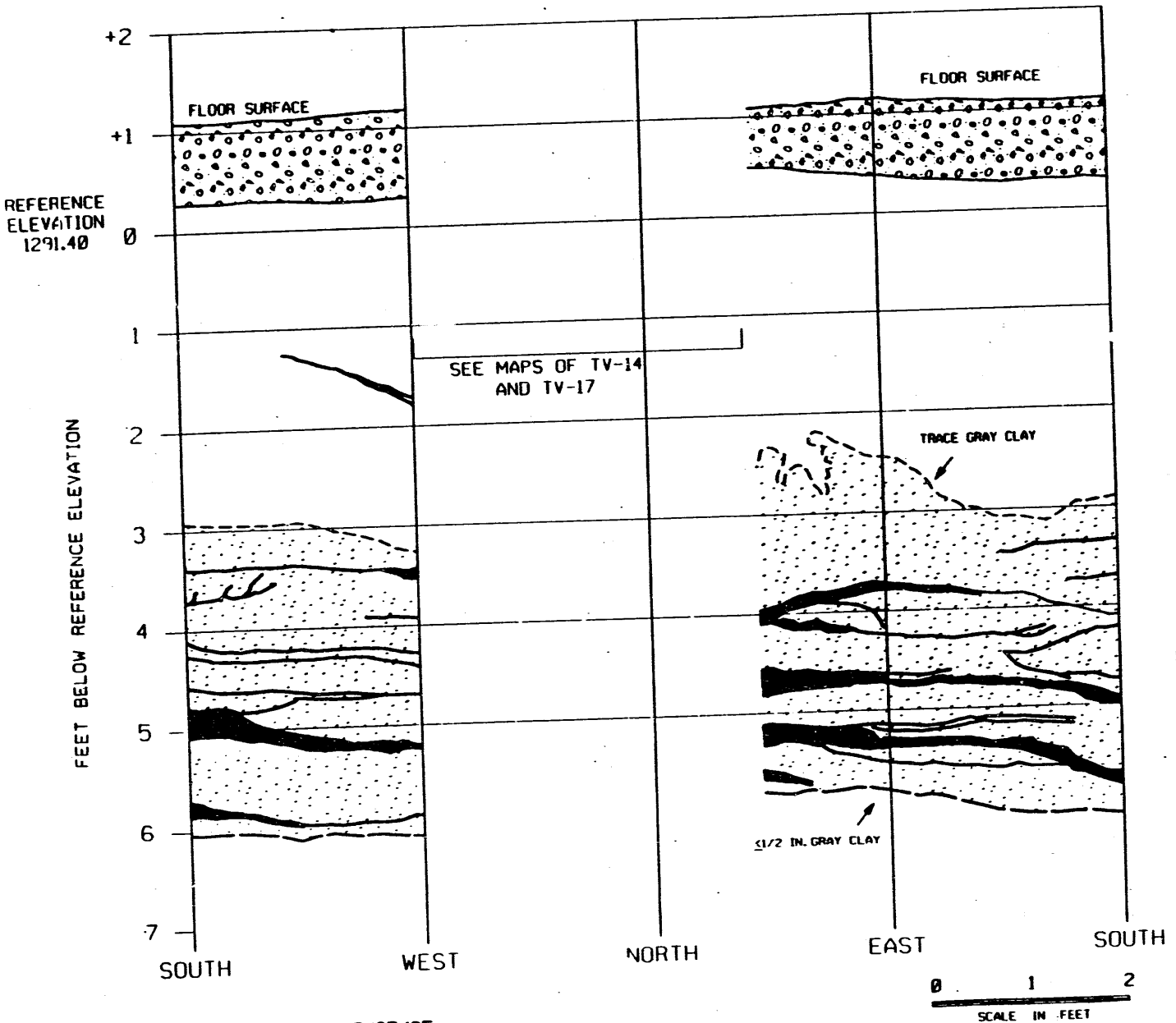
- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT B
- CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-21

GEOLOGIC MAP OF DRILL HOLE TV-12



DATE MAPPED: 10/25/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

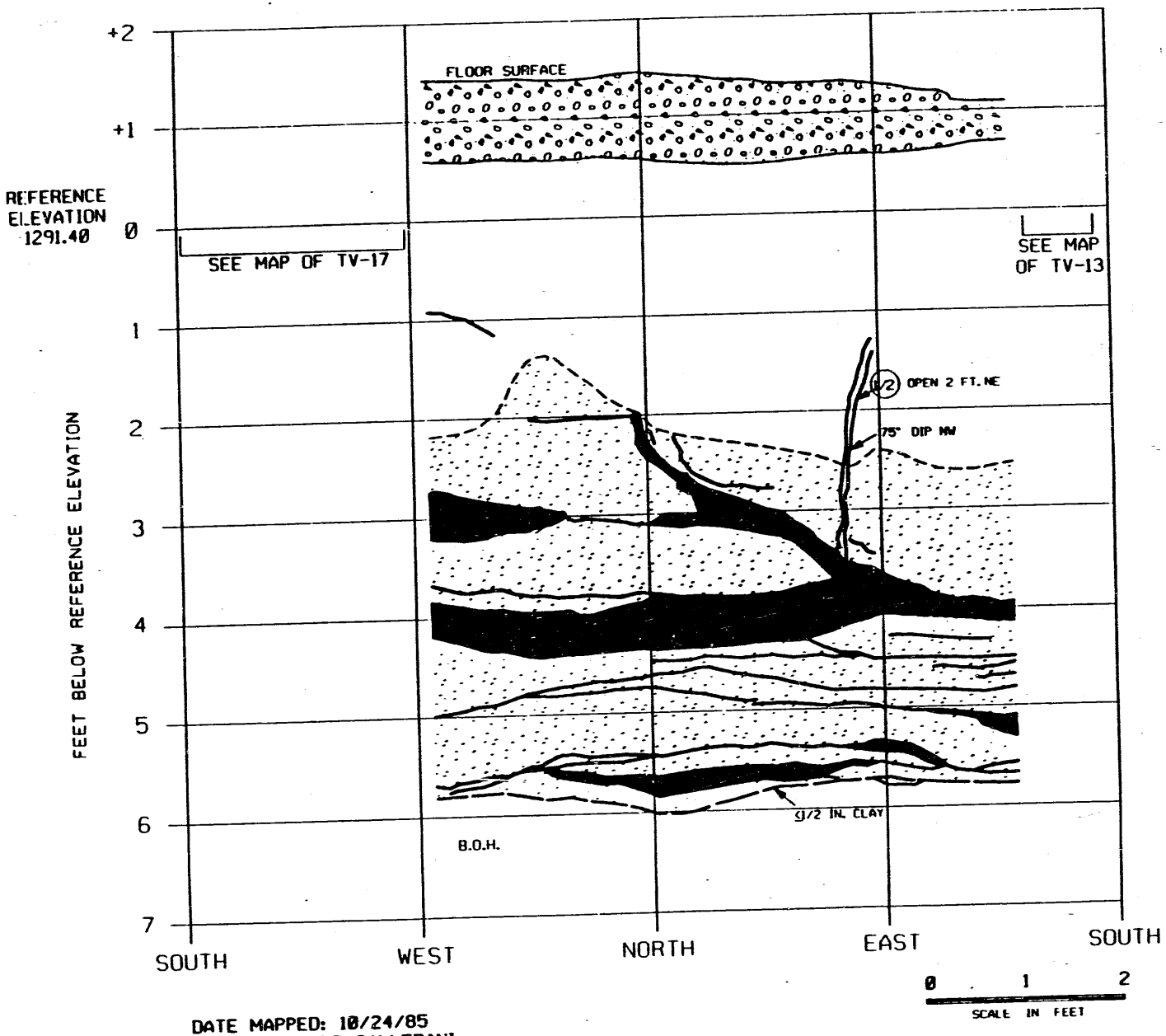
- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT B
- CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-22

GEOLOGIC MAP OF DRILL HOLE TV-13



DATE MAPPED: 10/24/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

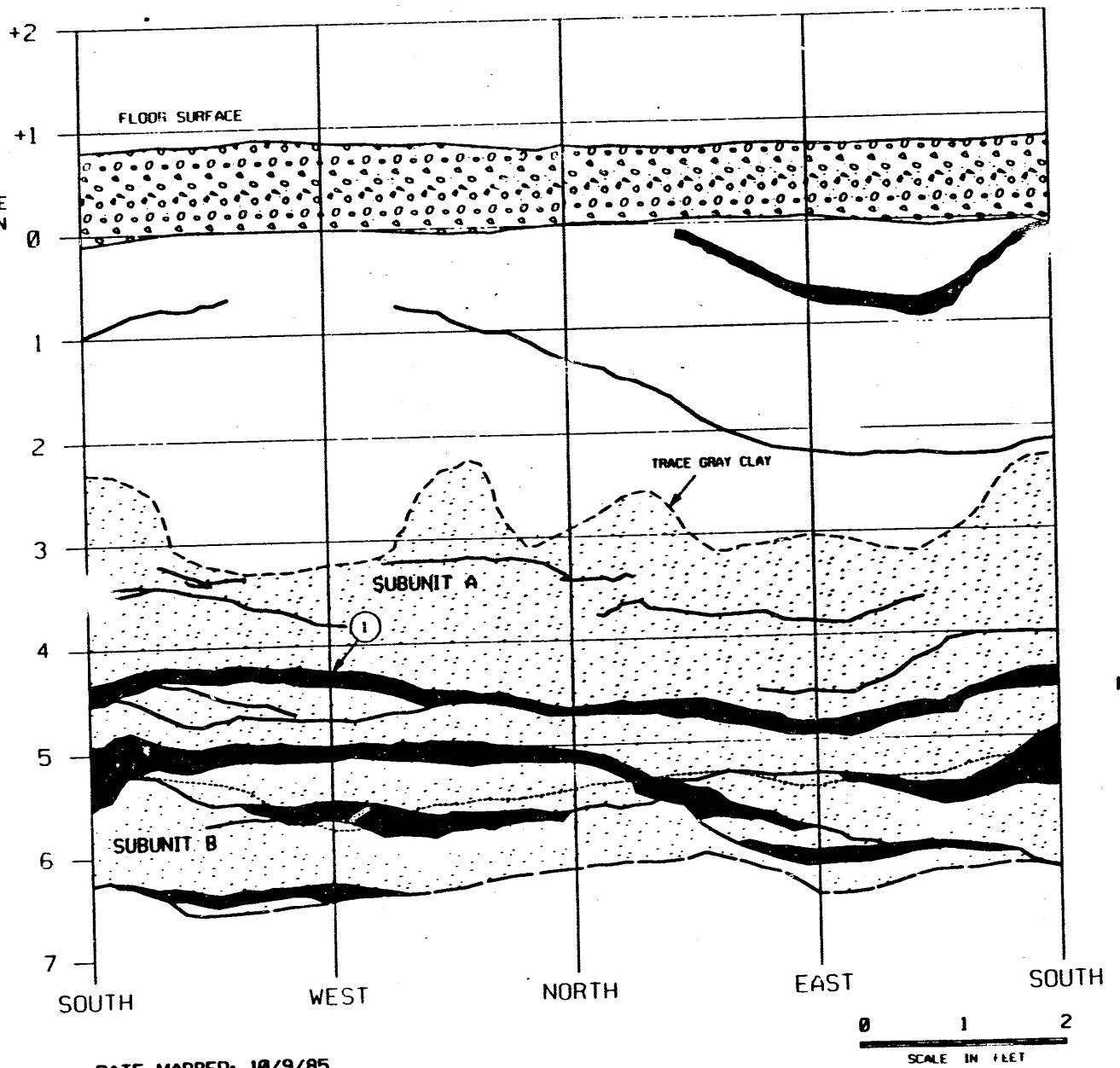
- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
  - UPPER CONTACT OF MB-139
  - UPPER CONTACT OF SUBUNIT B
  - CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-23

GEOLOGIC MAP OF DRILL HOLE TV-14



DATE MAPPED: 10/9/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

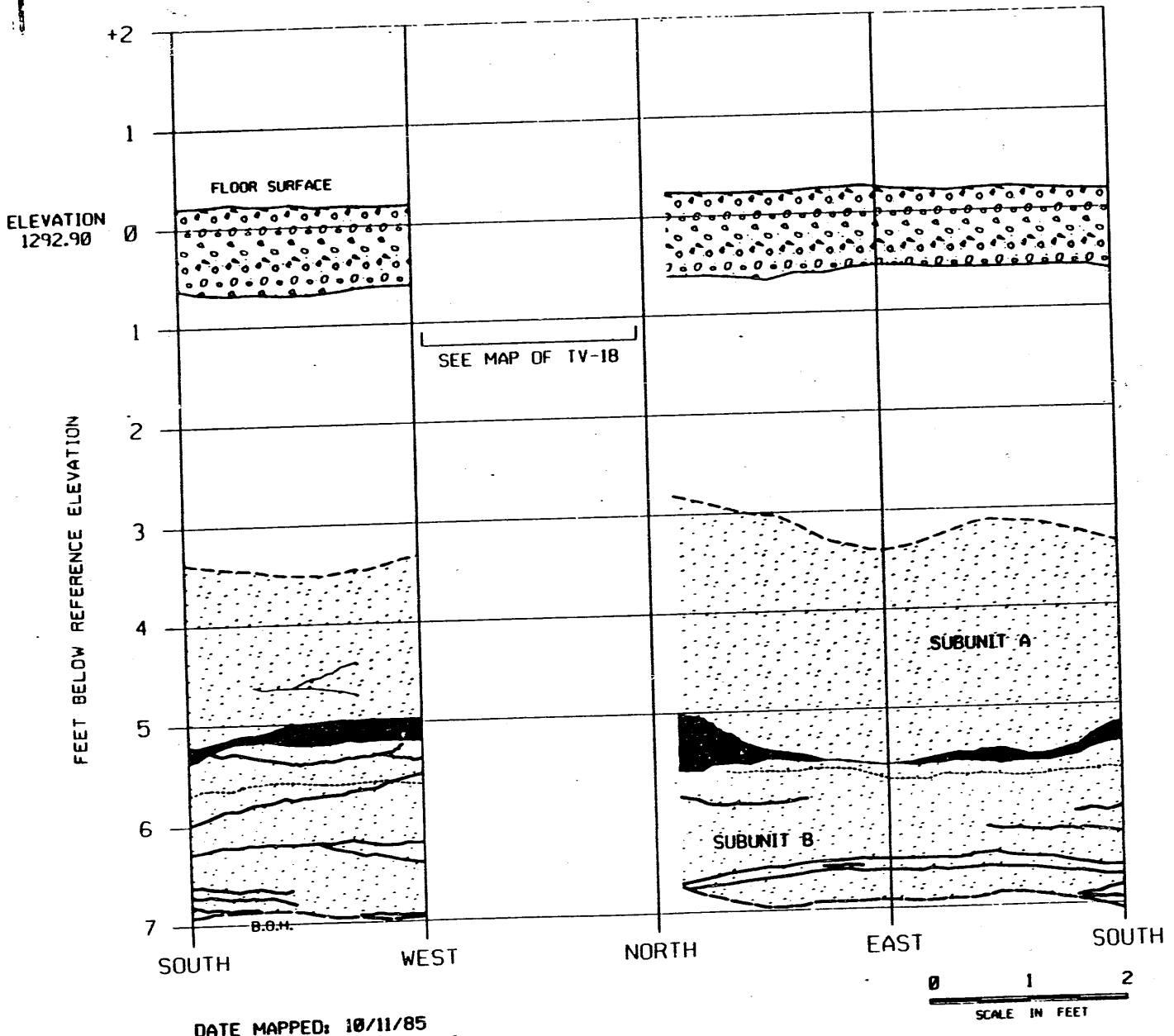
- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139
- UPPER CONTACT OF SUBUNIT B
- CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS NOTED OTHERWISE, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-24

GEOLOGIC MAP OF DRILL HOLE TV-15



DATE MAPPED: 10/11/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

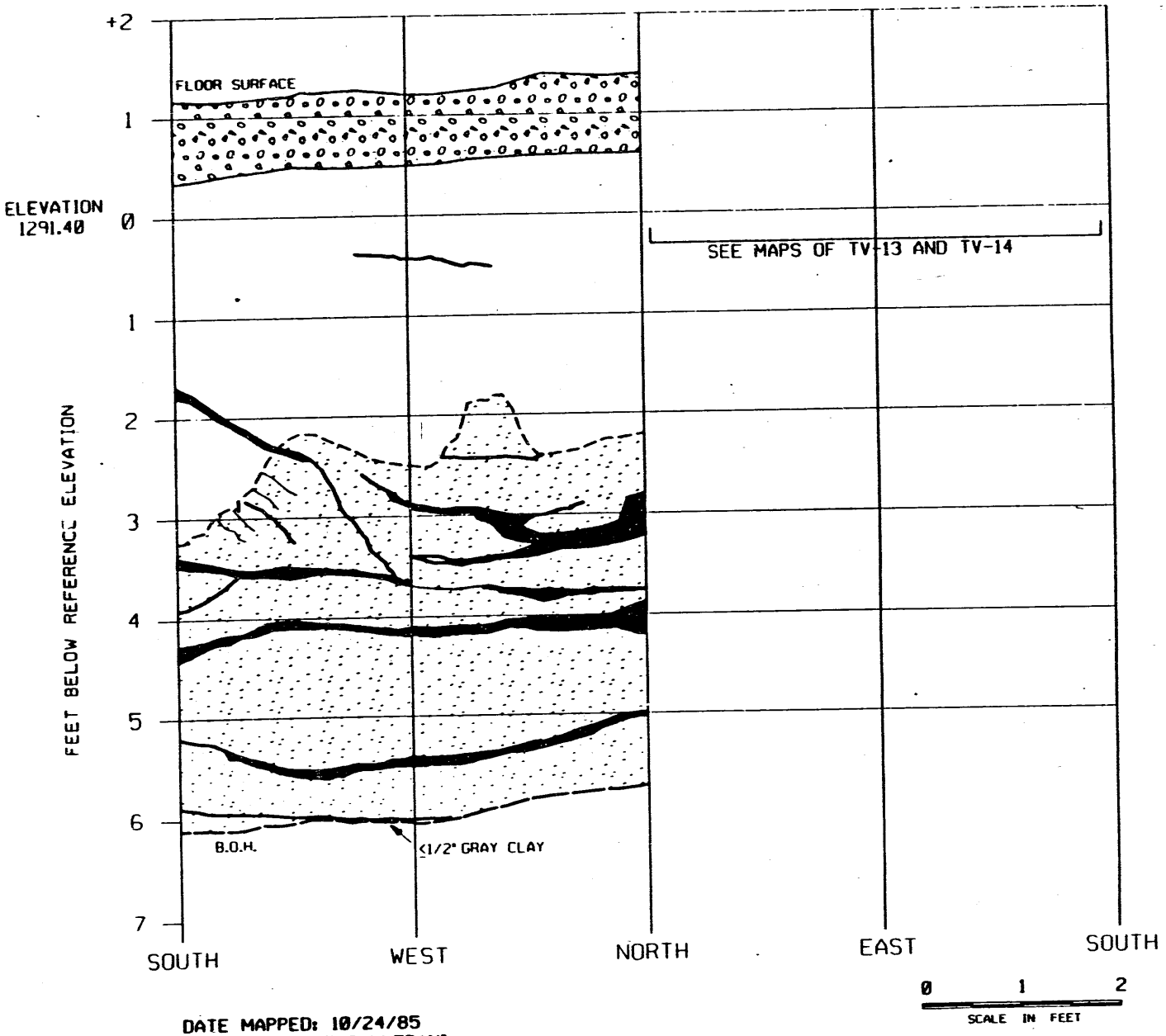
- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139 AND SUBUNIT A
- UPPER CONTACT OF SUBUNIT B
- CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE EACH HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS OTHERWISE NOTED, THE BOTTOM OF EACH DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-25

GEOLOGIC MAP OF DRILL HOLE TV-16



EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139 AND SUBUNIT A
- UPPER CONTACT OF SUBUNIT B
- CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

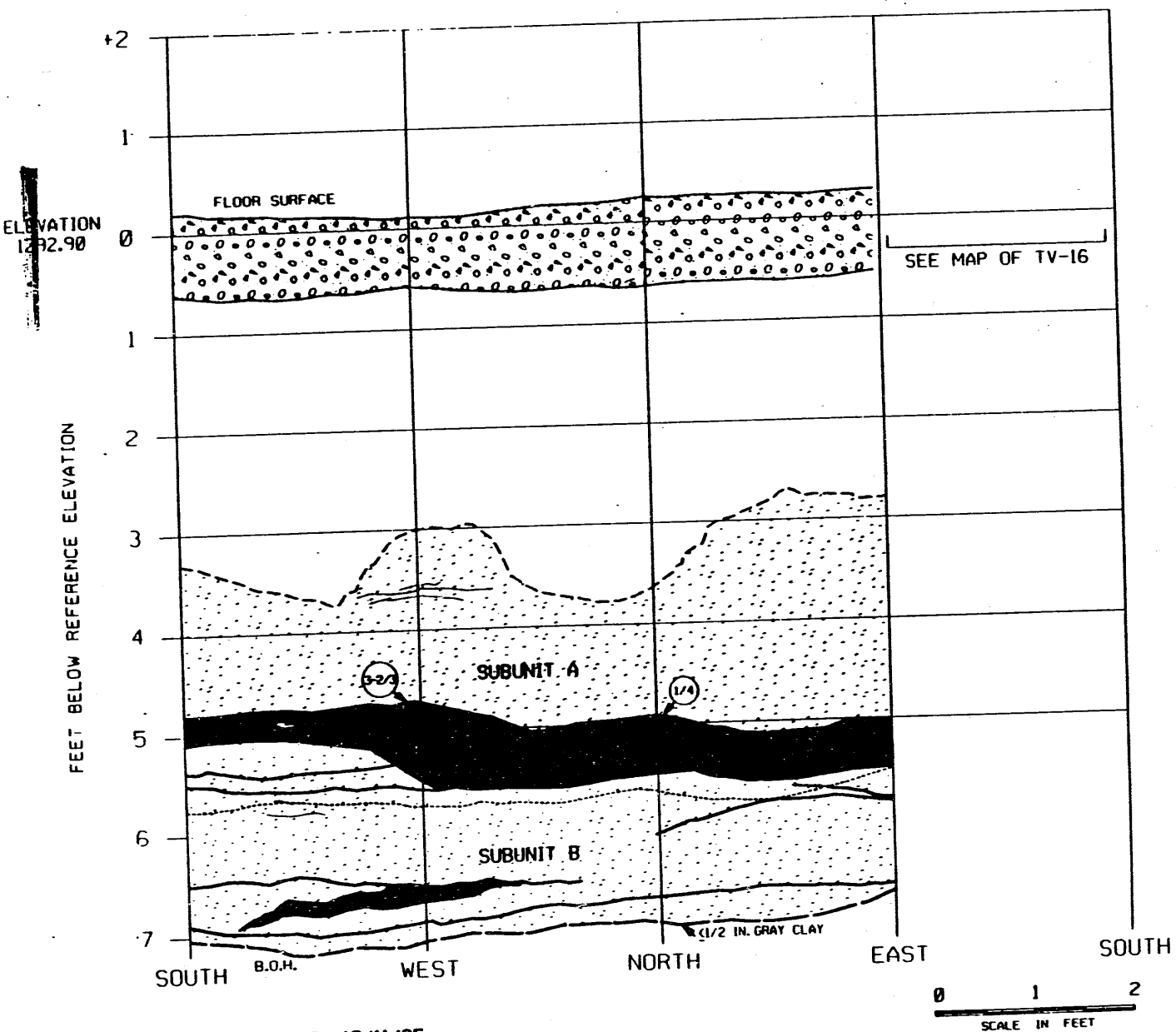
NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE EACH HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS OTHERWISE NOTED, THE BOTTOM OF EACH DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

DATE MAPPED: 10/24/85
MAPPED BY: J.E. GALLERANI

FIGURE G-26

GEOLOGIC MAP OF DRILL HOLE TV-17



DATE MAPPED: 10/11/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

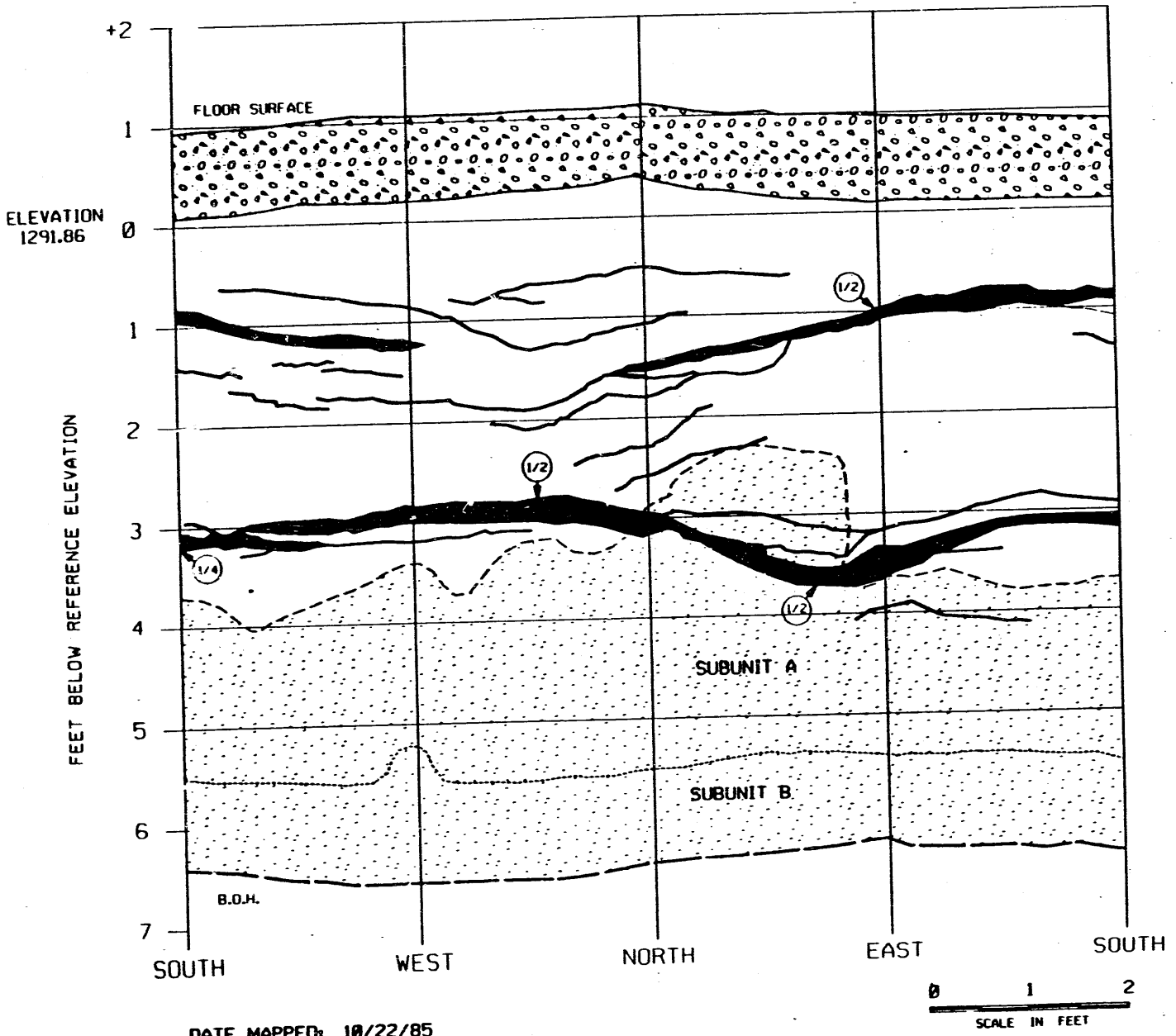
- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139 AND SUBUNIT A
- UPPER CONTACT OF SUBUNIT B
- CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE EACH HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS OTHERWISE NOTED, THE BOTTOM OF EACH DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-27

GEOLOGIC MAP OF DRILL HOLE TV-18



DATE MAPPED: 10/22/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

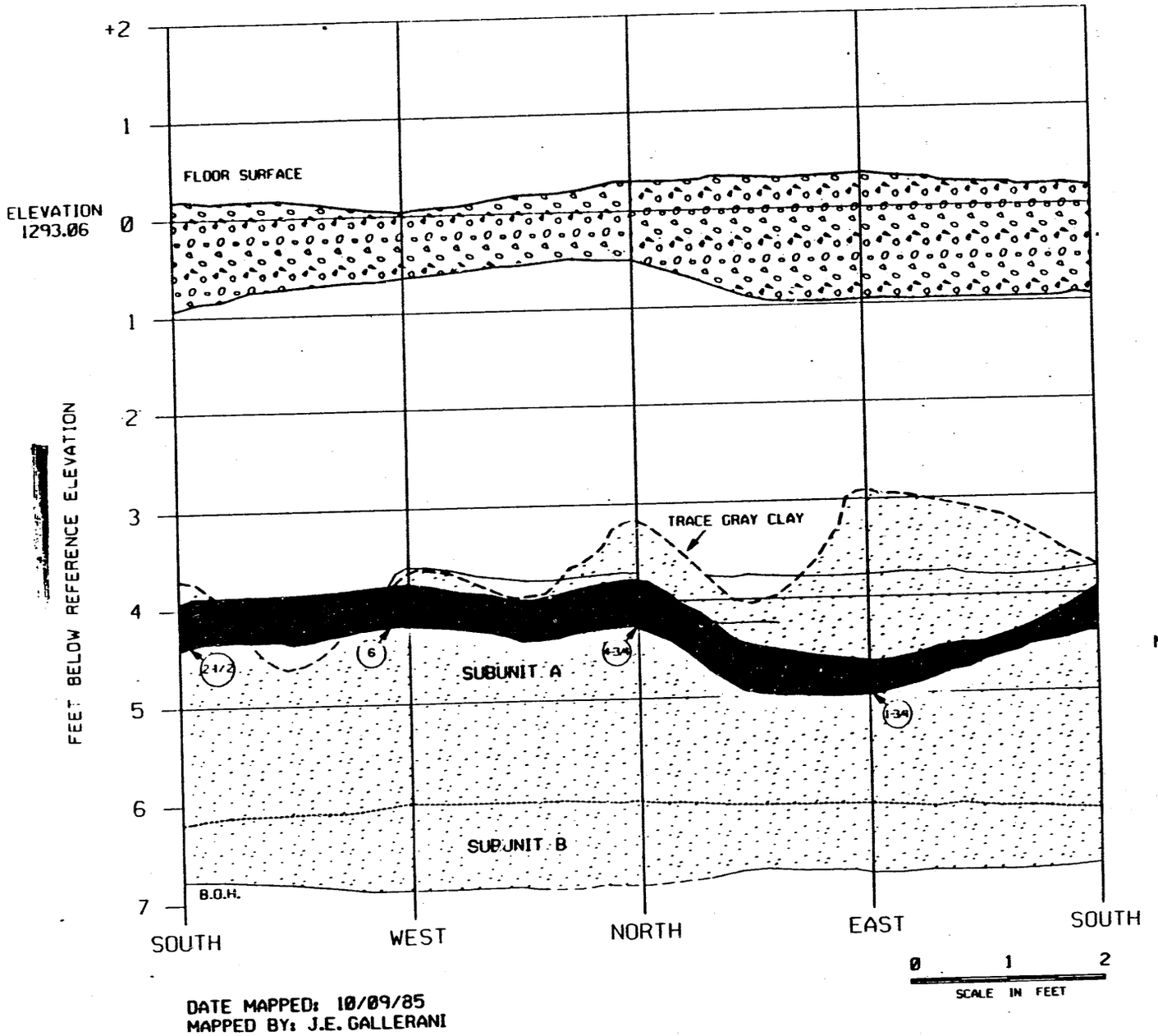
- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139 AND SUBUNIT A
- UPPER CONTACT OF SUBUNIT B
- CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE EACH HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS OTHERWISE NOTED, THE BOTTOM OF EACH DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-28

GEOLOGIC MAP OF DRILL HOLE TV-19



DATE MAPPED: 10/09/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

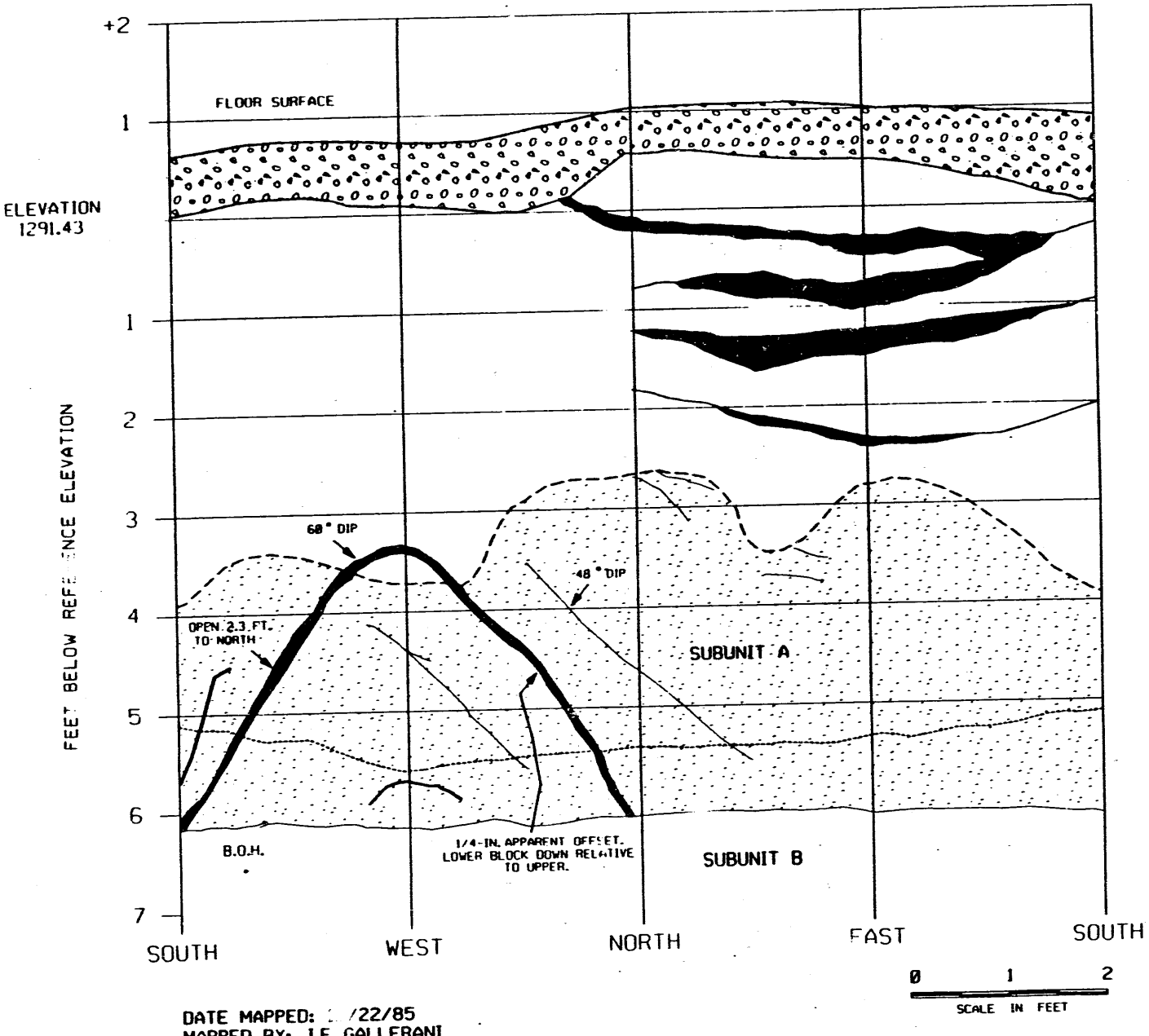
- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139 AND SUBUNIT A
- UPPER CONTACT OF SUBUNIT B
- CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE EACH HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS OTHERWISE NOTED, THE BOTTOM OF EACH DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-29

GEOLOGIC MAP OF DRILL HOLE TV-20



DATE MAPPED: 1 /22/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139 AND SUBUNIT A
- UPPER CONTACT OF SUBUNIT B
- CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

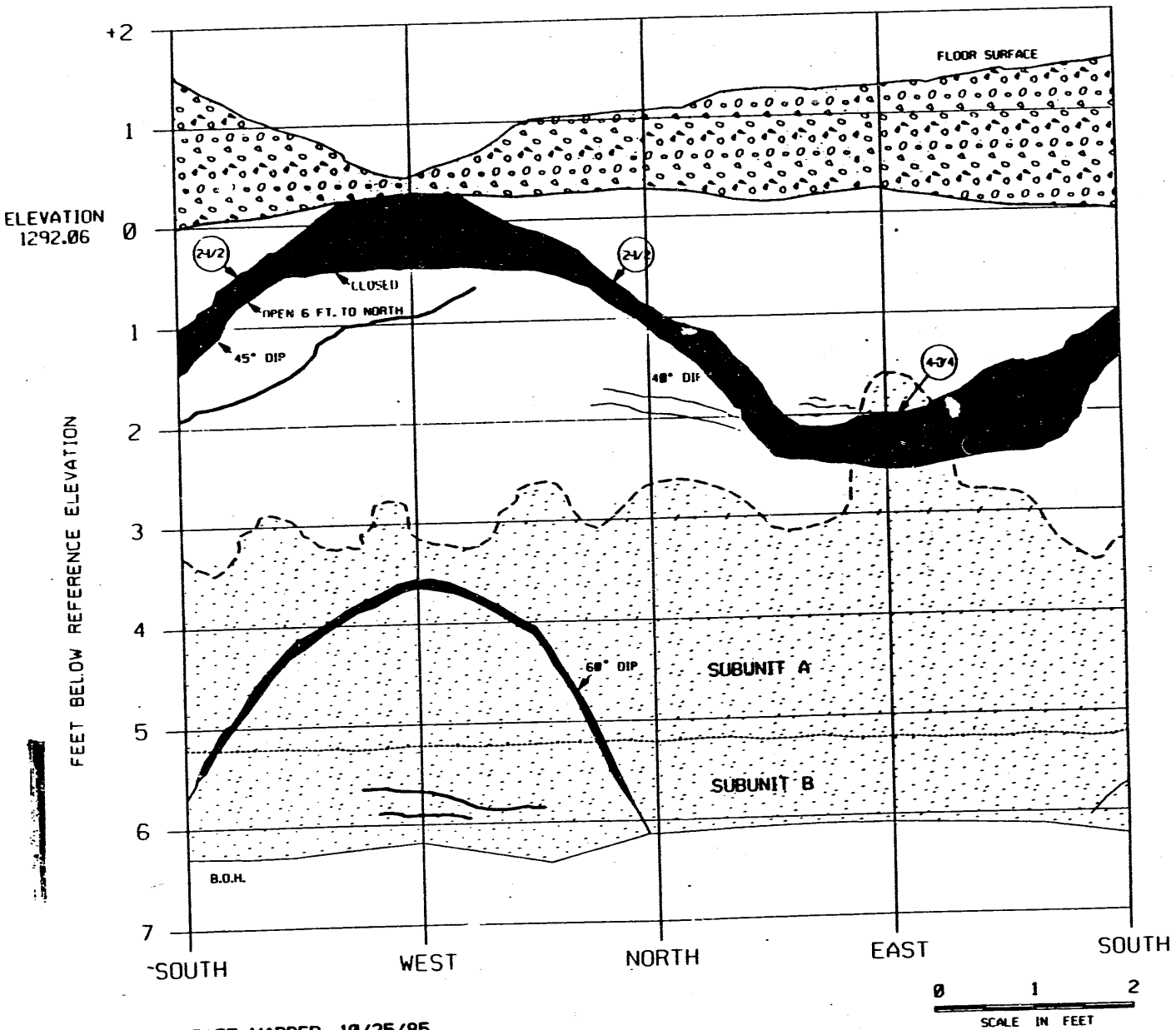
NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE EACH HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.

UNLESS OTHERWISE NOTED, THE BOTTOM OF EACH DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-30

GEOLOGIC MAP OF DRILL HOLE TV-21



DATE MAPPED: 10/25/85
MAPPED BY: J.E. GALLERANI

EXPLANATION

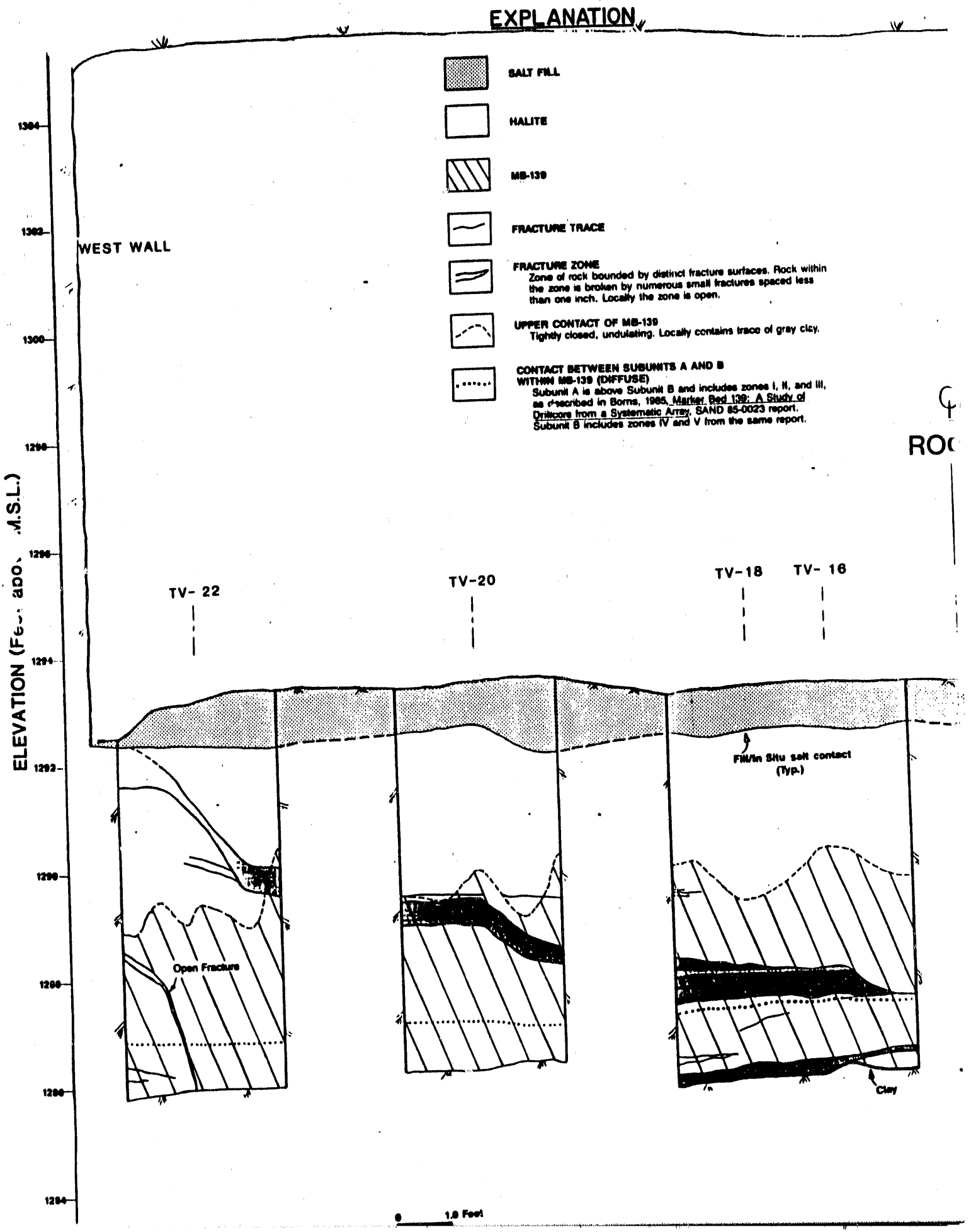
- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
- UPPER CONTACT OF MB-139 AND SUBUNIT A
- UPPER CONTACT OF SUBUNIT B
- CLAY E/LOWER CONTACT OF MB-139
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN THE FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE EACH HOLE. ALL FEATURES WERE MEASURED FROM A SURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS OTHERWISE NOTED, THE BOTTOM OF EACH DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.

FIGURE G-31

GEOLOGIC MAP OF DRILL HOLE TV-22


EXPLANATION
SALT FILL
HALITE
MB-139
FRACTURE TRACE
FRACTURE ZONE
Zone of rock bounded by distinct fracture surfaces. Rock within the zone is broken by numerous small fractures spaced less than one inch. Locally the zone is open.
UPPER CONTACT OF MB-139
Tightly closed, undulating. Locally contains trace of gray clay.
CONTACT BETWEEN SUBUNITS A AND B WITHIN MB-139 (DIFFUSE)
Subunit A is above Subunit B and includes zones I, II, and III, as described in Borns, 1985, Marker Bed 139: A Study of Drillcore from a Systematic Array, SAND 85-0023 report. Subunit B includes zones IV and V from the same report.
WEST WALL
ELEVATION (Feet above M.S.L.)
1304
1302
1300
1298
1296
1294
1292
1290
1288
1286
1284
TV- 22
TV-20
TV-18
TV- 16
Open Fracture
Fill/In Situ salt contact (Typ.)
Clay
0
1.0 Feet

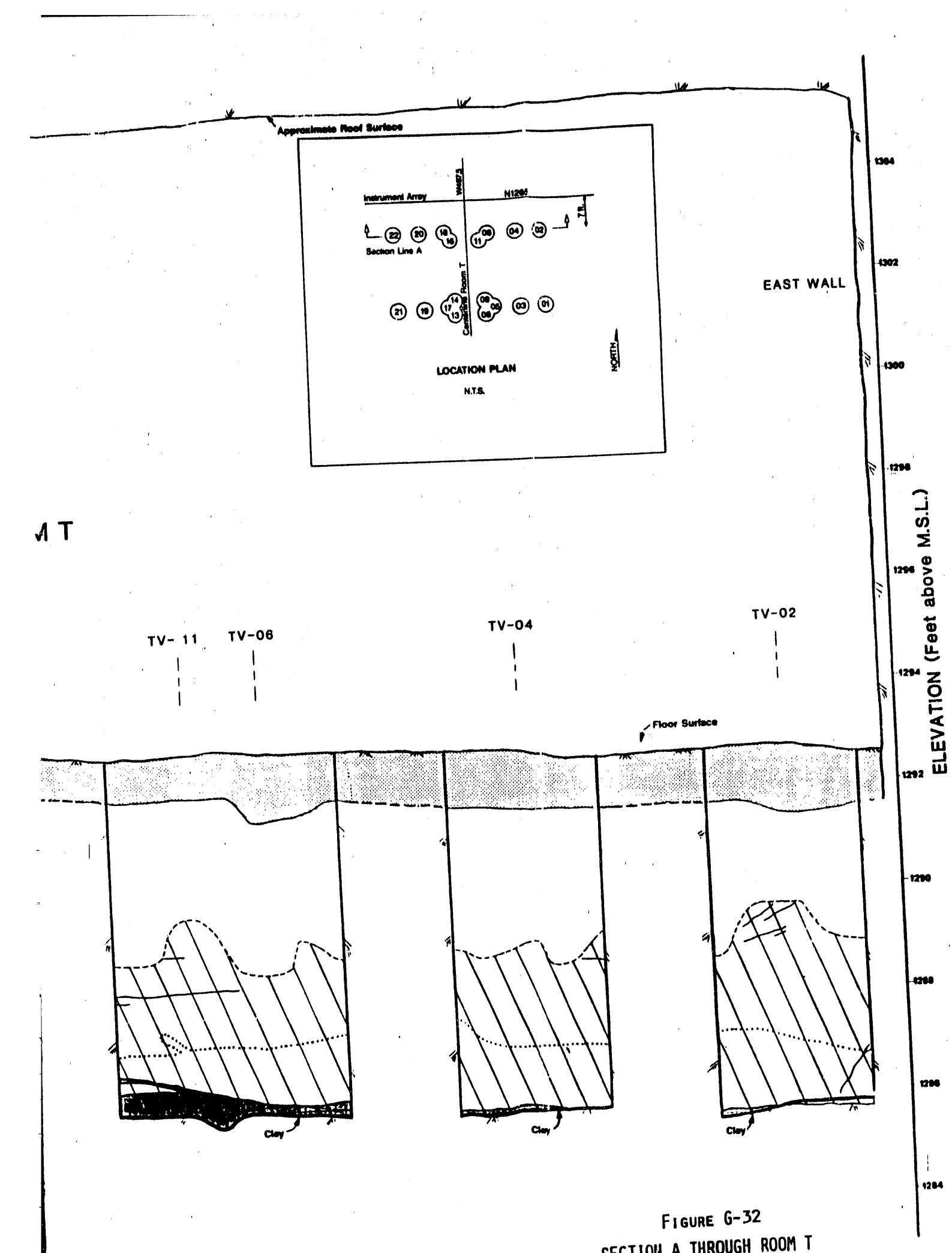
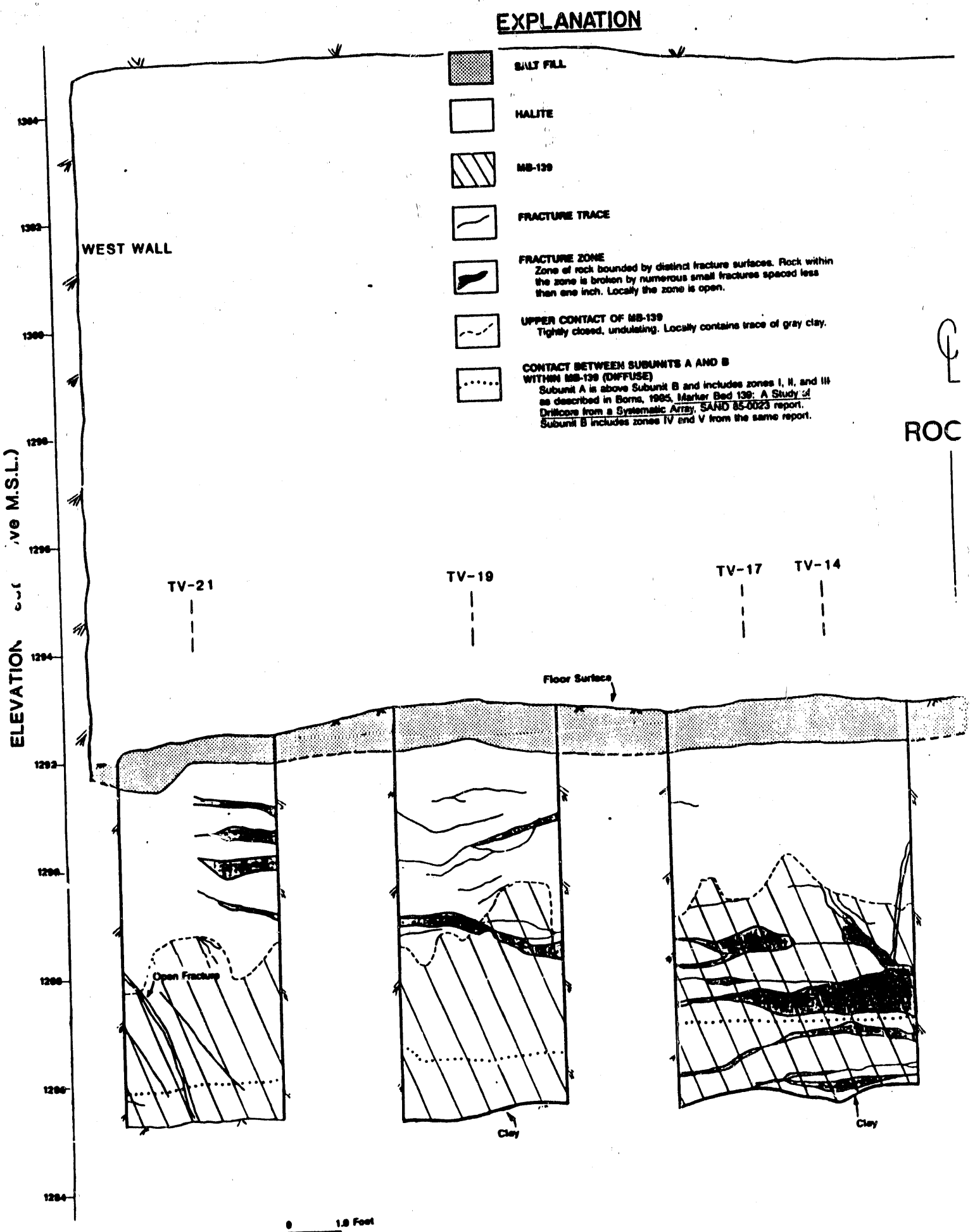


FIGURE G-32

SECTION A THROUGH ROOM T


EXPLANATION
SALT FILL
HALITE
MB-139
FRACTURE TRACE
FRACTURE ZONE
Zone of rock bounded by distinct fracture surfaces. Rock within the zone is broken by numerous small fractures spaced less than one inch. Locally the zone is open.
UPPER CONTACT OF MB-139
Tightly closed, undulating. Locally contains trace of gray clay.
CONTACT BETWEEN SUBUNITS A AND B WITHIN MB-139 (DIFFUSE)
Subunit A is above Subunit B and includes zones I, II, and III as described in Borns, 1985, Marker Bed 139: A Study of Drillcore from a Systematic Array, SAND 85-0023 report. Subunit B includes zones IV and V from the same report.
WEST WALL
ELEVATION (ft M.S.L.)
1304
1302
1300
1298
1296
1294
1292
1290
1288
1286
1284
TV-21
TV-19
TV-17
TV-14
Floor Surface
Open Fracture
Clay
Clay
0
1.0 Foot

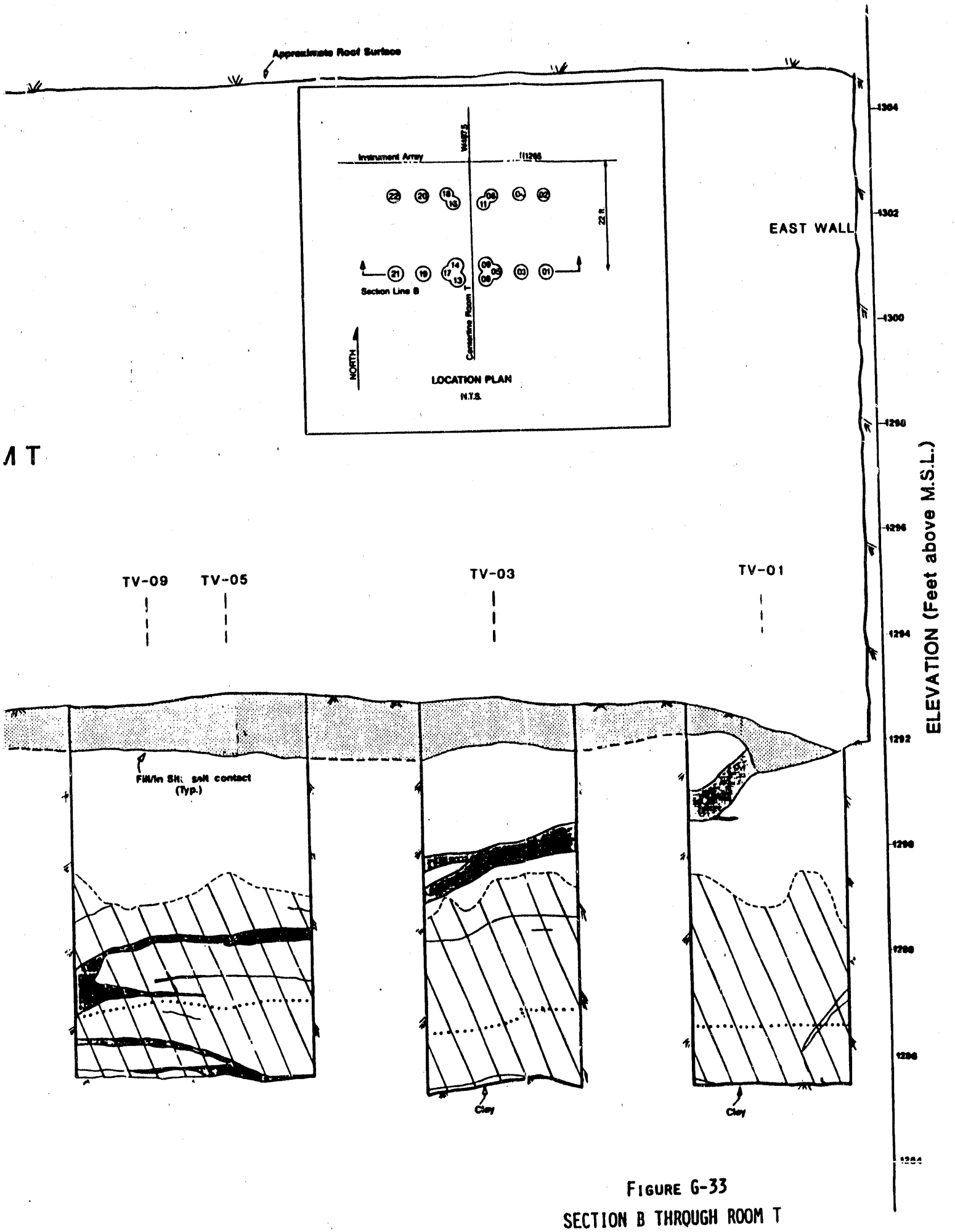
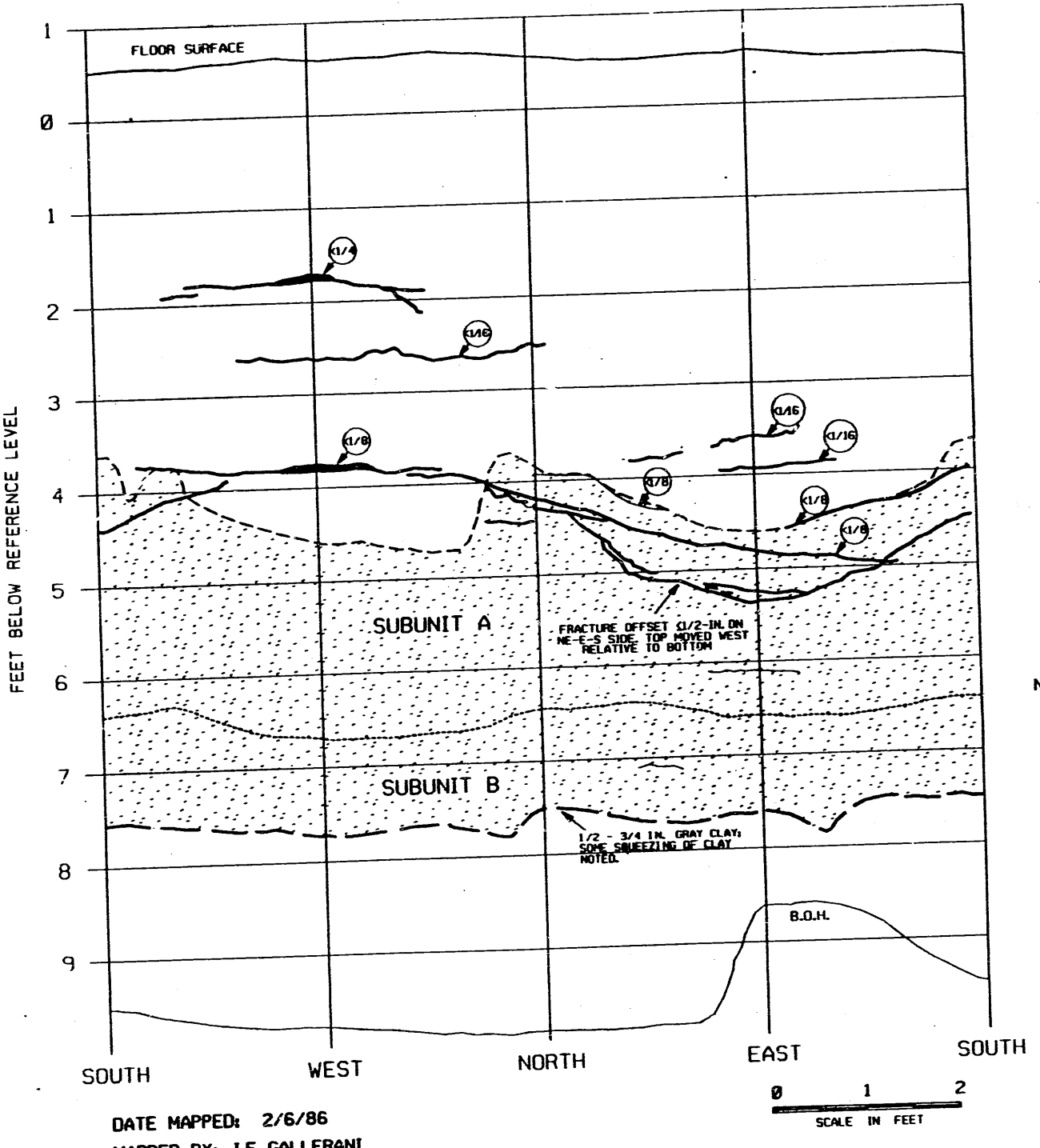


FIGURE G-33

SECTION B THROUGH ROOM T



DATE MAPPED: 2/6/86

MAPPED BY: J.E. GALLERANI

EXPLANATION

- MINED SALT BACKFILL
- HALITE
- MARKER BED 139
  - UPPER CONTACT OF MB-139
  - UPPER CONTACT OF SUBUNIT B
  - CLAY E (LOWER CONTACT OF MB-139)
- FRACTURE TRACE
  DISTINCT FRACTURES, USUALLY CLOSED WITHIN A FEW INCHES OF THE DRILL HOLE SIDE.
- FRACTURE ZONE
  ZONE OF FRACTURED ROCK BOUNDED BY DISTINCT FRACTURES.
- SMALL FRACTURE
  CLOSED HAIRLINE FRACTURES, USUALLY FORMING FRACTURE ZONES LESS THAN ONE INCH WIDE.
- (1/2) APPROXIMATE FRACTURE SEPARATION, IN INCHES. SEPARATIONS ARE MEASURED WITHIN FRACTURE OR ZONE 12 INCHES IN FROM DRILL HOLE WALL.

NOTES:

1. DRILL HOLE IS IN SOUTHWEST CORNER OF TEST ROOM 4 AND IS 36 INCHES IN DIAMETER.
2. MAPPING WAS PERFORMED FROM INSIDE THE HOLE. ALL FEATURES WERE MEASURED FROM AN UNSURVEYED REFERENCE LINE.
3. ORIGINAL MAPPING WAS PERFORMED AT A SCALE OF ONE INCH TO ONE FOOT.
4. UNLESS OTHERWISE NOTED, THE BOTTOM OF THE DRILL HOLE (B.O.H.) COINCIDES WITH CLAY E.
5. HOLE CONTAINS SALT FILL AT BOTTOM.

FIGURE G-34

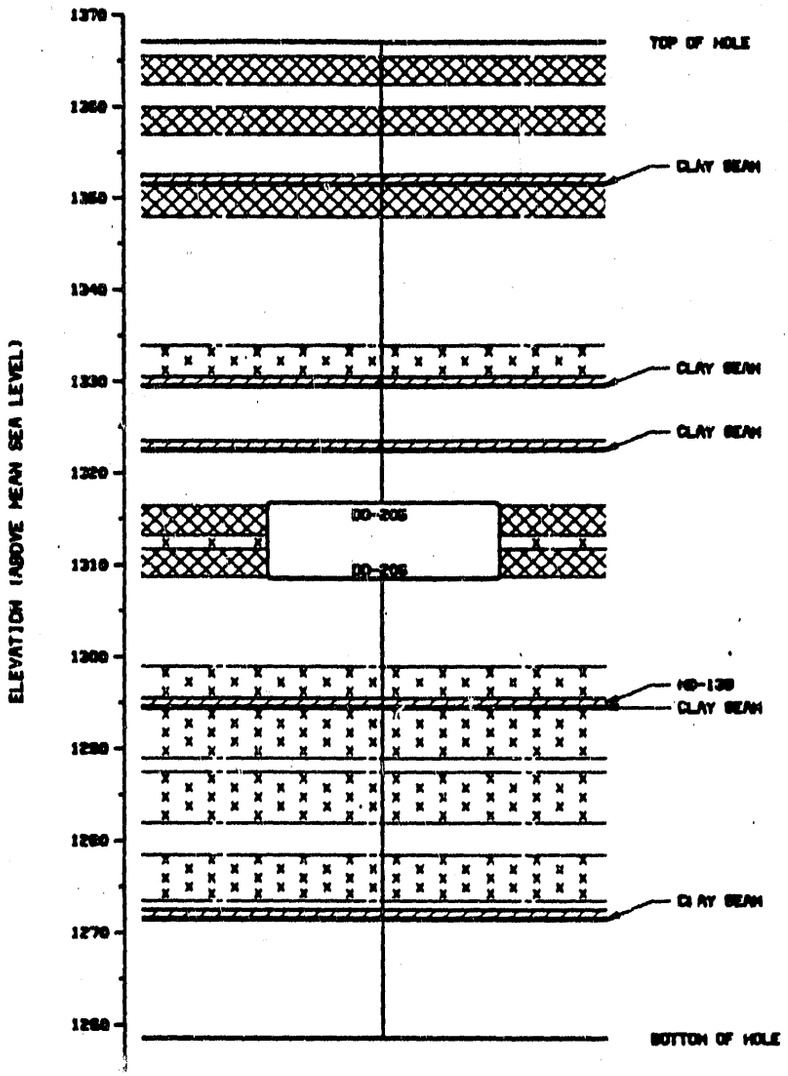
GEOLOGIC MAP OF DRILL HOLE P4X-84

APPENDIX H

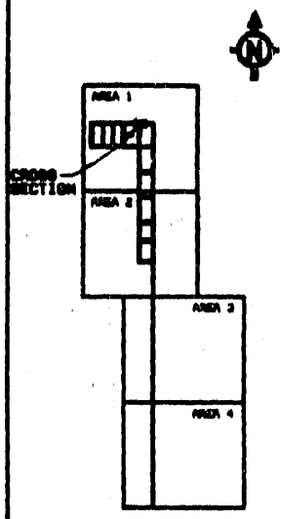
DRIFT CROSS SECTIONS

CONTENTS

Figure No.	Title/Description
H-1	East-West Cross Section - E0 Drift at N1410
H-2	East-West Cross Section - E0 Drift at N1110
H-3	East-West Cross Section - E0 Drift at N621
H-4	East-West Cross Section - E0 Drift at N146
H-5	East-West Cross Section - W30 Drift at S406
H-6	East-West Cross Section - E140 Drift at S1320
H-7	East-West Cross Section - E140 Drift at S1960
H-8	East-West Cross Section - E140 Drift at S2421
H-9	East-West Cross Section - E140 Drift at S3079
H-10	East-West Cross Section - E140 Drift at S3656



KEY PLAN



NOTES

LEGEND

INSTRUMENTS

GE - EXTENSOMETER (MULTIPLE POINT)

DO - CORE DRILL HOLE

RC - RADIAL CONVERGENCE POINT

TC - TEMPORARY CONVERGENCE POINT

WG - ROCK BOLT LOAD CELL

GEOLOGY

CLEAR HALITE

ANHYDRITE

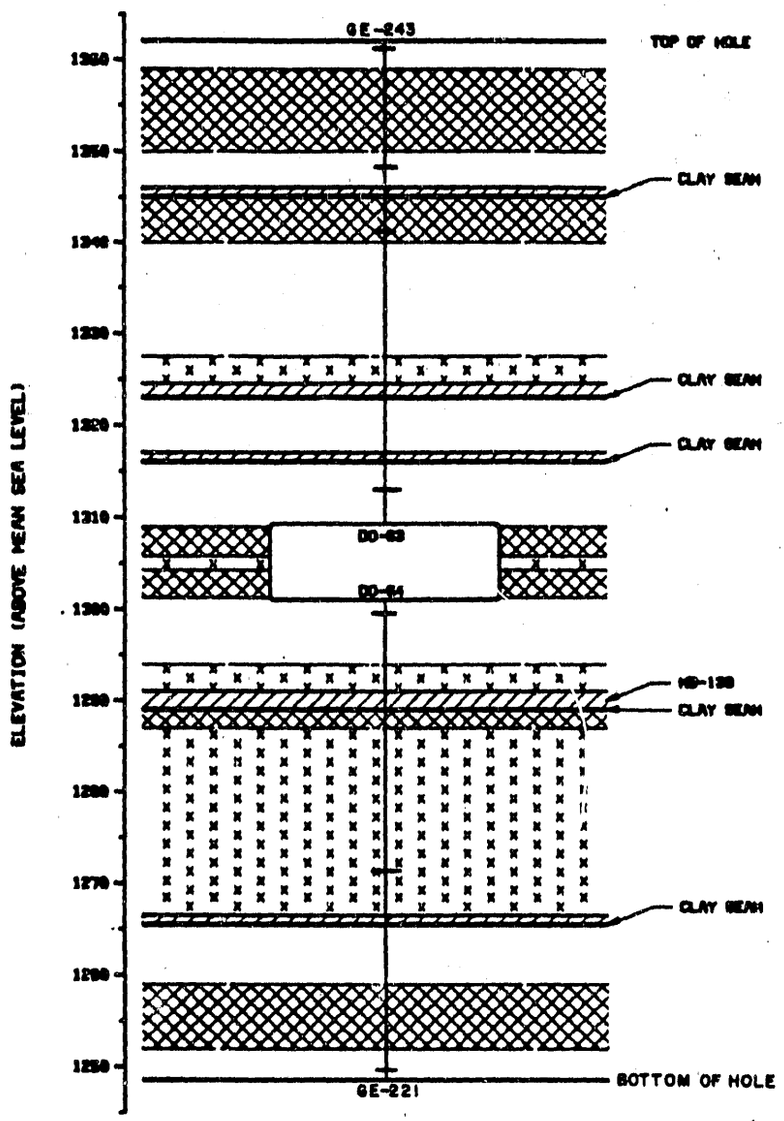
ARGILLACEOUS HALITE

POLYHALITIC HALITE

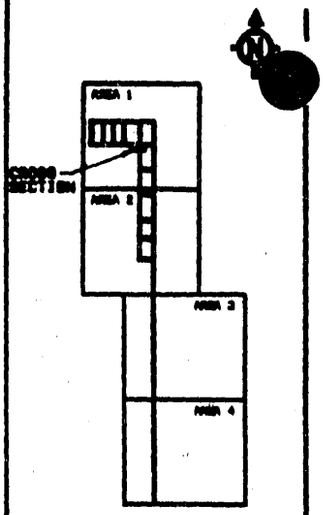
POLYHALITE

EAST-WEST CROSS SECTION EO DRIFT AT N1410

FIGURE H-1



KEY PLAN



NOTES

LEGEND

INSTRUMENTS

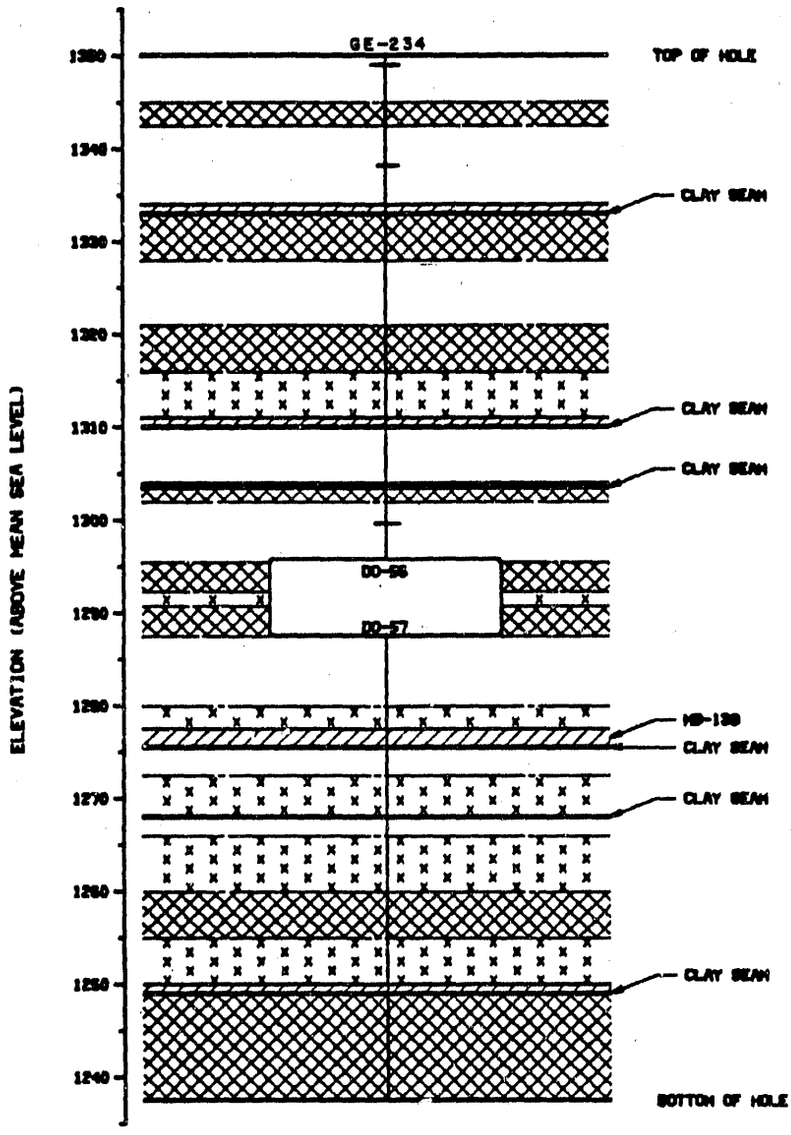
- GE - EXTENSOMETER (MULTIPLE POINT)
- DO - CORE DRILL HOLE
- RC - RADIAL CONVERGENCE POINT
- TC - TEMPORARY CONVERGENCE POINT
- WG - ROCK BOLT LOAD CELL

GEOLOGY

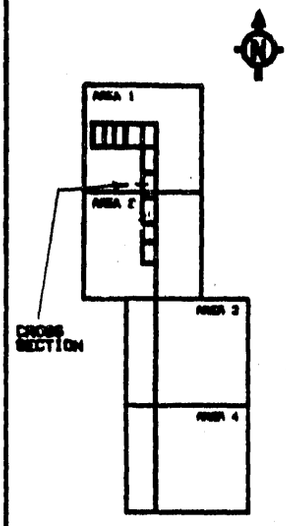
- CLEAR HALITE
- ANHYDRITE
- ARGILLACEOUS HALITE
- POLYHALITIC HALITE
- POLYHALITE

EAST-WEST CROSS SECTION EO DRIFT AT N1110

FIGURE H-2



KEY PLAN



NOTES

LEGEND

INSTRUMENTS

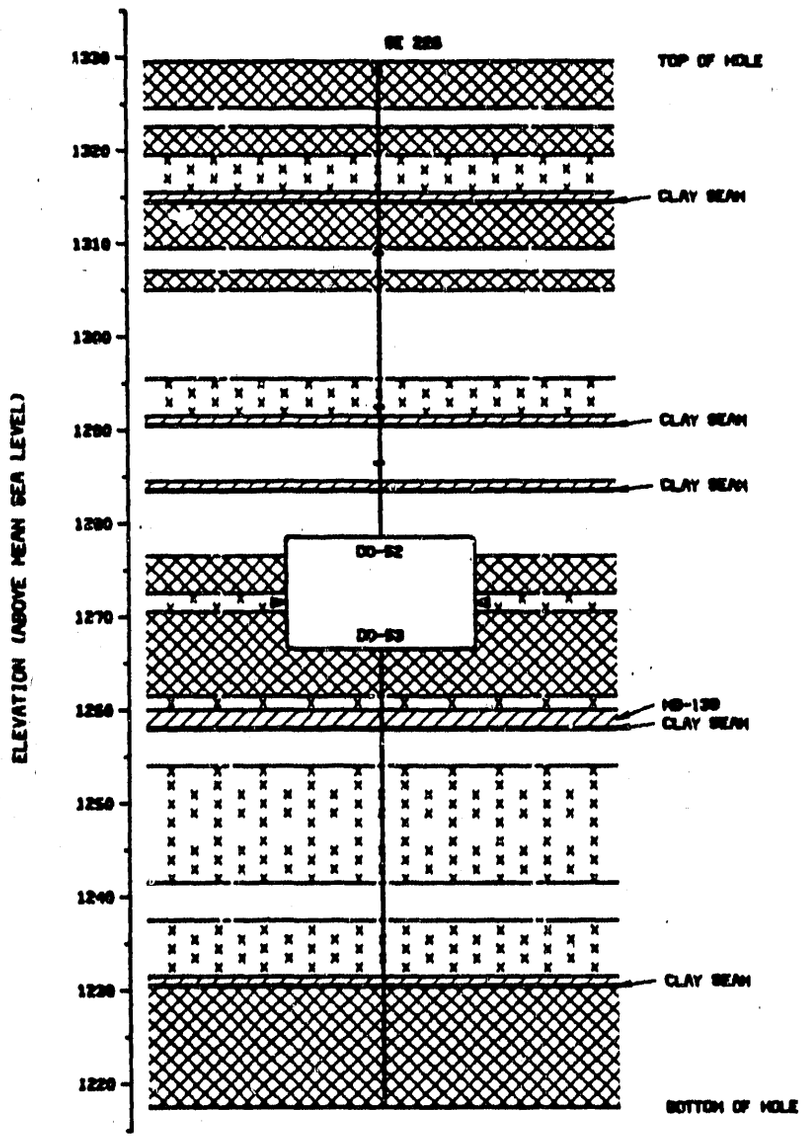
- GE - EXTENSOMETER (MULTIPLE POINT)
- DO - CORE DRILL HOLE
- RC - RADIAL CONVERGENCE POINT
- TC - TEMPORARY CONVERGENCE POINT
- WG - ROCK BOLT LOAD CELL

GEOLOGY

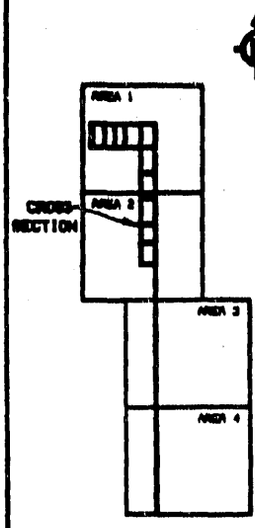
- CLEAR HALITE
- ANHYDRITE
- ARGILLACEOUS HALITE
- POLYHALITIC HALITE
- POLYHALITE

EAST-WEST CROSS-SECTION EO DRIFT AT N621

FIGURE H-3



KEY PLAN



NOTES

LEGEND

INSTRUMENTS

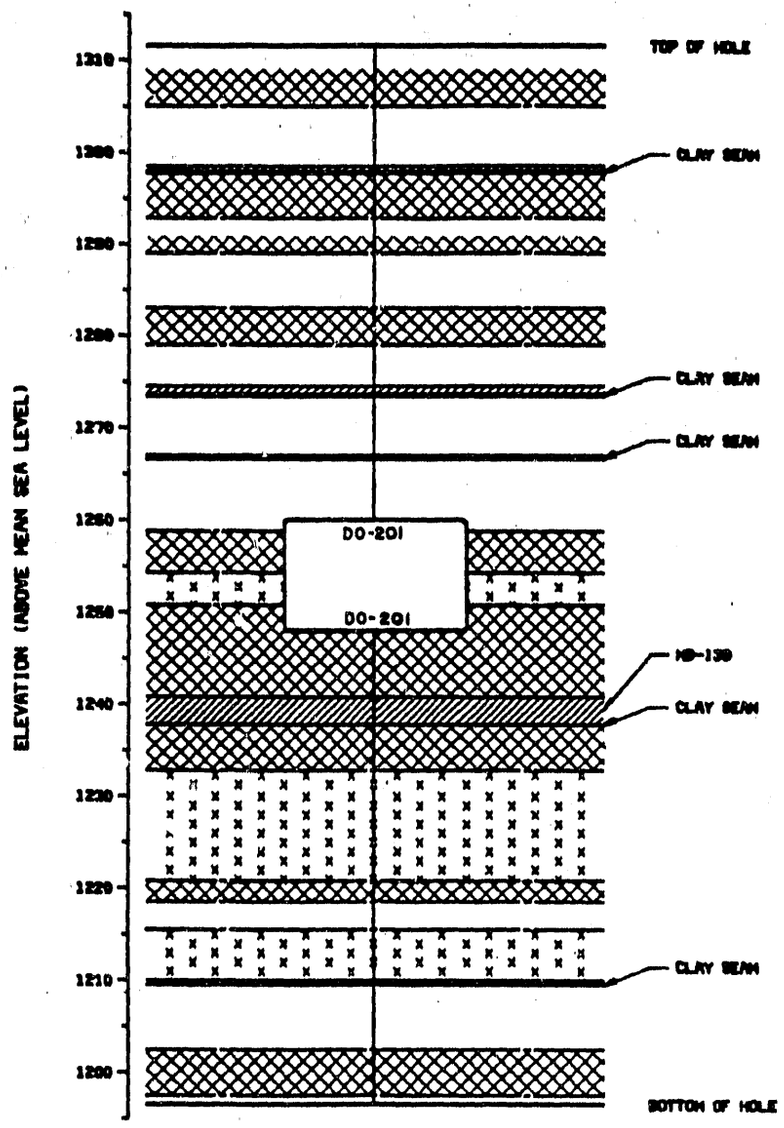
- GE - EXTENSOMETER (MULTIPLE POINT)
- DO - CORE DRILL HOLE
- RC - RADIAL CONVERGENCE POINT
- TC - TEMPORARY CONVERGENCE POINT
- WG - ROCK BOLT LOAD CELL

GEOLOGY

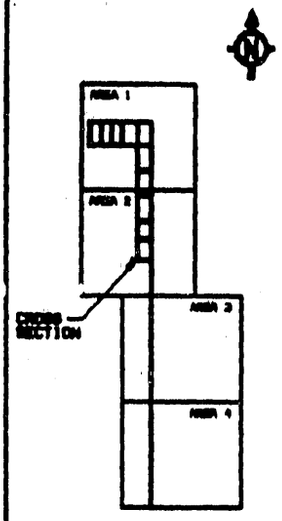
- CLEAR HALITE
- ANHYDRITE
- ARGILLACEOUS HALITE
- POLYHALITIC HALITE
- POLYHALITE

EAST-WEST CROSS SECTION EO DRIFT AT N146

FIGURE H-4



KEY PLAN



NOTES

LEGEND

INSTRUMENTS

GE - EXTENSOMETER (MULTIPLE POINT)

DO - CORE DRILL HOLE

RC - RADIAL CONVERGENCE POINT

TC - TEMPORARY CONVERGENCE POINT

WG - ROCK BOLT LOAD CELL

GEOLOGY

CLEAR HALITE

ANHYDRITE

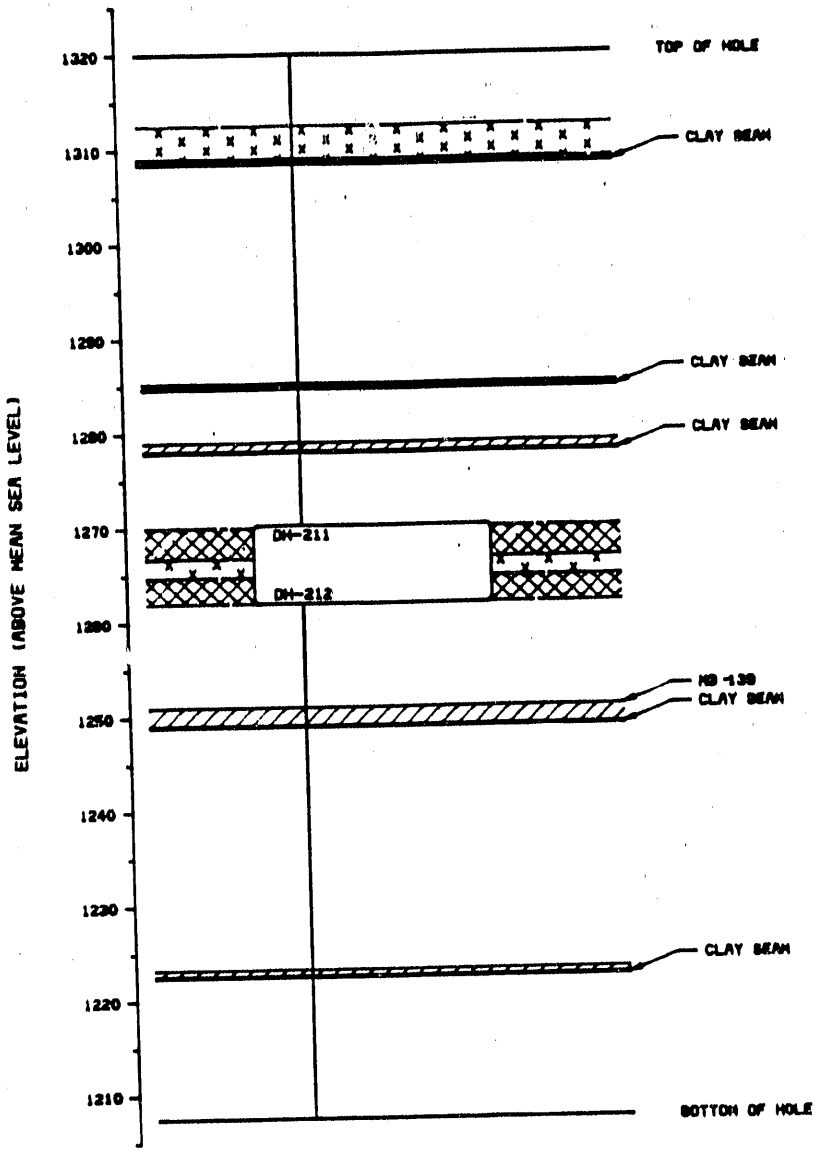
ARGILLACEOUS HALITE

POLYHALITIC HALITE

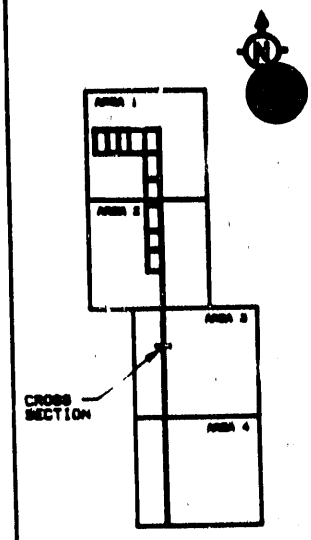
POLYHALITE

EAST–WEST CROSS SECTION W30 DRIFT AT S403

FIGURE H-5



KEY PLAN



NOTES

LEGEND

INSTRUMENTS

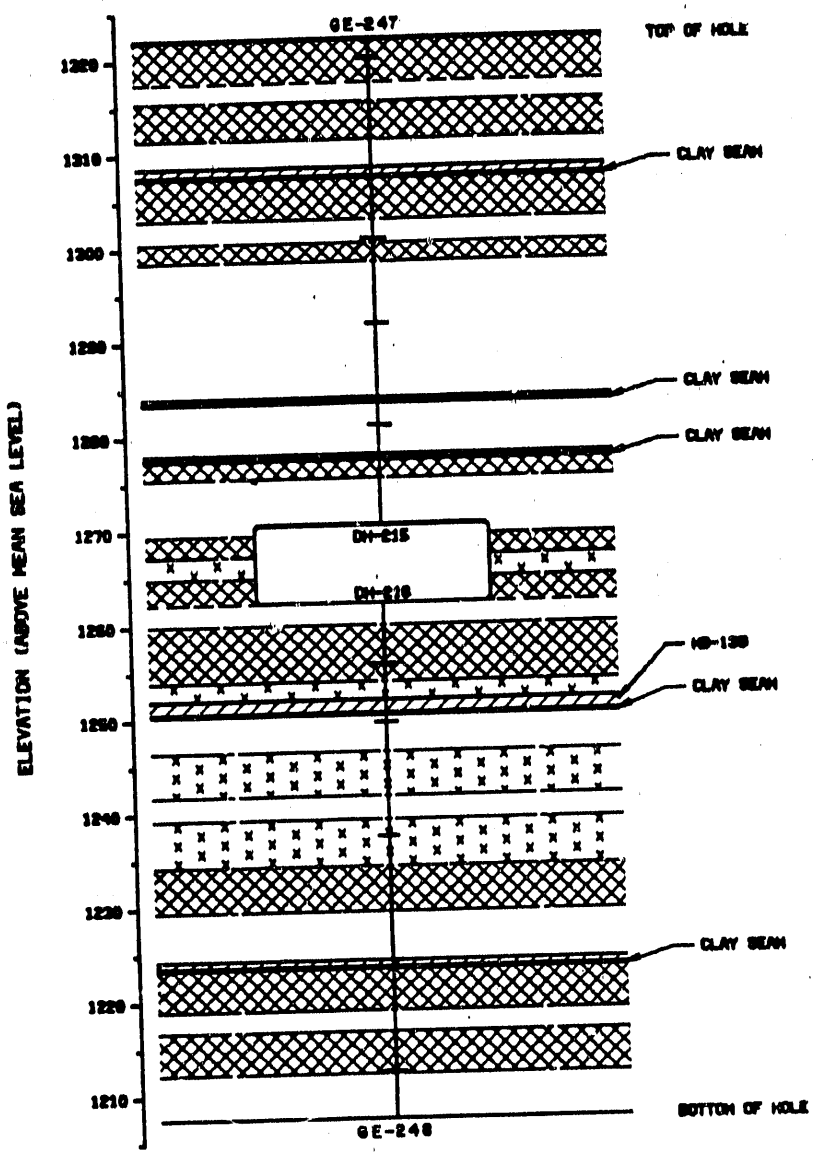
GE - EXTENSOM (MULTIPLE POI
DH - CORE DRILL HOLE
RC - RADIAL CONVERGENCE POINT
TC - TEMPORARY CONVERGENCE POINT
WG - ROCK BOLT LOAD CELL

GEOLOGY

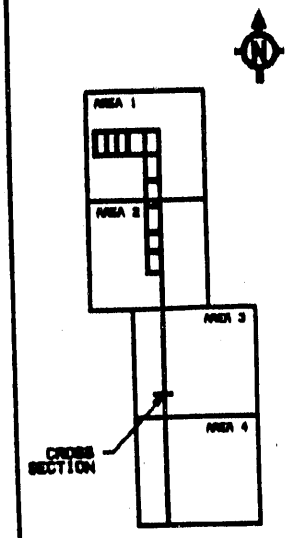
CLEAR HALITE
ANHYDRITE
ARGILLACEOUS HALITE
POLYHALITIC HALITE
POLYHALITE

EAST–WEST CROSS SECTI
E140 DR T AT S152

FIGURE H-6



KEY PLAN



NOTES

LEGEND

INSTRUMENTS

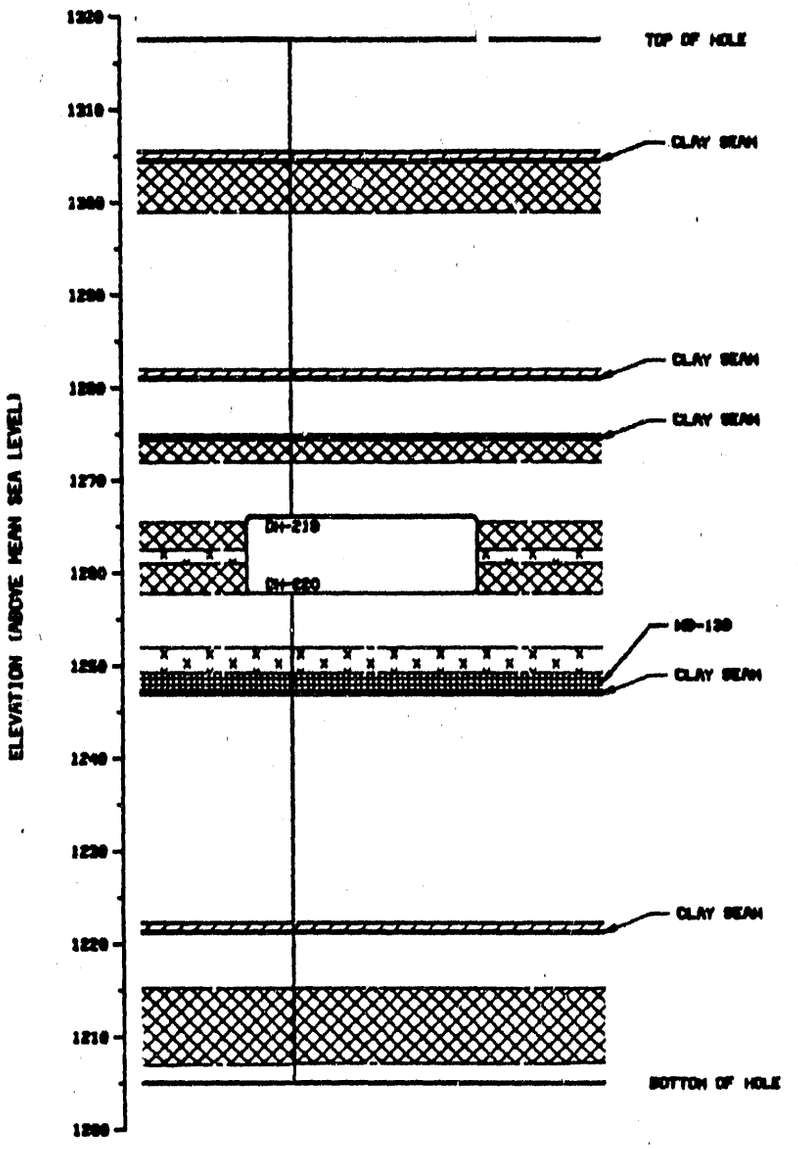
- GE - EXTENSOMETER (MULTIPLE POINT)
- DH - CORE DRILL HOLE
- RC - RADIAL CONVERGENCE POINT
- TC - TEMPORARY CONVERGENCE POINT
- WG - ROCK BOLT LOAD CELL

GEOLOGY

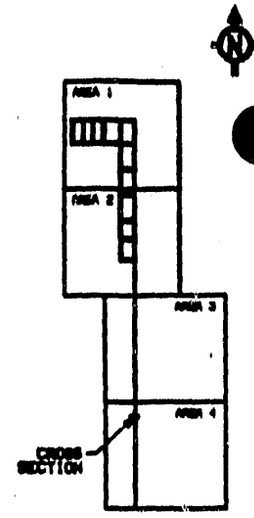
- CLEAR HALITE
- ANHYDRITE
- ARGILLACEOUS HALITE
- POLYHALITIC HALITE
- POLYHALITE

EAST–WEST CROSS SECTION E140 DRIFT AT S1960

FIGURE H-7



KEY PLAN



NOTES

LEGEND

INSTRUMENTS

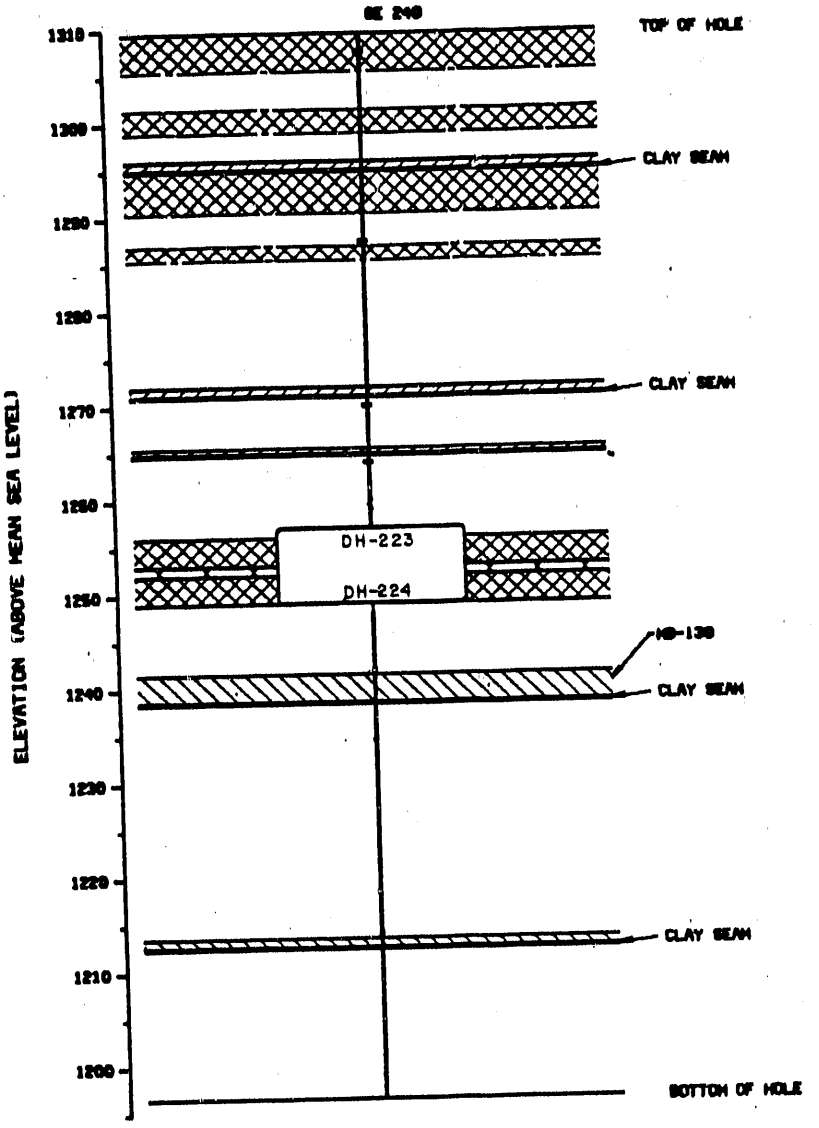
- GE - EXTENSOMETER (MULTIPLE POINT)
- DH - CORE DRILL HOLE
- RC - RADIAL CONVERGENCE POINT
- TC - TEMPORARY CONVERGENCE POINT
- WG - ROCK BOLT LOAD CELL

GEOLOGY

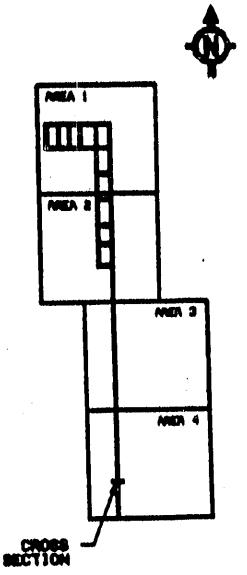
- CLEAR HALITE
- ANHYDRITE
- ARGILLACEOUS HALITE
- POLYHALITIC HALITE
- POLYHALITE

EAST–WEST CROSS SECTION E140 DRIFT AT S

FIGURE H-8



KEY PLAN



NOTES

LEGEND

INSTRUMENTS

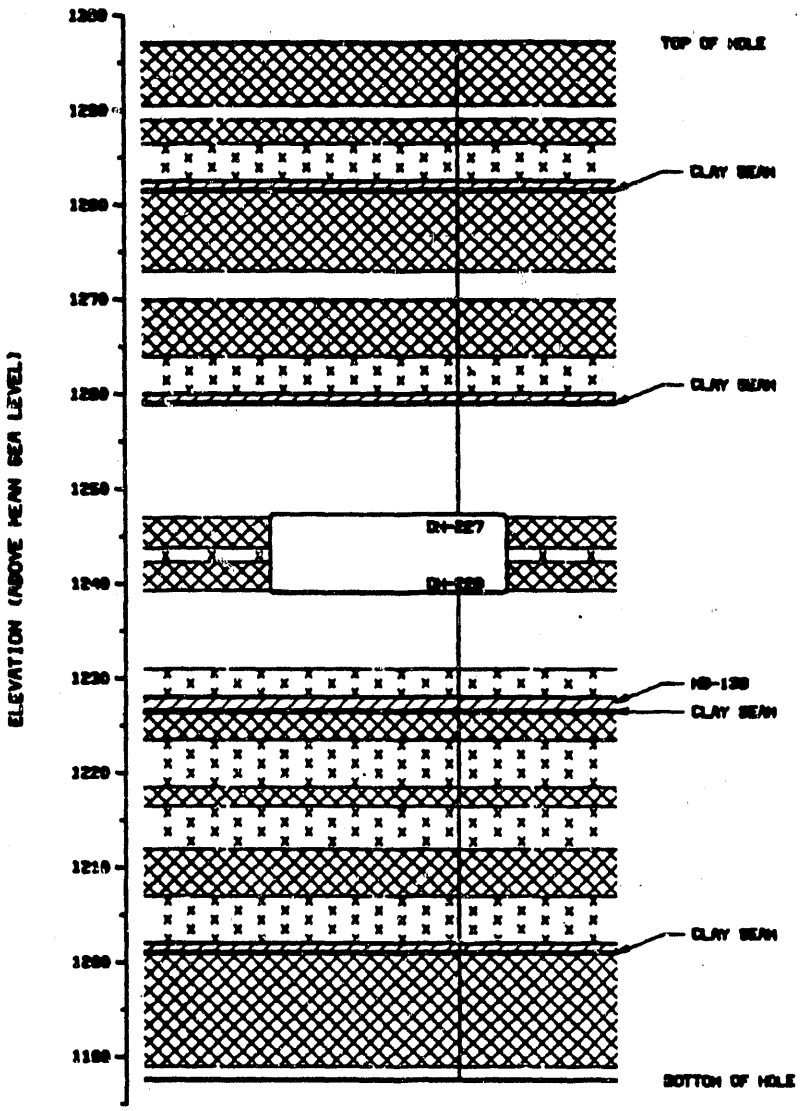
- GE - EXTENSOMETER (MULTIPLE POINT)
- DH - CORE DRILL HOLE
- RC - RADIAL CONVERGENCE POINT
- TC - TEMPORARY CONVERGENCE POINT
- WG - ROCK BOLT LOAD CELL

GEOLOGY

- CLEAR HALITE
- ANHYDRITE
- ARGILLACEOUS HALITE
- POLYHALITIC HALITE
- POLYHALITE

EAST–WEST CROSS SECTION E140 DRIFT AT S3079

FIGURE H-9



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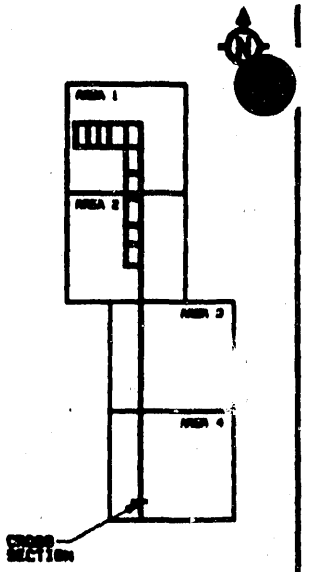


NOTES

LEGEND

INSTRUMENTS

GE - EXTENSOMETER (MULTIPLE POINT)

DH - CORE DRILL HOLE

RC - RADIAL CONVERGENCE POINT

TC - TEMPORARY CONVERGENCE POINT

WG - ROCK BOLT LOAD CELL

GEOLOGY

CLEAR HALITE

ANHYDRITE

ARGILLACEOUS HALITE

POLYHALITIC HALITE

POLYHALITE

EAST–WEST CROSS SECTION
E140 DRIFT AT S3656

FIGURE H-10

APPENDIX I

FACILITY LEVEL
GEOLOGIC CORE HOLE LOGS

CONTENTS

Table No.	Title/Description
I-1	Summary of Core Hole Data

Core Hole Logs

See Table I-1 for listing of enclosed logs.

Table I-1

SUMMARY OF CORE HOLE DATA

Core Hole No.	Direction	Collar Elevation (Ft-MSL)	Approximate Station (Ft)		Facility Coordinates (Ft)		Depth/ Penetration (Ft)	Instrument Designation
MB-139-1	Down	1264.1	N79	W6	N9766	E6888	10.0	None
MB-139-2	Down	1251.2	S410	E150	N9277	E7044	15.7	None
MB-139-3	Down	1260.5	S101	E157	N9586	E7051	16.0	None
MB-139-4	Down	1258.7	S99	W17	N9588	E6877	16.2	None
DH-01	Up	1318.2	N1424	E439.5	N11110.9	E7335.5	50.8	None
DH-02(1)	Down		N1424	E440	N11110.9	E7336.06	50.2	None
DH-02A(1)	Down		N1424	E435	N11110.9	E7331.29	49.2	None
DH-02B	Down	1306.3	N1424	E442	N11110.9	E7331.29	53.0	None
DH-03	Up	1318.1	N1112	E444	N10799.2	E7335.4	48.8	None
DH-03A	Up	1317.4	N1112	E450.5	N10779.2	E7341.92	49.9	None
DH-04	Down	1309.6	N1112.5	E444	N10799.2	E7335.4	45.8	None
DH-04A(1)	Down	1309.6	N1113	E446			11.2	None
DH-04B	Down	1309.7	N1112	E450.5	N10799.70	E7341.85	51.4	None
DH-05	Up	1329.9	N1463	E972	N11140.6	E7865.0	51.0	None
DH-06	Down	1317.9	N1463	E972	N11149.7	E7864.9	49.75	None
DH-07	Up	1326.7	N1112	E976.5	N10799.3	E7870.8	49.8	None
DH-08	Down	1318.8	N1112	E976.5	N10799.4	E7870.9	38.3	None
DH-08A(1)	Down	1318.7	N1112	E975			50.7	None
DH-08B	Down	1318.0	N1112	E979.5	N10799.47	E7866.66	51.4	None
DH-09	Up	1324.5	N1432	E1332.5	N11108.71	E8227.11	51.1	None
DH-10	Down	1312.1	N1432	E1332.5	N11108.70	E8227.09	52.0	None
DH-11	Up	1320.5	N1112	E1332.5	N10799.8	E8227.3	50.9	None
DH-12	Down	1311.1	N1112	E1332.5	N10799.4	E8227.2	51.3	None
DH-13	Up	1311.4	N1424	E1690	N11112	E8585	13.8	None
DH-13A	Up	1311.5	N1424.5	E1691	N11112	E8586	49.0	None
DH-13B	Up	1311.4	N1425	E1695	N11112.6	E8590.1	21.0	None
DH-14	Down	1299.5	N1425	E1695	N11112.6	E8590.1	49.1	None
DH-15	Up	1308.9	N1104	E1688.5	N10793.26	E8589.96	51.0	None
DH-16	Down	1300.3	N1104	E1688	N10792.89	E8589.39	51.0	None
DH-17	Up	1316.5	N1427	E178	N11114.2	E7071.8	52.0	None
DH-18	Down	1305.1	N1429	E181	N11114.2	E7071.8	50.8	None
DH-19	Up	1314.7	N1107	E206.5	N10794.2	E7101.7	51.6	None
DH-20	Down	1306.2	N1109	E206	N10794.2	E7101.7	51.1	None
DH-21	Up	1331.0	N1421	E786	N11109.1	E7680.9	50.4	None
DH-22	Down	1318.8	N1421.5	E785.5	N11109.2	E7680.9	51.0	None
DH-23	Up	1328.0	N1112	E781	N10799.2	E7679.9	51.0	None
DH-24	Down	1319.5	N1112	E781	N10799.2	E7679.8	49.4	None
DH-24A	Down	1319.5	N1112	E780	N10799.08	E7678.59	50.4	None
DH-25	Up	1318.8	N1422	E1510	N11109.7	E8403.8	51.8	None
DH-26	Down	1307.2	N1427	E1510	N11114.3	E8403.8	53.0	None
DH-27	Up	1300.8	N1107	W682	N10793.7	E6218.4	50.5	None
DH-28	Down	1289.9	N1107	W682	N10793.8	E6218.3	50.5	None
DH-29	Up	1298.3	N1099	W982	N10785.4	E5932.4	50.4	None
DH-29A	Up	1298.1	N1099	W987	N10786.1	E5927.3	35.0	None
DH-30	Down	1289.2	N1099	W982	N10785.5	E5932.2	50.1	None
DH-31	Up	1298.5	N1099	W1282	N10784.9	E5632.3	50.5	None
DH-31A	Up	1298.5	N1099	W1280	N10784.8	E5630.5	49.2	None
DH-31B	Up	1298.5±	N1099	W1261	N10786.7	E5652.2	4.9	None
DH-32	Down	1289.6	N1099	W1282	N10784.9	E5632.2	50.0	None
DH-32A	Down	1289.5	N1099	W1261	N10786.7	E5652.2	5.5	None
DH-33	Up	1298.6	N1099	W1582	N10786.0	E5331.1	50.5	None
DH-33A	Up	1297.4	N1099	W1570	N10786.8	E5342.0	4.1	None
DH-34	Down	1289.4	N1099	W1582	N10786.5	E5331.7	51.5	None
DH-34A	Down	1289.2	N1099	W1570	N10786.8	E5341.9	3.6	None
DH-35	Up	1294.4	N1102	W1882	N10789.4	E5032.2	52.0	None
DH-36	Down	1284.6	N1102	W1882	N10789.4	E5032.2	51.5	None
DH-37	Up	1297.4	N1101	W2182	N10788.9	E4732.0	51.5	None
DH-38	Down	1287.0	N1101	W2182	N10788.8	E4731.9	47.5	None
DH-39	Up	1296.0	N1101	W2482	N10789.2	E4430.7	50.7	None
DH-40	Down	1286.1	N1101	W2482	N10789.2	E4431.0	51.0	None
DH-41	Up	1295.8	N1101	W2782	N10789.0	E4132.6	49.9	None
DH-42	Down	1285.9	N1101	W2782	N10789.0	E4132.4	51.2	None
DH-42A	Down	1285.7	N1101	W2789	N10789.2	E4125.5	40.5	None

(1) Survey data not available.

Table I-1 (continued)

SUMMARY OF CORE HOLE DATA

Core Hole No.	Direction	Collar Elevation (Ft-MSL)	Approximate Station (Ft)		Facility Coordinates (Ft)		Depth/ Penetration (Ft)	Instrument Designation
DH-207	Up	1259.8	S697	E155	N8989.7	E7049.1	53.0	GE-246
DH-208	Down	1251.6	S698	E150	N8988.8	E7044.0	49.2	None
DH-211	Up	1270.5	S1320	E163	N8366.5	E7057.1	50.0	None
DH-212	Down	1261.7	S1320	E163	N8366.5	E7057.1	52.1	None
DH-215	Up	1272.0	S1960	E153	N7727.2	E7046.9	52.0	GE-247
DH-216	Down	1262.6	S1960	E153	N7727.2	E7046.9	54.2	GE-248
DH-219	Up	1266.3	S2422	E162	N7264.9	E7056.6	51.0	None
DH-219A	Up	1266.1	S2418	E162	N7268.5	E7056.2	11.3	None
DH-220	Down	1257.4	S2421	E162	N7265.5	E7055.9	51.8	None
DH-223	Up	1255.1	S3079	E154	N6607.2	E7048.5	52.6	GE-249
DH-224	Down	1246.6	S3079	E154	N6607.5	E7048.5	52.5	None
DH-227	Up	1247.0	S3656	E147	N6030.7	E7041.2	51.7	None
DH-228	Down	1237.8	S3656	E147	N6030.7	E7041.2	50.4	None
DH-301	Up	1276.9	N150	W170	N9830.5	E6724.5	50.75	None
DH-302	Down	1264.9	N150	W170	N9830.5	E6724.5	50.6	None
DH-303	Up	1267.2	S400	W170	N9282.3	E6726.1	51.4	None
DH-304	Down	1254.3	S400	W170	N9282.5	E6726.1	50.5	None
DH-306	Down	1244.1	S400	E140	N9287.3	E7049.9	52.0	None
DH-306A	Down	1244.0	S400	E125	N9287.9	E7034.6	8.5	None
DH-307	Up	1262.6	S400	E300	N9286.7	E7194.2	52.0	GE-263
DH-309	Up	1259.8	S700	E220	N8987.1	E7123.0	52.3	GE-265
DH-311	Up	1264.4	S1000	E300	N8686.3	E7194.9	52.0	GE-264
DH-313	Up	1270.6	S1300	E300	N8385.9	E7190.6	19.6	None
DH-313A	Up	1270.9	S1300	E299	N8386.6	E7189.5	50.2	None
DH-314	Down	1258.3	S1300	E300	N8386.5	E7189.5	50.75	None
DH-315	Up	1272.1	S1300	W170	N8387.3	E6725.5	50.3	None
DH-316	Down	1259.9	S1300	W170	N8387.2	E6725.3	50.1	None
DH-317	Up	1271.3	S1600	W33	N8077.4	E6875.9	50.1	None
DH-317A	Up	1271.2	S1600	W30	N8077.5	E6879.5	5.0	None
DH-317B	Up	1271.2	S1597	W30	N8080.3	E6881.0	51.0	None
DH-318	Down	1258.5	S1600	W30	N8077.3	E6876.1	50.0	None
DH-319	Up	1260.0	S700	E300	N8988.1	E7191.6	51.05	None
DH-321	Up	1261.4	S400	E0	N9792.0	E6891.8	52.0	GE-268
DH-323	Up	1261.2	S400	E55	N9291.7	E6952.5	52.5	GE-267
DO-45	Up	1285.5	N254	E147	N9941.0	E7041.3	52.4	GE-230
DO-46	Down	1276.5±	N254	E147	N9941.0	E7041.3	51.5	None
DO-52	Up	1280.4	N146	W4	N9832.5	E6890.5	51.6	GE-226
DO-53	Down	1266.6	N146	W4	N9832.5	E6890.5	49.2	None
DO-56	Up	1296.8	N621	E0	N10311.8	E6892.3	52.1	GE-234
DO-57	Down	1288.1	N621	E0	N10311.8	E6892.4	52.1	None
DO-63	Up	1310.6	N1110	E0	N10796.0	E6891.9	52.8	GE-243
DO-64	Down	1301.5	N1110	E0	N10796.0	E6891.6	52.8	GE-221
DO-67	Down	1296.8	N1265	W231.5	N10952.1	E6662.9	51.7	GE-220
DO-69	Up	1310.1	N1265	W231.5	N10951.9	E6662.5	51.4	GE-218
DO-77	Down	1294.6	N1270	W364.5	N10962.5	E6529.6	53.4	GE-216
DO-79	Up	1307.7	N1270	W364.5	N10962.6	E6529.5	51.8	GE-214
DO-88	Up	1305.9	N1265	W497.5	N10952.8	E6396.5	52.7	GE-212
DO-90	Down	1292.1	N1265	W497.5	N10952.6	E6396.4	53.6	GE-210
DO-91	Down	1292.1	N1275	W630.5	N10961.5	E6263.9	51.8	GE-209
DO-93	Up	1304.9	N1275	W630.5	N10961.1	E6263.9	52.0	GE-207
DO-201	Up	1262.2	S406	W19	N9280.6	E6874.9	51.7	None
DO-202	Down	1248.6	S406	W19	N9280.6	E6874.9	51.4	None
DO-203	Up	1298.2	N624	E140	N10308.6	E7041.7	52.0	GE-235
DO-204	Down	1290.5	N640	E140	N10308.5	E7041.5	51.6	None
DO-205	Up	1316.5	N1410	E0	N11095	E6892	50.7	None
DO-206	Down	1308.0	N1410	E0	N11095	E6892	50.6	None
DO-229	Up	1259.8	S401	E153	N9287	E7049	50.6	None
OH-9	Up	1310	N1433	W231.5	N11125.6	E6662.9	15.4	None
OH-11	Up	1308	N1433	W364.5	N11125.6	E6529.6	19.7	None
OH-13	Down	1298	N1433	W231.5	N11125.6	E6662.9	9.5	None
OH-14	Down	1296	N1433	W364.5	N11125.6	E6529.6	9.7	None

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. MB-139-1 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 79' N of Exploratory Shaft centerline, midspan

STATION N79,W6 COLLAR ELEV. 1264.1' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9766, E6888 DEPTH OF BOREHOLE 10.0'

DRILLING METHOD Air & Brine DRILL MAKE/MODEL Longyear 38

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/26/83

SHEET 1 OF 1

RUN NUMBER	DEPTH (ft)	RECOVERY(ft.)	% RECOVERED	ROD	PROFILE	DESCRIPTION	REMARKS
1	0	1.5	100	–		0.0' – 4.4' **HALITE:** clear halite, coarsely crystalline, 1-2% moderate reddish-orange (10R 6/6) polyhalite, 1-2% brown clay, ~1% gray clay, all in discrete blebs.	Hole was cored on 27 October 1982. The first 5' interval was drilled with air. Recovery was poor, and the core was covered with oil. At 5', drilling with brine commenced and continued to 10'. At 10', the water pump failed and the rods became stuck in the hole. Rods were pulled and drilling halted at 10'.
2		0.8	24	–			
3	5	1.0	100	–		4.4' – 6.8' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) halite, coarsely crystalline, 5% polyhalite in blebs above 6.0', in blebs and disseminated below 6.0', clay absent, 10-50% anhydrite from 6.7'-6.8'.	
4		3.5	88	–		6.8' – 8.6' **ANHYDRITE:** (Marker Bed 139) light gray (N7), microcrystalline anhydrite, 5-50% polyhalitic halite from 6.8'-8.1' decreasing downward, gray clay parting at 8.6'.	
	10					8.6' – 9.5' **HALITE:** clear to moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, 1-2% mostly disseminated polyhalite, ~1% gray clay.	Total depth = 10.0'.
	15						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. MB-139-2 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION Intersection of South 400 and East 140 Drifts, 14.5' N of S rib of South 400 Drift, 18' W of E rib of East 140 Drift

STATION S410, E150 COLLAR ELEV. 1251.2' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9277, E7044 DEPTH OF BOREHOLE 15.7'

DRILLING METHOD Air and Brine DRILL MAKE/MODEL Longyear D-65

PREPARED BY RMB/Bechtel DATE 11/27/82 SHEET 1 OF 1

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0	1.6	89	-		0.0' - 1.1' **HALITE:** clear halite, medium to coarsely crystalline, trace polyhalite, gray clay break at 0.4'.	Coring started at 12:00 hours on 27 November 1982.
2		1.9	90	-		1.1' - 2.8' **HALITE:** medium reddish-orange (10R 5/6), translucent halite, medium crystalline, moderately hard, 2 - 5% clay, ~5% polyhalite, gray clay parting at 1.1', brown clay parting at 1.4'.	
3	5	0.6	27	-		2.8' - 6.5' **HALITE:** predominantly clear halite, coarsely crystalline, trace polyhalite in places, trace gray clay blebs in places.	From ground surface to 8.7', core was recovered directly into drill rod without use of inner barrel. Inner barrel was used below 8.7'.
4		1.3	100	-		6.5' - 8.1' **HALITE:** medium reddish-orange (10R 5/6), translucent halite, medium crystalline, ~2% polyhalite, trace gray clay blebs in places, polyhalite absent from 7.4' - 8.1'.	
5		1.3	100	-		8.1' - 9.7' **POLYHALITIC HALITE:** medium reddish-orange (10R 5/6), translucent halite, medium to coarsely crystalline, moderately hard, 20 - 25% polyhalite.	
6	10	4.9	98	-		9.7' - 12.9' **ANHYDRITE:** (Marker Bed 139) medium light (N6) to very light gray (N8) to light brownish-gray (5YR 6/1) anhydrite, hard, dense, up to 30% halite from 9.7' - 10.5' in "mesh" network with anhydrite, some halite from 10.5' - 12.9', polyhalite band 9.7' - 9.75', 10.5' - 12.9' mostly broken into "poker chips".	At ~11'-12', brine drilling fluid started bubbling back out of hole. Hit trace pressurized gas.
7	15	1.9	95	-		12.9' - 13.7' **HALITE:** light gray (N7) mottled with medium reddish-orange (10R 5/6) translucent halite, clay occurs predominantly as closely-spaced breaks, 1" gray clay seam at 12.9', gray clay breaks at 13.1', 13.2', and 13.3'.	
						13.7' - 15.7' **HALITE:** brownish-gray and medium reddish-orange (10R 5/6) translucent halite, medium to coarsely crystalline, ~1% gray clay, trace polyhalite in places, especially 15.3' - 15.7', gray clay breaks at 13.9', 14.3', and 14.7'.	Finished coring at 14:15 hours, gas still evident in hole. Total depth = 15.7'.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. MB-139-3 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION Intersection of South 90 and East 140 Drifts, 1' N of S rib of the South 90 Drift, 14.5' E of W rib of the East 140 Drift

STATION S101,E157 COLLAR ELEV. 1260.5' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9586, E7051 DEPTH OF BOREHOLE 16.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JAK,RLB/TSC DATE 1/26/83 SHEET 1 OF 1

RUN NUMBER	DEPTH (ft.)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0	1.1	49	-		0.0' - 7.9' HALITE: clear to moderate reddish-orange (10R 6/6) to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, 1-5% polyhalite, 1-3% gray clay predominantly at top, 1-3% brown clay predominantly at bottom, 0.0'-0.6' has <1% polyhalite, ~1% disseminated polyhalite and no clay from 4.2'-4.8', otherwise polyhalite is in discrete blebs.	Hole cored on 28 December 1982.
2		0.75	45	-			
3	5	1.2	39	-			
4		1.8	83	-		7.9' - 9.6' POLYHALITIC HALITE: clear to moderate reddish-orange (10R 6/6) halite, 2-5% polyhalite disseminated and in blebs, <1% gray clay, brown clay absent.	
5	10	4.6	92	-		9.6' - 11.9' ANHYDRITE: (Marker Bed 139) light gray (N7) microcrystalline anhydrite, trace halite from 9.6'-11.2', gray clay seam at 11.9'.	Gas encountered while drilling through MB 139.
						11.9' - 16.0' HALITE: clear to moderate reddish-brown (10R 4/6) halite, finely to coarsely crystalline, 1-2% disseminated polyhalite, 1-2% gray clay above 14.3', 1-3% brown clay below 14.8', clay absent elsewhere, 14.3'-14.8' is relatively pure halite. pure halite.	
6	15	1.8	100	-			Total depth = 16.0'.
	20						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. MB-139-4 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION Intersection of O East and South 90 Drifts, 5' E of W rib of O East Drift, 3' N of S rib of South 90 Drift

STATION S99,W17 COLLAR ELEV. 1258.7' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9588, E6877 DEPTH OF BOREHOLE 16.2'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/26/83 SHEET 1 OF 1

RUN NUMBER	DEPTH (ft)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0	0.5	25	–			Hole cored on 29 November 1982.
2	5	3.5	95	–		0.0' - 5.6' HALITE: mottled white to clear to dark reddish-brown (10R 3/4) halite, coarsely crystalline, 1 - 5% polyhalite and 1 - 5% brown clay, both concentrated in discrete blebs within otherwise clear halite.	Run 1 recovery seems to be from bottom of run.
3		3.5	95	–		5.6' - 8.5' POLYHALITIC HALITE: clear halite, coarsely crystalline, 5 - 10% moderate reddish-brown (10R 5/6) polyhalite in discrete blebs, <1% gray clay.	
4	10	4.6	97	–		8.5' - 11.9' ANHYDRITE: (Marker Bed 139) light gray (N7) anhydrite, 30 - 40% halite from 8.5' - 10.7, 5 - 10% halite from 10.7' - 11.1', gray clay seam at 11.9'.	Drilled with solution of vent shaft water and added salt.
5	15	2.1	100	–		11.9' - 16.2' HALITE: clear to moderate reddish-brown (10R 4/6) to light gray (N7) halite, finely to coarsely crystalline, 1 - 5% polyhalite and 1 - 2% gray clay in bands, ~1% brown clay.	Most core shows signs of dissolution by drilling fluid. Smooth, rounded features of halite, polyhalite and clay stand out in relief.
	20						Total depth = 16.2'.

WIPP

WASTE ISOLATION PILOT PLANT

GEOLOGIC DRILL LOG

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-01

LOCATION N 1420 DRIFT: ROOF

STATION N 1424 ± E 439.5 ± COLLAR ELEV. 1318.2 DIRECTION OF DRILLING VERTICAL-UP

MINE COORDINATES N 11,110.9 E 7335.5 DEPTH OF BOREHOLE 50.8 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 2/9/84 (SWING) DATE COMPLETED 2/10/84 (SWING) SHEET 1 OF 2

LOGGED BY: J.E. GALLERANI DATE: 3/5/84

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						Watson drill; AW rods, NX double tube core barrel.
1		3.2	3.2	100		0.0'-4.4' HALITE: Clear with scattered moderate reddish orange (10R 6/6) polyhalite, coarsely crystalline with some fine to medium locally. (1,2)	Run 1. Broken zone 2.5'-2.8' ±.
	3.2					4.4'-7.05' HALITE: Clear to light gray (N7) medium to coarsely crystalline. ≤1% gray clay and < 1/2% polyhalite. (11)	Drilling Time: 7 hrs ±.
2		4.8	4.8	100		7.05'-7.2' ANHYDRITE b: Light gray (N7) to medium gray (N5) microcrystalline. ≤ 3/16" gray clay at 7.05'.	No gas; dry hole Run 2. Broken up last 15" ± of run 2.
	8.0					7.2'-11.8' HALITE: Clear, fine to coarsely crystalline to 8', then predominantly clear, coarsely crystalline. Slight moderate reddish orange color to 8'. (1,2)	Run 3. Broken last 6".
3		4.0	4.0	100		11.8'-13.25' HALITE: Clear with some light moderate reddish brown (10R 4/6) and light gray (N7) medium to coarsely crystalline with fine locally. < 1/2% gray gray and dispersed polyhalite. (9)	
	12.0						
4		1.0	1.0	100			
	13.0					13.25'-13.85' ANHYDRITE a: White to medium gray (N5) microcrystalline. Scattered halite growths especially from 13.5'. Trace of gray clay at 13.25'; Some core grinding noted here.	Run 5. Broken up 16.0'-16.8' ±.
5		4.2	4.2	100			
	17.2					13.85'-17.6' HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 2% locally, polyhalite blebs. (2,3)	Run 6. Broken up last 4" of run.
6		4.8	4.8	100			
	22.0					17.6'-22.9' HALITE: Clear, some light gray (N7); medium to coarsely crystalline. < 1% gray intercrystalline clay. Break at 20.1'. Gray clay break, trace of anhydrite at 22.9'. (1,9)	
7		5.3	4.9	92.5		22.9'-27.3' HALITE: Clear, coarsely crystalline, some medium. Scattered white anhydrite/magnesite? stringers. (1)	Run 7. Broken zones from 25'-27.3' within core.

BORING NO. DH-01

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-01

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
7		5.3	5.3	92.5		27.3'-28.6' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4), fine to coarsely crystalline. < 1 to 3% clay, predominantly brown with trace of gray. Breaks at 27.9' and 28.35'. ≤5% brown clay from 28.35' to 28.6'. (17)	
27.3							
8		4.7	4.7	100		28.6'-31.5' HALITE: Clear, coarsely crystalline ≤ 1/2% gray clay and polyhalite locally. (1)	Run 8. Broken up 30.2'- 32' ±.
	30					31.5'-34.0' ARGILLACEOUS HALITE: Clear to medium brown (5YR 4/4) and dark reddish brown (10R 3/4) medium to coarsely crystalline. < 1 to 4% brown clay. Scattered breaks at 33.2'-34'. (10)	
32.0							
9		5.0	5.0	100		34.0'-35.0' HALITE: Clear, coarsely crystalline. < 1/2% brown clay. (1,8)	Run 9. Broken up discs 33.8'-35' ±.
	35					35.0'-35.85' ANHYDRITE: Very light gray (N8) to medium gray (N5) microcrystalline anhydrite: partially laminated. Scattered halite growths, especially 35.55'-35.85'. ≤ 1/4" brown clay at 35.0'.	
37.0							
10		4.3	4.3	100		35.85'-37.2' HALITE: Clear, coarsely crystalline. <1% polyhalite blebs and patches up to 1/2" white anhydrite layer at 36.7'. (1,2)	Run 10. Broken zones in core 38'-39.5' ±.
	40					37.2'-39.9' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline < 1 to 3% polyhalite blebs and patches. < 1/2% gray clay. (3,4,7)	
41.3							
11		4.7	4.7	100		39.9'-42.3' HALITE: Clear to light brown (5YR 5/6), medium to coarsely crystalline. ≤ 1% brown intercrystalline clay. 1/2" brown clay seam at 41.3'. < 1% polyhalite. Argillaceous halite at 41.8' to 42.3'. (8,10)	Run 11. Small broken zones in core 45'-46' ±.
	45					42.3'-45.4' HALITE: Clear, coarsely crystalline. < 1% polyhalite and < 1/2% gray clay. (1,7)	
46.0							
12		4.8	4.8	100		45.4'-47.0' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4) (5YR 3/4) medium to coarsely crystalline. < 1 to 5% brown clay, intercrystalline and breaks. Breaks from 46.5' to 46.9'. (12)	
	50					47.0'-49.0' HALITE: Clear to medium brown (5YR 4/4) to moderate yellowish brown (10R 5/4) medium to coarsely crystalline, some fine. < 1 to 2% brown clay. Up to 4% clay from 48.7'-49.0'. Scattered breaks here, 3/8" brown clay seam at 49.0'. (12,17)	
50.8							
						49.0'-50.8' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite blebs and patches. < 1/2% gray clay. (4,7)	
	55						

BORING NO. DH-01

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-02

LOCATION N1420 DRIFT - FLOOR

STATION N1424 ± E440 ± COLLAR ELEV. ____ DIRECTION OF DRILLING VERTICAL - DOWN

MINE COORDINATES N11,110.9 E7336.06 DEPTH OF BOREHOLE 50.2'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 2/7/84 (SWING) DATE COMPLETED 2/8/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/5/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		4.5	4.5	100		0.0'-4.8' HALITE: Clear with some light gray (N7); coarsely crystalline, some medium. ≤1% gray intercrystalline clay and < 1/2% polyhalite blebs.	Watson drill NX double tube barrel, AW rods. Total time: 3-1/2 hours. Had to bolt machine to floor. Vibration of track boom is considerable No gas; dry hole. Contacts below run 2 not able to be determined accurately due to core loss.
	4.5					4.8'-5.3' POLYHALITIC HALITE: Clear to moderate reddish orange; coarsely crystalline. < 1 to 3% polyhalite.	
2	5	5.0	4.5	90		5.3'-8.5' MB-139: Moderate reddish orange anhydrite mixed with halite to 5.4', then predominantly white to medium light gray (N6) anhydrite. Some "swallowtail" pattern in upper part. Scattered halite growths throughout. Abundant polyhalitic halite mixed with the anhydrite from 7.25'-8.0'. < 1/4" gray clay at 8.5'.	Run 2. Core loss probably upper 1-1/2'.
	9.5					8.5'-11.8' HALITE: Clear, medium to coarsely crystalline. < 1% gray clay and polyhalite.	
3	10	5.3	4.6	86.8		11.8'-15.7' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 2% polyhalite. < 1/2% gray clay. Some anhydrite at 15.5 to 15.7'. Gray clay parting at 15.7'.	
	14.8					15.7'-16.4' HALITE: Clear, medium to coarsely crystalline. < 1% gray clay and dispersed polyhalite.	
4	15	5.2	3.3	63.5		16.4'-25.0' ± POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. < 1/2% gray clay below 22.5' ±.	
	20.0					25.0'-30.0' ± HALITE: Clear, fine to coarsely crystalline. < 1/2% clay and polyhalite.	
5	20	5.0	4.0	80			
	25.0						

BORING NO. DH-02

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-02

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
25.0							
6		5.0	2.7	54		30.0'-33.9' ± HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1/2% dispersed polyhalite. 1/2" anhydrite layer at 30'.	Run 7. Poor core recovery. Run 8. Poor core recovery. Took apart core barrel. Air ports were plugged. Cleaned up but still poor recovery.
30.0	30					33.9'-45.8' ± HALITE: Clear to light gray (N7) and medium light gray (N6); medium to coarsely crystalline, some fine. < 1% clay and < 1/2% dispersed polyhalite.	
7		3.9	1.0	25.6		45.8'-50.2' HALITE: Clear, medium to coarsely crystalline. None to < 1% gray clay. < 1/2% polyhalite from 49.3' to 50.2'.	
33.9							
8	35	5.6	1.2	21.4		Note: Core recovery from 4.5' is below 95%. Unable to accurately determine contacts. Hole was redrilled twice. Refer to logs for DH-02A and DH-02B.	
39.5							
9	40	5.1	1.2	23.5			
44.6							
10	45	5.6	4.5	80.4			
50.2	50						

BORING NO. DH-02

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER ____ - ____ HOLE TYPE/SIZE NX CORE BORING NO. DH-02A

LOCATION N1420 DRIFT FLOOR

STATION N1424 ± E435 ± COLLAR ELEV. ____ DIRECTION OF DRILLING VERTICAL - DOWN

MINE COORDINATES N11,110.9 E7331.29 DEPTH OF BOREHOLE 49.2'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 2/8/84 (SWING) DATE COMPLETED 2/9/84 (DAY) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/5/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		5.0	5.0	100		0.0'-2.75' HALITE: Clear to light gray (N7) coarsely crystalline. <1% gray clay. <1/2% polyhalite.	Watson drill with NX double tube barrel. AW rods. Drilling time: 6 hours and 45 minutes. No gas/brine.
						2.75'-5.6' HALITE: Clear with some moderate reddish orange (10R 6/6); coarsely crystalline. <1% polyhalite.	
	5.0						
2		5.0	4.3	86		5.6'-8.2' MB-139: "Swallowtail" pattern of halite and anhydrite from 5.6' to 7.5'. 1" layer of clear halite at 7.2'. From 7.5' to 8.2' predominantly light gray anhydrite with scattered halite growths. Some irregular laminated present. No clay at 8.2' but core grinding evident.	Run 2. Loss appears to be at top of run. Run 4. Core looks good in run; loss possibly throughout.
						8.2'-11.8' HALITE: Clear with some light moderate reddish orange and light gray (N7). Medium to coarsely crystalline. <1% gray clay. Breaks at 10.75' to 11.05'.	
	10.0						
3		4.8	4.7	97.9		11.8'-13.0' HALITE: Clear, coarsely crystalline. <1% polyhalite. <1/2% gray clay.	
						13.0'-17.2' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite. 1-1/2" anhydrite layer at 17'±. Core loss makes contacts ±8".	
	14.8						
4		5.3	3.8	71.7		17.2'-20.1' HALITE: Clear to moderate reddish orange (10R 6/6); medium to coarsely crystalline. <1% dispersed polyhalite. <1/2% gray clay.	
	20.1						
5		4.9	4.9	100		20.1'-25.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline, some medium. <1 to 3% polyhalite. <1% gray intercrystalline clay at 22.4' to 25'.	
						25.0'-28.6' HALITE: Clear, medium to coarsely crystalline. None to <1/2% dispersed polyhalite and gray clay.	
	25.0						

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-02A

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25.0						
6	25	5.0	5.0	100		28.6'-33.6' HALITE: Clear to moderate reddish orange; coarsely crystalline. < 1 to 2% polyhalite. Scattered anhydrite stringers. < 1/2% gray clay locally.	Run 8. Broken zone 37.4'-37.7', ±
	30.0					33.6'-34/3' HALITE: Clear, coarsely crystalline. None to < 1/2% polyhalite.	Run 10. Broken up last 8" of Run 10. Core loss probably here.
7	30	5.0	5.0	100		34.3'-34.6' ANHYDRITE: V. light (N8) to medium light gray (N6) anhydrite. Faintly laminated scattered halite growths. Clay break at 34.6'.	Beyond 35', core is more broken up with evidence of more vibration damage.
						34.6'-41.4' HALITE: Clear, some light to medium light gray (N7 to N6); coarsely crystalline. < 1% gray clay. Core loss Runs 8, 9 make contact at 41.4' approximate.	Contacts at 5.6', 17.2'; 41.4' and 45.9' are approximate due to core loss.
	35.0						
8	35	4.2	1.5	35.7		41.4'-45.9' HALITE: Clear to moderate brown some fine. < 1 to 3" brown clay, intercrystalline and scattered breaks. Contacts approximate, due to core loss.	
	39.2						
9	40	5.0	3.8	76		45.9'-49.2' HALITE: Clear with some light gray (N7) and medium light gray (N6); medium to coarsely crystalline, some fine. < 1% gray clay.	
	44.2					Note: Average core recovery for hole is less than 95% Some contacts not able to be determined accurately. Replacement hole DH-2B drilled. Refer to log for this hole.	
10	45	5.0	4.2	84			
	49.2						
	50						

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-02B

LOCATION N1420 DRIFT - FLOOR

STATION N1424 ± E442 ± COLLAR ELEV. 1306.3 DIRECTION OF DRILLING VERTICAL - DOWN

MINE COORDINATES N11110.9 E7331.29 DEPTH OF BOREHOLE 53.0'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3/22/84 (SWING) DATE COMPLETED 3/23/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/30/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						Watson post mounted drill MW split tube barrel. AW rods. Drilling Time: 5 hours
1		2.1	2.1	100		0.0'-2.7' HALITE: Clear, trace of light gray (N7); coarsely crystalline. <1/2% gray clay and scattered polyhalite blebs. [1, 2]	Core condition fair. Some discing and vibration damage noted.
	2.1						
2		1.5	1.4	93		2.7'-5.7' HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline, some medium. 1/2% gray clay locally. <1% polyhalite. (2-4)	
	3.6						
3		1.7	0.4	24			
	5.3					5.7'-8.3' MB-139: From 5.7' to 6.5' is a mixture of halite and anhydrite. Some "Swallowtail" pattern present. Below 6.5' mostly light gray (N7) to medium light gray (N6) anhydrite. Scattered halite growths. 3/16" halite layer at 8.15'. 3/8" hard gray clay at lower contact.	
4		1.3	1.3	100			
	6.6						
5		1.5	1.5	100			
	8.1						
6		4.7	4.7	100		8.3'-11.7' HALITE: Clear to medium light gray (N6) and moderate reddish orange (10R 6/6); medium to coarsely crystalline <1% gray clay and <1/2% dispersed polyhalite. [2, 9]	
	12.8						
7		5.1	5.1	100		11.7'-16.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1% to 3% polyhalite. Scattered anhydrite. 1/2" anhydrite layer with irregular gray clay parting at 16.35-16.4'. [3, 4, 7]	
	17.9					16.4'-20.3' HALITE: Clear to light gray (N7) and light bluish gray (5B 7/1); trace of moderate reddish orange. Coarsely crystalline, some medium <1% gray clay and <1% polyhalite grades into unit below. [2, 9]	
8		5.0	5.0	100		20.3'-24.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline, some medium. <1 to 3% polyhalitic. <1% gray clay locally. [2-4, 7]	
	22.9					24.0'-27.9' HALITE: Clear to light moderate reddish orange (10R 6/6); medium to coarsely crystalline. <1/2% dispersed polyhalite and light gray clay. Break at 24.05'. [2, 9]	

BORING NO. DH-02B

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-02B

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
9	25	5.0	4.9	98		27.9'-33.9' HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 2% polyhalite blebs and patches. Scattered anhydrite from 31'. Predominantly anhydrite at 33.05 to 33.2' with dark gray along core break in anhydrite. [2, 4]	
27.9							
10	30	5.0	5.0	100		33.9'-34.3' ANHYDRITE: White to medium light gray (N6) microcrystalline. Scattered halite growths. Trace of gray clay at 34.4'.	
						34.3'-41.2' HALITE: Clear with some medium light gray (N6), light bluish gray (5B 7/1) and moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1% gray intercrystalline clay. <1/2% dispersed polyhalite. [2, 9, 11]	
32.9							
11	35	5.0	5.0	100		41.2'-44.75' HALITE: Clear to moderate brown (5YR 4/4) and moderate reddish brown 10R 4/6). Medium to coarsely crystalline. <1 to 2% brown clay, trace of gray. <1/2% dispersed polyhalite. [13, 17]	
37.9							
12	40	5.0	5.0	100		44.75'-47.9 HALITE: Clear, some medium light gray (N6); coarsely crystalline. ≤1% gray clay. <1/2% polyhalite. [2, 11]	
						47.9'-49.6 HALITE: Clear, coarsely crystalline. <1/2% gray clay at 48.9' ±. [1]	
42.9							
13	45	5.0	5.0	100		49.6'-53.0' HALITE: Clear to light moderate reddish orange (10R 6/6); coarse, some medium crystalline. ≤1% polyhalite. <1/2% gray clay to 52.4', then increases to 1% clay. [2, 9 from 52.4'-53.0']	
47.9							
14	50	5.1	5.0	98			
53.0							

BORING NO. DH-02B

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-03

LOCATION N1100 DRIFT - FLOOR

STATION N 1112 ± E 444 ± COLLAR ELEV. 1318.14 DIRECTION OF DRILLING UP-VERTICAL

MINE COORDINATES N 10,799.2 E 7335.4 DEPTH OF BOREHOLE 48.8 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL CP-65

DATE STARTED 2/6/84 (DAY) DATE COMPLETED 2/7/84 (DAY 11AM) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/5/84 1 OF 2

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0		0						
1.3	1		1.3	1.3	100		0.0'-4.5' HALITE: Clear, coarsely crystalline, some medium from 3.9 to 4.5'. < 1% polyhalite blebs.	CP-65 drill, EW rods. No gas or brine. Run 1. 6" diameter core from 0-0 to 1.3'.
2.7	2		1.4	1.0	71	X		
3.9	3		1.2	1.1	92	X	4.5'-8.2' HALITE: Clear to light gray medium to coarsely crystalline. ≤ 1% gray intercrystalline clay. < 1/2% polyhalite.	
6.6	4	5	2.7	2.1	78	X	8.2'-8.4' ANHYDRITE b: white to light gray (N7) microcrystalline anhydrite with scattered halite growths. Trace of gray clay at 8.2'. < 1/2" halite layer, then trace of gray clay at 8.4'.	Because of poor core recovery, contacts at 4.8'; 22.9'; 26.0'; 30.75'; and 44.9' are approximate only.
10.7	5	10	4.1	4.1	100	X	8.4'-12.0' HALITE: Clear, coarsely crystalline. Scattered white anhydrite/magnesite? Stringers.	
15.8	6	15	5.1	4.9	96	X	12.0'-13.6' HALITE: Clear, some light moderate reddish orange, fine to medium, some coarsely crystalline. < 1% dispersed polyhalite and <1/2% gray intercrystalline clay.	Run 6. Core broken up below anhydrite zone.
						X X X X	13.6'-14.3' ANHYDRITE a: White to light gray (N7) microcrystalline anhydrite. Scattered halite growths, especially common 13.95'-14.3'. Thin halite layer at 13.85'-13.9'. Trace of gray clay at 13.6'. Core grinding evident.	
21.0	7	20	5.2	4.9	94	X X	14.3'-18.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 3% polyhalite.	Run 8. Broken core zones.
	8	25	5.0	3.1	62	X	18.4'-22.9' HALITE: Clear with local zones of medium brown (5YR 3/4) medium to coarsely crystalline. 1% predominantly brown clay. Local zones of ≤ 2% clay at 19.8'-20.7'±; 21.0'-21.4'±. < 1/2% polyhalite. Brown clay break at 22.9'±. No anhydrite.	

BORING NO. DH-03

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-03

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
8	25	5.0	3.1	62		22.9'-26.0' HALITE: Clear, coarsely crystalline. Scattered white anhydrite/magnesite stringers.	Run 10. Broken up core last 1/2 of run.
26.0							
9		1.5	1.3	87			Run 12. Borrowed SML stabilizer for EW rods. Tried it on Run 12.. Core much better.
27.5							
10		2.5	1.0	40		26.0'-30.75' HALITE: Clear to medium brown (5YR 3/4), medium to coarsely crystalline. < 1/2% dispersed polyhalite <1 to 2% brown clay. Some core grinding noted.	Run 13. Discs of clear halite, some broke up.
30.0	30						
11		3.0	1.5	50		30.75'-34.0' ARGILLACEOUS HALITE: Clear to medium brown (5YR 3/4), medium to coarsely crystalline. < 1 to 3% brown clay. Break at 34'.	Run 14. Moved stabilizer 15' from barrel. Core broken up in clear halite and lower 6" of run. Drilling going slow. Much trouble with rod chatter.
33.0							
12		2.1	2.0	95		34.0'-35.05' HALITE: Clear with some grayish brown, medium to coarsely crystalline. <1% brown clay, some gray.	Run 15. Core broken. Rods measured 48.8'. May have lost core in bottom of hole.
35.1	35						
13		4.0	4.0	100		35.05'-35.7' ANHYDRITE: Light gray to medium gray (N5) anhydrite with scattered halite growths. Increase of halite from 35.5'-35.7' ≤ 1/16" brown clay at 35.05'. Some core grinding evident.	
39.1							
14	40	4.4	4.4	100		35.7'-39.9' HALITE: Clear, coarsely crystalline, none to ≤ 1% moderate reddish orange polyhalite blebs and patches. Scattered white stringers.	
						39.9'-41.0' HALITE: Clear to moderate reddish brown (10R 4/6) coarsely crystalline ≤ 1% brown clay and polyhalite.	
43.5							
15	45	5.3	4.5	85		41.0'-41.6' ARGILLACEOUS HALITE: Clear to medium brown (5YR 3/4) coarsely crystalline <1 to 4% brown clay. Break at 41.5' ±.	
						41.6'-44.9' HALITE: Clear to moderate reddish brown (10R 4/6) coarsely crystalline. None to 2% polyhalite and < 1/2% clay.	
48.8	50					44.9'-48.8' ARGILLACEOUS HALITE: Clear to medium brown (5YR 3/4), medium to coarsely crystalline. <1 to 4% brown intercrystalline clay. Breaks at 47.1'; 47.6' ±. Predominantly fine to medium crystalline at 47.8'-48.8'.	Measurements on Run 15 made from top of run.
						NOTE: Because of poor recovery, replacement hole DH-03A drilled later. Refer to log for DH-03A.	

BORING NO. DH-03

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER ____ - ____ HOLE TYPE/SIZE NX CORE BORING NO. DH-03A

LOCATION N1100 DRIFT - ROOF

STATION N1112± E450.5± COLLAR ELEV. 1317.4 DIRECTION OF DRILLING VERTICAL-UP

MINE COORDINATES N10,779.20 E7341.92 DEPTH OF BOREHOLE 49.9 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3-10-84 (SWING) DATE COMPLETED 3-12-84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3-12-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		2.1	2.1	100	X	0.0'-4.9' HALITE: Clear, coarsely crystalline, some medium. < 1% polyhalite. [2]	Watson drill post mounted. AW rods. Used 2' double tube barrel to start hole. NW split tube core barrel from Run 2.
	2.1						
2		3.5	3.5	100	X	4.9'-7.3' HALITE: Clear to light gray (N7) and light bluish gray (5B 7/1); medium to coarsely crystalline < 1% gray clay. < 1% polyhalite at 6.6'-7.3'. [9, 11]	Drill time: 6 hours.
	5						
	5.6				—		
3		4.4	4.4	100	— X	7.3'-7.55' ANHYDRITE b - White to light gray (N7) anhydrite with growths of halite trace of gray clay at 7.3'. Upper contact irregular tightly welded.	Run 3. Broken up 7.6'-10'. Run 4. Broken core.
						7.55'-12.8' HALITE: Clear, coarsely crystalline. ≤ 1% polyhalite at 11.8'-12.8'. [1, 2]	
	10.0						
	10						
4		0.9	0.9	100		12.8'-13.7' HALITE: Clear to light gray (N7), some moderate reddish orange (10R 6/6) and moderate brown (5YR 4/4). Medium crystalline, some coarse. < 1% polyhalite and gray clay. [9]	Used piece of foam rubber in barrel to keep core from falling down in barrel. Drill has jerky motion.
	10.9						
5		4.6	4.6	100	X —	13.7'-14.3' ANHYDRITE a: White to light gray (N7) anhydrite. Faintly laminated. Couple of very thin anhydrite layers at 13.9'-14'. Scattered halite growths increasing from 14.0'-14.3'. Trace of gray clay at 13.7'.	Core broken up. Vibration damage evident. Discing and broken up zones.
	15				X		
	15.5				X	14.3'-18.65' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6). Coarsely crystalline. < 1 to 3% polyhalite. Scattered white anhydrite stringers. [3, 4, 7]	Jerky drill motion is cause of core damage. No gas; dry hole.
6		5.0	5.0	100	X		
	20				X		Run 5. Broken zone 14.3'-15'.
	20.5				—	18.65'-23.4' HALITE: Clear some light brownish gray (5YR 6/1); moderate reddish orange (10R 6/6) and moderate brown (5YR 4/4) fine to coarsely crystalline. < 1% brown clay, some gray. < 1/2% polyhalite. Brown clay at 23.35' with anhydrite layer above it. [13, 17]	
7		4.4	4.4	100	— X		
	25					23.4'-27.7' HALITE: Clear, coarsely crystalline. < 1% brown clay from 27.0'. [1]	Run 8. Broken up measured core in run rods.
	24.9						

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-03A

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
8	25	2.7	2.7	100		27.7'-28.9' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline. < 1 to 3% brown clay. Scattered breaks. Parting at 28.85'. [12]	Run 9. Core broken up recovery difficult to measure.
27.6							
9	30	4.0	4.0	100		28.9'-35.05' HALITE: Clear to moderate brown (5YR 4/4); coarsely crystalline. ≤ 1% brown clay, both intra and intercrystalline. Locally argillaceous. Scattered breaks. Clear halite at 34.7' to 35.05'. [1, 10]	Run 10. Broken zones of core.
31.6							
10		3.5	3.5	100		35.05'-35.95' ANHYDRITE: White to light gray (N7), partially laminated. Scattered growths of halite 35.1' to 35.6' ±. Then becomes a mixture of anhydrite and polyhalitic halite grading upwards to less amount of anhydrite. 1/2" ± brown clay at 35.05'.	Run 11. Broken core last 3' of run. Run 12. Broken up last 2' of run.
35.1	35					35.95'-40.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite scattered white anhydrite to 37.3'. [2-4, 7]	
11		4.9	4.9	100		40.0'-43.1' HALITE: Clear to moderate brown (5YR 4/4), some moderate reddish orange. Medium to coarsely crystalline, some fine ≤ 1% brown clay and < 1/2% dispersed polyhalite. [17]	Run 13. Some broken core.
40.0	40						
12		4.9	4.9	100		43.1'-43.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10P 6/6) coarsely crystalline. < 1 to 3% polyhalite. [3, 4, 7]	
						43.6'-46.1' HALITE: Clear, some moderate brown (5YR 4/4). Coarsely crystalline. ≤ 1% brown clay blebs and patches. [8]	
44.9	45						
13		5.0	5.0	100		46.1'-48.9' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4) to moderate red (5R 4/6) and light moderate reddish orange (10R 6/6). Fine to coarsely crystalline. < 1 to 3% brown clay. Clear halite at 47.4'-47.7' ± 1" brown clay seam at 48.7'. Halite crystals within. [10, 12]	
49.9	50					48.9'-49.9' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6). Coarsely crystalline. < 1 to 3% polyhalite. [3, 4]	
	55						

BORING NO. DH-03A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-04

LOCATION N1100 DRIFT - FLOOR

STATION N1112.5 ± E444 ± COLLAR ELEV. 1309.56 DIRECTION OF DRILLING VERTICAL - DOWN

MINE COORDINATES N10,799.2 E7335.4 DEPTH OF BOREHOLE 45.8'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL CP-65

DATE STARTED 2/2/84 (DAY) DATE COMPLETED 2/4/84 (DAY) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/5/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		1.0	1.0	100		0.0'-4.5' HALITE: Clear to light gray (N7) coarsely crystalline. ≤1% gray intercrystalline clay. <1/2% polyhalite.	NW drill rods. 2' lengths. No gas. Dry hole. Good core to 33.8' Then core recovery poor. Quality not good. Grinding, broken up core. Core barrel problems and rod chatter during drilling.
2		1.8	1.8	100			
3		2.0	2.0	100		4.5'-8.1' HALITE: Clear, medium to coarsely crystalline. <1/2% polyhalite blebs and <1/2% gray clay locally.	
4	5	2.0	2.0	100		8.1'-9.25' POLYHALITIC HALITE: Clear to mod. reddish orange (10R 6/6) coarsely blebs and patches.	
5		2.0	2.0	100		9.25'-11.65' MB-139: Mixture of moderate reddish orange polyhalitic halite and anhydrite to 9.85'. Then predominantly white to light gray, microcrystalline anhydrite. Scattered halite growths. Some laminae in anhydrite. Up to 3/4" hard, dry gray clay at lower contact.	Run 1. 6" single tube 0.0' to 1.0' because 8-1/2' back of drift too low to start with NX barrel.
6	10	5.0	5.0	100		11.65'-13.6' HALITE: Clear to moderate reddish orange (10R 6/6) and some moderate brown (5YR 3/4), fine to coarsely crystalline. ≤1% brown clay and dispersed polyhalite.	
7	15	5.0	5.0	100		13.6'-15.35' HALITE: Clear to light gray (N7), some moderate reddish orange, fine to coarsely crystalline. ≤1% gray intercrystalline clay. Breaks at 14.1; 15.35'. <½% polyhalite.	
8	20	5.0	5.0	100		15.35'-19.9' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. 1 to 3% polyhalitic. Scattered anhydrite in core mixture of anhydrite and halite at 19.75'-19.9'. Trace of gray clay at 19.9'.	
						19.9'-21.1' HALITE: Clear to moderate reddish orange (10R 6/6), fine to medium crystalline. <1/2% dispersed polyhalite.	
9	25	5.0	5.0	100			Run 9. Broken zones within polyhalitic halite. Core barrel stuck at 27' ± from 11:30 am to 2:10 pm. broken up 23.8'-26.3'.

0.0
1.0
2.8
4.8
6.8
8.8
13.8
18.8
23.8

BORING NO. DH-04

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-04

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
9		5.0	5.0	100		21.1'-27.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. Clay break at 21.55'. < 1/2% gray intercrystalline clay from 25'-27.6'.	
28.8							
10	30	5.0	4.9	98		27.6'-30.2' HALITE: Clear to light gray (N7) to moderate reddish orange (10R 6/6), fine to coarsely crystalline. ≤ 1% gray clay. Breaks at 28.2', 28.45'. < ½% polyhalite.	Run 10. Core grinding.
						30.2'-35.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 3% polyhalite.	Run 11. Core grinding throughout run. 0.8' of core left in hole at end of run.
33.8							Runs 12, 13, 14. Broken up core.
11	35	4.2	2.5	60		35.0'-35.6' ANHYDRITE: Moderate reddish orange to medium gray from 35'-35.3 ±. Then very light to medium gray. No clay at lower contact but core grinding evident.	Contacts from 35' are approximate due to core loss.
38.0						35.6'-43' HALITE: Clear mottled with some light gray (N7) and moderate reddish orange, medium to coarsely crystalline. < 1/2% gray clay and polyhalite.	Note: Hole beyond 33' not able to be logged accurately because of poor core recovery and quality. Replacement hole DH-04B drilled at later date. Refer to log for hole DH-04B.
12	40	5.0	1.4	28		43.0'- 45.8': Not able to classify due to poor quality and poor recovery of core.	
43.0							
13		1.8	0.4	22	NO LOG		
44.8	45						
14		1.0	0.3	30			
45.8							
	50						

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-4A

LOCATION N1100 DRIFT; FLOOR

STATION N1113 ± E446 ± COLLAR ELEV. 1309.6± DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES DEPTH OF BOREHOLE 11.2 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL BOYLES JVA

DATE STARTED 3-8-84 (SWING) DATE COMPLETED 3-9-84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3-9-84 1 OF 1

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0	0.0						
1	0.6	1.7	1.5	88	X —	0.0' - 7.0' HALITE: Clear to moderate reddish orange; coarsely crystalline. ≤ 1% polyhalite. < 1% gray clay.	Used Boyles JVA screw feed drill. Used roller bit to 0.6', then NX double tube core barrel.
2	2.3	1.8	1.5	83	X	7.0' - 8.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) to light brown (5YR 5/6). Coarsely crystalline. < 1 to 3% polyhalite.	No gas. Dry hole.
3	4.1	2.3	2.3	100	— X	8.6' - 11.2' MB-139: From 8.6 to 9.6', mixture of halite and anhydrite. "Swallowtail" patterns. Then predominantly medium gray to very light gray (N8) anhydrite with scattered halite growths.	Driller stopped hole at 11.2' because of core loss. Drilled replacement hole DH-4B using Watson drill. Refer to log for DH-4B.
4	6.4	4.8	3.5	73	X X X X X X		
	11.2						

BORING NO. DH-4A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-04B

LOCATION N1100 DRIFT; FLOOR

STATION N1112 ± E450.5 ± COLLAR ELEV. 1309.7 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N10,799.70 E7341.85 DEPTH OF BOREHOLE 51.4 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3-9-84 (SWING) DATE COMPLETED 3-10-84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3-24-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		2.0	2.0	100		0.0'-7.9' HALITE: Clear, some moderate reddish orange (10R 6/6) and medium bluish gray (5B 5/1) coarsely crystalline. < 1% gray clay and polyhalite blebs. [2, some 9]	Watson drill. Post mounted NW split tube core barrel. AW rods.
	2.0						
2		3.2	3.2	100		7.9'-8.55' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1 to 2% polyhalite. [3, 7]	Drilling time: 3-1/2 hours. No brine or gas. Core coming out good.
	5.2						
3		2.7	1.0	37		8.55'-11.6' MB-139: From 8.55' to 9.85'± is a mixture of halite and anhydrite. From 9.85' is predominantly white to light gray (N7) anhydrite with growths of halite. Anhydrite is irregularly laminated. Upper contact is tightly closed and dips 25°±. Several tightly closed hairline fractures at 10.9' to 11.0'±. Gray clay at 11.6'.	NW core barrel has stepped diamond bit. Barrel made by Christensen. No gas; dry hole.
	7.9						
4		3.1	3.1	100		11.6'-15.45' HALITE: Clear to light gray (N7), moderate brown (5YR 4/4) and moderate reddish orange (10R 6/6); medium to coarsely crystalline, some fine. ≤ 1% gray clay, trace of brown. ≤1% polyhalite. Gray clay breaks at 12.5', 14.35', 14.6". [9]	
	11.0						
5	11.7	0.7	0.7	100			
6		4.3	4.3	100		15.45'-19.85' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) and brown (10R 4/6); coarsely crystalline. < 1 to 3% polyhalite. < 1/2% gray intercrystalline clay to 15.9'. Moderate reddish orange/brown anhydrite and some halite at 19.75' to 19.85'. Gray clay parting at 19.85'. [7]	
	16.0						
7		5.0	5.0	100		19.85'-21.0' HALITE: Clear to moderate reddish orange (10R 6/6); medium to coarsely crystalline. ≤1% polyhalite and < 1% gray clay. [5, 9]	
	21.0						
8		5.1	5.1	100		21.0'-26.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), moderate reddish brown (10R 4/6); coarsely crystalline, some medium. < 1 to 3% polyhalite. < 1% brown clay at 21.0-21.6'. < 1/2% gray clay locally below 21.6'. [7]	

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-04B

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
8	25	5.1	5.1	100		26.1'-27.8' HALITE: Clear with some light gray (N7) and moderate reddish orange (10R 6/6); coarsely crystalline with some medium. < 1/2% polyhalite. < 1% gray clay. Some of clay is medium plastic, moist. [9]	
26.1							
9		5.1	5.1	100		27.8'-29.3' HALITE: Clear to moderate reddish orange (10R 6/6), brownish gray (5YR 4/1) and moderate brown (5YR 3/4). Medium to coarsely crystalline. < 1 to 2% brown clay, trace gray. Break at 28.95'. < 1% polyhalite. [12]	
	30						
31.2							
10		5.0	5.0	100		29.3'-31.6' HALITE: Clear to moderate reddish orange (10R 6/6); medium to coarsely crystalline. < 1% gray clay and polyhalite. Break at 29.55'. [9, 17]	
	35					31.6'-36.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. Scattered anhydrite stringers. [3, 4, 7]	
36.2							
11		5.0	5.0	100		36.1'-36.8' HALITE: Clear, some moderate reddish orange; medium to coarsely crystalline. < 1/2% polyhalite. Anhydrite stringers from 36.55' to 36.8'. [1]	
	40					36.8'-37.0' ANHYDRITE: Very light (N8) to light gray (N7) anhydrite. Scattered halite growths, especially last 0.5'. Trace gray clay at 37.0'. Core grinding evident here. [8]	
41.2							
12		5.1	5.1	100		37.0'-49.35' HALITE: Clear with light bluish gray (5B 7/1), light gray (N7), moderate brown (5YR 4/4) and moderate reddish orange/brown (10R 6/6-10R 4/6). Medium to coarsely crystalline. ≤ 1% brown and gray clay. < 1% polyhalite. Clear halite at 41.2' to 41.9'. Predominantly brown clay (≤ 1%) from 44.3' to 45.3' and 47.0' to 48.5'. [9, 11, 17]	
	45						
46.3							
13		5.1	5.1	100		49.35'-51.4' HALITE: Clear, coarsely crystalline < 1/2% gray clay locally. [1, 8]	Several pieces in Run 13 are up to 1-1/2' long before taking out of tube.
	50						
51.4							
	55						

BORING NO. DH-04B

WIPP

WASTE ISOLATION PILOT PLANT

GEOLOGIC DRILL LOG

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE 4" CORE BORING NO. DH-05

LOCATION N1420 DRIFT IN ALCOVE AT RM. B INTERSECTION

STATION N1463 E972 COLLAR ELEV. 1329.9 DIRECTION OF DRILLING VERTICAL - UP

MINE COORDINATES N11149.6 E7865.0 DEPTH OF BOREHOLE 51.0'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL LONGYEAR 65

DATE STARTED 3/3/84 (DAY) DATE COMPLETED 3/9/84 (DAY) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/14/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		3.3	3.2	97		0.0'-0.35' HALITE: Clear, some light moderate reddish orange (10R 6/6), medium-coarsely crystalline. < 1/2% dispersed polyhalite.	Hole drilled by SNL. Longyear 65 drill with 4" dia. masonry single thin wall core barrel. Diamond bit.
	3.3					0.35'-1.25' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline < 1 to 2% polyhalite.	Run 2. Core grinding at anhydrite-clay layer.
2		3.35	3.35	100		1.25'-3.05' HALITE: Clear to light gray (N7), medium-coarsely crystalline. ≤ 1% intercrystalline gray clay. < 1/2% dispersed polyhalite. Breaks at 1.35', 4.8'. Very light gray anhydrite stringer at 2.6', 1/2" anhydrite, trace of clay at 5.0'. Some core grinding noted.	Some difficulty removing core from barrel. Possibly due to moisture in air line. This occurred to 23'±. Core trays hit by passing muck truck. Core partly disturbed in Runs 3, 4, 5.
	5						
	6.65						
3		2.70	2.4	89			
	9.35					5.05' -9.3' HALITE: Clear, coarsely crystalline. Scattered white magnesite? stringers.	
	10						
4		3.65	3.65	100		9.3'-9.95' HALITE: Clear with some light gray intercrystalline clay (≤ 1%). Medium-coarsely crystalline.	Run 5. Loss at 13'-14', some grinding.
	13.0						
5		4.15	3.95	95		9.95'-11.0' ARGILLACEOUS HALITE: Clear to medium brown (5YR 3/4) to moderate reddish orange (10R 6/6), fine-medium, some coarsely crystalline. < 1 to 3% brown clay. < 1/2% dispersed polyhalite coloration. Gray clay along tightly closed irregular upper contact.	
	15						
	17.15						
6		4.0	4.0	100		11.0'-14.1' HALITE: Clear, coarsely crystalline. No clay to 12.9', From 12.9'-14.1', < 1/2% gray and brown clay.	Core quality improves beyond 10' depth; some grinding on ends of core pieces.
	20						
	21.15						
7		3.15	3.10	98		14.1'-17.15' ARGILLACEOUS HALITE: Clear to moderate reddish orange (10R 6/6) medium brown, fine to medium, some coarsely crystalline. < 1 to 4% brown clay, trace of gray. Irregular break at 16.35'.	
	24.3						
	25						

BORING NO. DH-05

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-05

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
8	26.6	2.3	2.3	100		17.15'-17.75' ANHYDRITE: Very light (N8) to light gray (N7) anhydrite to 17.4'. Then mixed with growths of halite. Tight welded irregular upper contact. Brown clay along lower contact. Core grinding evident here.	Run 8. Some grinding on core ends.
9	30 / 30.5	3.9	3.6	92		17.75'-22.7' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline, < 1% dispersed polyhalite and scattered blebs. White very light gray anhydrite stringer up to 1/2" thick at 19.25'.	
10	33.7	3.2	3.2	100		22.7'-26.6' HALITE: Clear, some moderate reddish brown (10R 4/6), coarsely crystalline with zones of fine-medium. < 1% polyhalite. ≤ 1% brown clay. Breaks at 23.15', 24.3', 26.1. Some core grinding evident.	Broken core 24' -25'.
11	35 / 36.9	3.2	3.2	100		26.6'-28.8' ARGILLACEOUS HALITE: Clear to medium brown (5YR 3/4), coarsely crystalline, < 1 to 3% brown clay. Core broken 26.6'-27.9'.	Core barrel plugged off with clay at 26.6'. Driller stopped hole here on 3/8/84 continued with 4-¼" ϕ roller bit to 26.6'. Then continued coring with 4" barrel.
12	40 / 40.6	3.7	3.7	100		28.8'-30.1' HALITE: Clear, coarsely crystalline. < 1/2% polyhalite.	
13	44.0	3.4	3.4	100		30.1'-32.5' POLYHALITIC HALITE: Clear mottled with moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 3% polyhalite. < 1/2% gray clay.	
14	45 / 47.75	3.75	3.75	100		32.5'-35.4' HALITE: Clear mottled with moderate brown (5YR 3/4) to dark reddish brown, coarsely crystalline. < 1 to 2% patches of brown clay. < 1/2% polyhalite. Parting at 35.4' ± dipping 30° ±.	
15	50 / 51.0	3.25	3.25	100		35.4'-36.8' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 2%, locally of dispersed polyhalite.	
						38.6'-40.9' HALITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline ≤ 1% polyhalite. Moderate reddish brown, polyhalitic at 38.6'-39.0'. Anhydrite stringers at 38.7'-38.8'.	
						40.9'-51.0' HALITE: Clear to moderate reddish brown (10R 4/6) to medium brown (5YR 3/4) medium-coarsely crystalline. < 1 to 3% brown clay, intergranular and in patches. < 1/2% polyhalite. Breaks at 41.85', 44.0'-44.2'.	

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE 4 INCH CORE BORING NO. DH-06

LOCATION I-3 ALCOVE - FLOOR

STATION N 1463 ± E 972 COLLAR ELEV. 1317.9 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N 11,149.7 E 7864.9 DEPTH OF BOREHOLE 49.75 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL LONGYEAR 65

DATE STARTED 3-4-84 (DAY) DATE COMPLETED 3-7-84 (DAY) SHEET

LOGGED BY: J. F. GALLEGANI DATE: 3-10-84 1 OF 2

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0		0						
	1		2.1	2.1	100		0.0'-4.2' HALITE: Clear, coarsely crystalline. < 1/2% polyhalite from 3.4' ±.	Longyear 65 drill EW rods; 4" diameter, 2' long core barrel with core catcher used.
2.1								
	2		2.05	2.05	100	X	4.2'-5.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 2% polyhalite.	Some grinding noted on ends of core in most runs. Lengths of core pieces generally 1" to 11". Average 3" ±.
4.15								
	3	5	2.1	2.1	100	X X X	5.6'-7.8' HALITE: Clear with trace of light gray (N7). Coarsely crystalline. < 1/2% gray intercrystalline clay. < 1/2% polyhalite.	
6.25								
	4		1.75	1.75	100	—		Run 4. Grinding on some core ends.
8.0						—	7.8'-9.0' HALITE: Clear to light gray (N7); medium to coarsely crystalline, trace fine. ≤ 1% gray intercrystalline clay. ≤ 1/4" gray clay seam at 7.8' and 1/8" clay seam at 8.45' ±.	
	5		1.85	1.85	100	—		Run 5. Some grinding at 9.3'.
9.85		10				— X		
	6		2.1	2.1	100	X X X	9.0'-10.8' HALITE: Clear, coarsely crystalline locally some medium. < 1/2% gray clay and polyhalite.	
11.95								
	7		1.65	1.65	100	X X X	10.8'-13.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. No clay to 12.35'; then < 1% gray clay.	
13.6								
	8		1.6	1.6	100	— X		
15.2		15						
	9		1.65	1.65	100	—	13.6'-18.65' HALITE: Clear to light gray (N7); coarsely crystalline. ≤ 1% gray intercrystalline clay. None to < 1% polyhalite.	
16.85								
	10		1.8	1.8	100	X		Run 10, 11, 12. Some grinding on core ends.
18.65								
	11		1.85	1.85	100	X — X	18.65'-20.6' HALITE: Clear, some moderate reddish orange (10R 6/6); coarsely crystalline. ≤ 1% polyhalite. < 1/2% gray clay.	No gas; dry hole.
20.5		20						
	12		2.5	2.5	100	X X X X	20.6'-22.3' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline ≤ 1% to 3% polyhalite. < 1/2% gray clay.	
23.0								
	13		2.0	1.9	95			
25.0		25						

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-06

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
14	25	1.2	1.2	100		22.3'-26.1' MB-139: "Swallowtail" pattern of halite and anhydrite from 22.3' to 24.2'. Then predominantly very light (N8) to light gray (N7) and some moderate reddish orange (10R 6/6) anhydrite mixed with growths of halite. No clay at lower contact but some core grinding on ends of core throughout MB-139.	
15	26.2	1.3	1.3	100			
16	27.5	1.6	1.6	100		26.1'-29.4' HALITE: Clear to light moderate reddish orange (10R 6/6); medium to coarsely crystalline. < 1% dispersed polyhalite and < 1/2% gray clay.	
17	29.1	1.9	1.9	100			
18	30	2.0	2.0	100		29.4'-33.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. Anhydrite mixed with halite at 33.2'-33.5'. Gray clay at 33.5'.	
19	31.0	2.0	2.0	100			
20	33.0	1.7	1.7	100		33.5'-35.6' HALITE: Clear to light gray (N7) and moderate reddish orange (10R 6/6); medium to coarsely crystalline. ≤ 1% gray clay and < 1/2% dispersed polyhalite.	
21	35	1.8	1.8	100			
22	35.0	1.5	1.5	100		35.6'-39.1' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6); coarsely crystalline. < 1 to 4% polyhalite.	
23	36.7	2.0	2.0	100			
24	38.5	3.0	0	0		39.1'-46.2' HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6) and grayish brown (5YR 3/2). Medium to coarsely crystalline. ≤ 1% brown clay, some gray. < 1% polyhalite. Core loss 42'-45'.	
25	40	2.0	2.0	100			
26	40.0	2.75	2.75	100		46.2'-49.75' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. Scattered white stringers of anhydrite/magnesite.	
	42.0						
	45						
	45.0						
	47.0						
	49.75						
	50						
	55						

BORING NO. DH-06

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-07

LOCATION N1100 DRIFT AT RM. B INTERSECTION; ROOF

STATION N1112 E976.5 COLLAR ELEV. 1326.7 DIRECTION OF DRILLING VERTICAL - UP

MINE COORDINATES N10,799.3 E7870.8 DEPTH OF BOREHOLE 49.8'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 2/21/84 (SWING) DATE COMPLETED 2/22/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/4/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0	0.9	0.9	100	X	0.0'-4.6' HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline ≤ 1% polyhalite blebs and patches. Up to 2% polyhalite from 3.1'-4.6'. [1,3]	Watson drill.AW rods. NX double tube core barrel. Drill Time: 9 hours ±.
2	0.9	2.0	2.0	100	X		
3	2.9	2.9	2.9	100	X	4.6'-9.0' HALITE: Clear to light gray (N7), some moderate reddish orange (10R 6/6). Medium to coarsely crystalline, some fine. ≤ 1% gray clay. < 1/2% polyhalite. 1/2" gray clay at 8.85'. Anhydrite and halite 8.9'-9.0'. [9, 11]	Run 2. Some discing. No gas. Dry hole.
4	5.8	5.0	5.0	100	X	9.0'-13.2' HALITE: Clear, coarsely crystalline, none to < ½% intercrystalline gray clay. [1]	Run 5. Broken up last 0.4'.
5	10.8	4.3	4.3	100		13.2'-14.7' HALITE: Clear to moderate brown (5YR 3/4; 4/4). Medium-coarsely crystalline, some fine. < 1 to 3% brown clay. Locally zones of argillaceous halite. [12, 17] 14.7'-16.5' HALITE: Clear with some moderate brown (5YR 4/4); coarsely crystalline. None to ≤ 1% brown clay. [1, 8]	
6	15.1	4.5	4.5	100		16.5'-20.85' ARGILLACEOUS HALITE: Clear to moderate brown, medium to coarsely crystalline. < 1 to 4% brown intercrystalline clay, trace of gray. Breaks at 20.0', 20.5'. [10, 15]	Run 7. Broken zones in clear halite.
7	19.6	4.4	4.4	100	X	20.85'-21.55' ANHYDRITE: White to light gray (N8), microcrystalline anhydrite with scattered halite growths. Up to 3/4" brown clay at 20.85'. 21.55'-24.9' HALITE: Clear, coarsely crystalline, < 1% polyhalite. [1] 24.9'-26.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1% intercrystalline clay. < 1 to 3% polyhalite. [4,5]	Run 8. Broken zones last 1.5'. Runs 9-11. Discing of core throughout.Discs 3/8-1" size.
	24.0				X		

BORING NO. DH-07

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-07

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
8	28.6	4.6	4.6	100		26.4'-27.5' HALITE: Clear to moderate brown (5YR 4/4); medium-coarsely crystalline. < 1 to 3% brown clay. Break at 27.2' ±. [17]	
9	32.6	4.0	4.0	100		27.5'-29.35' HALITE: Clear mottled with moderate reddish orange (10R 6/6) polyhalite blebs, coarsely crystalline. ≤ 1% polyhalite. [1-3]	Run 12. Broken and discing entire run. Core quality to 27' is fair. Able to determine depth to to clay/anhydrite at 8.85' accurately. Below 27', core is in discs 3/8 to 1" size. Scattered broken zones. Difficult to measure recovery accurately.
10	37.1	4.5	4.5	100		29.35'-30.85 HALITE: Clear mottled with moderate brown (5YR 4/4); coarsely crystalline. ≤ 1% brown intercrystalline, intracrystalline blebs, pockets of brown clay. [8, 10]	
11	41.1	4.0	4.0	100		30.85'-32.3' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4) coarsely crystalline. Brown clay < 1 to 5%, locally. 3/4" brown clay seam at 32.25'. [10, 15]	Run 13. Longest piece is 2".
12	45.4	4.3	4.3	100		32.3'-45.0' HALITE: Clear mottled with moderate reddish orange/brown (10R 6/6; 4/6) and moderate brown (5YR 3/4; 4/4). Coarsely crystalline. Core varies from zones containing mostly blebs and patches of modern reddish orange polyhalite, < 1 to 3%, to zones containing blebs and patches of brown clay < 1 to 2%. Reddish orange color, in part, probably due to iron staining. [3, 4, 10]	
13	49.8	4.4	4.4	100		45.0'-47.8' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4); medium-coarsely crystalline. < 1 to 3% intercrystalline brown clay. Breaks at 45.6'; 46.4'. [15]	
						47.8'-49.8' HALITE: Clear with some moderate brown (10R 4/6); medium to coarsely crystalline. ≤ 1% brown clay, trace of gray. [17]	

30 35 40 45 50 55

BORING NO. DH-07

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ HOLE TYPE/SIZE NX CORE BORING NO. DH-08

LOCATION N1100 DRIFT AT RM. B INTERSECTION - FLOOR

STATION N1112 ± E976.5 ± COLLAR ELEV. 1318.80 DIRECTION OF DRILLING DOWN-VERTICAL

MINE COORDINATES N10,799.4 E 7870.9 DEPTH OF BOREHOLE 38.3 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 2/22/84 (SWING) DATE COMPLETED 2/23/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/6/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		2.2	2.2	100		0.0'-2.6' HALITE: Clear to light gray (N7) coarsely crystalline. < 1% intergranular gray clay. < 1/2% polyhalite blebs locally.	Watson post mounted, air drill; AW rods. NX double tube core barrel.
	2.2						
2		2.4	2.4	100		2.6'-5.85' HALITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline. < 1% polyhalite blebs and dispersed polyhalite.	Drilling time: 8 hours and 15 minutes. Mining while drilling.
	4.6						
3		1.1	1.0	90.9			Core condition is pretty good. Only a few broken up zones.
	5.7						
4		3.3	2.0	60.6		5.85'-10.1' HALITE: Clear to light gray (N7) medium to coarsely crystalline. ≤ 1% intergranular gray clay. < 1% polyhalite blebs.	Run 4. Loss throughout. Core grinding bottom of run.
	9.0					10.1'-12.8' HALITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline, some fine to medium. < 1% polyhalite except 12.3'-12.5', where core is polyhalitic, up to 3% polyhalite. Contact at 12.8' approximate due to core loss.	
5		1.8	1.7	94.4			
	10.8						
6		5.0	4.5	90		12.8'-19.5' HALITE: Clear to light bluish gray (5B 7/1), light gray (N7) and light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. ≤ 1% gray clay. Break at 14.7'.	Run 6. Broken up about 12.4' in run. Loss possibly here
	15.8					19.5'-23.0' HALITE: Clear mottled with some moderate reddish orange (10R 6/6) < 1% polyhalite. < 1/2% gray clay 23.0' contact measured from bottom of run 8.	
7		4.7	4.7	100		23.0'-26.6' MB-139: Upper 1.5' of MB-139 shows "swallowtail" pattern, a mixture of anhydrite and halite. Below this is light gray to white anhydrite with scattered halite growths. Some laminae within. Hairline, tightly closed low angle fractures. Trace gray clay at 26.6'.	Run 7. Broken top of run and at 18.5'-19.5' ±.
	20.5						
8		4.7	3.8	80.9			Run 8. Some grinding, broken up top of run. Most lost probably here. Some grinding at top and bottom of MB-139 also.
	25.2						

BORING NO. DH-08

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-08

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25.2						
9		5.2	4.1	78.8		26.6'-30.4' HALITE: Clear to moderate reddish orange 10R 6/6, some light gray, medium to coarsely crystalline. < 1% dispersed polyhalite and gray clay.	Run 9. Grinding at top of run.
	30					30.4'-33.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), some light gray, medium to coarsely crystalline. <1 to 3% polyhalite.	
	30.4						
10		3.0	3.0	100		33.4'-35.8' HALITE: Clear to light gray (N7), medium to coarsely crystalline. ≤ 1% gray clay, < 1/2% dispersed polyhalite. Clay break at 34.6' ±.	
	33.4						
11	35	4.9	3.9	79.6		35.8'-38.3' HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline, some medium. ≤ 1% polyhalite. < 1/2% gray clay. Polyhalitic (1 to 3%) from 36.8'-38.3' ±.	Run 11. Loss throughout. Some grinding at top of run.
	38.3					Note: Hole stopped at 38.3' due to core loss. Replacement holes DH-8A and DH-8B drilled in same vacinity. Refer to these drill logs.	Following contacts are approximate due to core loss: 12.8' 23.0' -measured from bottom of run 8. 26.6' -assumed most loss was in MB-139. 35.8'-is ± 0.5'.
	40						
	45						
	50						

BORING NO. DH-08

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-08A

LOCATION N 1100 DRIFT; FLOOR

STATION N1112 ± E 975 ± COLLAR ELEV. 1318.7± DIRECTION OF DRILLING DOWN - VERTICAL

MINE COORDINATES _____ DEPTH OF BOREHOLE 50.7 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 2/24/84 (SWING) DATE COMPLETED 2/29/84 (SWING) SHEET

LOGGED BY: J.E. GALLERANI DATE: 3/6/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0							
1		1.6	1.6	100		0.0'-6.6'± 0.4' HALITE: Clear to light (N7) gray coarsely crystalline. None to < 1% gray clay. < 1/2% polyhalite locally. Clear 3.4'-4.2'. Gray clay break at 6.6'.	Watson post mounted. AW rods. NX double tube core barrel.
1.6							
2		0.5	0.3	60			Drilling Time: 10 hours.
2.1							
3		2.1	2.1	100		6.6'-9.65' HALITE: Clear to light bluish gray (5B 7/1) and light gray (N7), medium-coarsely crystalline. ≤ 1% intergranular gray clay. < 1/2% dispersed polyhalite.	No gas; dry hole.
4.2							
4	5	3.6	2.8	78		9.65'-13.1' HALITE: Clear with some light moderate reddish orange (10R 6/6), coarsely crystalline. < 1% polyhalite. < 1/2% gray clay.	
7.8							
5		2.9	2.9	100		13.1'-15.8' HALITE: Clear to light gray (N7), coarsely crystalline. ≤ 1% gray intergranular clay and < 1% polyhalite blebs.	
10.7	10						
6		4.6	4.6	100		15.8'-20.95' HALITE: Clear to light bluish gray (5B 7/1) and light moderate, reddish orange (10R 6/6) medium-coarsely crystalline; scattered fine. <1/2% intergranular gray clay and < 1/2% dispersed polyhalite. Clay break at 20.8'.	
15.3	15					20.95'-23.15' HALITE: Clear, coarsely crystalline. < 1% polyhalite blebs.	
7		4.9	4.7	96		23.15'-26.4' MB-139: Very light gray (N7) to white anhydrite mixed with halite growths to 25.6'. Then mostly microcrystalline anhydrite partially laminated. Gray clay ≤ 1/8" at 26.4'.	Run 7. Loss probably top of run.
20.2	20						
8		4.9	4.9	100			
25.1	25						

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-08A

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
25.1		25						
	9		5.1	5.1	100		26.4'-29.5' HALITE: Clear to light bluish gray (5B 7/1) and light gray, medium to coarsely crystalline. < 1% dispersed gray clay. < 1/2% dispersed polyhalite. Break at 29.05'.	
							29.5'-33.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. Anhydrite mixed with halite from 33.4'-33.6'. Gray clay break at 33.6'.	Overall core condition is fair. Scattered broken zones and discing shows vibration stress.
30.2		30						
	10		1.7	1.0	59		33.6'-35.6' HALITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline. < 1/2% gray clay. < 1% polyhalite.	Contact at 33.6' is ±0.35' due to core loss.
31.9								
	11		3.7	3.0	81		35.6'-40.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite.	
35.6		35						
	12		3.3	3.0	91		40.1'-44.5' HALITE: Clear with some moderate reddish orange and light gray (N7), medium to coarsely crystalline. ≤ 1% polyhalite and gray clay.	
38.9								
	13	40	2.1	1.1	52		44.5'-48.75' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite.	Run 13. Broken up at top.
41.0								
	14		4.7	4.7	100		48.75'-50.0' HALITE: Clear coarsely crystalline. < 1/2% polyhalite.	
							50.0'-50.3' ANHYDRITE: Very light (N8) to medium light gray (N6) to white microcrystalline anhydrite with scattered halite growths. Up to 1/2" halite layer at 50.1'. No clay at lower contact but possibly ground up.	
45.7		45						
	15		5.0	5.0	100		50.3'-50.7' HALITE: Clear to light gray (N7), medium to coarsely crystalline. < 1% gray intercrystalline clay.	Contact at 40.1' is ±0.5' due to core loss.
							Note: Core recovery is below 95%. Replacement hole DH-08B drilled later. Refer to log for DH-08B.	Run 15. Discing in run 15.
50.7		50						

BORING NO. DH-08A

WIPP

WASTE ISOLATION PILOT PLANT

GEOLOGIC DRILL LOG

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-08B

LOCATION N1100 DRIFT - FLOOR

STATION N1112± E979.5± COLLAR ELEV. 1318.00 DIRECTION OF DRILLING VERTICAL-DOWN

MINE COORDINATES N 10,799.47 E 7866.66 DEPTH OF BOREHOLE 51.4 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3-16-84 (SWING) DATE COMPLETED 3-17-84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3-23-84 1 OF 2

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0		0.0						
0.9	0		0.9	0.0	0		0.0'-6.4' HALITE: Clear; medium to coarsely crystalline. <1/2% polyhalite blebs and <1/2% gray clay locally. (1,2)	Watson drill: post mounted. AW rods. NW split tube barrel.
1.3	1		0.4	0.3	75			
	2		2.7	2.7	100		6.4'-11.4' HALITE: Clear to medium bluish gray (5B 5/1) and medium gray (N5). Coarsely crystalline, some medium ≤1% gray clay. 1/4" ± gray clay seam at 8.9'. (11)	Drilling time: 6 hours ±.
4.0								Core is fair. Some discing of coarse crystalline polyhalitic halite and chipping of outer surface of core due to vibration but pieces tend to fit together fairly well in barrel.
4.9	3		0.9	0.6	67			
	4	5	1.5	1.5	100		11.4'-13.15' HALITE: Clear, some moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 2% polyhalite blebs and dispersed. (2,3)	
6.4	5		2.8	2.8	100		13.15'-21.75' HALITE: Clear to medium bluish gray (5B 5/1) and some moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1/2% dispersed polyhalite. ≤1% gray intercrystalline clay. (9)	Run 0. Salt loose and broke up, cased to 0.9'. No core.
9.2								Runs 2 & 3. Some discing of core.
	6	10	5.0	5.0	100		21.75'-23.75' HALITE: Clear, coarsely crystalline. None increasing to <1% polyhalite with depth. (1,2,)	
14.2								
	7	15	5.0	5.0	100		23.75'-26.9' MB-139: "Swallowtail" pattern of halite and anhydrite to 24.55'. Then predominantly very light (N8) to light gray (N7) to white, partially laminated, anhydrite with scattered halite growths. Several tightly closed hairline fractures at 26.7' to 26.9'. <1/8" gray clay along lower contact.	Run 7. Some chipping of outer surface of core due to vibration last 3' of the run.
19.2								
	8	20	5.1	5.1	100			
24.3		25						

BORING NO. DH-08B

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-08B

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
9	25	2.6	2.6	100		26.9'-29.6' HALITE: Clear to light gray (N7); light bluish gray (5B 7/1), and moderate reddish orange (10R 6/6). Medium to coarsely crystalline ≤1% gray clay and <1/2% dispersed. (9)	
26.9							
10	30	4.5	4.5	100		29.6'-33.8' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline with some fine to 30.15'. <1 to 3% polyhalite. Anhydrite with halite from 33.75 to 33.8'. Clay break at 33.8'. (2-5,7)	Runs 10 thru 12. Discing in polyhalitic halite.
31.4							
11	35	5.0	5.0	100		33.8'-35.8' HALITE: Clear to light gray (N7) and light bluish gray (5B 7/1). Medium to coarsely crystalline. <1% gray clay. <1/2% polyhalite. (9)	
						35.8'-39.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) and some moderate reddish brown (10R 4/6). Coarsely crystalline. <1 to 3% polyhalite. (3,4,7)	
36.4							
12	40	5.0	5.0	100		39.0'-45.2' HALITE: Clear to moderate reddish orange (10R 6/6); light gray (N7) and light bluish gray (5B 7/1). Medium to coarsely crystalline. ≤1% gray clay and <1 to 2% polyhalite. (2,9)	
41.4						45.2'-50.2' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite 1" anhydrite/halite layer at 49.7'. (3,4,7)	
13	45	5.0	5.0	100		50.2'-50.5' HALITE: Clear, coarsely crystalline, some medium. Scattered white anhydrite stringers at 50.2'-50.25' ±. (1)	
46.4						50.5'-50.8' ANHYDRITE: Very light gray (N8) to white anhydrite with scattered halite growths. ≤3/8" gray clay at 50.8'.	
14	50	5.0	5.0	100		50.8'-51.4' HALITE: Clear to light gray (N7) and light bluish gray (5B 7/1) with some moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1/2% dispersed polyhalite. ≤1% gray clay. Break at 51.1'. (9)	Run 14. Discing, chipping of core most of run.
51.4							
	55						

BORING NO. DH-08B

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-09

LOCATION N1420 DRIFT, ROOF

STATION N1432± E1332.5± COLLAR ELEV. 1324.5 DIRECTION OF DRILLING VERTICAL-UP

MINE COORDINATES N11,108.71 E8227.11 DEPTH OF BOREHOLE 51.1'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3-14-84 (SWING) DATE COMPLETED 3/14/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3-15-84 1 OF 3

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1	0.0	2.75	2.75	100		0.0'-4.1' HALITE: Clear to light gray (N7) and medium light gray (N6), medium to coarsely crystalline. ≤ 1% gray clay. < 1/2% polyhalite. 3/8" gray clay at 4.1'. Trace of anhydrite associated. [9,11]	Watson drill. AW rods. NW split tube barrel. Drill Time: 7 hours ±.
2	2.75	2.75	2.65	96		4.1'-7.7' HALITE: Clear, coarsely crystalline. Trace anhydrite at 4.6'. Scattered white stringers. [1]	No gas; dry hole.
3	5.5	2.9	2.2	76		7.7'-9.1' HALITE: Clear to light gray (N7); medium light gray (N6). Coarsely crystalline. ≤ 1% gray clay, trace brown. [11]	All core shows varying degrees of vibration damage. Jerky drill feed is cause for much of this.
4	8.4	4.6	3.8	83		9.1'-10.3' HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline. < 1 to 3% brown clay. [13, 14]	Run 3. Much of core broken up.
	10					10.3'-12.3' HALITE: Clear, some light gray (N7) coarsely crystalline. None to < 1% gray, some brown clay. [1, some 9]	Run 4. Broken up badly last 2' ±.
5	13.0	3.1	3.1	100		12.3'-16.1' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline. < 1 to 4% brown clay. Interdcrystalline and scattered breaks. Parting at 14.75'. 1/2" brown clay seam at 16.05'. [14]	Run 6. Core loss probably above anhydrite. Run 7 thru 13. Broken zones and discing especially in the coarsely crystalline, polyhalitic halite.
	15						
6	16.1	4.3	3.8	88		16.1'-16.75' ANHYDRITE: White to light gray anhydrite mixed with halite to 16.45'. Then mostly laminated anhydrite.	
	20					16.75'-20.9' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. < 1% from 18.4'-20.4'. [2-4,7]	
7	20.4	4.8	4.8	100		20.9'-21.9' HALITE: Clear to light gray (N7); coarsely crystalline. ≤ 1% gray clay. [11]	
	25						
	25.2						

BORING NO. DH-09

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 3 — BORING NO. DH-09

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25.0						
25.2							
8		3.6	3.6	100		21.9'-23.5' HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline, some fine. < 1 to 2% brown clay. [12, 13]	
						23.5'-26.7' HALITE: Clear, some moderate brown (5YR 4/4), coarsely crystalline. < 1% brown clay. <1/2% polyhalite blebs. Increasing clay content from 26.1'. [2, 10]	
28.8							
	30						
9		4.8	4.8	100		26.7'-29.9' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4) and moderate reddish brown (10R 4/6), medium to coarsely crystalline. < 1 to 4% brown clay. Scattered partings. Breaks at 27.5';27.6'. 1/2" clay mixed with halite seam at 29.9' <1 to 2% clay from 27.8'-29.1'. [10, 16]	
33.6							
10	35	2.5	2.5	100		29.9'-35.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. [3, 4, 7]	
36.1							
11		5.0	5.0	100		35.1'-36.2' HALITE: Clear to moderate brown (5YR 4/4) to moderate reddish brown (10R 4/6). Coarsely crystalline. < 1 to 2% brown clay. 3/8" clay seam at 35.2'. Breaks at 35.85' and 36.2'. [10]	
	40					36.2'-38.7' POLYHALITIC HALITE: Clear mottled with moderate reddish orange/brown (10R 6/6; 4/6). Coarsely crystalline. < 1 to 3% polyhalite blebs and patches. < 1/2% blebs of brown clay. [3, 4, 7]	
41.1							
12	45	5.1	5.1	100		38.7'-39.7' HALITE: Clear mottled with moderate brown (5YR 4/4) and moderate reddish brown (10R 4/6) clay. Coarsely crystalline. ≤ 1 to 2% clay. 1/2" seam at 39.5'. 3/4" anhydrite mixed with halite at 39.65'. [10]	
46.2						39.7'-41.3' HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 2% polyhalite. Polyhalite from 39.7' to 40.1'. [1-3]	
13	50	4.9	4.9	100		41.3'-42.3' HALITE: Clear to moderate brown (5YR 4/4), coarsely crystalline. < 1 to 2% brown clay. [8, 10]	
51.1						42.3'-45.1' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline. < 1 to 3% brown clay. Scattered breaks. [10, 15]	
	55						

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 3 OF 3 — BORING NO. DH-09

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
						45.1-48.6' HALITE: Clear mottled with moderate brown (5YR 4/4), coarsely crystalline ≤ 1% brown clay, trace gray. Locally up to 2% clay. Scattered breaks last 1". [10, 12] 48.6'-51.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) and moderate reddish brown (10R 4/6); coarsely crystalline. < 1 to 3% polyhalite. [3, 4, 7]	

BORING NO. DH-09

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-10

LOCATION N1420 DRIFT - FLOOR

STATION N1432± F1332.5± COLLAR ELEV. 1312.1 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N 11,108.70 E 8227.09 DEPTH OF BOREHOLE 52.0 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3-15-84 (SWING) DATE COMPLETED 3-15-84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3-17-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1	0.5	0.5	0.5	100			
2	3.6	3.1	3.1	100		0.0'-6.1' HALITE: Clear; coarsely crystalline, some fine. < 1% gray clay and 1/2% polyhalite locally. [1]	Watson drill. AW rods. 2' barrel for 1st run, then 5' L.J split tube barrel used. No gas; dry hole. Drill Time: 9-1/2 hours
3	8.2	4.6	4.6	100		6.1'-10.6' HALITE: Clear mottled with medium dark gray (N4); coarsely crystalline, some medium locally. ≤ 1% gray clay. Dark gray clay break at 8.0'. < 1/2% polyhalite. [11]	Core is brittle and will break with low hand pressure into smaller discs and pieces. Jerky, surging feed on drill. Core shows chipping on surface.
4	13.3	5.1	5.1	100		10.6'-13.5' POLYHALITIC HALITE: Clear mottled with moderate reddish orange (10R 6/6). Coarsely crystalline. < 1 to 2% polyhalite blebs and patches. < 1/2% gray clay. [3, 4, 7] 13.5'-19.4' HALITE: Clear, some light gray (N7) and medium light gray (N6). Medium to coarsely crystalline. ≤ 1% gray intercrystalline clay. Breaks at 15.2'-15.3'. < 1/2% polyhalite. [2, 11]	Runs 2, 3. Some broken core, discing, vibration fractures. Run 4. Good core.
5	15.9	2.6	2.6	100		19.4'-22.6' HALITE: Clear mottled with some moderate reddish orange (10R 6/6); coarsely crystalline; some medium. ≤ 1% polyhalite blebs and patches. < 1/2% gray clay. [2, 5]	
6	20.9	5.0	5.0	100		22.6'-24.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. [3, 4] 24.0'-26.65' MB-139: Moderate reddish orange (10R 6/6 to white anhydrite mixed with halite to 25.4'. Then predominantly light gray (N7) to white anhydrite with scattered halite growths faintly laminated. 1/2" clay seam at lower contact.	Runs 2, 3. Some broken core, discing, vibration fractures. Run 4. Good core.
7	25	5.2	5.2	100		26.65'- 29.3' HALITE: Clear to medium light gray (N6 and moderate reddish orange (10R 6/6) medium to coarsely crystalline. ≤ 1% gray clay and dispersed polyhalite. Clay break at 27.95' and 29.3'. [2, 11]	

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-10

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
7	25	5.2	5.2	100		29.3' -34.8' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline line. < 1 to 3% polyhalite. 1/2" anhydrite with gray clay break at 34.75'-34.8'. [3-5, 7]	Run 8. Barrel plugged because of clay seam.
26.1 8 26.8		0.7	0.7	100			Run 9 thru 13. Core quality fair. Discing in some runs.
9	30	4.7	4.7	100		34.8'-37.0' HALITE: Clear to moderate reddish orange (10R 6/6); some light gray (N7) and light bluish gray (5B 7/1). Medium to coarsely crystalline. ≤ 1% gray clay. < 1 to 2% polyhalite. [2, 11]	
31.5 10	35	5.1	5.1	100		37.0'-42.5' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6) coarsely crystalline. < 1 to 3% polyhalite. Trace brown and gray clay locally. [2-5]	
36.6 11	40	5.2	5.2	100		42.5'-46.75 HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6) with some medium light gray (N6). Medium to coarsely crystalline. Up to 2% brown clay with some gray clay and polyhalite to 43.3'. Below this is < 1% clay and polyhalite. [1, 17]	
41.8 12	45	5.1	5.1	100		46.75'-51.8' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. Moderate reddish orange anhydrite at 51.5' to 51.6' ±. [2-4, 7]	
46.9 13	50	5.1	5.1	100		51.8'-52.0' HALITE: Clear, coarsely crystalline. [1]	
52.0	55						

BORING NO. DH-10

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-11

LOCATION N1100 DRIFT AT ROOM A-2 CENTERLINE, ROOF

STATION N1112± E1332.5± COLLAR ELEV. 1320.5 DIRECTION OF DRILLING UP-VERTICAL

MINE COORDINATES N10,799.8 E8227.3 DEPTH OF BOREHOLE 50.9 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3/5/84 (SWING) DATE COMPLETED 3/6/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/6/84 1 OF 2

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0		0						
0.4	1		0.4	0.4	100	X		
	2		1.5	1.5	100	X X X	0.0'-0.5' HALITE: Clear, trace of moderate reddish orange. Coarsely crystalline. < 1/2% polyhalite. [2]	Watson drill. AW rods MX double tube core barrel. Drilling Time: 7 hours. ±
1.9	3		1.9	1.7	90	X X X	0.5'-4.1' POLYHALITIC HALITE: Clear to moderate reddish orange; coarsely crystalline. < 1 to 3% polyhalite. [3]	Throughout hole much discing and broken core. Quality poor.
3.8	4	5	1.9	1.9	100	—		No gas; dry hole.
5.7	5		4.5	4.5	100	—	4.1'-8.8' HALITE: Clear to light gray (N7) and medium light gray (N6), some moderate brown (5YR 4/4) medium to coarsely crystalline, some fine. ≤ 1% clay. [2,9]	
							8.8'-13.1' HALITE: Clear, coarsely crystalline. 1/2" ± gray anhydrite layer at 9.3' with trace of gray clay anhydrite stringers to 10.5' ±. [1]	
10.2	6	10	2.1	2.1	100			
12.3	7		3.3	3.0	91	— — — — —	13.1'-15.2' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4); fine to medium, some coarsely crystalline. < 1 to 3% brown clay. [12]	
							15.2'-17.0' HALITE: Clear, trace of light brown (5YR 6/4). Coarsely crystalline. [1]	
15.6	8	15	1.5	1.5	100	—		
17.1	9		3.5	3.5	100	— — — — —	17.0'-20.6' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline. < 1 to 3% brown clay, intercrystalline and breaks. ≥10% clay at 20.5'-20.6'. [10, 15]	
		20					20.6'-21.2' ANHYDRITE: White to light gray (N7) microcrystalline, partially laminated anhydrite. Scattered halite growths. 1/2" brown clay seam at 20.6'.	Run 10. Some core grinding evident here.
20.6	10		1.1	1.1	100	X		
21.7	11		2.1	2.1	100	X		
23.8		25						

WIPP

WASTE ISOLATION PILOT PLANT SHEET 2 OF 2 BORING NO. DH-11

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
12	25	3.4	3.4	100		21.2'-24.9' HALITE: Clear, some light moderate reddish orange; coarsely crystalline. ≤ 1% polyhalite. [1,3]	
27.2							
13		2.5	2.5	100	X	24.9'-30.7' HALITE: Clear, some moderate brown (5YR 4/4); coarsely crystalline except medium at 25.5' to 26.1'. < 1 to 2%, locally, brown clay. < 1/2% dispersed polyhalite. [2, 10]	
29.7	30						
14		2.4	2.4	100		30.7'-33.5' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline. < 1 to 3% brown clay. Breaks at 31.5', 32.8'. [12, 14]	
32.1							
15		3.9	3.9	100	X	33.5'-50.9' HALITE: Clear to moderate brown (5YR 3/4; 4/4) and mottled with moderate reddish orange/brown (10R 6/6; 4/6). Coarsely crystalline. < 1 to 3% brown clay with trace of gray. < 1 to 2% polyhalite blebs and patches. Core varies from zones containing polyhalite blebs with no clay to zones with mixed clay and polyhalite and zones containing only patches of clay. [5, 10] Zones with polyhalite blebs and patches and only trace of clay are the following approximate depths: 33.5' -33.7', 40.4' -41.3', 43.1' -44.9', 49.2' -49.7'.	
	35						
36.0					X		
16		4.5	4.5	100	X		
	40						
40.5							
17		2.4	2.4	100	X		
42.9							
18	45	4.7	4.7	100	X		
					X		
47.6							
19		3.3	3.3	100	X		
	50						
50.9							

BORING NO. DH-11

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-12

LOCATION N1100 DRIFT AT ROOM A-2 INTERSECTION, FLOOR

STATION N1112 ± E1332.5 ± COLLAR ELEV. 1311.1 DIRECTION OF DRILLING VERTICAL - DOWN

MINE COORDINATES N10,799.4 E 8227.2 DEPTH OF BOREHOLE 51.3'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3-7-84 (SWING) DATE COMPLETED 3-7-84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3-24-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 1.8	1.8	1.8	100		0.0–4.25' HALITE: Clear to light gray (N7) and light bluish gray (5B 7/1); coarsely crystalline. < 1% gray intercrystalline clay. < 1/2% polyhalite. [11]	Watson Drill. NW split tube core barrel. AW rods. Drill Time: 6-1/2 hours ±.
2	1.8 – 5.8	4.0	4.0	100		4.25'–5.55' HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1% polyhalite. [3]	
3	5.8 – 11.1	5.3	5.3	100		5.55'–10.0' HALITE: Clear to light gray (N7) and medium light gray (N6); some moderate reddish orange and brown. Coarsely crystalline, some medium. < 1% gray clay. Partings at 7.4' and 8.55'. < 1% polyhalite. [11,2]	Core quality shows significant improvement over previously drilled core.
4	11.1 – 16.1	5.0	5.0	100		10.0'–12.65' HALITE: Clear to moderate reddish orange, (10R 6/6) coarsely crystalline. ≤ 1% polyhalite. Gray clay break at 12.25'. [2] 12.65'–19.8' HALITE: Clear to light bluish gray (5B 7/1) and moderate reddish orange (10R 6/6) medium to coarsely crystalline. ≤1% gray clay; trace brown < 1% polyhalite. [11.2]	
5	16.1 – 21.2	5.1	5.1	100		19.8'–20.9' HALITE: Clear, some moderate reddish orange (10R 6/6). Coarsely crystalline. < 1% polyhalite. [1] 20.9'–21.45' HALITE: Clear to light gray (N7) medium to coarsely crystalline. ≤ 1% gray clay. [11]	
6	21.2 – 25	5.1	5.1	100		21.45'–22.75' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline < 1 to 2% polyhalite blebs and patches. [1-3]	

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-12

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
6	25					22.75'-25.9' MB-139: From 22.75' to 23.85' is a "swallowtail" pattern of halite and anhydrite. Below this is predominantly white to light gray (N7) to medium light gray (N6) microcrystalline anhydrite with scattered halite growths. Anhydrite is partially laminated. < 1/2" moist gray clay at lower contact.	
26.3							
7		5.0	5.0	100		25.9'-29.0' HALITE: Clear to moderate reddish orange (10R 6/6) and light gray (N7). Medium to coarsely crystalline. ≤ 1% gray clay and < 1% dispersed polyhalite. [9,11]	
	30						
31.3							
8		5.0	5.0	100		29.0'-32.2' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 4% polyhalite. None to < 1% gray clay. [4-6]	
	35					33.2'-35.35' HALITE: Clear to moderate reddish orange (10R 6/6); medium to coarsely crystalline. < 1% gray clay and dispersed polyhalite. [1,2]	
36.3							
9		5.0	5.0	100		35.35'-39.9' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite blebs and patches. < 1/2% gray clay locally. [2-4]	
	40					39.9'-44.8' HALITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline, some medium. ≤ 1% gray clay and ≤ 1% polyhalite, locally up to 2%. [1, 10]	
41.3							
10		5.0	5.0	100		44.8'-49.5' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6); coarsely crystalline. < 1 to 4% polyhalite average ≤1 to 2%. < 1% gray clay. Moderate reddish orange/brown microcrystalline anhydrite/polyhalite at 49.1' to 49.3'. Lower surface is irregular and slightly polished. [2-4, 7]	
	45						
46.3							
11		5.0	5.0	100		49.5'-49.8' ANHYDRITE: White to light gray (N7); microcrystalline, faintly laminaed anhydrite. Scattered halite growths. Trace of gray clay at 49.8'.	
	50					49.8'-51.3' HALITE: Clear, some light bluish gray (5B 7/1) and moderate reddish orange (10R 6/6). Medium to coarsely crystalline. ≤ 1% gray clay. < 1/2% polyhalite. [9, locally 2]	
51.3							
	55						

BORING NO. DH-12

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-13

LOCATION N1420 DRIFT & ROOM D INTERSECTION

STATION N 1424, E1690 COLLAR ELEV. 1311.4 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N11 112, E8585 DEPTH OF BOREHOLE 13.8 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON MODEL 750

DATE STARTED 3/28/84 (SWING) DATE COMPLETED 3/28/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/30/84 1 OF 1

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0	1		2.4	2.4	100	X	0.0'-3.9'HALITE: Clear to moderate reddish orange (10R 6/6); medium to coarsely crystalline. <1% dispersed polyhalite. <1/2% gray clay. 1/2" anhydrite at 3.9'±. Gray clay below.	Watson drill, AW rods, NW split-tube barrel.
2.4	2	5	5.5	3.6	65.5	X	3.9'-8.7' HALITE: Clear, coarsely crystalline. None to <1% gray clay.	Set-up time: 7 hrs. Drilling time: 2-1/2 hrs.
							8.7'-9.4' HALITE: Clear to moderate brown (5YR 4/4); some light gray (N7). Medium to coarsely crystalline. ≤1% brown and gray clay.	No gas. Dry hole.
7.9							9.4'-13.8' HALITE: Clear, some light gray (N7); coarsely crystalline. <1% dispersed gray clay.	Contacts approximate due to core loss.
8.7	3		0.8	0.8	100			Run 2. Core broken-up much of run.
	4	10	5.1	4.1	80.4		Note: This hole was stopped at 13.8' due to core loss. Refer to drill logs for replacement holes DH-13A and DH-13B.	
13.8		15						
		20						
		25						

BORING NO. DH-13

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ HOLE TYPE/SIZE NX CORE BORING NO. DH-13A

LOCATION 6" N.E. OF DH-13; N1420 DRIFT AT ROOM D INTERSECTION

STATION N 1424.5, E1691 COLLAR ELEV. 1311.5± DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N11112, E8586 DEPTH OF BOREHOLE 49.0 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON MODEL 750

DATE STARTED 3/28/84 (SWING) DATE COMPLETED 3/29/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/30/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 2.5	2.5	2.5	100		0.0'-4.25' HALITE: Clear, some light gray (N7), medium to coarsely crystalline. < 1% dispersed gray clay. < 1/2% dispersed polyhalite. Break at 4.25'.	Watson drill, AW rods. Used NW double-tube barrel and split-tube barrel.
2	2.5 – 3.2	0.7	0.65	93		4.25'-6.3' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. 1/4" anhydrite layer at 4.55'.	Drilling time: 5 hrs. ±
3	3.2 – 6.1	2.9	2.9	100		6.3'-10.6' HALITE: Clear to light moderate reddish orange (10R 6/6); some light bluish gray (5B 7/1). Medium to coarsely crystalline. < 1/2% dispersed polyhalite and gray clay.	Run 2. Barrel plugged.
4	6.1 – 8.9	2.8	0.6	21		10.6'-13.4' HALITE: Clear to light gray (N7) and medium light gray (N6). Coarsely crystalline. None to < 1% gray clay. Upper 12" of recovered core is clear.	Contacts at 6.3' and 10.6' are approximate due to core loss.
5	8.9 – 10.9	2.0	2.0	100		13.4'-16.55' ARGILLACEOUS HALITE: Clear to medium brown (5YR 4/4); medium to coarsely crystalline. < 1 to 3% brown clay. Scattered breaks.	
6	10.9 – 12.9	2.0	1.0	50		16.55'-17.25' ANHYDRITE: Light gray, microcrystalline; faintly laminated. Scattered halite growths, especially 16.75'-16.95'±. 2-1/2" gray clay seam at 16.55'-16.75', medium plastic. Contains scattered halite crystals.	Run 6. Much of core broken-up.
7	12.9 – 15.1	2.2	2.2	100		17.25'-22.2' HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 2% polyhalite. Scattered anhydrite.	Run 7. Tried 3' MX double-tube barrel. Core OK.
8	15.1 – 16.7	1.6	1.6	100			Run 8. NW split-tube plugged-off at clay seam.
9	16.7 – 20.7	4.0	3.3	83		22.2'-24.5' HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline. < 1 to 2% brown clay. Breaks at 22.4' and 23.25'. [12,17]	Run 9. Core broken-up in polyhalitic halite.
						24.5'-26.7' HALITE: Clear mottled with some moderate reddish orange (10R 6/6); coarsely crystalline. < 1/2% gray clay and < 1% polyhalite. [2 - 4, some 9]	
10	20.7 – 24.0	3.3	3.3	100		26.7'-28.3' HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline. < 1 to 2% brown clay. [8, 10]	Runs 10-15. Used Sprague and Henwood double-tube core barrel. A piece of foam rubber was used inside barrel to prevent core from falling in barrel.
11	24.0 – 25	5.0	5.0	100			

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-13A

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
11		5.0	5.0	100		28.3'-30.6' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline. < 1 to 3% brown clay. Break at 28.4'. 1-1/2" brown clay mixed with halite at 30.4'-30.6'±. [12]	
						30.6'-35.55' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. 1/2" gray clay seam at 33.9'. [2 - 5]	
29.0							
	30						
12		4.9	4.9	100		35.55'-36.8' HALITE: Clear with some moderate brown (5YR 4/4); coarsely crystalline. < 1/2% polyhalite. ≤ 1% brown clay patches. Irregular break at 35.55'. [10, 17]	
						36.8'-39.0' HALITE: Clear mottled with some moderate reddish orange (10R 6/6) and moderate brown (5YR 4/4). Coarsely crystalline < 1% brown clay blebs. ≤ 1 to 2% polyhalite blebs. [1 - 3, 8]	
33.9							
	35						
13		5.0	5.0	100		39.0'-39.9' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4; 3/4); medium to coarsely crystalline. Brown clay < 1 to 3%. Break at 39.6' and 1/2" seam at 39.85'. [12]	
						39.9'-41.7' HALITE: Clear mottled with moderate reddish orange; coarsely crystalline. ≤ 1% polyhalite. 1-1/2" anhydrite and halite at 39.9'-40.0'. [1, 2]	
38.9							
	40						
14		5.1	5.1	100		41.7-43.3' HALITE: Clear with some moderate brown (5YR 4/4); coarsely crystalline, some medium. ≤ 1% brown clay. [8, 10]	
						43.3'-46.9' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4; 3/4); medium to coarsely crystalline. < 1 to 3% brown clay. Parting at 43.3'. Breaks at 45.5'; 45.6'. [10]	
44.0							
	45						
15		5.0	5.0	100		46.9'-49.0' HALITE: Clear to moderate reddish brown (10R 4/6) and moderate brown (5YR 4/4). Medium to coarsely crystalline. ≤ 1% brown clay, trace of gray. < 1% polyhalite. [10]	
49.0							
	50						
	55						

BORING NO. DH-13A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-13B

LOCATION N1420 DRIFT; ROOF AT RM. D INTERSECTION

STATION N1425, E1695 COLLAR ELEV. 1311.4 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N11112.62, E8590.14 DEPTH OF BOREHOLE 21.0 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON MODEL 750

DATE STARTED 4-5-84 (SWING) DATE COMPLETED 4-5-84 (SWING) SHEET

LOGGED BY: J. F. GALLERANI DATE: 4-5-84 1 OF 1

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0	1		2.7	2.7	100		0.0'-2.7' HALITE: Clear to medium light gray (N6) and some light moderate reddish orange (10R 6/6). Coarsely crystalline. ≤ 1% gray clay. [9]	AW rods, S&H NX double-tube core barrel. Drilling time: 1 hr. ±
2.7	2	5	4.8	4.8	100		2.7'-5.5' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. < 1/4" gray clay seam at 5.5' with some anhydrite just above. [1] 5.5'-9.9' HALITE: Clear, trace of light gray (N7), medium to coarsely crystalline. < 1/2% clay. [1, 9]	
7.5	3	10	4.9	4.9	100		9.9'-12.1' HALITE: Clear, coarsely crystalline. [1] 12.1'-15.8' HALITE: Clear with some medium light gray (N6) and medium brown (5YR 4/4). Medium to coarsely crystalline, trace fine locally. < 1/2% dispersed polyhalite and ≤ 1% gray clay, some brown. Scattered discontinuous breaks. [9, 17] 15.8'-16.8' HALITE: Clear, coarsely crystalline. [1]	
12.4	4	15	4.5	4.5	100		16.8'-17.5' ANHYDRITE: Light gray (N7) to medium light gray (N6) microcrystalline anhydrite with scattered halite growths. Partially laminated. 1/2" layer of mostly halite at 17.4'. Tightly closed upper contact. Up to 1-1/4" hard gray clay at ~~16.8'-16.9'~~. -. 17.5'-18.3' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 2% polyhalite. [7]	
16.9	5	20	4.1	4.1	100		18.3'-21.0' HALITE: Clear with some moderate reddish orange. < 1% polyhalite locally. ≤ 1/2" white anhydrite layer at 18.9'±. [1, 2]	
21.0		25						

BORING NO. DH-13B

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ HOLE TYPE/SIZE NX CORE BORING NO. DH-14

LOCATION N1420 DRIFT, FLOOR AT INTERSECTION OF RM. D

STATION N 1425, E 1695 COLLAR ELEV. 1299.5 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N11112.62, E8590.14 DEPTH OF BOREHOLE 49.1 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON MODEL 750

DATE STARTED 4/6/84 DATE COMPLETED 4/6/84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 4/27/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		3.2	3.2	100		0.0'-5.8' HALITE: Clear with some light gray (N7), coarsely crystalline. < 1% gray clay and polyhalite. [1, 11]	Watson drill, AW rods, NX double-tube core barrel.
	3.2					5.8'-13.15' HALITE: Clear to medium light gray (N6), coarsely crystalline, some medium. ≤ 1% gray clay. < 1/2% dispersed polyhalite. [9, 11]	No gas. Dry hole.
2		4.9	4.9	100		13.15'-16.2' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1% polyhalite. [1-3]	Core shows some discing and surface vibration damage.
	8.1					16.2'-21.3' HALITE: Clear to light moderate reddish orange (10R 6/6) and light gray (N7), medium to coarsely crystalline. < 1/2% dispersed polyhalite. < 1% gray clay. [9, 11]	
3		5.0	5.0	100		21.3'-23.7' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), medium to coarsely crystalline. < 1 to 2% polyhalite. Scattered anhydrite. [3, 7]	
	13.1					23.7'-26.45' MB-139: Light gray to moderate reddish orange mixture of predominantly anhydrite with some polyhalitic halite to 25.55'. Then light gray anhydrite with scattered halite growths and laminae. Trace of gray clay at 26.45'.	
4		5.0	5.0	100		26.45'-29.5' HALITE: Clear to moderate reddish orange (10R 6/6) and some light gray (N7). Medium to coarsely crystalline. < 1/2% dispersed polyhalite and < 1% gray clay. [9]	
	18.1					29.5'-33.9' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. Anhydrite mixed with some halite from 33.75'-33.9'. Gray clay at 33.9'. [7]	
5		5.0	5.0	100		33.9'-36.25' HALITE: Clear to light moderate reddish orange (10R 6/6) and some light gray (N7). Medium to coarsely crystalline. < 1/2% dispersed polyhalite. < 1% gray clay. [9]	
	23.1						
6		5.0	5.0	100			

BORING NO. DH-14

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-14

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
6	25	5.0	5.0	100		36.25'-41.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline, < 1 to 3% polyhalite, < 1/2% gray clay with up to 1% clay at 39.5'-40.3'. Break at 39.5'. [3, 4, 7]	
28.1						41.1'-44.7' HALITE: Clear to moderate reddish orange (10R 6/6) and some light gray (N7). Medium to coarsely crystalline, some fine. < 1/2% dispersed polyhalite. < 1% gray clay. [9]	
7	30	5.0	5.0	100		44.7'-49.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline, < 1 to 3% polyhalite. [3, 7]	
33.1							
8	35	5.0	5.0	100			
38.1							
9	40	5.0	5.0	100			
43.1							
10	45	5.0	5.0	100			
48.1							
11		1.0	1.0	100			
49.1	50						
	55						

BORING NO. DH-14

WIPP

WASTE ISOLATION PILOT PLANT

GEOLOGIC DRILL LOG

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-15

LOCATION N1100 DRIFT, ROOF

STATION N1104± E1688.5± COLLAR ELEV. 1308.9 DIRECTION OF DRILLING VERTICAL - UP

MINE COORDINATES N10,793.26 E8589.96 DEPTH OF BOREHOLE 51.0'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3/20/84 (SWING) DATE COMPLETED 3/21/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/25/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		2.4	2.4	100	X	0.0'-4.5' HALITE: Clear, coarsely crystalline. < 1% polyhalite from 3.7'-4.5' ±. Scattered white anhydrite/magnesite? Stringers. [1 2]	Watson post mounted drill. AW rods. NW split tube barrel. Drilling Time: 6-1/2 hours.
	2.4						
2		3.9	3.9	100	X	4.5'-9.2' HALITE: Clear to light gray (N7) medium to coarsely crystalline. ≤ 1% gray clay. < 1/8" clay seam at 9.1'. From 9.1' to 9.2' anhydrite mixed with halite. [2,11]	Core generally all together in split tube. Tends to break up some when put in box.
	5						
	6.3					9.2'-13.0' HALITE: Clear, coarsely crystalline. Scattered white stringers. [1]	
3		1.2	1.2	100			
	7.5						
4		4.2	4.2	100		13.0'-14.7' HALITE: Clear to light gray (N7) and moderate brown (5YR 4/4); medium to coarsely crystalline, some fine. < 1% brown clay with trace gray. Sugary texture 14.1'-14.7'. [9,17]	Run 4. Discing of core in clear halite.
	10						
	11.7					14.7'-18.1' HALITE: Clear, coarsely crystalline none to ≤ 1% gray clay. [1, some 11]	Run 5. Some broken core.
5		4.9	4.9	100		18.1'-20.85' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4) and grayish red (10R 4/2) medium to coarsely crystalline. < 1 to 3% brown clay. 1/2" ± brown clay seam at 19.6'. (12,16)	
	15						
	16.6					20.85'-21.35' ANHYDRITE: Light (N7) to medium gray (N5) to white anhydrite. Scattered halite growths up to 1/2" brown clay seam at 20.85'.	
6		4.3	4.3	100		21.35'-26.0' HALITE: Clear, coarsely crystalline. Stringers of anhydrite mixed with halite 21.35'-21.75'. Scattered white stringers throughout core. [1,2]	
	20						
	20.9						
7		4.5	4.5	100			
	25						
	25.4						

BORING NO. DH-15

WIPP

WASTE ISOLATION PILOT PLANT

SHEET 2 OF 2 BORING NO. DH-15

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
25.4							
8		4.5	4.5	100		26.0'-31.2' HALITE: Clear to dark reddish brown and moderate brown (5YR 4/4). Predominantly coarse with zones of fine-medium from 26.5'-26.9' ± and 28.0'-28.5' ±. < 1 to 2% brown clay. [8, 10, 12]	
29.9	30					31.2'-34.75' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4) and moderate reddish brown (10R 4/6); medium to coarsely crystalline. < 1 to 5% brown clay intercrystalline and breaks. From 34.45' to 34.65' clay ≥ 10%. (10,12)	
9		4.9	4.9	100		34.75'-43.2' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. 1" anhydrite layer at 37.25'. < 1 to 3% brown clay at 40.25' -41.45. [3, 4, 7]	
34.8	35						
10		5.0	5.0	100		43.2'-44.1' HALITE: Clear mottled with dark reddish brown and moderate brown (5YR 4/4). Coarsely crystalline. ≤ 1% brown clay. [8, 10]	Run 10. Some discing of core.
						44.1"-44.6' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4); fine to medium crystalline, some coarse. < 1 to 3% brown clay, intercrystalline and breaks. Anhydrite/halite at 44.4'-44.6'. [12, 17]	
39.8	40						
11		4.8	4.8	100		44.6'-47.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite. [3, 4, 7]	
						47.1'-51.0' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4); medium to coarsely crystalline. < 1 to 3% brown clay. [10, 12]	
44.6	45						
12		1.4	1.4	100			
46.0							
13		5.0	5.0	100			
	50						
51.0							
	55						

BORING NO. DH-15

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER ____ - ____ HOLE TYPE/SIZE NX CORE BORING NO. DH-16

LOCATION N1100 DRIFT - FLOOR

STATION N1104 ± E1688 ± COLLAR ELEV. 1300.3 DIRECTION OF DRILLING VERTICAL - DOWN

MINE COORDINATES N10792.89 E8589.39 DEPTH OF BOREHOLE 51.0'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3/19/84 (SWING) DATE COMPLETED 3/19/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/20/84 1 OF 2

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0		0.0						
	1		2.0	2.0	100		0.0'-6.1' HALITE: Clear, coarsely crystalline, some medium. < 1/2% polyhalite and gray clay. [1, 2]	Watson drill.
2.0								Post mounted AW rods.
	2		0.3	0.1	33			NW split tube barrel.
2.3	3		1.1	1.1	100		6.1'-10.4' HALITE: Clear to light gray (N7); coarsely crystalline, some medium. ≤ 1% gray clay. < 1/2% dispersed polyhalite. [11]	Drilling Time: 4-1/2 hours.
3.4								No gas. Dry hole.
	4	5	2.6	2.5	96			
6.0							10.4'-12.35' HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline, some medium. < 1 to 2% polyhalite. < 1% gray clay at 11.85'-11.95'. [1-3]	Overall core quality is satisfactory. Can fit ends together fairly well. Some discing of core, especially in coarsely crystalline material.
	5		5.1	5.1	100		12.35'-16.0' HALITE: Clear to light gray (N7); light bluish gray (5B- 7/1) and moderate reddish orange (10R 6/6) medium to coarsely crystalline. ≤ 1% polyhalite and gray clay. [9]	Runs 4 and 5.
		10						Some discing of core.
11.1							16.0'-20.1' HALITE: Clear to light bluish gray (5B 7/1) and light gray (N7); coarsely crystalline. ≤ 1% gray clay. [11]	
	6		4.9	4.9	100		20.1'-21.5' HALITE: Clear, scattered moderate reddish orange polyhalite blebs. Coarsely crystalline. < 1/2% polyhalite. [2, 3]	
		15						
16.0							21.5'-25.2' MB-139: Mixture of halite and anhydrite in "swallowtail" pattern from 21.5'-23.6'. From 23.6', predominantly anhydrite with some halite growths. Some laminae, especially noted from 24.5'. 1/2" ± clay at lower contact.	
	7		5.1	5.1	100			
		20					25.2'-29.6' HALITE: Clear, some moderate reddish orange (10R 6/6) and light gray (N7). Medium to coarsely crystalline. < 1/2% polyhalite and gray clay. Coarsely crystalline with no clay from 29.2-29.6'. [9]	
21.1								
	8		4.9	4.9	100			
		25						

BORING NO. DH-16

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-16

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
8	25	4.9	4.9	100		29.6'–33.05' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite. 1/2" hard gray clay. Seam at lower contact. [3, 4, 7]	
26.0							
9	30	5.0	5.0	100		33.05'–34.9' HALITE: Clear mottled with some moderate reddish orange polyhalite blebs. Coarsely crystalline, some medium. <1/2% polyhalite and gray clay. [2]	
31.0						34.9'–40.35' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline except some medium at 39.65' to 40.35'. <1 to 3% polyhalite <1/2% gray clay. [2–5, 9]	
10	35	5.0	5.0	100		40.35'–42.1' HALITE: Clear, coarsely crystalline. None to 1% gray clay and<1/2% dispersed polyhalite. [1, 2]	
36.0						42.1'–46.3' HALITE: Clear to moderate reddish orange/ brown (10R 6/6;4/6) with some light gray (N7). Coarsely crystalline. ≤1% gray intercrystalline clay. <1 to 2% polyhalite. Locally polyhalitic. [9]	
11	40	5.0	5.0	100			
41.0						46.3'–49.15' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite. Moderate reddish orange anhydrite mixed with some halite at 48.95–49.05' ±. [2–4, 7]	
12	45	5.1	5.1	100		49.15–49.45' ANHYDRITE: White to light gray (N7), microcrystalline. Scattered halite growths. ≤1/16" gray clay at 49.45'.	
46.1						49.45'–51.0' HALITE: Clear, medium to coarsely crystalline. <1/2% clay at 50.8' to 51.0'. [2]	
13	50	4.9	4.9	100			
51.0	55						

BORING NO. DH-16

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-17

LOCATION N 1420 DRIFT: ROOF

STATION N1427 ± E178 ± COLLAR ELEV. 1316.45 DIRECTION OF DRILLING UP-VERTICAL

MINE COORDINATES N11114.2 E7071.8 DEPTH OF BOREHOLE 52.0 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 1/18/84 (DAY) DATE COMPLETED 1/19/84 (DAY) SHEET

LOGGED BY: J.E. GALLERANI DATE: 3/6/84 1 OF 3

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		3.7	3.7	100		0.0'-4.2' HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline, some medium. Scattered polyhalite < 1%, < 1/2% gray clay. [3,9)	Watson drill. AW rods. NX double tube core barrel.
	3.7					4.2'-7.2' HALITE: Clear to light gray (N7) coarsely crystalline. ≤ 1% gray intercrystalline clay. < 1/2% polyhalite. [9,11)	Drilling time: 5 hours. Dry hole; no gas.
2	5	5.0	5.0	100		7.2'-7.4' ANHYDRITE b: Very light (N8) to light gray (N7) microcrystalline anhydrite. Trace of dry gray clay at 7.2'. Some core grinding noted. Tightly closed irregular upper contact. Some halite growths 7.3'-7.4'.	Overall core condition good. Only several small broken up zones.
	8.7					7.4'-12.8' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. ≤ 1% polyhalite 7.3'-7.7' and 12.0'-12.6'. [1,2)	
3	10	4.9	4.9	100		12.8'-14.1' HALITE: Clear to light bluish gray (5B 7/1), fine to medium crystalline. ≤ 1% gray intercrystalline clay. Trace of dispersed polyhalite. (9)	
	13.6					14.1'-14.8' ANHYDRITE a: White to medium light (N6) and very light (N8) gray microcrystalline anhydrite some laminae. Growths of halite present. < 1/32" halite laminate at 14.4'. Trace of gray clay at 14.1'.	Run 4. Core broken up last 6" of run.
4	15	4.8	4.8	100		14.8'-19.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 3% polyhalite blebs, patches. [3,4,7]	
	18.4					19.0'-21.0' HALITE: Clear to light gray (N7), fine to medium crystalline with some coarse. < 1 to 2% gray clay. < 1/2% dispersed polyhalite. [1,2,9)	
5	20	5.0	5.0	100			
	23.4						
	25						

BORING NO. DH-17

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 3 — BORING NO. DH-17

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
6		4.8	4.8	100		21.0'-23.6' HALITE: Clear, coarsely crystalline. Trace < 1% gray clay. fine-medium crystalline 22.4'-22.9'. < 1/2% polyhalite blebs. Clay parting at 23.5'. 3/4" anhydrite layer above this. [2,9)	
28.2							
7	30	5.0	5.0	100		23.6'-28.3' HALITE: Clear, coarsely crystalline. Scattered white anhydrite/magnesite stringers from 23.6'-25.6'. [1)	Run 7. Core broken up zone 32.2'-32.7' ±
33.2						28.3'-29.6' ARGILLACEOUS HALITE: Clear to grayish brown, fine to medium crystalline. < 1 to 2% brown and gray clay. Scattered breaks. [12,15)	
8	35	4.0	4.0	100		29.6'-32.0' HALITE: Clear, coarsely crystalline. [1,8)	Run 8. Bit plugged off went only 4' and pulled barrel.
37.2						32.0'-36.3' HALITE: Clear to moderate brown (5YR 4/4) and grayish brown, coarsely crystalline, some medium. < 1% brown and gray clay to 33.1' ±. Core is argillaceous, 1 to 3% brown clay, from 32.9-35.2'. Clear from 35.8'-36.3'. [8,10)	
9	40	5.0	5.0	100	X X	36.3'-37.2' ANHYDRITE: Very light (N8) to light gray (N7) microcrystalline anhydrite. Halite growths within 1" brown clay seem at 36.2'. Slightly plastic, low moisture.	
42.2						37.2'-40.7' HALITE: Clear mottled with moderate reddish orange (10R 6/6), coarsely crystalline. < 1% polyhalite blebs anhydrite mixed with halite from 37.2' to 37.6'. [2-4)	
10	45	4.8	4.8	100	X X	40.7'-41.5 HALITE: Clear to moderate brown (5YR 4/4) coarsely crystalline. ≤ 1% brown intercrystalline clay. [2,8]	
47.0						41.5'-43.4' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4) coarsely crystalline. < 1 to 3% brown intercrystalline clay. Trace of Gray. Breaks at 41.5', 42.2'. (10,16)	
11	50	5.0	5.0	100	X	43.4'-45.4' HALITE: Clear, coarsely crystalline. 1% polyhalite at 43.4'-44.0'. [2)	
52.0							
	55						

WIPP

WASTE ISOLATION PILOT PLANT SHEET 3 OF 3 BORING NO. DH-17

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
						45.4'-47.05' HALITE: Clear, coarsely crystalline. < 1% brown intercrystalline clay. < 1/2% polyhalite blebs. [8]	
						47.05'-50.3' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4) medium to coarsely crystalline. < 1 to 5% brown clay, intercrystalline and breaks. 1" brown clay mixed with halite crystals at 50.2'. [16]	
						50.3'-52.0 POLYHALITIC HALITE: Clear mottled with moderate reddish orange (10R 6/6) coarsely crystalline. < 1%, locally 2% polyhalite. < 1/2% gray clay. [4, 7]	

BORING NO. DH-17

WIPP

WASTE ISOLATION PILOT PLANT

GEOLOGIC DRILL LOG

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-18

LOCATION N1420 DRIFT - FLOOR

STATION N1429± F181± COLLAR ELEV. 1305.1 DIRECTION OF DRILLING VERTICAL - DOWN

MINE COORDINATES N11,114.2 E7071.8 DEPTH OF BOREHOLE 50.8'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 1/19/84 (SWING) DATE COMPLETED 1/20/84 (DAY) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/5/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						Watson drill.
1		5.1	5.1	100		0.0'-4.7' HALITE: Clear, coarsely crystalline, < 1% gray clay locally. < 1/2% polyhalite blebs. [1]	AW rods, NX double tube barrel.
						4.7'-5.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1% to 3% polyhalite. [7]	Drilling time: 5-1/2 hours.
	5.1						Dry hole. No Gas.
2		4.0	3.1	78		5.6'-9.1' MB-139: From 5.6' to 6.7' is light gray (N7) to moderate reddish orange (10R 6/6) mixture of halite, polyhalite and anhydrite. Shows "swallowtail" pattern. From 6.1' to 9.1' ± is white to medium gray (N5) anhydrite with scattered halite growths. Very thin layers of halite lower part of unit. Lower contact approximate because of core loss.	Run 1. Small broken zone 2.2'-2.4' ±.
	9.1						Run 2. Left some core in hole. Ground up in run 3.
3		4.5	4.5	100		9.1'-12.1' HALITE: Clear to light bluish gray (5B 7/1) and moderate reddish orange (10R 6/6) medium to coarsely crystalline. ≤ 1% polyhalite and intercrystalline gray clay. [9]	
	13.6					12.1'-18.2' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. ≤ 1% polyhalite, locally 2%. 1" anhydrite layer at 15.6'. 1/2" clay and anhydrite at 15.8'. Dips at 10°±. < 1% gray clay at 15.8'-16.8'. < 1/2% polyhalite from 15.8'-18.2'. [7, 2]	
4		4.7	4.7	100		18.2'-22.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline, scattered medium < 1 to 4%. [3, 4, 7]	
	18.3						
5		4.8	4.8	100		22.4'-27.9' HALITE: Clear to light gray (N7) and moderate reddish orange (10R 6/6) medium to coarsely crystalline. < 1% polyhalite and dispersed gray clay.	
	23.1						
6		5.2	5.2	100			

BORING NO. DH-18

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-18

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
6		5.2	5.2	100		27.9'-33.7' HALITE: Clear mottled with moderate reddish orange, coarsely crystalline. < 1 to 2% polyhalite with most concentration at 27.9' to 30.0'. 1" anhydrite layer at 33.0'. [7, 1]	
28.3							
7	30	4.8	4.8	100		33.7'-34.05' ANHYDRITE: Very light (N8) to medium gray (N5) microcrystalline anhydrite with scattered halite growths. Trace of dry gray clay at 34.05'.	
						34.05'-41.2' HALITE: Clear mottled with some light gray, fine to coarsely crystalline. ≤ 1% gray intercrystalline clay and polyhalite. Clear, fine to medium crystalline from 35.2' to 36.1'. [9, 4]	
33.1							
8	35	5.0	5.0	100		41.2'-44.6' HALITE: Clear to medium brown (5YR 4/4) to grayish brown (5YR 3/2) medium to coarsely crystalline. <1 to 2% brown, trace gray. [10]	
38.1						44.6'-47.2' HALITE: Clear to light gray (N7) coarsely crystalline. <1% gray intercrystalline clay. < 1/2% dispersed polyhalite. [11]	
9	40	5.0	5.0	100		47.2'-50.1' HALITE: Clear, coarsely crystalline. 1/2% gray clay at 48.6' to 48.7'. <1% dispersed polyhalite at 48.7' to 50.1'. [2]	Run 9. Small broken zone. 38.1'-38.4' ±.
43.1						50.1'-50.8' HALITE: Clear, with some light gray (N7), coarsely crystalline. <1% gray intercrystalline clay. Break at 50.5'. [11]	Run 10-11. Time to put rods in hole, drill, and come out of hole and empty barrel and put rods back in hole: 43 minutes.
10	45	4.6	4.6	100			
47.7							
11	50	3.1	3.1	100			
50.8							

BORING NO. DH-18

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-19

LOCATION N1100 DRIFT - ROOF

STATION N 1107 ± E 206.5 ± COLLAR ELEV. 1314.7 DIRECTION OF DRILLING UP-VERTICAL

MINE COORDINATES N 10,794.2 E 7101.7 DEPTH OF BOREHOLE 51.6 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 1/20/83 (DAY) DATE COMPLETED 1/21/84 (DAY) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/5/84 1 OF 3

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 0.6	0.6	0.6	100		0.0'–4.0' HALITE: Clear, coarsely crystalline. < 1/2% gray intercrystalline clay and < 1% polyhalite blebs. (2)	Watson drill. AW Rods; NW double tube barrel 6" diameter barrel used to start hole. Roof only 8-1/2' high so unable to get NX core barrel on drill. Drill Time: 7-1/2 hours. Dry hole; no gas.
2	0.6 – 5.0	4.4	4.4	100		4.0'–7.55' HALITE: Clear with some light gray (N7), medium to coarse crystalline. ≤ 1% gray, intercrystalline clay < 1/2% dispersed polyhalite. (2,9)	
3	5.0 – 9.6	4.6	4.6	100		7.55'–7.75' ANHYDRITE b: Very light (N8) to medium gray (N5) microcrystalline anhydrite. Scattered halite growths. Several near-horizontal hairline fractures with anhydrite. Trace clay at 7.55'.	
4	9.6 – 13.2	3.6	3.6	100		7.75'–8.2' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. 1 to 2% polyhalite. (7) 8.2'–12.1' HALITE: Clear, coarsely crystalline. <1/2% dispersed polyhalite locally. Very clear at 8.2' to 8.7' ±. (1)	
5	13.2 – 17.0	3.8	3.8	100		12.1'–13.9' HALITE: Clear to light gray (N7) coarsely crystalline to 13'; then fine to medium < 1% gray intercrystalline clay. < 1% polyhalite to 13'. (2,9)	Run 5. Core broken in discs from 14.5 to 17' ±.
6	17.0 – 21.6	4.6	4.6	100		13.9'–14.5' ANHYDRITE a: Very light (N8) to medium gray (N5) microcrystalline anhydrite. Scattered halite growths. Thin, irregular halite layer at 14.3' ±. 14.5'–18.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. Scattered anhydrite to 16' ±. < 1 to 3% polyhalite, dispersed and blebs. (3,4,7)	
7	21.6 – 25	4.4	4.4	100			Run 7. Core broken up last 2' of run in clear halite.

BORING NO. DH-19

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 3 — BORING NO. DH-19

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
		25						
26.0	7		4.4	4.4	100		18.5'-23.8' HALITE: Clear to grayish brown (5YR 3/2) fine to coarsely crystalline. ≤ 1% clay, predominantly brown with some gray. Brown break at 19.8' ±. Coarse crystalline from 22.9', 3/4" anhydrite layer with grayish-brown clay break at 23.2'. Trace of dispersed polyhalite. (17)	
	8		4.4	4.4	100			Run 8. Broken up last 3".
		30					23.8'-27.5' HALITE: Clear, coarsely crystalline. Scattered irregular anhydrite laminae. (1, 8)	
30.4								
	9		4.7	4.7	100		27.5'-29.2' ARGILLACEOUS HALITE: Clear to medium brown (5YR 4/4) fine to coarsely crystalline. < 1 to 3% brown intercrystalline clay. ≤ 1/2% dispersed polyhalite. Trace of gray clay. (12)	Run 9. Core broken up last 2' of run but within one unit.
							29.2'-31.4' HALITE: Clear, coarsely crystalline. (1)	
35.1		35						
	10		4.2	4.2	100		31.4'-32.4' HALITE: Clear with some moderate brown (5YR 4/4, 3/4) coarsely crystalline < 1% brown clay. (8)	Run 10 & 11. Core broken up 38'-39.6'± all in clear halite.
							32.4'-35.3' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4; 3/4) medium to coarsely crystalline. < 1 to 4% brown clay. (10,16)	
39.3								
		40						
	11		4.8	4.8	100		35.3'-36.4' HALITE: Clear to moderate reddish orange 10R 6/6 and light gray (N7) fine to medium crystalline < 1/2% dispersed polyhalite and < 1% gray clay. (9)	
							36.4'-37.1' ANHYDRITE: Very light to light gray microcrystalline anhydrite. Scattered halite growths. Some horizontal laminae 1/2" brown clay seam at 36.4'.	
44.1								
	12	45	3.0	3.0	100			Run 12. Some broken core last 1.5'.
							37.1'-40.6' HALITE: Clear mottled with moderate reddish orange (10R 6/6) coarsely crystalline. ≤ 1% polyhalite blebs. Scattered white very light gray anhydrite/magnesite? (1,2)	
47.1	13		4.5	4.5	100			
		50					40.6'-43.0' HALITE: Clear with some moderate brown (5YR 3/4; 4/4) and mottled with moderate reddish orange (10R 6/6) fine to coarsely crystalline. < 1% polyhalite. < 1% clay. (2,17)	
51.6								
		55						

BORING NO. DH-19

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 3 OF 3 — BORING NO. DH-19

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
						43.0'-44.4' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4; 4/4) coarsely crystalline. <1 to 3% brown intercrystalline clay. (10)	
						44.4'-46.0' HALITE: Clear, coarsely crystalline. < 1% polyhalite blebs. (2)	
						46.0'-51.35' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4; 4/4) fine to coarsely crystalline. <1 to 3% brown clay, intercrystalline and scattered breaks. 3/8" brown clay seam at 51.0'. (12,16)	
						51.35'-51.6' HALITE: Clear, coarsely crystalline. ≤1% polyhalite blebs. (2)	

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-20

LOCATION N1100 DRIFT, FLOOR

STATION N1109± E206± COLLAR ELEV. 1306.2 DIRECTION OF DRILLING VERTICAL - DOWN

MINE COORDINATES N10,794.2 E7101.7 DEPTH OF BOREHOLE 51.1'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 1/31/84 (DAY) DATE COMPLETED 1/31/84 (DAY) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/5/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1	0.0–2.3	2.3	2.3	100		0.0'-2.05' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline. < 1 to 4% brown clay, intercrystalline. Break at 0.7'. [10]	Watson Drill. AW Rods. 3' single tube barrel to start hole from 0.0' to 4.6'. Then 5' NX double tube barrel.
2	2.3–4.6	2.3	2.3	100		2.05'-8.15' HALITE: Clear, medium to coarsely crystalline. ≤ 1% clay. Brown clay to 2.4', then gray. < 1/2% polyhalite. [2, 8]	Drill time: 5 hours. Dry; No gas.
3	4.6–8.6	4.0	4.0	100		8.15'-10.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 4% polyhalite. [7]	
4	8.6–13.6	5.0	5.0	100		10.4'-13.0' MB-139: From 10.4'-11.15' mixture of moderate reddish orange halite and anhydrite. From 11.15', predominantly white to light gray (N7) to medium gray (N5) microcrystalline anhydrite, some halite intergrowths. Tightly welded upper contact. Up to 1/2" gray, hard clay at lower contact dipping 15° ±. Halite laminae just above clay. Anhydrite is laminated. Near-horizontal, irregular tightly closed hairline fractures in core 12.2'-12.5'.	Core locally, broken up, disturbed due to drilling.
5	13.6–18.0	4.4	4.1	93.2		13.0'-17.15' HALITE: Clear to moderate reddish orange (10R 6/6) medium to coarsely crystalline. ≤ 1% polyhalite ≤ 1% gray and some brown clay. Break at 15.3'. [9, 17]	
6	18.0–22.9	4.9	4.5	91.8		17.15'-20.7' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 4% polyhalite increasing content 18.0'-20.7'. Gray clay < 1/16" at 20.7'. Some anhydrite mixed with halite 20.4'-20.7'. [3, 4, 7] 20.7'-22.85' HALITE: Clear mottled with moderate reddish orange and gray medium to coarsely crystalline. ≤ 1% polyhalite. ≤ 1% gray intercrystalline clay. Clear from 21.5'-21.9'. [9]	
7	22.9–25	5.0	4.9	98			

BORING NO. DH-20

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-20

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
7		5.0	4.9	98		22.85'-29.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 3% polyhalite. <1% gray intercrystalline clay. Some anhydrite 28.35'-28.55'±. [3, 4, 7]	
27.9							
8	30	4.9	4.9	100		29.0'-32.2' HALITE: Clear with some moderate reddish orange (10R 6/6) medium to coarsely crystalline. < 1/2% gray intercrystalline clay. < 1/2% dispersed polyhalite. [2,9]	
						32.2'-36.8' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 3% polyhalite. < 1% polyhalite from 34'-35.05'. Scattered anhydrite stringers below 35'. [3, 4, 7]	
32.8							
9	35	4.8	4.8	100		36.8'-37.8' HALITE: Clear, coarsely crystalline. ≤ 1% polyhalite. Scattered anhydrite stringers. Mixture of halite and some anhydrite at 37.1' to 37.5'. [2]	
37.6						37.8'-38.3' ANHYDRITE: White to light gray (N7), microcrystalline. Growths of halite especially common to 37.95'. Hard gray clay parting at 38.3'.	
10	40	5.0	5.0	100		38.3'-42.6' HALITE: Clear, some light gray (N7) to medium with some coarsely crystalline. ≤ 1% gray clay, locally up to 2%. Some brown clay present. Gray break at 39.25'. Brown colored break at 39.8'. [9, 11]	
42.6							
11	45	5.0	5.0	100		42.6'-45.8' HALITE: Clear, coarsely crystalline. <1/2% gray intercrystalline clay and polyhalite blebs. Break at 45.45'. [2, 11]	
						45.8'-47.6' HALITE: Clear to grayish brown, medium to coarsely crystalline. ≤ 1% brown clay, trace of gray. < 1% polyhalitic. [17]	
47.6							
12	50	3.5	3.5	100		47.6'-51.1' HALITE: Clear medium to coarsely crystalline. ≤ 1% dispersed gray clay and polyhalite. [9]	
51.1							
	55						

BORING NO. DH-20

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-21

LOCATION N1420 DRIFT, ROOF

STATION N1421 ± E786 ± COLLAR ELEV. 1331.0 DIRECTION OF DRILLING VERTICAL-UP

MINE COORDINATES N11,109.1 E7680.9 DEPTH OF BOREHOLE 50.4'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 2/26/84 (SWING) DATE COMPLETED 2/27/84 (SWING) SHEET

LOGGED BY: J. F. GALLERANI DATE: 3/6/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		2.3	2.3	100		0.0'-6.7' HALITE: Clear with some moderate reddish orange (10R 6/6); medium to coarsely crystalline. < 1% polyhalite and < 1/2% intercrystalline gray clay. 1/2" gray clay seam at 6.7'. [3, 9]	Watson drill: AW rods; NX double tube core barrel. Drilling time: 8 hrs±
2.3							No gas. Dry hole.
2	5	4.7	4.8	98		6.7'-11.0' HALITE: Clear, coarsely crystalline. Scattered white stringers of anhydrite/magnesite. [1]	Core shows discing, broken zones throughout.
						11.0'-11.8' HALITE: Clear to light gray (N7) coarsely crystalline, < 1% intercrystalline gray clay. [11]	
7.0							
3	10	4.6	4.3	94		11.8'-13.1' HALITE: Clear, medium to coarsely crystalline. < 1/2% dispersed polyhalite and gray clay. [1, 9]	Run 2. Some broken core.
11.6						13.1'-17.9' HALITE: Clear to light gray (N7) and locally grayish brown. Coarsely crystalline. None to ≤ 1% intercrystalline gray clay. Trace brown clay at 17.3'-17.5'±. Clear halite at 13.1'-14.4' and 17.7'-17.9' ±. [11]	Run 3. Broken core, discing.
4	15	4.1	4.1	100			Run 4. Discing throughout.
							Run 5. Broken core much of run.
15.7						17.9'-19.2' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline. < 1 to 3% intercrystalline brown clay, trace of gray. Break at 18.95'. [12, 17]	Run 6. Discing below anhydrite in this run.
5		3.0	2.7	90		19.2'-19.8' ANHYDRITE: White to light gray (N7) microcrystalline anhydrite to 19.6'. Then mixture of polyhalitic halite and anhydrite. Irregular laminae in some of the anhydrite. Up to 3/4" hard brown clay at 19.2'. Some core grinding noted.	
18.7							
6	20	4.6	4.6	100		19.8'-26.0' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6 ; 10R 4/6). Coarsely crystalline. < 1/2% clay and anhydrite locally. [3-5, 7]	Contact at 26.0' is approximate due to broken up core.
23.3							
	25						

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-21

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
7		4.7	4.2	89		26.0'-27.0' HALITE: Clear to light moderate reddish orange (10R 6/6). Fine to medium, some coarsely crystalline. < 1% dispersed polyhalite.	Run 7. Much of the core is broken up.
						27.0'-29.3' HALITE: Clear, mottled with moderate brown (5YR 3/4), and dark reddish brown (10R 3/4). Coarsely crystalline. < 1/2% polyhalite and < 1% brown clay. [2, 8]	Run 8. Discing, broken core in part of run.
28.0							Run 9. Discing, broken core in most of run.
8	30	5.0	4.7	94		29.3'-31.1' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4) and dark reddish brown (10R 3/4). Medium to coarsely crystalline. < 1 to 4% brown clay, intercrystalline and breaks throughout. [15]	Runs 10, 11, 12. Discing in coarse crystalline halite.
33.0							
9	35	4.7	4.7	100		31.1'-33.0' HALITE: Clear to moderate brown (5YR 4/4) and light moderate reddish orange (10R 6/6). Fine to coarsely crystalline. < 1/2% dispersed polyhalite. < 1% intercrystalline brown clay. Mostly brown clay mixed with some halite at 32.7-32.9'. Break at 33.0'. [12, 17]	
37.7							
10	40	4.3	4.3	100		33.0'-41.35' POLYHALITIC HALITE: Clear mottled with moderate reddish orange (10R 6/6), moderate reddish brown (10R 4/6), and moderate brown (5YR 3/4). Coarsely crystalline. < 1 to 3% polyhalite blebs and patches. < 1/2% brown intercrystalline and intracrystalline clay. [4, 5, 7]. Mostly brown clay with some halite at 37.7-37.95'. ≥ 5% clay at 38.45-38.65'±. [10]	
42.0						41.35'-42.0' ARGILLACEOUS HALITE: Moderate brown (5YR 3/4; 4/4) to reddish brown (10R 3/4), medium crystalline. < 3 to 10% brown clay. [10, 16]	
11	45	4.0	4.0	100		42.0'-44.9' HALITE: Clear mottled with moderate reddish orange/brown (10R 6/6; 4/6) polyhalite blebs and patches. Coarsely crystalline. ≤ 1% polyhalite. 1/2" anhydrite layer at 42.2'. No clay. This core is similar to some found from 33-35' but less polyhalite. [2-4]	
46.0							
12	50	4.4	4.4	100		44.9'-48.6' HALITE: Clear to moderate brown (5YR 3/4; 4/4), coarsely crystalline. < 1 to 2% brown intercrystalline and intracrystalline clay. > 10% brown clay at 46.0-46.3'±. Break at 46.4'±. [10]	
50.4							
	55					48.6'-50.4' HALITE: Clear, some moderate brown (5YR 4/4), medium to coarsely crystalline. < 1% brown, trace gray, intercrystalline clay. < 1/2% polyhalite. [8]	

BORING NO. DH-21

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-22

LOCATION N1420 DRIFT - FLOOR

STATION N 1421.5 ± E 785.5 COLLAR ELEV. 1318.8 DIRECTION OF DRILLING VERTICAL - DOWN

MINE COORDINATES N 11,109.2 E 7680.9 DEPTH OF BOREHOLE 51.0'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 2/27/84 (SWING) DATE COMPLETED 2/29/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/6/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		4.8	4.8	100		0.0'-5.1' HALITE: Clear, coarsely crystalline, < 1% gray intercrystalline clay locally, < 1/2% polyhalite. [1]	Watson drill AW rods. NX double tube core barrel. Drilling time: 8-1/2 hours ±
	4.8					5.1'-9.5' HALITE: Clear to light and medium gray (N7, N5) coarsely crystalline. ≤ 1% gray intercrystalline clay. Steeply dipping, irregular break at 7.65'-7.8'. [11]	Overall core quality is good. Only a couple of broken zones. No gas. Dry hole.
2	5	4.0	4.0	100		9.5'-11.7' HALITE: Clear to light moderate reddish orange (10R 6/6), coarsely crystalline. ≤ 1% polyhalite, blebs and dispersed. [3]	
	8.8					11.7'-15.0' HALITE: Clear to light gray (N7), some moderate reddish orange (10R 6/6), coarsely crystalline. ≤ 1% gray intercrystalline clay and < 1/2% dispersed polyhalite. [9]	
3	10	1.7	1.7	100			
	10.5					15.0'-21.55' HALITE: Clear, coarsely crystalline. None to < 1% polyhalite blebs. < 1/2% gray intercrystalline clay locally. [1.2]	Run 4. Broken up top 0.2' of run.
4		4.6	4.6	100			
	15.1					21.55'-24.3' MB-139: From 21.55' to 23.10' core shows "swallowtail" pattern a mixture of anhydrite and halite. Slight trace of gray clay on upper contact which dips 35°±. Predominantly halite from 23.10'-23.2'. Then mostly it gray (N7) to white anhydrite with scattered halite growths irregular laminae. Several hairline, tightly closed fractures at 23.9'-24.15' ±. Horizontal halite laminae at 23.2' ±. Trace of gray clay at 24.3'.	
5	15	2.0	2.0	100			Run 5. Core spring worn out. Left 3' of core in hole.
	17.1						
6		3.9	3.1	79		24.3'-28.0' HALITE: Clear to light gray (N7), medium to coarsely crystalline. ≤ 1% gray intercrystalline clay. < 1/2% polyhalite. Break at 25.2'. [9]	Run 6. Broken up 17.5' - 18.5'.
	20						
	21.0						
7		4.1	4.1	100			
	25						
	25.1						

BORING NO. DH-22

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-22

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
25.1	8		4.7	4.7	100		28.0'-32.25' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 3% polyhalite. Anhydrite mixed with halite at 32.0'-32.25'. (7)	
29.8	9	30	4.7	4.7	100		32.25'-34.5' HALITE: Clear with some light gray (N7), coarsely crystalline. ≤1% gray clay. Breaks at 33.85', 34.3'. (9,11) 34.5'-40.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% gray intercrystalline clay. Breaks at 38.0', 38.25'. <1 to 3% polyhalite. (3,4,7)	
34.5	10	35	4.1	4.1	100		40.5'-43.7' HALITE: Clear, medium to coarsely crystalline. <1% gray clay and<1/2% dispersed polyhalite. Break at 41.3'. (9) 43.7'-47.85' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 4% polyhalite. < 1/2% gray clay locally. (7)	
38.6	11	40	5.1	5.1	100		47.85'-48.4' ANHYDRITE: mixed halite and moderate reddish brown (10R 4/6) anhydrite to 48.1'. From 48.1', mostly very light gray (N8) to white and moderate reddish brown (10R 4/6) anhydrite with scattered halite growths. <1/8" clay seam at 48.4'. 48.4'-50.0' HALITE: Clear, coarsely crystalline. <1% gray intercrystalline clay. Break at 49.75'. (11)	
43.7	12	5	2.0	2.0	100			
45.7	13		4.3	4.3	100			Run 13. Broken up upper part of run.
50.0		50						

BORING NO. DH-22

WIPP

WASTE ISOLATION PILOT PLANT

GEOLOGIC DRILL LOG

INSTRUMENT TYPE & NUMBER ____ - ____ HOLE TYPE/SIZE NX CORE BORING NO. DH-23

LOCATION N1100 DRIFT; ROOF

STATION N1112± E781± COLLAR ELEV. 1328.03 DIRECTION OF DRILLING VERTICAL - UP

MINE COORDINATES N10,799.2 E7679.9 DEPTH OF BOREHOLE 51.0'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 2/13/84 (SWING) DATE COMPLETED 2/15/84 (SWING) SHEET

LOGGED BY: J. E. GALLERANI DATE: 3/5/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1	0.0	2.1	2.1	100		0.0'-1.2' HALITE: Clear to light moderate reddish orange (10R 6/6), fine to coarsely crystalline. < 1/2% gray clay. Break at 0.25'. [2, 9]	NX Double tube core barrel. AW Rods. Watson drill mounted on single post jacked to floor/roof. Drilling time: 7 hours ±.
2	2.1	2.2	2.2	100		1.2'-1.9' ANHYDRITE a: White to medium light gray (N6) microcrystalline anhydrite. Growths of halite within. Gray clay seam < 1/16" at 1.2'.	No gas. Dry hole.
3	4.3	2.0	2.0	100		1.9'-6.25' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. [3]	Core recovery difficult to measure because core is sometimes broken up into 1/2" to 1-1/2" discs and gravel size pieces.
4	6.3	1.7	1.7	100			
5	8.0	1.75	1.75	100		6.25'-11.05' HALITE: Clear, some moderate brown (5YR 4/4), coarsely crystalline, some fine to medium. Brown and gray clay < 1%. Brown clay seam ≤ 1/16" with some anhydrite at 11.05'. [9, 17]	Run 2. Broken up last 0.6'.
6	9.75	4.5	4.5	100		11.05'-14.25' HALITE: Clear, coarsely crystalline. Scattered white stringers of anhydrite/magnesite?. [1]	Run 3. Broken up some/ discing.
							Run 6. Broken up 12-14'±.
7	14.25	1.45	1.45	100		14.25'-19.3' HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline. None to 2% brown clay. < 1 to 2% clay from 14.25-15.7' and 18.5-19.3'. Clear from 17.0-18.5'. [8, 10]	Run 7. Zones of broken core.
8	15.7	2.0	2.0	100			Run 8. Broken up last 0.6' of run.
9	17.7	3.0	3.0	100		19.3'-23.5' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4), coarsely crystalline. Some fine to medium. < 1 to 4% brown clay. [8, 10]	Run 10. Some broken zones above and below anhydrite.
10	20.7	4.75	4.75	100		23.5'-24.4' ANHYDRITE: White to very light gray (N8) microcrystalline anhydrite. Scattered polyhalitic halite growths, especially common 24-24.4'±. 3/4" brown clay seam at 23.5'.	
	25						

BORING NO. DH-23

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-23

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
25.45	10	25	4.75	4.75	100		24.4'-28.15' HALITE: Clear, some moderate reddish orange, coarsely crystalline. < 1% polyhalite blebs. 1/2" white anhydrite layer at 25.1'±. Up to 3% polyhalite with trace gray clay at 27.45-27.95'. [2]	Run 11. Broken zones beyond 26.7'.
	11		4.3	4.3	100		28.15'-31.45' HALITE: Clear to moderate brown (5YR 4/4) and moderate reddish orange (10R 6/6), coarsely crystalline, some fine. Brown clay < 1 to 2%, locally. < 1 to 2% polyhalite blebs and patches. [17]	Run 15. Broken up last 12"± of run.
29.75		30						Contact at 28.15 is approximate due to broken core in Run 11.
	12		4.25	4.25	100		31.45'-33.2' HALITE: Clear, coarsely crystalline. < 1% brown clay blebs. [8]	
34.0							33.2'-36.5' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4) and some moderate reddish orange (10R 6/6). Coarsely crystalline. < 1 to 3% brown clay, intercrystalline and breaks. 1/4"± brown clay seam at 33.8'±. ≤ 1/16" clay partings at 35.4' and 36.5'. [10]	
	13	35	4.4	4.4	100		36.5'-38.1' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. ≤ 1% polyhalite blebs and patches. Scattered anhydrite stringers. [2, 3]	
38.4							38.1'-41.65' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite blebs and patches. < 1/2% gray clay. Trace brown clay at 41.65'. [4, 5]	
	14	40	5.0	4.9	98		41.65'-42.9' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4), coarsely crystalline, some medium. < 1 to 5% brown clay. 1" brown clay seam with some halite at 42.7'. [12, 17]	
43.4							42.9'-44.3' ANHYDRITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline. ≤ 1% polyhalite. [2, 5]	
	15	45	4.4	4.4	100		44.3'-46.2' HALITE: Clear to moderate reddish orange (10R 6/6) and moderate brown (5YR 4/4). Coarsely crystalline to 44.9', then fine to medium. ≤ 1% brown and gray clay. < 1% dispersed polyhalite. < 1/4" brown clay seam at 46.05'. Anhydrite at 46.05-46.2'. [9, 17]	
47.8							46.2'-48.25' HALITE: Clear, coarsely crystalline. < 1% moderate reddish orange polyhalite blebs. [1]	
	16	50	3.2	3.2	100		48.25'-51.0' HALITE: Clear to moderate reddish brown (10R 4/6) coarsely crystalline. < 1 to 2% brown clay and ≤ 1% polyhalite blebs. [8, 10]	
51.0		55						

BORING NO. DH-23

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-24

LOCATION N1100 DRIFT; FLOOR

STATION N 1112 ± E 781 ± COLLAR ELEV. 1319.51 DIRECTION OF DRILLING DOWN - VERTICAL

MINE COORDINATES N10,799.2 E7679.8 DEPTH OF BOREHOLE 49.4'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 2/15/84 (SWING) DATE COMPLETED 2/16/84 (DAY) SHEET

LOGGED BY: J.E. GALLERANI DATE: 3/5/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		1.6	1.5	94		0.0'-3.3' HALITE: Clear, coarsely crystalline. < 1/2% polyhalite blebs.	Watson drill. AW rods. NX double tube core barrel mounted on post jacked to floor/roof. Still vibration from drill motor, but post is stable.
2	1.6	1.5	1.5	100		3.3'-5.2' HALITE: Clear, coarsely crystalline. < 1/2% gray clay and polyhalite blebs.	
3	3.1	2.9	2.9	100		5.2'-7.15' HALITE: Clear to light gray (N7) medium to coarsely crystalline. ≤1% gray clay, locally up to 2%. Breaks and intercrystalline. Breaks at 6.05'; 6.85'. < 1/2% polyhalite.	
4	6.0	4.5	4.5	100		7.15'-10.7' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline < 1% to 2% polyhalite blebs and dispersed increasing content from 9.1' to 10.7'. Gray clay break at 10.35'.	Run 5. Several broken zones in core. Loss throughout. Contacts at 10.7'; 12.6' approximate only.
5	10.5	5.3	3.6	68		10.7'-12.6' HALITE: Clear to light gray (N7) and light bluish gray (5B 7/1) medium to coarsely crystalline. ≤ 1% gray intercrystalline clay. Break at 10.9'.	
6	15.8	5.0	5.0	100		12.6'-20.8' HALITE: Clear, coarsely crystalline. 1/2% polyhalite blebs. None to < 1% gray intercrystalline clay. Break at 20.75'.	
7	20.8	5.0	5.0	100		20.8'-24.0' MB-139: From 20.8' to 22.4' is mixture of anhydrite and halite. "Swallowtail" pattern. From 22.4 to 24.0' is white to medium gray (N5) microcrystalline anhydrite. Scattered halite growths. Irregular laminae in core. Tightly closed hairline fractures in core from 23.5' to 24.0'. Up to 3/4" gray clay.	
						24.0'-28.3' HALITE: Clear with some moderate reddish orange (10R 6/6) and light gray (N7), medium to coarsely crystalline, some fine. < 1/2% dispersed polyhalite and < 1% gray intercrystalline clay. Breaks at 24.4'; 24.8'.	

BORING NO. DH-24

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-24

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
7	25.8	5.0	5.0	100		28.3'–31.8' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. Up to 1" anhydrite layer in core.	
8	30.7	4.9	4.9	100		31.8'–34.2' HALITE: Clear with some light gray (N7), medium to coarsely crystalline < 1% gray intercrystalline clay. < 1/2% dispersed polyhalite. Core broken up in this section. Some core loss.	Run 9. Broken up last 1/2 of core. Probable loss from 32.1'–34.2'.
9	34.2	3.5	3.5	100		34.2'–35.2' HALITE: Clear, coarsely crystalline. < 1% polyhalite blebs.	
10	39.4	5.2	5.2	100		35.2'–38.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), some medium light gray (N6), coarsely crystalline. < 1 to 3%, locally to 5%, polyhalite. < 1/2% gray clay.	Run 11. Measured rods 42.4". Probable loss within last 2" of run.
						38.4'–43.0' HALITE: Clear with some light moderate reddish orange (10R 6/6) fine to coarsely crystalline. < 1/2% dispersed polyhalite and gray clay. 0.5' core loss within this zone.	
11	42.4	3.0	2.5	83		43.0'–44.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. < 1 to 5% polyhalite.	
12	47.7	5.3	5.3	100		44.4'–48.25' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. ≤ 1% polyhalite blebs, patches and dispersed. Predominantly polyhalite 47.35'–47.45'.	
						48.25'–48.6' ANHYDRITE: Very light gray (N8) to medium light gray (N6) microcrystalline anhydrite. Scattered halite growths. Up to 1" clear, coarsely crystalline halite from 48.3'–48.4' ±. < 1/16" gray clay at 48.6'. Some core grinding evident.	
13	49.4	1.7	1.7	100		48.6'–49.4' HALITE: Clear to light gray (N7); medium to coarsely crystalline. < 1 to 2% gray clay. Breaks at 48.7' and 49.0'.	
						Note: Overall recovery below 95%. Replacement hole DH-24A drilled later. Refer to the drill log for DH-24A.	

BORING NO. DH-24

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-24A

LOCATION N1100 DRIFT - FLOOR

STATION N1112 ± E780 ± COLLAR ELEV. 1319.49 DIRECTION OF DRILLING VERTICAL - DOWN

MINE COORDINATES N10799.08 E7678.59 DEPTH OF BOREHOLE 50.4'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL WATSON

DATE STARTED 3/21/84 (SWING) DATE COMPLETED 3/22/84 (SWING) SHEET 1 OF 2

LOGGED BY: J. E. GALLERANI DATE: 3/23/84

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0						
1	0.0	2.2	2.0	91	X	0.0'-0.1' FILL:	Watson Drill AW rods.
2	2.2	2.8	2.8	100	—	0.1'-3.3' HALITE: Clear to light moderate reddish orange (10R 6/6); coarsely crystalline. < 1/2% dispersed polyhalite. [1, 2]	Run 1. Used 3' double tube barrel first run to start hole.
	5						
3	5.0	5.1	5.1	100	— X X X	3.3'-7.4' HALITE: Clear to medium gray (N5); coarsely crystalline. ≤ 1% gray clay. [1, 11] 7.4'-10.2' HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. ≤ 1% polyhalite, increasing content 9.2' to 10.2'. [2, 3]	NW split tube barrel used after first run.
	10						
4	10.1	5.1	5.1	100	— X — X	10.2'-15.9' HALITE: Clear to medium light gray (6); light bluish gray (5B-7/1) and light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. ≤ 1% gray clay. Breaks at 10.95'; 11.85'. < 1/2% polyhalite. [11]	Drill Time: 5 hours ±.
	15						
5	15.2	5.1	4.9	96	— X —	15.9'-21.3' HALITE: Clear with some light moderate reddish orange; coarsely crystalline, some medium. < 1/2% gray clay and polyhalite. [2] 21.3'-23.95' MB-139: From 21.3' to 22.5' is mixture of anhydrite and halite partially in a "swallowtail" pattern. Upper contact dips 20° ± with tightly closed fracture along base. Below 22.5' is white to light gray (N7) to moderate reddish orange anhydrite scattered halite growths. 1/2" gray clay at lower contact.	
	20						
6	20.3	5.1	5.1	100	— X	23.95'-28.6' HALITE: Clear to light moderate reddish orange 10R 6/6 and trace of light gray (N7) medium to coarsely crystalline. < 1% dispersed polyhalite and < 1/2% gray clay. [2, 3, 9]	
	25						
	25.4						

BORING NO. DH-24A

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-24A

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
7		5.0	5.0	100		28.6'-32.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. Irregular gray clay break at 32.1'. [2, 4, 7]	
	30					32.1'-34.4' HALITE: Clear to medium light gray (N6) and light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. < 1/2% dispersed polyhalite and < 1/2% gray clay. [9]	
8		5.0	5.0	100		34.4'-40.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline with some medium. None to 3% polyhalite. < 1/2% gray clay locally. [2-5, 7]	
	35					40.5'-43.7' HALITE: Clear to medium light gray (N6) and some light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. ≤ 1% gray intercrystalline clay and < 1/2% dispersed polyhalite. [9]	Run 9. Driller increased RPM's on last 2' of run.
9		5.0	3.0	60		43.7'-48.55' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite. < 1/2% gray clay locally. [3, 4, 7]	
	40					48.55'-49.2' HALITE: Clear, coarsely crystalline, some medium. Scattered white anhydrite stringers. [1, 2]	
10		4.9	4.9	100		49.2'-49.5' ANHYDRITE: White to medium light gray (N6), microcrystalline. Scattered halite growths. Trace of gray clay at 49.5'.	
	45					49.5'-50.4' HALITE: Clear with some moderate reddish orange (10R 6/6); medium to coarsely crystalline. < 1% polyhalite. < 1/2% gray clay. [1, 9]	
11		5.1	5.1	100			
	50						
	55						

25.4 — 30.4 — 35.4 — 40.4 — 45.3 — 50.4

BORING NO. DH-24A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ HOLE TYPE/SIZE NX BORING NO. DH-25

LOCATION N1420 Drift at Room C-2 Intersection

STATION N 1422, E 1510 COLLAR ELEV. 1318.8 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N 11109.72, E 8403.78 DEPTH OF BOREHOLE 51.8'

DRILLING METHOD Rotary/Air DRILL MAKE/MODEL Watson Model 750

DATE STARTED 3/29/84 (swing) DATE COMPLETED 3/30/84 (swing) SHEET

LOGGED BY: J. E. Galleroni DATE: 4/18/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0						
0.0							
1		2.5	2.5	100		0.0'-4.6' HALITE: Clear to light gray (N7) and light moderate reddish orange (10R 6/6), medium to coarsely crystalline. < 1% gray clay. < 1/2% dispersed polyhalite. [1, 9]	Watson drill, post-mounted, AW rods, S&H NX double-tube.
5							Drilling time: 5 hrs. ±
2		4.4	4.4	100		4.6'-7.0' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. 1/2" gray anhydrite layer at 4.85'. Trace of gray clay at 4.85'. [1]	
	5					7.0'-9.3' HALITE: Clear to light gray (N7) and some moderate brown (5YR 4/4). Fine to coarsely crystalline. ≤1% gray clay. ≤ 1% brown clay from 8.5'-8.85'. Clay break at 8.6'. [11]	
6.9							
3		4.0	4.0	100		9.3'-12.4' HALITE: Clear, coarsely crystalline. [1]	
	10					12.4'-15.4' HALITE: Clear to light gray (N7), medium light gray (N6), and locally some moderate reddish orange (10R 6/6). Medium to coarsely crystalline. ≤ 1% gray clay. 1/2" clay and halite seam at 15'. < 1/2% dispersed polyhalite. [11]	
10.9							
4		5.0	5.0	100		15.4'-16.9' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline. < 1 to 3% brown clay, trace gray. [12, 16]	
	15						
15.9							
5		1.0	1.0	100		16.9'-17.4' HALITE: Clear, coarsely crystalline. < 1/2% dispersed polyhalite. [2]	
16.9							
6		3.6	3.6	100		17.4'-18.15' ANHYDRITE: White to medium light gray (N6), microcrystalline anhydrite. Faintly laminated. Growths of halite within. Trace of brown clay at 17.4'. Some polyhalite along upper contact.	Run 6: Broken-up last 12" of run.
	20					18.15'-21.6' HALITE: Clear mottled with moderate reddish orange (10R 6/6), coarsely crystalline. None to 2% polyhalite. [1, 2]	
20.5							Run 7. Discing of core.
7		5.4	5.4	100			
	25						

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-25

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
25.9	7	25	5.4	5.4	100		21.6'-27.4' HALITE: Clear to moderate brown (5YR 4/4), fine to coarsely crystalline. < 1 to 2% brown clay, locally argillaceous. Breaks at 21.8'±, 23.6'±,24.0'±. Brown clay seam at 24.05'. Coarsely crystalline 24.1'-27.4'. [8, 10, 12]	
	8	30	5.0	5.0	100		27.4'-29.6' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline, some fine. < 1 to 4% brown clay, intergranular and scattered breaks. [12]	
30.9	9		4.4	4.4	100		29.6'-34.3' POLYHALITIC HALITE: Clear to moderate reddish orange, coarsely crystalline. < 1 to 3% polyhalite. Average <2%. [3, 4]	Run 9. Broken-up core, discing.
							34.3'-35.3' HALITE: Clear, coarsely crystalline. < 1/2% polyhalite blebs. [1]	
35.3	10	35	0.9	0.9	100		35.3'-48.5' HALITE: Clear with patches of moderate brown (5YR 3/4; 4/4) and traces of moderate reddish orange (10R 6/6). Coarsely crystalline, some medium to 36.4'. < 1 to 2% brown clay. 1/2" brown clay seam with some halite at 36.25'. Mostly brown clay mixed with halite from 38.9-39.2'. > 30% clay here. ≤ 1% polyhalite blebs and patches. Clay breaks at 46.6'±, 46.8'±, 47.2'±, 48.5'. Argillaceous halite at 46.35'-47.2'. [1, 8, 10]	Run 10. Broken-up core.
36.2	11	40	4.6	4.6	100		48.5'-49.7' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. [3, 4]	
40.8	12		1.3	1.3	100		49.7'-51.8' HALITE: Clear with some light gray (N7) and moderate reddish orange (10R 6/6). Coarsely crystalline. ≤ 1% gray clay and polyhalite blebs and patches. [9, 11]	Run 12. Broken-up core.
42.1	13	45	4.7	4.7	100			
46.8	14	50	5.0	5.0	100			
51.8								

BORING NO. DH-25

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ HOLE TYPE/SIZE NX Core BORING NO. DH-26

LOCATION N1420 Drift at Room C-2 Intersection

STATION N 1427, E 1510 COLLAR ELEV. 1307.2 DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N 11114.32, E 8403.78 DEPTH OF BOREHOLE 53.0 Ft.

DRILLING METHOD Rotary/Air DRILL MAKE/MODEL Watson Model 750

DATE STARTED 3/30/84 (swing) DATE COMPLETED 3/30/84 (swing) SHEET

LOGGED BY: J. E. Gallerani DATE: 4/19/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		4.2	4.2	100		0.0'-6.2' HALITE: Clear, coarsely crystalline, some medium. < 1/2% gray intercrystalline clay. < 1/2% polyhalite. [1, 2]	Watson drill, AW rods, NX double-tube core barrel, except run 4 where NW split-tube barrel was used.
	4.2					6.2'-9.8' HALITE: Clear to medium light gray (N6), coarsely crystalline. ≤ 1% gray clay. Breaks at 7.75', 8.1', 9.6'. [11]	Drill time: 4 hrs. No gas. Dry hole.
2	5	3.3	3.3	100		9.8'-12.5' HALITE: Clear to light moderate reddish orange (10R 6/6), coarsely crystalline. ≤ 1% polyhalite [1, 2]	Overall core is fair with some broken zones and discing.
	7.5					12.5'-19.3' HALITE: Clear to medium light gray (N6) and light moderate reddish orange (10R 6/6). Fine to coarsely crystalline. ≤ 1% gray clay. < 1/2% polyhalite. [1, 9]	Run 2. Discing of core.
3	10	4.6	4.6	100		19.3'-21.8' HALITE: Clear with some moderate reddish orange (10R 6/6), coarsely crystalline. None to < 1% polyhalite. [1, 2]	
	12.1					21.8'-23.3' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. Scattered anhydrite. < 1/2% gray clay. [4, 6]	Run 4. Tried split-tube core barrel but barrel plugged-off while drilling.
4		1.4	0.85	61			
	13.5					23.3'-25.9' MB-139: Very light gray (N8) to medium light gray (N6) anhydrite with scattered halite growths. Anhydrite is partly laminated. 1-1/2" hard gray clay seam at lower contact.	
5	15	4.7	4.7	100		25.9'-29.8' HALITE: Clear to moderate reddish orange (10R 6/6) and light gray (N7). Medium to coarsely crystalline. ≤ 1% gray clay and < 1% polyhalite. [2, 9]	
	18.2					29.8'-33.3' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. Gray clay break at 33.3'. Anhydrite mixed with halite from 33.05'-33.3'. [7]	
6	20	5.0	5.0	100		33.3'-36.0' HALITE: Clear with some moderate reddish orange (10R 6/6) and light gray (N7). Medium to coarsely crystalline. < 1/2% dispersed polyhalite. < 1% gray intercrystalline clay. [9]	
	23.2						
	25						

BORING NO. DH-26

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-26

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
7		5.0	5.0	100		36.0'-41.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline to 39.6', then medium to coarse. < 1 to 3% polyhalite blebs and dispersed. < 1/2% gray clay locally. Scattered anhydrite 39.6'-40.0'±. [3, 7]	
28.2							
8	30	4.8	4.8	100		41.0'-44.0' HALITE: Clear to light bluish gray (5B 7/1) and light gray (N7) and some moderate reddish orange, medium to coarsely crystalline. ≤ 1/4" gray clay seams at 36.1'± and 41.7'±. ≤ 1% clay. [9]	
						44.0'-48.8' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. < 1 to 3% polyhalite. [7]	
33.0							
9	35	5.0	5.0	100		48.8'-49.6' ANHYDRITE: Moderate reddish orange anhydrite to 49'. Then halite with some anhydrite from 49'-49.1'. Then medium light gray (N6) to light gray (N7) anhydrite. Trace of gray clay at 49.6'.	
						49.6'-53.0' HALITE: Clear to medium light gray (N6), medium to coarsely crystalline. ≤ 1% gray clay. < 1/2% dispersed polyhalite. [1, 9]	
38.0							
10	40	5.0	5.0	100			
43.0							
11	45	5.0	3.6	72			Run 11. Discing of core.
48.0							Run 12. Broken-up in upper one foot. Considerable chipping of core surface below the anhydrite.
12	50	5.0	5.0	100			
53.0							
	55						

BORING NO. DH-26

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-27

LOCATION ROOM G ACCESS DRIFT - ROOF

STATION N1107, W682 COLLAR ELEV. 1300.8 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10,793.7, E6218.4 DEPTH OF BOREHOLE 50.5'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 7-26-84 DATE COMPLETED 7-27-84 SHEET

LOGGED BY: J. GALLERANI DATE: 7-28-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0	3.0	2.8	93		0.0'-4.5' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline, <1% polyhalite. [1, 2]	NC double tube wireline core barrel. NC rods.
	3.0					4.5'-5.8' HALITE: Clear to moderate brown (5YR 3/4), coarsely crystalline, some medium ≤1% to 2% locally, brown clay.. Parting @ 5.5'. [8, 10]	Note: Drilled 0.0-3.0' with 2-5/8" inside diameter single tube core barrel. Total drilling time: 13 hrs.
2		3.3	3.3	100		5.8'-6.95' HALITE: Clear to moderate reddish brown (10R 4/6), grayish red (10R 4/2), medium to coarsely crystalline, some fine ≤1% to 2% dispersed polyhalite and <1% gray and brown clay.	
	6.3					6.95'-7.20' ANHYDRITE b: Light (N7) to medium light gray (N6), microcrystalline anhydrite. Halite growths within, most common in middle of unit.	
3	8.5	2.2	2.2	100		7.20'-12.95' HALITE: Clear, coarsely crystalline, scattered white stringers of anhydrite. <1/2% polyhalite. Trace of gray clay @ 12.3'. [1]	
4	13.0	4.5	4.5	100		12.95'-13.95' HALITE: Clear to moderate reddish orange (10R 6/6), fine to coarsely crystalline. ≤1% polyhalite and <1% gray clay. [9]	
5	18.0	5.0	5.0	100		13.95'-14.55' ANHYDRITE a: Very light (N8) to medium light gray (N6), microcrystalline anhydrite, irregular laminae. Scattered halite growths most common from 14.25 to 14.55'. Pinkish gray color here. Trace of gray clay @ 13.95'.	
						14.55'-18.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline, <1% to 3% polyhalite. [4, 7]	
6	21.2	3.2	3.2	100		18.4'-23.9' HALITE: Clear to moderate brown (10R 4/6), some moderate reddish orange (10R 6/6), coarsely crystalline, some medium. None to 2% brown clay. ≤1% polyhalite from 22.1'-22.9' ±. Scattered anhydrite to 19.4' [8, 10]. ≤3/8" brown clay seam at 23.7'. 1/2" anhydrite above @ 23.85'.	
7		4.8	4.3	90		23.9'-28.6' HALITE: Clear, coarsely crystalline, trace brown clay from 27.2'± and some medium crystalline. [1] [8 from 27.2']	Runs 7-12: Broken core zones in coarsely crystalline, clear halite.

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-27

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
26.0	7	25	4.8	4.3	90		28.6'-30.5' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4), fine to medium, some coarsely crystalline. <1% to 3% brown clay. [12]	
	8	30	4.8	3.5	79		30.5'-32.4' HALITE: Clear, trace of light moderate brown, coarsely crystalline. <1/2% brown clay. Core broken up @ 30.8'-31.4'. [1, 8]	39% of core recovered was ≥2 inches in length.
30.8							32.4'-36.2' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4), some light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1% to 3% brown clay. <1/2% dispersed polyhalite. Scattered breaks. [10, 12]	
	9		3.8	3.7	97		36.2'-36.95' ANHYDRITE: Very light (N8) to light gray (N7), some moderate reddish orange anhydrite. Scattered halite growths within. 3/4" hard brown clay @ 36.2'.	
34.6		35					36.95'-40.3' HALITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline <1%, locally 2%, polyhalite, scattered white anhydrite stringers. [1, 3]	
	10		3.4	2.9	85			
38.0							40.3'-41.4' POLYHALITIC HALITE: Clear, to moderate reddish orange (10R 6/6), coarsely crystalline, <1% to 3% polyhalite. [4, W]	
	11	40	4.5	3.9	87		41.4'-42.55' HALITE: Clear, some moderate brown (5YR 4/4) coarsely crystalline, some medium, <1% brown clay, break @ 42.5'. [1, 8]	
42.5							42.55'-46.4' HALITE: Clear to moderate reddish orange (10R 6/6), some moderate brown (5YR 4/4). Coarsely crystalline, some medium. ≤2% polyhalite to 43'±; then <1% [1, 2]. ≤2% brown clay at 43.65'-43.9' [12]. Break @ 44.3'.	
	12	45	4.7	4.7	100		46.4'-47.2' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4), coarsely crystalline, <1% to 3% brown clay. Mixture of brown clay and halite seam at 47.1'-47.2'. [10]	
47.2							47.2'-48.3' HALITE: Clear to moderate reddish orange/brown (10R 6/6, 4/6), medium to coarsely crystalline. ≤1% brown clay, <1% polyhalite. [17]	
	13	50	3.3	3.3	100		48.3'-50.5' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline, some fine <2% to 5% brown clay. Scattered clay breaks [10, 15].	
50.5		55						

BORING NO. DH-27

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ - HOLE TYPE/SIZE NC-CORE BORING NO. DH-28

LOCATION ROOM G ACCESS DRIFT - FLOOR

STATION N1107, W682 COLLAR ELEV. 1289.9 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N10793.8, E6218.3 DEPTH OF BOREHOLE 50.5'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 7-25-84 DATE COMPLETED 7-26-84 SHEET

LOGGED BY: J. F. GALLERANI DATE: 7-27-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1	0	3.0	2.7	90		0.0'-4.2' HALITE: Clear, coarsely crystalline, some medium. <1% polyhalite, <1% clay, predominantly gray with trace of brown. [1, 2]	NC double tube wire-line core barrel with NC rods, Used 2-5/8" core bit, single tube barrel from 0.0'-3.0', Total drilling time: 4.5 hrs. Core quality good, 75% of core recovered is ≥ 2" lengths.
	3.0						
2	5	4.8	4.75	98		4.2'-5.6' HALITE: Clear, mottled with some moderate reddish orange (10R 6/6). Coarsely crystalline. ≤1% polyhalite blebs. Trace of anhydrite. [2, 4]	
						5.6'-9.9' MB-139: Mixture of polyhalitic halite and anhydrite to 7.6'. Some "swallowtail" pattern. Then predominantly anhydrite with scattered halite growths. Light gray and moderate reddish orange to 8.4', then predominantly light (N7) to medium light (N6) gray. <1/8" gray clay at 9.9'.	
	7.8						
3	10	5.2	5.1	98		9.9'-13.65' HALITE: Clear to medium light gray (N6) and light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1% dispersed polyhalite. <1% gray clay. [9]	
						13.65'-18.3' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. Scattered anhydrite. Anhydrite/halite @ 18.05'-18.25'. Irregular gray clay break at 18.3'. [4, 7]	
	13.0						
4	15	5.0	5.0	100		18.3'-20.4' HALITE: Clear to light gray (N7) and light moderate reddish orange (10R 6/6), medium to coarsely crystalline. ≤1% dispersed polyhalite and gray clay. [9]	
						20.4'-24.9' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite, trace of gray clay at 23.85'. [3, 4, 7]	
	18.0						
5	20	5.0	5.0	100		24.9'-25.9' HALITE: Clear to light moderate reddish orange (10R 6/6), medium to coarsely crystalline, ≤1% dispersed polyhalite. [2]	
						25.9'-28.1' HALITE: Clear to moderate reddish brown (10R 4/6) and medium brown (5YR 3/4), medium to coarsely crystalline. <1% to 2% brown clay. ≤1% polyhalite. [17]	
	23.0						
6	25	5.1	5.1	100			

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-28

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
6		5.1	5.1	100		28.1'-30.6' HALITE: Clear, medium to coarsely crystalline, <1/2% dispersed polyhalite, trace of gray clay locally. [2]	
28.1						30.6'-35.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline, <1% to 3% polyhalite [7]. Moderate reddish orange to light gray anhydrite, some halite, at 34.65'-34.9'.	
7	30	5.0	4.9	98		35.1'-35.35' ANHYDRITE: Light (N7) to medium light (N6) gray, microcrystalline. Scattered halite growths. ≤3/8" hard gray clay layer at lower contact.	
33.1						35.35'-42.55' HALITE: Clear to light moderate reddish orange (10R 6/6) and medium gray (N5). Medium to coarsely crystalline. <1% dispersed polyhalite, ≤1% gray clay. [9, 11]	
8	35	5.0	5.0	100		42.55'-44.6' HALITE: Clear to moderate reddish brown (10R 4/6) and moderate brown (5YR 3/4). Medium to coarsely crystalline, <1% to 2% brown clay, some gray, <1% polyhalite dispersed. [17, some 9]	
35.1						44.6'-47.9' HALITE: Clear to moderate reddish orange (10R 6/6), some medium gray (N5). Medium to coarsely crystalline, ≤1% polyhalite and ≤1/2% gray clay. [9]	
9	40	4.9	4.6	94		47.9'-50.5' HALITE: Clear, coarsely crystalline. [1]	
43.0							Core broken up at 39.6'-39.8'±.
10	45	5.0	5.0	100			
48.0							
11	50	2.5	2.5	100			
50.5							

BORING NO. DH-28

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC-CORE BORING NO. DH-29

LOCATION ROOM G ACCESS DRIFT - ROOF

STATION N1099, W982 COLLAR ELEV. 1298.3 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10785.4, E5932.4 DEPTH OF BOREHOLE 50.4'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 7-23-84 DATE COMPLETED 7-25-84 SHEET

LOGGED BY: J. F. GALLERANI DATE: 7-25-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		2.2	2.2	100		0.0'-3.9' HALITE: Clear, coarsely crystalline. [1]	NC double tube wire line core barrel, NC stepped diamond bit. Used 2 ft starter barrel (2-5/8" core) from 0'-6.1' Total drilling time: 13±hrs.
	2.2					3.9'-6.3' HALITE: Clear to moderate brown (5YR 3/4), coarsely crystalline, <1% to 2% brown clay.	
2		1.8	1.8	100		6.3'-7.55' HALITE: Clear to moderate brown (5YR 4/4) and grayish red. Fine to medium, some coarse, ≤1% clay, brown and gray. <1/2% dispersed polyhalite.	
	4.0						
3		2.1	2.1	100		7.55'-7.75' ANHYDRITE b: Light gray (N7), micro-crystalline, scattered halite growths. Trace of gray clay at 7.55'.	
	6.1						Run 4: 6.1'-10.0', core not good, discing in clear halite.
4		4.6	4.6	100		7.75'-13.25' HALITE: Clear, coarsely crystalline. <1/2% polyhalite, Scattered white stringers.	
	10.7					13.25'-14.3 HALITE: Clear to moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1% gray clay. ≤1% to 2% polyhalite dispersed.	Run 5: core not good, average length ~1" (discing).
5		4.1	4.1	100		14.3'-14.8' ANHYDRITE a: Light gray to medium light gray microcrystalline anhydrite. Scattered halite growths. Trace of gray clay at 14.2'.	
	14.8					14.8'-19.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline, <1% to 3% polyhalite.	
6		4.7	4.7	100		19.6'-22.5' HALITE: Clear, some moderate brown, coarsely crystalline, some fine and medium. ≤1% brown clay. <1/2% dispersed polyhalite. Breaks at 20.75', 21.5'.	
	19.5					22.5'-24.4' HALITE: Clear, to moderate brown, fine to medium, some coarsely crystalline. <1% brown clay. <1/2% dispersed polyhalite.	
7		4.9	4.9	100		24.4'-27.7' HALITE: Clear, coarsely crystalline. Scattered white anhydrite.	Run 7: bottomed in brown clay seam. Vibrated and broke core.
	24.4					27.7'-29.9' HALITE: Clear, mottled with moderate brown, coarsely crystalline, some medium. ≤1% to 2% brown clay. Core broken up to 29.2'.	

BORING NO. DH-29

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-29

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					29.9'-31.7' HALITE: Clear, coarsely crystalline.	
8		4.8	4.8?	100?		31.7'-32.4 HALITE: Clear, some light moderate brown. Coarsely crystalline. <1/2% brown clay.	
	29.2					32.4'-37.35' ARGILLACEOUS HALITE: Clear to moderate brown, medium to coarsely crystalline. <1% to 3% brown clay, scattered breaks.	Run 9: Very bad core 29.2'-33.0'.
9	30	5.0	5.0	100		37.35'-38.25 ANHYDRITE: Light gray to medium light gray, microcrystalline anhydrite. Scattered halite growths. 1" hard brown clay layer at 37.35".	
	34.2					38.25'-44.4' HALITE: Clear, coarsely crystalline. None to <1% brown clay. Scattered white stringers. [1], [2]. Brown clay parting at 44.4'.	Circulation blocked @ 37.3'. Hit mud seam.
10	35	5.0	5.0	100		44.4'-46.65 HALITE: Clear to moderate brown, coarsely crystalline, some zones of medium. <1% to 3%, locally, brown clay. Breaks at 46.35', 46.5' Argillaceous 44.4'-45.0' and 46.35'-46.5'.	
						46.65'-47.4' HALITE: Clear, coarsely crystalline.[1]	
	39.2					47.4'-47.9' HALITE: Clear, some moderate brown. Coarsely crystalline. 61% brown clay.	Run 11: Some discing, broken in clear halite.
11	40	3.5	3.5	100		47.9'-48.9' ARGILLACEOUS HALITE: Clear to moderate brown, medium crystalline, some coarse. 3% brown clay. 1" halite and brown clay seam @ 47.9'.	
	42.7					48.9'-50.4' HALITE: Clear, mottled with moderate brown clay, coarse, some medium. <1% to 2% brown clay, <1/2% dispersed polyhalite.[10]	
12	45	4.7	4.7	100			39% of recovered core was ≥2 inch length.
	47.4						Interval from 20 to 35' was replaced with corehole DH-29A.
13		3.0	3.0	100	X		
	50						
	50.4						

WIPP

WASTE ISOLATION PILOT PLANT

GEOLOGIC DRILL LOG

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC-CORE BORING NO. DH-29A

LOCATION ROOM G ACCESS DRIFT - ROOF

STATION N1099, W987 COLLAR ELEV. 1298.1 DIRECTION OF DRILLING VERTICAL - UP

MINE COORDINATES N10,786.1 E5927.3 DEPTH OF BOREHOLE 35.0'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL CP-65

DATE STARTED 9-12-84 DATE COMPLETED 9-12-84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 9-29-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0					0.0'-20.0' NON-CORE: Refer to log for DH-29.	NC double tube core barrel used. This hole was drilled to replace 20'-35' zone of poor quality core in DH-29. Refer to log for DH-29 for core descriptions at 0'-20' and 35'-50'
	5					20.0'-25.0' HALITE: Clear to moderate brown (5YR 4/4), some moderate reddish orange (10R 6/6). Medium to coarsely crystalline, some fine. <1% to 2% brown clay. <1% polyhalite locally. Anhydrite seam at 25'±. ≤1/4" hard brown clay associated. [12, 17]	
	10					25.0'-28.4' HALITE: Clear, coarsely crystalline. Scattered anhydrite stringers. [1]	
	15					28.4'-30.9' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4, 4/4), medium to coarsely crystalline. <1% to 3% brown clay. <1/2% dispersed polyhalite. [10, 15, 17]	
						30.9'-35.0' HALITE: Clear, some moderate brown (5YR 3/4, 4/4), coarsely crystalline, some medium. ≤1% brown clay. [10]	
	20						
1		5.0	4.6	92	X		
	25						

20.0

25.0

BORING NO. DH-29A

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-29A

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
25.0							
2		5.0	4.7	94			
30.0	30						
3		5.0	4.5	90			
35.0	35						
	40						

BORING NO. DH-29A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ HOLE TYPE/SIZE NC CORE BORING NO. DH-30

LOCATION ROOM 6 ACCESS DRIFT - FLOOR

STATION N1099, W982 COLLAR ELEV. 1289.2 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N10785.5, E5932.3 DEPTH OF BOREHOLE 50.1'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 7-25-84 DATE COMPLETED 7-25-84 SHEET

LOGGED BY: J GALLERANI DATE: 7-26-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		1.7	1.7	100		0.0'-8.6' HALITE: Clear, some light medium gray. Coarsely crystalline, some medium. ≤1% gray clay. Trace of brown at 1.0'-1.7'. [1, 11]	NC double tube wireline core barrel. Used 2 ft single tube barrel from 0'-5.8'. Had to ream hole to 5.8 ft to accommodate NC core barrel. Total drilling time 5.5 hrs.
	1.7						
2		4.1	4.1	100		8.6'-11.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite. [7]	
	5					11.5'-16.0' MB-139: Mixture of halite and anhydrite to 13'. Then predominantly very light to medium light gray anhydrite with scattered halite growths. Irregular hairline fracture at 14'±. Gray clay at lower contact.	
	5.8						
3		4.1	4.1	100		16.0'-19.2' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. ≤1% gray clay. <1% to 3% polyhalite. Scattered anhydrite. [some 5]	
	9.9					19.2'-20.7' HALITE: Clear, some light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1% dispersed polyhalite. <1/2% gray clay.	
	10						
4		5.0	5.0	100		20.7'-25.45' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. [5, 7]	
	14.9					25.45'-30.1' HALITE: Clear to light moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1% polyhalite dispersed. ≤1% gray clay. [9]	66% of core recovered is ≥2 inch length.
	15						
5		5.0	5.0	100		30.1'-35.2' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. Scattered anhydrite [5, 7]. Anhydrite/halite layer at 34.9'-35.1'±.	
						35.2'-35.6' ANHYDRITE: Light gray (N7) to medium light gray (N6), microcrystalline. Scattered halite growths. No clay.	
	19.9						
	20						
6		5.1	5.1	100		35.6'-43.75' HALITE: Clear to light moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1% dispersed polyhalite and gray clay [9]. Polyhalitic at 42.9'-43.5'±.	
	25.0						
	25						

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-30

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
25.0							
7		5.1	5.1	100		43.75'–44.8' HALITE: Clear to moderate reddish orange (10R 6/6), some moderate brown (10R 4/6). Medium to coarsely crystalline. <1% to 2% brown clay, some gray. Breaks at 44.35' and 45.10'± [14, 17].	Runs 7, 8, 9: Some breakage in medium to coarsely crystalline halite.
						44.8'–46.9' HALITE: Clear to light moderate reddish orange (10R 6/6), some bluish gray. Medium to coarsely crystalline. <1/2% dispersed polyhalite. <1% gray clay.	
30.1	30						
8		5.1	5.1	100		46.9'–50.1' HALITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline. <1% polyhalite. <1/2% gray clay. 1% to 2% polyhalite at 46.9' to 47.7'±. [1, 2, 11]	
35.1	35						
9		5.1	5.1	100			
40.1	40						
10		5.1	5.1	100			
45.1	45						
11		5.1	5.1	100			
50.1	50						

BORING NO. DH-30

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ HOLE TYPE/SIZE NC-CORE BORING NO. DH-31

LOCATION ROOM G ACCESS DRIFT - ROOF

STATION N1099, W1282 COLLAR ELEV. 1298.5 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10,784.9, E5632.3 DEPTH OF BOREHOLE 50.5'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 7-18-84 DATE COMPLETED 7-19-84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 7-20-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0 0					0.0'-5.0' NON-CORE.	NC double tube wire line core barrel, NC stepped diamond bit. 2 ft starter barrel with impregnated bit caused too much vibration. Went to plugged diamond bit from 0.0 ft to 5.0 ft. Total drilling time 11.5 hrs.
0		Non-Core			Non-Core	5.0'-7.25' HALITE: Clear to moderate brown (5YR 4/4), coarsely crystalline, some medium, ≤1% to 2% brown clay.	
						7.25'-7.5' ANHYDRITE b: Light gray microcrystalline anhydrite. Scattered halite growths. ≤1/4" gray clay at 7.25'.	
	5.0 5						
1		2.7	2.65	98		7.5'-13.6' HALITE: Clear, some light moderate reddish orange, coarsely crystalline. <1/2% polyhalite. Scattered white stringers.	
	7.7						
2	10	5.0	4.9	98		13.6'-14.4' HALITE: Clear to moderate reddish brown, medium to coarsely crystalline. ≤1% brown clay, some gray, and dispersed polyhalite.	
						14.4'-15.1' ANHYDRITE a: Light gray to medium light gray. Scattered halite growths. Trace gray clay at 14.4'. Core grinding evident.	
	12.7					15.1'-19.05' POLYHALITIC HALITE: Clear to moderate reddish orange, coarsely crystalline. ≤1% to 2% polyhalite.	
3	15	4.8	4.8	100		19.05'-21.4' ARGILLACEOUS HALITE: Clear to moderate brown, medium to coarsely crystalline, <1% to 3% brown clay. <1% dispersed polyhalite.	28% of core recovered was ≥2 inch length.
	17.5					21.4'-23.95' HALITE: Clear to light moderate reddish orange, medium to coarsely crystalline. <1% polyhalite. <1/2% brownish gray clay. Brown clay seam at 23.9' with associated anhydrite to 23.95.	
4	20	4.0	4.0	100		23.95'-27.9' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. [1]	
						27.9'-29.65' HALITE: Clear to moderate brown, medium to coarsely crystalline. None to 3% brown clay.	
	21.5						
5		4.5	4.2	95		29.65'-31.1' HALITE: Clear, coarsely crystalline.	
	25						

BORING NO. DH-31

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-31

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					31.1'-32.7' HALITE: Clear, medium to coarsely crystalline. <1/2% brown clay.	Run 6: Core broken up. Difficult to measure recovery.
6	26.0 30	4.5	4.1	91		32.7'-33.6' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4, 4/4), medium to coarsely crystalline. <1% to 3% brown clay. [10] 33.6'-34.5' HALITE: Clear, coarsely crystalline. <1/2% brown clay.	Run 7: Discing, some broken core.
7	30.5 35	5.0	4.7	94		34.5'-36.55' ARGILLACEOUS HALITE: Clear to moderate brown, medium to coarsely crystalline. <1% to 3% brown clay. 36.55'-37.35' ANHYDRITE: Very light gray to medium light gray, scattered halite growths and irregular laminae. ≤1/8" brown clay at 36.55'.	Run 8: 1'± core is broken up.
8	35.5 40	5.0	.8	96		37.35'-41.5' HALITE: Clear to moderate reddish orange, coarsely crystalline. <1% to 2% polyhalite. Locally polyhalitic. 41.5'-44.3' ARGILLACEOUS HALITE: Clear to moderate brown, medium to coarsely crystalline. <1% to 3%, locally, brown clay, scattered breaks. 44.3'-45.5' HALITE: Clear, coarsely crystalline. <1% polyhalite. <1/2% clay.	
9	40.5 45	5.0	5.0	100		45.5'-47.0' HALITE: Clear, mottled with moderate brown (5YR 4/4), coarsely crystalline. <1% to 2% brown clay. 47.0'-50.5' ARGILLACEOUS HALITE: Clear to moderate brown, medium to coarsely crystalline. <1% to 3% brown clay. Breaks from 47.5' to 50.5'.	
10	45.5 50	5.0	5.0	100		Note: Hole redrilled due to poor core quality. See log for hole DH-31A.	
	50.5						

BORING NO. DH-31

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ HOLE TYPE/SIZE NC-CORE BORING NO. DH-31A

LOCATION ROOM G ACCESS DRIFT - ROOF

STATION N1099 W1280 COLLAR ELEV. 1298.5 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10784.8, E5630.5 DEPTH OF BOREHOLE 49.2'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 7-20-84 DATE COMPLETED 7-24-84 SHEET

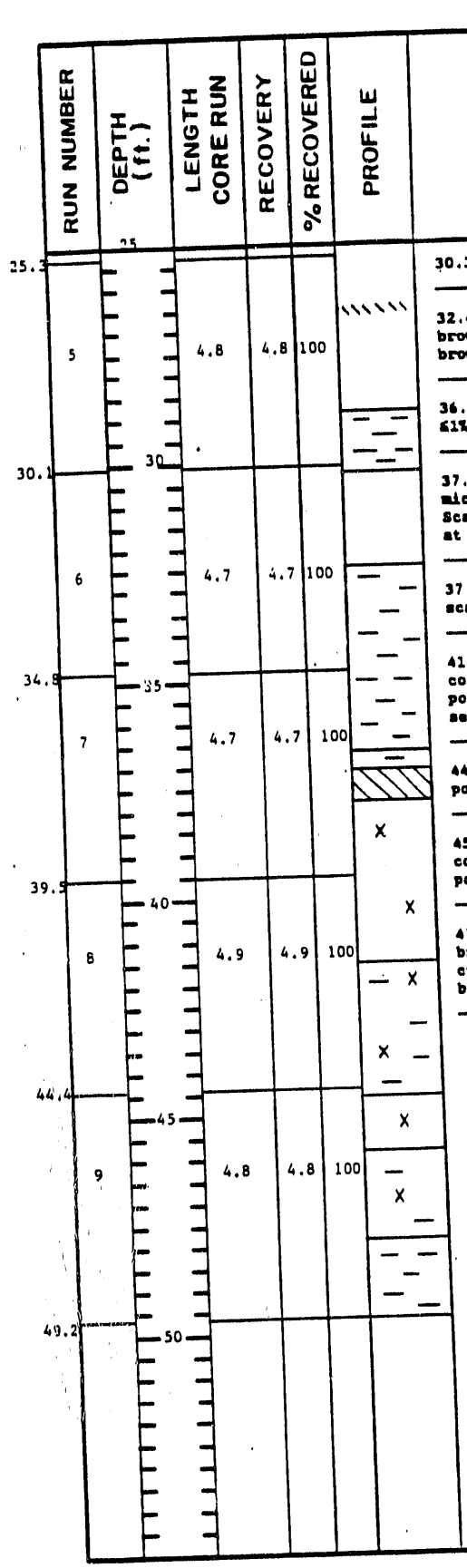
LOGGED BY: J. E. GALLERANI DATE: 7-24-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0					0.0'-5.1' NON-CORE: Used plugged diamond bit.	NC double tube wireline core barrel. Wireline rod and stepped diamond bit. Total drilling time: 10.5± hrs. 46% of core recovered was ≥2 inch length.
0		Non-Core				5.1'-7.15' HALITE: Clear to moderate brown, some light to moderate reddish orange. Medium to coarsely crystalline. ≤1% brown clay with trace of gray. <1/2% dispersed polyhalite. [8, 17]	
						7.15'-7.35' ANHYDRITE b: Light gray (N7), microcrystalline, partially laminated. Scattered halite growths. Gray clay at 7.15'. Contact dips 10°±.	Upper 4.9' of hole was replaced with corehole DH-32B.
	.1						
1	5	4.9	4.8	97		7.35'-13.85' HALITE: Clear, some light to moderate reddish orange. Coarsely crystalline. <1/2% polyhalite. Scattered white stringers. [1, 2]	
						13.85'-14.65' HALITE: Clear to moderate brown. Fine to medium crystalline, some coarsely crystalline. ≤1% brown clay. [12]	
	10.0						
2	10	5.2	5.2	100		14.65'-15.3' ANHYDRITE a: Light to medium light gray microcrystalline. Scattered halite growths. ≤3/16" gray clay at 14.65. Vertical fracture noted from 14.35' to 14.85'.	
						15.3'-19.5' POLYHALITIC HALITE: Clear to moderately reddish orange, (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. <1/2% gray clay locally. [5, 7]	Run 2: Several broken zones in clear halite.
	15.2						
3	15	5.1	5.1	100		19.5'-24.75' HALITE: Clear, some lightly moderate reddish orange. Medium to coarsely crystalline with with some fine crystalline. <1% brown with some gray clay and polyhalite dispersed. 1/2" grayish brown hard clay at 24.7'. Scattered halite within. [12, 17]	
						24.75'-28.8' HALITE: Clear, coarsely crystalline. Scattered white anhydrite. 3/4" anhydrite layer at 26.4'±. Appears to be vertical fracture at 24.75'-25.15'±. Probably caused when banging end piece of core from barrel. [1]	
	20.3						
4	20	5.0	5.0	100		28.8'-30.3' ARGILLACEOUS HALITE: Clear to moderate brown. Fine to medium crystalline with some coarsely crystalline. ≤1% to 3% brown clay. Break at 30.3'. [12]	
	25						

WIPP

WASTE ISOLATION PILOT PLANT

SHEET 2 OF 2 BORING NO. DH-31A



DESCRIPTION	REMARKS
30.3'-32.4' HALITE: Clear, coarsely crystalline. [1]	Run 5: Badly broken by drilling.
32.4'-36.7' ARGILLACEOUS HALITE: Clear to moderately brown, medium to coarsely crystalline. ≤1% to 3% brown clay. Scattered breaks. [15]	
36.7'-37.1' HALITE: Clear to coarsely crystalline. ≤1% brown clay. [8, 10]	Run 6: Badly broken to 33.3' in very coarse halite.
37.1'-37.85' ANHYDRITE: Light to medium light gray, microcrystalline anhydrite. Partly laminated. Scattered halite growths. ≤3/4" hard brown clay seam at 37.1'.	
37.85'-41.5' HALITE: Clear, coarsely crystalline, scattered medium. ≤1/2% polyhalite. [1]	
41.5'-44.6' HALITE: Clear to moderate brown. Medium to coarsely crystalline. <1% to 2% brown clay. <1% polyhalite blebs. Irregular 1" brown clay and halite seam at 44.5'±. [8, 17]	
44.6'-45.8' HALITE: Clear, coarsely crystalline. <1% polyhalite blebs. [2]	
45.8'-47.8' HALITE: Clear, mottled with moderate brown, coarsely crystalline. ≤1% brown clay blebs. <1/2% polyhalite blebs. [8, 10]	
47.8'-49.2' ARGILLACEOUS HALITE: Clear to moderate brown. Fine to medium crystalline, some coarsely crystalline. <1% to 3% brown clay with scattered breaks. [12]	Run 9: Core disced from 45.5' to 48'.

BORING NO. DH-31A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE 2 3/4" CORE BORING NO. DH-31B

LOCATION ROOM G ACCESS DRIFT - ROOF

STATION N1099, W1261 COLLAR ELEV. 1298.5± DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10786.7 E5652.2 DEPTH OF BOREHOLE 4.9 FT.

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL CP-65

DATE STARTED 9-12-84 DATE COMPLETED 9-12-84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 9-29-84 1 OF 1

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		4.9	4.9	100	X X	0.0'-2.4' HALITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline. ≤1% to 2% polyhalite. Scattered anhydrite stringers. [2]	Single tube barrel used.
					— —	2.4'-4.9' HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline. ≤1% brown clay, trace of gray.[8, some 10].	
	4.9						This hole drilled to replace non-core section of DH31A.

BORING NO. DH-31B

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC-CORE BORING NO. DH-32

LOCATION ROOM G ACCESS DRIFT - FLOOR

STATION N1099, W1282 COLLAR ELEV. 1289.6 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N10784.9, E5632.2 DEPTH OF BOREHOLE 50.0'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 7-19-84 DATE COMPLETED 7-20-84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 7-20-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0					0.0'-5.3' NON-CORE: Used plugged bit.	NC double tube wire-line core barrel, NC rods and stepped diamond bit. Total drilling time: 6± hrs.
0		Non-Core				5.3'-7.4' HALITE: Clear, mottled with some moderate reddish orange and brown. Coarsely crystalline. <1% polyhalite. <1/2% brown and gray clay 6.75'-7.05'. [3]	Upper 5.5' of hole replaced with corehole DH-32A.
	5					7.4'-8.5' POLYHALITIC HALITE: Clear to moderate reddish orange to coarsely crystalline. <1% to 2% polyhalite [3, 4].	
5.3							
1		5.0	4.9	98		8.5'-11.3' MB-139: (upper contact dips 40°±). Mixture of halite and anhydrite to 9.6± with some "swallowtail" structure. From 9.6'±, predominently Light to light medium gray anhydrite with scattered halite growths @ 9.15' to 10.75'. Clear halite layers at 10.3'-10.4'. 3/16" gray clay @ 11.3' Core grinding evident here.	
	10						
10.3						11.3'-14.2' HALITE: Clear, some moderate reddish orange (10R 6/6), moderate brown, medium to coarse. ≤1% clay, gray to 12.7', then brown clay. Irregular brownish gray break @ 14.2'. <1/2% dispersed polyhalite. [9, 17]	56% of recovered core was ≥2 inch length.
2		4.8	4.2	95		14.2'-18.85' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. Scattered anhydrite. Gray clay parting @ 18.85'. [3, 5, 7]	
15.1	15					18.85'-20.1' HALITE: Clear to light moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1% dispersed polyhalite. <1/2% gray clay. [9]	
3		5.0	4.8	96		20.1'-25.25' POLYHALITIC HALITE: Clear to moderate reddish orange and brown (10R 6/6, 4/6), coarse, some medium. <1% to 3% polyhalite. <1/2% brown and gray clay. Vertical fracture in core at 23.4'-23.8'. Looks like stress fracture. [4, 6, 7]	
20.1	20						
4		4.9	4.9	100		25.25'-30.4' HALITE: Clear to moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1% to 2% polyhalite. <1% gray clay, locally. <1% brown clay at 28.3'-29.9'. Vertical fractures in core at 27.35'-27.55' and 28.6'-29.2'±. [9, some 17]	Run 4: Vertical fracture at 20.1', 23.5' and 26.0'. Probably caused by overshot tool impact on barrel.
	25						
25							

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-32

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
5		5.2	4.9	94.5		30.4'-35.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. <1% gray clay to 31'. [7]	
						35.0'-35.9' ANHYDRITE: Moderate reddish orange (10R 6/6) to medium light gray (N6), microcrystalline anhydrite with scattered halite growths. Gray clay at 35.9'. Contact irregular, low angle here.	
	30						
30.2						35.9'-40.8' HALITE: Clear to light moderate brown (5YR 4/4) and light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1/2% dispersed polyhalite. <1% clay, predominantly gray. Brown clay at 37.3'-37.9' [9, 11, some 17]	
6		5.0	5.0	100			
						40.8'-44.2' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 2% polyhalite, locally 3% from 43.0'-43.9'±. <1% gray clay [4, 9].	
35.2	35						
						44.2'-46.1' HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline. <1% brown clay. <1/2% dispersed polyhalite [17].	
7		4.8	4.7	97		46.1'-47.75' HALITE: Clear, some medium light gray. Medium to coarsely crystalline. <1% gray clay and <1/2% polyhalite [9].	
						47.75'-50.0' HALITE: Clear mottled with moderate reddish orange (10R 6/6). Coarsely crystalline. <1% polyhalite. <1/2% gray clay locally. [2]	
40.0	40						
8		5.1	5.1	100			
45.1	45						
9		4.9	4.9	100			
50.0	50						

BORING NO. DH-32

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE 2 3/4" CORE BORING NO. DH-32A

LOCATION ROOM G ACCESS DRIFT - FLOOR

STATION N1099, W1261 COLLAR ELEV. 1289.5 DIRECTION OF DRILLING VERTICAL ~~DOWN~~

MINE COORDINATES N10 786.7 E5652.2 DEPTH OF BOREHOLE 5.5 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL CP-65

DATE STARTED 9-13-84 DATE COMPLETED 9-13-84 SHEET

LOGGED BY: J. F. GALLERANI DATE: 9-29-84 1 OF 1

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 5.5	5.5	5.5	100	X — X — X	0.0'-5.5' HALITE: Clear, some moderate reddish orange, coarsely crystalline, some fine and medium, <1% to 2% locally polyhalite. <1% clay, gray except at 1.7'-2.6'± where it is brown. [2, 9]	Single tube barrel used. 45% of core recovered was ≥2 inch length. This hole was drilled to replace non-core section of DH-32.

BORING NO. DH-32A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC-CORE BORING NO. DH-33

LOCATION ROOM G ACCESS DRIFT - ROOF

STATION N1099, W1582 COLLAR ELEV. 1298.6 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10786.0, E5331.1 DEPTH OF BOREHOLE 50.5'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 7-16-84 DATE COMPLETED 7-18-84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 7-18-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0					0.0'-4.0' NON-CORE: Roller bit to 4' in order to accommodate long core barrel.	NC double tube wireline core barrel, NC rods and stepped diamond bit used from 4.0' depth. Upper 4.0' of hole replaced with corehole DH-33A. Total drilling time: 16¼ hrs.
0		Non-core				4.0'-5.9' HALITE: Clear with some moderate brown (5YR 4/4). Coarsely crystalline with some medium crystalline. <1% brown clay. [8, 13]	
4.0							
1	5	5.0	4.9	98		5.9'-7.15' HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline, <1% to 2% brown clay. Irregular break at 6.0'. [10]	
						7.15'-7.25' ANHYDRITE b: Light gray to medium gray (N7, N6). Microcrystalline. Gray clay ≤3/16" at 7.15'.	
9.0						7.25'-12.9' HALITE: Clear with some light to moderate reddish orange (10R 6/6). Coarsely crystalline. Scattered white stringers of anhydrite and/or magnesite. None to <1/2% polyhalite. [1]	
2	10	4.0	4.0	100		12.9'-13.1' HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline, ≤1% polyhalite, ≤1% brown clay. [17]	40% of recovered core was ≥2 inch length.
13.0						13.1'-13.85' HALITE: Clear to light moderate brown (5YR 4/4). Fine to medium crystalline with some coarse crystalline. <1/2% polyhalite and <1% clay, brown with some gray. [9]	
3	15	5.0	5.0	100		13.85'-14.4' ANHYDRITE a: Light gray to light medium gray (N7, N6), microcrystalline anhydrite with scattered halite growths. ≤1/8" gray clay at lower contact.	
18.0						14.4'-19.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite with scattered anhydrite. [4, 7]	
4	20	5.0	5.0	100		19.0'-21.25' HALITE: Clear with some lightly moderate brown (5YR 3/4), medium to coarsely crystalline with some fine crystalline. ≤1% brown clay and some gray clay with ≤1/8" anhydrite at 21.2'-21.25'. [9, 12]	
23.0						21.25'-24.1' HALITE: Clear with some moderate brown (5YR 4/4), coarsely crystalline, some fine to medium crystalline, <1% brown clay, <1/2% polyhalite. 1/2" brown clay seam at 23.95' with associated halite/anhydrite to 24.1'. [8]	
5	25	5.0	5.0	100			

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-33

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					24.1'-28.7' HALITE: Clear, coarsely crystalline, trace of brown clay locally..[1]	
28.0						28.7'-30.3' HALITE: Clear to moderate brown (5YR 4/4). Fine to medium crystalline with some coarse crystalline. <1/2% dispersed polyhalite. <1% to 2% brown clay, some gray. [12]	
6	30	5.0	4.8	96		30.3'-32.0' HALITE: Clear, coarsely crystalline. [1]	
						32.0'-36.8' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4). Medium to coarsely crystalline. <1% to 3% brown clay. Scattered breaks. [15, 16]	
33.0						36.8'-37.3' ANHYDRITE: Light gray to light medium gray (N7, N6), microcrystalline anhydrite. Scattered halite growths. Brown clay at 36.8'. Core grinding here.	
7	35	4.0	4.0	100		37.3'-38.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline, <1% to 3% polyhalite. [5, 7]	
37.0						38.0'-42.0' HALITE: Clear with some light to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% polyhalite. [1, 2]	
8	40	5.0	5.0	100		42.0'-47.5' HALITE: Clear to lightly moderate reddish orange and moderate brown (5YR 3/4, 4/4). Medium to coarsely crystalline. Some fine crystalline locally. ≤1% brown clay. <1% polyhalite. Fairly clear, coarsely crystalline between 45.3' and 46.3'±. [1] [10, 17]	
42.0						47.5'-50.5' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4, 3/4), medium to coarsely crystalline. <1% to 3% brown clay with scattered breaks. [10, 14]	
9	45	5.0	4.8	96			
47.0							
10	50	3.5	3.5	100			
50.5							

BORING NO. DH-33

WIPP

WASTE ISOLATION PILOT PLANT

GEOLOGIC DRILL LOG

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE 2 3/4" CORE BORING NO. DH-33A

LOCATION ROOM G ACCESS DRIFT - ROOF

STATION N1099, W1570 COLLAR ELEV. 1297.4 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10786.8 E5342.0 DEPTH OF BOREHOLE 4.1

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 9-13-84 DATE COMPLETED 9-13-84 SHEET

LOGGED BY: J. F. GALLERANI DATE: 9-29-84 1 OF 1

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0							
1	4.1	4.1	4.1	100	X X —	0.0'-3.2' HALITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline, some medium from 2.3'±. ≤1% polyhalite. [1, 3] 3.2'-4.1' HALITE: Clear, some moderate brown (5YR 4/4), coarsely crystalline. <1% brown clay. [8]	Single tube barrel used. 51% of core recovered was ≥2 inch length. This hole was drilled to replace non-core section of DH-33.
4.1							

BORING NO. DH-33A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-34

LOCATION ROOM G ACCESS DIRFT - FLOOR

STATION N1099, W1582 COLLAR ELEV. 1289.4 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N10786.5, E5331.7 DEPTH OF BOREHOLE 51.5±

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 7-16-84 DATE COMPLETED 7-17-84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 7-18-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0	0					0.0'-3.5' NON-CORE.	CP65 mounted on scissor lift. NW split tube core barrel, NW rods used plugged diamond bit to 3.5' because of low drift back. Unable to use longer core barrel. Upper 3.5' of hole replaced with corehole DH-34A. Total drill time: 13 hrs ±.
	0	Non-core					
3.5						3.5'-4.2- HALITE: Clear, some moderate brown (5YR 4/4) and moderate reddish orange (10R 6/6). Coarsely crystalline. <1% brown clay, some gray. Trace polyhalite. [8]	
	1	2.5	2.3	92		4.2'-7.8' POLYHALITIC HALITE: Clear, mottled with moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite blebs and patches. ≤1% gray clay to 6.1', then no clay. Scattered anhydrite. [5, 7]	
5.9	5						
	2	3.4	3.4	100		7.8'-11.05' MB-139: Mixture of anhydrite and halite ("swallowtail" pattern) from 7.8' to 8.6'±. Then becomes mostly anhydrite. Moderate reddish orange with irregular patches of white and light gray to 9.7'±. Increase in halite content 9.8'-10.3'±. Below 10.3' is light gray anhydrite. Trace of gray clay at 11.05'. Core grinding evident.	
9.3							
	3	4.7	4.7	100		11.05'-12.1' HALITE: Clear, medium to coarsely crystalline. [1]	
	10					12.1'-14.2' HALITE: Clear to light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. [1]	
14.0						14.2'-18.9' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. [5, 6, 7] Moderate reddish orange anhydrite mixed with halite from 18.65'-18.9'±. Break at 14.45'±.	
	4	5.0	5.0	100			40% of core recovered was ≥2 inch length.
	15					18.9'-20.95' HALITE: Clear to light moderate reddish orange (10R 6/6), some moderate brown (5YR 4/4). Medium to coarsely crystalline. ≤1% brown clay, trace of gray. ≤1% dispersed polyhalite. Break @ 20.75'. [17]	
19.0							
	5	5.0	4.75	95		20.95'-27.45' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. Medium to coarsely crystalline from 25.2'±. Anhydrite-halite from 24.1'-24.2', ≤1% gray clay from 26.5'-26.8'±. [7]	
	20						
24.0	6	5.0	5.0	100			

BORING NO. DH-34

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-34

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					27.45'-29.9' HALITE: Clear, some moderate brown (5YR 4/4) and light moderate reddish orange (10R 6/6), medium to coarsely crystalline, some fine. ≤1% brown clay, some gray from 29.4'-29.9'. <1/2% dispersed polyhalite. [17, some 9]	
						29.9'-35.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. 2" anhydrite/halite layer at 35.15'-35.3'. [4, 7]	
29.0							
7	30	5.0	5.0	100		35.4'-36.15' ANHYDRITE: Light gray (N7) to moderate reddish orange (10R 6/6), microcrystalline. Halite growths within. Trace of gray clay at 36.15'.	Run 7: Some vibration this run. Tightened tie down bolts and feed beam.
						36.15'-43.0' HALITE: Clear, coarsely crystalline, some medium. <1/2% dispersed polyhalite. <1% gray clay. [9]	
34.0							
8	35	5.1	5.1	100		43.0'-44.2' HALITE: Clear, some moderate reddish orange, coarsely crystalline. <1/2% polyhalite. [2]	
						44.2'-45.4' HALITE: Clear with some moderate brown (5YR 4/4), coarsely crystalline. <1% brown clay. Break at 45.4'. [8, some 10]	
39.1						45.5'-51.5' HALITE: Clear, coarsely crystalline, some medium, <1% gray clay, trace brown. [8, 11]	Run 9: Core barrel blocked up this run. Some brown clay on inner tube.
9	40	3.9	1.8	46			
43.0							
10	45	5.0	5.0	100			Run 11: Dropped core barrel 4" when pulling rods. Day shift driller drilled over this run. Core broken up because of this.
48.0							
11	50	3.5	3.5	100			
± 51.5							

BORING NO. DH-34

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE 2 3/4" CORE BORING NO. DH-34A

LOCATION ROOM G ACCESS DRIFT - FLOOR

STATION N1099, W1570 COLLAR ELEV. 1289.2 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N10 786.8 E5341.9 DEPTH OF BOREHOLE 3.6'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 9-13-84 DATE COMPLETED 9-13-84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 9-29-84 1 OF 1

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0							
1		3.6	3.6	100	X	0.0'-1.3' HALITE: Clear, coarsely crystalline, some medium, <1/2% polyhalite blebs. [1]	Used single tube starter barrel.
						1.3'-3.6' HALITE: Clear, some moderate brown (5YR 4/4), coarsely crystalline. ≤1% brown clay. [8, 10]	
3.6							
							94% of recovered core was ≥2 inch length.
							This hole was drilled to replace non-core section of DH-34.

BORING NO. DH-34A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-35

LOCATION ROOM G - ROOF

STATION N1102, W1882 COLLAR ELEV. 1294.4 FT DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10789.4, E5032.2 DEPTH OF BOREHOLE 52.0 FT.

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 1-26-85 DATE COMPLETED 1-27-85 SHEET

LOGGED BY: J. E. GALLERANI DATE: 2-13-85 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1	0	2.2	2.0	91		0.0'-4.4' HALITE: clear to moderate brown (5YR 4/4), coarsely crystalline. <1% brown clay. Scattered polyhalite blebs. [1,8]	NC single-tube barrel used for run 1. NC double-tube wireline barrel used for remainder of hole.
	2.2						
2		5.0	4.5	90		4.4'-6.2' HALITE: Clear to moderate brown (5YR 4/4; 3/4); fine to medium crystalline, some coarse. ≤1% brown clay, trace of gray. [8,10,12]	Partially broken core upper 2' of Run 2.
	5					6.2'-6.4' ANHYDRITE "b": Light medium to medium gray microcrystalline anhydrite with polyhalitic halite growths. Trace of hard gray clay at 6.2'. Anhydrite is laminated close to clay contact, low angle.	26% of core recovered was 2-inch lengths.
	7.2						Dry hole. No gas detected.
3		5.0	4.8	96		6.4'-12.1' HALITE: Clear, coarsely crystalline. Trace of anhydrite stringers. [1]	
	10					12.1'-13.2' HALITE: Clear to light moderate reddish orange (10R 6/6); fine to medium crystalline. < 1/2% dispersed polyhalite. ≤ 1% clay, brown and gray. Brown break at 12.35'. [9,12]	
	12.2					13.2'-13.85' ANHYDRITE "a": Very light to medium gray microcrystalline anhydrite. Irregular laminae. Scattered halite growths. From 13.6', Up to 1/4" hard gray clay at 13.2'. Core grinding evident.	
4	15	5.0	4.9	98		13.85'-18.0' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6), coarsely crystalline. <1 to 3% polyhalite. [4,7]	Run 6 partially broken in clear halite.
	17.2					18.0'-21.9' HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6); fine to coarsely crystalline. ≤1% gray clay, some brown. < 1% polyhalite. [9, some 12]	Run 7 broken most of run.
5	20	5.3	4.7	89		21.9'-24.05' HALITE: Clear, scattered moderate brown (5YR 4/4). Coarsely crystalline, some medium, <1/2% polyhalite. ≤1% brown clay. Up to 3/8" hard brown clay at 24.0'. Trace of anhydrite above. Near horizontal, irregular. [8,10]	
	2.5						
6		5.0	3.5	70			
	25						

BORING NO. DH-35

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-35

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					24.05'-27.8' HALITE: Clear, coarsely crystalline. [1]	
6		5.0	3.5	70		27.8'-28.7' HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline. ≤1 to 2% brown clay. [10]	Broken core in Run 9.
27.5							
7	30	5.0	3.3	66		28.7'-32.5' HALITE: Clear, coarsely crystalline. None to <1% brown clay. [1, some 10]	
						32.5'-36.5' ± 0.3' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline. <1 to 3% brown clay, trace brownish-gray locally scattered breaks. [10,15]	Broken zones throughout Run 10.
32.5							
8	35	5.0	4.3	86		36.5'-37.1' ANHYDRITE: Very light to light medium gray, microcrystalline anhydrite. Scattered small polyhalitic halite growths. Up to 1/2" hard brown clay at 36.5'. Near horizontal. Core grinding evident.	Broken zones, especially last 18" of Run 11.
						37.1'-42.6' HALITE: Clear, coarsely crystalline. <1/2% scattered polyhalite blebs. Scattered white anhydrite. [1]	
37.5							
9	40	5.0	3.2	64		42.6'-46.1' HALITE: Clear, some moderate brown (5YR 4/4), coarsely crystalline, except fine to medium from 43.7' to 44.5'. <1/2% moderate reddish orange polyhalite here. <1% brown clay. Irregular break at 44.55'±.	
						46.1'-50.6' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4; 3/4); medium to coarsely crystalline. <1 to 3% brown clay, up to 5% locally. Seam of clay mixed with halite crystals from 50.4' to 50.6'. [10,12,15]	
42.5							
10	45	5.0	5.0	100		50.6'-52.0' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6); coarsely crystalline. <1 to 3% polyhalite. Moderate reddish brown polyhalite/anhydrite at 50.75' to 50.95'±.	
47.5							
11	50	4.5	4.5	100			
52.0							
	55						

BORING NO. DH-35

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE T-YPE/SIZE NC-CORE BORING NO. DH-36

LOCATION ROOM G - FLOOR

STATION N1102, W1882 COLLAR ELEV. 1284.6 FT DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N10789.4, E5032.2 DEPTH OF BOREHOLE 51.5 FT

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 1-26-85 DATE COMPLETED 1-26-85 SHEET

LOGGED BY: J. E. GALLERANI DATE: 1-27-85 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0						
1		2.0	2.0	100		0.0'-2.7' HALITE: Clear, some moderate brown, coarsely crystalline. <1% brown clay.	NC single-tube core barrel used for Runs 1 and 2. For remaining runs, NC double-tube wireline core barrel used.
	2.0						
2		1.5	1.4	93		2.7'-7.0' ± 0.2' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1 to 3% polyhalite. Trace clay. [2,5,7]	Total drilling time: 6 hrs.
	3.5						
3		4.5	4.2	93		7.0'-10.4' ± 0.3' MB-139: Moderate reddish orange and medium gray to 8.7'±. From 8.7', predominantly light to medium gray anhydrite with halite growths. Gray clay, up to 1/2" at 10.4'.	43% of core recovered was à 2-inch lengths.
	5						In salt, used second gear (74 rev./inch).
						10.4'-14.3' HALITE: Clear to light bluish gray; medium to coarsely crystalline. < 1/2% dispersed polyhalite. ≤1% gray clay. [9,11]	In anhydrite, used third gear (100 rev./inch).
	8.0						Dry hole. No gas detected.
4		3.2	2.5	78		14.3'-18.6' POLYHALITIC HALITE: Clear to moderate reddish orange/brown, coarsely crystalline. <1 to 3% polyhalite. Gray clay, some anhydrite at 18.3'-18.6'±. Irregular gray seam at 18.6'.	
	10						
	11.2						
5		5.0	5.0	100		18.6'-20.6' HALITE: Clear to light moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1% gray clay and polyhalite. [9]	
						20.6'-24.7' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. <1 to 3% polyhalite. Average is <2%. [2,4,7]	
	15						
	16.2					24.7'-29.4' HALITE: Clear, some moderate reddish orange (10R 6/6); coarsely crystalline. ≤1% polyhalite. Locally polyhalitic. <1% gray clay. [9]	
6		5.0	5.0	100		29.4'-33.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite. Trace anhydrite.	
	20						
	21.2					33.4'-34.9' HALITE: Clear, some light moderate reddish orange; coarsely crystalline. <1% polyhalite.	Core partly broken in Run 10.
7		5.3	5.3	100			
	25						

BORING NO. DH-36

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-36

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
7	26.5					34.9'-35.5' ANHYDRITE: Moderate reddish orange microcrystalline anhydrite mixed with halite growths to 35.15'±. Very irregular upper contact. Consists of anhydrite intermixed with halite. From 35.15', light to light medium gray anhydrite with scattered halite growths. Some "swallowtail" pattern noted. 1/2" hard gray clay at lower contact. Dips 10°±.	
8	30	5.0	4.8	96		35.5'-41.2' HALITE: Clear, some light medium gray. Coarsely crystalline, some medium. <1% gray clay and <1/2% polyhalite blebs. [1,11]	
	31.5					41.2'-42.7' HALITE: Clear, some moderate reddish orange. Coarsely crystalline. <1% gray clay. [9]	
9	35	5.0	5.0	100		42.7'-44.9' HALITE: Clear to moderate reddinh orange/ brown (10R 6/6; 4/6); medium to coarsely crystalline. <1 to 2% polyhalite, locally polyhalitic. ≤1% brown clay. [17]	
	36.5					44.9'-51.5' HALITE: Clear, coarsely crystalline, some medium. <1/2% dispersed polyhalite locally. <1% gray clay at 47'-47.3' and 48.5'-49.3'. Scattered breaks at 50.5'-51.2'. [1,11]	
10	40	5.0	5.0	100			
	41.5						
11	45	5.0	4.5	90			
	46.5						
12	50	5.0	4.6	92			
	51.5						
	55						

BORING NO. DH-36

WIPP

WASTE ISOLATION PILOT PLANT

GEOLOGIC DRILL LOG

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-37

LOCATION ROOM G - ROOF

STATION N1101, W2182 COLLAR ELEV. 1297.4 FT DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10788.9, E4732.0 DEPTH OF BOREHOLE 51.5 FT.

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 1-25-85 DATE COMPLETED 1-26-85 SHEET

LOGGED BY: J. E. GALLERANI DATE: 1-26-85 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0	2.2	2.2	100	X	0.0'-1.8' HALITE: Clear, some light moderate reddish orange (10R 6/6), coarsely crystalline. <1/2% polyhalite. [1]	NC single-tube core barrel used for Run 1. NC double-tube core barrel used for remainder of hole.
	2.2				—	1.8'-5.3' ± 0.15' HALITE: Clear to moderate brown (5YR 3/4), medium to coarsely crystalline. None to 1% brown clay, some gray. Scattered breaks at 3.7', 4.0', 5.1'±.	42% of core recovered was was à 2" lengths.
2	5	5.8	5.3	91	—	5.3'-5.5' ANHYDRITE "b". Light to medium gray, microcrystalline anhydrite. Partially laminated. Trace of gray clay along irregular, low-angle surface at 5.3'. Core broken along this.	Dry hole. No gas detected.
	8.0				\\\\\\	5.5'-11.3' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. [1]	
3	10	3.5	3.2	91	\\\\\\	11.3'-12.2' HALITE: Clear, some moderate brown (5YR 4/4). Fine to medium crystalline, some coarse. ≤1% brown clay.	Run 4: Some broken core.
	11.5				—	12.2'-12.7' ANHYDRITE "a": Light to medium gray microcrystalline anhydrite. Up to 1/8" brown clay along low-angle, smooth surface at 12.2'. Some core grinding evident.	First 1' of Run 5 broken.
4	15	5.0	4.8	96	X X X X X X	12.7'-16.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite.	
	16.5				X	16.5'-21.6' HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline. ≤1% brown clay, trace of gray. <1/2% dispersed polyhalite. Up to 1/2" hard brown clay seam at 21.35'. Low-angle, irregular. Some anhydrite associated to 21.6'. [10, 17]	First 1' of Run 6 broken.
5	20	5.0	5.0	100	— X — X	21.6'-24.5' HALITE: Clear, coarsely crystalline. <1/2% brown clay to 23'. [8 to 23'; then 1]	Broken zones through Run 7, espacially first 18".
	21.5				X	24.5'-26.5' HALITE: Clear to light moderate reddish orange (10R 6/6) and moderate brown (5YR 4/4). Fine to medium, crystalline, some coarse. <1% brown clay, trace gray. <1/2% dispersed polyhalite. [12]	
6	25	5.0	4.2	84	— — —		

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-37

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
6	25					26.5'–30.2' HALITE: clear, coarsely crystalline. <1/2% brown clay to 28'. [8,1]	Broken clear halite in Run 9.
7	26.5 – 30	5.0	5.0	100		30.2'–35.15' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline, some fine. ≤1% brown clay to 31.5'; then 1 to 3%. Scattered breaks. [10,15]	
	31.5					35.15'–35.85' ANHYDRITE: Light to medium gray, microcrystalline anhydrite with scattered halite growths. Up to 1" hard brown clay at 35.15'. Low angle.	
8	31.5 – 35	5.0	4.5	90		35.85'–39.7' ± 0.7' HALITE: Clear, coarsely crystalline. <1/2% polyhalite. Scattered white anhydrite stringers.	
						39.7'–42.6' HALITE: Clear, some moderate brown (5YR 4/4); coarsely crystalline. ≤1% brown clay. Irregular break at 41.7'±. [10]	
9	36.5	1.5	1.5	100		42.6'–44.9' HALITE: Clear with <1% moderate reddish orange polyhalite blebs. Coarsely crystalline. [1]	
10	38.0 – 40	3.5	2.1	60		44.9'–47.25' HALITE: Clear to moderate brown (5YR 4/4); coarsely crystalline. ≤1% brown clay. [10]	
11	41.5 – 45	4.5	4.5	100		47.25'–51.5' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline, some fine. <1 to 3% brown clay, locally up to 5% from 49.8'–50.9'. Scattered breaks at 47.6'; 50.9', 51.2'±. <1/2% polyhalite. [15]	
12	46.0 – 50	5.5	5.5	100			
	51.5 – 55						

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER ____ - ____ HOLE TYPE/SIZE NC CORE BORING NO. DH-38

LOCATION ROOM G - FLOOR

STATION N1101, W2182 COLLAR ELEV. 1287.0 FT DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N10788.8, E4731.9 DEPTH OF BOREHOLE 47.5 FT

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 1-25-85 DATE COMPLETED 1-26-85 SHEET

LOGGED BY: J. E. GALLERANI DATE: 1-26-85 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0						
1		2.4	2.3	96		0.0'-2.5' HALITE: Clear to moderate brown (5YR 3/4); coarsely crystalline, some medium. ≤1% brown clay. [8,10]	HC double-tube wireline core barrel, except Run 1 where HC single-tube barrel was used
	2.4						
2	5	5.0	4.9	98		2.5'-3.1' HALITE: Clear, coarsely crystalline. <1/2% polyhalite blebs. [1,2]	47% of core recovered was à 2-inch lengths.
						3.1'-7.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite. Anhydrite mixed with halite from 5.4' to 7.4'. Some "swallowtail" structure evident. [4,7 to 5.4']	Dry hole. No gas detected.
	7.4						
3		4.1	3.9	95		7.4'-9.45' HB-139: Gray anhydrite mixed with growths of polyhalitic halite/halite to 9'; then predominantly light to light medium gray anhydrite. Scattered halite growths. Gray clay at lower contact. Core grinding evident.	
	10						
	11.5					9.45'-13.2' HALITE: Clear to light moderate reddish orange (10R 6/6), medium to coarsely crystalline. ≤1% polyhalite and gray clay. [9]	
4		5.0	4.2	84		13.2'-17.35' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite. Some anhydrite and gray clay from 17.05' to 17.3'±. [7]	
	15						
	16.5					17.35'-18.8' HALITE: Clear to light moderate reddish orange (10R 6/6); coarsely crystalline, some medium. <1% polyhalite. < 1/2% clay, brown and gray. [8,9]	
5		5.0	4.7	94		18.8'-22.3' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6); coarsely crystalline. <1 to 3% polyhalite. Trace gray clay at 21.5'. [7]	
	20						
	21.5					22.3'-28.7' HALITE: Clear to moderate reddish orange/brown (10R 6/6, 4/6). Coarsely crystalline, some medium. ≤1 to 2% polyhalite locally. ≤1% light bluish gray clay, slight trace of brown.	
6		5.0	5.0	100		28.7'-34.3' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6), coarsely crystalline. <1 to 3% polyhalite. Clear halite 34-34.3'. [7]	
	25						

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-38

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
6	25					34.3'-34.6' ANHYDRITE: Very light to light medium gray microcrystalline anhydrite. Scattered small halite growths common from 34.45'± with larger growths present above this. Some irregular laminae within anhydrite. 1/4" hard dry gray clay at lower contact. Low angle.	Dropped core barrel on last run. After retrieving barrel, did not continue drilling.
26.5							
7	30	5.0	5.0	100		34.6'-41.55' HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6). Medium to coarsely crystalline with zones of fine to medium, sugary-textured halite. None to ≤1% polyhalite. <1% gray clay, some brown. Polyhalitic 41.2'-41.55'. [9, some 17]	Total time on hole was 12 hrs ±.
31.5							
8	35	5.0	5.0	100		41.55'-44.1' HALITE: Clear to moderate brown (5YR 4/4; 3/4), coarsely crystalline, some medium. <1 to 2% brown clay. Trace of polyhalite. [10]	
36.5							
9	40	5.0	5.0	100		44.1'-47.5' HALITE: Clear to light moderate reddish orange (10R 6/6); medium to coarsely crystalline, some fine. <1% polyhalite. ≤ gray clay. [2,9]	
41.5							
10	45	6.0	5.1	85			
47.5	50						
	55						

WIPP

WASTE ISOLATION PILOT PLANT

GEOLOGIC DRILL LOG

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-40

LOCATION ROOM G - FLOOR

STATION N1101, W2482 COLLAR ELEV. 1286.1 FT DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N10789.2, E4431.0 DEPTH OF BOREHOLE 51.0 FT

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 1-24-85 DATE COMPLETED 1-25-85 SHEET

LOGGED BY: J. E. GALLERANI DATE: 1-25-85 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0	2.0	1.9	95		0.0'-2.6' HALITE: Clear, some moderate brown (5YR 4/4), coarsely crystalline, some medium. <1/2% polyhalite. ≤1% brown clay, trace of gray. [8,10]	NC double-tube wireline core barrel, except for Runs 1 and 2 where NC single-tube barrel used.
2	2.0	0.7	0.7	100		2.6'-5.4' HALITE: Clear, some moderate reddish orange (10R 6/6), coarsely crystalline. ≤1% polyhalite blebs. Trace gray clay locally. [2,4]	Total drilling time: 8 hrs. ±.
3	2.7 5	3.8	3.7	97		5.4'-7.05' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline, except fine to medium from 5.4' to 5.8'±. <1 to 3% polyhalite. Trace anhydrite from 6.55'. [4,7]	Dry hole. No gas detected.
4	6.5 10	5.0	5.0	100		7.05'-10.95' MB-139: Moderate reddish orange to light gray anhydrite and polyhalitic halite to 9.5'±. Then light to light medium gray anhydrite with scattered growths of halite within. 3/4" hard, gray, dry clay at lower contact.	74% of core recovered was ≥2-inch lengths. Good core.
5	11.5 15	5.0	5.0	100		10.95'-15.1' HALITE: Clear with some light moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1/2% dispersed polyhalite. <1/2% gray clay. [9]	
6	16.5 20	5.0	5.0	100		15.1'-18.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1 to 3% polyhalite. Average 2%. 1-1/2" polyhalite/anhydrite at 18.25'. Gray clay parting at 18.4'. [7]	
7	21.5 25	5.1	5.1	100		18.4'-20.2' HALITE: Clear to light moderate reddish orange (10R 6/6). Some light gray (N7). Medium to coarsely crystalline. <1% gray clay. <1/2 % polyhalite. [9]	
						20.2'-24.3' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1 to 3% polyhalite. [4,7]	
						24.3'-26.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline, some medium. <1 to 3% polyhalite. ≤1% gray clay.	

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-40

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
7	26.6	5.1	5.1	100		26.4'-29.7' HALITE: Clear, some light moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1/2% dispersed polyhalite and brown clay. Trace gray clay locally. [17, locally 9]	
8	30	4.9	4.9	100		29.7'-35.05' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1 to 3% polyhalite. Moderate reddish orange polyhalite/anhydrite from 34.7'-34.95'. [4,7]	
9	31.5	4.5	4.5	100		35.05'-35.4' ANHYDRITE: Light to very light (N7, N8) gray anhydrite to 35.15'. Then anhydrite with scattered halite growths throughout. 1/4" hard, dry gray clay at lower contact.	
10	35	5.0	5.0	100		35.4'-36.75' HALITE: Clear to light moderate reddish orange, fine to medium crystalline. <1/2% dispersed polyhalite and gray clay. [2,9]	
11	36.0	5.0	5.0	100		36.75'-41.0' HALITE: Clear, trace of moderate brown, coarsely crystalline. <1% brown clay. [8]	
12	40	5.0	5.0	100		41.0'-47.0' HALITE: Clear to moderate reddish orange/brown (10R 6/6, 4/6). Coarsely crystalline, some medium. <1 to 2% polyhalite. <1% gray clay, some brown. Locally polyhalite. [2,4,6]	
	41.0					47.0'-48.8' HALITE: Clear to light moderate reddish orange (10R 6/6), coarsely crystalline. <1% polyhalite. [1,2]	
	45					48.8'-51.0' HALITE: Clear to light moderate reddish orange (10R 6/6). Medium to coarsely crystalline, some fine. <1/2% polyhalite and gray clay locally. Break at 50.6'± which dips 45°±. Trace of gray clay along contact of fine-medium crystalline and coarse crystalline halite at 49'-50.5'±. [1,9]	
	46.0						
	50						
	51.0						
	55						

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-39

LOCATION ROOM G - ROOF

STATION N1101, W2482 COLLAR ELEV. 1296.0 FT DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10789.2, E4430.7 DEPTH OF BOREHOLE 50.7 FT

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 1-24-85 DATE COMPLETED 1-24-85 SHEET

LOGGED BY: J. E. GALLERANI DATE: 2-9-85 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0						
1		3.7	3.0	81		0.0'-3.6' HALITE: Clear, coarsely crystalline, some medium. [1]	Run 1 made with NC single-tube barrel. Remainder of hole with NC double-tube wireline core barrel.
						3.6'-6.6' ± 0.3' HALITE: Clear, some moderate brown (5YR 3/4), coarsely crystalline to 5', then medium to coarse. ≤ 1% clay, increasing content from 5'. Brown, some gray. Break at 5.9'±.	Dry hole. No gas detected.
3.7							
2	5	5.0	4.3	86		6.6'-6.8' ANHYDRITE "b": Medium gray, microcrystalline. Gray clay at 6.6'. Core broken. Halite growths especially within 0.05' of lower contact.	30% of core recovered was ≤ 2-inch lengths.
						6.8'-13.2' HALITE: Clear, coarsely crystalline. <1/2% polyhalite from 12.2'. [1]	Core broken in parts of Runs 3 and 4.
8.7							
3	10	5.0	4.8	96		13.2'-13.9' HALITE: Clear to moderate brown (5YR 3/4) and light moderate reddish orange. Fine to medium crystalline. ≤1% brown clay. <1/2% dispersed polyhalite. [9,17]	
						13.9'-14.45' ANHYDRITE "a": Light gray to light medium gray, microcrystalline anhydrite. Near-horizontal laminae. Scattered halite growths. 3/8" gray clay at 13.9'.	Last 0.2' of Run 3 broken.
13.7							
4	15	5.0	5.0	100		14.45'-18.75' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1 to 3% polyhalite, average 2%. Anhydrite stringer at 15.8'. [2,3,5]	Run 6: Core broken; discing throughout.
						18.75'-23.7' HALITE: Clear to moderate brown (5YR 4/4) and some moderate reddish orange (10R 6/6). Medium to coarsely crystalline. ≤1% brown clay, locally up to 2%. <1% polyhalite, dispersed and blebs. [10,17]	Run 8: Mostly broken zones. Run 9: Discing of core. Run 10: Several broken zones.
18.7							
5	20	5.0	4.8	96		23.7'-28.2' HALITE: Clear, coarsely crystalline. <1/2% brown clay to 25'. <1/4" brown clay at 25.0' with associated anhydrite layer to 25.15'. [1]	Runs 11 and 12: Broken core.
						28.2'-30.0' HALITE: Clear to moderate brown, some moderate reddish orange. Fine to medium, some coarse. ≤1 brown clay. <1/2% dispersed polyhalite. [12]	Run 13: Core is badly broken.
23.7							
6	25	4.7	4.7	100			

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-39

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
6	25	4.7	4.7	100		30.0'-32.6' HALITE: Clear, some moderate brown (5YR 4/4), coarsely crystalline. None to <1% brown clay. [1,8]	
	28.4					32.6'-34.9' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4; 4/4). Medium to coarsely crystalline. <1 to 3% brown clay. Trace of dispersed polyhalite.	
7		1.8	1.8	100		34.9'-35.9' HALITE: Clear to light moderate reddish orange; medium to coarsely crystalline. <1/2% dispersed polyhalite and gray clay [2,9].	
	30.2						
8		1.5	1.5	100		35.9'-36.5' ANHYDRITE: Light gray to medium gray microcrystalline anhydrite. Some halite growth. Trace brown clay at 35.9'. Core grinding evident.	
	31.7						
9		1.4	1.4	100			
	33.1					36.5'-41.4' HALITE: Clear, some light moderate reddish orange (10R 6/6) coarsely crystalline. <1/2% polyhalite. [1,2]	
10		2.8	2.8	100			
	35.9					41.4'-45.7' ± 0.6' HALITE: Clear with some moderate brown and moderate reddish orange. Fine to medium crystalline to 43.5'±, then coarsely crystalline. <1/2% dispersed polyhalite. <1% brown clay.	
11		2.0	1.7	85			
	37.9					45.7'-50.7' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4). Medium to coarsely crystalline, some fine. <1 to 5% brown clay.	
12		5.0	5.0	100			
	42.9						
13		4.0	2.5	62			
	46.9						
14		3.8	2.5	66			
	50.7						
	55						

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER ____ - ____ HOLE TYPE/SIZE NC CORE BORING NO. DH-41

LOCATION ROOM G - ROOF

STATION N1101, W2782 COLLAR ELEV. 1295.8 FT DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N10789.0, E4132.6 DEPTH OF BOREHOLE 49.9 FT

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 1-23-85 DATE COMPLETED 1-24-85 SHEET

LOGGED BY: J. E. GALLERANI DATE: 1-24-85 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0						
1		3.0	1.1	37		0.0'-3.0' HALITE: Clear, coarsely crystalline, some medium. [1]	NC single-tube core barrel for Run 1. All other runs used NC double-tube wireline core barrel.
	3.0					3.0'-5.9' HALITE: Clear, some light moderate brown, coarsely crystalline. <1/2% brown clay. [8]	Total drilling time: 8 hrs ±.
2	5	4.0	3.3	82		5.9'-7.0' HALITE: Clear to moderate brown (5YR 4/4), fine to medium, some coarse crystalline. ≤1%, locally 2%, brown clay with trace of gray. <1/2% dispersed polyhalite.	Dry hole. No gas detected.
	7.0					7.0'-7.3' ANHYDRITE "b": Light to light medium gray (N7, N6), microcrystalline anhydrite. Laminated to 7.1'. Scattered halite growths. ≤1/2" gray clay at 7.0'. Some core grinding evident.	31% of recovered core was ≥2-inch lengths. Run 1: Some broken core. Run 3: Broken last 1/2'.
3		4.0	2.8	70		7.3'-12.9'± 0.4' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. <1/2% polyhalite locally. [1]	Much of Run 5 broken.
	10						
	11.0					12.9'-13.8'± 0.4' HALITE: Clear to moderate brown (5YR 4/4), medium to coarsely crystalline. ≤1% brown clay, some gray. Only 0.4' core recovered.	
4		5.0	4.2	84		13.8'± -14.4' ANHYDRITE "a": Light to light medium gray (N7, N6); microcrystalline anhydrite. Irregular dark/light laminae. Trace of brown clay at 13.8'. Low-angle contact.	Run 8: Zones of broken core.
	15						
	16.0					14.4'-18.8'± POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1 3% polyhalite. [5,7]	
5		5.0	3.4	68		18.8'-25.0' HALITE: Clear to moderate brown (5YR 4/4), some moderate reddish orange. Medium to coarsely crystalline, some fine. ≤1% brown clay, trace of gray. <1/2% of polyhalite locally. Irregular, low-angle brown clay seam at 24.8'. Up to 1/4". Associated anhydrite to 25'. Core broken. [1,10]	Run 10: Some broken zones.
	20						
	21.0					25.0'-27.7' HALITE: Clear, coarsely crystalline. Scattered polyhalite and anhydrite stringers.	Run 12: Partially broken last 3'.
6		5.0	5.0	100			
	25						

BORING NO. DH-41

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-41

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
6	25	5.0	5.0	100		27.7'-29.4' HALITE: Clear, some moderate brown (5YR 4/4) and moderate reddish orange (10R 6/6). Medium to coarsely crystalline, some fine. ≤1% brown clay and <1/2% dispersed polyhalite locally. [12]	
26.0							
7		1.5	1.5	100			
27.5						29.4'-31.4' HALITE: Clear, coarsely crystalline. [1]	
8	30	5.0	5.0	100		31.4'-36.5' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4; 3/4), fine to coarsely crystalline. <1 to 3% brown clay. Scattered breaks. [10,15]	
32.5						36.5'-37.25' ANHYDRITE: Light to medium gray (N7,N5), microcrystalline anhydrite. Laminae most noticeable from 37.0'. Prominent halite growths to 36.75'. Up to 1/4" brown clay at 36.5' but core broken here.	
9	35	4.0	4.0	100		37.25'-42.55' HALITE: Clear, coarsely crystalline. None to 2% polyhalite. Scattered anhydrite. [1,2] ≤2% polyhalite from 38.9-41.1'. [4]	
36.5						42.55'-47.0' HALITE: Clear, some moderate brown (5YR 4/4), coarsely crystalline, some fine to medium locally. <1% brown clay. [8,10]	
10	40	4.6	4.6	100		47.0'-49.9' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4; 4/4). Medium to coarsely crystalline, some fine. <1 to 3% brown clay, locally up to 5%. Scattered breaks. [10,15]	
41.1							
11		1.4	1.4	100			
42.5							
12	45	4.4	4.4	100			
46.9							
13		3.0	3.0	100			
49.9	50						
	55						

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER: - HOLE TYPE/SIZE: NC CORE BORING NO. DH-42

LOCATION: ROOM G - FLOOR

STATION: N1101, W2782 COLLAR ELEV. 1285.9 FT DIRECTION OF DRILLING: VERTICAL DOWN

MINE COORDINATES: N10789.0, E4132.4 DEPTH OF BOREHOLE: 51.2 FT

DRILLING METHOD: ROTARY AIR DRILL MAKE/MODEL: CP-65

DATE STARTED: 1-23-85 DATE COMPLETED: 1-23-85 SHEET 1 OF 2

LOGGED BY: J. E. GALLERANI DATE: 2-14-85

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED
1	0 – 3.6	3.6	3.6	100
2	3.6 – 8.6	5.0	5.0	100
3	8.6 – 13.2	4.6	4.6	100
4	13.2 – 18.2	5.0	5.0	100
5	18.2 – 23.0	4.8	4.8	100
6	23.0 –	5.3	4.4	83

DESCRIPTION

0.0'-5.3' HALITE: Clear, some light moderate brown (5YR 4/4) and light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1% brown clay. [1,2,8]

5.3'-6.2' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% polyhalite from 5.6'±. [1,2]

6.2'-7.3' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6, 4/6). Coarsely crystalline. <1 to 3% polyhalite. [7]

7.3'-10.1' MB-139: Mixture of halite/anhydrite with "swallowtail" pattern from 7.3' to 8.9'. Then predominantly light to medium gray (N7, N5) microcrystalline anhydrite. Scattered halite growths. Up to 1/2" dry gray clay at lower contact. Contact dips 20°±.

10.1'-14.5' HALITE: Clear to light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1% dispersed polyhalite. <1/2% gray clay. Brown clay at 12.9'-13.3'. [9]

14.5'-17.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1 to 3% polyhalite. [7]

17.6'-24.5'± 0.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. 1 to 3% polyhalite. ≤1% gray clay to 20.8'. Scattered anhydrite. [5,7]

24.5'-28.3' HALITE: Clear, some light moderate reddish orange (10R 6/6) and moderate brown (5YR 4/4). Medium to coarsely crystalline. ≤1% brown clay. <1/2% dispersed polyhalite.

28.3'-39.8' Unable to log due to poor recovery and quality.

REMARKS

2-3/4" I.D. single-tube barrel used for Run 1. NC rods and NC double-tube core barrel used from Run 2.

Dry hole. No gas detected.

Total drilling time: 8 hrs ±.

45% of core recovered was ≥2-inch length.

Interval 20'-40.5' replaced with hole DH-42A.

Barrel plugged during Run 6.

No core recovery in Run 7.

Poor core quality in Runs 8 and 9.

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-42

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
6		5.3	4.4	83		39.8'± -43.3' HALITE: Clear, some moderate brown (5YR 4/4); medium gray (N5) and moderate reddish orange. Coarsely crystalline. 61% clay, gray with some brown. 61% polyhalite. BRUSH-gray break at 43.3'.	
28.3							
7	30	5.0	0.0	0	Unable to log due to poor core recovery and quality.	43.3'-44.65' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4), fine to medium crystalline, some coarse. <1/2% polyhalite. <1 to 3% brown clay. Scattered breaks.	
33.3						44.65'-47.2' HALITE: Clear, some moderate reddish orange (10R 6/6). Coarsely crystalline, some fine to medium. <1% gray clay. Predominantly brown clay to 46'. <1% polyhalite. [9,11, some 17]	
8	35	3.5	2.0	57		47.2'-51.2' HALITE: Clear, coarsely crystalline. <1/2% polyhalite. [1]	
36.8							
9		3.0	0.4	13			
39.8	40						
10		3.1	3.1	100			
42.9							
11	45	5.1	5.0	98			
48.0							
12		3.2	2.0	63			
51.2	50						
	55						

BORING NO. DH-42

WIPP

WASTE ISOLATION PILOT PLANT

GEOLOGIC DRILL LOG

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-42A

LOCATION ROOM G - FLOOR

STATION N1101, W2789 COLLAR ELEV. 1285.7 FT DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N10789.2, E4125.5 DEPTH OF BOREHOLE 40.5 FT

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 1-25-85 DATE COMPLETED 1-25-85 SHEET

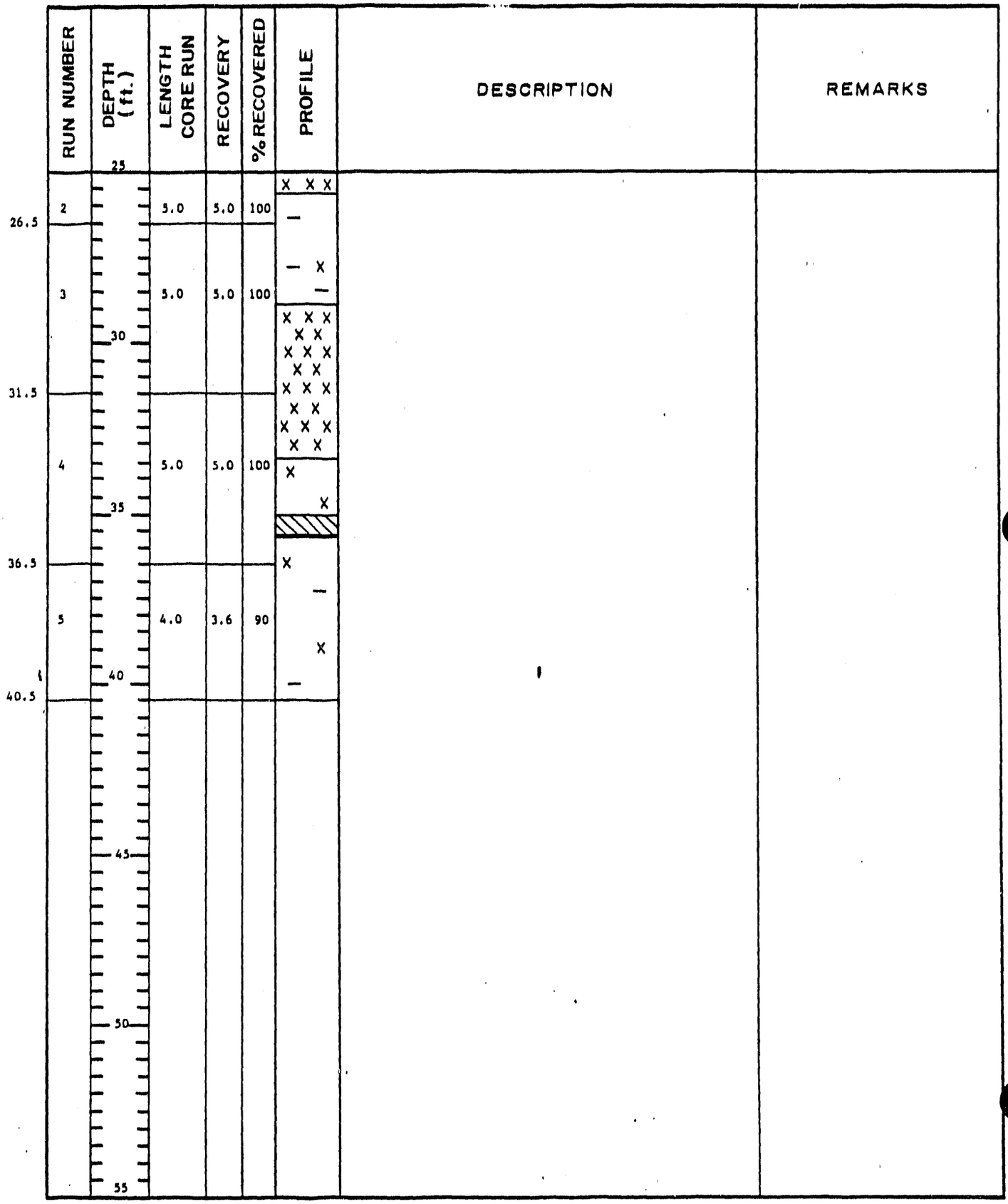
LOGGED BY: J. E. GALLERANI DATE: 1-25-85 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0					0.0'-20.0' No core. Refer to DH-42 log.	Replacement hole for portion of core hole DH-42.
						20.0'-25.7' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6) coarsely crystalline. <1 to 3% polyhalite. <1% gray clay from 24.7-25.7'. Some brown clay. [7, some 9]	MC double-tube wireline barrel used. MC rods 20.0'-40.5'.
						25.7'-28.9' HALITE: Clear, some moderate reddish orange (10R 6/6) and moderate brown (5YR 4/4). Medium to coarsely crystalline, some fine. <1% polyhalite and brown clay. Scattered breaks from 26.8'. [17]	58% of core recovered was ≥2-inch length.
		No Core				28.9'-33.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1 to 3%, average 2%, polyhalite. [4,7]	Total drilling time: 5 1/2 hrs ±.
						33.4'-35.0' HALITE: Clear, some light moderate reddish orange (10R 6/6), coarsely crystalline. <1% polyhalite, locally 2%. Small moist vug in core. Gradational contact at 33.4'. [1,2,4]	Dry hole. No gas detected.
						35.0'-35.7' ANHYDRITE: Moderate reddish orange/brown (10R 6/6, 4/6), intermixed with polyhalitic halite to 35.3'. Then moderate reddish orange to light gray anhydrite. Scattered halite growths. Up to 3/4" gray clay at 35.7'. Irregular, low-angle contact.	Very good core.
						35.7'-40.5' HALITE: Clear to light moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1/2% polyhalite. 0 to <1% gray clay. Breaks at 37.2' and 37.55'±. [9,11]	
	20.0						
1		1.5	1.5	100			
	21.5						
2		5.0	5.0	100			
	25						

BORING NO. DH-42A

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-42A



BORING NO. DH-42A

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-207 INSTRUMENT TYPE & NUMBER Extensometer GE-246 HOLE SIZE NX

LOCATION East 140 Drift, 300' S of centerline of South 400 Drift, near E rib

STATION S697, E155 COLLAR ELEV. 1259.8' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N8989.7, E7049.1 BOREHOLE PENETRATION 53.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/26/83

SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
9	25	5.0	100	—			
8	20	5.0	100	—		20.7' - 25.8' **HALITE:** mottled colorless to moderate reddish-orange (10R 6/6) to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, 0-1% polyhalite, 0-7% brown clay, banded clay/polyhalite appearance.	
7	15	4.7	92	—		16.4' - 20.7' **POLYHALITIC HALITE:** colorless to moderate reddish-orange (10R 5/6) halite, medium to coarsely crystalline, 10-20% polyhalite from 16.4'-17.2', 1-5% from 17.2'-20.7', clear, pure halite from 16.9'-17.0,' anhydrite stringer (~1/2") at 17.0', no clay, discontinuous anhydrite stringer (~1/16") at 18.1'.	
						15.7' - 16.4' **ANHYDRITE:** (Anhydrite "a") light gray (N7) microcrystalline anhydrite, 0-5% halite, no basal clay but core is badly broken and chipped up at bottom of anhydrite—clay may be washed away.	
6	10	4.2	84	—		8.9' - 15.7' **HALITE:** clear to colorless halite, medium to coarsely crystalline, <1% polyhalite from 8.8'-10.0' and 13.9'-15.3', absent elsewhere, ~1% gray clay from 13.9'-15.3', clay absent elsewhere, anhydrite stringer (1/16") at 9.0'.	Pressurized gas encountered at 11.9' pushed drill rods back slightly and blew water out of hole.
						8.75' - 8.9' **ANHYDRITE:** (Anhydrite "b") light gray (N7), microcrystalline anhydrite, 8.8'-8.9' core lost.	Gas encountered at ~8.8'.
5		040	80	—			
4	5	2.0	59	—		3.3' - 8.75' **HALITE:** colorless to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, fining upwards, 0-1% polyhalite, 1-5% brown clay locally concentrated, few blebs of gray clay, gray clay break at 8.75'.	Core runs 1 through 4 were drilled without inner barrel.
3		1.7	85	—			
2		0.7	88	—		0.0' - 3.3' **HALITE:** clear halite, coarsely crystalline, <1% polyhalite, <1% gray clay, <1% brown clay increasing upward, grades into next higher unit.	0' - 1' drilled with 6" single-tube core barrel.
1		0.8	67	—			Drilling started at 09:30 hours on 10 December 1982.
	0						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-207 INSTRUMENT TYPE & NUMBER Extensometer GE-246 HOLE SIZE NX

LOCATION East 140 Drift, 300' S of centerline of South 400 Drift, near E rib

STATION S697, E155 COLLAR ELEV. 1259.8' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N8989.7, E7049.1 BOREHOLE PENETRATION 53.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/26/83

RUN NUMBER	PENETRATION (ft.)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
14	50	4.0	100	—		(see description on next sheet)	
13	45	4.6	92	—		46.9' - 49.0' **HALITE:** colorless halite, coarsely crystalline, <1% polyhalite, few blebs of clay 46.9'-48.0', increasing to 1-2% (total brown and gray) from 48.0'-49.0', grades into unit above. 43.0' - 46.9' **HALITE:** mottled colorless to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, <1% polyhalite, 1-5% brown clay locally concentrated, brown clay parting at 43.5', 45.3'-46.6' is relatively pure halite with one brown clay seam impossible to locate because of condition of core.	
12	40	4.7	94	—		39.9' - 43.0' **HALITE:** colorless to moderate reddish-orange (10R 6/6) halite, coarsely crystalline, 1-3% disseminated polyhalite, several anhydrite stringers but core too broken to locate. 39.1' - 39.9' **ANHYDRITE:** (Marker Bed 138) light gray (N7) microcrystalline anhydrite, moderate (10R 4/6) to dark reddish-brown (10R 3/4) polyhalite band from 39.8'-39.9', 30-40% halite in upper 0.2'.	
11	35	4.6	92	—		33.9' - 39.1' **HALITE:** mottled colorless to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, fining upward, few blebs of polyhalite except for 1-2% at 38.2', 5% brown clay, <1% gray clay, brown clay seams at 38.3' and 39.1', brown clay break at 37.6', 0.1' of clear halite with trace gray clay at top of unit.	
10	30	5.0	100	—		31.4' -33.9' **HALITE:** colorless halite, coarsely crystalline, <1% polyhalite. 29.4' - 31.4' **ARGILLACEOUS HALITE:** colorless to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, few blebs of polyhalite, 1-2% brown and gray clay 29.4'-30.0', 10-20%, brown clay 30.0'-31.4', brown clay partings at 30.6', 30.8', 31.0', and 31.3', anhydrite stringer (<1/16") at 31.2'.	
9	25	5.0	100	—		25.8'-29.4' **HALITE:** colorless halite, coarsely crystalline, few blebs of polyhalite, brown clay parting at 26.3', clay absent elsewhere, anhydrite stringer zone 26.3'-26.7', anhydrite stringers (<1/16") at 26.9', 27.2', 27.6', and 28.3'.	
						(as below)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-207 INSTRUMENT TYPE & NUMBER Extensometer GE-246 HOLE SIZE NX

LOCATION East 140 Drift, 300' S of centerline of South 400 Drift, near E rib

STATION S697, E155 COLLAR ELEV. 1259.8' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N8989.7, E7049.1 BOREHOLE PENETRATION 53.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/26/83

SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55						total penetration = 53.0'.
14	50	4.0	100	—		49.0' - 53.0' **ARGILLACEOUS HALITE:** mottled colorless to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, fining upward, <1% polyhalite, 1-20% brown clay, increasing upward, brown clay partings at 50.1', 51.9', 52.6', and 52.9', brown clay seam at 50.2'.	Drilling completed on 11 December 1982.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-208 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 300' S of centerline of South 400 Drift, near E rib

STATION S698, E150 COLLAR ELEV. 1251.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N8988.8, E7044.0 DEPTH OF BOREHOLE 49.2'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12 B

PREPARED BY DGK, JPS/Bechtel DATE 1/26/83

RUN NUMBER	DEPTH (ft)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0	1.5	75	—			Drilling started 10:00 hours, 10 December 1982 RUN 1 - unclear where core loss occurred. No inner barrel used.
2	5	1.5	38	—		0.0' - 9.1' HALITE: clear to moderate reddish-orange (10R 6/6) and moderate reddish-brown (10R 4/6) halite, moderately hard, medium to coarsely crystalline, scattered blebs of orange polyhalite throughout. Trace (<1/2%) of brown interstitial clay. Polyhalite content increases to ~2% below 8.0'. Clear halite from 6.5' to 8.0'.	RUN 2 - no inner barrel used.
3		4.2	100	—			
4	10	4.4	88	—		9.1' - 12.6' ANHYDRITE: (Marker Bed 139) light gray (N7) anhydrite, moderately hard, very finely crystalline, core broken into 1/4" to 3/4" pieces. 12.6' - 12.7' CLAY: medium light gray (N6) clay seam, stiff, moderately plastic. 12.7' - 16.9' HALITE: clear to mottled medium gray (N5) to pale reddish-brown (10R 5/4) halite, moderately hard, finely to coarsely crystalline. Clay comprises 3-5% with trace (2-3%) interstitial polyhalite and scattered polyhalite blebs. Clay breaks at 13.6', 13.9', 14.0', 14.4', 14.7', 15.5', 16.1', and 16.7'.	RUN 4 - MB 139 is broken up--core loss probably from this bed.
5	15	5.1	100	—			
6	20	4.9	98	—		16.9' - 28.1' HALITE: clear halite with some moderate reddish-orange (10R 6/6) polyhalite zones, finely to coarsely crystalline, moderately hard. Trace (<1%) interstitial, light gray (N7) clay from 21.5'-2[illegible].8'. Polyhalite content ranges from 0 to 2% throughout and increases to 2-3% from 26.5'-28.1'. Clear halite from 24.7' to 26.0'.	
	25						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-208 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 300' S of centerline of South 400 Drift, near E rib

STATION S698, E150 COLLAR ELEV. 1251.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N8988.8, E7044.0 DEPTH OF BOREHOLE 49.2'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY DGK, JPS/Bechtel DATE 1/26/83 SHEET 2 OF 2

RUN NUMBER	DEPTH (ft)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	25					(as above)	
7		5.1	100	—			
	30					28.1' - 34.0' HALITE: clear to very light gray (N8) to light brownish-gray (5YR 6/1) halite, moderately hard, medium to coarsely crystalline, clay in part comprises up to 3% of core. Few polyhalite blebs throughout. Very light gray (N8) halite from 29.3'-30.2'. Clay breaks at 28.4', 29.3', 29.8', 30.9', and 32.0'.	Averaging 1 in approximately 2 1/2 minutes of drilling.
8		4.8	96	—			
	35					34.0' - 39.2' HALITE: polyhalitic, clear to moderate reddish-orange (10R 6/6) halite, moderately hard, coarsely crystalline. Polyhalite occurs as interstitial layers and scattered blebs and comprises 2-5% of core. Polyhalite lens from 38.5'-39.0'.	
9		3.9	98	—			
	40					39.2' - 39.4' ANHYDRITE: very light gray (N8) anhydrite, dense, hard, very finely crystalline, few blebs of clear halite.	
10		5.0	100	—			
	45					39.4' - 49.2' ARGILLACEOUS HALITE: clear to mottled medium dark gray (N4) to pale yellowish-brown (10YR 6/2), to pale red (10R 6/2) halite, moderately hard, finely to coarsely crystalline, clay content ranges from 0 to 10%. Scattered, near-horizontal clay breaks at 40.5', 40.7', 42.7', 42.9', 43.7', 47.6', 48.2', and 48.5'. Finely crystalline below 46.5'.	
11		4.8	96	—			
	50						Drilling finished 14:30 hours, 10 December 1982. Total depth = 49.2'. Hole slowly discharging gas on 13 December 1982.

WIPP-SPDV
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-211 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

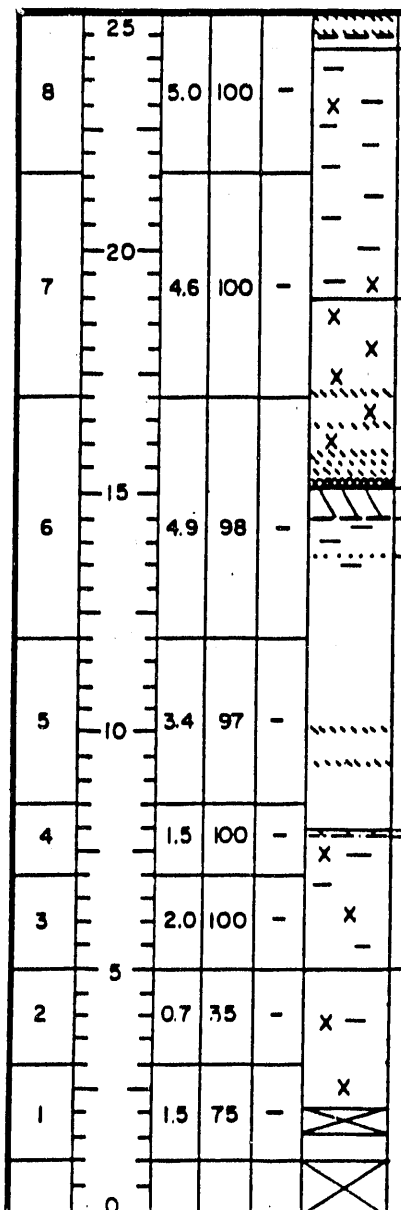
LOCATION East 140 Drift, 930' S of South 400 Drift centerline, near E rib

STATION S1320, E163 COLLAR ELEV. 1270.5' DIRECTION OF DRILLING Vertical UP

MINE COORDINATES N8366.5, E7057.1 BOREHOLE PENETRATION 50.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/26/83



RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	ROD	PROFILE	DESCRIPTION	REMARKS
						(see description on next sheet)	
8		5.0	100	-		19.0' - 24.2' HALITE: mottled colorless to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, fining upward, < 1% polyhalite, 1-5% brown clay locally concentrated, <1% gray clay.	
7		4.6	100	-		15.1' - 19.0' HALITE: colorless to moderate reddish-orange (10R 6/6) halite, coarsely crystalline, 1-2% polyhalite, polyhalite stringers at 15.1'; anhydrite stringer zone from 15.1'-15.8', anhydrite stringers at 16.3' and 17.1'.	
						14.5' - 15.1' ANHYDRITE: (Anhydrite "a") light gray (N7) microcrystalline anhydrite.	
6		4.9	98	-		13.7' - 14.5' HALITE: mottled colorless to grayish-orange-pink (5YR 7/2) to moderate brown (5YR 3/4) halite, medium to finely crystalline, <1% polyhalite, 2-5% disseminated brown clay, <1% gray clay, gray clay parting at 14.5'.	Advancing 5' in 0.5 hr.
5		3.4	97	-		7.9' - 13.7' HALITE: colorless halite, coarsely crystalline, <1% polyhalite and clay, anhydrite stringers at 9.3' (0.5") and 10.0' (0.1"), gray clay increases from 0-1% from 13.3' - 13.7', grades into unit above.	
4		1.5	100	-		7.8' - 7.9' ANHYDRITE: (Anhydrite "b") light gray (N7), microcrystalline anhydrite, mixed with halite at upper contact.	Gas at about 8'. Flow rate measured for 30 seconds = 11.8 cfm.
3		2.0	100	-		5.0' - 7.8' HALITE: colorless to mottled moderate reddish-orange (10R 6/6) to medium light gray (N6) halite, medium to coarsely crystalline, <1-3% polyhalite locally concentrated, ~1% gray clay, gray clay break at 7.8'.	Gas at moderate pressure at just under 8'.
2		0.7	35	-		0.0' - 5.0' HALITE: colorless halite, coarsely crystalline, < 1% polyhalite, few blebs of gray clay.	CORE LOSS: Run #1, at 1.6'-2.1' Run #2, throughout run
1		1.5	75	-			0' - 1.0' drilled with 6" single-tube core barrel. Drilling started at 13:45 hours on 18 December 1982.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-211 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 930' S of South 400 Drift centerline, near E rib

STATION S1320, E163 COLLAR ELEV. 1270.5' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N8366.5, E7057.1 BOREHOLE PENETRATION 50.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/26/83 SHEET 2 OF 2

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
13	50	3.0	100	-		48.1' - 50.0' **HALITE:** mottled, clear/colorless to moderate brown (5YR 3/4) halite, coarsely to finely crystalline, fining upward, 1-2% disseminated polyhalite from 49.6'-50.0', few blebs elsewhere, 1-5% brown clay locally concentrated.	Total penetration = 50.0'. Finished at 15:00 hours on 19 December 1982.
12	45	5.1	100	-		46.2' - 48.1' **HALITE:** clear to colorless halite, coarsely crystalline, <1% polyhalite and brown and gray clay, brown clay increases upward to 1% as unit grades into unit above. 42.3' - 46.2' **HALITE:** mottled colorless to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, <1% polyhalite except 45.5'-45.9' where 1-2% disseminated, 1-5% brown clay locally concentrated, brown clay break at 46.0'.	
11	40	4.6	92	-		38.5' - 42.3' **POLYHALITIC HALITE:** colorless to moderate reddish-orange (10R 6/6) halite, coarsely crystalline, 2-5% polyhalite with localized elongate blebs of polyhalite, anhydrite stringers 38.5'-38.7', 38.9', and 39.1', few blebs of clay, grades into unit above. 38.0' - 38.5' **ANHYDRITE:** (Marker Bed 138) light gray (N7) microcrystalline anhydrite.	
10	35	5.1	100	-		32.7' - 38.0' **HALITE:** mottled whitish to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, <1% polyhalite except 1-2% from 36.8'-37.1', 5% brown clay locally concentrated, brown clay break at 35.9', brown clay seam at 38.0'.	
9	30	5.2	100	-		30.5' - 32.7' **HALITE:** clear halite, coarsely crystalline, <1% polyhalite and clay. 28.5' - 30.5' **HALITE:** mottled whitish to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, fining upward, <1% polyhalite, 1-5% brown clay locally concentrated, <1% gray clay, brown clay break at 29.4', brown clay parting at 30.5'.	
8	25	5.0	100	-		24.2' - 28.5' **HALITE:** colorless halite, coarsely crystalline, <1% polyhalite and clay, anhydrite/gray clay parting at 24.6', anhydrite parting at 24.8', both ~0.5".	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-212 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 930' S of South 400 Drift centerline, near E rib

Vertical

STATION S1320, E163 COLLAR ELEV. 1261.7' DIRECTION OF DRILLING Down

MINE COORDINATES N8366.5, E7057.1 DEPTH OF BOREHOLE 52.1'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY DGK, JPS/Bechtel DATE 1/26/83

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0 – 5	5.6	80	–		0.0' - 4.3' **HALITE:** clear to medium gray (N5) halite, moderately hard, coarsely crystalline, 5% clay in part. Gray clay breaks at 2.0', 2.8', and 3.3'. Trace (<1/2%) polyhalite at 1.9'.	Started at 14:00 hours on 17 December 1982.
						4.3' - 10.7' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6) halite, moderately hard, finely to coarsely crystalline with trace of moderate brown (5YR 3/4) clay bands. 1% clay from 7.1'-7.7'. Polyhalite occurs as blebs and interstitially and ranges from <1% to 10%.	Drilling rate is 20' per hour. Core loss in Run #1 from 0.0'-1.4'. Brine saturation measured at 100%.
2	10	5.1	100	–		10.7' - 12.6' **ANHYDRITE:** (Marker Bed 139) banded, medium gray (N5) and very light gray (N8) anhydrite, hard, dense, finely crystalline. Core is broken into 1/4"-1/2" chips from 12.1' to 12.6'. Medium light gray (N6) clay seam at 12.6', moderately soft and plastic, ±1/2" thick.	Trace of gas detected in first 7'.
3	15	5.0	100	–		12.6' - 14.3' **HALITE:** clear, coarsely crystalline halite, moderately hard, <1% clay throughout. Medium light gray (N6) clay breaks at 13.0' and 13.2'.	
4	20	5.3	100	–		14.3' - 27.9' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6) halite, moderately hard, medium to coarsely crystalline. Polyhalite is interstitial and occurs as blebs and ranges from 0% to 10%. Discontinuous, very thin clay breaks at 15.6', 18.8', 19.9', 21.6', 22.0', and 27.4'.	
5	25	5.1	100	–			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-212 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 930' S of South 400 Drift centerline, near E rib

STATION S1320, E163 COLLAR ELEV. 1261.7' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N8366.5, E7057.1 DEPTH OF BOREHOLE 52.1'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY DGK, JPS/Bechtel DATE 1/26/83

RUN NUMBER	DEPTH (ft)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
5	25	5.1	100	-		(as above)	Drilling on 18 December 1982 started at 08:45 hours.
6	30	5.3	100	-		27.9' - 32.8' **HALITE:** argillaceous in part, clear to mottled grayish-red (5R 4/2) and medium light gray (N6) halite, moderately hard, finely to medium crystalline. Clay is interstitial and comprises up to 5%. Few medium light gray (N6) and moderate brown (5YR 3/4) clay breaks at 28.2', 28.4', 29.4', 29.7', 30.0', 30.1', and 31.3'. Trace (<1/2%) orange polyhalite blebs scattered from 31.2' to 32.8'.	
7	35	4.7	94	-		32.8' - 38.6' **HALITE:** polyhalitic, clear and moderate reddish-orange (10R 6/6) halite, slightly banded in part, moderately hard, finely to coarsely crystalline. Polyhalite is interstitial and occurs as blebs and ranges from 2-5%.	Drilling stopped at 09:30 due to electrical problems with drill motor. Resumed at 11:30.
						38.6' - 38.9' **ANHYDRITE:** light gray (N7) anhydrite, dense, hard, very finely crystalline. At 38.9', trace of light gray (N7) clay on anhydrite fragments.	
8	40	4.1	100	-		38.9' - 51.9' **ARGILLACEOUS HALITE:** clear to medium gray (N5) and pale yellowish-brown (10YR 6/2) halite, moderately hard, medium to coarsely crystalline, clay content from <1% to 10%. Few orange polyhalite blebs scattered throughout. Clay breaks at 43.0', 45.9', 48.1', 48.6', and 50.3'.	
9	45	5.2	100	-			
10	50	4.8	96	-			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-212 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 930" S of South 400 Drift centerline, near E rib

STATION S1320, E163 COLLAR ELEV. 1261.7' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N8366.5, E7057.1 DEPTH OF BOREHOLE 52.1'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY DGK,JPS/Bechtel DATE 1/26/83

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
10	50	4.8	96	-	X	(as above) 51.9' - 52.1' HALITE: clear halite, moderately hard, coarsely crystalline.	Finished hole at 12:45 hours on 18 December 1982. Total depth = 52.1'.
	55						

WIPP-SPDV
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-215 INSTRUMENT TYPE & NUMBER Extensometer GE-247 HOLE SIZE NX

LOCATION East 140 Drift, 1960' S of Exploratory Shaft centerline, 13' from E rib

STATION S1960, E153 COLLAR ELEV. 1272.0' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N7727.2, E7046.9 BOREHOLE PENETRATION 52.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY BWH/TSC//RMB,JPS/Bechtel DATE 1/5-6/83

SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
7	25	4.9	98	-		23.2' - 28.8' HALITE: clear, fine to coarsely crystalline halite, moderately hard, few white anhydrite seams. At 24.7', anhydrite seam, 0.1' with brown clay parting. At 25.6', 1/2" white anhydrite seam, near horizontal and irregular.	
						22.4' - 23.2' HALITE: clear, medium to coarsely crystalline halite. 1% to 2% polyhalite blebs. Trace of interstitial brown clay.	
6	20	4.3	86	-		18.0' - 22.4' HALITE: clear halite with 10-15% brown clay, coarsely crystalline. Clay breaks at 19.2', 19.7', and 20.3'. 2% interstitial polyhalite from 20.0' to 20.3'. At 20.6', anhydrite bleb.	
						14.5' - 18.0' HALITE: clear, coarsely crystalline halite, 5% polyhalite in blebs. At 14.8', 1/2" thick anhydrite seam, sub-horizontal, irregular surface. From 15.1' - 17.0' polyhalite reduced to 1%. From 17.0' - 18.0' trace of gray clay.	
5	15	5.0	100	-		14.0' - 14.5' ANHYDRITE: (Anhydrite "a") gray brown (5YR 3/2) to light gray, microcrystalline anhydrite.	
						7.6' - 14.0' HALITE: clear to light brown (10YR 4/2), coarsely crystalline halite. Less than 5% polyhalite, trace (<5%) of interstitial light gray clay. Gray clay seam at 14.0'.	
4	10	4.9	98	-		7.4' - 7.6' ANHYDRITE: (Anhydrite "b") gray (N4), hard anhydrite, gray halite, clay seam at 7.4'.	From 7.0' - 8.0', hit trace of pressurized gas.
3		1.7	85	-		5.5' - 7.4' ARGILLACEOUS HALITE: dark gray (N4) to brown (5YR 5/2), coarsely crystalline halite, 5-10% interstitial brown clay, trace of polyhalite.	
2	5	0.7	35	-		0.0' - 5.5' HALITE: clear coarsely crystalline halite, from less than 5% to 10% polyhalite.	0' - 1.0' drilled with 6" single-tube core barrel.
1		1.5	75	-			Set casing to 4.5" at 09:00 hr. Began NX coring with brine at 09:30 hrs, 5 January 1983.
	0						

WIPP-SPDV
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-215 INSTRUMENT TYPE & NUMBER Extensometer GE-247 HOLE SIZE NX

LOCATION East 140 Drift, 1960' S of Exploratory Shaft centerline, 13' rom E rib

STATION S1960, E153 COLLAR ELEV. 1272.0' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N7727.2, E7046.9 BOREHOLE PENETRATION 52.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY BWH/TSC//RMB,JPS/Bechtel DATE 1/5-6/83

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
12	50	5.0	100	–		42.0' - 52.0' **ARGILLACEOUS HALITE:** halite with trace polyhalite, mottled grayish brown and reddish orange (10YR 6/5). From 42.0' - 45.4', 20-30% brownish clay, coarsely crystalline with less than 1% polyhalite. Clay breaks at: 42.6', 42.9', 44.0', 44.2', 44.5', and 45.3'. From 45.4' - 47.4', clear, medium to coarsely crystalline, trace of gray clay, less than 1% polyhalite. From 47.4' - 52.0', argillaceous with 10-15% clay, fine to coarsely crystalline, moderately hard. Clay breaks at: 48.2', 48.8', 49.3', 49.4', 49.5', 50.4', 50.7', 50.9', 51.1', and 51.4'. From 51.2' - 52.0', finely crystalline with less than 2% interstitial polyhalite.	Stopped coring on 5 January 1983 at 15:30 hrs. at 42.0 ft.
11	45	5.0	100	–			
10	40	5.0	100	–		38.4' - 42.0' **HALITE:** polyhalitic (5-10%) halite, clear and mottled reddish-orange, polyhalite as blebs in part. Moderately hard, medium crystalline. Trace of gray clay throughout. At 38.7', thin <1/4" anhydrite stringer. 37.8' - 38.4' **ANHYDRITE:** (Marker Bed 138) light gray (N5) anhydrite, hard, dense, with light and dark gray banding. At 37.8', 0.1' thick brown clay seam, moderately stiff. 36.6' - 37.8' **HALITE:** polyhalitic (25%) halite to 37.0', finely crystalline, mottled gray, brown, and reddish orange, moderately hard. Argillaceous (10-15%) to 37.8', finely to medium crystalline, gray brown.	
9	35	5.0	100	–		32.8' - 36.6' **ARGILLACEOUS HALITE:** dark grayish brown (5YR 3/2) halite with some clear halite. Moderately hard, medium to coarsely crystalline. Clay breaks at 33.2', 33.3', 34.1', 34.4', 34.6', 34.9', 35.0', 35.4', 35.8', 36.3', and 36.6'.	
8	30	5.0	100	–		30.4' - 32.8' **HALITE:** clear halite, moderately hard, finely to medium crystalline. 28.8' - 30.4' **ARGILLACEOUS HALITE:** brownish gray (5YR 4/1), finely to coarsely crystalline halite, moderately hard. Clay (10-20%) is dark brown with trace of gray. Polyhalite (1%) from 30.2' to 30.4'. At 29.6', brown clay break.	
7	25	4.9	98	–		(As below)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-215 INSTRUMENT TYPE & NUMBER Extensometer GE-247 HOLE SIZE NX

LOCATION East 140 Drift, 1960' S of Exploratory Shaft centerline, 13' from E rib

STATION S1960, E153 COLLAR ELEV. 1272.0' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N7727.2, E7046.9 BOREHOLE PENETRATION 52.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY BWH/TSC//RMB.JPS/Bechtel DATE 1/5-6/83

SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	ROD	PROFILE	DESCRIPTION	REMARKS
12	50	5.0	100	–		(As below)	Total penetration = 52.0' Completed hole at 10:00 hours on 6 January 1983.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-216 INSTRUMENT TYPE & NUMBER Extensometer GE-248 HOLE SIZE NX

LOCATION East 140 Drift, 1960' S of Exploratory Shaft centerline, 13' from E rib

STATION S1960, E153 COLLAR ELEV. 1262.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N7727.2, E7046.9 DEPTH OF BOREHOLE 54.2'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RMB, JPS/Bechtel DATE 1/8-10/83

RUN NUMBER	DEPTH (ft.)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
0	0	0.7	70	-		0.0' - 2.0' HALITE: clear, fine to coarsely crystalline halite, trace of polyhalite.	NX coring began at 10:00 hours on 6 January 1983. From 0-7', core loss due to grinding throughout runs 0 & 1.
1	5	4.8	80	-		2.0' - 8.0' ARGILLACEOUS HALITE: clear and medium gray (N5) halite, moderately hard, 10-20% gray intercritial clay throughout, medium to coarsely crystalline. Clay breaks at 3.5' and 7.6'. At 4.2', blebs and trace of polyhalite.	0' - 1' drilled with 6" single-tube core barrel.
2	10	4.0	100	-		8.0' - 9.2' POLYHALITIC HALITE: clear and medium reddish-orange (10R 6/5) halite, coarsely crystalline, hard, brittle. 30-50% finely crystalline polyhalite. 9.2' - 9.9' POLYHALITE: medium reddish-orange (10R 6/5) polyhalite, hard, finely crystalline, with 20-30% clear halite. 9.9' - 11.5' ANHYDRITE: (Marker Bed 139) light gray to pale brown (5YR 5/2) anhydrite, banded, hard, dense.	Trace of gas at 11.0'.
3	15	5.2	100	-		11.5' - 12.3' POLYHALITE: medium reddish-orange (10R 6/5) polyhalite, trace of light gray anhydrite partings. 12.3' - 12.5' CLAY: brownish-gray (5YR 4/1) clay seam, stiff to firm, subhorizontal with irregular lower contact. 12.5' - 15.6' HALITE: medium reddish-orange (10R 6/5) and mottled brownish-gray (5YR 4/1) halite, finely to coarsely crystalline, moderately hard, argillaceous in part (< 2%). 5% polyhalite in part. Clay breaks at 12.7', 13.1', 13.8', 14.8', 15.5'.	
4	20	5.3	100	-		15.6' - 27.8' POLYHALITIC HALITE: clear and medium reddish-orange (10R 6/5) halite, moderately crystalline, hard. 5-30% blebs of polyhalite. Polyhalite < 1% from 20.5'-23.0'. Gray clay break at 26.9'.	
5	25	5.2	100	-			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-216 INSTRUMENT TYPE & NUMBER Extensometer GE-248 HOLE SIZE NX

LOCATION East 140 Drift, 1960' S of Exploratory Shaft centerline, 13' from E rib

STATION S1960, E153 COLLAR ELEV. 1262.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N7727.2, E7046.9 DEPTH OF BOREHOLE 54.2'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RMB, JPS/Bechtel DATE 1/8-10/83

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
5	25	5.2	100	-		(As above)	
6	30	5.3	100	-		27.8' - 32.4' ARGILLACEOUS HALITE: mottled brownish-gray (5YR 4/1) halite with trace of orange polyhalite. Moderately hard, finely to coarsely crystalline. Abundant interstitial clay at 30.9'. Clay breaks at 27.85', 28.1', 28.5', 29.2', 29.3', 29.9', 30.2', 30.6', 31.4'.	
7	35	5.2	100	-		32.4' - 38.2' HALITE: clear and medium reddish orange (10R 6/5) halite, finely to coarsely crystalline, moderately hard, few blebs of polyhalite throughout. Polyhalite generally less than 5%. At 37.2', sub-horizontal polyhalite seam.	
8	40	5.1	100	-		38.2' - 38.4' ANHYDRITE: medium light gray (N6) anhydrite, hard, dense, underlain by light gray clay parting of unknown thickness.	
						38.4' - 42.9' ARGILLACEOUS HALITE: mottled medium gray (N5) halite, finely to medium crystalline, 10% gray clay throughout. Clay breaks at: 39.4', 39.6', 40.2', 40.6', 41.8'. From 40.9' to 41.8', trace of polyhalite.	
9	45	5.3	100	-		42.9' - 45.2' HALITE: clear to moderate reddish-orange (10R 6/6) halite, finely to medium crystalline, trace of interstitial gray clay throughout.	
						45.2' - 49.7' ARGILLACEOUS HALITE: light grayish-brown halite, finely to medium crystalline, moderately hard, brown clay 2-5%. Clay breaks at: 45.7', 46.3', 46.7', 47.5', 49.0'. Trace of polyhalite.	
10	50	5.1	100	-		(see description on next sheet)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-216 INSTRUMENT TYPE & NUMBER Extensometer GE-248 HOLE SIZE NX

LOCATION East 140 Drift, 1960' S of Exploratory Shaft centerline, 13' from E rib

STATION S1960, E153 COLLAR ELEV. 1262.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N7727.2, E7046.9 DEPTH OF BOREHOLE 54.2'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RMB,JPS/Bechtel DATE 1/8-10/83

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
10	50	5.1	100	-		49.7' - 54.2' HALITE: clear, medium to coarsely crystalline halite, moderately hard. Trace of gray clay throughout.	Hole completed on 6 January 1983 at 15:00 hours. Total depth = 54.2'
11		1.5	100	-			
	55						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-219 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 2422' S of Exploratory Shaft centerline, 5' from E rib

STATION S2422, E162 COLLAR ELEV. 1266.3' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N7264.9, E7056.6 BOREHOLE PENETRATION 51.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/18/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft.)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
8	25	5.1	100	—		24.0' - 28.8' HALITE: clear, medium to coarsely crystalline halite, moderately hard, few scattered white anhydrite blebs. At 24.3', 1/2" thick medium gray (N5) clay seam, dense, highly plastic.	
7	20	5.0	100	—		21.7' - 24.0' HALITE: clear to light brownish-gray (5YR 4/1) halite, finely crystalline, moderately hard. Trace (< 1%) of brown, interstitial argillaceous material throughout.	
						19.0' - 21.7' HALITE: argillaceous, clear to mottled brownish-gray (5YR 4/1) and moderate brown (5YR 3/4) halite, finely to medium crystalline, moderately hard. Light and dark brown interstitial argillaceous zones (5%) throughout. Clay breaks at: 19.0', 19.4', 19.9', 20.5', 20.7' and 21.5'.	
6	15	5.0	100	—		15.1' - 19.0' HALITE: clear, medium to coarsely crystalline halite, moderately hard. At 15.7', 45° dipping very light gray (N8) anhydrite seam, 1" thick. Few blebs of reddish-orange (10R 5/6) polyhalite throughout. Polyhalite content increases to 1/2% below 18.2'.	Trace of pressurized gas encountered at 15.0'.
						14.5' - 15.1' ANHYDRITE: (Anhydrite "a") banded light (N7) to dark (N3) gray anhydrite, hard, dense, trace of clear interstitial halite throughout.	
						14.4' - 14.5' CLAY: very light gray (N8) clay seam, subhorizontal, moderately soft.	
5	10	4.8	96	—		8.0' - 14.4' HALITE: clear to very pale orange (10YR 8/2) halite, finely to coarsely crystalline, moderately hard. From 13.0' to 14.4', argillaceous content up to 1%. Few polyhalite blebs at 14.2'.	CORE LOSS:
4		0.7	70	—			RUN 1: WHERE LOST 0.0' - 0.2'
3	5	2.1	52	—		5.8' - 8.0' HALITE: argillaceous, clear to mottled brownish-gray (5YR 4/1) to moderate brown (5YR 3/4) halite, moderately hard, slightly brittle, finely to coarsely crystalline.	RUN 3: 4.1' - 4.8'; 5.2' - 6.0'; 6.5' - 6.9'
						0.0' - 5.8' HALITE: clear halite, medium to coarsely crystalline, moderately hard, trace (<1%) of interstitial polyhalite and few scattered blebs of medium reddish-orange (10R 5/6) polyhalite throughout.	RUN 4: 7.9' - 8.2'
2		2.1	95	—			NX coring began at 13:00 hours on 13 January 1983.
1	0	1.1	85	—			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO DH-219 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 2422' S of Exploratory Shaft centerline, 5' from E rib

STATION S2422, E162 COLLAR ELEV. 1266.3' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N7264.9, E7056.6 BOREHOLE PENETRATION 51.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/18/83

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	FOD	PROFILE	DESCRIPTION	REMARKS
	50					(see description on next sheet)	
13		4.0	100	—		42.8' - 49.9' **HALITE:** argillaceous, clear to mottled grayish-brown (5YR 3/2) halite, moderately hard, finely to coarsely crystalline. Numerous scattered, brown clay breaks throughout. Argillaceous content ranges from 0% to 2%. Reduction in clay content from 46.8'-48.0'. Clay breaks at: 43.2', 43.8', 44.8', 44.9', 45.4', 45.9', 46.4', 46.5', 49.0', and 49.6'.	
12	45	3.1	100	—			
11		5.0	100	—		38.9' - 42.8' **HALITE:** clear, medium to coarsely crystalline halite, moderate hard. Few scattered stringers of light gray (N7) anhydrite throughout. Irregular anhydrite partings at: 39.0', 39.1', 39.7', and 40.2'.	
	40					38.1' - 38.9' **ANHYDRITE:** (Marker Bed 138) white (N9) to very light gray (N8) anhydrite, dense, hard, finely crystalline.	
10		4.8	96	—	-X-	38.0' - 38.1' **CLAY:** moderate brown (5YR 3/4) clay seam, moderately soft and plastic, subhorizontal contact with overlying anhydrite.	Trace of pressurized gas at 37.0'.
	35					32.5' - 38.0' **ARGILLACEOUS HALITE:** clear to mottled grayish-brown (5YR 3/2) halite, finely to medium crystalline, moderately hard. Argillaceous content 10-20%, but less than 5% from 32.5'-33.5'. From 37.3'-38.0', trace of interstitial dark yellowish-orange (10YR 6/6) polyhalite. Clay breaks at 34.0', 34.2', 34.4', 35.6', 36.2', 36.3', and 36.9'	
9		5.3	100	—		30.3' - 32.5' **HALITE:** clear, medium to coarsely crystalline halite, moderately hard.	
	30					28.8' - 30.3' **HALITE:** argillaceous, clear to brownish-gray (5YR 4/1) halite, finely crystalline. Argillaceous content 2-3% from 28.8' to 29.3' and < 1% from 29.3' to 30.3'.	
8		5.1	100	—		(As below)	
	25						

WIPP-SPDV
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-219 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 2422' S of Exploratory Shaft centerline, 5' from E rib

STATION S2422, E162 COLLAR ELEV. 1266.3' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N7264.9, E7056.6 BOREHOLE PENETRATION 51.0'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/18/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55						
13	50	4.0	100	—	—	49.9' - 51.0' **HALITE:** argillaceous, clear, moderate brown (5YR 3/4) halite, very finely crystalline, sugary texture in part, moderately hard, 2-5% argillaceous content. Irregular,, moderate brown (5YR 3/4) clay breaks at 50.0' and 50.2'.	Total penetration = 51.0'. Hole completed at 15:15 hours on 14 January 1983.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-219A INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 2418' S of Exploratory Shaft centerline, 5' from E rib

STATION S2418, E162 COLLAR ELEV. 1266.1' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N7268.5, E7056.2 BOREHOLE PENETRATION 11.3'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/18/83 SHEET 1 OF 1

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	ROD	PROFILE	DESCRIPTION	REMARKS
	10					8.2' - 11.3' HALITE: clear halite, moderately hard, medium to coarsely crystalline. Few scattered hairline stringers of very light gray (N8) anhydrite at: 8.5', 8.8', 9.8', 10.0', 10.8' and 11.1'.	Total penetration = 11.3'.
5		5.3	100	—		8.2' ANHYDRITE: (Anhydrite "b") light gray (N7), very finely crystalline anhydrite, hard, dense, 3/8" thick.	Hole cored to determine exact location, thickness, and character of clay parting and anhydrite lens at 8.2' not recovered in DH-219.
4		0.3	100	—		5.3' - 8.2' ARGILLACEOUS HALITE: clear to mottled moderate brown (5YR 3/4) halite, medium to coarsely crystalline, moderately hard. Interstitial argillaceous material comprises 20% of core. Trace of grayish-orange (10YR 7/4) polyhalite (< 1%) from 7.0' to 7.3'. Brown clay break at 7.3' and gray clay parting at 8.2'.	
3	5	2.0	100	—			0' - 1.0' drilled with 6" single-tube core barrel.
2		1.7	100	—		0.0' - 5.5' HALITE: clear halite, finely to coarsely crystalline, moderately hard, trace of medium reddish-orange (10R 5/6) polyhalite and scattered polyhalite blebs.	RUN 1 core lost between 1.7' - 2.0'.
1		0.7	70	—			NX coring began at 10:00 hours and ended at 11:15 hours on 17 January 1983.
	0						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-220 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 2421' S of Exploratory Shaft centerline, 5' from E rib

STATION S2421, E162 COLLAR ELEV. 1257.4' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N7265.5, E7055.9 DEPTH OF BOREHOLE 51.8'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/19/83

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0 – 5	4.1	68	–		0.0' - 6.5' HALITE: clear, finely to coarsely crystalline halite, moderately hard. Trace (< 1%) of reddish-orange (10R 5/6) polyhalite blebs throughout. Few grayish-brown argillaceous zones, < 1%.	NX coring began at 08:30 hours on 15 January 1983. CORE LOSS: RUN 1: WHERE LOST 1.3' - 1.4', 2.3' - 2.8', 3.3' - 4.0', 4.1' - 4.7' RUN 2: 6.0' - 6.1' RUN 4: 12.2' - 12.3' RUN 8: 33.4' - 33.7'
2		0.9	90	–		6.5' - 8.8' POLYHALITIC HALITE: clear to moderate reddish-orange (10R 6/6) halite, moderately hard, medium to coarsely crystalline. Polyhalite (5-10%) occurs as blebs and interstitial layers.	
3	10	5.2	100	–		8.8' - 11.0' ANHYDRITE: (Marker Bed 139) polyhalitic, pale reddish-brown (10R 5/4) and medium gray (N5) anhydrite, dense, finely crystalline, hard, numerous polyhalite seams and partings comprise up to 50% of core, slightly banded. Medium gray (N5) clay parting at 11.0'.	
4	15	4.9	98	–		11.0' - 19.9' HALITE: polyhalitic in part, clear halite, light gray (N7) and moderate reddish-orange (10R 6/6). Finely to coarsely crystalline, moderately hard. Interstitial gray clay at 12.2'. Polyhalite content 2% (3-5% from 16.0' to 19.9'). Scattered polyhalite blebs at 14.0', seam at 19.3'.	
5	20	5.3	100	–		19.9' - 22.0' HALITE: clear to light gray (N7) halite, medium to coarsely crystalline, moderately hard, trace clay (< 1%) in part. Gray clay break at 20.0'. 22.0' - 28.4' HALITE: polyhalitic, clear to moderate reddish-orange (10R 6/6) and light brownish-gray (5YR 6/1) halite, finely to coarsely crystalline, moderately hard, 2-3% polyhalite and trace (< 1%) clay from 26.8'-28.4'. Finely crystalline from 24.9'-27.0'. Polyhalite occurs as interstitial layers and irregular blebs. Below 26.8', 5% interstitial gray clay, with clay breaks at 26.8', 27.0' and 27.4'.	
6	25	5.0	100	–			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-220 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 2421' S of Exploratory Shaft centerline, 5' from E rib

STATION S2421, E162 COLLAR ELEV. 1257.4' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N7265.5, E7055.9 DEPTH OF BOREHOLE 51.8'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/19/83

RUN NUMBER	DEPTH (ft.)	RECOVERY (ft.)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.0	100	–		(as above)	*From 28.3' to 29.5' core is broken into very small 1/8"-1/16" fragments.
7	30	5.0	100	–		28.4' - 30.4' **HALITE:** clear to light gray (N7) halite, medium to coarsely crystalline, soft* to moderately hard. Clay content < 1%.	
						30.4' - 36.3' **HALITE:** polyhalitic, clear to moderate reddish-orange (10R 6/6) halite, moderately to coarsely crystalline, moderately hard. Blebs and interstitial polyhalite comprise 3-5% of core. Few scattered, discontinuous hairline breaks of white anhydrite. At 35.7', light gray horizontal anhydrite parting with irregular surfaces.	
8	35	4.7	94	–		36.3' - 36.5' **ANHYDRITE:** light (N7) and dark (N3) gray anhydrite bands, dense, hard, very finely crystalline. At 36.5' light gray (N7) clay seam, firm to stiff, moderately plastic.	
9	40	5.3	100	–		36.5' - 42.6' **HALITE:** clear to light gray (N7) to light brownish-gray (5YR 6/1) halite, moderately to coarsely crystalline, moderately hard. Trace (< 1%) clay in part.	
10	45	5.1	100	–		42.6' - 50.5' **ARGILLACEOUS HALITE:** mottled medium light gray (N6) to grayish-brown (5YR 3/2) and clear, finely to coarsely crystalline halite, moderately hard. Clay content 10-20% with clay breaks at: 44.5', 44.6', 45.1', 45.4', 47.4', 47.8', 48.2' and 48.9'.	
11	50	3.9	100	–			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-220 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 2421' S of Exploratory Shaft centerline, 5' from E rib

STATION S2421, E162 COLLAR ELEV. 1257.4' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N7265.5, E7055.9 DEPTH OF BOREHOLE 51.8'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/19/83 SHEET 3 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	3.9	100	–	— —	(As above) 50.5' - 51.8' HALITE: clear halite, moderately hard, moderately to coarsely crystalline.	Hole completed at 15:00 hours on 15 January 1983. Trace of gas encountered after completion of hole. Total depth = 51.8'.
	55						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

INSTRUMENT TYPE & NUMBER: Extensometer GE-249 HOLE SIZE: NY

BORING NO. DH-223

LOCATION: East 140 Drift 3079' S of Exploratory Shaft centerline, 13' from E rib

Vertical

STATION: S3079, E154 COLLAR ELEV. 1255.1' DIRECTION OF DRILLING: Up

MINE COORDINATES: N6607.2, E7048.5 BOREHOLE PENETRATION: 52.6'

DRILLING METHOD: Wet (brine) DRILL MAKE/MODEL: Joy 12B

PREPARED BY: RMB, JPS/Rechtel DATE: 1/26/83

SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
8	25	5.0	100	-		19.2' - 28.9' **HALITE:** argillaceous and polyhalitic in part; clear to mottled light gray (N7) and moderate brown (5YR 3/4) halite, moderately hard, finely to coarsely crystalline. Clay content <2%. Polyhalite <1% from 20.8' to 21.1'. Clay breaks at 19.3', 22.3', 23.1', 23.8', clay parting at 24.3'. At 24.3', anhydrite stringer, 1/8" thick, bluish-white (5B 9/1), hard, dense.	
7	20	5.2	100	-		15.2' - 19.2' **HALITE:** clear halite, medium to coarsely crystalline, moderately hard, trace (<1%) moderate reddish-orange (10R 5/6) polyhalite blebs throughout.	
						14.2' - 15.2' **ANHYDRITE:** (Anhydrite "a") very light (N8) to light gray (N7) anhydrite, dense, hard, finely crystalline, faintly banded in part. Some interstitial clear halite from 14.8' to 15.2'.	Pressurized gas at 15' blew return line out of reserve pond.
6	15	4.9	98	-			
5	10	5.3	100	-		0.0' - 14.2' **HALITE:** clear to medium gray (N5) halite, medium to coarsely crystalline, moderately hard. Core is moderately fractured and broken from 1.0' to 4.5'. Trace clay (<1%) from 5.0' to 8.3' and from 13.5' to 14.2'. Clay breaks at 5.0', 6.7', 6.9', 7.3', 8.1', and 13.4'. 1/4" clay seams at 8.2' and 14.2'. 1/2"-thick, hard, dense, medium dark gray (N4) anhydrite (Anhydrite "b") lens at 8.2'.	Trace of gas between 8' and 9'.
4	5	1.1	58	-			CORE LOSS:
3		1.2	80	-			RUN / WHERE LOST 2 / 1.0' - 1.3' 3 / Throughout run 4 / Throughout run
2		1.7	85	-			Core Run #1 was a 1' run with a 6" O.D. core barrel.
1	0	1.0	100	-			Drilling started 09:30 hours on 22 January 1983

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

INSTRUMENT TYPE & NUMBER: Extensometer GE-249 HOLE SIZE: NX

BORING NO. DH-223

LOCATION: East 140 Drift, 3079' S of Exploratory Shaft centerline, 13' from E rib

STATION: S3079, E154 COLLAR ELEV. 1255.1' DIRECTION OF DRILLING: Vertical Up

MINE COORDINATES: N6607.2, E7048.5 BOREHOLE PENETRATION: 52.6'

DRILLING METHOD: Wet (brine) DRILL MAKE/MODEL: Joy 12B

PREPARED BY: RMB, JPS/Bechtel DATE: 1/26/83

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
13	50	5.2	100	-		(see description on next sheet)	
						44.9' – 48.6' **HALITE:** clear halite, moderately hard, coarsely crystalline. Trace interstitial dark reddish-brown (10R 3/4) clay from 44.9' – 45.4'.	
12	45	5.0	100	-		42.0' – 44.9' **ARGILLACEOUS HALITE:** clear and dark reddish-brown (10R 3/4) halite, finely to coarsely crystalline, moderately hard. Clay content up to 30%, clay breaks at 42.0', 42.5', 42.9', 43.0', 43.25', 43.6', and 44.7'.	
11	40	5.2	100	-		38.6' – 42.0' **HALITE:** clear halite, medium to coarsely crystalline, moderately hard, trace interstitial moderate reddish-orange (10R 6/6) polyhalite and medium gray (N5) clay. Very light gray (N8) anhydrite stringers at 39.0' and 39.5'.	
						37.9' – 38.6' **ANHYDRITE:** (Marker Bed 138) light gray (N7) anhydrite, dense, hard, very finely crystalline.	
10	35	5.1	100	-		33.5' – 37.9' **ARGILLACEOUS HALITE:** brownish-gray (5YR 4/1) to grayish-brown (5YR 3/2) halite, finely to coarsely crystalline, moderately hard, 15-30% interstitial clay with clear halite. Clay breaks at 34.6', 35.1', 35.5', 35.7', 35.9', 36.3', 37.0', 37.2', 37.3', and 37.8'. At 37.9', 3/4"-thick clay seam, grayish-brown (5YR 3/2), stiff, moderately plastic.	
						30.3' – 33.5' **HALITE:** clear halite, coarsely crystalline, moderately hard, trace (<1/2%) clay from 32.7' to 33.5'.	Pressurized gas encountered at ±30'.
9	30	5.2	100	-		28.9' – 30.3' **ARGILLACEOUS HALITE:** clear to moderate brown (5YR 3/4) halite, moderately hard, finely to moderately crystalline, 10-15% clay. Clay breaks at 29.1', 29.9', 30.0'. Core is slightly vesicular at 30.0'. Clay seam, 1/4" thick, medium light gray (N6), stiff and moderately plastic at 30.2'.	
8	25	5.0	100	-		(as below)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-223 INSTRUMENT TYPE & NUMBER Extensometer GE-249 HOLE SIZE NX

LOCATION East 140 Drift, 3079' S of Exploratory Shaft centerline, 13' from E rib

STATION S3079, E154 COLLAR ELEV. 1255.1' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N6607.2, E7048.5 BOREHOLE PENETRATION 52.6'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RMP, JPS/Bechtel DATE 1/26/83

RUN NUMBER	PENETRATION (ft.)	RECOVERY (ft.)	% RECOVERED	ROD	PROFILE	DESCRIPTION	REMARKS
13	50–55	5.2	100	–		48.6' – 52.6' ARGILLACEOUS HALITE: clear to moderate brown (5YR 3/4) halite, moderately hard, finely to coarsely crystalline. Clay comprises 20-35% in part. Finely crystalline from 50.8'–52.6'. Clay breaks at 48.8', 49.0', 50.1', 52.0', 52.3', and 52.6'.	Total penetration = 52.6'. Completed hole at 08:30 hours on 23 January 1983.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-224 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 3079' S of Exploratory Shaft centerline, 13' from E rib

STATION S3079, E154 COLLAR ELEV. 1246.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N6607.5, E7048.5 DEPTH OF BOREHOLE 52.5'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/25/83

RUN NUMBER	DEPTH (ft)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0	1.0	100	–			Coring began at 08:40 hours on 23 January 1983.
2		1.7	40	–		0.0' – 7.6' **HALITE:** clear halite, moderately hard, medium to coarsely crystalline, trace clay (<1/2%) from 1.0'-3.0', few moderate reddish-orange (10R 6/6) polyhalite blebs.	Core Run #1, from 0.0' to 1.0', using 6" single-tube core barrel.
3	5 – 10	5.2	100	–		7.6' – 10.7' **ANHYDRITE:** (Marker Bed 139), banded light bluish-gray (5B 7/1) to medium light gray (N6) to moderate reddish-brown (10R 4/6) anhydrite, very finely crystalline, hard, dense slightly halitic and polyhalitic. Medium gray (N5) clay seam, moderately soft and plastic, ±1/2" thick at 10.7'.	**CORE LOSS:** **RUN** **WHERE LOST** 2 Throughout run 4 10.2' – 10.3'
4		0.9	90	–			
5	15	5.3	100	–		10.7' – 15.2' **HALITE:** clear and mottled moderate reddish-orange (10R 6/6) to light gray (N7) to grayish-orange (10YR 7/4) halite, moderately hard, finely to medium crystalline. Polyhalite and clay content varies throughout from <1% to 3%. Polyhalite is interstitial with some blebs. Medium light gray (N6) clay breaks at 11.7', 12.0', and 14.5'.	
						15.2' – 18.6' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) halite, moderately hard, medium to coarsely crystalline, polyhalite content ranges from <1% to 10% in blebs and interstitially, clay-filled fracture at 15.25'.	
6	20	5.0	100	–		18.6' – 21.7' **HALITE:** clear and brownish-gray (5YR 4/1) halite with trace of moderate reddish-orange (10R 6/6), moderately hard, medium to coarsely crystalline, trace (<2%) clay in part with trace (<5%) interstitial polyhalite throughout, clay breaks at 18.75', 19.9', and 20.75'.	
7	25	5.2	100	–		21.7' – 25.0' **HALITE:** polyhalitic, clear and moderate reddish-orange (10R 6/6) halite, moderately hard, coarsely crystalline, polyhalite occurs as blebs and interstitial layers, ranging from 3-5%.	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-224 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 3079' S of Exploratory Shaft centerline, 13' from E rib

STATION S3079, E154 COLLAR ELEV. 1246.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N6607.5, E7048.5 DEPTH OF BOREHOLE 52' 5'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/25/83 SHEET 2 OF 3

RUN NUMBER	DEPTH (ft)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
7	25	5.2	100	-			
8	30	5.0	100	-		25.0' - 30.0' HALITE: clear to mottled pale reddish-brown (10R 5/4) to pale brown (5YR 5/2) halite, finely to medium crystalline, slightly argillaceous and polyhalitic in part, clay content about 2% with breaks at 25.1', 26.5', 26.7', and 27.4'.	
9	35	5.3	100	-		30.0' - 35.4' HALITE: clear and moderate reddish-orange (10R 6/6) halite, moderately hard, medium to coarsely crystalline. Polyhalite (<3%) is interstitial or occurs as blebs. At 34.6', medium light gray (N6) anhydrite stringer 3/8" thick.	
						35.4' - 35.7' ANHYDRITE: banded very light gray (N8) and dark gray (N1) anhydrite, hard, dense, very finely crystalline.	
						35.7' - 35.8' CLAY: medium dark gray (N4) clay seam, moist, soft, near horizontal.	
10	40	5.0	100	-			
11	45	5.3	100	-		35.8' - 49.1' ARGILLACEOUS HALITE: clear to medium dark gray (N4) halite, finely to coarsely crystalline, moderately hard. Clay content ranges from <1% to 10% with few orange polyhalite blebs at 43.7'. Clay breaks at 36.6', 43.8', 44.3', and 44.4'.	
12	50	5.2	100	-			
						(see description on next sheet)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-224 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 3079' S of Exploratory Shaft centerline, 13' from E rib

STATION S3079, E154 COLLAR ELEV. 1246.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N6607.5, E7048.5 DEPTH OF BOREHOLE 52.5'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/25/83 SHEET 3 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
12	50	5.2	100	-		49.1' - 52.5' HALITE: clear and mottled pale reddish-brown (10R 5/4) to light gray (N7) halite, finely to coarsely crystalline, moderately hard. Trace (<1/2%) polyhalite and clay throughout. At 52.0', 3/8"-thick, light gray (N7) clay seam, firm, moderately plastic. Thin clay break at 52.3'.	Hole completed at 14:30 hours on 23 January 1983. Total depth = 52.5'.
	55						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-227 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 3656' S of Exploratory Shaft centerline, 5' from W rib

STATION S3656, E147 COLLAR ELEV. 1247.0' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N6030.7, E7041.2 BOREHOLE PENETRATION 51.7'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/28/83

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft.)	% RECOVERED	ROD	PROFILE	DESCRIPTION	REMARKS
	25					(see description on next sheet)	
7		5.3	100	-		18.0' - 24.3' **ARGILLACEOUS HALITE:** clear and medium light gray (N6) halite with isolated bands of moderate reddish-orange (10R 6/6) polyhalite, finely to coarsely crystalline, moderately hard. Argillaceous content 5-10% with clay breaks at 18.1', 18.5', 19.0', 19.6', 20.2', 20.5', 21.5', 22.4', 22.6, and 23.3'. Isolated bands of polyhalite at 19.2', 19.9', and 20.9'.	
6	20	5.0	100	-		14.5' - 18.0' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, moderately hard. Polyhalite generally <2% and occurs as scattered blebs or interstitially.	
5	15	5.1	100	-		13.8' - 14.5' **HALITE:** clear halite, coarsely crystalline, moderately hard. At 14.5', very light gray (N8) anhydrite lens. 13.0' - 13.8' **ANHYDRITE:** (Anhydrite "a") banded very light gray (N8) and medium gray (N5) anhydrite, hard, dense, microcrystalline. 12.9' - 13.0' **CLAY:** light gray (N7) clay, moderately soft, moist.	
4	10	5.0	100	-		7.1' - 12.9' **HALITE:** clear halite, medium to coarsely crystalline, moderately hard. From 12.1'-12.9', few interstitial argillaceous and polyhalitic zones. Clay content about 1-2% from 12.1'-12.5', and polyhalite about 1% from 12.5'-12.9'.	Trace of gas at 7.0'.
3		1.0	100	-		0.0' - 7.1'. **HALITE:** clear to medium gray (N5) halite, moderately hard, coarsely crystalline, slightly (<1/2%) argillaceous in part. Few discontinuous clay breaks throughout. Few orange polyhalitic blebs from 6.0'-6.3'. At 7.1', olive gray (5Y 4/1) anhydrite stringer (Anhydrite "b"), hard, dense, with trace of medium gray (N5) clay.	**Core Loss:** Run 1 — Throughout Run Run 2 — Throughout Run Run 12 — 46.7'-46.8' 0' - 1.0' drilled with 6" single-tube core barrel. Hole began at 13:00 hours on 28 January 1983.
2	5	0.5	25	-			
1		0.6	30	-			
0	0	1.0	100	-			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-227 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 3656' S of Exploratory Shaft centerline, 5' from W rib

STATION S3656, E147 COLLAR ELEV. 1247.0' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N6030.7, E7041.2 BOREHOLE PENETRATION 51.7'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/28/83

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft.)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
12	50	4.9	98	–		45.6' - 50.4' **ARGILLACEOUS HALITE:** clear to grayish-brown (5YR 3/2) halite, finely to coarsely crystalline, moderately hard, finely crystalline from 49.8'-50.6'. Clay content generally 0-15% and about 1% from 45.6'-47.4'. Clay breaks at 47.1', 47.4', 47.5', 47.8', 48.3', 48.5', 48.7', 49.3', 49.4', 49.5', and 50.2'. From 50.4' - 50.6', grayish-red (10R 4/2) clay seam, moderately soft, highly plastic.	
11	45	5.1	100	–		44.0' - 45.6' **HALITE:** clear halite, coarsely crystalline, moderately hard. 41.7' - 44.0' **ARGILLACEOUS HALITE:** clear to grayish-brown (5YR 3/2) halite, finely to coarsely crystalline, moderately hard. Argillaceous content ranges from 0-15% with clay breaks at 42.0', 42.9', 43.5', 43.7, and 43.9'.	
10	40	5.0	100	–		37.5' - 41.7' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) halite, polyhalite occurs as isolated blebs or interstitially, and comprises about 5-8% of core. 36.6' - 37.5' **HALITE:** clear halite, coarsely crystalline, moderately hard, few isolated stringers of gray anhydrite.	
9	35	5.2	100	–		35.9' - 36.6' **ANHYDRITE:** (Marker Bed 138) olive gray (5Y 4/1) anhydrite, hard, dense, microcrystalline, core broken into 1/4" chips. 35.8' - 35.9' **CLAY:** pale brown (5YR 5/2) clay, moist, moderately soft, moderately plastic.	
8	30	5.0	100	–		27.0' - 35.8' **ARGILLACEOUS HALITE:** clear to mottled pale brown (5YR 5/2) and moderate brown (5YR 4/4) halite, moderately hard, finely to coarsely crystalline. Argillaceous content ranges from 0 to 10%. Clear and clay-free from 29.0'-30.2'. Brown and gray clay partings and breaks at 27.9', 28.0', 28.2', 28.5', 28.8', 30.5' (gray), 30.6' (gray), 30.8' (gray), 32.4' 32.5', 33.0', 33.1', 33.5', 33.8', 34.4', 34.7', 34.9', 35.5', and 35.6'.	
7	25	5.3	100	–		24.3' - 27.0' **HALITE:** clear halite, moderately hard, medium to coarsely crystalline, few scattered hairline breaks of light gray (N7) anhydrite.	

WIPP-SPDV
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DH-227 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 3656' S of Exploratory Shaft centerline, 5' from W rib

STATION S3656, E147 COLLAR ELEV. 1247.0' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N6030.7, E7041.2 BOREHOLE PENETRATION 51.7'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 1/28/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft.)	% RECOVERED	ROD	PROFILE	DESCRIPTION	REMARKS
	55						
12	50	4.9	98	-	X	50.6' - 51.7' HALITE: clear and moderate reddish-orange (10R 6/6) halite, moderately hard coarsely crystalline. Polyhalite occurs as isolated blebs and comprises 2-3% of core.	Total penetration = 51.7'.
						(as below)	Hole completed at 17:30 hours on 28 January 1983.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-228 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 3656' S. of Exploratory Shaft centerline, 5' from W rib

STATION S3656, E147 COLLAR ELEV. 1237.8' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N6030.7, E7041.2 DEPTH OF BOREHOLE 50.4'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/2/83

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0 – 5	3.0	58	—		0.0' – 7.3' **HALITE:** clear and medium gray (N5) halite, coarsely crystalline, moderately hard with numerous gray clay-filled hairline breaks. Slightly (<1%) argillaceous in part. Few (1%) polyhalitic blebs and interstitial layers from 5.9'-6.2'.	Coring began at 17:45 hours on 28 January 1983 Hole cored from 0' to 5.2' without inner tube in drill rod. From 5.2' to 50.4', hole cored using NX double tube core barrel.
2	5 – 10	5.3	100	—		7.3' – 9.4' **POLYHALITIC HALITE** clear and moderate reddish-orange (10R 6/6) halite, moderately hard, medium to coarsely crystalline, few grayish-pink (5R 8/2) anhydrite stringers. Polyhalite comprises up to 15% of rock. 9.4' – 10.2' **POLYHALITE:** pale reddish-brown (10R 5/4) to moderate reddish-orange (10R 6/6) polyhalite, microcrystalline, moderately hard, grades into underlying anhydrite.	
3	10 – 15	5.2	100	—		10.2' – 11.5' **ANHYDRITE:** (Marker Bed 139) light gray (N7) anhydrite, dense, hard, microcrystalline, banded medium dark gray (N4) in part, core broken into 1/8"-1/16" chips. At 11.5', medium gray (N5) clay seam, 1/4" thick, soft, moist. 11.5' – 14.4' **ARGILLACEOUS HALITE:** clear and medium light gray (N6) halite, finely to coarsely crystalline with 5-15% argillaceous material. Gray clay breaks at 11.7', 12.0', 12.4', 13.5', 13.8', 14.2', and 14.4'.	
4	15 – 20	5.3	100	—		14.4' – 19.4' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, moderately hard. Polyhalite comprises 10-15% of core and occurs as blebs or interstitial zones. 19.4' – 21.4' **ARGILLACEOUS HALITE:** clear and brownish-gray (5YR 4/1) halite, finely to coarsely crystalline, moderately hard, few clay breaks throughout. Clay content ranges from 0 to 5%. At 19.4', 1/2"-thick, very light gray (N8) anhydrite seam. At 19.5', medium gray (N5) clay parting, subhorizontal. Clay breaks at 20.7' and 21.3'.	
5	20 – 25	5.0	100	—		(see description on next sheet)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-228 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 3656' S of Exploratory Shaft centerline, 5' from W rib

STATION S3656, E147 COLLAR ELEV. 1237.8' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N6030.7, E7041.2 DEPTH OF BOREHOLE 50.4'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/2/83 SHEET 2 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft)	% RECOVERED	ROD	PROFILE	DESCRIPTION	REMARKS
5	25	5.0	100	–		21.4' – 25.7' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, moderately hard. Polyhalite content ranges from 0–10% and occurs as interstitial layers and scattered blebs.	
6	30	5.3	100	–		25.7' – 30.7' **HALITE:** argillaceous, clear and light gray (N7) halite, moderately hard, finely to coarsely crystalline. Clay content ranges from 2–5% with clay breaks at 27.7', 28.6', 29.5', 29.6', and 30.1'. Some (5%) interstitial polyhalite from 26.2' to 27.4' and at 28.8'.	
7	35	4.9	100	–		30.7' – 36.3' **HALITE:** polyhalitic, clear and moderate reddish-orange (10R 6/6) halite, moderately hard, coarsely crystalline, 0–3% polyhalite. At 35.5', light gray (N7) 1/2" horizontal anhydrite seam.	
8	40	5.2	100	–		36.3' – 36.5' **ANHYDRITE:** banded medium dark gray (N4) and very light gray (N8) anhydrite, hard, dense, microcrystalline.	
9	45	5.0	100	–		36.5' – 49.1' **ARGILLACEOUS HALITE:** clear and medium light gray (N6) to grayish-orange (10YR 7/4) halite, finely to coarsely crystalline, moderately hard. Clay content about 5–10%, and clay breaks at 37.7', 38.2', 42.1', 43.3', 44.0', 45.0', and 47.0'. Finely crystalline from 44.1'–46.4'.	
10	50	4.0	85	–		49.1' – 50.4' **HALITE:** clear halite, moderately hard, coarsely crystalline.	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DH-228 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 3656' S of Exploratory Shaft centerline, 5' from W rib

STATION S3656, E147 COLLAR ELEV. 1237.8' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N6030.7, E7041.2 DEPTH OF BOREHOLE 50.4'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/2/83

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft.)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
10	50	4.0	85	-		(as above)	Hole completed at 22:00 hours on 28 January 1983. Total depth = 50.4'.
	55						

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-301

LOCATION INTERSECTION N150, W170 DRIFTS - ROOF

STATION N150, W170 COLLAR ELEV. 1276.9 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N9830.5, E6724.5 DEPTH OF BOREHOLE 50.75'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 8-29-84 DATE COMPLETED 8-30-84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 8-31-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0						
1		2.0	2.0	100		0.0'-5.3' HALITE: Clear, mottled with blebs of moderate reddish orange polyhalite. Coarsely crystalline. ≤1% polyhalite. [1, 2]	NC double tube wireline core barrel. NC rods. Total drill time: 26 hrs ±.
	2.0						
2		5.0	5.0	100		5.3'-8.0' HALITE: Clear, some moderate brown (5YR 3/4, 4/4). Coarsely crystalline, ≤1% brown clay. [8, 17]	
	5					8.0'-8.9' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% polyhalite and gray clay. [9]	No gas. Dry hole.
	7.0					8.9'-9.15' ANHYDRITE b: Light gray (N7), microcrystalline, faintly laminated. Halite growths within. Trace of gray clay at 8.9'.	
3		5.0	5.0	100		9.15'-14.3' HALITE: Clear, some light moderate reddish orange (10R 6/6). Coarsely crystalline. Scattered anhydrite. [1]	
	10					14.3'-15.65' HALITE: Clear to light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1% dispersed polyhalite and gray clay, trace of brown clay. [9]	39% of core recovered was ≥2 inch length.
	12.0					15.65'-16.45' ANHYDRITE a: Light (N7) to medium light (N6), microcrystalline. Faintly laminated. Scattered halite growths, especially at 15.95'-16.45'. Trace of gray clay at 15.65'.	
4		4.6	4.6	100			
	15					16.45'-20.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. [7]	
	16.6						
5		5.0	5.0	100		20.4'-25.7' HALITE: Clear to moderate brown and reddish orange (10R 4/6, 6/6). Medium to coarsely crystalline. <1% brown clay. ≤1/2% polyhalite except at 20.4'-21.9' where polyhalite is 1% to 2%. [17]. 3/4" hard grayish-brown clay seam at 25.65'. Trace of associated anhydrite.	
	20						
	21.6					25.7'-29.4' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers.[1]	
6		5.0	5.0	100		29.4'-32.1' HALITE: Clear, some moderate brown (5YR 4/4), coarsely crystalline, some fine to medium. ≤1% brown clay. [8, some 10]	
	25						

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-301

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					32.1'-34.05' HALITE: Clear, coarsely crystalline. [1]	
26.6							
7		2.0	2.0	100		34.05'-39.2' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4, 4/4), medium to coarsely crystalline. <1% to 3% brown clay. Clear halite 36.0'-36.2'±. [10, 15]	
28.6							
8	30	3.7	3.7	100		39.2'-39.7' ANHYDRITE: Light (N7) to medium light (N6) gray anhydrite, laminated. Scattered halite growths. Trace of grayish-brown clay at 39.2'.	
						39.7'-46.75' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline, locally some fine to medium, <1% to 3% polyhalite to 40.5', <1% polyhalite at 40.5'-41.95' and 42.85' to 44.85'. Trace brown clay at 44.6'± [2, 5].	
32.3							
9	35	5.0	4.9	98		46.75'-47.55' HALITE: Clear to moderate brown, some moderate reddish orange (5YR 4/4, 6/6). Medium to coarsely crystalline. ≤1% brown clay. Parting at 47.55'. [17]	
						47.55'-49.75' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline, <1% to 3% polyhalite. [3, 5, 7]	
37.3							
10	40	4.45	4.45	100		49.75'-50.75' HALITE: Clear mottled with moderate brown (5YR 4/4), coarsely crystalline. ≤1% brown clay. [8, 10]	
41.75							
11		2.0	2.0	100			
43.75							
12	45	4.0	4.0	100			
47.75							
13	50	3.0	2.9	97			
50.75							

BORING NO. DH-301

WIPP

WASTE ISOLATION PILOT PLANT

GEOLOGIC DRILL LOG

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-302

LOCATION INTERSECTION N150, W170 DRIFTS - FLOOR

STATION N150, W170 COLLAR ELEV. 1264.9 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N9830.5, E6724.5 DEPTH OF BOREHOLE 50.6'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 8-30-84 DATE COMPLETED 8-30-84 SHEET

LOGGED BY: J. E. GALLERANI DATE: 8-31-84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0						
1		1.7	0.6	35.3		0.0'-2.8' HALITE: Clear, c[illegible]ly crystalline. <1/2% gray clay to 1.7'. <1/2% p[illegible]alite from 1.7' to 2.8'. [1]	NC double tube core barrel. Set up time: 30 minutes. Total drill time: 6 hrs±. Run 1: Bit plugged. Core broken up badly.
1.7							
2		4.9	4.8	97.9		2.8'-7.3' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. [7]	
	5					7.3'-9.6' MB-139: Mixture of halite and anhydrite to 8.1'±. Light gray to light moderate reddish orange. Some "swallowtail" pattern. From 8.1', very light (N8) to medium light (N6) gray anhydrite with scattered halite growths. Faintly laminated. Trace of gray clay at 9.6'.	No ga[illegible] Dry hole.
6.6							
3		5.0	5.0	100		9.6'-12.9' HALITE: Clear to light moderate reddish orange (10R 6/6), medium to coarsely crystalline, some fine. <1% gray clay and dispersed polyhalite. [9]	82% of core recovered is ≥2 inch length.
	10					12.9'-17.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite [7]. Anhydrite/halite layer at 16.8'-17.0' with ≤1/4" gray clay @ 17'.	
11.6							
4		5.0	5.0	100		17.0'-19.3' HALITE: Clear, some moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1% gray clay and dispersed polyhalite [9].	
	15					19.3'-25.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline to 23.5' then medium to coarse. <1% to 3% polyhalite locally up to 5%. ≤1% gray clay from 22.2'±. [5, 6, 7]	
16.6							
5		5.0	5.0	100		25.6'-29.6' HALITE: Clear, some light bluish gray, medium to coarsely crystalline. ≤1% gray clay. <1% polyhalite dispersed. [9, some 11]	
	20					29.6'-34.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite [3, 7]. Anhydrite layers up to 3/4" thick at 34.4'-34.6'.	
21.6							
6		5.0	5.0	100		34.6'-35.7' HALITE: Clear, some light moderate reddish orange, coarsely crystalline. ≤1% polyhalite. Scattered anhydrite. [2]	
	25						

BORING NO. DH-302

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-302

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					35.7'-35.9' ANHYDRITE: Light (N7) to very light (N8) gray microcrystalline anhydrite., Scattered small halite growths. Trace of gray clay at 35.9'.	
26.6							
7						35.9'-43.3' HALITE: Clear, some moderate reddish orange (10R 6/6) and medium light gray (N6). Coarsely crystalline, some medium and fine. ≤1% dispersed polyhalite to 38.2', then <1/2% dispersed and blebs. ≤1% gray clay. Low angle gray clay parting at 43.3'. [9, some 11]	
	30	5.0	4.9	98			
31.6						43.3'-47.4' HALITE: Clear to moderate reddish orange (10R 6/6). Some moderate brown (5YR 4/4) from 44.8'-45.5'±. Medium to coarsely crystalline. <1% to 2% polyhalite. <1% gray clay except 1% to 2% brown clay at 44.8' to 45.5'.	
8							
	35	5.0	5.0	100		47.4'-50.6' HALITE: Clear, coarsely crystalline. <1% gray clay. Trace of polyhalite blebs. [1, 11]	
36.6							
9							
	40	5.0	5.0	100			
41.6							
10							
	45	5.0	5.0	100			
46.6							
11							
	50	4.0	4.0	100			
50.6							

WIPP

WASTE ISOLATION PILOT PLANT

GEOLOGIC DRILL LOG

INSTRUMENT TYPE & NUMBER: -

HOLE TYPE/SIZE: NC CORE

BORING NO.: DH-303

LOCATION: W170 DRIFT - ROOF

STATION: S400, W170

COLLAR ELEV.: 1267.2

DIRECTION OF DRILLING: VERTICAL UP

MINE COORDINATES: N9282.3, E6726.1

DEPTH OF BOREHOLE: 51.4'

DRILLING METHOD: ROTARY AIR

DRILL MAKE/MODEL: CP-65

DATE STARTED: 9-4-84

DATE COMPLETED: 9-4-84

SHEET 1 OF 2

LOGGED BY: J. E. GALLERANI

DATE: 9-4-84

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0						
1		2.5	2.5	100	X	0.0'-5.45' HALITE: Clear, coarsely crystalline. <1/2% scattered polyhalite blebs. [1]	NC double tube wireline core barrel. NC rods.
	2.5						
2	5	5.0	5.0	100	X	5.45'-8.6' HALITE: Clear with some moderate brown (5YR 4/4). Medium to coarsely crystalline. <1% brown clay [8]. Break at 6.75'. <1/2% dispersed polyhalite at 7.5'-8.6'. [17]	No gas. Dry hole.
						8.6'-8.8' ANHYDRITE b: Light to light medium gray (N7, N6). Microcrystalline with scattered halite growths. Trace of gray clay at 8.6'.	
					— X —	8.8'-14.5' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. [1]	48% of recovered core is ≥2 inch length.
	7.5						
3	10	4.7	4.7	100		14.5'-15.75' HALITE: Clear with some light moderate reddish orange (10R 6/6), medium to coarsely crystalline. <1% dispersed polyhalite. <1% gray clay [9]	
						15.75'-16.45' ANHYDRITE a: Very light to light medium gray (N8, N6). Microcrystalline. Partially laminated, scattered halite growths. Trace of gray clay at 15.75'.	
	12.2						
4	15	5.0	5.0	100	— X	16.45'-20.65' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3%, average 2% polyhalite. Scattered anhydrite. [2, 3, 5]	Run 4: Core broken last 6" of run.
						20.65'-26.4' HALITE: Clear to light moderate reddish orange (10R 6/6), some medium brown (5YR 4/4). Medium to coarsely crystalline with some fine crystalline. <1/2% dispersed polyhalite. ≤1% brown clay. <1/2" hard, dry brown clay seam at 20.3' with anhydrite associated to 26.4'. [8, 17]	
	17.2				X X X X X X		
5	20	4.8	4.8	100		26.4'-30.7' HALITE: Clear, coarsely crystalline with scattered anhydrite. [1]	Run 5: Some broken core in polyhalitic halite.
					X	30.7'-37.7' HALITE: Clear with some medium brown (5YR 3/4). Medium to coarsely crystalline with some fine. None to ≤1% brown clay with traces of gray. <1/2% polyhalite. [1, 8] with [12] at 30.7'-32.1'.	
	22				— X		
6	25	5.0	5.0	100			

BORING NO. DH-303

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-303

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					37.7'-39.5' ARGILLACEOUS HALITE: Clear to moderate brown 5YR 4/4, 3/4). Medium to coarsely crystalline with <1/2% dispersed polyhalite. <1% to 3% brown clay with a trace of gray clay. Brown break at 38.3'. [15, 17]	
27						39.5'-40.15' ANHYDRITE: Very light to medium light gray (N8, N6). Scattered halite growths with irregular low angle laminae. ≤1/2" hard, dry brown clay at 39.5'.	
	7					40.15'-44.2' HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline with scattered white anhydrite. ≤1% polyhalite [2, 3] except at 41.3'-42.9' where there is > 1% to 3% polyhalite. [7]	Run 8: Isolated broken zones.
31.9							
	30	4.9	4.9	100		44.2'-47.3' HALITE: Clear to moderate brown (5YR 4/4, 3/4). Coarsely crystalline with locally fine to medium crystalline. ≤ 1% brown clay with trace gray locally. Break at 47.2' with some thin anhydrite stringers at 47.2'-47.3'. [8, 10]	
	8					47.3'-49.6' HALITE: Clear, coarsely crystalline with < 1/2% polyhalite. Slight trace of very small brown clay blebs from 49'±.	Run 9: Some broken core 39.5'-41.9 ft.
36.9						49.6'-51.4' ARGILLACEOUS HALITE: Clear to moderate brown ((5YR 3/4, 4/4). Coarsely crystalline with fine to medium crystalline from 51.3'. <1% to 3% brown clay, averaging 1% to 2%. Scattered clay breaks. [12, 15]	
	35	5.0	5.0	100			
	9						
41.9							
	40	5.0	4.9	98			
	10						
46.9							
	45	5.0	5.0	100			
	11						
51.4							
	50	4.5	4.5	100			

BORING NO. DH-303

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER _____ HOLE TYPE/SIZE NC CORE BORING NO. DH-304

LOCATION S 400, W 170 DRIFT INTERSECTION - FLOOR

STATION S 400, W 170 COLLAR ELEV. 1254.3 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N 9282.5,E6726.1 DEPTH OF BOREHOLE 50.5'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 08/31/84 DATE COMPLETED 08/31/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 08/31/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0	5.0	4.9	98		0.0'-4.0' HALITE: Clear to light moderate reddish orange (10R 6/6), coarsely crystalline. <1% gray clay. <1/2% dispersed polyhalite. [9]	NC double tube wireline core barrel. NC rods. Total drill time: 6 hrs± 81% of core recovered is ≥2 inch length.
						4.0'-6.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. [5, 7]	
2	5.0	1.9	1.9	100		6.1'-8.75' MB-139: Mixture of moderate reddish orange (10R 6/6) halite and anhydrite to 7.15'±. Then predominently light gray, microcrystalline anhydrite with scattered halite growths. Some near-horizontal lighter-darker gray laminae. Gray clay at 8.75'.	No gas. Dry hole.
	6.9					8.75'-12.4' HALITE: Clear to light moderate reddish orange (10R 6/6), some light gray (N7). Medium to coarsely crystalline. <1/2% dispersed polyhalite. <1% gray clay. [9]	
3		5.0	5.0	100		12.4'-16.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. Scattered anhydrite, <1% to 3% polyhalite. [5, 7] 1/4" gray clay seam at 16.5', dipping 40°±.	
	11.9					16.5'-18.6' HALITE: Clear to light moderate reddish orange (10R 6/6), some light gray (N7). Medium to coarsely crystalline, some fine. <1% dispersed polyhalite and gray clay. [9]	
4		5.0	5.0	100		18.6'-25.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. Scattered anhydrite. <1% to 3% polyhalite [3, 7]. <1% gray clay, some medium crystalline at 23.5'-25.5'.	
	16.9					25.5'-29.05' HALITE: Clear, some light moderate reddish orange (10R 6/6) and light gray (N7). Medium to coarsely crystalline, some fine. <1/2% polyhalite and <1% gray clay. Scattered anhydrite. [9]	
5		5.0	5.0	100		29.05'-34.7' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. Scattered anhydrite from 33.8'. [3, 5, 7]	
	21.9					34.7'-35.15' ANHYDRITE: Very light gray (N8) to light gray (N7) anhydrite with scattered halite growths. Gray clay parting at 35.1'.	
6		5.0	5.0	100			

BORING NO. DH-304

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-304

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					35.15'-48.2' HALITE: Clear, some light moderate reddish orange (10R 6/6) and light medium bluish gray. Medium to coarsely crystalline, some fine to 37.7', then predominently coarse, <1/2% dispersed polyhalite. ≤1% gray clay. [9, 11]	
26.9							
7		5.0	5.0	100			
	30					48.2'-50.5' HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline, ≤1% polyhalite and gray clay. [2, 9]	
31.9							
8		5.1	5.1	100			
	35						
37.0							
9		5.0	5.0	100			
	40						
42.0							
10		4.8	4.8	100			
	45						
46.8							
11		3.7	3.7	100			
	50						
50.5							

BORING NO. DH-304

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-306

LOCATION S 400, E 140 DRIFT INTERSECTION - FLOOR

STATION S 400, E 140 COLLAR ELEV. 1244.1 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N9287.3 E7049.9 DEPTH OF BOREHOLE 52.0'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL CP-65

DATE STARTED 09/11/84 DATE COMPLETED 09/12/84 SHEET

LOGGED BY: J.E. GALLERANI DAT 09/12/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0							
1	5	4.9	3.2	65		0.0'-1.9' HALITE: Some moderate reddish orange (10R 6/6). <1/2% gray clay and polyhalite. Recovery poor. 1.9'-2.9' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 2% polyhalite. [3, 4]	MW Split Tube Core Barrel. Total drill time: 13 hrs. Probed hole with "scratcher rod." Separation at 3.9' and 5' depth in hole.
4.9							
2		3.5	2.5	.71		2.9'-5.0'± MB-139: Mixture of some halite with anhydrite to 4'±. Then light gray to light medium gray (N7, N6) microcrystalline anhydrite. Scattered halite growths. Core moist from 4.6'±. 5.0'±-8.7' HALITE: Clear to moderate reddish orange (10R 6/6), some light gray (N7). Medium to coarsely crystalline, some fine. <1/2% dispersed polyhalite. <1% gray clay, some brown locally.	
8.4							
3	10	2.2	2.2	100		8.7'-10.2' HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline, 61% polyhalite. [2, 3]	Water encountered in hole at 2' ± depth. Noted inflow of water at 5' depth. Water level rose to 4' ± from surface immediately after completing each drill run to 20' depth. Flow of water decreased significantly by 9-12-84. Source of this water appears to be simply from water dumped in area by contractor and is not natural brine water.
10.6							
4		5.0	4.2	84		10.2'-15.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline to 14'±, then medium to coarsely crystalline, some fine. <1% to 3% polyhalite. [3, 5, 7] <1/2% gray clay from 14'±. 15.6'-15.5' HALITE: Clear to lightly moderate reddish orange (10R 6/6). Coarsely crystalline. 61% polyhalite blebs. [2, 3] Grades into unit below.	
15.6	15						
5		4.9	4.7	96		17.5'-20.7' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite. [3, 5, 7] 20.7'-25.2' HALITE: Clear to light moderate reddish orange (10R 6/6). Coarsely crystalline with some medium. <1% dispersed polyhalite. <1% gray clay. Clear between 23.0' and 24.7'±. [1, 9]	
20.5	20						
6		4.0	4.0	100		25.2'-30.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3%, average <2% polyhalite. [3, 5, 7]. Moderate reddish orange polyhalite/anhydrite at 30.2'-30.5'±.	
24.5	25						

BORING NO. DH-306

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-306

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
7		5.0	5.0	100		30.6'-31.0' ANHYDRITE: Very light to light gray (N8, N7), microcrystalline. Scattered halite growths especially below 30.75'. No clay evident.	
						31.0'-39.7'± HALITE: Clear to lightly moderate reddish orange (10R 6/6). Coarsely crystalline, some medium. <1/2% dispersed polyhalite and gray clay. Anhydrite runs down to 31.5' within halite. [1, some 9, 11]	
29.5							
	30					39.7'-42.3' HALITE: Clear, some moderate brown (5YR 4/4). Coarsely crystalline. ≤1% brown clay. [8, 10]	
8		5.0	4.6	92		42.3'-44.9' HALITE: Clear, coarsely crystalline. <1% light bluish gray clay.	Had problems with core recovery in some runs. Core spring not holding core probably due to water in the hole. Had to adjust spring.
						44.9'-48.0' HALITE: Clear, coarsely crystalline. Slight trace of brownish clay to 45.5'±. [1]	
34.5							
	35					48.0'-49.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite. Trace of anhydrite. [5]	
9		4.0	1.9	48		49.6'-52.0' HALITE: Clear to lightly moderate reddish orange and some light bluish gray. Coarsely crystalline, some medium. <1/2% polyhalite dispersed and ≤1% bluish gray clay. [9]	35% of core recovered was ≥2 inch length.
38.5							
	40						
10		3.0	1.8	60			
41.5							
11		1.5	1.5	100			
43.0							
	45						
12		5.0	5.0	100			Note: Drilled hole DH-306A approximately 15' west of DH-306 to replace upper 8.5' of DH-306 and to check for brine here. DH-306A was a dry hole drilled to 8.5' depth.
48.0							
	50						
13		4.0	4.0	100			
52.0							

BORING NO. DH-306

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-306A

LOCATION S 400 DRIFT - FLOOR

STATION S 400, E125 COLLAR ELEV. 1244.0 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N9287.9 E7034.5 DEPTH OF BOREHOLE 8.5

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL CP-65

DATE STARTED 09/12/84 DATE COMPLETED 09/12/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 09/12/84 1 OF 1

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0								
	1	5	4.6	4.6	100		0.0'-0.7' HALITE: Clear to light moderate reddish orange (10R 6/6), coarsely crystalline. <1/2% dispersed polyhalite. [1, 2]	NC double tube wireline core barrel. NC rods.
							0.7'-2.1' POLYHALITIC HALITE: Clear to light moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite, average 2%. [3, 7]	No gas. Dry hole.
4.6								
	2		3.9	3.9	100		2.1'-5.45' MB-139: Very light to medium light (N8, N6) gray microcrystalline anhydrite to 3.9'. Some "swallowtail" pattern in upper 1'. From 3.9' is partially laminated anhydrite. 1 in. hard gray clay seam at lower contact. Contact dips 10°±. Slight moisture along contact.	
							5.45'-8.5' HALITE: Clear to light moderate reddish orange (10R 6/6), medium to coarsely crystalline, <1% dispersed polyhalite. 61% clay, predominently gray with some brown locally at 6.9'-7.5'±. [9]	This is replacement hole for upper 8.5' of DH-306.
8.5								

BORING NO. DH-306A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER GE-263 HOLE TYPE/SIZE NX CORE BORING NO. DH-307

LOCATION INTERSECTION OF E 300; S 400 DRIFTS - ROOF

STATION S 400, E 300 COLLAR ELEV. 1262.6 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N9286.7 E7194.2 DEPTH OF BOREHOLE 52.0'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 08/21/84 DATE COMPLETED 08/21/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 08/27/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		5.0	1.3	26		0.0'-4.7'± (Core Loss) HALITE: Clear, coarsely crystalline. [1]	NW split tube core barrel. NW rods.
						4.7'-7.5' HALITE: Clear with some light moderate brown (5YR 4/4). Coarsely crystalline with fine to medium crystalline between 7'-7.5'± [9]. <1% brown clay with some gray clay at 7'-7.5'. [8]	No gas. Dry hole.
	5.0						
2		3.0	3.0	100		7.5'-7.7' ANHYDRITE b: Very light to light gray (N8, N7). Microcrystalline with scattered halite. Gray clay at 7.5'.	Overall core quality not too good. Box #2 is good. Most other boxes show much discing. 21% of core recovered is ≥2 inch length.
						7.7'-12.95' HALITE: Clear, coarsely crystalline with scattered anhydrite. <1/2% gray clay locally. [1]	
	8.0						
3	9.0	1.0	1.0	100		12.95'-14.05' HALITE: Clear to lightly moderate reddish orange (10R 6/6) and light medium brown (5YR 4/4). Medium to coarsely crystalline. <1/2% dispersed polyhalite and <1% brown, gray clay. [9, 17]	
4		2.5	1.1	44			
	11.5					14.05'-15.0' ANHYDRITE a: Light to very light gray (N7, N8), microcrystalline anhydrite with scattered irregular laminae in light to darker gray. Halite growths common at 14.5'-15.0'. Trace of clay at 14.05'.	
5		5.0	5.0	100		15.0'-19.3' POLYHALITIC HALITE: Clear to moderate reddish orange, coarsely crystalline, <1% to 3% polyhalite, averaging <2%. Scattered anhydrite.	
	16.5					19.3'-24.7' HALITE: Clear to moderate brown (5YR 3/4, 4/4) with light moderately reddish orange (10R 6/6). Medium to coarsely crystalline with some fine crystalline. <1/2% dispersed polyhalite. ≤1% brown clay with trace of gray locally. At 24.5'-24.7' hard, grayish brown clay associated with anhydrite. Core broken up here. [9, 17]	
6		5.0	5.0	100			
	20					24.7'-27.1' HALITE: Clear, coarsely crystalline with scattered anhydrite stringers. [1]	
	11.5					27.1'-30.0'± HALITE: Clear to medium brown (5YR 4/4). Coarsely crystalline, ≤2% brown clay to 27.9'± then <1%. [8, 10]	
7		5.0	5.0	100			
	25						

BORING NO. DH-307

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-307

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					30.0'-32.7' HALITE: Clear, coarsely crystalline. [1] (much discing)	
26.5							
8	30	5.0	5.0	100		32.7'-37.75'± HALITE: Clear to medium brown (5YR 4/4, 3/4) with some light moderate reddish orange (10R 6/6). Medium to coarsely crystalline with some fine. Average ≤1% brown clay to 36.7'±, then gray. Argillaceous halite with 1% to 3% brown clay from 35'-36.8'±. [9, 12, 17]	
31.5						37.75'-38.5' ANHYDRITE: Light to very light gray (N7, N8). Microcrystalline with scattered halite growths. Up to 1" of hard brown clay at 37.75'.	
9	35	4.5	4.5	100		38.5'-40.1'± POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite with some anhydrite [4, 5]. Much discing.	
36.0						40.1'-42.0'± HALITE: Clear, coarsely crystalline with <1% moderate reddish orange polyhalite blebs. Much discing. [1, 2]	
10		2.5	2.5	100		42.0'-45.5'± POLYHALITIC HALITE: Clear, mottled with some moderate reddish orange (10R 6/6). Coarsely crystalline with some localized medium and fine crystalline. <1% to 3% polyalite blebs/patches. <1/2% gray clay locally. Brown clay parting at 44.5'± with some anhydrite above. [2, 1, 5]	
38.5							
11	40	4.9	4.9	100		45.5'-47.7' HALITE: Clear with some light to moderate brown (5YR 4/4). Coarsely crystalline. <1% brown clay. [8]	
43.4						47.7'-51.7' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4, 3/4). Medium to coarsely crystalline. <1% to 3% brown clay with scattered breaks and <1/2% dispersed polyhalite. [15, 17]	
12	45	4.8	4.8	100		51.7'-52.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. 1% to 3% polyhalite. [5]	
48.2							
13	50	3.8	3.8	100			
52.0							

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER GE-265 HOLE TYPE/SIZE NX CORE BORING NO. DH-309

LOCATION INTERSECTION OF E 300, S 700 DRIFTS - ROOF

STATION S 700, E 220 COLLAR ELEV. 1259.8 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N 8987.1, E7123.0 DEPTH OF BOREHOLE 52.3'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 08/23/84 DATE COMPLETED 08/23/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 08/28/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		4.0	3.4	85		0.0'-2.5' HALITE: Clear to light, moderately reddish orange (10R 6/6). Coarsely crystalline with some medium crystalline. <1/2% dispersed polyhalite. [1]	NW split tube core barrel. NW rods.
	4.0					2.5'-8.95' HALITE: Clear to moderate brown (5YR 4/4) with some moderate reddish orange (10R 6/6). Coarsely crystalline with some medium crystalline. ≤1% brown clay. <1/2% polyhalite dispersed. [8, 17]	18% of recovered core is ≥2 inch length. Overall core quality is poor.
2		2.5	2.5	100		8.95'-9.1' ANHYDRITE b: Light to medium light gray (N7, N6). Microcrystalline with halite growths common between 9.0'-9.1'. Trace of gray clay at 8.95'.	
	6.5					9.1'-14.7' HALITE: Clear, coarsely crystalline with scattered anhydrite. [1]	
3		5.0	5.0	100		14.7'-15.75' HALITE: Clear to moderate brown (5YR 4/4). Medium with some coarse crystalline. ≤1% brown clay with a trace of gray. <1/2% dispersed polyhalite. Break at 15.05'±.	
	11.5					15.75'-16.35' ANHYDRITE a: Light to medium light gray (N7, N6), with scattered laminae. Scattered halite growths. Trace of gray clay at 15.75'.	
4		4.5	4.4	98		16.35'-20.7' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% (average ≤1%) polyhalite. Core broken up, disced. [3, 4]	Runs 4 to 11: Shows much discing between 12' and 45'±.
	16.0					20.7'-25.5' HALITE: Clear to light moderate brown (5YR 4/4) with some light moderately reddish orange (10R 6/6). Medium to coarsely crystalline with some fine. ≤1% brown clay. <1/2% dispersed polyhalite. 3/4" brown clay seam at 25.45' with some anhydrite stringers above. [8, 10, 17]	Accurate logging was difficult where core was badly disced.
5		5.0	5.0	100		25.5'-28.8' HALITE: Clear, coarsely crystalline with scattered anhydrite. [1]	
	21.0					28.8'-35.7' HALITE: Clear, some moderate brown (5YR 4/4). Coarsely crystalline with locally medium crystalline. ≤1% brown clay. Clear 32.1'-33'±. [1, 8, locally 10]	
6		5.0	5.0	100			

BORING NO. DH-309

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-309

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					35.7'-39.1' HALITE: Clear to moderate brown (5YR 4/4, 3/4). Medium to coarsely crystalline. ≤1% brown clay locally argillaceous where 1% to 3% clay at 35.7'-37.3'±.	
26.0							
7	30	5.0	4.5	90		39.1'-39.65' ANHYDRITE: Very light to light gray (N8, N7). Microcrystalline with scattered halite growths and light to dark laminae. Brown hard clay seam at 39.1'.	* Six gas flows were encountered during drilling at the following depths: 15.6', 20.6', 25.0', 25.6', 31.0' and 39.1'. Gas flows varied in duration from about 10 seconds to 5 minutes and smelled sweet. Dry hole.
31.0						39.65'-44.4' HAL... Clear with some lightly moderate reddish orange (10R 6/6). Coarsely crystalline. <1/2% polyhalite. [1]	
8	35	5.0	3.2	64		44.4'-47.0' HALITE: Clear with some moderate brown (5YR 4/4). Coarsely crystalline ≤1% brown clay. Breaks at 45.4'-45.5'±. [8, some 10]	
36.0						47.0'-48.4' HALITE: Clear to lightly moderate reddish orange (10R 6/6) with some moderate brown (5YR 4/4). Medium to coarsely crystalline. ≤1% brown clay. <1/2% dispersed polyhalite [17] Irregular break at 47.9'.	
37.1							
9		1.1	1.1	100		48.4'-50.5' HALITE: Clear, mottled mi... some ...ht moderate brown. Coarsely crystalline. <1% brown clay. [8]	
10	40	3.6	3.6	100		50.5'-52.3' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4, 3/4). Coarse with some medium crystalline. <1% to 3% brown clay. >5% brown clay between 51.6' and 51.85'±. [10, 15]	
40.7							
11		3.4	2.8	82			
44.1							
12	45	4.9	4.3	88			
49.0							
13	50	3.3	3.3	100			
52.3							

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER: GE-264 | HOLE TYPE/SIZE: NX CORE | BORING NO.: DH-311

LOCATION: E 300 DRIFT - ROOF

STATION: E 300; S 1000 | COLLAR ELEV.: 1264.4 | DIRECTION OF DRILLING: VERTICAL UP

MINE COORDINATES: N 8686.3, E7194.9 | DEPTH OF BOREHOLE: 52.0'

DRILLING METHOD: ROTARY AIR | DRILL MAKE/MODEL: CP-65

DATE STARTED: 08/24/84 | DATE COMPLETED: 08/24/84 | SHEET

LOGGED BY: J.E. GALLERANI | DATE: 08/27/84 | 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0 – 1.6	1.6	1.6	100	—	0.0'-2.5' HALITE: Clear, coarsely crystalline. <1/2% gray clay. [1]	NW split tube core barrel. NW rods.
2	1.6 – 5.7	4.1	3.0	73	—	2.5'-8.4' HALITE: Clear to moderate brown (5YR 4/4), coarsely crystalline. <1% to 2% brown clay. Becomes medium crystalline at 7.7'-8.4' with trace of polyhalite dispersed. [8, 10]	No gas. Dry hole.
3	5.7 – 8.8	3.1	3.1	100	— X	8.4'-8.8' ANHYDRITE b: Very light gray (N8) to medium light gray (N6). Microcrystalline with scattered halite growths especially last 0.2'. Trace gray clay at 8.4'.	Overall core is poor quality. Much discing in halite. Only 8% of recovered core is ≥2 inch length.
						8.8'-14.1' HALITE: Clear and coarsely crystalline with scattered white anhydrite/magnesite. [1]	
4	8.8 – 11.0	2.2	1.6	73		14.1'-15.1' HALITE: Clear to moderate brown and moderate yellowish brown (10YR 5/4).. Medium crystalline. <1% brown with a trace of gray clay. <1/2% dispersed polyhalite. [17]	
5	11.0 – 15.8	4.8	4.2	88	— X	15.1'-15.8' ANHYDRITE a: Very light to medium light gray (N8, N6). Microcrystalline anhydrite, partially laminated. More halite pinkish color between 15.4'-15.8'. Trace of gray clay at 15.1'.	
						15.8'-19.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. <1/2% gray clay locally. Traces of anhydrite locally. [3, 5, 7]	
6	15.8 – 18.1	2.3	2.3	100	X X X —	19.5'-25.4' HALITE: Clear to moderate brown (5YR 3/4, 4/4) and light moderate reddish orange. Medium to coarsely crystalline with some fine. <1/2% dispersed polyhalite. ≤1% brown clay with trace of gray locally. Gray clay seam at 25.2'. Anhydrite laminae mixed with halite to 25.4'. [10, 17] - some [8]	
7	18.1 – 18.4	.3	.3	100	X X X		
8	18.4 – 21.5	3.1	3.1	100	— X —	25.4'-29.7' HALITE: Clear, coarsely crystalline. [1]	
						29.7'-31.5' HALITE: Clear with some moderately brown (5YR 3/4). Coarsely crystalline with some medium to fine. <1% brown clay except at 30.2'-30.6'± where ≤2% brown clay. Break at 30.6'. [8, 17]	
9	21.5 – 25	5.0	5.0	100	X —		

BORING NO.: DH-311

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-311

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					31.5'-33.8' HALITE: Clear, coarsely crystalline with <1% brown clay. [1, 8]	
26.5							
10	30	5.0	5.0	100		33.8'-38.65' ARGILLACEOUS HALITE: Clear to moderately brown (5YR 3/4). Coarsely crystalline with scattered medium. <1% to 2%, locally 3% brown clay. [10, 15]	
						38.65'-39.3' ANHYDRITE: Very light to light gray (N8, N7), microcrystalline. Scattered lighter to darker gray laminae and scattered halite growths. 1" brown hard clay seam at 38.65'.	
31.5						39.3'-43.7' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite with scattered anhydrite. [3, 5]	
11	35	5.0	5.0	100		43.7'-48.6'± HALITE: Clear to light moderate brown and some moderate reddish orange (10R 6/6). Coarsely crystalline. ≤1% brown clay. <1% polyhalite. [10] <1% to 2% polyhalite blebs at 46.7'-47.7'. No clay. [3]	
36.5						48.6'-51.2' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4, 4/4). Medium to coarsely crystalline. <1% to 3% brown clay. [10, 15]	
12		2.8	2.8	100			
39.3						51.2'-52.0' HALITE: Clear to moderate brown (5YR 3/4, 4/4), fine to medium crystalline. <1% to 2% brown clay. Trace of dispersed polyhalite. [12]	
13	40	2.8	2.8	100			
42.1							
14	45	5.0	4.0	80			
47.1							
15	50	4.9	4.5	92			
52.0							

BORING NO. DH-311

WIPP

WASTE ISOLATION PILOT PLANT

GEOLOGIC DRILL LOG

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NW CORE BORING NO. DH-313

LOCATION INTERSECTION OF E 300; S 1300 DRIFTS - ROOF

STATION S 1300, E 300 COLLAR ELEV. 1270.6 DIRECTION OF DRILLING VERTICAL DIP

MINE COORDINATES N 8385.9, E 7190.6 DEPTH OF BOREHOLE 19.6'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 07/09/84 DATE COMPLETED 07/10/84 SHEET 1 OF 1

LOGGED BY: J.E. GALLERANI DATE: 07/10/84

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		5.0	3.7	74		0.0'-7.9' (±0.6') HALITE: Clear and coarsely crystalline. <1/2% gray clay and polyhalite locally. From 6.5' (±0.6') ≤1% clay with some medium crystalline.	NW split tube core barrel and rods with diamond stepped bit.
						7.9'-8.1' ANHYDRITE b: Light gray (N7), microcrystalline. Halite growths with a trace of clay at lower contacts.	No gas. Dry hole.
	5.0					8.1'-13.1' HALITE: Clear, coarsely crystalline.	
2		5.0	3.8	76		13.1'-14.0' HALITE: Clear, fine to medium crystalline with some coarsely crystalline. <1/2% light gray clay.	
						14.0'-14.85' ANHYDRITE a: Light gray (N7), microcrystalline with scattered halite growths. Trace of clay at 14.0'.	
	10.0					14.85'-19.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite.	
3		2.1	2.0	95			
	12.1					Stopped hole at 19.6 ft due to core loss and poor core quality. Refer to log for replacement hole DH-313A.	
4		3.2	3.2	100			
	15.3						
5		4.3	3.3	77			14% of core recovered was ≥2 inch length.
	19.6						

BORING NO. DH-313

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NW CORE BORING NO. DH-313A

LOCATION INTERSECTION OF E 300, S 1300 DRIFTS - ROOF

STATION S 1300, E 299 COLLAR ELEV. 1270.9 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N 8386.6, E 7189.5 DEPTH OF BOREHOLE 50.2'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL CP-65

DATE STARTED 07/10/84 DATE COMPLETED 07/12/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 07/12/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		1.8	1.8	100		0.0'-5.2' HALITE: Clear, coarsely crystalline with some fine to medium crystalline locally. <1/2% polyhalite blebs and gray clay. [1, 11]	NW split tube core barrel. NW rods.
	1.8						
2		1.6	1.6	100		5.2'-7.9' HALITE: Clear to moderate brown (5YR 4/4). Medium to coarsely crystalline <1% to 2% brown clay to 7.3', then <1% gray clay. [8, 10, 12]	
	3.4						
3		2.1	2.1	100		7.9'-8.05' ANHYDRITE b: Light gray microcrystalline. Trace of gray clay at 7.9'.	Total drill time: 12 hrs. Total down time: 5 hrs.
	5						
	5.5						
4		3.0	3.0	100		8.05'-13.3' HALITE: Clear and coarsely crystalline. <1/2% polyhalite with scattered white stringers of anhydrite/magnesite. [1]	No gas. Dry hole.
	8.5						
5		2.4	1.9	79		13.3'-14.0' HALITE: Clear with medium to coarsely crystalline. <1/2% gray clay. Gray break at 13.3'.	Down time due to power outage.
	10						
	10.9					14.0'-15.0' ANHYDRITE a: Light gray microcrystalline anhydrite. Partially laminated. Halite growths increasing in percent from 14.4'. Trace of gray clay at 14.0'.	
6		1.6	1.6	100			
	12.5					15.0'-19.0' POLYHALITIC HALITE: Clear to moderately reddish orange. Coarsely crystalline. <1% to 3% polyhalite. Scattered anhydrite mixed with halite to 15.65'-15.85'. [3, 4]	Broken core, discing between 8.5' and 30.0'.
7		3.35	3.0	90			
	15						
	15.85					19.0'-24.5' HALITE: Clear to moderate brown (5YR 4/4). Medium to coarsely crystalline. ≤1% brown clay. <1/2% dispersed polyhalite. Clear halite at 21.9' to 22.35'±. [8, 17]	22% of total core recovered was ≥2 inch length.
8		2.15	1.9	88			
	18.0					24.5'-27.3' HALITE: Clear and coarsely crystalline with scattered anhydrite. [1]	
9		2.85	2.85	100		27.3'-32.35' HALITE: Clear with some moderate brown (5YR 4/4). Coarsely crystalline except fine to medium crystalline between 29.2'-30.3'. <1% brown clay except 29.2'-30.3' where clay is ≤1%. [1, 8, 10] Graditional upper contact.	
	20						
	20.85						
10		2.65	2.65	100			
	23.5						
11		2.35	1.7	72			
	25						

BORING NO. DH-313A

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-313A

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					32.35'-37.5' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4). Medium to coarsely crystalline with some fine. <1% to 2% brown clay with trace of gray clay <1/2% dispersed polyhalite. [10, 15]	
25.85							
12		2.65	2.1	79			
28.5						37.5'-38.2' ANHYDRITE: Light to medium grey, micro-crystalline anhydrite. Scattered halite growths especially common to 37.9'. 1/2" brown clay seam at 37.5'.	
13	30	2.35	1.75	74			
30.85						38.2'-42.25' HALITE: Clear to light moderate reddish orange. Coarsely crystalline. ≤1% polyhalite with scattered anhydrite to 39.2'±. [2, 3]	
14		2.65	2.65	100			
33.5						42.25'-45.7' HALITE: Clear to moderate brown (5YR 4/4). Coarsely crystalline. ≤1% brown clay with ≤2% between 45.25'-45.7'±. [10]	
15	35	2.35	2.35	100		45.7'-47.15' HALITE: Clear coarsely crystalline 0% to 1/2% brown clay. [1, 8]	
35.85							
16		2.65	2.65	100		47.15'-48.7' HALITE: Clear and coarsely crystalline with some medium. <1% brown clay. [10, 17]	
38.5							
17	40	2.35	2.35	100		48.7'-50.2' HALITE: Clear to moderate reddish orange (10R 6/6) and moderate brown (5YR 4/4). Medium to coarsely crystalline with some fine. <1/2% dispersed polyhalite. <1% to 2% locally brown clay. [12, 17]	
40.85							
18		2.65	2.65	100			
43.5							
19	45	2.35	2.1	89			
45.85							
20		2.65	2.65	100			
48.5							
21	50	1.7	1.7	100			
0.2							

BORING NO. DH-313A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NW CORE BORING NO. DH-314

LOCATION INTERSECTION OF S 1300, E 300 DRIFTS - FLOOR

STATION S1300, E 300 COLLAR ELEV. 1258.3 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N 8386.5, E 7[illegible] DEPTH OF BOREHOLE 50.75'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 07/12/84 DATE COMPLETED [illegible]13/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 07/13/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		3.75	3.1	83		0.0'-1.5' HALITE: Clear, some moderate reddish orange (10R 6/6). Coarsely crystalline. <1/2% polyhalite. [1, 2]	NW split tube core barrel with NW rods.
	3.75					1.5'-4.55' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite. <1/2% gray clay locally. [3, 6, 7]	
2		2.0	2.0	100		4.55'-7.6' HB-139: "Swallowtail" pattern to 5.45'±. Mixture of halite and anhydrite. Moderate reddish orange (10R 6/6) to light gray color. Then light to medium gray anhydrite with scattered halite growths. Scattered laminae. Trace of gray clay at 7.6'. Some grinding evident.	Total drill time: 7 hrs.
	5.75						No gas. Dry hole.
3		4.95	4.95	100		7.6'-10.3' HALITE: Clear to light moderate reddish orange (10R 6/6), some light gray (N7). Fine to medium crystalline with some coarse. <1% dispersed polyhalite. <1/2% gray clay. [ ]	Core quality good.
	10.7					10.3'-11.8' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), some moderate brown (5YR 4/4). Coarsely crystalline. <1% to 3% polyhalite. <1% brown clay. [some 17]	
4		5.1	5.1	100		11.8'-16.1' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. Anhydrite mixed with halite at 15.8'-16.1'. [7]	
	15.8					16.1'-18.2' HALITE: Clear to lightly moderate reddish orange (10R 6/6). Medium to coarsely crystalline, some fine. ≤1% brown and gray clay. <1% dispersed polyhalite. [9, 17]	46% of core recovered was ≥2 inch length.
5		5.1	5.1	100		18.2'-22.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. [7]	
	20.9					22.5'-28.3' HALITE: Clear to lightly moderate reddish orange (10R 6/6), some light gray. Fine to coarsely crystalline, ≤1% dispersed polyhalite and gray clay. Some scattered anhydrite. [9]	
6		5.1	5.1	100			

BORING NO. DH-314

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-314

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
	26.0					28.3'-33.2' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite, generally dispersed. Moderate reddish orange (10R 6/6) anhydrite mixed with halite at 32.85'-33.05'. [7]	
7		5.0	5.0	100		33.2'-33.65' ANHYDRITE: Very light to light gray (N8, N7). Microcrystalline anhydrite. Scattered halite growths throughout. No clay.	
	30						
	31.0					33.65'-39.25' HALITE: Clear medium to coarsely crystalline. <1% gray clay. [9, 11]	
8		5.0	4.9	98		39.25'-41.15' HALITE: Clear, some lightly moderate reddish orange (10R 6/6). Coarsely crystalline with some fine to medium. <1% gray clay and dispersed polyhalite.	
	35						
	36.0					41.15'-43.45' HALITE: Clear, some lightly moderate reddish orange (10R 6/6). Medium to coarsely crystalline, some fine. ≤1% brown clay and 1/2% dispersed polyhalite.[17]	
9		4.85	4.7	97		43.45'-48.25' HALITE: Clear, coarsely crystalline with some medium. <1% gray clay. Trace of polyhalite locally.[11]	
	40						
	40.85					48.25'-50.75' HALITE: Clear, coarsely crystalline. <1/2% polyhalite. Gray clay break at 50.25'.[1]	
10		5.1	5.1	100			
	45						
	45.95						
11		4.8	4.8	100			
	50						
	50.75						

BORING NO. DH-314

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-315

LOCATION INTERSECTION OF W 170, S 1300 DRIFTS - ROOF

STATION S 1300, W 170 COLLAR ELEV. 1272.1 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N 8387.3, E 6725.5 DEPTH OF BOREHOLE 50.3'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 09/05/84 DATE COMPLETED 09/06/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 09/06/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1	0	1.5	1.1	73	X	0.0'-7.0' HALITE: Clear, coarsely crystalline with some medium. <1/2% polyhalite. <1/2% gray clay locally. [1]	NC double tube wireline core barrel with NC rods. Run 1: Broken core.
	1.5						
2		5.0	4.5	90		7.0'-8.4' HALITE: Clear, some moderate brown (5YR 4/4) and light moderate reddish orange. Medium to coarsely crystalline. <1/2% dispersed polyhalite. <1% brown clay to 7.7'±, then gray. [9, 17]	Run 2: Broken zones within run.
	5						
	6.5				X	8.4'-8.6' ANHYDRITE b: Very light to medium light gray (N8, N6) microcrystalline anhydrite. Scattered halite within. Hard, dry, gray clay at 8.4'	No gas. Dry hole.
3		5.0	5.0	100	X	8.6'-14.3' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. [1]	
	10					14.3'-15.1' HALITE: Clear to lightly moderate brown (5YR 4/4), some lightly moderate reddish orange (10R 6/6). Fine to medium crystalline. <1/2% dispersed polyhalite. <1% brown clay.	
	11.5					15.1'-15.95' ANHYDRITE a: Very light to medium light gray (N8, N6), microcrystalline. Partially laminated. Scattered halite growths especially from 15.5'±. <1/4" gray clay at 15.1'.	
4		5.0	5.0	100	X	15.95'-20.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite, average <1% to 2%. [2, 4, 7]	
	15						
	16.5				X X	20.0'-25.1' HALITE: Clear to light moderate reddish orange (10R 6/6), some moderate brown (5YR 4/4). Medium to coarsely crystalline, some fine. ≤1% brown clay. <1/2% dispersed polyhalite. Some scattered breaks. [8, 17] <1/4" hard, dry, brown clay at 25.0' with associated anhydrite stringers to 25.1'	39% of recovered core was ≥2 inch length.
5		5.0	5.0	100	X X X		
	20					25.1'-29.8' HALITE: Clear, coarsely crystalline. Scattered anhydrite stringers.[1]	
	21.5				X	29.8'-31.5' ARGILLACEOUS HALITE: Clear to medium brown (5YR 4/4), fine to medium crystalline, some coarse. <1% to 3% brown clay.[12]	
6		4.8	4.8	100	X		
	25						

BORING NO. DH-315

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-315

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					31.5'-34.7' HALITE: Clear, some moderate brown (5YR 4/4). Coarsely crystalline, <1% brown clay. [1, 8]	
26.3							
7	30	5.0	5.0	100		34.7'-39.0' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4, 3/4), some light moderate reddish orange (10R 6/6). Fine to medium crystalline, some coarse. <1% to 3% brown clay. <1/2% dispersed polyhalite locally. Scattered breaks. [12, 15]	
31.3						39.0'-39.45' ANHYDRITE: Very light gray to light medium gray (N8, N6). Microcrystalline, faintly laminated. Scattered small halite growths. 1/2" hard, dry, brown clay seam at 39.0'.	
8	35	4.8	4.8	100		39.45'-40.6' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite. [2, 7]	
36.1						40.6'-43.7' HALITE: Clear, coarsely crystalline. Locally <1/2% polyhalite. Very clear to 41.6'±. [1]	
9	40	5.0	5.0	100		43.7'-49.1' HALITE: Clear to moderate brown (5YR 4/4), scattered lightly moderate reddish orange (10R 6/6). Coarsely crystalline, some medium. Generally <1% brown clay with zones 1% to 3%. Break at 44.0'±; parting at 44.15±. Predominantly brown clay mixed with halite at 45.8'-46.0'±. Broken up here. [1, 8, 10, locally 12]. Trace of polyhalite.	Run 9: Broken between 40.0'-41.1'. Scattered broken zones throughout.
41.1						49.1'-50.3' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4). Medium to coarsely crystalline. <1% to 5% brown clay. Break at 50.3' [15]	
10	45	4.9	4.9	100			
46.0							
11	50	4.3	4.3	100			
50.3							

BORING NO. DH-315

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-316

LOCATION INTERSECTION S 1300, W 170 DRIFTS - FLOOR

STATION S 1300, W 170 COLLAR ELEV. 1259.9 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N 8387.2, E6725.3 DEPTH OF BOREHOLE 50.1'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 09/06/84 DATE COMPLETED 09/06/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 09/06/84 1 OF 2

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0		0						
	1		1.6	1.6	100		0.0'-1.7' HALITE: Clear with some moderate reddish orange. (10R 6/6) Coarsely crystalline. <1/2% polyhalite and gray clay locally. [1, 2]	NC double tube wireline core barrel. NC rods. Total drill time: 7 hrs.
1.6								
	2		4.9	4.9	100		1.7'-5.0' POLYHALITIC HALITE: Clear to moderate reddish orange. (10R 6/6) Coarsely crystalline. <1% to 3% polyhalite with scattered anhydrite. [3, 7]	
		5					5.0'-7.65' MB-139: Mixture of very light to light medium gray anhydrite and moderate reddish orange halite (10R 6/6) to 6.25'±. Then predominantly light gray and moderate reddish orange anhydrite mixed with some halite. Low angle irregular layering and laminae throughout. Dry hard gray clay at 7.65'.	No gas. Dry hole.
6.5								
	3		5.0	5.0	100		7.65'-11.85' HALITE: Clear to lightly moderate reddish orange (10R 6/6). Medium to coarsely crystalline with some fine. <1/2% polyhalite dispersed and gray clay except locally at 9.2'-10.7' where polyhalite is 1% to 2%. [9]	
		10						
11.5							11.85'-24.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline with some medium crystalline locally. Scattered anhydrite. <1% to 3% polyhalite, locally up to 5%. <1% gray clay below 15.8'. [3, 5, 7]	
	4		5.0	5.0	100		24.0'-25.2' HALITE: Clear to moderate reddish brown (10R 6/6). Coarsely crystalline. ≤1% polyhalite and brown clay with a trace of gray.	79% of core recovered was ≥ 2 inch length.
		15						
16.5							25.2'-26.95' HALITE: Clear with some moderate brown (5YR 4/4). Fine to medium, some coarsely crystalline. <1% brown clay. Breaks at 25.2' and 25.25', parting at 25.55'±. [8, 10]	
	5		5.0	5.0	100		26.95'-33.05' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3%polyhalite with scattered anhydrite. .1"± irregular anhydrite layer at 33'±.	
		20						
21.5							33.05'-34.0' HALITE: Clear coarsely crystalline Scattered white anhydrite stringers. [1]	
	6		5.0	5.0	100			
		25						

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-316

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					34.0'-34.4' ANHYDRITE: Very light to light medium gray microcrystalline anhydrite. Scattered halite growths and pods, especially below 34.2'±. <1/4" gray clay at 34.4'.	
26.5							
7		5.0	5.0	100		34.4'-39.1' HALITE: Clear to light moderate reddish orange (10R 6/6). Medium to coarsely crystalline with some fine. <1/2% dispersed polyhalite and gray clay. [1, 9]	
	30						
31.5						39.1'-46.1' HALITE: Clear to moderate brown (5YR 4/4) with some lightly moderate reddish orange. Medium to coarsely crystalline. <1% brown clay. <1/2% polyhalite. [8, 10, 17]	
8		5.0	5.0	100		46.1'-47.5' HALITE: Clear with some light bluish gray. Coarsely crystalline, some medium. <1/2% gray clay. <1/2% scattered polyhalite blebs.	
	35					47.5'-49.7' HALITE: Clear, coarsely crystalline. <1/2% polyhalite blebs. [1]	
36.5						49.7'-50.1' POLYHALITIC HALITE: Clear to moderate reddish-orange. Coarsely crystalline. <1% to 3% polyhalite. [7]	
9		5.0	5.0	100			Run 9: First 2' of run contained locally broken zones.
	40						
41.5							
10		5.0	5.0	100			
	45						
46.5							
11		3.6	3.6	100			
50.1	50						

BORING NO. DH-316

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-317

LOCATION INTERSECTION OF S 1600, W 30 DRIFTS - ROOF

STATION S 1600, W 33 COLLAR ELEV. 1271.3 DIRECTION OF DRILLING VERTICAL

MINE COORDINATES N 8077.4, E 6875.9 DEPTH OF BOREHOLE 50.1'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 07/05/84 DATE COMPLETED 07/06/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 07/6/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		4.8	3.2	66	X —	0.0'-7.3' HALITE: Clear, coarsely crystalline to 5.0', then medium to coarsely crystalline. <1/2% polyhalite and gray clay locally. [1, 11]	NW split tube core barrel and NW rods. Total drill time: 11 hrs. Runs 1, 6, 7, 8, 10 and 11 contain broken zones.
	4.8					7.3'-8.4' HALITE: Clear to moderate reddish orange (10R 6/6), some medium brown (5YR 4/4). Medium to coarsely crystalline. <1% brown/gray clay and polyhalite [17]	
2	5	5.0	5.0	100	X —	8.4'-8.7' ANHYDRITE b: Very light to medium light gray (N8, N6). Microcrystalline anhydrite. Scattered halite growths. Trace of gray clay at 8.4'	No gas. Dry hole.
					— X	8.7'-11.8' (±0.15') HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. [1]	
	9.8					11.8'-12.65' HALITE: Clear, some medium brown (5YR 3/4) and moderate reddish orange (10R 6/6). Medium crystalline, some coarse. <1% brown to gray clay. <1% polyhalite. [9, 17]	
3	10	1.0	1.0	100			
	10.8					12.65'-13.15' ANHYDRITE a: Light gray to medium light gray (N7, N6). Microcrystalline. Scattered halite growths, trace of clay at 12.65'.	
4		5.0	4.7	94	X —		Runs 4 and 5 contain discing.
					X	13.15'-19.2' HALITE: Clear, trace of medium reddish orange (10R 6/6). Coarsely crystalline. <1/2% polyhalite. [1, 2]	
	15						
	15.8					19.2'-22.9' (±0.5') HALITE: Clear, some moderate brown (5YR 4/4) to moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1% dispersed polyhalite and brown clay. [17]	18% of core recovered was ≥2 inch length.
5		5.0	5.0	100	X	22.9'-28.6' (±0.6') HALITE: Clear, coarsely crystalline. [1] <1/8" brown clay seam at 24.7' ±0.45'. 3/4" anhydrite at 24.75±.	
	20						
	20.8				X —	28.6'±-30.6'± HALITE: Clear to moderate brown (5YR 4/4). Medium coarsely crystalline. <1% to 2% brown clay. <1% polyhalite. [10] ≤1/4" brown clay seam at 30.6' some anhydrite associated.	
6		5.0	4.1	82		30.6'-35.6' HALITE: Clear, coarsely crystalline. <1% brown clay. [8, some 10]	
	25						

BORING NO. DH-317

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-317

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					35.6'–36.2' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4). Medium to coarsely crystalline. <1% to 3% brown clay, trace gray. [15]	
25.8							
7		5.0	3.9	78		36.2'–36.8' ANHYDRITE: Light gray (N7). Microcrystalline. Scattered halite growths. Trace brown clay at 36.2'.	
	30					36.8'–40.1' HALITE: Clear, coarsely crystalline. <1% polyhalite. [1]	
30.8							
8		4.8	4.0	83		40.1'–42.4' HALITE: Clear, some moderate reddish orange (10R 6/6). Coarsely crystalline. ≤1% polyhalite blebs, locally 2%. Gray clay break at 42.4'. [2, 4]	
	35					42.4'–44.0' HALITE: Clear, some moderate brown (5YR 4/4). Coarsely crystalline. <1% brown clay. [8, 10]	
35.6						44.0'–44.7' HALITE: Clear to moderate brown (5YR 3/4). Medium crystalline. <1% to 2% brown clay. <1/2% dispersed polyhalite. [17]	
9		5.0	5.0	100		44.7'–49.2' HALITE: Clear, some medium brown (5YR 4/4). Coarsely crystalline. ≤1% brown clay. Locally <1/2% polyhalite blebs. [10]	
	40					49.2'–50.1' HALITE: Clear to moderate reddish orange (10R 6/6), medium brown, medium to coarsely crystalline. ≤1% brown clay and polyhalite. [17]	
40.6							
10		5.0	5.0	100			Because of poor quality and recovery of core, holes DH-317A, 317B were drilled. Refer to logs for these holes.
	45						
45.6							
11		4.5	4.5	100			
	50						
50.1							

BORING NO. DH-317

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE \ NUMBER - HOLE TYPE/SIZE NW CORE BORING NO. DH-317A

LOCATION INTERSECTION OF S 1600, W 30 DRIFTS - ROOF

STATION S 1600, W 30 COLLAR ELEV. 1271.2 DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N 8077.5, E 6879.5 DEPTH OF BOREHOLE 5.0'

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL CP-65

DATE STARTED 07/06/84 DATE COMPLETED 07/06/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 07/06/84 1 OF 1

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0	2.0	2.0	100	—	0.0'-5.0' HALITE: Clear, coarsely crystalline. <1/2% polyhalite and gray clay. [1, 2]	NW split tube core barrel and NW rods. Drill time: 45 minutes. This hole was drilled to replace first run of hole 317.
2	2.0	3.0	2.9	97	X		
	5.0						No gas. Dry hole.

BORING NO. DH-317A

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-317B

LOCATION INTERSECTION OF W 30, S 1600 DRIFTS - ROOF

STATION S 1597, W 30 COLLAR ELEV. 1271.2 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N8080.3, E6881.0 DEPTH OF BOREHOLE 51.0'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 09/07/84 DATE COMPLETED 09/07/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 09/08/84 1 OF 2

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0								
	1		1.75	1.4	80	X	0.0'-5.1' HALITE: Clear with some lightly moderate reddish orange (10R 6/6). Coarsely crystalline with some medium. <1/2% polyhalite.[1]	NC double tube wireline core barrel with NC rods. Total drilling time: 12 hrs ±. This is a replacement hole for 317 and 317A. Runs 1, 2: broken core.
1.75								
	2		4.65	4.65	100	X	5.1'-7.1' HALITE: Clear, medium to coarsely crystalline. <1% gray clay and dispersed polyhalite.[1, 11]	
		5					7.1'-8.1' HALITE: Clear to moderate brown (5YR 4/4) with some light moderate reddish orange (10R 6/6). Medium to coarsely crystalline. <1% brown clay. Trace of polyhalite.	
6.4						X		
	3		4.9	4.9	100	X	8.1'-8.7' HALITE: Clear, some lightly moderate reddish orange (10R 6/6). <1/2% gray clay and polyhalite. [9]	
						X	8.7'-8.9' ANHYDRITE b: Very light to medium light gray, microcrystalline anhydrite with growths of halite. ≤1/4" dry gray clay at 8.7'.	
		10					8.9'-13.9' HALITE: Clear, coarsely crystalline with scattered white anhydrite stringers. [1]	
11.3								
	4		5.0	5.0	100	X	13.9'-15.1' HALITE: Clear to lightly moderate reddish orange (10R 6/6). Medium crystalline with some fine and coarsely crystalline. <1/2% polyhalite with ≤1% between 14.9' and 15.1'. ≤1% gray clay.	
						X	15.1'-15.85' ANHYDRITE a: Very light to lightly medium gray (N8, N6) anhydrite. Scattered halite growths. Trace of moist gray clay at 15.1'.	Run 4: Water seepage from hole after rods were broken at end of run. Probably from anhydrite a.
		15						
16.3								
	5		5.0	5.0	100	X	15.85'-20.1' HALITE: Clear to lightly moderate reddish orange (10R 6/6). Coarsely crystalline anhydrite mixed with halite between 16'-16.2'. Scattered white anhydrite stringers throughout core. ≤1% polyhalite blebs. [1, 2] Core broken up between 15.85'-16.05'±. Very clear.	
		20					20.1-26.0' HALITE: Clear, some moderate brown (5YR 4/4). Medium to coarsely crystalline, some fine. ≤1% brown clay. <1/2% dispersed polyhalite. 1/4" brown hard clay seam at 25.8' with associated anhydrite stringers to 26.0'.	
21.3								
	6		5.0	4.7	94	X		
		25						

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-317B

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
		25					26.0'-30.1' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. [1]	
26.3								
	7	30	5.0	4.5	90		30.1'-33.8' HALITE: Clear with zones of moderate brown. Coarsely crystalline with some medium. ≤1% brown clay. [1, 8, some 10]	
							33.8'-39.6' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4, 4/4). Coarsely crystalline, some medium. <1% to 3% brown clay. <1/2% dispersed polyhalite. Scattered breaks. [8, 10, 15, 17]	Run 8: Broken zones of core.
31.3								
	8	35	5.0	4.6	92		39.6'-40.2' ANHYDRITE: Very light to light medium gray (N8, N6), microcrystalline anhydrite. Faintly laminated, low angle. Scattered very small halite growths. ≤3/8" brown clay seam at 39.6'. Dips 15°±.	
							40.2'-44.3' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite, average <2%. [3, 7]	
36.3								
	9	40	5.0	4.6	92		44.3'-51.0' HALITE: Clear, some moderate brown (5YR 4/4). Coarsely crystalline, locally fine to medium. ≤1% brown clay. <1/2% polyhalite patches, blebs, locally up to 2%. Scattered brown clay breaks 47.1'-47.7±. Clear halite, scattered polyhalite blebs at 48'-49.1'±. [1, 8, 10]	
41.3								Run 10: Broken core beyond 43 ft. Hit gas pocket at 45.9'. No reading on methane detection meter. No sound of gas leak.
	10	45	5.0	5.0	100			34% of recovered core is ≥2 inch length.
46.3								
	11	50	4.7	4.7	100			
51.0								

BORING NO. DH-317B

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NX CORE BORING NO. DH-318

LOCATION INTERSECTION OF S 1600, W 30 DRIFTS - FLOOR

STATION S 1600, W 30 COLLAR ELEV. 1258.5 DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N 8077.3, E 6876.1 DEPTH OF BOREHOLE 50.0'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 07/02/84 DATE COMPLETED 07/03/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 07/03/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		4.2	4.2	100		0.0'-4.75' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. Scattered anhydrite. ≤1% to 3% polyhalite. [7]	NW split tube core barrel. NW rods. Scissor lift.
	4.2					4.75'-7.3' MB-139: From 4.75'-5.75'± is mixture of anhydrite and halite. Then predominantly anhydrite with scattered halite growths. Light gray with some moderate reddish orange. Gray clay parting at 7.3'.	Total drill time: 7 hrs.
2	5	5.3	5.3	100		7.3'-11.0' HALITE: Clear to light gray (N7) and light moderate reddish orange. Medium to coarsely crystalline. ≤1% gray clay. <1% dispersed polyhalite. Gray clay break at 9'. ≤3% polyhalite to 7.8'±. [9]	No gas. Dry hole.
	9.5					11.0'-15.45' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 2% polyhalite dispersed. Scattered anhydrite. 3/4" anhydrite layer at 15.35'. Gray clay parting at 15.45'. [4, 7]	33% of core recovered is ≥2 inch length.
3	10	5.2	5.2	100		15.45'-17.2' HALITE: Clear, some light gray (N7) and moderate reddish orange (10R 6/6). Medium to coarsely crystalline. ≤1% gray clay. <1/2% dispersed polyhalite. [9]	
	14.7					17.2'-20.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. ≤1% to 3% polyhalite. [5, 6, 7]	
4	15	5.0	5.0	100		20.5'-27.0' HALITE: Clear (some light gray (N7) to lightly moderate reddish orange (10R 6/6). Medium to coarsely crystalline. ≤1% gray clay, some brown. <1% polyhalite dispersed. Breaks at 21.5' and 21.9'±. [9, 17]	
	9.7					27.0'-32.7' HALITE: Clear to moderate reddish orange (10R 6/6). coarsely crystalline. <1% to 2% dispersed polyhalite. Trace of gray clay at 27.1'. Up to 1" anhydrite at 32.6'. Scattered anhydrite stringers between 31.6'-32.6'. [2, 4]	
5	20	5.1	5.1	100		32.7'-33.65' HALITE: Clear, medium to coarsely crystalline. <1/2% dispersed polyhalite. [1]	
	24.8						
	25						

BORING NO. DH-318

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-318

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
6		5.2	5.2	100		33.65'-33.95' ANHYDRITE: Very light to light gray (N8, N7). Microcrystalline. Scattered halite growths. 1/2" halite layer just below upper contact. ≤1/8" gray clay seam at lower contact. Core grinding here.	
						33.95'-40.3' HALITE: Clear, some moderate reddish orange (10R 6/6). <1/2% polyhalite. <1% gray clay to 34.95'±, then 0 - <1/2%. [2], [some 9]	
30.0	30					40.3'-44.2' HALITE: Clear, some medium brown (5YR 4/4). Coarsely crystalline, some medium. ≤1% brown clay. <1/2% polyhalite. [8, 10]	
7		5.0	5.0	100		44.2'-50.0' HALITE: Clear, coarsely crystalline, some medium. Zero to <1% gray clay. <1/2% polyhalite. [1, 11]	
35.0	35						
8		5.0	5.0	100			
40.0	40						
9		5.0	5.0	100			
45.0	45						
10		5.0	3.0	60			
.0	50						

BORING NO. DH-318

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE NC CORE BORING NO. DH-319

LOCATION INTERSECTION OF S 700, E 300 DRIFTS -- ROOF

STATION S 700, E 300 COLLAR ELEV. 1260.0 DIRECTION OF DRILLING UP VERTICAL

MINE COORDINATES N8988.1 E7191.6 DEPTH OF BOREHOLE 51.05'

DRILLING METHOD ROTARY AIR DRILL MAKE/MODEL CP-65

DATE STARTED 09/10/84 DATE COMPLETED 09/10/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 09/10/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		2.0	2.0	100		0.0'-5.4' HALITE: Clear to lightly moderate reddish orange (10R 6/6). Coarsely crystalline, some medium locally. <1/2% polyhalite. Trace brown clay from 4.7'. [1]	NC double tube wireline core barrel. NC rods.
	2.0						
2		4.6	4.6	100		5.4'-8.45' HALITE: Clear to moderate brown (5YR 4/4). Coarsely crystalline. ≤1% brown clay, locally up to 2%. Gray clay from 5.05'. Scattered polyhalite. Some anhydrite close to contact at 8.45'. [8, 10]	No gas. Dry hole.
	5						
						8.45'-8.65' ANHYDRITE b: Very light to light medium gray (N8, N6). Microcrystalline. Trace gray clay at 8.45'.	
	6.6						
3		5.1	5.1	100		8.65'-14.3' HALITE: Clear, coarsely crystalline. Scattered white anhydrite. [1]	
	10					14.3'-15.65' HALITE: Clear, some lightly moderate reddish orange and moderate brown (5YR 4/4). Fine to coarsely crystalline. ≤1% polyhalite and gray, brown clay. [17]	
	11.7						
4		5.0	5.0	100		15.65'-16.35' ANHYDRITE a: Very light to medium light gray anhydrite. Scattered halite growths, especially from 16.15'. Trace gray clay at 15.65'. Core grinding evident here.	
	15					16.35'-20.85' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline. <1% to 3% polyhalite. Average 1% to 2%. [3, 4]	
	16.7						
5		5.0	4.9	98		20.85'-25.35' HALITE: Clear to moderate brown (5YR 4/4). Medium to coarsely crystalline. ≤1% brown clay, some gray. Trace dispersed polyhalite. [10, 17, some 12] 1/4" hard brown grayish clay seam at 25.3'± with associated anhydrite/halite to 25.35'.	
	20					25.35'-30.9' HALITE: Clear, coarsely crystalline. Slight trace clay. [1]	
						30.9'-32.7' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4, 3/4). Medium to coarsely crystalline. Scattered breaks. <1% to 3% brown clay. [10, 15]	Run 5: Some broken core.
	.7						
6		4.7	4.7	100		32.7'-33.9' HALITE: Clear, coarsely crystalline. [1]	
	25						

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-319

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25					33.9'–36.55' HALITE: Clear, some moderate brown (5YR 4/4). Coarsely crystalline. ≤1% brown clay. [8, 10]	
26.4							
7		4.9	4.9	100		36.55'–40.05' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4, 4/4). Medium to coarsely crystalline. <1% to 3% brown clay. Scattered breaks. [15]	Run 7: Broken core.
	30					40.05'–40.6' ANHYDRITE: Very light to light medium gray (N8, N6). Microcrystalline. Scattered halite growths. Partially laminated. 1/2" halite layer at 40.4'±.	
31.3							Run 8: Broken zones within run.
8		4.75	4.75	100		40.6'–48.3' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6). Coarsely crystalline, some fine to medium between 45.8'–46.8'±. <1% to 3% polyhalite, locally 5%. Scattered anhydrite. Scattered brown clay 45.8'–46.8'±.	
	35					48.3'–51.05' HALITE: Clear mottled with moderate brown (5YR 4/4). Coarsely crystalline. ≤1%, locally 2% brown clay. <1/2% polyhalite blebs.	
36.05							
9		5.0	5.0	100			
	40						
41.05							
10		5.0	5.0	100			40% of core recovered was ≥2 inch length.
	45						
46.05							
11		5.0	5.0	100			
	50						
51.05							

BORING NO. DH-319

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER: GE-268 HOLE TYPE/SIZE: NX CORE BORING NO.: DH-321

LOCATION: S 400 DRIFT JUST WEST OF WASTE SHAFT - ROOF

STATION: S 400 E0 COLLAR ELEV.: 1261.4 DIRECTION OF DRILLING: VERTICAL UP

MINE COORDINATES: N9792.0 E6891.8 DEPTH OF BOREHOLE: 52.0'

DRILLING METHOD: ROTARY/AIR DRILL MAKE/MODEL: CP-65

DATE STARTED: 09/14/84 DATE COMPLETED: 09/14/84 SHEET

LOGGED BY: J.E. GALLERANI DATE: 09/29/84 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	0.0						
1		5.0	5.0	100		0.0'-4.3' HALITE: Clear, coarsely crystalline. <1/2% polyhalite and gray clay. [1]	NW split tube core barrel with NW rods. Overall core quality good.
						4.3'-6.6' HALITE: Clear to moderate brown (5YR 4/4), coarsely crystalline. ≤1% brown clay [10]	
	5.0					6.6'-7.8' HALITE: Clear to medium light gray (N6) and light moderate reddish orange (10R 6/6). Fine to medium, some coarsely crystalline. <1/2% dispersed polyhalite. ≤1% gray clay.	
2		5.0	5.0	100		7.8'-8.05' ANHYDRITE b: Light gray (N7) microcrystalline, some laminae. Scattered halite growths. Trace of gray clay at 7.8'.	
						8.05'-14.0' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. [1]	
	10.0					14.0'-14.65' HALITE: Clear to moderate brown (5YR 4/4) and light moderate reddish orange (10R 6/6), medium crystalline. ≤1% brown clay. <1% dispersed polyhalite.	
3		5.0	5.0	100		14.65'-15.5' ANHYDRITE a: Light to medium gray (N7, N5) microcrystalline anhydrite. Irregular laminae Scattered halite growths especially from 15.1'. Trace of gray clay at 14.65'.	
	15.0					15.5'-19.9' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite, average ≤2% scattered anhydrite. [3, 4, 7]	
4		5.0	5.0	100		19.9'-22.4' HALITE: Clear to moderate reddish orange (10R 6/6). Some moderate brown. Medium to coarsely crystalline. ≤1% polyhalite and brown clay. [17]	
	20.0					22.4'-24.3' HALITE: Clear to light moderate reddish orange and some light bluish gray. Medium to coarsely crystalline. <1/2% polyhalite. <1% gray clay. [9]	
5		5.0	5.0	100		24.3'-29.6' HALITE: Clear, coarsely crystalline. Scattered anhydrite. Up to 1/2" hard brown clay seam at 25.1' with trace of associated anhydrite. <1/2% polyhalite locally. [1]	
	25.0						

BORING NO. DH-321

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF 2 — BORING NO. DH-321

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
6	30.0	5.0	5.0	100		29.6'-31.2' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4, 4/4), medium to coarsely crystalline, some fine. <1% to 3% brown clay. [12]	
						31.2'-33.3' HALITE: Clear, coarsely crystalline. [1]	
						33.3'-35.2' HALITE: Clear, some moderate reddish brown (10R 4/6), coarsely crystalline. None to ≤2% brown clay [1, 10]	
7	35.0	5.0	5.0	100		35.2'-38.7' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4, 3/4), medium to coarsely crystalline. <1% to 3% brown clay, trace gray. 1/2" brown clay seam at 37.45'. <1/2% polyhalite dispersed. [14, 17].	
						38.7'-39.4' ANHYDRITE: Light to medium light gray (N7, N6) microcrystalline anhydrite. Partially laminated. 3/4" hard brown clay seam at 38.7'.	
8	40.0	5.0	5.0	100		39.4'-40.2' HALITE: Clear, coarsely crystalline. <1/2% polyhalite, scattered anhydrite. [1]	
						40.2'-43.0' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6), coarsely crystalline. <1% to 3% polyhalite. [7]	
9	45.0	5.0	5.0	100		43.0'-47.0' HALITE: Clear to moderate reddish orange (10R 6/6), some moderate brown (5YR 4/4). Coarsely crystalline with zones of fine-medium. <1% to 2% brown clay. <1% polyhalite. [8, 12]	
						47.0'-48.9' HALITE: Clear mottled with some moderate reddish orange (10R 6/6), coarsely crystalline. ≤1% polyhalite. <1/2% gray clay. [1, 3]	
10	50.0	5.0	5.0	100		48.9'-52.0' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 3/4, 4/4), medium to coarsely crystalline. <1% to 3% brown clay. [10, 15]	
11	52.0	2.0	2.0	100			
	55						

BORING NO. DH-32

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER: GE-267 HOLE TYPE/SIZE: NX BORING NO.: DH-323

LOCATION: WASTE SHAFT STATION - ROOF - EAST OF WASTE SHAFT

STATION: S400, E55 COLLAR ELEV.: 1261.2 DIRECTION OF DRILLING: VERTICAL UP

MINE COORDINATES: N9291.7, E6952.5 DEPTH OF BOREHOLE: 52.5 FT

DRILLING METHOD: ROTARY AIR DRILL MAKE/MODEL: CP-65

DATE STARTED: 2-22-85 DATE COMPLETED: 2-22-85 SHEET

LOGGED BY: J. E. GALLERANI DATE: 2-28-85 1 OF 2

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0.0	3.0	0.9	30		0.0'-3.6' HALITE: Clear, medium to coarsely crystalline. [1]	NX split-tube core barrel.
2	3.0	1.3	1.2	92		3.6'-8.0' HALITE: Clear, some moderate brown (5YR 4/4); medium to coarsely crystalline. <1% brown clay. [8]	8.7% of core recovered was a 2-inch lengths.
3	4.3	2.7	2.7	100		8.0'-8.3' ANHYDRITE "b": Very light to medium gray anhydrite. Scattered halite growths. Up to 1/2" dark gray clay at 8.0'. Irregular, low angle.	
4	7.0	5.0	5.0	100		8.3'-14.5' HALITE: Clear, coarsely crystalline. Scattered white anhydrite stringers. [1]	Poor core quality.
5	12.0	5.0	3.5	70		14.5'-15.6'± HALITE: Clear to moderate brown (5YR 4/4); fine to medium crystalline. ≤ 2% brown clay, some gray. <1/2% dispersed polyhalite. [12]	
						15.6'-16.25'± ANHYDRITE "a": Light to light medium gray anhydrite. 1/4" gray clay at 15.6'. Low angle.	
						16.25'±-20.5' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 3% polyhalite. Scattered anhydrite. [5,7]	
						20.5'-23.5' HALITE: Clear, some moderate brown (5YR 4/4); medium to coarsely crystalline, some fine. ≤1% brown clay. Trace polyhalite. Up to 1" brown clay seam at 23.25'. Irregular, low angle. Some hairline halite-filled fractures in clay. Some associated anhydrite to 23.5'. [8,10]	
6	17.0	2.0	1.1	55		23.5'-30.4' HALITE: Clear, coarsely crystalline, some medium. [1]	
7	19.0	2.5	2.5	100		30.4'-35.4' HALITE: Clear to moderate brown (5YR 4/4); medium to coarsely crystalline, some fine. ≤1% brown clay, locally 2%. Break at 31.7'±. [8,10]	
8	21.5	1.5	0.9	60		35.4'-37.8' ± 0.5' ARGILLACEOUS HALITE: Clear to moderate brown (5YR 4/4; 3/4), fine to medium crystalline. <1 to 3% brown clay. [12,15]	
9	23.0	3.4	1.2	35		37.8'-38.8' ANHYDRITE: Light to medium gray, microcrystalline anhydrite. Up to 1" brown clay at 37.8'. Irregular, undulating surfaced core is disced.	
	25						

WIPP

WASTE ISOLATION PILOT PLANT — SHEET 2 OF ____ — BORING NO. DH-323

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
	25						
9	26.4	3.4	1.2	35		38.8'–42.0' POLYHALITIC HALITE: Clear to moderate reddish orange/brown (10R 6/6; 4/6). Coarsely crystalline. <1 to 3% polyhalite blebs and patches. Core broken.	Note: Core is badly disced from about Run 10. It is broken from about 33' to 52.5'. Difficult to log hole due to broken core and core loss.
10	27.2	0.8	0.6	75			
11		3.2	1.2	38		42.0'–50.5'± HALITE: Clear to moderate brown (5YR 4/4), coarsely crystalline. ≤1% patches of brown clay, increasing to ≤2% beyond 48'±. Core badly disced. [8,10]	
	30						
12	30.4	5.0	2.6	52		50.5'–52.5' ARGILLACEOUS HALITE: Clear to moderate brown, fine to medium crystalline, some coarse. <1 to 3% brown clay.	
	35						
13	35.4	3.4	2.3	68			
14	38.8	3.2	2.0	62			
	40						
15	42.0	3.0	1.5	50			
16	45.0	2.5	1.0	40			
	45						
17	47.5	5.0	3.5	70			
	50						
	52.5						
	55						

BORING NO. DH-323

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-45 INSTRUMENT TYPE & NUMBER Extensometer GE-230 HOLE SIZE NX

LOCATION East 140 Drift, 114' N of N rib of North 140 Drift, midspan

STATION N254,E147 COLLAR ELEV. 1285.5' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N9941.0, E7041.3 BOREHOLE PENETRATION 52.4'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/25/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
8	25	5.0	100	–		21.8' – 26.9' **HALITE:** colorless to moderate reddish-orange (10R 6/6) to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, 1–2% polyhalite, 1–5% brown and gray clay. Clay is largely interstitial from 21.8'–24.0', in discontinuous partings and breaks from 24.0'–26.9', brown clay break at 25.9'.	Run 8 from 24.0'–29.0' is broken and separated along clay seams. Clay may be washed out.
7	20	5.0	100	–		16.6' – 21.8' **HALITE:** colorless to moderate reddish-orange (10R 6/6) halite, coarsely crystalline, ~2% dispersed polyhalite, two undulatory anhydrite stringers (~1/8") at 17.2'.	
6		4.0	78	–		16.0' – 16.6' **ANHYDRITE:** (Anhydrite "a") very light (N8) to medium gray (N5) microcrystalline anhydrite, 10–20% halite from 16.3'–16.6', light gray (N7) clay parting at 16.0'.	
						14.8' – 16.0' **HALITE:** mottled colorless to moderate brown (5YR 3/4) halite, medium crystalline, 5% brown (and gray) clay, polyhalite band at 15.8'–15.9', otherwise polyhalite absent.	
5	15	3.3	66	–		7.9' – 14.8' **HALITE:** clear, colorless to moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, trace (1–2%) polyhalite from 7.9'–10.8' and 12.1'–14.8', undulatory very light gray (N8) anhydrite stringers at 11.1' (~1/16"), 11.35' (~1/16"), and 11.55' (<1/16").	
						7.0' – 7.9' **HALITE:** mottled colorless to medium gray (N5) to moderate reddish-orange (10R 6/6) halite, finely to medium crystalline, 5% gray and brown clay, 7.0'–7.1' is pure, medium to coarsely crystalline halite, brown clay break at 7.2', brown and gray clay break at 7.9', 1% polyhalite.	
4	10	2.0	100	–		6.9' – 7.0' **ANHYDRITE:** (Anhydrite "b") light (N7) to very light gray (N8) microcrystalline anhydrite, dense, ~20% halite.	
3		1.8	95	–		5.0' – 6.9' **HALITE:** mottled colorless to grayish-brown (5YR 3/2) halite, medium to coarsely crystalline, 2–3% interstitial grayish-brown and medium light gray (N6) clay, <1% polyhalite.	
2	5	0.8	40	–		3.8' – 5.0' Core lost.	Runs 1 – 4 were not cored with the inner barrel.
1		1.8	86	–		0.0' – 3.8' **HALITE:** colorless to clear halite, medium to coarsely crystalline, 0–3% moderate reddish-orange (10R 6/6) polyhalite dispersed, trace (1%) brown and gray clay from 3.0'–3.8'.	0' – 0.9' drilled with 6" single-tube core barrel.
	0						Drilling started 09:45 hours, 3 December 1982.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-45 INSTRUMENT TYPE & NUMBER Extensometer GE-230 HOLE SIZE NX

LOCATION East 140 Drift, 114' N of N rib of North 140 Drift, midspan

STATION N254,E147 COLLAR ELEV. 1285.5' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N9941.0, E7041.3 BOREHOLE PENETRATION 52.4'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/25/83

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	ROD	PROFILE	DESCRIPTION	REMARKS
13	50	3.2	100	–		(see description on next sheet)	
12	45	5.0	100	–		44.8' - 49.3' **HALITE:** clear to moderate reddish-orange (10R 6/6) to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, <1-3% polyhalite, concentration (5-10%) of brown clay at 46.25'-46.5', brown clay break at 46.6', discontinuous break at 48.4', trace to absent clay elsewhere.	
						43.4' - 44.8' **ARGILLACEOUS HALITE:** clear to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, 5% brown clay locally concentrated, 1-2% polyhalite, brown clay parting at 43.4', break at 44.7'.	
11	40	4.8	100	–		40.0' - 43.4' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) halite, coarsely crystalline, 5-10% polyhalite, clay is absent to 43.0', trace above, anhydrite stringers decreasing in frequency from 40.0'-41.0'.	
						39.4' - 40.0' **ANHYDRITE:** (Marker Bed 138) very light (N8) to medium gray (N5) microcrystalline anhydrite, 5-10% halite increasing upwards, grades into anhydritic halite above.	
10	35	4.5	83	–		35.6' - 39.4' **ARGILLACEOUS HALITE:** clear to moderate brown (5YR 3/4) halite, coarsely to medium crystalline, fining upwards, 5-10% brown clay locally concentrated, <1% polyhalite, clay is ~1% from 38.7'-39.4' and polyhalite is ~2%, pale brown (5YR 5/2) clay parting at 39.4'.	Run 10 (34.0'-39.4') Bottom (around 34.0'-35.0') is more broken up. Core loss was assumed to be at 34.0'-35.0'.
						32.1' - 35.6' **HALITE:** clear, coarsely crystalline halite, few blebs of polyhalite, clay is absent 32.1'-33.0', ~1% from 33.0'-35.6', increasing upsection.	
9	30	4.4	88	–		30.6' - 32.1' **ARGILLACEOUS HALITE:** clear to moderate brown (5YR 3/4) halite, coarsely crystalline at base, fining upwards to sugary texture, 5-10% clay (mostly brown), brown clay parting at 30.7', break at 32.1', trace polyhalite.	Run 9 (29.0'-34.0') is also very broken and clay may have been lost at breaks.
						26.9' - 30.6' **HALITE:** clear, coarsely crystalline halite, few blebs of polyhalite, discontinuous anhydrite stringers (<1/16") at 27.1' and 28.1'.	
8	25	5.0	100	–		(as below)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-45 INSTRUMENT TYPE & NUMBER Extensometer GE-230 HOLE SIZE NX

LOCATION East 140 Drift, 114' N of N rib of North 140 Drift, midspan

STATION N254,E147 COLLAR ELEV. 1285.5' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N9941.0, E7041.3 BOREHOLE PENETRATION 52.4'

DRILLING METHOD Wet (Brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/25/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55					52.2' - 52.4' **HALITE:** clear, coarsely crystalline halite, 1% polyhalite.	
13	50	3.2	100	—	X — X — — X — — X —	49.3' - 52.2' **ARGILLACEOUS HALITE:** mottled clear to moderate brown (5YR 3/4) to moderate reddish-brown (10R 4/6) halite, finely to coarsely crystalline, 5-10% brown clay, 1-5% polyhalite, pale (10R 5/4) to moderate reddish-brown (10R4/6) clay seam at 52.1', brown clay break at 49.4'.	Total penetration = 52.4'. Hole finished at 15:00 hours, 4 December 1982.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-46 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 114' N of N rib of North 140 Drift, midspan

STATION N254, E147 COLLAR ELEV. ~1276.5' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9941.0, E7041.3 DEPTH OF BOREHOLE 51.5'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY DGK,JPS/Bechtel DATE 1/26/83 SHEET 1 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0	3.2	64	—		0.0' - 7.0' **HALITE:** clear to brownish-gray (5YR 4/1) halite, medium to coarsely crystalline, trace (<1/2%) of moderate reddish-orange (10R 6/6) polyhalite. Clay content up to 3% occurring as diffuse zones or interstitially.	Drilling started 15:20 hours, 4 December 1982. Stopped at 15:40 hours, with 5.0' drilled. Run 1 - core loss seems to have occurred at top of core.
2	5	0.4	40	—			
3		5.0	100	—		7.0' - 8.9' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6) halite, coarsely crystalline, moderately hard. Polyhalite occurs interstitially and as scattered blebs from 0 to 10%. Light gray (N7) clay parting (1/8") at 7.8'.	
	10					8.9' - 13.0' **ANHYDRITE:** (Marker Bed 139) light gray (N7) anhydrite, microcrystalline, hard, zones of moderate reddish-orange (10R 6/6) polyhalite from 8.9'-9.5', hairline anhydrite breaks in clear halite matrix at top. Core broken into 1/2" chips from 11.0'-13.0'. Light gray (N7) clay seam, stiff, at 13.0'.	
4		4.3	86	—		13.0' - 16.4' **HALITE:** clear medium to coarsely crystalline halite, with clay and polyhalite in discrete bands and interstitially. Several brown clay partings (1/16") at 13.4'-13.5', and a brown clay break (1/32") at ~15.2'. Light gray (N7) clay is less abundant and occurs interstitially. Clay content ranges from 0 to 3% and polyhalite content to 2%.	
	15						
5		5.1	100	—		16.4' - 27.9' **POLYHALITIC HALITE:** clear, medium to coarsely crystalline halite, with 5-10% moderate reddish-orange (10R 6/6) polyhalite, brown clay break (1/32") at 20.6', trace interstitial gray clay from 20.6'-21.8' and at 26.7'.	
	20						
6		4.7	94	—			
	25						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-46 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 114' N of N rib of North 140 Drift, midspan

STATION N254, E147 COLLAR ELEV. ~1276.5' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9941.0, E7041.3 DEPTH OF BOREHOLE 51.5'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY DGK, JPS/Bechtel DATE 1/26/83

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	4.7	94	—		(as above)	
7	30	5.2	100	—		27.9' - 32.6' HALITE: clear, mottled light gray (N7), light brown (5YR 6/4) to moderate reddish-orange (10R 6/6) halite, moderately hard, finely to coarsely crystalline. Orange interstitial polyhalite represents about 2% of unit, gray and brown clay about 2-3%. Brown clay breaks at 28.8', 29.2', 30.2', and 30.3'. Gray clay breaks at 27.9', 28.0', 28.3', 28.5', 29.8', and 30.0'.	
8	35	5.0	100	—		32.6' - 38.7' POLYHALITIC HALITE: clear and moderate reddish-orange (10R 6/6) halite, coarsely crystalline, with 2-5% polyhalite. Polyhalite is generally interstitial but also occurs as thin layers (1/16"-1/8"). Anhydrite layer (1/16") at 37.8'.	
9	40	5.1	100	—		38.7' - 38.9' ANHYDRITE: light bluish-gray (5B 7/1), microcrystalline anhydrite, with light gray (N7) clay parting (1/8") at 38.9'.	
10	45	4.7	94	—		38.9' - 51.5' HALITE: argillaceous, clear to mottled medium gray (N5) and pale yellowish-brown (10YR 6/2) halite, finely to coarsely crystalline, moderately hard. Clay content ranges from 0 to ±5%, with <1% interstitial polyhalite, clay breaks at 44.5', 47.5', 48.2', 48.4', 48.7', 48.8', and 50.8'. Clear halite lenses from 43.1'-43.7' and 48.9'-49.5'.	
11	50	5.1	100	—			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-46 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 114' N of N rib of North 0 Drift, midspan

STATION N254, E147 COLLAR ELEV. ~1276.5' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9941.0, E7041.3 DEPTH OF BOREHOLE 51.5'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY DGK, JPS/Rechtel DATE 1/26/83

SHEET 3 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft.)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	5.1	100	—	— X —	(as above)	Hole finished at 13:30 hours, 5 December 1982. Total depth = 51.5'.
	55						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-52 INSTRUMENT TYPE & NUMBER Extensometer GE-226 HOLE SIZE NX

LOCATION 0 East Drift, 146' N of Exploratory Shaft centerline, midspan

STATION N146; W4 COLLAR ELEV. 1280.4' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N9832.5, E6890.5 BOREHOLE PENETRATION 51.6'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/25/83

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	ROD	PROFILE	DESCRIPTION	REMARKS
5	25	5.0	100	–		22.3' – 26.8' **HALITE:** clear to colorless halite, medium to coarsely crystalline, few blebs of polyhalite, trace disseminated clay at 25.9'–26.0', anhydrite stringers (~0.1") at 22.7' and 23.9'.	
4	20	6.0	100	–		16.8' – 22.3' **HALITE:** colorless to moderate reddish-orange (10R 6/6) to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, 5% brown and gray clay (mostly brown) locally concentrated, ~1% polyhalite, brown clay break at 19.2', anhydrite/clay zone at 22.2'–22.3'.	
						12.5' – 16.8' **POLYHALITIC HALITE:** colorless to moderate reddish-orange (10R 6/6) halite, coarsely crystalline, 2–10% polyhalite in bands, anhydrite stringer, somewhat diffuse, at 13.7'.	
3	15	5.0	100	–		12.0' – 12.5' **ANHYDRITE:** (Anhydrite "a") light to very light gray (N7–8), microcrystalline anhydrite, 30–50% halite from 12.4'–12.5'.	
						10.8' – 12.0' **HALITE:** mottled clear to moderate reddish-orange (10R 6/6) to moderate brown (5YR 3/4) halite, medium crystalline, 5% brown clay, 0–3% polyhalite increasing upward, light gray (N7) clay parting at 12.0'.	
2	10	4.9	98	–		5.3' – 10.8' **HALITE:** clear to moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, 0–2% polyhalite, anhydrite stringers (<1/16") at 5.6', 5.9', 6.7', 6.9', and 7.4'.	
						5.3' – 5.3' **ANHYDRITE:** (Anhydrite "b") light gray (N7), microcrystalline anhydrite, undulatory bedding, 20–30% halite.	Most core shows circumferential scoring.
1	5	5.0	100	–		0.0' – 5.3' **HALITE:** colorless to clear halite, medium to coarsely crystalline, 1–3% polyhalite, 0–5% brown clay increasing upward, light gray (N7) clay parting at 5.3'.	Drilling water was recycled through the drill in such a manner that previous cuttings are pushed back into the hole.
	0						Hole was cored from 2 – 4 November 1982.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-52 INSTRUMENT TYPE & NUMBER Extensometer GE-226 HOLE SIZE NX

LOCATION 0 East Drift, 146' N of Exploratory Shaft centerline, midspan

STATION N146, W4 COLLAR ELEV. 1280.4' DIRECTION OF DRILLING Up Vertical

MINE COORDINATES N9832.5, E6890.5 BOREHOLE PENETRATION 51.6'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12 B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/25/83

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	5.0	100	–		46.6' – 51.1' **ARGILLACEOUS HALITE:** colorless to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, 1-2% polyhalite, 1-10% brown clay locally concentrated, brown clay partings at 47.2', 48.3', 48.7', 50.5' and 51.0', coarsely crystalline halite with <1% clay and polyhalite from 49.0'-49.3'.	
10	45	5.1	100	–		44.5' – 46.6' **HALITE:** colorless to moderate reddish-orange (10R 6/6) halite, coarsely crystalline, 1-3% polyhalite, few blebs of gray and brown clay.	
						41.5' – 44.5' **ARGILLACEOUS HALITE:** mottled colorless to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, ~1% polyhalite, 2-10% brown clay locally concentrated, 41.5'-41.9' is purer halite, with only trace brown and gray clay, brown clay partings at 43.0', 43.5', and 44.5', brown clay seam at 43.2'.	
9	40	5.0	100	–		36.9' – 41.5' **POLYHALITIC HALITE:** colorless to moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, 1-10% polyhalite locally concentrated, polyhalite stringer zone from 38.15'-38.35', anhydrite stringers at 36.95', 37.2', 37.6', and 38.8'.	
						36.5' – 36.9' **ANHYDRITE:** (Marker Bed 138) light gray (N7), microcrystalline anhydrite, undulatory, halitic upper contact.	
8	35	3.9	78	–		31.0' – 36.5' **ARGILLACEOUS HALITE:** mottled colorless to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, <1% polyhalite, 2-10% brown clay locally concentrated, brown clay partings at 33.8', 34.1', 34.5', and 36.3', brown clay break at 35.4', gray clay seam at 36.5'.	
7		0.2	40	–			Drill rods stuck at ~30' after being left in the hole overnight.
6	30	5.0	100	–		28.5' – 31.0' **HALITE:** colorless halite, coarsely crystalline, few blebs of polyhalite, clay is absent to 30.0', increasing to 2% interstitial brown blebs at 31.0'.	
						26.8' – 28.5' **ARGILLACEOUS HALITE:** colorless to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, <1% polyhalite in 1/8"-1/2" blebs, 5-10% brown clay, brown clay breaks at 27.1', 27.7', 27.8', and 28.4'.	
5	25	5.0	100	–		(as below)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-52 INSTRUMENT TYPE & NUMBER Extensometer GE-226 HOLE SIZE NX

LOCATION 0 East Drift, 146' N of Exploratory Shaft centerline, midspan

STATION N146, W4 COLLAR ELEV. 1280.4' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N9832.5, E6890.5 BOREHOLE PENETRATION 51.6'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RLB/TSC//DGK/Bechtel DATE 1/25/83

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55					51.1' - 51.6' HALITE: colorless to moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, 1-2% polyhalite, <1% gray and brown clay, anhydrite stringer (0.1") at 51.25'.	Total penetration = 51.6'.
11	50	5.0	100	–		(as below)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-53 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 146' N of Exploratory Shaft centerline, midspan

STATION N146, W4 COLLAR ELEV. 1266.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9832.5, E6890.5 DEPTH OF BOREHOLE 49.2'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Longyear 38

PREPARED BY DGK,JPS/Bechtel DATE 1/26/83

RUN NUMBER	DEPTH (ft)	RECOVERED (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	0						
1		3.1	78	–		0.0' – 4.9' **ARGILLACEOUS HALITE:** clear, coarsely crystalline halite, with some moderate reddish-orange (10R 6/6) to moderate reddish-brown (10R 4/6) polyhalite, and some light gray (N7) clay that occurs in small patches, especially around 3.2'.	0' – 1.0' was drilled with 6" single-tube core barrel.
2	5	1.0	50	–		4.9' – 6.5' **POLYHALITIC HALITE:** clear, coarsely crystalline halite, with abundant polyhalite.	RUN 1 core broken. Impossible to determine location of core loss.
3		5.0	100	–		6.5' – 8.6' **ANHYDRITE:** (Marker Bed 139) very light gray (N8), microcrystalline anhydrite, with clear, fine-grained halite. Anhydrite becomes purer with depth. Light gray (N7) clay parting (1/8"–1/4") at base of anhydrite.	
	10					8.6' – 12.4' **HALITE:** clear, white, and mottled pale red (10R 6/2) coarsely crystalline halite, with approximately 1% moderate reddish-orange (10R 6/6) polyhalite, and trace (<5%) moderate brown (5YR 4/4) interstitial clay.	Drilling was very slow due to problems with the Longyear drill. The first 7 core runs were relatively easy (relative to the last 4 runs). All later cores were completed with great difficulty. The vertical control for the drill was broken so there was no mechanical means of pulling the core barrel. The drilling brine is not filtered.
4	15	5.0	100	–			
5	20	4.9	100	–		12.4' – 25.2' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, moderately hard. Polyhalite represents 3–5% of core and occurs as scattered blebs or interstitially. Gray clay parting (1/8"–1/4") at 17.1'. Light gray (N7) clay seams at 24.8'–25.2'.	
6	25	5.0	100	–			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-53 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 146'N of Exploratory Shaft centerline, midspan

STATION N146, W4 COLLAR ELEV. 1266.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9832.5, E6890.5 DEPTH OF BOREHOLE 49.2'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Longyear 38

PREPARED BY DGK,JPS/Bechtel DATE 1/26/83

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft.)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.0	100	-	X—X —X—	(as above)	
7		4.8	98	-	X—X —X— X—X —X— X—X	25.2' - 29.5' HALITE: clear, coarsely crystalline halite, with some (10-15%) interstitial moderate brown (5YR 4/4) clay, a light gray (N7) clay seam at 26.2', and some (10-15%) polyhalite. Laminations at 26.2' dip about 10°.	RUN 7 core lost from 26.8' - 26.9'.
8	30	5.0	100	-	X X X X X X X X X X X X	29.5' - 35.5' POLYHALITIC HALITE: clear, coarsely crystalline halite, with 5-10% moderate reddish-orange (10R 6/6) polyhalite. Polyhalite occurs as discontinuous breaks, blebs or interstitially. Clear halite from 35.0'-35.5'.	
	35					35.5' - 35.7' ANHYDRITE: very light gray (N8), microcrystalline anhydrite, with gray clay parting (1/8") at base.	
9	40	5.0	100	-	X X X X X X X X X X X X	35.7' - 49.2' ARGILLACEOUS HALITE: clear halite, finely to medium crystalline, moderately hard, with interbedded brown clay (5%) and polyhalite (1-5%). Color ranges from medium gray (N5) to light brown (5YR 6/4). Polyhalite occurs as interstitial layers.	
10	45	4.5	100	-	X X X X X X X X X X X X		
11		2.9	100	-	X X X X		Total depth = 49.2'.
	50						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-56 INSTRUMENT TYPE & NUMBER Extensometer Ge-234 HOLE SIZE NX

LOCATION 0 East Drift, 621.3' N of Exploratory Shaft Centerline, 12.5' from E rib

STATION N621, E0 COLLAR ELEV. 1296.8 DIRECTION OF DRILLING Vertical up

MINE COORDINATES N10311.8 E6892.3 BOREHOLE PENETRATION 52.1'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/4/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.1	100	–		20.2'-25.1' **ARGILLACEOUS HALITE:** clear to mottled pale brown (5YR 5/2) and brownish-gray (5YR 4/1), medium to coarsely crystalline and moderately hard. Clay occurs interstitially with some clay breaks and partings and represents from 0-10% of core. From 23.3'-24.1', zone of moderate reddish-orange (10R 6/6) interstitial polyhalite. Clay breaks at: 20.3', 20.5', 21.3', 22.0', and 24.5'. At 24.9', 1/4" thick brownish-gray (5YR 4/1) clay partings.	
5	20	5.0	100	–		15.3'-20.2' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6), finely to coarsely crystalline, moderately hard. Finely crystalline from 19.5'-20.0'. Polyhalite occurs as isolated blebs or interstitially and comprises 5-10% of core.	
						14.7'-15.3' **ANHYDRITE:** banded, very light gray (N8) and medium dark gray (N4), microcrystalline, hard, dense. Core broken into 1/2" chips.	
4	15	5.0	100	–		13.5'-14.7' **HALITE:** argillaceous and polyhalite in part. Mottled pale brown (5YR 4/2) and moderate reddish-brown (10R 4/6) and brownish-gray (5YR 4/1). Finely crystalline, moderately hard. Clay and polyhalite comprised 5-10% of core.	Core Loss: Run / Where Lost 2 / 2.0'-6.0' 3 / 11.6'-11.7' 11 / 47.1'-47.2'
3	10	4.9	98	–		8.0'-13.5' **HALITE:** clear, medium to coarse crystalline, moderately hard, few scattered, light gray (N8) anhydrite stringers throughout.	
						7.8'-8.0' **ANHYDRITE:** medium gray (N5), hard, dense, microcrystalline.	
						5.8'-7.8' **ARGILLACEOUS HALITE:** clear and brownish-gray (5YR 4/1), medium to coarsely crystalline, moderately hard. Argillaceous content up to 10%.	
2	5	2.7	47	–		0.0'-5.8' **HALITE:** polyhalitic, clear and moderate reddish-orange (10R 6/6), coarsely crystalline, moderately hard. Polyhalite occurs as isolated blebs and comprises up to 3% core.	Hole begun at 13:00 hours on 2 February 1983. Cored from 0 to 1.0' using 6" diameter single tube barrel. Cored from 1.0'-52.1' using NX core barrel with brine.
1		1.0	100	–			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-56 INSTRUMENT TYPE & NUMBER Extensometer GE-234 HOLE SIZE NX

LOCATION 0 East Drift, 621.3' N of Exploratory Shaft Centerline, 12.5' from E rib

STATION N621, E0 COLLAR ELEV. 1296.8 DIRECTION OF DRILLING Vertical up

MINE COORDINATES N10311.8 E6892.3 BOREHOLE PENETRATION 52.1'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/4/83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	5.1	100	–		47.0'-49.5' **ARGILLACEOUS HALITE:** clear and moderate brown (5YR 3/4), finely to coarsely crystalline, moderately hard. Clay content ranges from 0 to 15%. Clay breaks at: 47.9', 48.5', 48.7', and 49.0'.	
10	45	5.0	100	–	X X	38.0'-47.0' **HALITE:** clear with trace of moderate reddish-orange (10R 6/6) polyhalite blebs throughout. Finely to coarsely crystalline, moderately hard. Polyhalite occurs interstitially or as scattered blebs and comprises up to 5% of core. Anhydrite stringer, 1/2"-3/4" thick at 39.0'. Finely crystalline, sugary texture from 44.3'-45.0', and argillaceous (2-5%). Brown clay breaks at: 44.6', and 44.9'.	
9	40	5.0	100	–	X	37.5'-38.0' **ANHYDRITE:** light gray (N7) to medium dark gray (N4), dense, hard, microcrystalline.	
						37.5' **CLAY:** pale brown (5YR 5/2), moderately plastic, moderately soft, moist, 1/2" thick seam.	
8	35	5.1	100	–		32.5'-37.5' **ARGILLACEOUS HALITE:** clear to grayish-brown (5YR 3/2), finely to coarsely crystalline, moderately hard. Clay content ranges from 2-10% with clay breaks at: 33.0', 33.5', 33.7', 33.9', 34.2', 34.4', 35.0', 35.6', 36.0', 36.6', and 37.1'. Finely crystalline from 35.2'-37.5'.	
7	30	5.2	100	–		25.1'-32.5' **HALITE:** clear and slightly argillaceous in part. Finely to coarsely crystalline, moderately hard. From 29.0'-31.0' clay content ranges from 0 to 2% with brown clay breaks at: 29.1', 29.9', 30.0', 30.7', and 30.8'.	
6	25	4.9	98	–			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-56 INSTRUMENT TYPE & NUMBER Extensometer GE-234 HOLE SIZE NX

LOCATION 0 East Drift, 621.3' N of Exploratory Shaft Centerline, 12.5' from E rib

STATION N621, E0 COLLAR ELEV. 1296.8 DIRECTION OF DRILLING Vertical up

MINE COORDINATES N10311[illegible]6892.3 BOREHOLE PENETRATION 52.1'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/4/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55						
	50				X X X	49.5'-52.1' **HALITE**: polyhalite, clear and mottled reddish-orange (10R 6/6) and grayish-red (5R 4/2). Finely to medium crystalline, moderately hard. Polyhalite occurs interstitially and as blebs and comprises 0-10% of core. Sugary texture from 50.5'-51.2'.	Hole completed at 22:00 hours on 2 February 1983. Total Penetration = 52.1'

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-57 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 621.3' N of Exploratory Shaft centerline, 12.5' from E rib

STATION N621, E0 COLLAR ELEV. 1288.1 DIRECTION OF DRILLING vertical down

MINE COORDINATES N10311.8 E6892.4 DEPTH OF BOREHOLE 52.1'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12R

PREPARED BY JPS/Bechtel DATE 2/4/83 SHEET 1 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	5	1.2	17	-		0.0'-7.9' HALITE: clear to pale brown (5YR 5/2). Coarsely crystalline, moderately hard, trace of gray and brown clay throughout.	Hole begun at 09:30 hours on 3 February 1983. Hole cored from 0' to 7' using NX size drill rods without inner barrel.
2	10	4.7	94	-	X X X X	7.9'-10.1' POLYHALITIC HALITE: clear and moderate reddish-orange (10R 6/6), moderately hard, coarsely crystalline.	
						10.1'-12.2' ANHYDRITE: banded light gray (N7) to olive gray (5YR 4/1), hard, dense, microcrystalline.	
						12.2'-12.3' CLAY: medium gray (N5) moist, moderately soft, highly plastic.	
3	15	5.1	100	-	— X — X	12.3'-15.5' HALITE: clear and mottled pale brown (5YR 5/2) and pale reddish-brown (10R 5/4), finely crystalline, moderately hard. Trace of clay and polyhalite throughout, up to 5%, locally. Brown clay break at 13.8'.	Core Loss: Run — Where Lost 1 — Throughout Run 2 — 7.0'-7.3' 7 — 33.6-33.7' 9 — 43.0'-43.1'
4	20	5.3	100	-	X X X X	15.5'-20.2' POLYHALITIC HALITE: clear and moderate reddish-orange (10R 6/6), coarsely crystalline, moderately hard.	
						20.2' CLAY: medium gray (N5), moist, highly plastic, moderately soft, 1/2"-3/4" thick, sub-horizontal.	
					— — —	20.2'-22.1' HALITE: argillaceous, coarsely crystalline, moderately hard. Clay content is 3-5% and occurs interstitially. Clay breaks at: 21.0' and 21.4'. Halite is clear and pale brown (5YR 5/2).	
5	25	5.1	100	-	X X X	22.1'-28.0' POLYHALITIC HALITE: clear and moderate reddish-orange (10R 6/6), medium to coarsely crystalline, moderately hard. Polyhalite comprises up to 10% of core and occurs as scattered blebs or interstitially. Few isolated seams of polyhalite throughout.	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-57 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 621.3' N of Exploratory Shaft centerline, 12.5' from E rib

STATION N621, E0 COLLAR ELEV. 1288.1 DIRECTION OF DRILLING vertical down

MINE COORDINATES N10311.8 E6892.4 DEPTH OF BOREHOLE 52.1'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/4/83

RUN NUMBER	DEPTH ( )	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
5	25	5.1	100	–		(as above)	
6	30	5.3	100	–		28.0'-32.8' **ARGILLACEOUS HALITE:** clear and mottled pale reddish-brown (10R 5/4) and medium light gray (N6), finely to coarsely crystalline, moderately hard. Clay content up to 10% with trace amounts of orange polyhalite throughout. Clay breaks at: 28.0', 28.4', 28.7', 29.2', 29.4', 29.7', 31.5', 32.0', and 32.4'.	
7	35	4.9	98	–		32.8'-37.8' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6), finely to coarsely crystalline, moderately hard. Polyhalite comprises up to 15% of core and occurs as isolated blebs or interstitial layers. Polyhalite seam from 36.7'-36.9'.	
8	40	5.2	100	–		37.8'-38.1' **ANHYDRITE:** light gray (N7), hard, dense, microcrystalline. 38.1'-51.3' **ARGILLACEOUS HALITE:** clear and mottled medium gray (N5), pale brown (5YR 5/2) and grayish-orange (10YR 7/4). Finely to coarsely crystalline, moderately hard, clay content varies from < 1% up to 10%. Clay breaks at: 38.5', 47.2', 47.3', 47.7', 48.2', 48.6', 50.0', and 50.6'. Few seams of interstitial, orange polyhalite. Clear halite from 42.6'-45.0'.	
9	45	4.9	98	–			
10	50	4.1	100	–			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-57 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 621.3' N of Exploratory Shaft centerline, 12.5' from E rib

STATION N621, E0 COLLAR ELEV. 1288.1 DIRECTION OF DRILLING vertical down

MINE COORDINATES N10311.8 E6892.4 DEPTH OF BOREHOLE 52.1'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/4/83 SHEET 3 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	50					(as above)	Hole completed at 14:30 hours on 3 February 1983.
10		4.1	100	-		51.3'-52.1' **HALITE:** clear, coarsely crystalline, moderately hard.	Total Depth = 52.1'
	52.1						

WIPP-SPDV
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-63 INSTRUMENT TYPE & NUMBER Extensometer GE-243 HOLE SIZE NX

LOCATION 0 East Drift, 1110' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1110, E0 COLLAR ELEV. 1310.6' DIRECTION OF DRILLING vertical up

MINE COORDINATES N10796.0, E6891.9 BOREHOLE PENETRATION 52.8'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/12/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
7	25	5.0	100	–		(see description on next sheet)	
6	20	5.0	100	–		17.9'-23.4' **HALITE:** argillaceous, moderately hard, finely to coarsely crystalline, clear to mottled grayish-brown (5YR 3/2) and pale yellowish-brown (10YR 6/2). Clay content up to 20% in part. Clay breaks at: 18.5', 19.2', 19.9', 20.2', 22.7', and 23.0'.	
5	15	5.2	100	–	X X X X X X	13.6'-17.9' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6), moderately hard, coarsely crystalline. Polyhalite content ranges from 5% with few polyhalite stringers and isolated blebs. 13.6'-14.8' **ANHYDRITE:** very light gray (N8) to pinkish-gray (5YR 8/1) hard, dense microcrystalline with some interstitial clear halite. 12.0'-13.6' **HALITE:** argillaceous, clear to mottled brownish-gray (5YR 4/1) to light gray (N7). Finely to coarsely crystalline, moderately hard. Clay content up to 15% and gray clay breaks at 13.0' and 13.1'. Trace of orange polyhalite from 13.3'-13.6'. Gray clay parting, moderately plastic at 13.6'.	
4		2.6	100	14			
3	10	4.6	92	–		6.7'-12.0' **HALITE:** clear, moderately hard, medium to coarsely crystalline, few white (N9) anhydrite stringers. 6.5'-6.7' **ANHYDRITE:** very light gray (N8), hard, dense, microcrystalline. Core broken into 1/4" chips.	Core Loss: Run 2: Where Lost 3.0'-3.2', 4.2'-4.5', 5.1'-5.5' Run 3: Where Lost 6.9'-7.0', 7.5'-7.7', 8.0'-8.1'
2	5	1.9	68	–	X X	3.8'-6.5' **HALITE:** argillaceous, medium light gray (N6) to light brownish-gray (5YR 6/1), moderately hard, finely to medium crystalline. Clay content ranges from 2-8%, with clay breaks at 4.4', 5.2', and 6.1'. Trace of intercitial polyhalite at 6.0'. Gray clay parting at 6.5'.	
1		2.0	100	–		0.0'-3.8' **HALITE:** polyhalitic in part, clear and moderate reddish-orange (10R 6/6) interstitial polyhalite. Moderately hard and medium to coarsely crystalline.	Began coring at 08:30 hours on 10 February 1983. Cored to 5.8' without inner barrel.
0	0	85	83	–	X X		

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. D0-63 INSTRUMENT TYPE & NUMBER Extensometer GE-243 HOLE SIZE NX

LOCATION 0 East Drift, 1110' N of Exploratory Shaft centerline, 124' from E rib

STATION N1110, E0 COLLAR ELEV. 1310.6' DIRECTION OF DRILLING vertical UP

MINE COORDINATES N10796.0, E6891.9 BOREHOLE PENETRATION 52.8'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/12/83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
12	50	4.0	100	60		40.6'-50.3' **ARGILLACEOUS HALITE:** clear to mottled medium gray (N5), moderate brown (5YR 3/4) to pale yellowish-brown (10YR 6/2), moderately hard, finely to coarsely crystalline. Finely crystalline from 41.6'-42.5' and from 47.0'-48.3'. Clear halite from 44.0'-45.3'. Clay content ranges from 0-20% with numerous clay breaks throughout. Clay breaks at: 41.4', 42.4', 43.3', 43.8', 46.5', 46.6', 47.0', and 49.5'. Brown clay parting, moist, highly plastic at 50.3'.	
11	45	5.1	100	-			
10	40	5.0	100	-	X	36.8'-40.6' **HALITE:** clear, moderately hard, medium to coarsely crystalline, few stringers of white anhydrite throughout. Slightly polyhalitic in part from 38.5'-40.0'.	
					X	36.1'-36.8' **ANHYDRITE:** light gray (N7) to medium dark gray (N4), hard, dense, microcrystalline, slightly banded in part. Trace of polyhalite at 36.5'.	
9	35	5.1	100	-	X	36.0'-36.1' **CLAY:** pale brown (5YR 5/2), moderately soft, moist, highly plastic near horizontal.	
					X	31.1'-36.0' **ARGILLACEOUS HALITE:** clear to grayish-brown (5YR 3/2), and moderate brown (5 YR 3/4), moderately hard, finely to coarsely crystalline; clay content ranges from 0 to 10%. Numerous clay breaks and partings and trace of polyhalitic halite at 35.5'. Clay breaks at: 32.0', 33.1', 33.3', 33.8', 34.2', and 35.0'. Brown clay parting at 34.4'.	
8	30	5.0	100	-			
					X	23.4'-31.1' **HALITE:** clear, coarsely crystalline, moderately hard, trace of white anhydrite in hairline stringers. From 27.3'-29.3' slightly argillaceous in part, finely crystalline and grayish-brown (5YR 3/2). Brown clay breaks at: 27.4', 27.6', and 29.1'. Trace of orange polyhalite from 28.6'-29.0'	
7	25	5.0	100	-			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-63 INSTRUMENT TYPE & NUMBER Extensometer GE-243 HOLE SIZE NX

LOCATION 0 East Drift, 1110' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1110, E0 COLLAR ELEV. 1310.6' DIRECTION OF DRILLING vertical up

MINE COORDINATES N10796.0, E6891.9 BOREHOLE PENETRATION 52.8'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/12/83

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	ROD	PROFILE	DESCRIPTION	REMARKS
	55						Hole completed at at 14:45 hours on 10 February 1983.
12	50	4.0	100	–	X X X	50.3'-52.8' HALITE: polyhalitic, clear and moderate reddish-orange (10R 6/6), coarsely crystalline, moderately hard. Polyhalite, which comprises about 0-10% of core, occurs interstitially and as isolated blebs.	Total Penetration = 52.8'

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-64 INSTRUMENT TYPE & NUMBER Extensometer GE-221 HOLE SIZE NX

LOCATION 0 East Drift, 1110' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1110, E0 COLLAR ELEV. 1301.5' DIRECTION OF DRILLING vertical down

MINE COORDINATES N10796.0, E6891.6 DEPTH OF BOREHOLE 52.8'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/12/83 SHEET 1 OF 3

RUN NUMBER	DEPTH ( )	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
0		1.0	100	-			Hole began at 15:00 hours on 10 February 1983. Hole cored from 0' to 1' using a 6" core barrel. From 1' to 7' hole cored without inner core barrel.
1	5	6.0	100	-		0.0'-8.0' **HALITE:** argillaceous and polyhalitic in part; clear to medium gray (N5) and moderate reddish orange (10R 6/6); moderately hard, finely to coarsely crystalline with few clay breaks. Clay and polyhalite up to 5% locally. Clay breaks at 1.5', 2.2', 2.5', 3.3', 3.7', 6.3', and 7.5'.	
2	10	4.9	98	-		8.0'-10.6' **POLYHALITIC HALITE:** clear and moderate reddish orange (10R 6/6). Polyhalite occurs as dense isolated stringers and blebs and comprises 15% of core. From 10.0'-10.6' polyhalite is finely crystalline, hard and comprises up to 100% of core.	Core Loss:
						10.6'-12.8' **ANHYDRITE:** light gray (N7) to light olive-gray (5Y 6/1), moderately hard, microcrystalline, highly fractured. Core broken into 1/4'-1/2' chips.	Run 2 Where Lost 9.3'-9.4'
3	15	5.1	100	-		12.8'-15.0' **ARGILLACEOUS HALITE:** light gray (N7) to medium dark gray (N4), finely crystalline, moderately hard with clay content up to 20%. Gray clay breaks at 13.2', 13.3', and 13.7'. Numerous interstitial clay layers from 14.0'-15.0'. Gray clay parting at 12.8'.	Run 8 Where Lost 40.8'-41.0'
4	20	5.0	100	-		15.0'-35.6' **POLYHALITIC HALITE:** clear and moderate reddish orange (10R 6/6), moderately hard, medium to coarsely crystalline. Polyhalite ranges from 0-15% with polyhalite blebs and interstitial zones. Slightly gray and argillaceous from 20.9'-21.9' and from 27.9'-28.2'. Clay breaks at: 20.9', 21.3', and 28.0'. Clear halite from 29.2'-29.9' and from 31.5'-32.4'.	
5	25	5.2	100	-			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-64 INSTRUMENT TYPE & NUMBER Extensometer GE-221 HOLE SIZE NX

LOCATION 0 East Drift, 1110' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1110, E0 COLLAR ELEV. 1301.5' DIRECTION OF DRILLING vertical down

MINE COORDINATES N10796.0, E6891.6 DEPTH OF BOREHOLE 52.8'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/12/83 SHEET 2 OF 3

RUN NUMBER	DEPTH ( )	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
5	25	5.2	100	–		(as above)	
6	30	5.1	100	–			
7	35	5.2	100	–		35.6'-36.2' **ANHYDRITE:** olive gray (5Y 4/1) highly fractured and broken, dense, microcrystalline. Core broken into 1/2" pieces. Gray clay seam 1/2" thick at 36.2'.	
8	40	4.8	96	–		36.2'-43.3' **HALITE:** argillaceous in part, clear and mottled medium gray (N5) to pale yellowish brown (10YR 6/2). Interstitial clay content up to 10% locally. Clay breaks at: 39.9' and 40.0'. Few zones of orange interstitial polyhalitic halite at: 37.5', 39.0', 40.1' and 42.7'.	
9	45	5.2	100	–		43.3'-50.0' **ARGILLACEOUS HALITE:** clear and mottled greyish brown (5YR 3/2) and medium gray (N5) moderately hard, finely to coarsely crystalline. Clay content ranges from <1% to 25%. Clay breaks at: 44.0', 44.7', 45.9', 46.5', 47.0', 47.3', 48.1', 48.6', and 49.4'. Few polyhalite stringers at 44.5' and 45.6'.	
10	50	5.2	100	–			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-64 INSTRUMENT TYPE & NUMBER Extensometer GE-221 HOLE SIZE NX

LOCATION 0 East Drift, 1110' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1110, E0 COLLAR ELEV. 1301.5' DIRECTION OF DRILLING vertical down

MINE COORDINATES N10796.0, E6891.6 DEPTH OF BOREHOLE 52.8'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/12/83 SHEET 3 OF 3

RUN NUMBER	DEPTH ( )	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
10	50	5.0	100	–	X	50.0'-52.8' HALITE: clear, coarsely crystalline, moderately hard. Core broken into 1/4" pieces from 51.5'-52.0', slightly polyhalitic from 52.5'-52.8'.	Hole completed at 19:00 hours on 10 February 1983 Total Depth = 52.8'
	55						

WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-67 INSTRUMENT TYPE & NUMBER Extensometer GE-220 HOLE SIZE NX

LOCATION Test Room 1, Centerline of Room at Station N1265, in Floor 16.5' From E and W Ribs.

STATION N1265, W231.5 COLLAR ELEV. 1296.8 DIRECTION OF DRILLING Down Vertical

MINE COORDINATES N10952.1, E6662.9 DEPTH OF BOREHOLE 51.7'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 5/5/83 SHEET 1 OF 3

RUN NUMBER	DEPTH (Ft)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
0	0	1.0	1.0	-		0.0' - 3.7' **POLYHALITIC HALITE:** Clear mottled with moderate reddish-orange (10R 6/6), coarsely crystalline, medium hard. Blebs of polyhalite <1 to 3%. Trace (<1%) gray clay.	Started Drilling at 09:45 hours on 18 April 1983. 5 1/2" single-tube barrel used to core 0.0 to 1.0'. NX single tube barrel used 1.0' to 4.8'. NX double tube barrel used 4.8' to 51.7'.
1		3.3	87	-		3.7' - 6.8' **ANHYDRITE:** (Marker Bed 139) Very light gray (N8) anhydrite mixed with moderate reddish- orange (10R 6/6), and reddish-brown (10R 4/6) polyhalite and polyhalitic halite from 3.7' to 6.0', core hard. From 5.0 to 6.0', core is predominantly moderate reddish-brown (10R 4/6) polyhalite. Core broken to "disc-like" pieces as thin as 0.01'. Core medium hard. From 6.0' to 6.8', core is all anhydrite, microcrystalline; hard gray clay at 6.7' to 6.8'.	
2	5	1.8	85	-			
3	10	4.8	100	-		6.8' - 9.8' **HALITE:** Clear to moderate reddish-orange (10R 6/6) and grayish-brown (5YR 4/1) medium to coarsely crystalline, medium hard. <1 to 3% polyhalite. <1 to 3% gray clay to 8.6', turning to brown clay. Clay parting at 9.1'. Numerous breaks throughout core.	Moderate gas flow at 6' to 7'. Flow for 3 to 4 minutes, then slowed down appreciably. Methane 3 to 4 1/2% at collar.
4	15	5.1	100	-		9.8' - 14.7' **POLYHALITIC HALITE:** Clear to moderate reddish-orange (10R 6/6), coarsely crystalline, hard polyhalite generally <1 to 3% with local zones >3%. From 14.3' to 14.7' polyhalite 20 to 60%.	
						14.7' - 16.6' **HALITE:** Clear to brownish-gray (5YR 4/1) with some moderate reddish-brown (10R 4/6), medium to coarsely crystalline, medium hard, trace (< 1%) of gray and brown clay. Trace (<1%) polyhalite. Clay breaks at 14.7' and 16.0'.	
5	20	4.8	100	-		16.6' - 20.5' **POLYHALITIC HALITE:** Clear to moderate reddish-orange (10R 6/6), coarsely crystalline, hard. <1 to 3% polyhalite. <1% gray clay.	
6	25	5.1	100	-		20.5' - 26.5' **HALITE:** Clear to moderate reddish-orange (10R 6/6) and moderate reddish-brown (10R 4/6), medium to coarsely crystalline, medium hard. <1 to 2% polyhalite and 1 to 2% clay. Clay breaks at 20.5', 23.4', [illegible]' and 25.2'.	

WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO DO-67 INSTRUMENT TYPE & NUMBER Extensometer GE-220 HOLE SIZE NX

LOCATION Test Room 1, Centerline of Room at Station N1265, in Floor 16.5' From E and W Ribs.

STATION N1265, W231.5 COLLAR ELEV. 1296.8 DIRECTION OF DRILLING Down Vertica

MINE COORDINATES N10952.1, E6662.9 DEPTH OF BOREHOLE 51.7'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 5/5/83 SHEET 2 OF 3

RUN NUMBER	DEPTH (Ft)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.1	100	-		As Above	
7	30	4.8	100	-		26.5' - 31.6' **HALITE**: Clear to moderate reddish-orange (10R 6/6), coarsely crystalline, hard blebs and patches of polyhalite <1 to 3%. Polyhalitic from 29.4' to 30.5'. Anhydrite stringers from 30.5' to 30.9'	
						31.6' - 31.9' **ANHYDRITE**: Very light (N8) to medium dark gray (N4), laminated, micro-crystalline, hard. Trace of clay at 31.9'. Some core grinding evident.	
8	35	4.95	99	-		31.9' - 38.7' **HALITE**: Clear to grayish brown (5Y 3/2) and moderate reddish-orange, fine to coarsely crystalline, medium hard. Contains <1 to 3% clay and <1% polyhalite. Argillaceous halite from 32.7' to 33.7'.	
9	40	5.0	100	-		38.7' - 41.5' **ARGILLACEOUS HALITE**: Clear to brownish gray (5YR 4/1), coarsely crystalline, medium hard. Gray and brown clay <1 to 5%. Breaks at 39.0', 40.3', 40.5' and 41.0'.	
10	45	5.2	100	-		41.5' - 51.7' **HALITE**: Clear to brownish-gray (5YR 4/1) to moderate reddish-orange, medium to coarsely crystalline, medium hard, <1% polyhalite. Clay, generally <1%. Zones from 42.4' to 43.3', 47.3' - 47.6' and 49.1' - 49.3' containing clay breaks and up to 5% clay. Core broken up at 46.8' to 47.1' due to extraction from core barrel. Core clear from 44.9' to 47.2'.	
11	50	4.8	96	-			

WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO DO-67 INSTRUMENT TYPE & NUMBER Extensometer GE-220 HOLE SIZE NX

LOCATION Test Room 1, Centerline of Room at Station N1265, in Floor 16.5' From E and W Ribs.

STATION N1265, W231.5 COLLAR ELEV. 1296.8 DIRECTION OF DRILLING Down Vertical

MINE COORDINATES N10952.1, E6662.9 DEPTH OF BOREHOLE 51.7'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 5/5/83

RUN NUMBER	DEPTH (FT)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	4.8	96	–	—	As Above	Completed drilling at 15:25 hours on 18 April 1983.
							Total penetration = 51.7 feet.
	55						

WIPP
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-69 INSTRUMENT TYPE & NUMBER Extensometer GE-218 HOLE SIZE NX

LOCATION Test Room 1, Centerline of Room at Station N1265, in Roof 16.5 Feet From E and W Ribs.

STATION N1265, W231.5 COLLAR ELEV. 1310.1 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10951.9, E6662.5 BOREHOLE PENETRATION 51.4'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 5/6/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.1	100	–	X X	19.6' – 27.0' **HALITE:** Clear to brownish gray (5YR 4/1), medium to coarsely crystalline, medium hard to hard. Trace of polyhalite 20.6' to 20.8' and 22.4' to 23.0'. Trace (1-2%) gray clay at 19.6' to 22.4'. Brown clay (<3%) mixed with halite at 23.8' to 24.0'. Core broken up.	
5	20	4.9	100	–	X X	16.4' – 19.6' **POLYHALITIC HALITE:** Clear mottled with moderate reddish orange (10R 6/6) and moderate reddish brown (10R 4/6) polyhalite, coarsely crystalline, medium hard to hard polyhalite <1 to 5%. Trace (<1%) clay.	
4	15	5.1	100	–	X	14.9' – 16.4' **HALITE:** Clear mottled with moderate reddish orange (10R 6/6) polyhalite, coarsely crystalline, medium hard. Polyhalite <1%.	Light to moderate gas flow at 14'±. 1 to 3% methane at return line. Flow for approximately 10 minutes. Smell of "rotten egg" noted.
						14.0' – 14.9' **ANHYDRITE:** (Anhydrite "a") white, very light (N8) to medium gray (N5), microcrystalline, hard. Trace of halite. Trace of clay at 14.0'.	
3	10	4.9	100	–	X	7.27' – 14.0' **HALITE:** Clear, medium to coarsely crystalline, hard. Contains minute traces (<1%) of polyhalite, scattered irregular anhydrite stringers. Gray clay break at 13.25'.	
					X	7.0' – 7.27' **ANHYDRITE:** (Anhydrite "b") Light gray (N7), microcrystalline, hard anhydrite mixed with some halite. Trace of gray clay at 7.0'.	Light-moderate gas flow at 7'±. Faint smell. Flow lasted several minutes. No methane measured at return line.
2	5	5.0	100	–	X	6.5' – 7.0' **ARGILLACEOUS HALITE:** Clear to grayish brown (5YR 3/2), medium crystalline, medium hard. Clay predominantly gray with some brown (<5%), clay breaks at 6.7' and 6.8'.	NX double-tube barrel used from 1.6' to 51.4'.
						5.1' – 6.5' **HALITE:** Clear to brownish gray (5YR 4/1) and medium gray (N5), medium to coarsely crystalline, medium hard. Trace of gray clay (<1% to 2%) throughout.	NX single-tube barrel used from 1.0' to 1.6'.
1		33	60	–			5 1/2" single-tube barrel used from 0.0' to 1.0'.
0	0	1.0	100	–	X	0.0' – 5.1' **HALITE:** Clear to mottled with scattered medium reddish orange (10R 6/6) blebs of polyhalite, coarsely crystalline, medium hard to hard, polyhalite <1%.	Coring started at 11:45 hours, 12 April 1983.

WIPP
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. D0-69 INSTRUMENT TYPE & NUMBER Extensometer GE-218 HOLE SIZE NX

LOCATION Test Room 1, Centerline of Room at Station N1265, in Roof
16.5 Feet From E and W Ribs

STATION N1265, W231.5 COLLAR ELEV. 1310.1 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10951.9, E6662.5 BOREHOLE PENETRATION 51.4'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 5/6/83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	50				X	As Above	
11		5.1	100	–	–	45.2' – 49.3' ARGILLACEOUS HALITE: Clear to dark reddish brown (10R 3/4), medium to coarsely crystalline, medium hard. Brown clay <1 to 10%. Clay breaks throughout.	
10	45	4.8	100	–	X	40.7' – 45.2' HALITE: Clear to grayish brown (5YR 3/2) to moderate reddish brown (10R 4/6) and dark reddish brown (10R 3/4), fine to coarsely crystalline, medium hard. Trace (1%) polyhalite. Predominantly brown clay (<1%) with locally >3%. Clay breaks at 42.7' and 43.4'. Broken up at 42.3' to 42.6' probably during removal from barrel.	
9	40	5.0	100	–	X X X	38.5' – 40.7' POLYHALITIC HALITE: Clear mottled with moderate reddish orange (10R 6/6) and reddish brown (10R 4/6), coarsely crystalline, medium hard to hard. Polyhalite <1 to 5%. Scattered anhydrite stringers. 36.7' – 38.5' HALITE: Clear to dark reddish brown (10R 3/4), coarsely crystalline, hard. Contains trace of polyhalite, generally <1% but locally >5%. Irregular anhydrite stringers scattered within core. Anhydrite >40% from 36.7' to 37.1'	
8	35	5.0	100	–	–	36.3' – 36.7' ANHYDRITE: (Marker Bed 138) : White to very light (N8) and medium gray (N5), microcrystalline, hard. 32.1' – 36.3' ARGILLACEOUS HALITE: Clear to dark reddish brown (10R 3/4), medium to coarsely crystalline, medium hard. Brown clay 2 to 10%. Clay breaks throughout. 1" brown clay seam at 36.3'.	
7	30	4.9	100	–	– X	29.3' – 32.1' HALITE: Clear, medium to coarsely crystalline, medium hard to hard. Trace (<1%) clay and polyhalite from 31.6'.	
6	25	5.1	100	–	– X	27.0' – 29.3' ARGILLACEOUS HALITE: Clear to grayish brown (5YR 3/2), predominantly coarsely crystalline; fine-medium crystalline from 28.6' to 29.3', medium hard. Predominantly brown clay <1 to 5%. Clay breaks at 28.6' and 29.3'. As Below	

WIPP
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-69 INSTRUMENT TYPE & NUMBER Extensometer GE-218 HOLE SIZE NX

LOCATION Test Room 1, Centerline of Room at Station N1265, in Roof 16.5 Feet From E and W Ribs.

STATION N1265, W231.5 COLLAR ELEV. 1310.1 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10951.9, E6662.5 BOREHOLE PENETRATION 51.4'

DRILLING METHOD Rotary W/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 5/6/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55						
11	50	5.1	100	–	X	49.3' – 51.4' **POLYHALITIC HALITE:** Clear mottled with moderate reddish orange (10R 6/6) polyhalite, coarsely crystalline, medium hard to hard. Polyhalite averages 1 to 3%, locally up to 5%. Trace (<1%) gray clay.	Total penetration = 51.4'. Drilling completed at 12:30 hours, 13 April 1983.

WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO DO-77 INSTRUMENT TYPE & NUMBER Extensometer GE-216 HOLE SIZE NX

LOCATION Test Room 2, Centerline of Room at Station N12 in Floor 16.5 Feet From E and W Ribs.

STATION N1270, W364.5 COLLAR ELEV. 1294.6 DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N10962.5, E6529.6 DEPTH OF BOREHOLE 53.4'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL [illegible] 12B

PREPARED BY JEG DATE 3/31/83

RUN NUMBER	DEPTH (Ft)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
0		0.8	100	—	X X	0.0' - 1.7' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) to moderate reddish brown (10R 4/6), coarsely crystalline, hard. Polyhalite comprises <5% to 15% of rock.	Started drilling 27 March 1983 at 9:10 a.m. 5 1/2" diameter single-tube core barrel used from 0.0' to 0.8'. NX single-tube core barrel used from 1.0' to 5.6'. NX double-tube core barrel used from [illegible]' to 53.4'.
1		1.0	50	—	X X X	1.7' - 4.1' **HALITE:** clear coarsely crystalline, moderately hard. Core is broken up, possible core loss. Trace (<2%) polyhalite blebs.	
2		1.9	68	—	X X X	4.1' - 7.25' **ANHYDRITE (Marker Bed 139):** moderate reddish-orange (10R 6/6) to moderate reddish-brown (10R 4/6) polyhalitic halite, medium to coarsely crystalline, mixed with very light (N8) to light gray (N7) anhydrite from 4.1' to 6.4'. Grades into medium (N5) to very light gray (N8) anhydrite at approximately 6.4'. Microcrystalline, hard, dense. Trace of gray clay at 7.25'. Core grinding evident within this zone.	
3	5	0.9	64	—	X X		
4		5.0	100	—	X X X X	7.25' - 23.6' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6), fine to medium crystalline, hard. Polyhalite averages <5% to 10% with <2% from 14.7' to 17.3'. Gray clay breaks at 7.8', 8.0', 9.8' and 14.5'. Scattered clay breaks at 21.0' to 22.5'. Core contains gray clay (2% to 4%) from 14.4' to 23.6'.	
5	10	5.3	100	—	X X X X — X		Possible Core Loss Zones: Run 1: Throughout Run 2: From 2.8' to 4.1'. Run 3: Throughout
6	15	5.2	100	—	X X X X X X — X		
7	20	5.2	100	—	X X — X	23.6' - 27.2' **HALITE:** clear and brownish gray (5YR 4/1) to moderate reddish-brown (10R 4/6), fine to coarsely crystalline, hard. Gray clay (<1% to 4%). Polyhalite content <1% to 5%, generally increasing with depth from 26.0'. Scattered clay breaks within cor[illegible]	
	25						

WIPP

ROCK CORING · LOG

WASTE ISOLATION PILOT PLANT

BORING NO. DO-77 INSTRUMENT TYPE & NUMBER Extensometer GE-216 HOLE SIZE NX

LOCATION Test Room 2, Centerline of Room at Station N1270 in Floor 16.5 Feet from E and W Ribs.

STATION N1270, W364.5 COLLAR ELEV. 1294.6 DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N10962.5, E6529.6 DEPTH OF BOREHOLE 53.4'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 3/31/83

RUN NUMBER	DEPTH (Ft)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
7	25	5.2	100	—		(as above)	
8	30	5.2	100	—		27.2' - 31.2' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) to moderate reddish brown (10R 4/6), coarsely crystalline, hard. Polyhalite occurs as blebs and irregular patches, generally <1% to 5% but locally >15%.	
						31.2' - 32.1' **HALITE:** clear, medium to coarsely crystalline, hard. Trace of polyhalite.	
9	35	5.2	100	—		32.1' - 32.3' **ANHYDRITE:** very light gray (N8) to medium light gray (N6), microcrystalline, banded. Trace of clear halite. Trace of clay at 32.3'. Some core grinding evident.	
						32.3' - 36.9' **HALITE:** clear to brownish gray (5YR 4/1), medium to coarsely crystalline, hard. Gray clay <1% to 3% scattered throughout. Trace of moderate reddish-orange (10R 6/6) polyhalite.	
10	40	5.1	100	—		36.9' - 43.5' **ARGILLACEOUS HALITE:** clear to brownish-gray (5YR 4/1), fine to coarsely crystalline, hard. Brown clay seam ($\frac{1}{4}$") at 40.8' and clay parting at 41.3'. Moderate reddish-orange (10R 6/6) polyhalite constitutes 1% to 2% of core. Several clay breaks from 41.0' to 41.7'.	
11	45	5.1	100	—		43.5' - 53.4' **HALITE:** clear to grayish red (10R 4/2), medium to coarsely crystalline, hard. Trace of gray clay and trace of polyhalite blebs. 1% to 2% gray clay from 51.0' to 52.15' and 52.75' to 53.1'.	
12	50	5.1	100	—			

WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-77 INSTRUMENT TYPE & NUMBER Extensometer GE-216 HOLE SIZE NX

LOCATION Test Room 2, Centerline of Room at Station N1270 in Floor 16.5 Feet From E and W Ribs.

STATION N1270, W364.5 COLLAR ELEV. 1294.6 DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N10962.5, E6529.6 DEPTH OF BOREHOLE 53.4'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 3/31/83 SHEET 3 OF 3

RUN NUMBER	DEPTH (Ft)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
12	50	5.1	100	—	X	43.5' - 53.4' HALITE: clear to grayish red (10R 4/2), medium to coarsely crystalline, hard. Trace of gray clay and trace of polyhalite blebs. 1% to 2% gray clay from 51.0' to 52.15' and 52.75' to 53.1'.	Completed drilling 27 March 1983 at 2:00 p.m. Total Depth = 53.4'
	55						

WIPP-SPDV
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-79 INSTRUMENT TYPE & NUMBER Extensometer GE-214 HOLE SIZE NX

LOCATION Test Room 2. Centerline of Room at Station N1270 in Roof 16.5 Feet From E and W Ribs.

STATION N1270. W364.5 COLLAR ELEV. 1307.7 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10962.6, E6529.5 BOREHOLE PENETRATION 51.8'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 3/24/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.3	100	—	X	23.4'-27.9' **HALITE:** clear, medium crystalline, moderately hard. Obscure traces of polyhalite and argillaceous material. Core broken up from 27.4' to 27.6'. Irregular white anhydrite stringers at 23.7'.	
					—	18.4'-23.4' **ARGILLACEOUS HALITE:** moderate brown (5YR 3/4) to moderate reddish-orange (10R 6/6) with some clear halite, medium to coarsely crystalline, hard. Scattered brown clay breaks. 1/4" brown clay seam at 23.3'. Trace polyhalite blebs (<1%) found locally. Argillaceous content varies from <1% to 5%.	
5	20	4.8	96	—	X	14.1'-18.4' **POLYHALITIC HALITE:** clear to mottled with moderate reddish-orange (10R 6/6) and moderate reddish-brown (10R 4/6) blebs of polyhalite. Medium to coarsely crystalline, hard. White anhydrite stringers from 15' to 15.1' and 15.2' to 15.3'. Polyhalite content varies from <2% to 5%. Scattered traces of argillaceous material from 17.1' to 18.4'.	
4	15	5.1	100	—	X	13.8'-14.1' **ANHYDRITE:** (Anhydrite "a") light gray (N7) to white, microcrystalline, hard, dense. Trace of gray clay at 13.8'. Some evidence of core grinding.	
					X	13.3'-13.8' **HALITE:** grayish-red (5R 4/2) to clear, fine to medium crystalline, hard. Contains few gray clay breaks and trace of polyhalite.	Trace of gas at 14'±. No methane at end of return line.
3	10	4.8	96	—		7.35'-13.3' **HALITE:** clear with scattered zones of moderate reddish-orange (10R 6/6) and moderate reddish-brown (10R 4/6), medium to coarsely crystalline, moderately hard to hard. Thin, very light gray (N8) to white anhydrite stringers at 8.0', 8.5' and 8.8'.	Possible Core Loss Zones: Run 2: throughout Run 5: throughout Run 7: 27.9' to 29.8'.
						7.1'-7.35' **ANHYDRITE:** (Anhydrite "b") light gray (N7) to medium gray (N5), banded, microcrystalline, hard, dense. Trace of brown clay.	
2	5	4.5	96	—	— X	4.5'-7.1' **ARGILLACEOUS HALITE:** grayish-brown (5YR 3/2), predominantly medium crystalline ranging to coarsely crystalline, moderately hard to hard. Trace of reddish-orange polyhalite throughout. Clay content <5%, predominantly gray ranging to brown. Gray clay break at 6.3'. Trace of gray clay at 7.1', with evidence of core grinding.	Hit gas at 7'. Measured < 2% methane at end of return line. Moderate gas flow. NX double-tube core barrel used from 2.4' to 51.8'. NX single-tube core barrel used from 1.0' to 2.4'.
1		1.4	100	—	X	0.0'-4.5' **HALITE:** clear to moderate reddish-orange (10R 6/6), medium to coarsely crystalline, moderately hard. Trace of polyhalite blebs and brown argillaceous material found throughout.	0' - 1.0' drilled with 5 1/2" single-tube core barrel. Drilling began at 11:35 a.m. on 21 March 1983
0	0	1.0	100	—	X		

WIPP-SPDV
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-79 INSTRUMENT TYPE & NUMBER Extensometer GE-214 HOLE SIZE NX

LOCATION Test Room 2, Centerline of Room at Station N1270
in Roof 16.5 Feet From E and W Ribs

STATION N1270, W364.5 COLLAR ELEV. 1307.7 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10962.6, E6529.5 BOREHOLE PENETRATION 51.8'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 3/24/83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	5.2	100	—		As Above	
10	45	5.1	100	—		44.4'-46.7' HALITE: clear mottled with some moderate reddish-brown (10R 4/6), medium to coarsely crystalline, hard. Trace of brown argillaceous material (<1%). 40.8'-44.4' HALITE: moderate reddish-brown (10R 4/6) to dark brown (10R 3/4) with some clear halite, fine to coarsely crystalline, moderately hard. Scattered zones of brown clay. Argillaceous content averages <2% but locally >5%.	
9	40	5.1	100	—	X X X	37.3'-40.8' HALITE: clear from 37.4' to 38.4', Clear, mottled with moderate reddish-orange (10R 6/6) and moderate reddish-brown (10R 4/6) comprises remaining portion of section; medium to coarsely crystalline, hard. Trace (2%) of polyhalite from 37.3' to 38.4' and 38.4' to 40.8'. Core broken up from 37.4' to 37.9' and 38.1' to 38.2'. 36.3'-37.3' ANHYDRITE: (Marker Bed 138) very light gray (N8) to medium dark gray (N4) to white, banded, microcrystalline, hard. Clear to reddish-orange (10R 6/6) halite is mixed with anhydrite from 36.9' to 37.3'.	
8	35	4.1	100	—		35.4'-36.3' HALITE: clear, [illegible]rsely crystalline, hard. Several scattered blebs of grayish-brown argillaceous material. 31.8'-35.4' ARGILLACEOUS HALITE: clear to dark reddish-brown (10R 3/4) to moderate brown (5YR 3/4) to brownish-gray (5YR 4/1) mottled, medium to coarsely crystalline, moderately hard. Brown and gray clay generally <2%. Numerous clay breaks.	
7	30	4.7	94	—	X	29.8'-31.8' HALITE: clear, medium to coarsely crystalline, moderately hard. Traces of brown clay (<1%). 27.9'-29.8' HALITE: clear to moderate brown (5YR 3/4), medium to coarsely crystalline, moderately hard. Trace of argillaceous material throughout. Contains thin (F 1/8 ") brown clay partings at 28.6', 29.5', and 29.8'.	
6	25	5.3	100	—		As Below	Air bubbles in return water continuously to 37'±. No methane at end of return line.

WIPP
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-79 INSTRUMENT TYPE & NUMBER Extensometer GE-214 HOLE SIZE NX

LOCATION Test Room 2, Centerline of Room at Station N1270
in Roof 16.5 Feet From E and W Ribs

STATION N1270, W364.5 COLLAR ELEV. 1307.7 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10962.6, E6529.5 BOREHOLE PENETRATION 51.8'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 3/24/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55					50.3'-51.8' POLYHALITIC HALITE: clear mottled with moderate reddish-orange (10R 6/6) and moderate reddish-brown (10R 4/6) polyhalite blebs and stringers; medium to coarsely crystalline, hard. Polyhalite content <5%.	
						46.7'-50.3' ARGILLACEOUS HALITE: clear to moderate reddish-orange (10R 6/6) mixed with moderate reddish-brown (10R 4/6), fine to coarsely crystalline, moderately hard. Argillaceous content typically < 3% but >5% from 46.7' to 47.8'; color of core through this interval mottled dark reddish brown (10R 3/4). Zone of fine crystalline halite mixed with argillaceous material from 49.7' to 50.0'. Clay breaks/partings from 49.1' to 49.2'.	Total Penetration = 51.8'
11	50	5.2	100	—	X		Hole completed at 5:30 p.m. on 21 March 1983.

WIPP
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-88 INSTRUMENT TYPE & NUMBER Extensometer GE-212 HOLE SIZE NX

LOCATION Test Room 3, Centerline of Room at Station N1265, in Roof 16.5 Feet From E and W Ribs

STATION N1265, W49 COLLAR ELEV. 1305.9 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10952.8, E6396.5 BOREHOLE PENETRATION 52.7'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 4/14/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.0	100	–		See Above	
5	20	5.2	100	–		19.3' – 24.1' **ARGILLACEOUS HALITE:** clear to moderate brown (5YR 3/4), medium to coarsely crystalline, hard. Trace of polyhalite. Anhydrite stringers at 23.4', 24.0' to 24.1' and scattered traces of anhydrite from 21.5' to 22.2'. Clay partings from 23.9' to 24.1'; clay breaks throughout. Clay content <3 to >5%.	
4	15	4.8	100	–		14.8' – 19.3' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) and moderate reddish-brown (10R 4/6), medium coarsely crystalline, hard. Blebs and irregular patches of polyhalite, up to 5%. Scattered anhydrite stringers from 15.4' to 16.6'.	
						14.3' – 14.8' **ANHYDRITE:** (Anhydrite "a") very light (N7) to medium gray (N5), micro-crystalline, hard. Trace of gray clay at 14.3'.	Gas hit again while drilling Anhydrite "a" (14.3' to 14.8'); 3 to 4% methane at end of return line. Strong flow to 15's then slowed appreciably.
						13.4' – 14.3' **HALITE:** clear to dark reddish brown (10R 3/4), fine to medium crystalline, hard. Contains trace of brown and gray clay, locally up to 3%.	
3	10	5.3	100	–		7.55' – 13.4' **HALITE:** clear, medium to coarsely crystalline, hard, trace of polyhalite (<1%).	
						7.33' – 7.55' **ANHYDRITE:** (Anhydrite "b") very light (N7) to medium gray (N5), micro-crystalline, hard. Contains scattered polyhalitic halite. Gray clay parting at 7.33'.	Gas hit at 7.33'. 2% to 4% methane at end of return l[illegible]. Moderate to strong gas flow for 3 to 4 minutes, decreasing to light flow with 1 1/2% methane. Gas gave off foul odor.
2		1.5	100	–		6.25' – 7.33' **ARGILLACEOUS HALITE:** clear to grayish-brown (5YR 3/2), fine to medium crystalline, hard. Contains brown and gray clay, up to 5%. Clay breaks at 6.3', 7.2', and 7.25'.	Drilled in low gear entire hole to minimize rod vibration.
1	5	5.3	100	–		4.7' – 6.25' **HALITE:** brownish-gray (5YR 4/1) to medium gray (N5), medium to coarsely crystalline, hard. Trace of gray clay scattered throughout.	NX double-tube core barrel used from 0.95' to 52.70'.
0	0	0.9	100	–		0.0' – 4.7' **HALITE:** clear to moderate reddish-orange (10R 6/6), medium to coarsely crystalline, moderately hard. Contains trace (<1%) polyhalite blebs. Slightly more polyhalite from 0.0' to 1.4'.	Drilling begun: 4 April 1983 at 11:00 a.m. 5 1/2" diameter single-tube core barrel used to core from 0.0' to 0.95'.

WIPP
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-88 INSTRUMENT TYPE & NUMBER Extensometer GE-212 HOLE SIZE NX

LOCATION Test Room 3, Centerline of Room at Station N1265, in Roof 16.5 Feet From E and W Ribs.

STATION N1265, W497.5 COLLAR ELEV. 1305.9 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10952.8, E6396.5 BOREHOLE PENETRATION 52.7'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 4-14-83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	4.4	100	—		46.0' - 49.8' **ARGILLACEOUS HALITE:** clear to dark reddish-brown (10R 3/4), fine to coarsely crystalline, moderately hard. Brown argillaceous material generally <1% up to 5%. Clay seams and soft clay/halite mixture (clay >50%) from 47.6' to 47.7' and 49.5' to 49.8'. Scattered clay breaks throughout.	
10	45	5.0	100	—	X	41.8' - 46.0' **HALITE:** clear to grayish-brown (5YR 3/2) to moderate reddish-brown (10R 4/6) and dark reddish-brown (10R 3/4) fine to coarsely crystalline, hard. Predominantly brown argillaceous material <1% with >5% locally. Argillaceous halite from 41.8' to 42.7' and 43.8' to 44.6'. Brown clay partings from 44.0' to 44.2' and clay breaks at 44.2' to 46.0'. Trace of polyhalite.	
9	40	5.0	100	—		37.15' - 41.8' **HALITE:** clear with moderate reddish-orange (10R 6/8) blebs and irregular stringers of polyhalite. Coarsely crystalline, hard. Polyhalite <1% to 2%. Trace of argillaceous material (<1%) from 41.1' to 41.8'. Scattered irregular anhydrite stringers from 38.0' to 41.8'.	
8	35	5.2	100	—	X	36.3' - 37.15' **ANHYDRITE:** (Marker Bed 138) very light (N8) to medium gray (N6), micro-crystalline, hard. Trace (<1%) polyhalite.	
					X	35.5' - 36.3' **HALITE:** clear, coarsely crystalline, moderately hard. Trace of polyhalite blebs and trace of clay (<1%) from 36.1'. Brown clay parting at 36.3'.	
						31.9' - 35.5' **ARGILLACEOUS HALITE:** clear to moderate brown (5YR 3/4) coarsely crystalline, moderately hard. Generally 1 to 3% brown clay with some gray, but locally >5% clay. Clay breaks throughout.	
7	30	5.0	100	—		29.6' - 31.9' **HALITE:** clear, coarsely crystalline, hard. Trace (<1%) argillaceous material from 31.1'.	
						27.2' - 29.6' **ARGILLACEOUS HALITE:** dark reddish-brown (10R 3/4) to brownish-gray (5YR 4/1). Fine to medium crystalline, hard. Numerous clay breaks. Clay content <2 to >5%. Predominantly brown clay to 29.1', then mixed brown & gray.	
6	25	5.0	100	—	X	24.1' - 27.2' **HALITE:** clear, coarsely crystalline, hard. Slight trace of polyhalite. Anhydrite stringers from 24.3' to 25.0', and 25.8' to 25.85'.	

WIPP
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. D0-88 INSTRUMENT TYPE & NUMBER Extensometer GE-212 HOLE SIZE NX

LOCATION Test Room 3, Centerline of Room at Station N1265, in Roof 16.5 Feet From E and W Ribs

STATION N1265, W497.5 COLLAR ELEV. 1305.9 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10952.8, E6396.5 BOREHOLE PENETRATION 52.7

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 4/14/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55						
11	50	4.4	100	–	X X X	50.55' – 52.70' **POLYHALITIC HALITE:** clear mottled with moderate reddish-orange polyhalite, coarsely crystalline, hard. Polyhalite <1% to 5%. Brown clay breaks from 50.55' to 50.75'. 49.8' – 50.55' **HALITE:** clear, coarsely crystalline, hard.	Drilling completed: 5 April 1983 at 1:10 p.m. Total Drilling Time: 8 hrs Total Penetration = 52.70'

WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-90 INSTRUMENT TYPE & NUMBER Extensometer GE-210 HOLE SIZE NX

LOCATION Test Room 3, Centerline of Room at Station N1265, in Floor 16.5' From E and W Ribs.

STATION N1265, W497.5 COLLAR ELEV. 1292.1 DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N10952.6, E6396.4 DEPTH OF BOREHOLE 53.6'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 4/14/83

RUN NUMBER	DEPTH (Ft)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
0	0	0.85	100	–	X	0.0' – 1.8' **HALITE:** clear, coarsely crystalline, hard. Trace (<1%) polyhalite.	Started drilling 5 April 1983 at 1:50 p.m. 5 ½" diameter single-tube core barrel used to drill 0.0' – 0.85'.
1		1.3	100	–	X X	1.8' – 2.65' **POLYHALITIC HALITE:** clear, mottled with moderate reddish-orange (10R 6/6), coarsely crystalline, hard. Blebs of polyhalite <1% to 5%. Trace of anhydrite from 2.25' to 2.65'.	
2		1.35	100	–			
3		0.95	100				
4	5	0.90	82	–	X X	2.65' – 4.45' **POLYHALITE:** moderate reddish brown (10R 4/6) polyhalite mixed with very light gray (N8) anhydrite. Fine to micro-crystalline, hard, dense.	NX single-tube core barrel used from 0.85' – 5.55'.
5		5.2	100	–	X – — X X –	4.45' – 5.7' **ANHYDRITE:** (Marker Bed 139) very light (N8) to medium gray (N6), micro-crystalline, hard, dense. Mixed with some polyhalite to 5'. Gray clay seam at 5.7'.	
	10				X X	5.7' – 9.25' **HALITE:** clear with scattered moderate reddish-orange (10R 6/6) medium crystalline, hard. Scattered polyhalite (<1%) and trace (<1%) gray clay.	
6		5.3	100	–	X X X X – X – X	9.25' – 21.35' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6) and grayish-brown (5YR 4/1), medium to coarsely crystalline, hard. Irregular patches and blebs of polyhalite 1% to 5%, locally >10%. Gray clay 1% to 2% from 13.7' to 16.0' and 20.35' to 21.35'.	
	15						
7		5.3	100	–	X X X X – X –		
	20						
8		5.3	100	–	X – — X	21.35' – 25.75' **HALITE:** clear to grayish-red (5R 4/2) medium to coarsely crystalline, moderately hard. Trace of polyhalite. 1% to 2% gray clay with lesser amounts of brown clay.	
	25						

WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-90 INSTRUMENT TYPE & NUMBER Extensometer GE-210 HOLE SIZE NX

LOCATION Test Room 3, Centerline of Room at Station N1265, in Floor 16.5' From E and W Ribs.

STATION N1265, W497.5 COLLAR ELEV. 1292.1 DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N10952.6, E6396.4 DEPTH OF BOREHOLE 53.6'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 4/14/83 SHEET 2 OF 3

RUN NUMBER	DEPTH (Ft)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
8	25	5.3	100	—	X —	See Above	
9	30	5.2	100	—	X / X / X / X	25.75' - 31.95' **POLYHALITIC HALITE:** clear mottled with moderate reddish-orange (10R 6/6), coarsely crystalline, hard. 1% to 5% polyhalite. Scattered irregular blebs and stringers of very light gray (N8) anhydrite from 27.05' to 31.95', one-half inch wide irregular anhydrite seam at 31.0'.	
					/ X	31.95' - 32.10' **ANHYDRITE:** very light gray (N8) to medium gray (N6), microcrystalline, hard, dense. Trace of gray clay at 32.1'.	
10	35	5.1	100	—	X — / — X / X — / — X	32.10' - 39.5' **HALITE:** clear to medium gray (N6), fine to coarsely crystalline, hard. Contains trace (<1%) polyhalite locally. Breaks and patches of gray clay <1% to 3%. Core clear with no argillaceous material from 36.65' to 37.05' and from 39.0' to 39.5'.	
11	40	5.2	100	—	— / — / — X / —	39.5' - 43.65' **ARGILLACEOUS HALITE:** clear to brownish-gray (5YR 4/1) medium to coarsely crystalline, moderately hard to hard. Contains <1% to 5% clay (average 2%), predominantly gray in color with lesser amounts of brown. Clay breaks throughout. Trace of polyhalite (<1%).	
12	45	5.25	100	—	— X — / — / —	43.65' - 49.50' **HALITE:** clear, coarsely crystalline, moderately hard. Trace of gray clay (<1%). Trace polyhalite from 44.45' to 44.65'.	
13	50	5.3	100	—	— / — / X —	See below	

WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-90 INSTRUMENT TYPE & NUMBER Extensometer GE-210 HOLE SIZE NX

LOCATION Test Room 3, Centerline of Room at Station N1265, in Floor 16.5' From E and W Ribs.

STATION N1265, W497.5 COLLAR ELEV. 1292.1 DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N10952.6, E6396.4 DEPTH OF BOREHOLE 53.6'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 4/14/83 SHEET 3 OF 3

RUN NUMBER	DEPTH (Ft)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
13	50	5.3	100	—	X —	49.50' - 52.10' **HALITE:** clear to moderate reddish-orange (10R 6/6) and brownish-gray (5YR 4/1). Contains trace of polyhalite (<1%) and <1% to 3% gray clay. Clay parting at 49.5' and scattered breaks within core.	
14		0.9	100	—	— X	52.10' - 53.6' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6), medium to coarsely crystalline, hard. Polyhalite 1% to 3%. Trace (<1%) of gray clay.	Drilling completed 7 April 1983 at 11:10 a.m. Total drilling time: 5.5 hours. Total Depth = 53.60'
	55						

WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-91 INSTRUMENT TYPE & NUMBER Extensometer CE-209 HOLE SIZE NX

LOCATION Test Room 4, Centerline of Room at Station N1275, in Floor 16 From E and W Ribs.

STATION N1275, W630.5 COLLAR ELEV. 1292.1 DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N10961.5, E6263.9 DEPTH OF BOREHOLE 51.8'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 5/5/83

RUN NUMBER	DEPTH (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
0	0	1.0	100	—		0.0' - 2.1' **HALITE:** Clear, coarsely crystalline, medium hard. Contains <1% polyhalite blebs and trace (<1%) gray clay.	Drilling started at 15:05 hours, 28 April 1983.
1		0.6	50	—			5 1/2" single tube barrel used 0.0' to 1.0'.
2		0.7	100	—		2.1' - 3.8' **POLYHALITIC HALITE:** Clear mottled with moderate reddish orange (10R 6/6) polyhalite. Polyhalite <1 to 5%. Trace (<1%) gray clay.	NX single tube barrel used 1.0' to 5.2'.
3		1.75	76	—		3.8' - 4.8' **POLYHALITE:** Moderate reddish brown (10R 4/6), very fine to microcrystalline, hard. Trace of anhydrite.	NX double tube barrel used 5.2' to 51.8'.
4	5	1.75	100	—		4.8' - 7.2' **ANHYDRITE:** (Marker Bed 139) Very light gray (N8), medium gray (N5) to moderate reddish brown (10R 4/6) and moderate reddish orange (10R 6/6) to approximately 6.5', with about 50% polyhalite. Then predominantly very light to medium gray anhydrite mixed with some polyhalite and polyhalitic halite. <1/8" gray clay parting at 7.2'. Core broken into disc-like pieces 5.2' to 6.2'.	Note: Run #3 originally drilled to 4.5'±. Core stayed in hole after pulling barrel. Had to redrill to 5.2' and retrieve core.
5		4.6	100	—		7.2' - 11.6' **HALITE:** Clear to moderate reddish orange (10R 6/6) to light gray (N7), fine to coarsely crystalline, medium hard. Contains <1% gray clay with up to 5% locally. Polyhalite <1% to 2%. Polyhalitic halite at 10.0' to 10.3'. Clay break at 7.7'.	Run #6 - core stayed in hole after barrel pulled. Had to return barrel, drill and pull core.
6	10	5.2	100	—		11.6' - 15.3' **POLYHALITIC HALITE:** Clear to moderate reddish orange (10R 6/6), medium to coarsely crystalline, medium hard to hard. Polyhalite 3% to >5%. Gray clay breaks at 14.9' and 15.0'. Irregular anhydrite stringers throughout.	Small gas flow at 7'±. Low flow. No methane. Very slight flow continued until entire hole was drilled.
7	15	5.0	100	—		15.3' - 16.8' **HALITE:** Clear to light gray (N7) to moderate reddish orange (10R 6/6), medium to coarsely crystalline, medium hard. Polyhalite <1% to 2%. Gray clay <2%.	Core Loss: Run 1, Throughout Run 2, Probably from 2.9' to 3.8'.
8	20	5.1	100	—		16.8' - 23.2' **POLYHALITIC HALITE:** Clear to moderate reddish orange (10R 6/6), coarsely crystalline, hard. Polyhalite average <1 to 3%, locally up to 5%. Trace gray clay at 20.8' to 23.2'. Scattered clay breaks.	
	25					23.2' - 25.4' **HALITE:** Clear, coarsely crystalline, hard. Trace (<1%) polyhalite and trace gray clay. Clay break at 23.7'.	

WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-91 INSTRUMENT TYPE & NUMBER Extensometer GE-209 HOLE SIZE NX

LOCATION Test Room 4, Centerline of Room at Station N1275, in Floor 16.5' From E and W Ribs.

STATION N1275, W630.5 COLLAR ELEV. 1292.1 DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N10961.5, E6263.9 DEPTH OF BOREHOLE 51.8'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEC DATE 5/5/83 SHEET 2 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	25					As Above	
8		5.1	100	—		25.4' - 31.8' **POLYHALITIC HALITE:** Clear to moderate reddish orange (10R 6/6) on moderate reddish brown (10R 4/6), coarsely crystalline, hard. Trace (<1%) gray clay. Polyhalite blebs and patches <1 to <5%, locally >5%. Scattered irregular anhydrite stringers from 27.2'. Polyhalite > 90% from 31.6' to 31.8'.	
9	30	4.9	100	—			
						31.8' - 32.1' **ANHYDRITE:** Very light (N8) to medium gray (N5), microcrystalline, hard. Mixed with some halite from 31.8'. Trace of clay at 32.1'.	
10	35	4.9	100	—		32.1' - 39.7' **HALITE:** Clear to medium gray (N5) to grayish red (10R 4/2), medium to coarsely crystalline, medium hard. Gray clay <1 to 3%. Trace (<1%) polyhalite. Core broken up at 37.2' to 37.3'.	
11	40	5.1	100	—		39.7' - 41.8' **ARGILLACEOUS HALITE:** Clear to medium gray (N5), medium to coarsely crystalline, medium hard to soft. Some core can be broken in hand with low pressure. Gray clay 1 to 5%. Core broken up at 41.5' to 41.6'.	
12	45	5.1	100	—		41.8' - 44.4' **POLYHALITIC HALITE:** Clear to moderate reddish orange (10R 6/6), coarsely crystalline, medium hard. Polyhalite blebs and patches <1 to 5%. Trace of gray clay at 43.3'.	
13	50	4.9	100	—		44.4' - 49.3' **HALITE:** Clear, coarsely crystalline, medium hard to hard. Trace (<1%) gray clay. Core broken up with trace of clay at 45.5' - 45.8'. Clay parting at 49.3' with up to 3% clay at 48.9' to 49.3'.	
						As Below	

WIPP

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-91 INSTRUMENT TYPE & NUMBER Extensometer GE-209 HOLE SIZE NX

LOCATION Test Room 4, Centerline of Room at Stations N1275, in Floor 16.5' From E and W Ribs.

STATION N1275, W630.5 COLLAR ELEV. 1292.1 DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N10961.5, E6263.9 DEPTH OF BOREHOLE 51.8'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 5/5 /83 SHEET 3 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY	% RECOVERED	ROD	PROFILE	DESCRIPTION	REMARKS
13	50	4.9	100	–	– X	49.3' – 51.8' HALITE: Clear to moderate reddish orange (10R 6/6), medium to coarsely crystalline, medium hard. Trace (<1%) gray clay. Polyhalite <1 to 3% dispersed throughout.	Hole completed at 14:50 hours, 29 April 1983. Total depth = 51.8'.
	55						

WIPP
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-93 INSTRUMENT TYPE & NUMBER Extensometer GE-207 HOLE SIZE NX

LOCATION Test Room 4, Centerline of Room at Station N1275, in Roof 16.5 Feet From East and West Ribs

STATION N1275, W630.5 COLLAR ELEV. 1304.9 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10961.1, E6263.9 BOREHOLE PENETRATION 52.0'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 5/5/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	25					As Above	
6		5.2	100	–		18.9' – 24.0' **ARGILLACEOUS HALITE:** Clear to dark reddish brown (10R 3/4) medium to coarsely crystalline, medium hard. Scattered traces of anhydrite. 1/4" layer anhydrite at 23.9'. Brown clay <1 to >5%. Scattered clay breaks. Parting at 23.9'.	
5	20	5.0	100	–	X	14.9' – 18.9' **POLYHALITIC HALITE:** Clear mottled with medium reddish orange (10R 6/6) and medium reddish brown (10R 4/6) coarsely crystalline, hard. Scattered white anhydrite stringers to 16.4'. Polyhalite blebs and irregular patches average 1 to 5% with locally >10% from 14.9' to 16.7'.	
4	15	5.1	100	–	X	14.2' – 14.9' **ANHYDRITE:** (Anhydrite "a") Very light (N8) to medium gray (N5), microcrystalline, hard. Some laminations noted. Some very finely crystalline halite mixed with anhydrite.	
					X	13.3' – 14.2' **ARGILLACEOUS HALITE:** Clear to medium reddish orange (10R 6/6) and dark reddish brown (10R 3/4), fine to medium crystalline, medium hard to hard. Brown clay <1 to >5%. Trace (<1%) polyhalite. Trace gray clay at 14.2'.	Drilling begun at 11:00 hours, 27 April 1983.
3	10	4.9	97	–	X	7.3' – 13.3' **HALITE:** Clear, coarsely crystalline, hard. Scattered white anhydrite stringers. 1/8" anhydrite layer at 7.7'. Trace (<1%) polyhalite.	Core loss: Run #1, Throughout #3, Throughout #8, Throughout
					X	7.15' – 7.3' **ANHYDRITE:** (Anhydrite "b") Medium light (N6) to medium gray (N5), microcrystalline, hard.	Moderate gas flow at 7'±. Flow for 5-10 minutes, H_2S - 0% and methane 1 to 3 1/2% measured at end of return line. Slight smell ro gas. Low flow of gas to 16'±. No H_2S recorded.
2	5	4.95	100	–	X	4.05' – 7.15' **HALITE:** Clear to medium brown (5YR 4/4) to medium gray (N5), medium to coarsely crystalline, medium hard. Trace (1 to 2%) brown and gray clay. Breaks at 6.6' and 7.1'. Trace clay at 7.2'.	5 1/2" single tube barrel used to core 0.0' to 1.0'.
.1		0.65	81	–	X	0.0' – 4.05' **HALITE:** Clear with some grayish red (5R 4/2), coarsely crystalline, medium to medium hard. Trace (<1%) polyhalite blebs and clay.	NX single tube barrel used 1.0' to 1.8'.
0	0	1.0	100	–	X		NX double tube barrel used 1.8' to 52.0'.

WIPP
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-93 INSTRUMENT TYPE & NUMBER Extensometer GE-207 HOLE SIZE NX

LOCATION Test Room 4, Centerline of Room at Stations N1275, in Roof 16.5 Feet From E and W Ribs

STATION N1275, W630.5 COLLAR ELEV. 1304.9 DIRECTION OF DRILLING Verrical Up

MINE COORDINATES N10961.1, E6263.9 BOREHOLE PENETRATION 52.0'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEG DATE 5/5/83 SHEET 2 OF 3

As Above

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	4.8	100	–	– – –	45.9' - 49.8' **ARGILLACEOUS HALITE:** Clear to medium brown (5YR 3/4), medium to coarsely crystalline, medium hard. Brown clay <1 to >5%. Clay breaks at 47.2', 47.4', 47.7', 48.3', 48.5', 48.9' and 49.3' to 49.4'. 3/4" clay seam at 49.7'.	Can be combined in hand with low to moderate pressure due to grain size and clay content.
10	45	5.1	100	–	X –	41.3' - 45.9' **HALITE:** Clear to dark reddish brown (10R 3/4), medium to coarsely crystalline, medium hard to hard. Trace polyhalite. Brown clay averages 1% with local zones >5%. Clay breaks at 41.9' and 43.7'. Argillaceous halite at 41.9' to 42.1', 42.4' to 43.0' and 44.1' to 44.3'.	
9	40	5.1	100	–	X X	37.0' - 41.3' **HALITE:** Clear, coarsely crystalline, hard. Scattered white anhydrite stringers. Trace (<1%) moderate reddish orange polyhalite blebs from 39.4' to 41.3'.	
						36.3' - 37.0' **ANHYDRITE:** (Marker Bed 138) Very light (N8) to medium gray (N5), microcrystalline, hard. Some <20% halite mixed with anhydrite 36.4' to 36.6'. Brown clay seam 36.3' to 36.4'.	
8	35	5.0	100	–	X – – – –	35.5' - 36.3' **HALITE:** Clear to medium reddish orange (10R 6/6), fine to medium crystalline, some coarse, medium hard. Trace polyhalite (<1%) and trace brown clay.	
						32.3' - 35.5' **ARGILLACEOUS HALITE:** Clear to medium brown (5YR 3/4), fine to medium crystalline, with some coarse. Soft to medium hardness. Core broken up approximately 32.6' to 33.2'. Brown clay generally 5 to 10% with zones <1%. Argillaceous >40% at 34.5' to 34.8'.	
7	30	4.8	100	–	– X	29.7' - 32.3' **HALITE:** Clear, coarsely crystalline, medium hard to hard. Trace (<1%) brown clay from 31.6'.	
						27.5' - 29.7' **HALITE:** Clear to medium brown (5YR 3/4) fine to coarsely crystalline, medium hard. Brown argillaceous <1 to 4%. Clay break at 27.6'. Trace (<1%) polyhalite from 29.2'-29.6'. Core medium reddish orange.	
6	25	5.2	100	–		24.0' - 27.5' **HALITE:** Clear, coarsely crystalline, hard. Few scattered white anhydrite stringers to 26.0'.	

WIPP
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-93 INSTRUMENT TYPE & NUMBER Extensometer GE-207 HOLE SIZE NX

LOCATION Test Room 4, Centerline of Room at Stations N1275, in Roof 16.5 Feet From E and W Ribs

STATION N1275, W630.5 COLLAR ELEV. 1304.9 DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N10961.1, E6263.9 BOREHOLE PENETRATION 52.0'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JEC DATE 5/5/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55						
11	50	4.8	100	—	X X	49.8' - 52.0' HALITE: Clear to medium reddish orange (10R 6/6). Coarsely crystalline, hard. Polyhalite blebs and patches <1 to 4%. Highest percentage is from 49.8' to 51.0'. A few scattered anhydrite stringers and blebs from 51.0' to 52.0'.	Hole completed at 11:15 hours, 28 April 1983. Total penetration = 52.0'.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-201 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION D East Drift, 406' S of Exploratory Shaft centerline, midspan

STATION S406, W19 COLLAR ELEV. 1262.2' DIRECTION OF DRILLING Vertical

MINE COORDINATES N9280.6, E6874.9 BOREHOLE PENETRATION 51.7'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JBM,RFM,RLB/TSC//DGK,RMB/Bechtel DATE 1/25/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	ROD	PROFILE	DESCRIPTION	REMARKS
8	25	5.0	100	-		20.3' - 25.4' HALITE: mottled colorless to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, ~1% polyhalite, 1-5% brown and gray (mostly brown) clay, 5-10% polyhalite from 24.3'-24.5', anhydrite/clay zone 25.3'-25.4'.	
7	20	4.9	98	-		15.5' - 20.3' POLYHALITIC HALITE: colorless to moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, 1-5% polyhalite, few blebs of clay, anhydrite stringers (<1/16") at 16.1', 16.3', 17.8', and 18.1'.	
						14.8' - 15.5' ANHYDRITE: (Anhydrite "a") light to very light gray (N7-8), microcrystalline anhydrite, 20-30% halite in upper 0.1', trace polyhalite near upper contact.	
6	15	4.6	92	-		14.0' - 14.8' HALITE: mottled colorless to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, 1-2% polyhalite, ~1% gray clay, 1-5% brown clay, gray clay parting at 14.8'.	
						7.9' - 14.0' HALITE: colorless to moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, 0-1% polyhalite, clay absent below 13.5', ~1% gray clay from 13.5'-14.0', anhydrite stringers (~1/16") at 9.5' and 9.8'.	
5	10	2.0	100	-			
						7.7' - 7.9' ANHYDRITE: (Anhydrite "b") light to very light gray (N7-8), microcrystalline anhydrite, 30-40% halite.	
4	5	4.3	86	-		0.0' - 7.7' HALITE: clear to mottled colorless and moderate reddish-orange (10R 6/6) halite, medium to coarsely crystalline, 2% polyhalite, <1% gray clay, brown clay absent to 4.0', 1-2% from 4.0'-7.7', light gray (N7) clay seam at 7.7'.	Hole begun 23 November 1982.
3		1.5	79	-			
2		1.15	96	-			0' - 0.85' drilled with 6" single-tube core barrel.
1		.55	92	-			
	0						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-201 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 406' S of Exploratory Shaft centerline, midspan

STATION S406, W19 COLLAR ELEV. 1262.2' DIRECTION OF DRILLING Vertical UP

MINE COORDINATES N9280.6, E6874.9 BOREHOLE PENETRATION 51.7'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JBM,RFM,RLB/TSC//DGK,RMB/Bechtel DATE 1/25/83

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	50					(see description on next sheet)	
13		5.0	100	–		46.3' – 49.4' **HALITE:** colorless to moderate reddish-orange (10R 6/6) halite, coarsely crystalline, 1–3% polyhalite, locally in blebs, <1% clay.	
12	45	5.0	96	–		44.4' – 46.3' **HALITE:** colorless to moderate brown (5YR 3/4) halite, medium to coarsely crystalline, ~1% polyhalite, 1–3% brown clay, brown clay break at 44.8'. 38.9' – 44.4' **HALITE:** colorless to moderate reddish-orange (10R 6/6) halite, coarsely crystalline, 1–7% polyhalite, 0–1% clay, anhydrite stringers at 39.0', 39.3', and 40.0'.	
11	40	5.0	100	–		38.3' – 38.9' **ANHYDRITE:** (Marker Bed 138) medium to light gray (N5–7), microcrystalline anhydrite, 10–20% halite in upper 0.05'. 33.2' – 38.3' **ARGILLACEOUS HALITE:** mottled colorless to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, <1% polyhalite, 1–10% brown clay locally concentrated, brown clay parting at 37.1', brown clay seam at 38.3'.	
10	35	5.0	100	–		31.4' – 33.2' **HALITE:** clear halite, coarsely crystalline, <1% polyhalite, <1% brown and gray clay.	
9	30	4.6	92	–		29.4' – 31.4' **ARGILLACEOUS HALITE:** colorless to moderate brown (5YR 3/4) halite, finely to coarsely crystalline, <1% polyhalite, 1–5% clay (mostly brown), anhydrite stringer (<1/16") at 31.4'. 25.4' – 29.4' **HALITE:** clear halite, medium to coarsely crystalline, <1% polyhalite, <1% brown and gray clay from 29.3'–29.4', absent elsewhere, anhydrite stringers at 25.6'–25.7', 26.0', and 26.6'.	
8	25	5.0	100	1		(as below)	

WIPP-SPDV
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-201 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 406' S of Exploratory Shaft centerline, midspan

STATION S406, W19 COLLAR ELEV. 1262.2' DIRECTION OF DRILLING Vertical Up

MINE COORDINATES N9280.6, E6874.9 BOREHOLE PENETRATION 51.7'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY JBM,RFM,RLB/TSC//DGK,RMB/Bechtel DATE 1/25/83

RUN NUMBER	PENETRATION (ft.)	RECOVERY(ft)	% RECOVERED	ROD	PROFILE	DESCRIPTION	REMARKS
	55						
13	50	50	100	—	— X	49.4' - 51.7' ARGILLACEOUS HALITE: colorless to moderate brown (5YR 4/6) halite, coarsely crystalline, 1-2% polyhalite, 1-5% brown clay to 50.7', 5-10% from 50.7'-51.7', brown clay breaks at 49.7', 50.6', 51.1', and 51.7'.	Total penetration = 51.7'. Hole finished at 13:30 hours, 24 November 1982.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-2D2 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 406' S of Exploratory Shaft centerline, midspan

STATION S406, W19 COLLAR ELEV. 1248.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9280.6, E6874.9 DEPTH OF BOREHOLE 51.4'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RMB,JPS/Bechtel DATE 11/24/82

SHEET 1 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0	14	70	—		0.0' – 3.7' HALITE: clear, medium to coarsely crystalline halite, with trace (<1%) polyhalite, and trace (<0.5%) gray clay blebs from 0'–2.0'.	Drilling started 14:00 hours, 24 November 1982. Coring with brine. Core Run #1 – broken in small pieces and partially dissolved. Longest piece = 0.2'.
2	5	4.5	90	—		3.7' – 4.8' POLYHALITIC HALITE: moderate reddish-orange (10R 5/6), translucent, coarsely crystalline, medium hard halite. Gradational lower contact. Clay parting at 4.5' (washed out by drilling).	
						4.8' – 7.6' ANHYDRITE: (Marker Bed 139) light gray (N7) hard, dense, very thinly bedded to laminated anhydrite. Core is broken "poker-chip" fashion along bedding. Medium light gray (N6), moderately stiff, anhydritic clay seam (~1/2") at 7.6'.	
3	10	4.9	98	—		7.6' – 11.5' ARGILLACEOUS HALITE: moderate reddish-orange (10R 6/6) translucent, medium crystalline halite, with some polyhalite (10–20%), some to abundant (about 25–30%) clay, and localized trace light gray (N7) clay blebs. Clay break at 7.8'. Clay parting at 11.1'.	Hit pressurized gas around 10'–12'. Drilling fluid bubbled at collar. Drilling stopped at 16:00 hours and 12.0' 24 November 1982 for Thanksgiving Holiday. Resumed coring at 08:20 hours, 26 November 1982.
4	15	4.9	98	—		11.5' – 24.3' POLYHALITIC HALITE: clear, coarsely crystalline halite, with 35–40% polyhalite. Polyhalite bands at 13.1', 14.4', 21.8'. Relatively clear halite from 11.5'–12.1' and 15.5'–17.0' with some (10–15%) clay.	From 12' to 32', drilling averaged 0.2 ft./min.
5	20	5.1	100	—		Argillaceous zone at 15.7'–15.85' Gray clay parting at 15.95' Gray clay break at 16.55' Brown clay break at 16.7' Argillaceous zone at 17.5' Gray clay break at 22.6' Gray clay parting at 23.0' Gray argillaceous zone (30–40% clay) at 23.1'–23.3'.	
6	25	5.1	100	—			Run 6 – longest piece = 1.3'.
						(see description on next sheet)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-202 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 406' S of Exploratory Shaft centerline, midspan

STATION S406, W19 COLLAR ELEV. 1248.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9280.6, E6874.9 DEPTH OF BOREHOLE 51.4'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RMB,JPS/Bechtel DATE 11/24/82

RUN NUMBER	DEPTH (ft)	RECOVERY (ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.1	100	—		24.3' - 28.0' **ARGILLACEOUS HALITE:** halite, with 20-25% clay, and 15-20% polyhalite. Gray-brown argillaceous zone at 24.4'-26.4', with clay breaks at 24.7', 25.1', 25.4', 25.6', 26.3'.	Run 8 - Longest piece = 1.1'; average = 0.3'.
7	30	5.2	100	—		28.0' - 34.6' **POLYHALITIC HALITE:** moderate reddish-orange (10R 6/6), translucent, medium crystalline halite, with 1% to 20% polyhalite, and localized trace gray clay blebs. Clear halite at 31.2'-31.7', 32.6'-32.7', and 33.8'-34.6'. Polyhalite bands at 33.6'-33.8' and 34.2'.	
8	35	5.0	100	—		34.6' - 35.0' **ANHYDRITE:** light gray (N7), hard, dense, halitic anhydrite. Gray clay parting at 35.0'.	
9	40	4.9	100	—		35.0' - 49.0' **ARGILLACEOUS HALITE:** translucent, finely to medium crystalline, medium hard halite, mottled light brown with some (10%) moderate reddish-orange (10R 6/6) polyhalite, and some (10-15%) light gray (N7) and moderate brown (5YR 3/4) clay as blebs. Clay breaks at 38.9', 39.2' (gray), 40.7' (gray), 41.1' (gray), 42.5' (gray), 42.7' (brown), 43.6' (brown), 43.7' (brown), 44.3' (brown), brown clay parting at 43.2', and trace polyhalite from 43.2' to 44.8'.	
10	45	5.0	100	—			
11	50	4.1	100	—		49.0' - 51.4' **HALITE:** clear halite, moderately hard and coarsely crystalline.	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-202 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 406' S of Exploratory Shaft centerline, midspan

STATION S406, W19 COLLAR ELEV. 1248.6' DIRECTION OF DRILLING Vertical Down

MINE COORDINATES N9280.6, E6874.9 DEPTH OF BOREHOLE 51.4'

DRILLING METHOD Wet (brine) DRILL MAKE/MODEL Joy 12B

PREPARED BY RMB,JPS/Bechtel DATE 11/24/82

RUN NUMBER	DEPTH (ft.)	RECOVERY(ft)	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	4 1	100	—		(as above)	Run 11 - pulled at 12:30 hours, 26 November 1982. Total depth = 51.4'.
	55						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-203 INSTRUMENT TYPE & NUMBER Extensometer GE-235 HOLE SIZE NX

LOCATION East 140 Drift, 624' N of Exploratory Shaft centerline, 6.8' from W rib

STATION N624, E140 COLLAR ELEV. 1298.2 DIRECTION OF DRILLING vertical UP

MINE COORDINATES N10308.6, E7041.7 BOREHOLE PENETRATION 52.0'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/23/83 SHEET 1/ OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.2	100	–		(see description on next sheet)	Began coring at 10:15 hours on 23 February 1983. Cored from 0'-1.0' using 6" single tube barrel. Cored from 1.0'-5.8' without inner core tube.
5	20	5.1	100	–	X	20.6'-24.0' **HALITE**: argillaceous, clear to pale brown (5YR 5/2) and medium gray (N5), finely to coarsely crystalline, moderately hard. Clay content 0-5% and occurs interstitially. Clay breaks at 20.8', 22.2', 22.7', 23.4', and 23.9'. Irregular light gray (N7) anhydrite seam (1/2") at 24.0'. 15.0'-20.6' **POLYHALITIC HALITE**: clear and moderate reddish-orange (10R 6/6), medium to coarsely crystalline, moderately hard. Polyhalite occurs as blebs and stringers and represents 0-5% of core. Clear halite from 19.8'-20.6'.	Core loss in Run #1 occurred throughout core run.
4	15	5.2	100	–	X	14.2'-15.0' **ANHYDRITE**: medium gray (N5) to very light gray (N8), hard, dense, microcrystalline. 13.1'-14.2' **HALITE**: argillaceous, mottled light brownish-gray (5YR 6/1) and pale yellowish brown (10YR 6/2), finely crystalline, moderately hard. Clay content 3-8%. Brown clay breaks at 13.5' and 14.2'.	Encountered trace of gas at 14.5'.
3		2.0	100	–	X	8.2'-13.1' **HALITE**: clear, medium to coarsely crystalline, moderately hard, trace of scattered blebs of orange polyhalite. Few hairline stringers of white (N9) anhydrite.	
2	10	5.2	100	–	X	8.0'-8.2' **ANHYDRITE**: medium gray (N5), hard, dense, microcrystalline. 5.5'-8.0' **HALITE**: argillaceous, clear to pale yellowish-brown (10YR 6/2) to brownish-gray (5YR 4/1). Finely to medium crystalline, moderately hard. Interstitial clay comprises 2-10% of core. Brown clay breaks at: 6.9', 7.1', 7.3'. Thin parting of gray clay at 8.0'.	
1	5	1.7	35	–	X	0.0'-5.5' **HALITE**: clear with trace of moderate reddish-orange (10R 6/6) polyhalite. Coarsely crystalline, moderately hard. Few isolated blebs of polyhalite.	
0	0	.9	90	–	X		

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-203 INSTRUMENT TYPE & NUMBER Extensometer GE-235 HOLE SIZE NX

LOCATION East 140 Drift, 624' N of Exploratory Shaft centerline, 6.8' from W rib

STATION N624, E140 COLLAR ELEV. 1298.2 DIRECTION OF DRILLING vertical up

MINE COORDINATES N10308.6, E7041.7 BOREHOLE PENETRATION 52.0'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/23/83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY'	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	2.9	100	–			
10	45	5.2	100	–		42.4'-50.1' **ARGILLACEOUS HALITE:** clear and mottled pale brown (5YR 5/2), pale yellowish-brown (10 YR 6/2) and brownish-gray (5YR 4/1). Finely to coarsely crstalline, moderately hard. Clay content from 0 to 25% with brown clay breaks at: 42.5', 43.0', 45.3', 45.8', 46.2', 47.0', 47.2', 48.9', 49.3', and 49.6'. At 49.9', 1/2" thick, moist, brown clay seam.	
9	40	5.0	100	–	XXXXXXX	37.6'-42.4' **HALITE:** clear, medium to coarsely crystalline, moderately hard. Trace of moderate reddish-orange (10R 6/6) polyhalite stringers from 39.5'-42.0'.	
8	35	5.2	100	–		36.9'-37.6' **ANHYDRITE:** medium light gray (N6), very hard, dense, microcrystalline. Few clear halite stringers at 37.6'.	
						32.0'-36.9' **ARGILLACEOUS HALITE:** clear and mottled medium gray (N5), brownish-gray (5YR 4/1) and pale yellowish-brown (10YR 6/2). Finely to coarsely crystalline, moderately hard. Finely crystalline from 35.9'-36.9'. Clay content ranges from 0-15% with numerous discontinuous clay breaks throughout. Clay breaks at: 33.0', 33.5', 35.1', 35.6', 35.7'. At 36.9', 1/2" thick, grayish-brown (5YR 3/2) soft, moist clay seam.	
7	30	5.2	100	–		29.8'-32.0' **HALITE:** clear, coarsely crystalline, moderately hard.	
						28.2'-29.8' **ARGILLACEOUS HALITE:** clear and light brownish-gray (5YR 6/1), moderately hard, medium crystalline. Clay content ranges from 0 to 15% with clay breaks at: 29.0', 29.3' and 29.7'.	
6	25	5.2	100	–		24.0'-28.2' **HALITE:** clear, coarsely crystalline, moderately hard. Few scattered, white (N9) anhydrite stringers.	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-203 INSTRUMENT TYPE & NUMBER Extensometer GE-235 HOLE SIZE NX

LOCATION East 140 Drift, 624' N of Exploratory Shaft centerline, 6.8' from W rib

STATION N624, E140 COLLAR ELEV. 1298.2 DIRECTION OF DRILLING vertical up

MINE COORDINATES N10308.6, E7041.7 BOREHOLE PENETRATION 52.0'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/23/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50–55	2.9	100	–	X	50.1'-52.0' HALITE: clear to moderate reddish-orange (10R 6/6), coarsely crystalline, moderately hard. Trace of orange polyhalite occurs as blebs and stringers	Total Penetration = 52.0' Hole completed at 19:00 hours on 23 February 1983.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-204 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 624' N of Exploratory Shaft centerline 6.8' from W rib

STATION N640, E140 COLLAR ELEV. 1290.5 DIRECTION OF DRILLING vertical down

MINE COORDINATES N10308.5, E7041.5 DEPTH OF BOREHOLE 51.6'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/24/83 SHEET 1 OF 3

RUN NUMBER	DEPTH ( )	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0	.7	35	–	—	0.0'-7.1' **HALITE:** argillaceous, clear and pale brown (5YR 5/2), coarsely crystalline, moderately hard. Interstitial brown clay content ranges from 0-3%. Clay breaks at: 3.0' and 5.0'.	Began coring at 18:45 hrs. on 23 February 1983. Cored from 0 to 0.3' with 6" single tube core barrel. Cored without inner tube from 0.3' to 6.4'.
2	5	1.9	46	–	—		
3	10	4.7	100	–	X	7.1'-8.9' **HALITE:** polyhalitic, clear and moderate reddish-orange (10R 6/6), coarsely crystalline, moderately hard. Polyhalite occurs as scattered stringers and blebs and represents from 0-3% of core. Dense polyhalite seam (1/4") at 8.9'.	
4	15	5.0	100	–	— X —	8.9'-11.5' **ANHYDRITE:** very light gray (N8) to medium light gray (N6), hard to very hard, dense, microcrystalline. Core broken into 1/8"-1/4" chips throughout; slightly banded in part.	Core Loss:
					— X —	11.5'-11.6" **CLAY:** medium gray (N5), moist, soft, highly plastic.	Run / Where Lost 1 Throughout Run 2 Throughout Run 3 0.7' lost between 32.0' to 33.0'
					— X —	11.6'-15.3' **HALITE:** argillaceous, clear and light gray (N7) to grayish orange-pink (5YR 7/2). Trace of polyhalite throughout. Medium to coarsely crystalline, moderately hard. Clay content ranges from 0 to 15% with gray clay breaks at: 11.7', 12.0', 13.0', 13.5', and 14.0'	
5	20	5.1	100	–	X X		
					X	15.3'-27.9' **HALITE:** polyhalitic, clear and moderate reddish-orange (10R 6/6), and grayish-orange (10YR 7/4). Medium to coarsely crystalline, moderately hard, polyhalite content ranges from 0 to 20% locally and occurs interstitially and as isolated blebs and stringers. Trace of argillaceous halite from 19.0'-21.0'. Clay breaks at: 19.6', 19.7', and 20.0'.	
6	25	5.2	100	–	—		
					X X		
					X X		

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-204 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 624' N of Exploratory Shaft centerline 6.8' from W rib

STATION N640, E140 COLLAR ELEV. 1290.5 DIRECTION OF DRILLING vertical down

MINE COORDINATES N10308.5, E7041.5 DEPTH OF BOREHOLE 51.6'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/24/83 SHEET 2 OF 3

RUN NUMBER	DEPTH ( )	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.2	100	–		(as above)	
7	30	4.9	100	–		27.9'-31.3' **HALITE:** argillaceous, clear and light gray (N7) to light brownish-gray (5YR 6/1), fine to medium crystalline, moderately hard. Clay content up to 5% with few isolated blebs of orange polyhalitic halite throughout. Gray clay breaks at 28.3', 30.0', and 31.1'.	
8	35	4.3	86	–		31.3'-37.2' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6), medium to coarsely crystalline, moderately hard. Polyhalite occurs as dense stringers and isolated blebs and represents 0-10% of core. At 35.7', 1/2" thick, hard, dense polyhalite seam.	
9	40	5.2	100	–		37.2'-37.4' **ANHYDRITE:** medium light gray (N6), very hard, dense microcrystalline. At 37.4', medium gray (N5) clay parting.	
10	45	4.8	100	–		37.4'-49.8' **ARGILLACEOUS HALITE:** clear and mottled light gray (N7), to light brownish-gray (5YR 6/1) to pale yellowish-brown (10YR 6/2). Finely to coarsely crystalline, moderately hard. Clay content ranges from 0-25% with trace of interstitial orange polyhalite below 43.9'. Numerous brown and gray clay breaks throughout. Dominant clay breaks at: 37.6', 38.0', 40.1', 44.3', 45.4', 45.5', 45.7', 46.4', 47.0', and 48.9'.	
11	50	5.3	100	–			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-204 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 624' N of Exploratory Shaft centerline, 6.8' from W rib

STATION N640, E140 COLLAR ELEV. 1290.5 DIRECTION OF DRILLING vertical down

MINE COORDINATES N10308.5, E7041.5 DEPTH OF BOREHOLE 51.6'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/24/83 SHEET 3 OF 3

RUN NUMBER	DEPTH ( )	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	5.3	100	–	—	49.8'-51.6' HALITE: clear, coarsely crystalline, moderately hard, with trace gray clay in part.	Hole completed at 10:00 hours on 24 February 1983. Total Depth = 51.6'
	55						

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-205 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 141 ' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1410, E0 COLLAR ELEV. 1316.5' DIRECTION OF DRILLING vertical up

MINE COORDINATES N11095, E6892 BOREHOLE PENETRATION 50.7'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/19/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	OD	PROFILE	DESCRIPTION	REMARKS
6	25	5.0	100	-		22.5'-31.5' HALITE: clear, coarsely crystalline, moderately hard, few isolated stringers of white (N9), anhydrite. At 22.7', 1/2" thick medium gray (N5) moist clay seam. From 27.5'-28.7', moderate brown (5YR 4/4), slightly argillaceous zone, medium crystalline. At 28.7' gray clay parting.	
5	20	5.2	100	-		17.4'-22.5' HALITE: argillaceous, clear to mottled dark gray (N4) to pale yellowish-brown (10YR 6/2). Finely to medium crystalline, moderately hard. Clay content ranges from 0 to 15%. Trace of orange polyhalitic halite from 19.3'-20.0'. Clay breaks at 18.3', 19.7', 20.0', 20.5', 21.0', 21.3', 21.9' and 22.3'.	
						13.5'-17.4' POLYHALITIC HALITE: clear and moderate reddish-orange (10R 6/6), moderately hard, coarsely crystalline. Few very light gray (N8) hard, anhydrite stringers throughout. 1/8" thick anhydrite stringer at 14.7'. Polyhalite occurs interstitially and in isolated blebs in 5-8% of core.	
4	15	4.8	100	-		12.8'-13.5' ANHYDRITE: medium gray (N5) to very light gray (N8); hard, dense, microcrystalline, slightly banded in part. Moist, gray clay parting at 12.8'.	At 12.9' encountered gas. No detectable gas after 5 minutes.
3	10	3.0	97	-		6.3'-12.8' HALITE: clear, coarsely crystalline, moderately hard, few white (N9), hairline anhydrite stringers throughout. Trace polyhalite from 6.3'-7.1'. Finely crystalline above 12.0'. Trace of light gray (N7) interstitial clay above 12.0'. Gray clay breaks at 12.5' and 12.7'.	
						6.1'-6.3' ANHYDRITE: very light gray (N8), hard, dense, microcrystalline, broken into 1/8" chips. Soft, gray clay parting at 6.1'.	
2	5	3.0	97	-		0.0'-6.1' HALITE: argillaceous and polyhalitic in part. Clear to moderate reddish-orange (10R 6/6) to light brown (5 YR 6/4) to medium gray (N5). Finely to coarsely crystalline, moderately hard. Finely crystalline above 4.6'. Few gray clay breaks at 4.4', 5.4' and 5.9'. Clay and polyhalite represent from 0-3% of core.	Coring began at 09:00 hours on 18 February 1983. Cored from 0'-1.0' with 6" core barrel. From 1.0'-6.1' cored without use of inner core barrel.
1		2.0	100	-			
0	0	.9	90	-			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

BORING NO. DO-205

LOCATION 0 East Drift, 1410' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1410, E0 COLLAR ELEV. 1316.5' DIRECTION OF DRILLING vertical up

MINE COORDINATES N11095, E6892 BOREHOLE PENETRATION 50.7'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/19/83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	50	4.1	100	-	X	46.1'-49.1' **ARGILLACEOUS HALITE:** clear to mottled brownish-gray (5YR 4/1) to medium light gray (N6) to moderate brown (5YR 3/4). Finely to coarsely crystalline, moderately hard. Numerous clay breaks and partings with clay composing 0-20% of core. Finely crystalline from 47.8'-48.9'. Brown clay breaks at 46.4', 46.7', 46.9', 47.4', 47.9', 48.0', 48.1', 48.5' and 48.7'. Clay partings at 46.8', 48.8' and 48.9'.	
10	45	5.0	100	-	X	43.1'-46.1' **HALITE:** clear, medium to coarsely crystalline, moderately hard, numerous blebs and stringers of very light gray (N7) anhydrite. Trace of orange polyhalite at 43.6'. Trace of brownish-gray (5YR 4/1) clay from 45.6'-45.8'.	
9	40	5.1	100	-	X	40.4'-43.1' **ARGILLACEOUS HALITE:** clear to mottled grayish-brown (5YR 3/2), pale yellowish-brown (10YR 6/2) and moderately reddish-orange (10R 6/6), finely to coarsely crystalline, moderately hard. Finely crystalline from 41.0'-43.0'. Clay content ranges from 0-15% with trace of interstitial polyhalite from 42.5'-43.0'. Clay breaks at 40.7', 40.8', 41.2', 41.4', 41.8', 42.0', 42.3' and 43.0'.	
8	35	5.1	100	-	X	36.2'-40.4' **HALITE:** clear, coarsely crystalline, moderately hard. Trace of polyhalite throughout. Some isolated stringers of very light gray (N8) anhydrite.	
						35.4'-36.2' **ANHYDRITE:** light gray (N7) to medium gray (N5), very hard, dense.	
						35.3'-35.4' **CLAY:** grayish brown (5YR 3/2), moist, firm to stiff, highly plastic, dense. Horizontal contact with anhydrite above.	
7	30	5.2	100	-		31.5'-35.3' **ARGILLACEOUS HALITE:** clear to pale yellowish-brown (10YR 6/2) and medium gray (N5), finely to coarsely crystalline, moderately hard, numerous brown clay breaks throughout; clay represents about 3-10% of core. Clay breaks at 31.5', 31.6', 32.9', 33.4', 33.6' and 34.0'.	
6	25	5.0	100	-			

WIPP-SPDV
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-205 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 1410' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1410, E0 COLLAR ELEV. 1316.5' DIRECTION OF DRILLING vertical up

MINE COORDINATES N11095, E6892 BOREHOLE PENETRATION 50.7'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12R

PREPARED BY JPS/Bechtel DATE 2/19/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	ROD	PROFILE	DESCRIPTION	REMARKS
11		4.1	100	17	X	49.1'-50.7' HALITE: polyhalitic, clear and moderate reddish orange (10R 4/6), coarsely crystalline, moderately hard. Polyhalite comprises 0-3% of core and occurs as isolated blebs and stringers.	Total Penetration = 50.7' Completed hole at 15:00 hours on 18 February 1983.

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-206 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 1410' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1410, E0 COLLAR ELEV. 1308.0' DIRECTION OF DRILLING vertical down

MINE COORDINATES N11095, E6892 DEPTH OF BOREHOLE 50.6'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/22/83 SHEET 1 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
1	0	3.3	55	–		0.0'-9.5' **HALITE:** argillaceous and polyhalitic in part. Clear to moderate reddish-orange (10R 6/6) and light gray (N7), finely to coarsely crystalline, moderately hard. Interstitial clay composes up to 1% of core as does isolated blebs and stringers of orange polyhalite. Clear halite from 8.5'-9.5'.	Hole began at 09:30 hours on 21 February 1983. Cored from 0' to 6.0' without inner core barrel.
2	5	5.3	100	–			
3	10	1.7	55	–		9.5'-13.2' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6), coarsely crystalline, moderately hard. Polyhalite is interstitial and locally represents up to 25% of core. Hard polyhalite seam at 13.1'.	Core Loss: Run 1 — Where Lost: Throughout Run; Run 3 — 11.3'-13.2'
						13.2'-14.4' **ANHYDRITE:** light gray (N7) to very light gray (N8), hard, dense, microcrystalline.	Encountered gas at 13.2'.
4	15	2.1	100			14.4'-20.6' **POLYHALITIC HALITE:** clear to moderate reddish-orange (10R 6/6), medium to coarsely crystalline, moderately hard. Polyhalite ranges from 0-20% and occurs as blebs and stringers throughout. At 18.0', hard, dense, 1/4" thick polyhalite seam. Trace of clay from 19.5'-19.9' with 1/2" thick gray clay seam at 19.5'.	
5	20	5.0	100	–			
						20.6'-21.8' **HALITE:** argillaceous, clear and medium gray (N5), medium to coarsely crystalline, moderately hard. Clay content ranges from 0-5% and occurs interstitially. Gray clay breaks at 20.9', 21.1', 21.2' and 21.5'.	
6	25	5.2	100	–		(see description on next sheet)	

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-206 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION 0 East Drift, 1410' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1410, E0 COLLAR ELEV. 1308.0' DIRECTION OF DRILLING vertical down

MINE COORDINATES N11095, E6892 DEPTH OF BOREHOLE 50.6'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/22/ SHEET 2 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
6	25	5.2	100	-		21.8'-27.3' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6), medium to coarsely crystalline, moderately hard. Polyhalite comprises up to 25% of core in dense stringers and blebs with some interstitial halite. Trace of clay at 25.3' and 25.9' with gray clay parting at 25.3'.	
7	30	5.1	100	-		27.3'-30.9' **HALITE:** argillaceous and polyhalitic, clear and mottled medium gray (N5) to light gray (N7) to moderate reddish-orange (10R 6/6). Finely to medium crystalline, moderately hard. Gray clay represents 3-5% of core and orange polyhalite 1-2%. Clay and polyhalite occur interstitially throughout. Gray clay breaks at 27.3', 27.5', 27.8', 28.4', 29.5', 29.7', 30.0' and 30.7'.	
8	35	5.2	100	-		30.9'-35.9' **POLYHALITIC HALITE:** clear and moderate reddish-orange (10R 6/6), medium crystalline, moderately hard. Polyhalite occurs interstitially and as isolated blebs and represents from 0-10% of core. 1/2" thick polyhalite seams at 35.4' and 35.8'.	
9	40	5.3	100	-		35.9'-36.9' **HALITE:** clear, medium to coarsely crystalline, moderately hard; very thin, hairline stringers of anhydrite at 36.5'.	
						36.9'-37.1' **ANHYDRITE:** light gray (N7), hard, dense, microcrystalline, with medium gray (N5) 1/8" thick, soft, moist, clay parting at 37.1'.	
10	45	5.3	100	-		37.1'-50.6' **HALITE:** argillaceous, clear to mottled brownish-gray (5YR 4/1), light gray (N7) and light brown (5YR 6/4). Medium to coarsely crystalline, moderately hard, trace polyhalitic halite from 45.2' to 46.3'. Clay content ranges from 0-15% and occurs interstitially. Clear halite from 37.5'-38.4', 41.0'-42.0', and 50.3'-50.6'. Gray or brown clay breaks at 38.9', 39.7', 44.3', 45.7', 46.0', 46.3', 46.4', 46.5', 47.3' and 49.0'.	
11	50	3.0	100	-			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG

BORING NO. DO-206 INSTRUMENT TYPE & NUMBER None HOLE SIZE NQ"

LOCATION 0 East Drift, 1410' N of Exploratory Shaft centerline, 12½' from E rib

STATION N1410, E0 COLLAR ELEV. 1308.0' DIRECTION OF DRILLING vertical down

MINE COORDINATES N11095, E6892 DEPTH OF BOREHOLE 50.6'

DRILLING METHOD Rotary w/brine DRILL MAKE/MODEL Joy 12B

PREPARED BY JPS/Bechtel DATE 2/22/83 SHEET 3 OF 3

RUN NUMBER	DEPTH (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
11	55	3.0	100	-	— —		Total Depth = 50.6' Hole completed at 14:30 hours on 21 February 1983

WIPP-SPDV
WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-229 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 401' S of Exploratory Shaft Centerline, 13.7' from E rib

STATION S 401, E 153 COLLAR ELEV. 1259.8 DIRECTION OF DRILLING Vertical up

MINE COORDINATES N9287 E7049 BOREHOLE PENETRATION 50.6'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY RMB/Bechtel DATE 3/4/83 SHEET 1 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION
	25					(see description on next sheet)
8		4.0	80	–	– X	20.8'-23.2' **ARGILLACEOUS HALITE:** (lower contact approximate) pale brown (5YR 5/2) to moderate brown (5YR 3/4), mottled, medium to coarsely crystalline, moderately hard. Contains 2-5% brown clay, trace only from 20.8'-21.5'. Contains several clay breaks.
7	20	4.5	88	–	X X X X	16.6'-20.8' **POLYHALITIC HALITE:** clear, mottled with moderate reddish-orange (10R 6/6) polyhalite, medium to coarsely crystalline. Polyhalite content varies from 1 to 5% and occurs as discrete blebs and stringers. Also contains 1-2% very light gray (N8), blebs and thin anhydrite stringers. Polyhalite absent from 18.6' to 19.3'.
					X	15.9'-16.6' **ANHYDRITE:** (Anhydrite "a") medium light gray (N6) to white, banded, microcrystalline, hard, dense. Trace of gray clay at 15.9'.
6	15	4.3	86	–	X X	8.6-15.9' **HALITE:** clear, medium to coarsely crystalline, moderately hard. 8.7'-8.9': light gray anhydrite stringers and reddish-orange polyhalite blebs. Very thin light gray anhydrite stringers at 9.6'. 1/8" light gray anhydrite stringer at 10.4'. Light gray anhydrite bleb and small polyhalite blebs at 14.7' and at 15.5'-15.6'.
					X	8.5'-8.6' **ANHYDRITE:** (Anhydrite "b") medium gray (N5), banded, hard, dense, microcrystalline. Trace of gray clay at 8.5'
5	10	5.1	100	–	– – – –	5.3'-8.5' **ARGILLACEOUS HALITE:** brownish-gray (5YR 4/1) medium crystalline, moderately hard. ≤2% clay from 5.3' to 6.8'. ±5% clay 6.8' to 8.5'. Brown clay breaks at 6.9', 7.1', 7.8', 7.9', 8.2', 8.3'.
4		1.3	100	–	–	
3	5	2.4	100	–	X	0.0'-5.3' **HALITE:** clear to moderate reddish-orange (10R 6/6), locally light brownish-gray (5YR 6/1), medium to coarsely crystalline, moderately hard. Trace polyhalite blebs throughout. Argillaceous (±2%) from 0.0' to 0.5'.
2		0.6	50	–	X	
		0.3	75	–		
0	0	1.0	100	–	–	

Core Loss:

Run 1 - at 1.4'
Run 2 - throughout
Run 6 - throughout
Run 7 - intermittently between 16.4'-20.8'
Run 8 - throughout

Stuffing box blown out of collar three times during Run #6, at approximately 12', 15', and 15.9'. Gas has high pressure but low volume. Flow lasted for about one minute in each case.

Brief flow of gas at moderate pressure at 8.5'.

Inner core barrel was used after 6.3'.

Run #3 was dropped by drillers. Core was not necessarily boxed in order.

Core Run #0 is a 5.5" diameter plug 1.0' long drilled out for stuffing

Coring began at 10:00 hours, 2 March 1983.

REMARKS

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-229 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 401' S of Exploratory Shaft Centerline, 13.7' from E rib

STATION S 401, E 153 COLLAR ELEV. 1259.8 DIRECTION OF DRILLING Vertical up

MINE COORDINATES N9287-E7049 BOREHOLE PENETRATION 50.6'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY RMB/Bechtel DATE 3/4/83 SHEET 2 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	ROD	PROFILE	DESCRIPTION	REMARKS
	50					(see description on next sheet)	
13		4.0	100	-		45.2'-48.1' **HALITE:** clear, mottled locally with moderate brown (5YR 3/4) clay, medium to coarsely crystalline, moderately hard. Clay content increases upward: trace brown clay 45.2'-47.0'; 2%± 47.0'-47.6'; 10%± with clay breaks 47.6'-48.0'. Trace polyhalite blebs 45.2'-47.0'.	
12	45	5.0	100	-		40.4'-45.2' **HALITE:** clear, mottled with moderate reddish-orange (10R 6/6) polyhalite, medium to coarsely crystalline, moderately hard. Contains 1-4% polyhalite as discrete blebs and stringers. Also contains trace very light gray anhydrite blebs.	
						39.9'-40.4' **ANHYDRITE:** medium gray (N5), banded with very light gray (N8), microcrystalline, hard, dense. Underlain by 1/2" thick brown clay seam.	Hit strong flow of pressurized gas at about 38'. Flow continued at moderate rate until about 41.5' (approximate 5 minute duration).
11	40	5.1	100	-		30.4'-39.9' **ARGILLACEOUS HALITE:** pale brown (5YR 5/2) to moderate brown (5YR 3/4), locally clear mottled with moderate reddish-orange polyhalite, fine to coarsely crystalline, moderately hard. Clay content about 3-5%. Numerous brown clay breaks. Trace polyhalite without clay from 31.7'-32.2' and 38.8'-39.5'. Clear halite from 32.4'-34.0'.	Core Loss: Run 9 - intermittently between 26.5'-28.0' Run 10 -throughout.
10	35	4.0	80	-			
9	30	4.8	96	-		23.2'-30.4' **HALITE:** clear, medium to coarsely crystalline, moderately hard. Traces of polyhalite and brown clay 23.2'-26.5'. Light gray anhydrite seam underlain by brown clay partings 26.5'-26.6'. Very light gray anhydrite seam, 1/8"-1/4", at 27.6', and a few hairline anhydrite stringers throughout.	Violent bursts of pressurized gas at about 20', and again at about 31'. Stuffing box blown out of collar both times. Very high flow for 30± seconds, then diminished to a strong flow for 2-5 minutes, then dissipated.
8	25	4.0	100	-			

WIPP-SPDV

WASTE ISOLATION PILOT PLANT

ROCK CORING LOG
UPWARD CORING

BORING NO. DO-229 INSTRUMENT TYPE & NUMBER None HOLE SIZE NX

LOCATION East 140 Drift, 401' S of Exploratory Shaft Centerline, 13.7' from E rib

STATION S 401, E 153 COLLAR ELEV. 1259.8 DIRECTION OF DRILLING Vertical up

MINE COORDINATES N9287 E7049 BOREHOLE PENETRATION 50.6'

DRILLING METHOD Rotary w/Brine DRILL MAKE/MODEL Joy 12B

PREPARED BY RMB/Bechtel DATE 3/4/83 SHEET 3 OF 3

RUN NUMBER	PENETRATION (ft.)	RECOVERY	% RECOVERED	RQD	PROFILE	DESCRIPTION	REMARKS
	55						
13	50	4.0	100	–	X –	48.1'-50.6' HALITE: predominately clear, locally mottled with moderate brown clay and moderate reddish-orange polyhalite, medium to coarsely crystalline, moderately hard. Contains trace polyhalite blebs throughout and trace brown clay 50.4'-50.6'. Poss e clay break at 48.4'.	Hole completed at 11:30 hours on 3 March 1983.

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE 4" CORE BORING NO. OH-9

LOCATION CENTERLINE OF ROOM L-1; TEST ROOM 1 INTERSECTION; ROOF

STATION N1433 W231.5 COLLAR ELEV. 1310 ± DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N11,125.6 E6662.9 DEPTH OF BOREHOLE 15.4 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL LONGYEAR 65

DATE STARTED 2-27-84 (DAY) DATE COMPLETED 2-28-84 (DAY) SHEET

LOGGED BY: J. E. GALLERANI DATE: 2-28-84 1 OF 1

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0	1		1.85	1.85	100	X	0.0' - 4.2' HALITE: Clear, coarsely crystalline. < 1% polyhalite. 1% from 1.0 to 2.0'±.	4" dia. thin wall masonry core barrel. Used with EW rods.
1.85	2		3.7	3.7	100	X	4.2' - 7.3' HALITE: Clear, coarsely crystalline to 6.3'. Then medium to coarse. ≤ 1% gray intercrystalline clay. < 1/2% dispersed polyhalite.	Hole drilled by SNL.
		5						
5.55	3		3.75	3.75	100	X	7.3' - 7.45' ANHYDRITE b: Gray, microcrystalline anhydrite. Up to 1/2" halite layer at 7.4'. Trace of gray clay at 7.3'. Upper contact tightly welded. Intact core.	Dry hole. No gas. Core broken in several pieces at lower contact of anhydrite b. Unable to determine if any separation exists.
							7.45' - 13.15' HALITE: Clear; coarsely crystalline. Scattered white stringers.	
9.3	4	10	3.05	3.05	100		13.15' - 13.95' HALITE: Clear to light gray (N7); medium to coarsely crystalline. ≤ 1% gray clay. < 1/2% dispersed polyhalite.	
12.35	5		3.05	3.05	100	X	13.95' - 14.45' ANHYDRITE a: Light gray to white anhydrite with scattered halite growths from 14.15'. Upper contact tightly welded. Lower contact has < 1/16" gray clay.	Core broken at 13.95'. Smooth, horizontal break. Unable to determine any separation from core here.
		15				X X		
15.4							14.45' - 15.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 3% polyhalite.	

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE 4" CORE BORING NO. OH-11

LOCATION CENTERLINE OF ROOM L-2 AND TEST ROOM 2 INTERSECTION; ROOF

STATION N1433 W364.5 COLLAR ELEV. 1308 ± DIRECTION OF DRILLING VERTICAL UP

MINE COORDINATES N11,125.6 E6529.6 DEPTH OF BOREHOLE 19.7 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL LONGYEAR 65

DATE STARTED 2-15-84 (DAY) DATE COMPLETED 2-16-84 (DAY) SHEET

LOGGED BY: J. E. GALLERANI DATE: 2-16-84 1 OF 1

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	%RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0								
	1		1.5	1.5	100		0.0' - 2.3' HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1 to 2% polyhalite blebs and patches.	Used 4" thin wall masonry core barrel with EW rods.
1.5								
	2		3.1	3.1	100		2.3' - 5.2' HALITE: Clear, some moderate reddish orange (10R 6/6); medium to coarsely crystalline. <1% polyhalite. Clay break at 3.0 - 3.2'.	Hole drilled by SNL. Drilling time: 8-1/2 hrs. ±.
4.6								
	3	5	3.0	3.0	100		5.2' - 7.6' HALITE: Clear mixed with medium light gray (N6); medium to coarsely crystalline. <1% gray clay and polyhalite.	
7.6								
	4		2.85	2.85	100		7.6' - 7.8' ANHYDRITE b: White to light gray (N7) anhydrite with scattered halite growths. Slight trace clay at 7.6'. Upper contact is tightly welded. Core intact.	Lower contact of anhydrite b shows some core grinding. Trace of gray clay.
10.45		10						
	5		3.65	3.65	100		7.8' - 13.0' HALITE: Clear; coarsely crystalline. Scattered white stringers.	
14.1							13.0' - 14.1' HALITE: Clear to moderate reddish orange (10R 6/6); medium to coarsely crystalline. <1/2% dispersed polyhalite and gray clay.	
	6	15	3.7	3.7	100		14.1' - 14.8' ANHYDRITE a: White to light gray (N7) microcrystalline anhydrite with scattered halite growths, especially common from 14.6 - 14.8'. <1/32" gray clay at 14.1'. Upper contact is irregular; tightly welded. Core intact. Grades into polyhalitic halite above.	Core broken at lower contact of anhydrite a but pieces fit together fairly well.
17.8								
	7		1.9	1.9	100		14.8' - 18.4' POLYHALITIC HALITE: Clear to moderate reddish orange; coarsely crystalline. <1 to 3% polyhalite. Anhydrite stringers at 15.9 and 16.05'.	
19.7		20					18.4' - 19.7' HALITE: Clear, medium to coarsely crystalline. <1% dispersed gray clay. Break at 18.4'.	

BORING NO. OH-11

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE 4" CORE BORING NO. OH-13

LOCATION CENTERLINE ROOM L-1 AND TEST ROOM 1 INTERSECTION; FLOOR

STATION N1433 W231.5 COLLAR ELEV. 1298 ± DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N11125.6 E6662.9 DEPTH OF BOREHOLE 9.5 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL LONGYEAR 65

DATE STARTED 2-28-84 (DAY) DATE COMPLETED 2-28-84 (DAY) SHEET

LOGGED BY: J. E. GALLERANI DATE: 2-28-84 1 OF 1

RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
1	0	2.5	2.5	100		0.0'-0.15' FILL	4" dia. wall masonry core barrel used with EW rods.
					X	0.15'-1.5' HALITE: Clear, coarsely crystalline. <1% gray intercrystalline clay.	
2	2.5	3.15	3.15	100	X	1.5'-4.4' HALITE: Clear with some moderate reddish orange (10R 6/6); coarsely crystalline. <1% polyhalite blebs and patches. Gray clay break at 2.5'.	Hole drilled by SNL.
	5						
3	5.65	3.85	3.85	100		4.4'-4.6'± POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. <1% gray clay. 1 to 3% polyhalite. Some anhydrite present.	
	9.5				X	4.6'-8.1' MB-139 : Upper contact, core is broken at 15°±, <1/32" gray clay along it. Mixture of anhydrite and halite to 7.3'. From 7.3' - 7.8' is light gray (N7) to white anhydrite. Irregular pattern of white and gray color. Near-horizontal laminae present. Hard, dry gray clay 7.8 to 8.1'± (lower contact dips from 7.95 to 8.1'). <1/16"halite layer at 7.85'.	20°± break in core at 5.65' but core pieces fit together very well. Core is broke at 7.9'± but core ends fit together. Below clay at lower contact, core is intact, and contact is tightly welded.
	10					8.1' - 8.6' HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline, some medium. <1/2% polyhalite. Steeply dipping, clean fracture extends from center of core at 8.0' to outer edge at 8.5'. Core not broken completely along this.	
						8.6' - 9.5' HALITE: Clear to light gray (N7), medium to coarsely crystalline, some fine. <1/2% polyhalite. ≤1% gray intercrystalline clay. Several steeply dipping, clean fractures in core. Core not broken completely along any fractures. Clay breaks at 8.6' and 9.3'.	

WIPP

GEOLOGIC DRILL LOG

WASTE ISOLATION PILOT PLANT

INSTRUMENT TYPE & NUMBER - HOLE TYPE/SIZE 4" CORE BORING NO. OH-14

LOCATION CENTERLINE OF ROOM L-2 AND TEST ROOM 2 INTERSECTION; FLOOR

STATION N1433 W364.5 COLLAR ELEV. 1296 ± DIRECTION OF DRILLING VERTICAL DOWN

MINE COORDINATES N11,125.6 E6529.6 DEPTH OF BOREHOLE 9.7 FT

DRILLING METHOD ROTARY/AIR DRILL MAKE/MODEL LONGYEAR 65

DATE STARTED 2-16-84 (DAY) DATE COMPLETED 2-17-84 (DAY) SHEET

LOGGED BY: J. E. GALLERANI DATE: 2-17-84 1 OF 1

	RUN NUMBER	DEPTH (ft.)	LENGTH CORE RUN	RECOVERY	% RECOVERED	PROFILE	DESCRIPTION	REMARKS
0.0	1		1.7	1.7	100	X	0.0' - 1.9' HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline with zones of fine to medium. ≤ 1% polyhalite. < 1/2% gray intercrystalline clay.	4-inch thin wall masonry core barrel used with EW rods. Hole drilled by SNL. Dry hole. No gas. Separation noted in walls of hole at 3.55'. While drilling hole, just below top of MB-139, had some air and drill cuttings coming out of 51X-GE-00262 hole. Coming out of extensometer hole at 4.8' depth. Core at lower contact of MB-139 is broken here. Difficult to determine any separation from looking at core. Put water in OH-14 and it came out in 51X-GE-00262 at 4.8' depth.
1.7	2		1.8	1.8	100	X X X X X	1.9' - 4.4' POLYHALITIC HALITE: Clear to moderate reddish orange (10R 6/6); coarsely crystalline. < 1 to 4% polyhalite. Scattered anhydrite from 3.8 to 4.4'. Clean, irregular break in core at 3.55'.	
3.5	3	5	3.45	3.45	100		4.4' - 6.95' MB-139: White to medium light gray (N6) with some moderate reddish orange (10R 6/6). Microcrystalline anhydrite from 4.4 - 5.4'. ≤ 1/16" halite layer at 6.75 - 6.8'. Continuous through core there is a hairline fracture 1/2" below this halite where core is broken along. Upper contact of MB-139 is tightly closed and dips 1°±. Less than 1/2" below is a parallel break in core. Core pieces fit tightly along this though 1/2 to 3/4" gray clay along lower contact.	
6.95	4		2.75	2.75	100	X	6.95' - 9.7' HALITE: Clear to light moderate reddish orange (10R 6/6); coarsely crystalline, some medium. < 1% dispersed polyhalite. < 1% gray clay, intercrystalline and scattered breaks.	
9.7		10						

APPENDIX J

GEOMECHANICAL INSTRUMENTATION DATA PLOTS

CONTENTS

Table No.	Title/Description
J-1	Index of Instrumentation Data Plots
J-2	Schematic Symbols for Data Plots
J-3	Description of Instrument Identification

Figures

See Table J-1 for listing of enclosed figures.

Table J-1

GEOMECHANICAL INSTRUMENTATION DATA

Figure No.	Title
J-1	Piezometer 31X-PE-00201 - Waste Shaft
J-2	Piezometer 31X-PE-00202 - Waste Shaft
J-3	Piezometer 31X-PE-00203 - Waste Shaft
J-4	Piezometer 31X-PE-00204 - Waste Shaft
J-5	Piezometer 31X-PE-00205 - Waste Shaft
J-6	Piezometer 31X-PE-00206 - Waste Shaft
J-7	Piezometer 31X-PE-00207 - Waste Shaft
J-8	Piezometer 31X-PE-00208 - Waste Shaft
J-9	Piezometer 31X-PE-00209 - Waste Shaft
J-10	Piezometer 31X-PE-00210 - Waste Shaft
J-11	Piezometer 31X-PE-00211 - Waste Shaft
J-12	Piezometer 31X-PE-00212 - Waste Shaft
J-13	Piezometer 35X-PE-00201 - Exhaust Shaft
J-14	Piezometer 35X-PE-00202 - Exhaust Shaft
J-15	Piezometer 35X-PE-00203 - Exhaust Shaft
J-16	Piezometer 35X-PE-00204 - Exhaust Shaft
J-17	Piezometer 35X-PE-00205 - Exhaust Shaft
J-18	Piezometer 35X-PE-00206 - Exhaust Shaft
J-19	Piezometer 35X-PE-00207 - Exhaust Shaft
J-20	Piezometer 35X-PE-00208 - Exhaust Shaft
J-21	Piezometer 35X-PE-00209 - Exhaust Shaft
J-22	Piezometer 35X-PE-00210 - Exhaust Shaft
J-23	Piezometer 35X-PE-00211 - Exhaust Shaft
J-24	Piezometer 35X-PE-00212 - Exhaust Shaft
J-25	Piezometer 35X-PE-00213 - Exhaust Shaft
J-26	Piezometer 35X-PE-00214 - Exhaust Shaft
J-27	Piezometer 35X-PE-00215 - Exhaust Shaft
J-28	Piezometer 35X-PE-00216 - Exhaust Shaft
J-29	Piezometer 35X-PE-00217 - Exhaust Shaft
J-30	Piezometer 35X-PE-00218 - Exhaust Shaft
J-31	Piezometer 35X-PE-00219 - Exhaust Shaft
J-32	Piezometer 35X-PE-00220 - Exhaust Shaft
J-33	Piezometer 35X-PE-00221 - Exhaust Shaft
J-34	Piezometer 37X-PE-00201 - C & SH Shaft
J-35	Piezometer 37X-PE-00202 - C & SH Shaft
J-36	Piezometer 37X-PE-00203 - C & SH Shaft
J-37	Piezometer 37X-PE-00204 - C & SH Shaft
J-38	Piezometer 37X-PE-00205 - C & SH Shaft
J-39	Piezometer 37X-PE-00206 - C & SH Shaft
J-40	Piezometer 37X-PE-00207 - C & SH Shaft
J-41	Piezometer 37X-PE-00208 - C & SH Shaft
J-42	Piezometer 37X-PE-00209 - C & SH Shaft
J-43	Piezometer 37X-PE-00210 - C & SH Shaft
J-44	Piezometer 37X-PE-00211 - C & SH Shaft

Table J-1 (continued)

J-45	Piezometer 37X-PE-00212 - C & SH Shaft
J-46	Pressure Cell 31X-WE-00201 - Waste Shaft
J-47	Pressure Cell 31X-WE-00202 - Waste Shaft
J-48	Pressure Cell 31X-WE-00203 - Waste Shaft
J-49	Pressure Cell 31X-WE-00204 - Waste Shaft
J-50	Pressure Cell 35X-WE-00201 - Exhaust Shaft
J-51	Pressure Cell 35X-WE-00202 - Exhaust Shaft
J-52	Pressure Cell 35X-WE-00203 - Exhaust Shaft
J-53	Pressure Cell 35X-WE-00204 - Exhaust Shaft
J-54	Pressure Cell 37X-WE-00201 - C & SH Shaft
J-55	Pressure Cell 37X-WE-00202 - C & SH Shaft
J-56	Pressure Cell 37X-WE-00203 - C & SH Shaft
J-57	Pressure Cell 37X-WE-00204 - C & SH Shaft
J-58	Welded Strain Gauge 37X-ZE-00201 - C & SH Shaft
J-59	Welded Strain Gauge 37X-ZE-00202 - C & SH Shaft
J-60	Welded Strain Gauge 37X-ZE-00203 - C & SH Shaft
J-61	Welded Strain Gauge 37X-ZE-00204 - C & SH Shaft
J-62	Welded Strain Gauge 37X-ZE-00205 - C & SH Shaft
J-63	Welded Strain Gauge 37X-ZE-00206 - C & SH Shaft
J-64	Welded Strain Gauge 37X-ZE-00207 - C & SH Shaft
J-65	Welded Strain Gauge 37X-ZE-00208 - C & SH Shaft
J-66	Embedment Strain Gauge 37X-ZE-00209 - C & SH Shaft
J-67	Embedment Strain Gauge 37X-ZE-00210 - C & SH Shaft
J-68	Embedment Strain Gauge 37X-ZE-00211 - C & SH Shaft
J-69	Embedment Strain Gauge 37X-ZE-00212 - C & SH Shaft
J-70	Embedment Strain Gauge 37X-ZE-00213 - C & SH Shaft
J-71	Embedment Strain Gauge 37X-ZE-00214 - C & SH Shaft
J-72	Embedment Strain Gauge 37X-ZE-00215 - C & SH Shaft
J-73	Embedment Strain Gauge 37X-ZE-00216 - C & SH Shaft
J-74	Welded Strain Gauge 37X-ZE-00217 - C & SH Shaft
J-75	Welded Strain Gauge 37X-ZE-00218 - C & SH Shaft
J-76	Welded Strain Gauge 37X-ZE-00219 - C & SH Shaft
J-77	Welded Strain Gauge 37X-ZE-00220 - C & SH Shaft
J-78	Welded Strain Gauge 37X-ZE-00221 - C & SH Shaft
J-79	Welded Strain Gauge 37X-ZE-00222 - C & SH Shaft
J-80	Welded Strain Gauge 37X-ZE-00223 - C & SH Shaft
J-81	Welded Strain Gauge 37X-ZE-00224 - C & SH Shaft
J-82	Embedment Strain Gauge 37X-ZE-00225 - C & SH Shaft
J-83	Embedment Strain Gauge 37X-ZE-00226 - C & SH Shaft
J-84	Embedment Strain Gauge 37X-ZE-00227 - C & SH Shaft
J-85	Embedment Strain Gauge 37X-ZE-00228 - C & SH Shaft
J-86	Embedment Strain Gauge 37X-ZE-00229 - C & SH Shaft
J-87	Embedment Strain Gauge 37X-ZE-00230 - C & SH Shaft
J-88	Embedment Strain Gauge 37X-ZE-00231 - C & SH Shaft
J-89	Embedment Strain Gauge 37X-ZE-00232 - C & SH Shaft
J-90	Embedment Strain Gauge 37X-ZE-00235 - C & SH Shaft
J-91	Embedment Strain Gauge 37X-ZE-00236 - C & SH Shaft
J-92	Embedment Strain Gauge 37X-ZE-00237 - C & SH Shaft
J-93	Embedment Strain Gauge 37X-ZE-00238 - C & SH Shaft
J-94	Embedment Strain Gauge 37X-ZE-00239 - C & SH Shaft
J-95	Embedment Strain Gauge 37X-ZE-00240 - C & SH Shaft
J-96	Embedment Strain Gauge 37X-ZE-00241 - C & SH Shaft
J-97	Embedment Strain Gauge 37X-ZE-00242 - C & SH Shaft

Table J-1 (continued)

J-98	Multiple-Point Extensometer 31X-GE-00201 - Waste Shaft
J-99	Multiple-Point Extensometer 31X-GE-00202 - Waste Shaft
J-100	Multiple-Point Extensometer 31X-GE-00203 - Waste Shaft
J-101	Multiple-Point Extensometer 31X-GE-00204 - Waste Shaft
J-102	Multiple-Point Extensometer 31X-GE-00205 - Waste Shaft
J-103	Multiple-Point Extensometer 31X-GE-00206 - Waste Shaft
J-104	Multiple-Point Extensometer 31X-GE-00207 - Waste Shaft
J-105	Multiple-Point Extensometer 31X-GE-00208 - Waste Shaft
J-106	Multiple-Point Extensometer 31X-GE-00209 - Waste Shaft
J-107	Multiple-Point Extensometer 35X-GE-00201 - Exhaust Shaft
J-108	Multiple-Point Extensometer 35X-GE-00202 - Exhaust Shaft
J-109	Multiple-Point Extensometer 35X-GE-00203 - Exhaust Shaft
J-110	Multiple-Point Extensometer 35X-GE-00204 - Exhaust Shaft
J-111	Multiple-Point Extensometer 35X-GE-00205 - Exhaust Shaft
J-112	Multiple-Point Extensometer 35X-GE-00206 - Exhaust Shaft
J-113	Multiple-Point Extensometer 35X-GE-00207 - Exhaust Shaft
J-114	Multiple-Point Extensometer 35X-GE-00208 - Exhaust Shaft
J-115	Multiple-Point Extensometer 35X-GE-00209 - Exhaust Shaft
J-116	Multiple-Point Extensometer 37X-GE-00201 - C & SH Shaft
J-117	Multiple-Point Extensometer 37X-GE-00202 - C & SH Shaft
J-118	Multiple-Point Extensometer 37X-GE-00203 - C & SH Shaft
J-119	Multiple-Point Extensometer 37X-GE-00204 - C & SH Shaft
J-120	Multiple-Point Extensometer 37X-GE-00205 - C & SH Shaft
J-121	Multiple-Point Extensometer 37X-GE-00206 - C & SH Shaft
J-122	Multiple-Point Extensometer 37X-GE-00207 - C & SH Shaft
J-123	Multiple-Point Extensometer 37X-GE-00208 - C & SH Shaft
J-124	Multiple-Point Extensometer 37X-GE-00209 - C & SH Shaft
J-125	Double-Point Extensometer 51X-GE-00206
J-126	Double-Point Extensometer 51X-GE-00207
J-127	Double-Point Extensometer 51X-GE-00208
J-128	Double-Point Extensometer 51X-GE-00209
J-129	Double-Point Extensometer 51X-GE-00210
J-130	Double-Point Extensometer 51X-GE-00211
J-131	Double-Point Extensometer 51X-GE-00212
J-132	Multiple-Point Extensometer 51X-GE-00213
J-133	Multiple-Point Extensometer 51X-GE-00214
J-134	Multiple-Point Extensometer 51X-GE-00215
J-135	Multiple-Point Extensometer 51X-GE-00216
J-136	Multiple-Point Extensometer 51X-GE-00217
J-137	Multiple-Point Extensometer 51X-GE-00218
J-138	Multiple-Point Extensometer 51X-GE-00219
J-139	Multiple-Point Extensometer 51X-GE-00220
J-140	Double-Point Extensometer 51X-GE-00221
J-141	Multiple-Point Extensometer 51X-GE-00222
J-142	Multiple-Point Extensometer 51X-GE-00223
J-143	Multiple-Point Extensometer 51X-GE-00224
J-144	Multiple-Point Extensometer 51X-GE-00225
J-145	Multiple-Point Extensometer 51X-GE-00226
J-146	Multiple-Point Extensometer 51X-GE-00227
J-147	Multiple-Point Extensometer 51X-GE-00228
J-148	Multiple-Point Extensometer 51X-GE-00229
J-149	Multiple-Point Extensometer 51X-GE-00230
J-150	Multiple-Point Extensometer 51X-GE-00231
J-151	Multiple-Point Extensometer 51X-GE-00232

Table J-1 (continued)

J-152	Double-Point Extensometer 51X-GE-00233
J-153	Double-Point Extensometer 51X-GE-00234
J-154	Double-Point Extensometer 51X-GE-00235
J-155	Double-Point Extensometer 51X-GE-00236
J-156	Multiple-Point Extensometer 51X-GE-00237
J-157	Multiple-Point Extensometer 51X-GE-00238
J-158	Multiple-Point Extensometer 51X-GE-00239
J-159	Multiple-Point Extensometer 51X-GE-00240
J-160	Multiple-Point Extensometer 51X-GE-00241
J-161	Multiple-Point Extensometer 51X-GE-00242
J-162	Multiple-Point Extensometer 51X-GE-00243
J-163	Single-Point Extensometer 51X-GE-00244
J-164	Multiple-Point Extensometer 51X-GE-00245
J-165	Multiple-Point Extensometer 51X-GE-00246
J-166	Multiple-Point Extensometer 51X-GE-00247
J-167	Multiple-Point Extensometer 51X-GE-00248
J-168	Multiple-Point Extensometer 51X-GE-00249
J-169	Multiple-Point Extensometer 51X-GE-00250
J-170	Multiple-Point Extensometer 51X-GE-00251
J-171	Double-Point Extensometer 51X-GE-00252
J-172	Double-Point Extensometer 51X-GE-00253
J-173	Single-Point Extensometer 51X-GE-00254
J-174	Multiple-Point Extensometer 51X-GE-00255
J-175	Multiple-Point Extensometer 51X-GE-00256
J-176	Multiple-Point Extensometer 51X-GE-00257
J-177	Multiple-Point Extensometer 51X-GE-00258
J-178	Multiple-Point Extensometer 51X-GE-00259
J-179	Multiple-Point Extensometer 51X-GE-00260
J-180	Multiple-Point Extensometer 51X-GE-00261
J-181	Multiple-Point Extensometer 51X-GE-00262
J-182	Multiple-Point Extensometer 51X-GE-00263
J-183	Multiple-Point Extensometer 51X-GE-00264
J-184	Multiple-Point Extensometer 51X-GE-00265
J-185	Multiple-Point Extensometer 51X-GE-00267
J-186	Multiple-Point Extensometer 51X-GE-00268
J-187	Multiple-Point Extensometer 51X-GE-00269
J-188	Multiple-Point Extensometer 51X-GE-00270
J-189	Double-Point Extensometer 51X-GE-00271
J-190	Convergence Meter 51X-CE-00201
J-191	Convergence Meter 51X-CE-00202
J-192	Rockbolt Load Cell 51X-WG-00201
J-193	Rockbolt Load Cell 51X-WG-00202
J-194	Rockbolt Load Cell 51X-WG-00203
J-195	Rockbolt Load Cell 51X-WG-00204
J-196	Rockbolt Load Cell 37X-WG-00206
J-197	Rockbolt Load Cell 37X-WG-00207
J-198	Rigid Stressmeter 51X-NG-00252
J-199	Rigid Stressmeter 51X-NG-00254
J-200	Rigid Stressmeter 51X-NG-00255
J-201	Rigid Stressmeter 51X-NG-00256
J-202	Convergence Points - Waste Shaft - El. 2338

Table J-1 (continued)

J-203	Convergence Points - Waste Shaft - El. 1843
J-204	Convergence Points - Waste Shaft - El. 1350
J-205	Convergence Points - C & SH Shaft - El. 3114
J-206	Convergence Points - C & SH Shaft - El. 2956
J-207	Convergence Points - C & SH Shaft - El. 2825
J-208	Convergence Points - C & SH Shaft - El. 2680
J-209	Convergence Points - C & SH Shaft - El. 2596
J-210	Convergence Points - C & SH Shaft - El. 2470
J-211	Convergence Points - C & SH Shaft - El. 2337
J-212	Convergence Points - C & SH Shaft - El. 2135
J-213	Convergence Points - C & SH Shaft - El. 1846
J-214	Convergence Points - C & SH Shaft - El. 1353
J-215	Convergence Points - E0 Drift, North 1266 Ft
J-216	Convergence Points - E0 Drift - N1100 Drift Intersection
J-217	Convergence Points - E0 Drift, North 940 Ft
J-218	Convergence Points - E0 Drift, North 626 Ft
J-219	Convergence Points - E0 Drift, North 290 Ft
J-220	Convergence Points - E0 Drift - N140 Crosscut Intersection
J-221	Convergence Points - 39 Ft North of C & SH Shaft
J-222	Convergence Points - 15 Ft North of C & SH Shaft
J-223	Convergence Points - 12 Ft West of C & SH Shaft
J-224	Convergence Points - 18 Ft South of C & SH Shaft
J-225	Convergence Points - 18.5 Ft South of C & SH Shaft
J-226	Convergence Points - 30 Ft South of C & SH Shaft
J-227	Convergence Points - 65 Ft South of C & SH Shaft
J-228	Convergence Points - W30 Drift, South 250 Ft
J-229	Convergence Points - W30 Drift, South 500 Ft
J-230	Convergence Points - W30 Drift - S700 Crosscut Intersection
J-231	Convergence Points - W30 Drift, South 850 Ft
J-232	Convergence Points - W30 Drift - S1000 Crosscut Intersection
J-233	Convergence Points - W30 Drift, South 1141 Ft
J-234	Convergence Points - E140 Drift, North 1266 Ft
J-235	Convergence Points - E140 Drift, North 626 Ft
J-236	Convergence Points - E140 Drift, North 240 Ft
J-237	Convergence Points - E140 Drift, North 5 Ft
J-238	Convergence Points - E140 Drift - S400 Crosscut Intersection
J-239	Convergence Points - E140 Drift, South 460 Ft
J-240	Convergence Points - E140 Drift, South 550 Ft
J-241	Convergence Points - E140 Drift, South 850 Ft
J-242	Convergence Points - E140 Drift, South 1150 Ft
J-243	Convergence Points - E140 Drift, South 1246 Ft
J-244	Convergence Points - E140 Drift, South 1450 Ft
J-245	Convergence Points - E140 Drift, South 1879 Ft
J-246	Convergence Points - E140 Drift, South 2066 Ft
J-247	Convergence Points - E140 Drift, South 2350 Ft
J-248	Convergence Points - E140 Drift, South 2625 Ft
J-249	Convergence Points - E140 Drift, South 2950 Ft
J-250	Convergence Points - E140 Drift, South 3250 Ft
J-251	Convergence Points - E140 Drift, South 3614 Ft
J-252	Convergence Points - E140 Drift, South 3639 Ft
J-253	Convergence Points - E140 Drift, South 3664 Ft
J-254	Convergence Points - E300 Drift - S700 Crosscut Intersection
J-255	Convergence Points - E300 Drift, South 850 Ft
J-256	Convergence Points - E300 Drift - S1000 Crosscut Intersecti

Table J-1 (continued)

J-257	Convergence Points - E300 Drift, South 1150 Ft
J-258	Convergence Points - E520 Drift, South 1775 Ft
J-259	Convergence Points - W170 Drift - S700 Crosscut Intersection
J-260	Convergence Points - W170 Drift, South 850 Ft
J-261	Convergence Points - W170 Drift - S1000 Crosscut Intersectio
J-262	Convergence Points - W170 Drift, South 1150 Ft
J-263	Convergence Points - N1100 Drift, West 1347 Ft
J-264	Convergence Points - N1100 Drift, West 1159 Ft
J-265	Convergence Points - N1100 Drift, West 951 Ft
J-266	Convergence Points - N1100 Drift, West 783 Ft
J-267	Convergence Points - N1100 Drift - Test Room 2 Intersection
J-268	Convergence Points - N1100 Drift, East 80 Ft
J-269	Convergence Points - N1100 Drift, East 319 Ft
J-270	Convergence Points - N1100 Drift, East 691 Ft
J-271	Convergence Points - N1100 Drift, East 846 Ft
J-272	Convergence Points - N1100 Drift, East 1135 Ft
J-273	Convergence Points - N1100 Drift, East 1582 Ft
J-274	Convergence Points - N1420 Drift, West 391 Ft
J-275	Convergence Points - N1420 Drift - Test Room 2 Intersection
J-276	Convergence Points - N1420 Drift, West 258 Ft
J-277	Convergence Points - N1420 Drift - Test Room 1 Intersection
J-278	Convergence Points - N1420 Drift, East 304 Ft
J-279	Convergence Points - N1420 Drift, East 716 Ft
J-280	Convergence Points - N1420 Drift, East 1106 Ft
J-281	Convergence Points - N1420 Drift, East 1547 Ft
J-282	Convergence Points - Substation 2A
J-283	Convergence Points - Test Room 1
J-284	Convergence Points - Test Room 2
J-285	Convergence Points - Test Room 3
J-286	Convergence Points - Test Room 4
J-287	Convergence Points - Room L1, North 1455 Ft
J-288	Convergence Points - Room L2, North 1455 Ft
J-289	Convergence Points - S90 Crosscut, East 91 Ft
J-290	Convergence Points - 17 Ft East of Waste Shaft
J-291	Convergence Points - 20 Ft West of Waste Shaft
J-292	Convergence Points - S700 Crosscut, East 205 Ft
J-293	Convergence Points - S1600 Drift, East 311 Ft
J-294	Convergence Points - S1600 Drift, East 332 Ft
J-295	Convergence Points - S1600 Drift, East 357 Ft
J-296	Convergence Points - S1600 Drift, East 382 Ft
J-297	Convergence Points - S1600 Drift, East 407 Ft
J-298	Convergence Points - S1600 Drift, East 432 Ft
J-299	Convergence Points - S1600 Drift, East 457 Ft
J-300	Convergence Points - S1600 Drift, East 482 Ft
J-301	Convergence Points - S1600 Drift, East 507 Ft
J-302	Convergence Points - S1600 Drift, East 520 Ft
J-303	Convergence Points - S1950 Drift, East 311 Ft
J-304	Convergence Points - S1950 Drift, East 332 Ft
J-305	Convergence Points - S1950 Drift, East 357 Ft
J-306	Convergence Points - S1950 Drift, East 382 Ft
J-307	Convergence Points - S1950 Drift, East 407 Ft
J-308	Convergence Points - S1950 Drift, East 432 Ft
J-309	Convergence Points - S1950 Drift, East 457 Ft
J-310	Convergence Points - S1950 Drift, East 482 Ft
J-311	Convergence Points - S1950 Drift, East 503 Ft

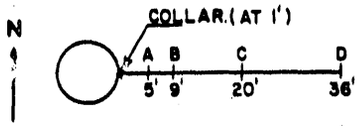
Table J-1 (continued)

J-312	Convergence Points - S1950 Drift, East 523 Ft
J-313	Convergence Points - S1950 Drift, East 586 Ft
J-314	Inclinometer 51X-IG-00201
J-315	Inclinometer 51X-IG-00202
J-316	Inclinometer 51X-IG-00203
J-317	Inclinometer 51X-IG-00204
J-318	Inclinometer 51X-IG-00205
J-319	Inclinometer 51X-IG-00206
J-320	Inclinometer 51X-IG-00211
J-321	Inclinometer 51X-IG-00212
J-322	Inclinometer 51X-IG-00213
J-323	Inclinometer 51X-IG-00214
J-324	Inclinometer 51X-IG-00215
J-325	Inclinometer 51X-IG-00216
J-326	Inclinometer 51X-IG-00217
J-327	Inclinometer 51X-IG-00218
J-328	Inclinometer 51X-IG-00219
J-329	Inclinometer 51X-IG-00220
J-330	Inclinometer 51X-IG-00221
J-331	Inclinometer 51X-IG-00222
J-332	Inclinometer 51X-IG-00223
J-333	Inclinometer 51X-IG-00224
J-334	Inclinometer 51X-IG-00225
J-335	Inclinometer 51X-IG-00226

Table J-2

SCHEMATIC SYMBOLS FOR DATA PLOTS

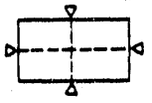
NOT TO SCALE



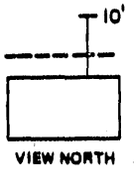
SHAFT IN PLAN, SHOWING EXTENSOMETER AND INSTRUMENT ANCHORS A, B, C, D AT DEPTHS 5, 9, 20, 36 FT., RESPECTIVELY.

SHAFT IN PLAN, SHOWING LOCATION OF STRAIN GAUGE.

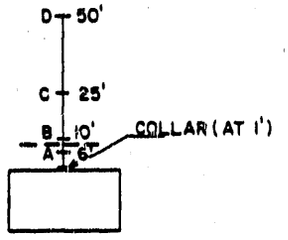
SHAFT IN PLAN, SHOWING PRESSURE CELL LOCATION.



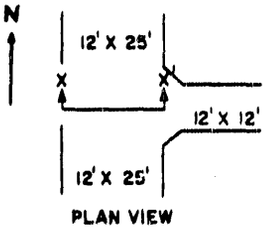
OPENING CROSS SECTION, SHOWING CONVERGENCE POINTS.



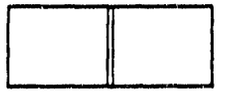
OPENING CROSS SECTION, SHOWING ROCK BOLT LOCATION AND DEPTH IN FT. CLAY PARTING SHOWN AT 3 FT.



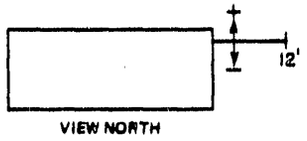
OPENING CROSS SECTION, SHOWING EXTENSOMETER IN ROOF AND INSTRUMENT ANCHORS A, B, C, AND D AT DEPTHS 6, 10, 25, AND 50 FT., RESPECTIVELY. CLAY PARTING SHOWN AT 8FT.



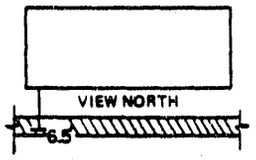
DRIFT INTERSECTION IN PLAN, SHOWING LOCATION OF DRIFT CROSS SECTION X-X' AND DIMENSIONS (HEIGHT x WIDTH) OF DRIFTS.



TEST ROOM CROSS SECTION, SHOWING LOCATION OF CONVERGENCE METER.



TEST ROOM CROSS SECTION, SHOWING INCLINOMETER LOCATION AND DEPTH IN FT. POSITIVE VALUE ON PLOT DENOTES UPWARD MOVEMENT.



TEST ROOM CROSS SECTION, SHOWING STRESSMETER LOCATION AND DEPTH IN FT. ANHYDRITE BED SHOWN AT 4 TO 7 FT.

Table J-3

DESCRIPTION OF INSTRUMENT IDENTIFICATION

Field Designation (assigned in Bechtel contract packages)

IJX	-	AB	-	002	NO	
>		>		>	>	
>		>		>	>	
>		>		>	>_____	Instrument number (01, 02, ...)
>		>		>		
>		>		>_____		Bechtel Drawing No. for contractors which illustrates item (37X-002, 51X-002, ...)
>		>				
>		>				
>		>_____				Notation for type of instrument (PE, GE, ...) listed below
>						
>						
>_____						General instrument location (31X, ...)

General instrument location:

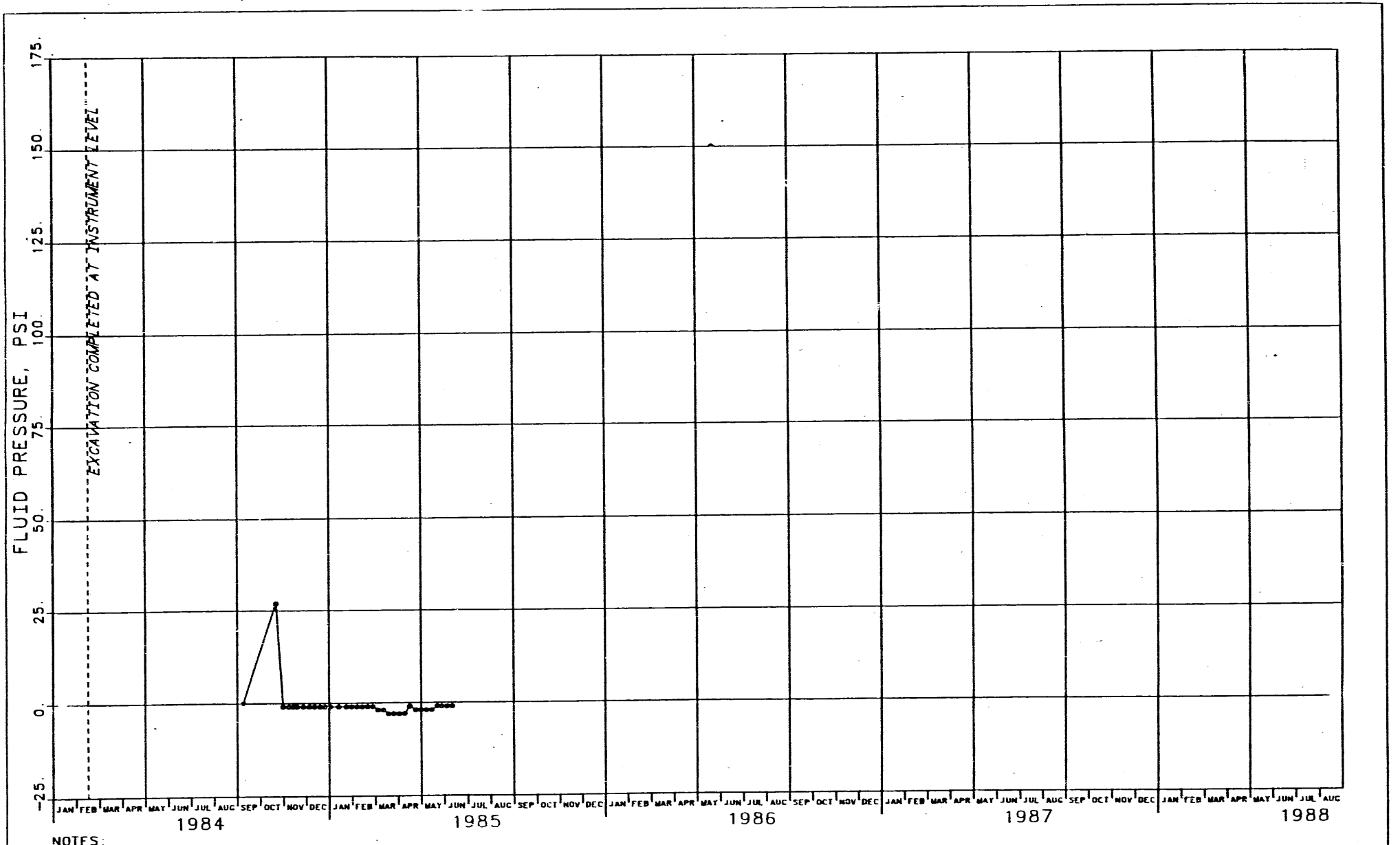
31X	Waste shaft
35X	Exhaust shaft
37X	C & SH shaft
51X	Drift level

Type of instrument:

CE	Convergence meter
GE	Extensometer
IG	Inclinometer
NG	Rigid-inclusion stressmeter
PE	Piezometer
RC	Permanent convergence points
TC	Temporary convergence points
RS	Wall shortening points
WE	Pressure cell
WG	Rockbolt load cell
ZE	Strain gauge

Example Field Designation

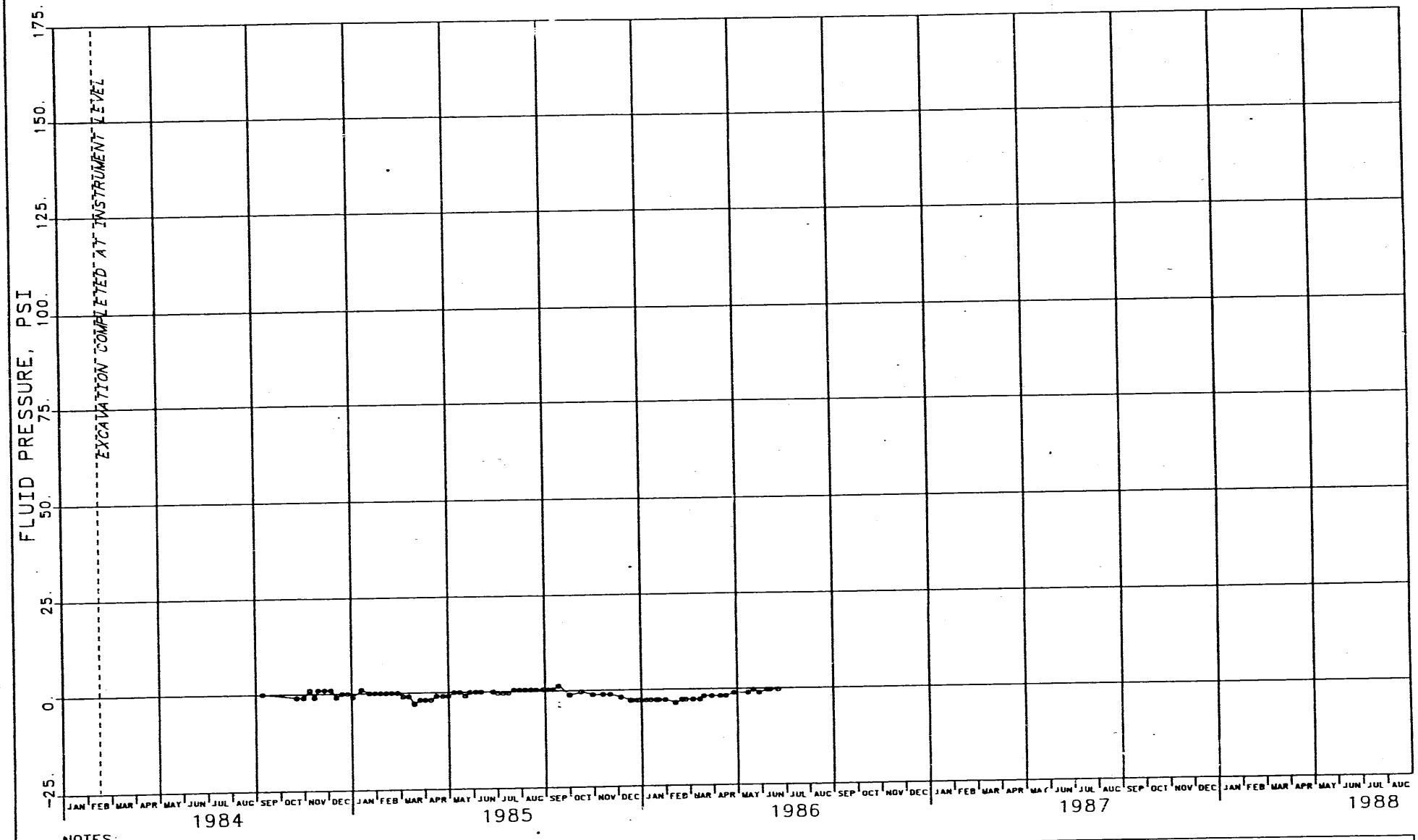
51X-GE-00246 is a drift level (51X) extensometer (GE) which may also be referred to as GE-246 on figures and tables in this report. However, convergence points are designated by approximate shaft depth or drift station.



NOTES:

1. CONCRETE LINER WAS PLACED NOV 1983 THROUGH APR 3, 1984
2. INSTRUMENT IS CURRENTLY NOT ACCESSIBLE FOR REPAIR

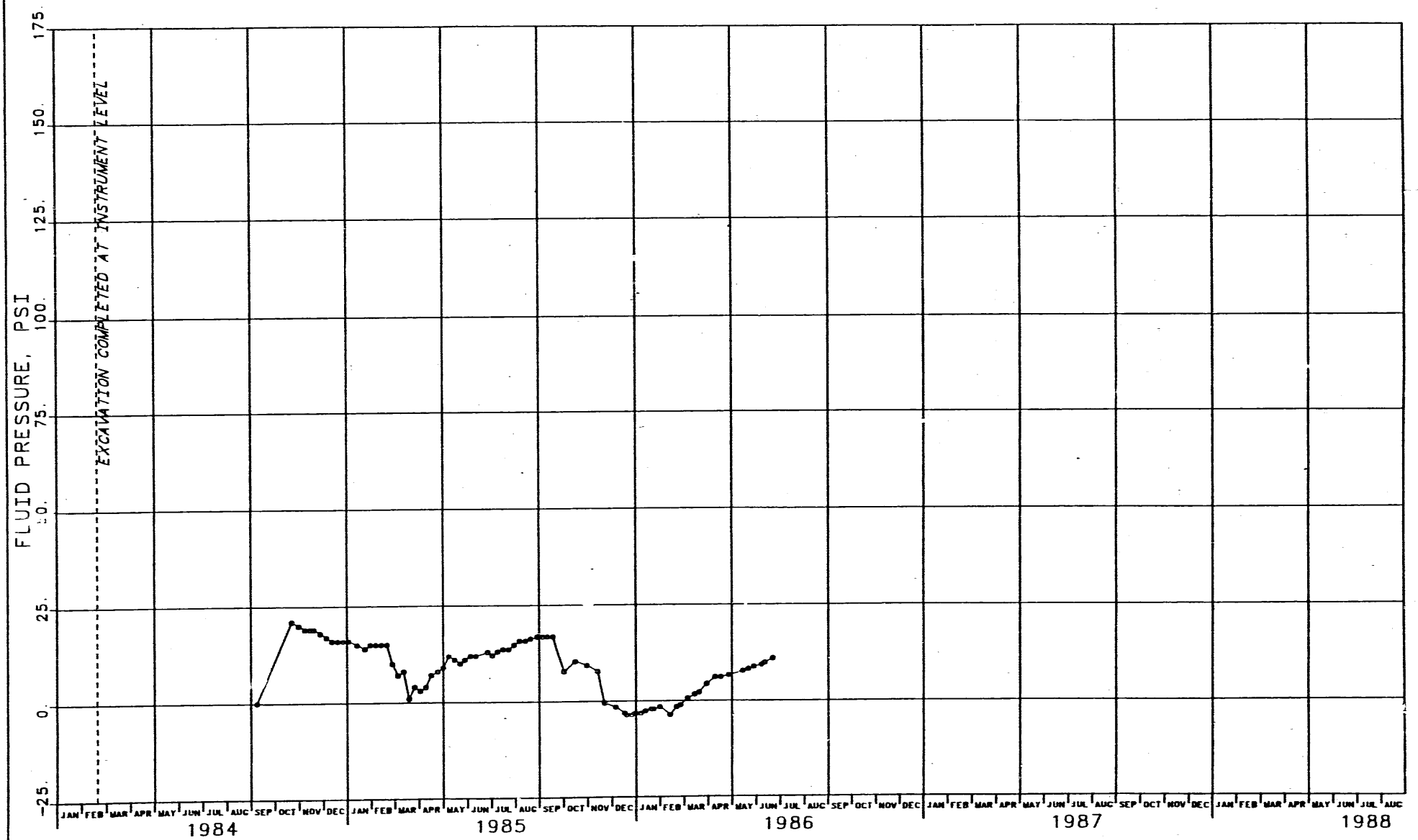
FIGURE J-1
PIEZOMETER 31X-PE-00201
WASTE SHAFT - EL 2877
PRESSURE VS. CALENDAR MONTH



NOTES

1. CONCRETE LINER WAS PLACED NOV 1983 THROUGH APR 3, 1984

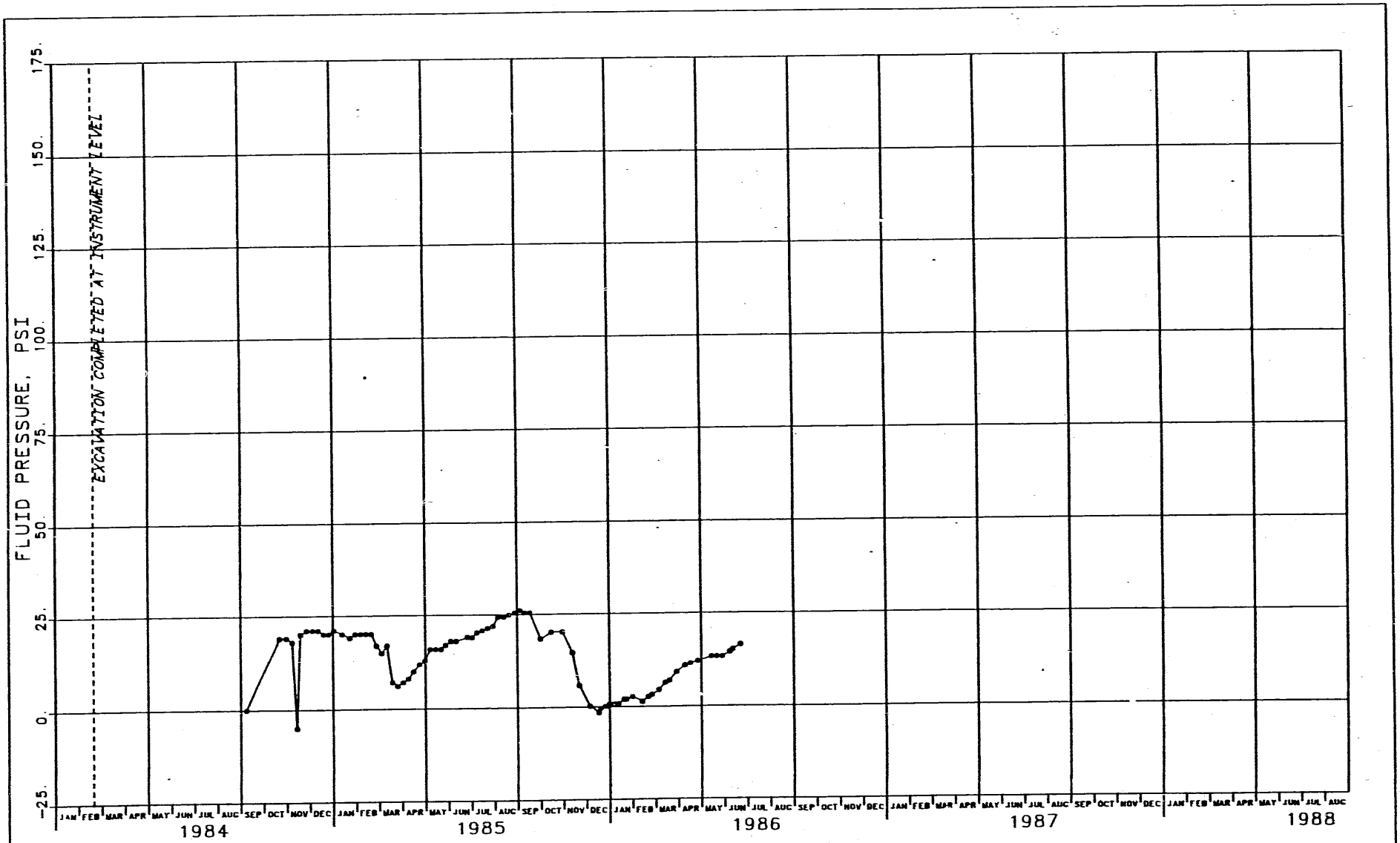
FIGURE J-2
PIEZOMETER 31X-PE-00202
WASTE SHAFT - EL 2877
PRESSURE VS. CALENDAR MONTH



NOTES:

1. CONCRETE LINER WAS PLACED NOV. 1983 THROUGH APR 3, 1984.

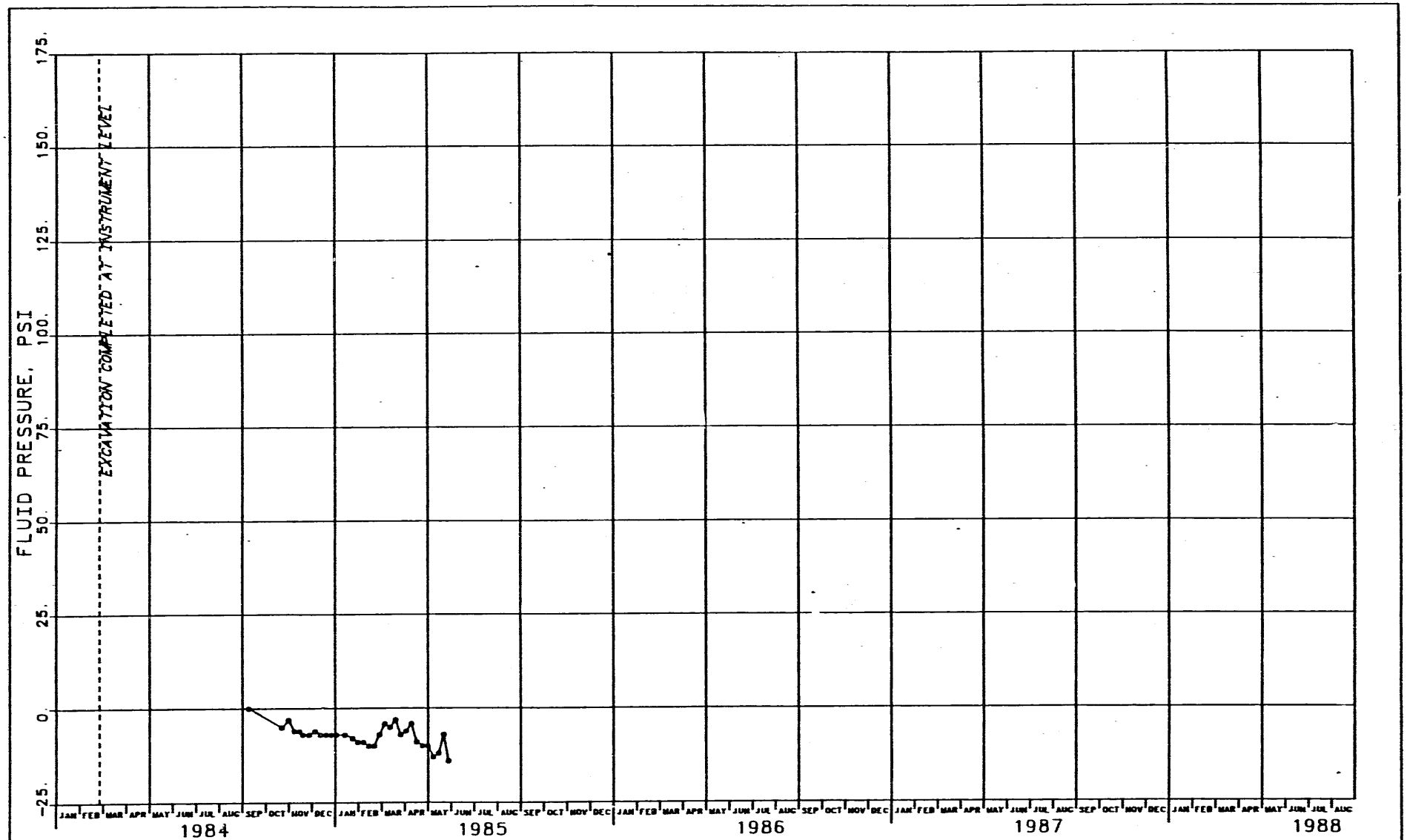
FIGURE J-3
PIEZOMETER 31X-PE-00203
WASTE SHAFT - EL 2798 (MAGENTA)
PRESSURE VS. CALENDAR MONTH



NOTES:

1. CONCRETE LINER WAS PLACED NOV. 1983 THROUGH APR. 3, 1984.

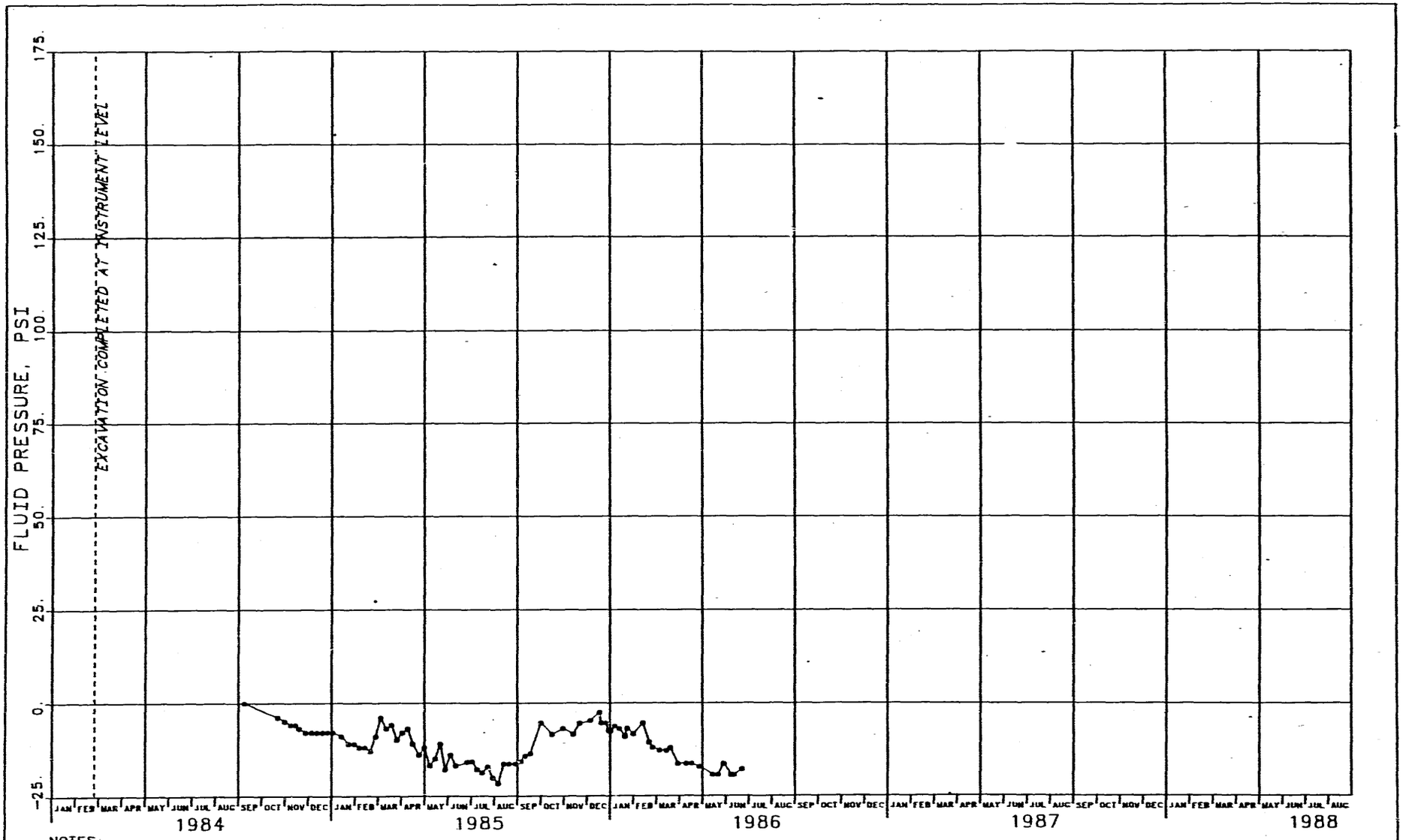
FIGURE J-4
PIEZOMETER 31X-PE-00204
WASTE SHAFT - EL 2798 (MAGENTA)
PRESSURE VS. CALENDAR MONTH



NOTES

1. CONCRETE LINER WAS PLACED NOV 1983 THROUGH APR 3, 1984.
2. INSTRUMENT IS CURRENTLY NOT ACCESSIBLE FOR REPAIR

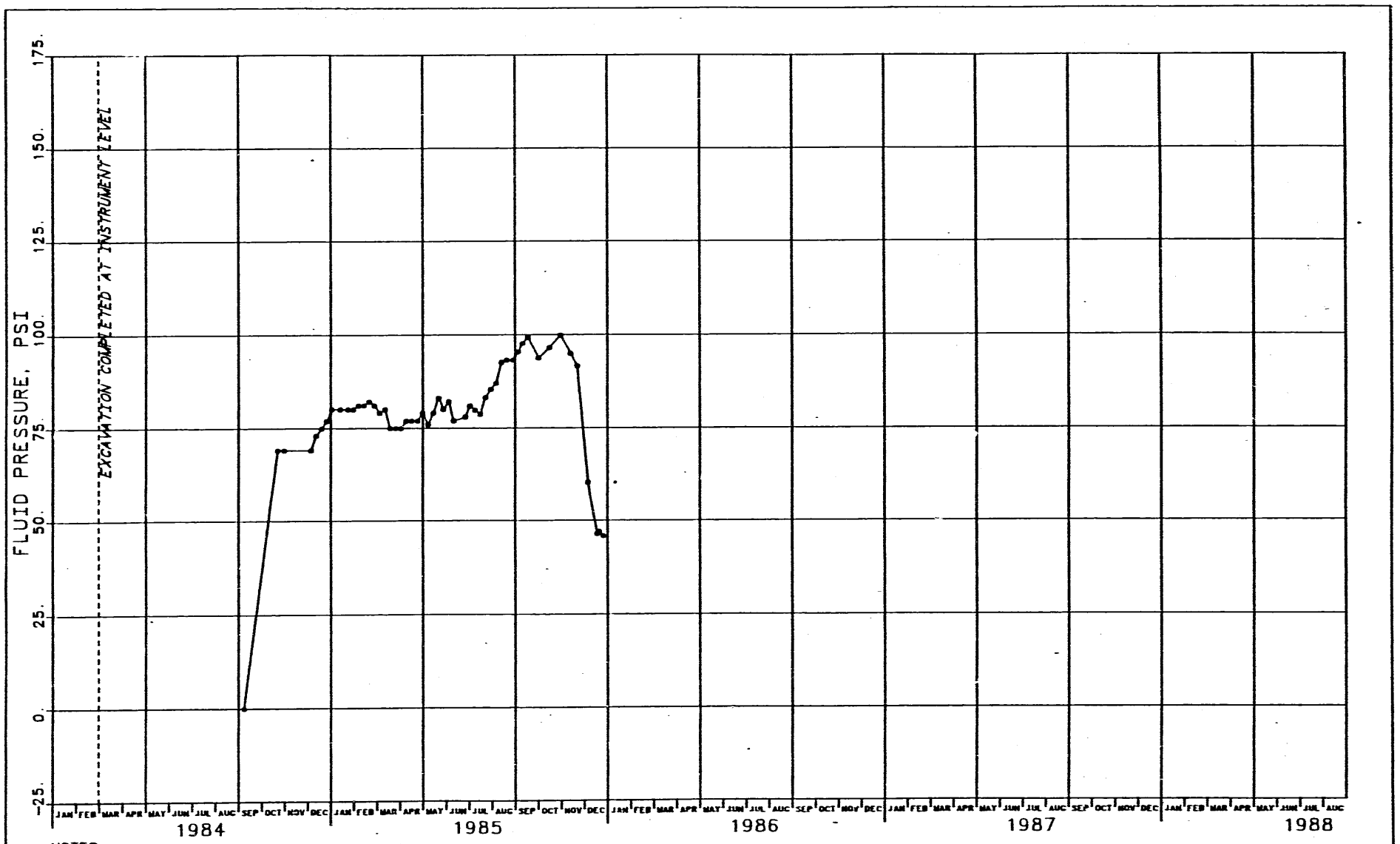
FIGURE J-5
PIEZOMETER 31X-PE-00205
WASTE SHAFT - EL 2740
PRESSURE VS. CALENDAR MONTH



NOTES

1. CONCRETE LINER WAS PLACED NOV. 1983 THROUGH APR. 3, 1984

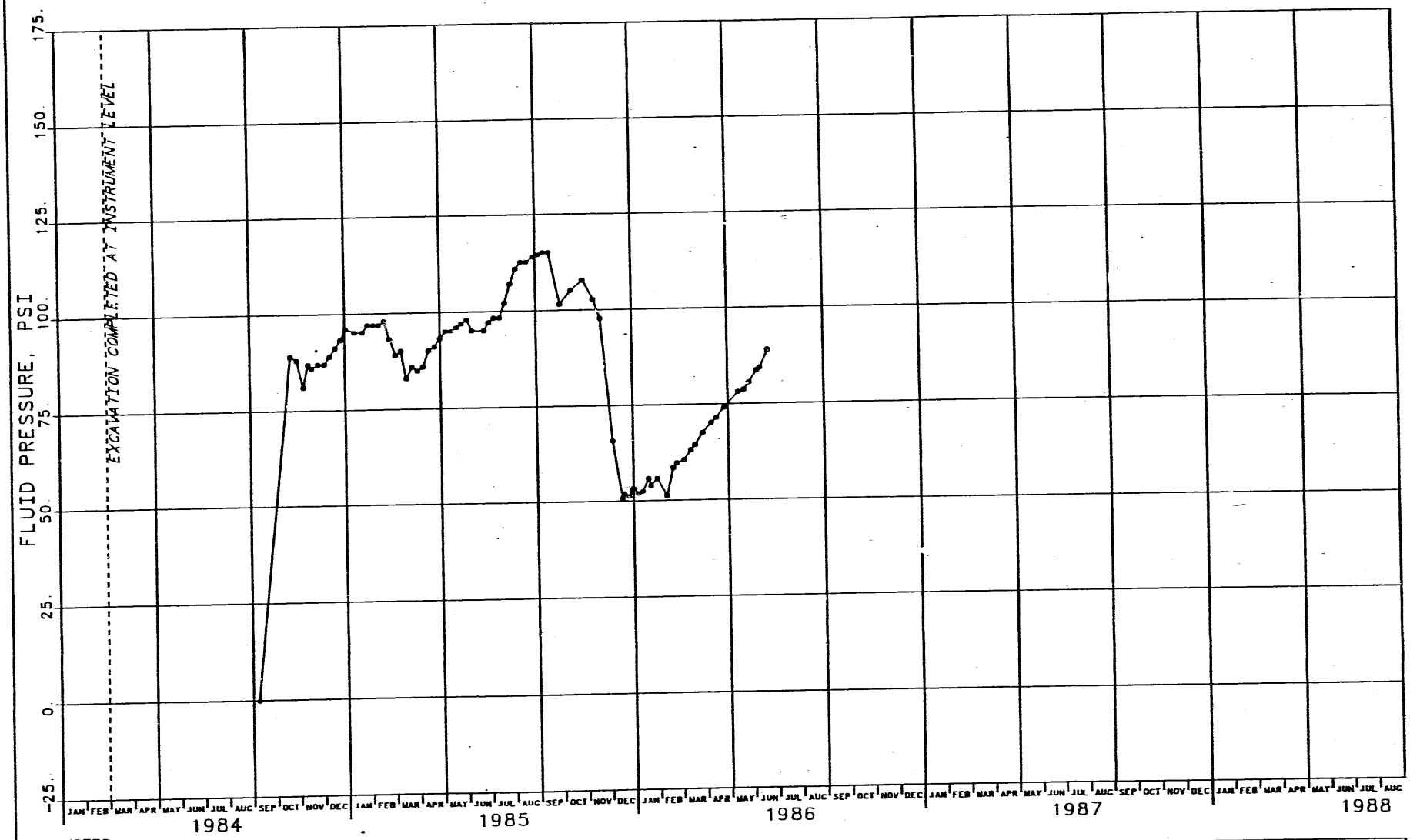
FIGURE J-6
PIEZOMETER 31X-PE-00206
WASTE SHAFT – EL 2740
PRESSURE VS. CALENDAR MONTH



NOTES:

1. CONCRETE LINER WAS PLACED NOV. 1983 THROUGH APR. 3, 1984.
2. INSTRUMENT IS CURRENTLY NOT ACCESSIBLE FOR REPAIR.

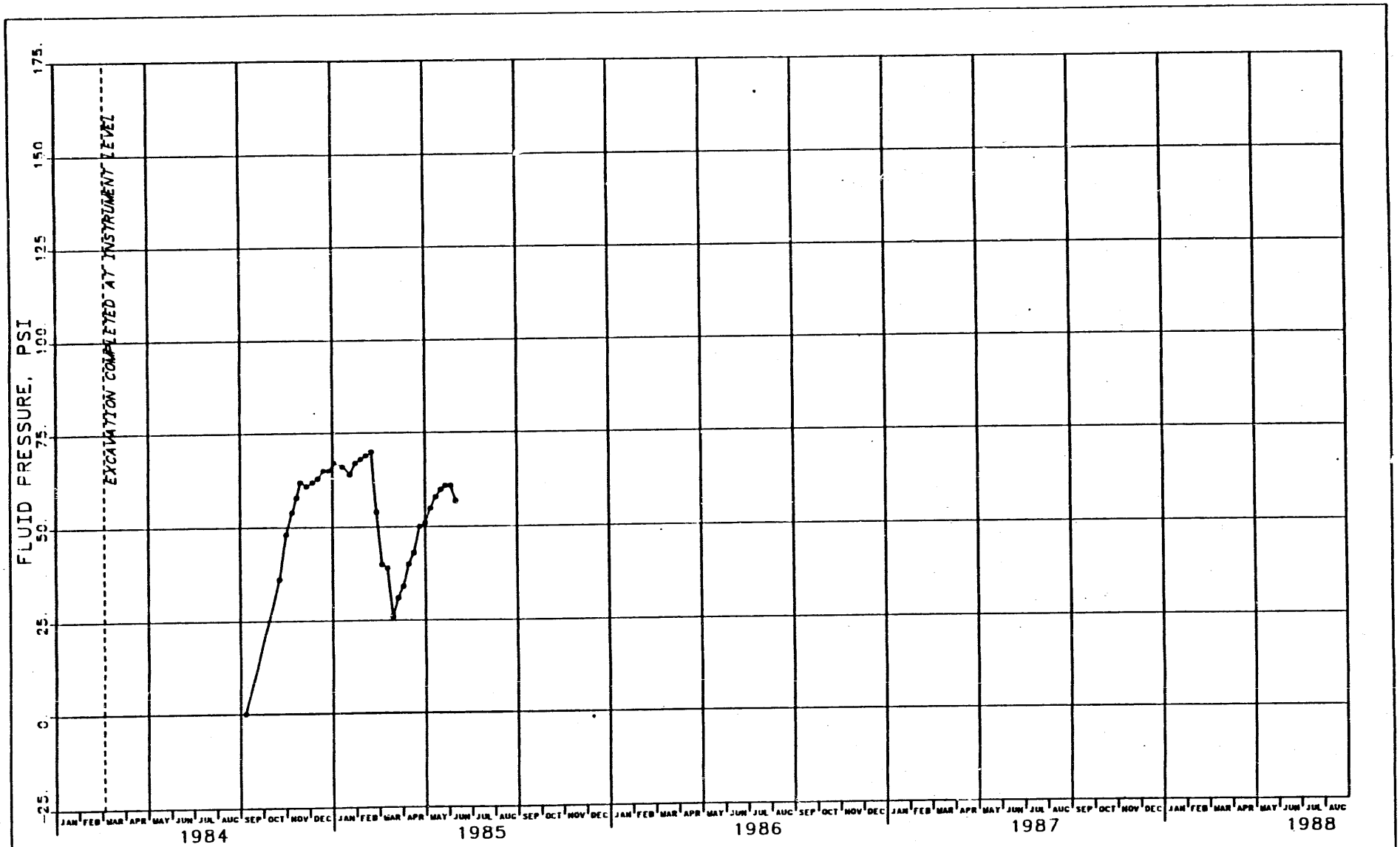
FIGURE J-7
PIEZOMETER 31X-PE-00207
WASTE SHAFT - EL 2692 (CULEBRA)
PRESSURE VS. CALENDAR MONTH



NOTES:

1. CONCRETE LINER WAS PLACED NOV. 1983 THROUGH APR. 3, 1984.

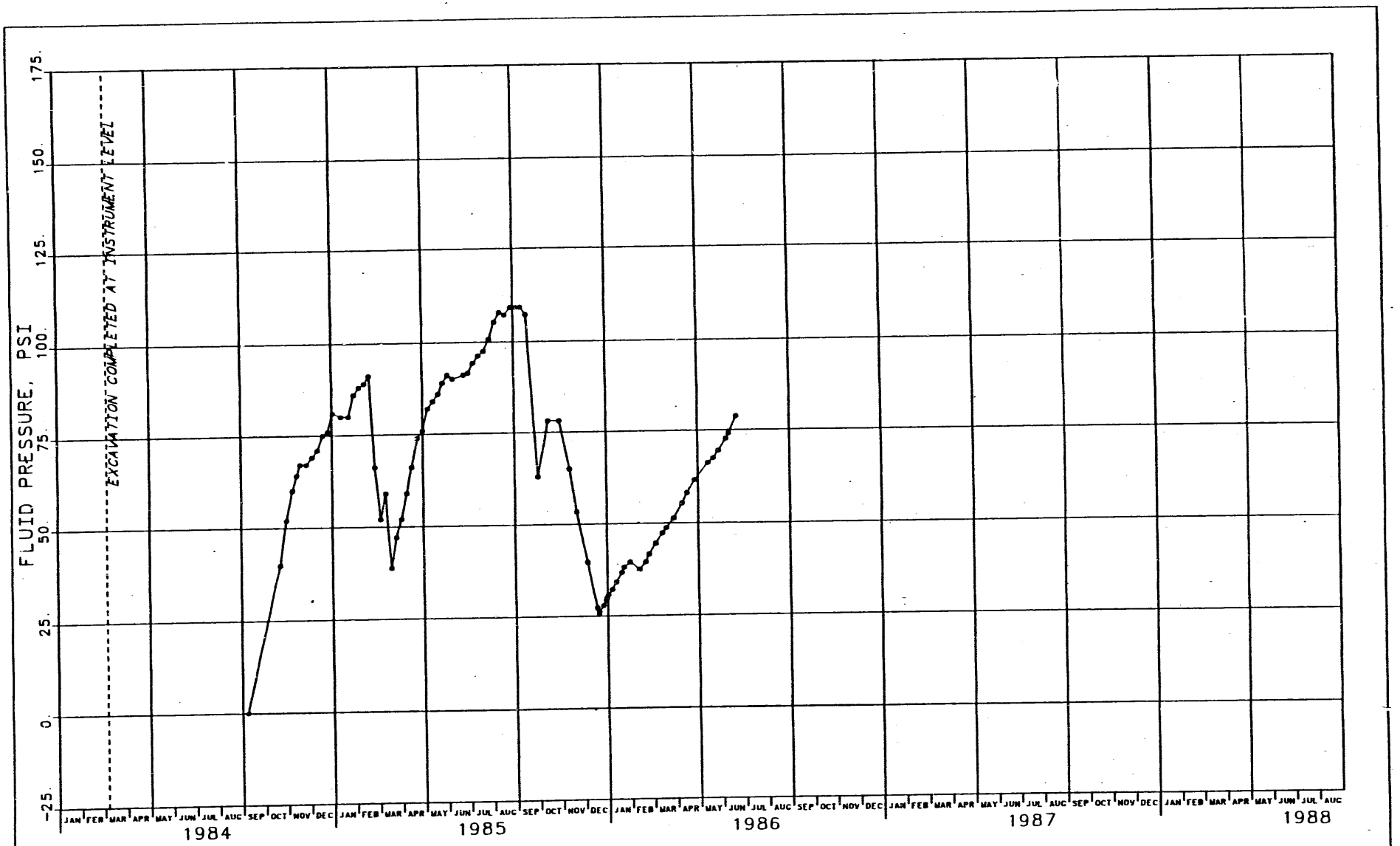
FIGURE J-8
PIEZOMETER 31X-PE-00208
WASTE SHAFT - EL 2692 (CULEBRA)
PRESSURE VS. CALENDAR MONTH



NOTES:

1. CONCRETE LINER WAS PLACED NOV 1983 THROUGH APR 3, 1984.
2. INSTRUMENT IS CURRENTLY NOT ACCESSIBLE FOR REPAIR

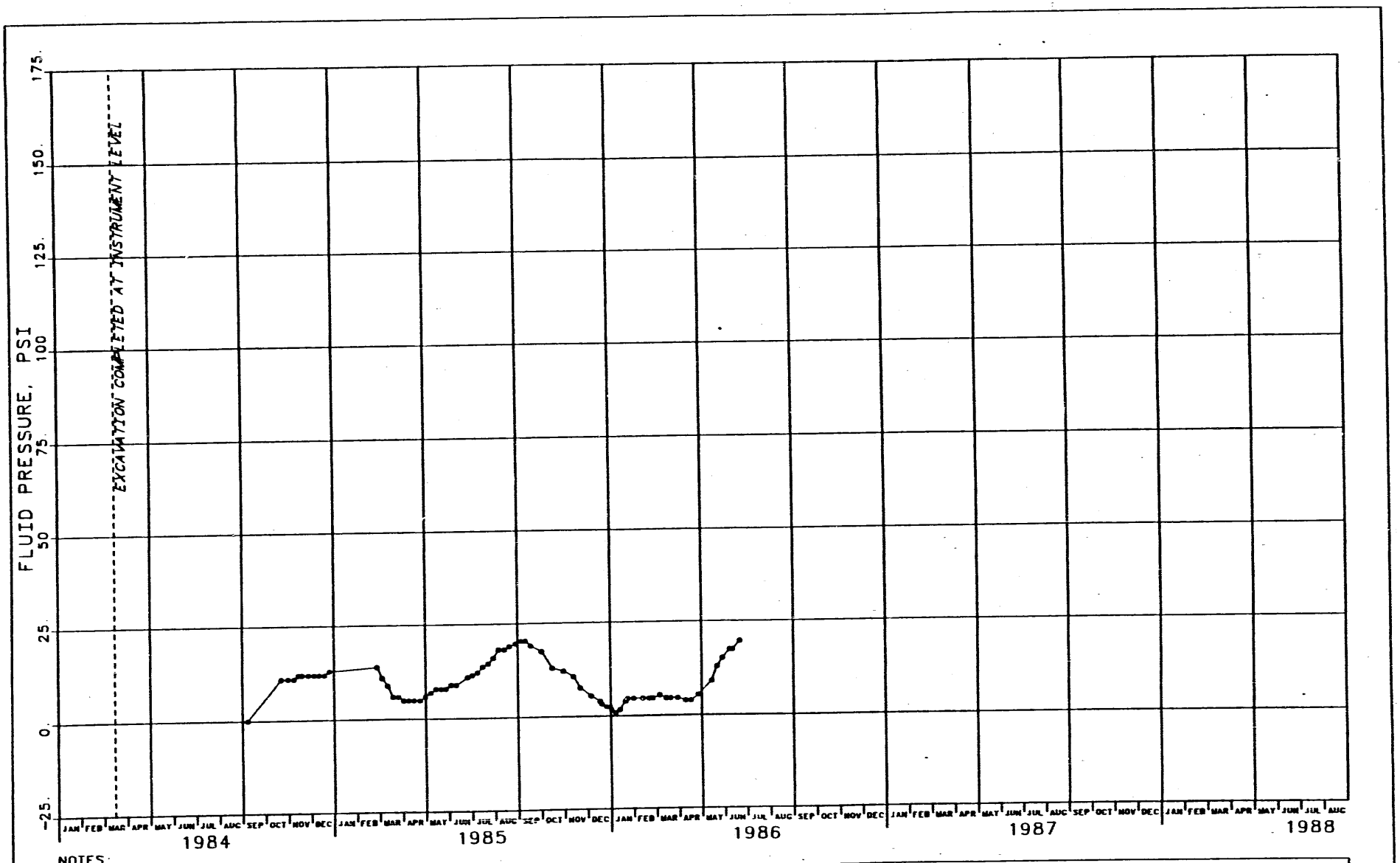
FIGURE J-9
PIEZOMETER 31X-PE-00209
WASTE SHAFT - EL 2651
PRESSURE VS. CALENDAR MONTH



NOTES:

1. CONCRETE LINER WAS PLACED NOV. 1983 THROUGH APR. 3, 1984.

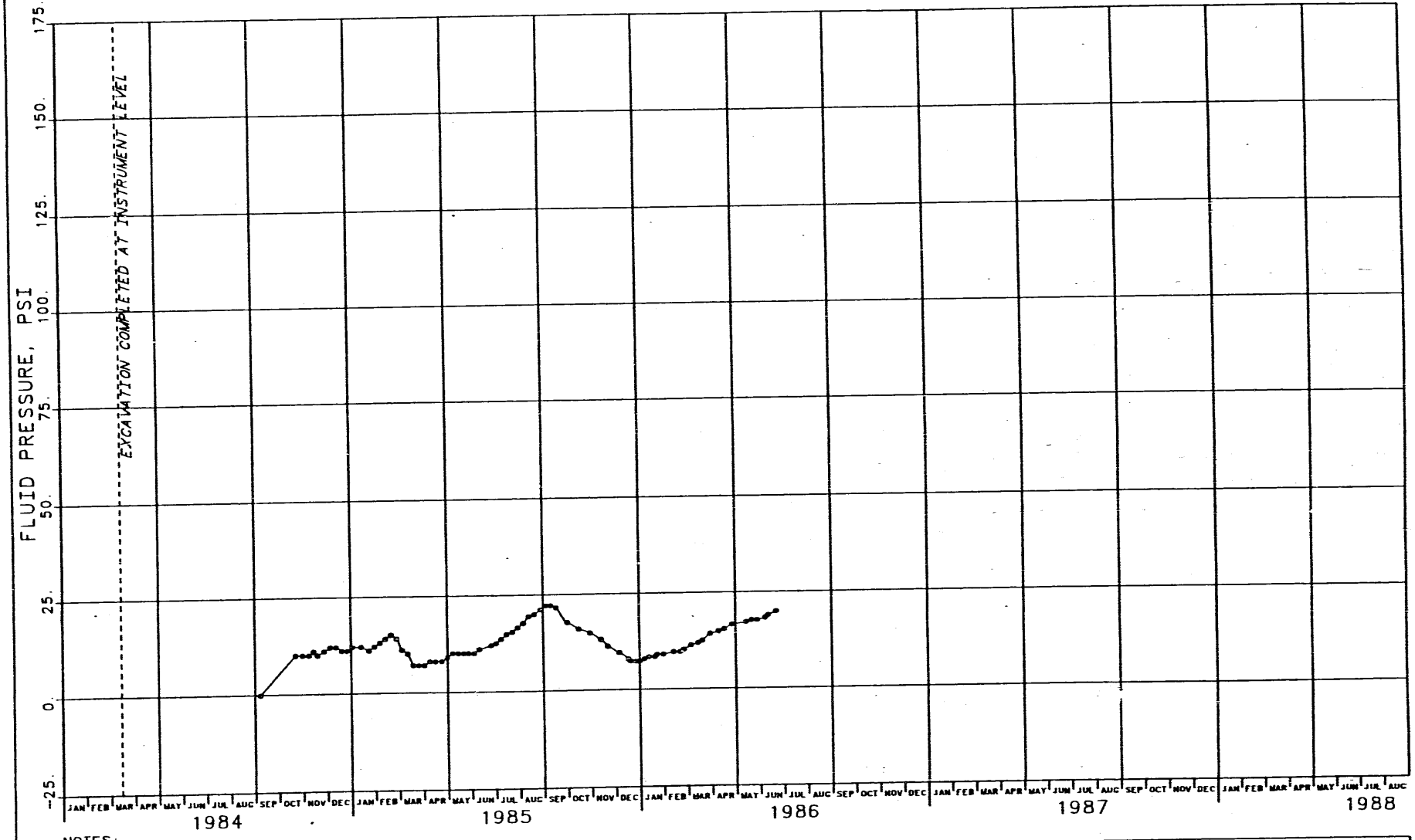
FIGURE J-10
PIEZOMETER 31X-PE-00210
WASTE SHAFT - EL 2651
PRESSURE VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED MARCH 23 THROUGH APRIL 3, 1984.

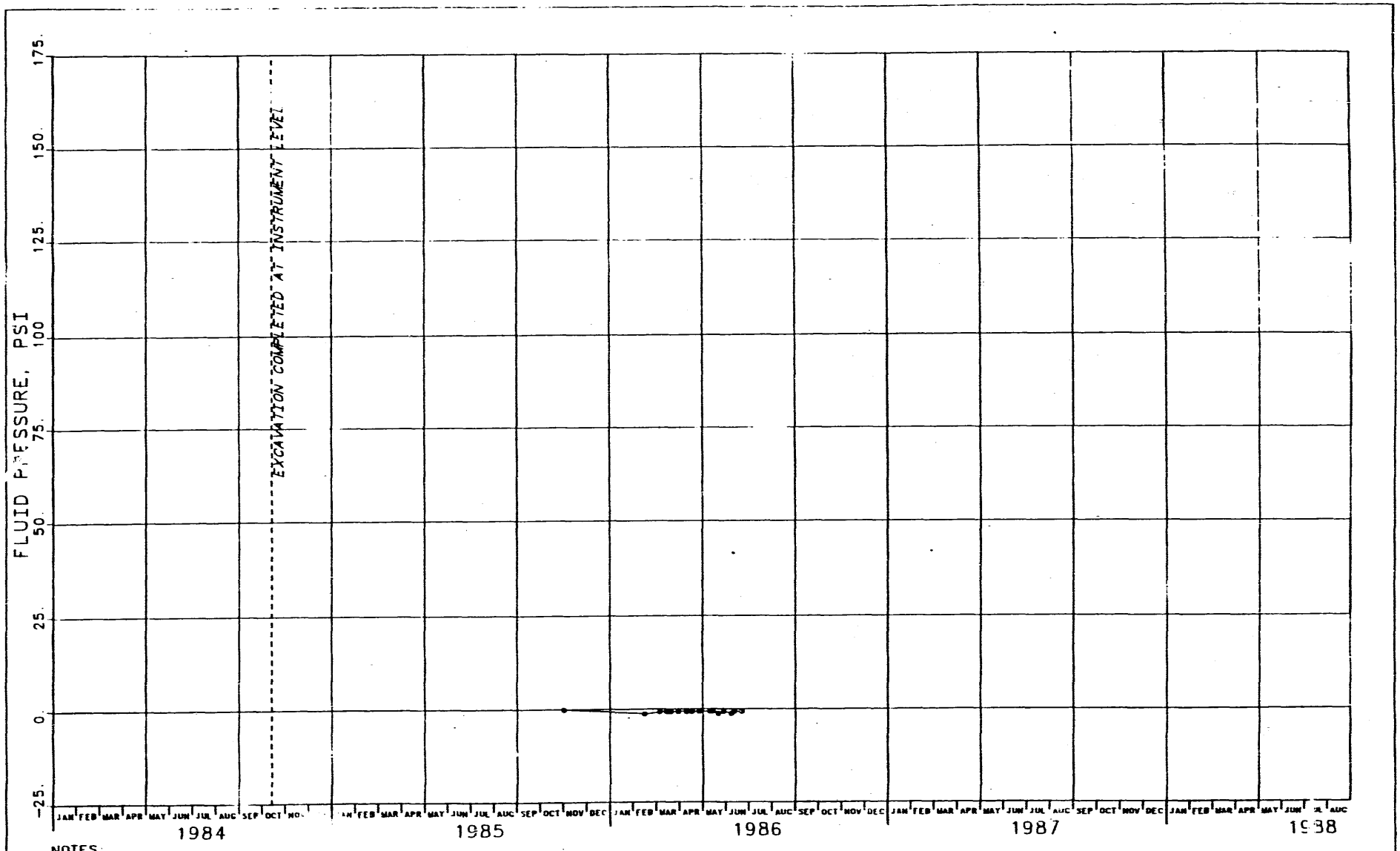
FIGURE J-11
PIEZOMETER 31X-PE-00211
WASTE SHAFT KEY - EL 2564
PRESSURE VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED MARCH 23 THROUGH APRIL 3, 1984.

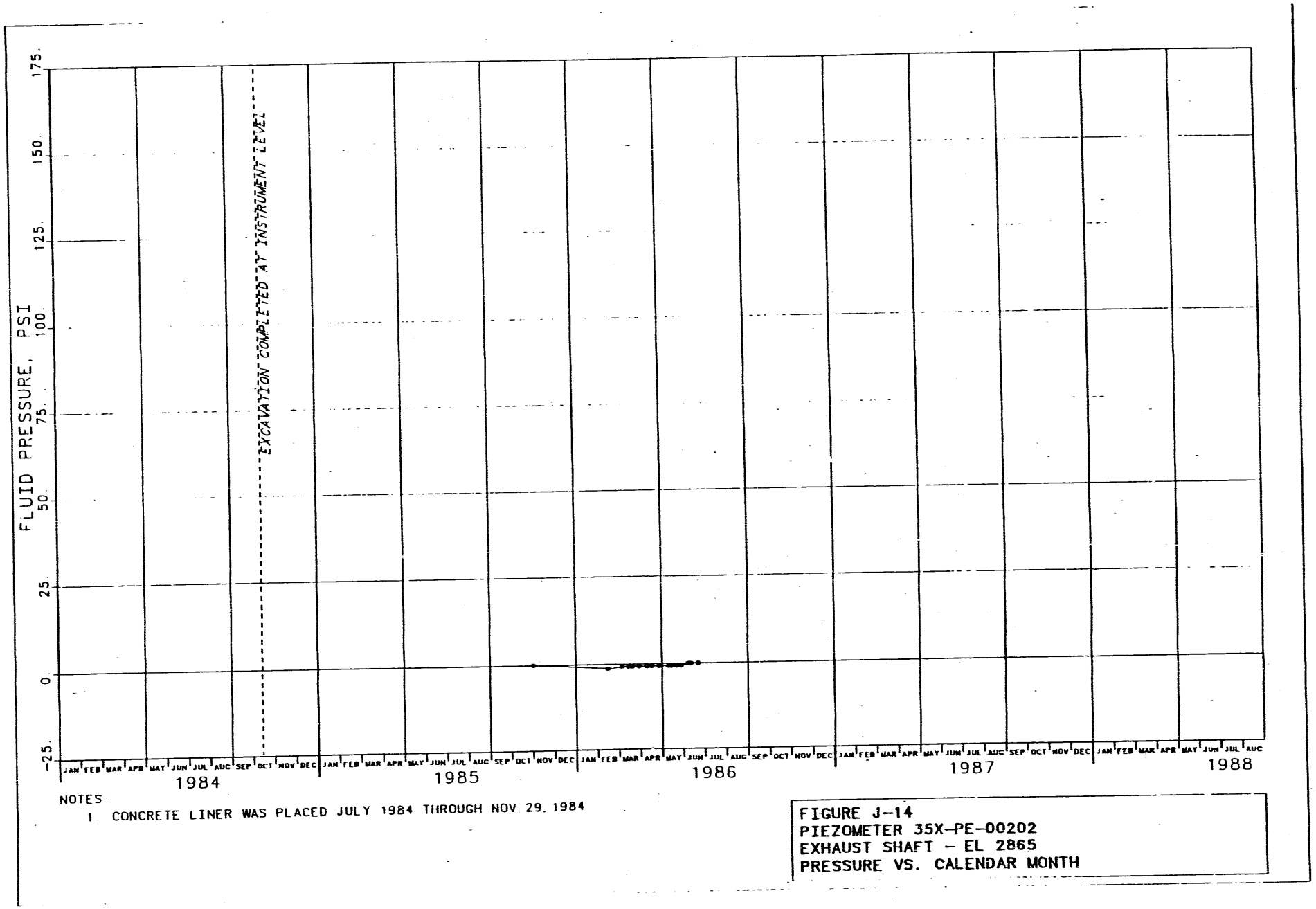
FIGURE J-12
PIEZOMETER 31X-PE-00212
WASTE SHAFT KEY - EL 2564
PRESSURE VS. CALENDAR MONTH



NOTES:

1 CONCRETE LINER WAS PLACED JULY 1984 THROUGH NOV. 29, 1984.

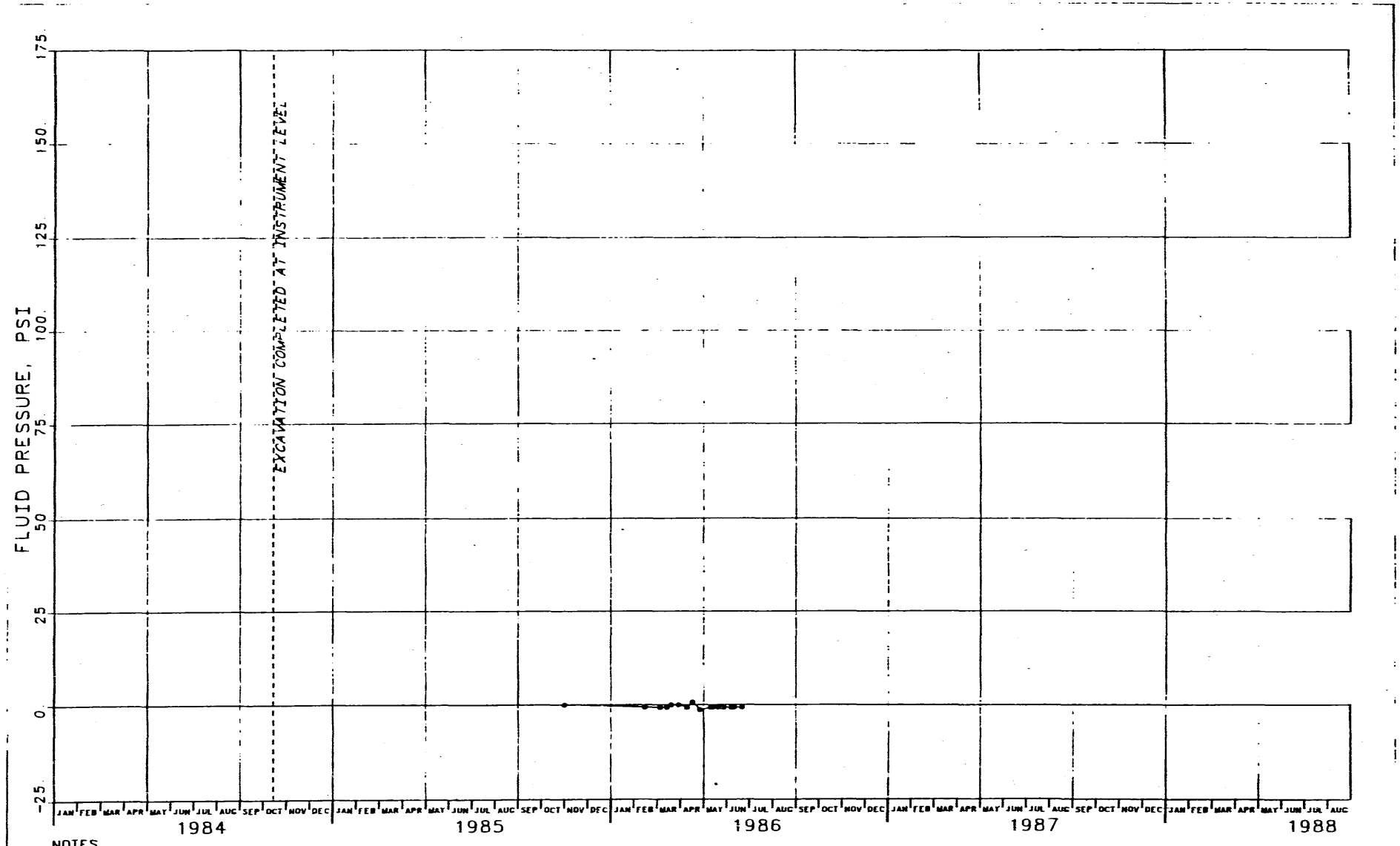
FIGURE J-13
PIEZOMETER 35X-PE-00201
EXHAUST SHAFT – EL 2865
PRESSURE VS. CALENDAR MONTH



NOTES

1. CONCRETE LINER WAS PLACED JULY 1984 THROUGH NOV. 29, 1984

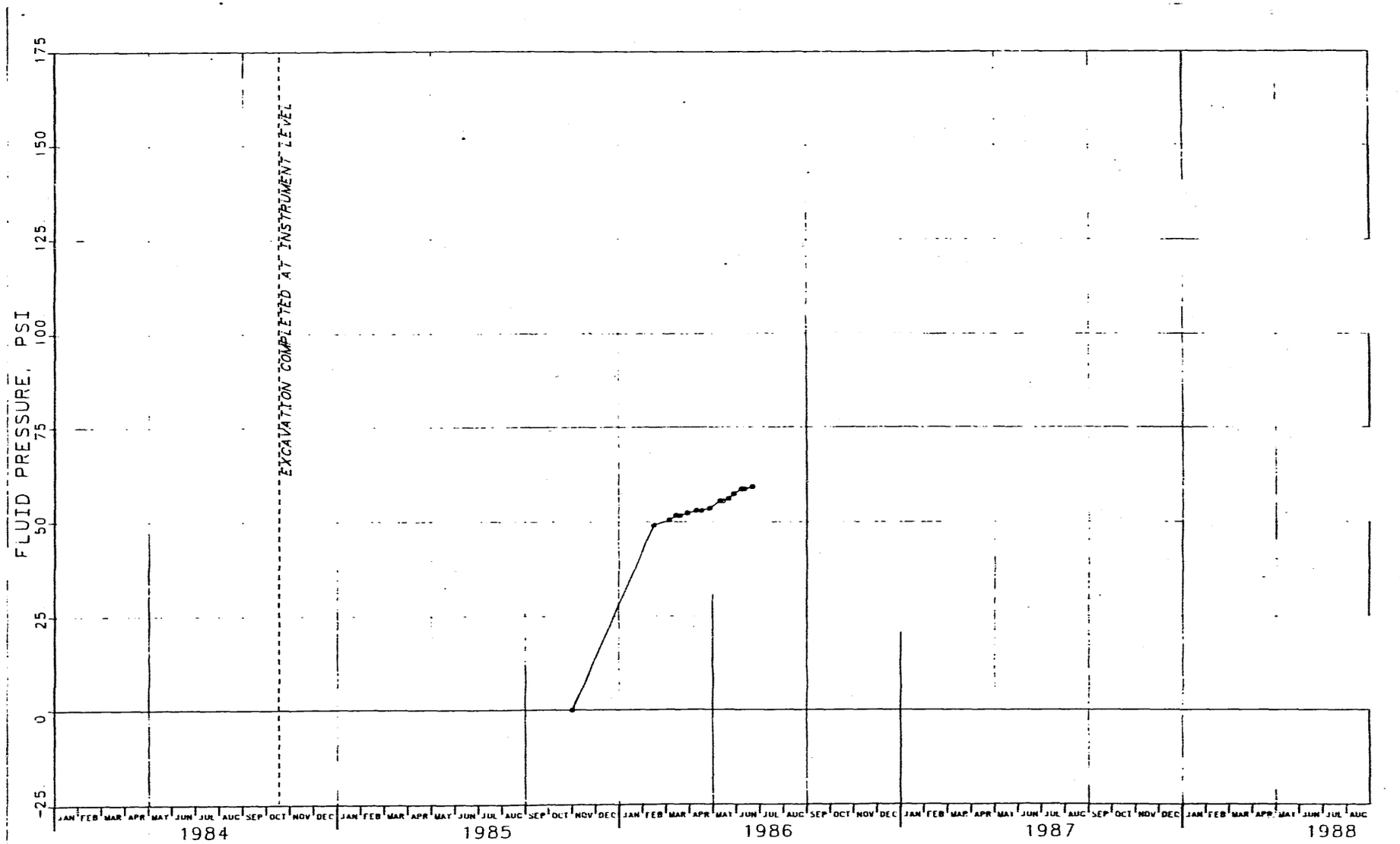
FIGURE J-14
PIEZOMETER 35X-PE-00202
EXHAUST SHAFT - EL 2865
PRESSURE VS. CALENDAR MONTH



NOTES

1. CONCRETE LINER WAS PLACED JULY 1984 THROUGH NOV 29, 1984

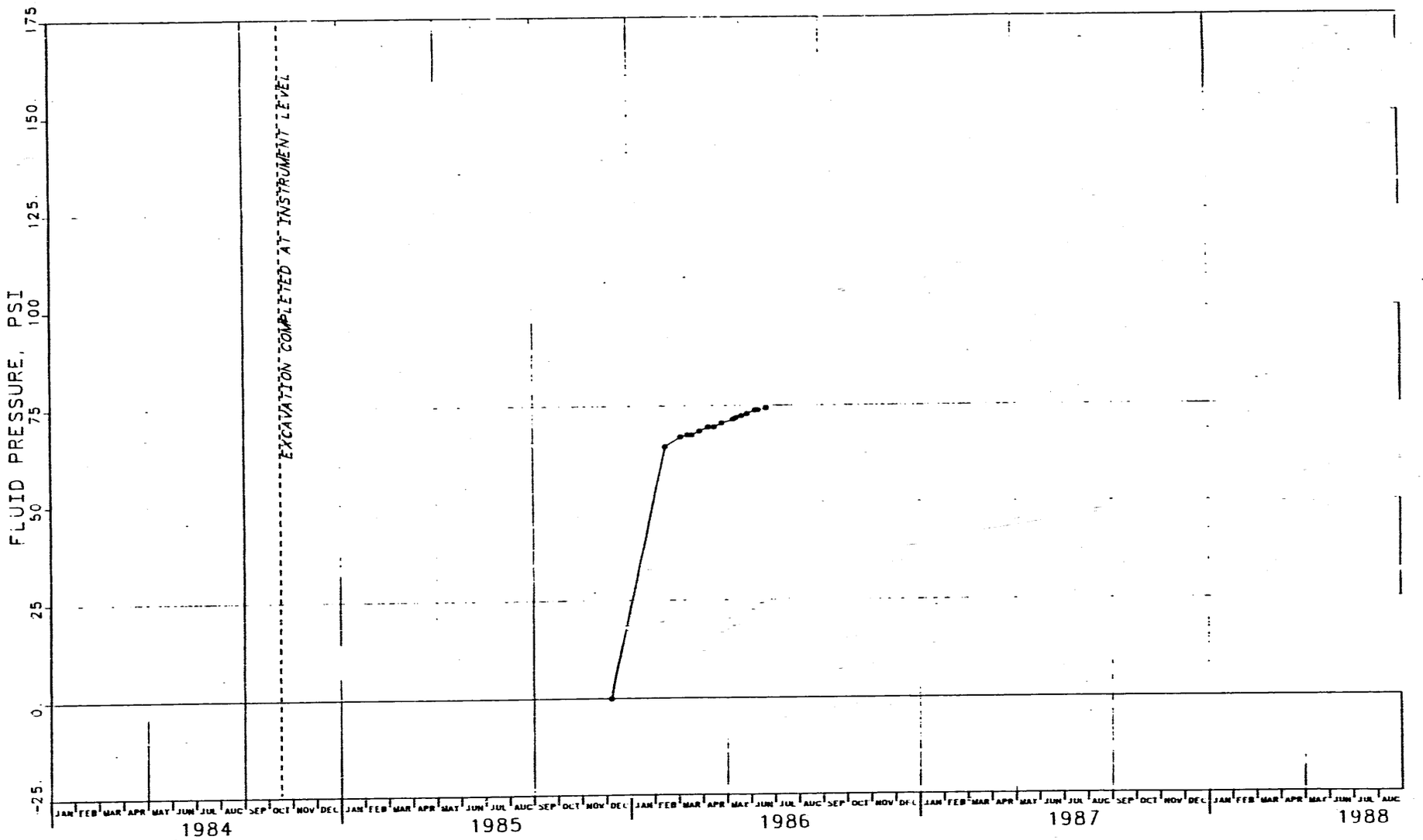
FIGURE J-15
PIEZOMETER 35X-PE-00203
EXHAUST SHAFT – EL 2865
PRESSURE VS. CALENDAR MONTH



NOTES

1 CONCRETE LINER WAS PLACED JULY 1984 THROUGH NOV 29, 1984

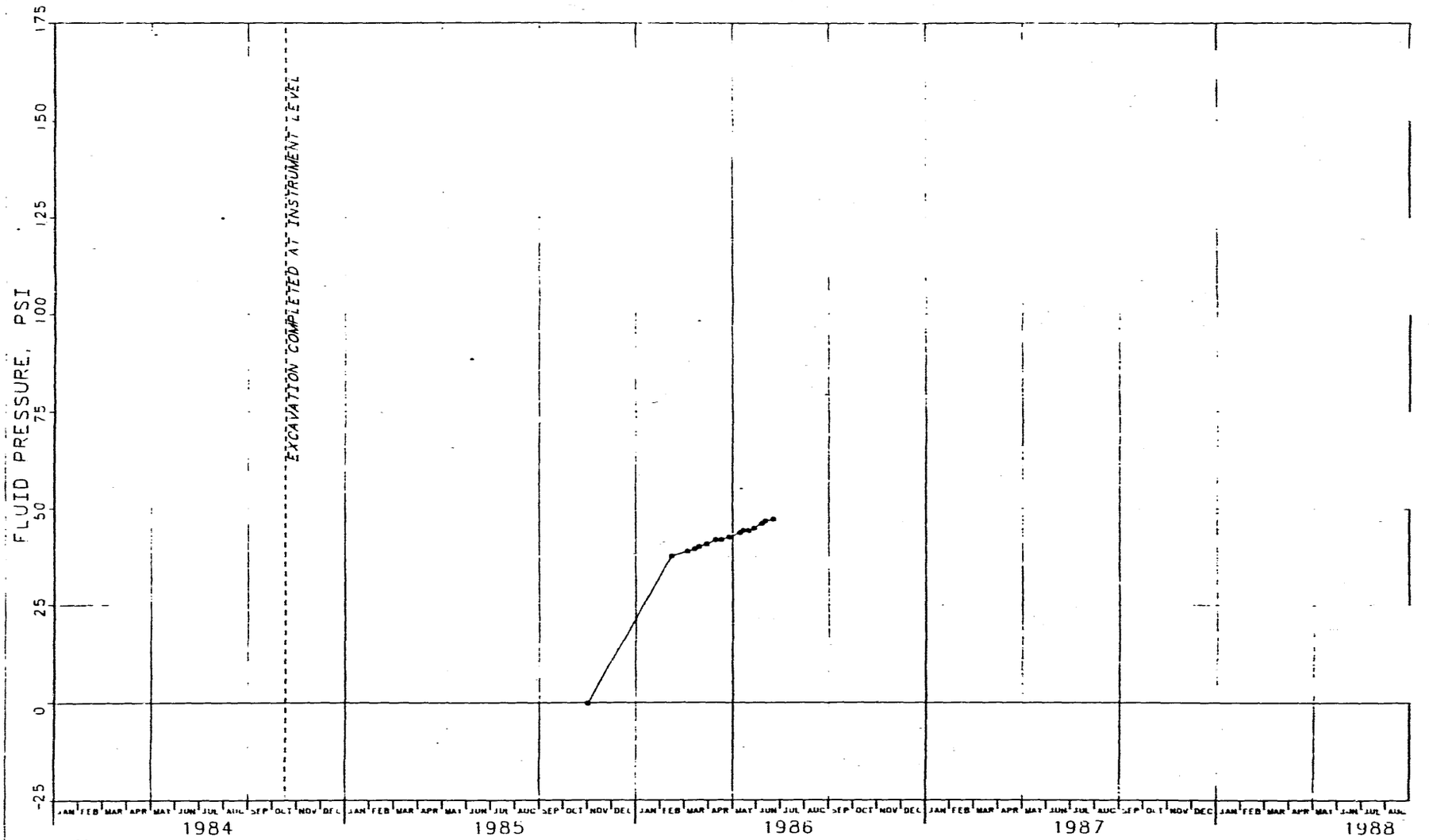
FIGURE J-16
PIEZOMETER 35X-PE-00204
EXHAUST SHAFT – EL 2794 (MAGENTA)
PRESSURE VS. CALENDAR MONTH



NOTES

1 CONCRETE LINER WAS PLACED JULY 1984 THROUGH NOV 29, 1984

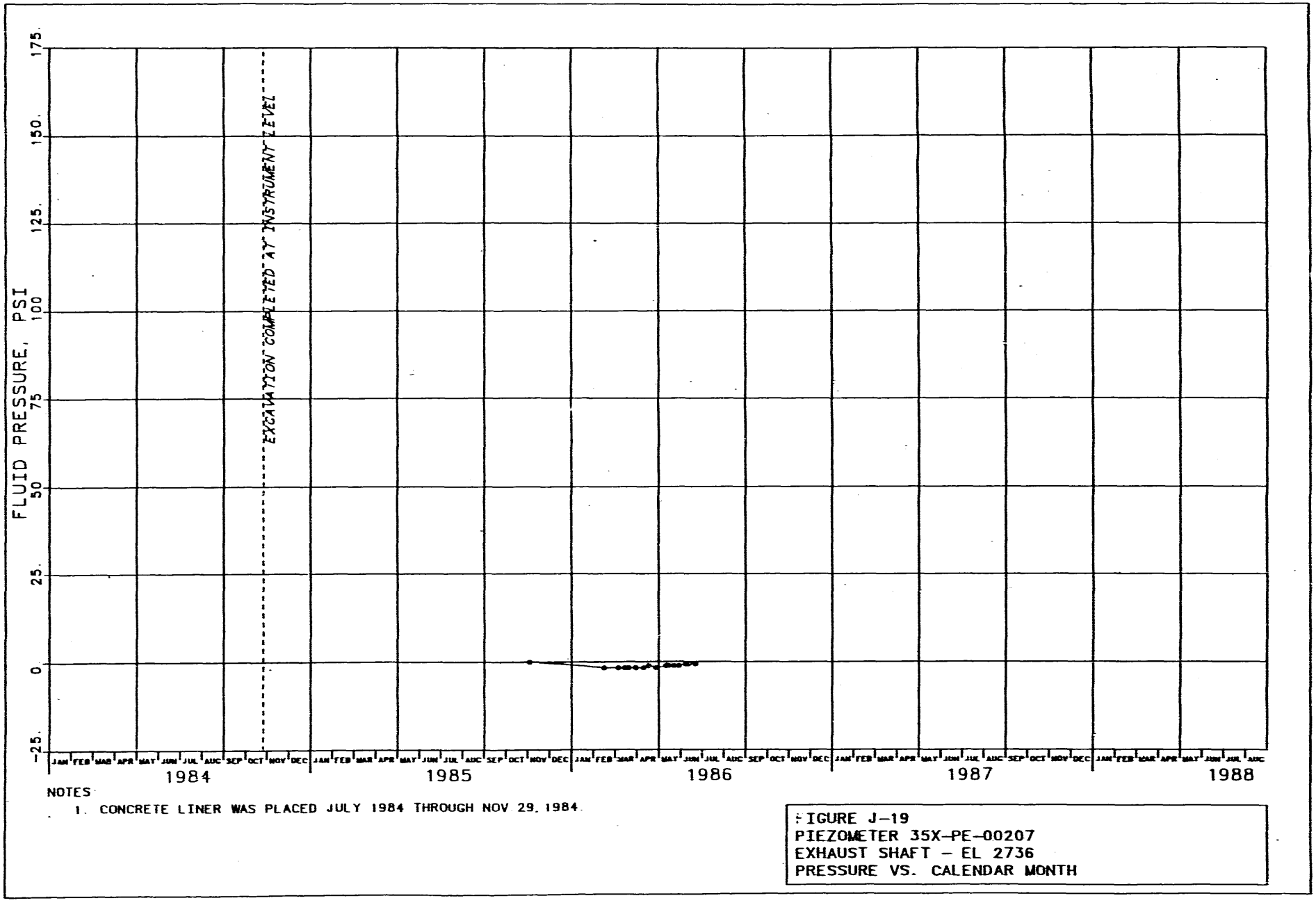
FIGURE J-17
PIEZOMETER 35X-PE-00205
EXHAUST SHAFT – EL 2794 (MAGENTA)
PRESSURE VS. CALENDAR MONTH



NOTES

1 CONCRETE LINER WAS PLACED JULY 1984 THROUGH NOV 29, 1984

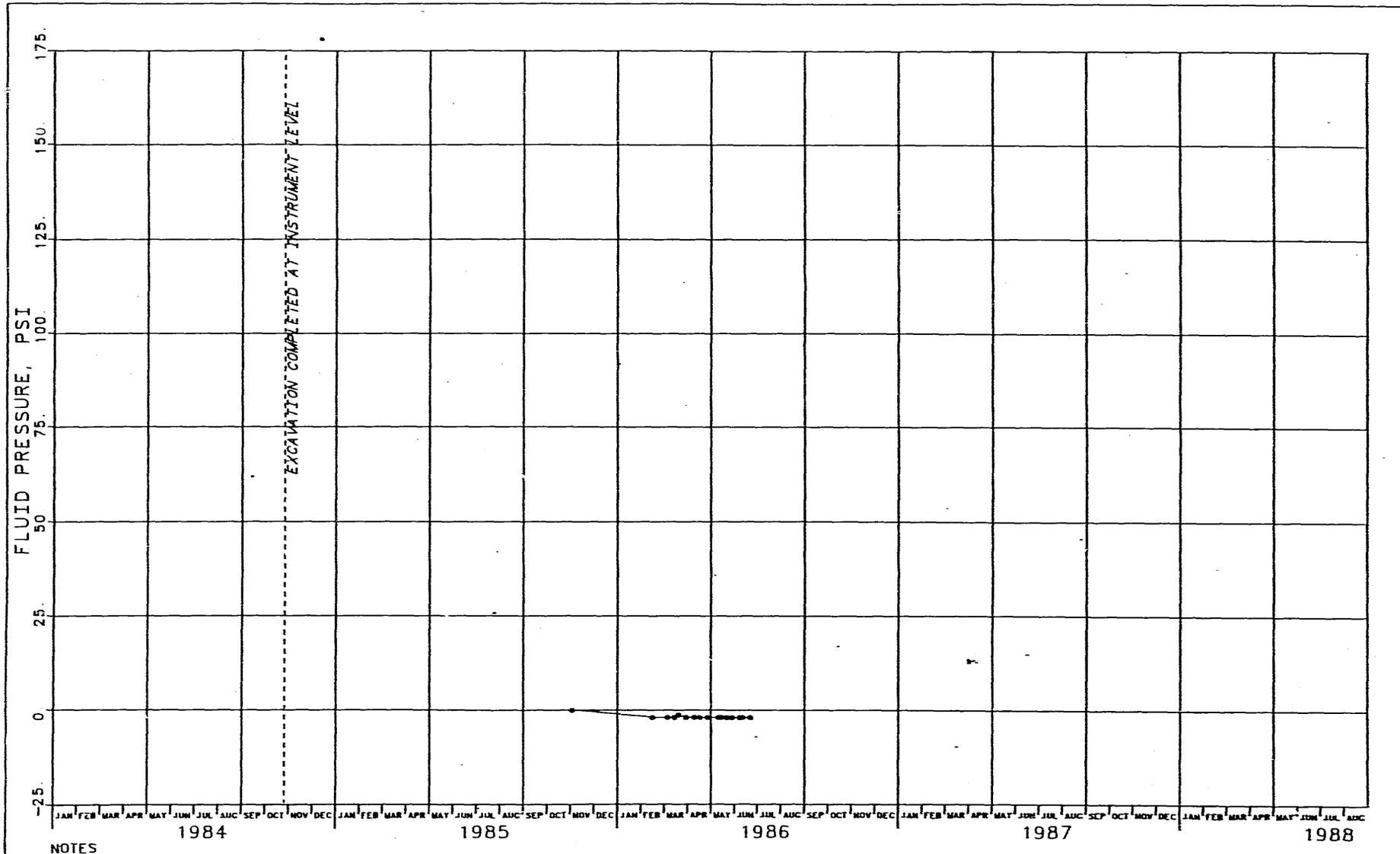
FIGURE J-18
PIEZOMETER 35X-PE-00206
EXHAUST SHAFT - EL 2794 (MAGENTA)
PRESSURE VS. CALENDAR MONTH



NOTES

1. CONCRETE LINER WAS PLACED JULY 1984 THROUGH NOV 29, 1984.

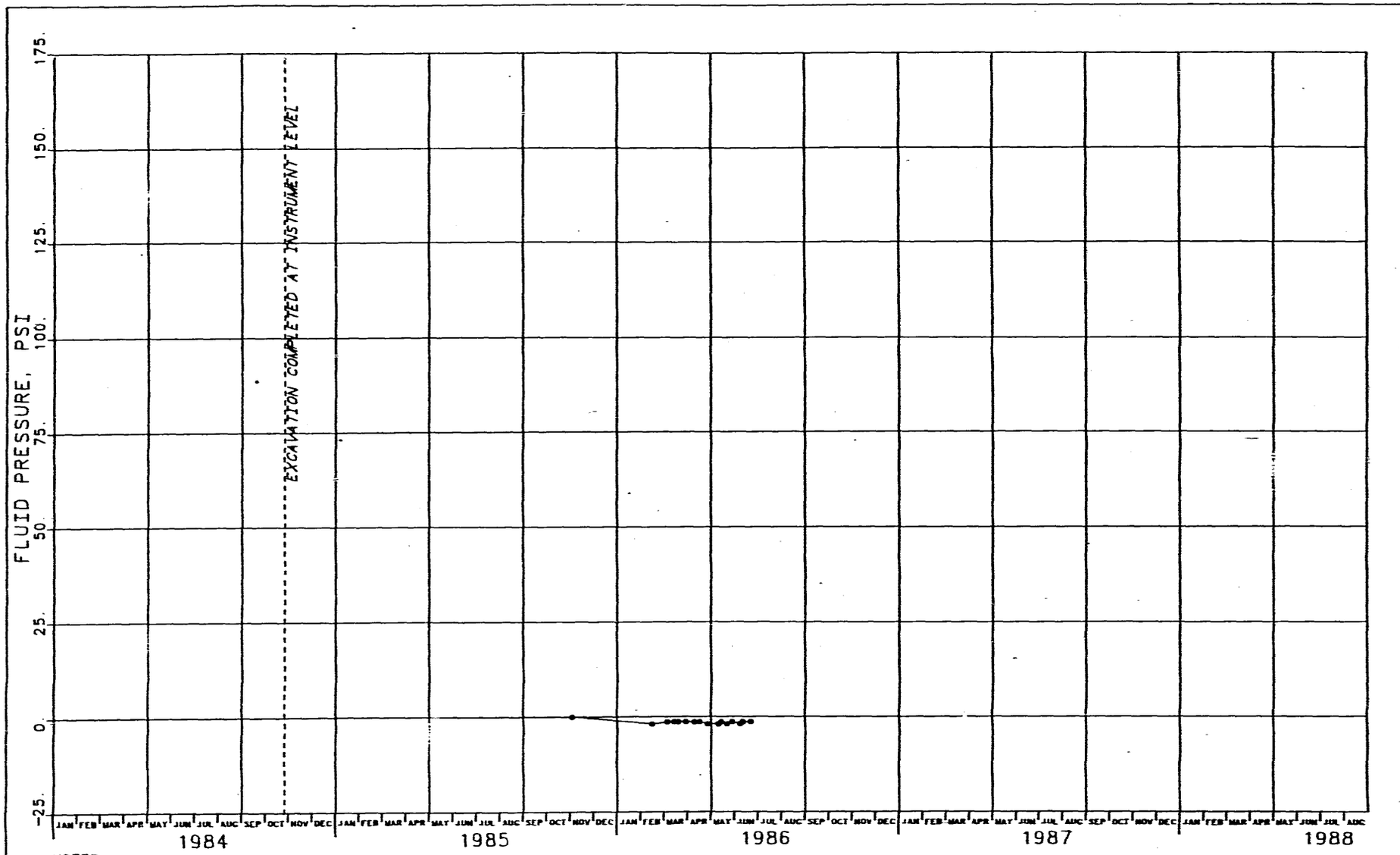
FIGURE J-19
PIEZOMETER 35X-PE-00207
EXHAUST SHAFT - EL 2736
PRESSURE VS. CALENDAR MONTH



NOTES

1. CONCRETE LINER WAS PLACED JULY 1984 THROUGH NOV 29, 1984

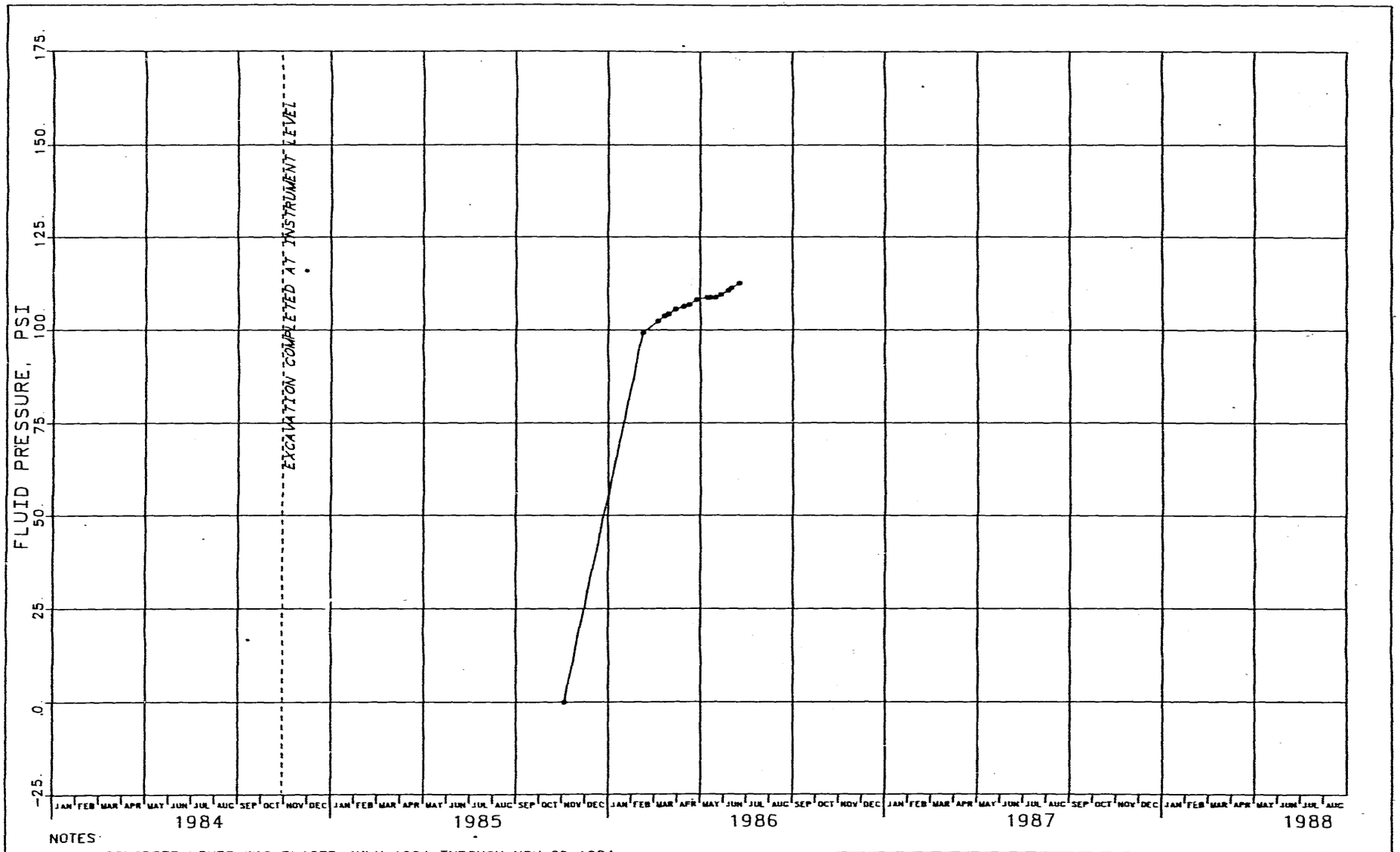
FIGURE J-20
PIEZOMETER 35X-PE-00208
EXHAUST SHAFT – EL 2736
PRESSURE VS. CALENDAR MONTH



NOTES:

1. CONCRETE LINER WAS PLACED JULY 1984 THROUGH NOV. 29, 1984.

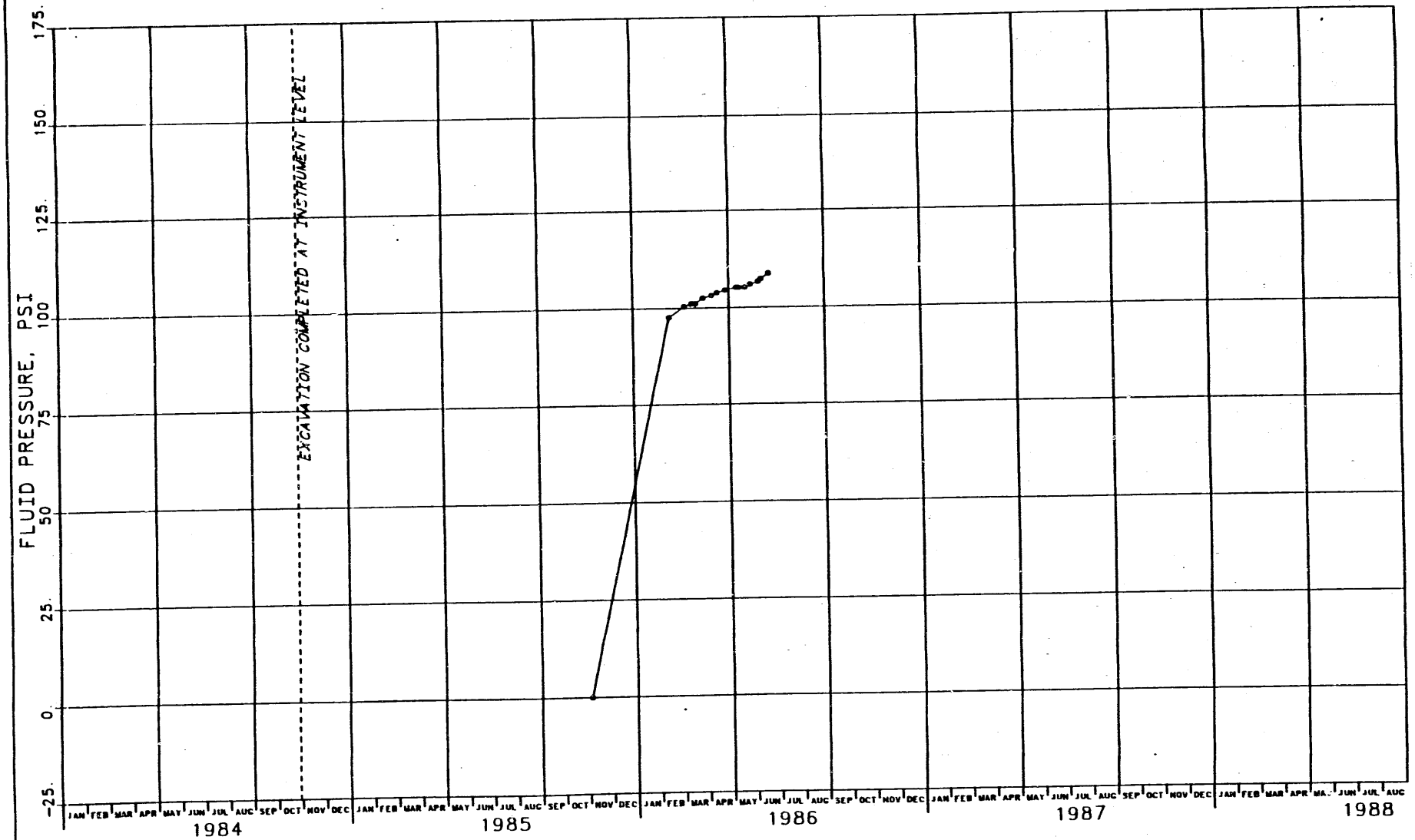
FIGURE J-21
PIEZOMETER 35X-PE-00209
EXHAUST SHAFT – EL 2736
PRESSURE VS. CALENDAR MONTH



NOTES:

1 CONCRETE LINER WAS PLACED JULY 1984 THROUGH NOV 29, 1984

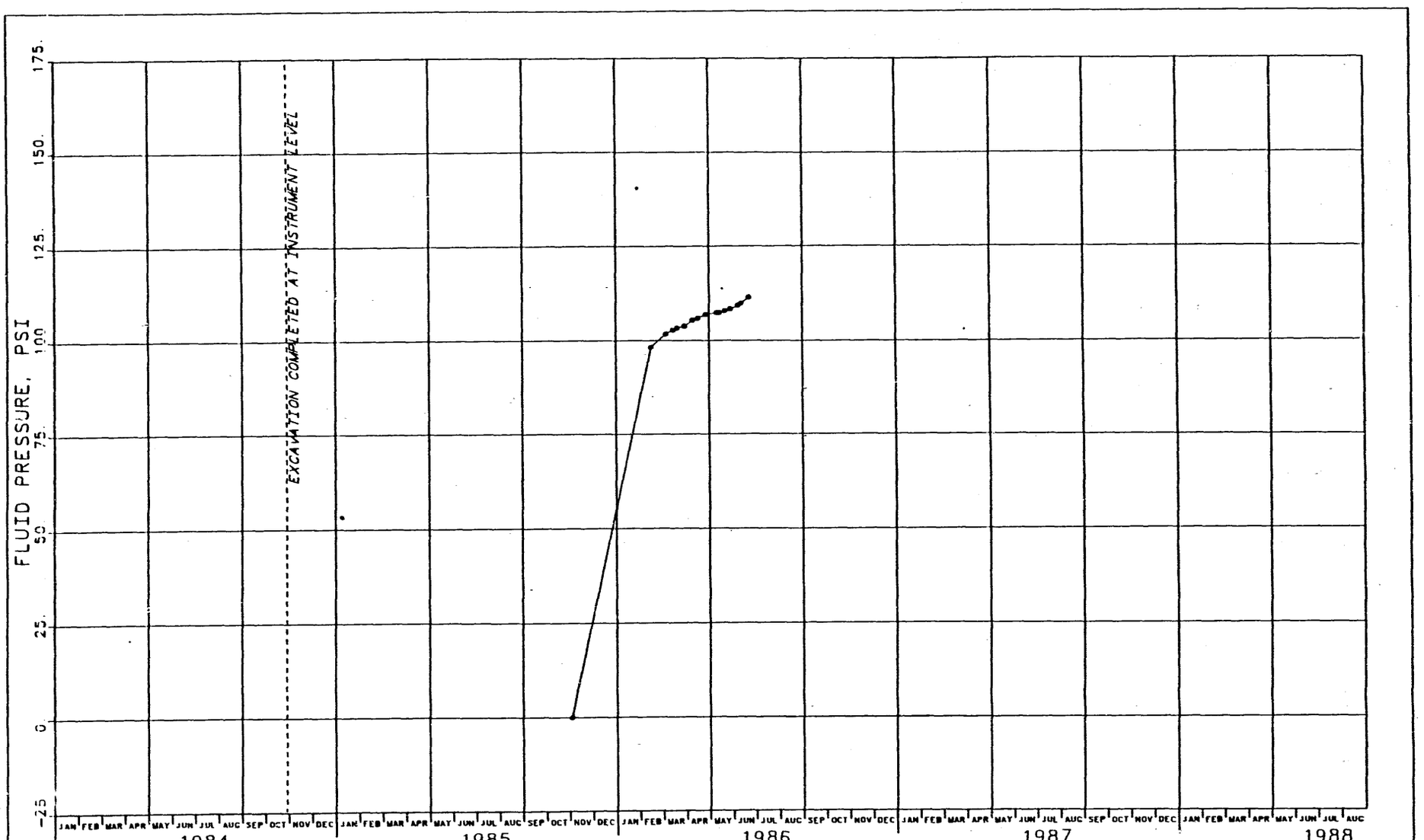
FIGURE J-22
PIEZOMETER 35X-PE-00210
EXHAUST SHAFT - EL 2688 (CULEBRA)
PRESSURE VS. CALENDAR MONTH



NOTES

1. CONCRETE LINER WAS PLACED JULY 1984 THROUGH NOV. 29, 1984.

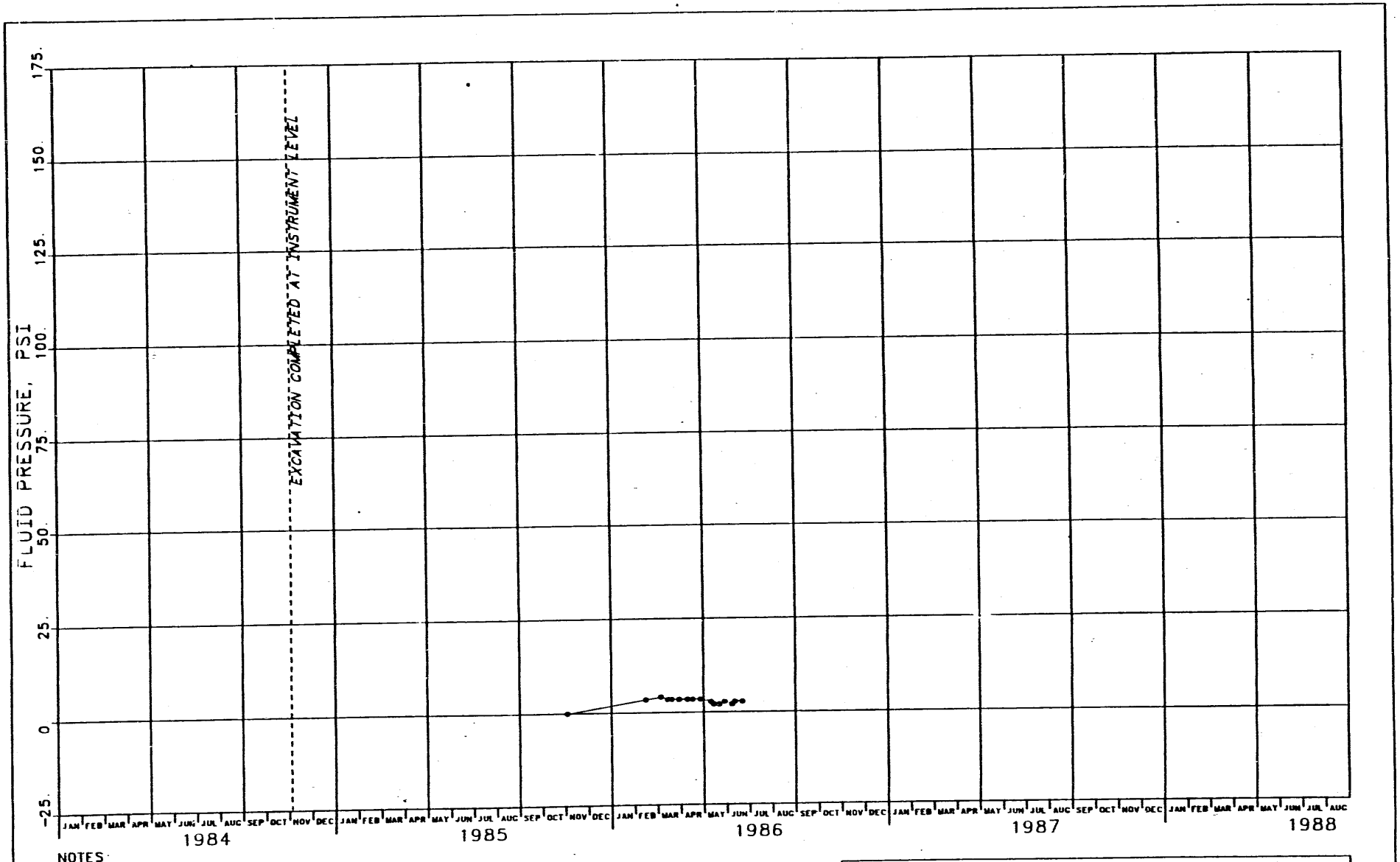
FIGURE J-23
PIEZOMETER 35X-PE-00211
EXHAUST SHAFT - EL 2688 (CULEBRA)
PRESSURE VS. CALENDAR MONTH



NOTES

1 CONCRETE LINER WAS PLACED JULY 1984 THROUGH NOV. 29, 1984.

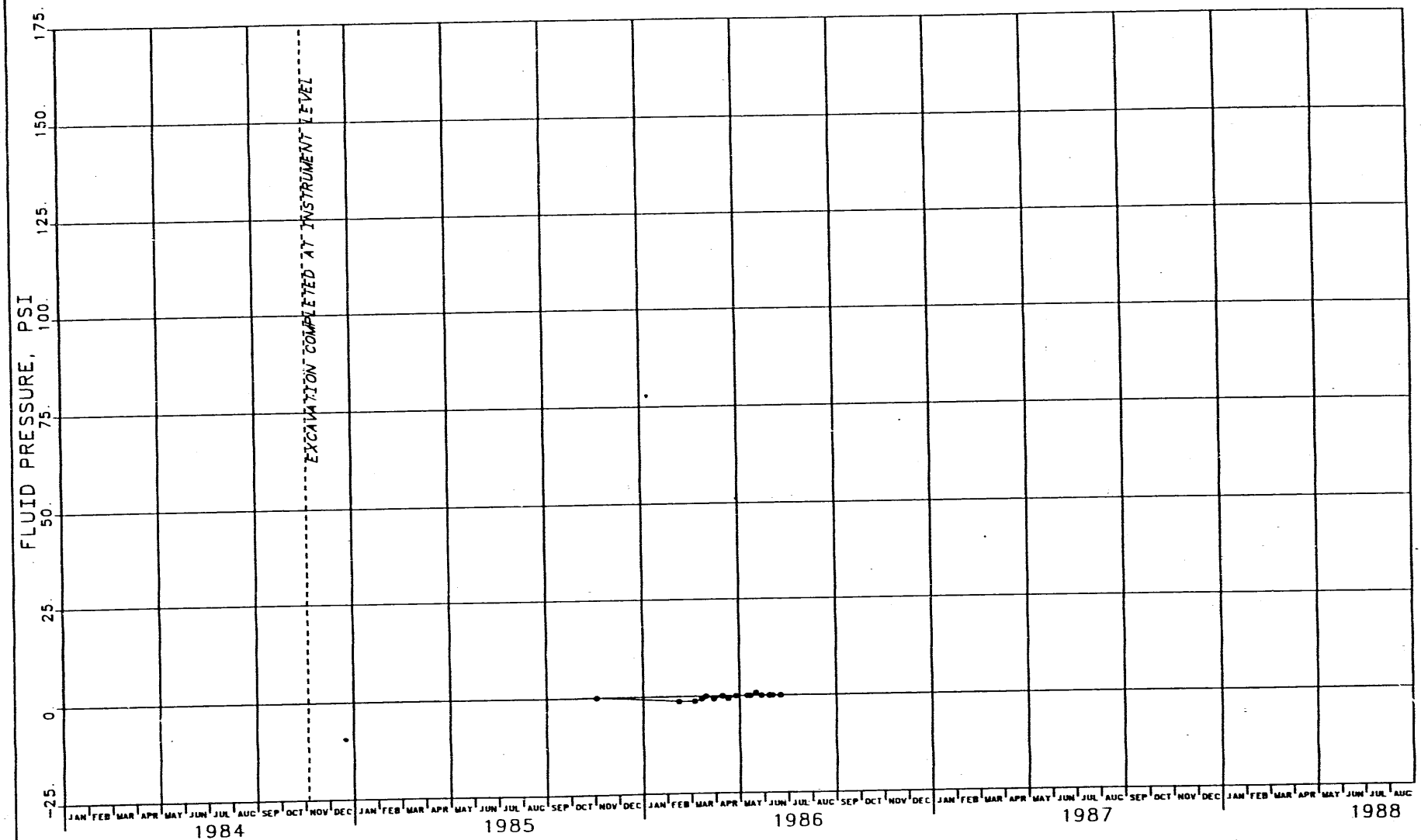
FIGURE J-24
PIEZOMETER 35X-PE-00212
EXHAUST SHAFT - EL 2688 (CULEBRA)
PRESSURE VS. CALENDAR MONTH



NOTES:

1 CONCRETE LINER WAS PLACED JULY 1984 THROUGH NOV. 29, 1984.

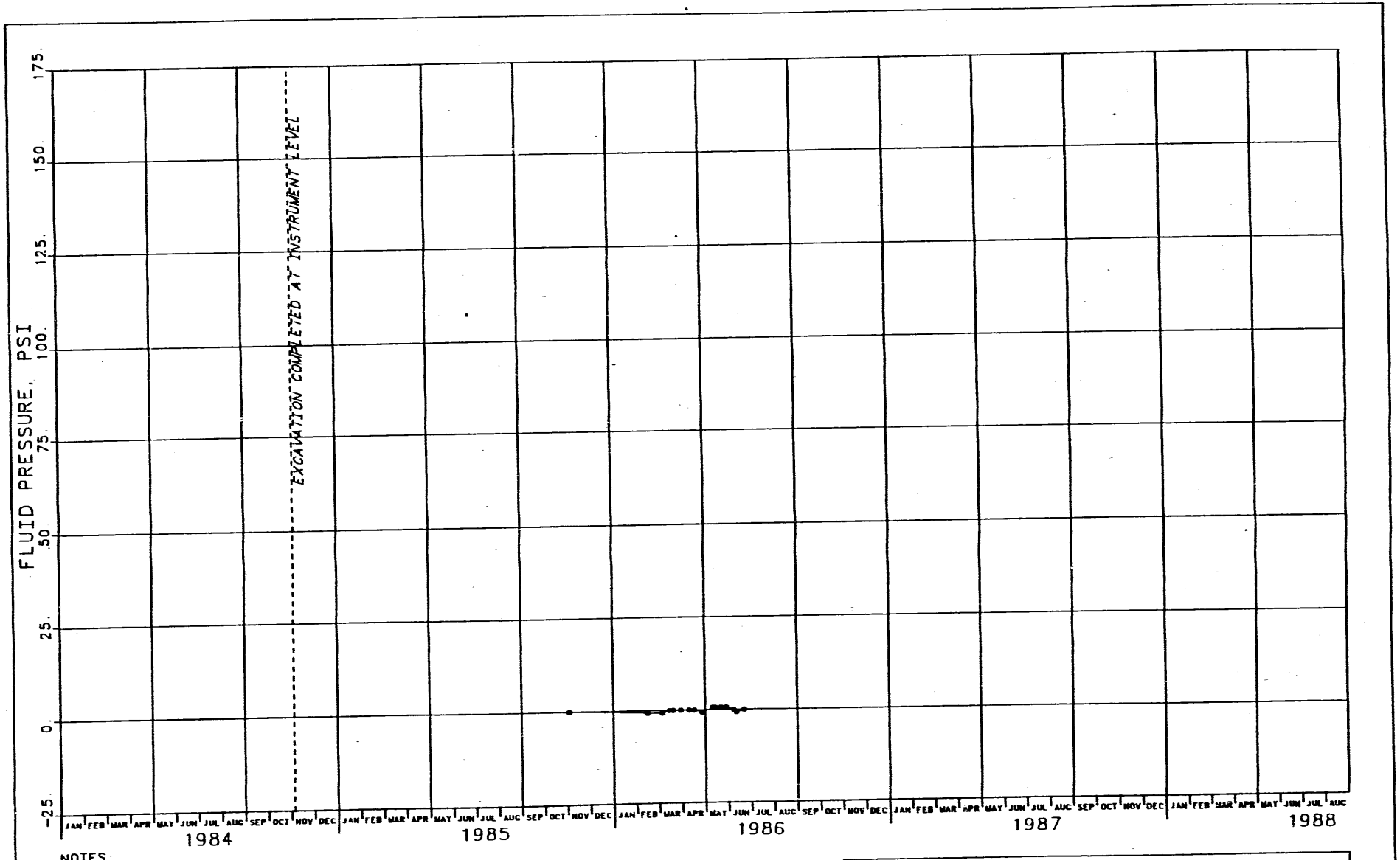
FIGURE J-25
PIEZOMETER 35X-PE-00213
EXHAUST SHAFT - EL 2641
PRESSURE VS. CALENDAR MONTH



NOTES

1. CONCRETE LINER WAS PLACED JULY 1984 THROUGH NOV. 29, 1984.

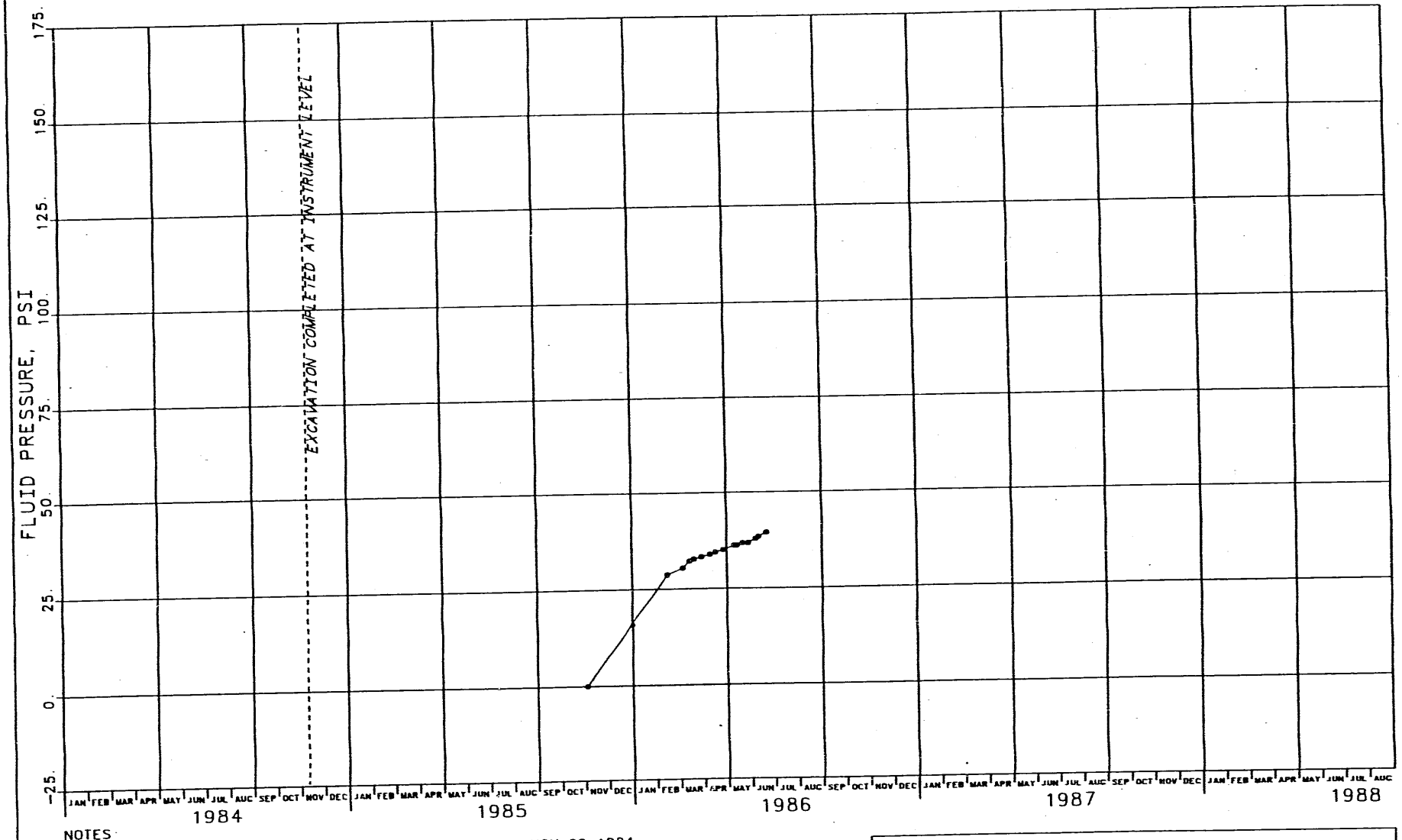
FIGURE J-26
PIEZOMETER 35X-PE-00214
EXHAUST SHAFT – EL 2641
PRESSURE VS. CALENDAR MONTH



NOTES:

1. CONCRETE LINER WAS PLACED JULY 1984 THROUGH NOV. 29, 1984.

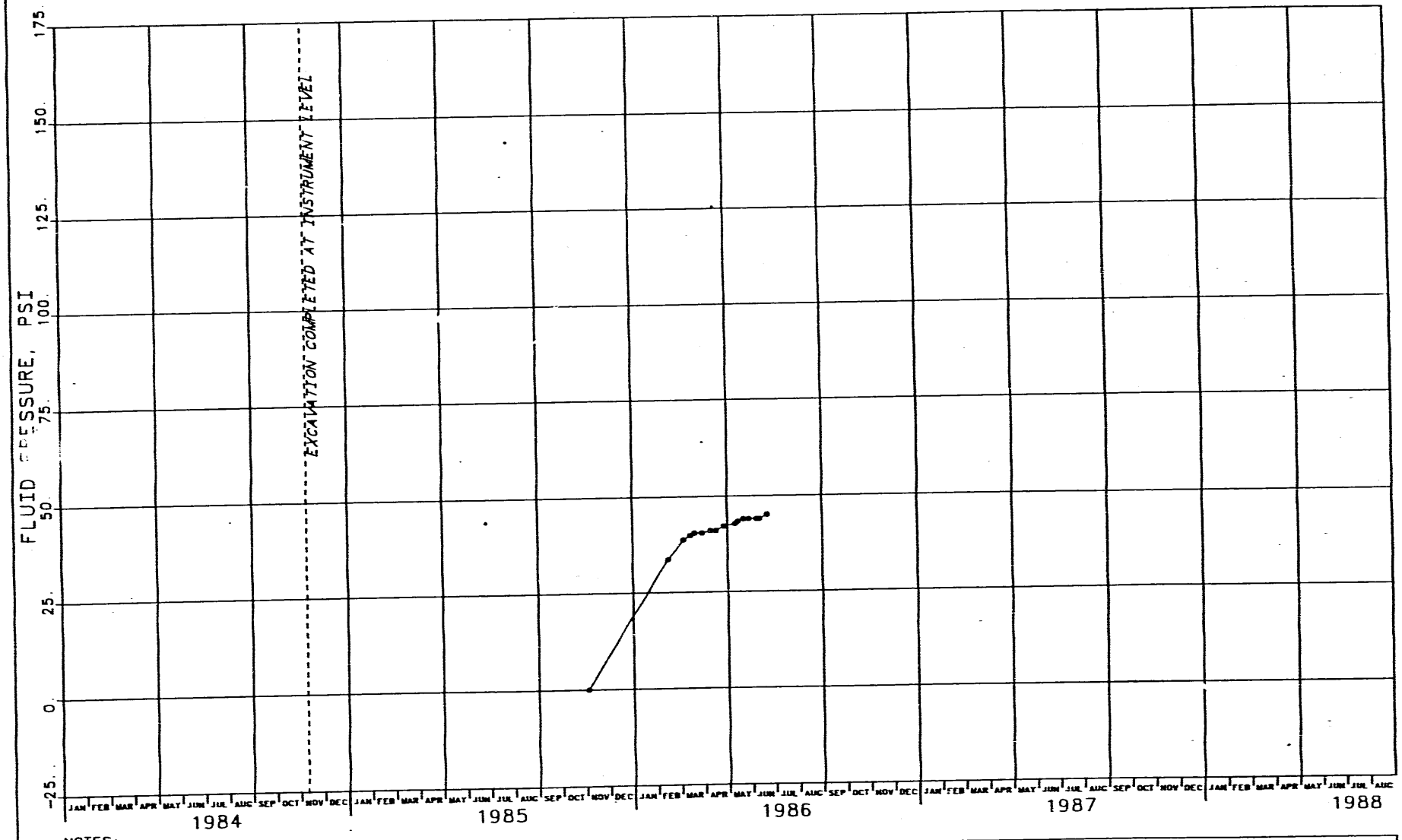
FIGURE J-27
PIEZOMETER 35X-PE-00215
EXHAUST SHAFT - EL 2641
PRESSURE VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED NOV. 19 THROUGH NOV 29, 1984

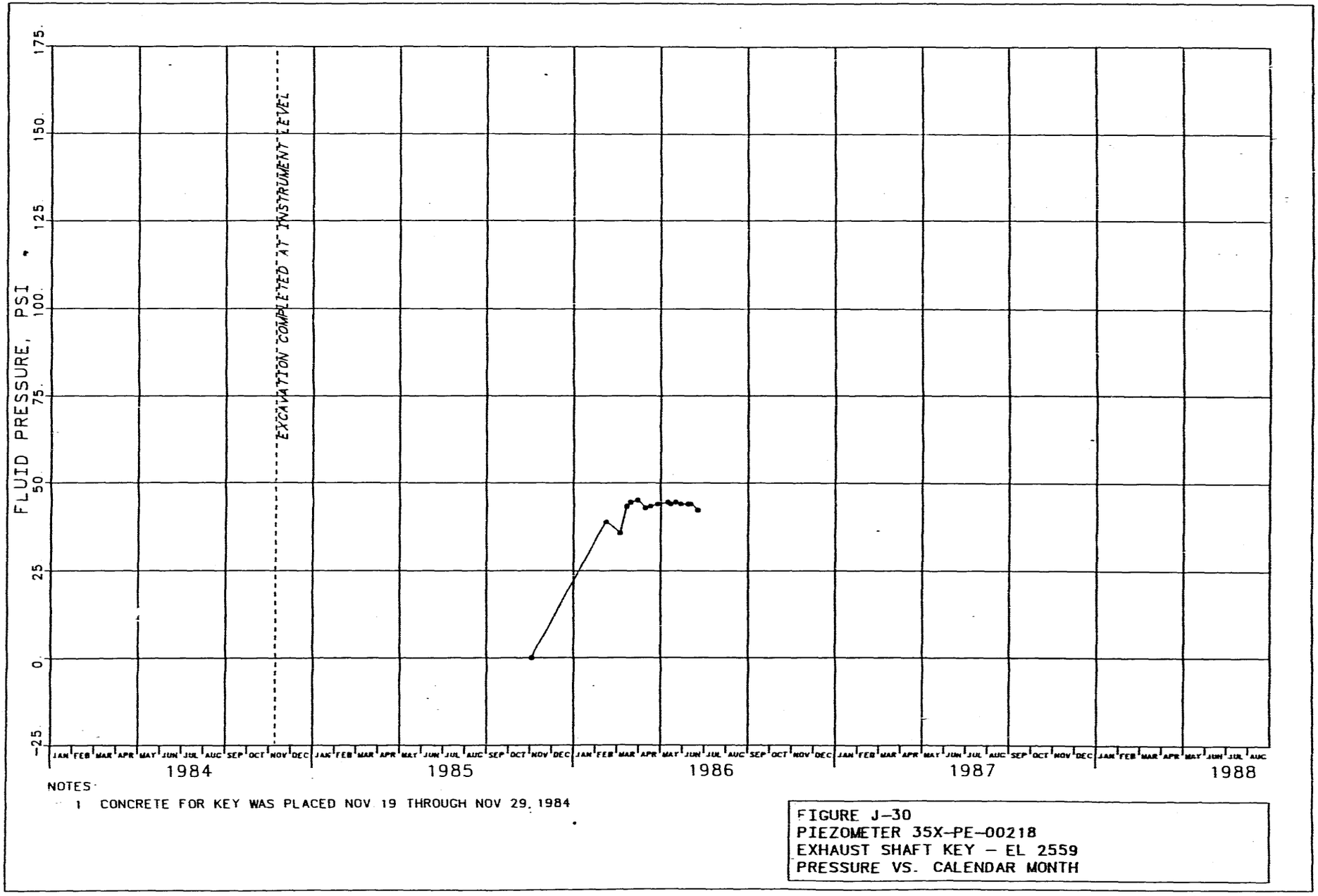
FIGURE J-28
PIEZOMETER 35X-PE-00216
EXHAUST SHAFT KEY - EL 2559
PRESSURE VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED NOV. 19 THROUGH NOV 29, 1984.

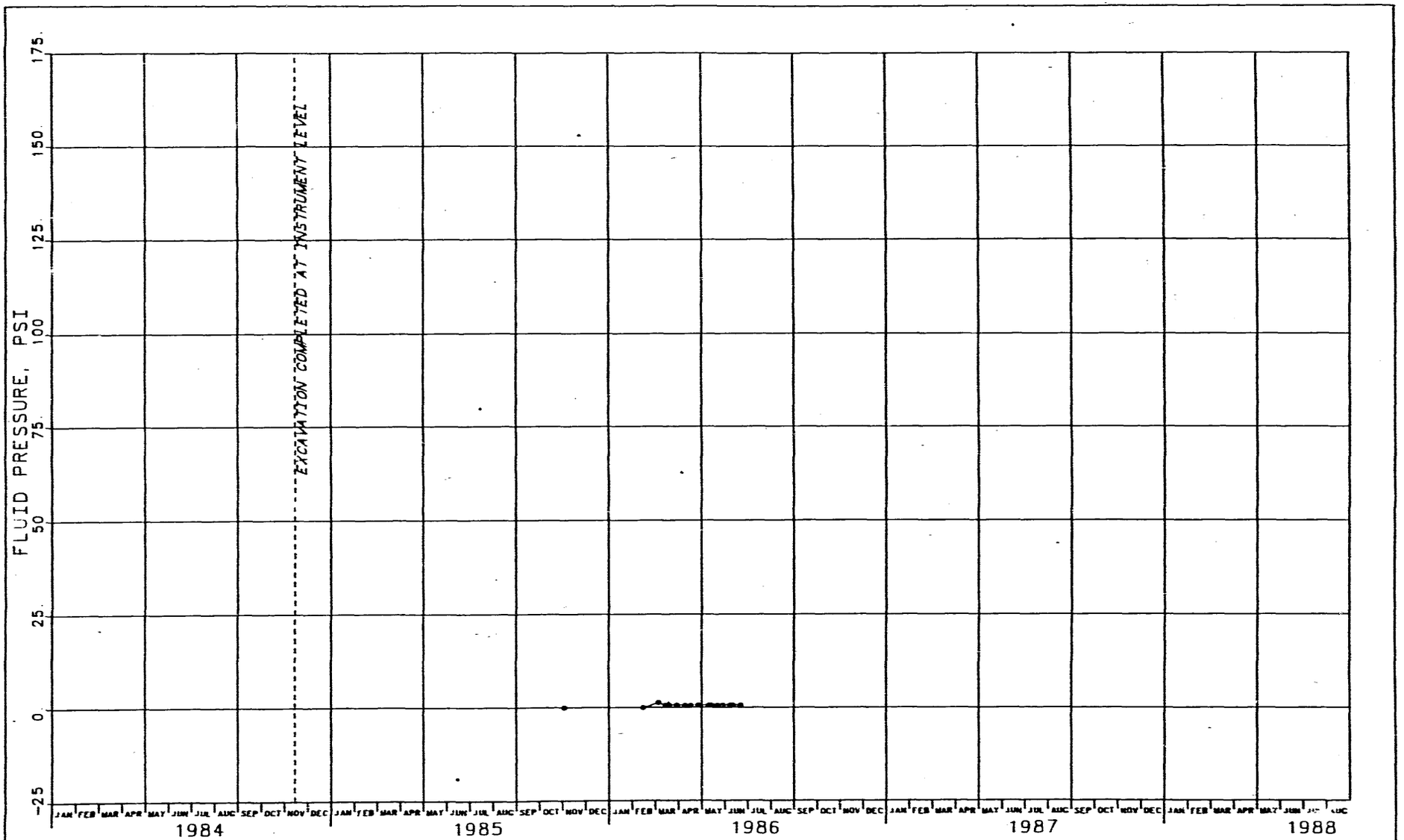
FIGURE J-29
PIEZOMETER 35X-PE-00217
EXHAUST SHAFT KEY - EL 2559
PRESSURE VS. CALENDAR MONTH



NOTES:

1 CONCRETE FOR KEY WAS PLACED NOV 19 THROUGH NOV 29, 1984

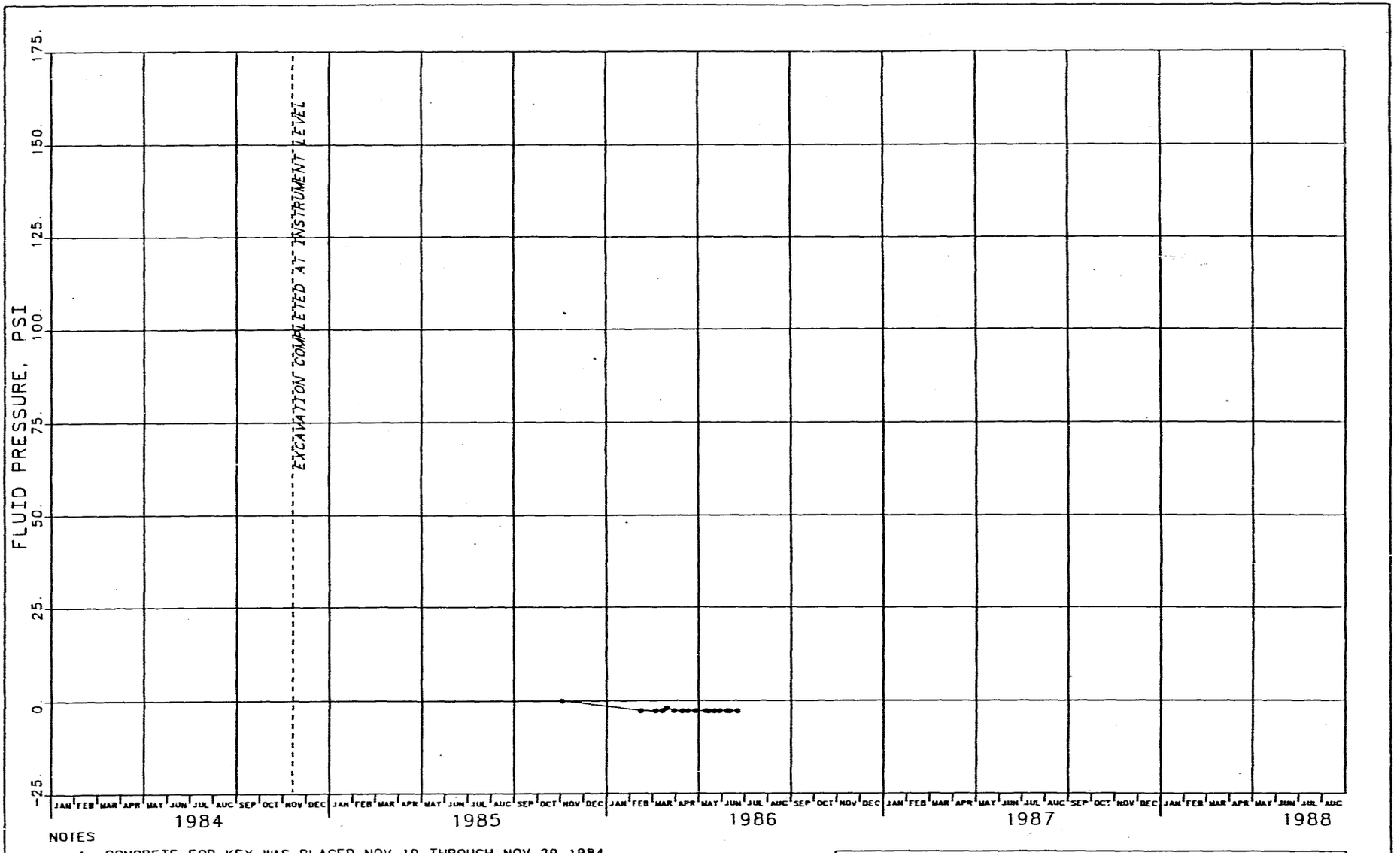
FIGURE J-30
PIEZOMETER 35X-PE-00218
EXHAUST SHAFT KEY - EL 2559
PRESSURE VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED NOV. 19 THROUGH NOV. 29, 1984

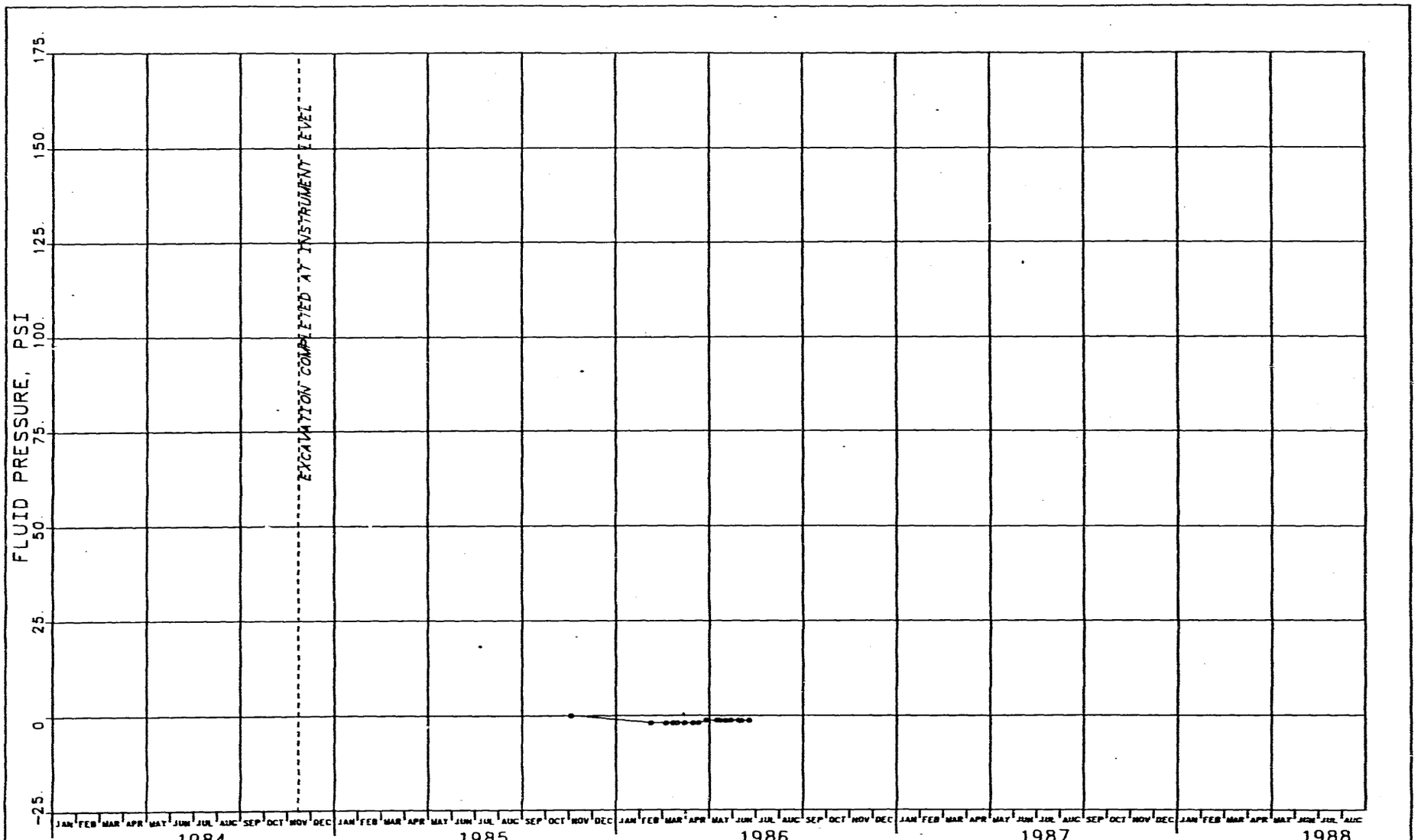
FIGURE J-31
PIEZOMETER 35X-PE-00219
EXHAUST SHAFT KEY - EL 2522
PRESSURE VS. CALENDAR MONTH



NOTES

1 CONCRETE FOR KEY WAS PLACED NOV 19 THROUGH NOV 29, 1984

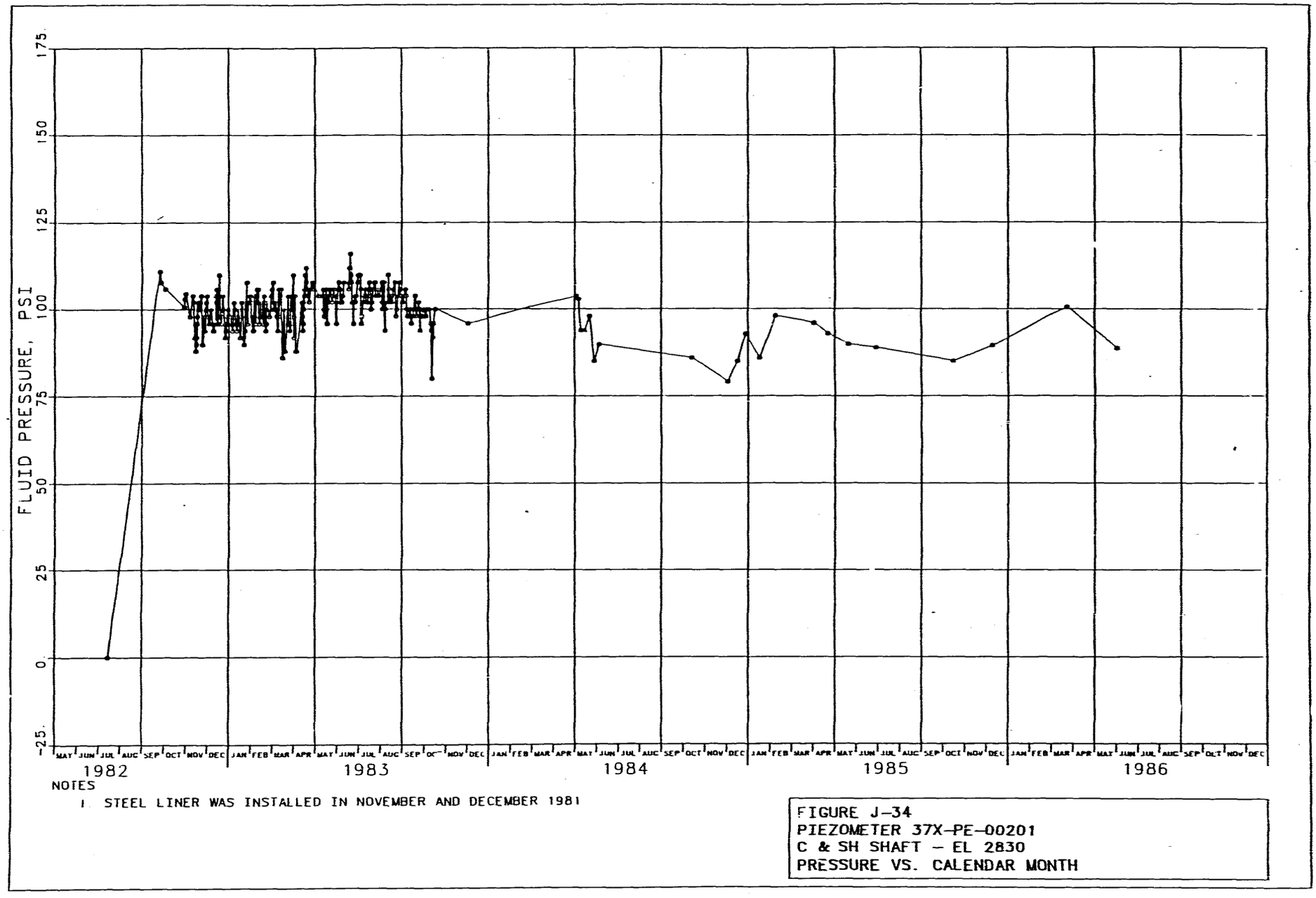
FIGURE J-32
PIEZOMETER 35X-PE-00220
EXHAUST SHAFT KEY - EL 2522
PRESSURE VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED NOV 19 THROUGH NOV 29, 1984

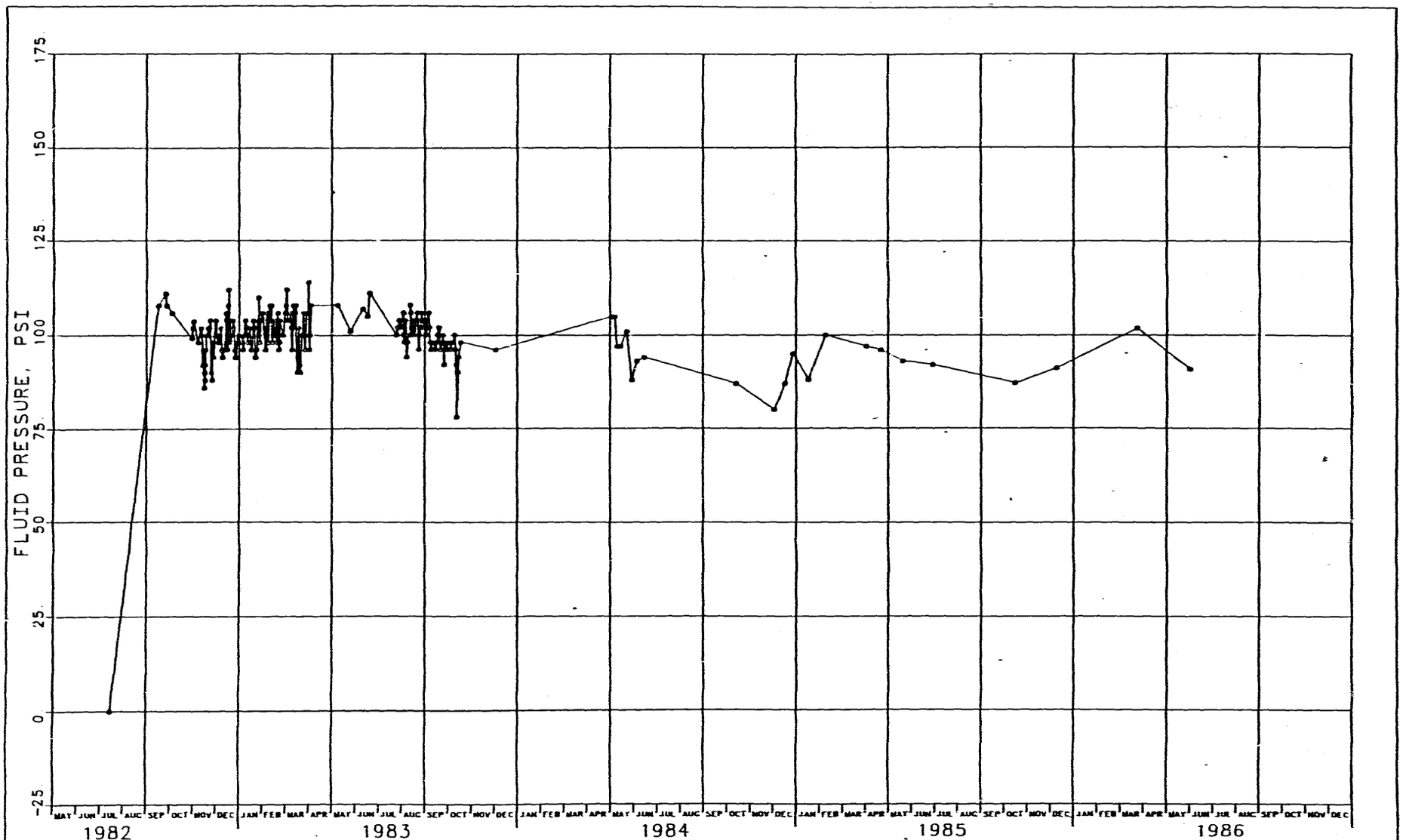
FIGURE J-33
PIEZOMETER 35X-PE-00221
EXHAUST SHAFT KEY - EL 2522
PRESSURE VS. CALENDAR MONTH



NOTES

1. STEEL LINER WAS INSTALLED IN NOVEMBER AND DECEMBER 1981

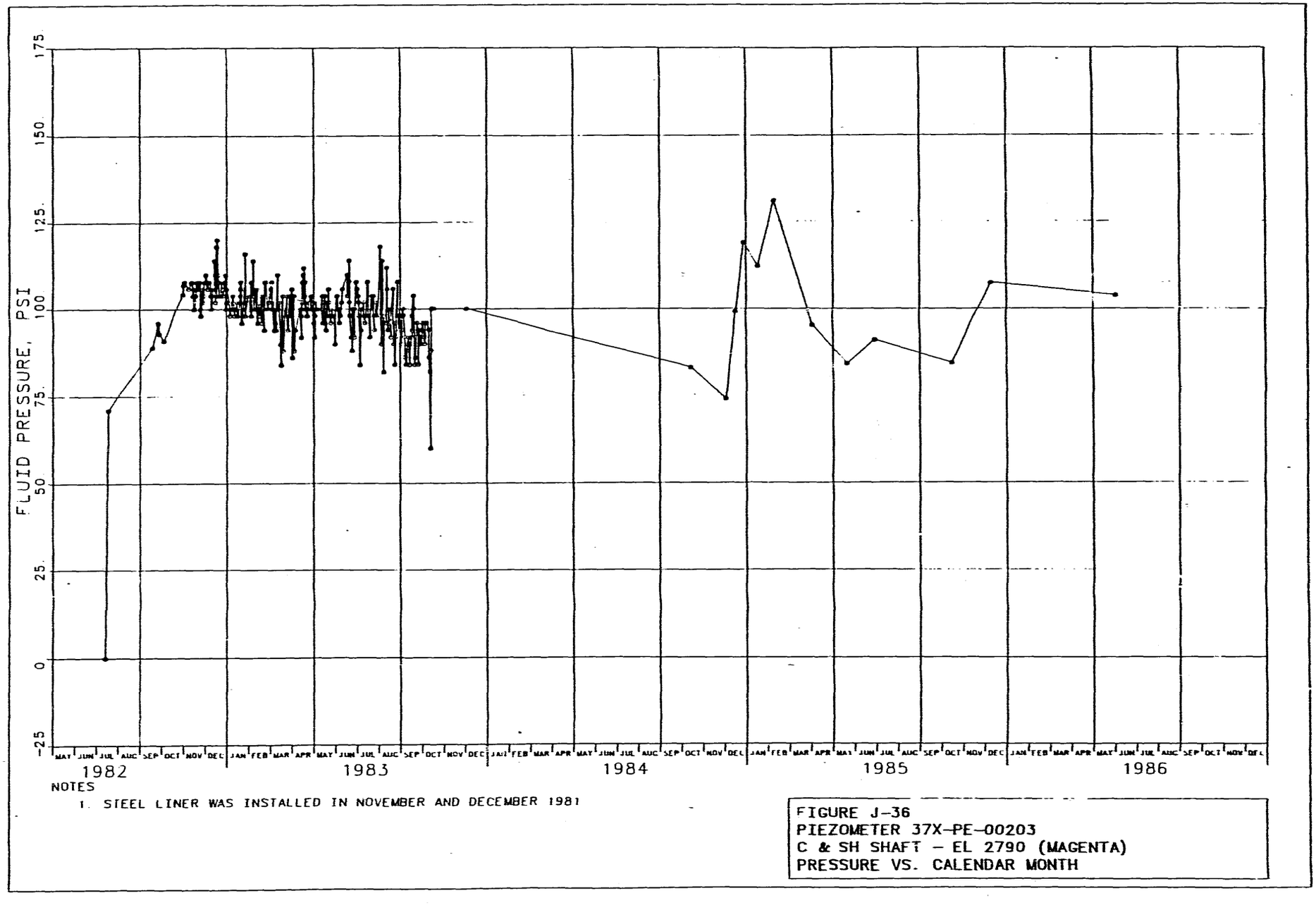
FIGURE J-34
PIEZOMETER 37X-PE-00201
C & SH SHAFT - EL 2830
PRESSURE VS. CALENDAR MONTH



NOTES

1. STEEL LINER WAS INSTALLED IN NOVEMBER AND DECEMBER 1981

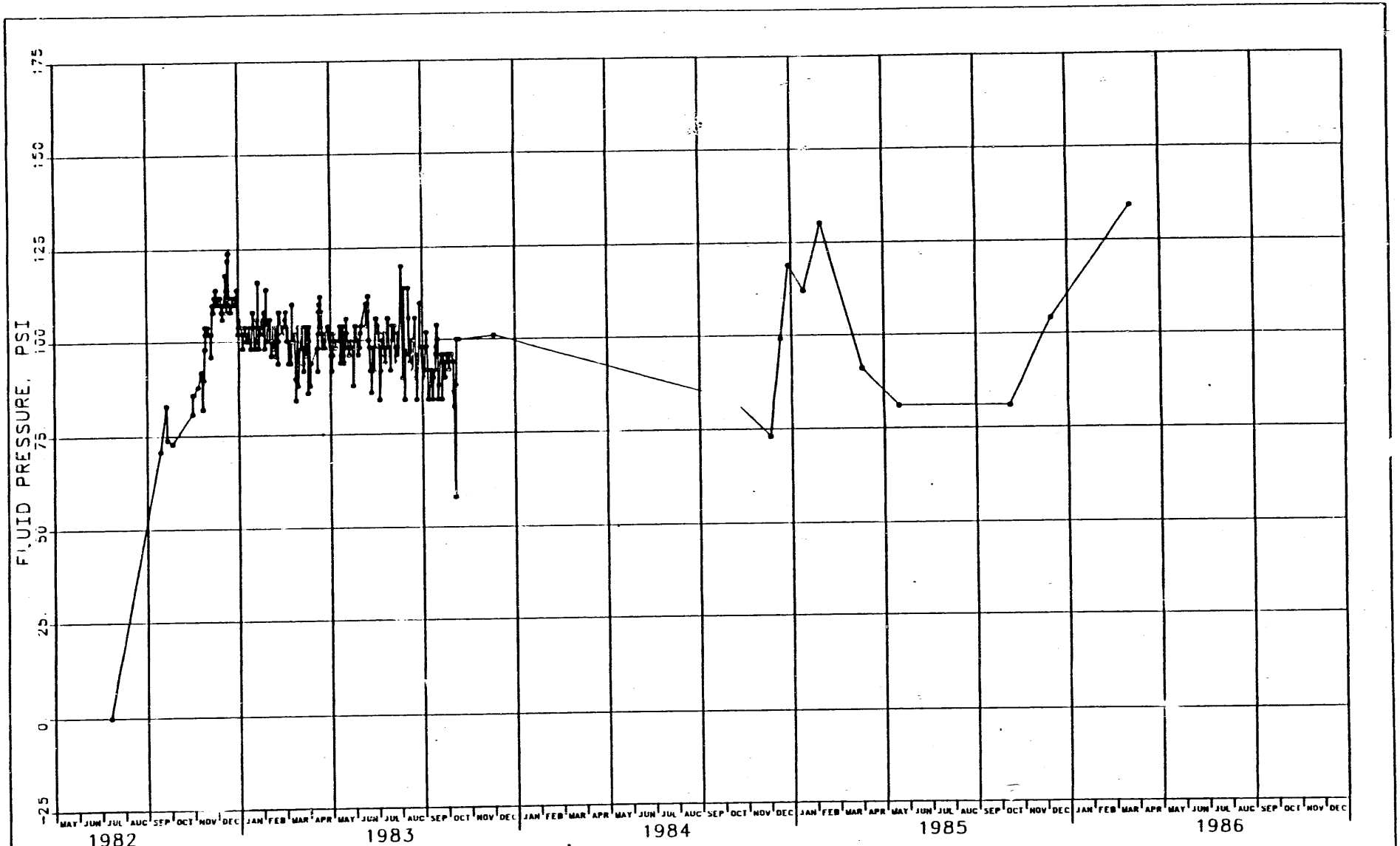
FIGURE J-35
PIEZOMETER 37X-PE-00202
C & SH SHAFT - EL 2830
PRESSURE VS. CALENDAR MONTH



NOTES

1. STEEL LINER WAS INSTALLED IN NOVEMBER AND DECEMBER 1981

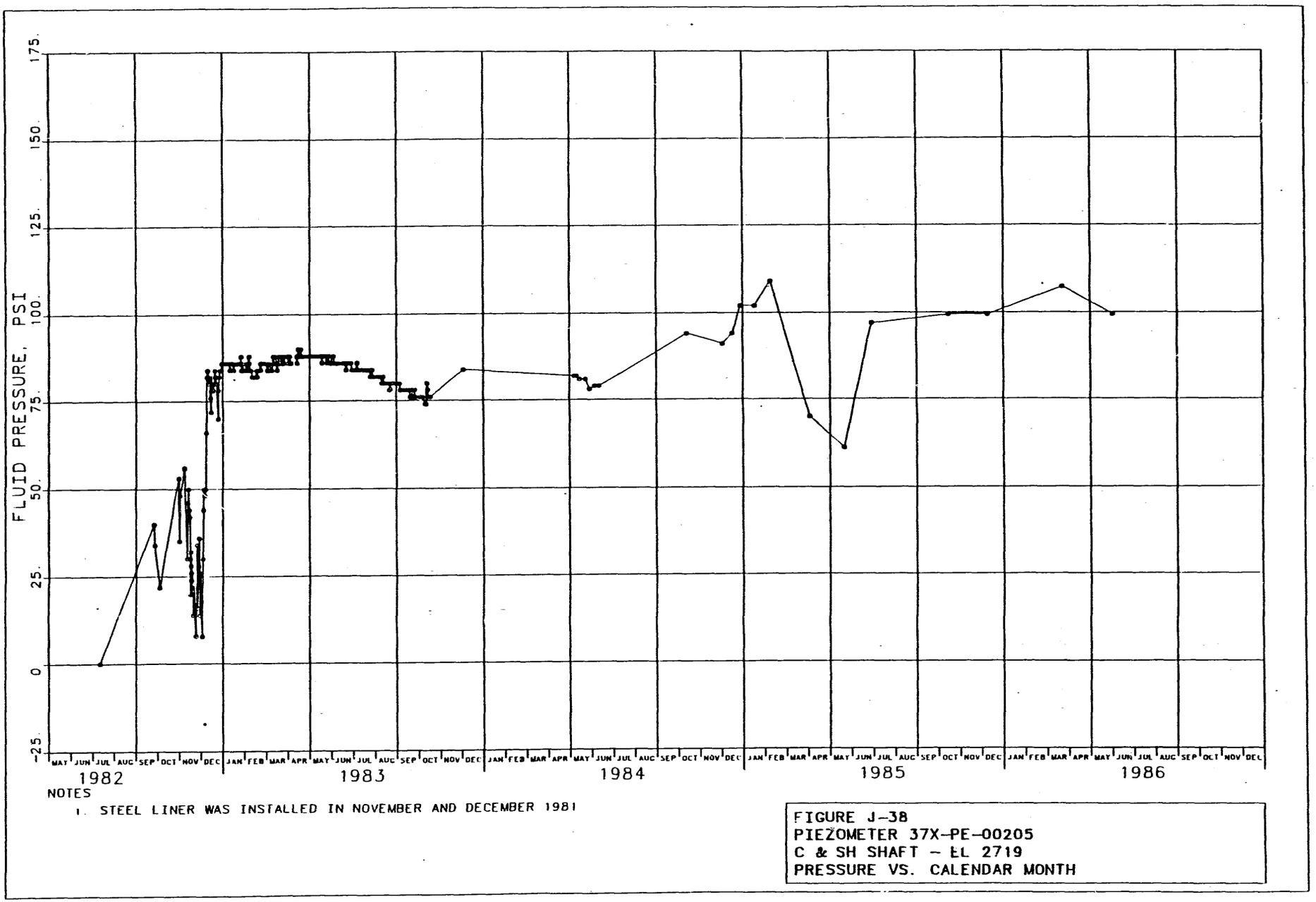
FIGURE J-36
PIEZOMETER 37X-PE-00203
C & SH SHAFT – EL 2790 (MAGENTA)
PRESSURE VS. CALENDAR MONTH



NOTES

1. STEEL LINER WAS INSTALLED IN NOVEMBER AND DECEMBER 1981
2. INSTRUMENT IS CURRENTLY NOT FUNCTIONING.

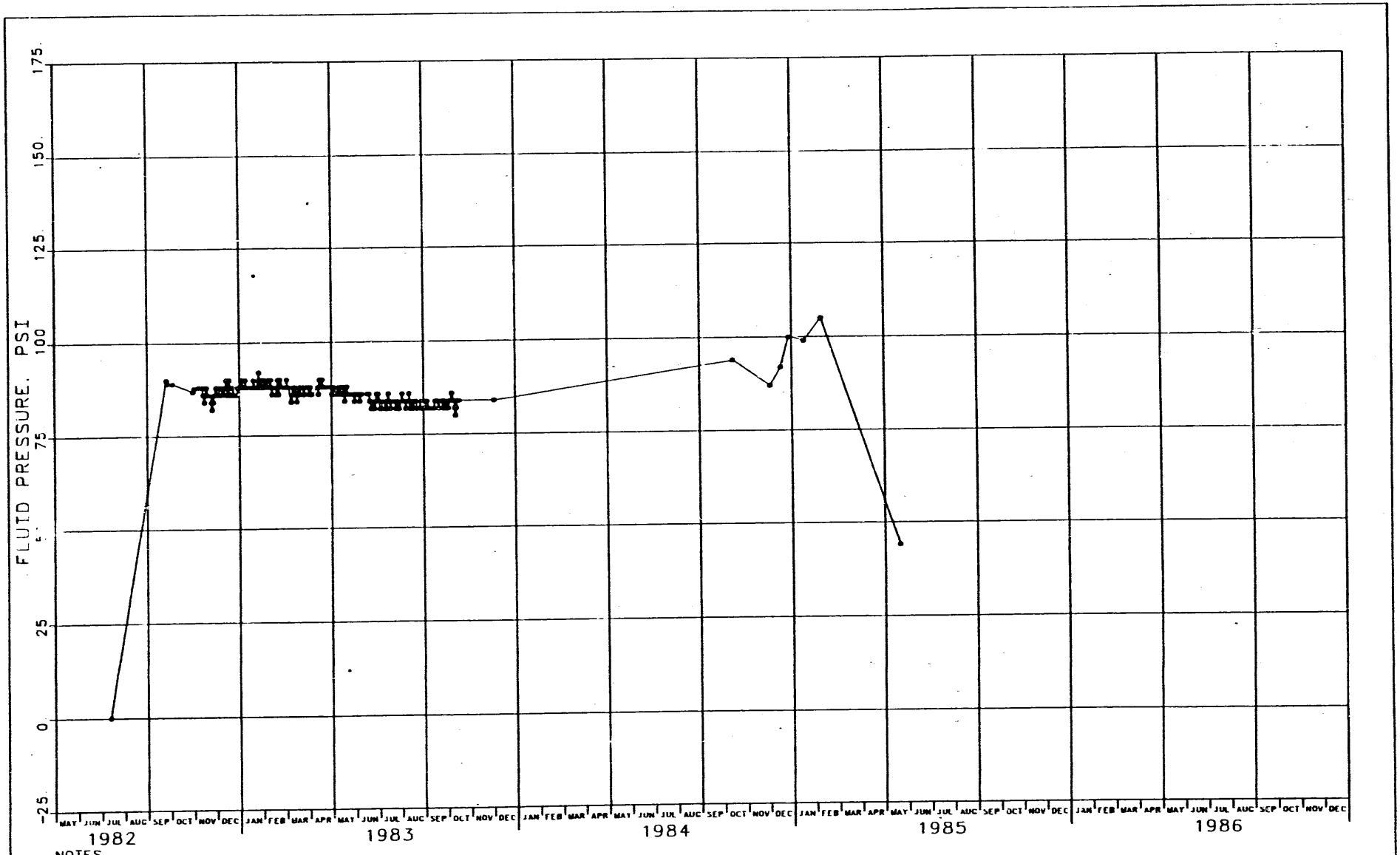
FIGURE J-37
PIEZOMETER 37X-PE-00204
C & SH SHAFT - EL 2790 (MAGENTA)
PRESSURE VS. CALENDAR MONTH



NOTES

1. STEEL LINER WAS INSTALLED IN NOVEMBER AND DECEMBER 1981

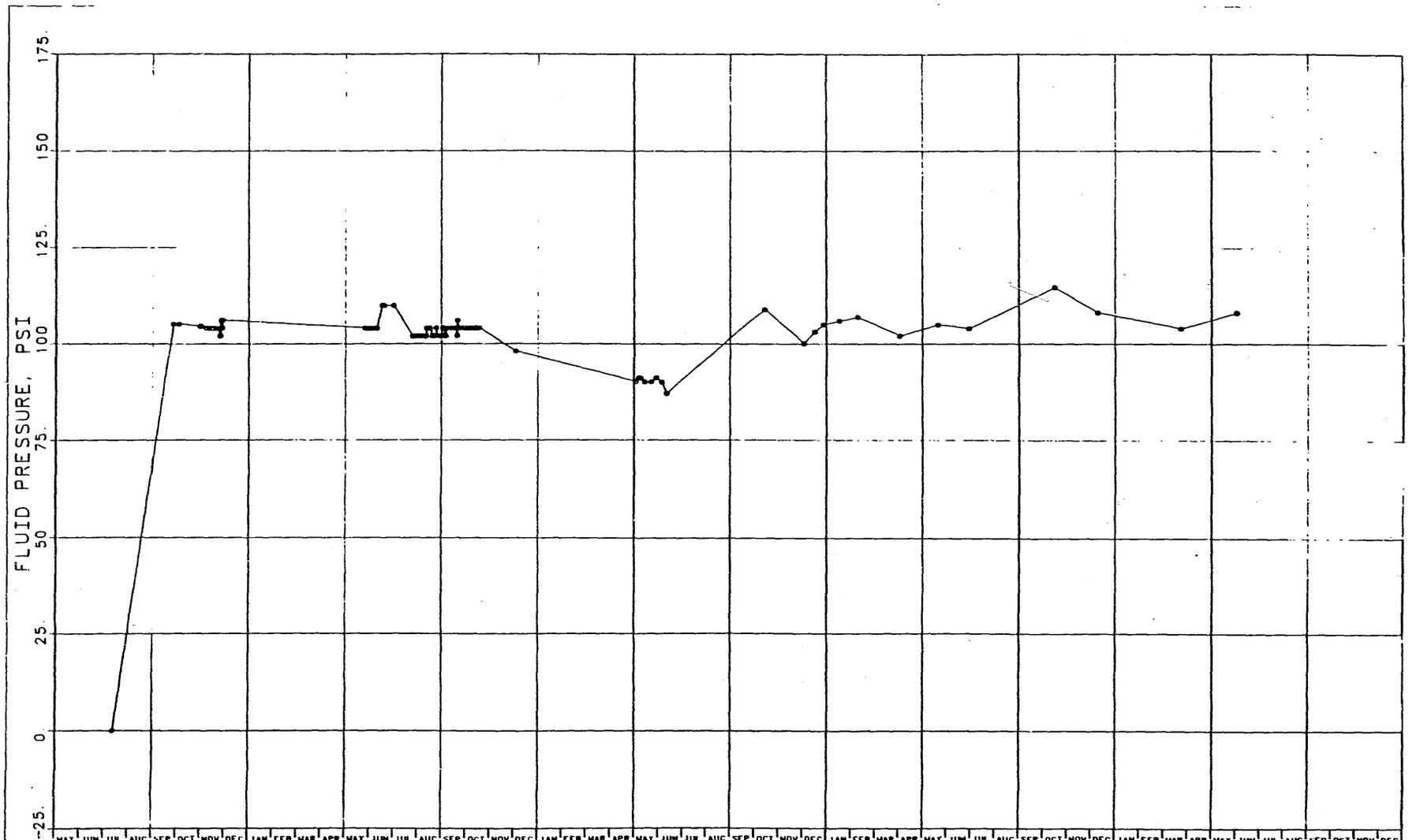
FIGURE J-38
PIEZOMETER 37X-PE-00205
C & SH SHAFT - EL 2719
PRESSURE VS. CALENDAR MONTH



NOTES

1. STEEL LINER WAS INSTALLED IN NOVEMBER AND DECEMBER 1981
2. INSTRUMENT HAS BEEN REMOVED FOR REPAIR

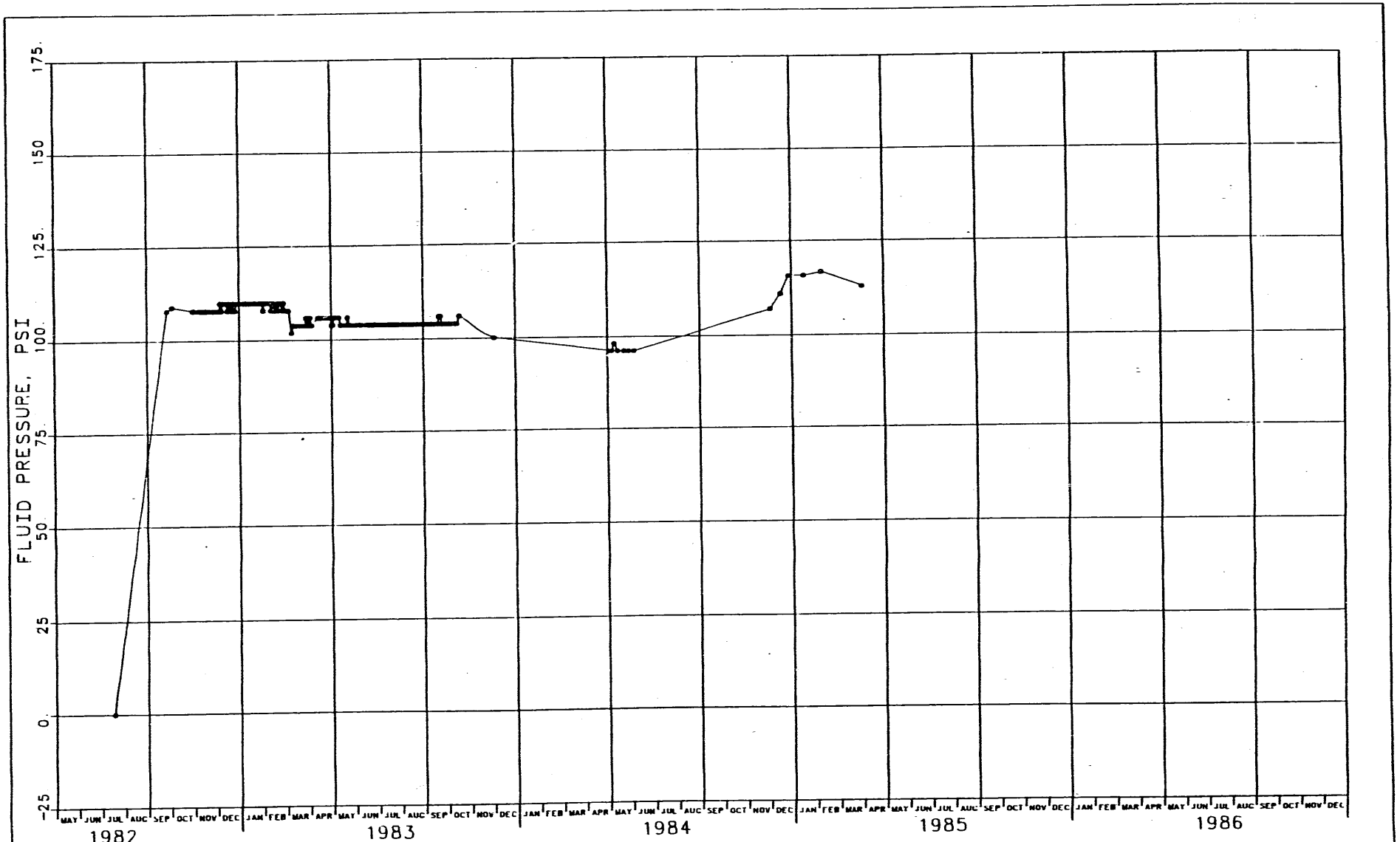
FIGURE J-39
PIEZOMETER 37X-PE-00206
C & SH SHAFT - EL 2719
PRESSURE VS. CALENDAR MONTH



NOTES

1 STEEL LINER WAS INSTALLED IN NOVEMBER AND DECEMBER 1981

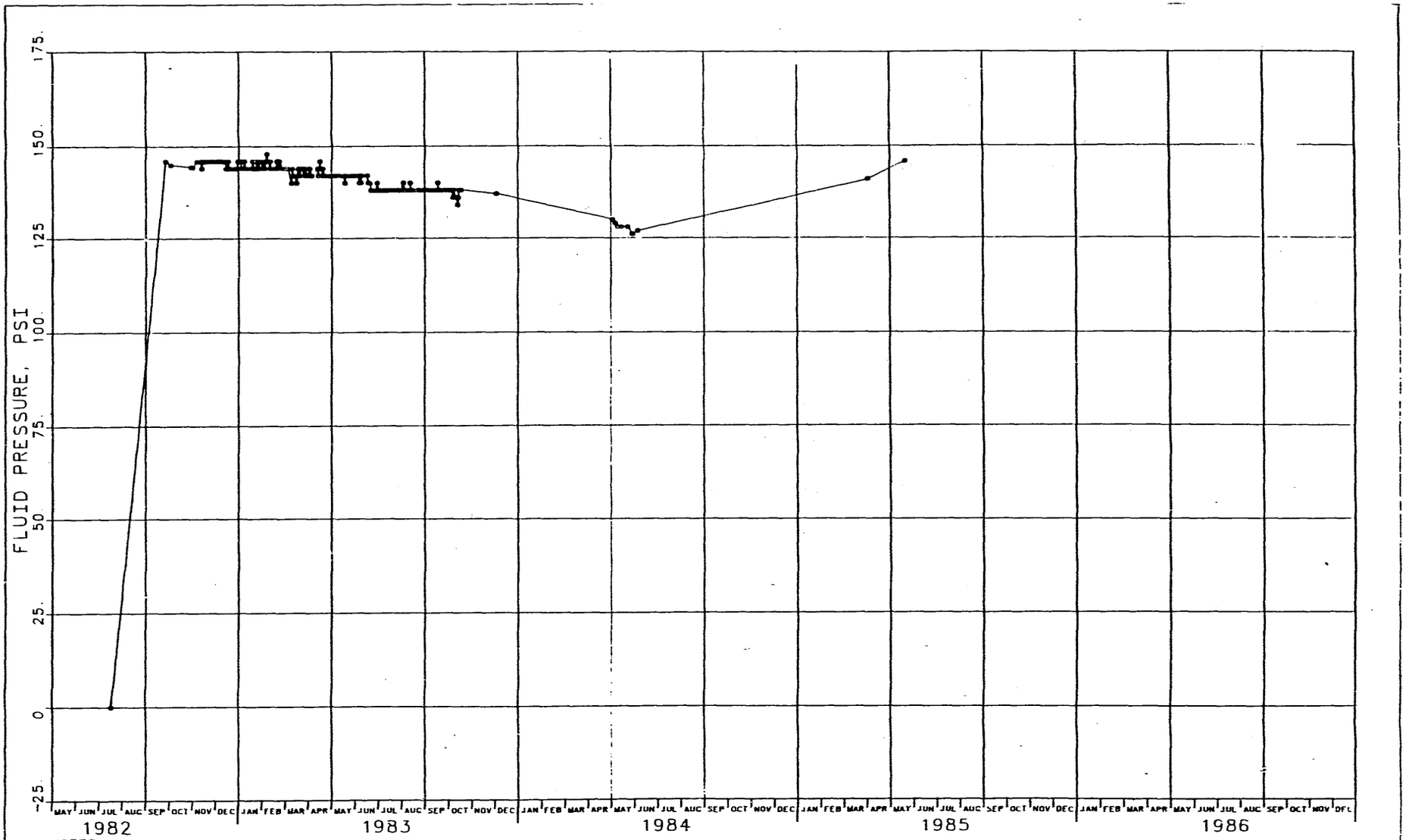
FIGURE J-40
PIEZOMETER 37X-PE-00207
C & SH SHAFT - EL 2684 (CULEBRA)
PRESSURE VS. CALENDAR MONTH



NOTES:

1. STEEL LINER WAS INSTALLED IN NOVEMBER AND DECEMBER 1981
2. INSTRUMENT HAS BEEN REMOVED FOR REPAIR

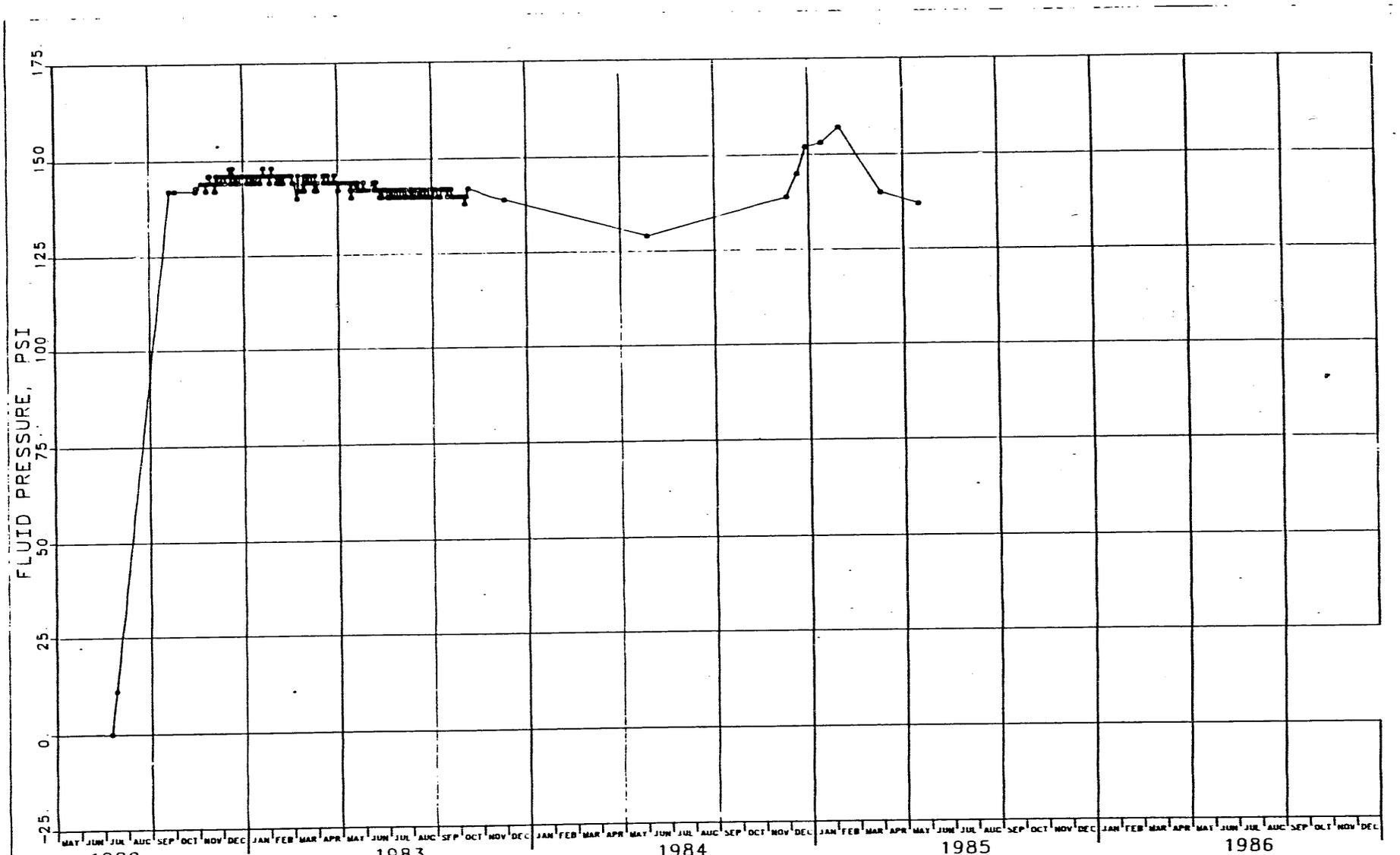
FIGURE J-41
PIEZOMETER 37X-PE-00208
C & SH SHAFT - EL 2684 (CULEBRA)
PRESSURE VS. CALENDAR MONTH



NOTES

1. STEEL LINER WAS INSTALLED IN NOVEMBER AND DECEMBER 1981
2. INSTRUMENT HAS BEEN REMOVED FOR REPAIR

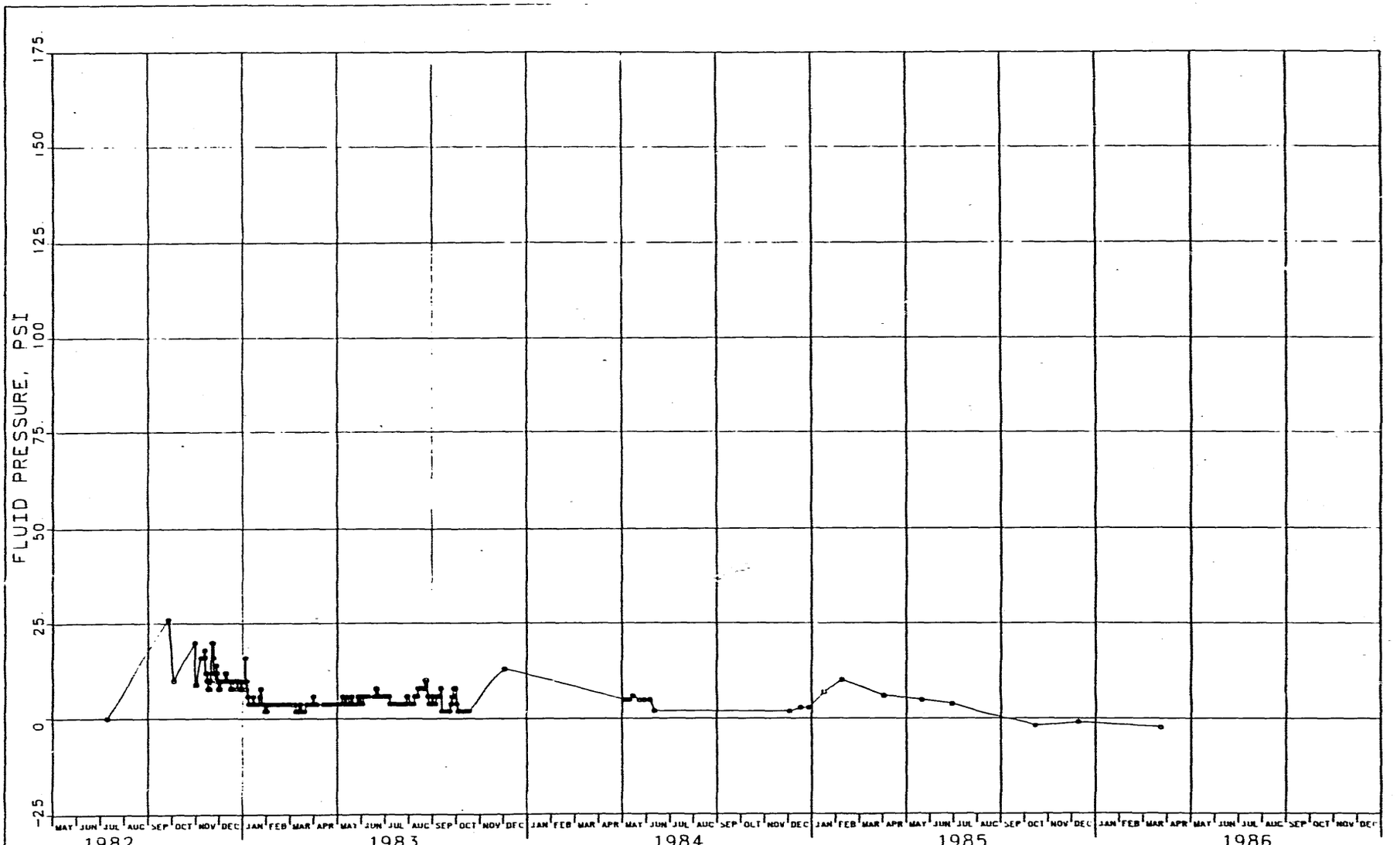
FIGURE J-42
PIEZOMETER 37X-PE-00209
C & SH SHAFT - EL 2608
PRESSURE VS. CALENDAR MONTH



NOTES

1. STEEL LINER WAS INSTALLED IN NOVEMBER AND DECEMBER 1981
2. INSTRUMENT HAS BEEN REMOVED FOR REPAIR

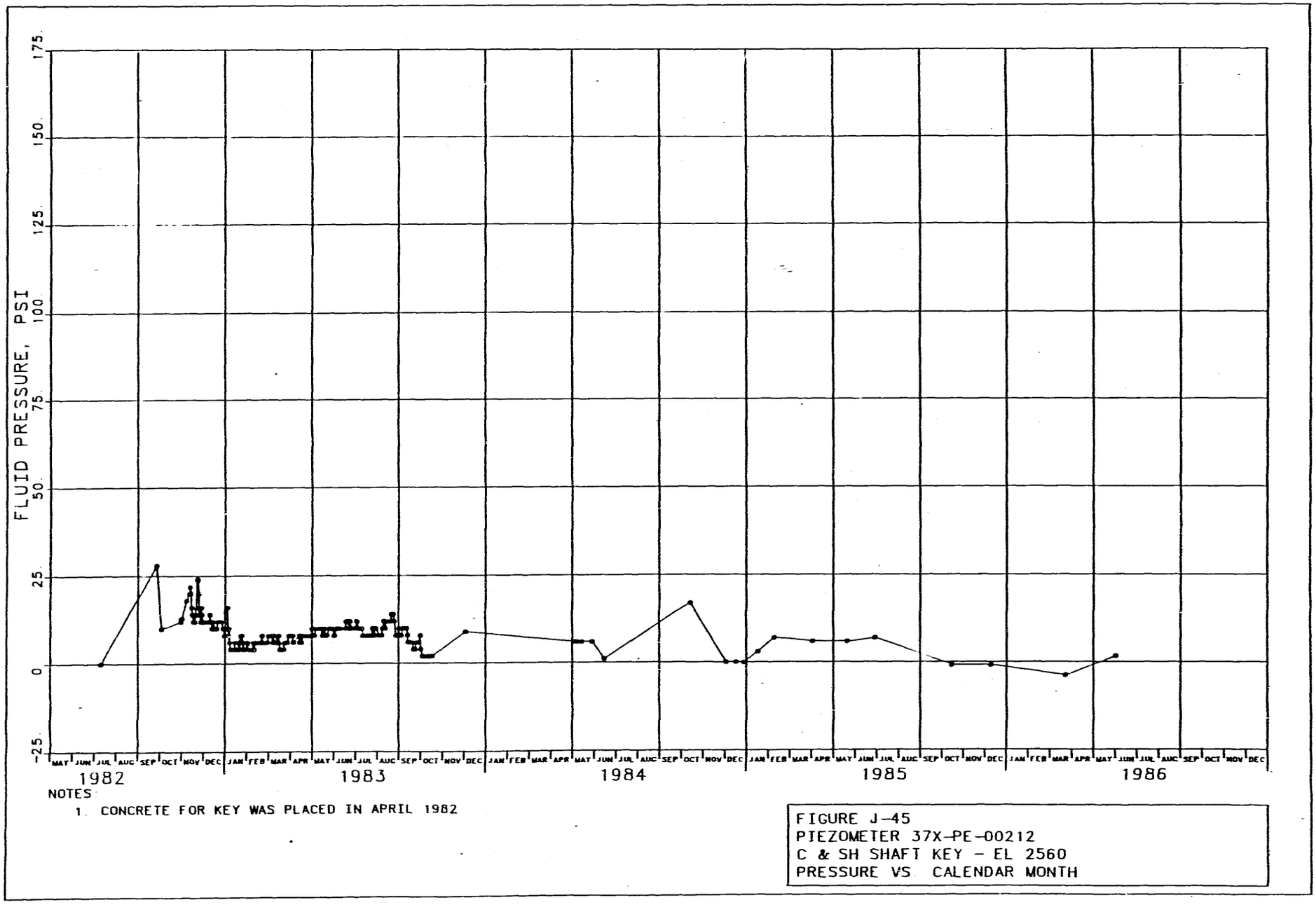
FIGURE J-43
PIEZOMETER 37X-PE-00210
C & SH SHAFT - EL 2608
PRESSURE VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982
2. INSTRUMENT IS CURRENTLY NOT FUNCTIONING

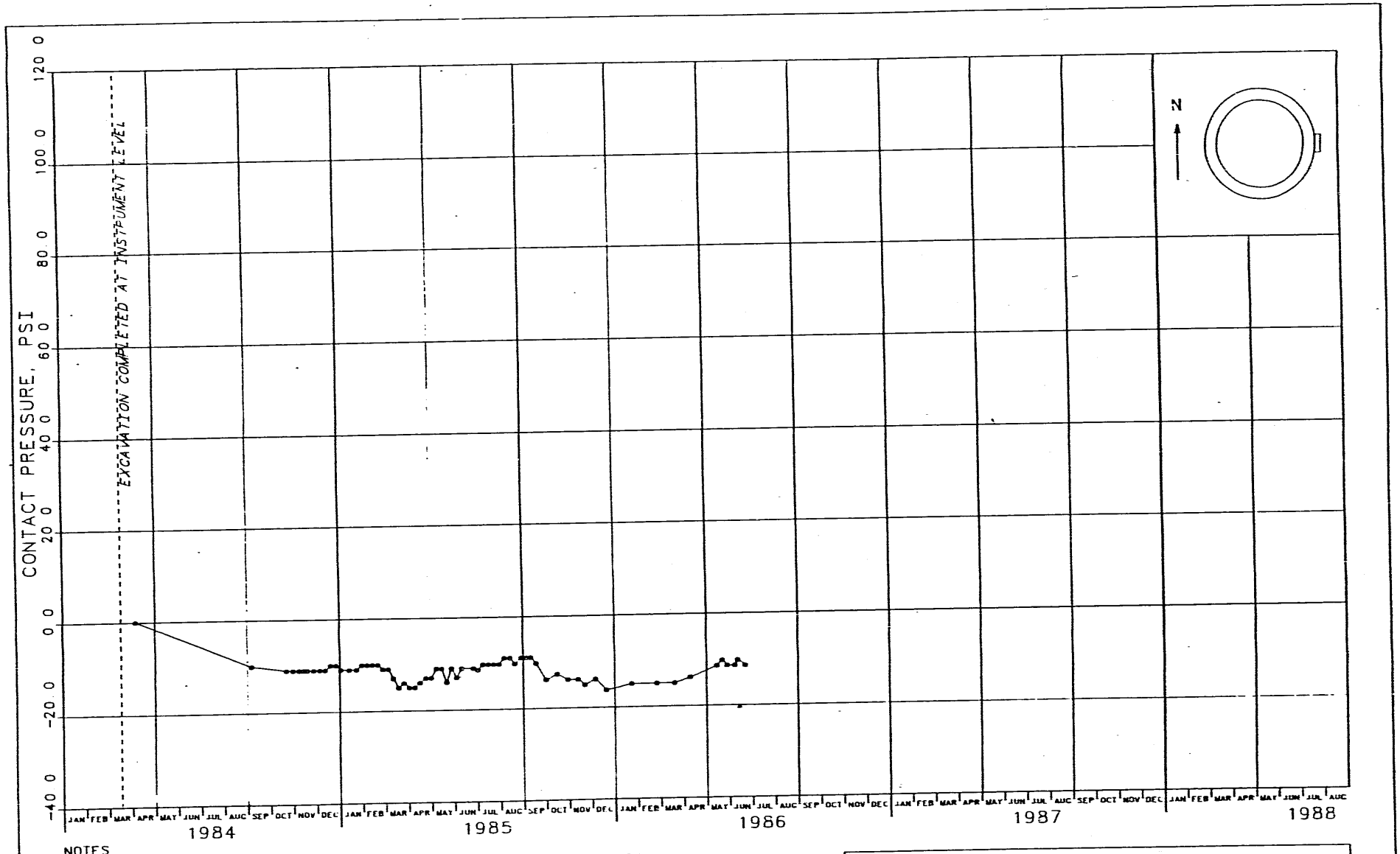
FIGURE J-44
PIEZOMETER 37X-PE-00211
C & SH SHAFT KEY - EL 2560
PRESSURE VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982

FIGURE J-45
PIEZOMETER 37X-PE-00212
C & SH SHAFT KEY - EL 2560
PRESSURE VS. CALENDAR MONTH

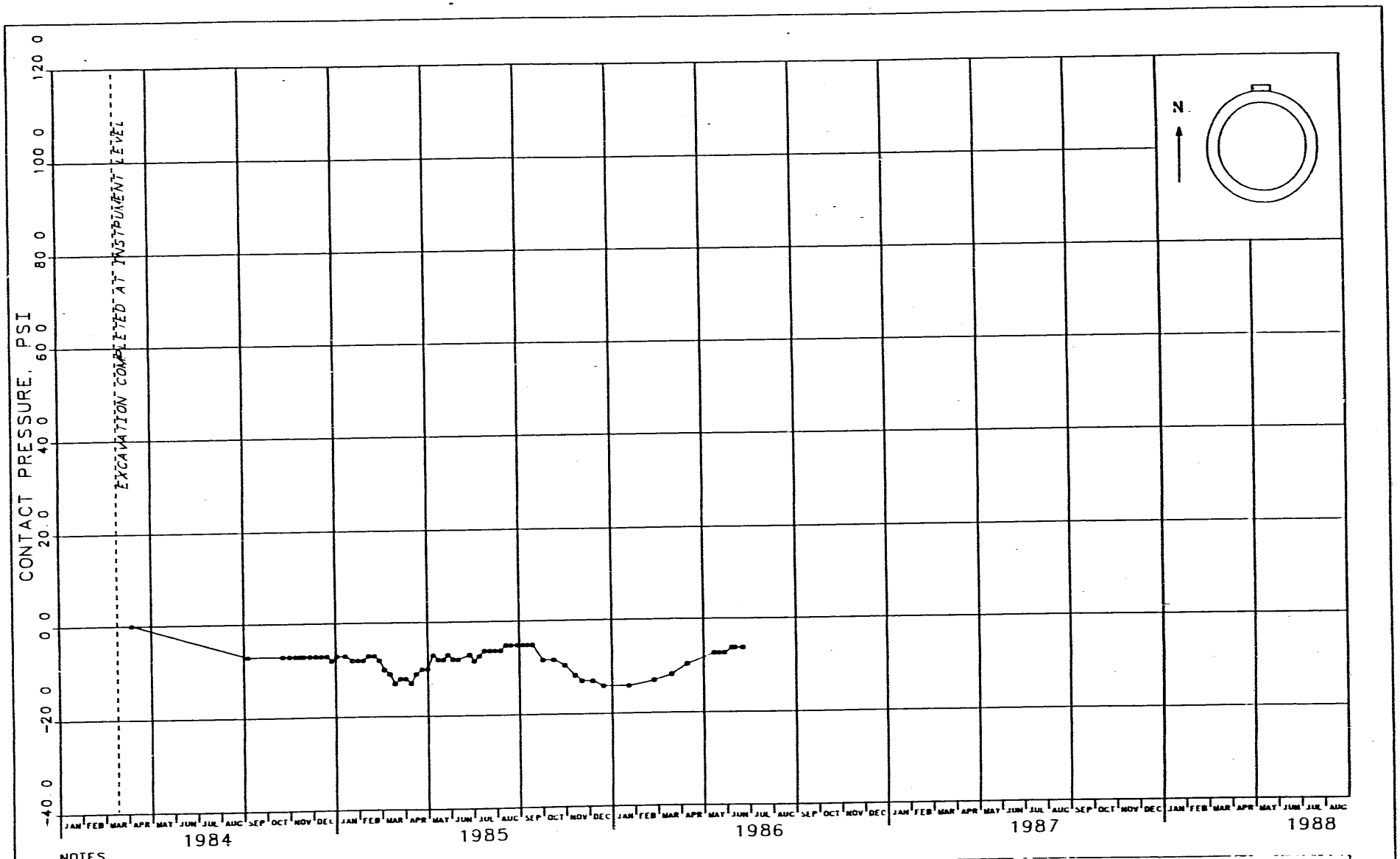


NOTES

1 CONCRETE FOR KEY WAS PLACED MARCH 23 THROUGH APRIL 3, 1984.

2 SIZE OF EXCAVATION 24 FT DIAM

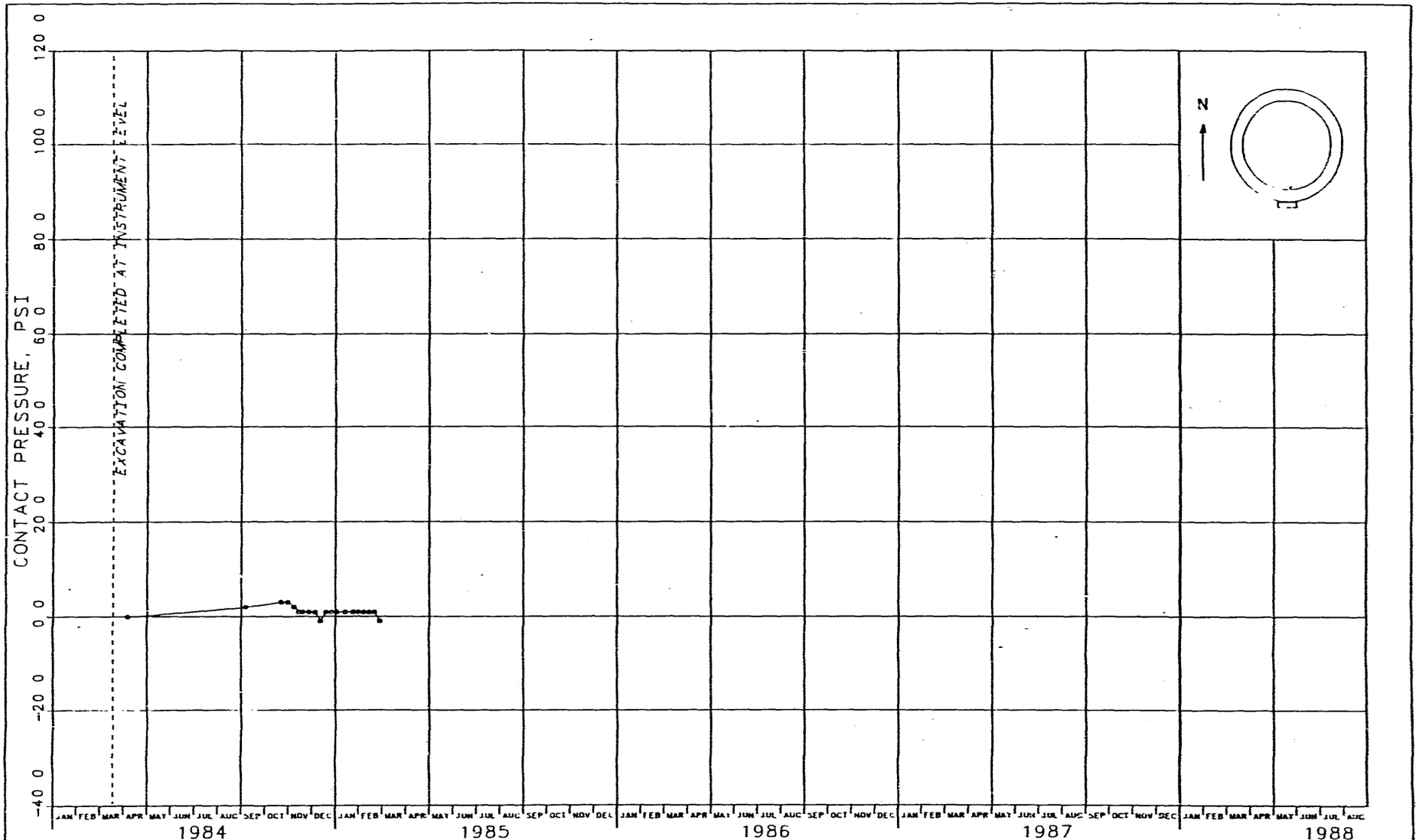
FIGURE J-46
PRESSURE CELL 31X-WE-00201
WASTE SHAFT - EL 2543 - EAST SIDE
PRESSURE VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED MARCH 23 THROUGH APRIL 3, 1984
2. SIZE OF EXCAVATION 24 FT DIAM

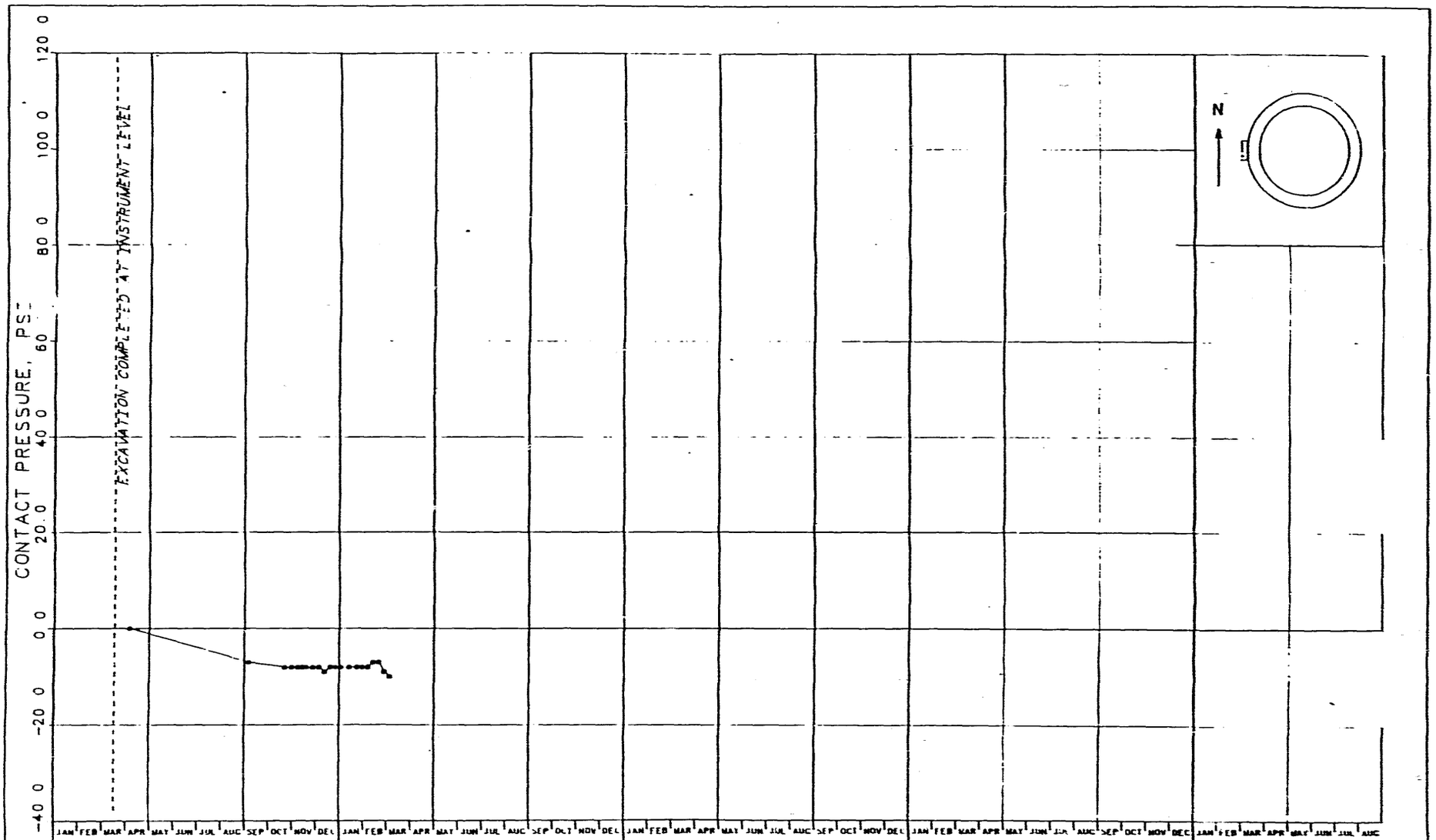
FIGURE J-47
PRESSURE CELL 31X-WE-00202
WASTE SHAFT - EL 2543 - NORTH SIDE
PRESSURE VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED MARCH 23 THROUGH APRIL 3, 1984
2. SIZE OF EXCAVATION 24 FT DIAM
3. INSTRUMENT IS CURRENTLY NOT FUNCTIONING

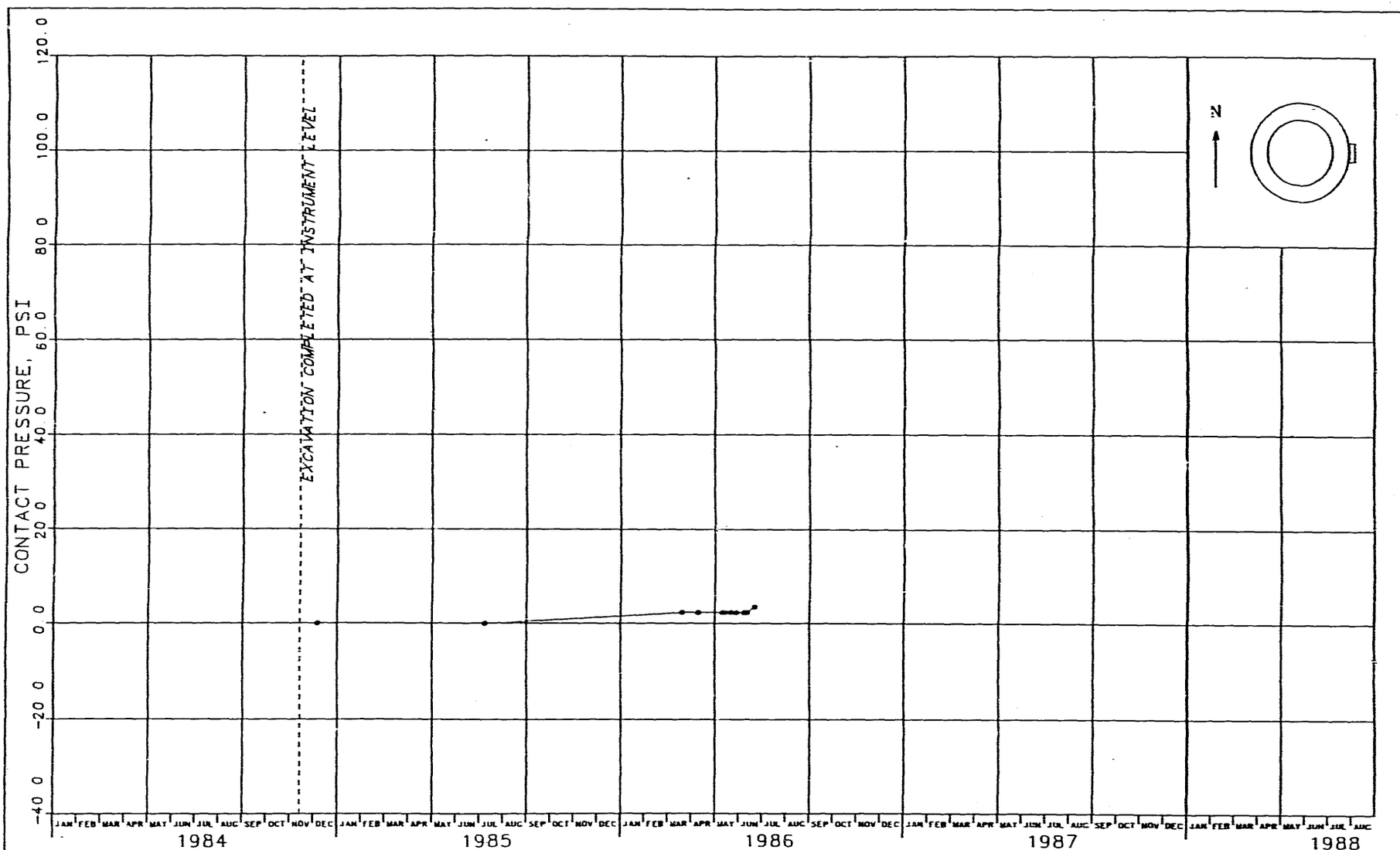
FIGURE J-48
PRESSURE CELL 31X-WE-00203
WASTE SHAFT – EL 2543 – SOUTH SIDE
PRESSURE VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED MARCH 23 THROUGH APRIL 3, 1984
2. SIZE OF EXCAVATION 24 FT DIAM
3. INSTRUMENT IS CURRENTLY NOT FUNCTIONING

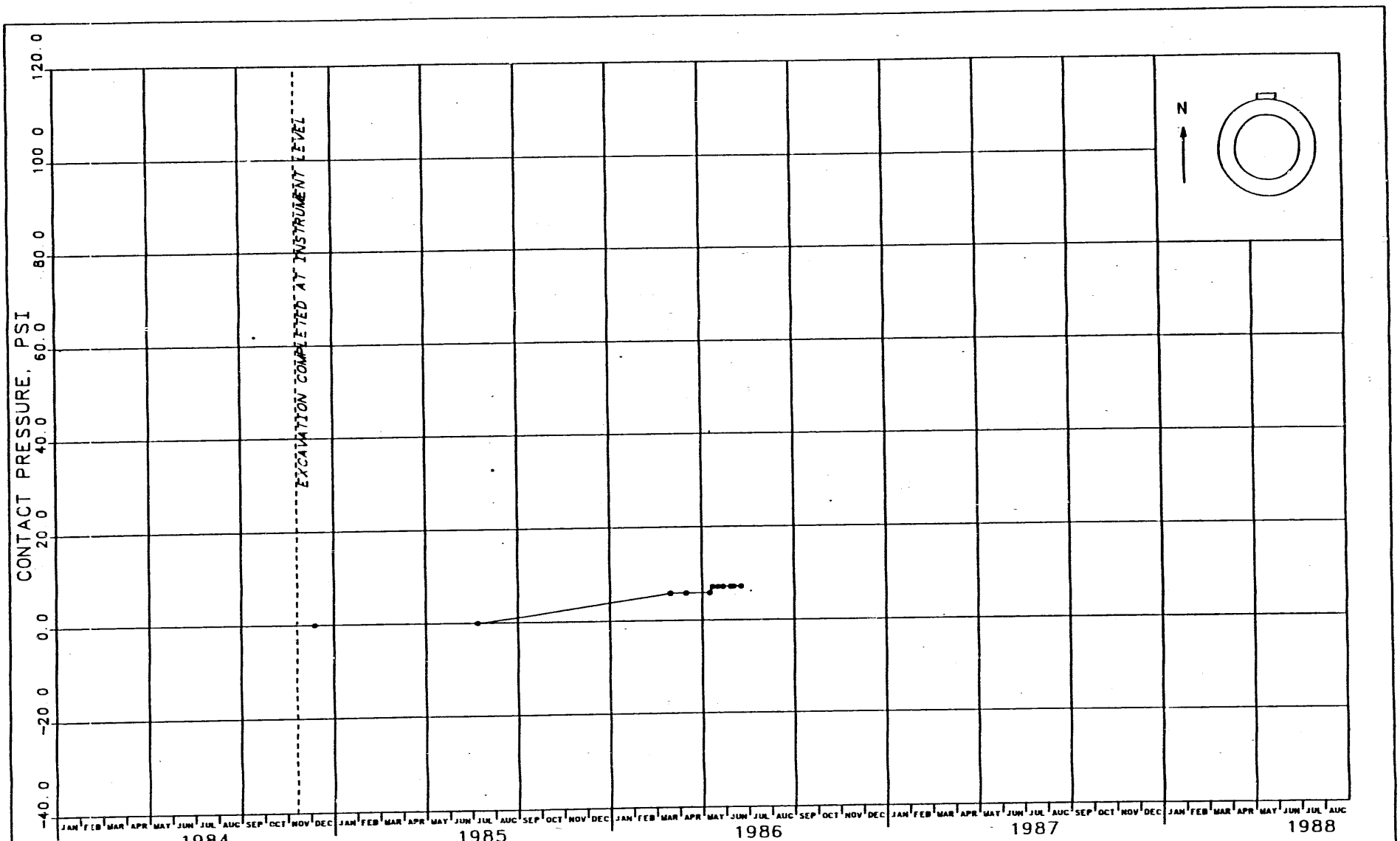
FIGURE J-49
PRESSURE CELL 31X-WE-00204
WASTE SHAFT - EL 2543 - WEST SIDE
PRESSURE VS. CALENDAR MONTH



NOTES

1 CONCRETE FOR KEY WAS PLACED NOV 19 THROUGH NOV 29, 1984.
2 SIZE OF EXCAVATION 21 FT DIAM

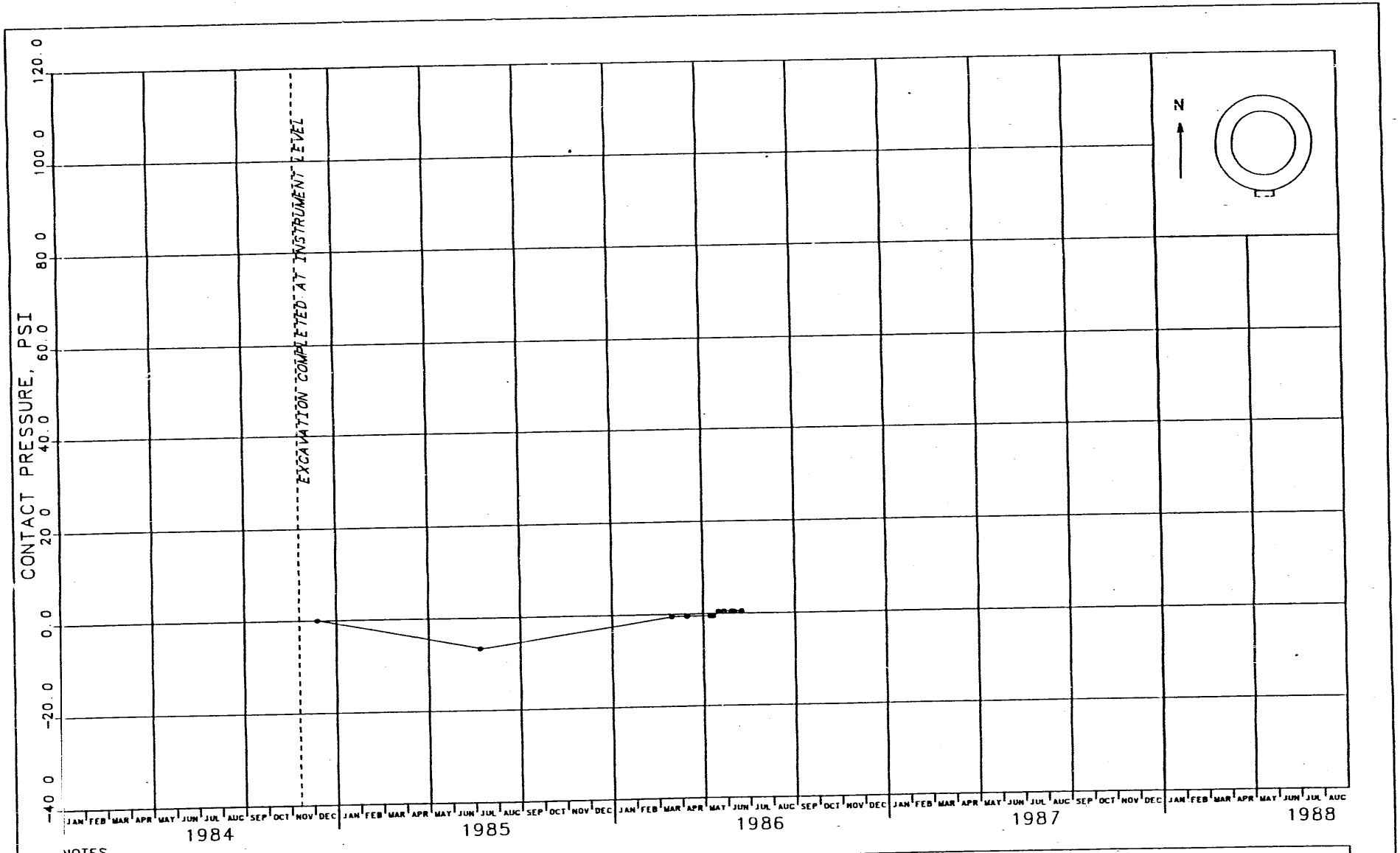
FIGURE J-50
PRESSURE CELL 35X-WE-00201
EXHAUST SHAFT KEY - EL 2535 - EAST SIDE
PRESSURE VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED NOV 19 THROUGH NOV 29, 1984
2. SIZE OF EXCAVATION: 21 FT DIAM

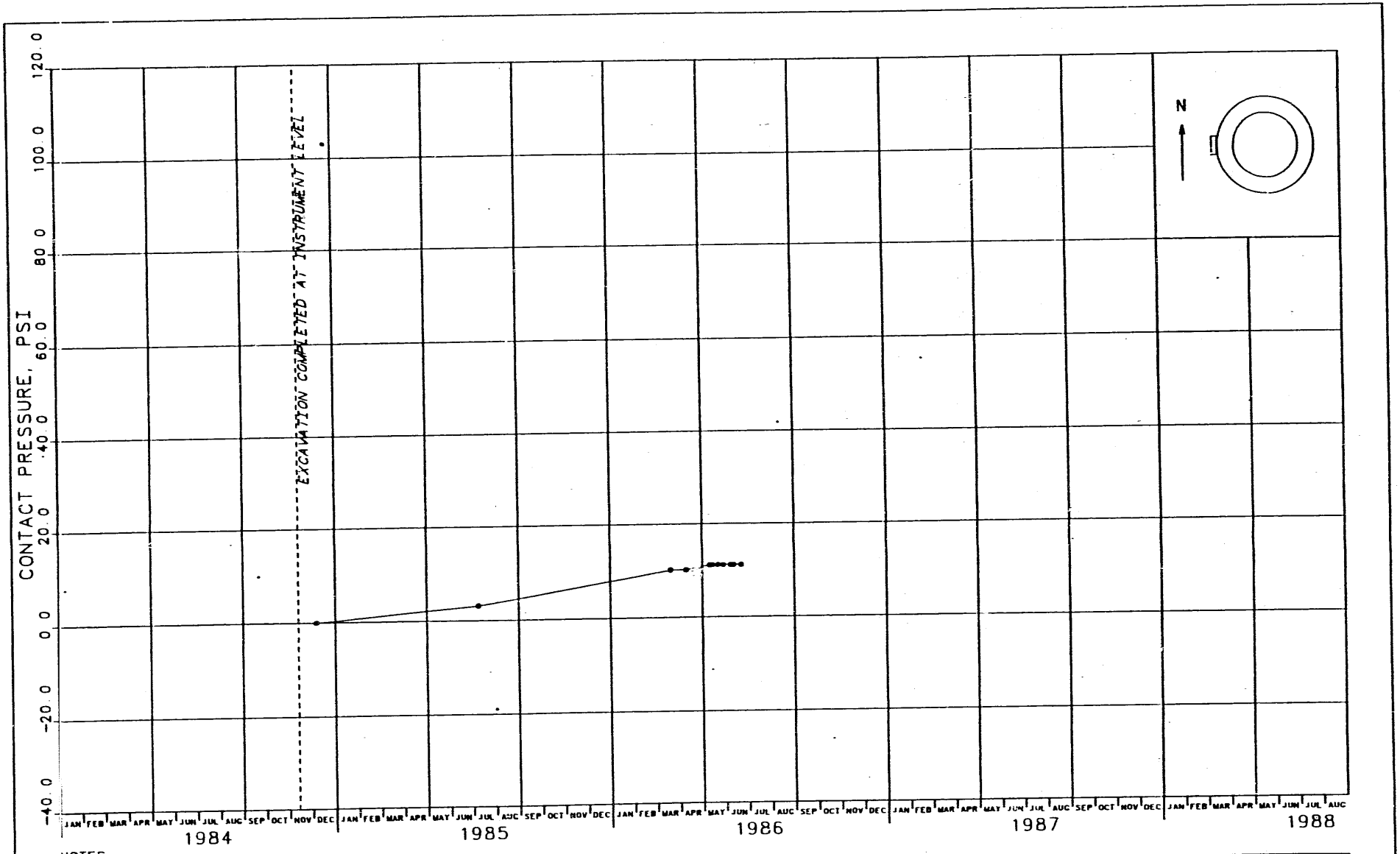
FIGURE J-51
PRESSURE CELL 35X-WE-00202
EXHAUST SHAFT KEY - EL 2535 - NORTH SIDE
PRESSURE VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED NOV 19 THROUGH NOV 29, 1984.
2. SIZE OF EXCAVATION 21 FT DIAM.

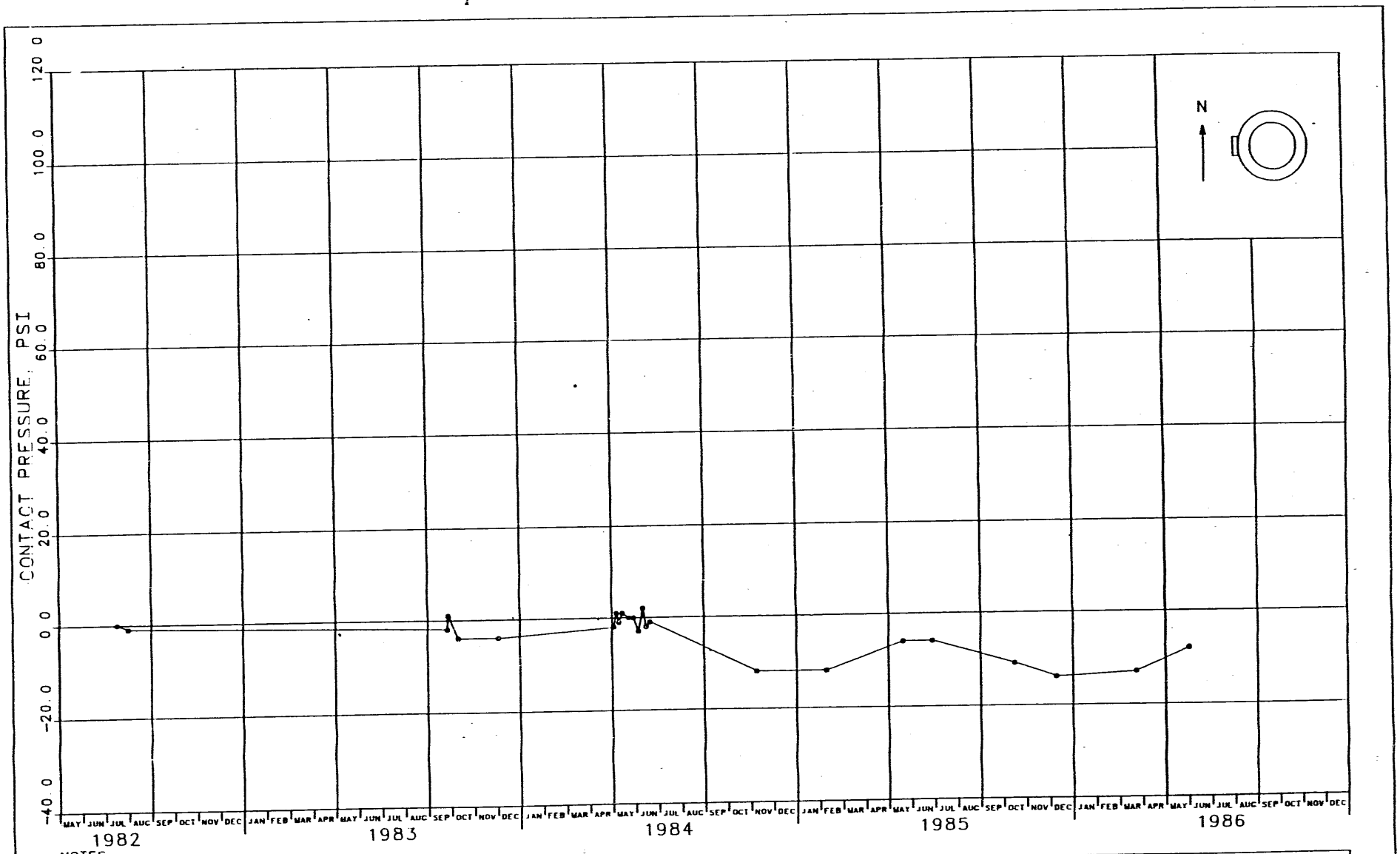
FIGURE J-52
PRESSURE CELL 35X-WE-00203
EXHAUST SHAFT KEY - EL 2535 - SOUTH SIDE
PRESSURE VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED NOV. 19 THROUGH NOV. 29, 1984
2. SIZE OF EXCAVATION: 21 FT DIAM

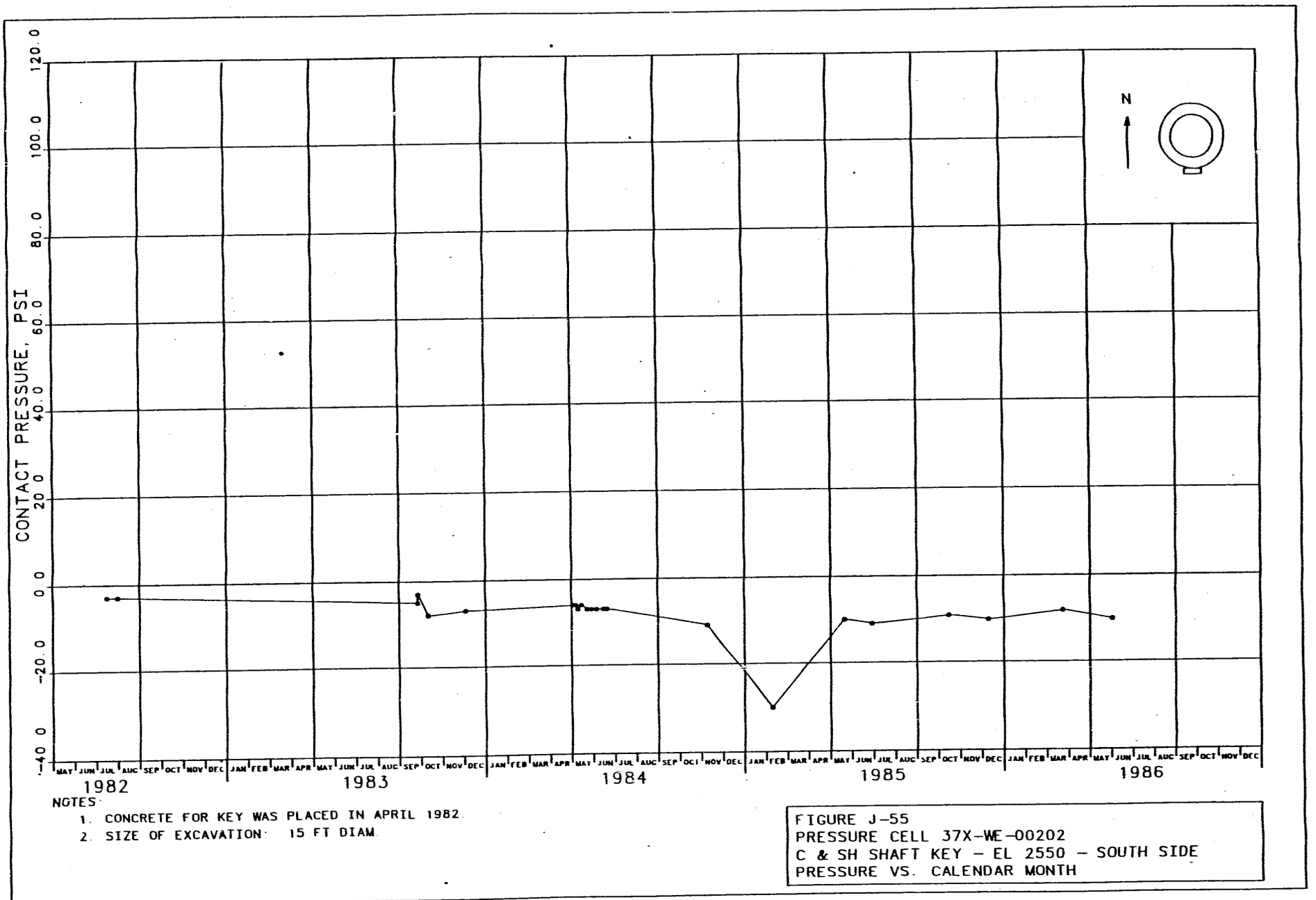
FIGURE J-53
PRESSURE CELL 35X-WE-00204
EXHAUST SHAFT KEY - EL 2535 - WEST SIDE
PRESSURE VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982
2. SIZE OF EXCAVATION: 15 FT DIAM

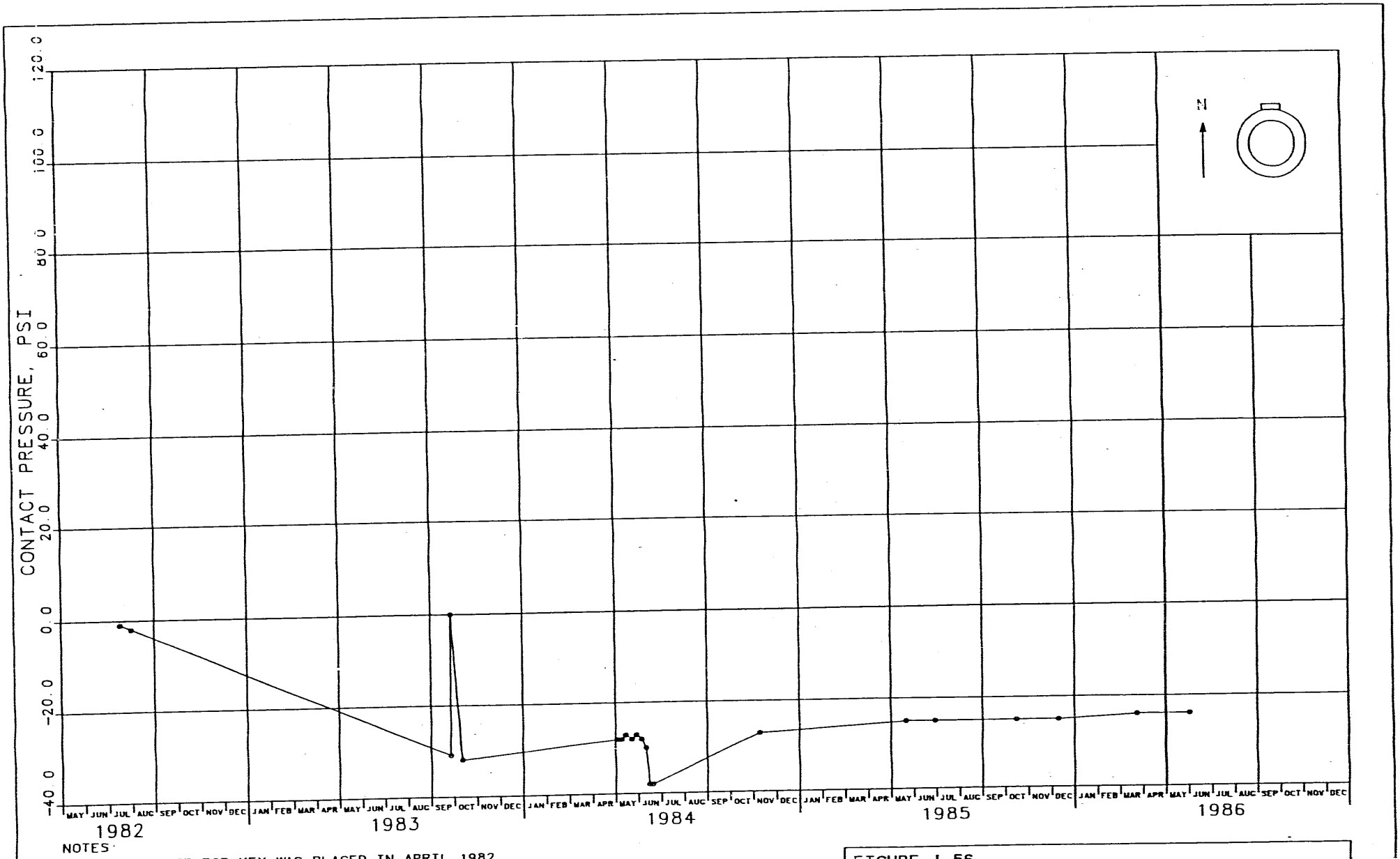
FIGURE J-54
PRESSURE CELL 37X-WE-00201
C & SH SHAFT KEY - EL 2550 - WEST SIDE
PRESSURE VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. SIZE OF EXCAVATION: 15 FT DIAM.

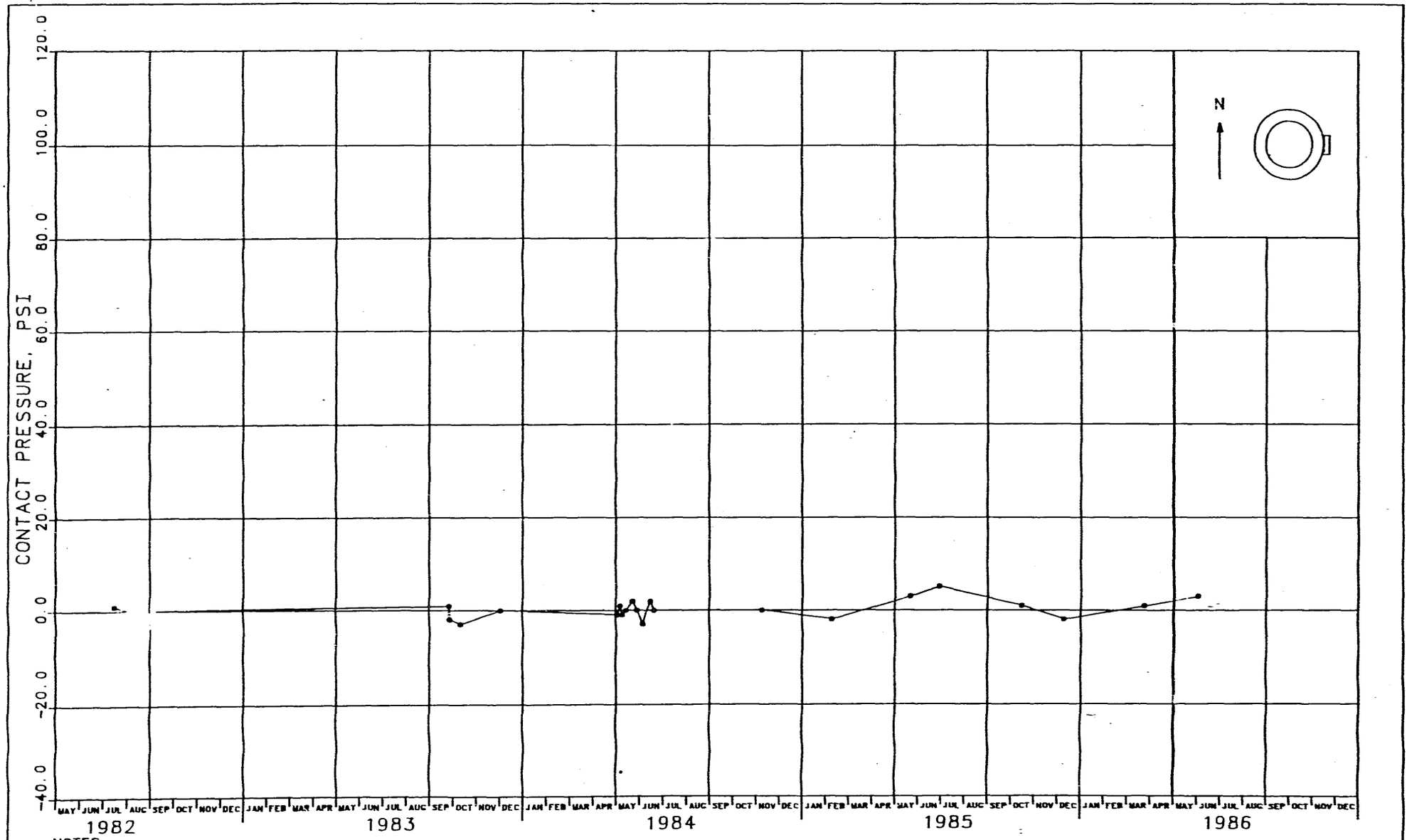
FIGURE J-55
PRESSURE CELL 37X-WE-00202
C & SH SHAFT KEY - EL 2550 - SOUTH SIDE
PRESSURE VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. SIZE OF EXCAVATION: 15 FT DIAM.

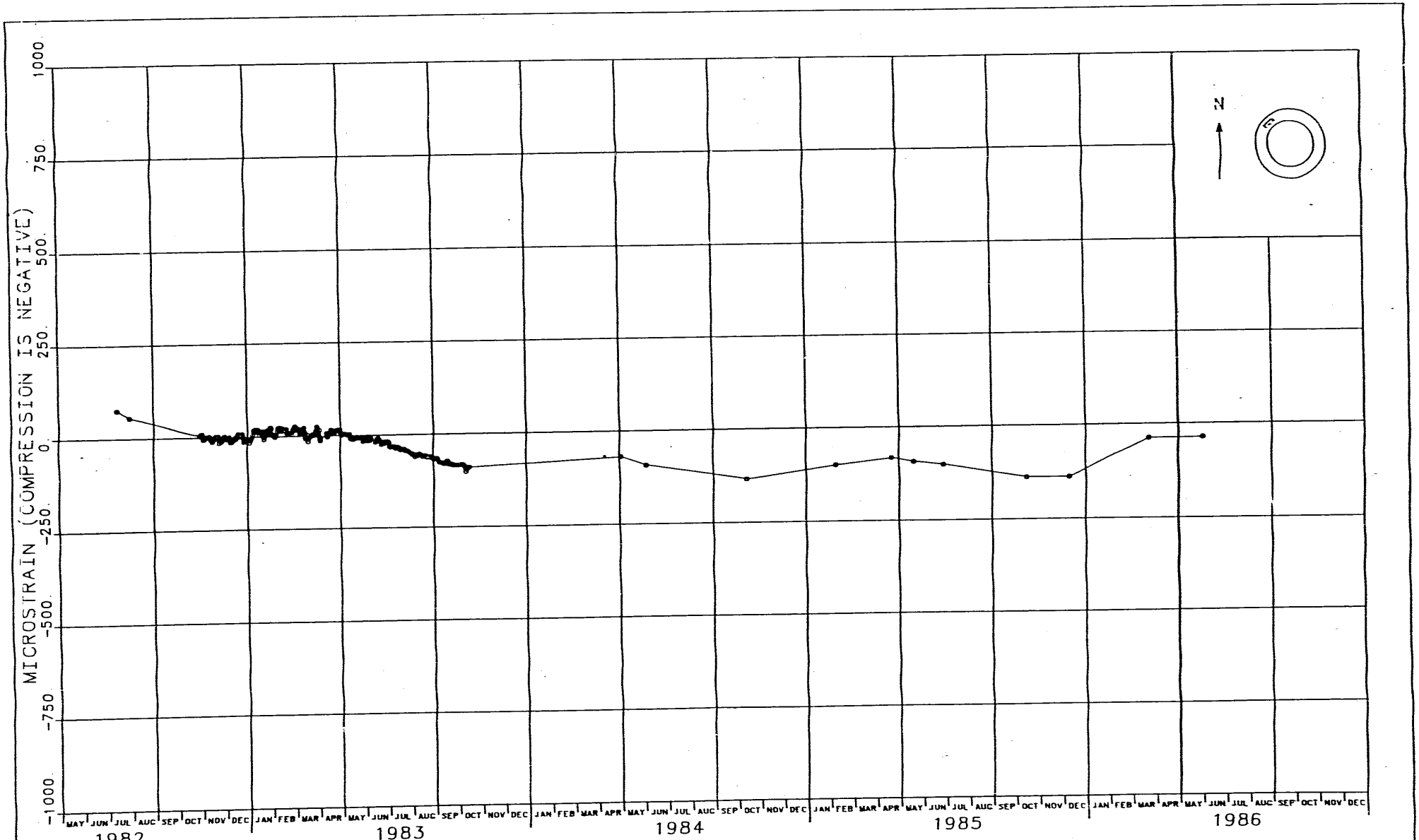
FIGURE J-56
PRESSURE CELL 37X-WE-00203
C & SH SHAFT KEY - EL 2550 - NORTH SIDE
PRESSURE VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982
2. SIZE OF EXCAVATION: 15 FT DIAM.

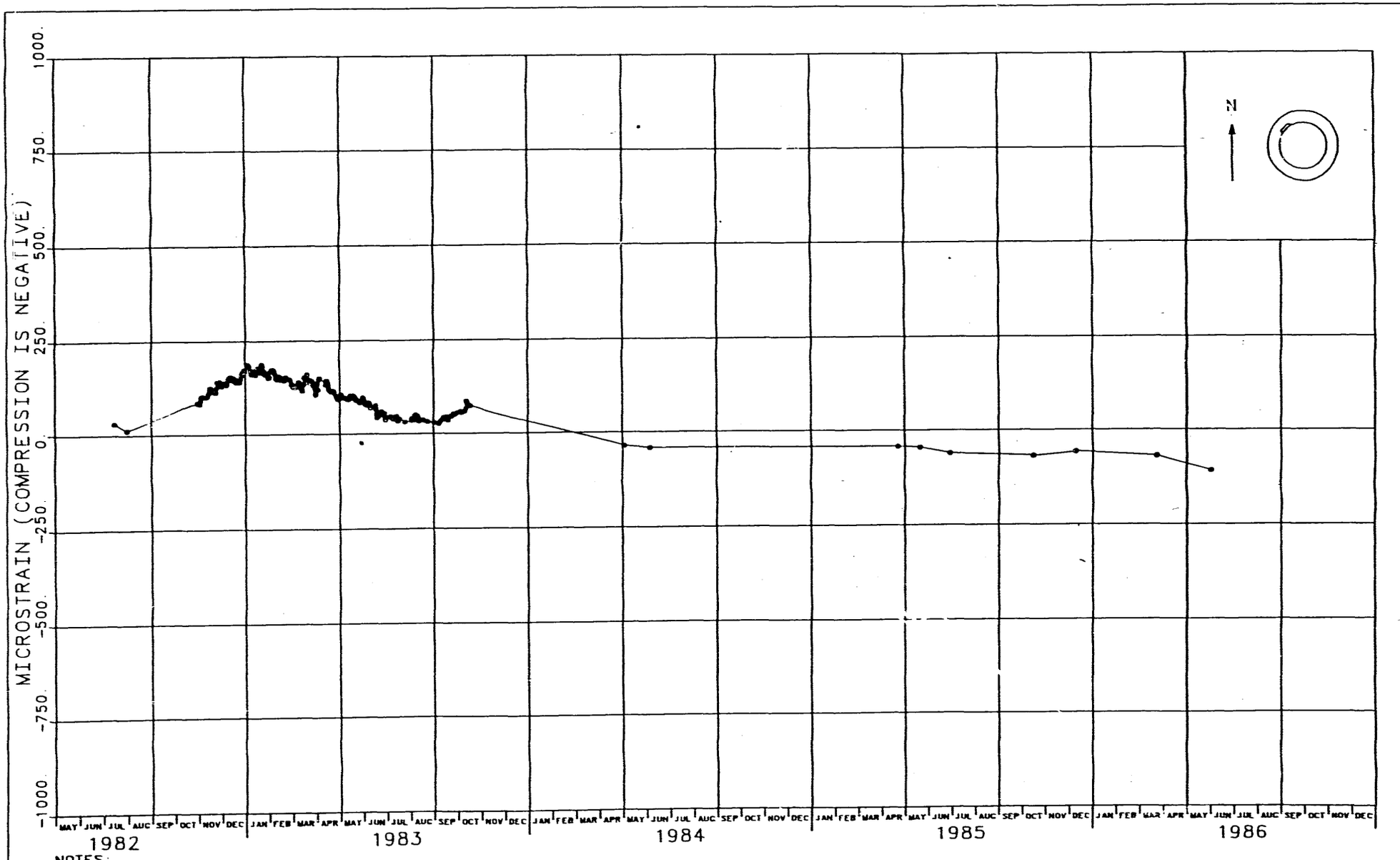
FIGURE J-57
PRESSURE CELL 37X-WE-00204
C & SH SHAFT KEY - EL 2550 - EAST SIDE
PRESSURE VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR 22, 1982.
3. GAUGE IS LOCATED 15 IN. FROM INNER FACE ON NW SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

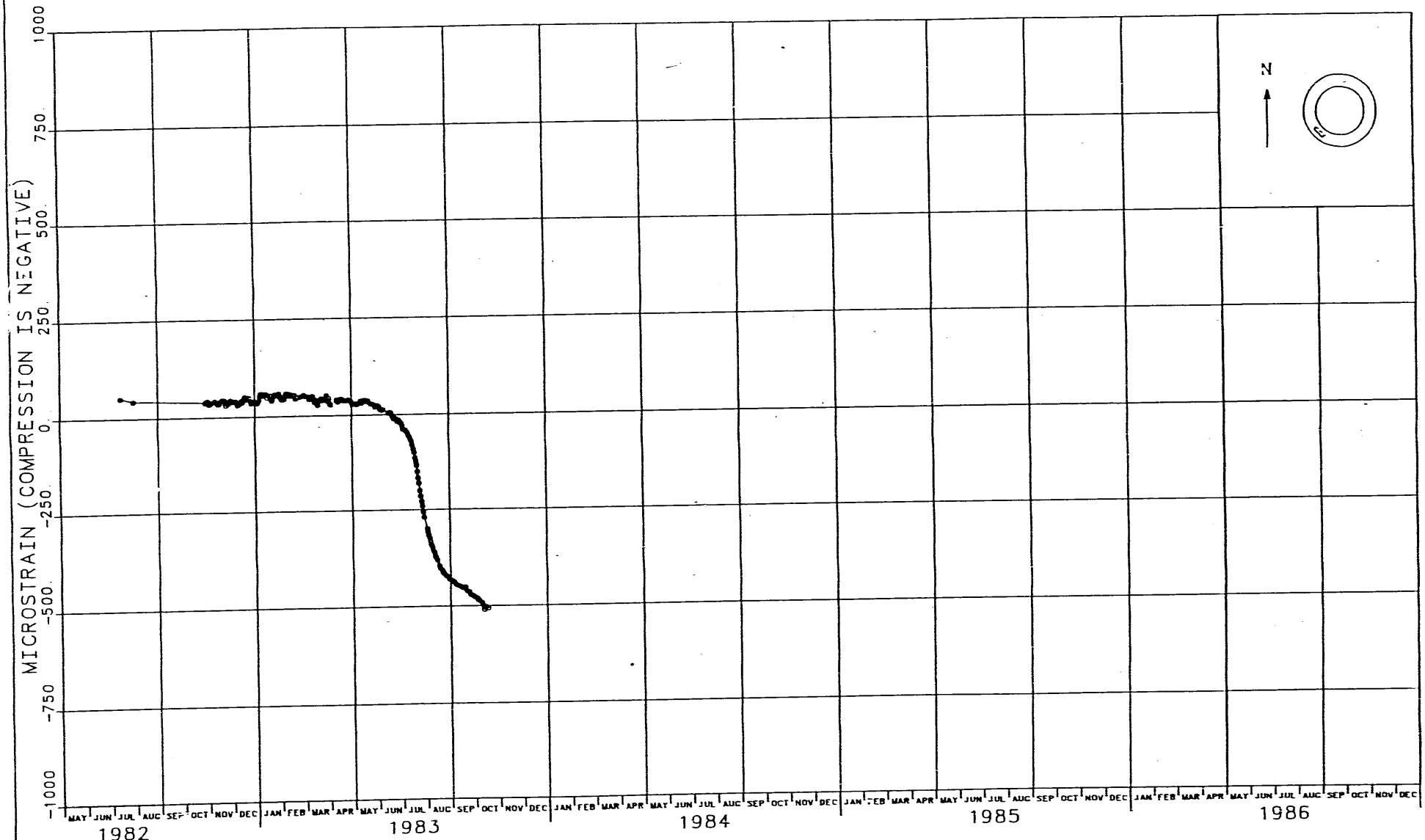
FIGURE J-58
WELDED STRAIN GAUGE 37X-ZE-00201
C & SH SHAFT KEY - EL 2553.7
STRAIN VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR 22, 1982.
3. GAUGE IS LOCATED 3 IN. FROM INNER FACE ON NW SIDE OF CONCRETE KEY
4. SIZE OF EXCAVATION: 15 FT DIAM

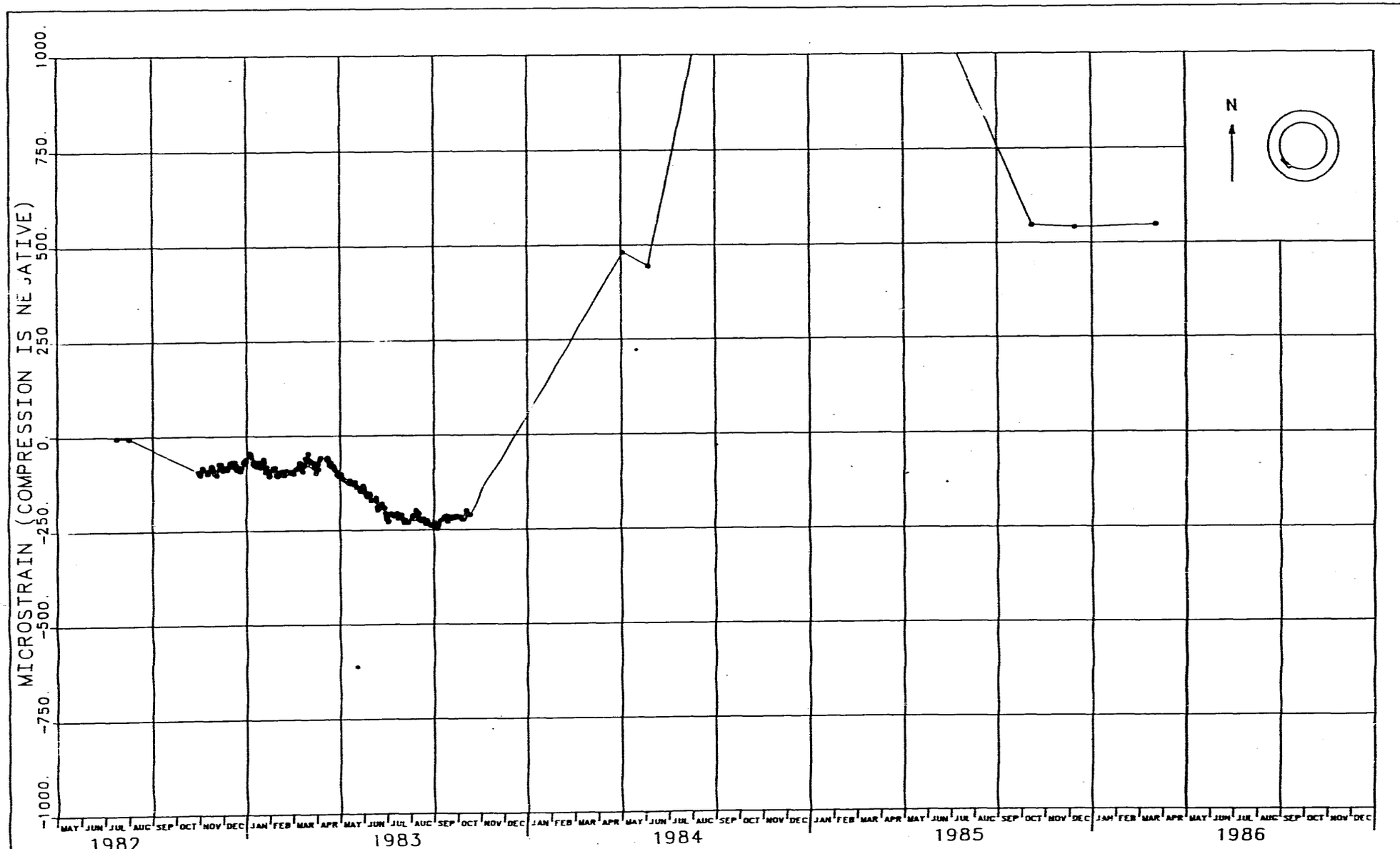
FIGURE J-59
WELDED STRAIN GAUGE 37X-ZE-00202
C & SH SHAFT KEY -- EL 2553.7
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 15 IN. FROM INNER FACE ON SW SIDE OF CONCRETE KEY
4. SIZE OF EXCAVATION: 15 FT DIAM.
5. INSTRUMENT HAS PERMANENTLY FAILED

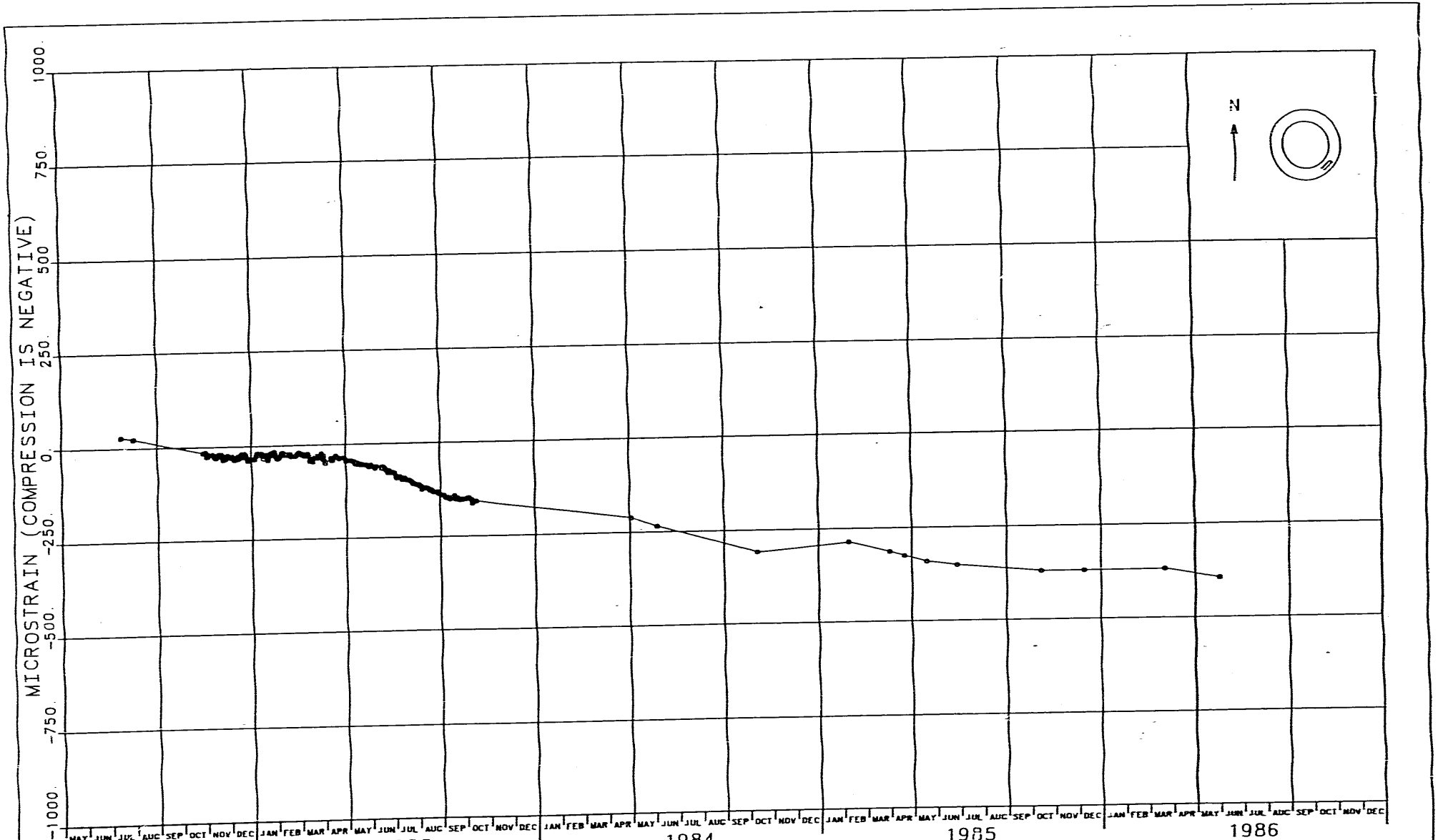
FIGURE C-60
WELDED STRAIN GAUGE 37X-ZE-00203
C & SH SHAFT KEY - EL 2553.7
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR 22, 1982
3. GAUGE IS LOCATED 3 IN. FROM INNER FACE ON SW SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION 15 FT DIAM.
5. INSTRUMENT IS CURRENTLY NOT FUNCTIONING

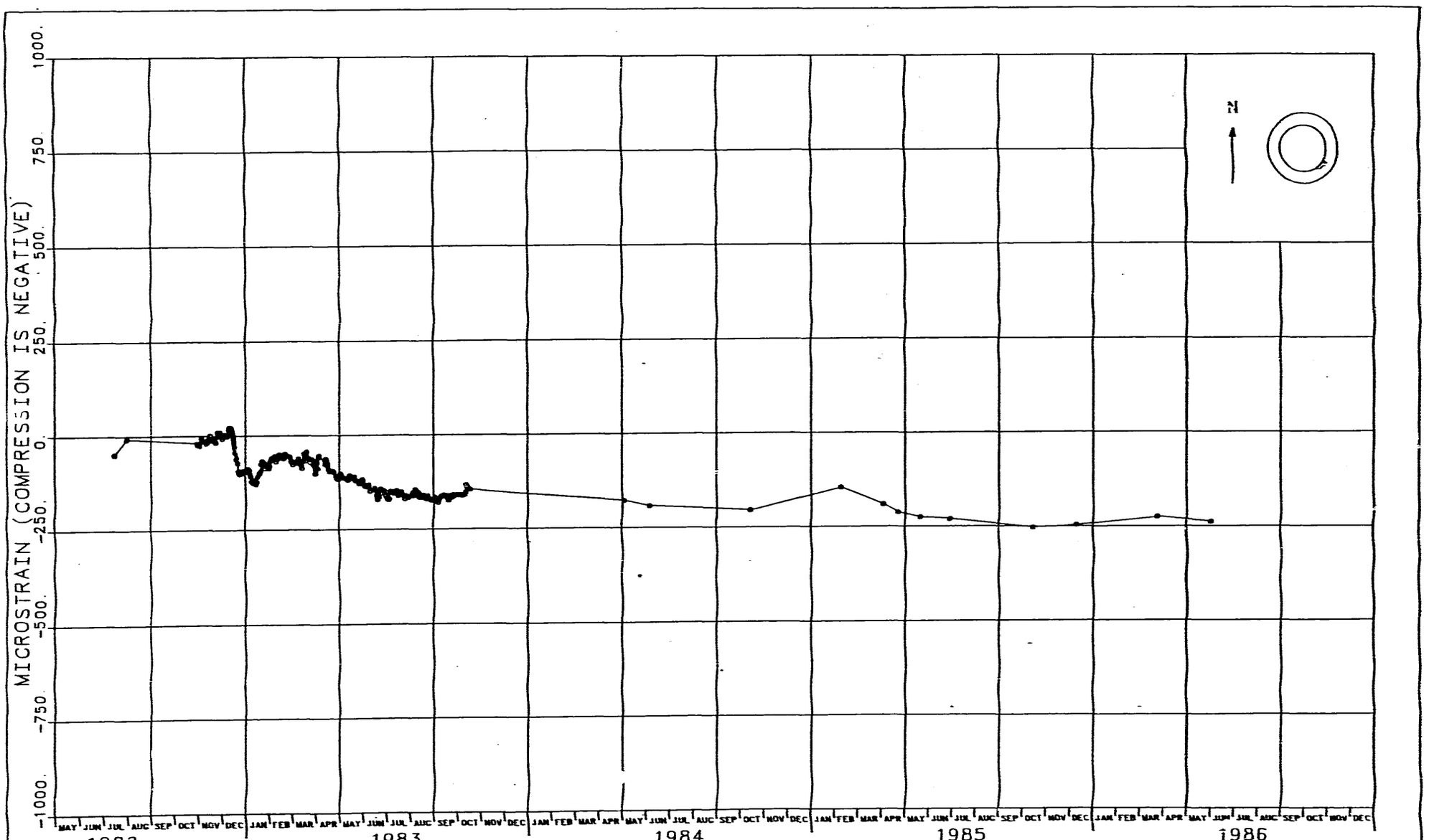
FIGURE J-61
WELDED STRAIN GAUGE 37X-ZE-00204
C & SH SHAFT KEY - El 2553.7
STRAIN VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR 22, 1982.
3. GAUGE IS LOCATED 15 IN. FROM INNER FACE ON SE SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

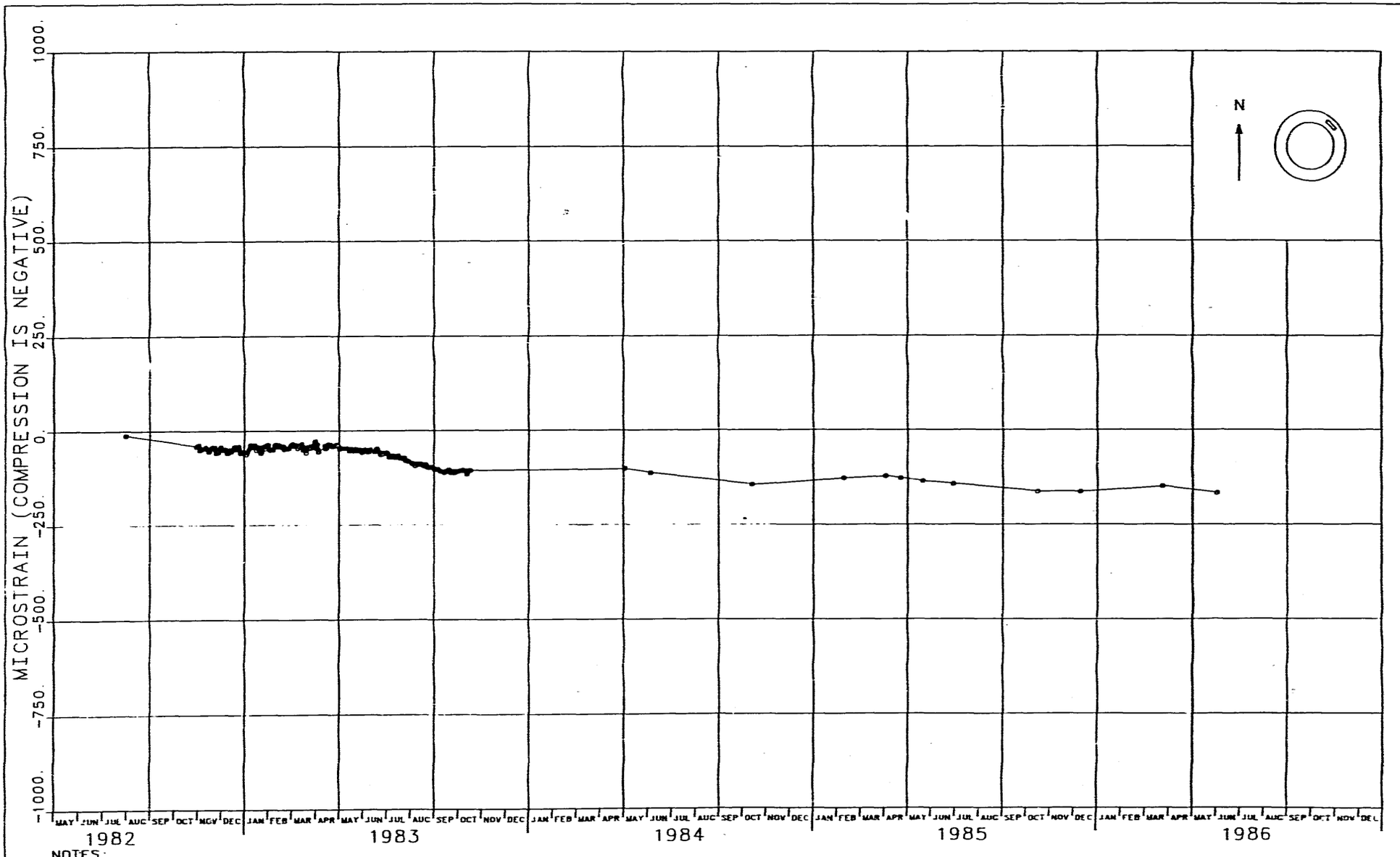
FIGURE J-62
WELDED STRAIN GAUGE 37X-ZE-00205
C & SH SHAFT KEY – EL 2553.7
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 3 IN. FROM INNER FACE ON SE SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

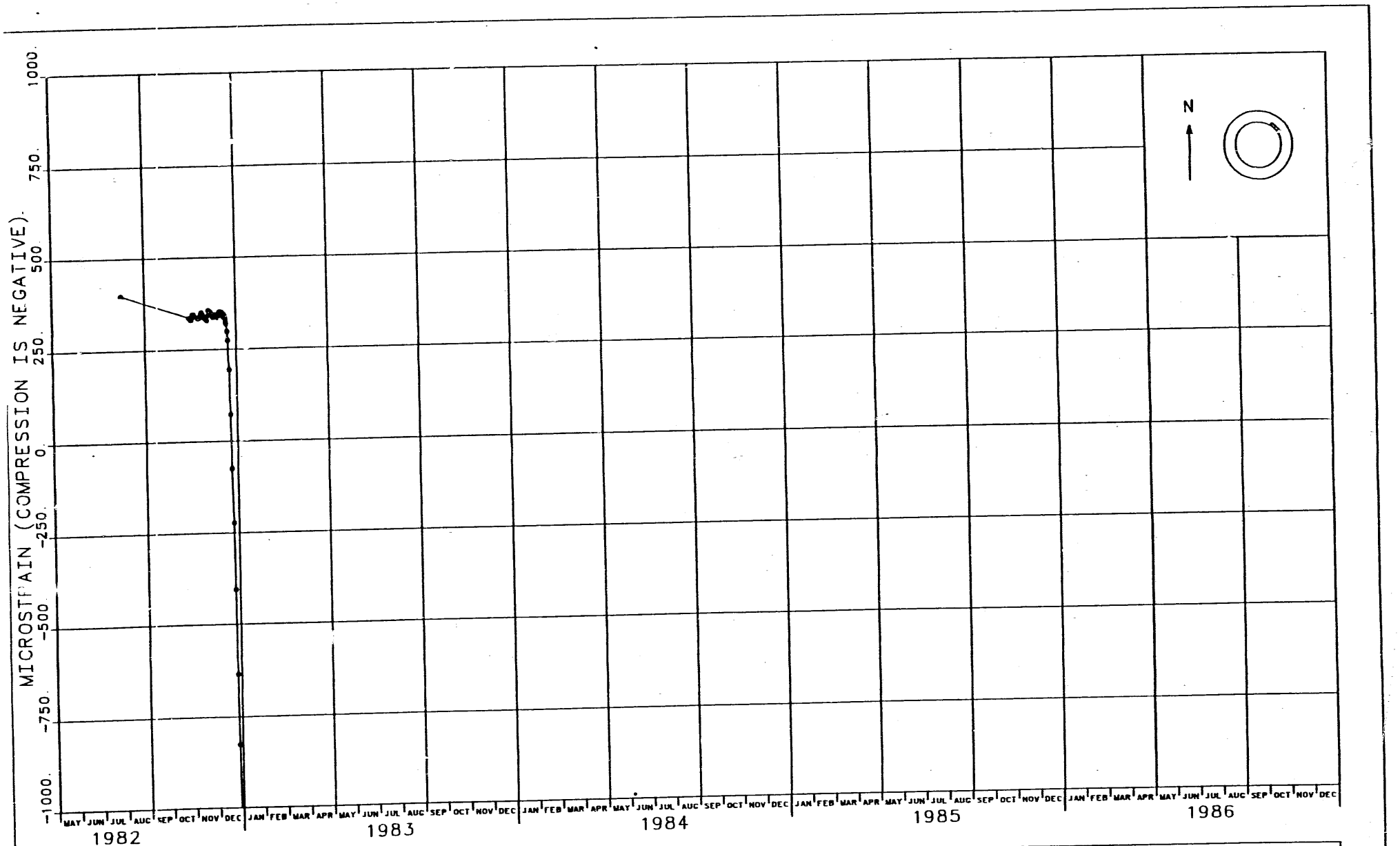
FIGURE J-63
WELDED STRAIN GAUGE 37X-ZE-00206
C & SH SHAFT KEY - EL 2553.7
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR 22, 1982.
3. GAUGE IS LOCATED 15 IN. FROM INNER FACE ON NE SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

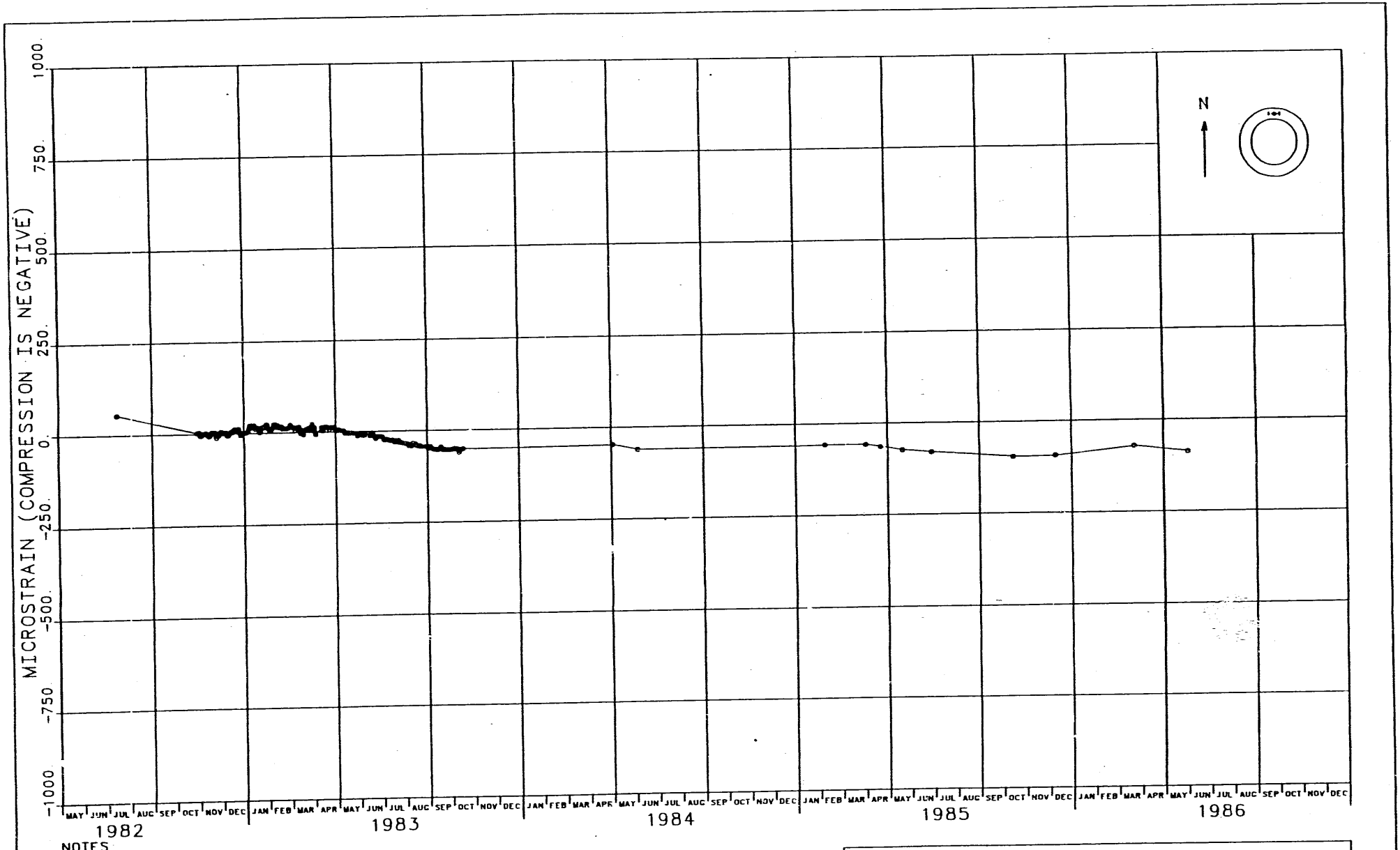
FIGURE J-64
WELDED STRAIN GAUGE 37X-ZE-00207
C & SH SHAFT KEY - EL 2553 7
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 3 IN. FROM INNER FACE ON NE SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.
5. INSTRUMENT HAS PERMANENTLY FAILED.

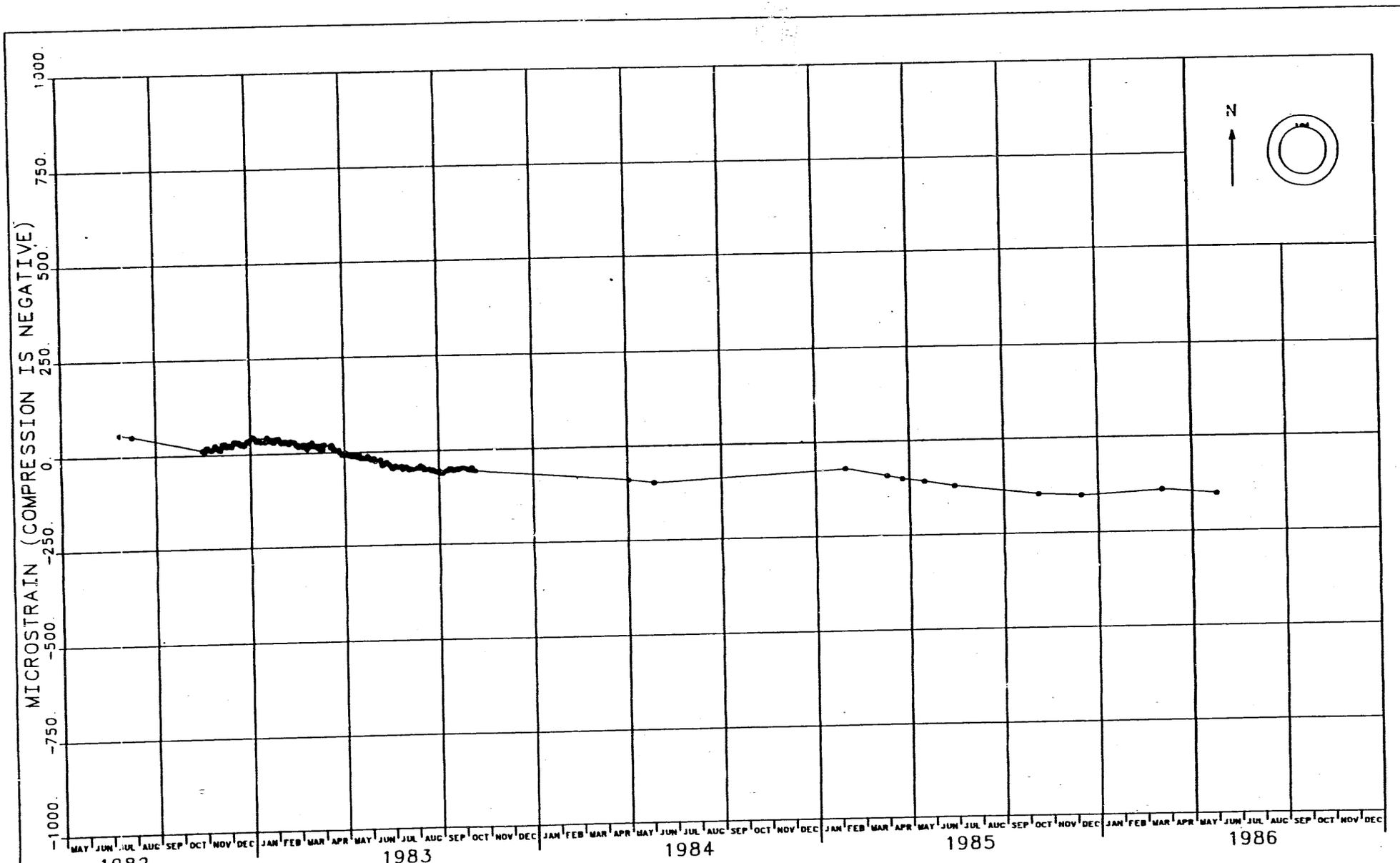
FIGURE J-65
WELDED STRAIN GAUGE 37X-ZE-00208
C & SH SHAFT KEY - EL 2553.7
STRAIN VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 14 5 IN FROM INNER FACE ON NORTH SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

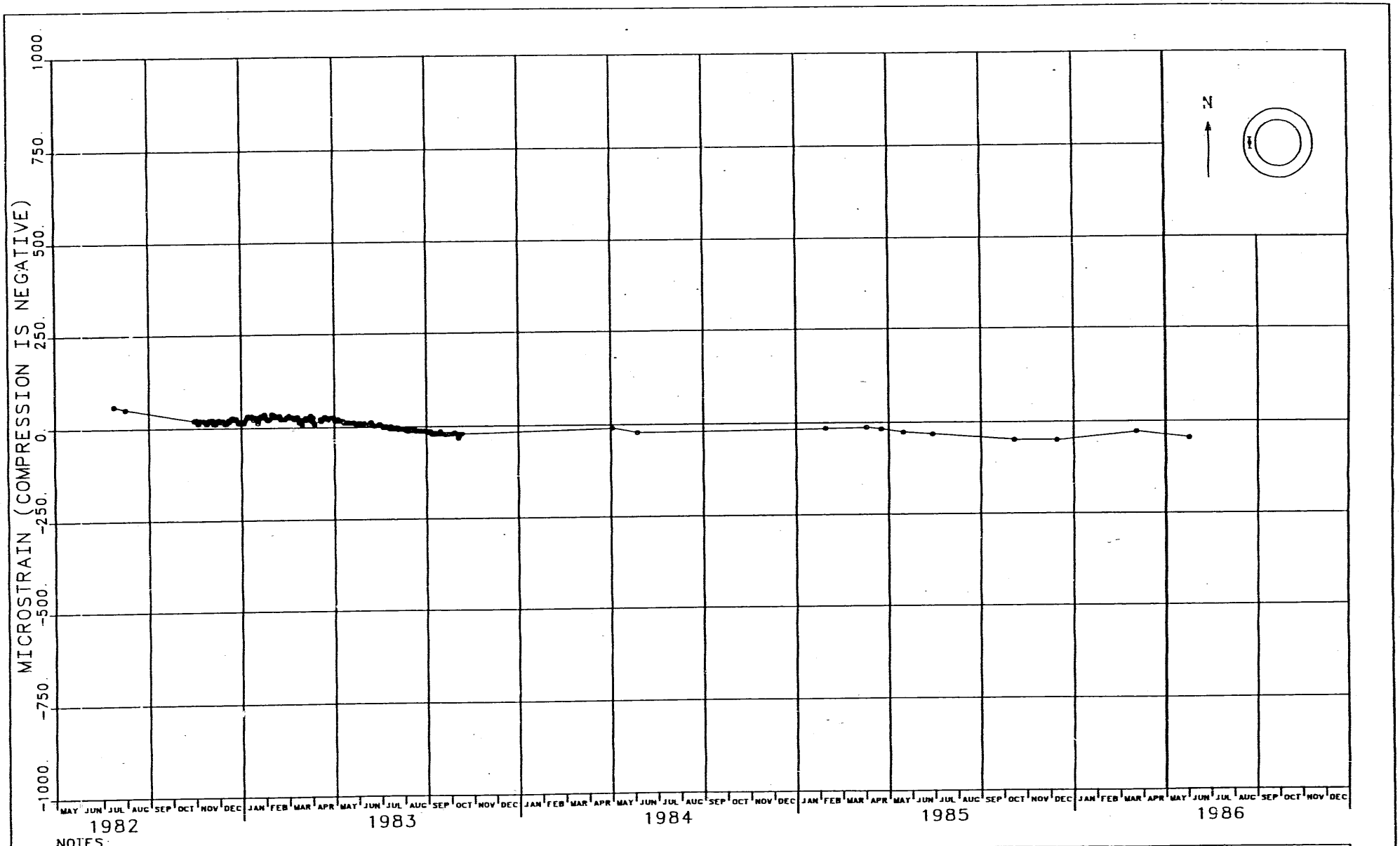
FIGURE J-66
EMBEDMENT STRAIN GAUGE 37X-ZE-00209
C & SH SHAFT KEY - EL 2553.7
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR 22, 1982.
3. GAUGE IS LOCATED 3.5 IN. FROM INNER FACE ON NORTH SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

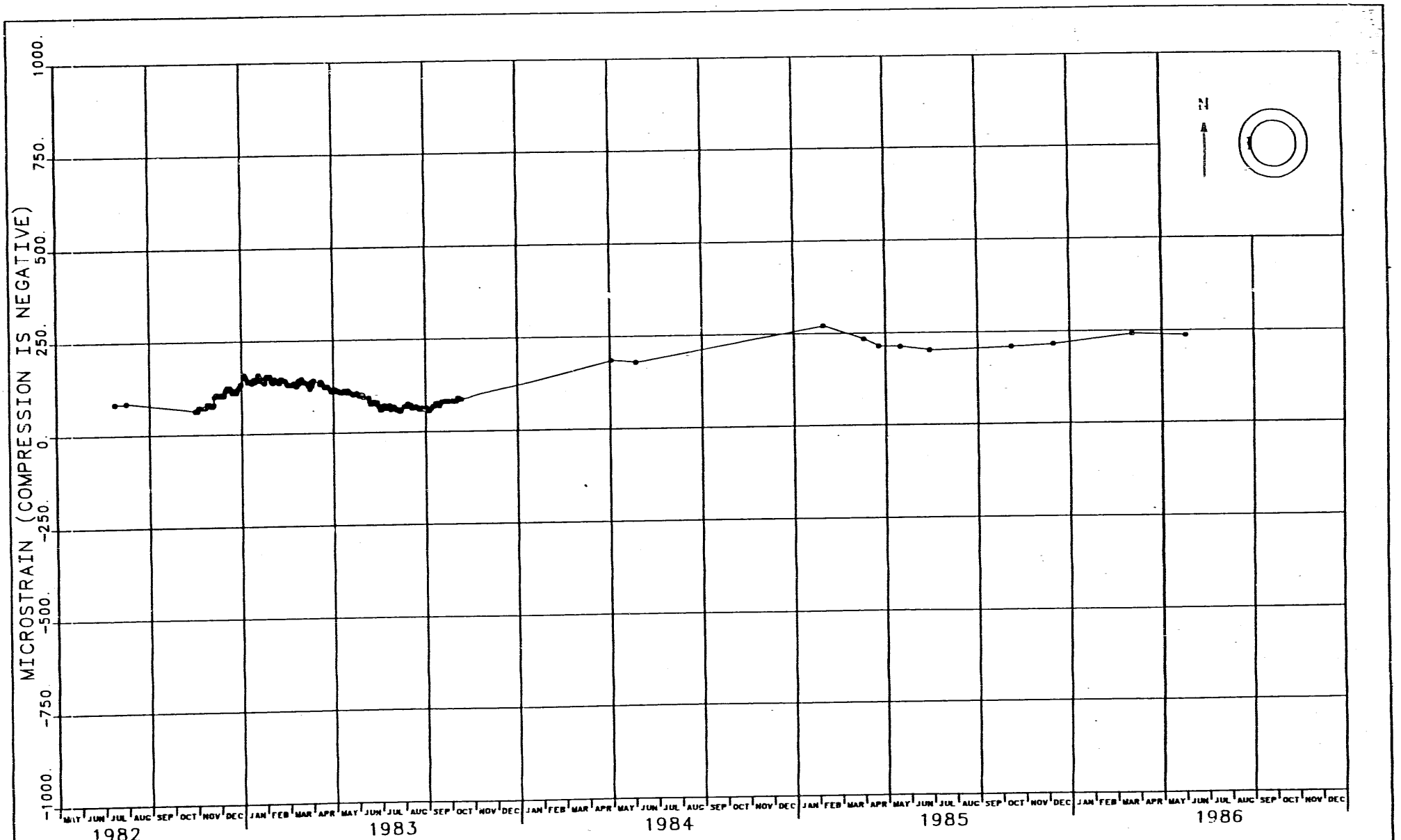
FIGURE J-67
EMBEDMENT STRAIN GAUGE 37X-ZE-00210
C & SH SHAFT KEY – EL 2553.7
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR 22, 1982.
3. GAUGE IS LOCATED 14.5 IN. FROM INNER FACE ON WEST SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

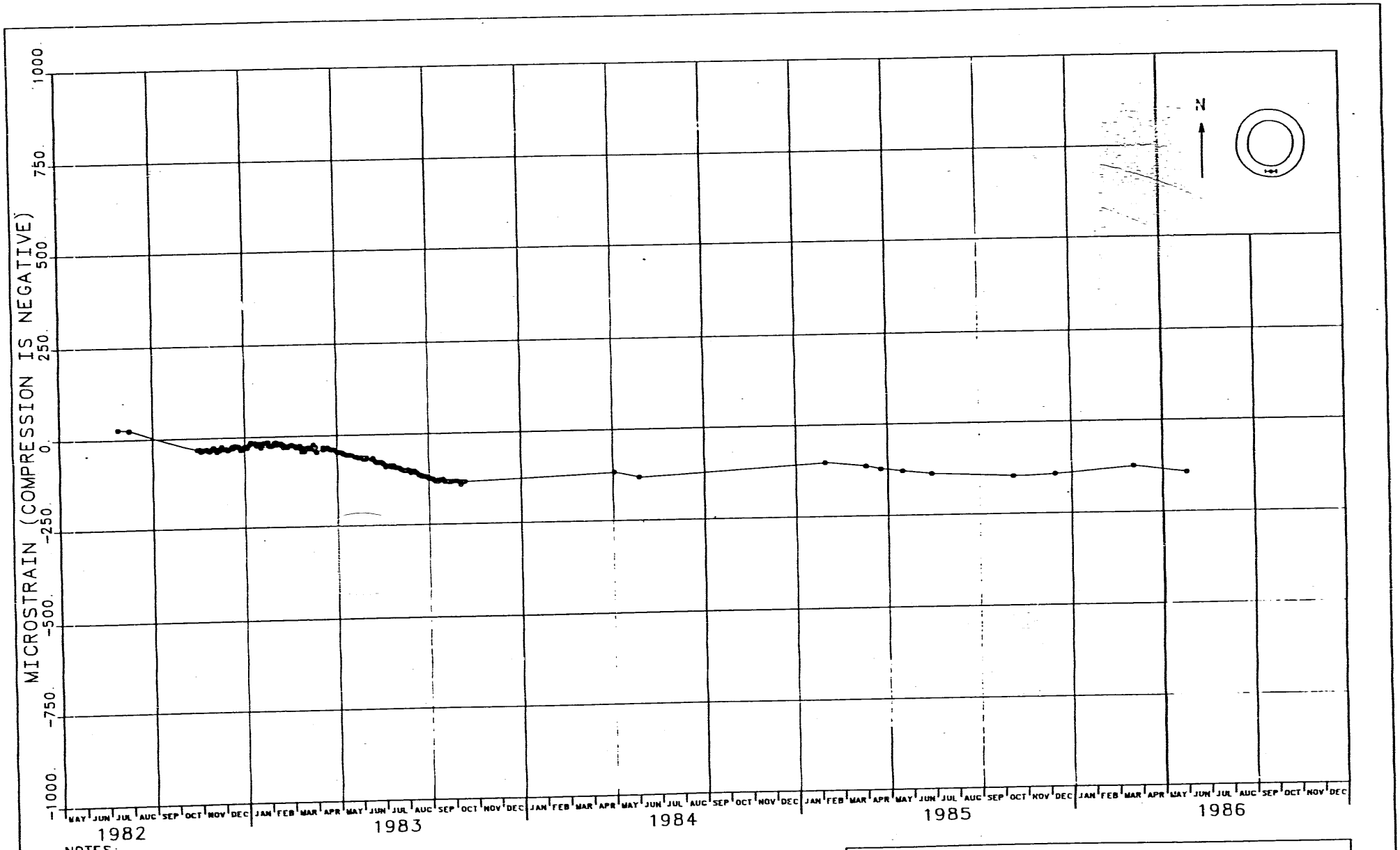
FIGURE J-68
EMBEDMENT STRAIN GAUGE 37X-ZE-00211
C & SH SHAFT KEY - EL 2553.7
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 3.5 IN. FROM INNER FACE ON WEST SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

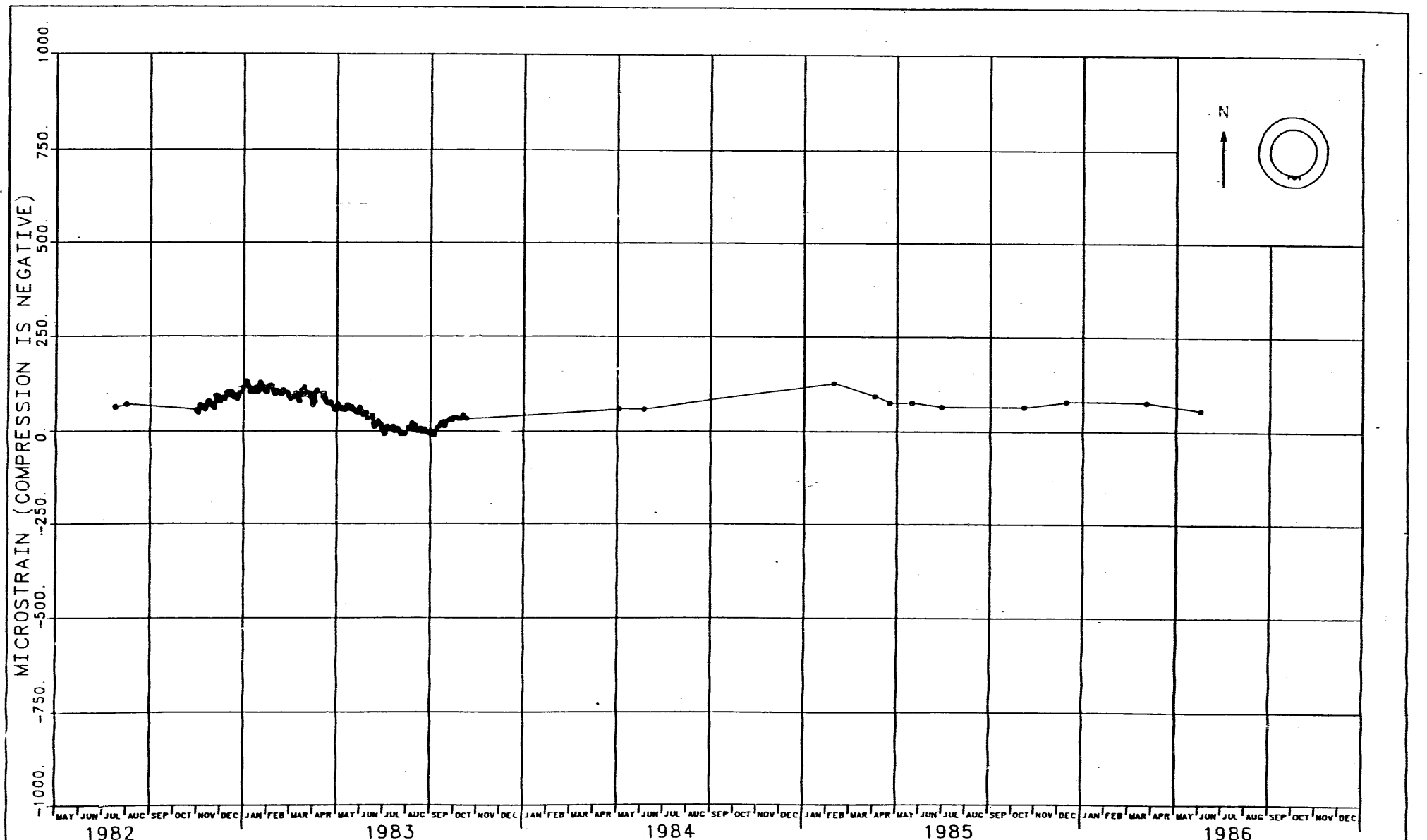
FIGURE J-69
EMBEDMENT STRAIN GAUGE 37X-ZE-00212
C & SH SHAFT KEY – EL 2553.7
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR 22, 1982
3. GAUGE IS LOCATED 14 5 IN FROM INNER FACE ON SOUTH SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

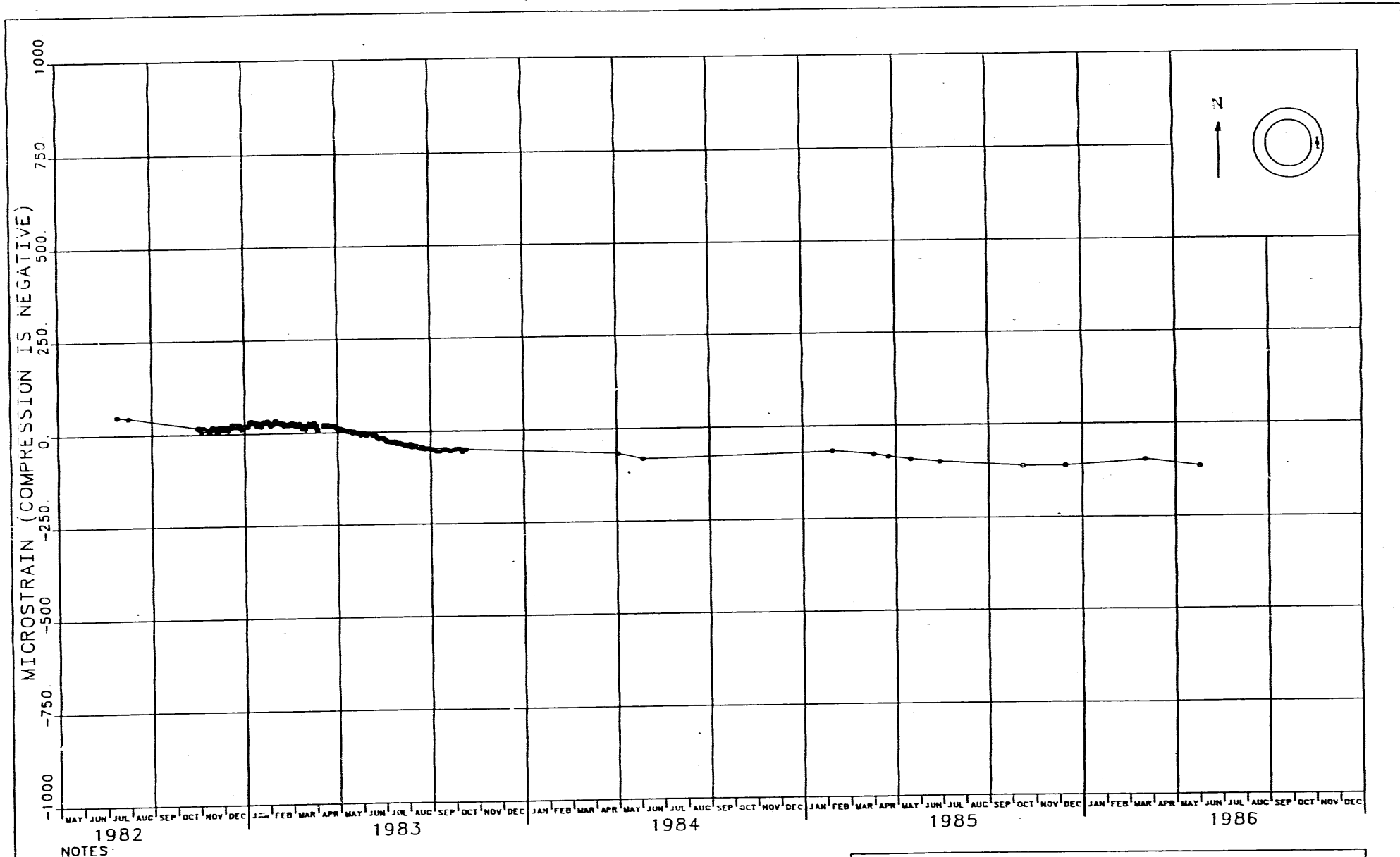
FIGURE J-70
EMBEDMENT STRAIN GAUGE 37X-ZE-00213
C & SH SHAFT KEY - EL 2553.7
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 3.5 IN. FROM INNER FACE ON SOUTH SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

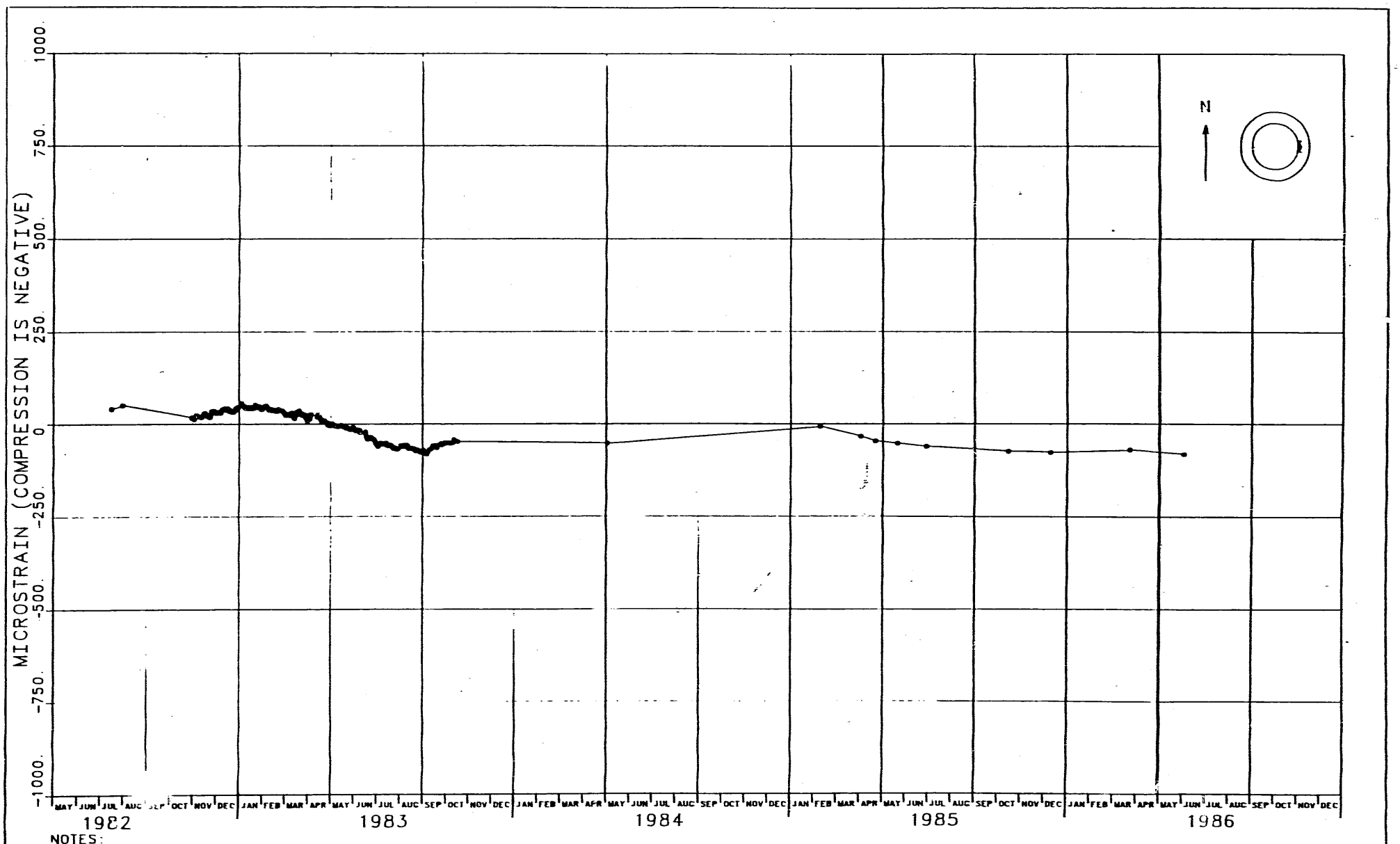
FIGURE J-71
EMBEDMENT STRAIN GAUGE 37X-ZE-00214
C & SH SHAFT KEY - EL 2553.7
STRAIN VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 14.5 IN. FROM INNER FACE ON EAST SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

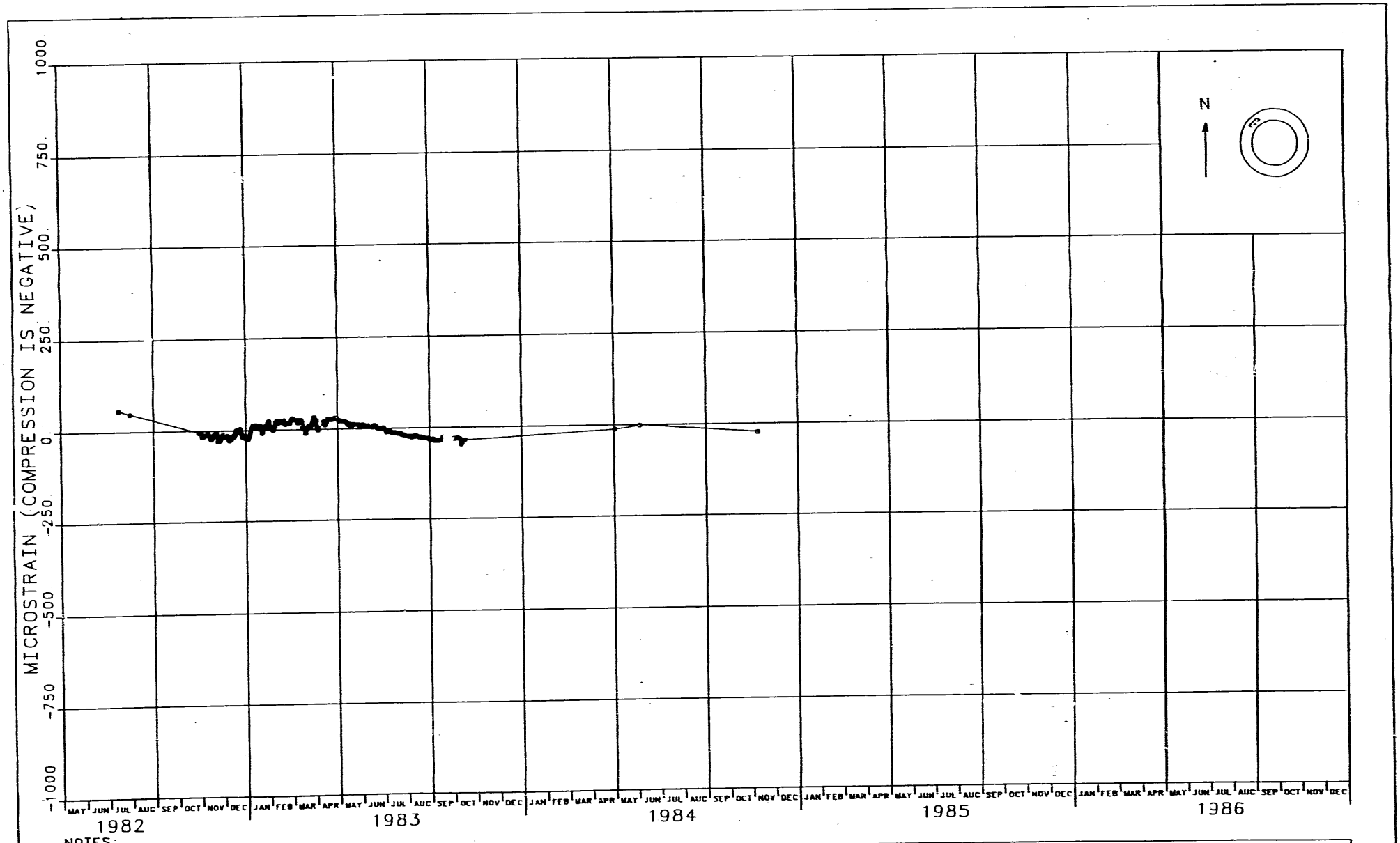
FIGURE J-72
EMBEDMENT STRAIN GAUGE 37X-ZE-00215
C & SH SHAFT KEY - EL 2553.7
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 3.5 IN FROM INNER FACE ON EAST SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

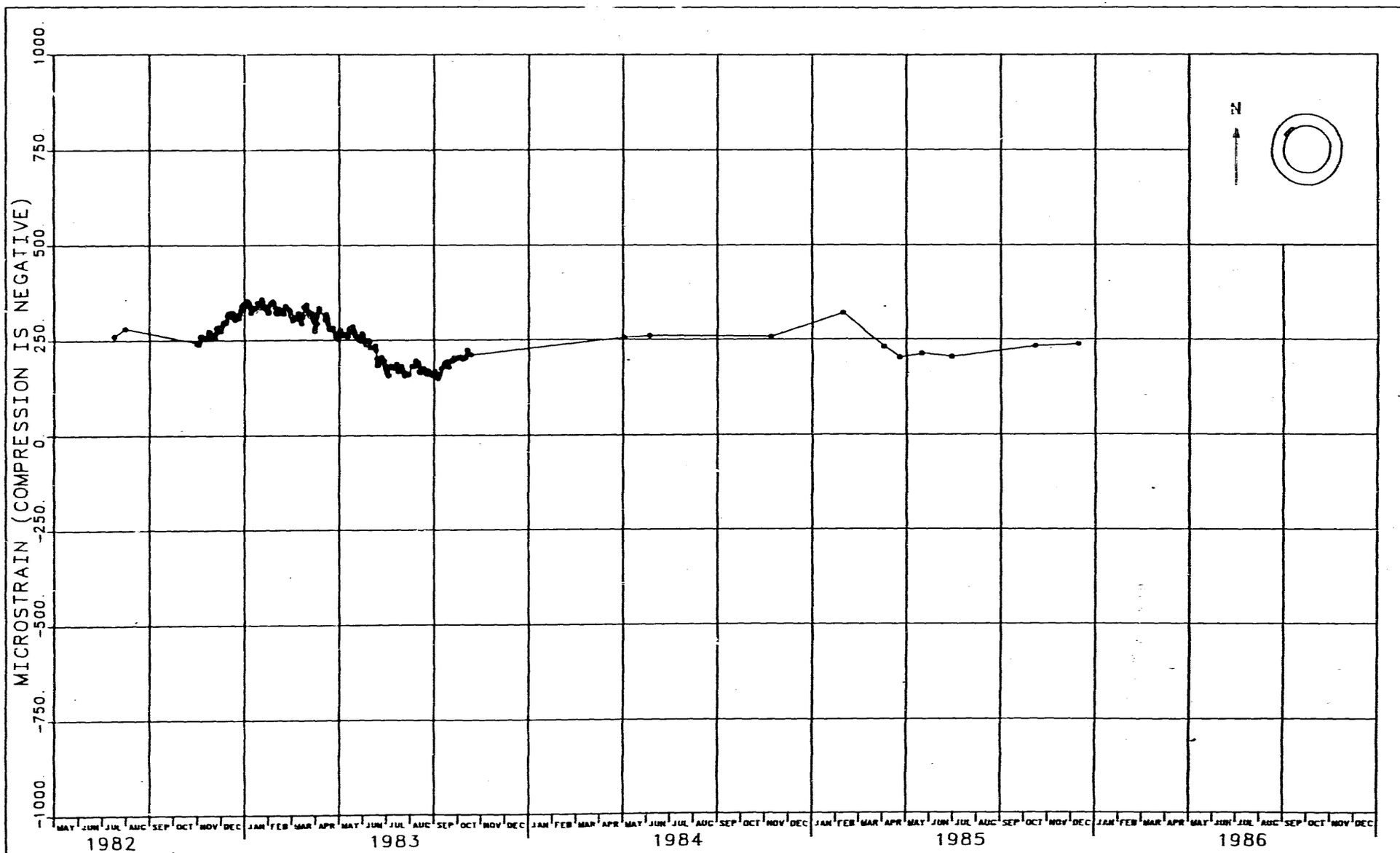
FIGURE J-73
EMBEDMENT STRAIN GAUGE 37X-ZE-00216
C & SH SHAFT KEY - EL 2553.7
STRAIN VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982
2. STRAIN SINCE READING ON APR 22, 1982.
3. GAUGE IS LOCATED 15 IN. FROM INNER FACE ON NW SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION 15 FT DIAM.
5. INSTRUMENT IS CURRENTLY NOT FUNCTIONING

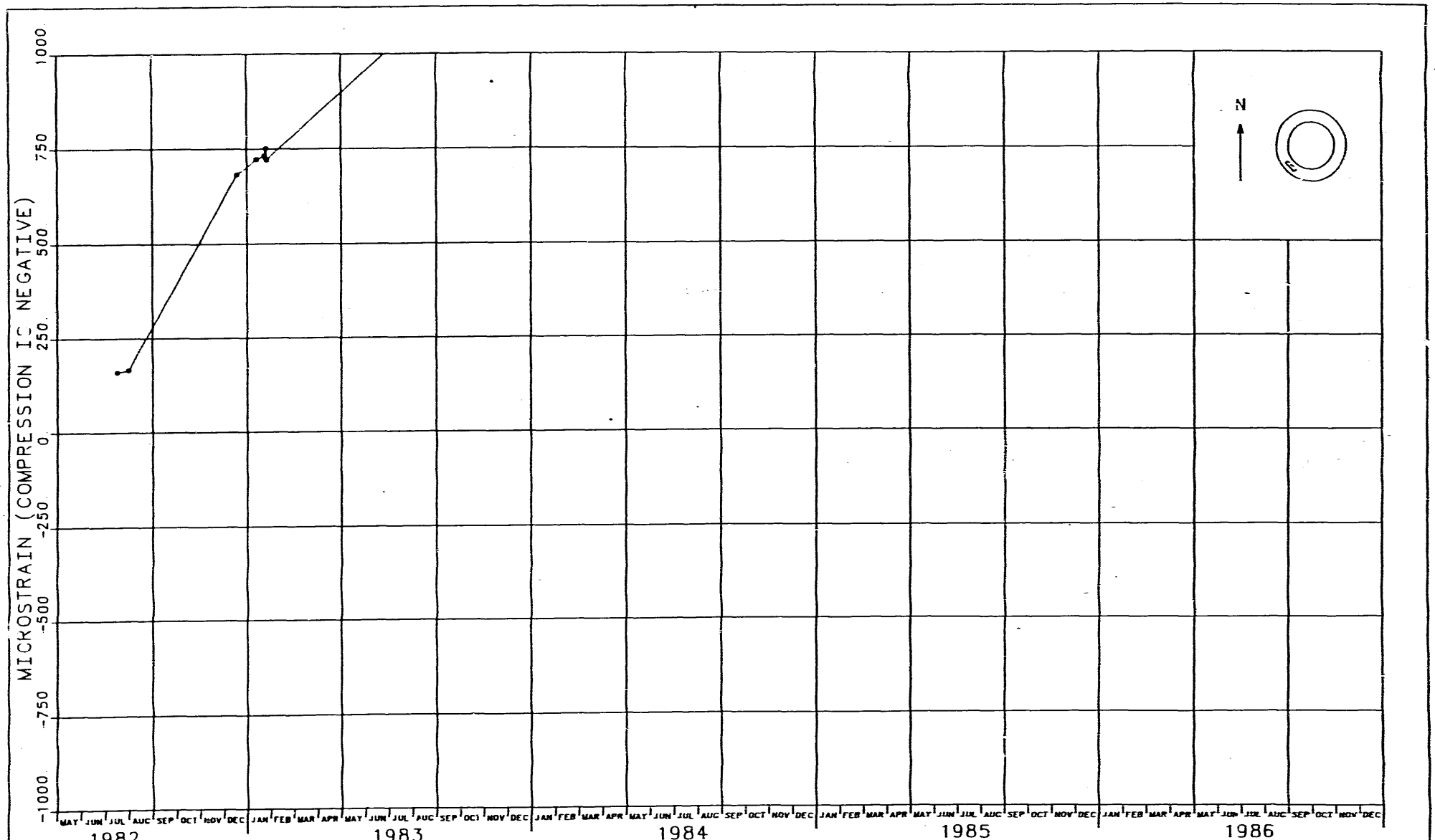
FIGURE J-74
WELDED STRAIN GAUGE 37X-ZE-00217
C & SH SHAFT KEY - EL 2547.6
STRAIN VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR 22, 1982.
3. GAUGE IS LOCATED 3 IN. FROM INNER FACE ON NW SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.
5. INSTRUMENT IS CURRENTLY NOT FUNCTIONING.

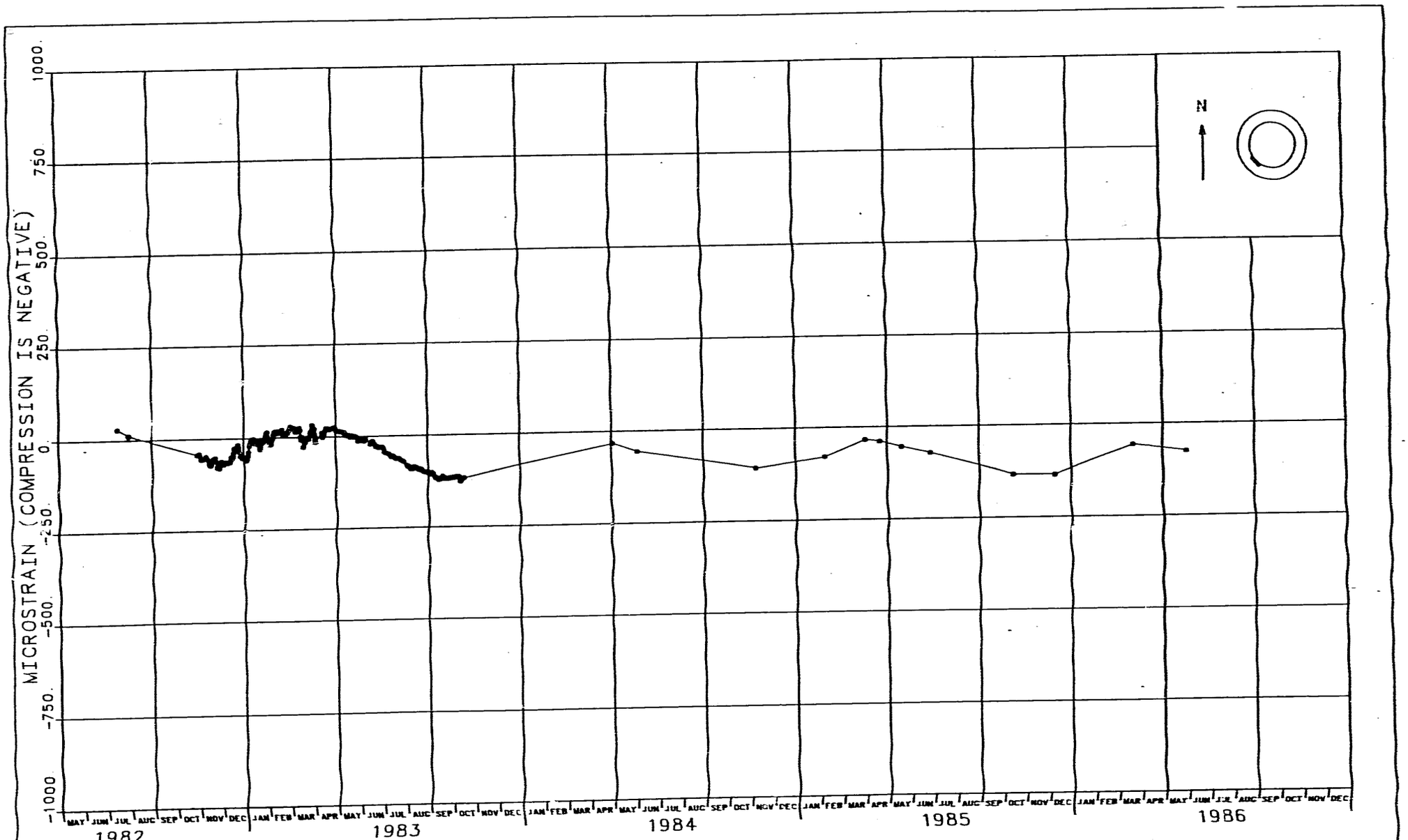
FIGURE J-75
WELDED STRAIN GAUGE 37X-ZE-00218
C & SH SHAFT KEY - EL 2547.6
STRAIN VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR 22, 1982
3. GAUGE IS LOCATED 15 IN FROM INNER FACE ON SW SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION 15 FT DIAM.
5. INSTRUMENT HAS PERMANENTLY FAILED

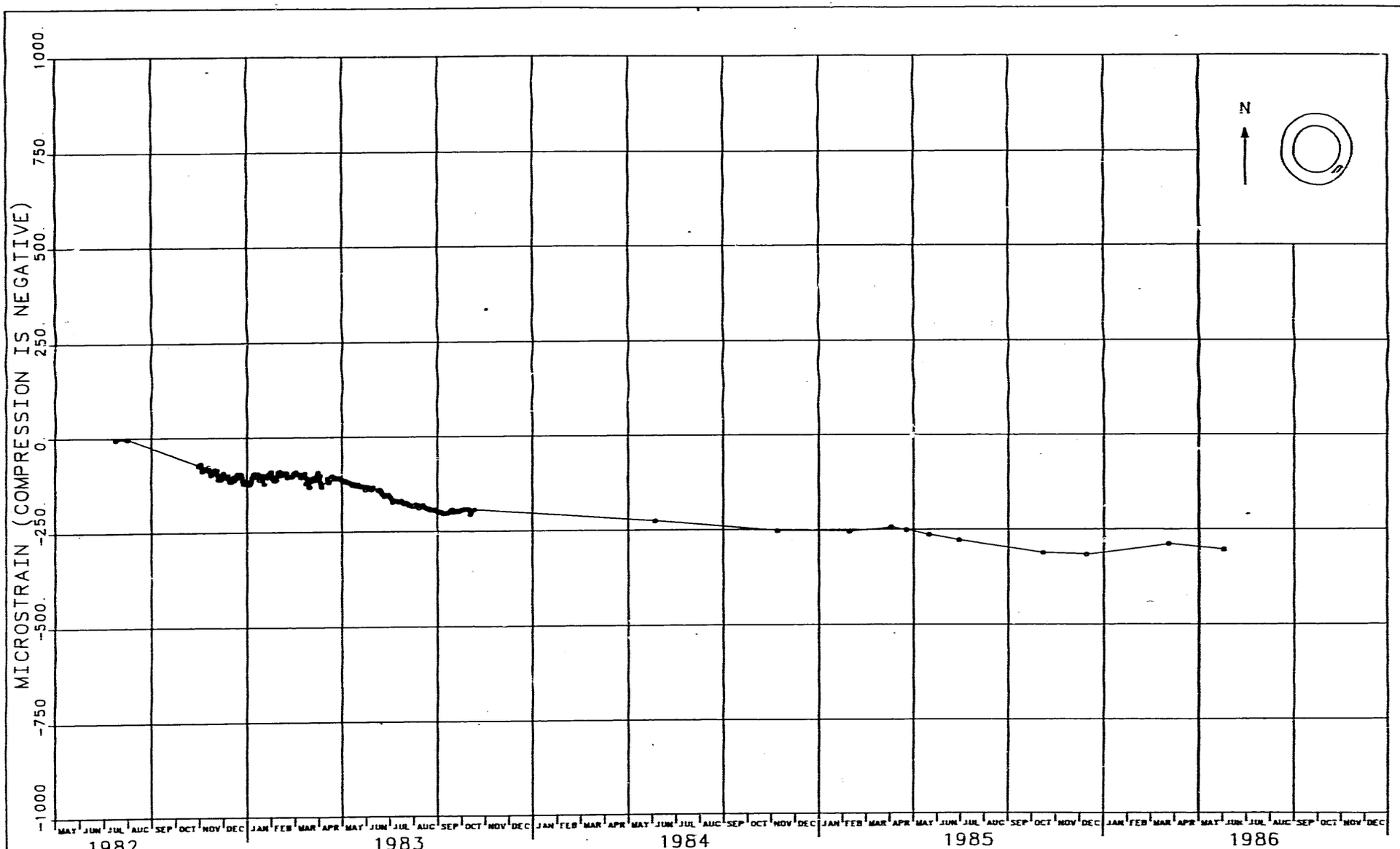
FIGURE J-76
WELDED STRAIN GAUGE 37X-ZE-00219
C & SH SHAFT KEY - EL 2547.6
STRAIN VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 3 IN. FROM INNER FACE ON SW SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

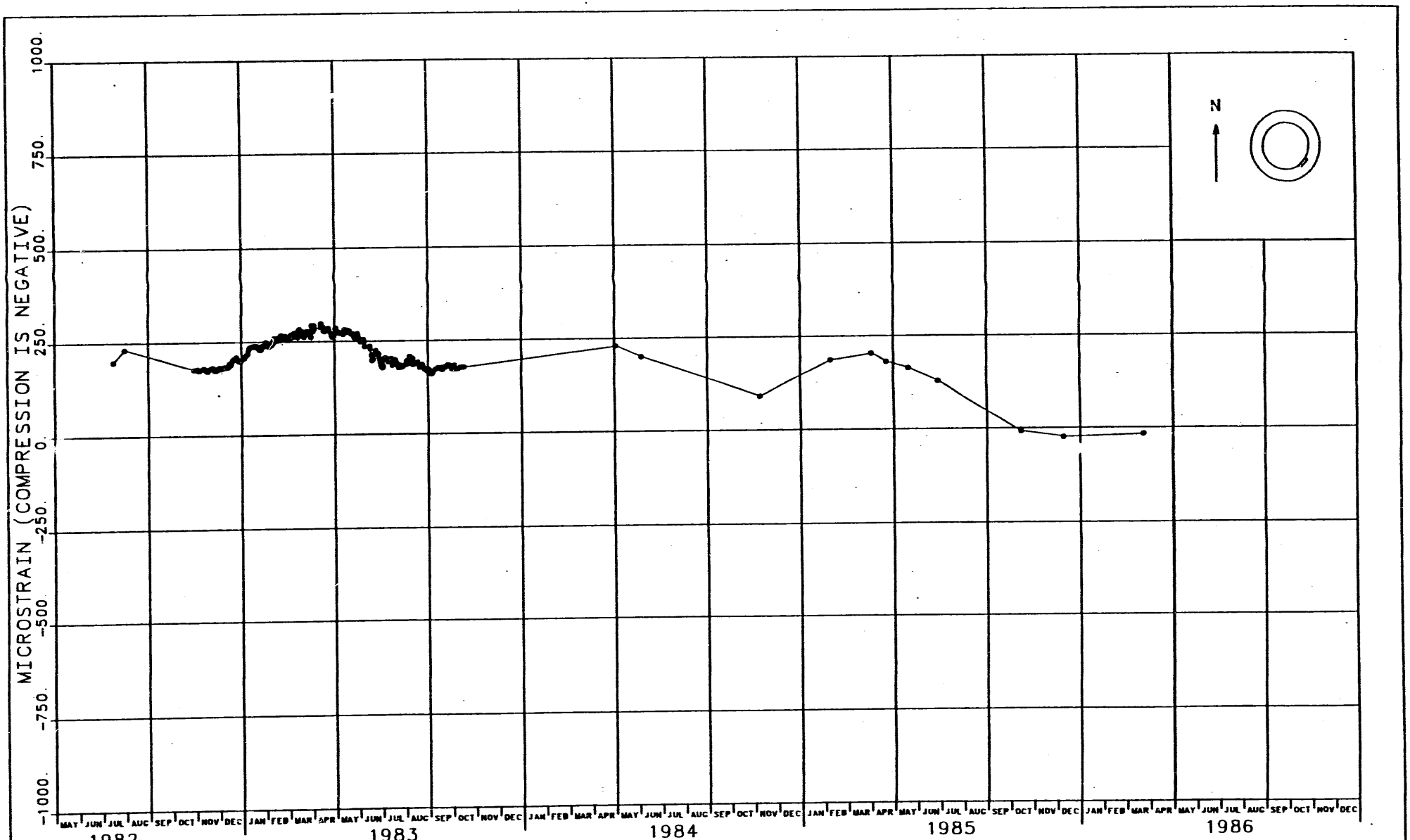
FIGURE J-77
WELDED STRAIN GAUGE 37X-ZE-00220
C & SH SHAFT KEY - EL 2547.6
STRAIN VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 15 IN. FROM INNER FACE ON SE SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION 15 FT DIAM.

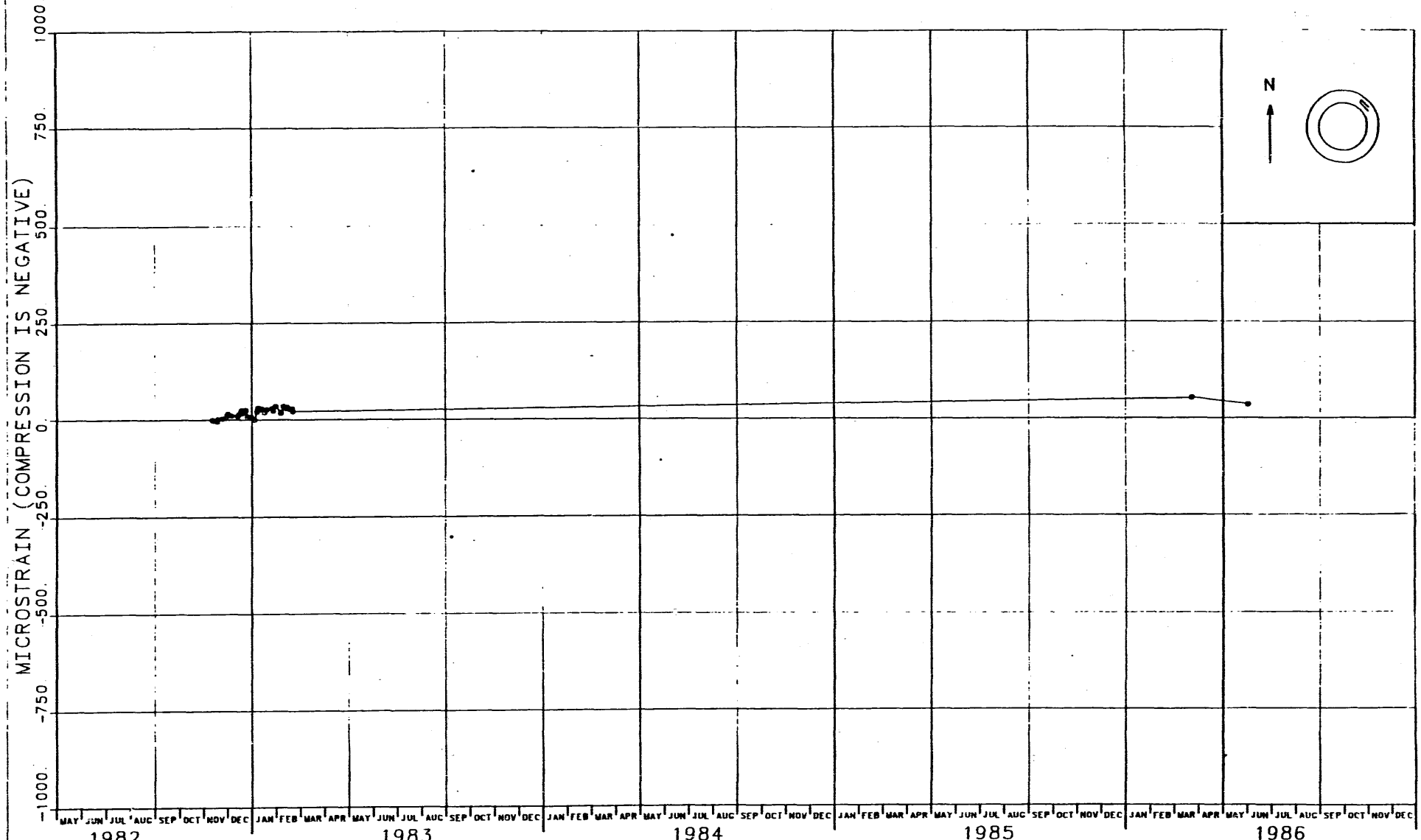
FIGURE J-78
WELDED STRAIN GAUGE 37X-ZE-00221
C & SH SHAFT KEY - EL 2547.6
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 3 IN. FROM INNER FACE ON SE SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.
5. INSTRUMENT IS CURRENTLY NOT FUNCTIONING.

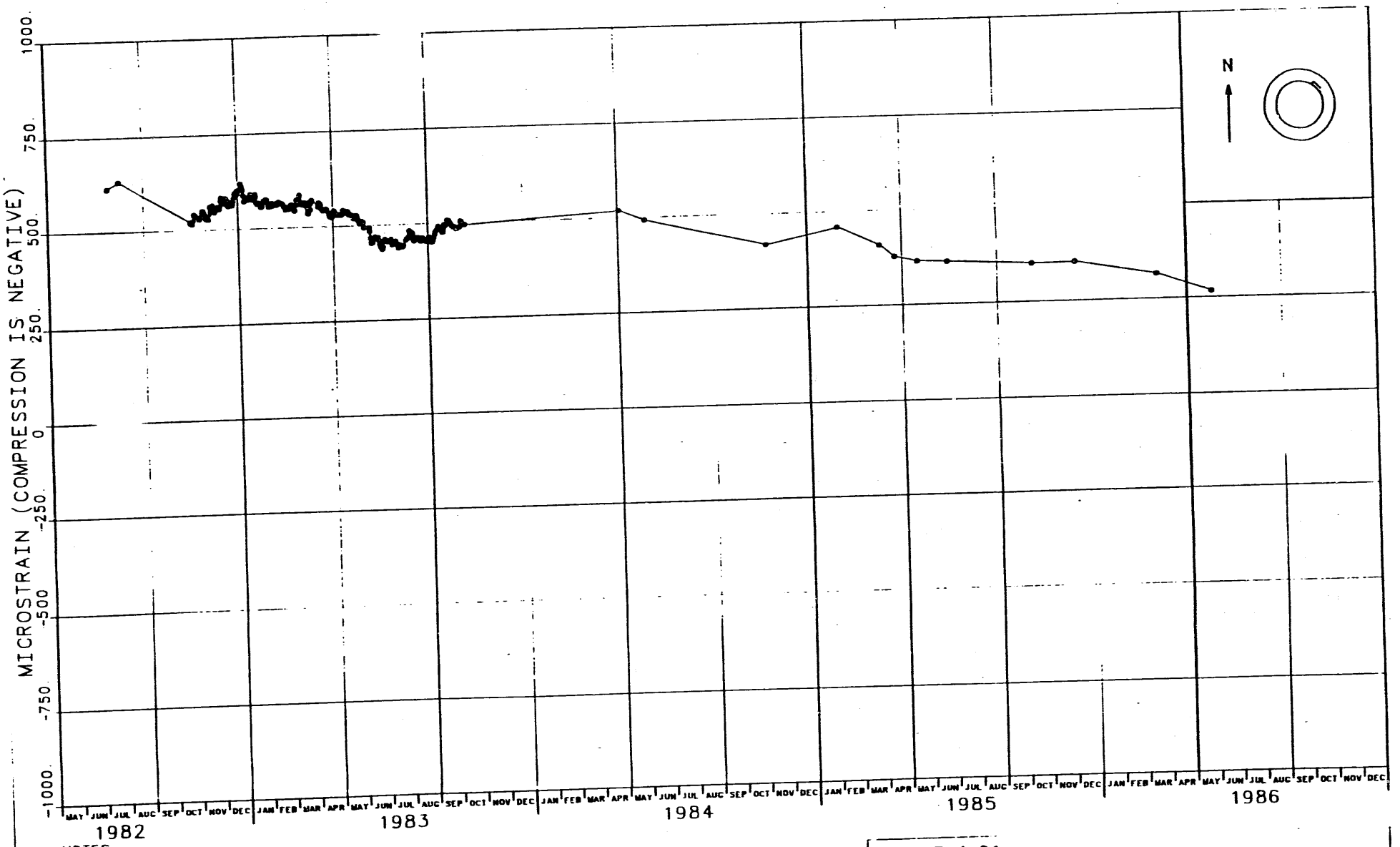
FIGURE J-79
WELDED STRAIN GAUGE 37X-ZE-00222
C & SH SHAFT KEY - EL 2547.6
STRAIN VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON NOV. 11, 1982
3. GAUGE IS LOCATED 15 IN. FROM INNER FACE ON NE SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

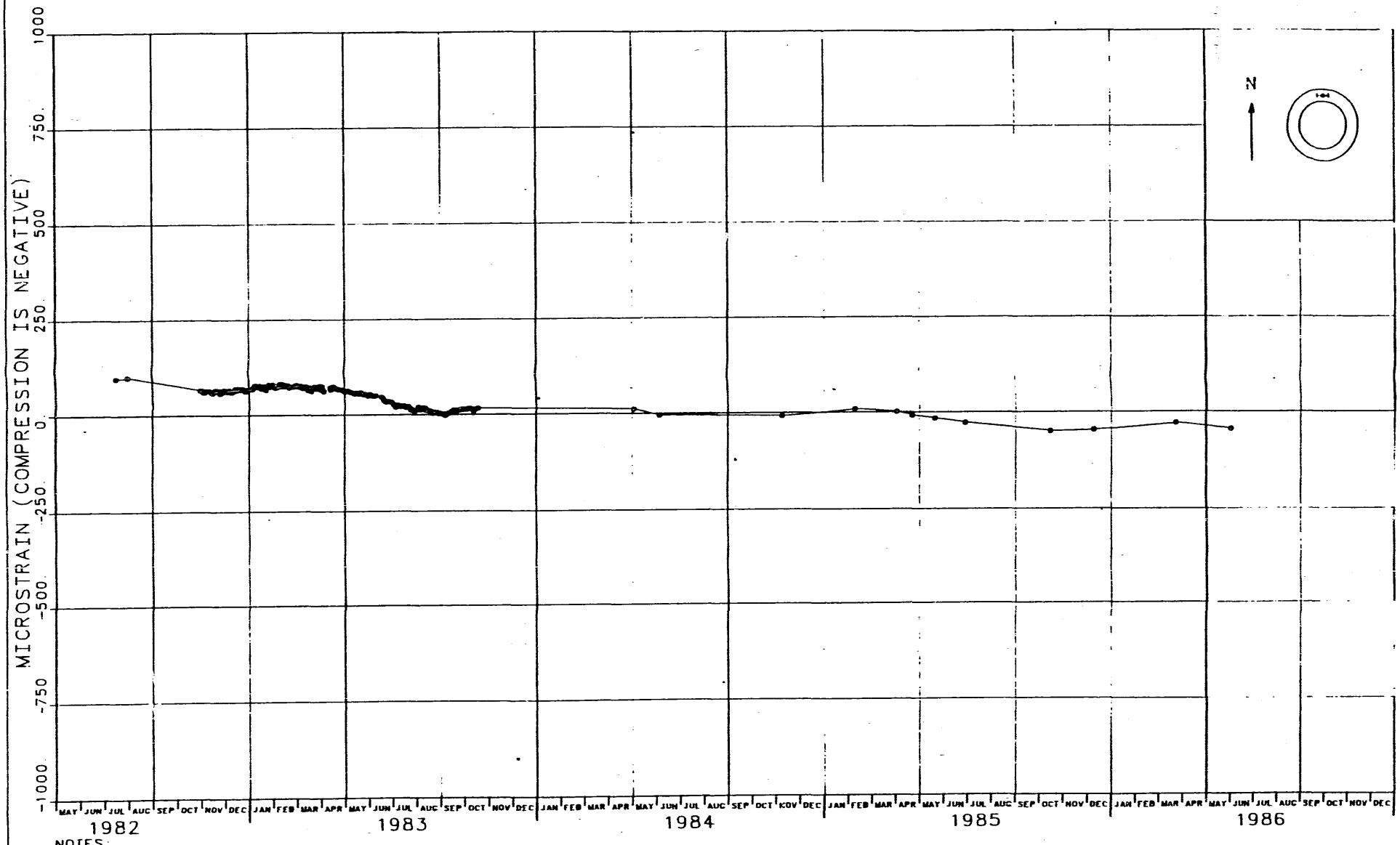
FIGURE J-80
WELDED STRAIN GAUGE 37X-ZE-00223
C & SH SHAFT KEY - EL 2547.6
STRAIN VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR 22, 1982.
3. GAUGE IS LOCATED 3 IN. FROM INNER FACE ON NE SIDE OF CONCRETE KEY
4. SIZE OF EXCAVATION 15 FT DIAM.

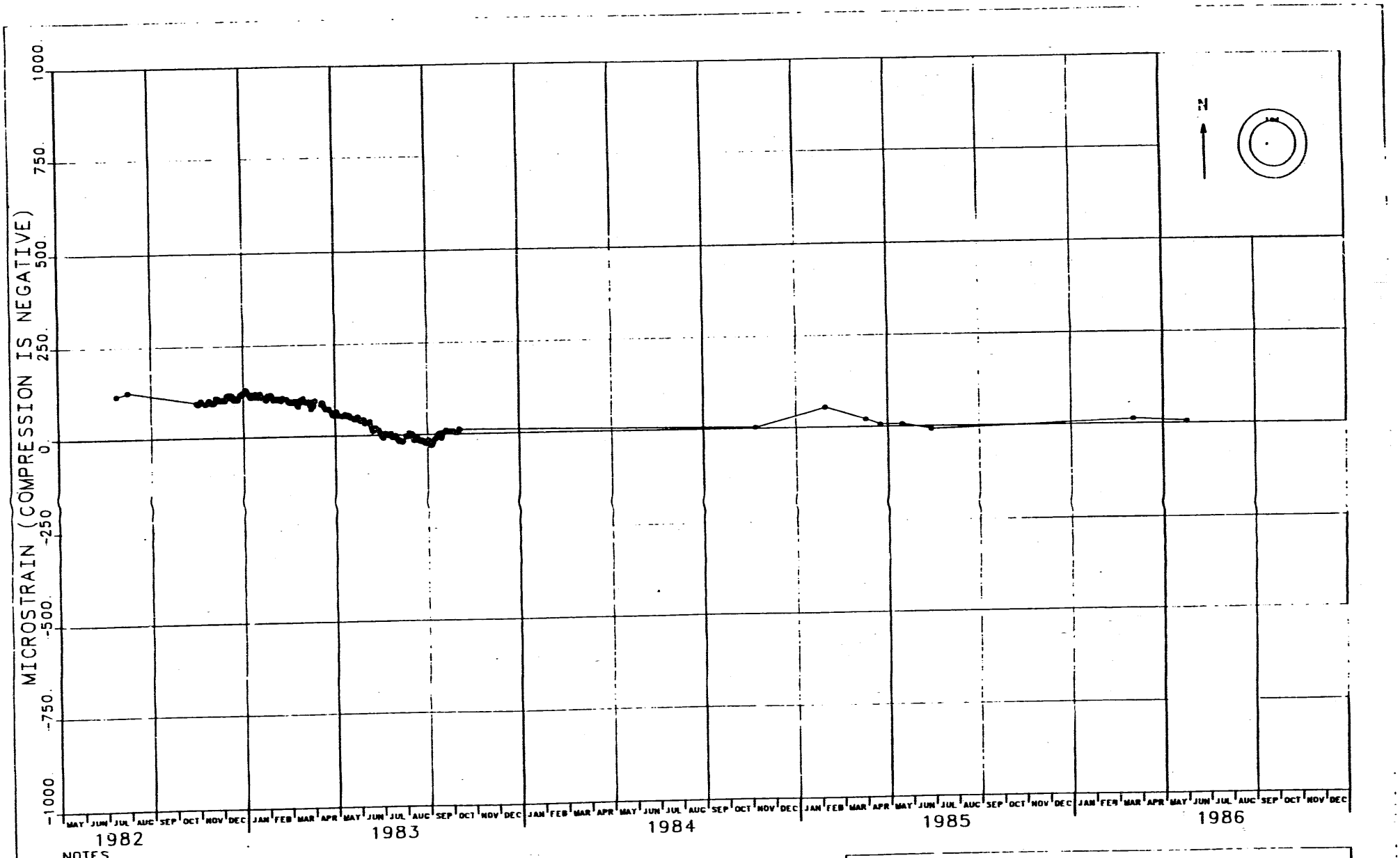
FIGURE J-81
WELDED STRAIN GAUGE 37X-ZE-00224
C & SH SHAFT KEY - EL 2547.6
STRAIN VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR 22, 1982
3. GAUGE IS LOCATED 14.5 IN. FROM INNER FACE ON NORTH SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

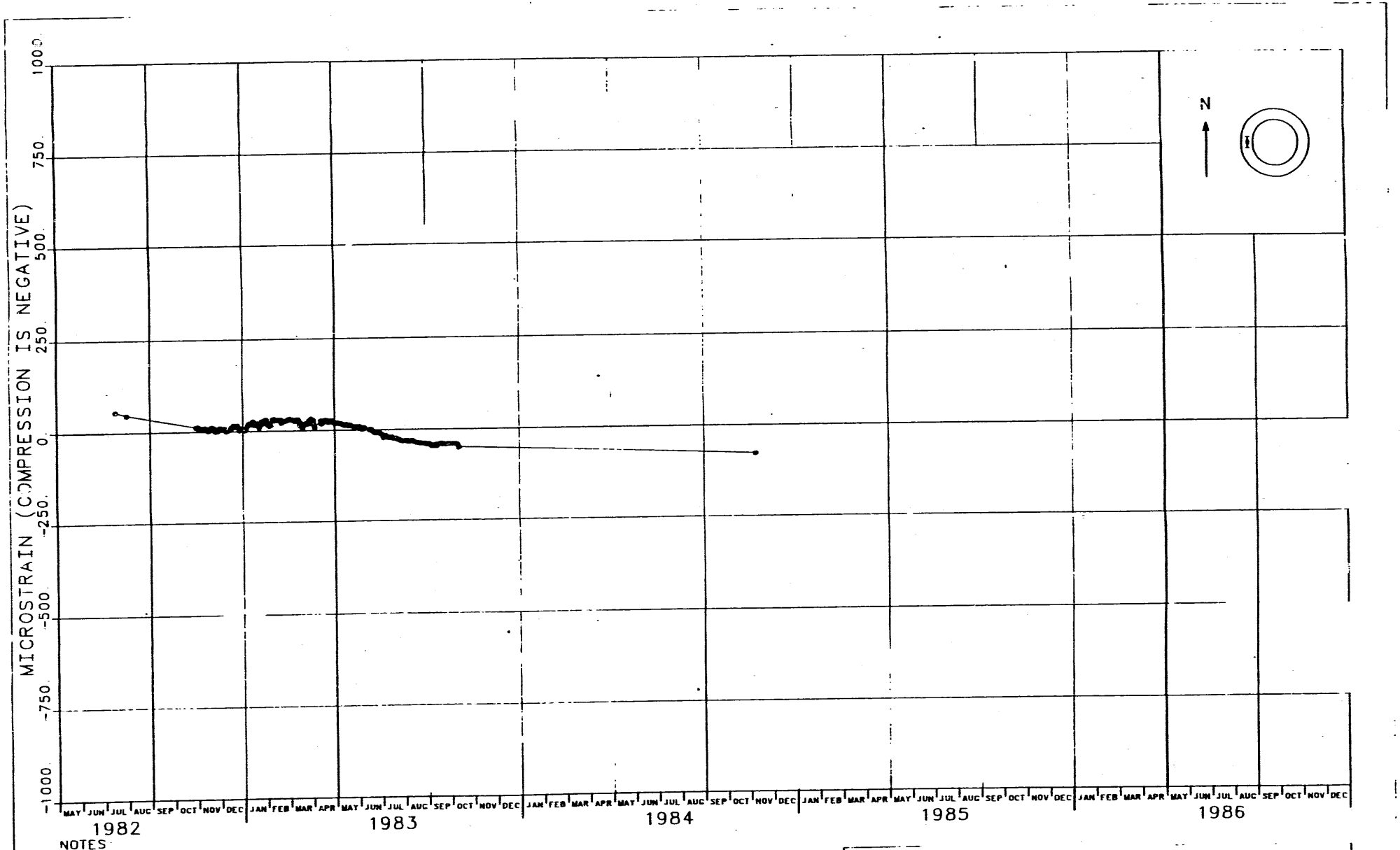
FIGURE J-82
EMBEDMENT STRAIN GAUGE 37X-ZE-00225
C & SH SHAFT KEY - EL 2547.6
STRAIN VS. CALENDAR MONTH



NOTES

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR 22, 1982.
3. GAUGE IS LOCATED 3.5 IN. FROM INNER FACE ON NORTH SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION 15 FT DIAM.

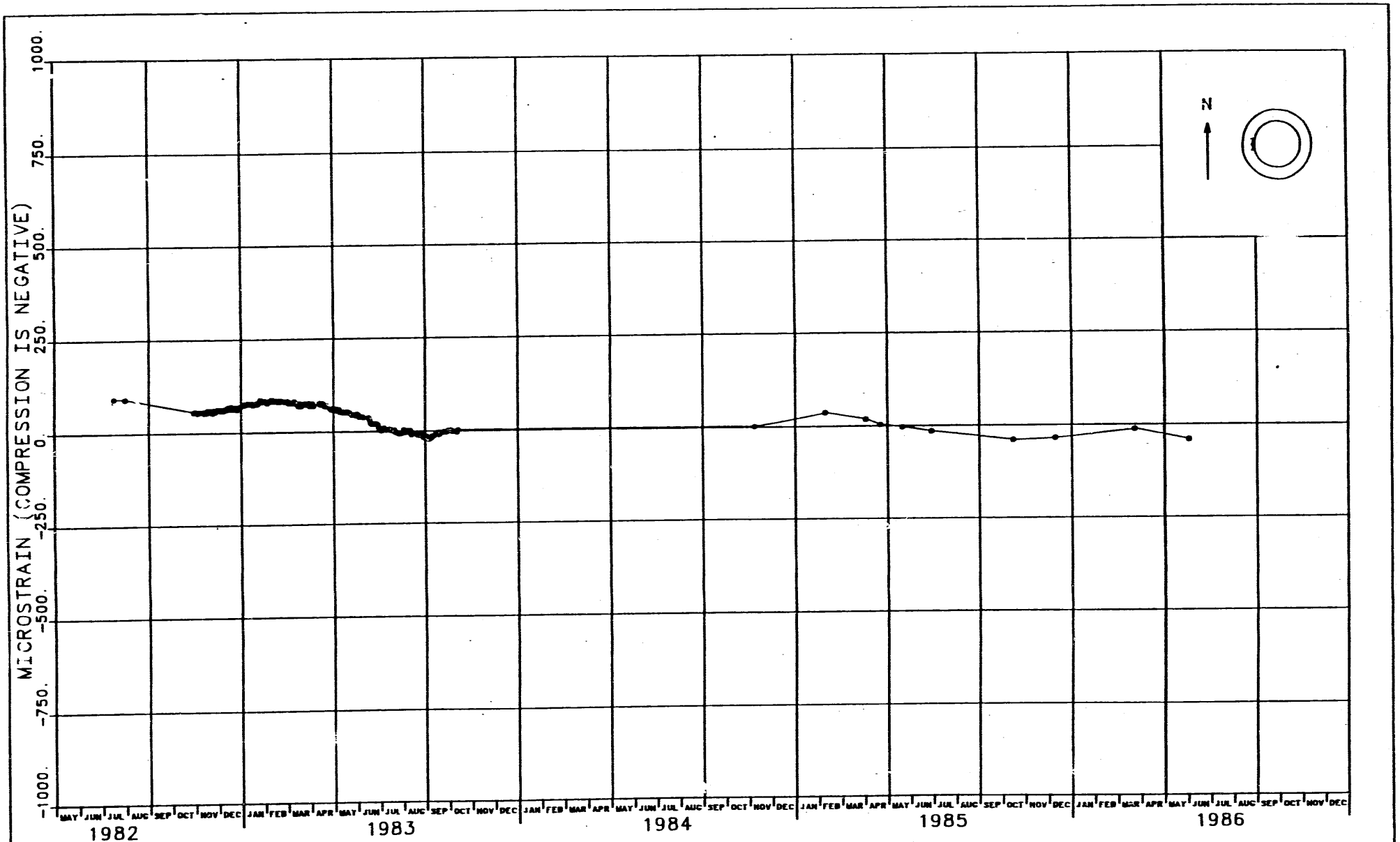
FIGURE J-83
EMBEDMENT STRAIN GAUGE 37X-ZE-00226
C & SH SHAFT KEY – EL 2547.6
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 14.5 IN. FROM INNER FACE ON WEST SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.
5. INSTRUMENT IS CURRENTLY NOT FUNCTIONING

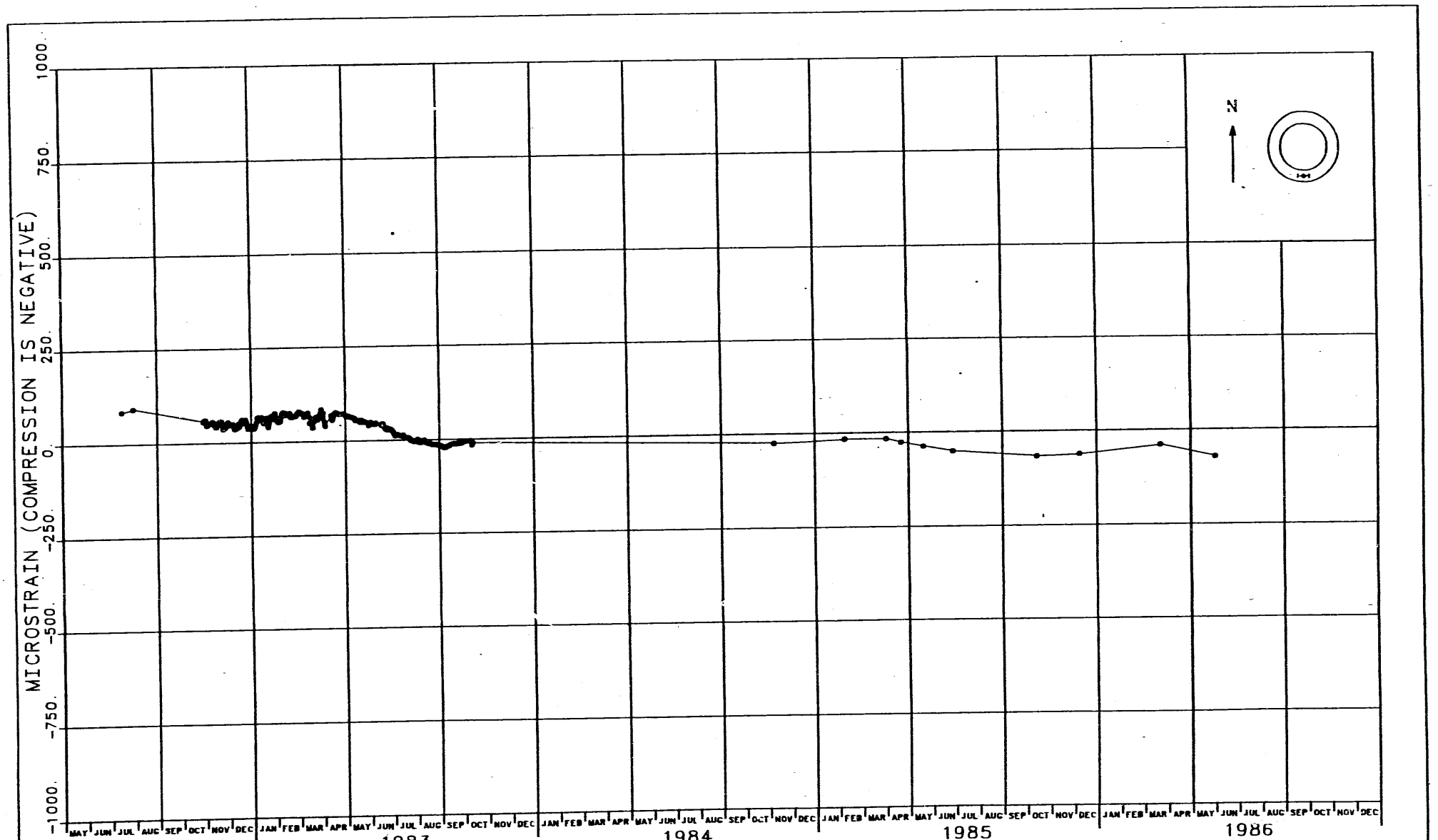
FIGURE J-84
EMBEDMENT STRAIN GAUGE 37X-ZE-00227
C & SH SHAFT KEY - EL 2547.6
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 3.5 IN. FROM INNER FACE ON WEST SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

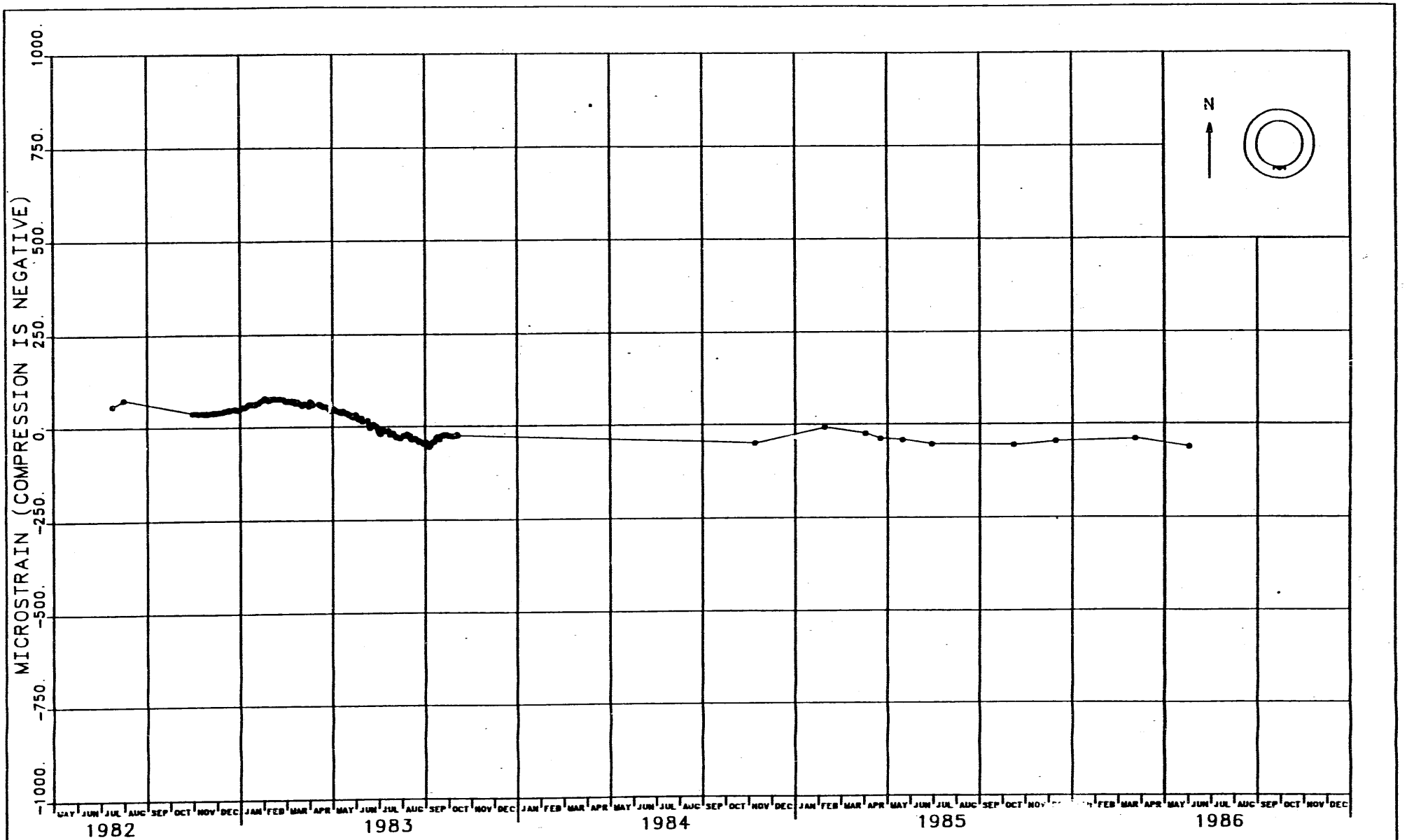
FIGURE J-85
EMBEDMENT STRAIN GAUGE 37X-ZE-00228
C & SH SHAFT KEY - EL 2547.6
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 14.5 IN. FROM INNER FACE ON SOUTH SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

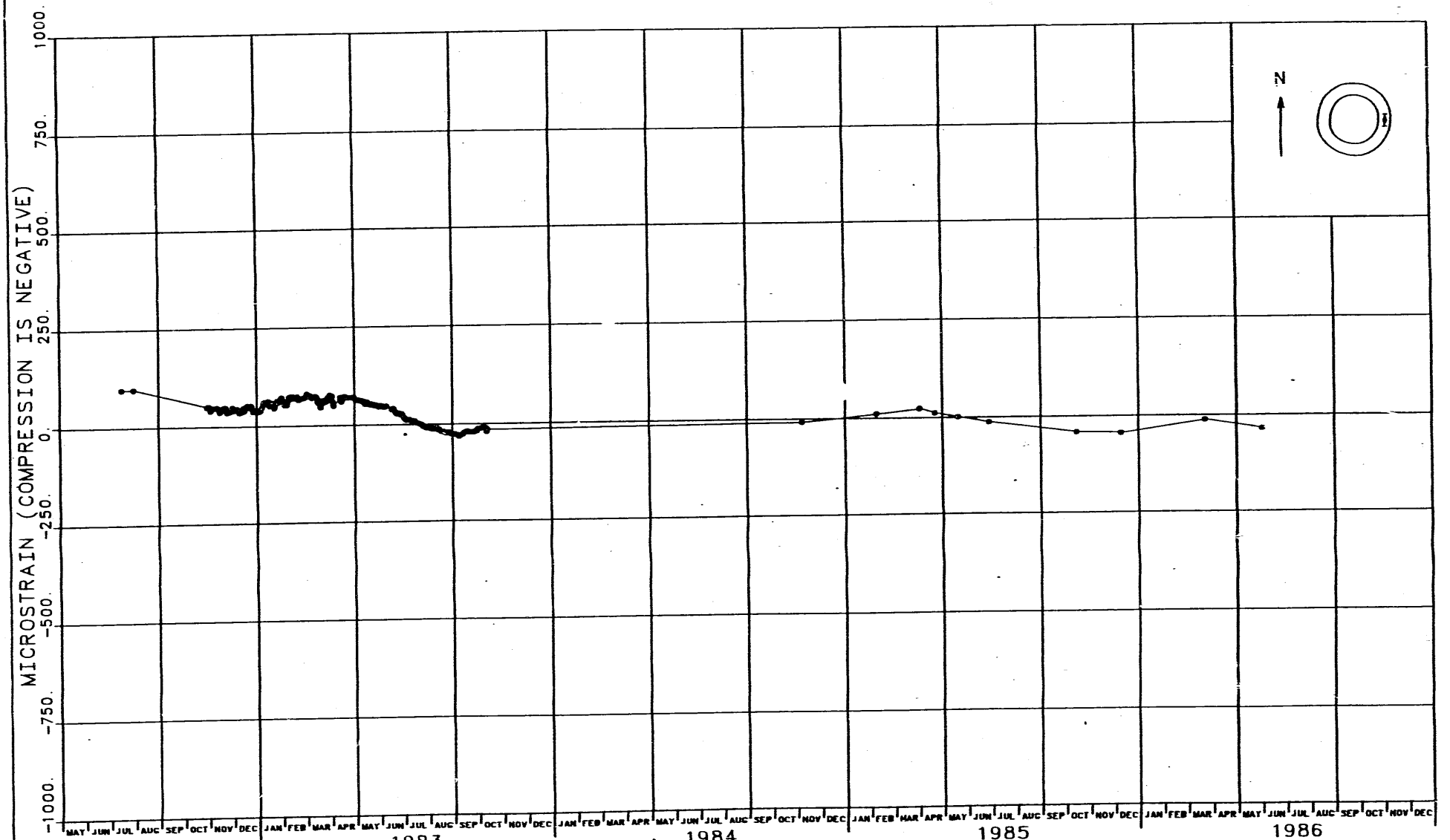
FIGURE J-86
EMBEDMENT STRAIN GAUGE 37X-ZE-00229
C & SH SHAFT KEY - EL 2547.6
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READI G ON APR. 22, 1982.
3. GAUGE IS LOCATED .5 IN. FROM INNER FACE ON SOUTH SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

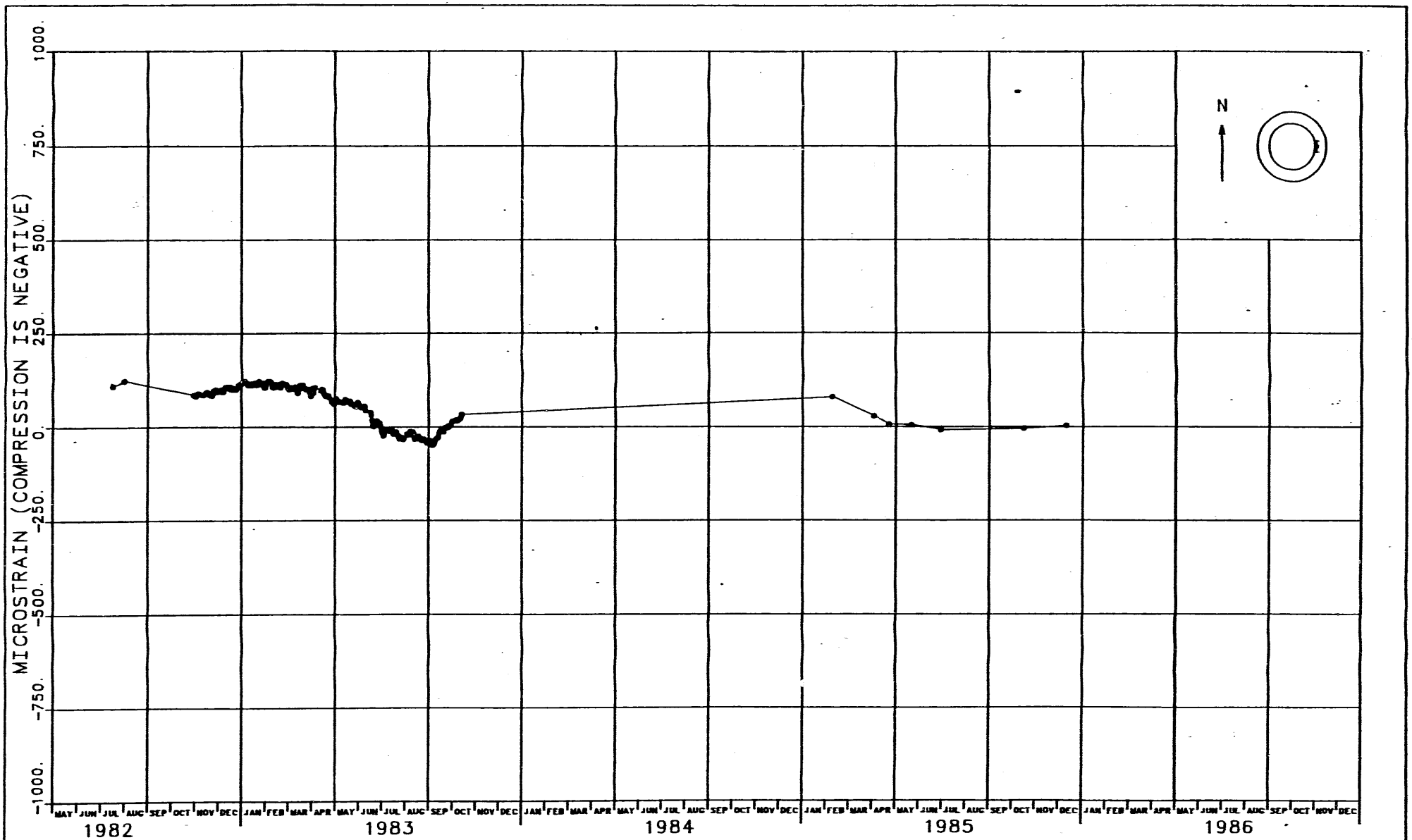
FIGURE J-87
EMBEDMENT STRAIN GAUGE 37X-ZE-00230
C & SH SHAFT KEY – EL 2547.6
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 14.5 IN. FROM INNER FACE ON EAST SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

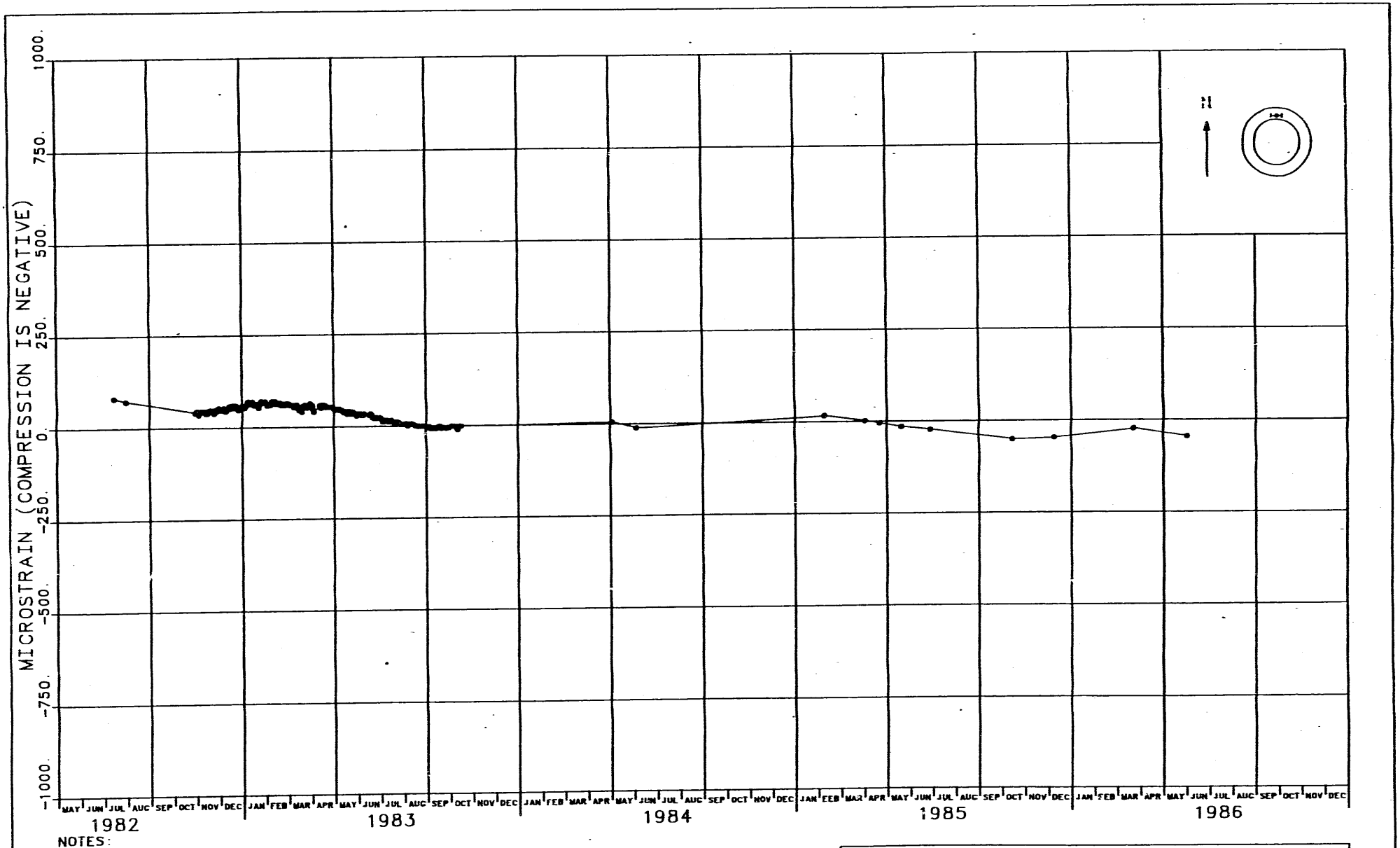
FIGURE J-88
EMBEDMENT STRAIN GAUGE 37X-ZE-00231
C & SH SHAFT KEY - EL 2547.6
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 3.5 IN. FROM INNER FACE ON EAST SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.
5. INSTRUMENT IS CURRENTLY NOT FUNCTIONING.

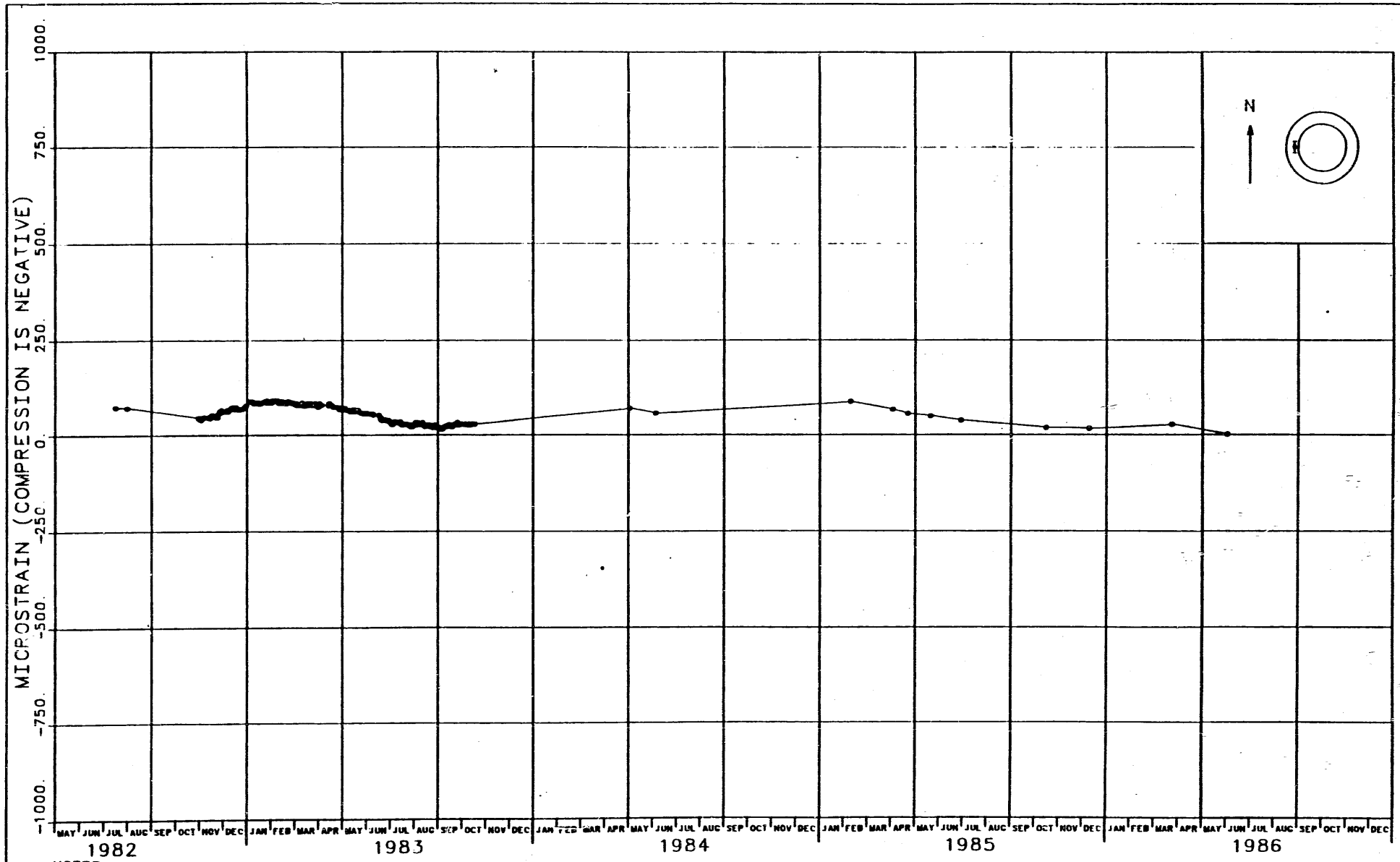
FIGURE J-89
EMBEDMENT STRAIN GAUGE 37X-ZE-00232
C & SH SHAFT KEY - EL 2547.6
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 9 IN. FROM INNER FACE ON NORTH SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

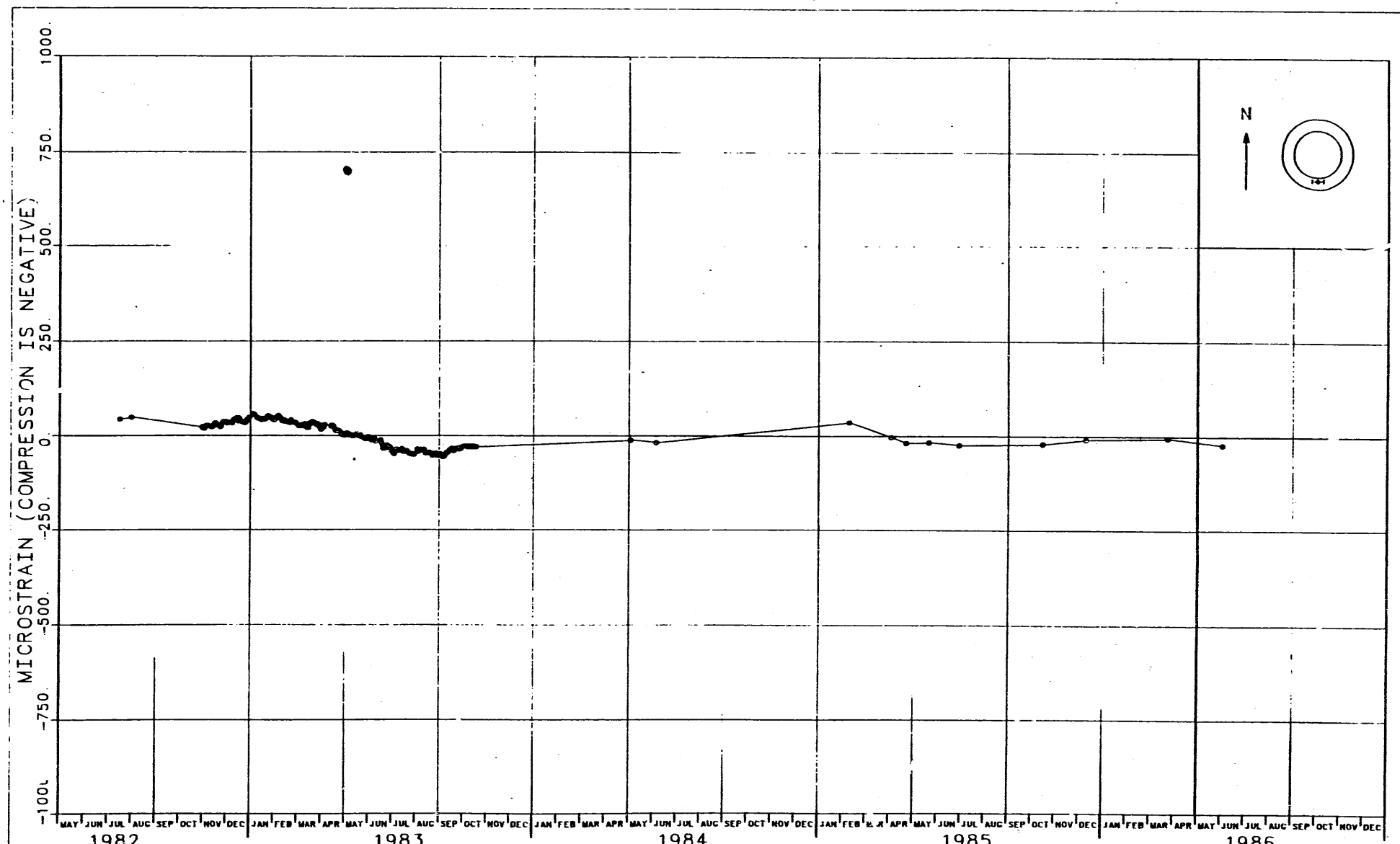
FIGURE J-90
EMBEDMENT STRAIN GAUGE 37X-ZE-00235
C & SH SHAFT KEY - EL 2553.7
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 9 IN. FROM INNER FACE ON WEST SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

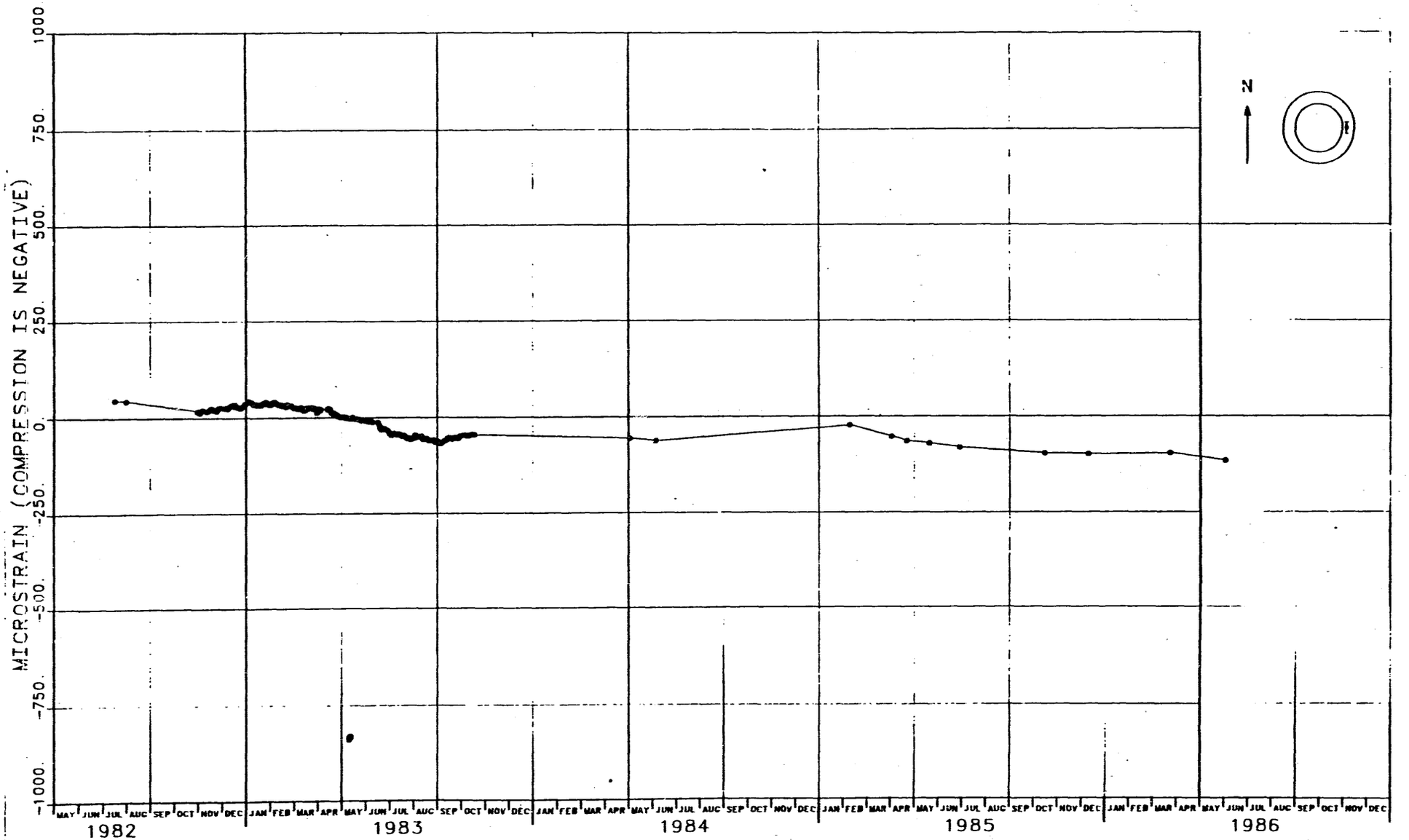
FIGURE J-91
EMBEDMENT STRAIN GAUGE 37X-ZE-00236
C & SH SHAFT KEY - EL 2553.7
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 9 IN. FROM INNER FACE ON SOUTH SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 17 FT DIAM.

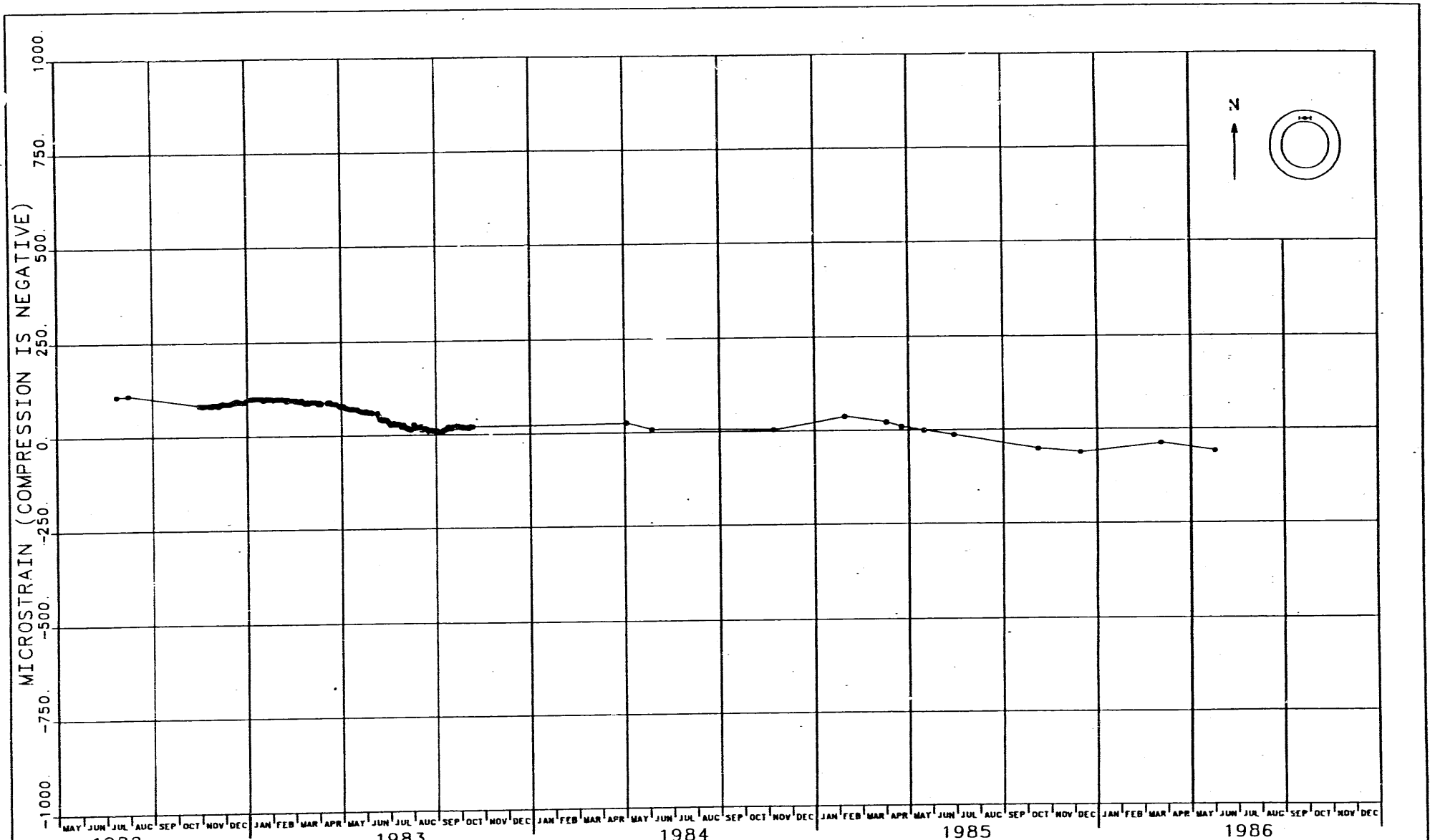
FIGURE J-92
EMBEDMENT STRAIN GAUGE 37X-ZE-00237
C & SH SHAFT KEY - EL 2553.7
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR 22, 1982.
3. GAUGE IS LOCATED 9 IN. FROM INNER FACE ON EAST SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

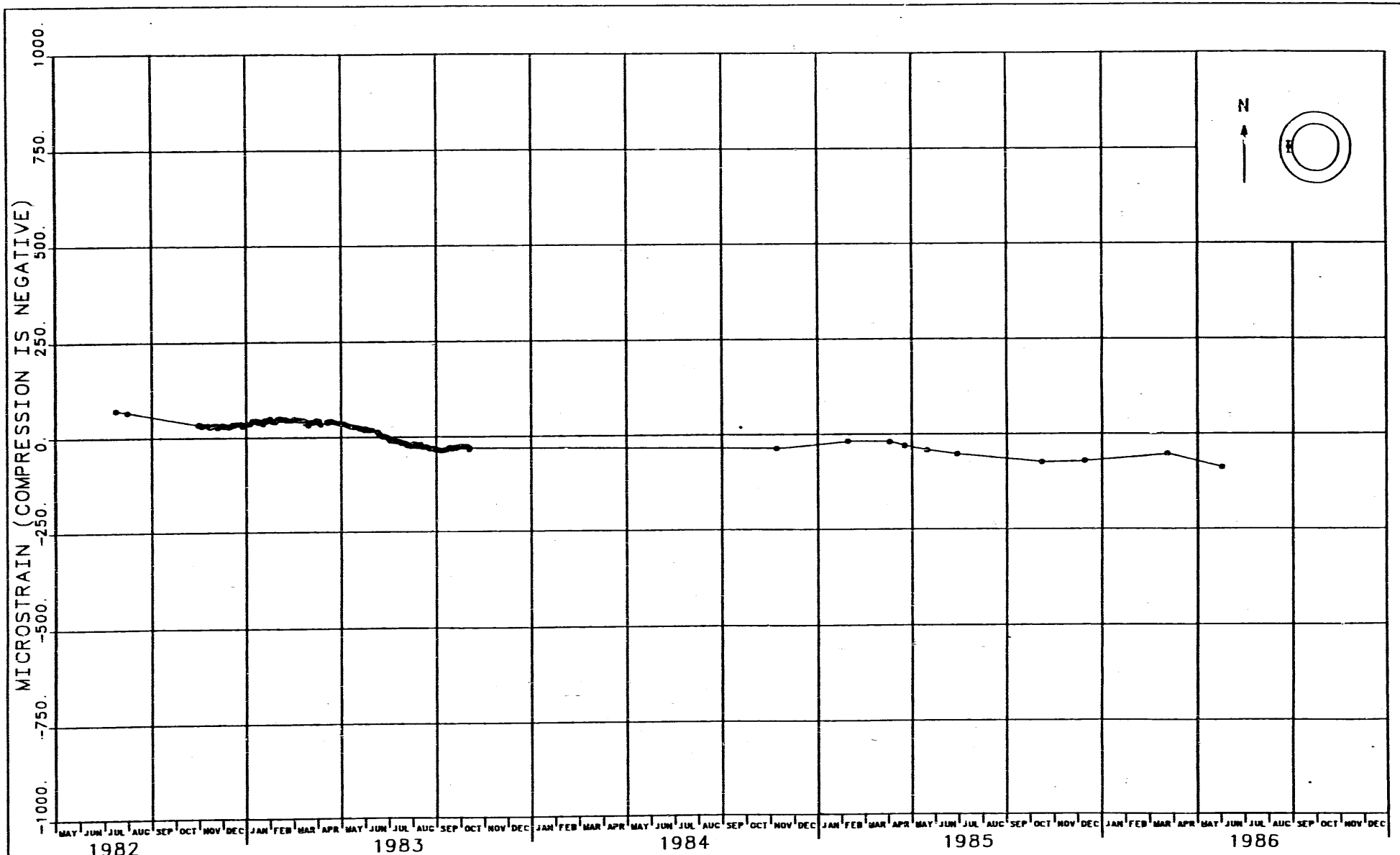
FIGURE J-93
EMBEDMENT STRAIN GAUGE 37X-ZE-00238
C & SH SHAFT KEY - EL 2553.7
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 9 IN. FROM INNER FACE ON NORTH SIDE OF CONCRETE KEY
4. SIZE OF EXCAVATION: 15 FT DIAM.

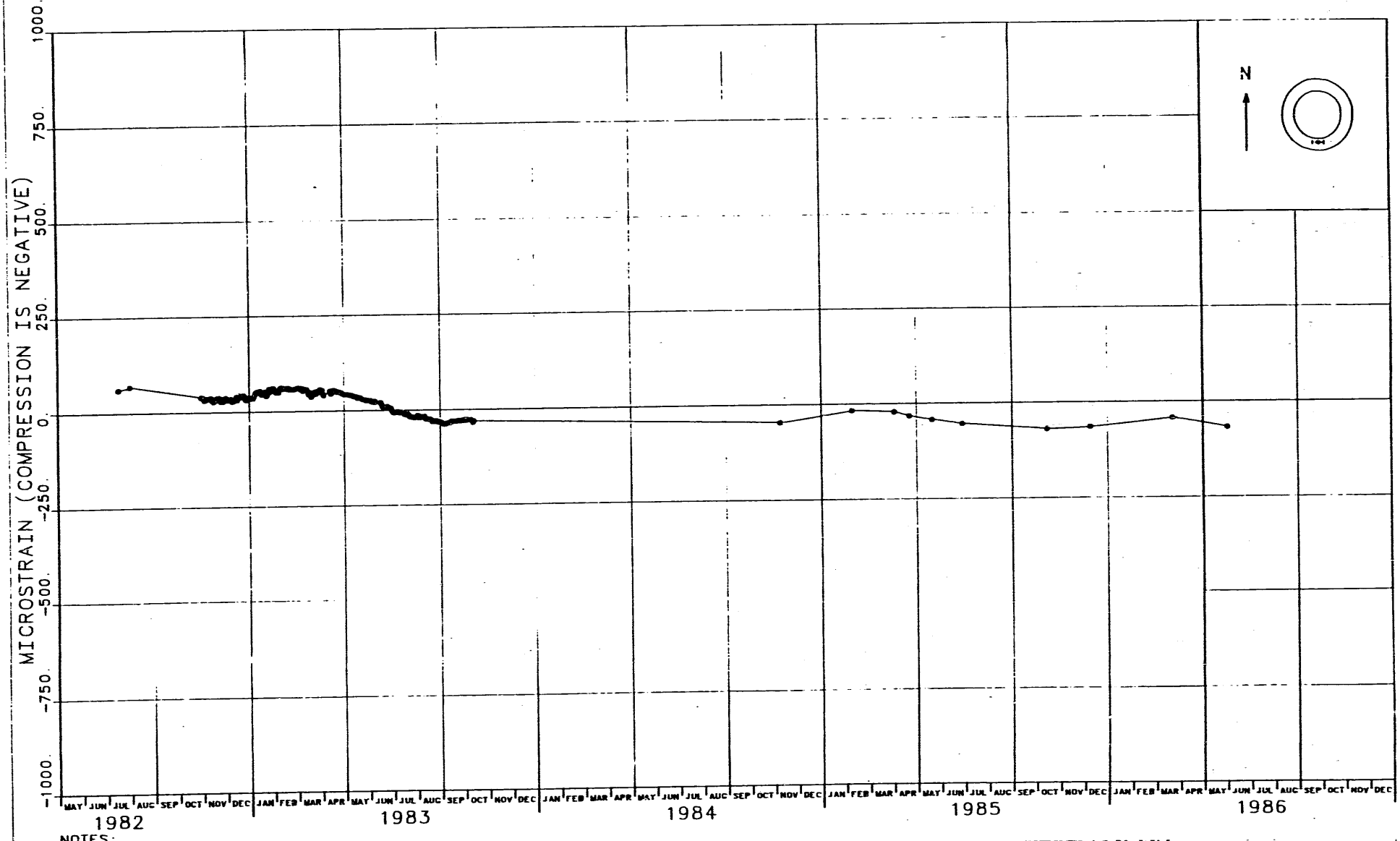
FIGURE J-94
EMBEDMENT STRAIN GAUGE 37X-ZE-00239
C & SH SHAFT KEY - EL 2547.6
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 9 IN. FROM INNER FACE ON WEST SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

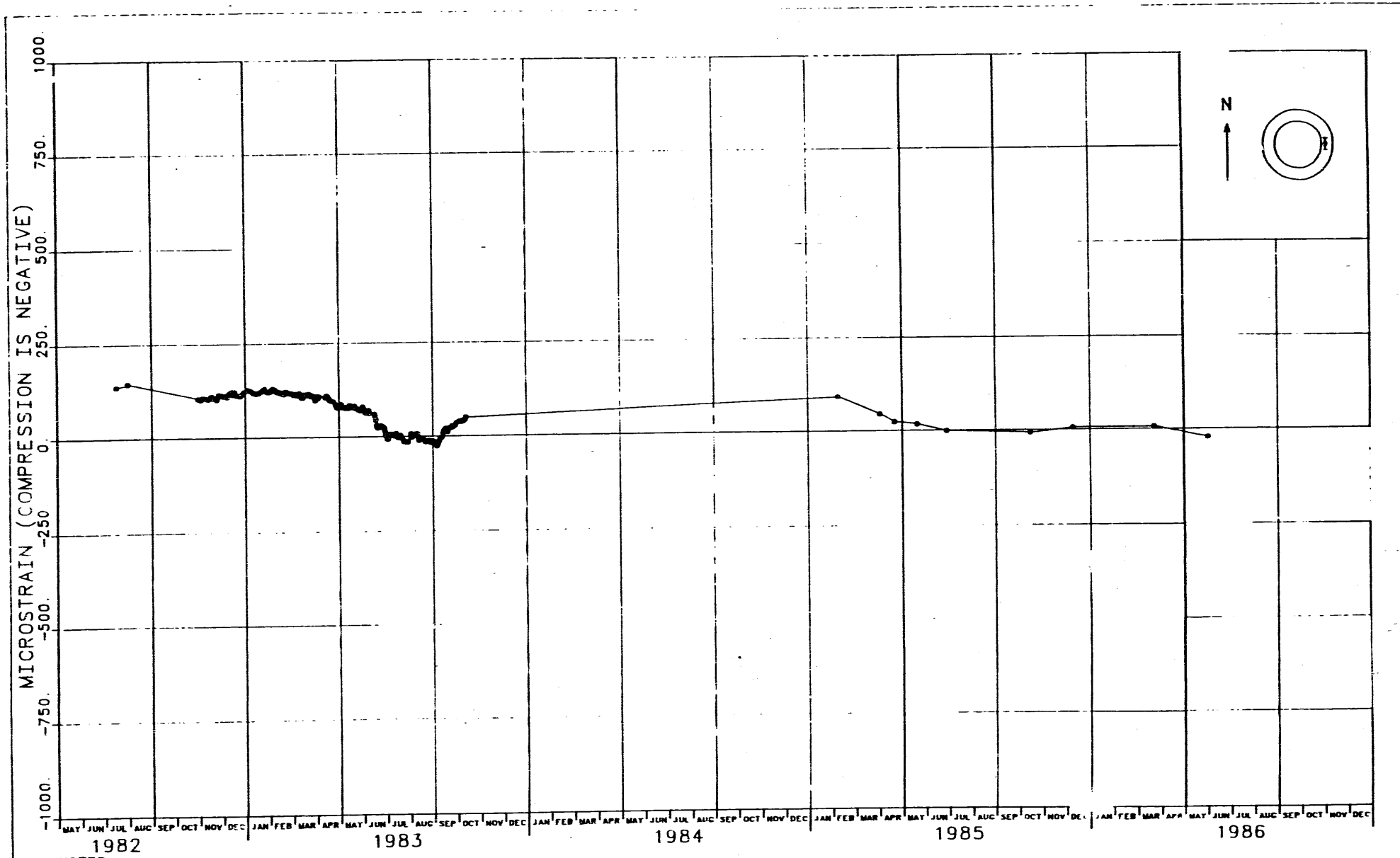
FIGURE J-95
EMBEDMENT STRAIN GAUGE 37X-ZE-00240
C & SH SHAFT KEY - EL 2547.6
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 9 IN. FROM INNER FACE ON SOUTH SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

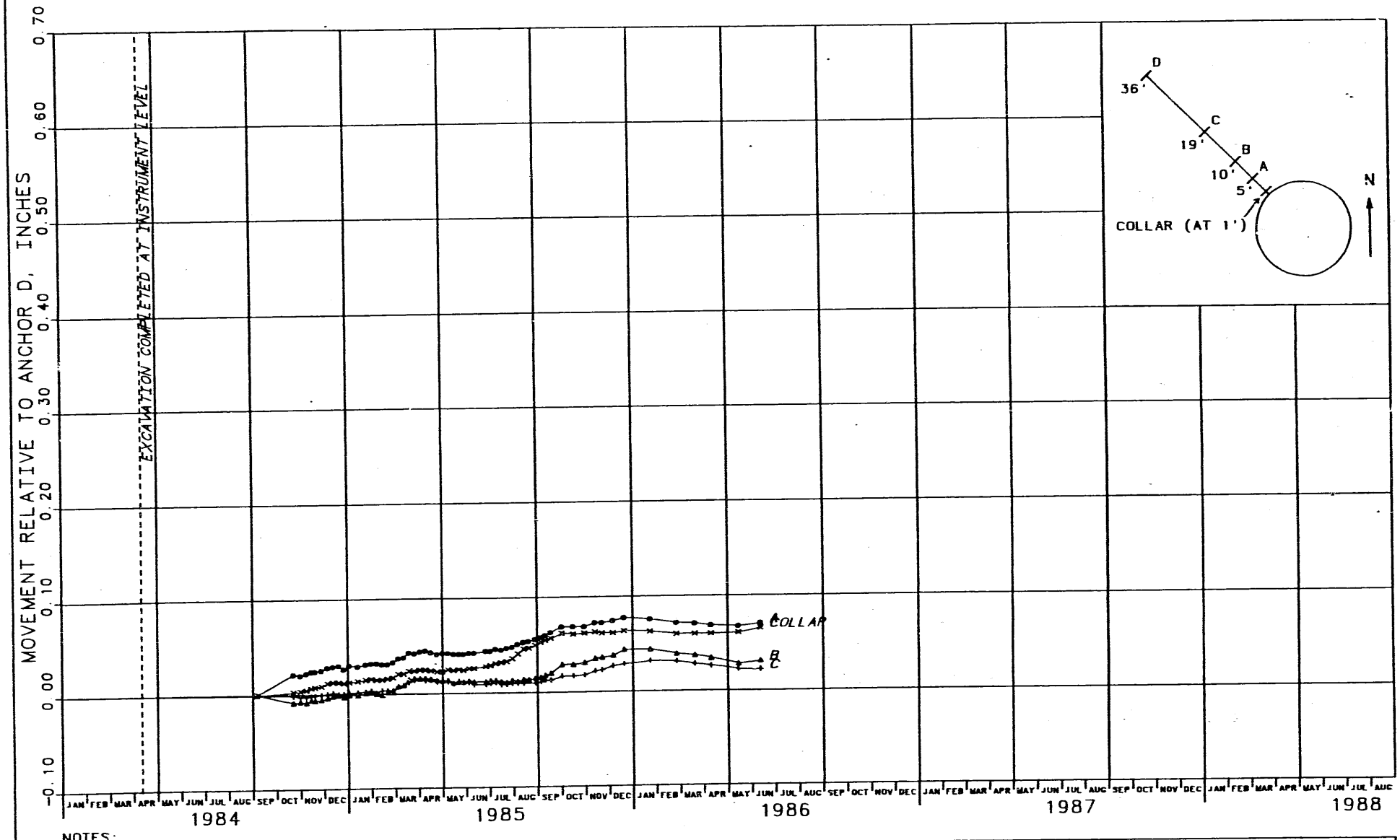
FIGURE J-96
EMBEDMENT STRAIN GAUGE 37X-ZE-00241
C & SH SHAFT KEY - EL 2547.6
STRAIN VS. CALENDAR MONTH



NOTES:

1. CONCRETE FOR KEY WAS PLACED IN APRIL 1982.
2. STRAIN SINCE READING ON APR. 22, 1982.
3. GAUGE IS LOCATED 9 IN FROM INNER FACE ON EAST SIDE OF CONCRETE KEY.
4. SIZE OF EXCAVATION: 15 FT DIAM.

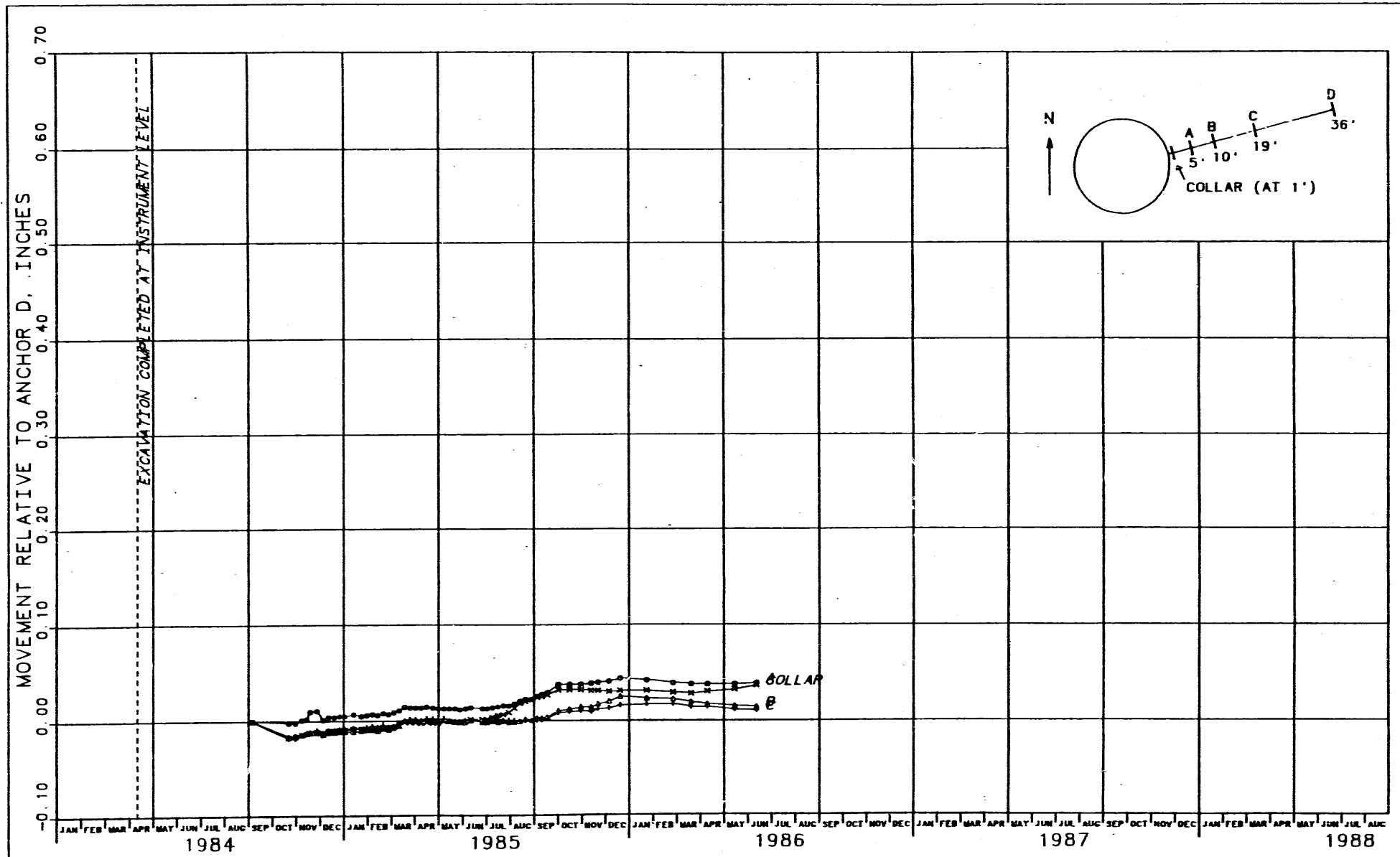
FIGURE J-97
EMBEDMENT STRAIN GAUGE 37X-ZE-00242
C & SH SHAFT KEY - EL 2547.6
STRAIN VS. CALENDAR MONTH



NOTES:

1. SIZE OF EXCAVATION: 20 FT DIAM.

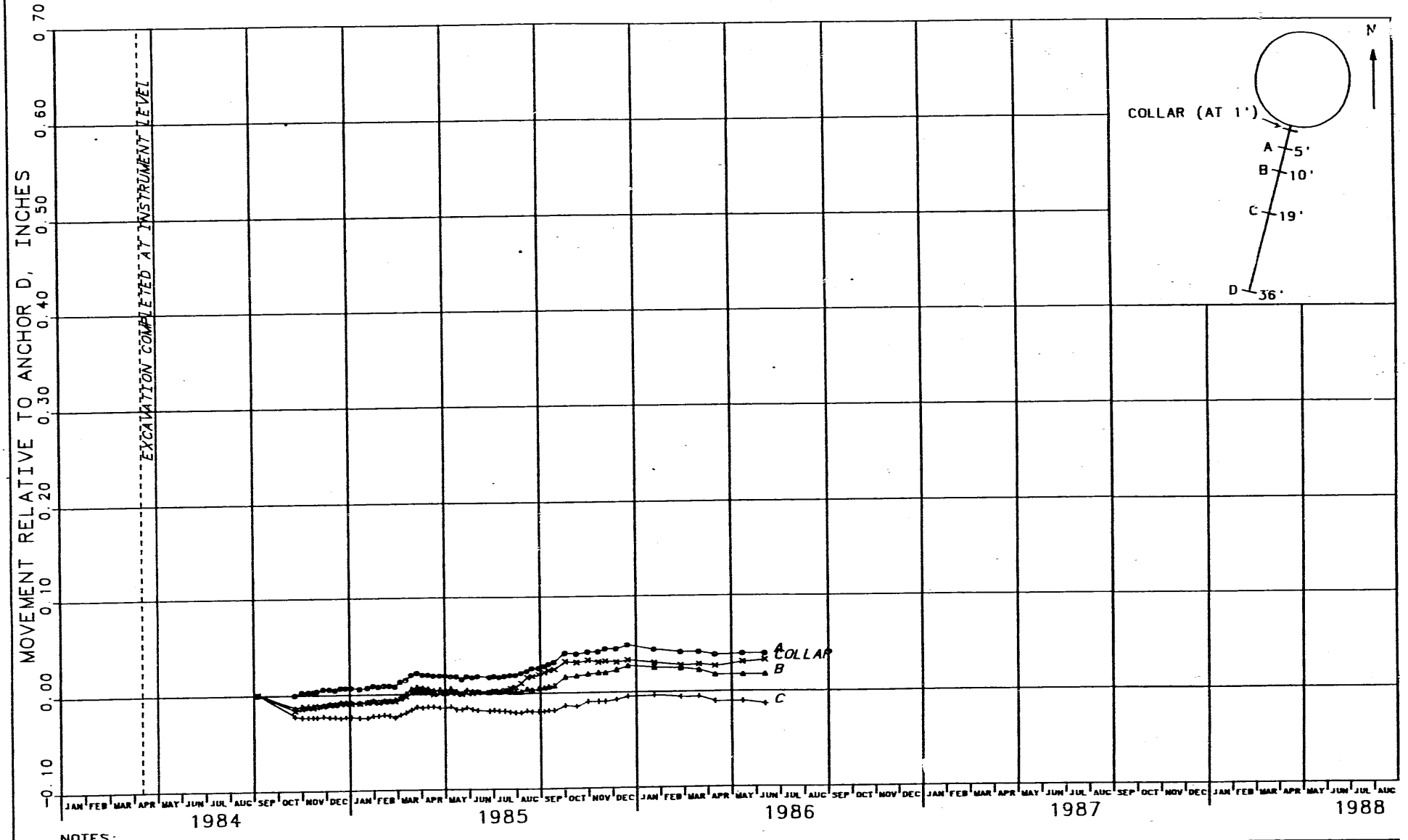
FIGURE J-98
MULTIPLE-POINT EXTENSOMETER 31X-GE-00201
WASTE SHAFT - EL 2338 - N 45 W
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. SIZE OF EXCAVATION: 20 FT DIAM.

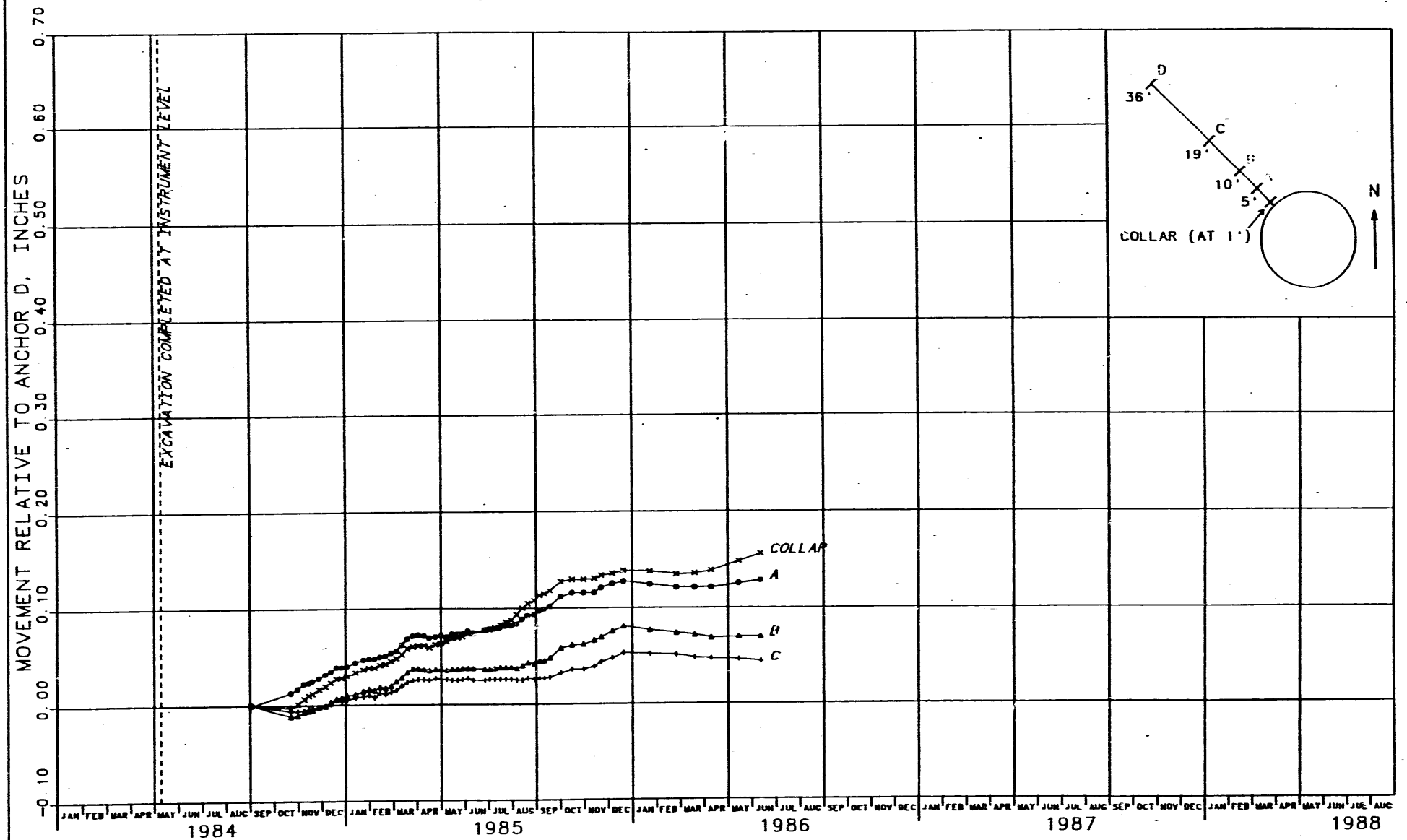
FIGURE J-99
MULTIPLE-POINT EXTENSOMETER 31X-GE-00202
WASTE SHAFT - EL 2338 - N 75 E
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. SIZE OF EXCAVATION: 20 FT DIAM.

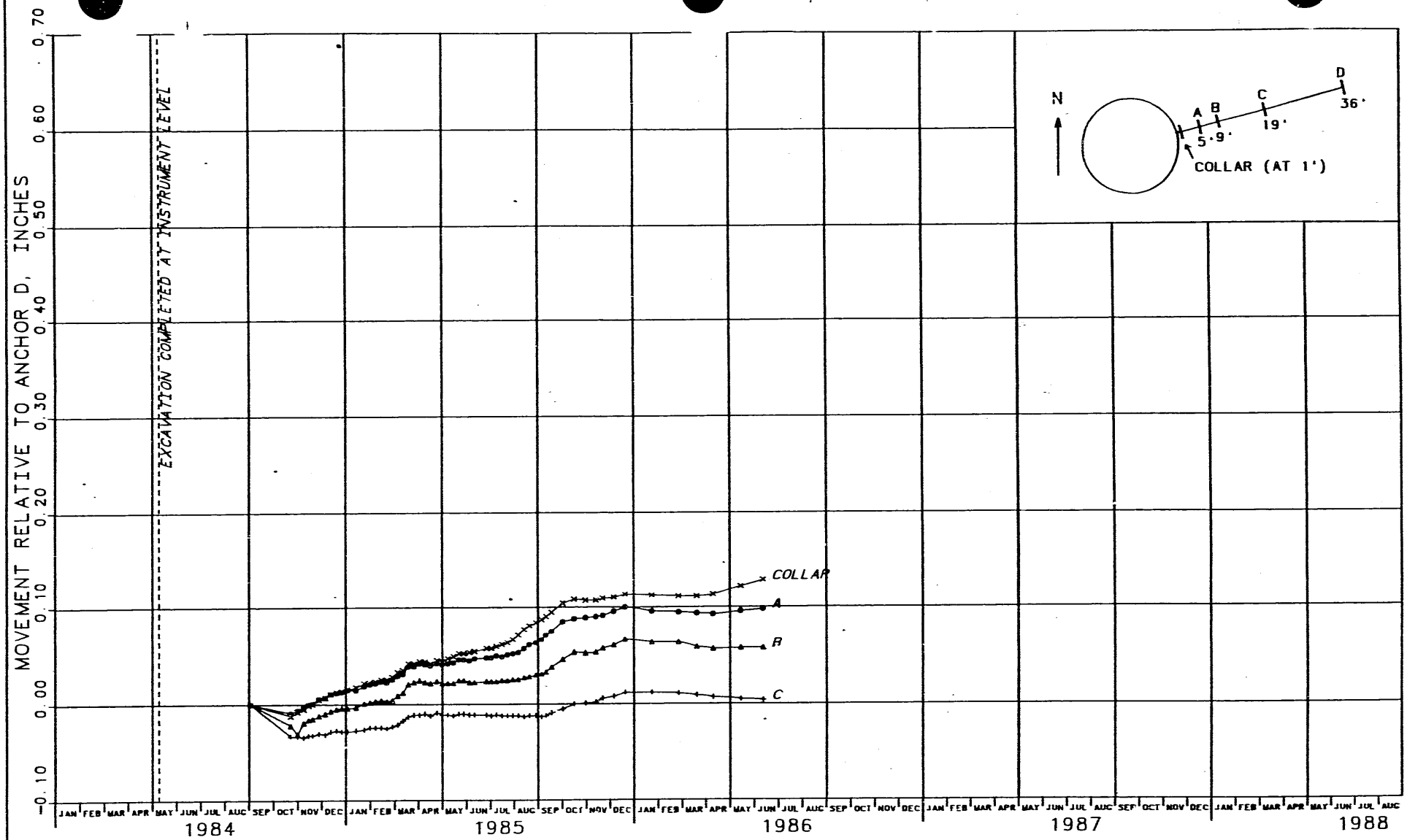
FIGURE J-100
MULTIPLE-POINT EXTENSOMETER 31X-GE-00203
WASTE SHAFT - EL 2338 - S 15 W
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. SIZE OF EXCAVATION: 20 FT DIAM.

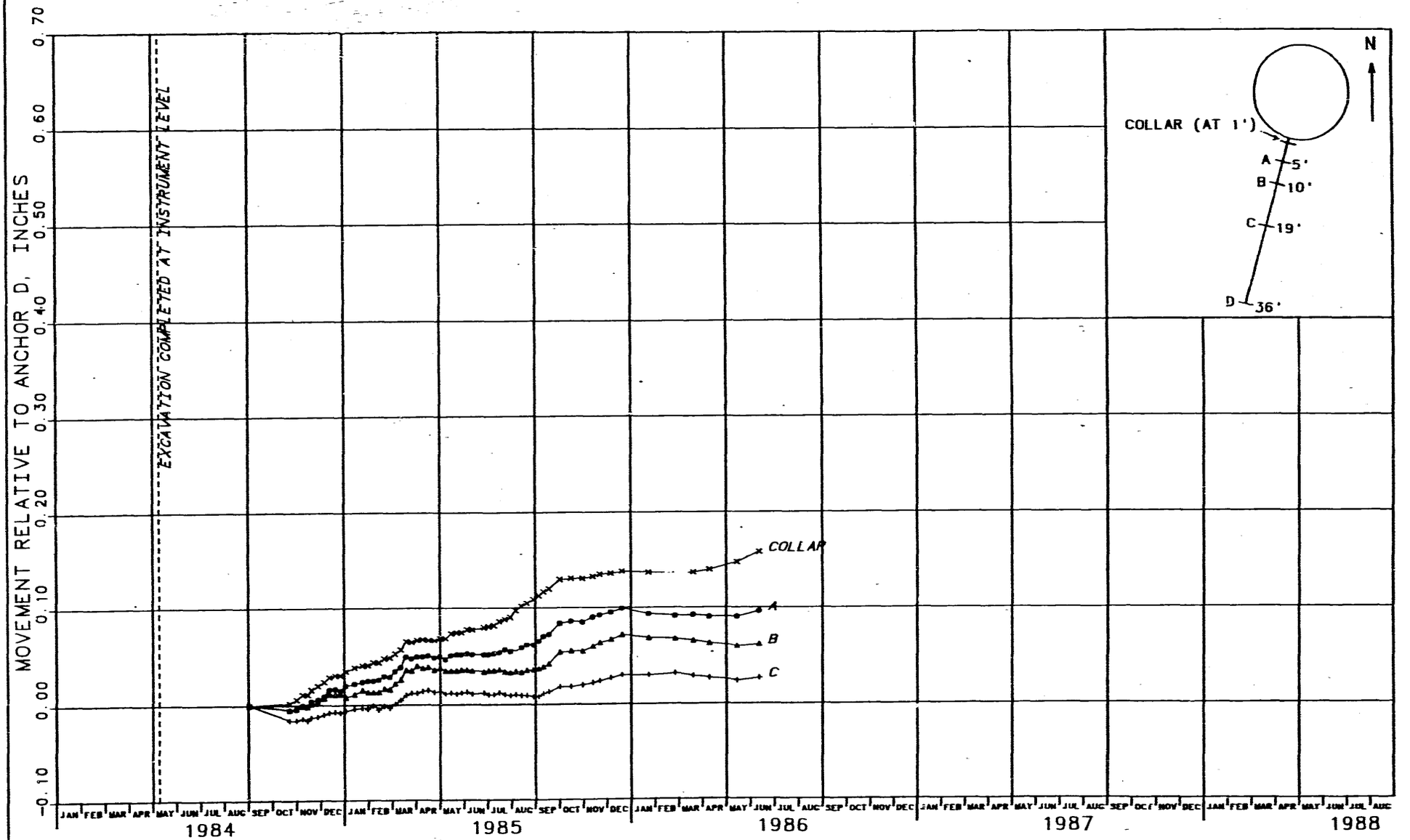
FIGURE J-101
MULTIPLE-POINT EXTENSOMETER 31X-GE-00204
WASTE SHAFT - EL 1843 - N 45 W
MOVEMENT VS. CALENDAR MONTH



NOTES

1. SIZE OF EXCAVATION 20 FT DIAM

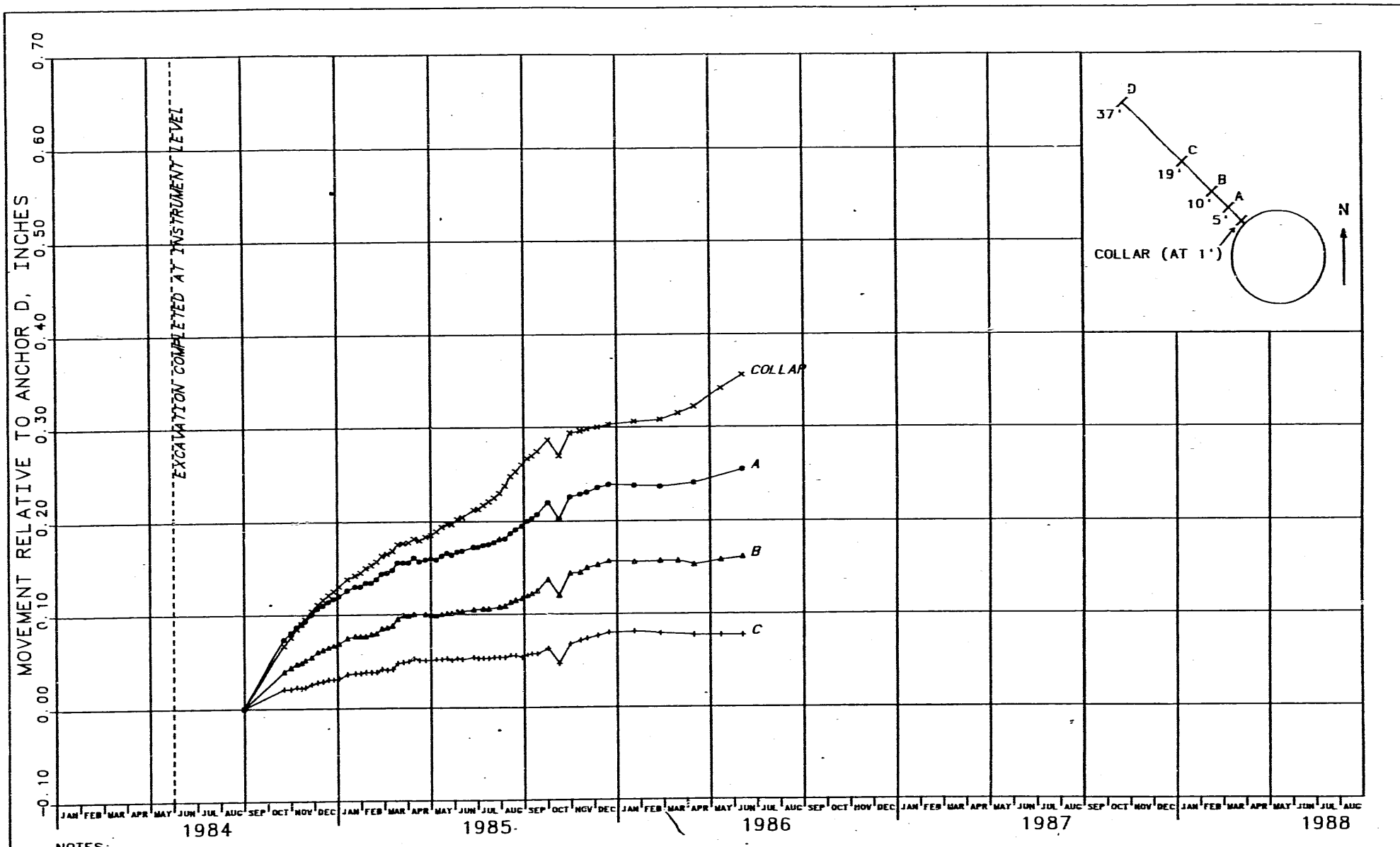
FIGURE J-102
MULTIPLE-POINT EXTENSOMETER 31X-GE-00205
WASTE SHAFT – EL 1843 – N 75 E
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. SIZE OF EXCAVATION: 20 FT DIAM.

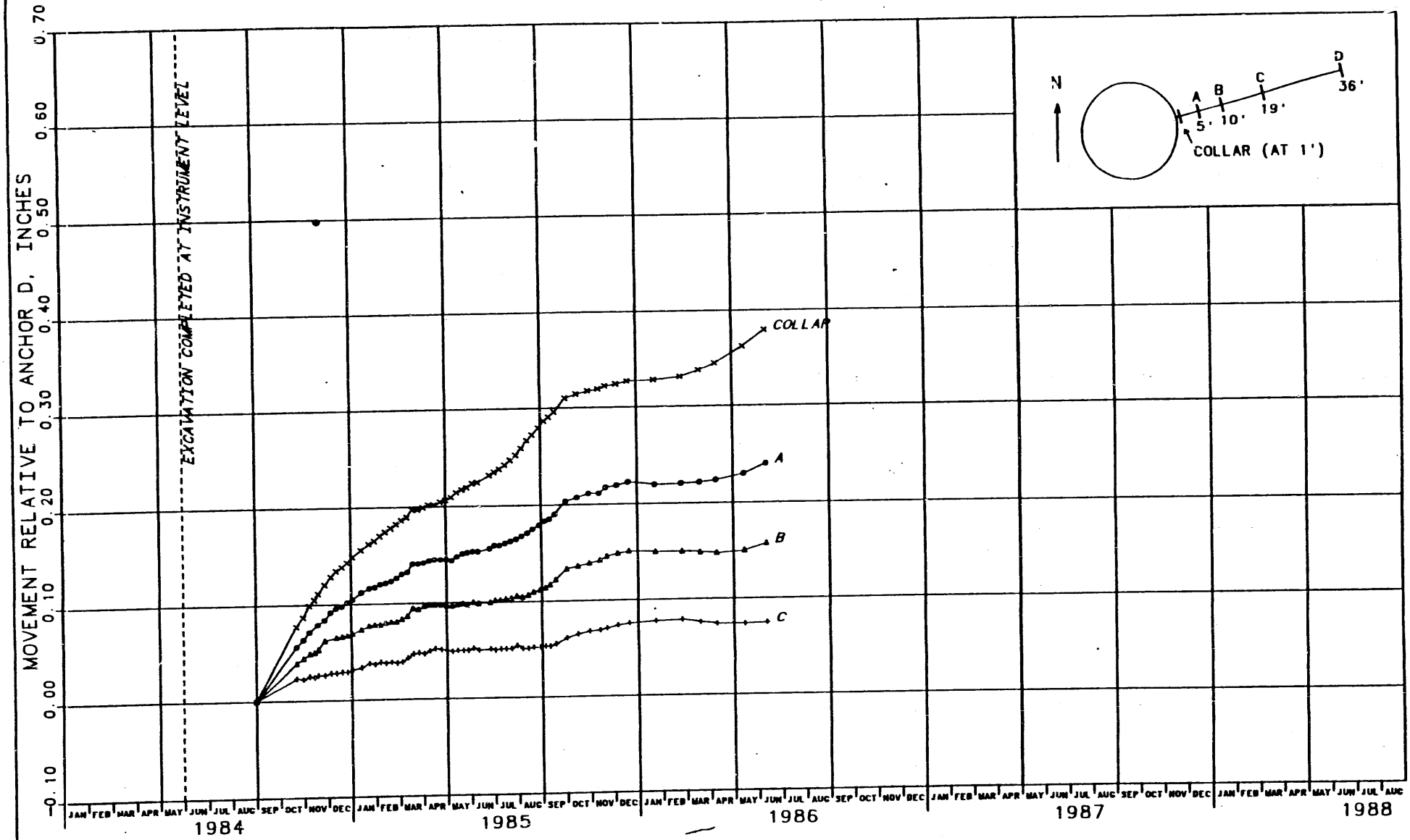
FIGURE J-103
MULTIPLE-POINT EXTENSOMETER 31X-GE-00206
WASTE SHAFT - EL 1843 - S 15 W
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. SIZE OF EXCAVATION: 20 FT DIAM.

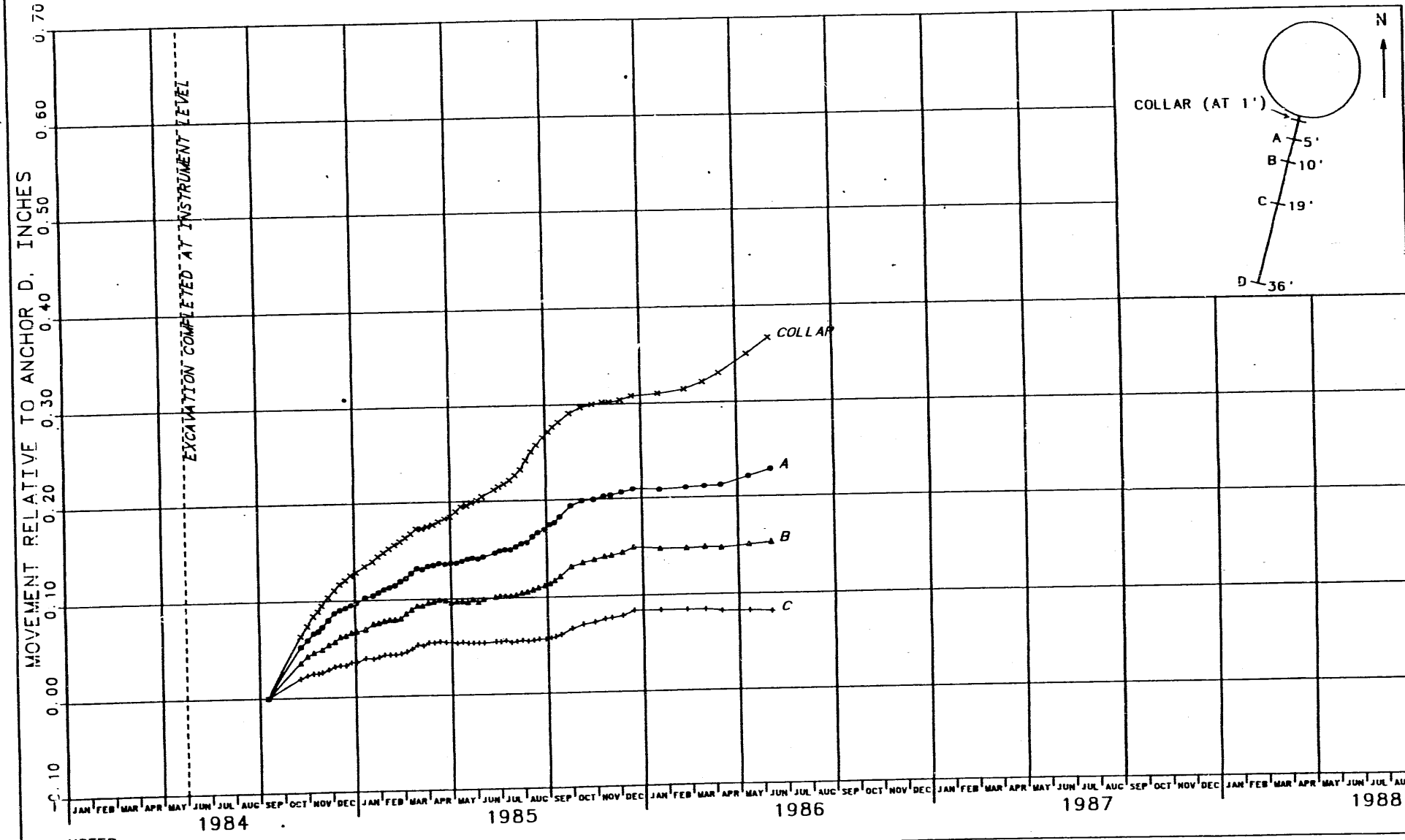
FIGURE J-104
MULTIPLE-POINT EXTENSOMETER 31X-GE-00207
WASTE SHAFT - EL 1350 - N 45 W
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. SIZE OF EXCAVATION: 20 FT DIAM.

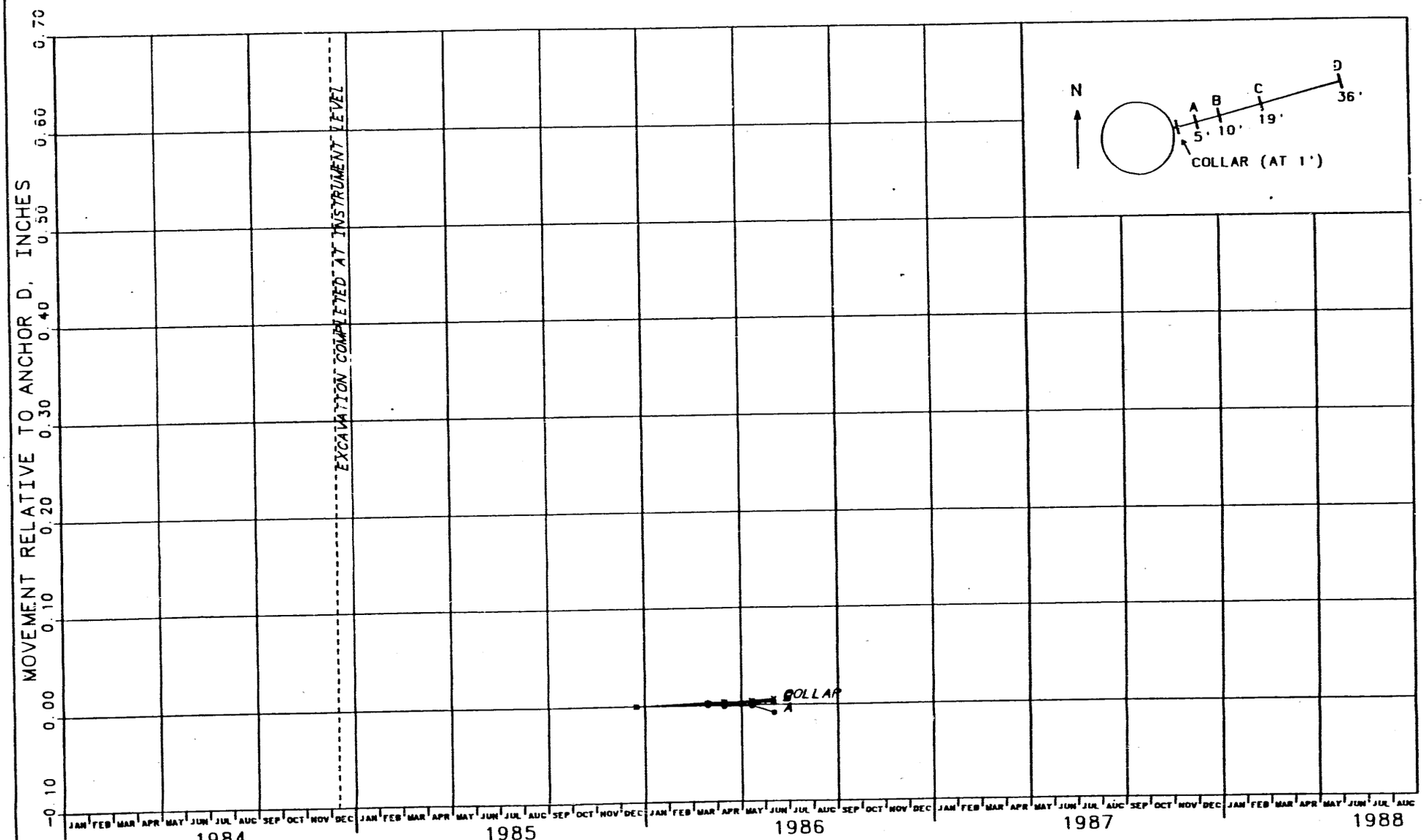
FIGURE J-105
MULTIPLE-POINT EXTENSOMETER 31X-GE-00208
WASTE SHAFT - EL 1350 - N 75 E
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. SIZE OF EXCAVATION: 20 FT DIAM.

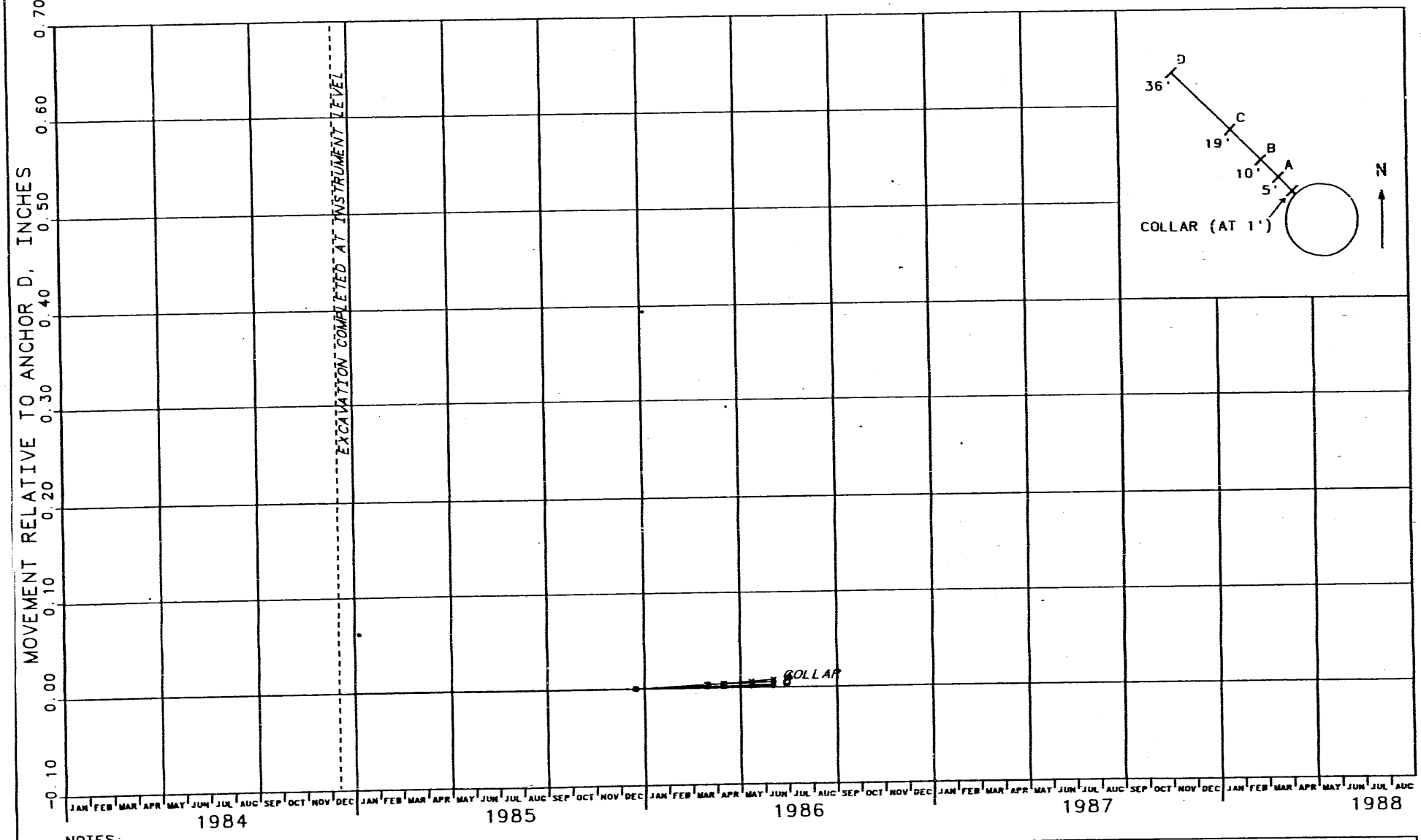
FIGURE J-106
MULTIPLE-POINT EXTENSOMETER 31X-GE-00209
WASTE SHAFT - EL 1350 - S 15 W
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. SIZE OF EXCAVATION: 15 FT DIAM.

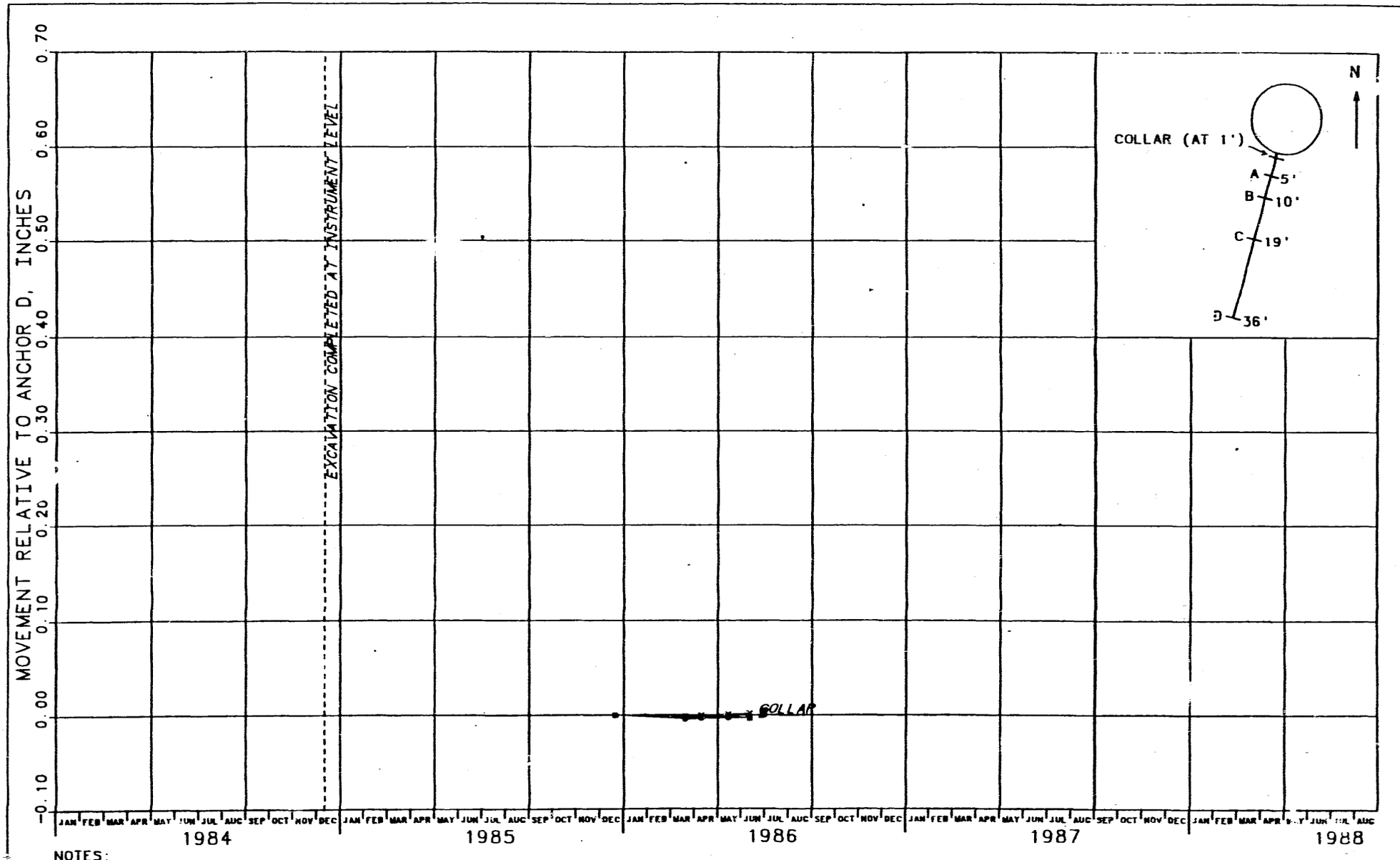
FIGURE J-107
MULTIPLE-POINT EXTENSOMETER 35X-GE-00201
EXHAUST SHAFT - EL 2331 - N 76 E
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. SIZE OF EXCAVATION: 15 FT DIAM.

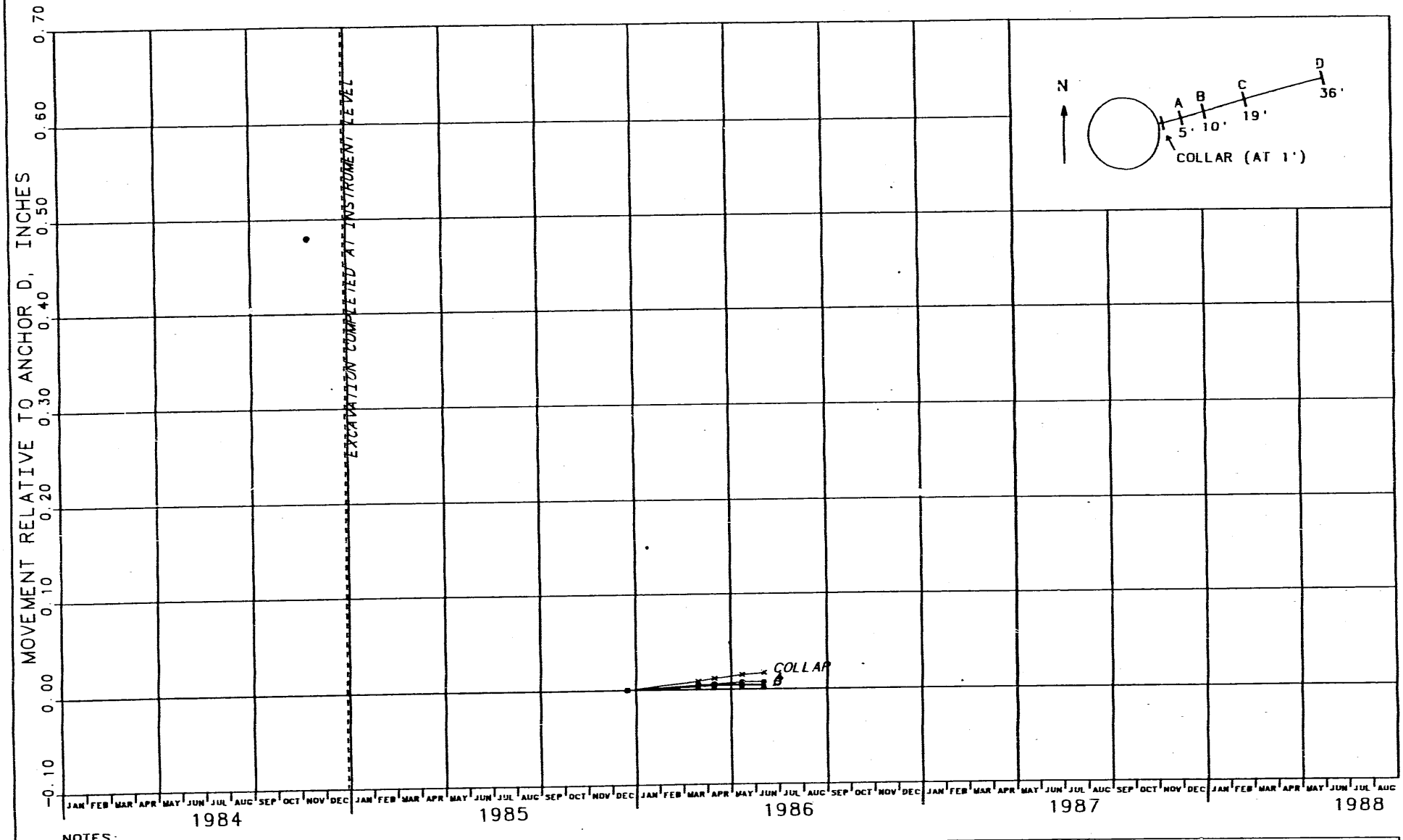
FIGURE J-108
MULTIPLE-POINT EXTENSOMETER 35X-GE-00202
EXHAUST SHAFT - EL 2331 - N 45 W
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. SIZE OF EXCAVATION: 15 FT DIAM.

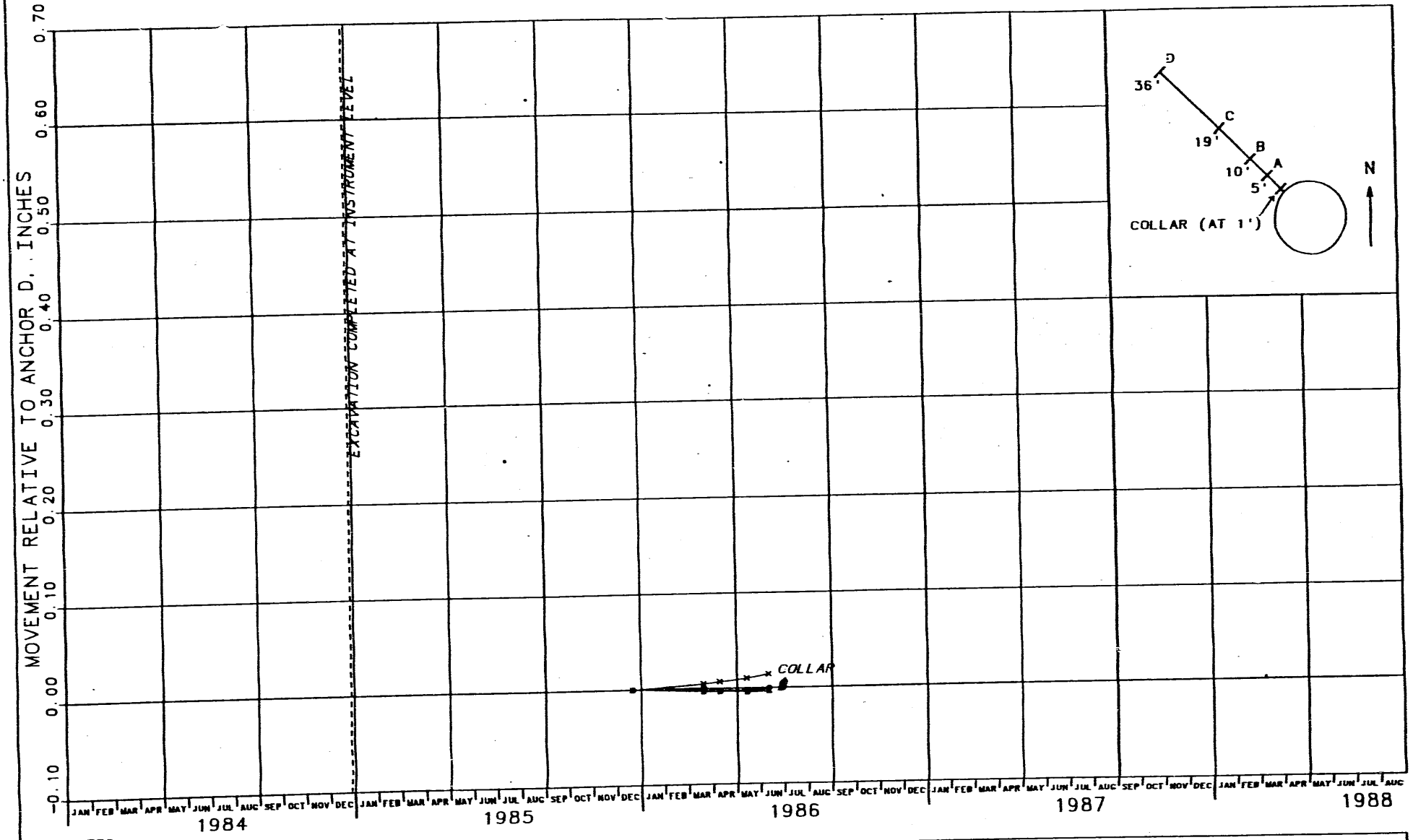
FIGURE J-109
MULTIPLE-POINT EXTENSOMETER 35X-GE-00203
EXHAUST SHAFT – EL 2331 – S 15 W
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. SIZE OF EXCAVATION: 15 FT DIAM.

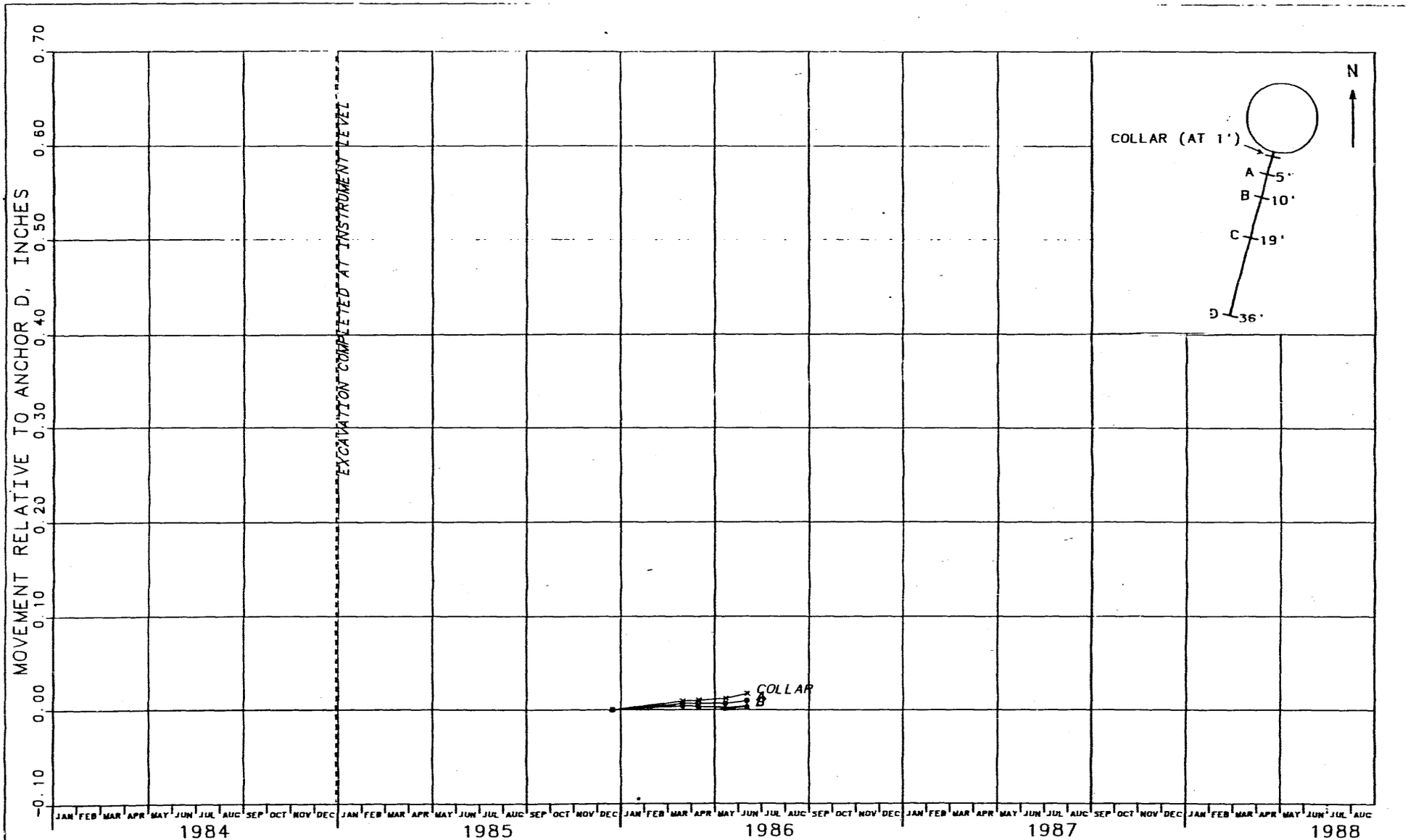
FIGURE J-110
MULTIPLE-POINT EXTENSOMETER 35X-GE-00204
EXHAUST SHAFT - EL 1835.5 - N 76 E
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. SIZE OF EXCAVATION: 15 FT DIAM.

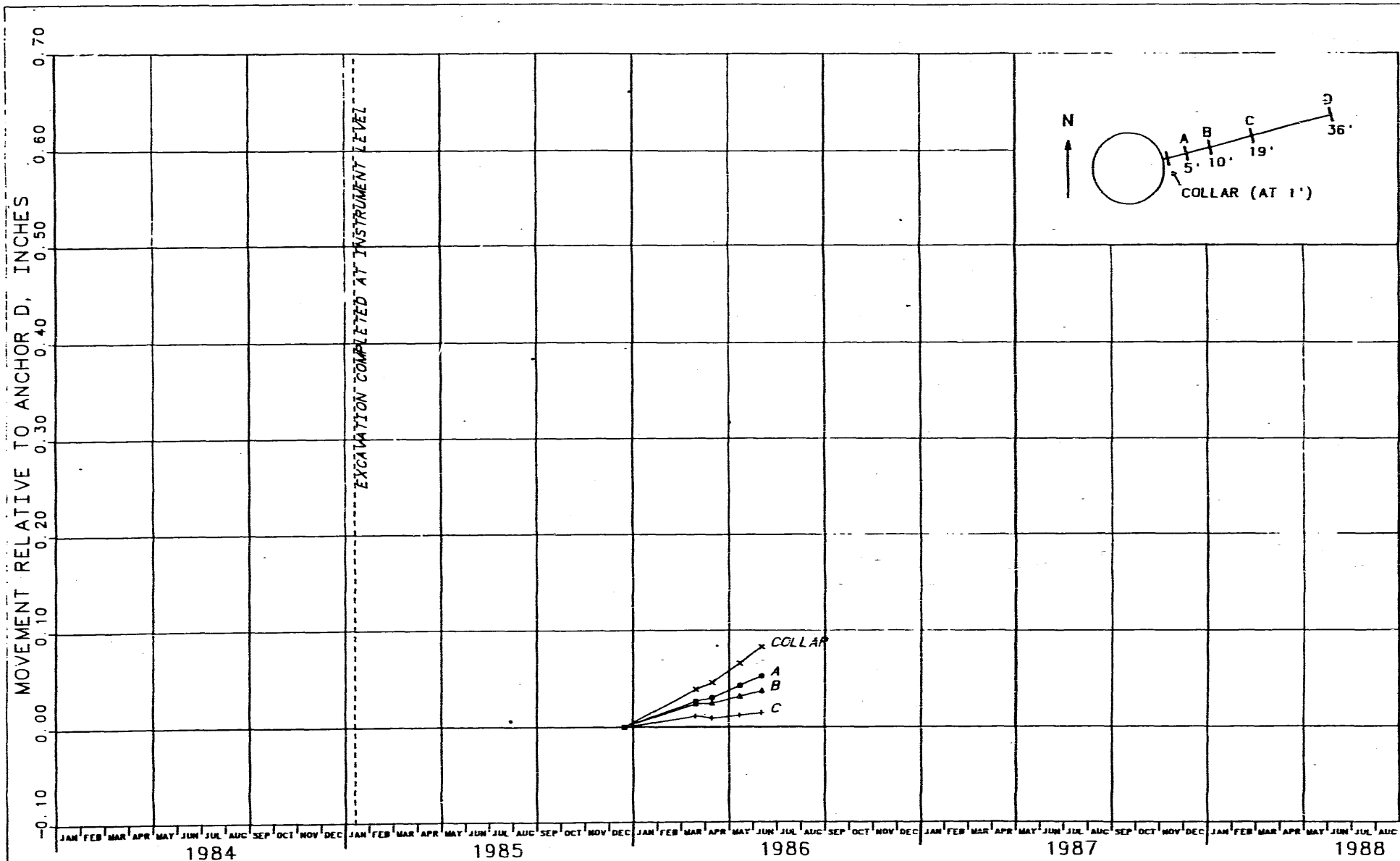
FIGURE J-111
MULTIPLE-POINT EXTENSOMETER 35X-GE-00205
EXHAUST SHAFT – EL 1835.5 – N 45 W
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. SIZE OF EXCAVATION: 15 FT DIAM.

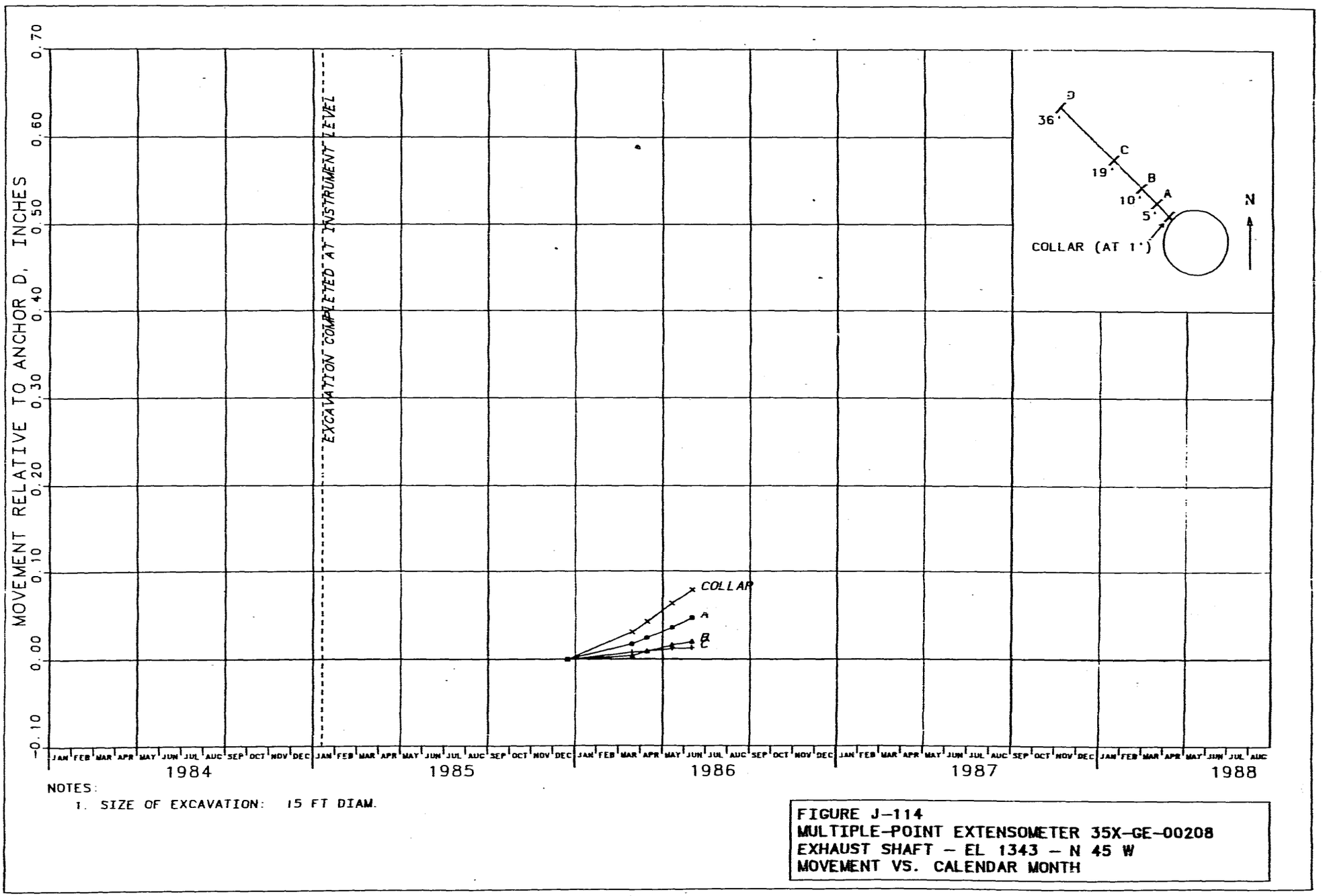
FIGURE J-112
MULTIPLE-POINT EXTENSOMETER 35X-GE-00206
EXHAUST SHAFT - EL 1835.5 - S 15 W
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. SIZE OF EXCAVATION: 15 FT DIAM.

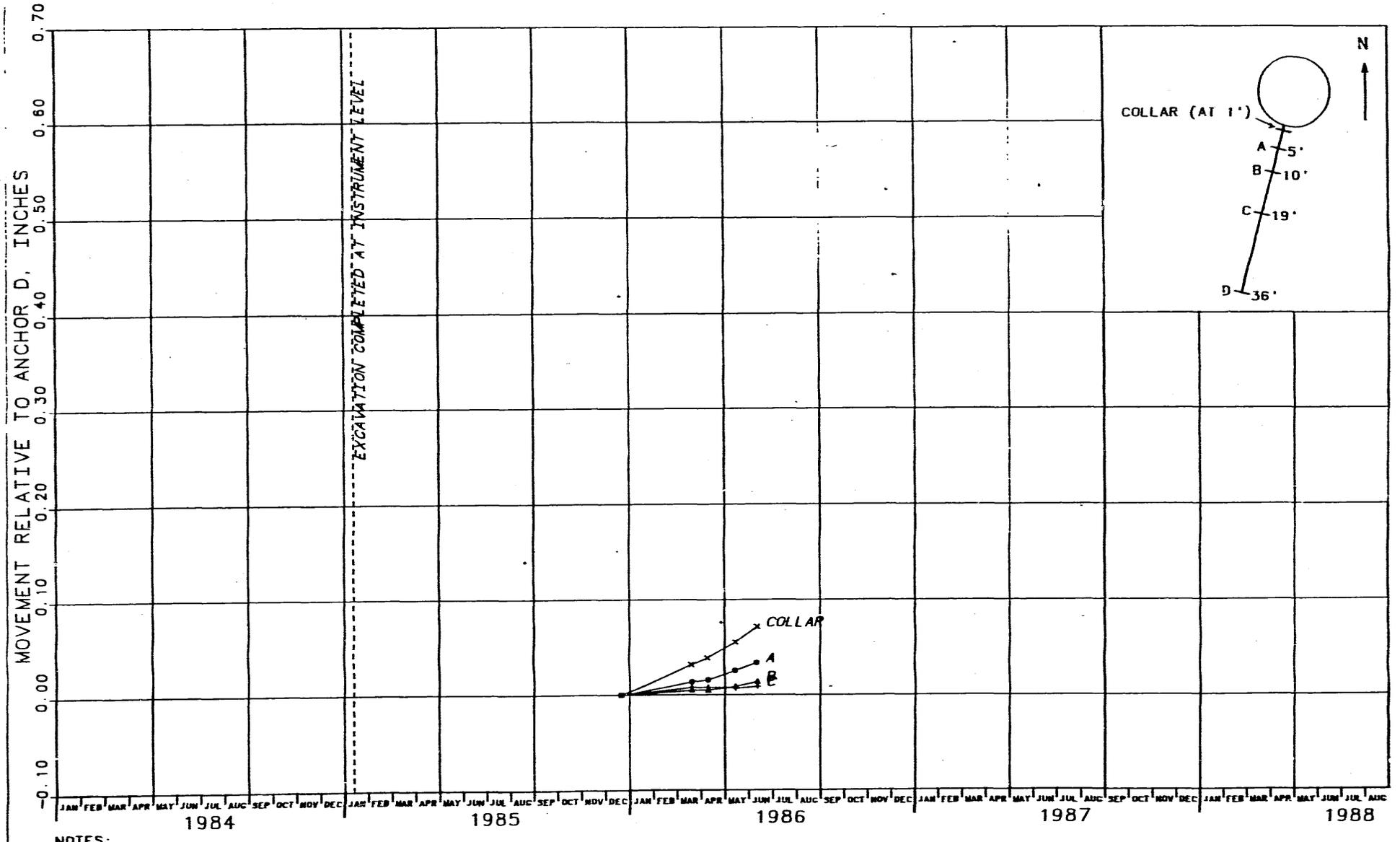
FIGURE J-113
MULTIPLE-POINT EXTENSOMETER 35X-GE-00207
EXHAUST SHAFT - EL 1343 - N 76 E
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. SIZE OF EXCAVATION: 15 FT DIAM.

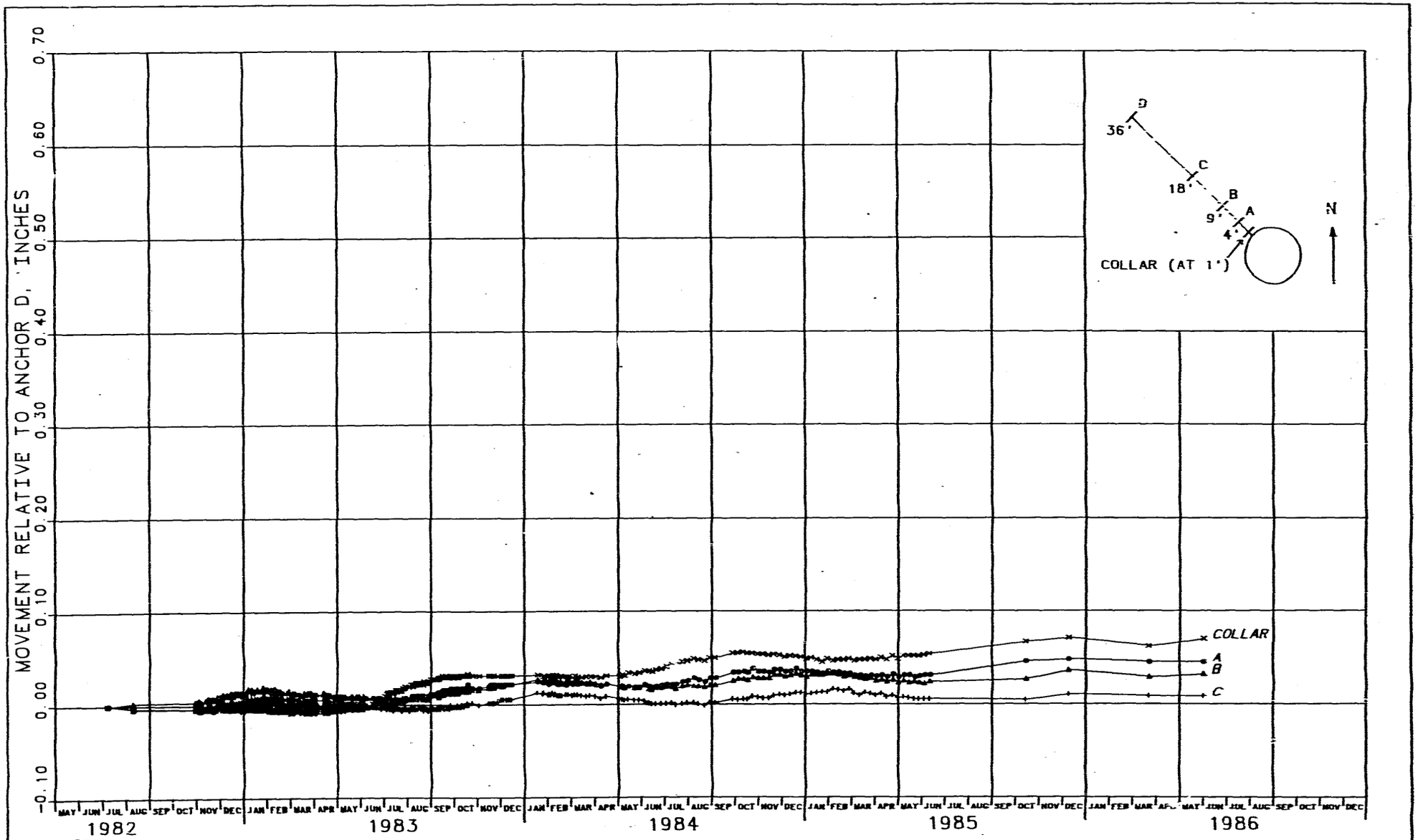
FIGURE J-114
MULTIPLE-POINT EXTENSOMETER 35X-GE-00208
EXHAUST SHAFT – EL 1343 – N 45 W
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. SIZE OF EXCAVATION: 15 FT DIAM.

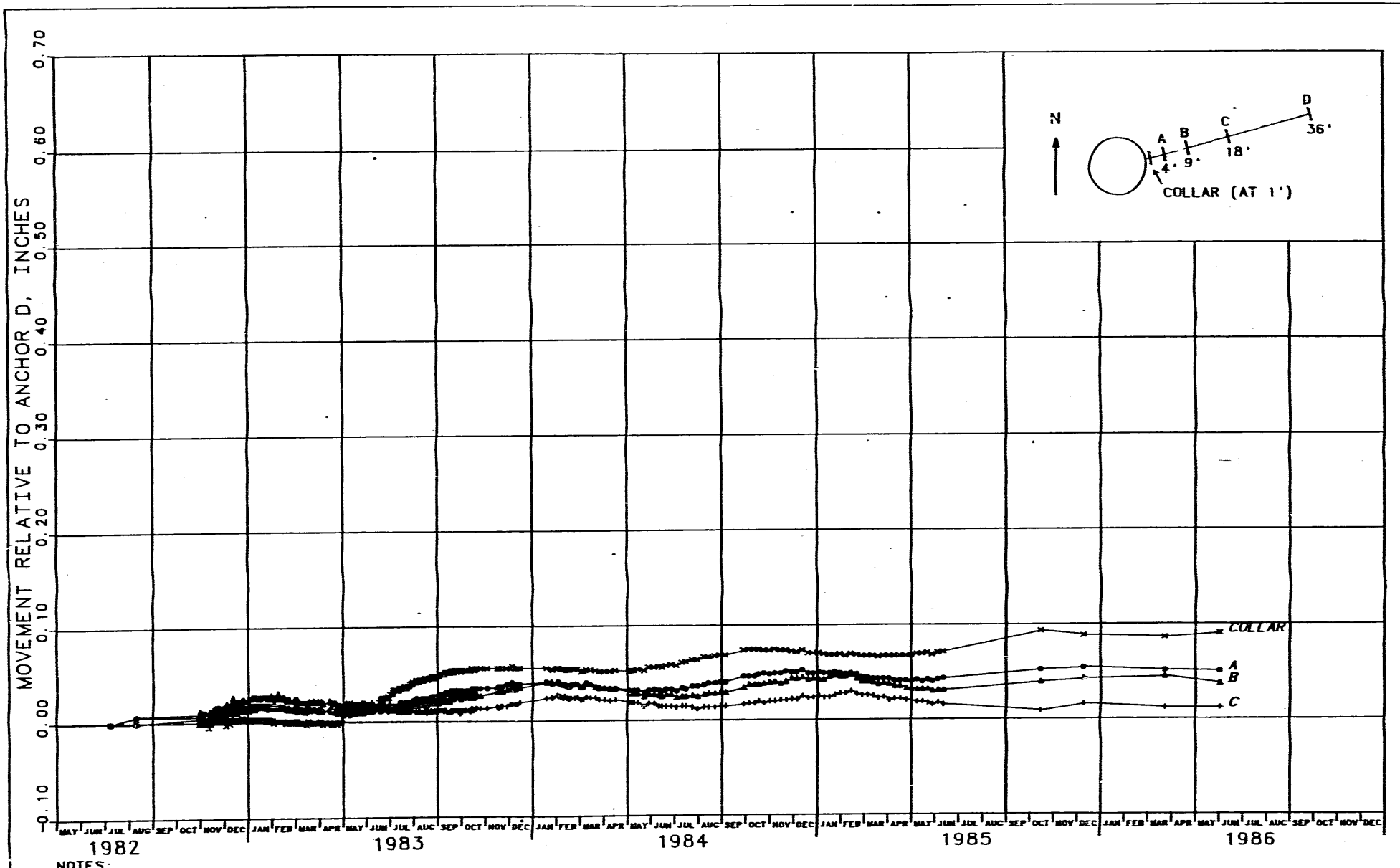
FIGURE J-115
MULTIPLE-POINT EXTENSOMETER 35X-GE-00209
EXHAUST SHAFT - EL 1343 - S 15 W
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. INSTRUMENT WAS INSTALLED 314 DAYS AFTER EXCAVATION STARTED ON AUG. 28, 1981.
2. SIZE OF EXCAVATION: 12 FT DIAM.

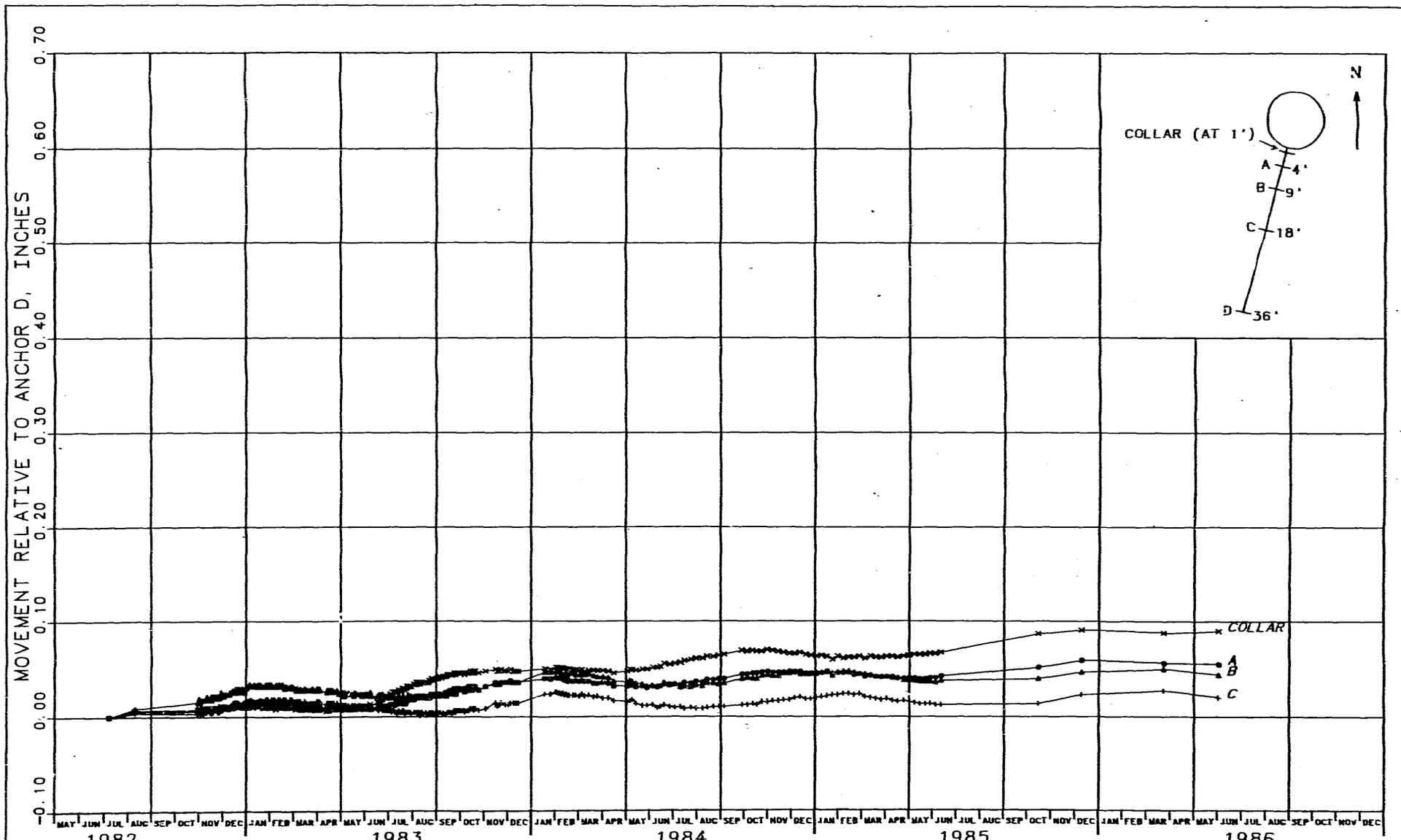
FIGURE J-116
MULTIPLE-POINT EXTENSOMETER 37X-GE-00201
C & SH SHAFT - EL 2337 - N 45 W
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. INSTRUMENT WAS INSTALLED 314 DAYS AFTER EXCAVATION STARTED ON AUG. 28, 1981.
2. SIZE OF EXCAVATION: 12 FT DIAM.

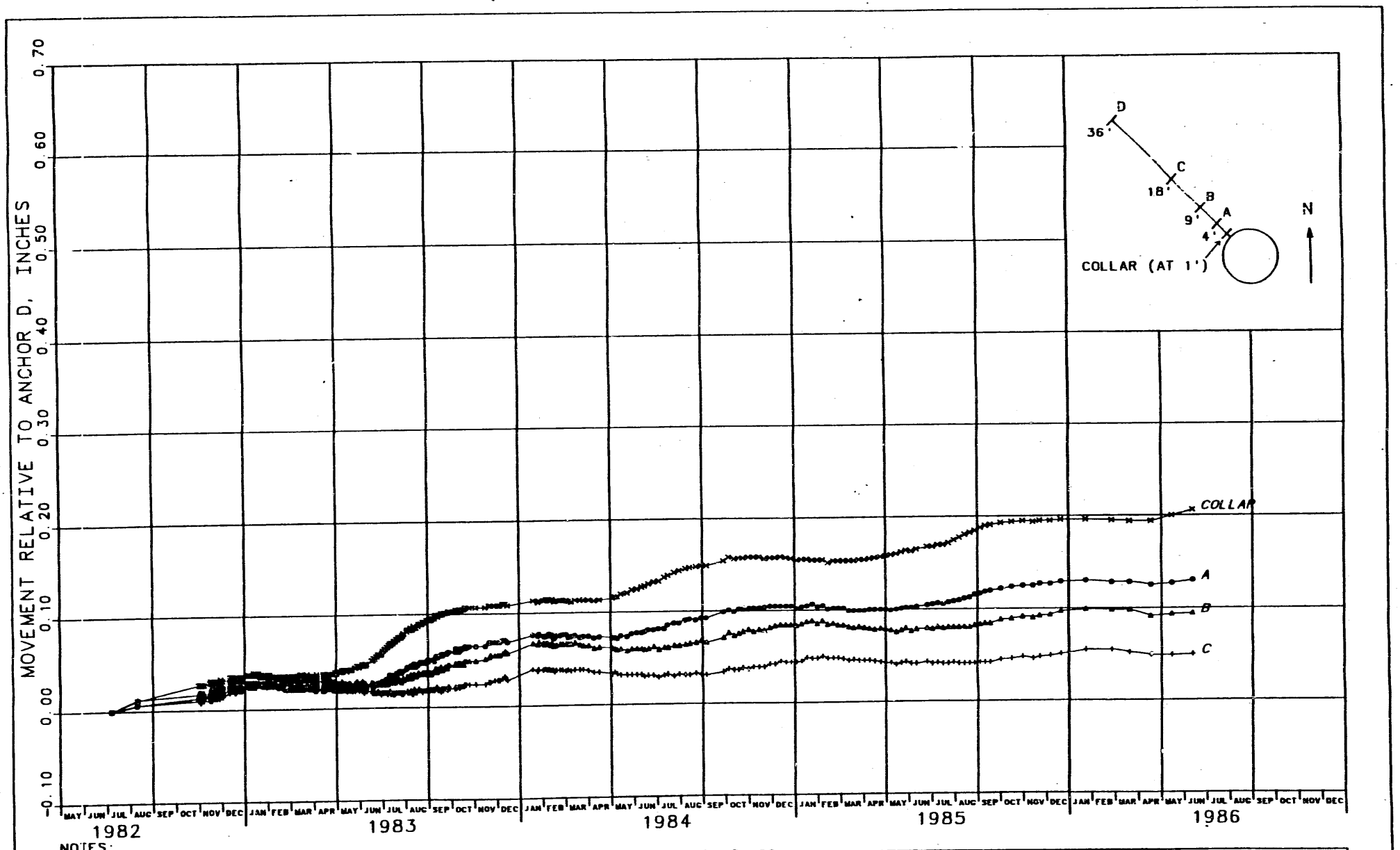
FIGURE J– 17
MULTIPLE–POINT EXTENSOMETER 37X–GE–00202
C & SH SHAFT – EL 2337 – N 75 E
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. INSTRUMENT WAS INSTALLED 314 DAYS AFTER EXCAVATION STARTED ON AUG. 28, 1981.
2. SIZE OF EXCAVATION: 12 FT DIAM.

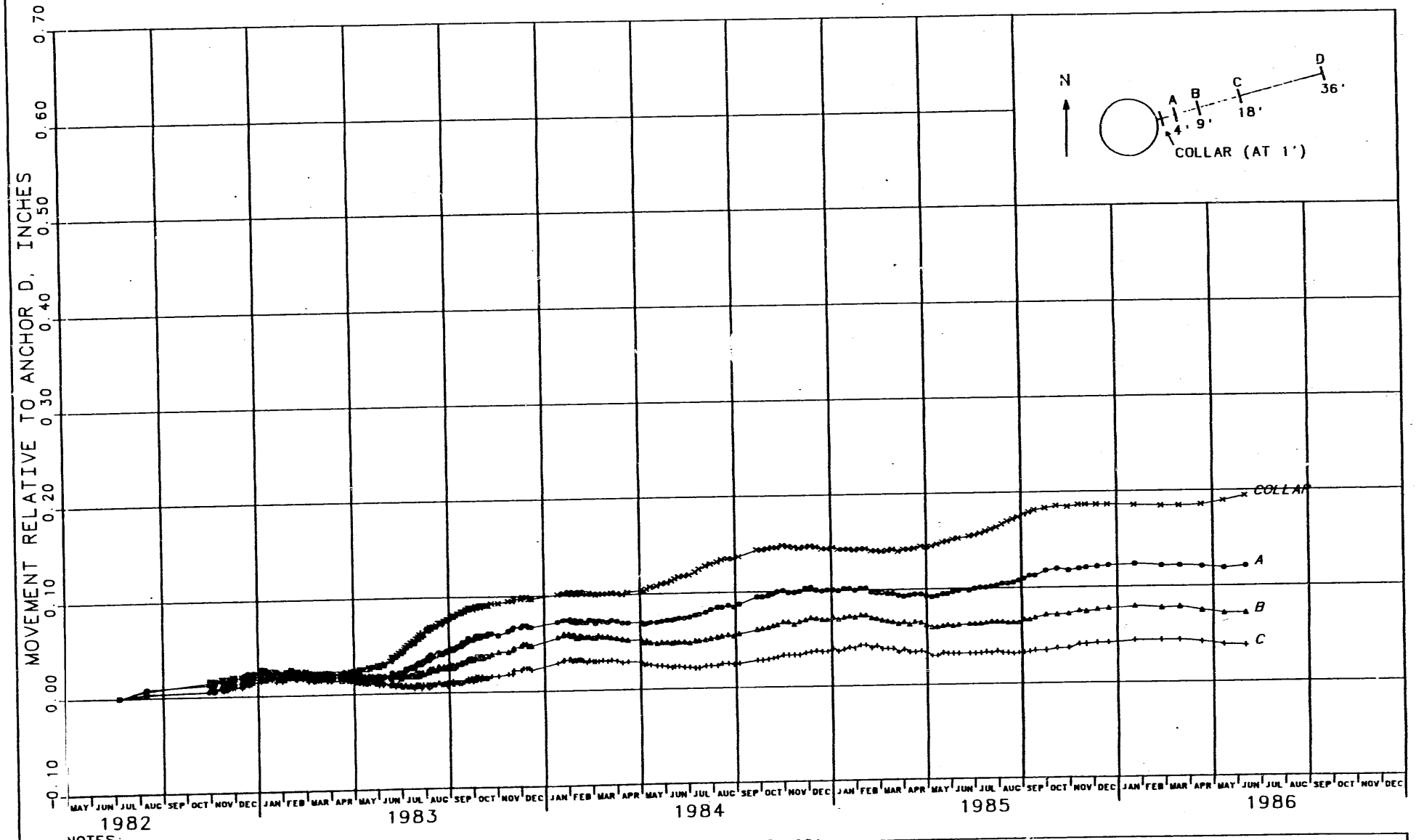
FIGURE J-118
MULTIPLE-POINT EXTENSOMETER 37X-GE-00203
C & SH SHAFT - EL 2337 - S 15 W
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. INSTRUMENT WAS INSTALLED 292 DAYS AFTER EXCAVATION STARTED ON SEP. 18, 1981.
2. ADJUSTMENT APPLIED TO ALL CURVES ON JAN 19, 1983.
3. SIZE OF EXCAVATION: 12 FT DIAM.

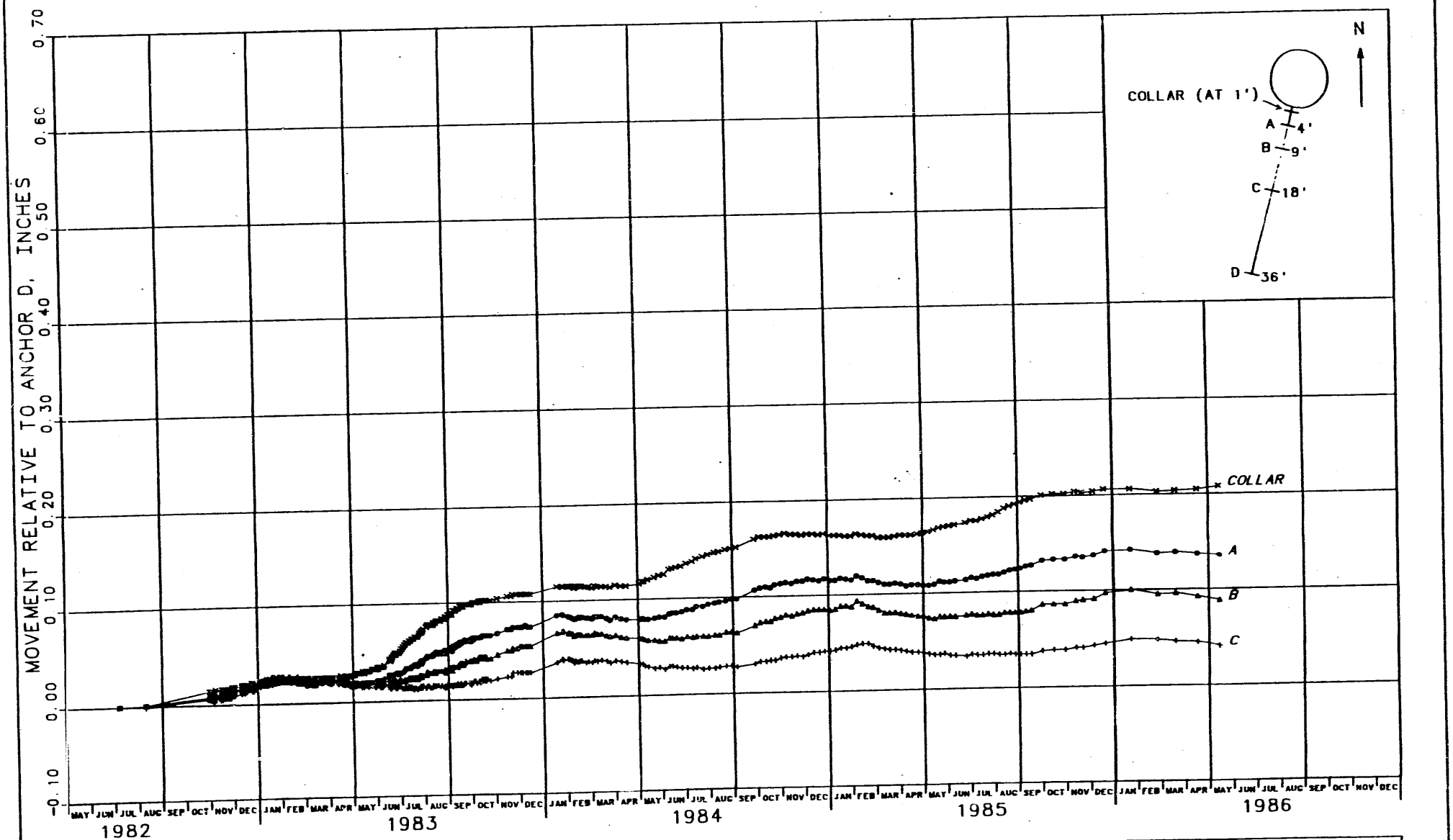
FIGURE J-119
MULTIPLE-POINT EXTENSOMETER 37X-GE-00204
C & SH SHAFT - EL 1844 - N 45 W
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. INSTRUMENT WAS INSTALLED 292 DAYS AFTER EXCAVATION STARTED ON SEP. 18, 1981.
2. ADJUSTMENT APPLIED TO ALL CURVES ON JAN 23, 1983.
3. SIZE OF EXCAVATION: 12 FT DIAM.

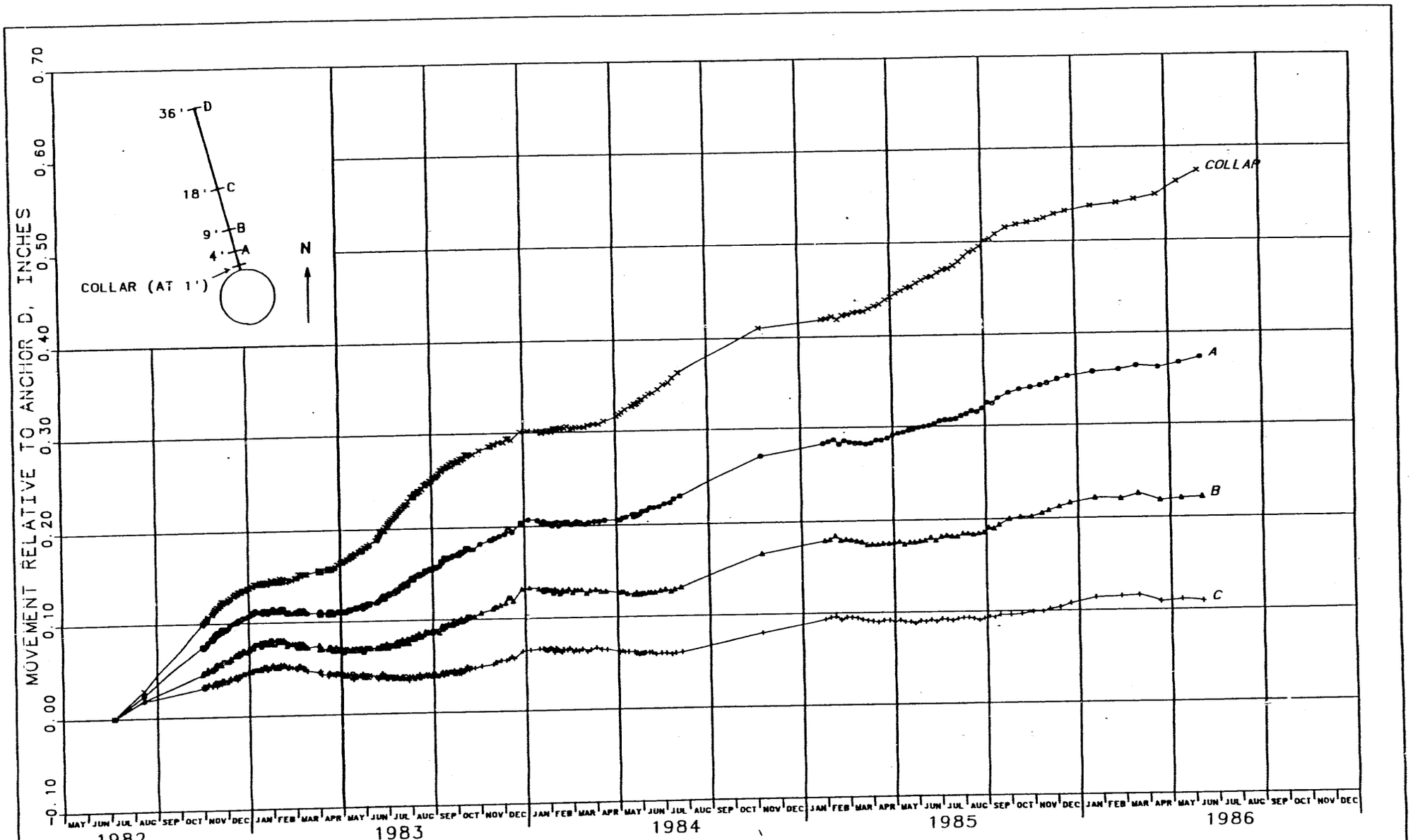
FIGURE J-120
MULTIPLE-POINT EXTENSOMETER 37X-GE-00205
C & SH SHAFT - EL 1844 - N 75 E
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. INSTRUMENT WAS INSTALLED 292 DAYS AFTER EXCAVATION STARTED ON SEP. 18, 1981.
2. SIZE OF EXCAVATION: 12 FT DIAM.

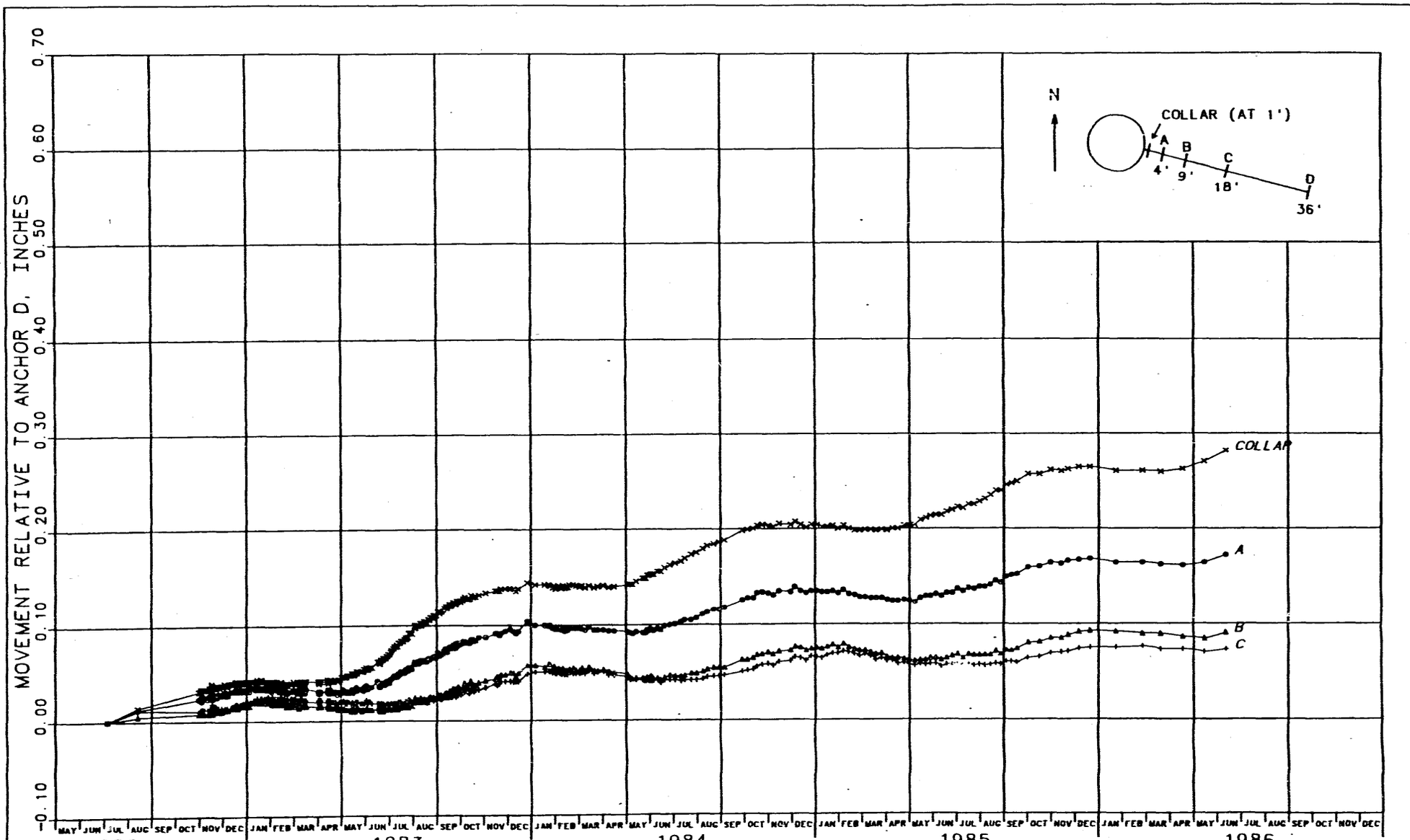
FIGURE J-121
MULTIPLE-POINT EXTENSOMETER 37X-GE-00206
C & SH SHAFT - EL 1844 - S 15 W
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. INSTRUMENT WAS INSTALLED 268 DAYS AFTER EXCAVATION STARTED ON OCT. 11, 1981.
2. ADJUSTMENT APPLIED TO ALL CURVES ON MAR 18, 1983.
3. SIZE OF EXCAVATION: 12 FT DIAM.

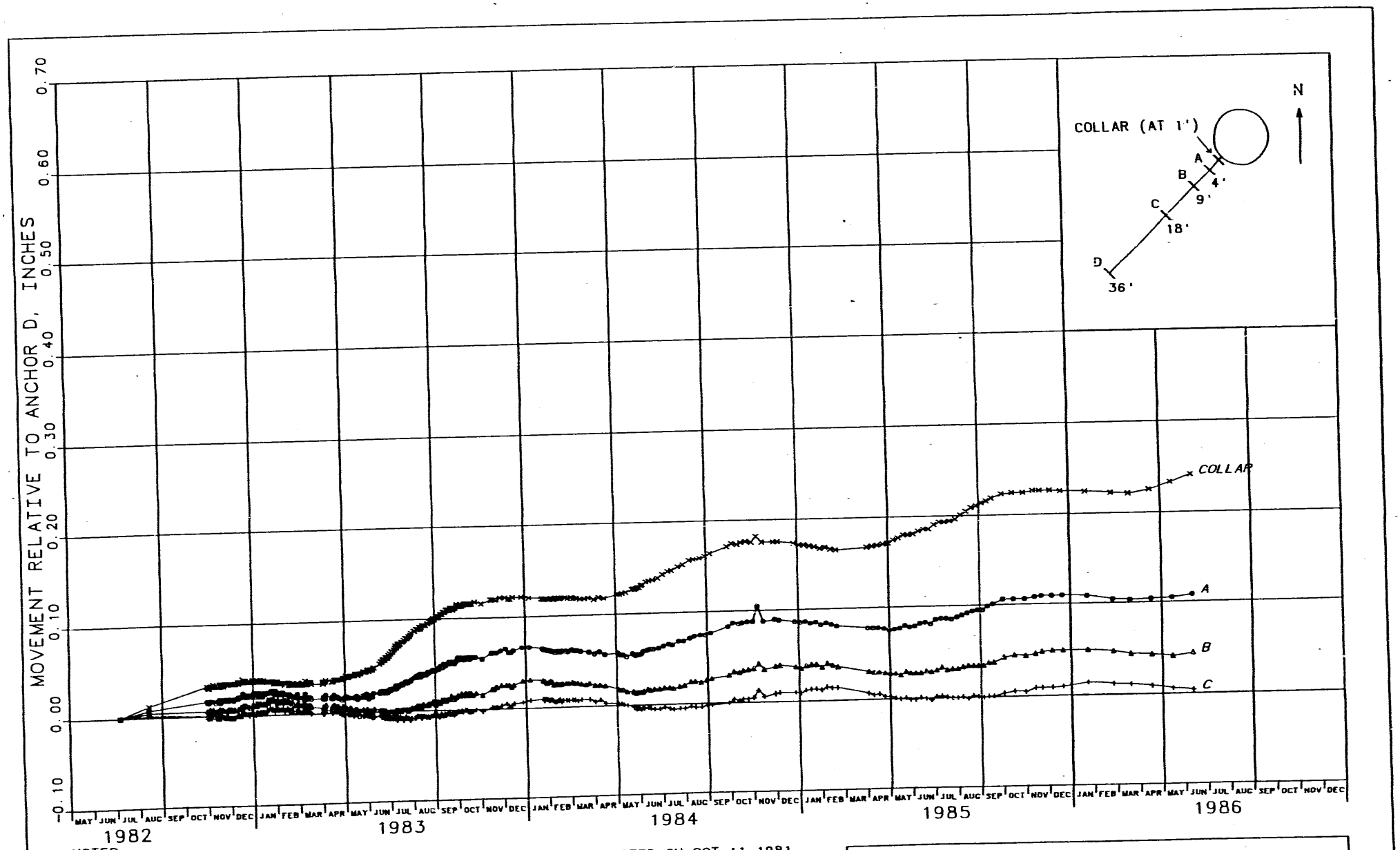
FIGURE J-122
MULTIPLE-POINT EXTENSOMETER 37X-GE-00207
C & SH SHAFT - EL 1351 - N 15 W
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. INSTRUMENT WAS INSTALLED 268 DAYS AFTER EXCAVATION STARTED ON OCT. 11, 1981.
2. ADJUSTMENT APPLIED TO ALL CURVES ON NOV 25, 1982.
3. SIZE OF EXCAVATION: 12 FT DIAM.

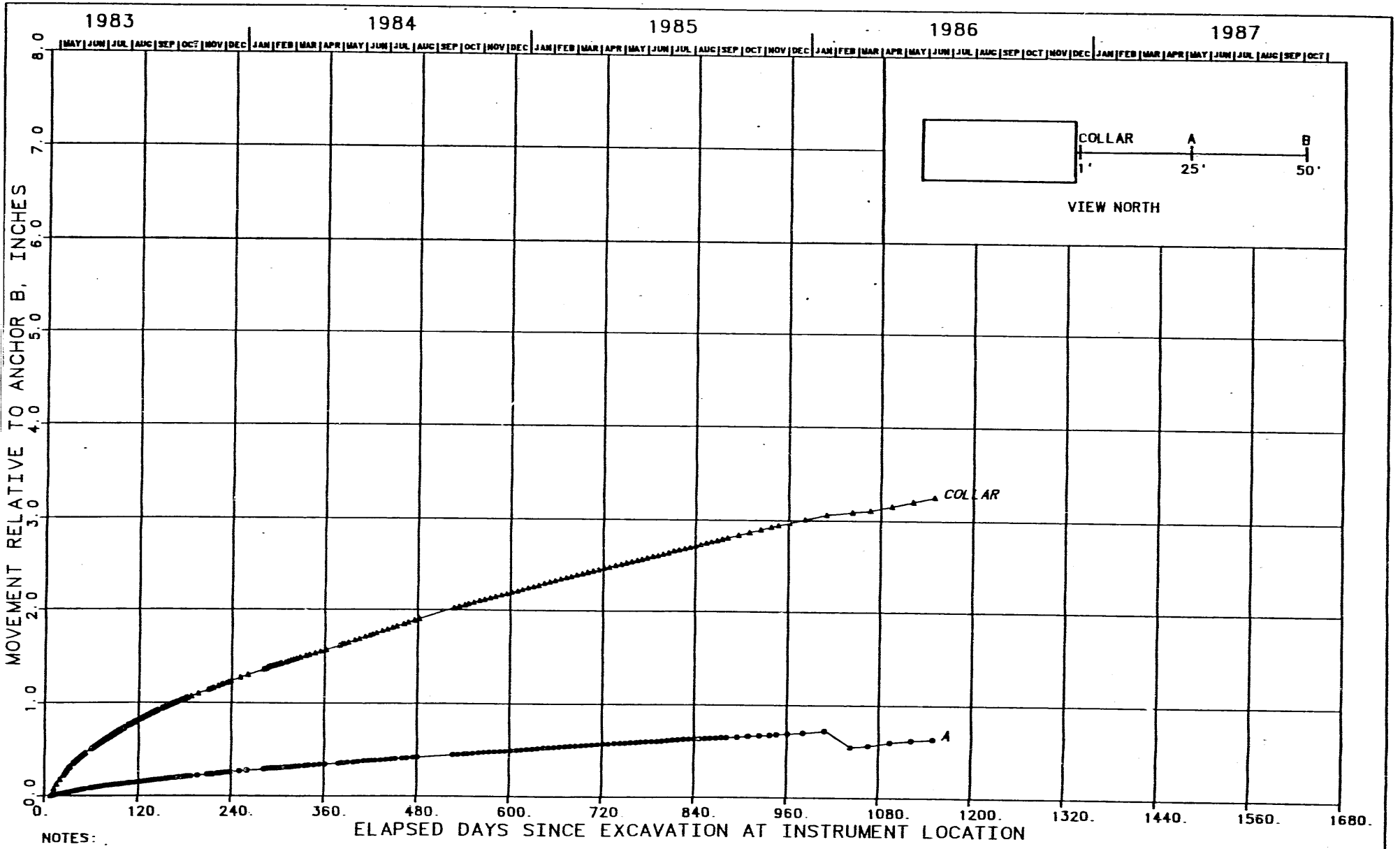
FIGURE J-123
MULTIPLE-POINT EXTENSOMETER 37X-GE-00208
C & SH SHAFT - EL 1351 - S 75 E
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. INSTRUMENT WAS INSTALLED 268 DAYS AFTER EXCAVATION STARTED ON OCT. 11, 1981.
2. ADJUSTMENT APPLIED TO ALL CURVES ON JAN 18, 1983.
3. SIZE OF EXCAVATION: 12 FT DIAM.

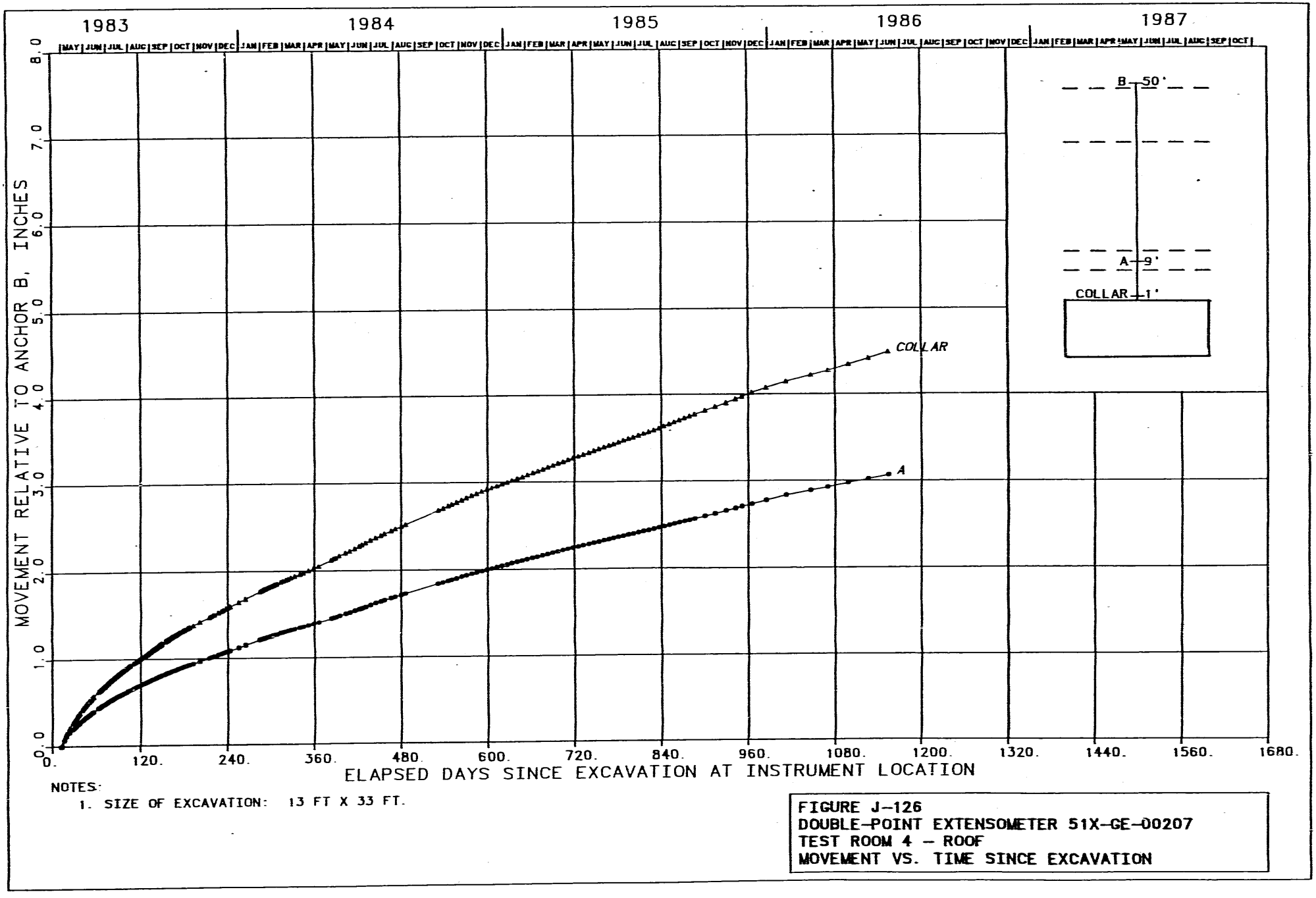
FIGURE J-124
MULTIPLE-POINT EXTENSOMETER 37X-GE-00209
C & SH SHAFT - EL 1351 - S 45 W
MOVEMENT VS. CALENDAR MONTH



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

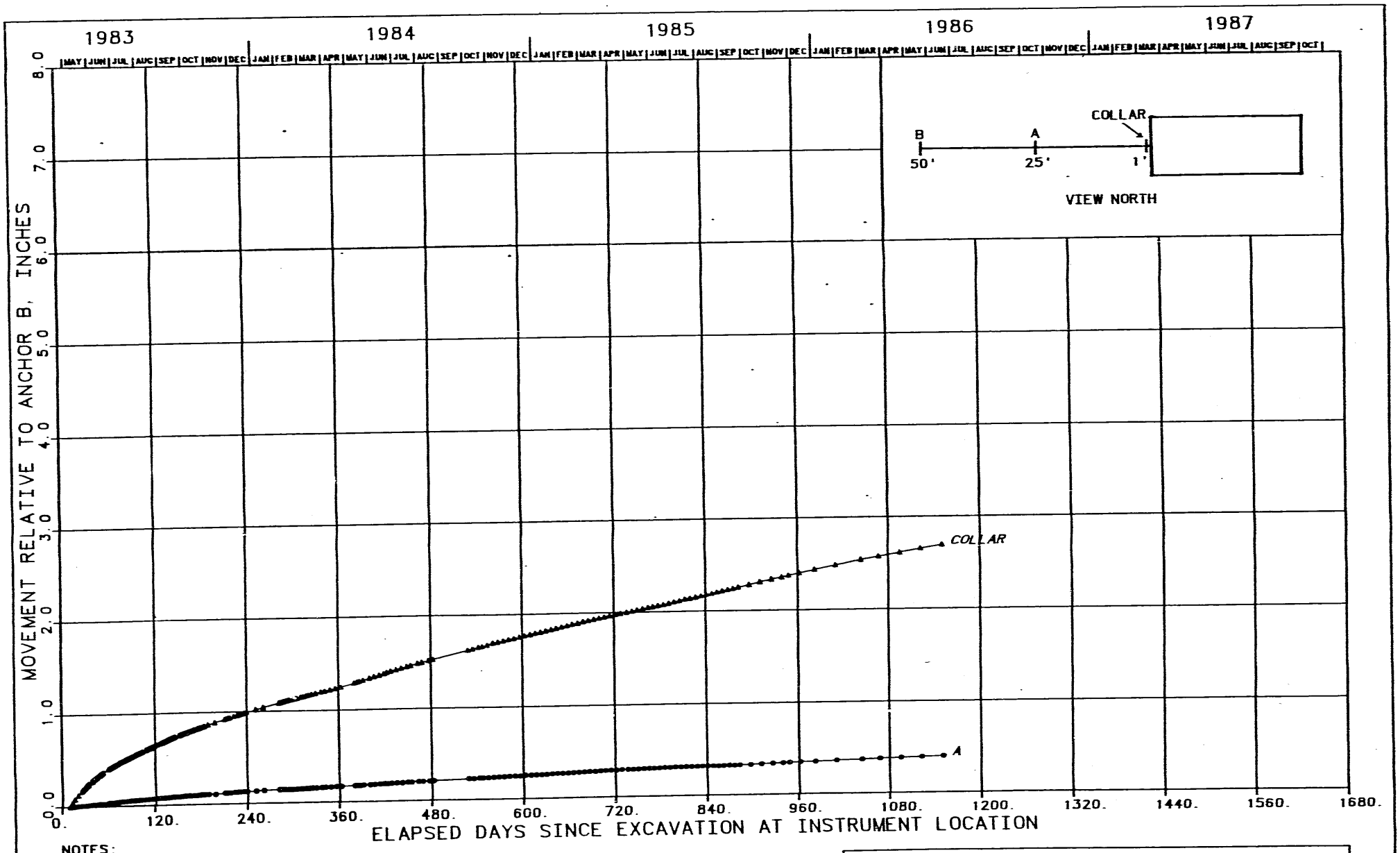
FIGURE J-125
DOUBLE-POINT EXTENSOMETER 51X-GE-00206
TEST ROOM 4 - E WALL
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

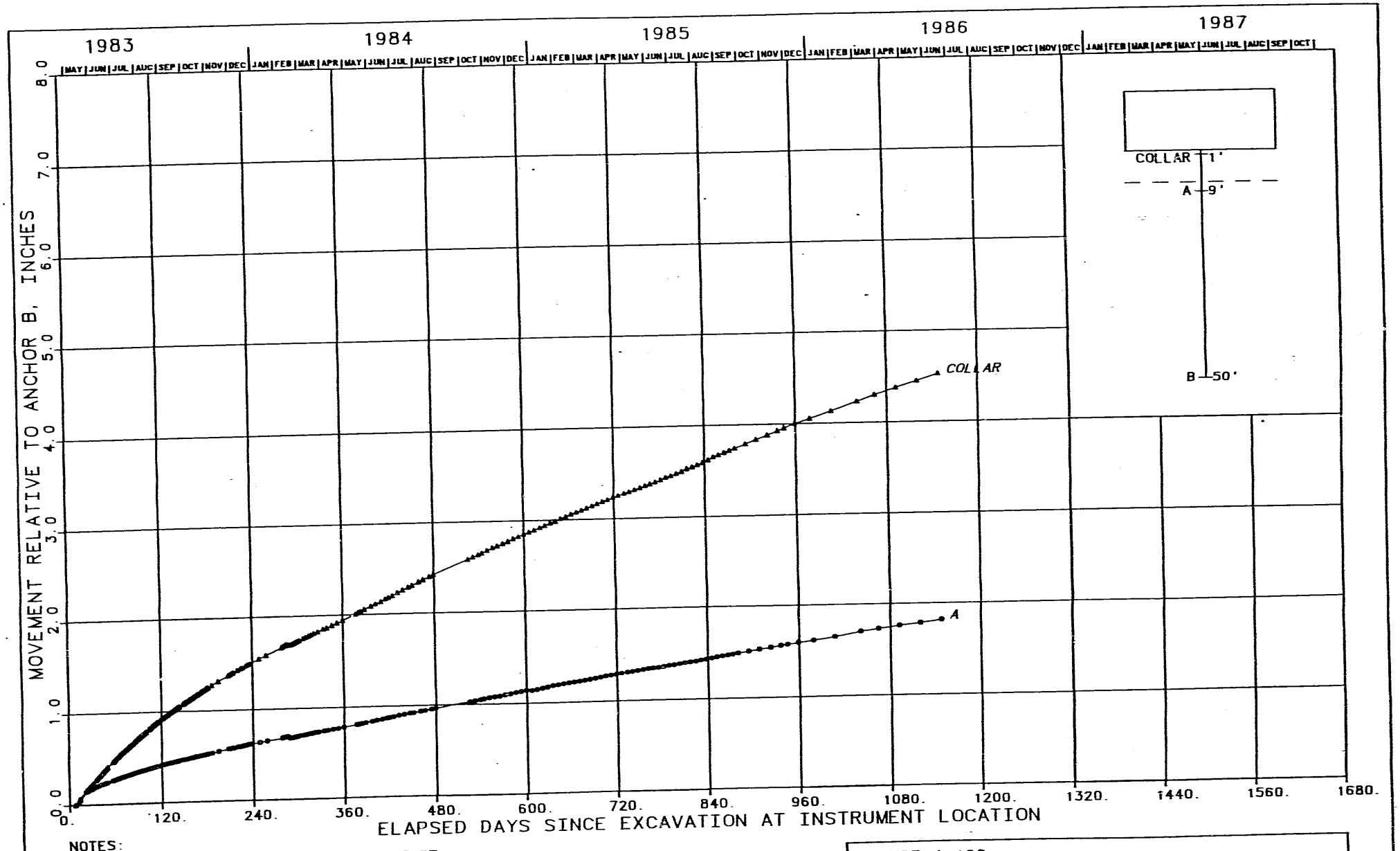
FIGURE J-126
DOUBLE-POINT EXTENSOMETER 51X-GE-00207
TEST ROOM 4 - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

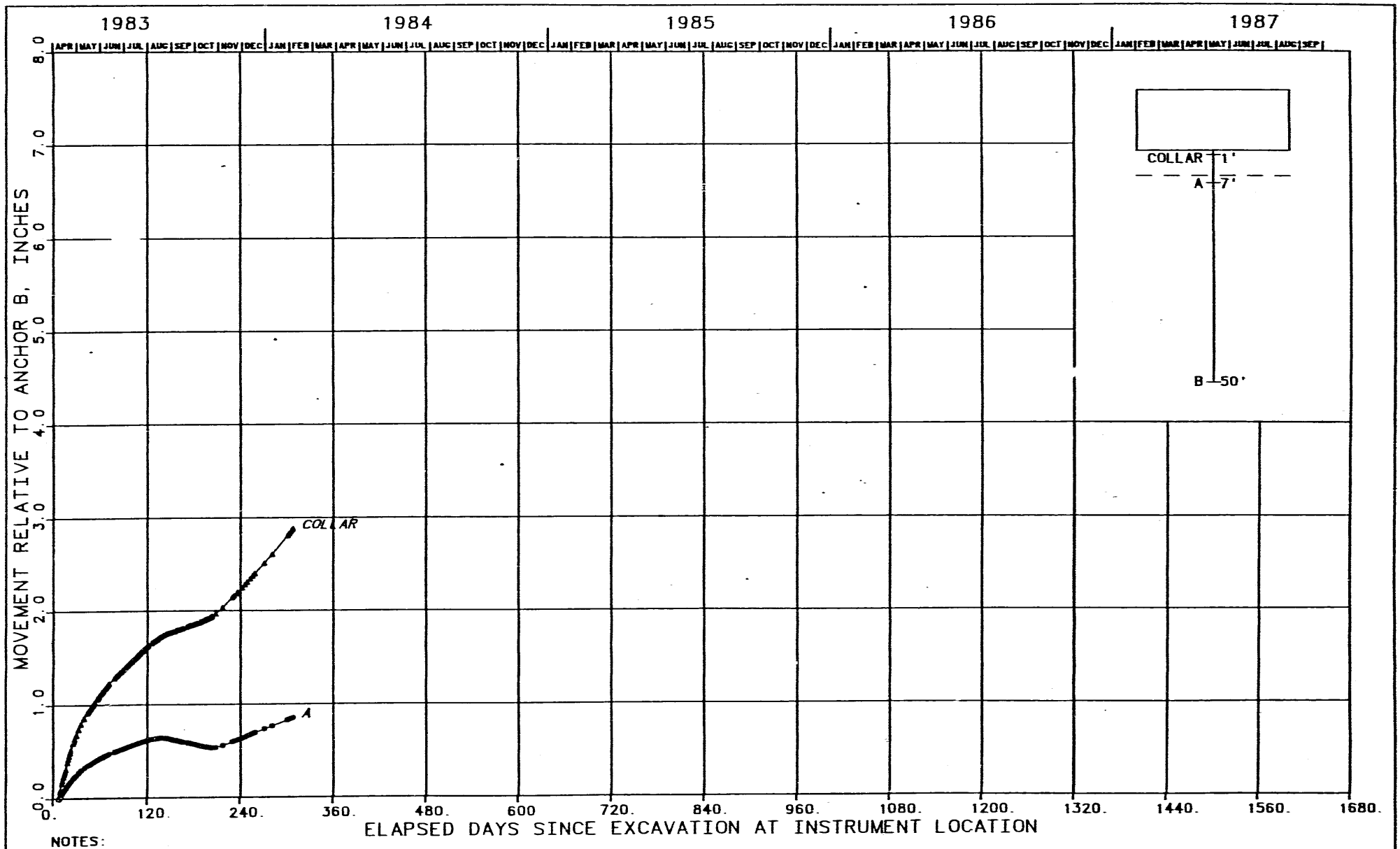
FIGURE J-127
DOUBLE-POINT EXTENSOMETER 51X-GE-00208
TEST ROOM 4 - W WALL
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

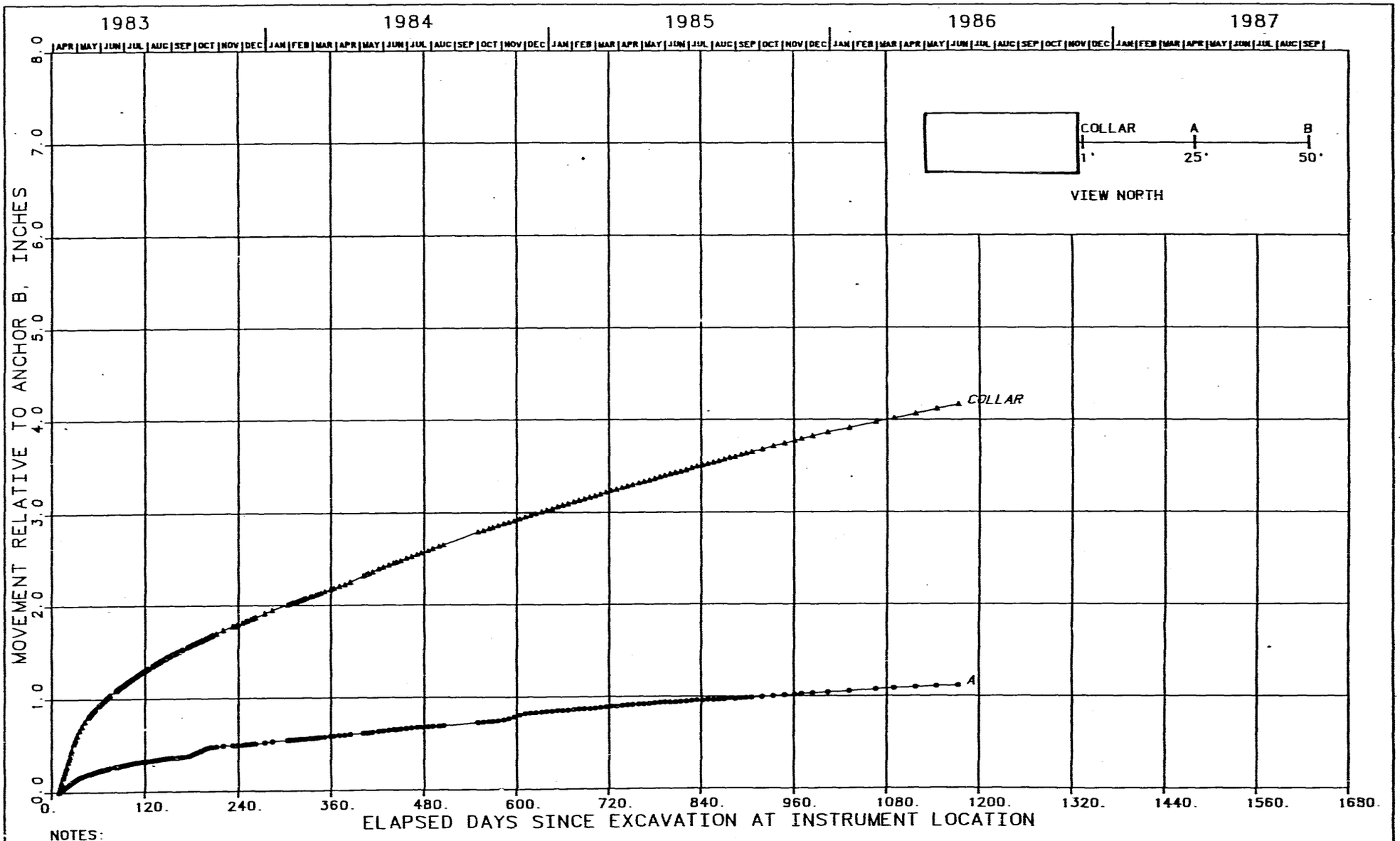
FIGURE J-128
DOUBLE-POINT EXTENSOMETER 51X-GE-00209
TEST ROOM 4 - FLOOR
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.
2. INSTRUMENT HAS PERMANENTLY FAILED.

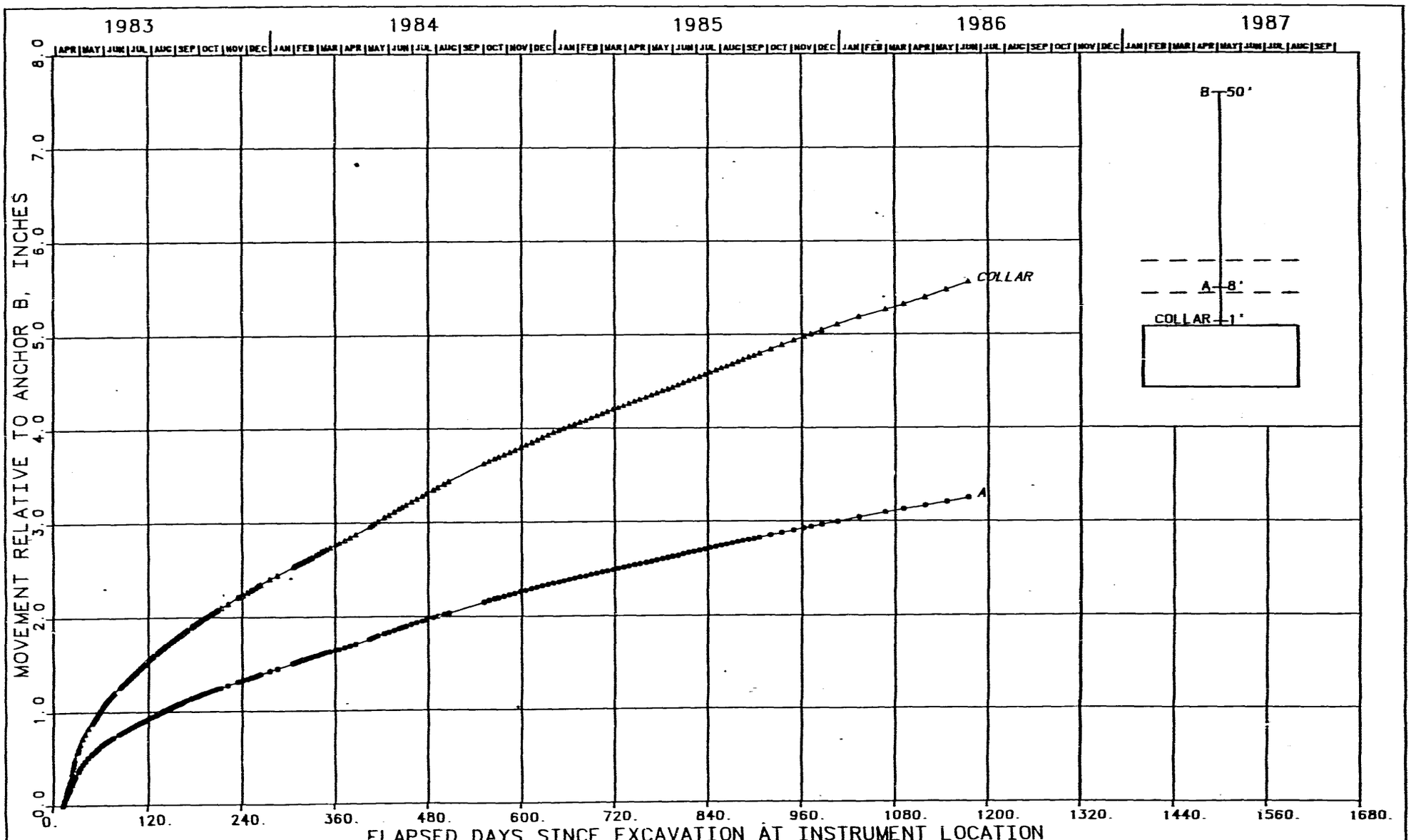
FIGURE J-129
DOUBLE-POINT EXTENSOMETER 51X-GE-00210
TEST ROOM 3 - FLOOR
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

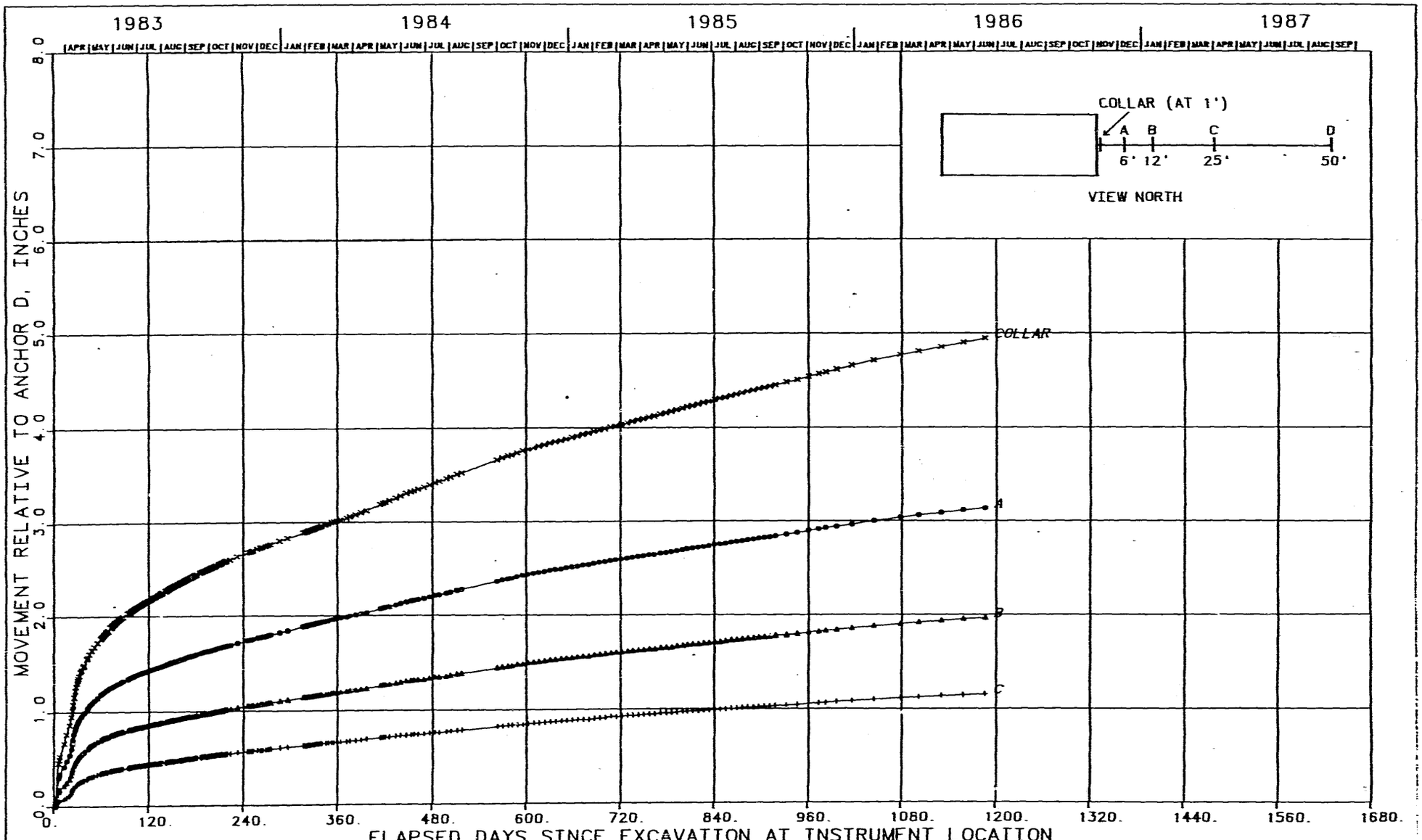
FIGURE J-130
DOUBLE-POINT EXTENSOMETER 51X-GE-00211
TEST ROOM 3 - E WALL
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

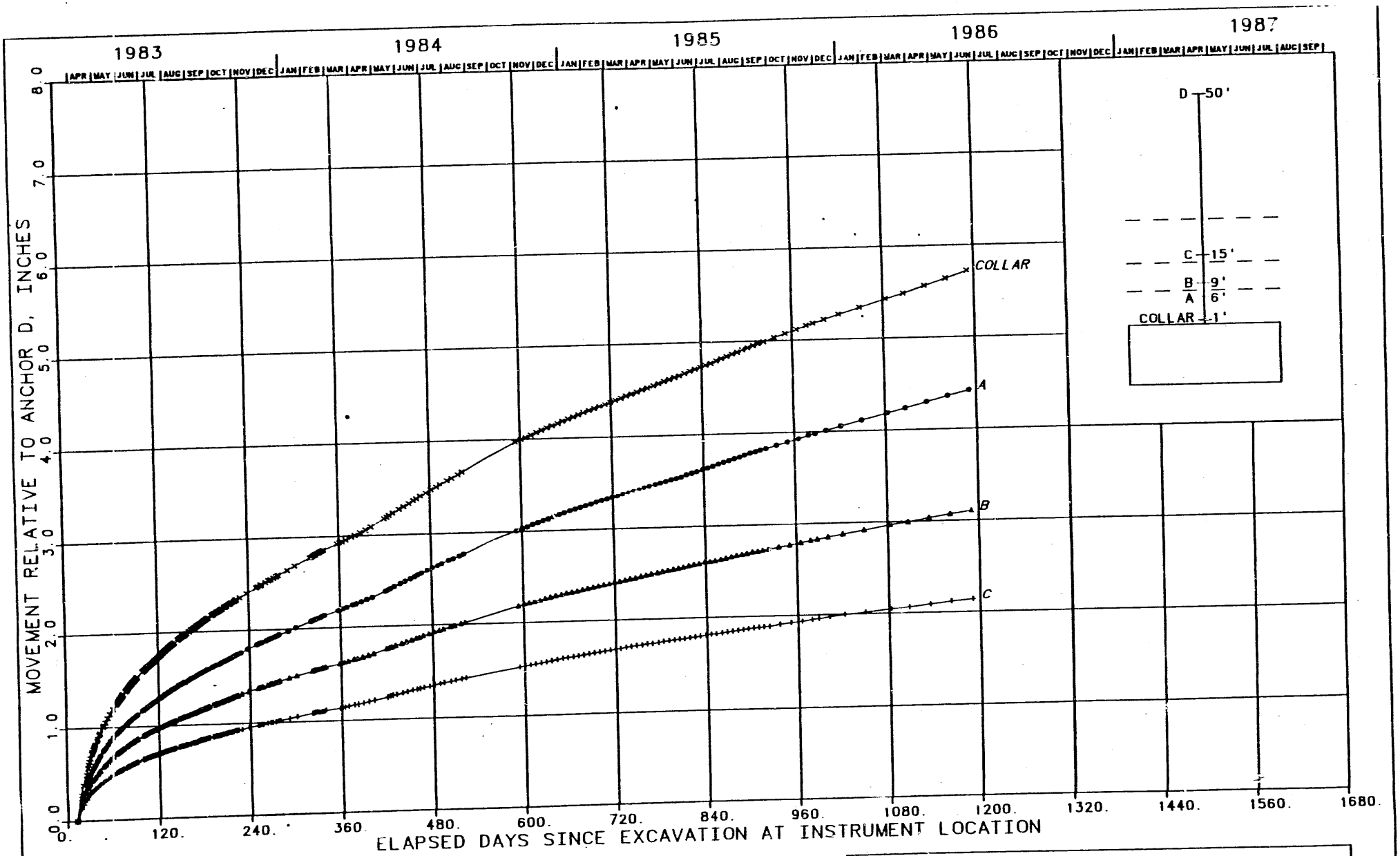
FIGURE J-131
DOUBLE-POINT EXTENSOMETER 51X-GE-00212
TEST ROOM 3 - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

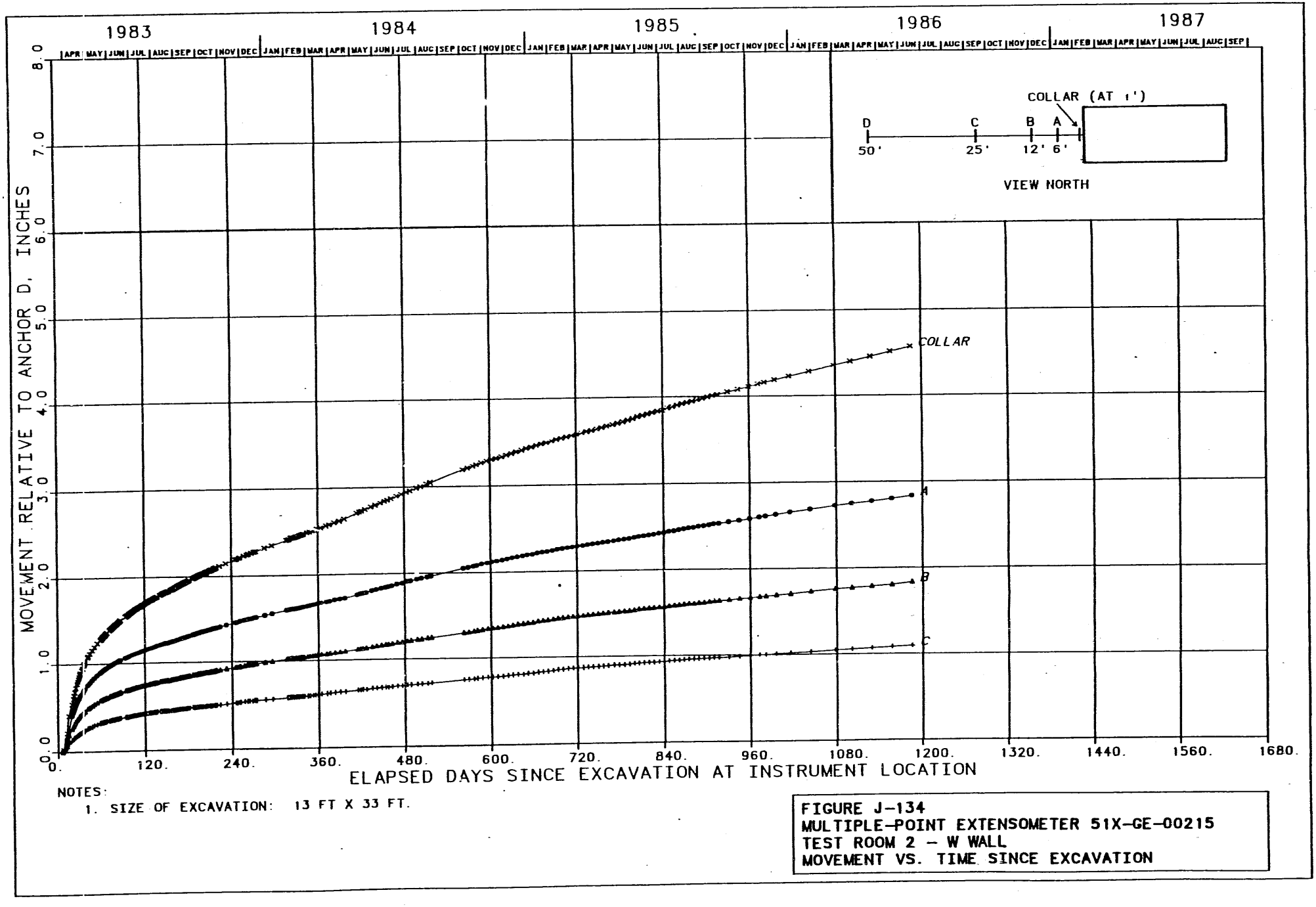
FIGURE J-132
MULTIPLE-POINT EXTENSOMETER 51X-GE-00213
TEST ROOM 2 - E WALL
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

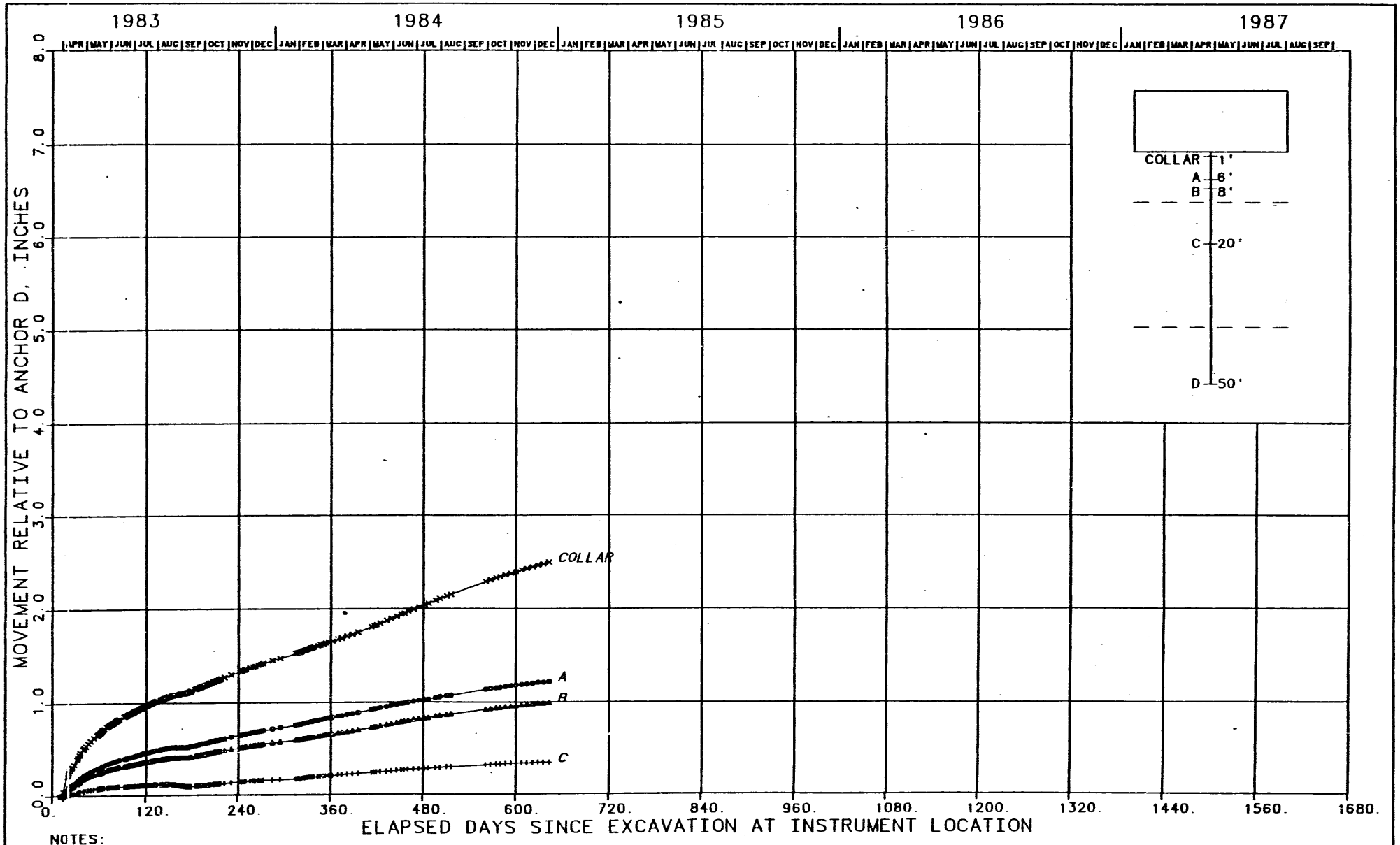
FIGURE J-133
MULTIPLE-POINT EXTENSOMETER 51X-GE-00214
TEST ROOM 2 - CENTER ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

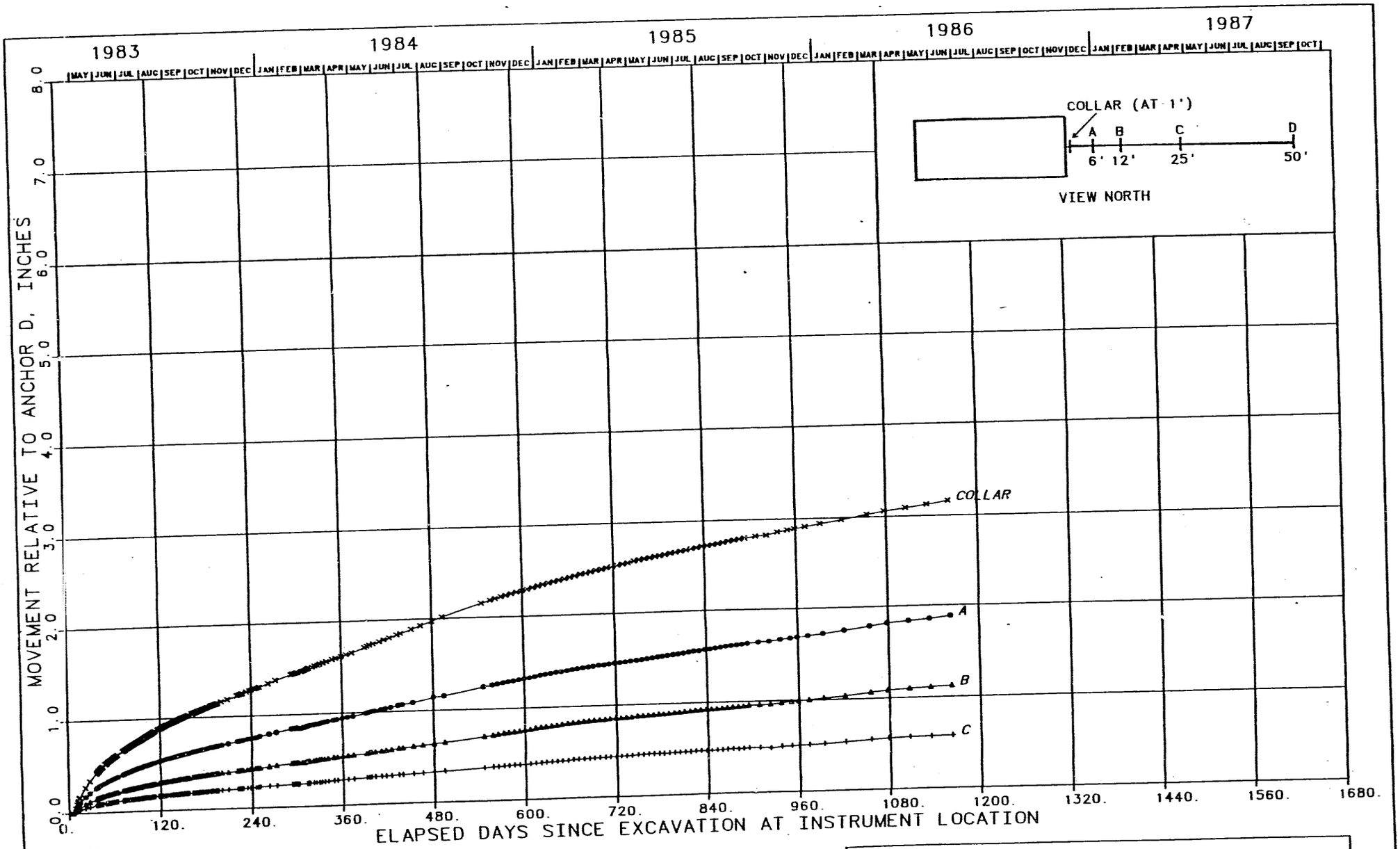
FIGURE J-134
MULTIPLE-POINT EXTENSOMETER 51X-GE-00215
TEST ROOM 2 - W WALL
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

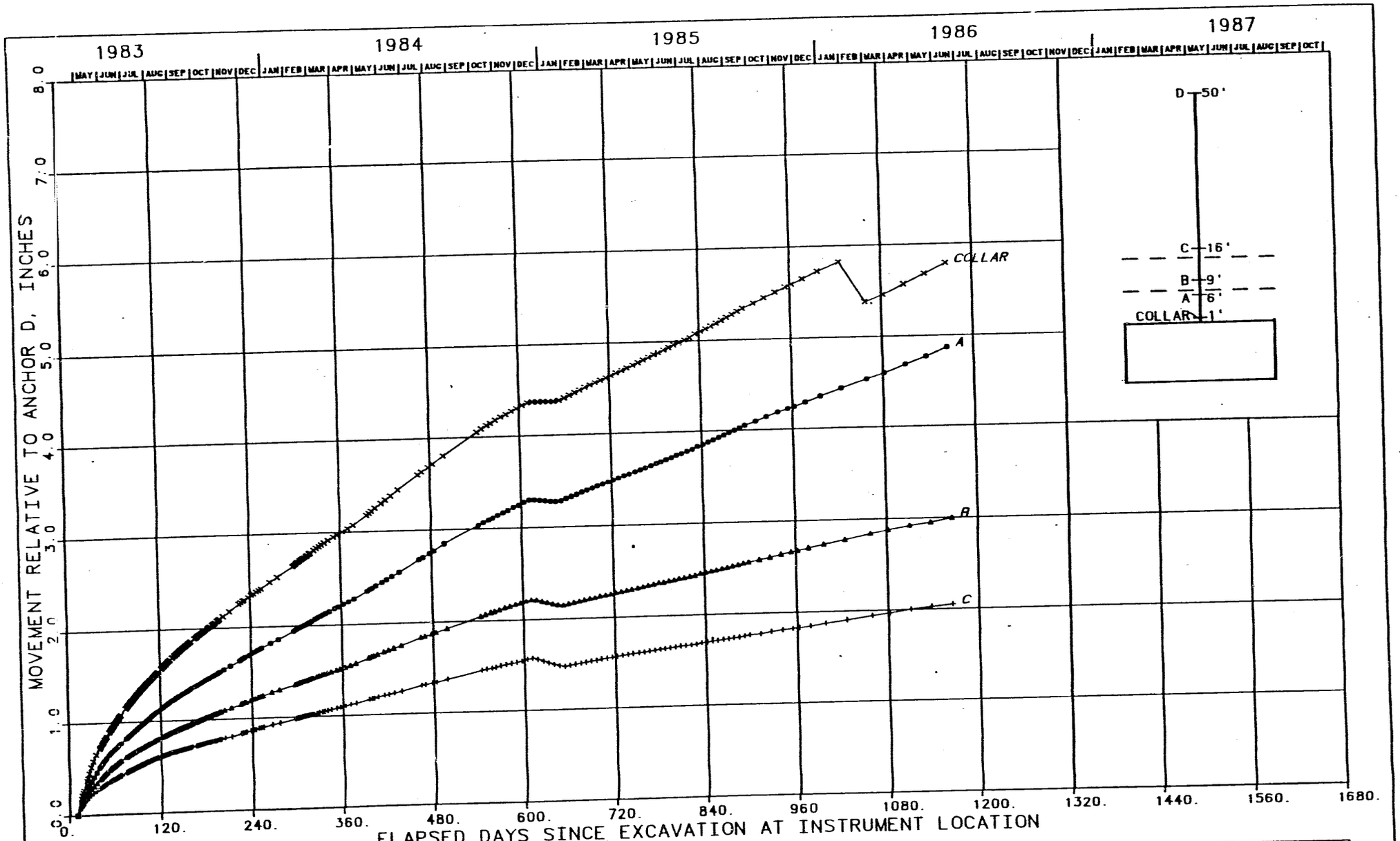
1. SIZE OF EXCAVATION: 13 FT X 33 FT.
2. INSTRUMENT HAS PERMANENTLY FAILED.

FIGURE J-135
MULTIPLE-POINT EXTENSOMETER 51X-GE-00216
TEST ROOM 2 - FLOOR
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:
1. SIZE OF EXCAVATION: 13 FT X 33 FT.

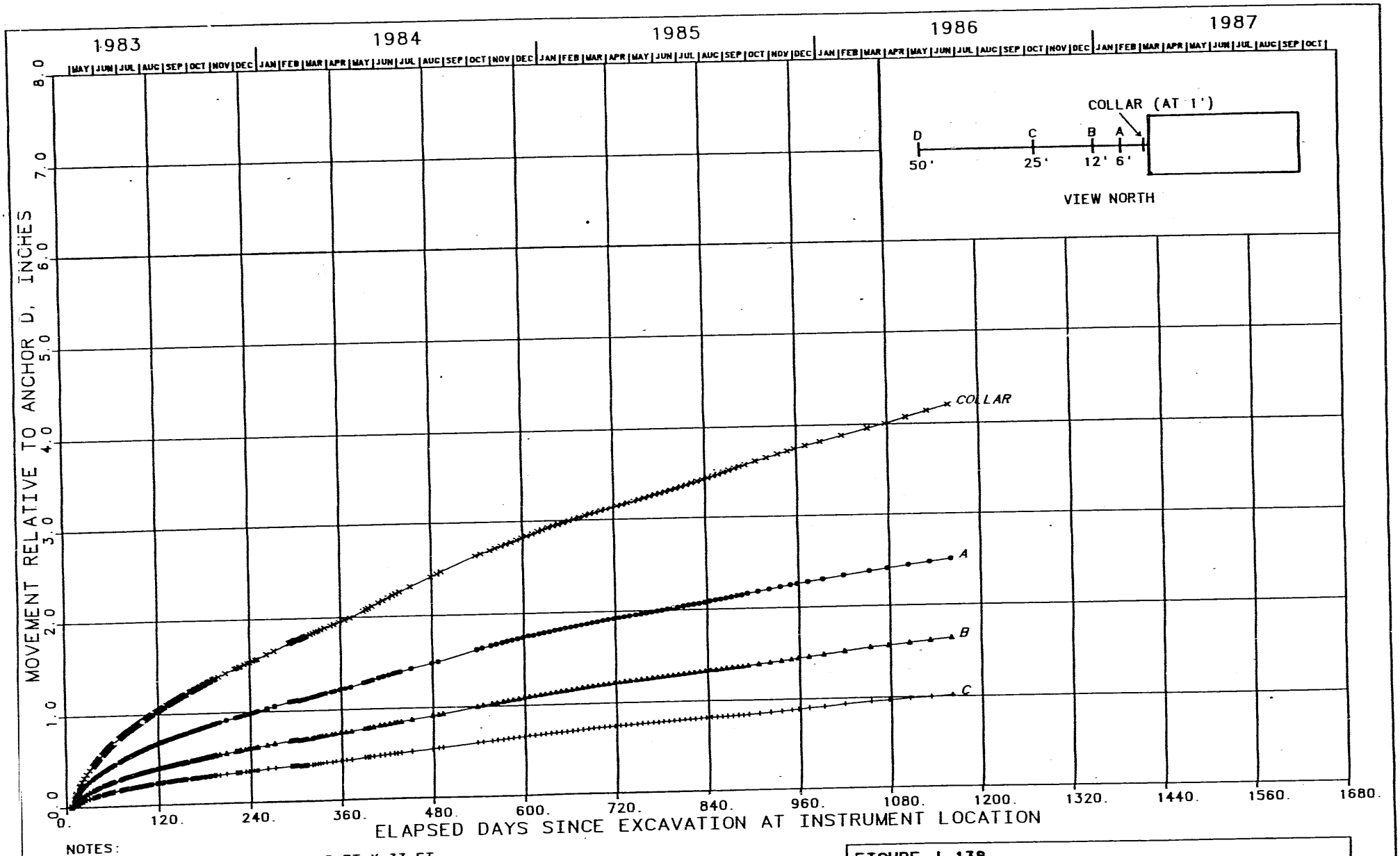
FIGURE J-136
MULTIPLE-POINT EXTENSOMETER 51X-GE-00217
TEST ROOM 1 - E WALL
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

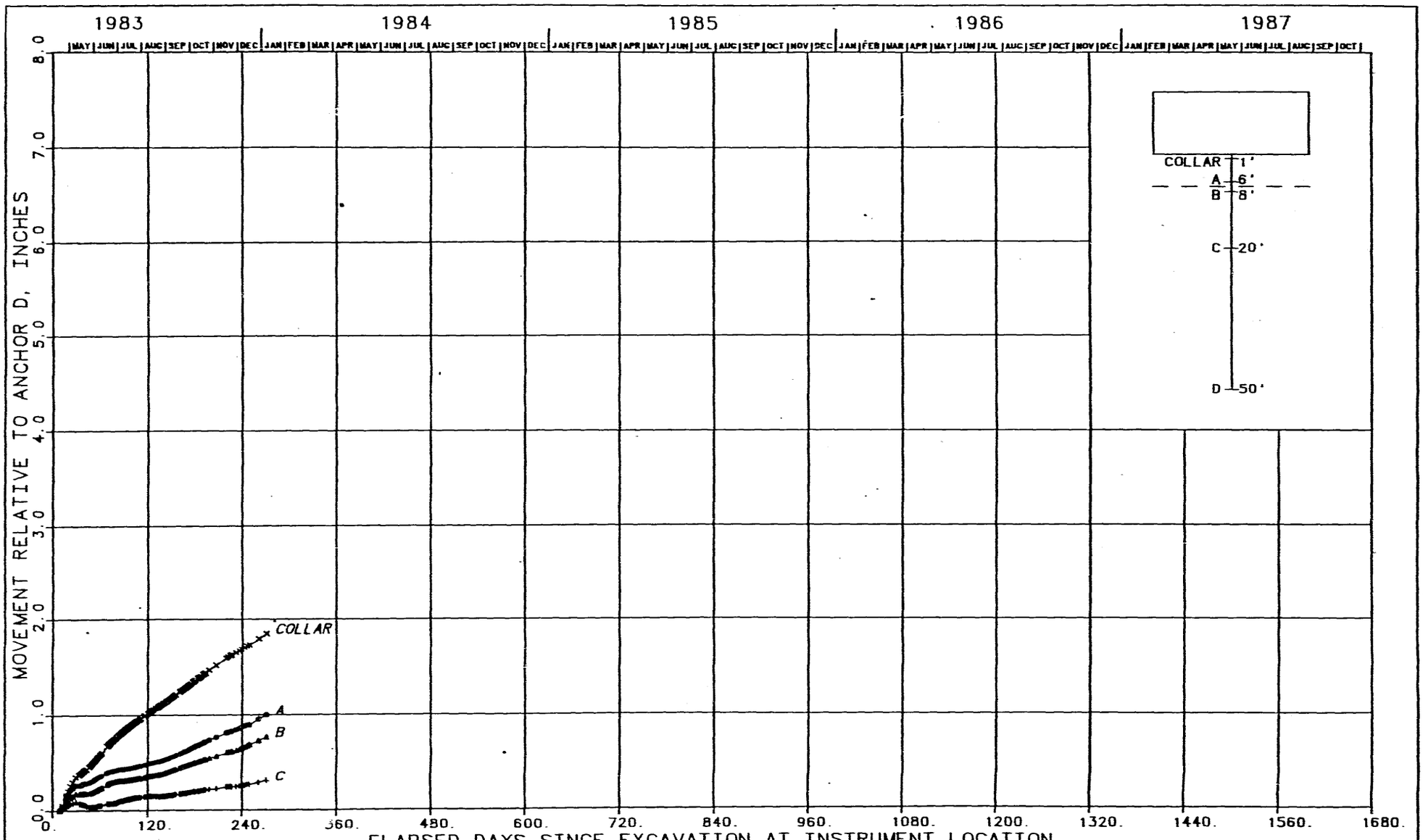
FIGURE J-137
MULTIPLE-POINT EXTENSOMETER 51X-GE-00218
TEST ROOM 1 – CENTER ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

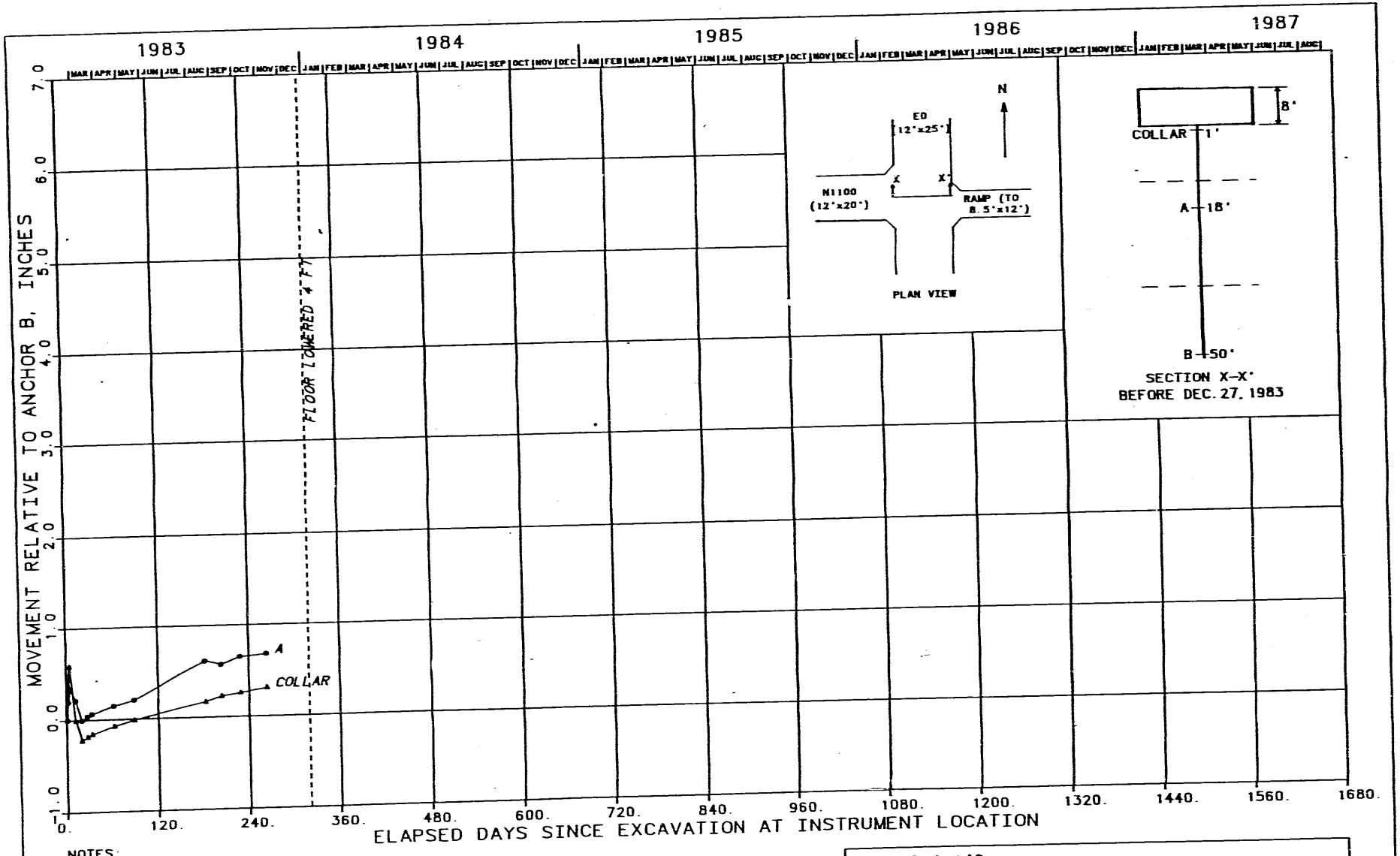
FIGURE J-138
MULTIPLE-POINT EXTENSOMETER 51X-GE-00219
TEST ROOM 1 - W WALL
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.
2. INSTRUMENT HAS PERMANENTLY FAILED.

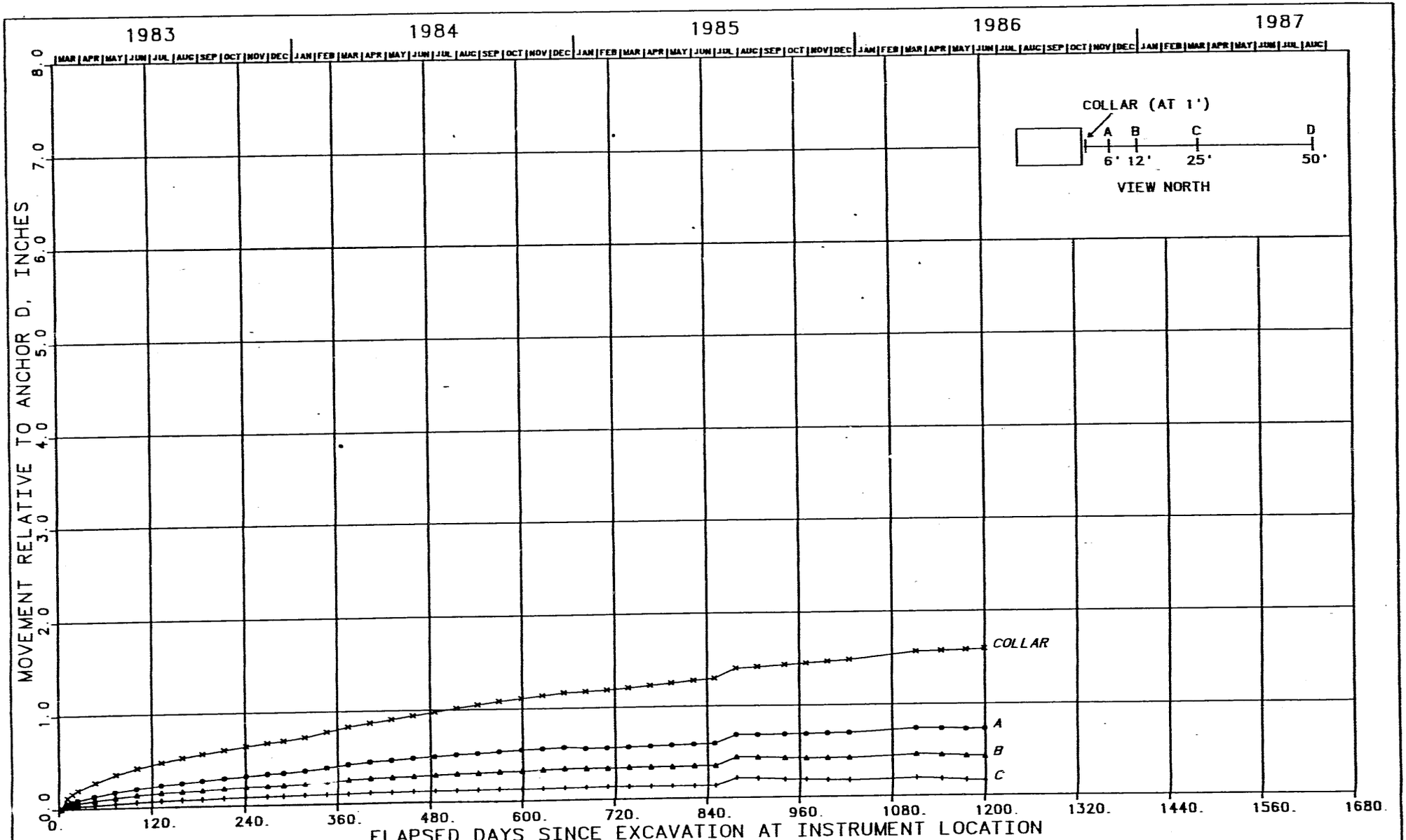
FIGURE J-139
MULTIPLE-POINT EXTENSOMETER 51X-GE-00220
TEST ROOM 1 - FLOOR
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. INSTRUMENT HAS BEEN DESTROYED.

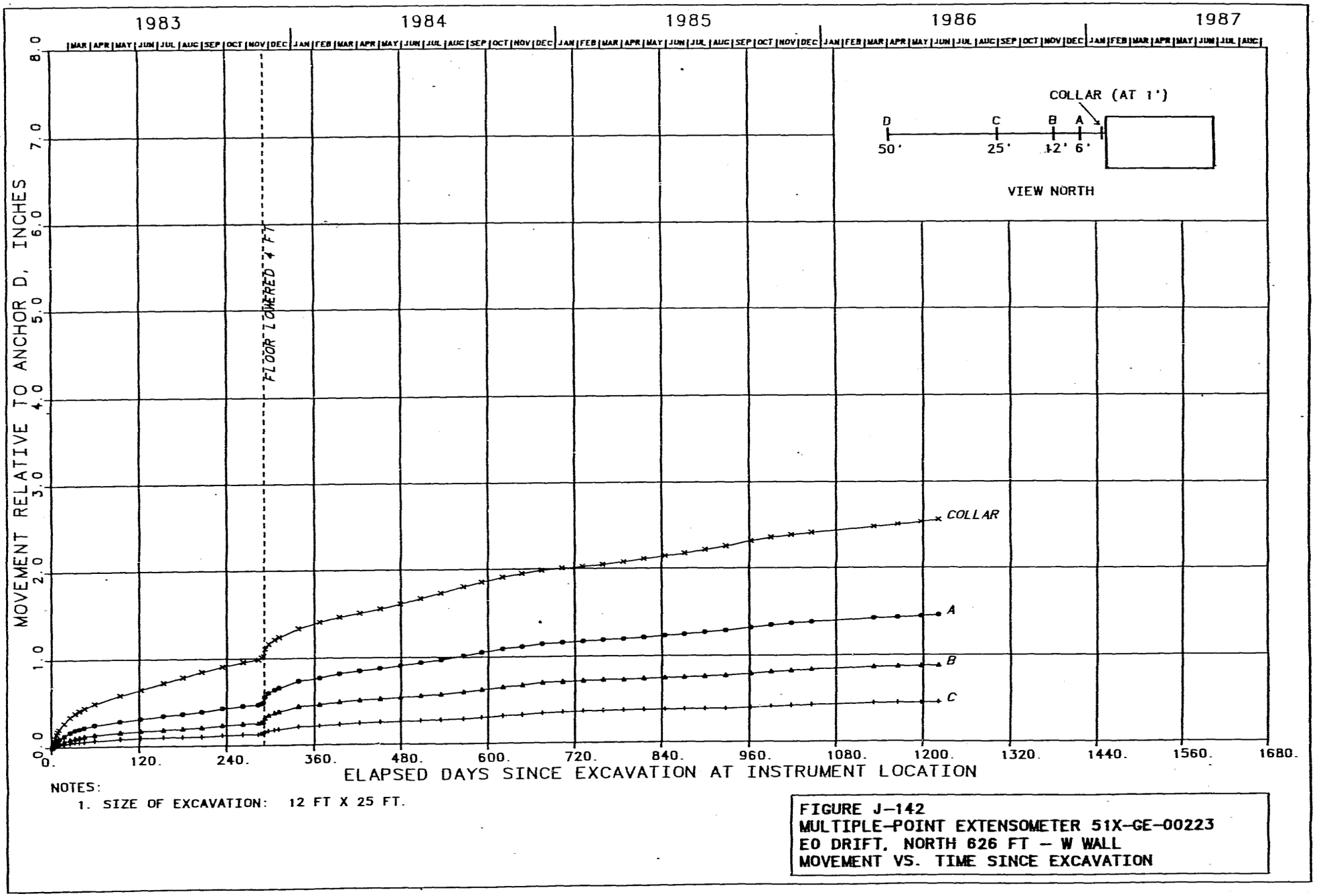
FIGURE J-140
DOUBLE-POINT EXTENSOMETER 51X-GE-00221
EO DRIFT - N1100 DRIFT INTERSECTION - FLOOR
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 8 FT X 14 FT.

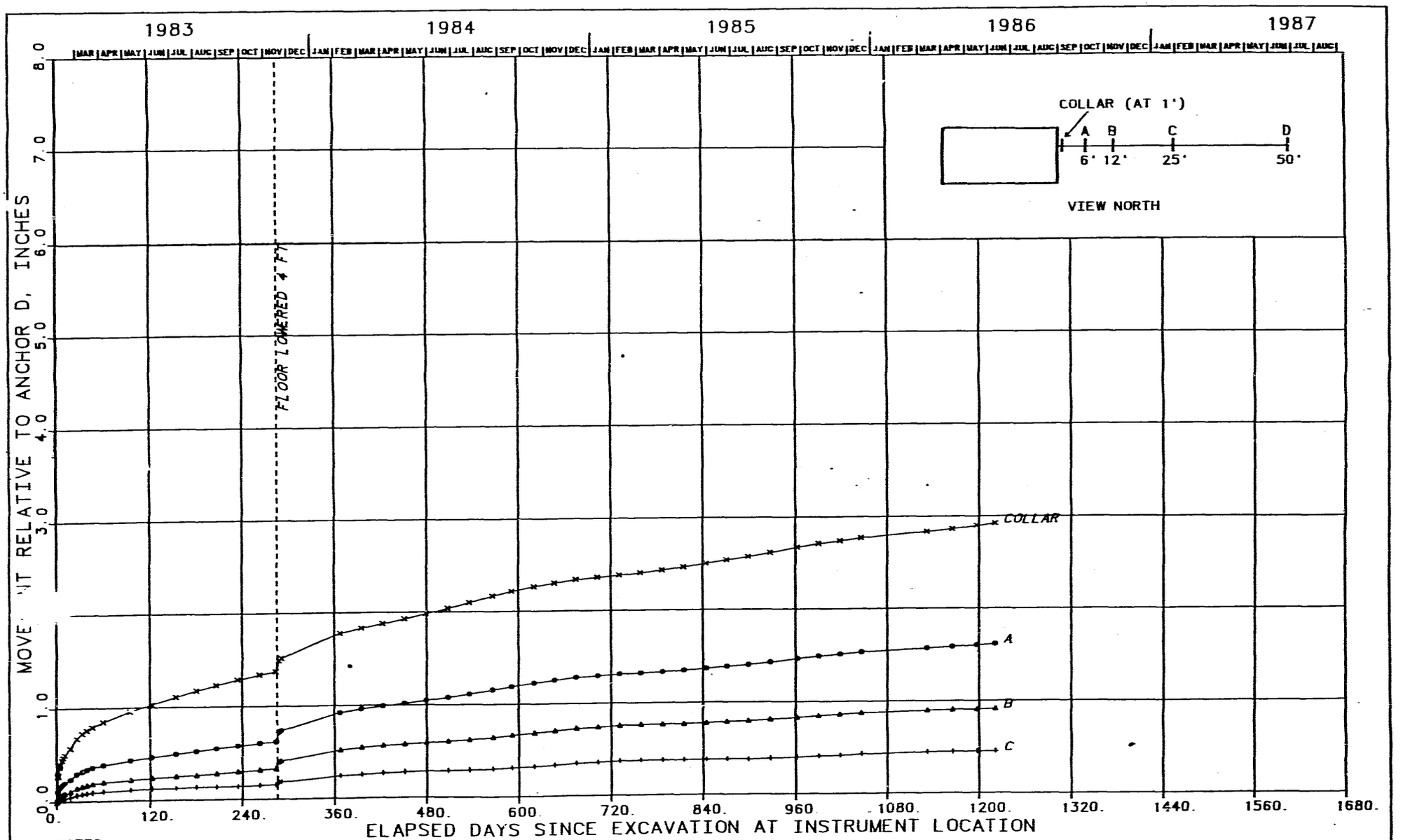
FIGURE J-141
MULTIPLE-POINT EXTENSOMETER 51X-GE-00222
E140 DRIFT, NORTH 1266 FT - E WALL
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 25 FT.

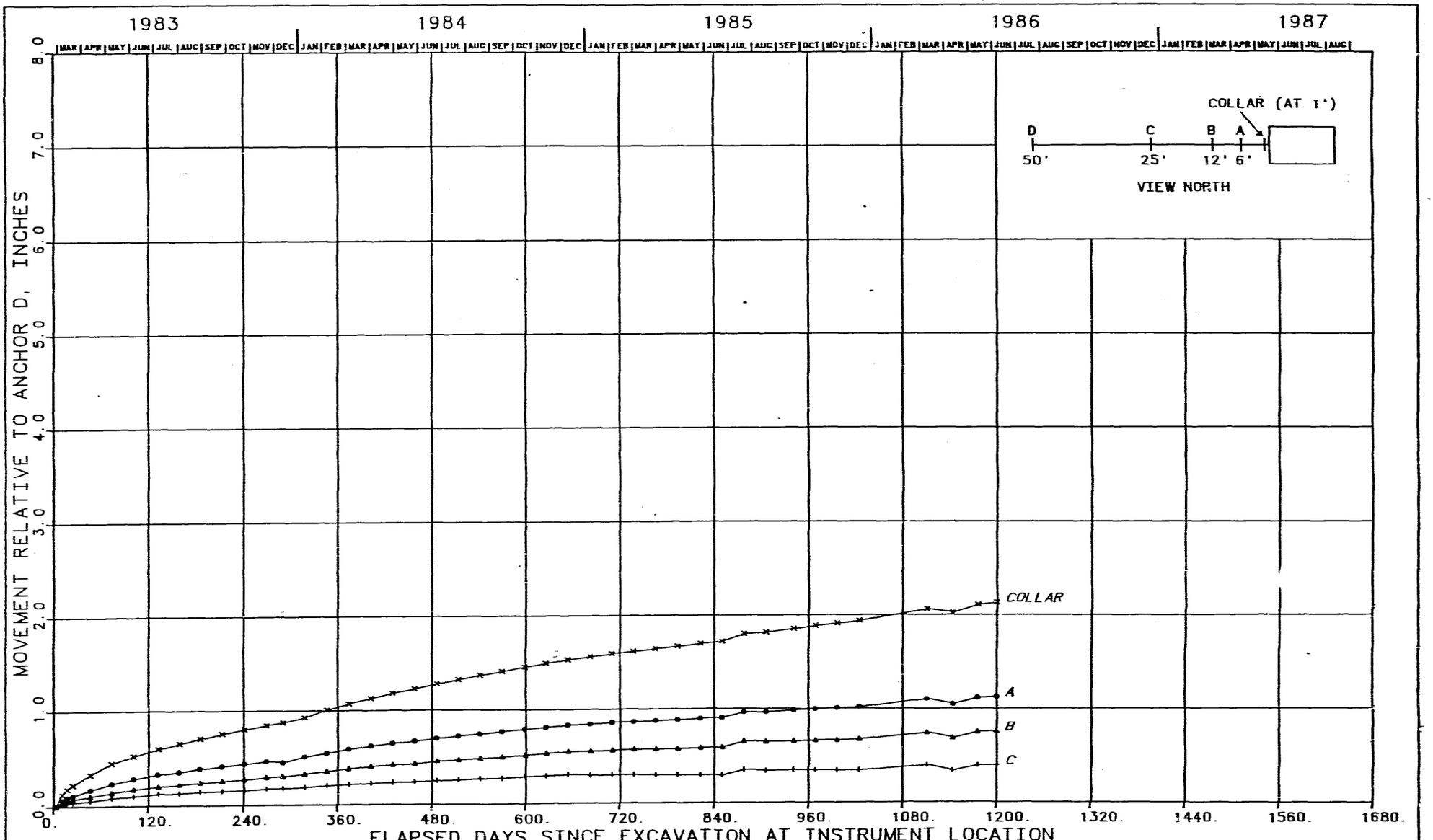
FIGURE J-142
MULTIPLE-POINT EXTENSOMETER 51X-GE-00223
EO DRIFT, NORTH 626 FT - W WALL
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 25 FT.

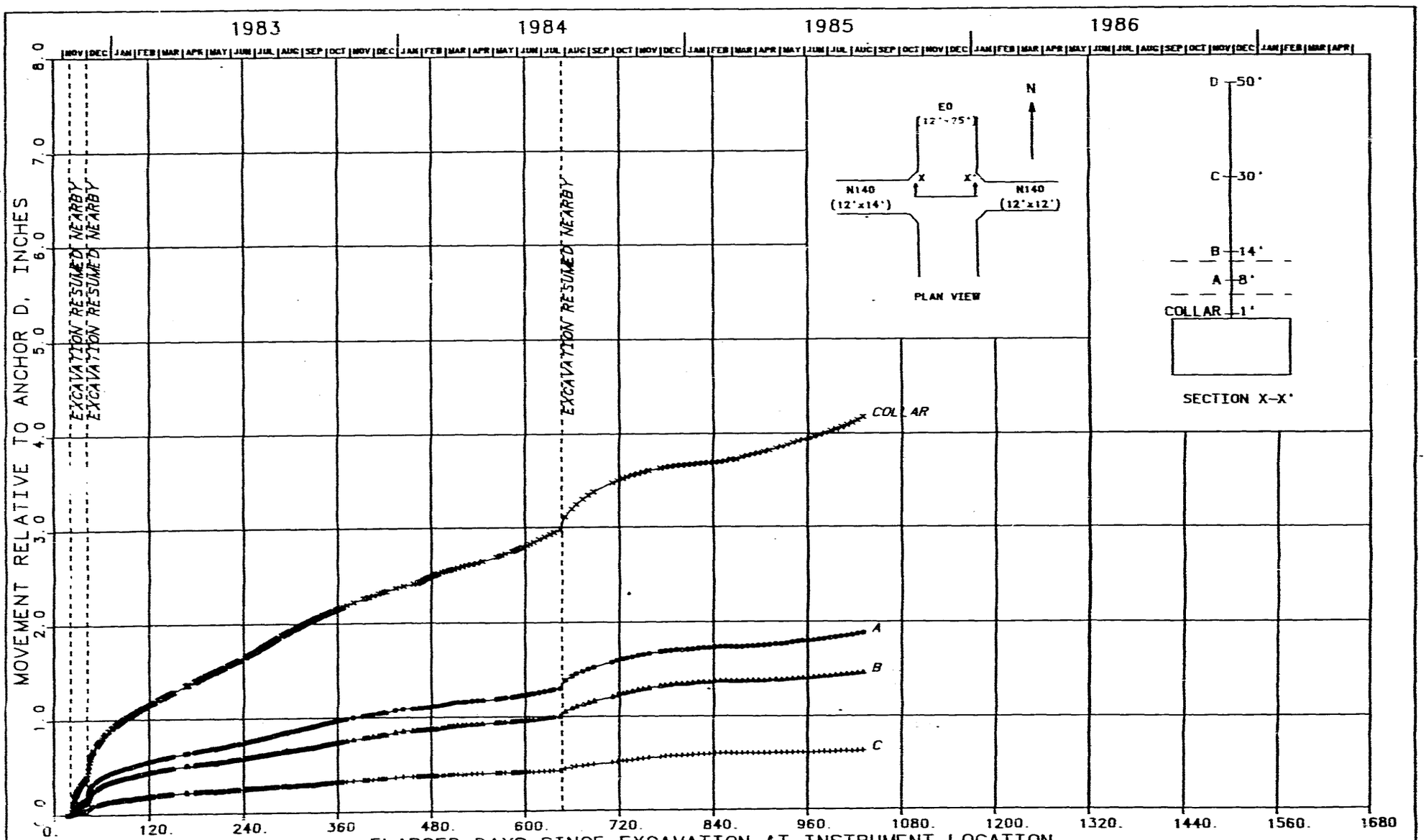
FIGURE J-143
MULTIPLE-POINT EXTENSOMETER 51X-GE-00224
EO DRIFT, NORTH 626 FT – E WALL
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 8 FT X 14 FT.

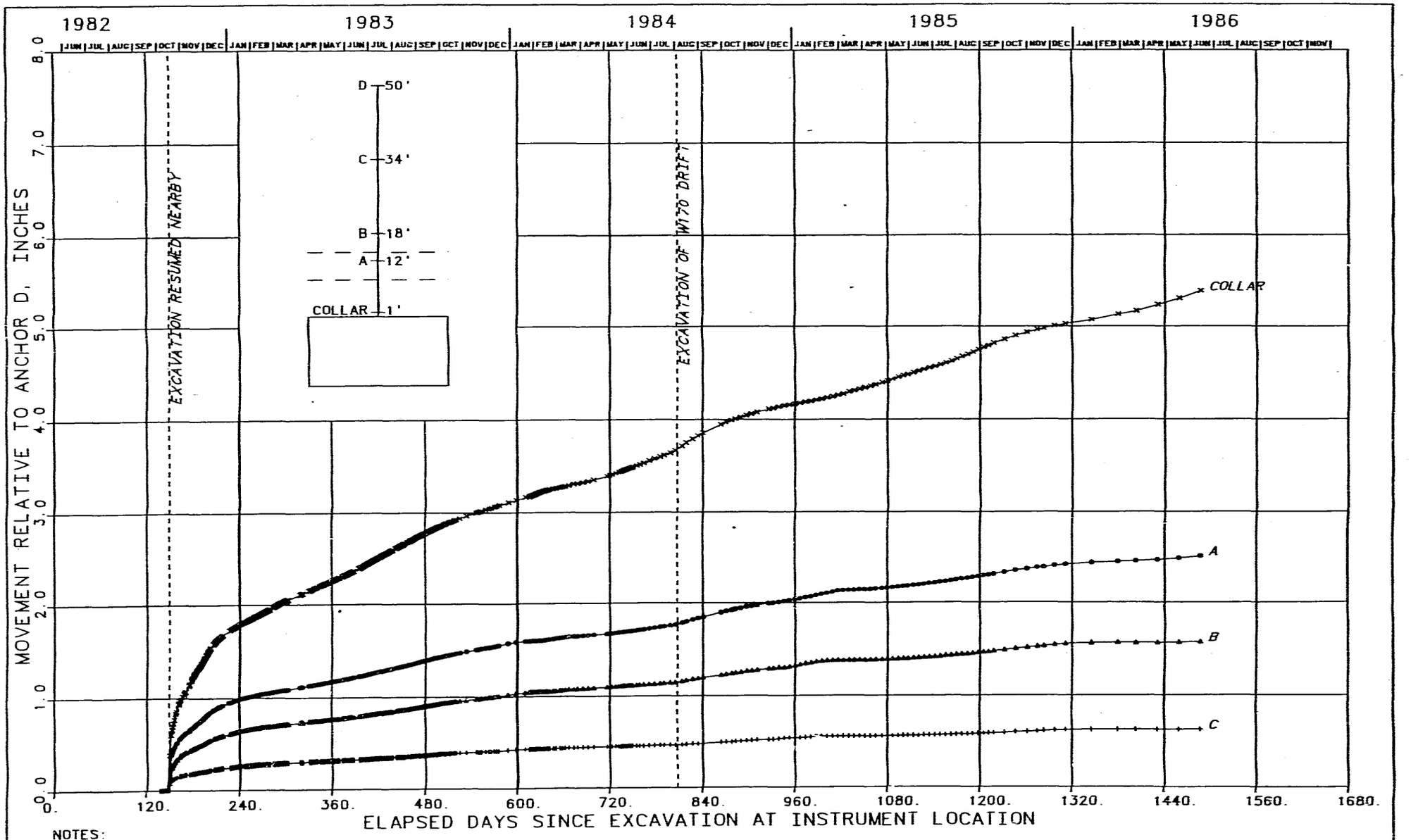
FIGURE J-144
MULTIPLE-POINT EXTENSOMETER 51X-GE-00225
E140 DRIFT, NORTH 1266 FT - W WALL
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. INSTRUMENT HAS BEEN DESTROYED.

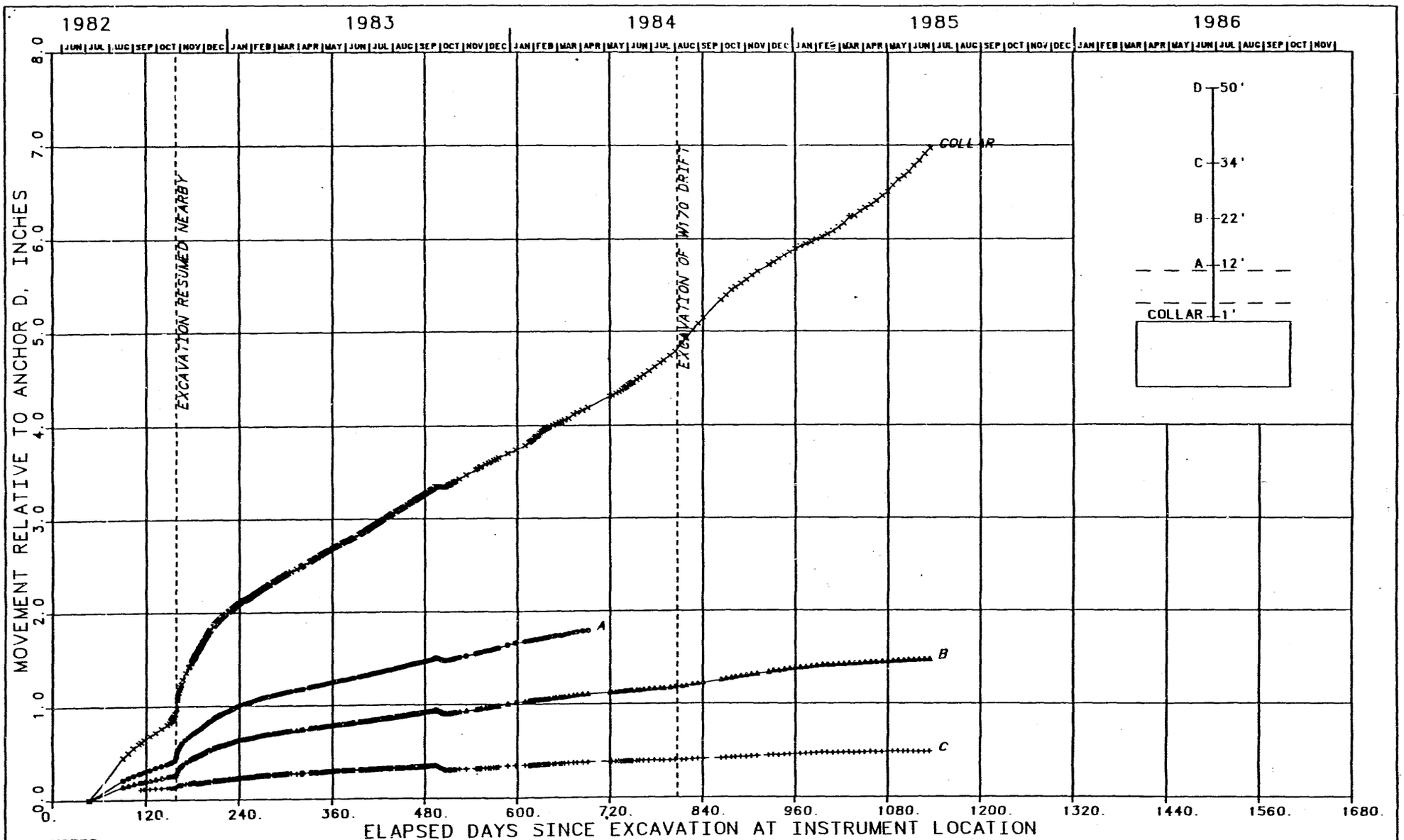
FIGURE J-145
MULTIPLE-POINT EXTENSOMETER 51X-GE-00226
EO DRIFT - N140 CROSSCUT INTERSECTION - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 15 FT X 30 FT.

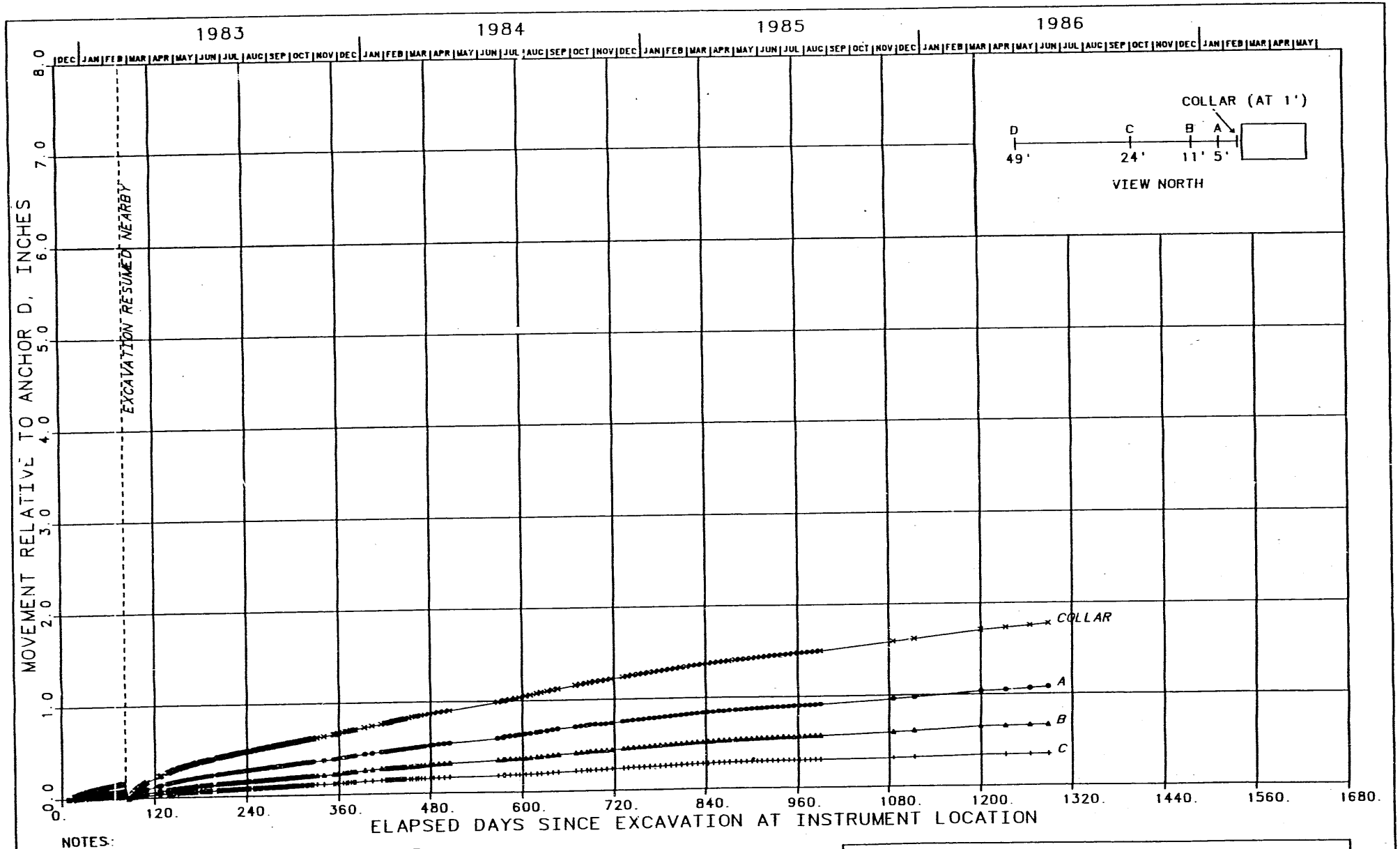
FIGURE J-146
MULTIPLE-POINT EXTENSOMETER 51X-GE-00227
35 FT NORTH OF C & SH SHAFT - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION: 14 FT X 33 FT.
2. INSTRUMENT HAS BEEN DESTROYED.
3. DASHED LINE INDICATES ADJUSTED DATA.

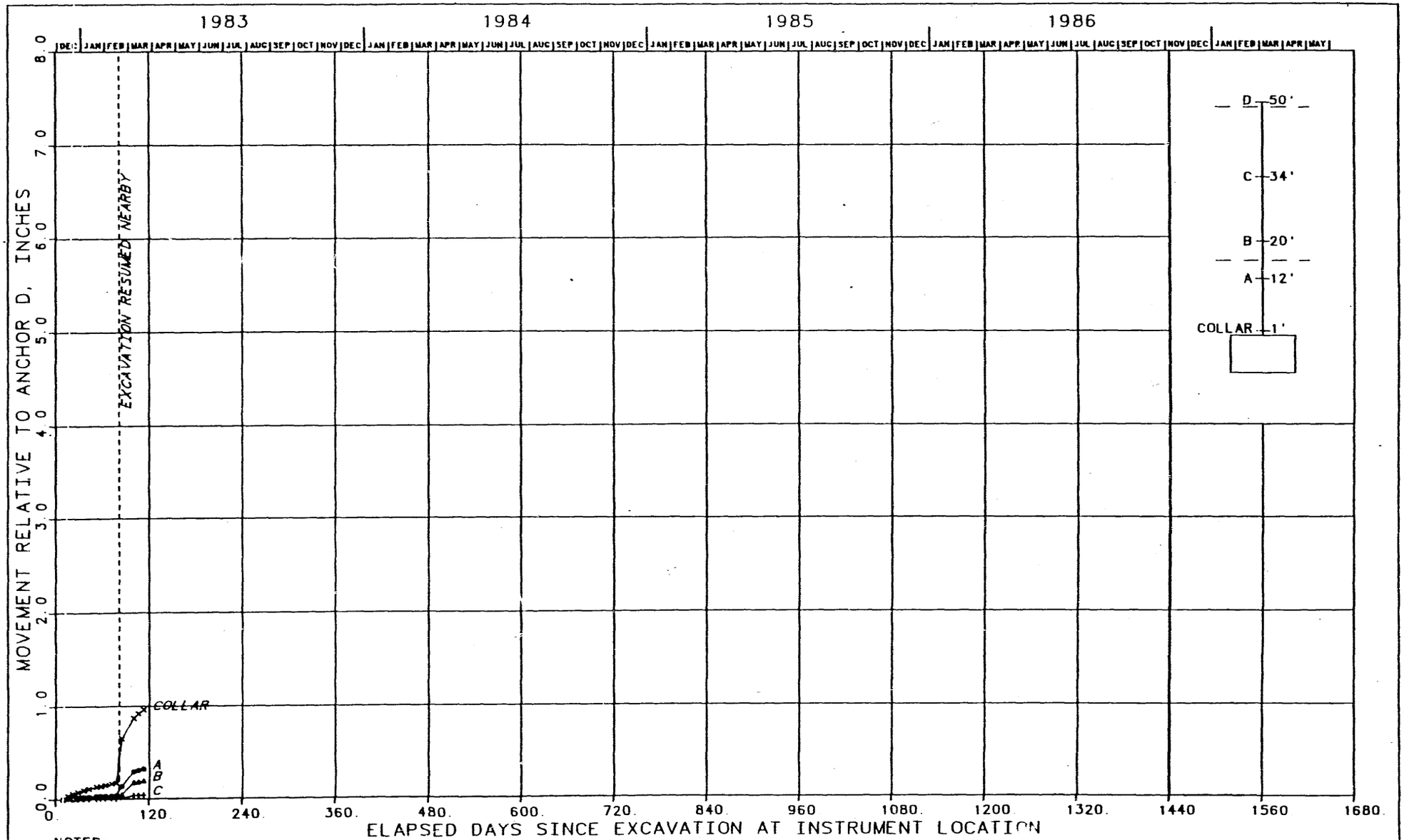
FIGURE J-147
MULTIPLE-POINT EXTENSOMETER 51X-GE-00228
65 FT SOUTH OF C & SH SHAFT - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 8 FT X 14 FT.

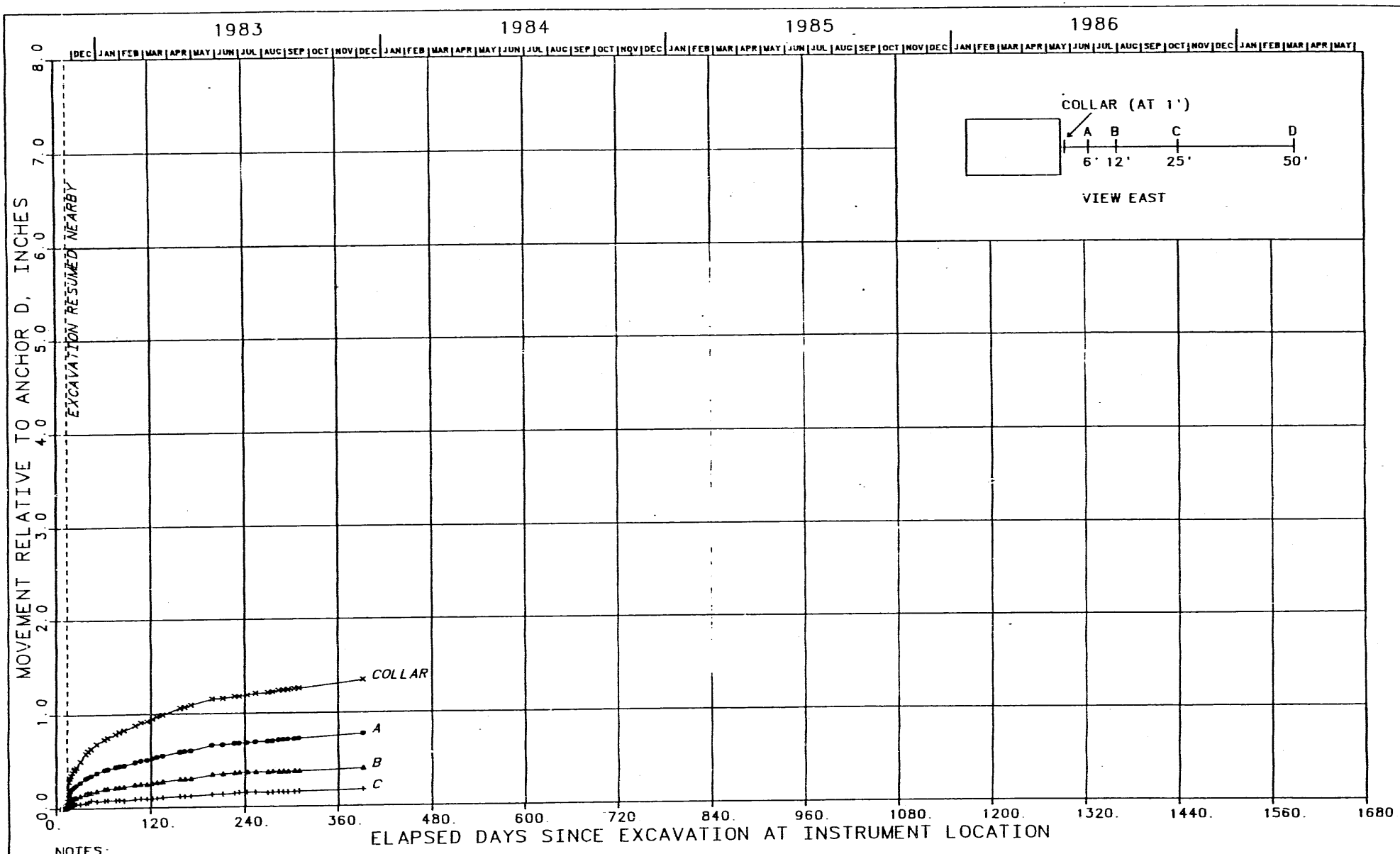
FIGURE J-148
MULTIPLE-POINT EXTENSOMETER 51X-GE-00229
E140 DRIFT, NORTH 240 FT - W WALL
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 8 FT X 14 FT.
2. INSTALLATION REJECTED. INSTRUMENT REPLACED BY 51X-GE-00255.

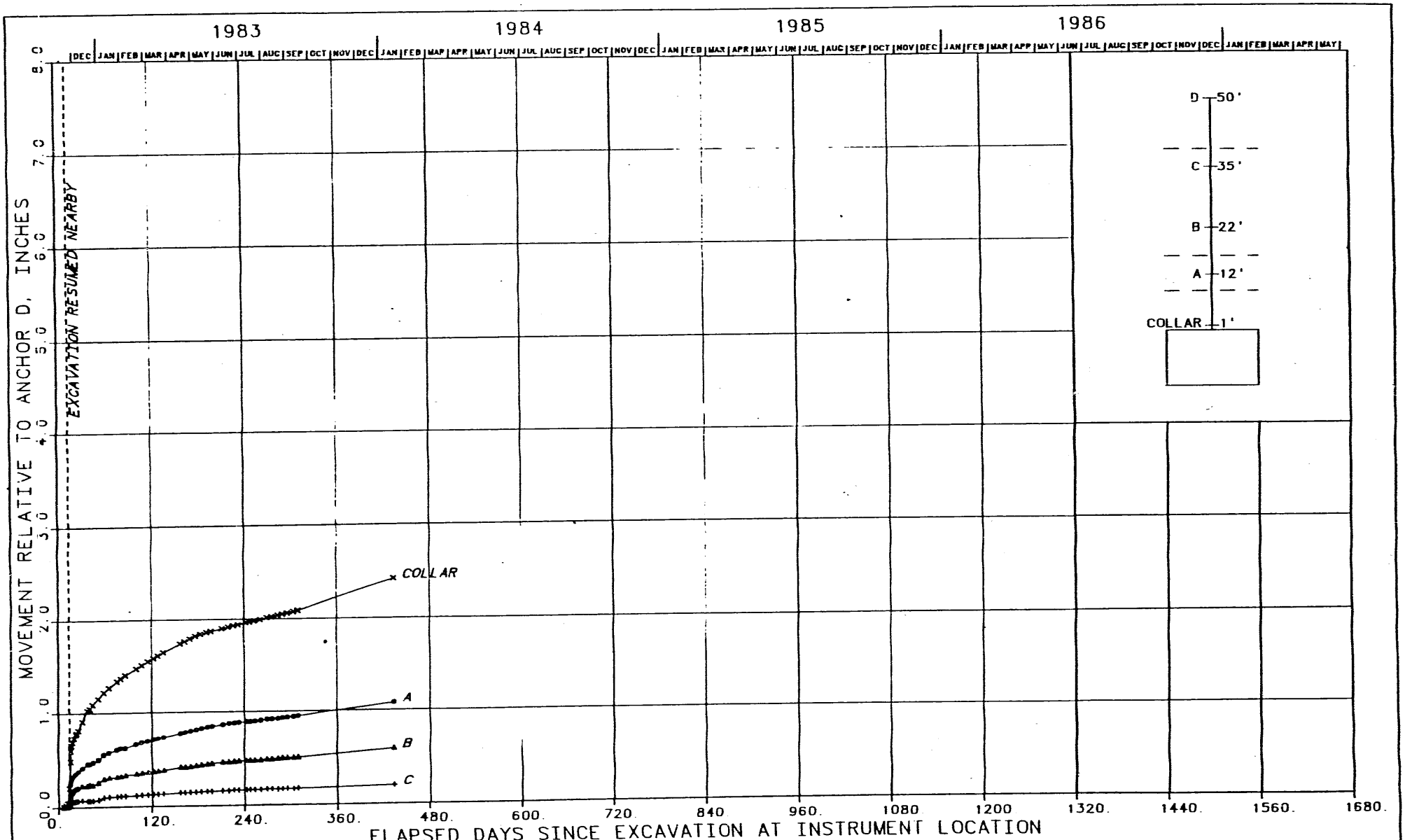
FIGURE J-149
MULTIPLE-POINT EXTENSOMETER 51X-GE-00230
E140 DRIFT, NORTH 240 FT – ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 20 FT.
2. INSTRUMENT HAS BEEN DESTROYED.

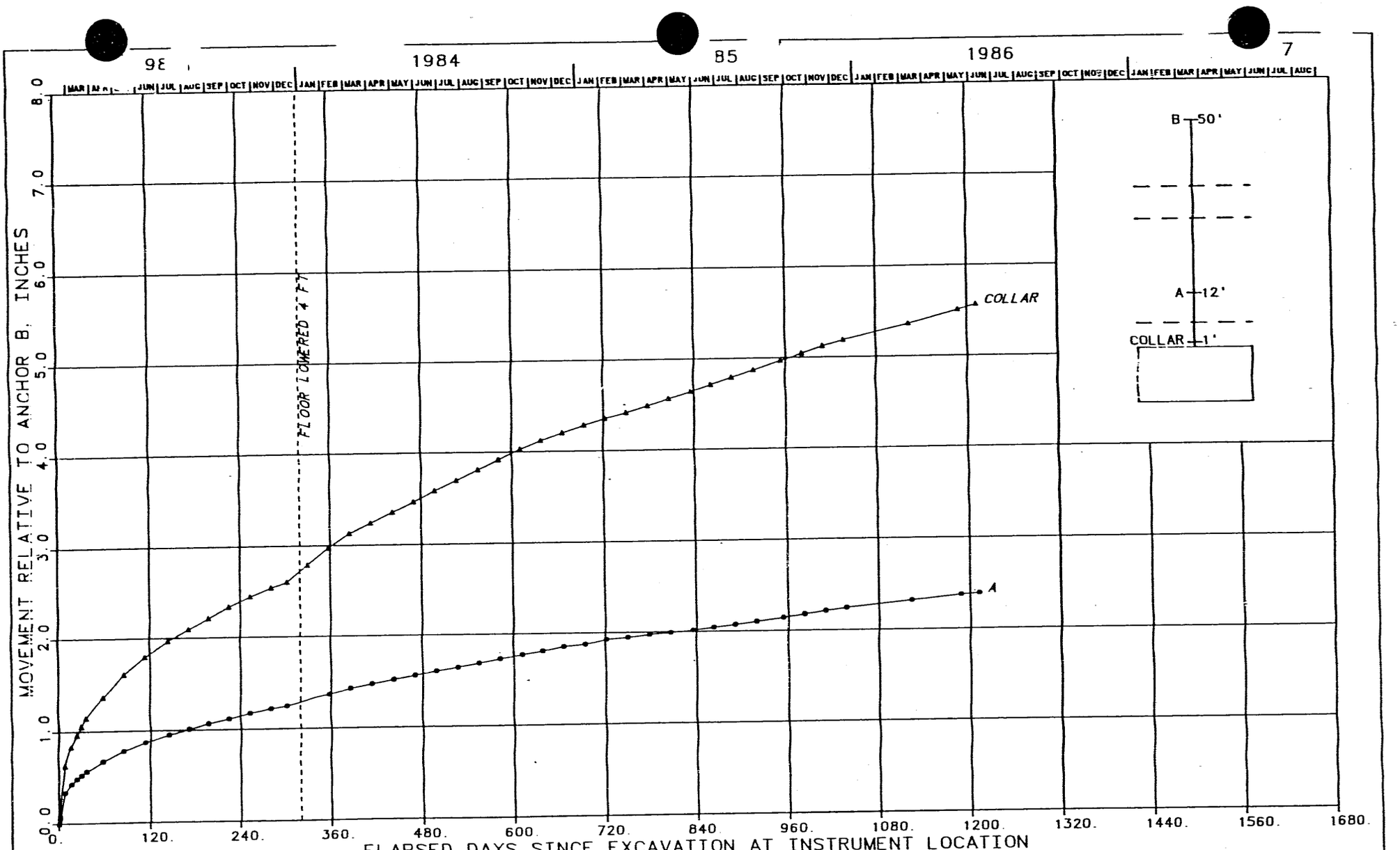
FIGURE J-150
MULTIPLE-POINT EXTENSOMETER 51X-GE-00231
7 FT EAST OF WASTE SHAFT - S WALL
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 20 FT.
2. INSTRUMENT HAS BEEN DESTROYED.

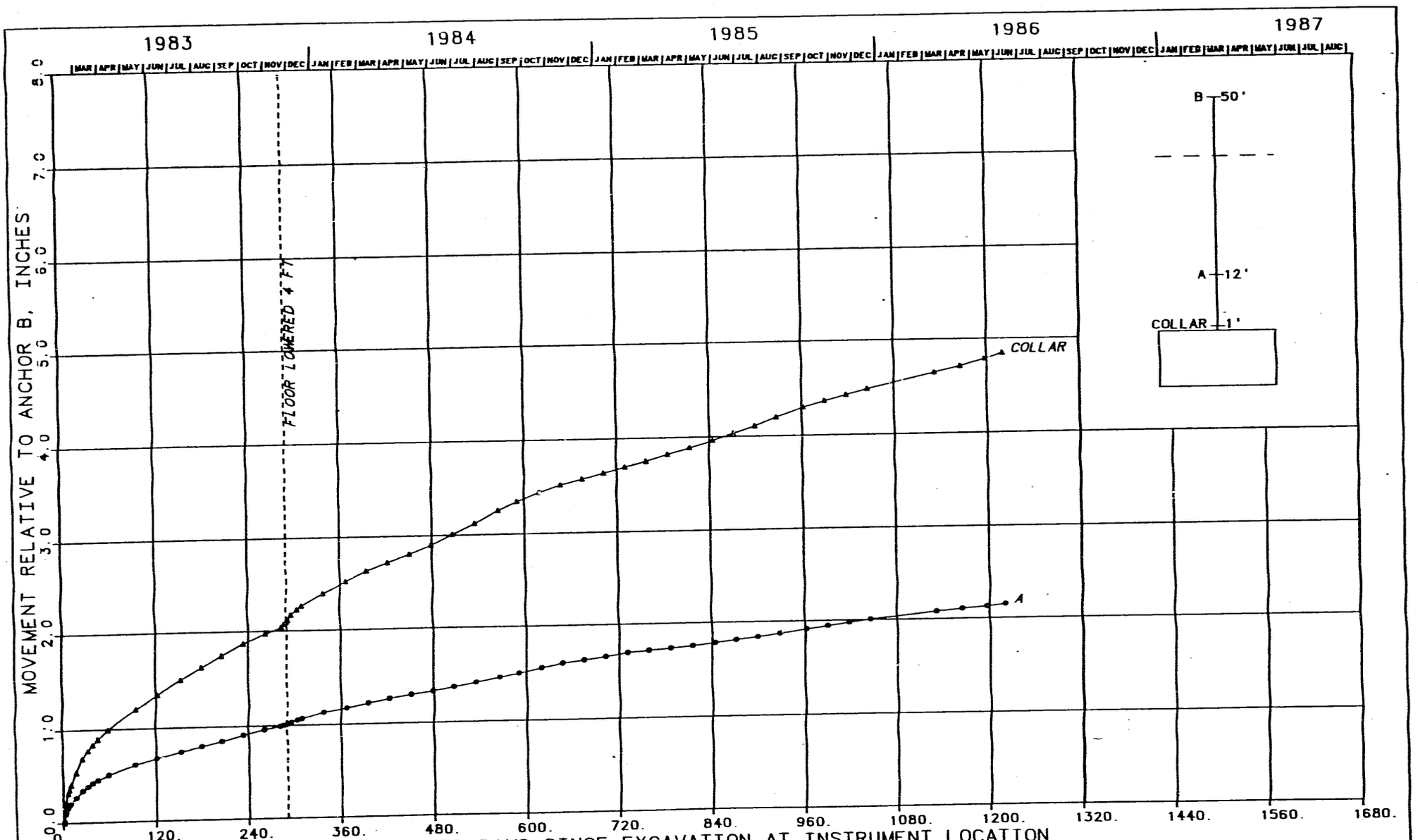
FIGURE J-151
MULTIPLE-POINT EXTENSOMETER 51X-GE-00232
17 FT EAST OF WASTE SHAFT - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 25 FT.

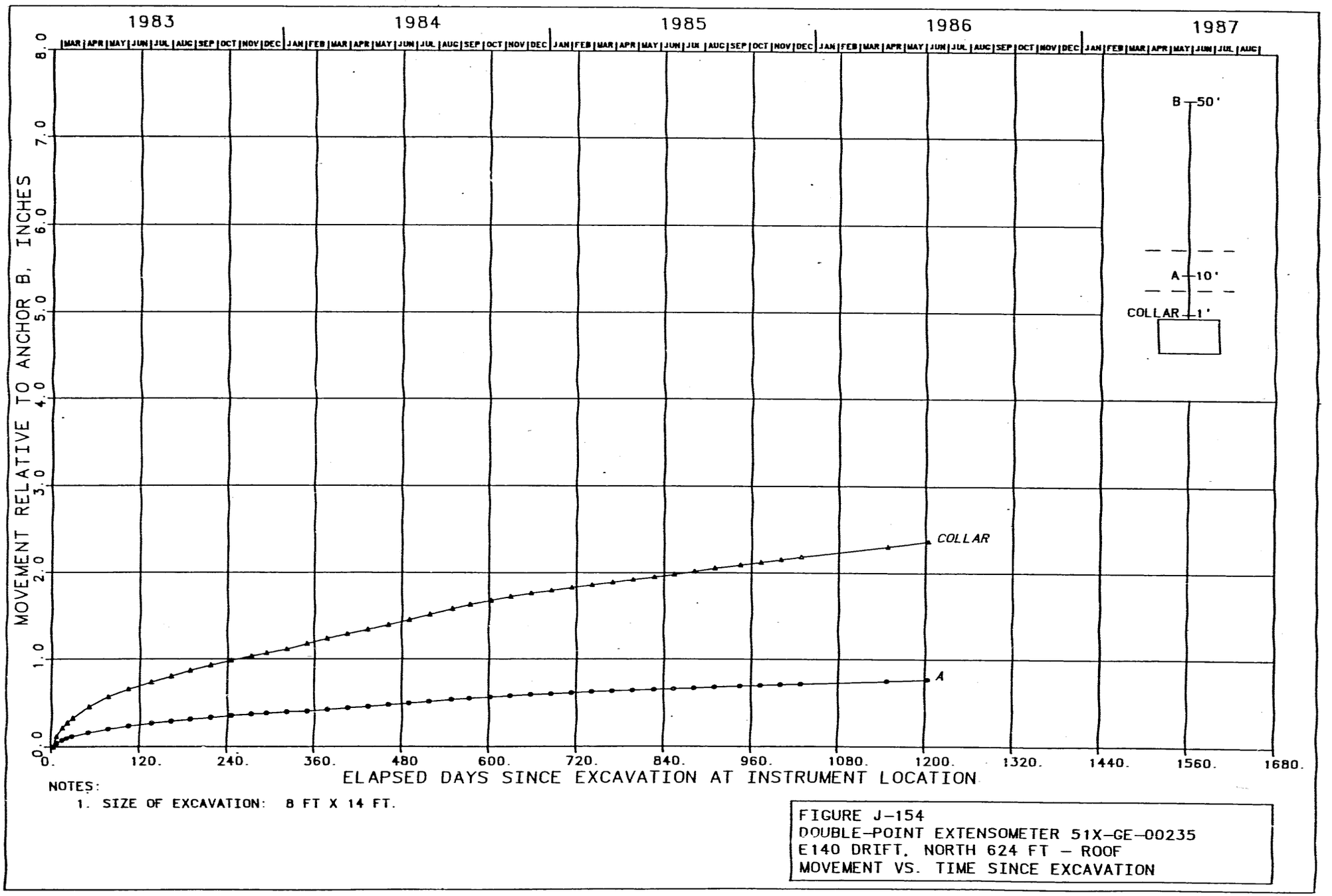
FIGURE J-152
DOUBLE-POINT EXTENSOMETER 51X-GE-00233
E0 DRIFT, NORTH 1266 FT - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 25 FT.

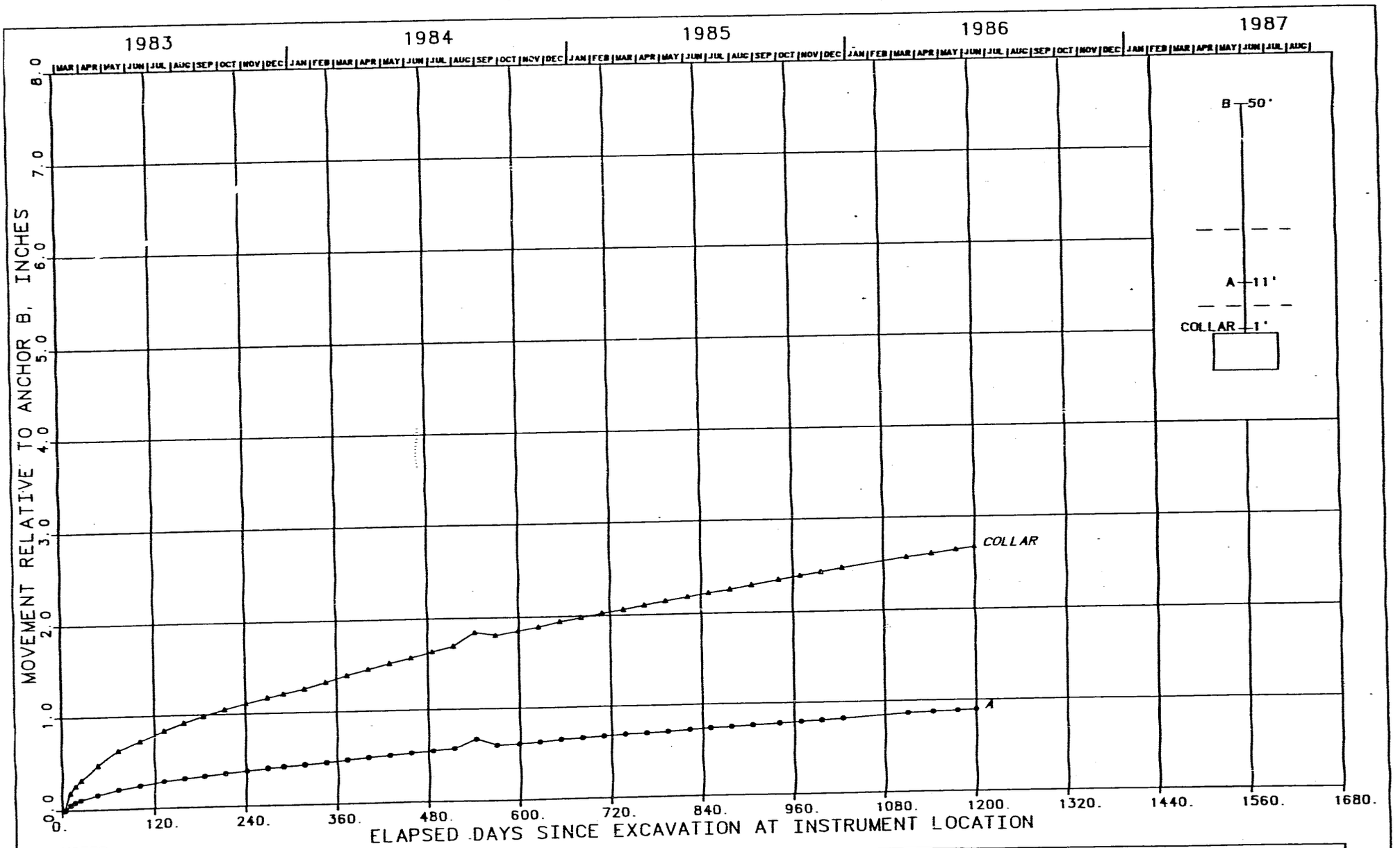
FIGURE J-153
DOUBLE-POINT EXTENSOMETER 51X-GE-00234
E0 DRIFT, NORTH 626 FT - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 8 FT X 14 FT.

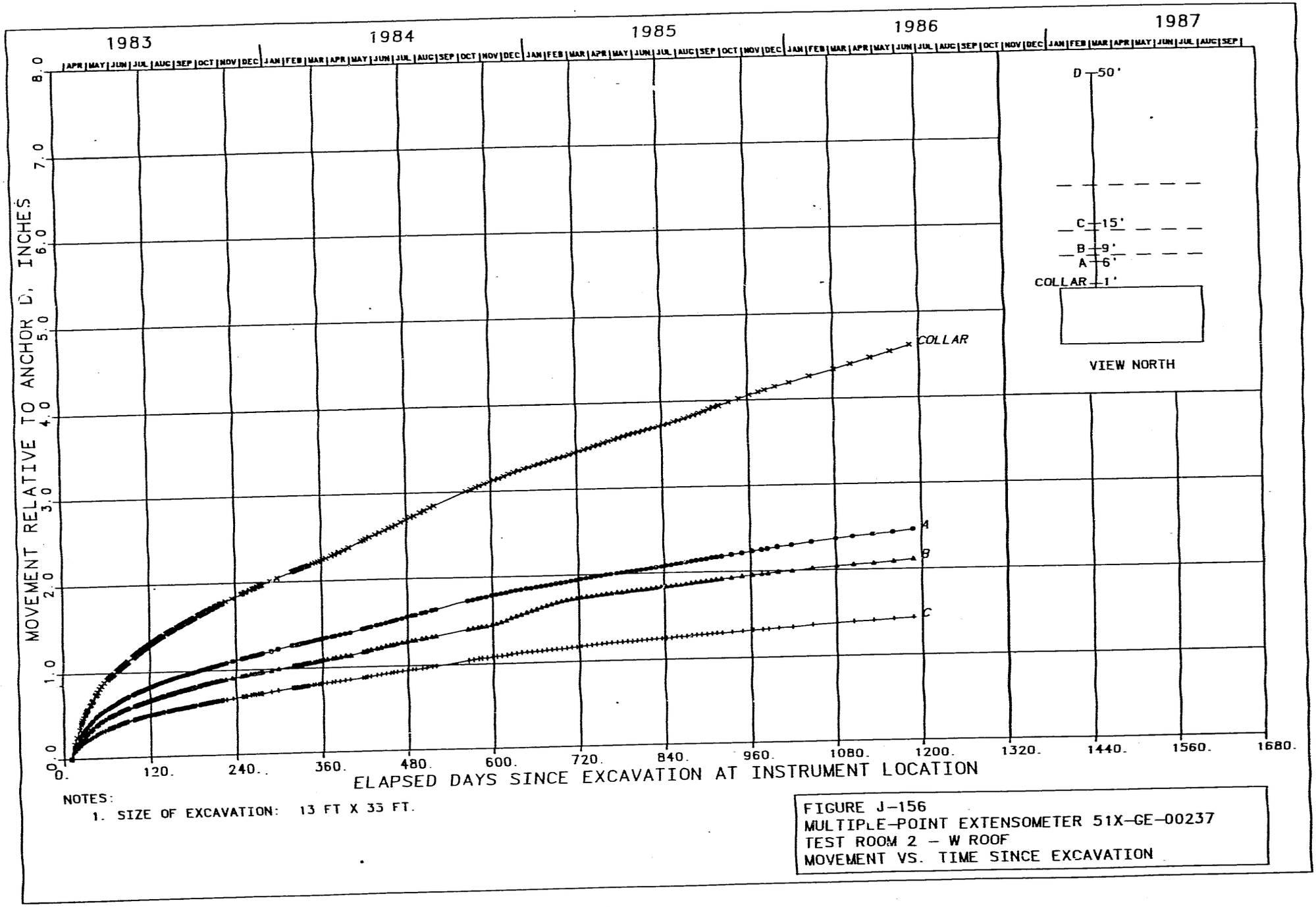
FIGURE J-154
DOUBLE-POINT EXTENSOMETER 51X-GE-00235
E140 DRIFT, NORTH 624 FT - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 8 FT X 14 FT.

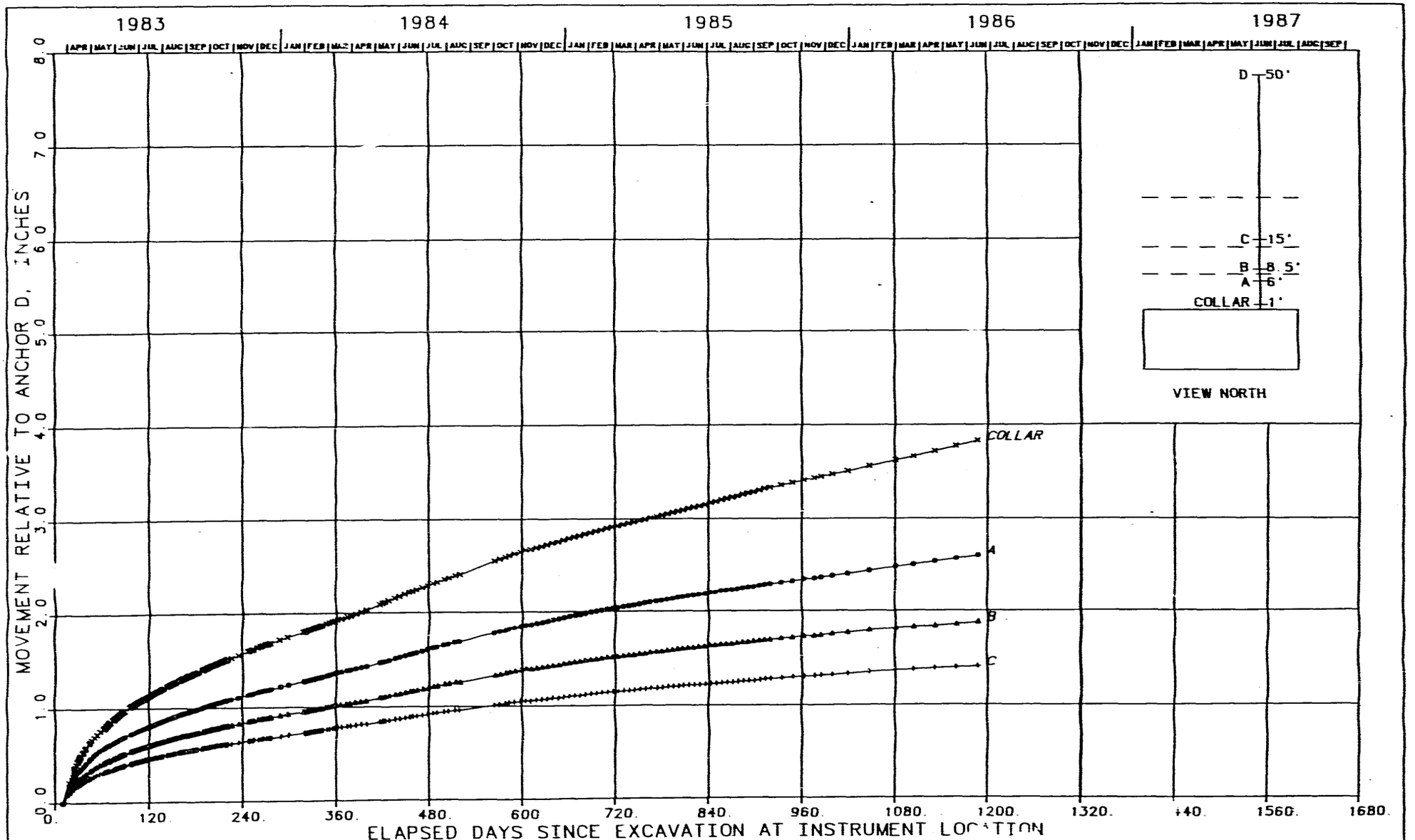
FIGURE J-155
DOUBLE-POINT EXTENSOMETER 51X-GE-00236
E140 DRIFT. NORTH 1266 FT – ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 35 FT.

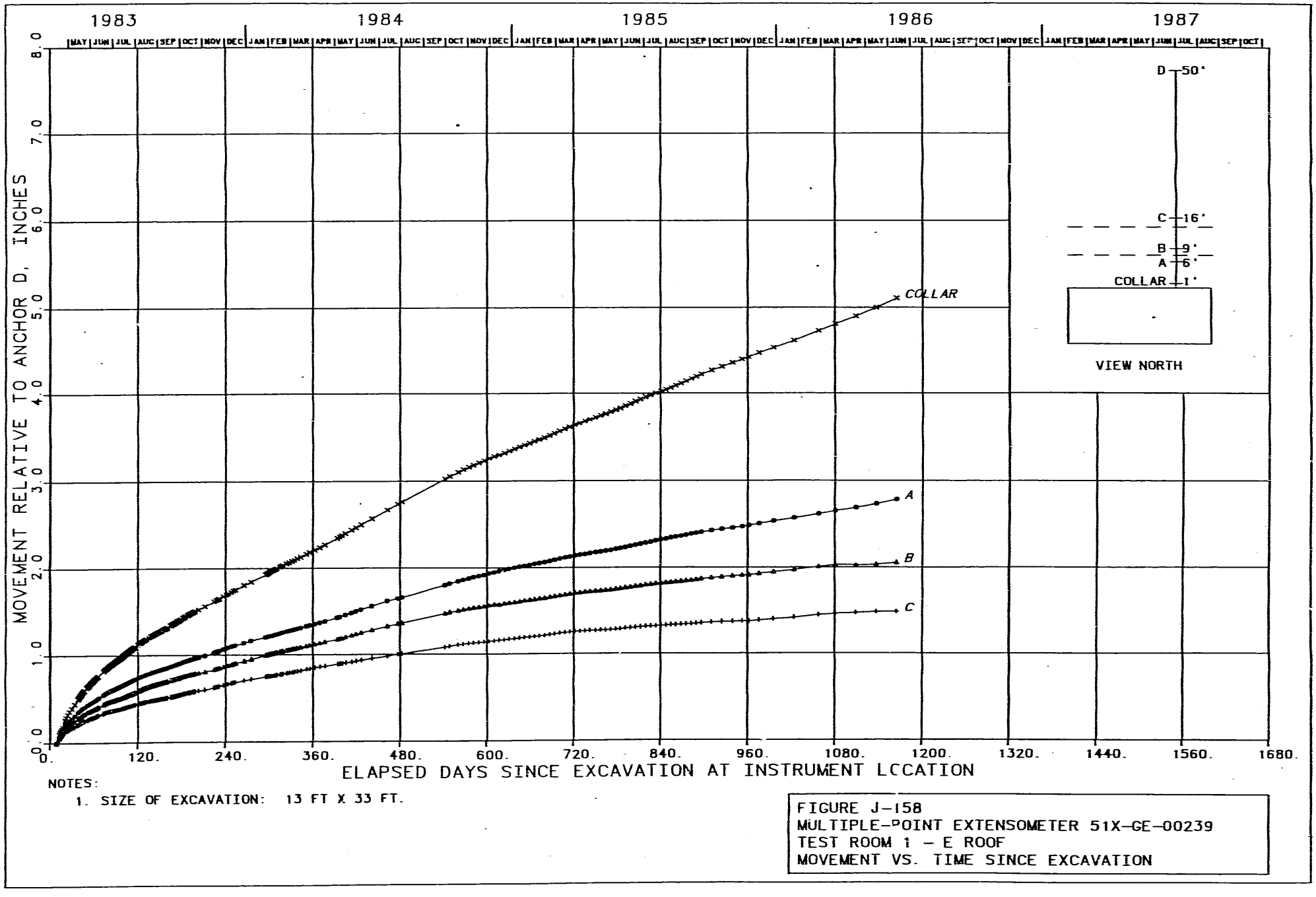
FIGURE J-156
MULTIPLE-POINT EXTENSOMETER 51X-GE-00237
TEST ROOM 2 - W ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

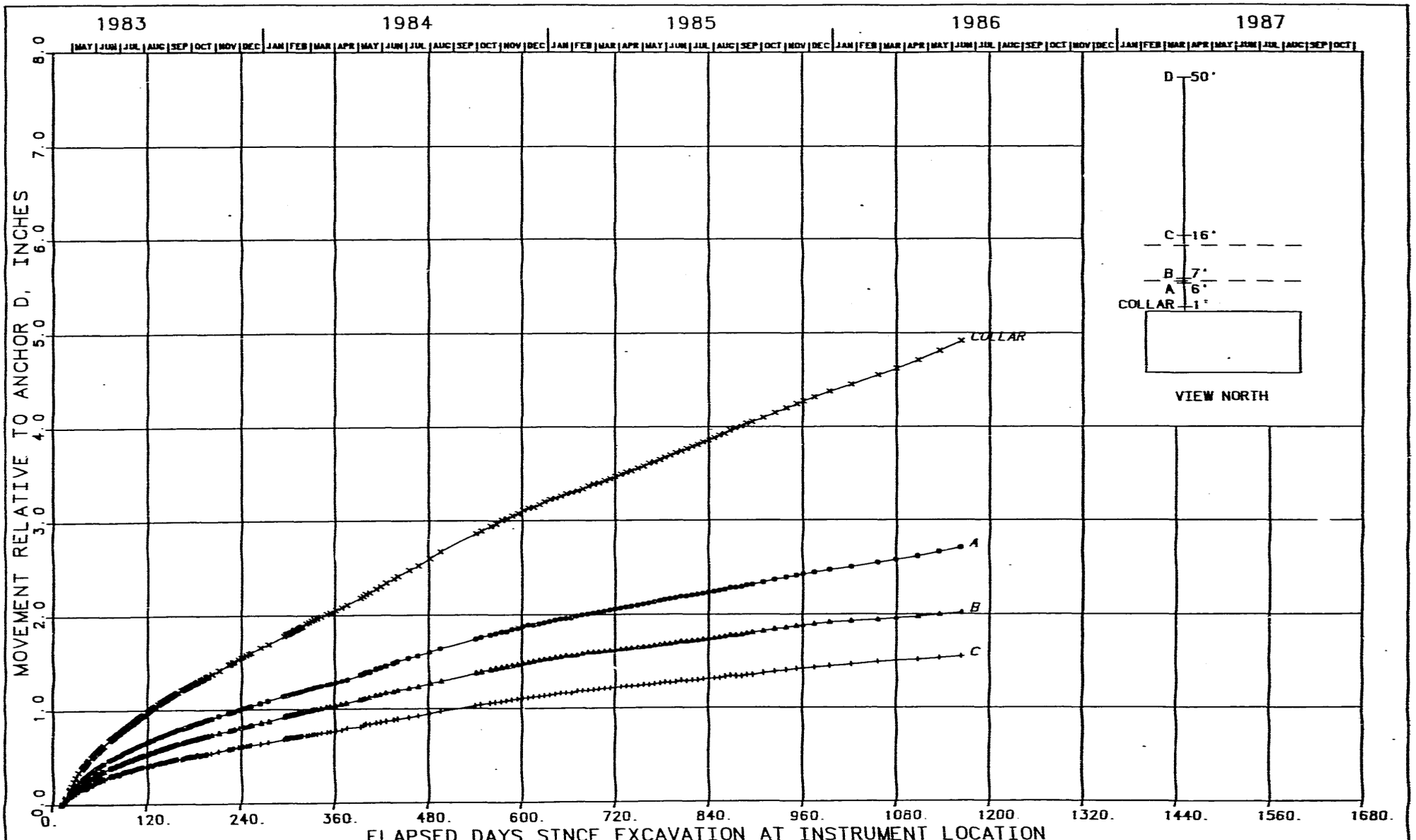
FIGURE J-157
MULTIPLE-POINT EXTENSOMETER 51X-GE-00238
TEST ROOM 2 - E ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

FIGURE J-158
MULTIPLE-POINT EXTENSOMETER 51X-GE-00239
TEST ROOM 1 - E ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

FIGURE J-159
MULTIPLE-POINT EXTENSOMETER 51X-GE-00240
TEST ROOM 1 - W ROOF
MOVEMENT VS. TIME SINCE EXCAVATION

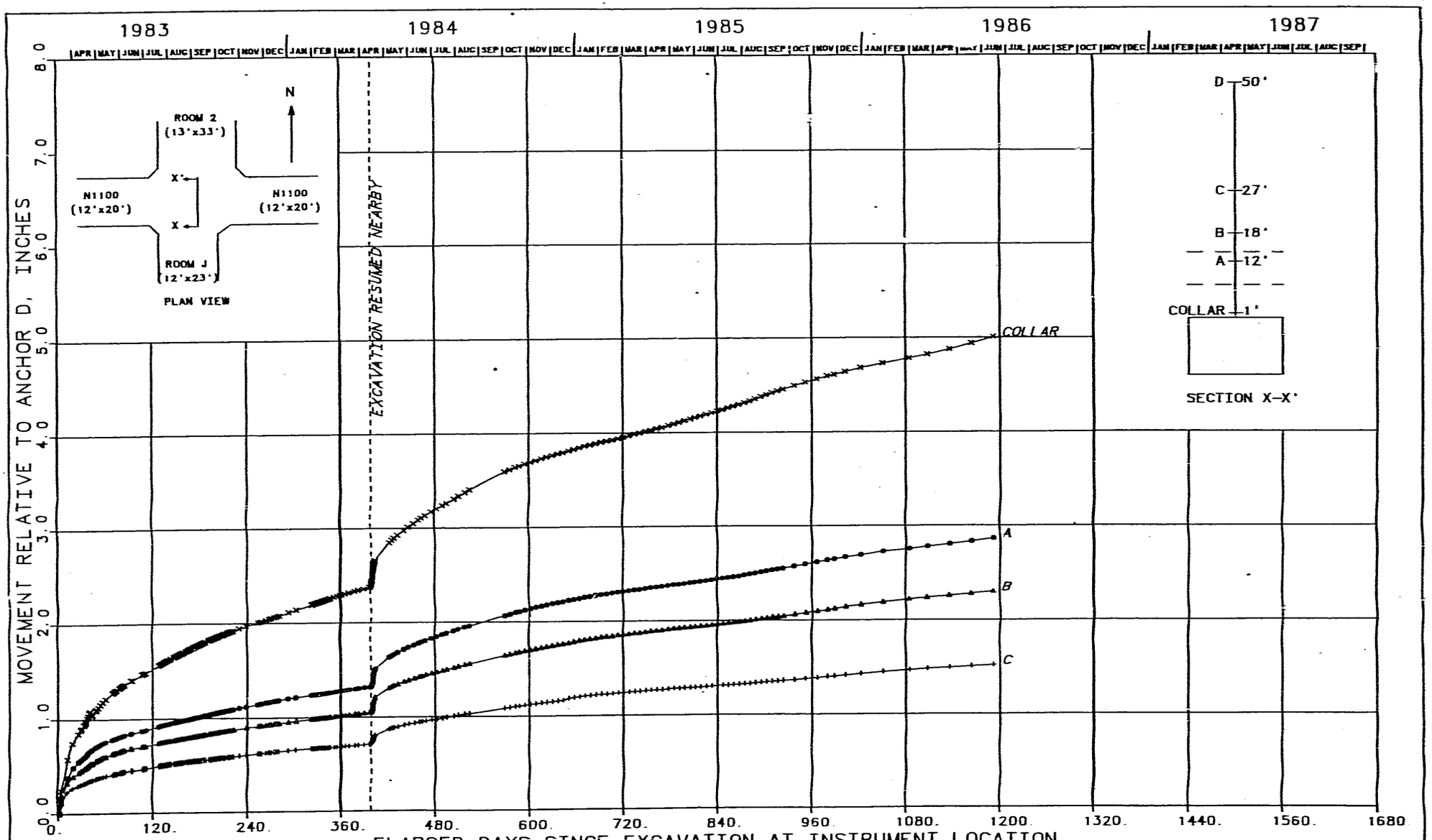


FIGURE J-160
MULTIPLE-POINT EXTENSOMETER 51X-GE-00241
N1100 - TEST ROOM 2 INTERSECTION - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION

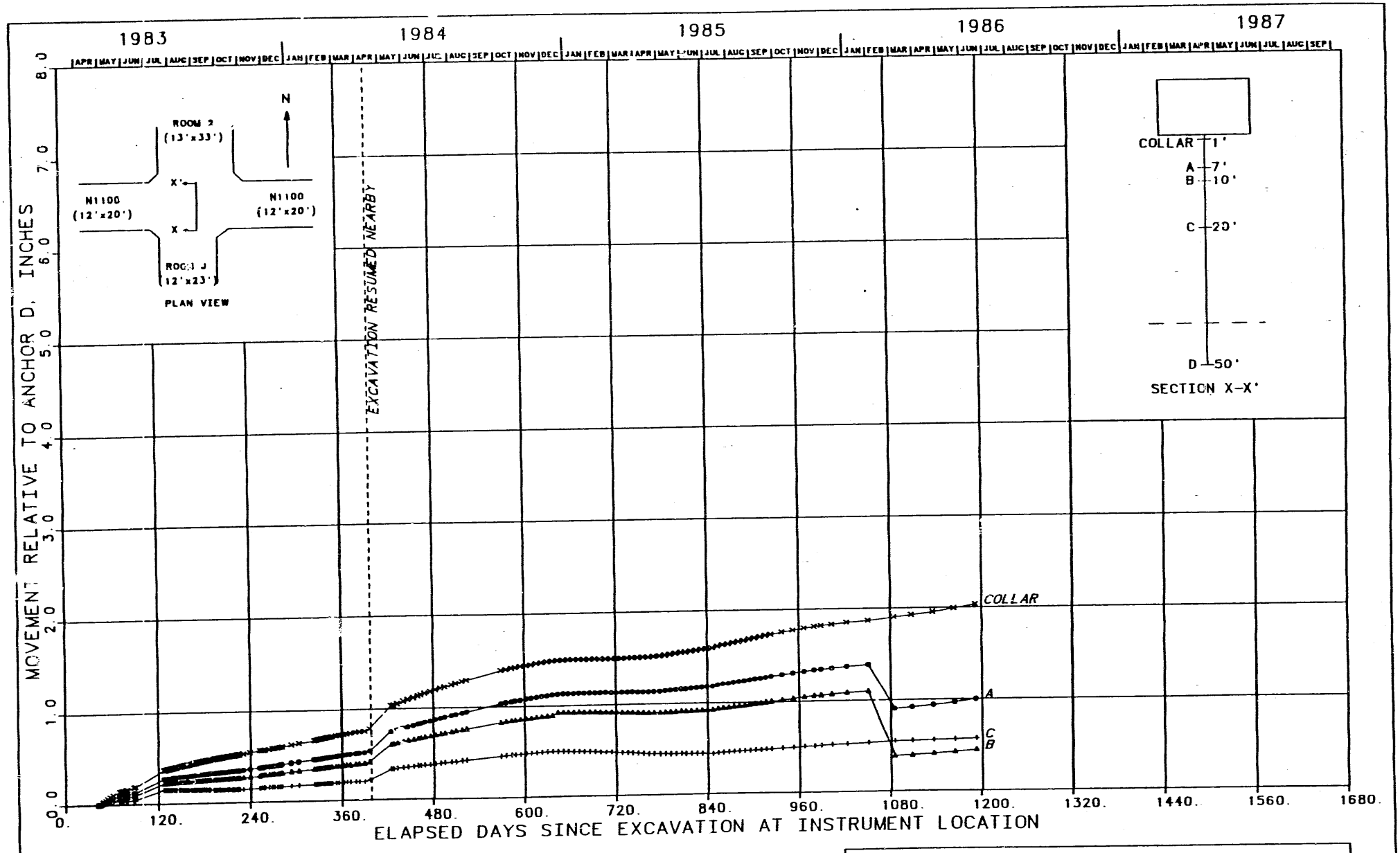


FIGURE J-161
MULTIPLE-POINT EXTENSOMETER 51X-GE-00242
N1100 - TEST ROOM 2 INTERSECTION - FLOOR
MOVEMENT VS. TIME SINCE EXCAVATION

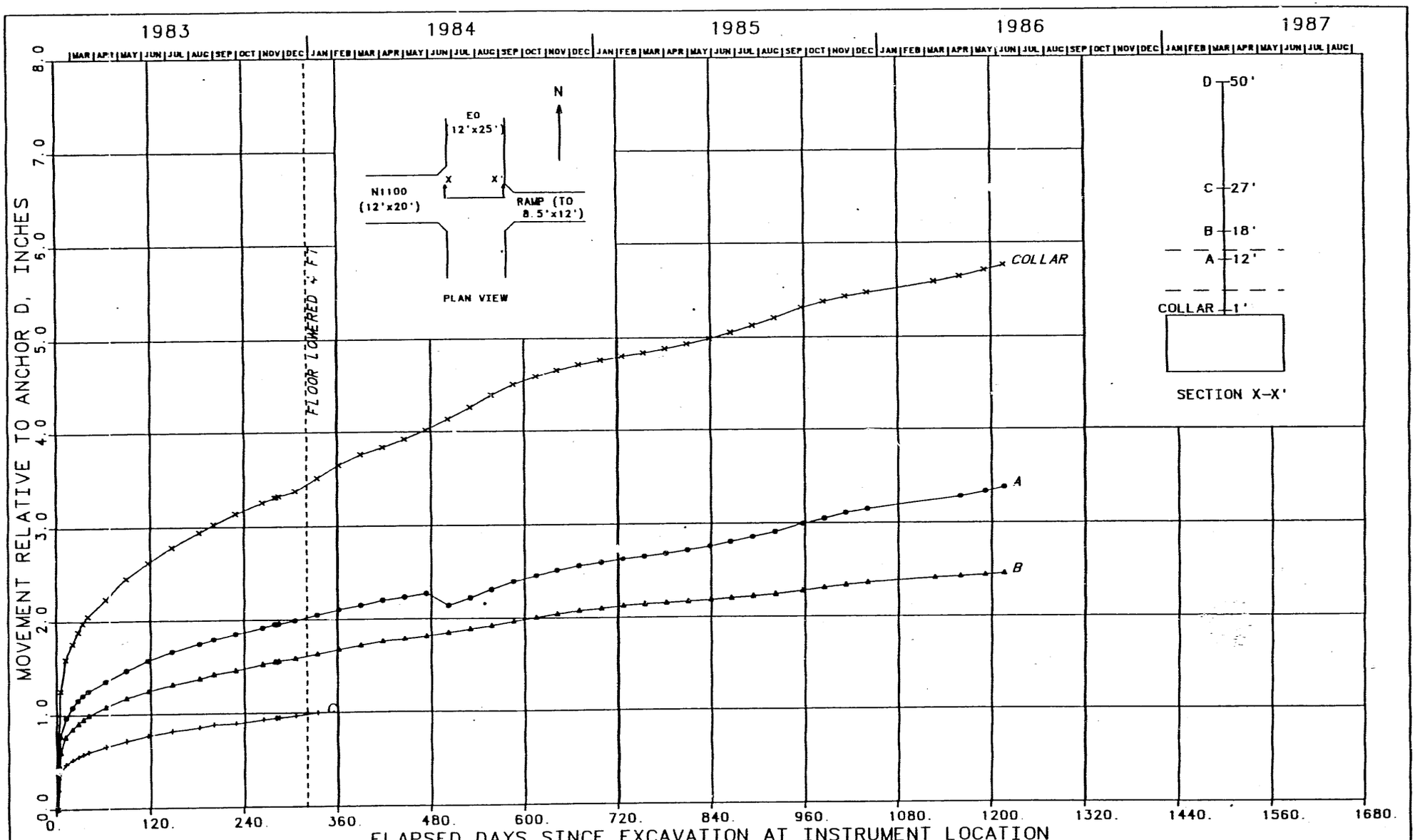
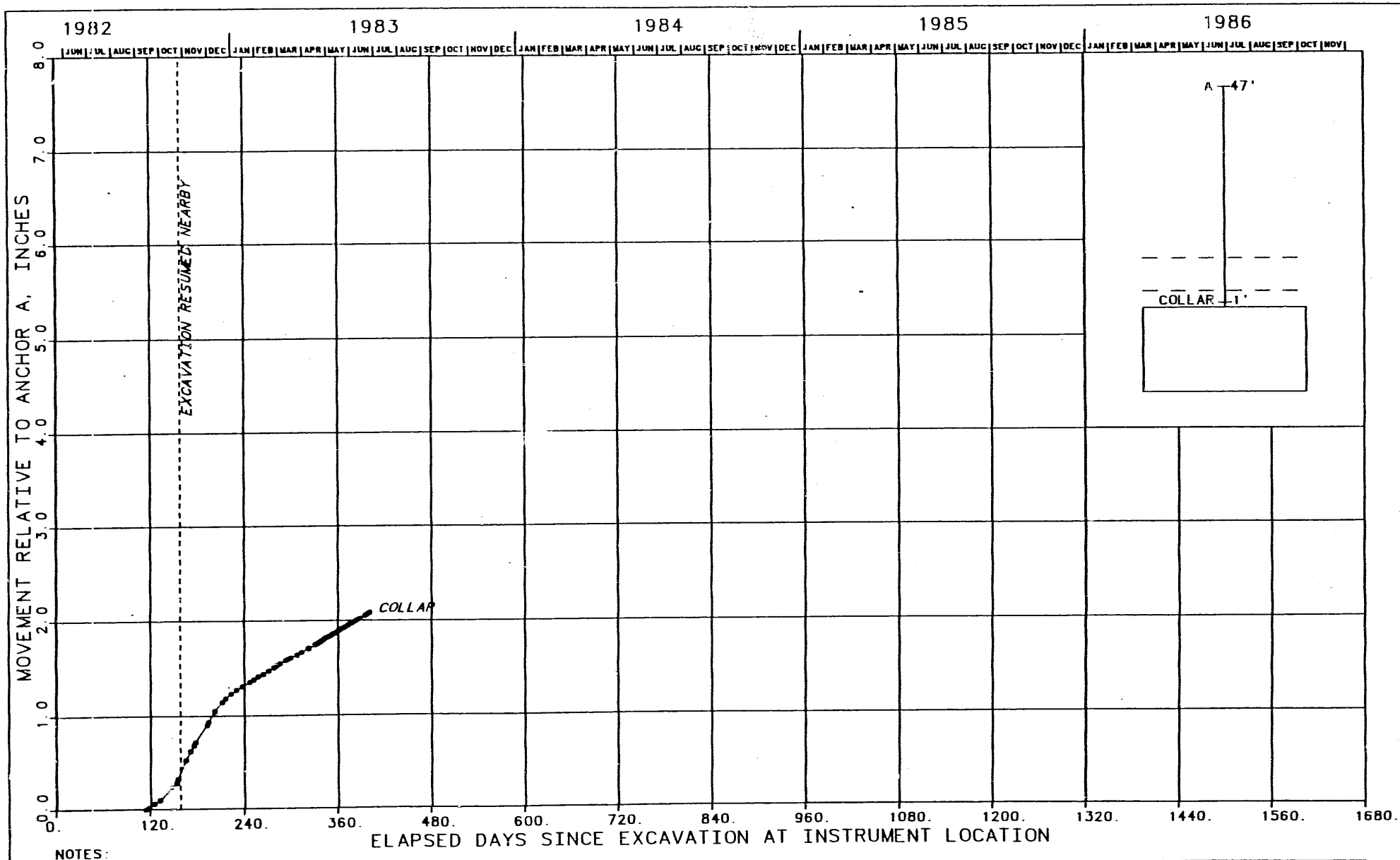


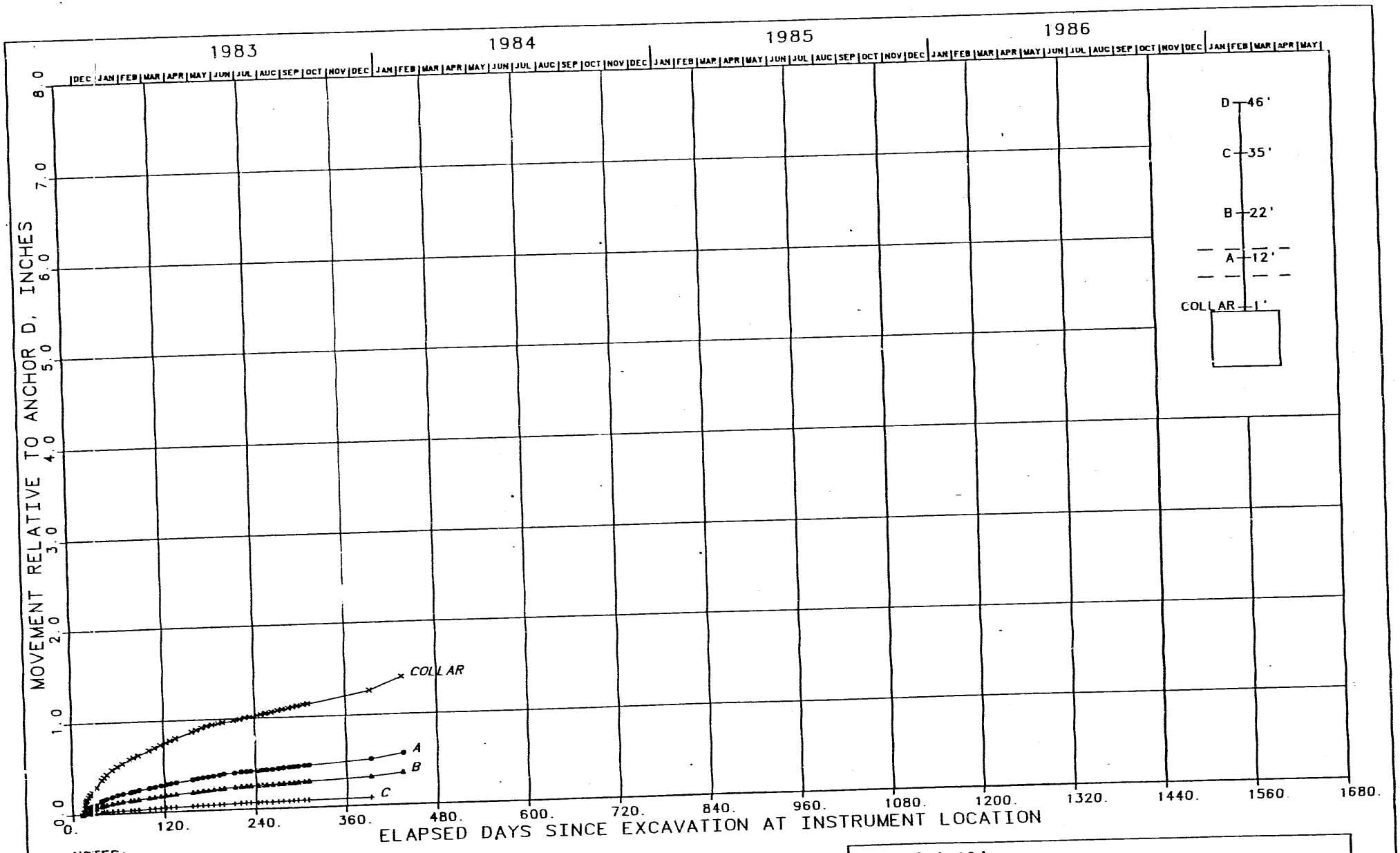
FIGURE J-162
MULTIPLE-POINT EXTENSOMETER 51X-GE-00243
EO DRIFT – N1100 DRIFT INTERSECTION – ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 18 FT X 35 FT.
2. INSTRUMENT HAS PERMANENTLY FAILED.

FIGURE J-163
SINGLE-POINT EXTENSOMETER 51X-GE-00244
30 FT SOUTH OF C & SH SHAFT - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:
1. SIZE OF EXCAVATION: 12 FT X 15 FT.
2. INSTRUMENT HAS BEEN DESTROYED.

FIGURE J-164
MULTIPLE-POINT EXTENSOMETER 51X-GE-00245
20 FT WEST OF WASTE SHAFT - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION

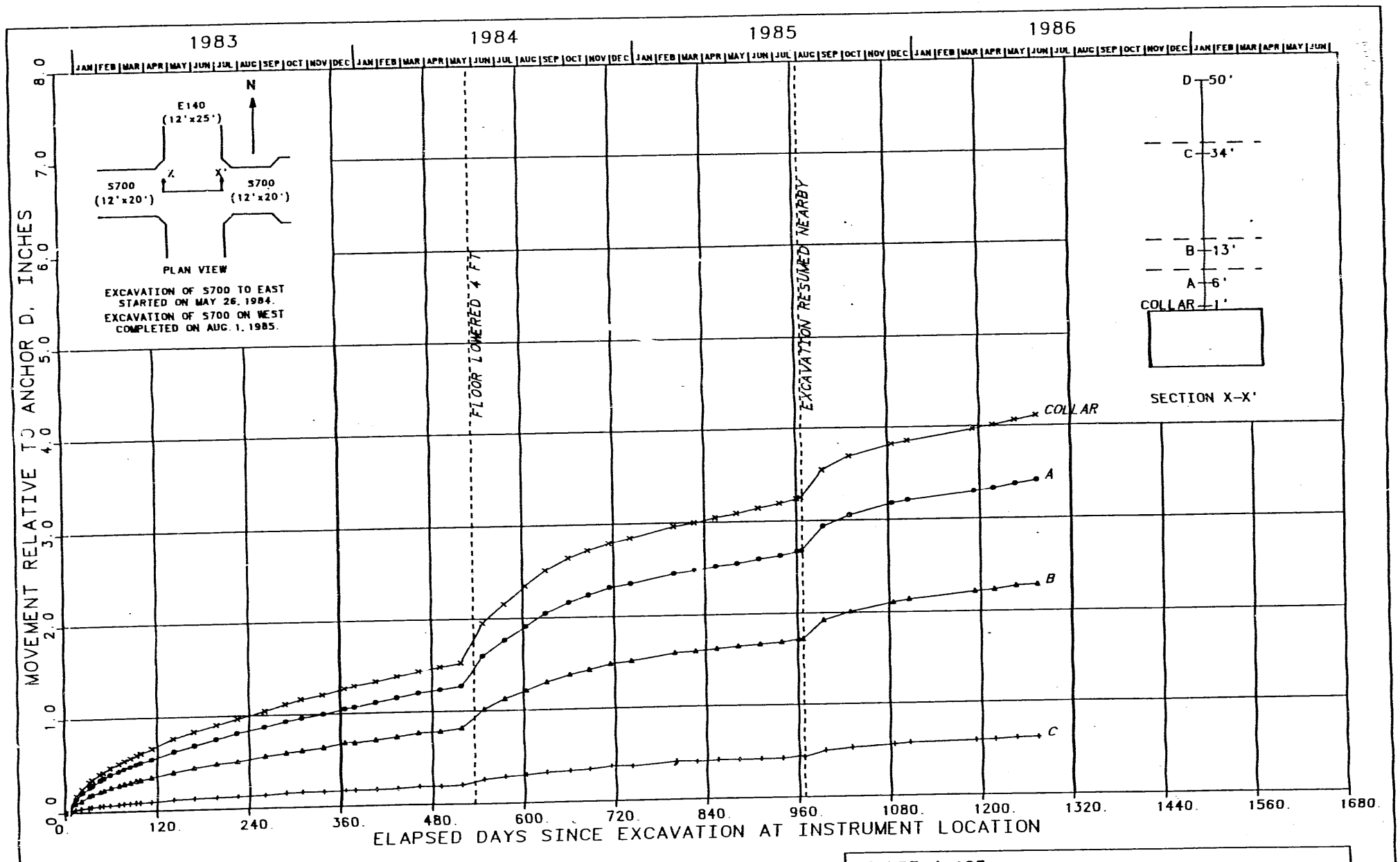
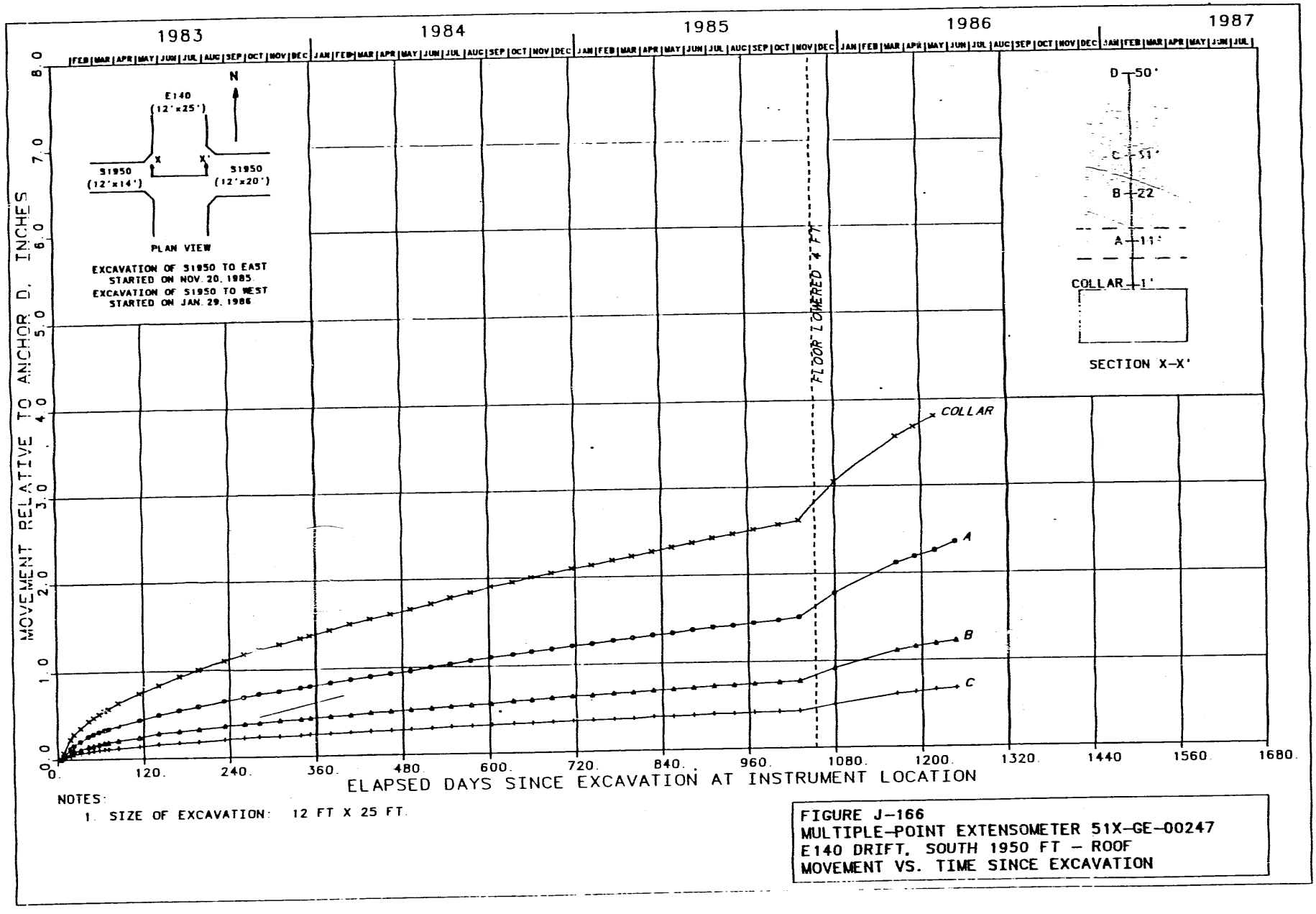


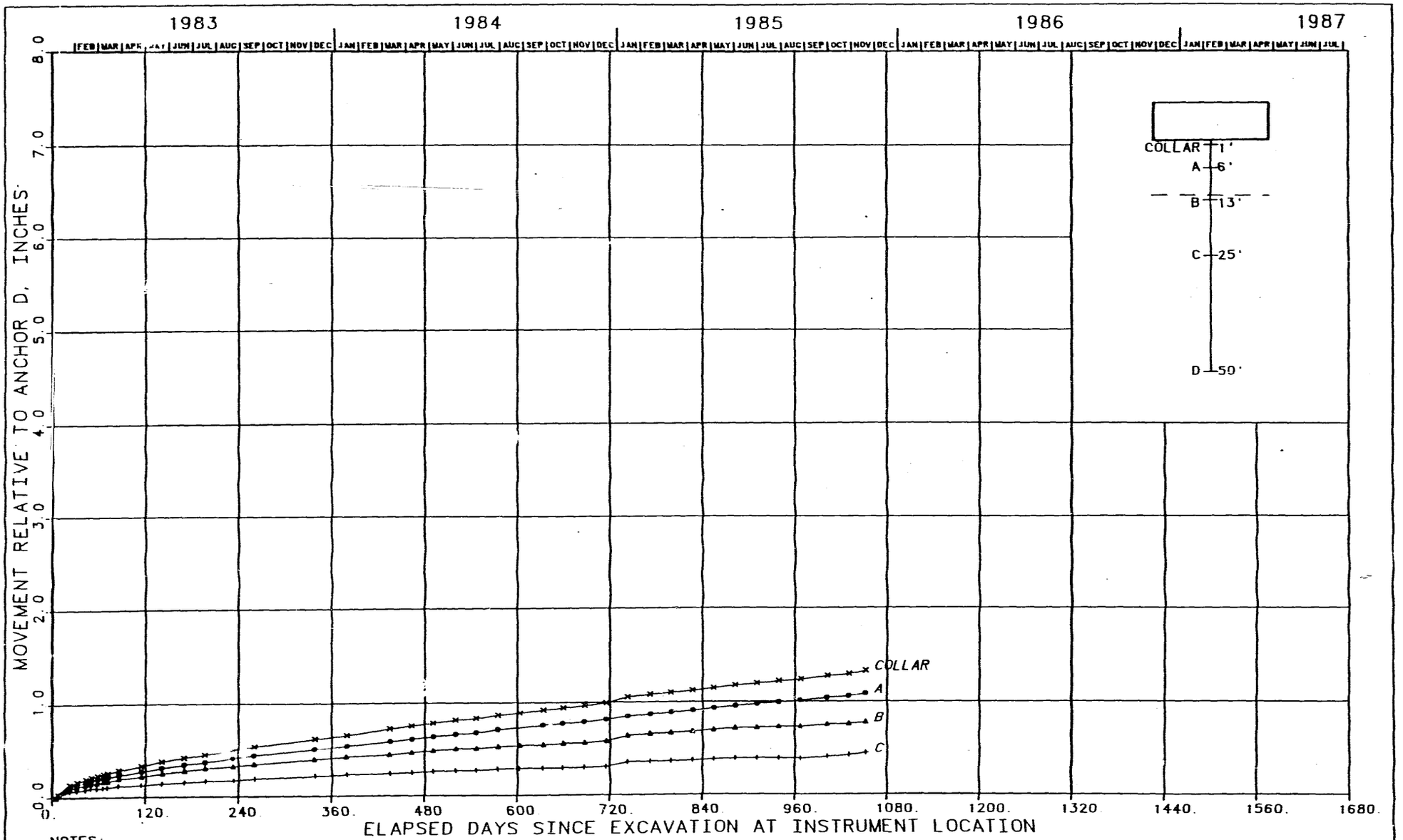
FIGURE J-165
MULTIPLE-POINT EXTENSOMETER 51X-GE-00246
E140 DRIFT - S700 INTERSECTION - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 25 FT.

FIGURE J–166
MULTIPLE–POINT EXTENSOMETER 51X–GE–00247
E140 DRIFT, SOUTH 1950 FT – ROOF
MOVEMENT VS. TIME SINCE EXCAVATION

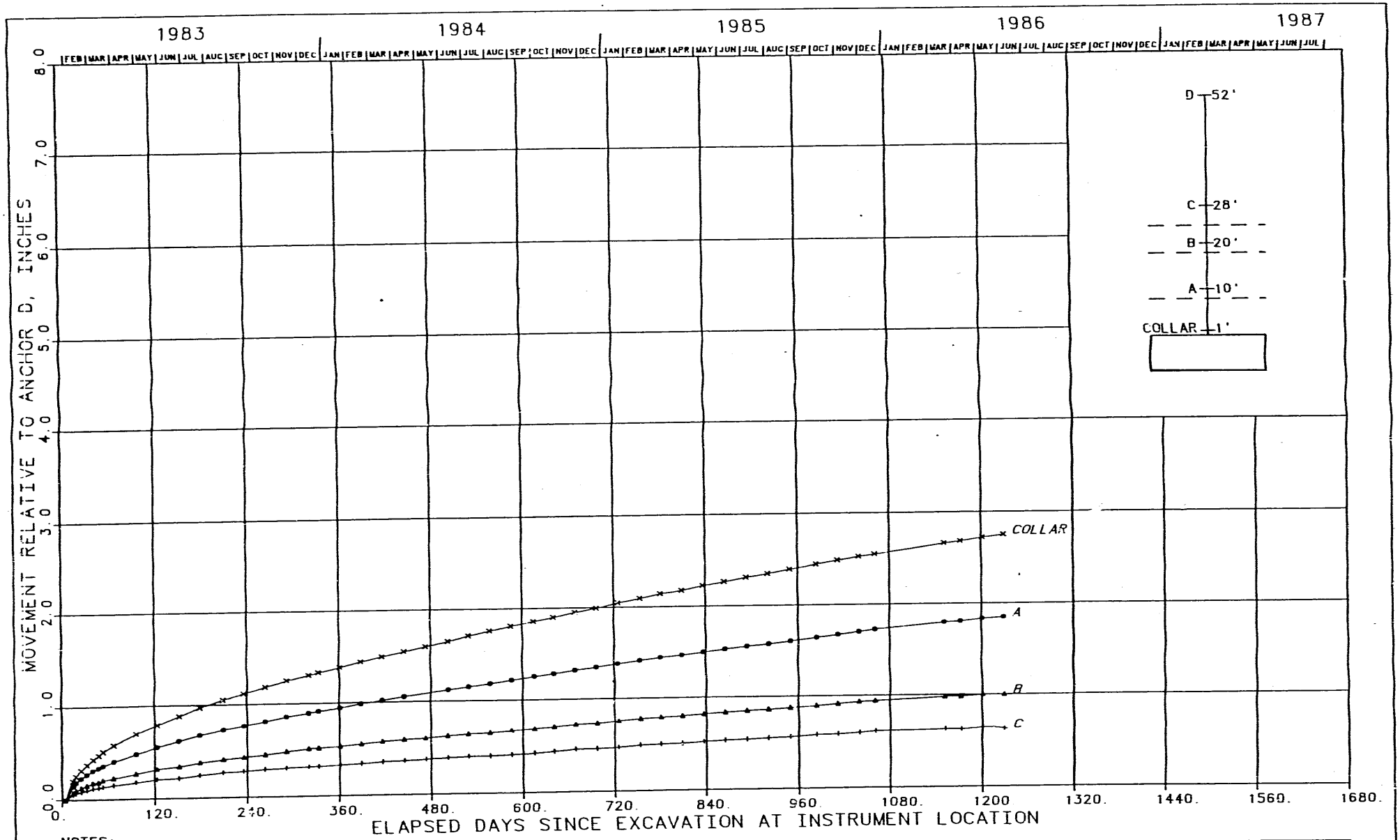


NOTES:

* SIZE OF EXCAVATION: 8 FT X 25 FT.

∠. INSTRUMENT HAS BEEN DESTROYED.

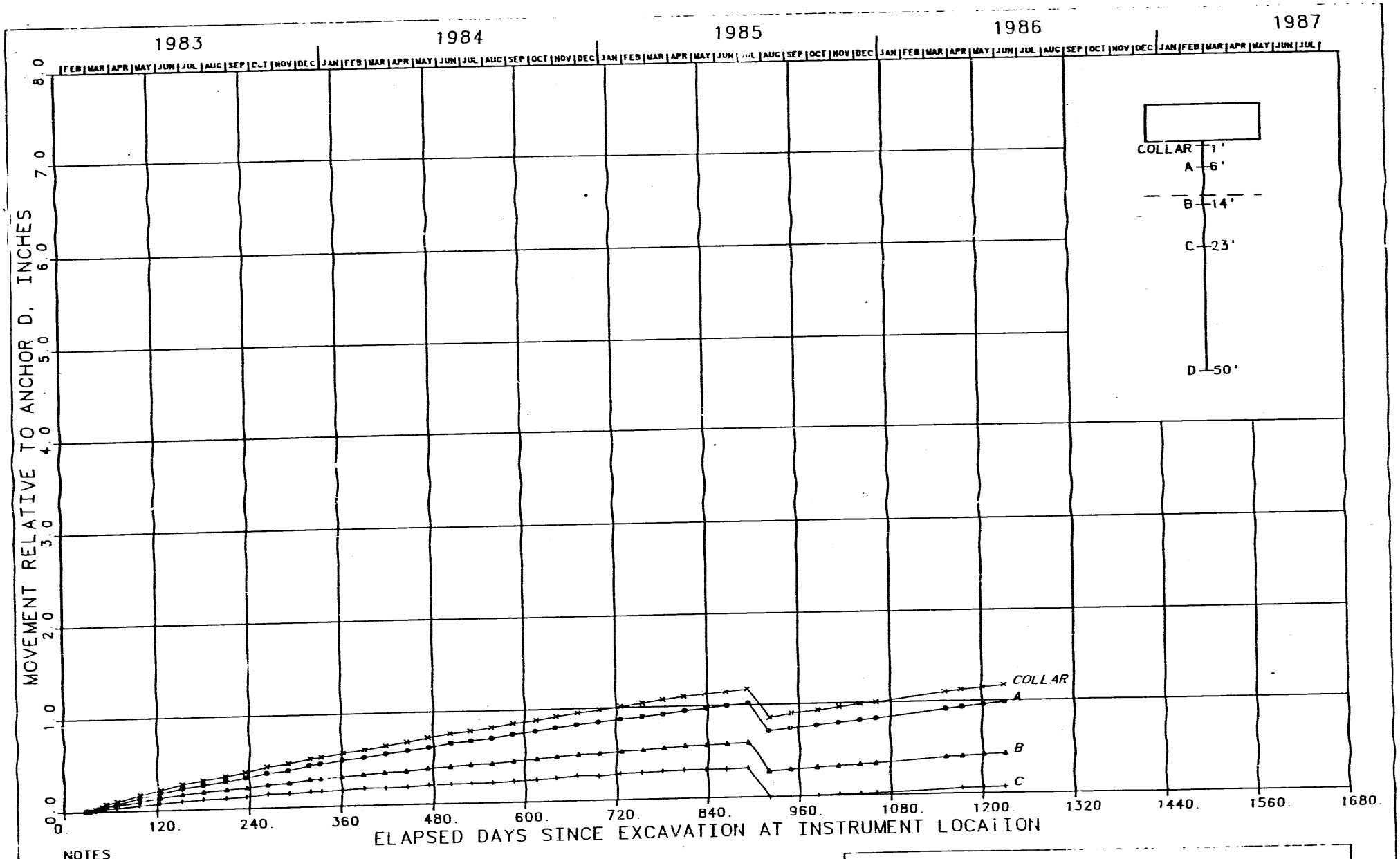
FIGURE J-167
MULTIPLE-POINT EXTENSOMETER 51X-GE-00248
E140 DRIFT, SOUTH 1950 FT - FLOOR
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 8 FT X 25 FT.

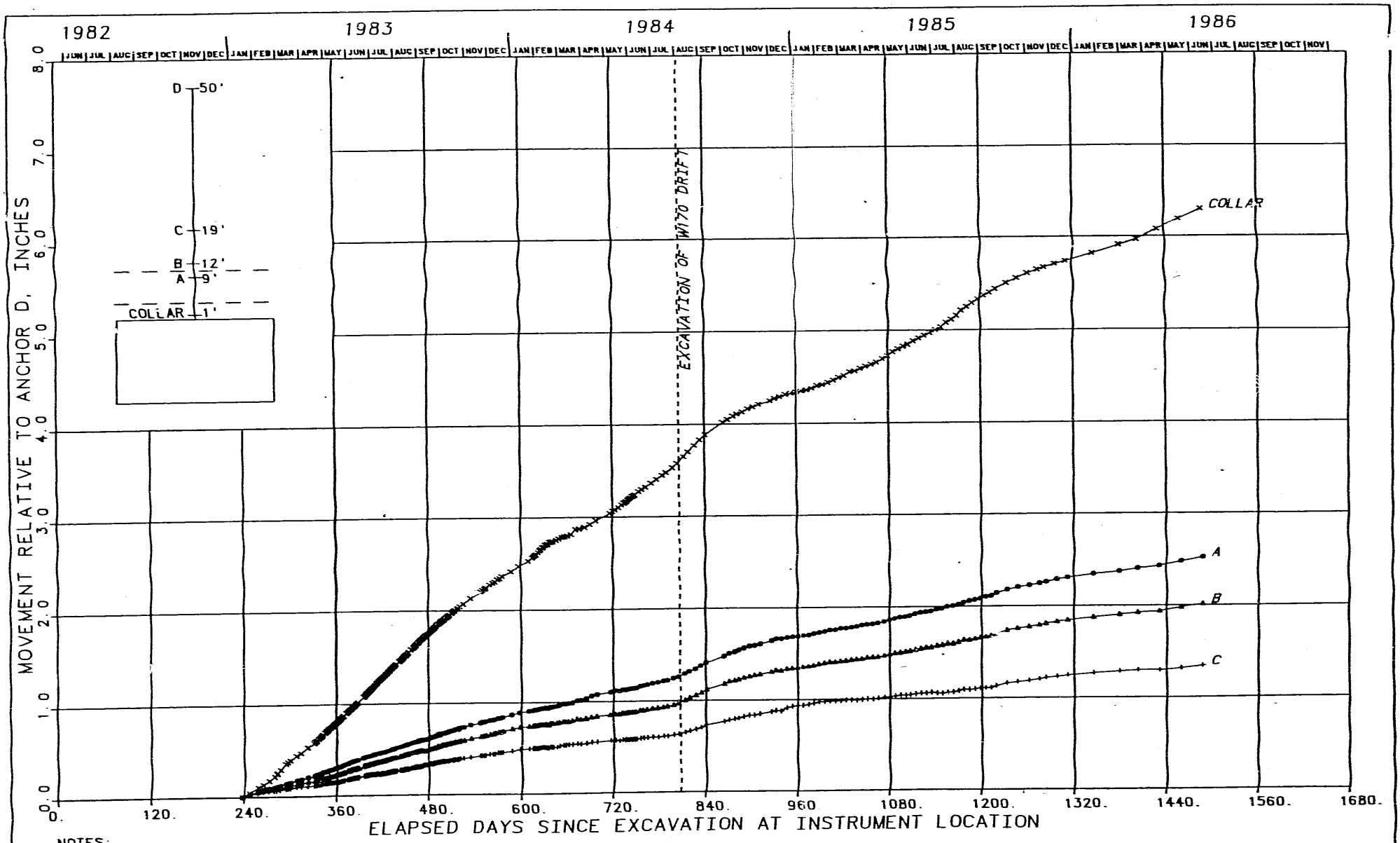
FIGURE J-168
MULTIPLE-POINT EXTENSOMETER 51X-GE-00249
E140 DRIFT, SOUTH 3080 FT - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION 8 FT X 25 FT.

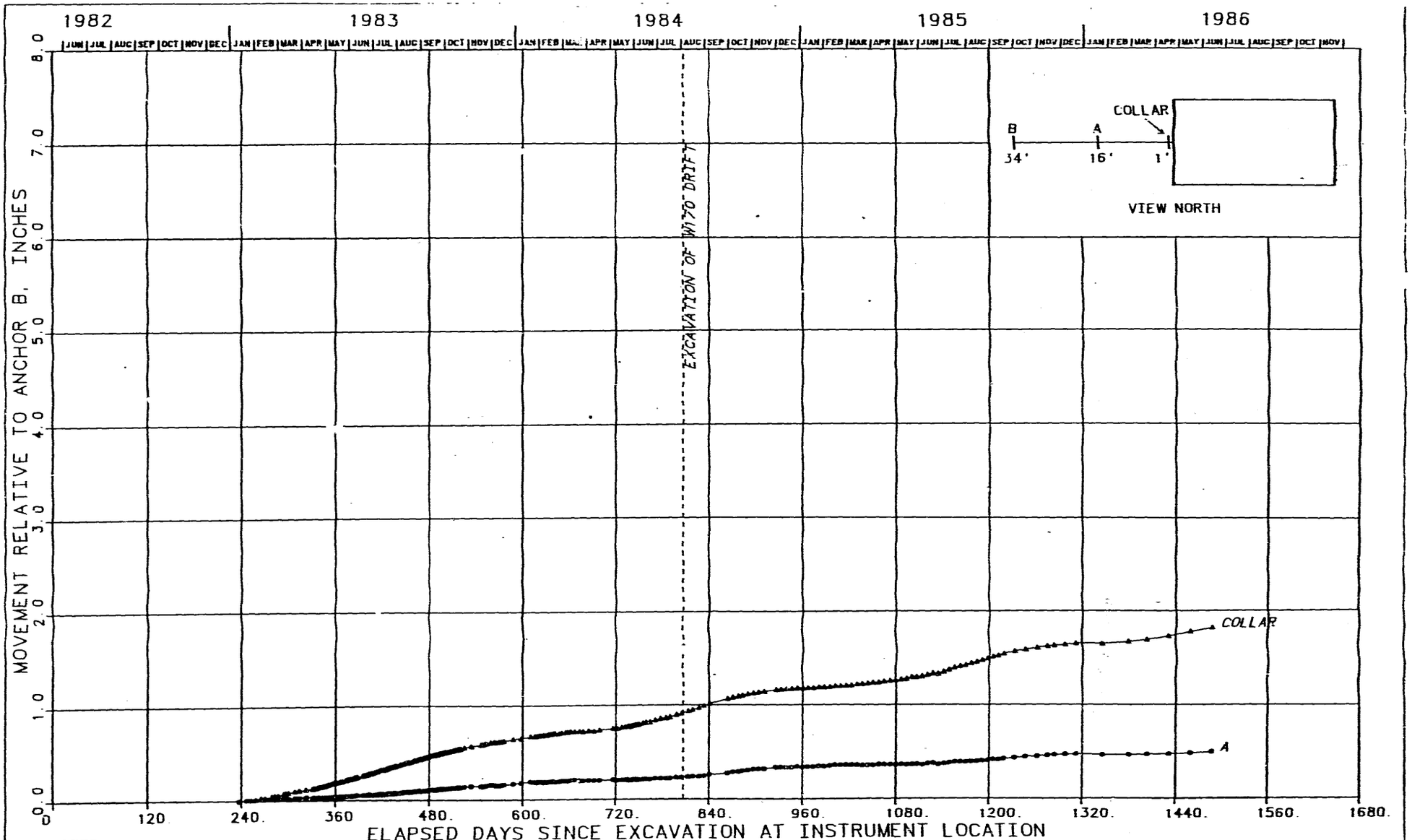
FIGURE J-169
MULTIPLE-POINT EXTENSOMETER 51X-GE-00250
E140 DRIFT, SOUTH 3045 FT - FLOOR
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 18 FT X 34 FT.

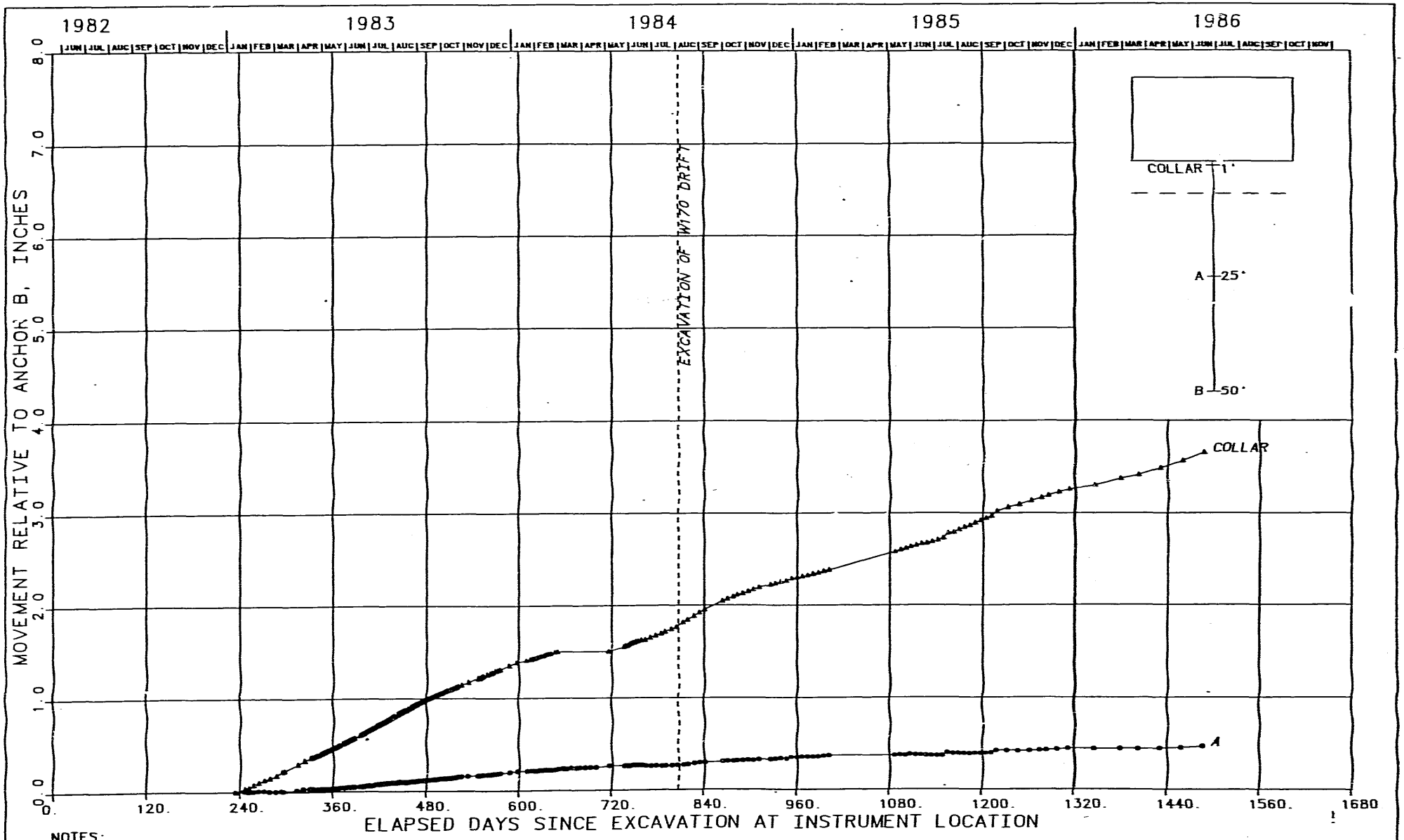
FIGURE J-170
MULTIPLE-POINT EXTENSOMETER 51X-GE-00251
18.5 FT SOUTH OF C & SH SHAFT - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1 SIZE OF EXCAVATION: 18 FT X 35 FT.

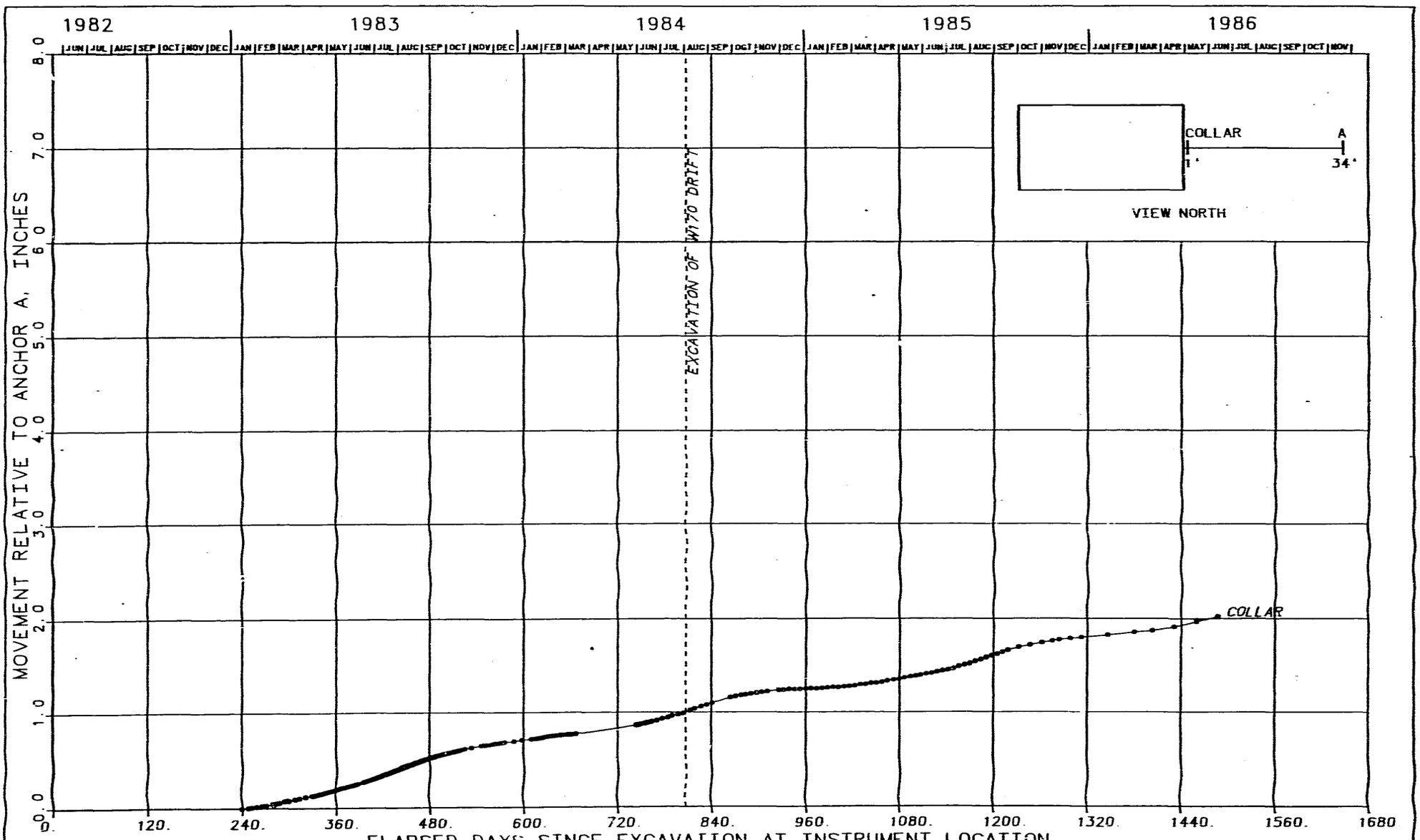
FIGURE J-171
DOUBLE-POINT EXTENSOMETER 51X-GE-00252
30 FT SOUTH OF C & SH SHAFT – W WALL
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 18 FT X 35 FT.

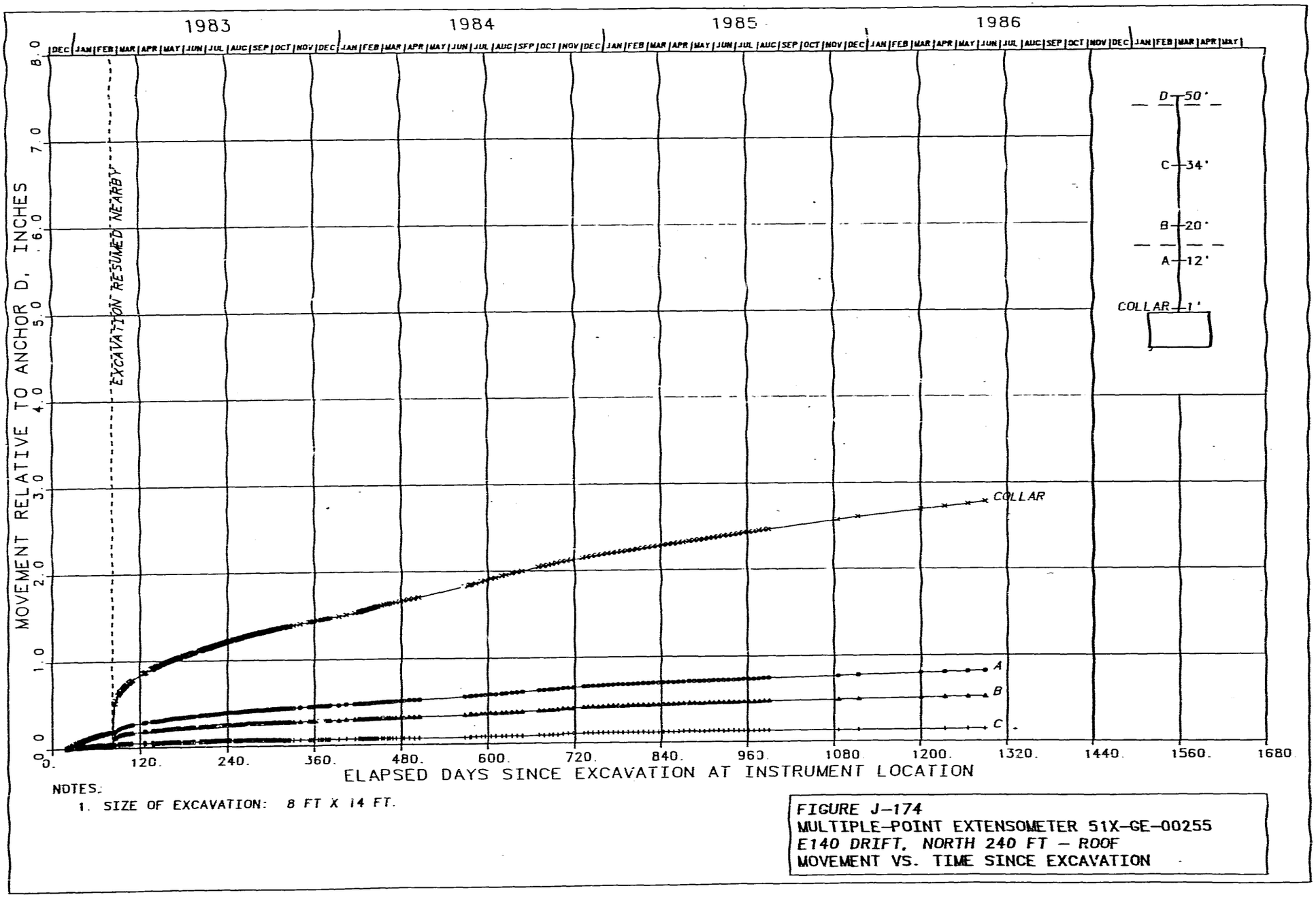
FIGURE J-172
DOUBLE-POINT EXTENSOMETER 51X-GE-00253
30 FT SOUTH OF C & SH SHAFT - FLOOR
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 18 FT X 35 FT.

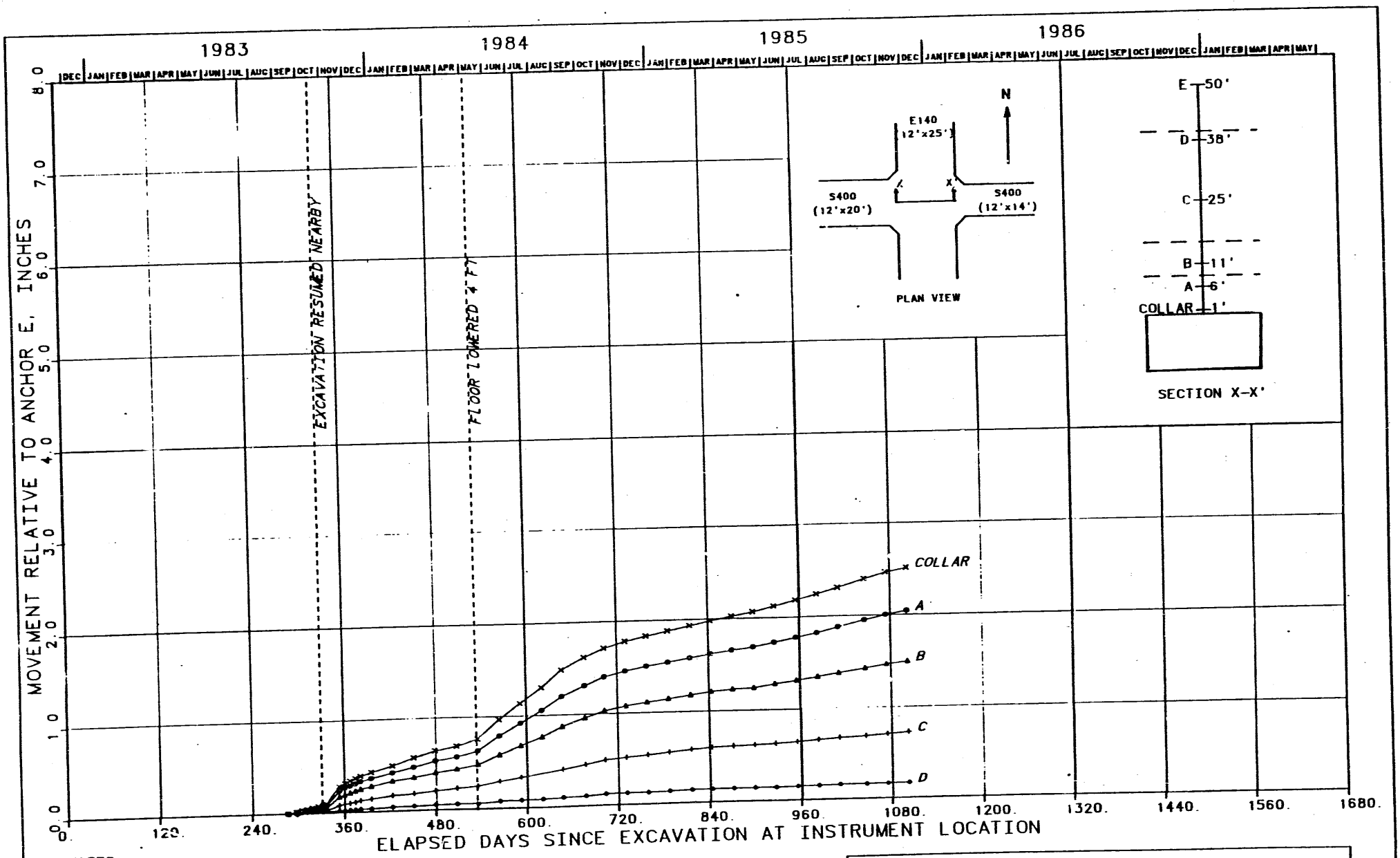
FIGURE J-173
SINGLE-POINT EXTENSOMETER 51X-GE-00254
30 FT SOUTH OF C & SH SHAFT – E WALL
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 8 FT X 14 FT.

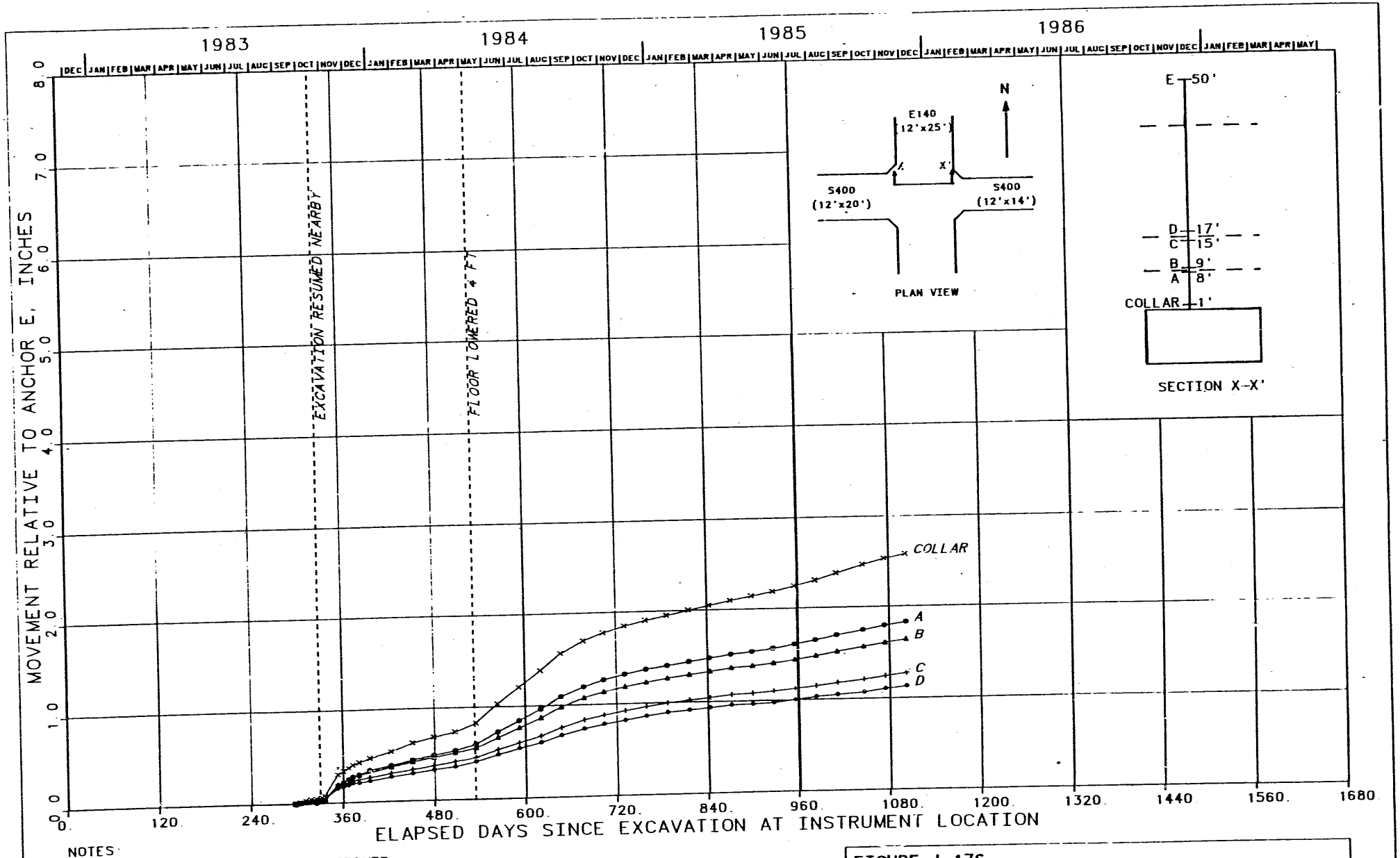
FIGURE J-174
MULTIPLE-POINT EXTENSOMETER 51X-GE-00255
E140 DRIFT, NORTH 240 FT – ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. INSTRUMENT HAS BEEN DESTROYED.

FIGURE J-175
MULTIPLE-POINT EXTENSOMETER 51X-GE-00256
E140 DRIFT - S400 INTERSECTION - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. INSTRUMENT HAS BEEN DESTROYED.

FIGURE J-176
MULTIPLE-POINT EXTENSOMETER 51X-GE-00257
E140 DRIFT - S400 INTERSECTION - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION

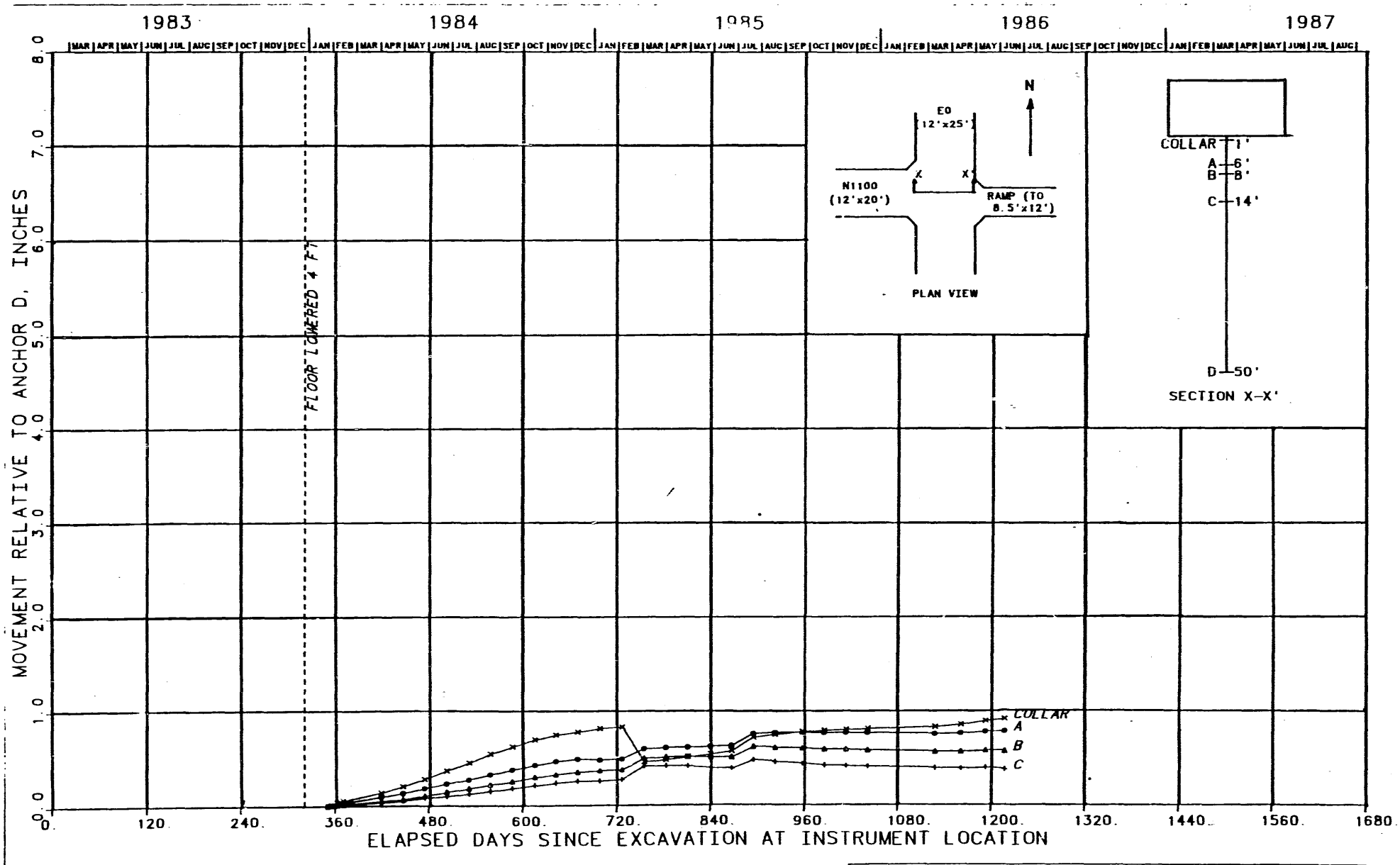


FIGURE J-177
MULTIPLE-POINT EXTENSOMETER 51X-GE-00258
EO DRIFT - N1100 DRIFT INTERSECTION - FLOOR
MOVEMENT VS. TIME SINCE EXCAVATION

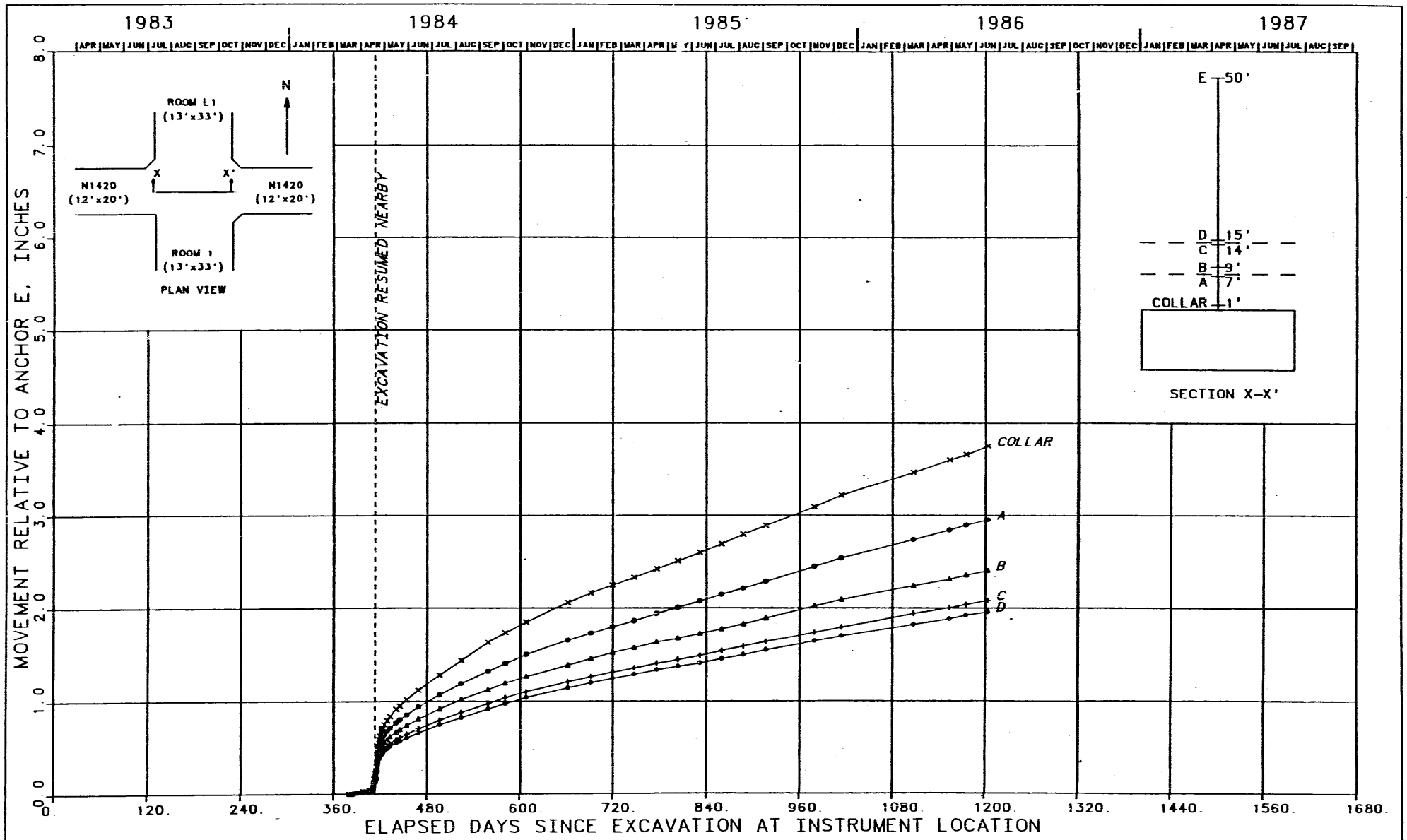


FIGURE J-178
MULTIPLE-POINT EXTENSOMETER 51X-GE-00259
N1420 - TEST ROOM 1 INTERSECTION - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION

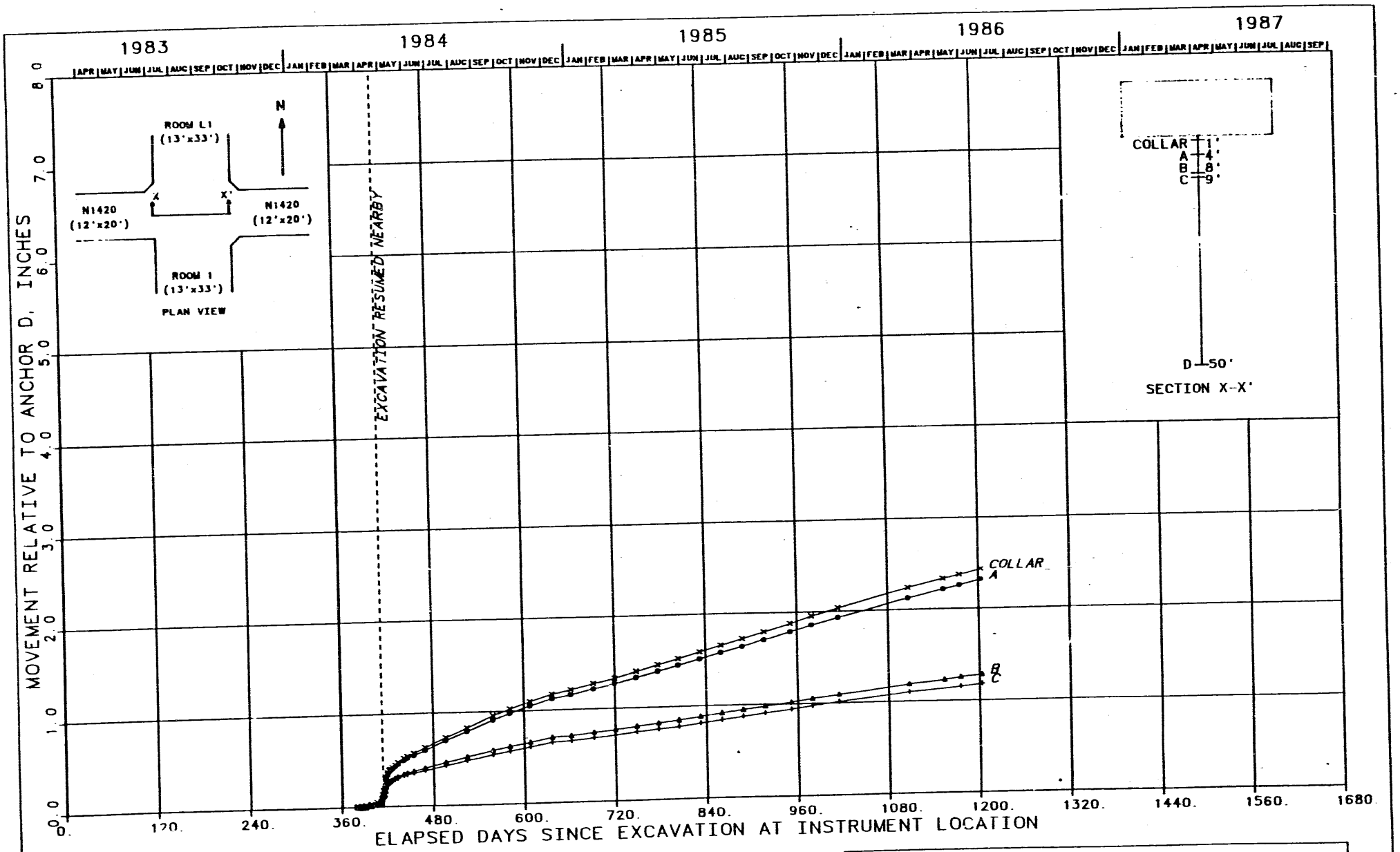


FIGURE J-179
MULTIPLE-POINT EXTENSOMETER 51X-GE-00260
N1420 - TEST ROOM 1 INTERSECTION - FLOOR
MOVEMENT VS. TIME SINCE EXCAVATION

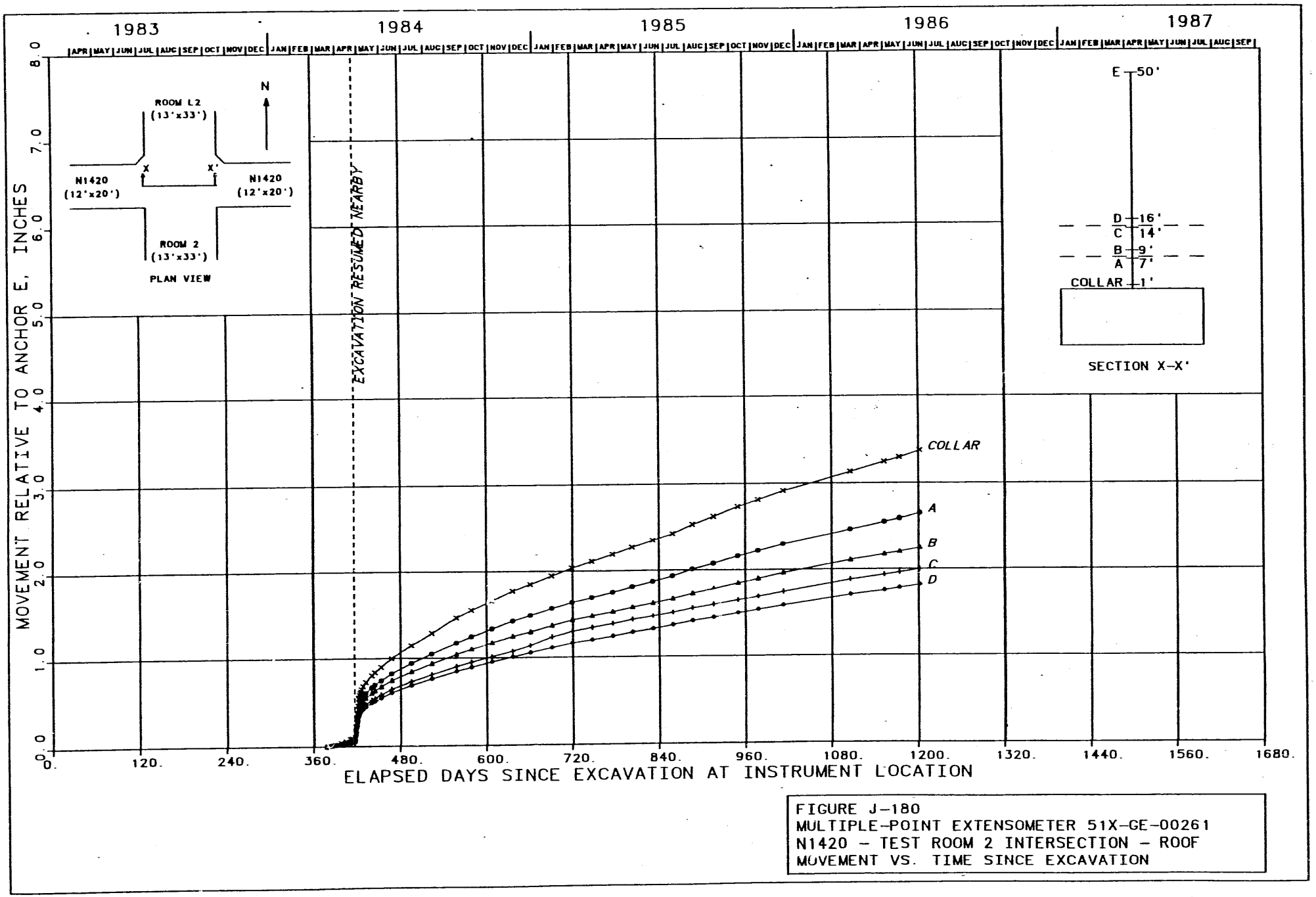


FIGURE J-180
MULTIPLE-POINT EXTENSOMETER 51X-GE-00261
N1420 - TEST ROOM 2 INTERSECTION - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION

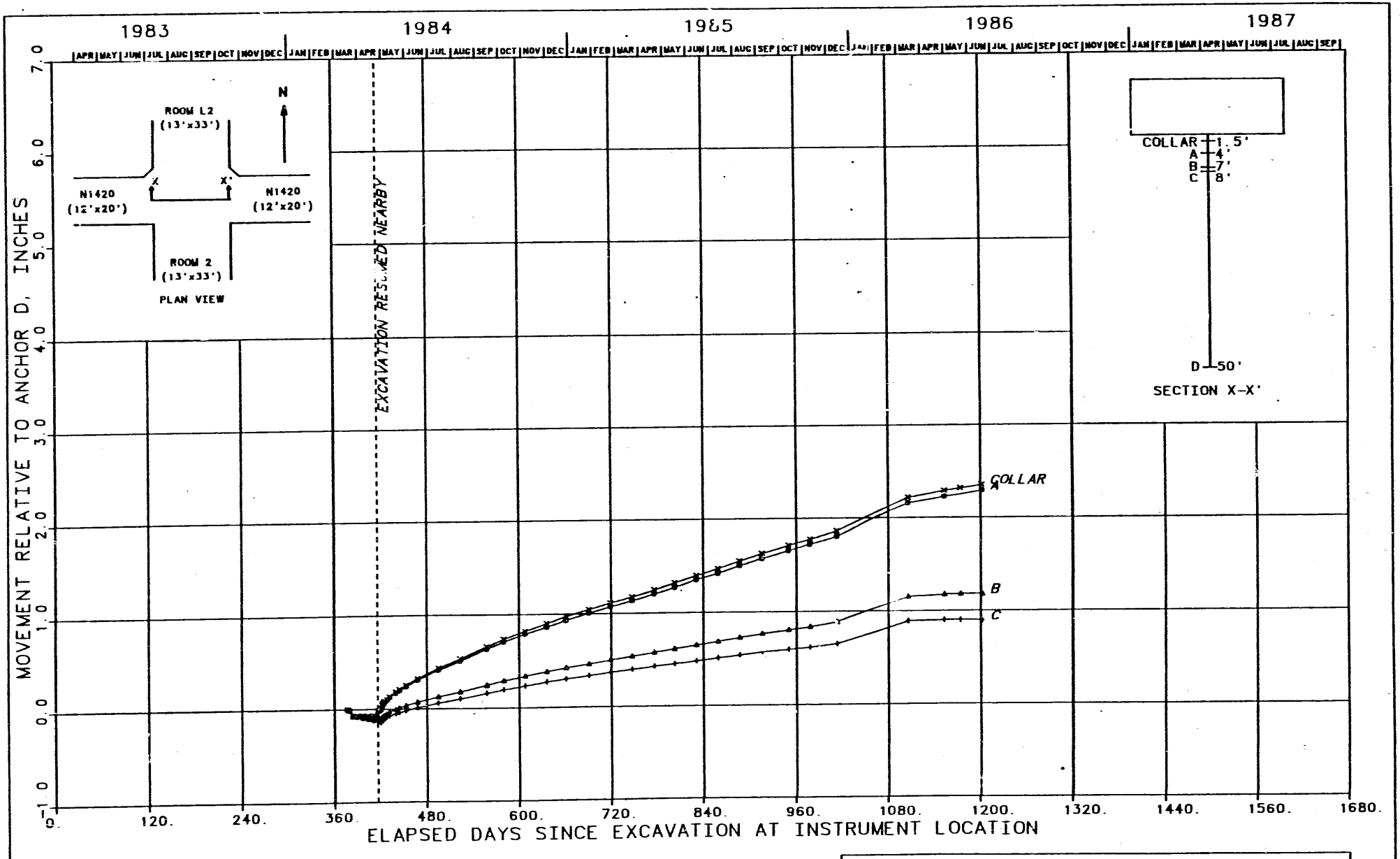


FIGURE J-181
MULTIPLE-POINT EXTENSOMETER 51X-GE-00262
N1420 - TEST ROOM 2 INTERSECTION - FLOOR
MOVEMENT VS. TIME SINCE EXCAVATION

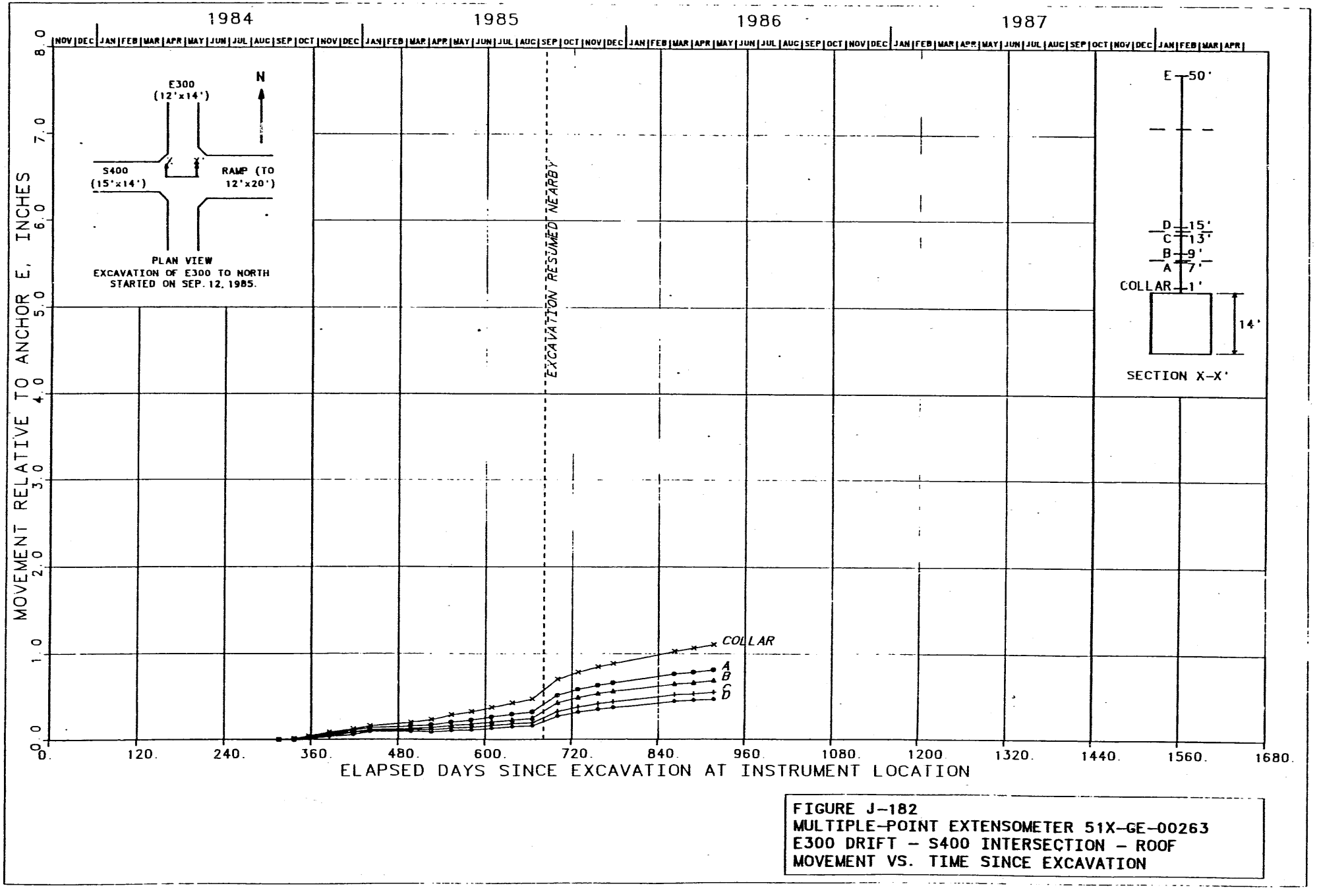
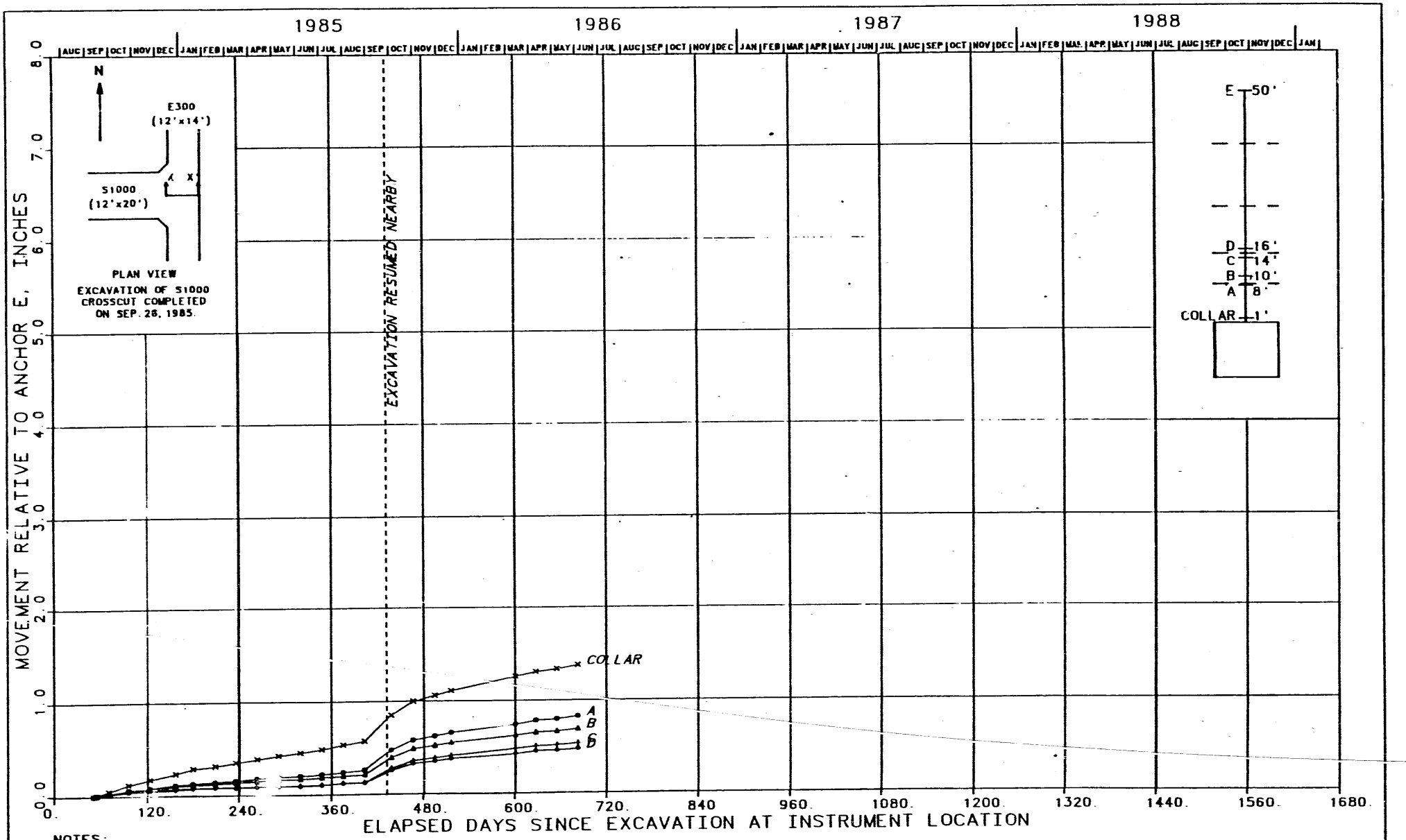


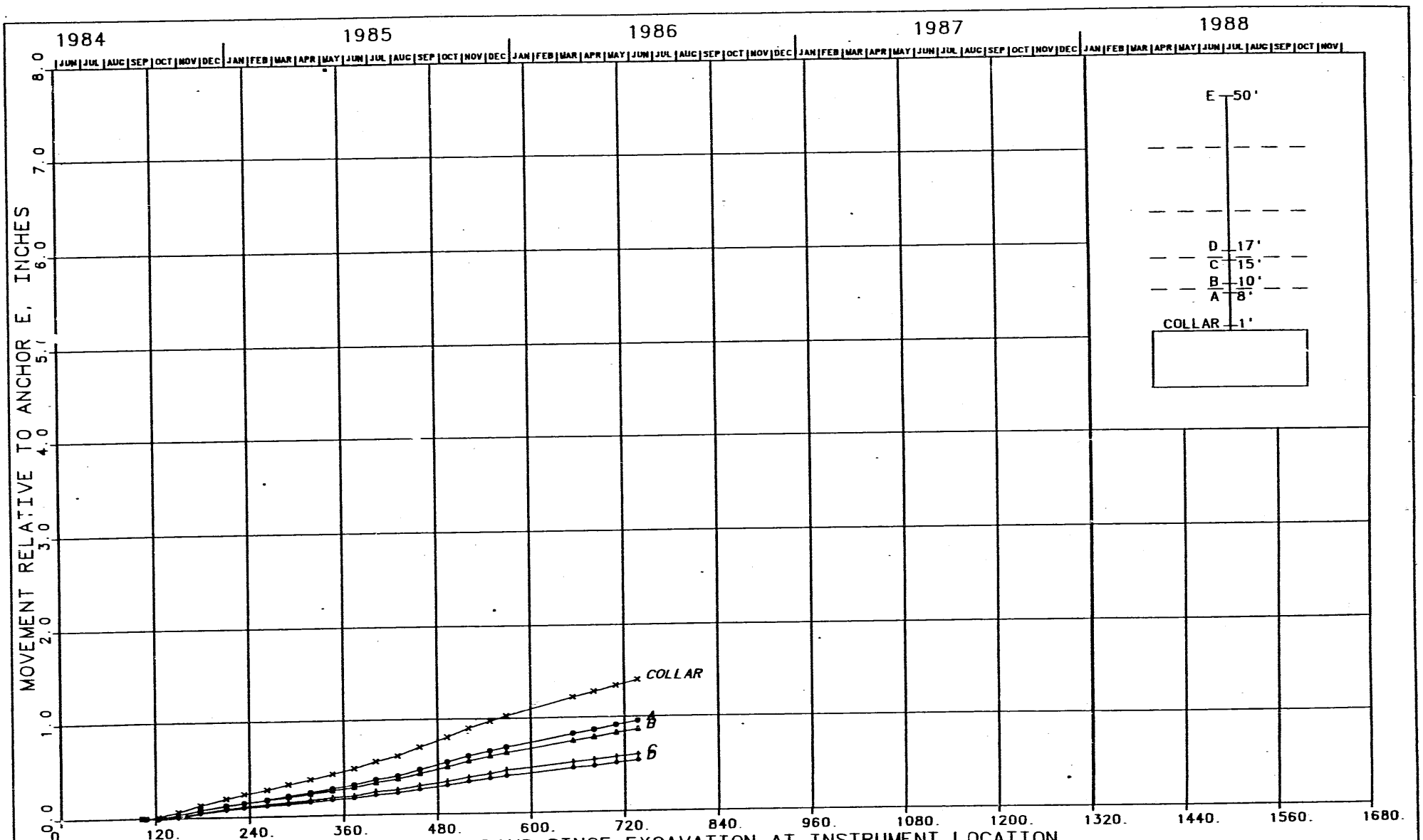
FIGURE J-182
MULTIPLE-POINT EXTENSOMETER 51X-GE-00263
E300 DRIFT - S400 INTERSECTION - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 14 FT.

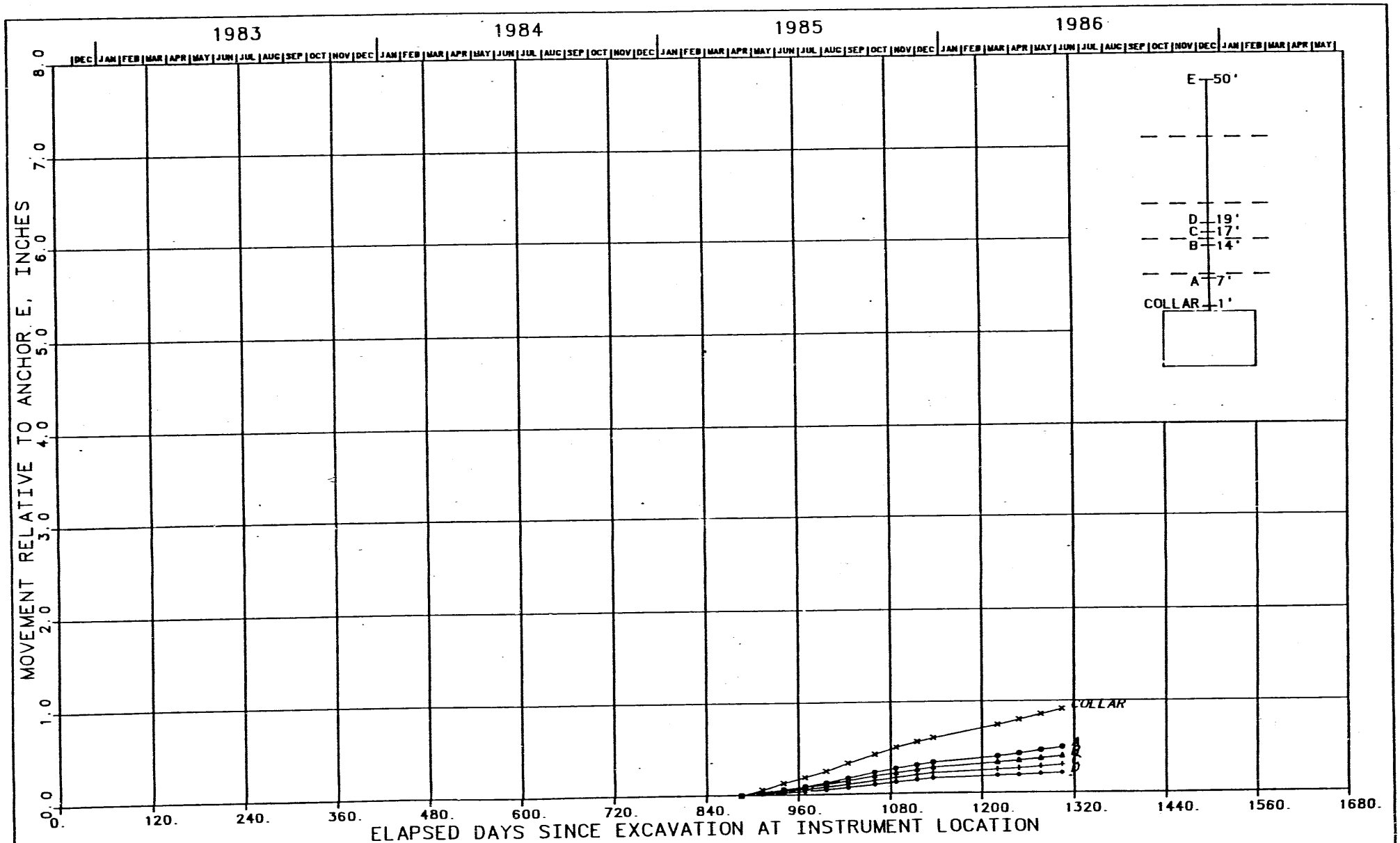
FIGURE J-183
MULTIPLE-POINT EXTENSOMETER 51X-GE-00264
E300 DRIFT - S1000 INTERSECTION - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 33 FT.

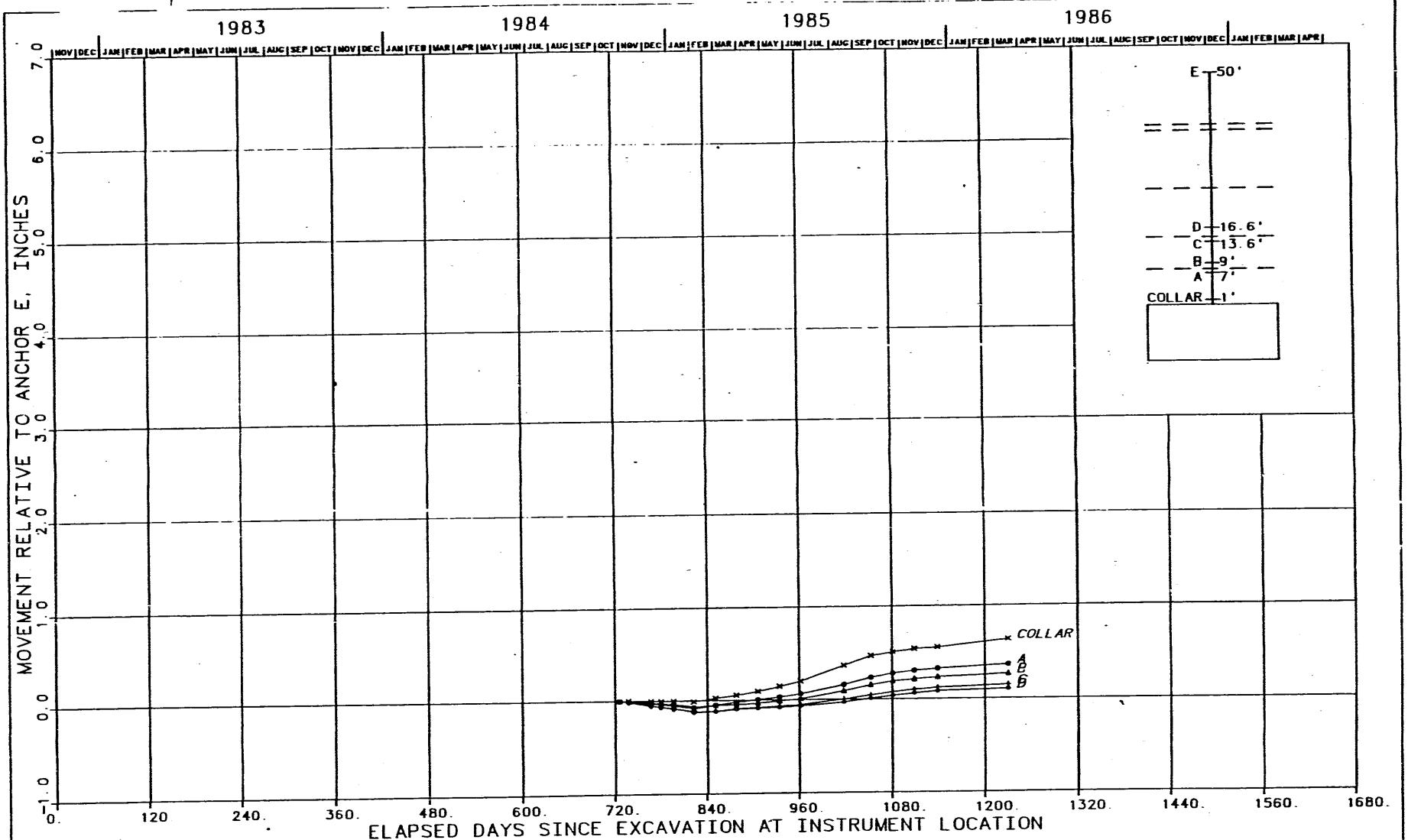
FIGURE J-184
MULTIPLE-POINT EXTENSOMETER 51X-GE-00265
S700 CROSSCUT, EAST 220 FT - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 20 FT.

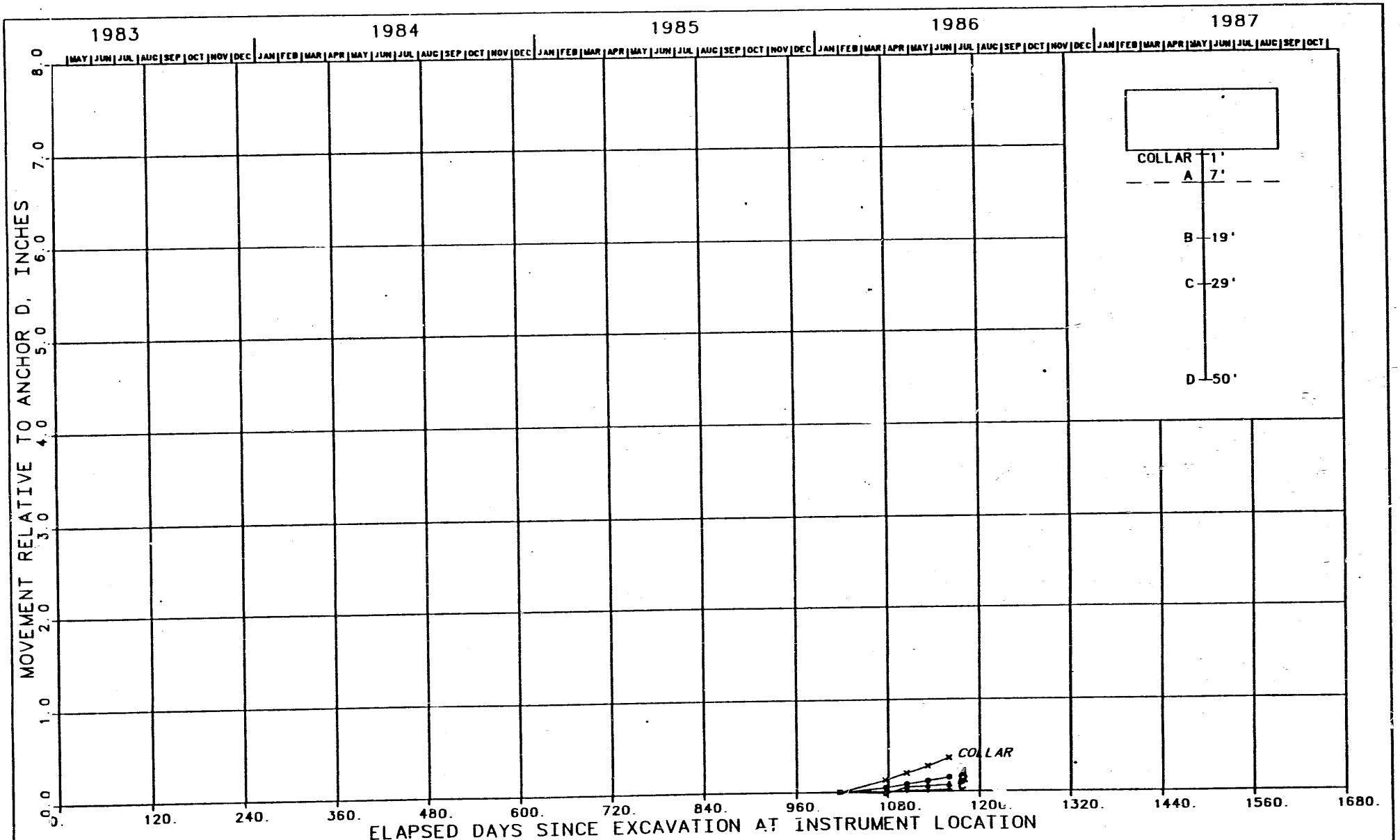
FIGURE J-185
MULTIPLE-POINT EXTENSOMETER 51X-GE-00267
30 FT EAST OF WASTE SHAFT – ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 28 FT.
2. INSTRUMENT IS CURRENTLY NOT ACCESSIBLE FOR READING.

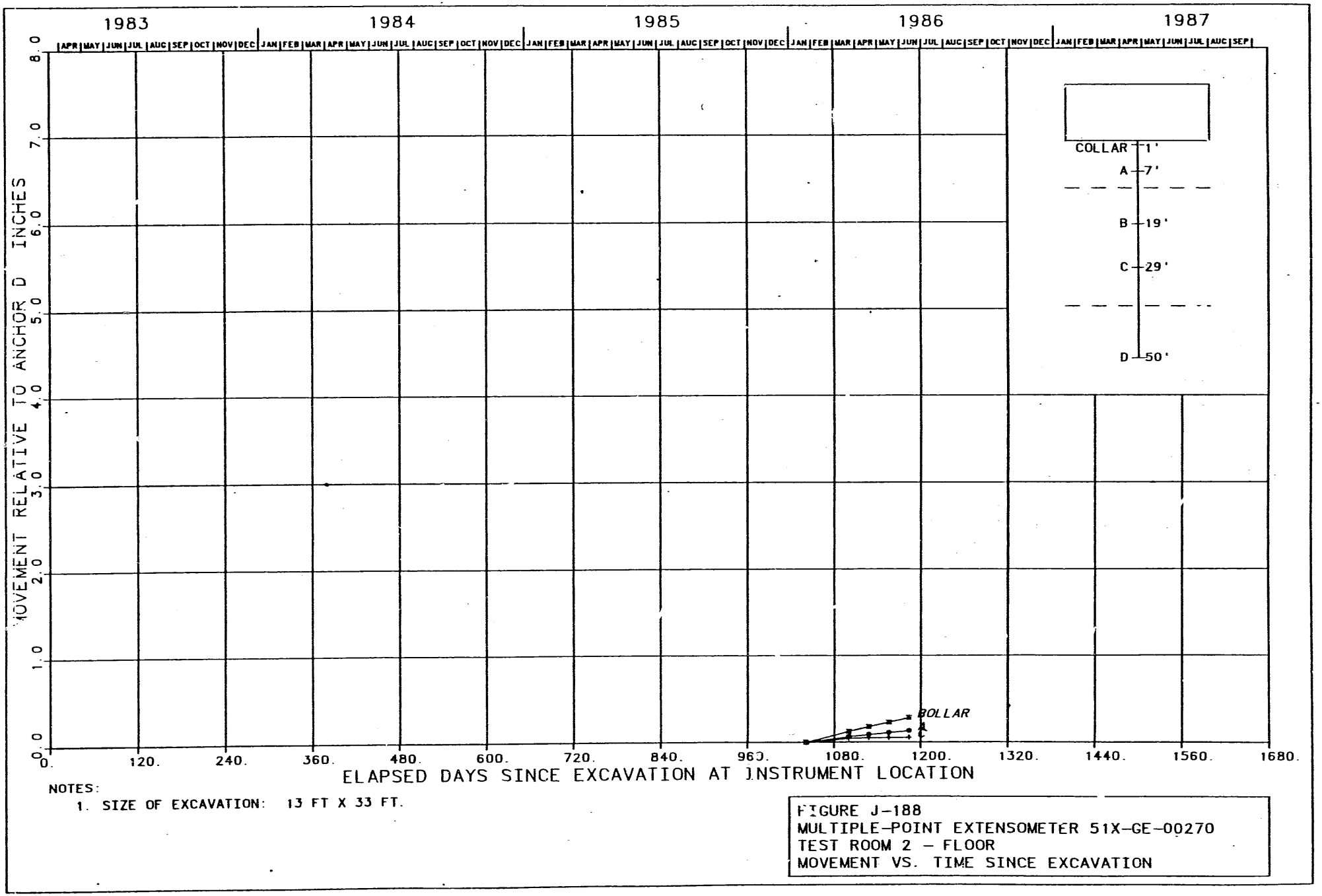
FIGURE J-186
MULTIPLE-POINT EXTENSOMETER 51X-GE-00268
30 FT WEST OF WASTE SHAFT - ROOF
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

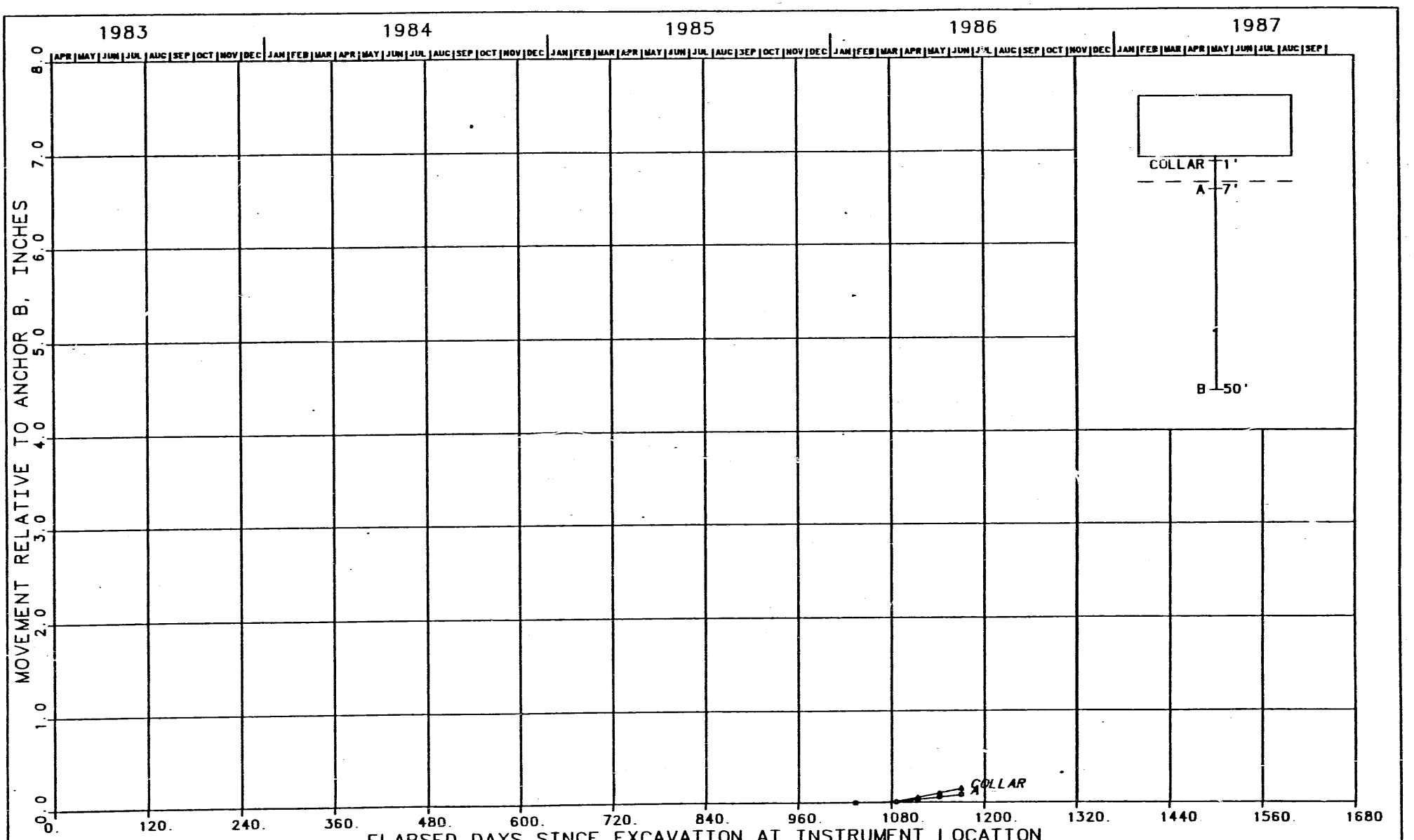
FIGURE J-187
MULTIPLE-POINT EXTENSOMETER 51X-GE-00269
TEST ROOM 1 - FLOOR
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

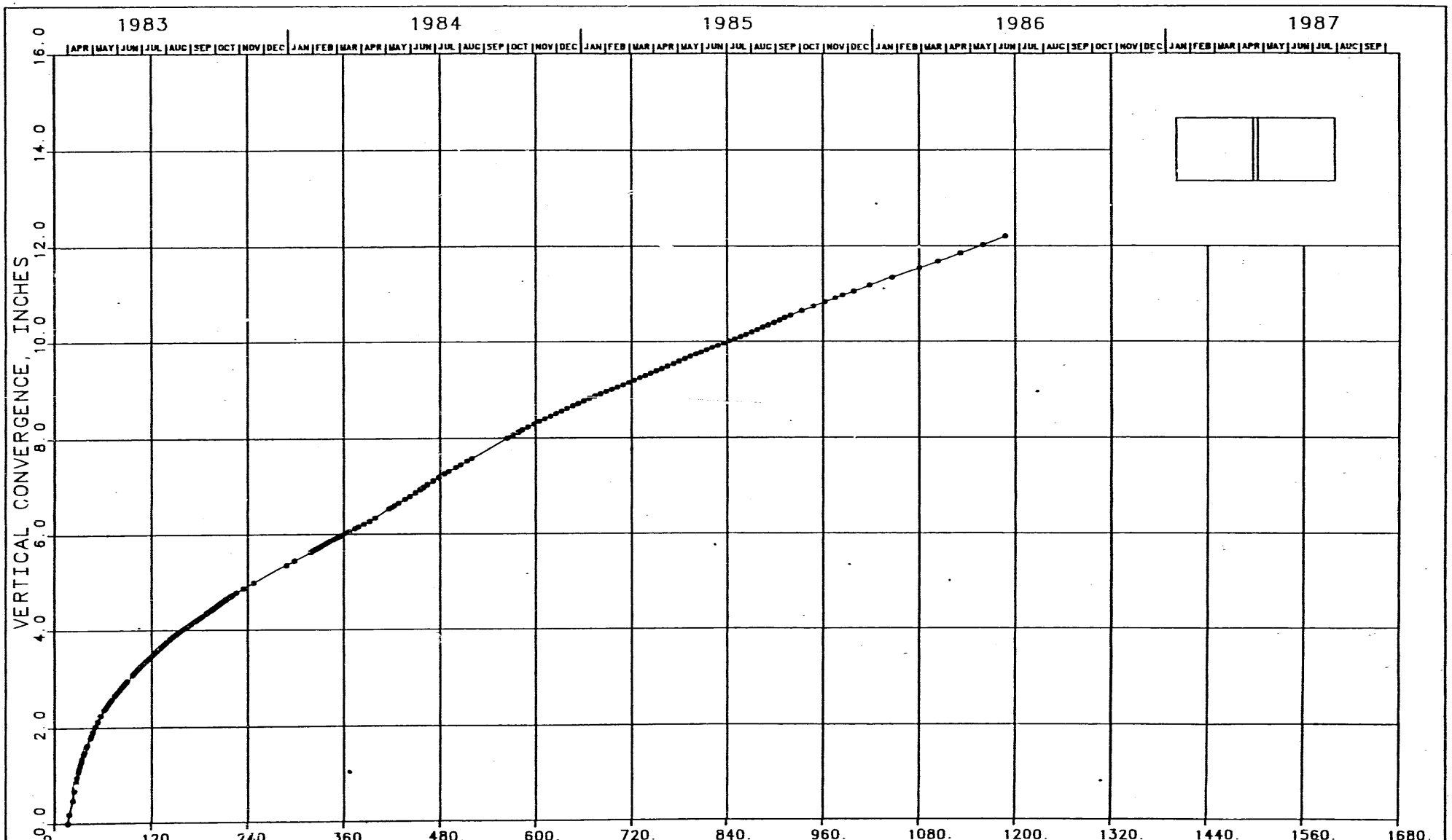
FIGURE J-188
MULTIPLE-POINT EXTENSOMETER 51X-GE-00270
TEST ROOM 2 - FLOOR
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

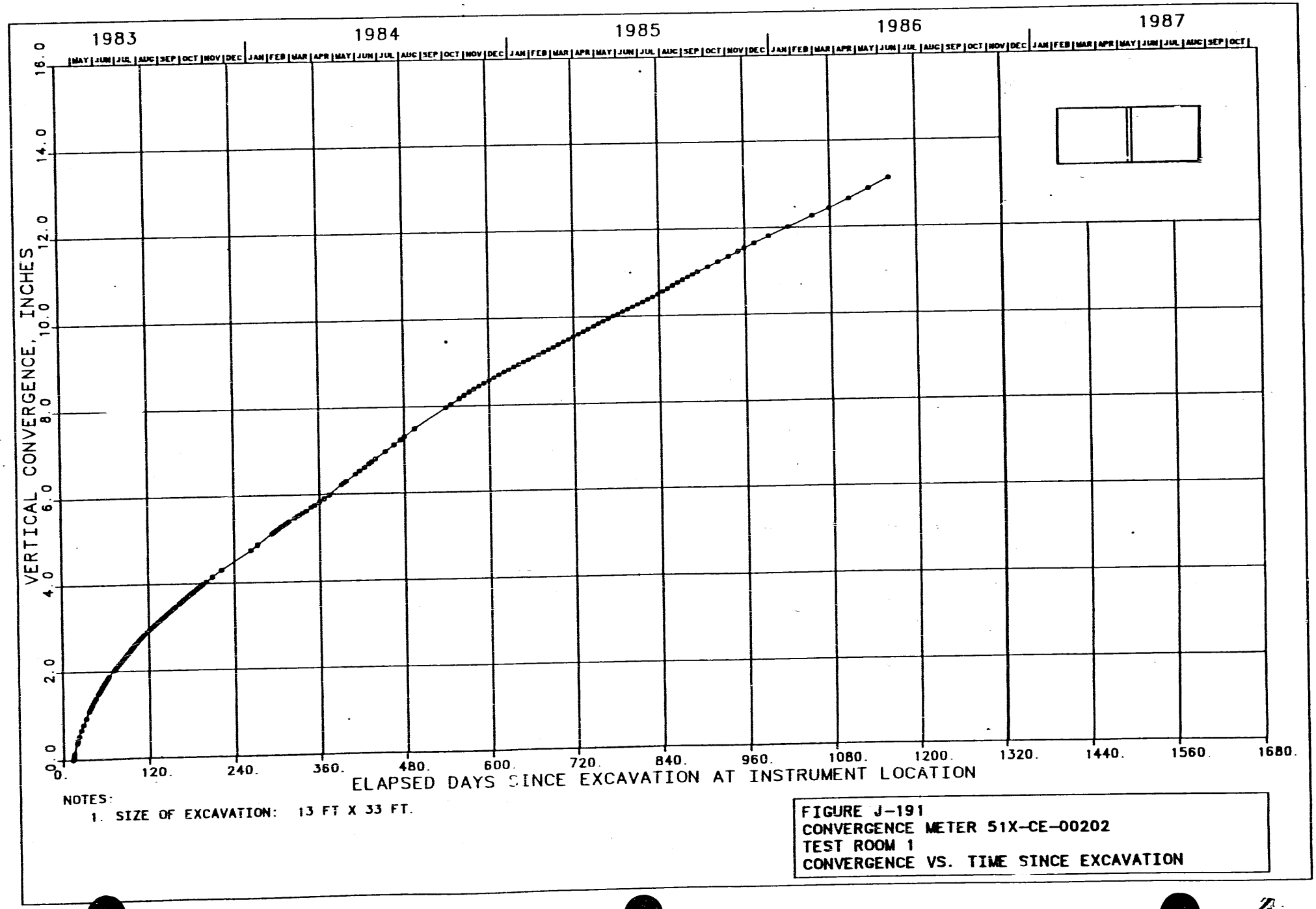
FIGURE J-189
DOUBLE-POINT EXTENSOMETER 51X-GE-00271
TEST ROOM 3 - FLOOR
MOVEMENT VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

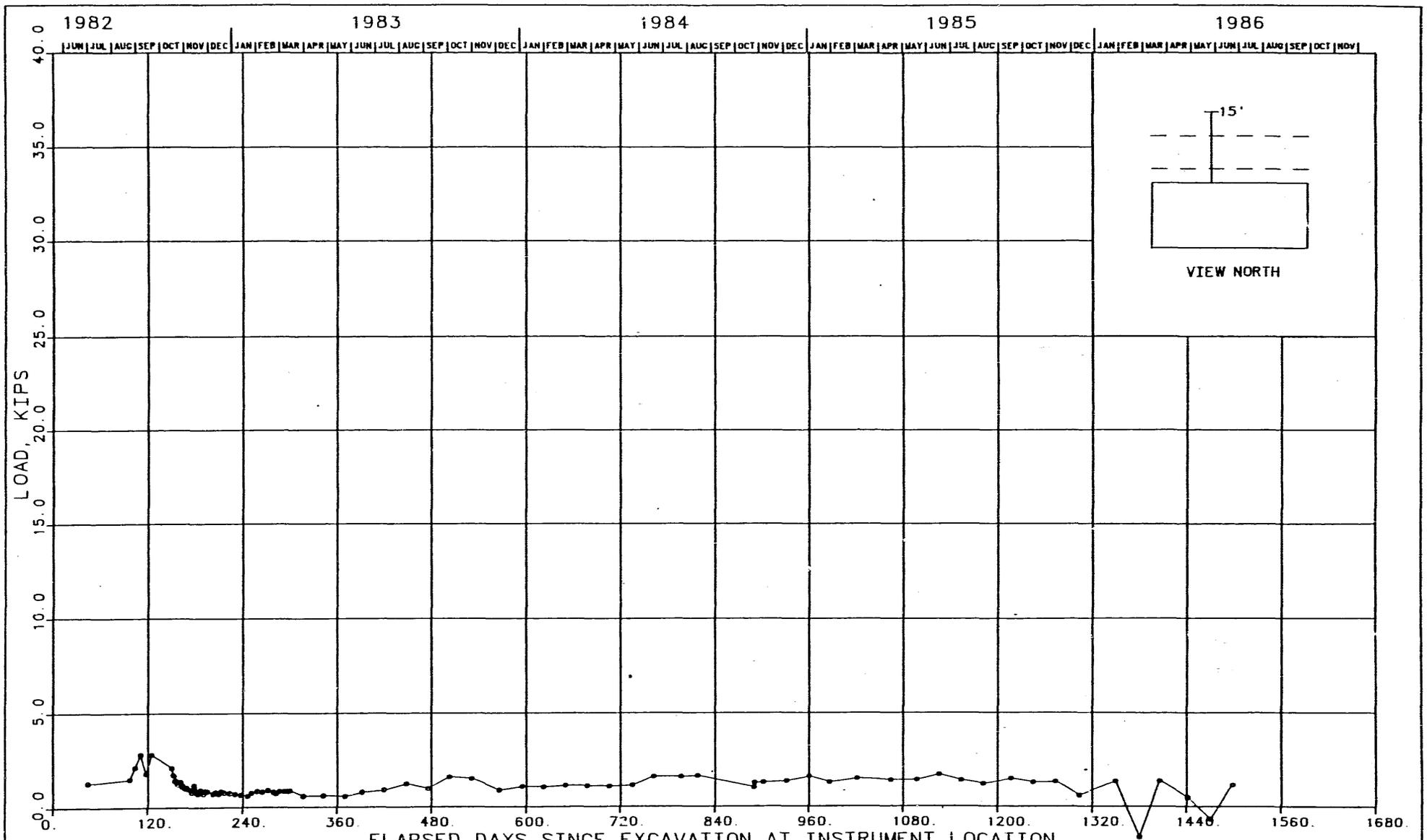
FIGURE J-190
CONVERGENCE METER 51X-CE-00201
TEST ROOM 2
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

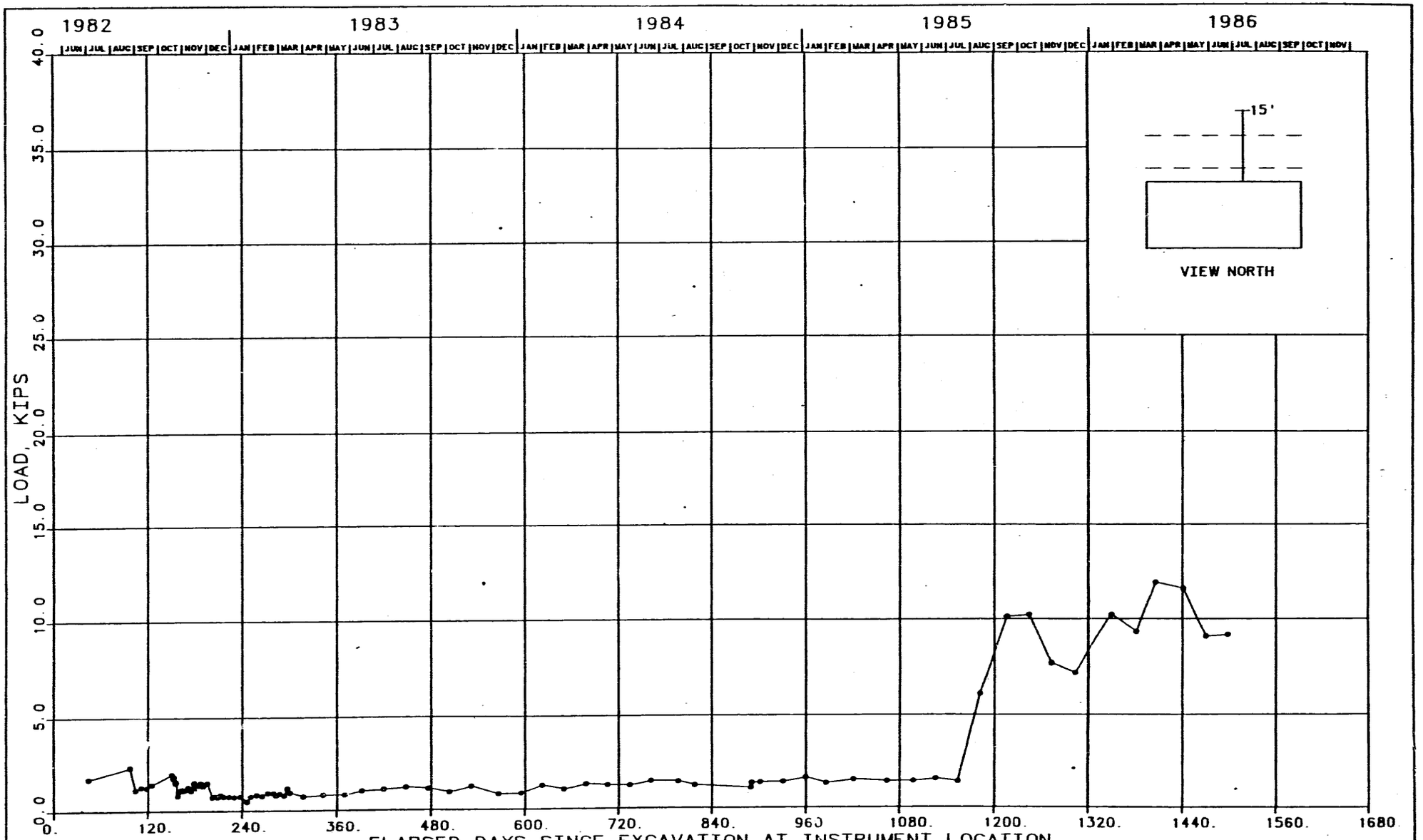
FIGURE J-191
CONVERGENCE METER 51X-CE-00202
TEST ROOM 1
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. ROCKBOLT LENGTH: 15 FT.
2. SIZE OF EXCAVATION: 18 FT X 35 FT.

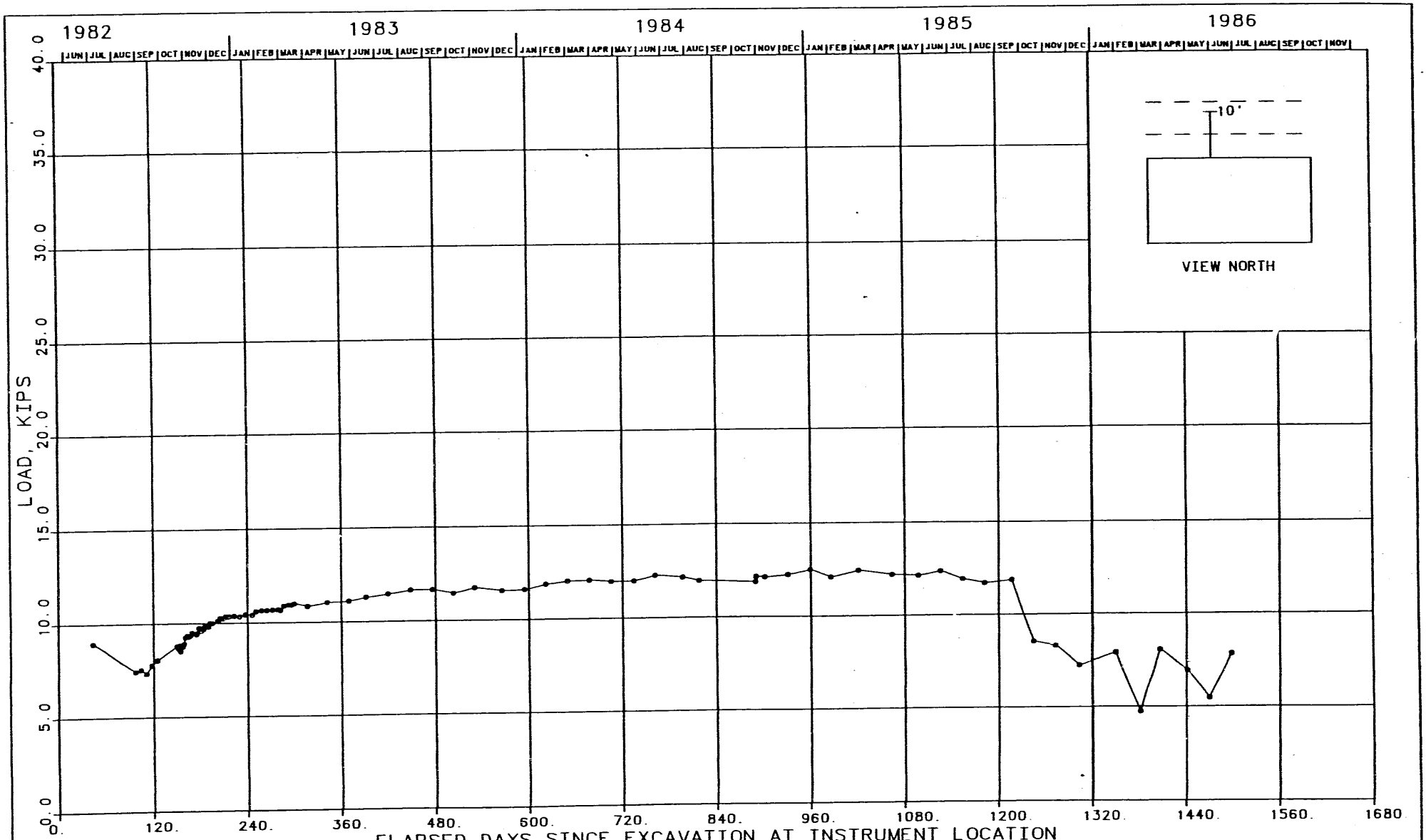
FIGURE J-192
ROCKBOLT LOAD CELL 51X-WG-00201
30 FT SOUTH OF C & SH SHAFT
LOAD VS. TIME SINCE EXCAVATION



NOTES:

1. ROCKBOLT LENGTH: 15 FT.
2. SIZE OF EXCAVATION: 18 FT X 35 FT.

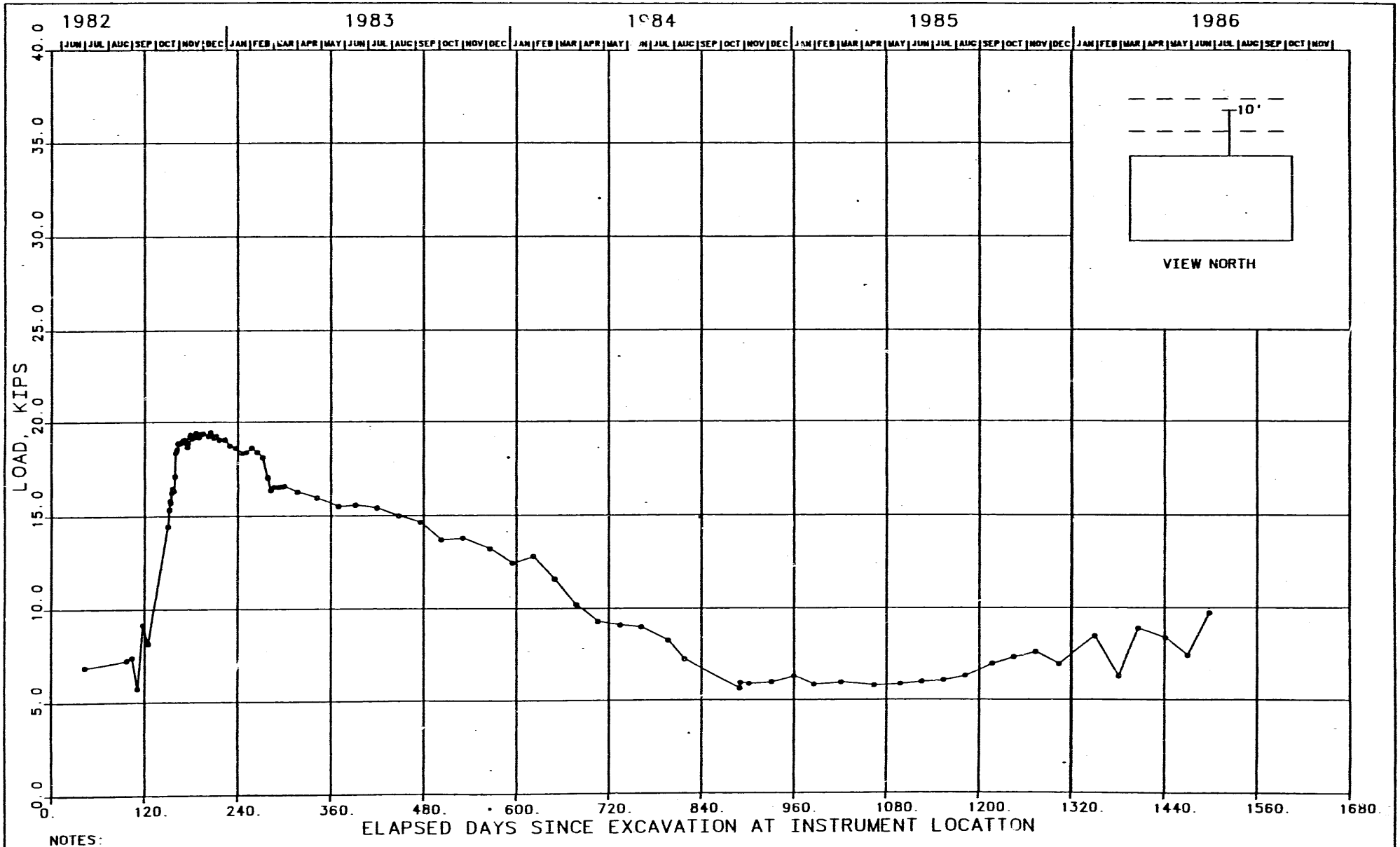
FIGURE J-193
ROCKBOLT LOAD CELL 51X-WG-00202
30 FT SOUTH OF C & SH SHAFT
LOAD VS. TIME SINCE EXCAVATION



NOTES:

1. ROCKBOLT LENGTH: 10 FT.
2. SIZE OF EXCAVATION: 14 FT X 33 FT.

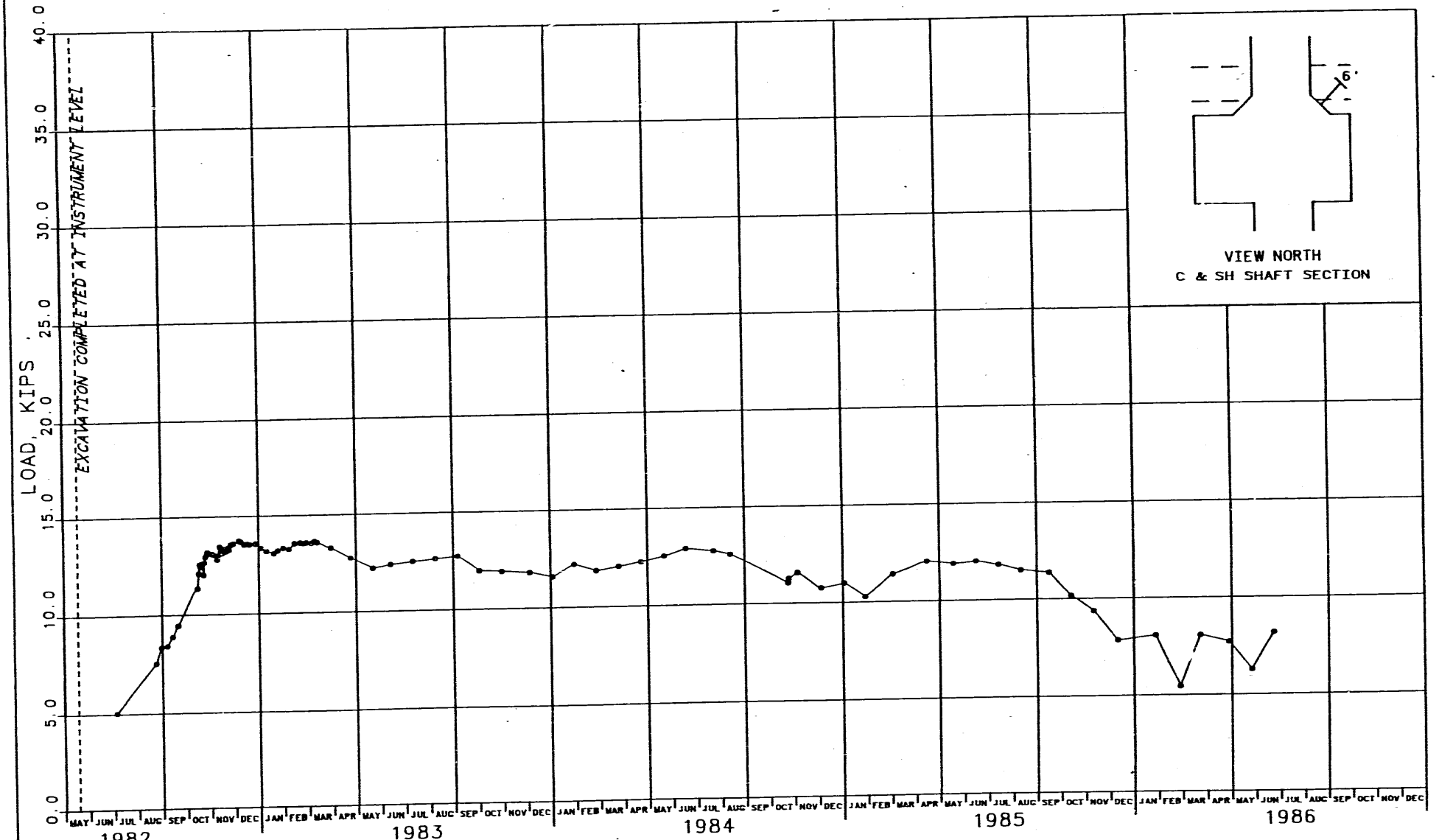
FIGURE J-194
ROCKBOLT LOAD CELL 51X-WG-00203
65 FT SOUTH OF C & SH SHAFT
LOAD VS. TIME SINCE EXCAVATION



NOTES:

1. ROCKBOLT LENGTH: 10 FT.
2. SIZE OF EXCAVATION: 14 FT X 33 FT.

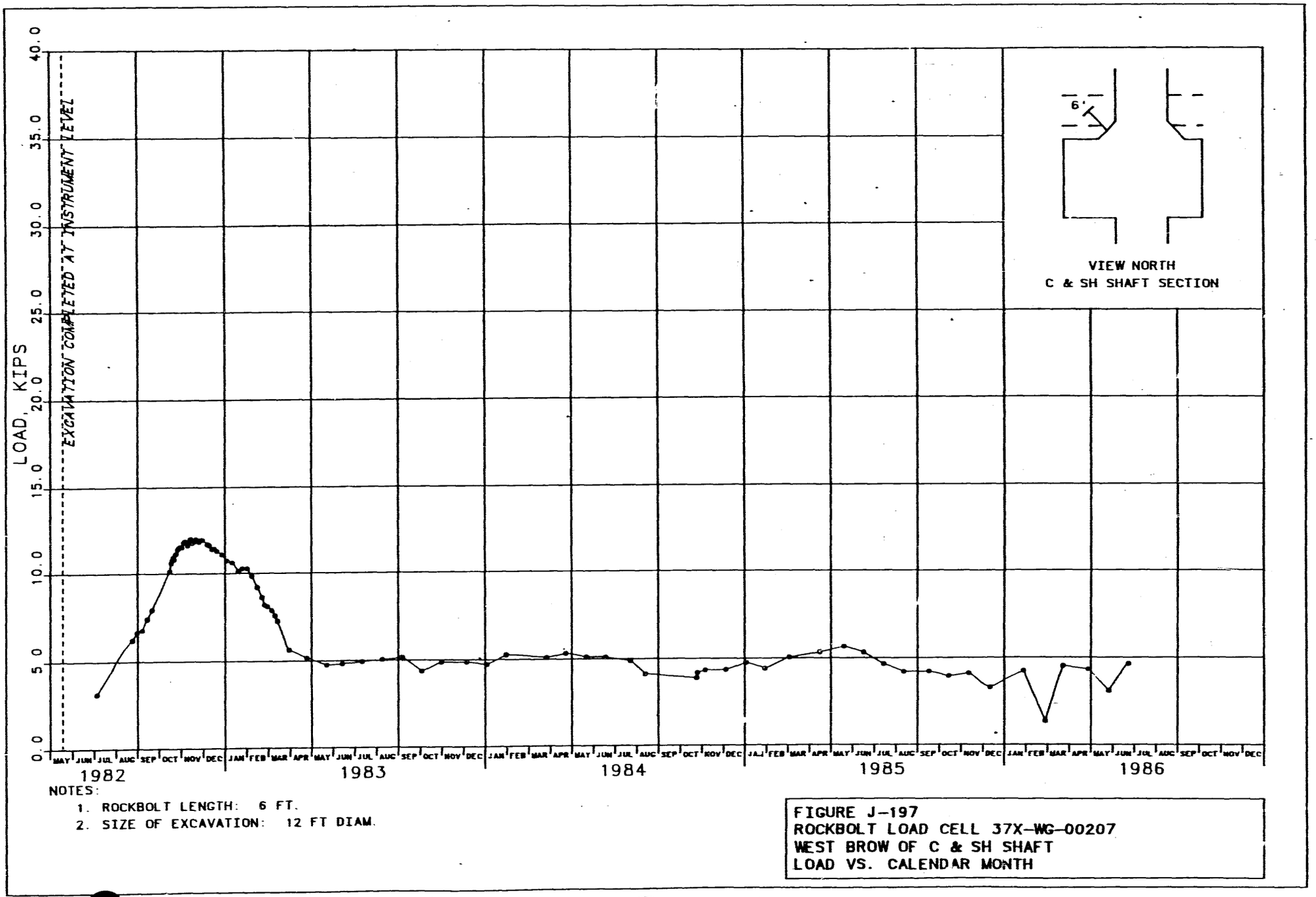
FIGURE J-195
ROCKBOLT LOAD CELL 51X-WG-00204
65 FT SOUTH OF C & SH SHAFT
LOAD VS. TIME SINCE EXCAVATION



NOTES:

1. ROCKBOLT LENGTH: 6 FT.
2. SIZE OF EXCAVATION: 12 FT DIAM.

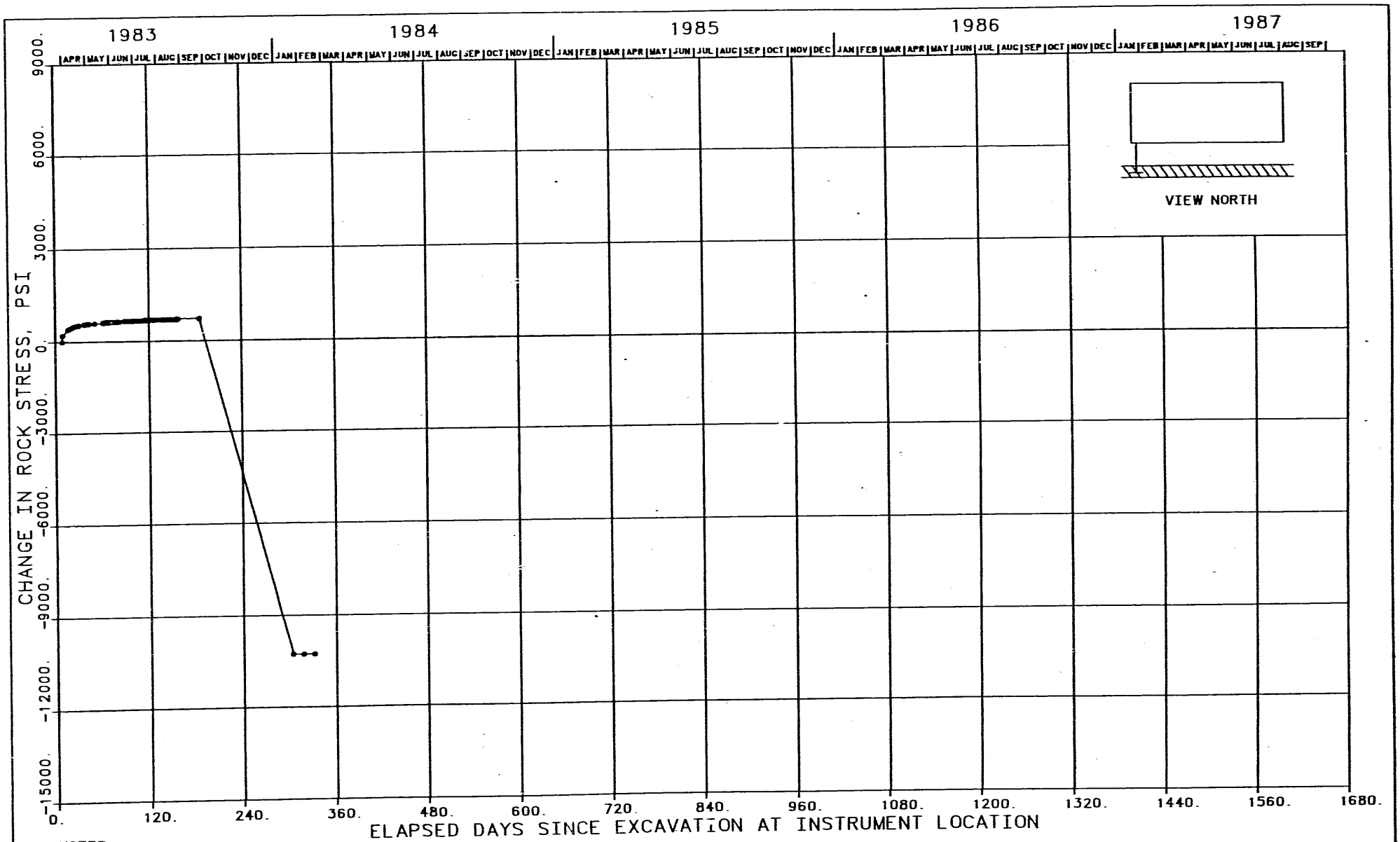
FIGURE J-196
ROCKBOLT LOAD CELL 37X-WG-00206
EAST BROW OF C & SH SHAFT
LOAD VS. CALENDAR MONTH



NOTES:

1. ROCKBOLT LENGTH: 6 FT.
2. SIZE OF EXCAVATION: 12 FT DIAM.

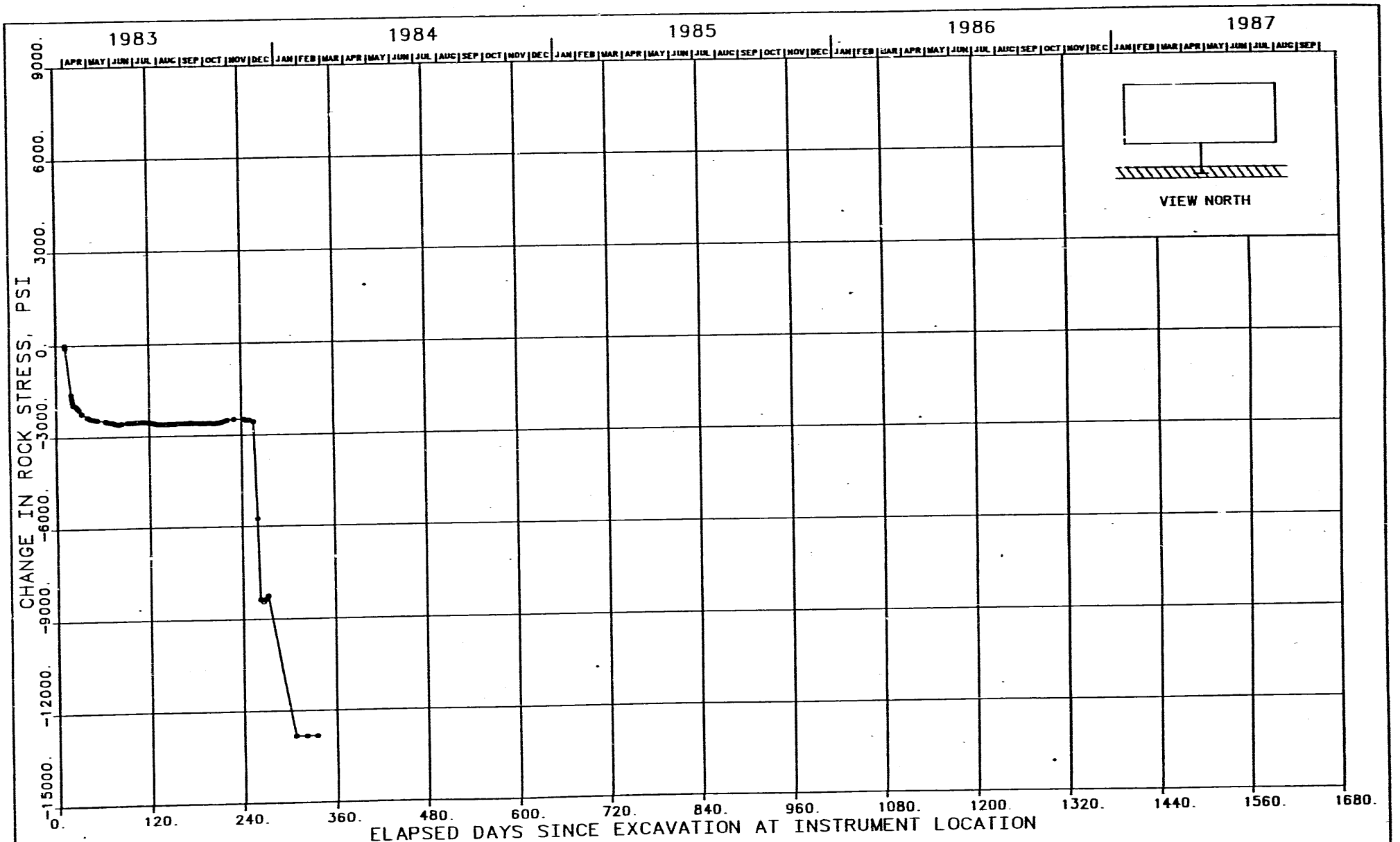
FIGURE J-197
ROCKBOLT LOAD CELL 37X-WG-00207
WEST BROW OF C & SH SHAFT
LOAD VS. CALENDAR MONTH



NOTES:

1. BASED ON WIRE STRESS DIVIDED BY 4.0 (E = 10,900,000 PSI).
2. STRESSMETER DEPTH: 6.5 FT.
3. SIZE OF EXCAVATION: 13 FT X 33 FT.
4. INSTRUMENT HAS PERMANENTLY FAILED.

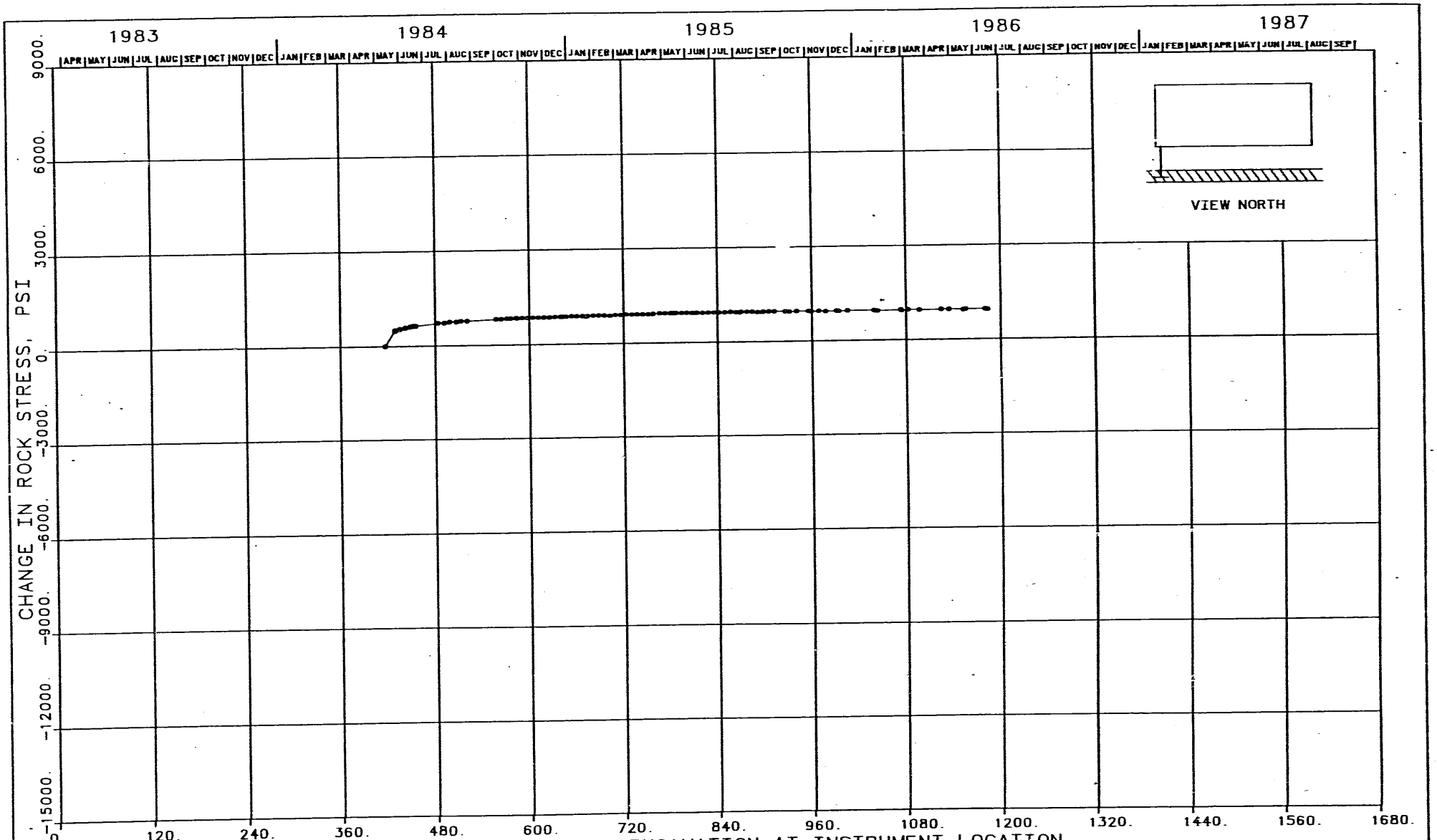
FIGURE J-138
RIGID STRESSMETER 51X-NG-00252
TEST ROOM 2 - W FLOOR (1 FT FROM WALL)
STRESS VS. TIME SINCE EXCAVATION



NOTES:

1. BASED ON WIRE STRESS DIVIDED BY 4.0 ($\underline{E}$ = 10,900,000 PSI).
2. STRESSMETER DEPTH: 6.5 FT.
3. SIZE OF EXCAVATION: 13 FT X 33 FT.
4. INSTRUMENT HAS PERMANENTLY FAILED.

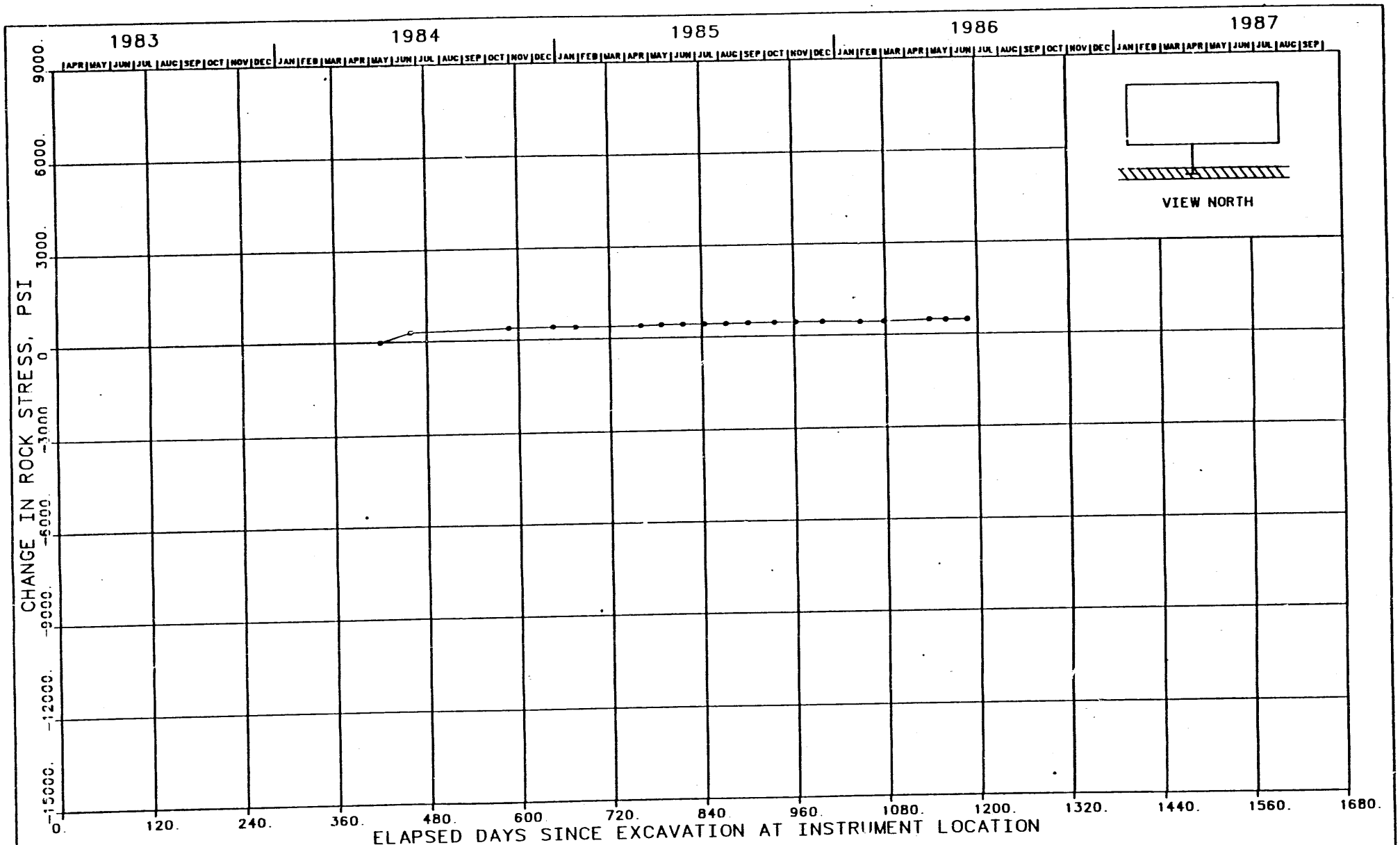
FIGURE J-199
RIGID STRESSMETER 51X-NG-00254
TEST ROOM 2 - CENTER FLOOR
STRESS VS. TIME SINCE EXCAVATION



NOTES:

1. BASED ON WIRE STRESS DIVIDED BY 4.0 (E = 10,900,000 PSI).
2. STRESSMETER DEPTH: 6.5 FT.
3. SIZE OF EXCAVATION: 13 FT X 33 FT.

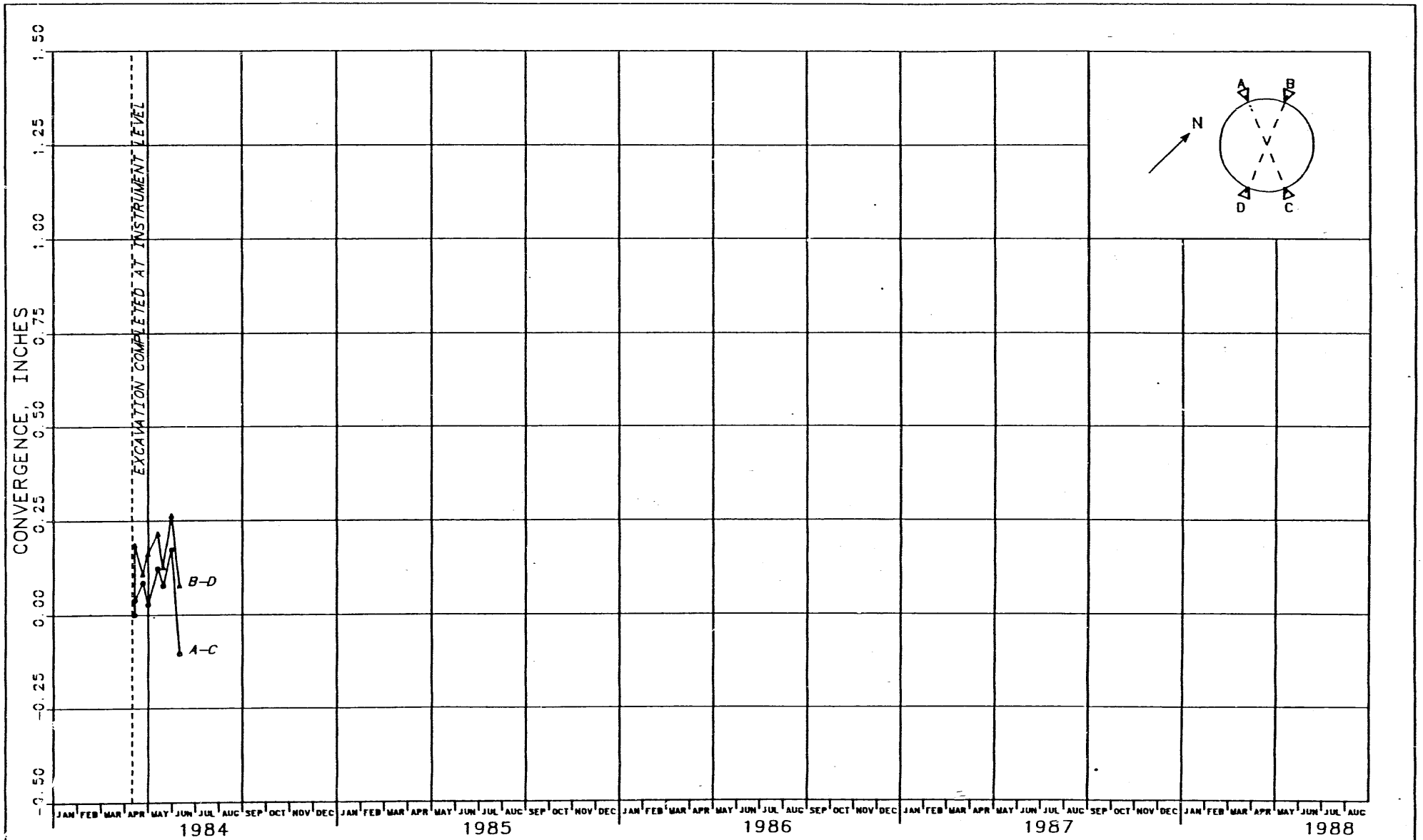
FIGURE J-200
RIGID STRESSMETER 51X-NG-00255
TEST ROOM 2 - W FLOOR (1 FT FROM WALL)
STRESS VS. TIME SINCE EXCAVATION



NOTES:

1. BASED ON WIRE STRESS DIVIDED BY 4.0 (E = 10,900,000 PSI).
2. STRESSMETER DEPTH: 6.5 FT.
3. SIZE OF EXCAVATION: 13 FT X 33 FT.

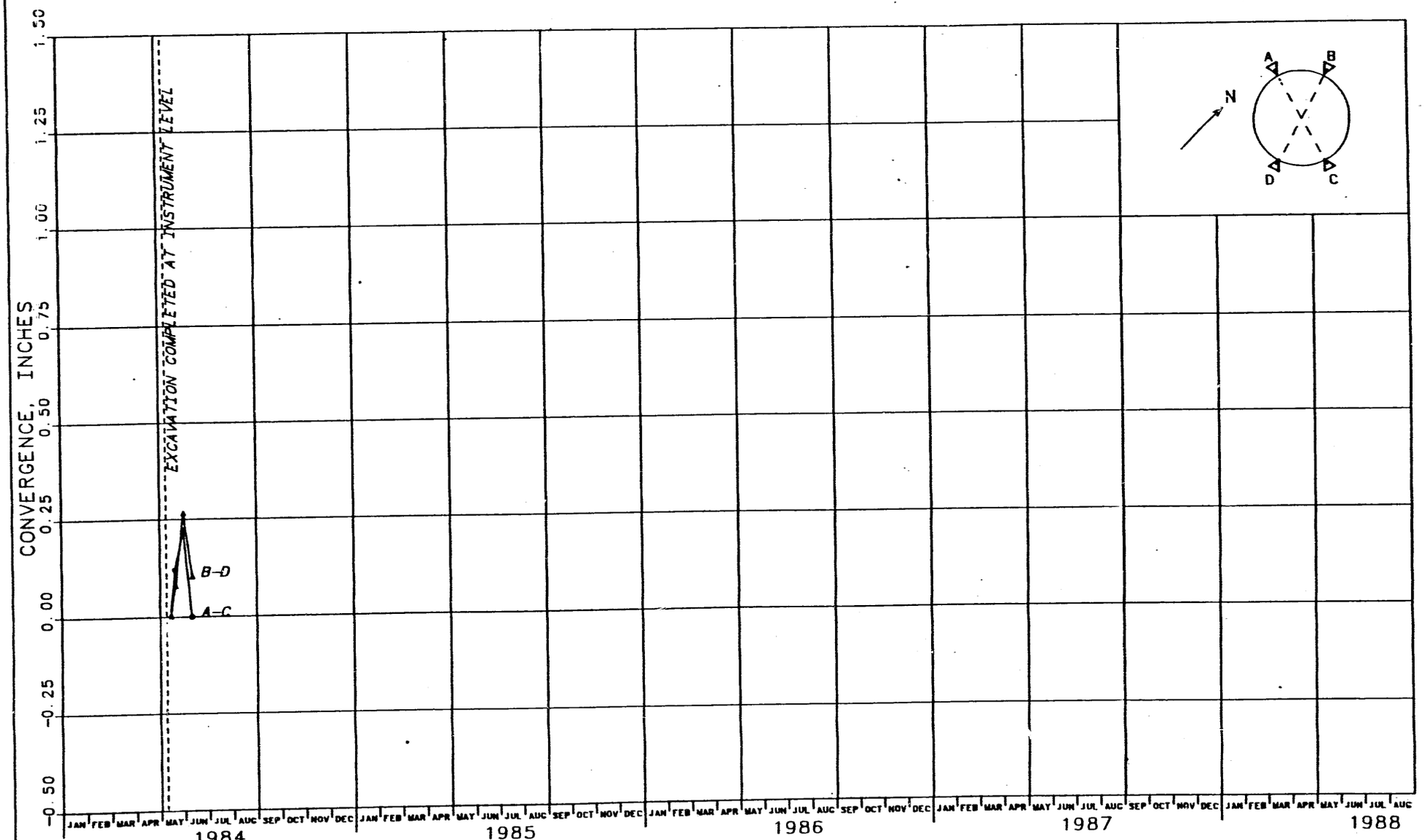
FIGURE J-201
RIGID STRESSMETER 51X-NG-00256
TEST ROOM 2 - FLOOR (2.5 FT WEST OF CENTER)
STRESS VS. TIME SINCE EXCAVATION



NOTES;

1. SIZE OF EXCAVATION: 20 FT DIAM.
2. INSTRUMENT IS CURRENTLY NOT ACCESSIBLE FOR READING.

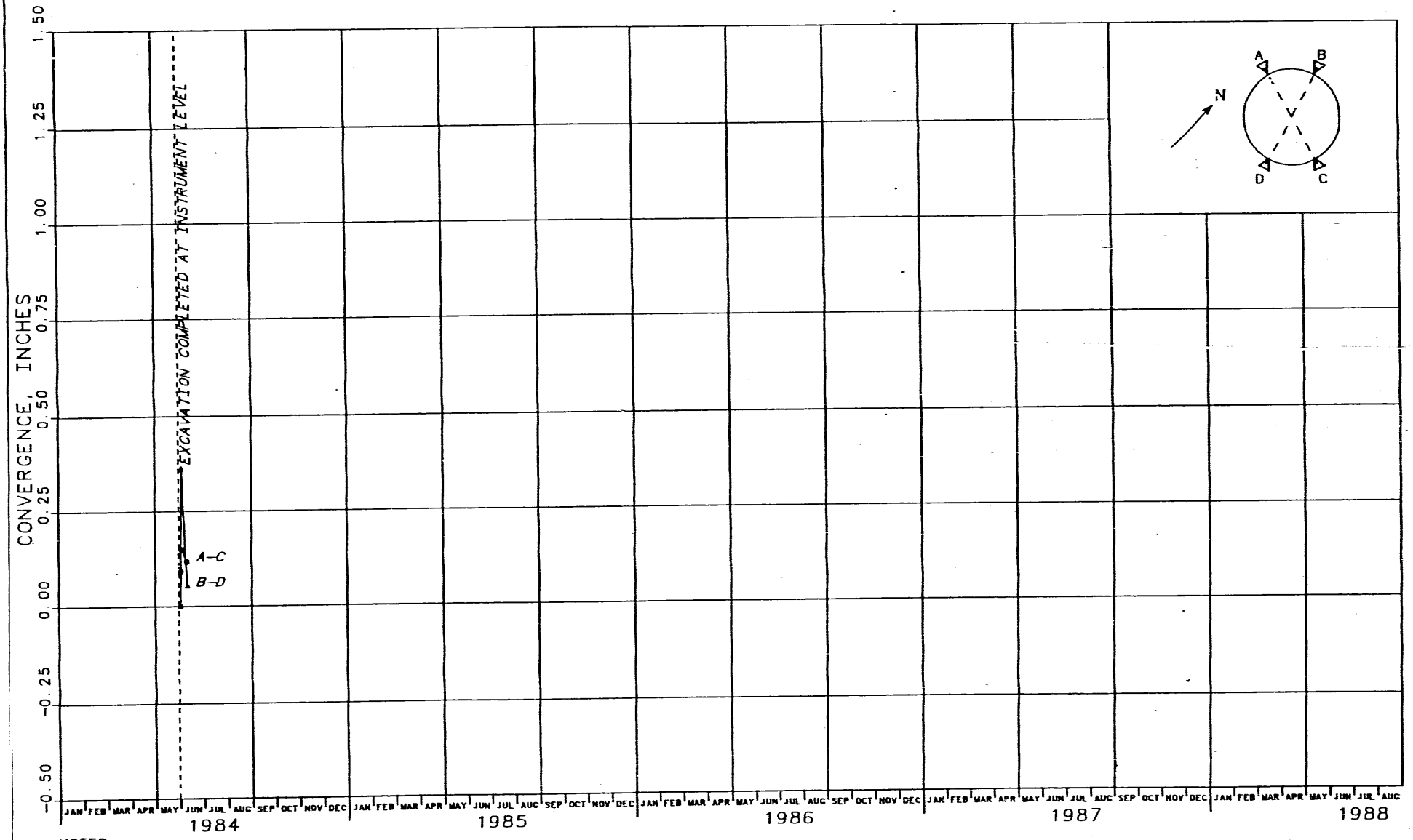
FIGURE J-202
CONVERGENCE POINTS
WASTE SHAFT - EL 2338 - BELOW KEY
CONVERGENCE VS. CALENDAR MONTH



NOTES:

1. SIZE OF EXCAVATION: 20 FT DIAM.
2. INSTRUMENT IS CURRENTLY NOT ACCESSIBLE FOR READING.

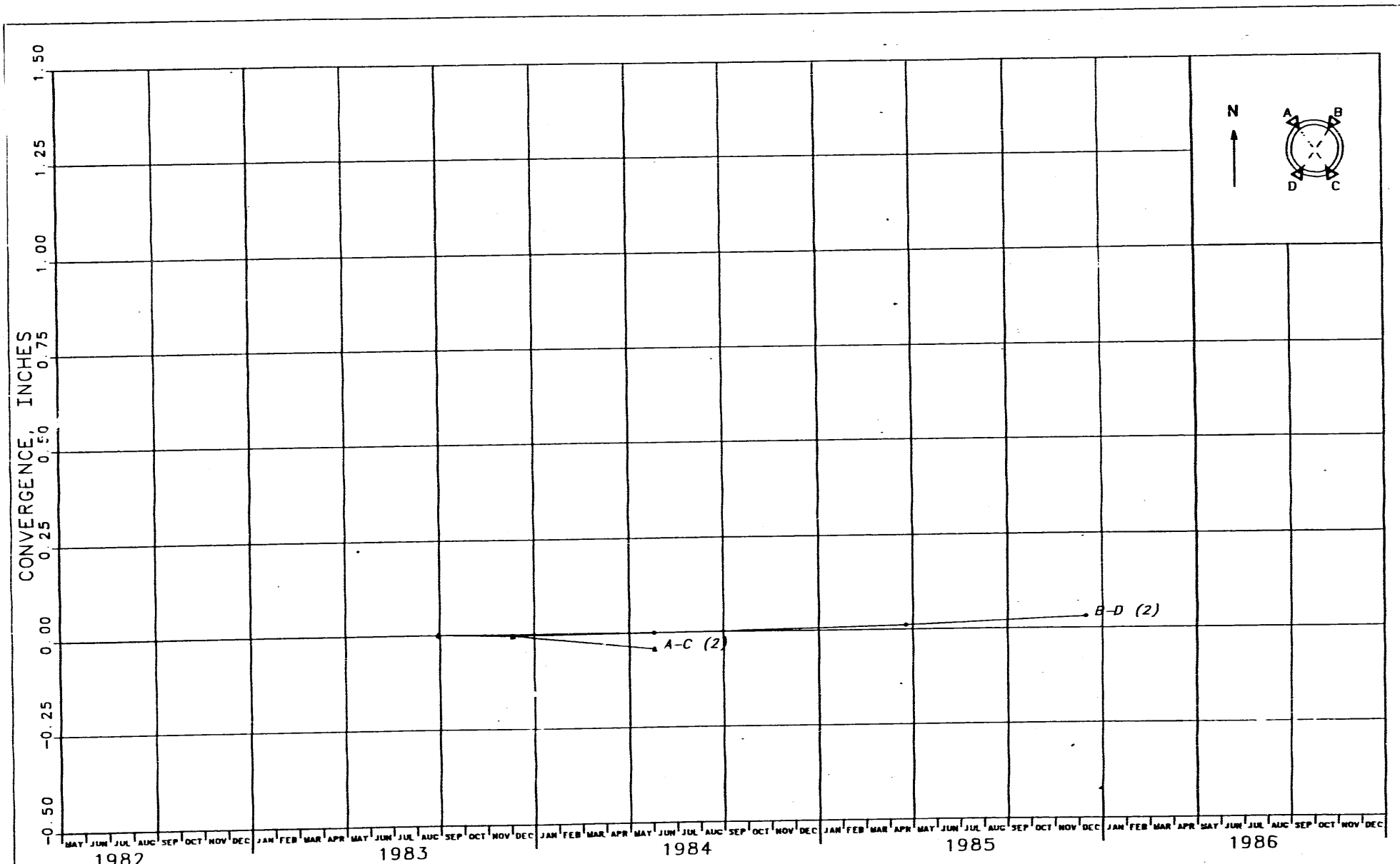
FIGURE J-203
CONVERGENCE POINTS
WASTE SHAFT - EL 1843 - BELOW KEY
CONVERGENCE VS. CALENDAR MONTH



NOTES:

1. SIZE OF EXCAVATION: 20 FT DIAM.
2. INSTRUMENT IS CURRENTLY NOT ACCESSIBLE FOR READING.

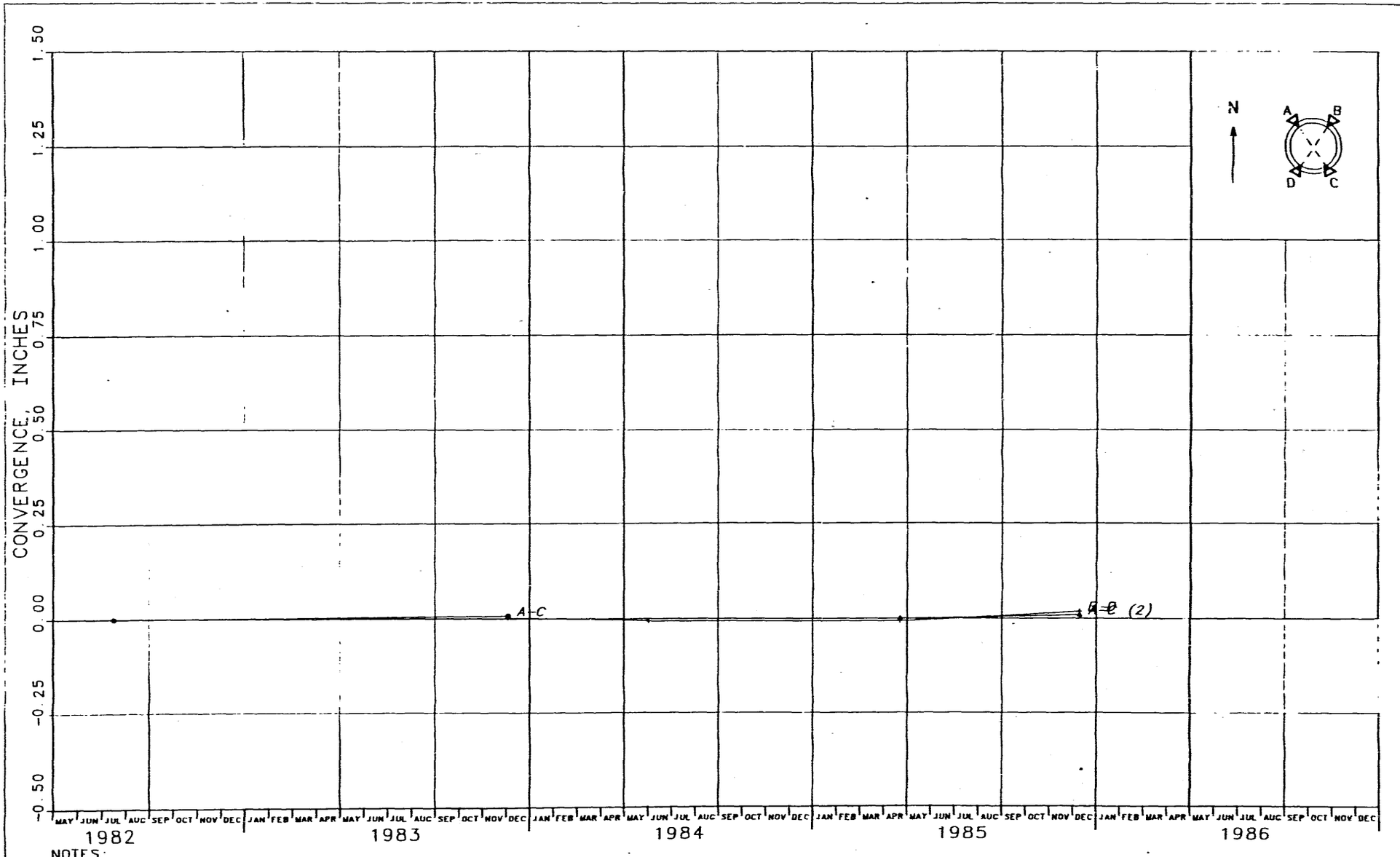
FIGURE J-204
CONVERGENCE POINTS
WASTE SHAFT – EL 1350 – BELOW KEY
CONVERGENCE VS. CALENDAR MONTH



NOTES:

1. INSTRUMENT WAS INSTALLED 778 DAYS AFTER EXCAVATION STARTED ON JUL. 12, 1981.
2. SIZE OF EXCAVATION: 12 FT DIAM.

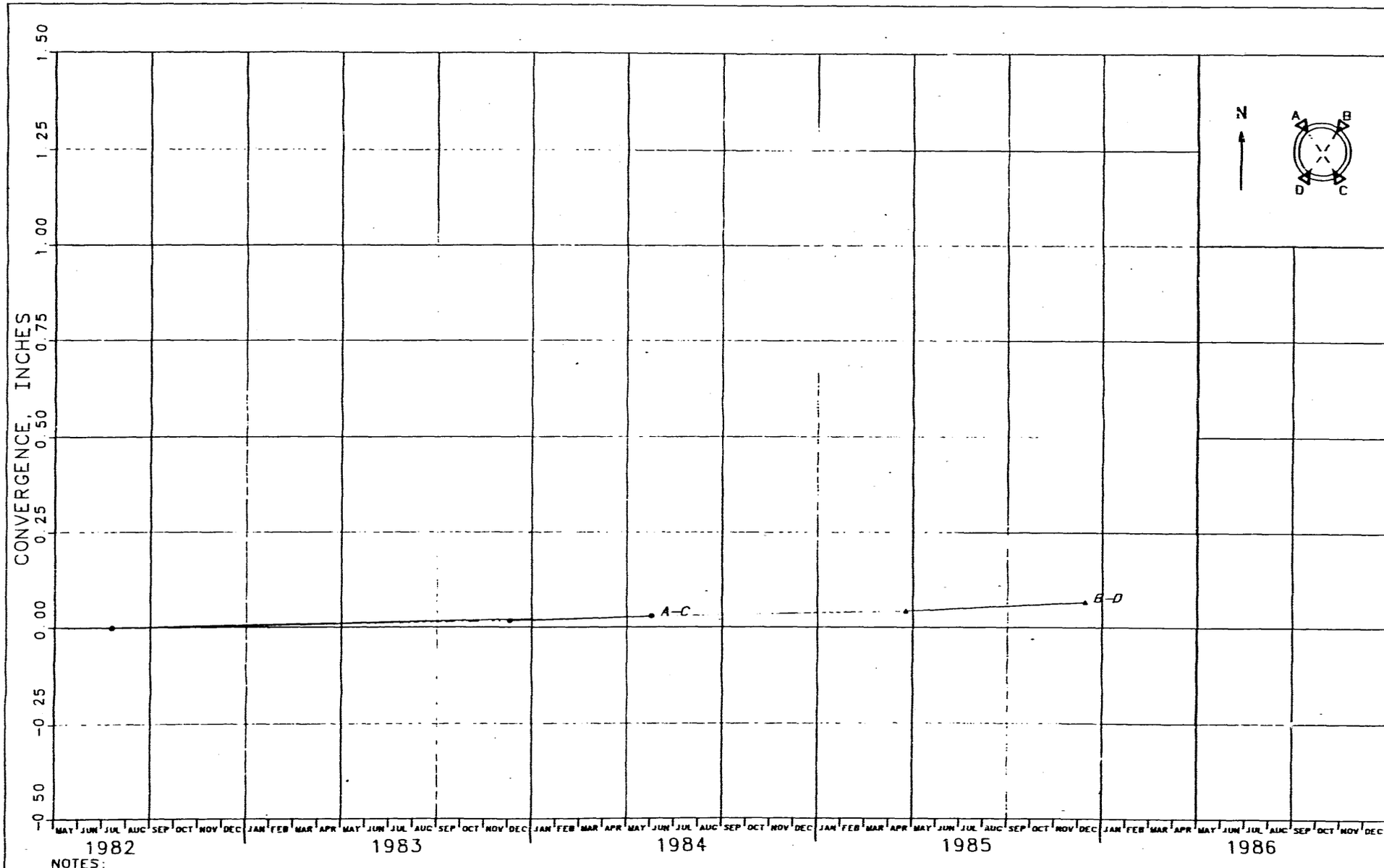
FIGURE J-205
CONVERGENCE POINTS
C & SH SHAFT – EL 3114 – ABOVE KEY
CONVERGENCE VS. CALENDAR MONTH



NOTES:

1. INSTRUMENT WAS INSTALLED 362 DAYS AFTER EXCAVATION STARTED ON JUL. 19, 1981.
2. SIZE OF EXCAVATION: 12 FT DIAM.

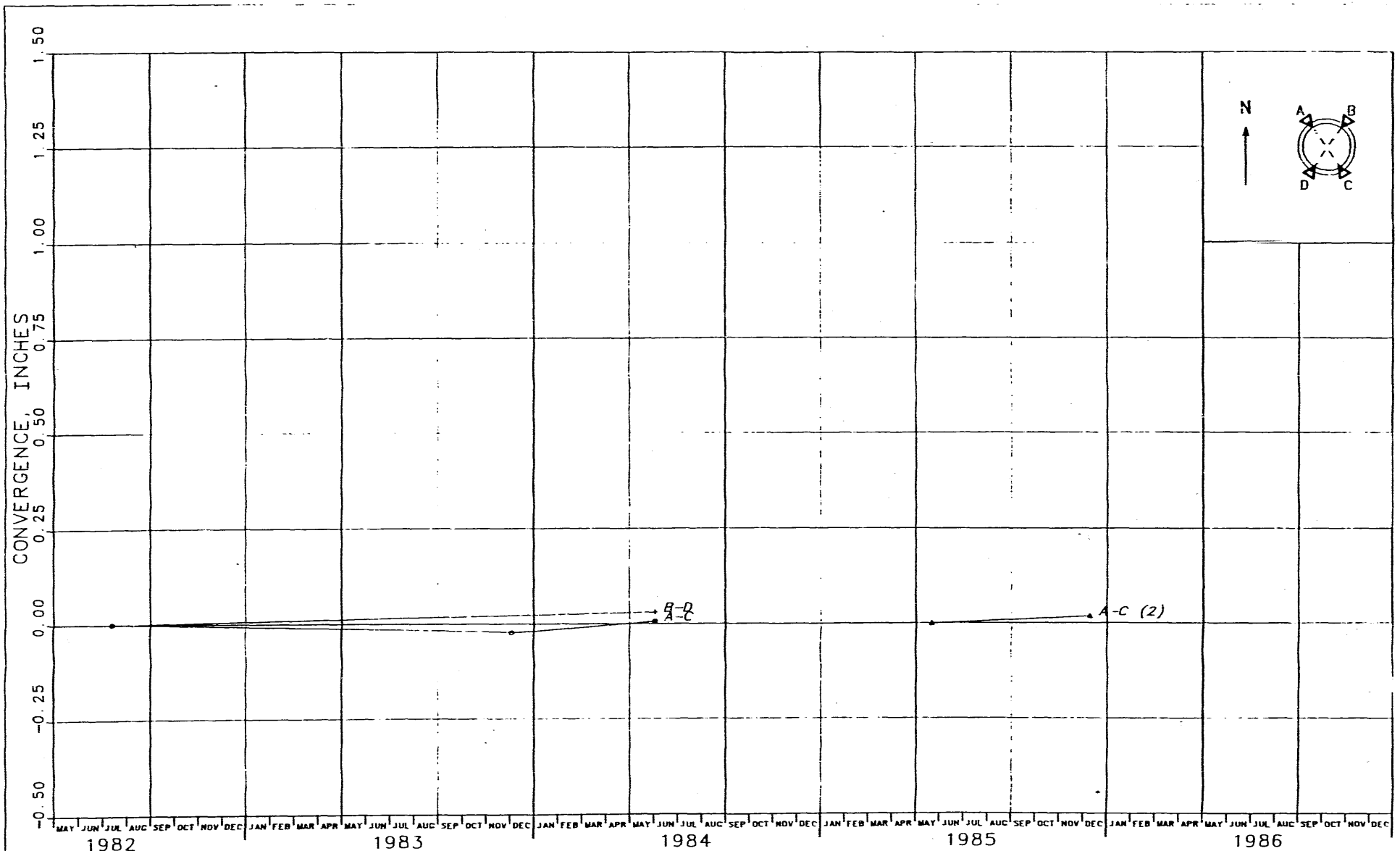
FIGURE J-206
CONVERGENCE POINTS
C & SH SHAFT - EL 2956 - ABOVE KEY
CONVERGENCE VS. CALENDAR MONTH



NOTES:

1. INSTRUMENT WAS INSTALLED 351 DAYS AFTER EXCAVATION STARTED ON JUL. 27, 1981
2. SIZE OF EXCAVATION: 12 FT DIAM.

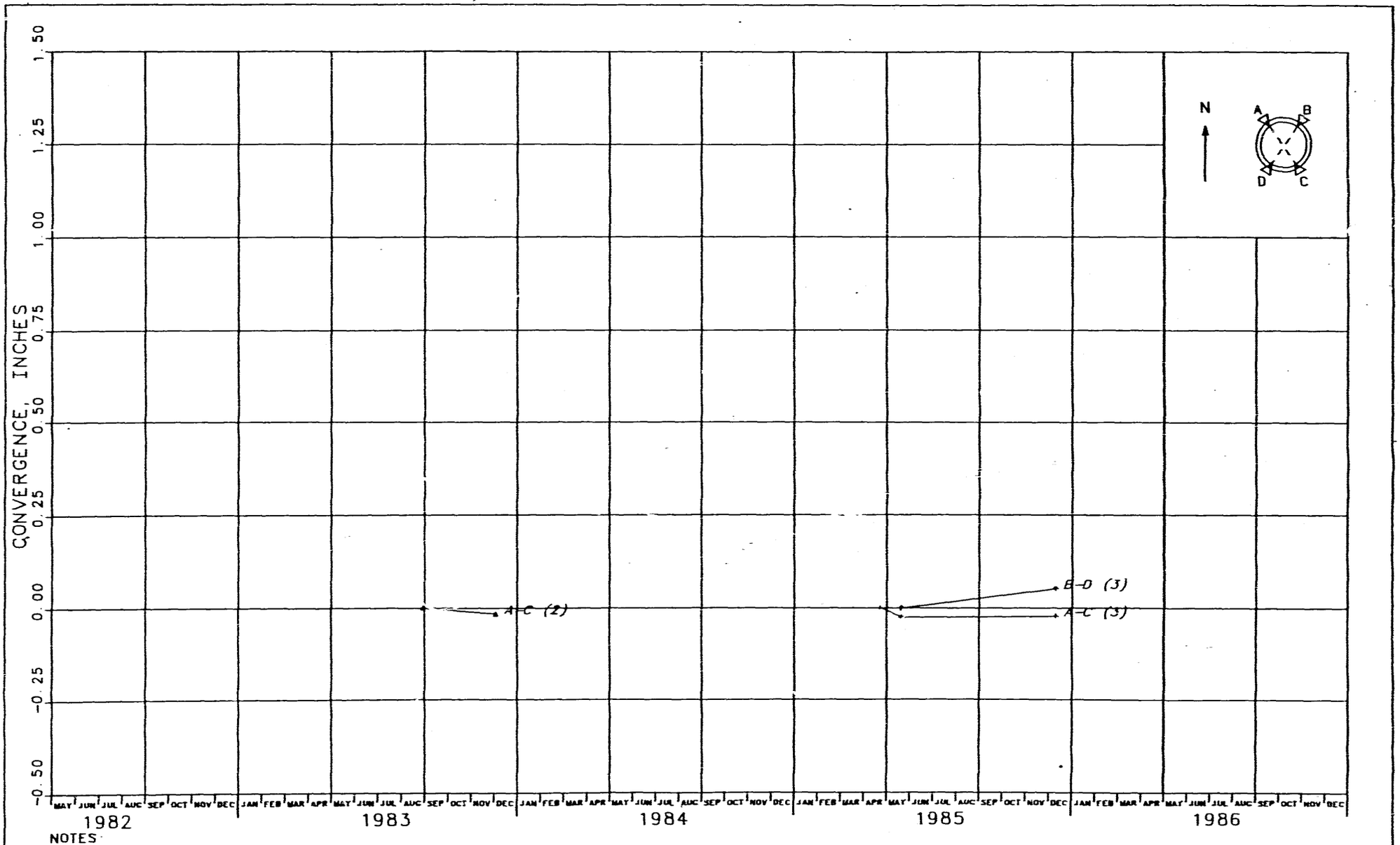
FIGURE J-207
CONVERGENCE POINTS
C & SH SHAFT – EL 2825 – ABOVE KEY
CONVERGENCE VS. CALENDAR MONTH



NOTES:

1. INSTRUMENT WAS INSTALLED 338 DAYS AFTER EXCAVATION STARTED ON AUG. 9, 1981 .
2. SIZE OF EXCAVATION: 12 FT DIAM.

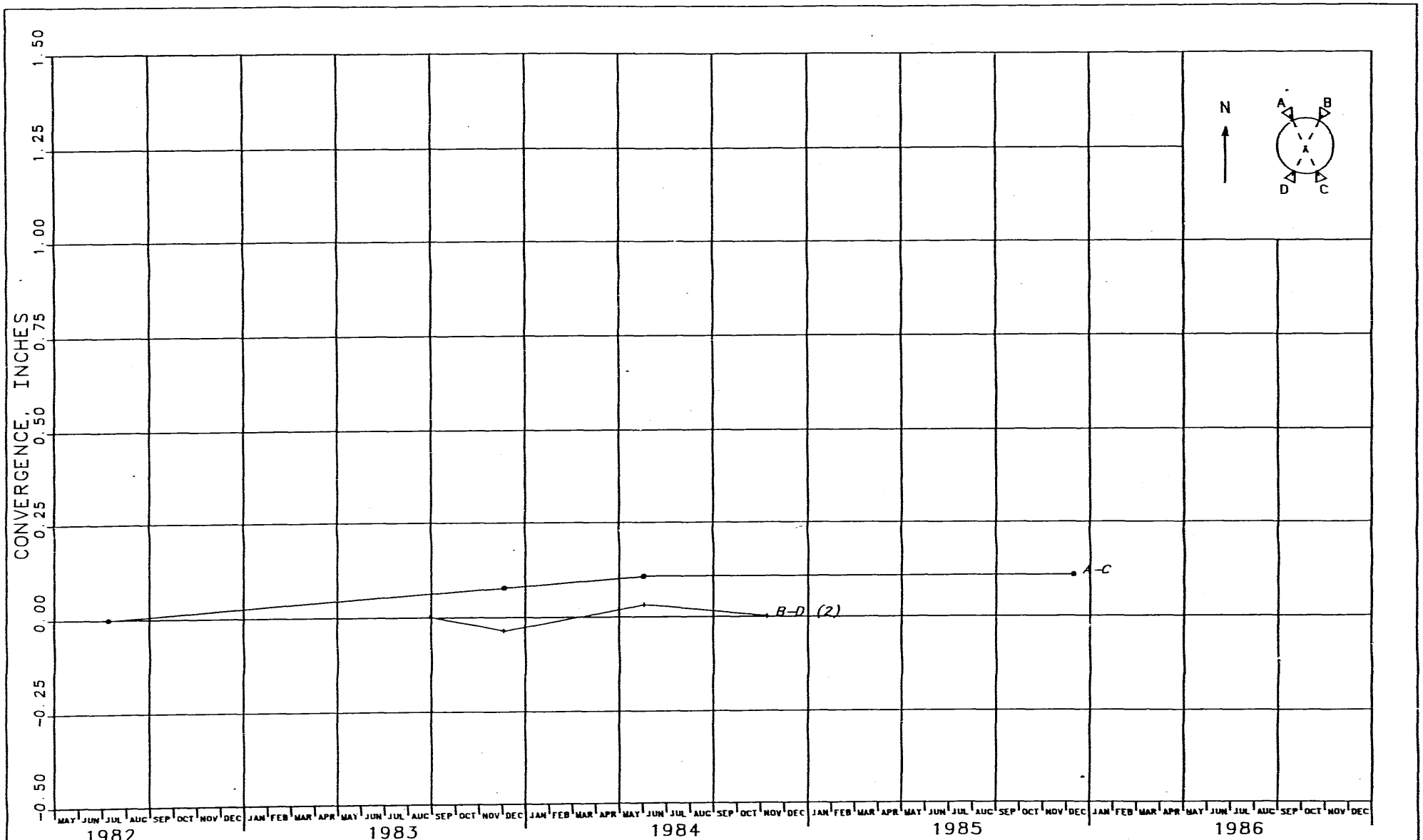
FIGURE J-208
CONVERGENCE POINTS
C & SH SHAFT – EL 2680 – ABOVE KEY
CONVERGENCE VS. CALENDAR MONTH



NOTES:

1. INSTRUMENT WAS INSTALLED 745 DAYS AFTER EXCAVATION STARTED ON AUG 14, 1981.
2. SIZE OF EXCAVATION: 12 FT DIAM.

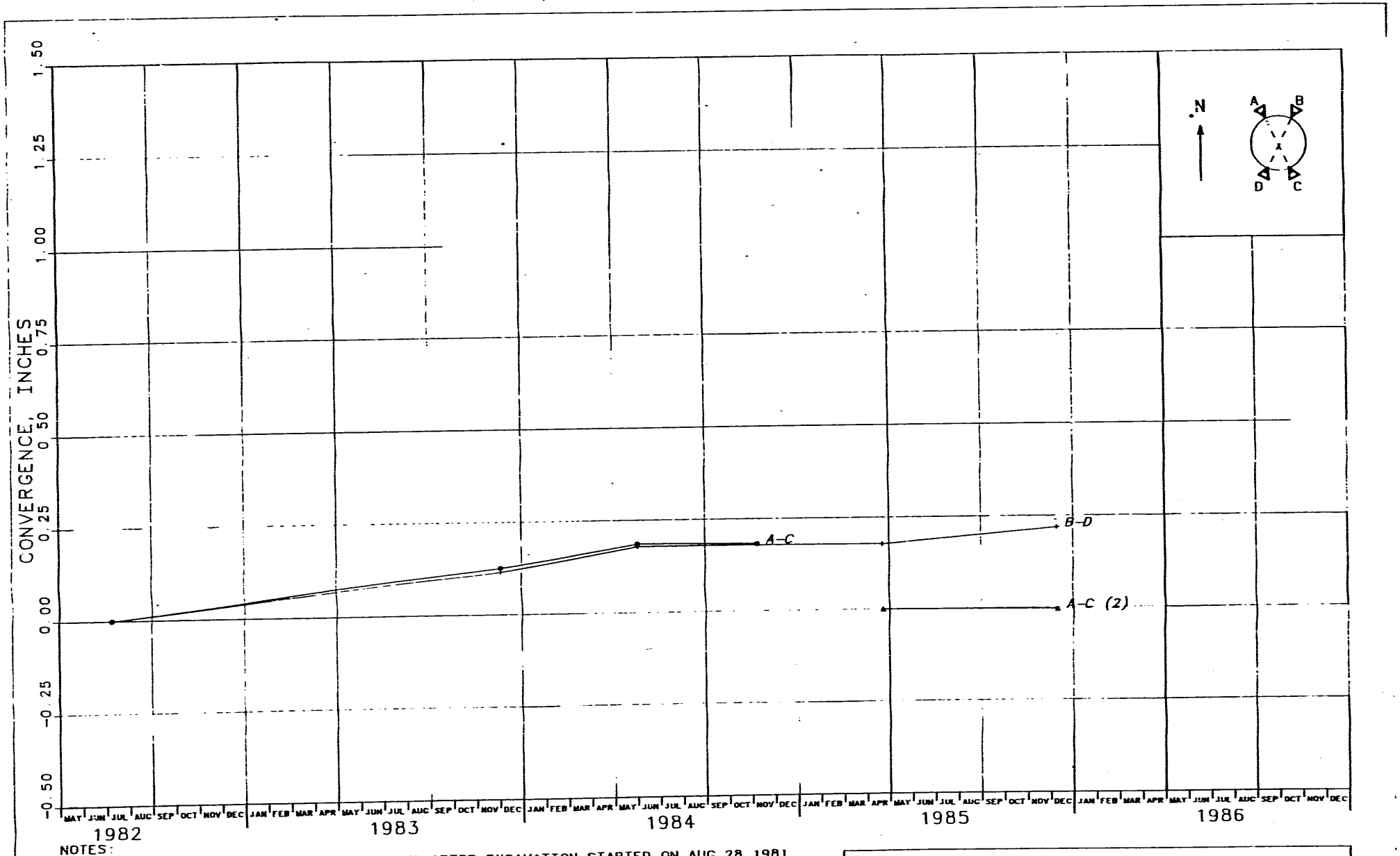
FIGURE J-209
CONVERGENCE POINTS
C & SH SHAFT - EL 2596 - ABOVE KEY
CONVERGENCE VS. CALENDAR MONTH



NOTES:

1. INSTRUMENT WAS INSTALLED 322 DAYS AFTER EXCAVATION STARTED ON AUG. 21, 1981.
2. SIZE OF EXCAVATION: 12 FT DIAM.

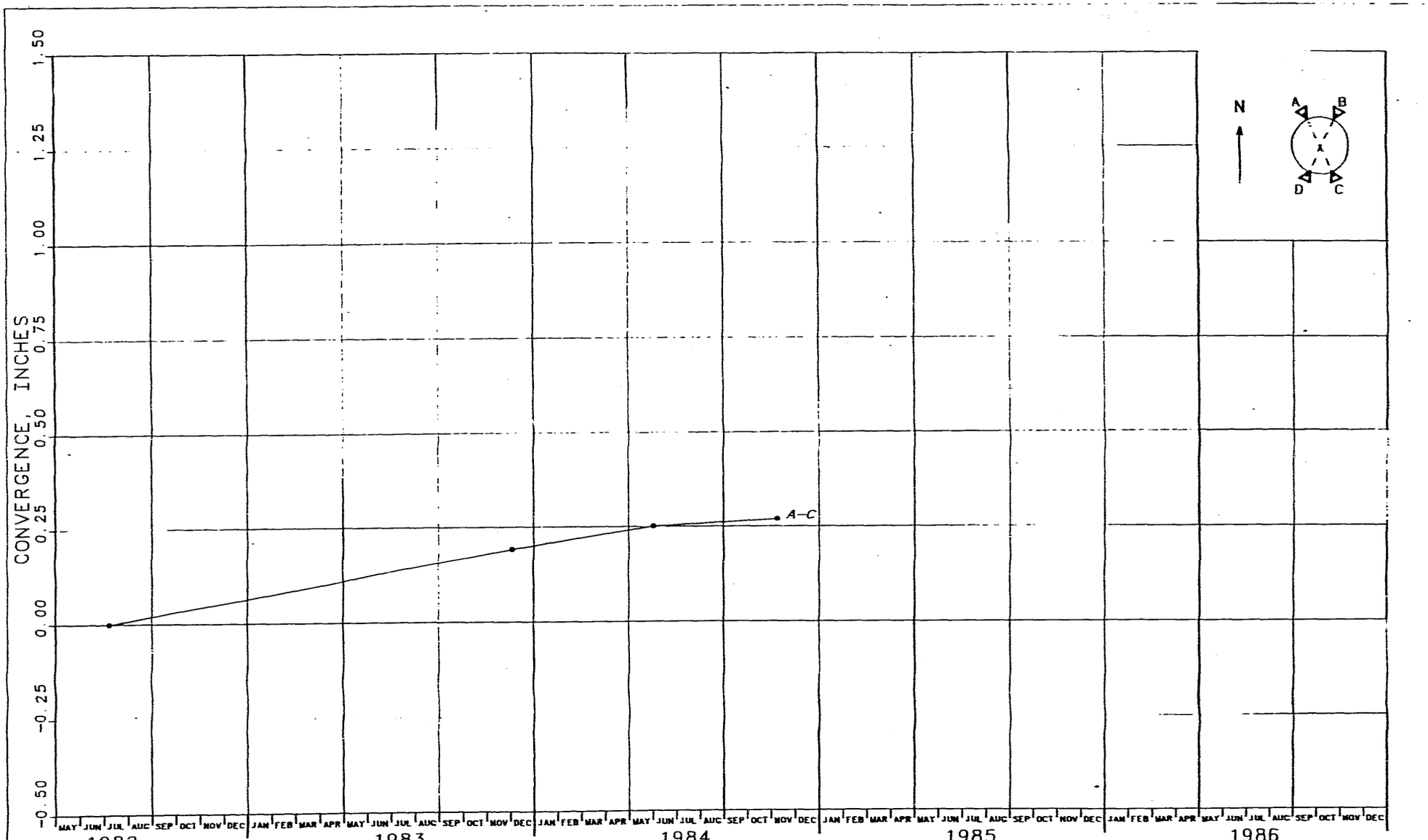
FIGURE J-210
CONVERGENCE POINTS
C & SH SHAFT - EL 2470 - BELOW KEY
CONVERGENCE VS. CALENDAR MONTH



NOTES:

1. INSTRUMENT WAS INSTALLED 314 DAYS AFTER EXCAVATION STARTED ON AUG. 28, 1981.
2. SIZE OF EXCAVATION: 12 FT DIAM.

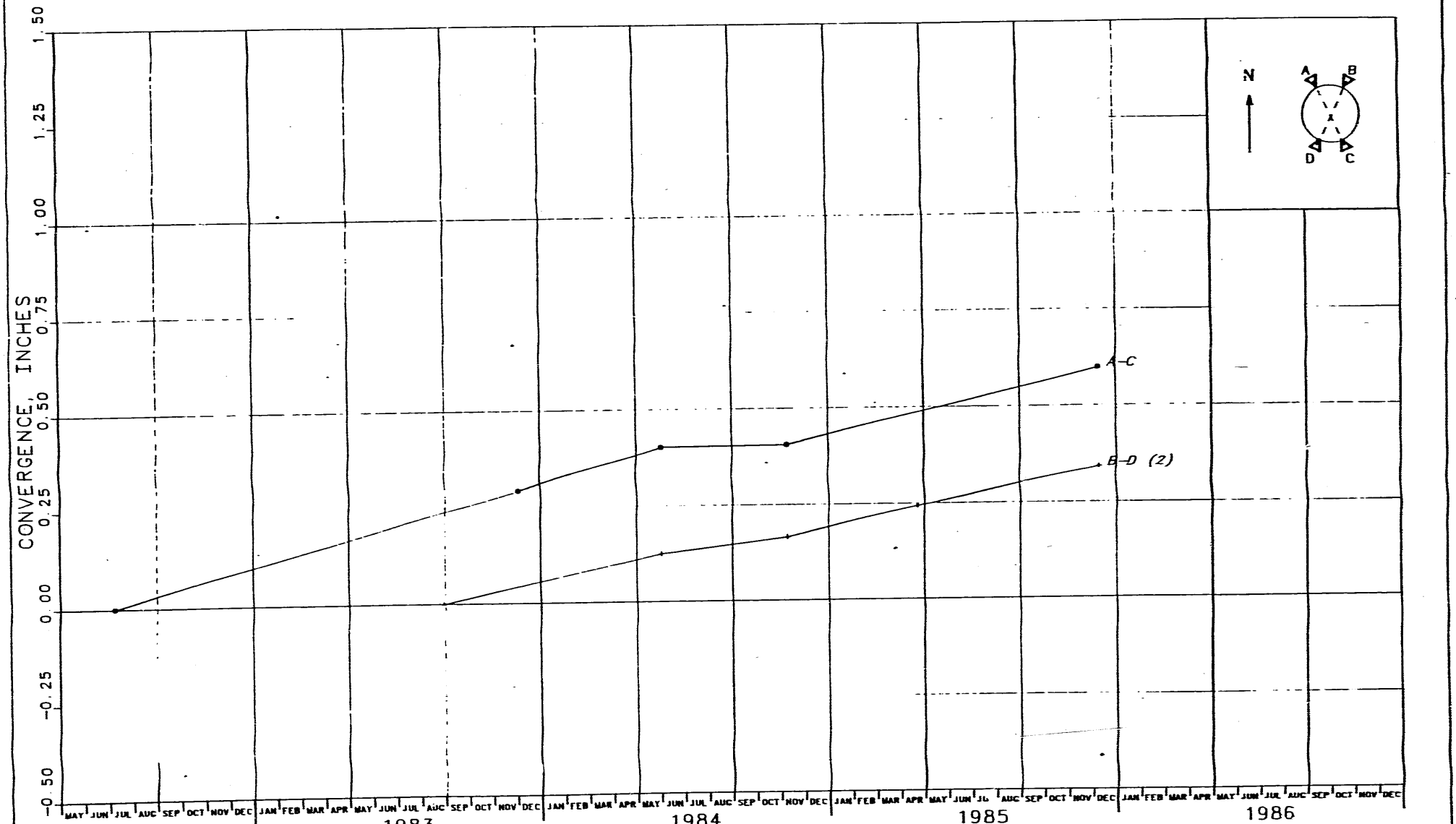
FIGURE J-211
CONVERGENCE POINTS
C & SH SHAFT – EL 2337 – BELOW KEY
CONVERGENCE VS. CALENDAR MONTH



NOTES:

1. INSTRUMENT WAS INSTALLED 306 DAYS AFTER EXCAVATION STARTED ON SEP. 5, 1981.
2. SIZE OF EXCAVATION: 12 FT DIAM.
3. INSTRUMENT HAS BEEN DESTROYED.

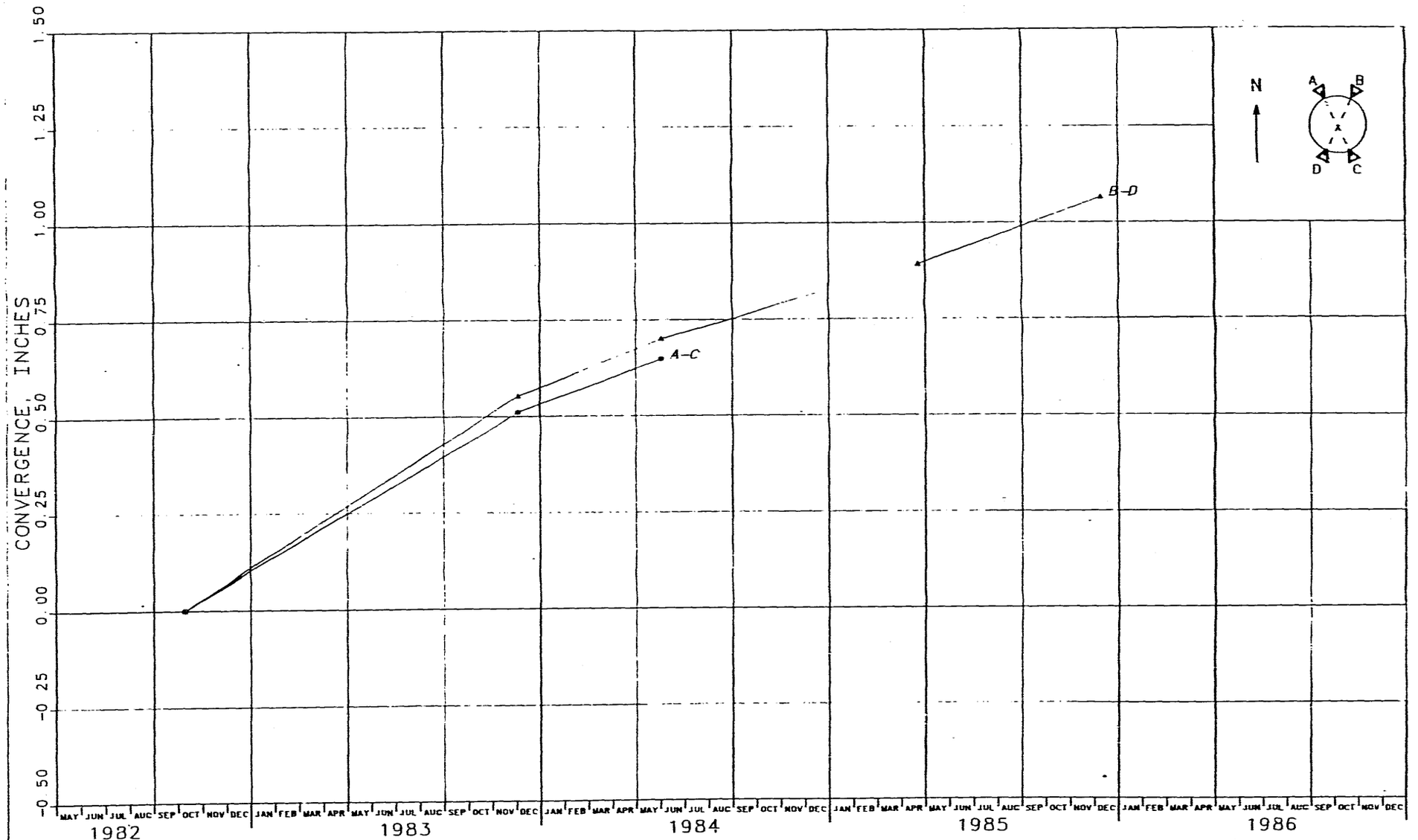
FIGURE J-212
CONVERGENCE POINTS
C & SH SHAFT – EL 2135 – BELOW KEY
CONVERGENCE VS. CALENDAR MONTH



NOTES

1. INSTRUMENT WAS INSTALLED 292 DAYS AFTER EXCAVATION STARTED ON SEP. 18, 1981.
2. SIZE OF EXCAVATION 12 FT DIAM.

FIGURE J-213
CONVERGENCE POINTS
C & SH SHAFT – EL 1846 – BELOW KEY
CONVERGENCE VS. CALENDAR MONTH

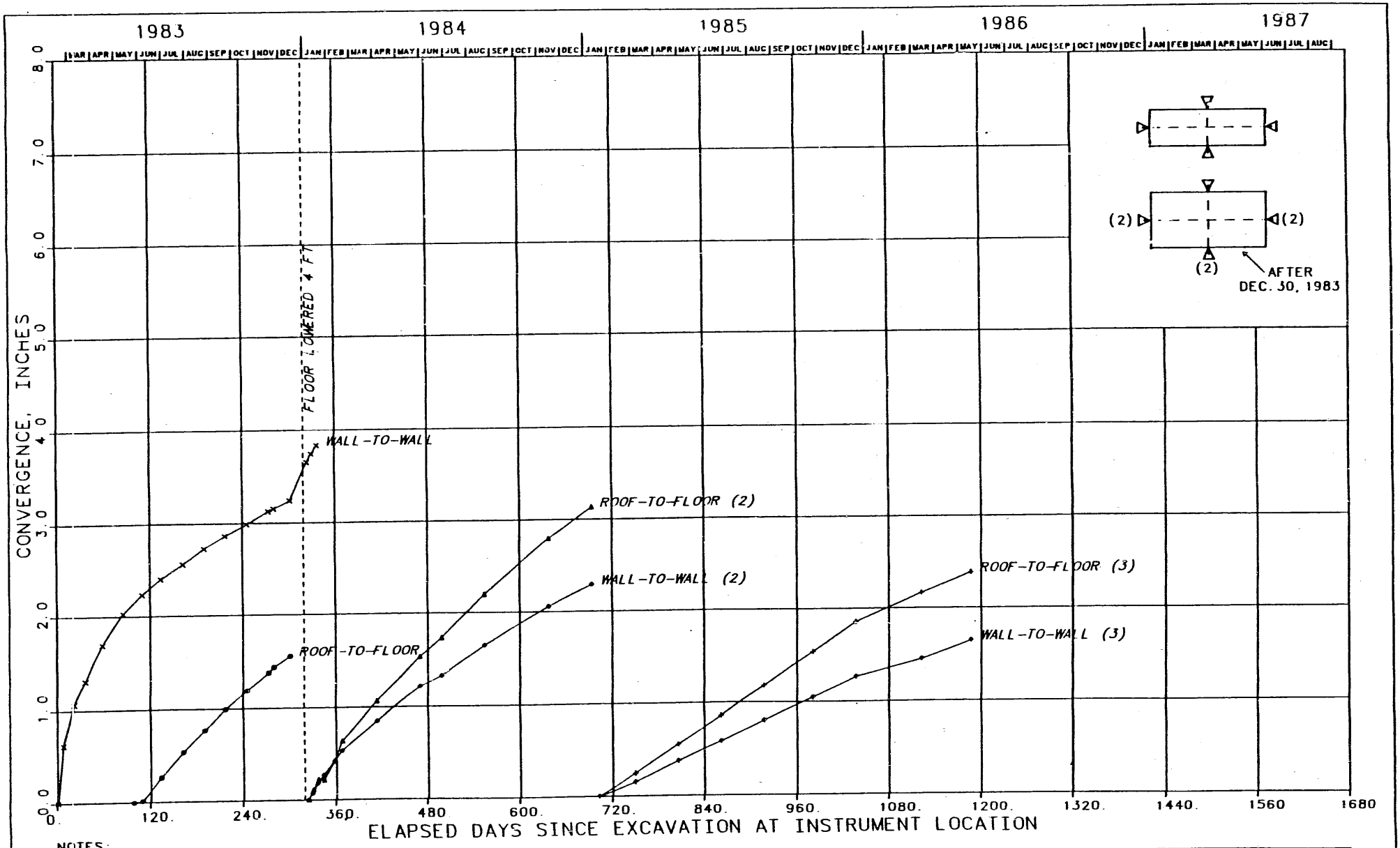


NOTES

1 INSTRUMENT WAS INSTALLED 362 DAYS AFTER EXCAVATION STARTED ON OCT. 11, 1981.

2 SIZE OF EXCAVATION 12 FT DIAM

FIGURE J-214
CONVERGENCE POINTS
C & SH SHAFT – EL 1353 – BELOW KEY
CONVERGENCE VS. CALENDAR MONTH



NOTES:
1. SIZE OF EXCAVATION: 12 FT X 25 FT.

FIGURE J-215
CONVERGENCE POINTS
EO DRIFT, NORTH 1266 FT
CONVERGENCE VS. TIME SINCE EXCAVATION

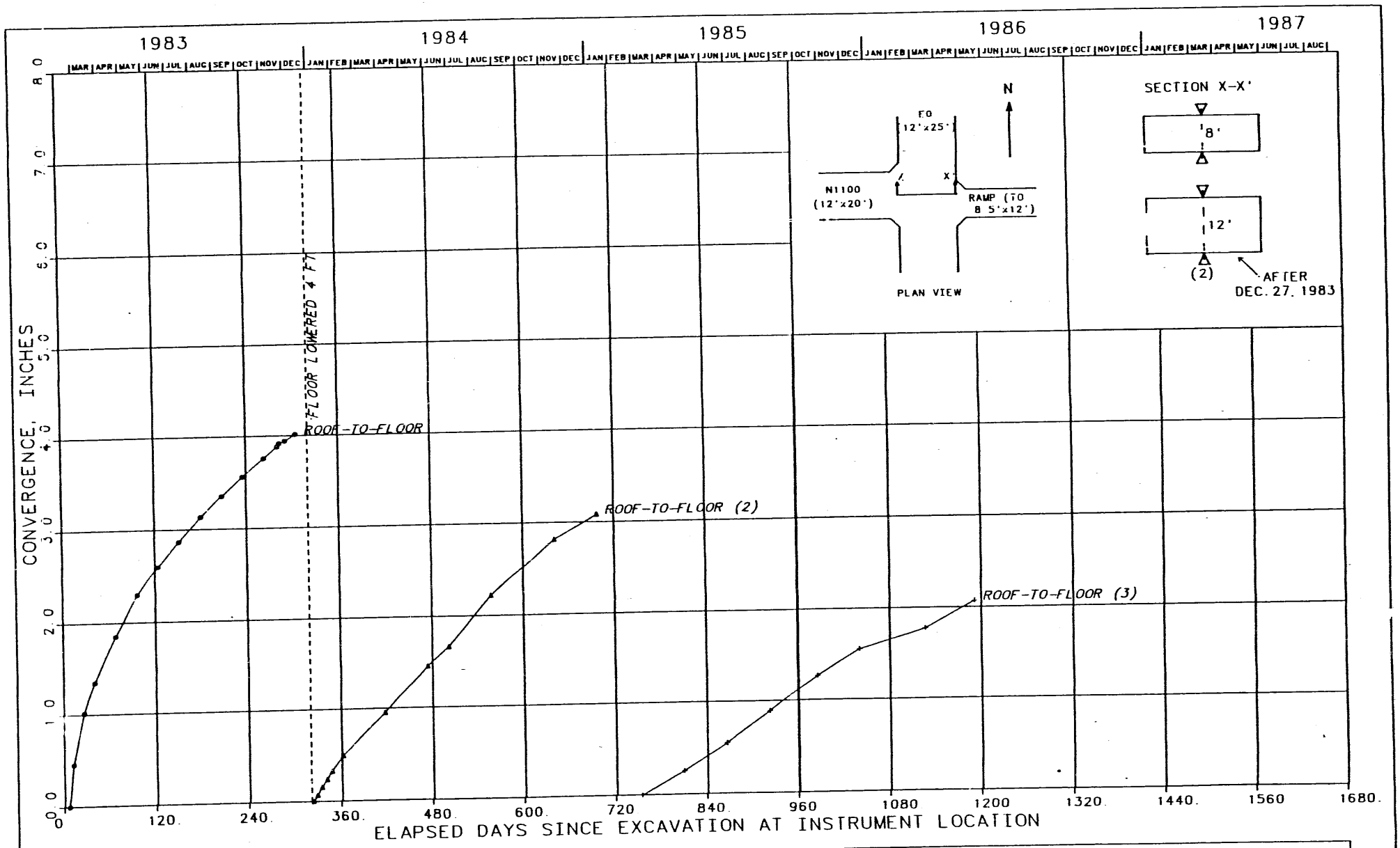
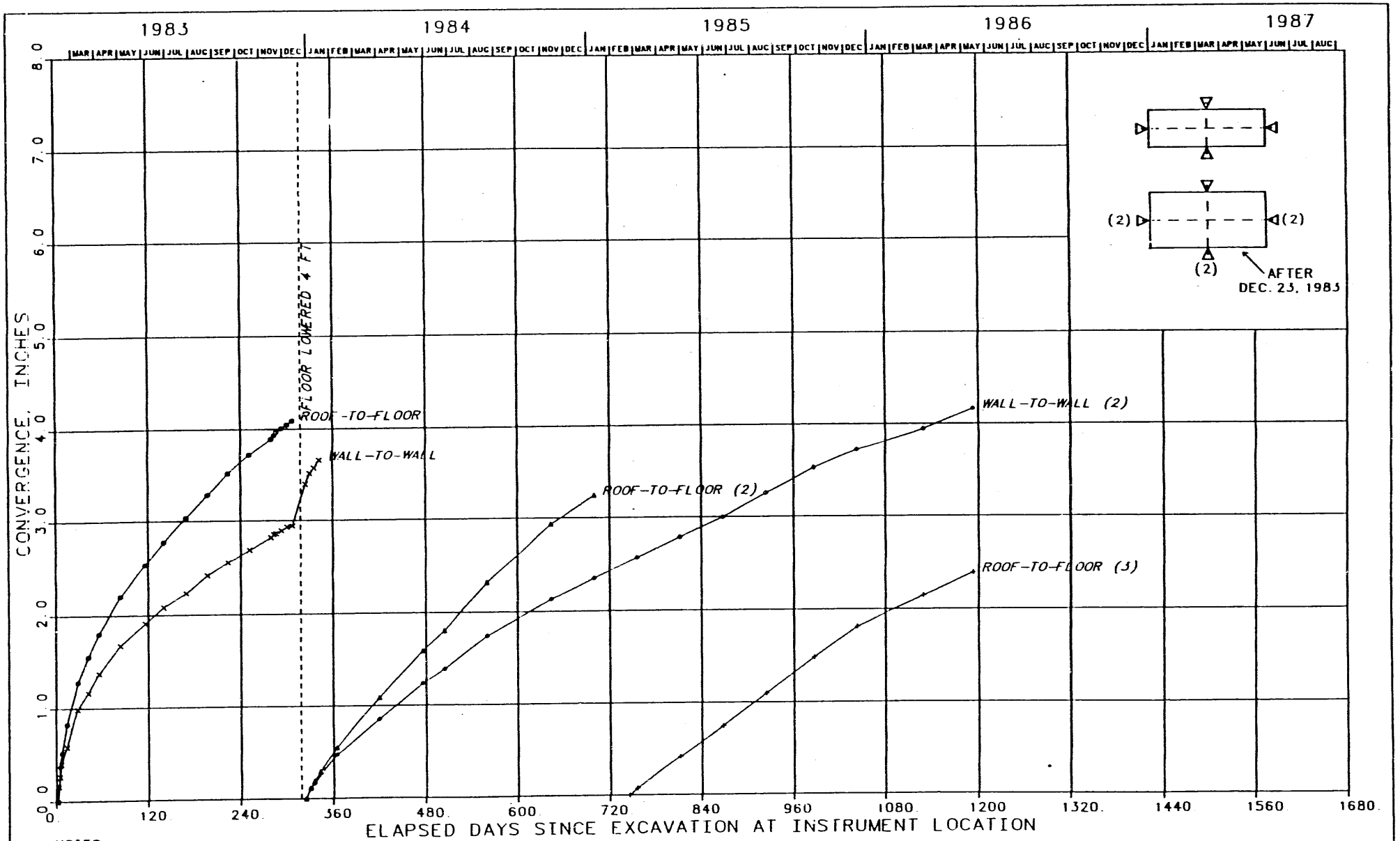


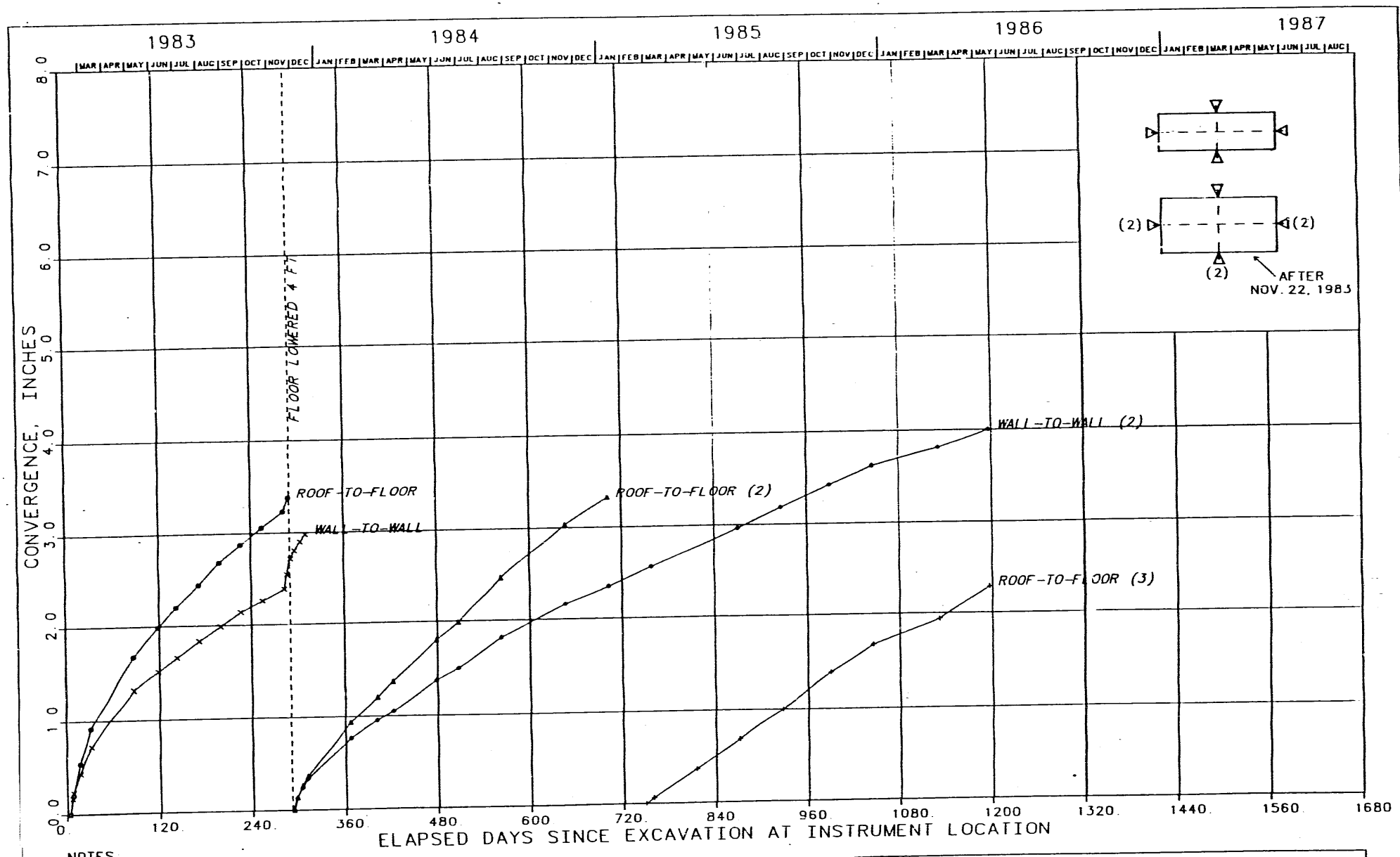
FIGURE J-216
CONVERGENCE POINTS
EO DRIFT – N1100 DRIFT INTERSECTION
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 25 FT

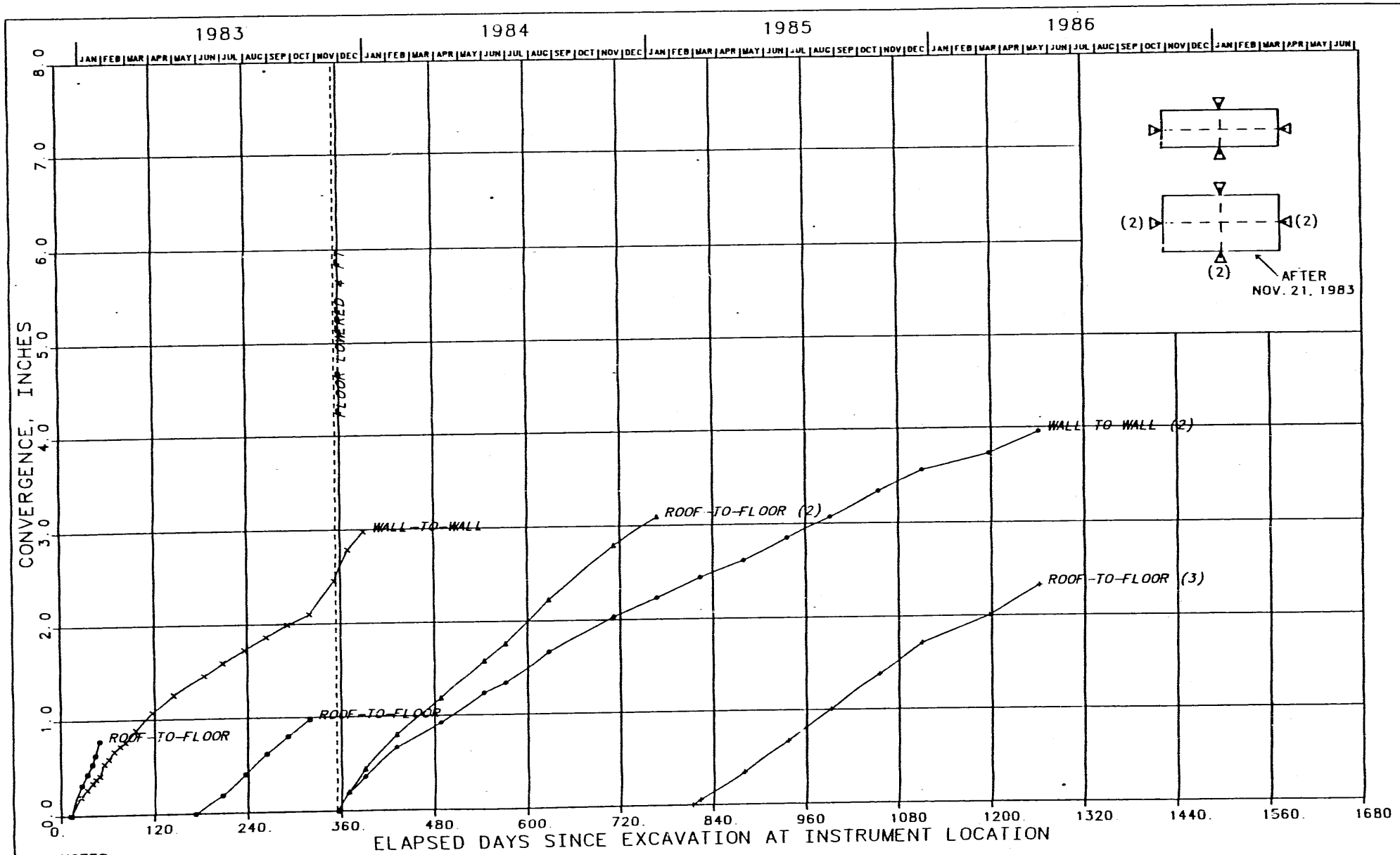
FIGURE J-217
CONVERGENCE POINTS
E0 DRIFT, NORTH 940 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION: 12 FT X 25 FT.

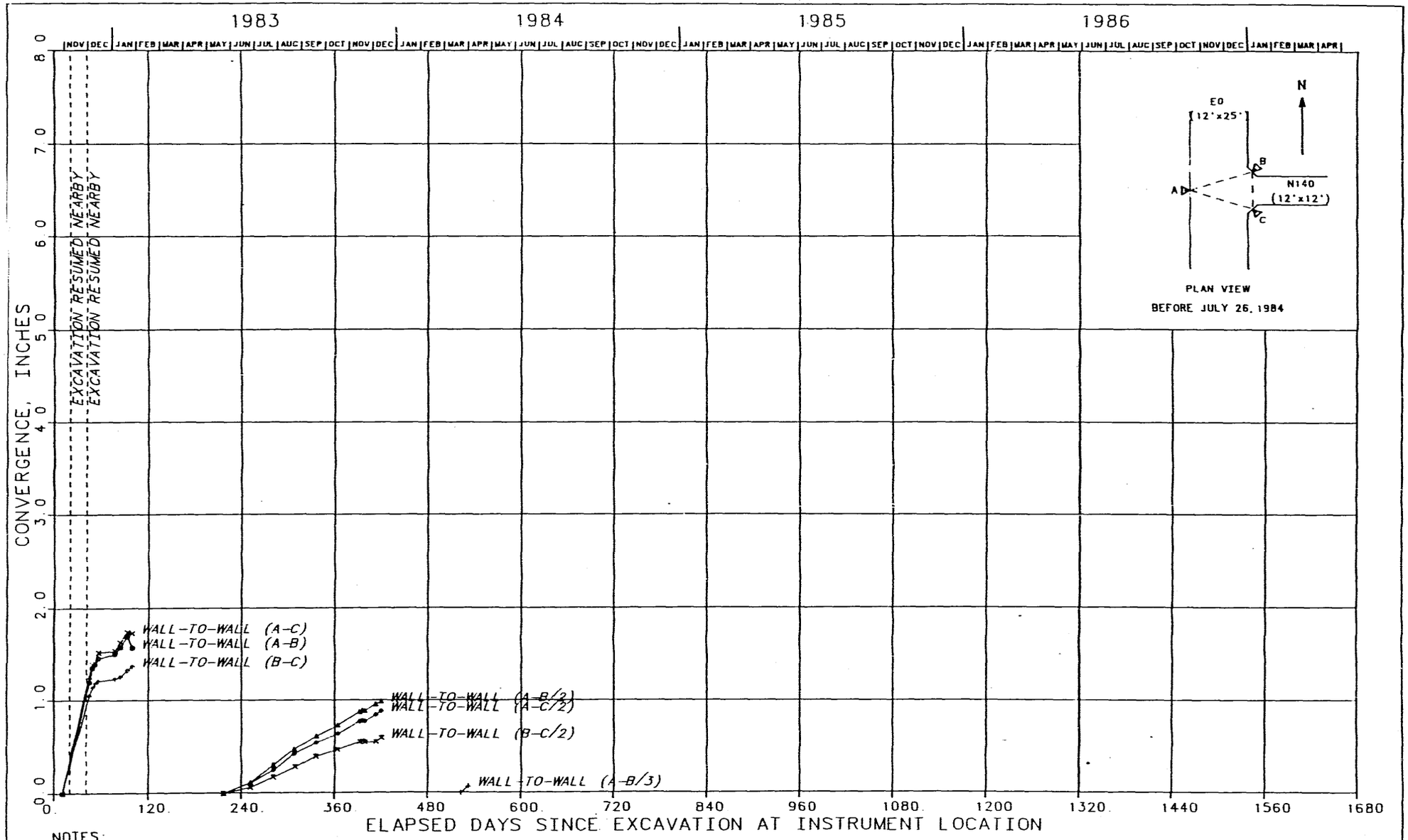
FIGURE J-218
CONVERGENCE POINTS
EO DRIFT, NORTH 626 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 25 FT.

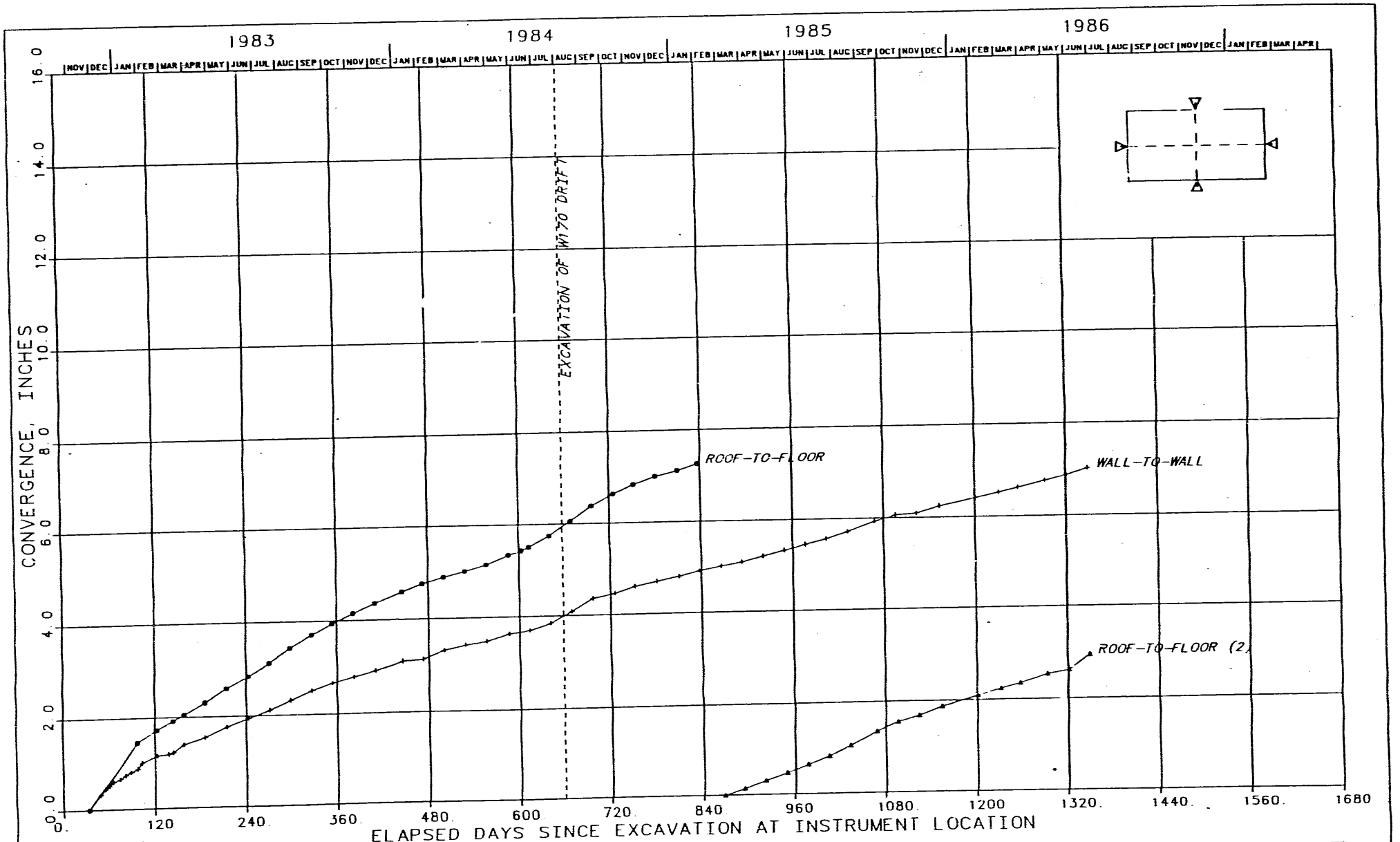
FIGURE J-219
CONVERGENCE POINTS
EO DRIFT, NORTH 290 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. INSTRUMENT HAS BEEN DESTROYED.

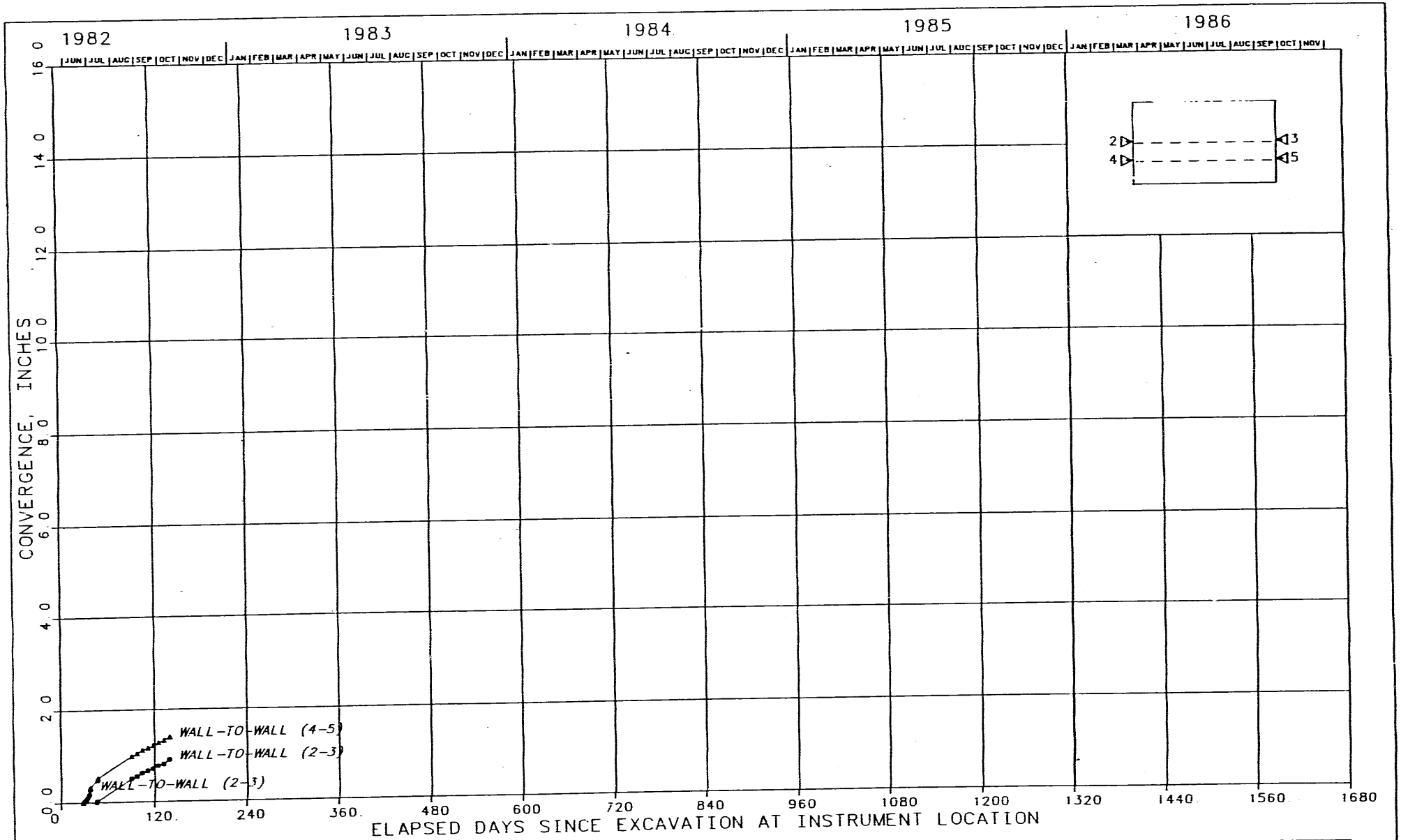
FIGURE J-220
CONVERGENCE POINTS
EO DRIFT – N140 CROSSCUT INTERSECTION
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 15 FT X 30 FT.

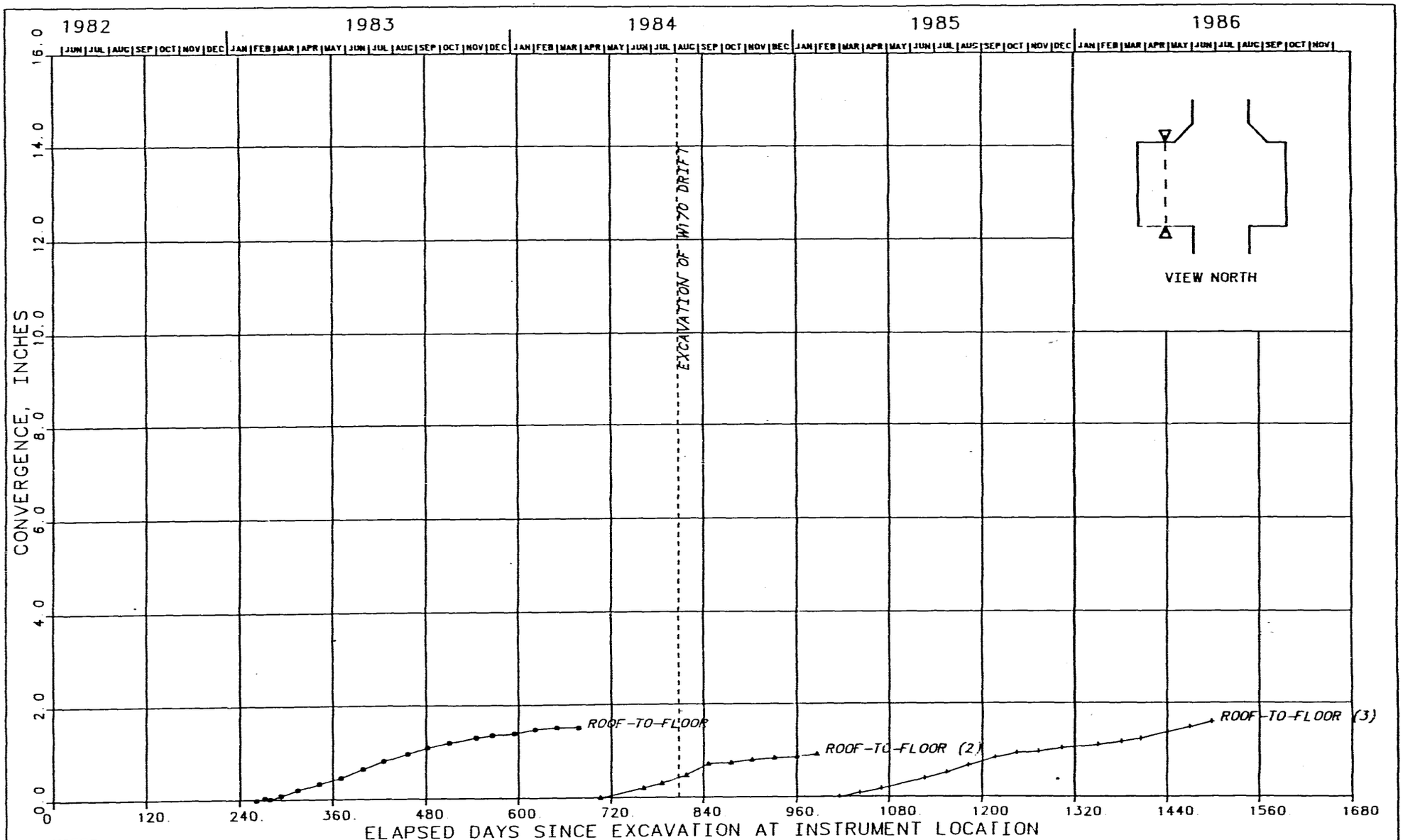
FIGURE J-221
CONVERGENCE POINTS
39 FT NORTH OF C & SH SHAFT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION: 18 FT X 31 FT
2. INSTRUMENT HAS BEEN DESTROYED.

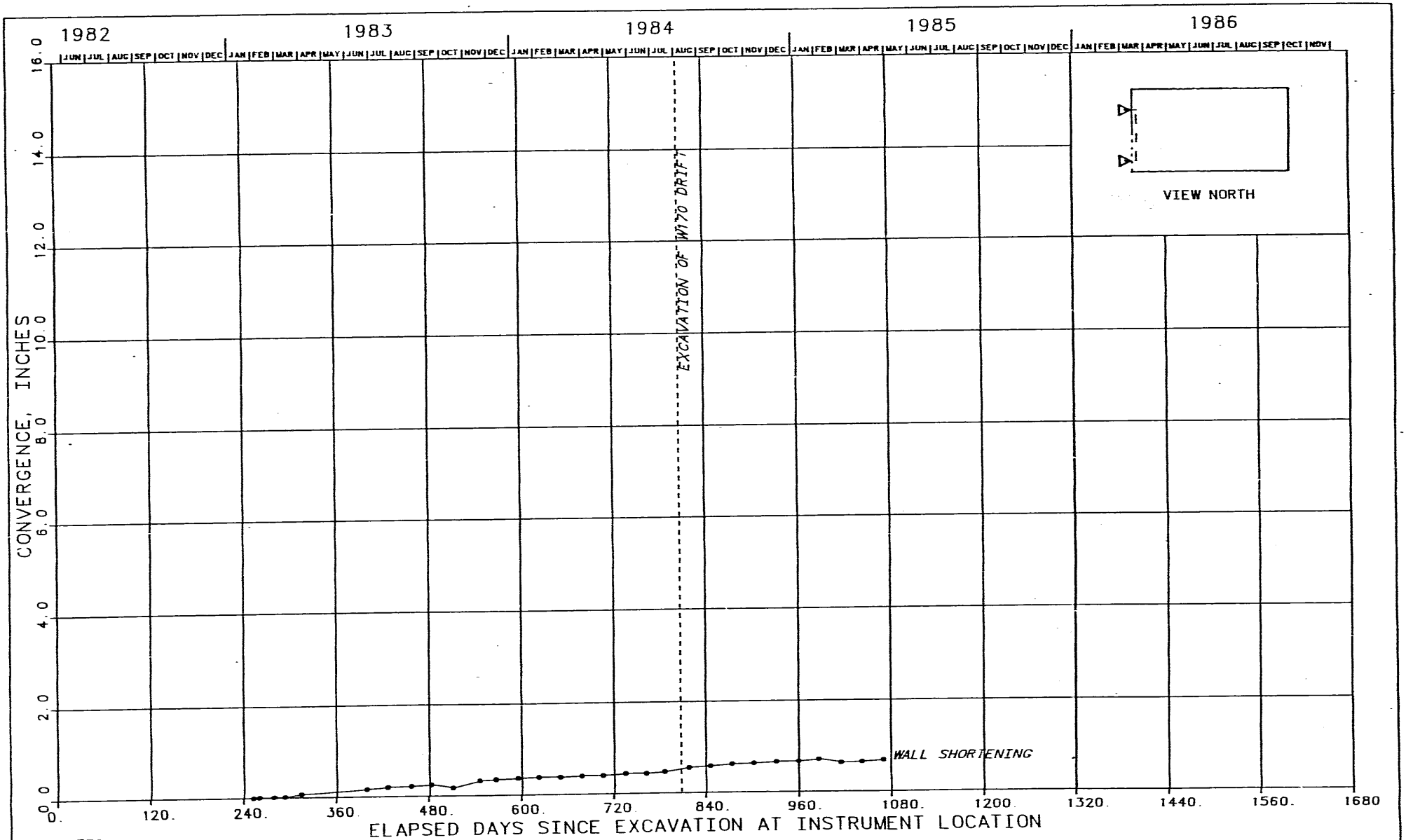
FIGURE J-222
CONVERGENCE POINTS
15 FT NORTH OF C & SH SHAFT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION: 18 FT X 32 FT.

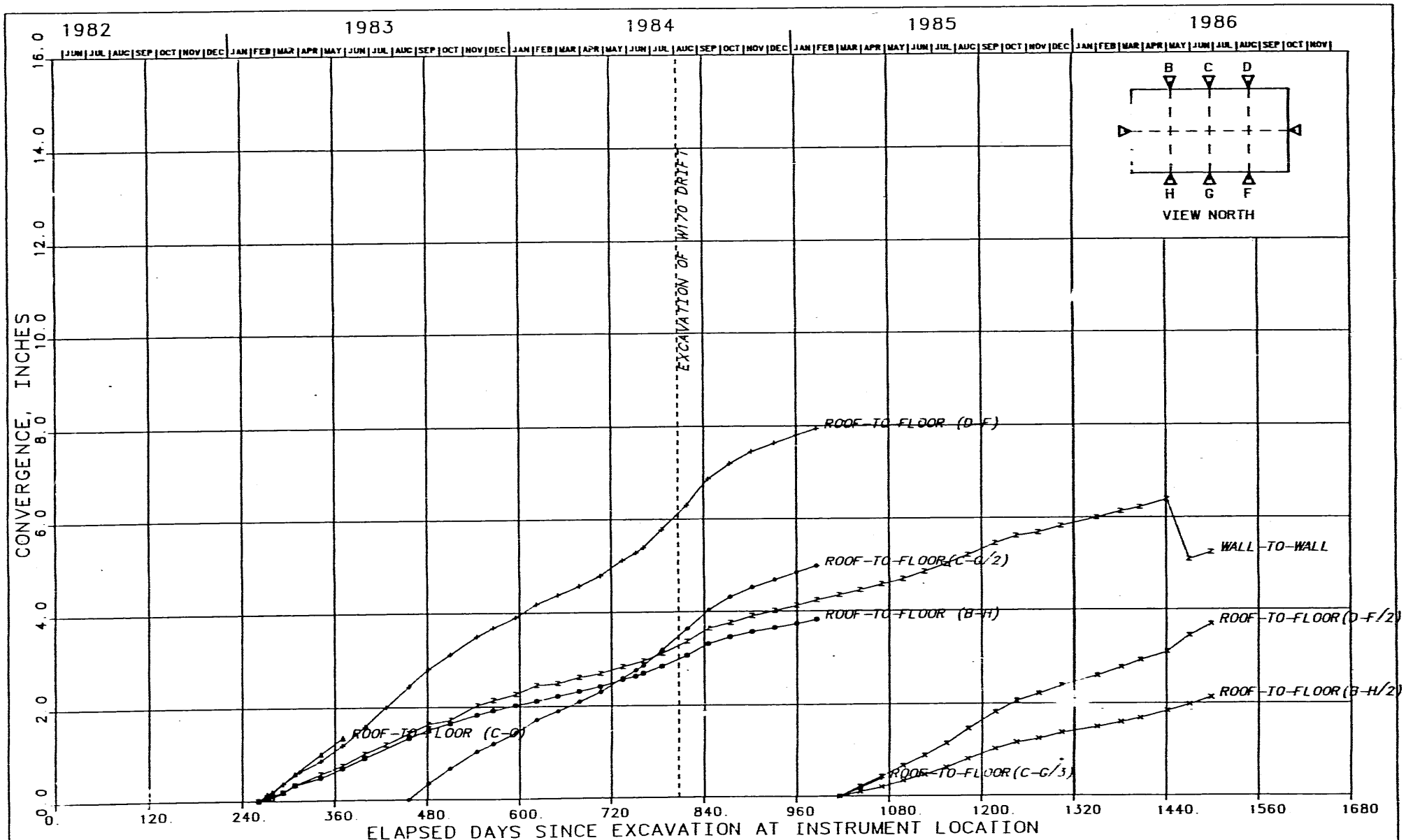
FIGURE J-223
CONVERGENCE POINTS
12 FT WEST OF C & SH SHAFT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1 SIZE OF EXCAVATION: 18 FT X 34 FT.
2 INSTRUMENT HAS BEEN DESTROYED.

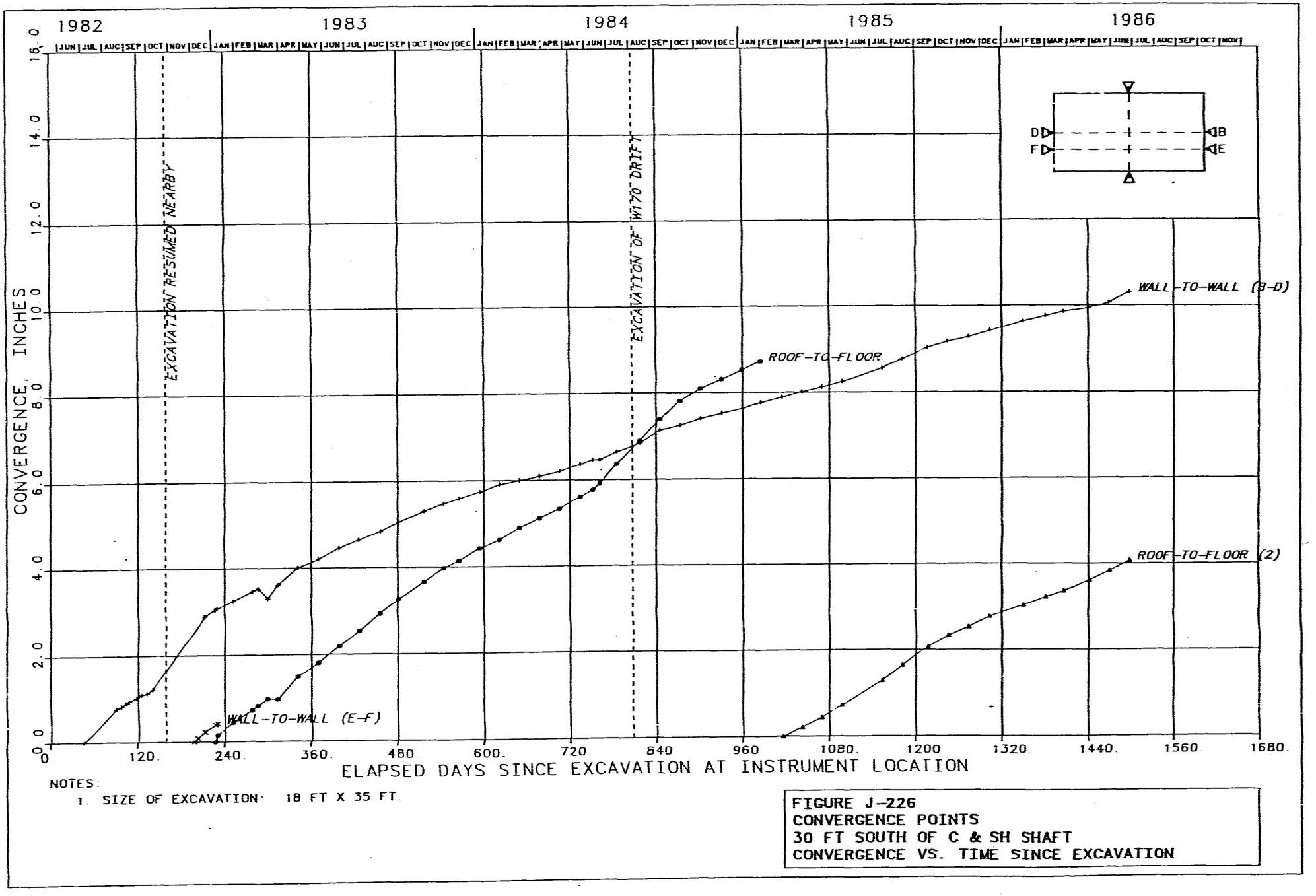
FIGURE J-224
CONVERGENCE POINTS
18 FT SOUTH OF C & SH SHAFT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 18 FT X 34 FT.

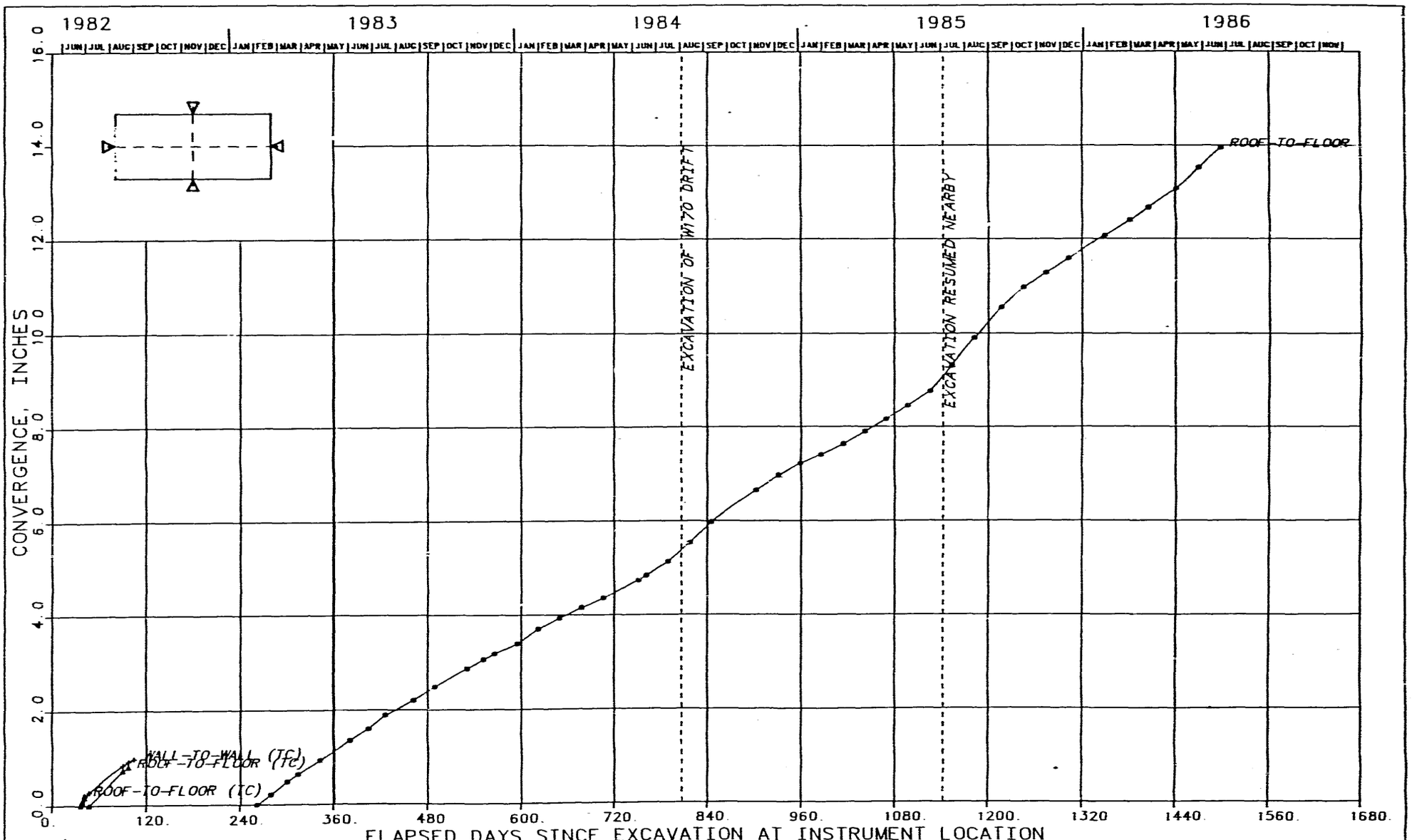
FIGURE J-225
CONVERGENCE POINTS
18.5 FT SOUTH OF C & SH SHAFT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 18 FT X 35 FT.

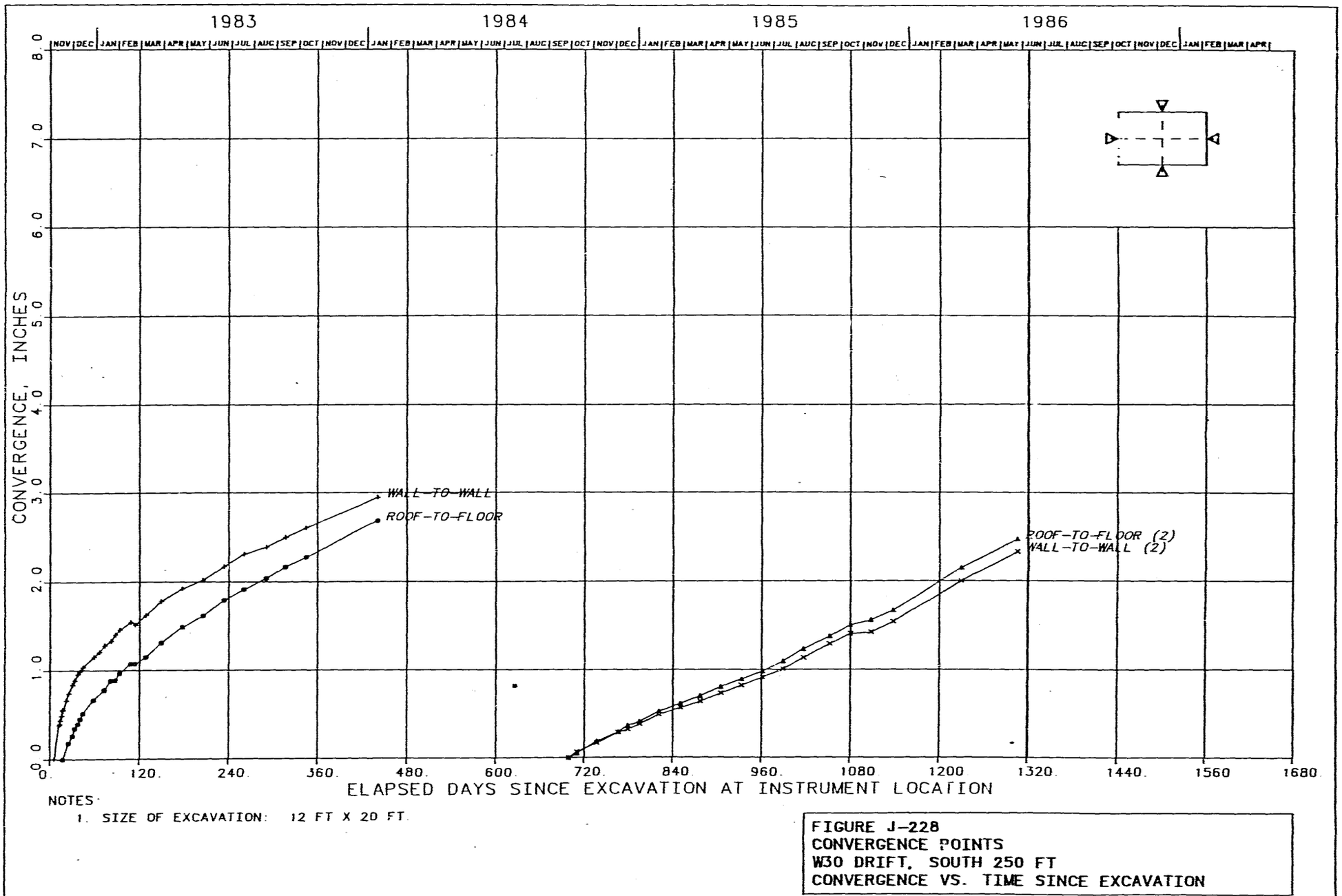
FIGURE J-226
CONVERGENCE POINTS
30 FT SOUTH OF C & SH SHAFT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 14 FT X 33 FT.

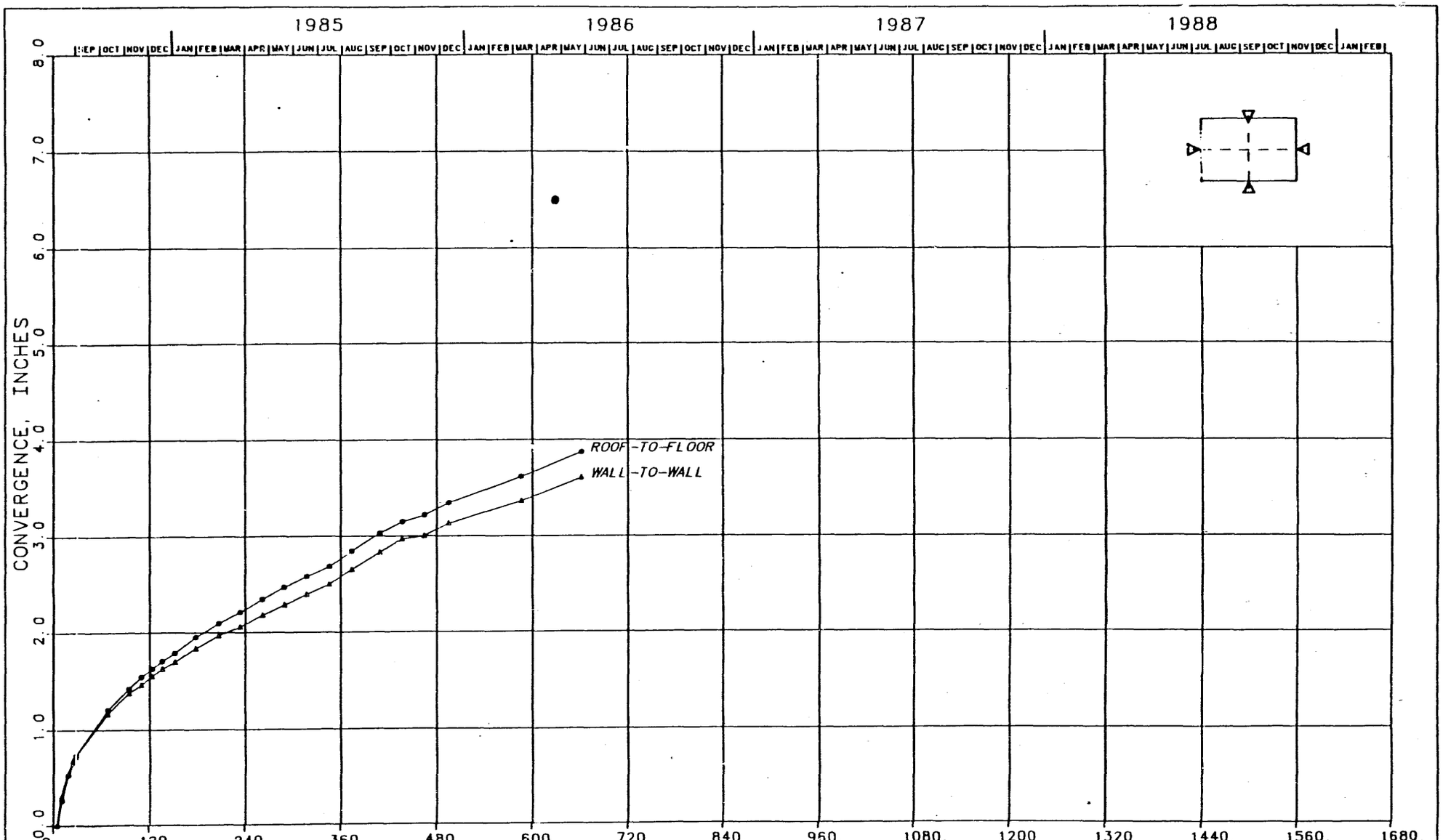
FIGURE J-227
CONVERGENCE POINTS
65 FT SOUTH OF C & SH SHAFT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 20 FT.

FIGURE J-228
CONVERGENCE POINTS
W30 DRIFT, SOUTH 250 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1 SIZE OF EXCAVATION: 13 FT X 20 FT.

FIGURE J-229
CONVERGENCE POINTS
W30 DRIFT, SOUTH 500 FT
CONVERGENCE VS. TIME SINCE EXCAVATION

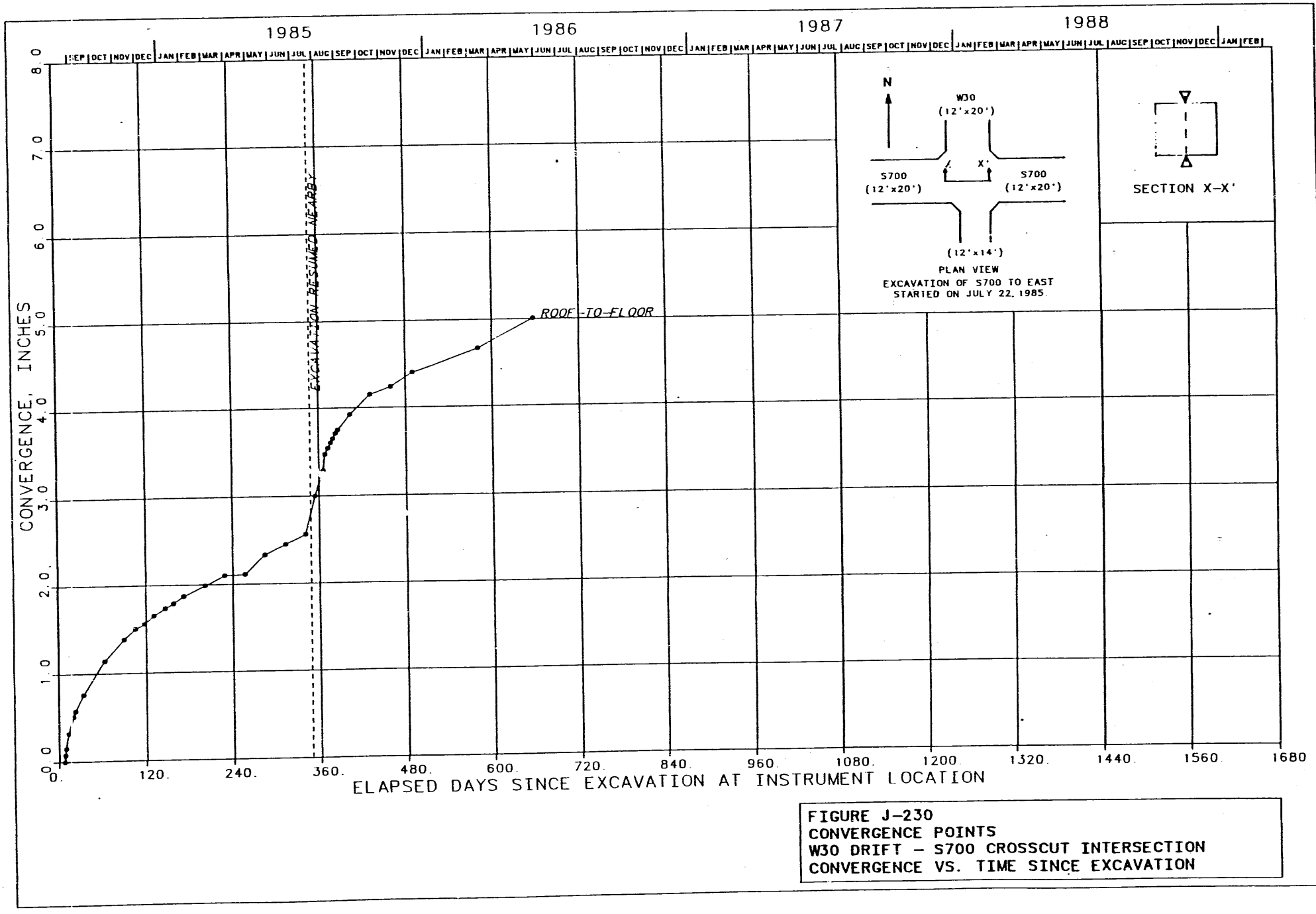
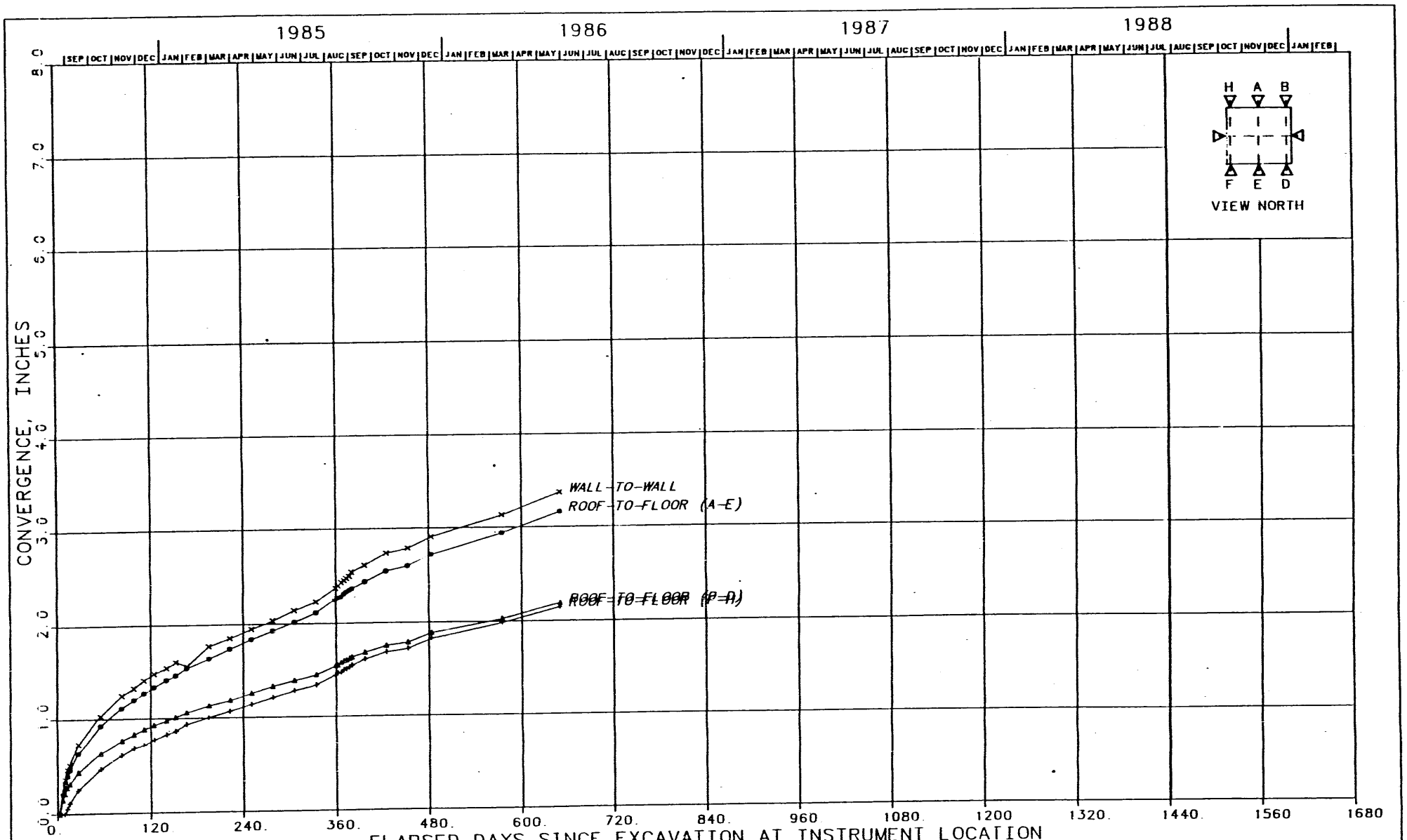


FIGURE J-230
CONVERGENCE POINTS
W30 DRIFT – S700 CROSSCUT INTERSECTION
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 14 FT.

FIGURE J-231
CONVERGENCE POINTS
W30 DRIFT, SOUTH 850 FT
CONVERGENCE VS. TIME SINCE EXCAVATION

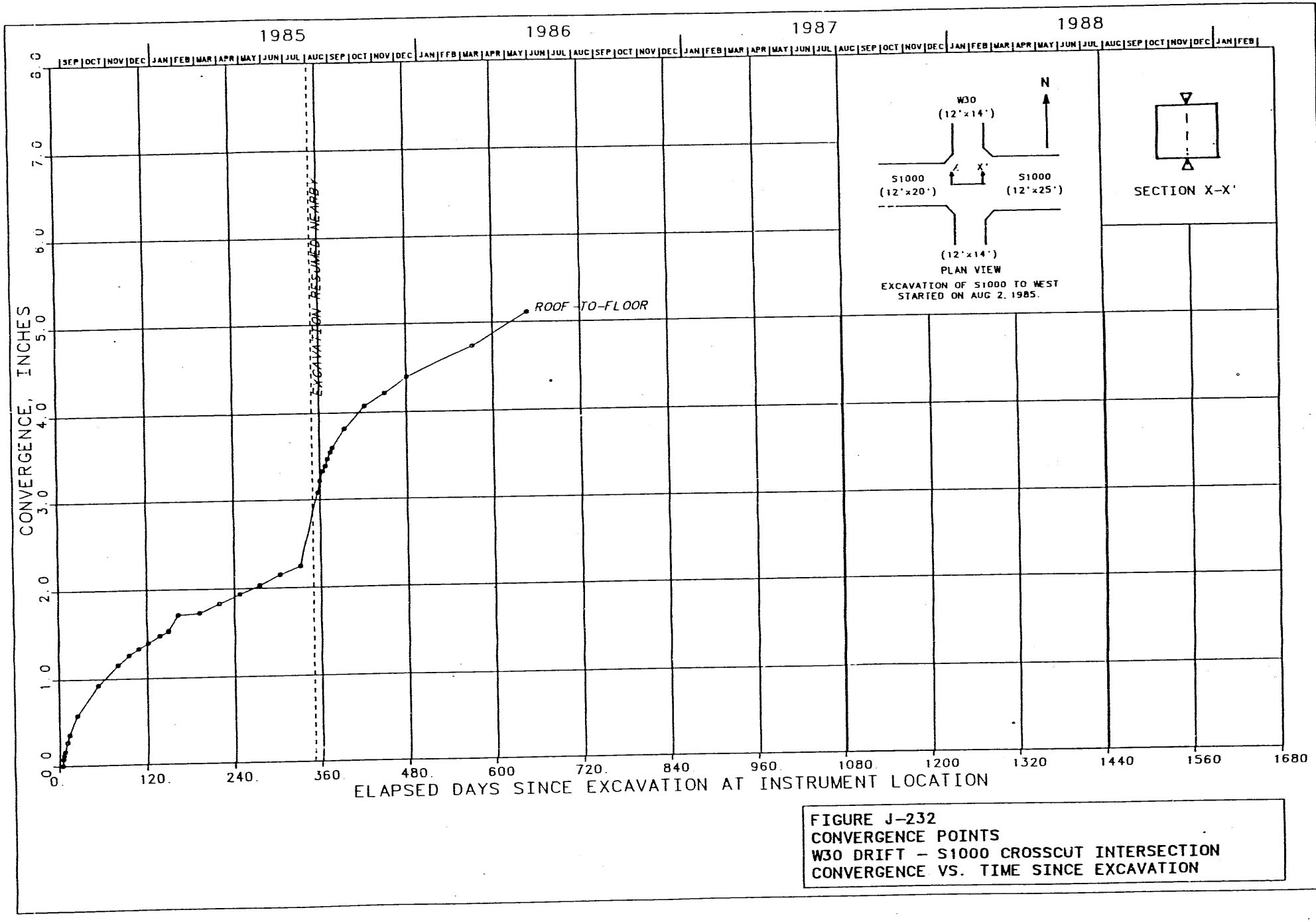
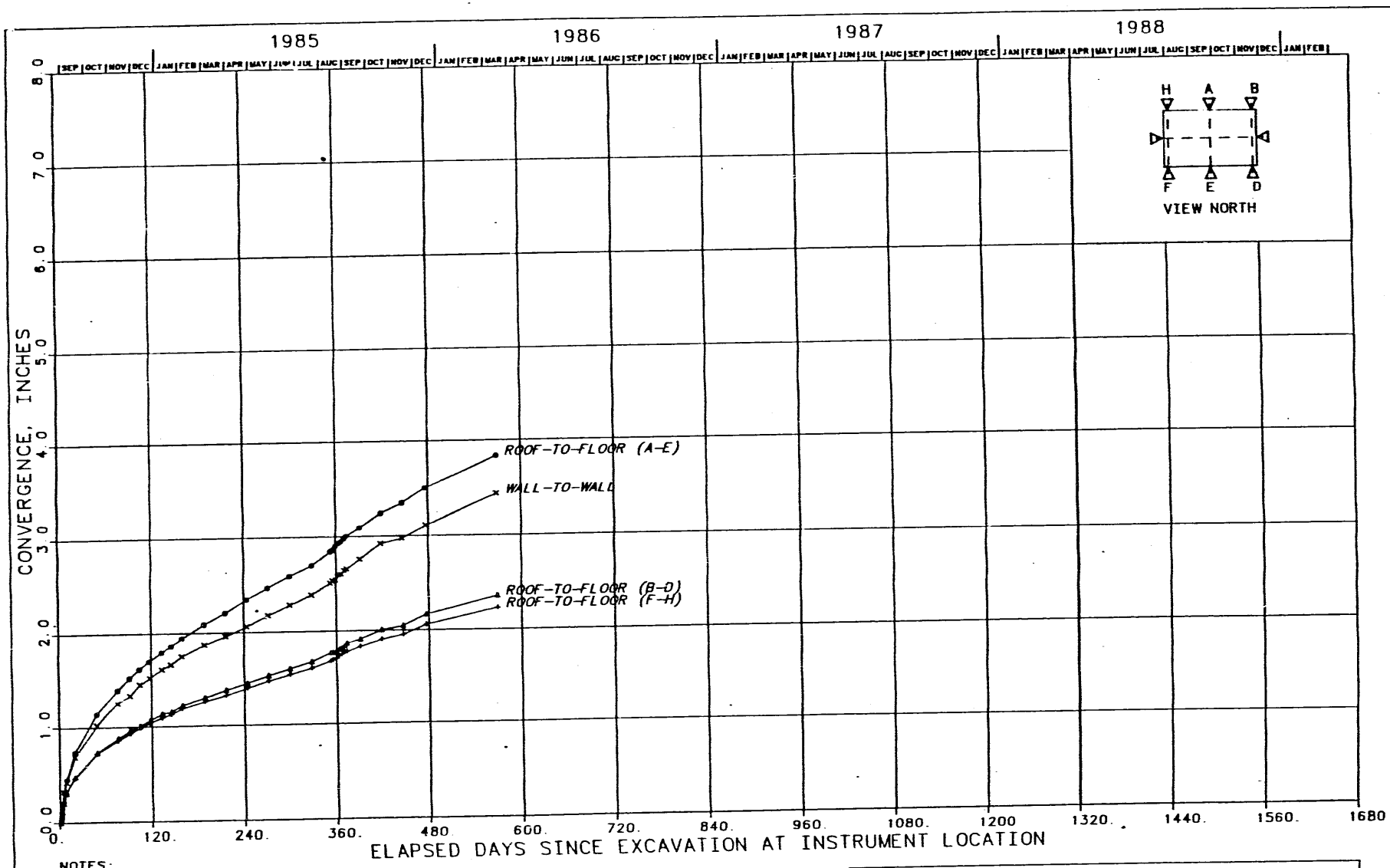


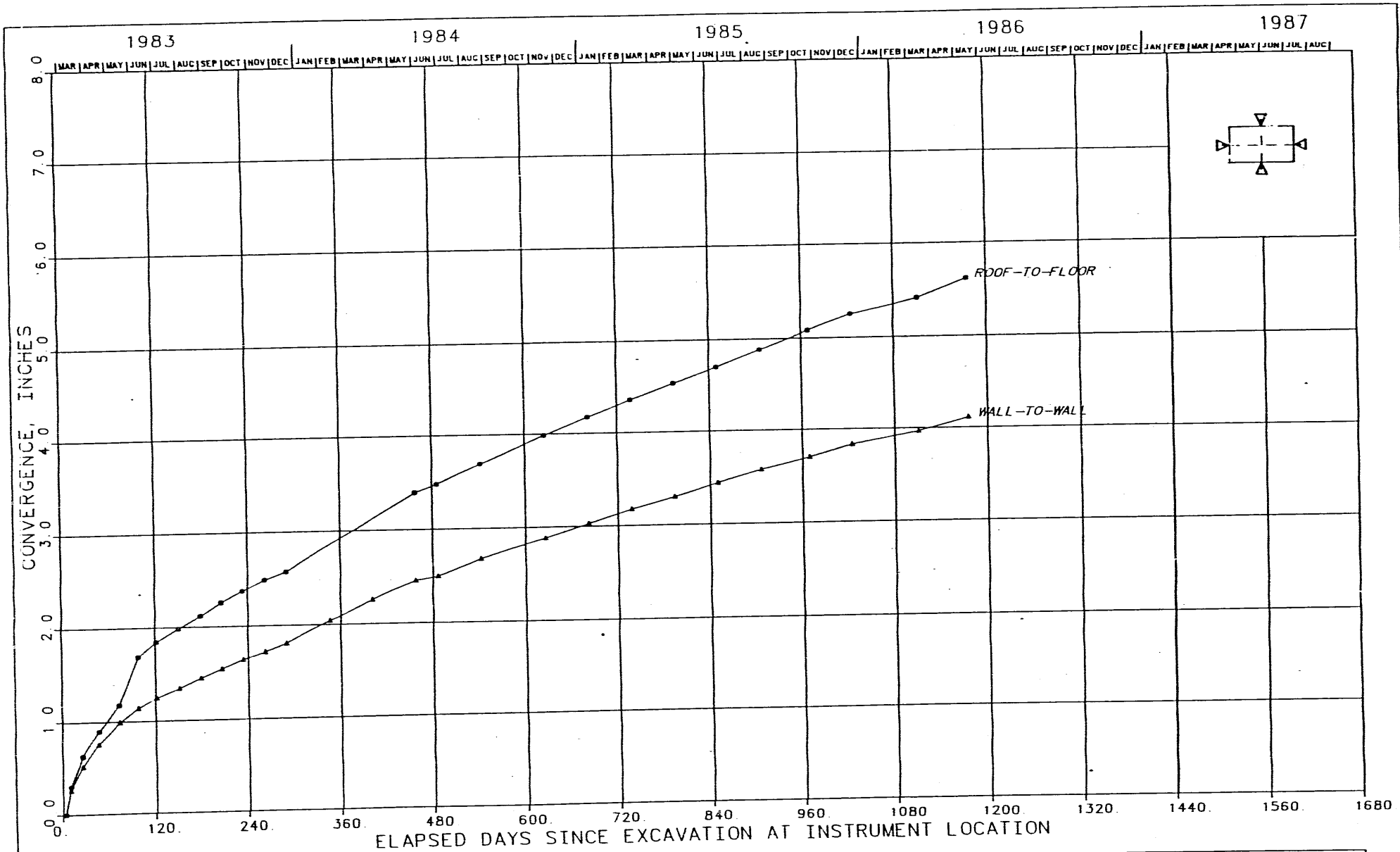
FIGURE J-232
CONVERGENCE POINTS
W30 DRIFT – S1000 CROSSCUT INTERSECTION
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 20 FT.
2. INSTRUMENT HAS BEEN DESTROYED.

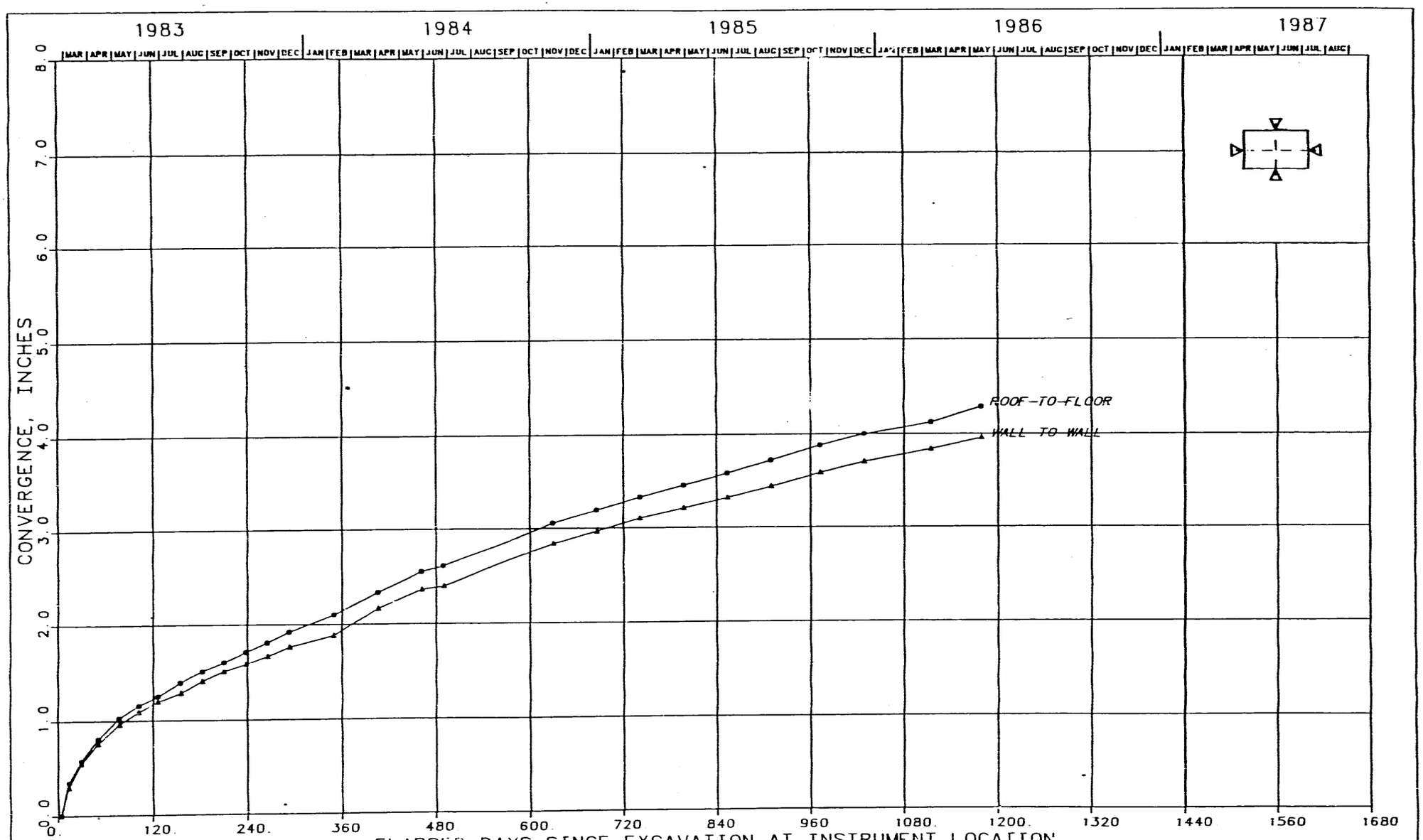
FIGURE J-233
CONVERGENCE POINTS
W30 DRIFT, SOUTH 1141 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 8 FT X 14 FT

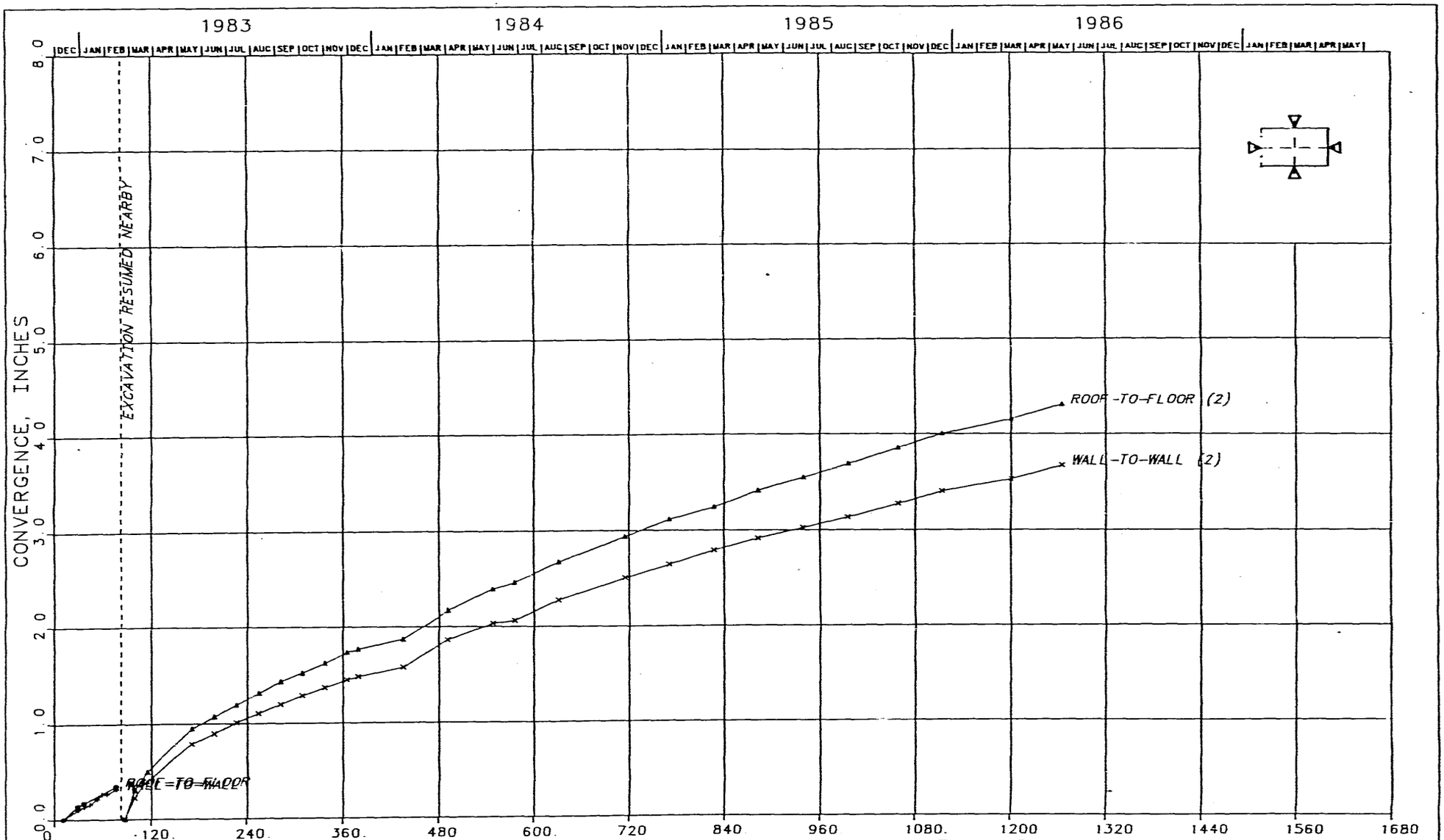
FIGURE J-234
CONVERGENCE POINTS
E140 DRIFT, NORTH 1266 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 8 FT X 14 FT.

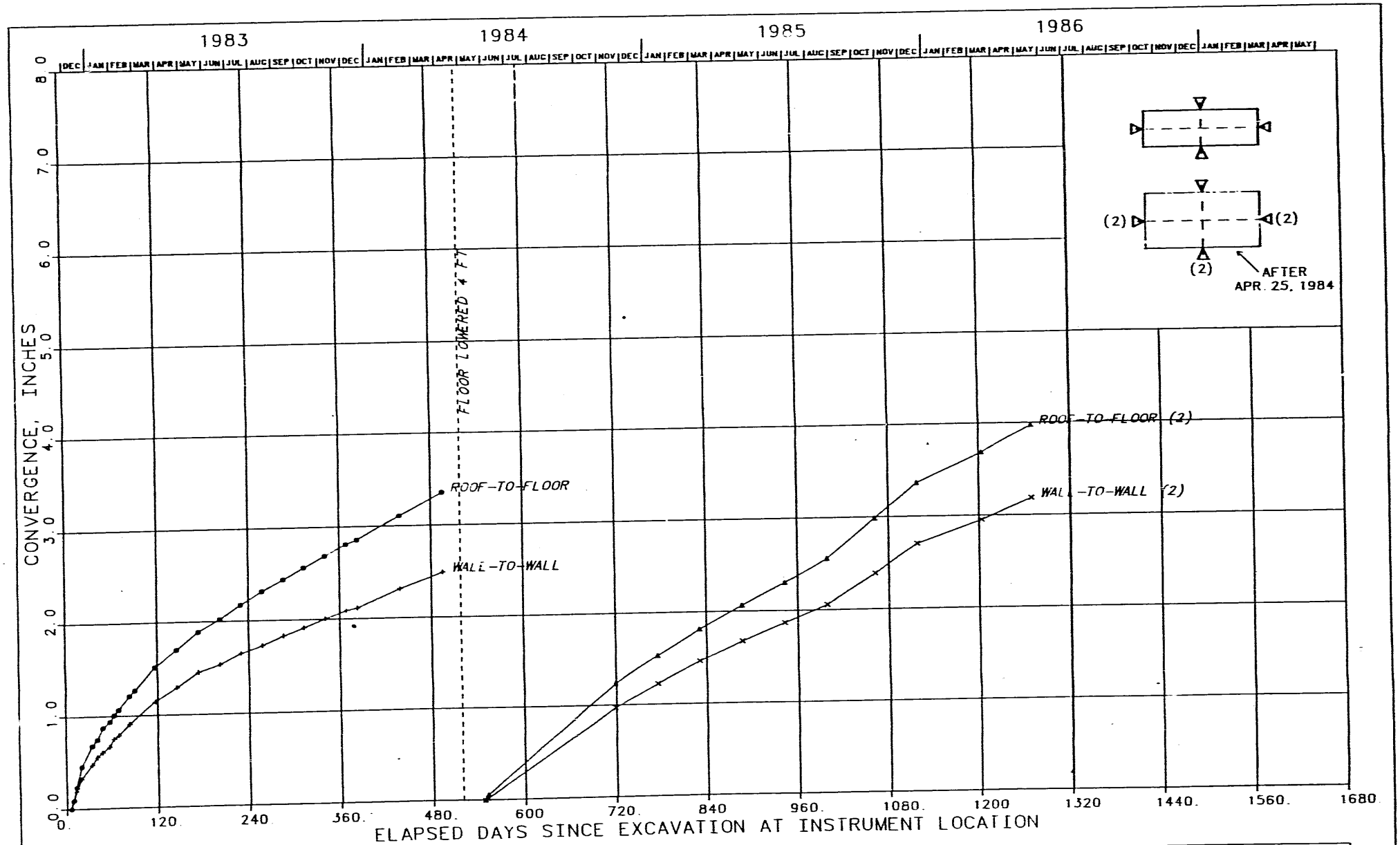
FIGURE J-235
CONVERGENCE POINTS
E140 DRIFT, NORTH 626 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

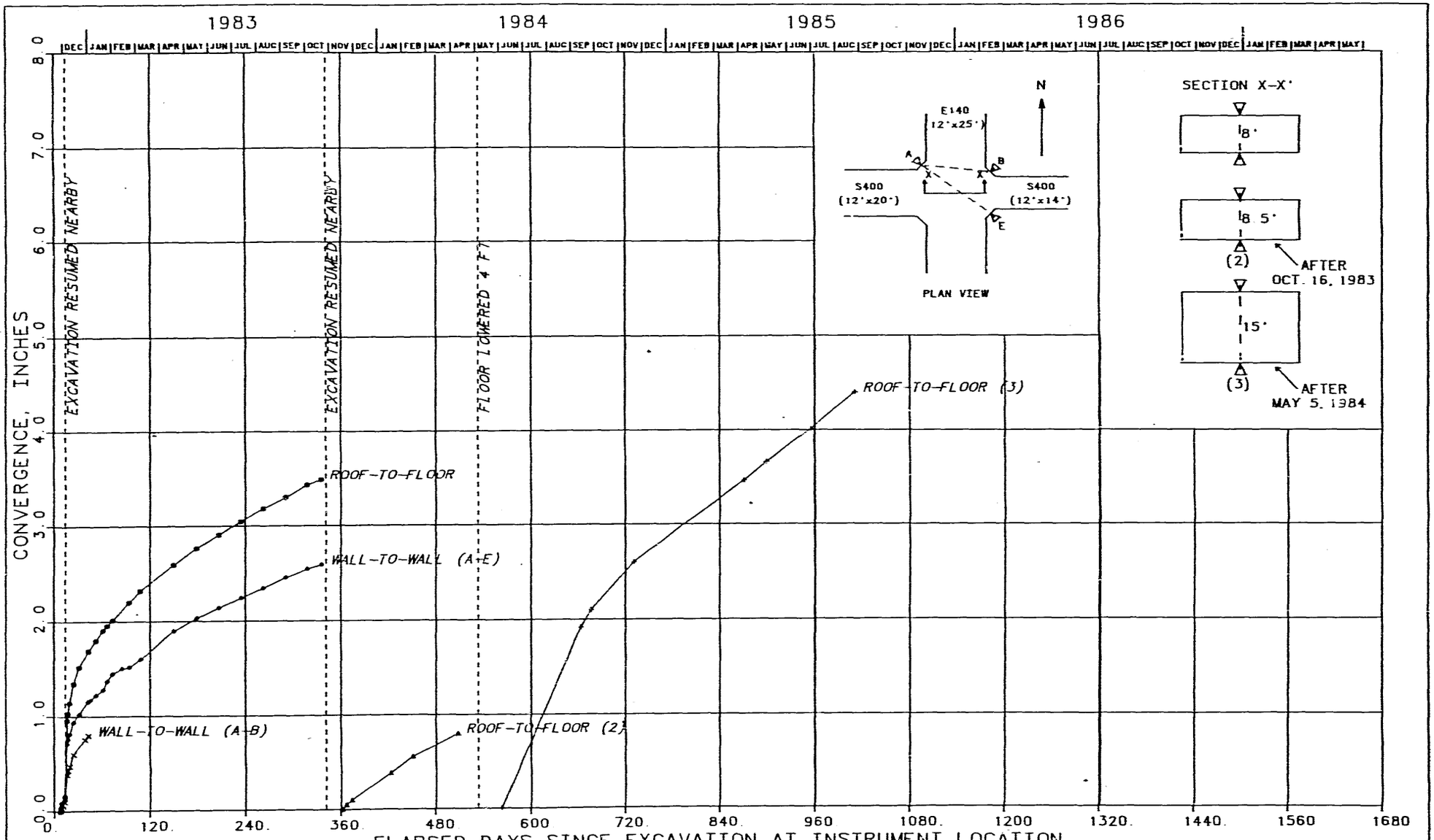
1. SIZE OF EXCAVATION: 8 FT X 14 FT.

FIGURE J-236
CONVERGENCE POINTS
E140 DRIFT, NORTH 240 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:
1 SIZE OF EXCAVATION: 12 FT X 25 FT.

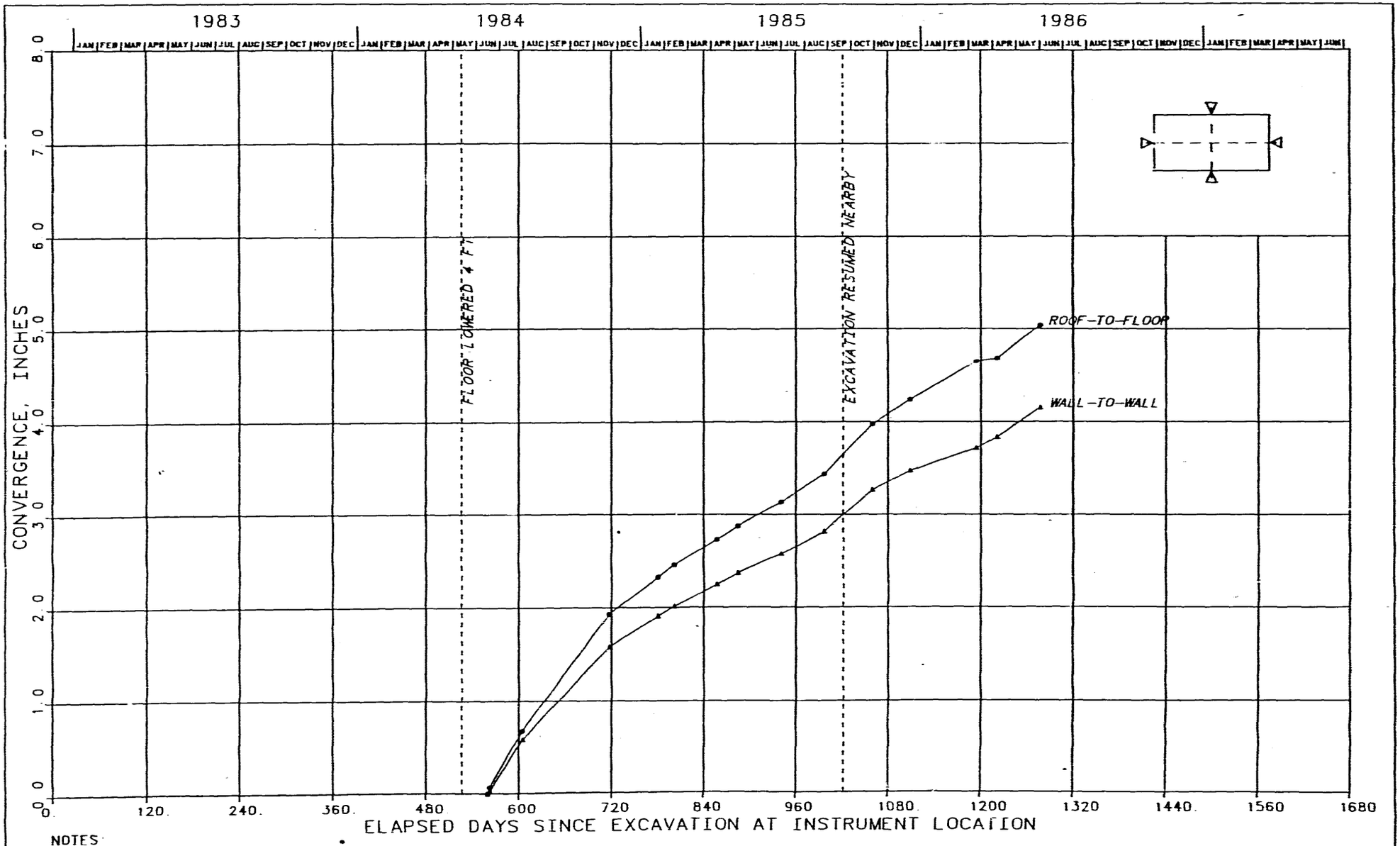
FIGURE J-237
CONVERGENCE POINTS
E140 DRIFT, NORTH 5 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. INSTRUMENT HAS BEEN DESTROYED.

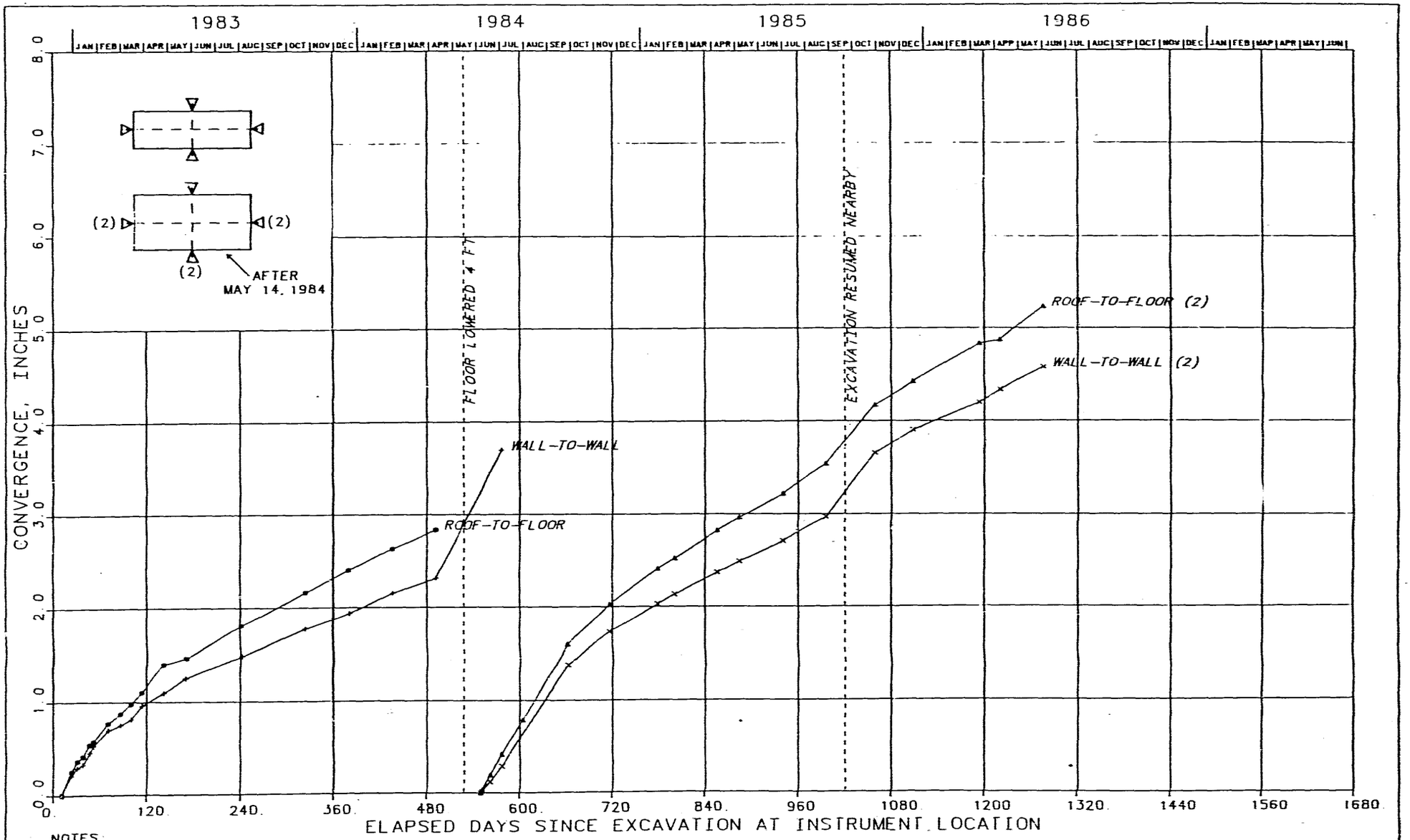
FIGURE J-238
CONVERGENCE POINTS
E140 DRIFT – S400 CROSSCUT INTERSECTION
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 25 FT.

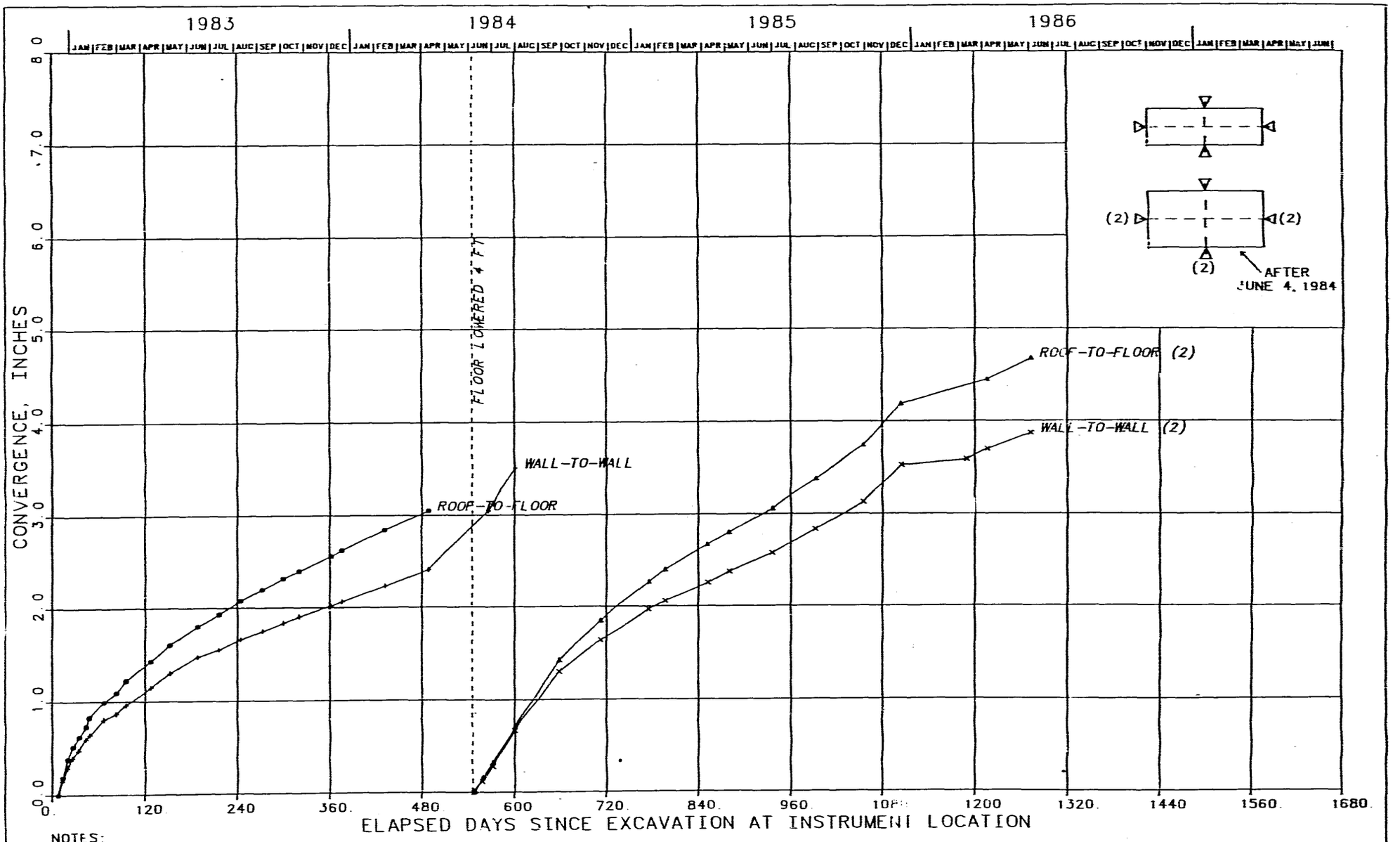
FIGURE J-239
CONVERGENCE POINTS
E140 DRIFT, SOUTH 460 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION: 12 FT X 25 FT.

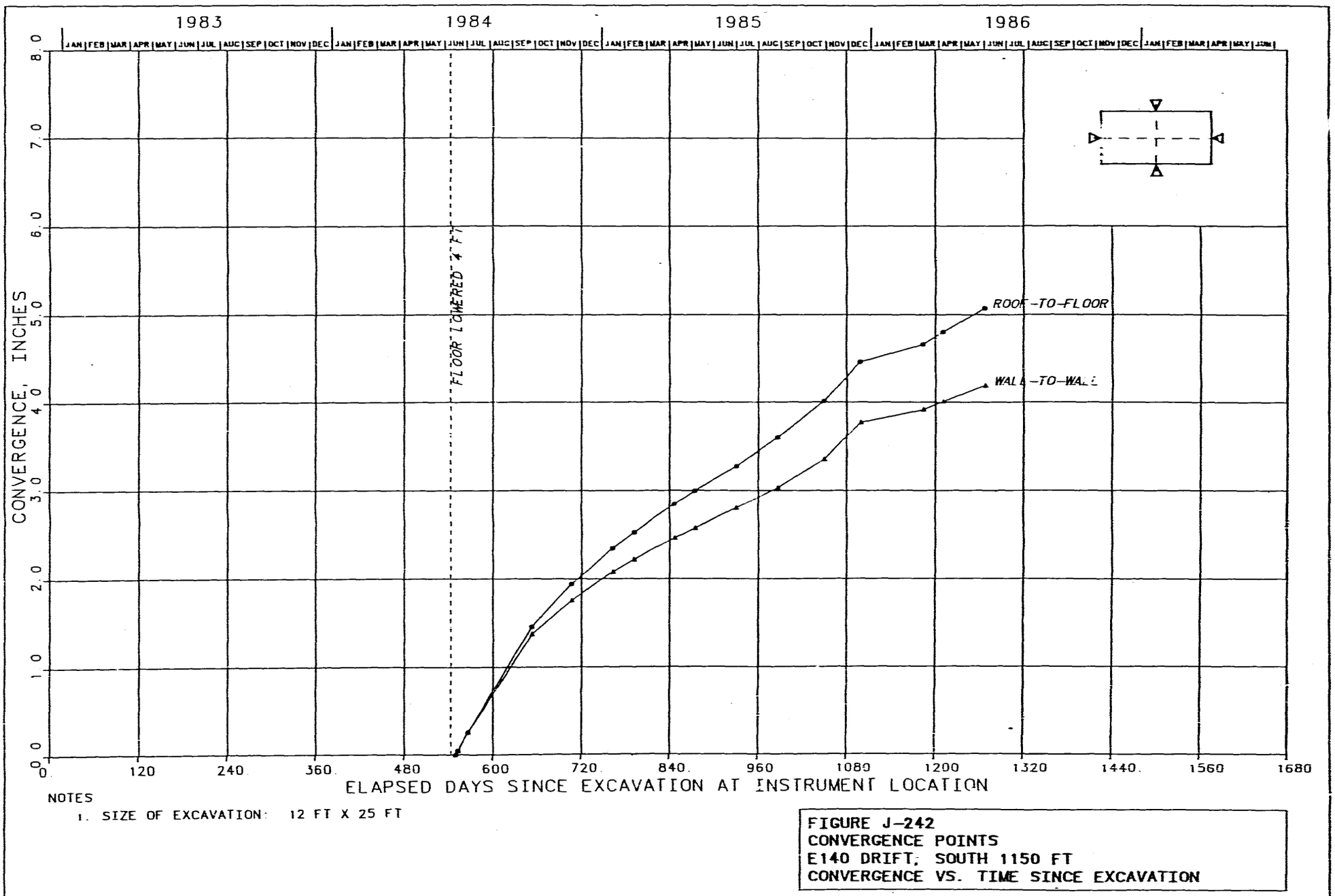
FIGURE J-240
CONVERGENCE POINTS
E140 DRIFT, SOUTH 550 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 25 FT.

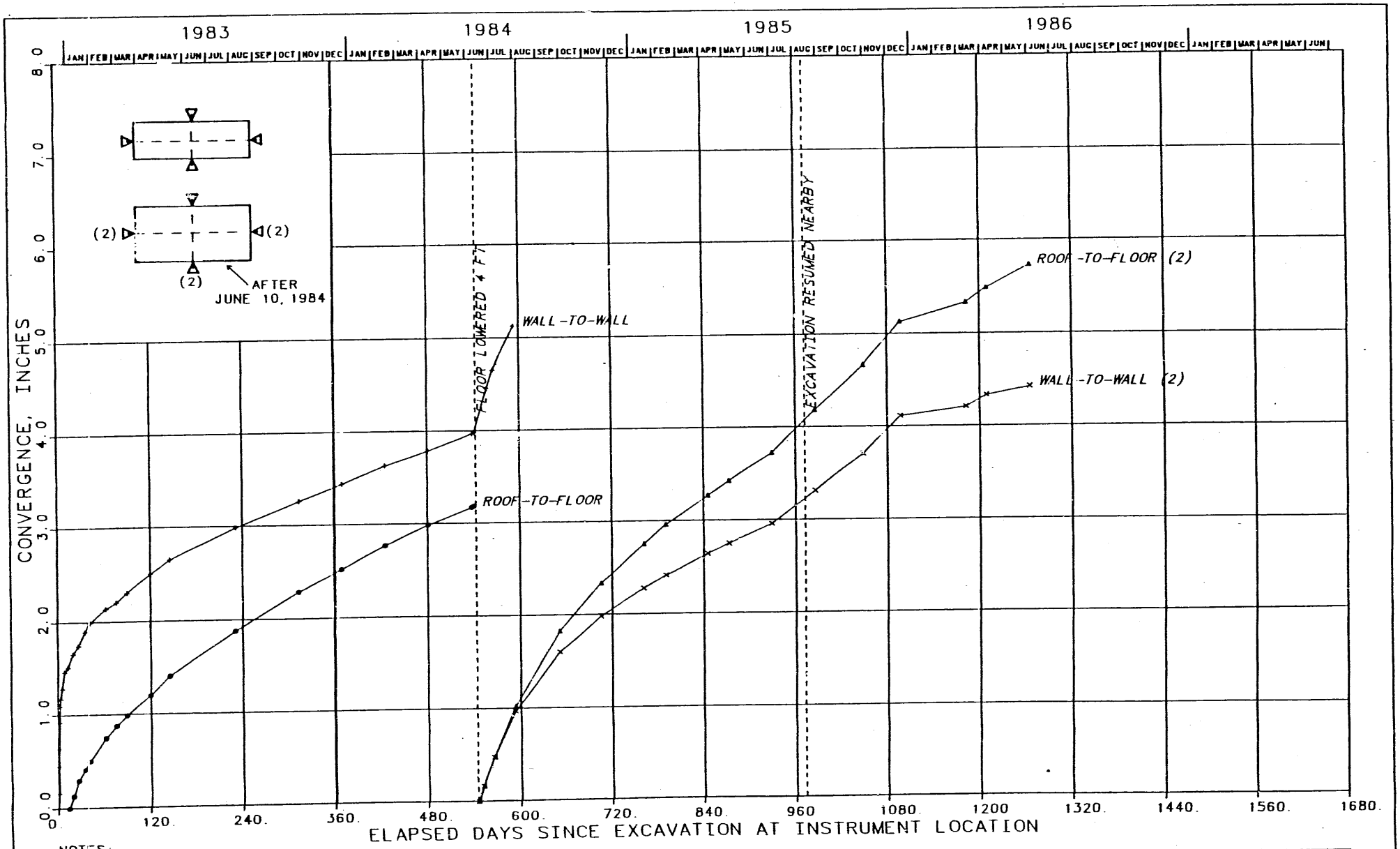
FIGURE J-241
CONVERGENCE POINTS
E140 DRIFT, SOUTH 850 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION: 12 FT X 25 FT

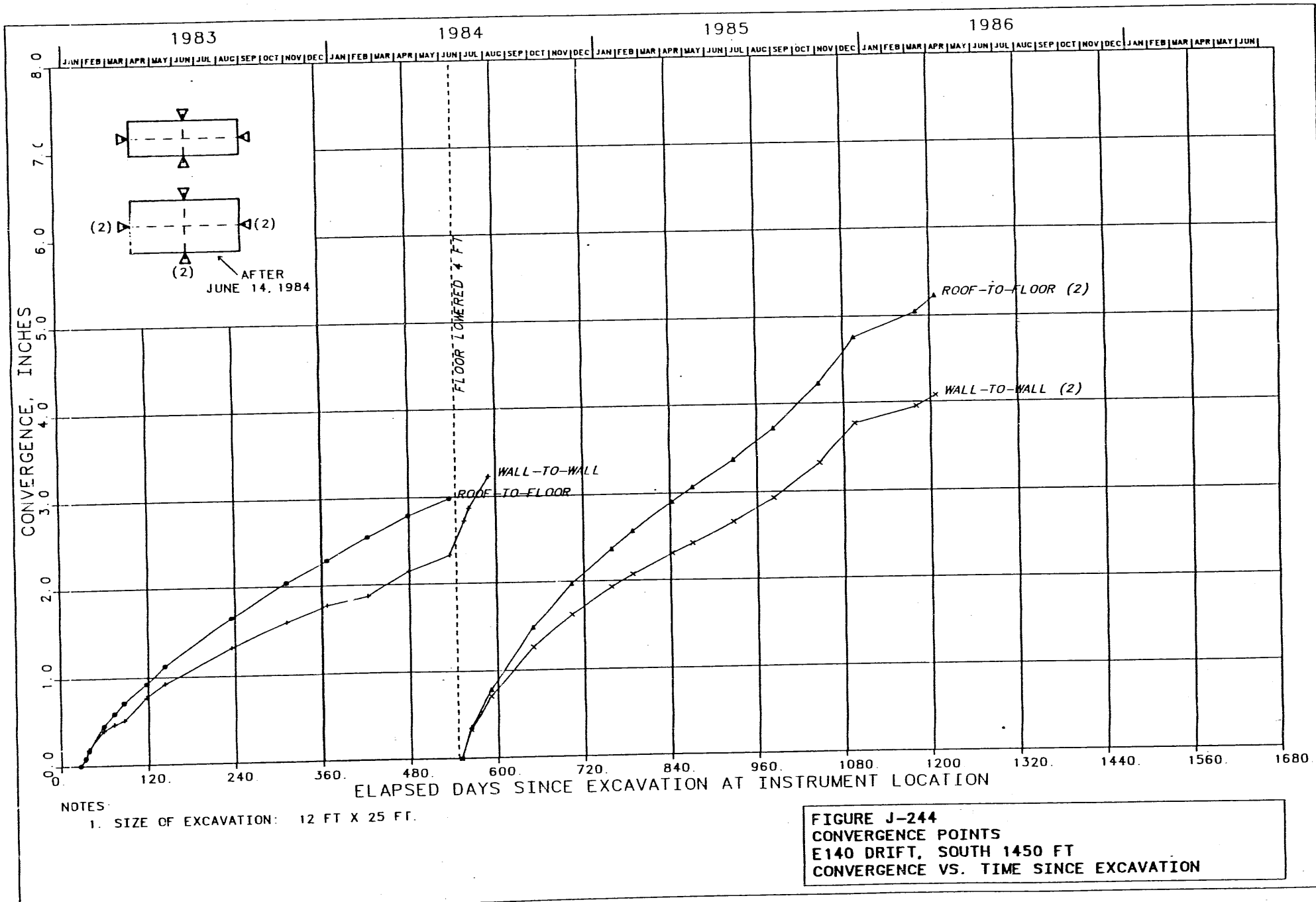
FIGURE J-242
CONVERGENCE POINTS
E140 DRIFT, SOUTH 1150 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1 SIZE OF EXCAVATION: 12 FT X 25 FT.

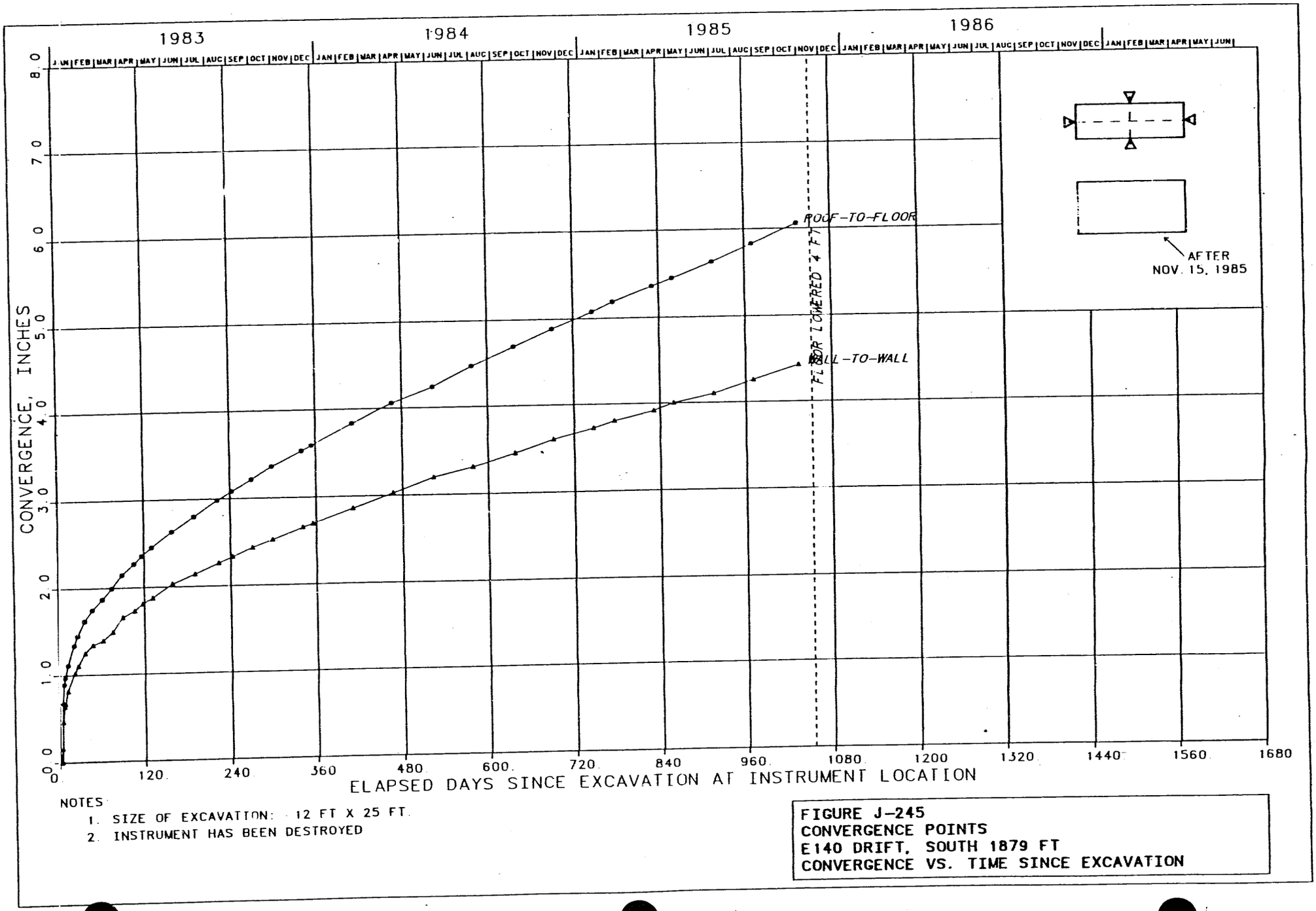
FIGURE J-243
CONVERGENCE POINTS
E140 DRIFT, SOUTH 1246 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 25 FT.

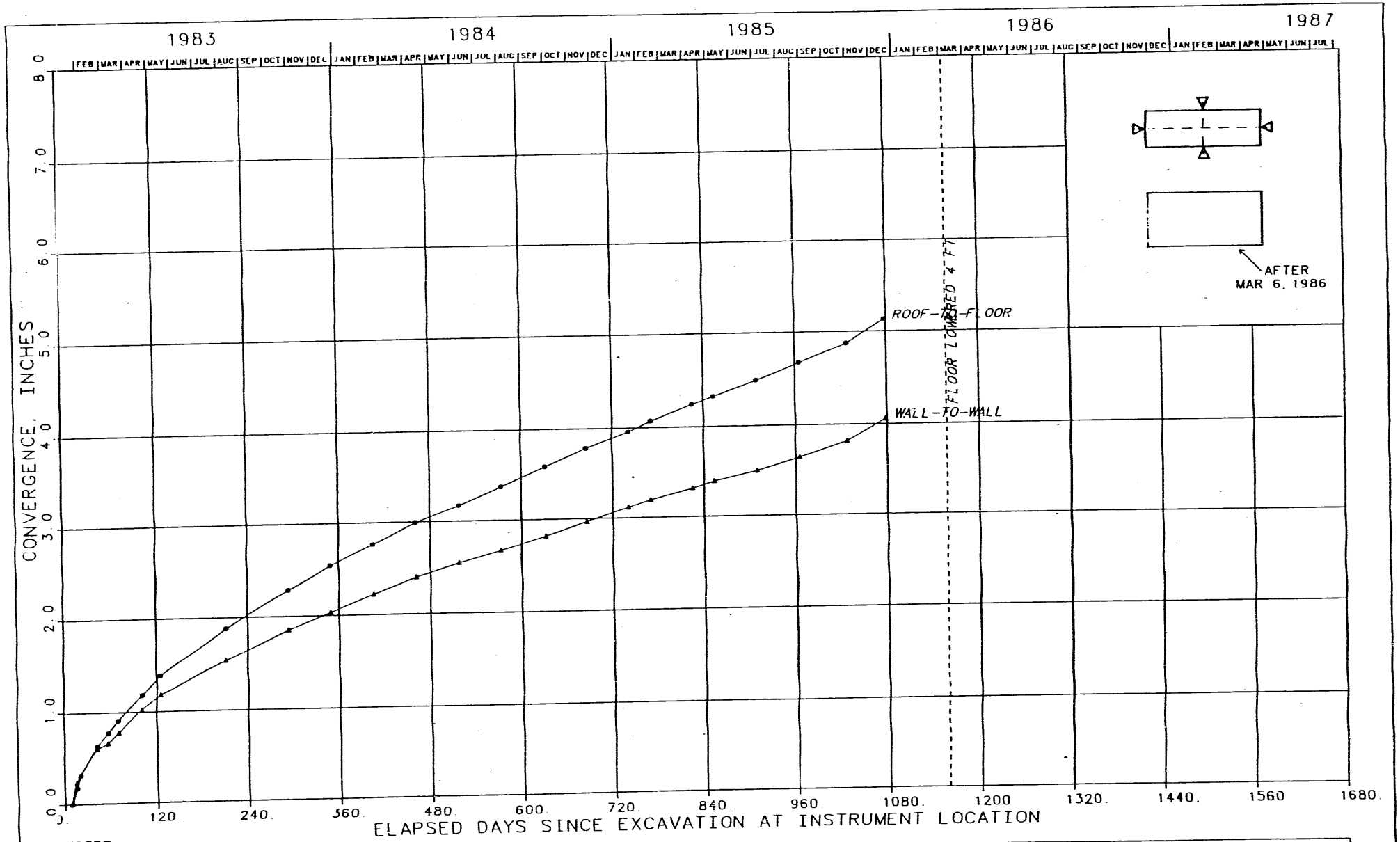
FIGURE J-244
CONVERGENCE POINTS
E140 DRIFT, SOUTH 1450 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION: 12 FT X 25 FT.
2. INSTRUMENT HAS BEEN DESTROYED

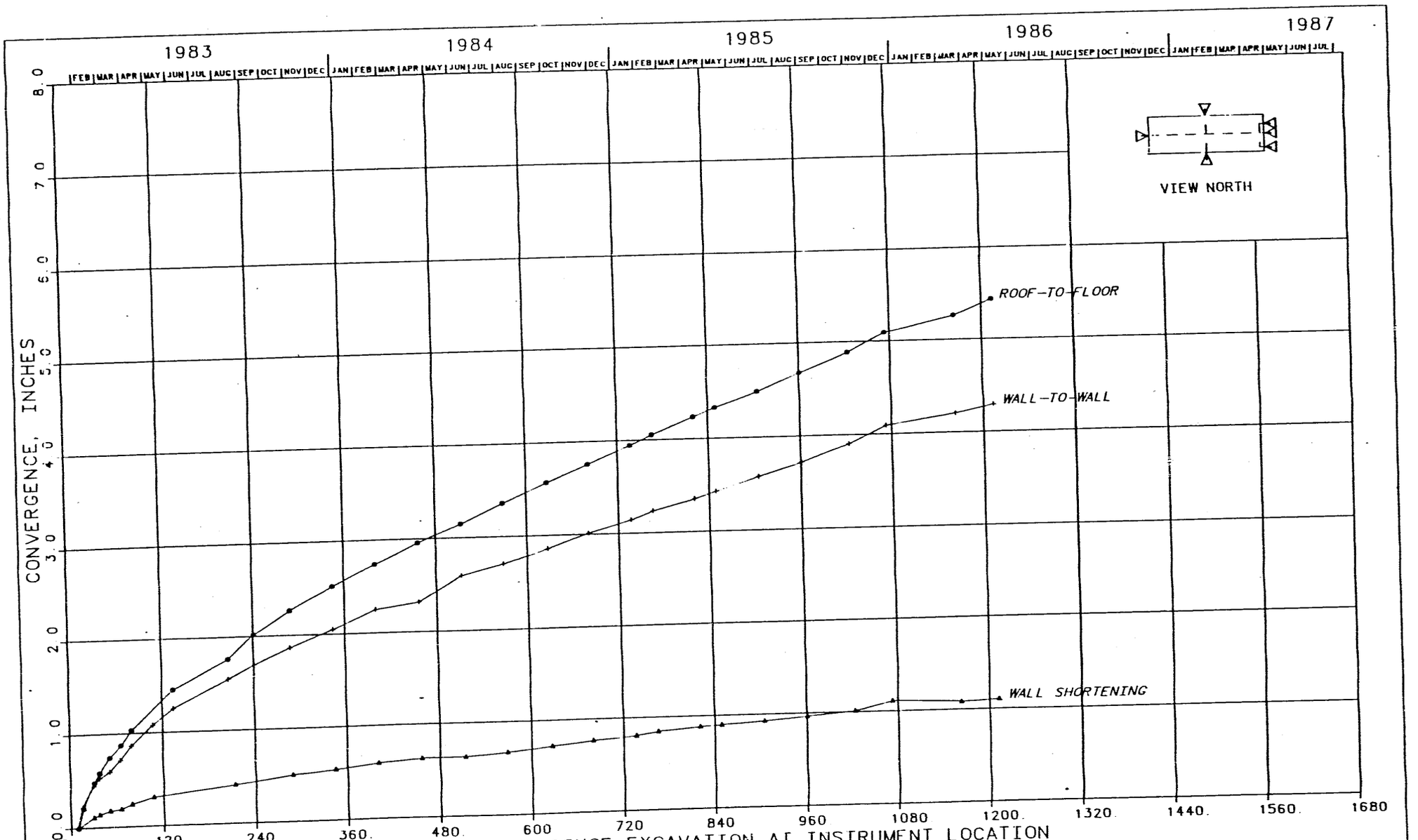
FIGURE J-245
CONVERGENCE POINTS
E140 DRIFT, SOUTH 1879 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

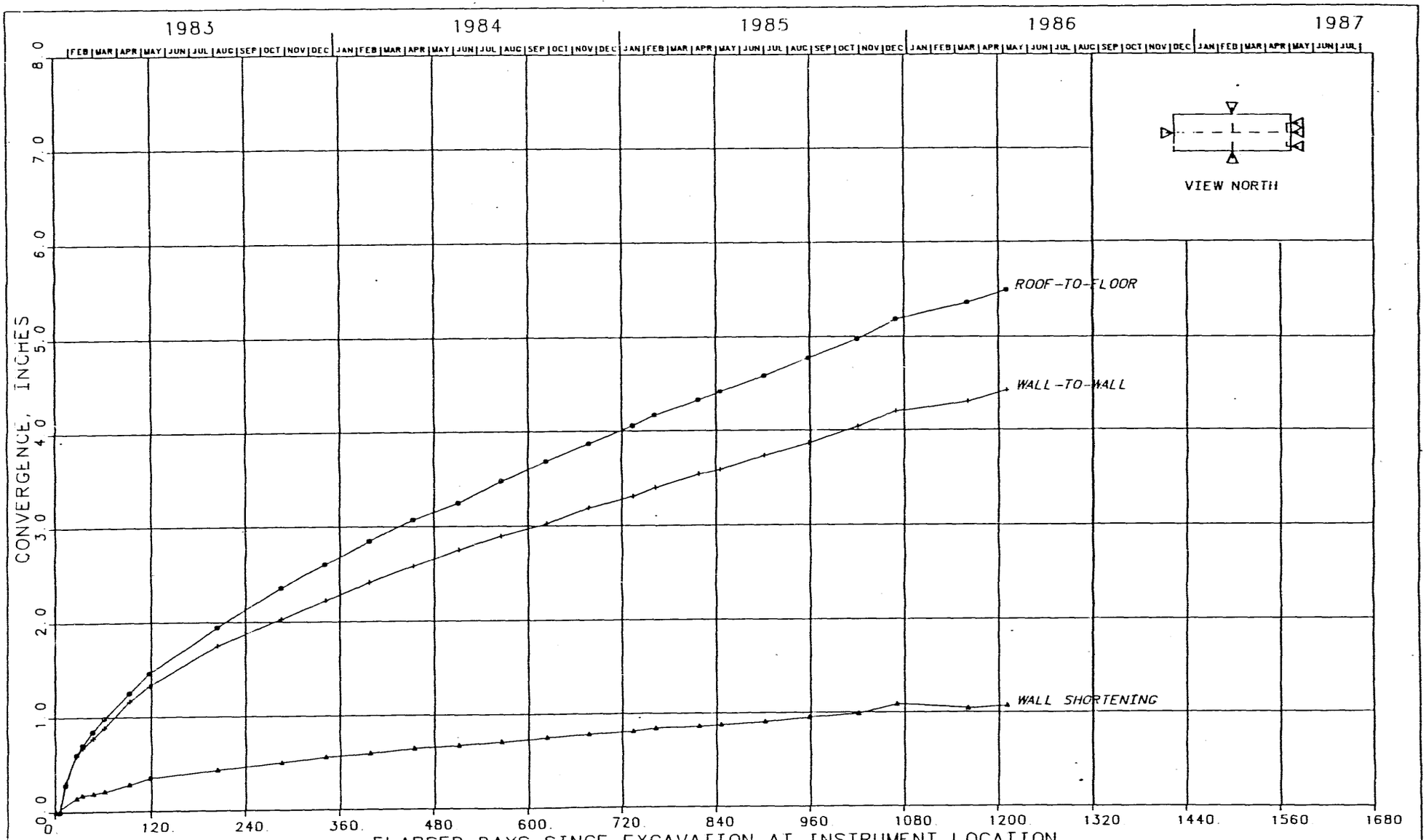
1. SIZE OF EXCAVATION 12 FT X 25 FT.
2. INSTRUMENT HAS BEEN DESTROYED.

FIGURE J-246
CONVERGENCE POINTS
E140 DRIFT, SOUTH 2066 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:
1. SIZE OF EXCAVATION: 8 FT X 25 FT.

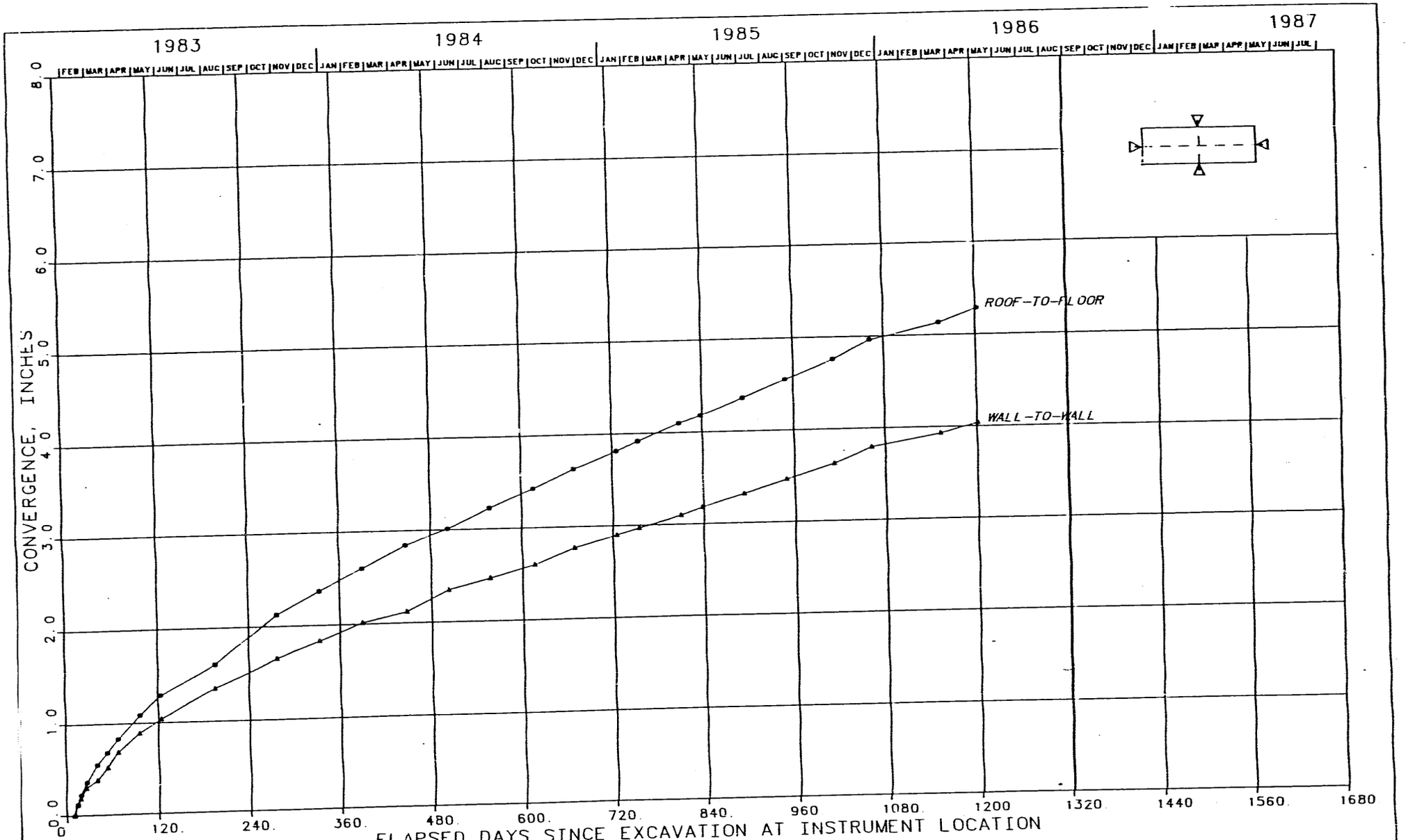
FIGURE J-247
CONVERGENCE POINTS
E140 DRIFT, SOUTH 2350 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION: 8 FT X 25 FT

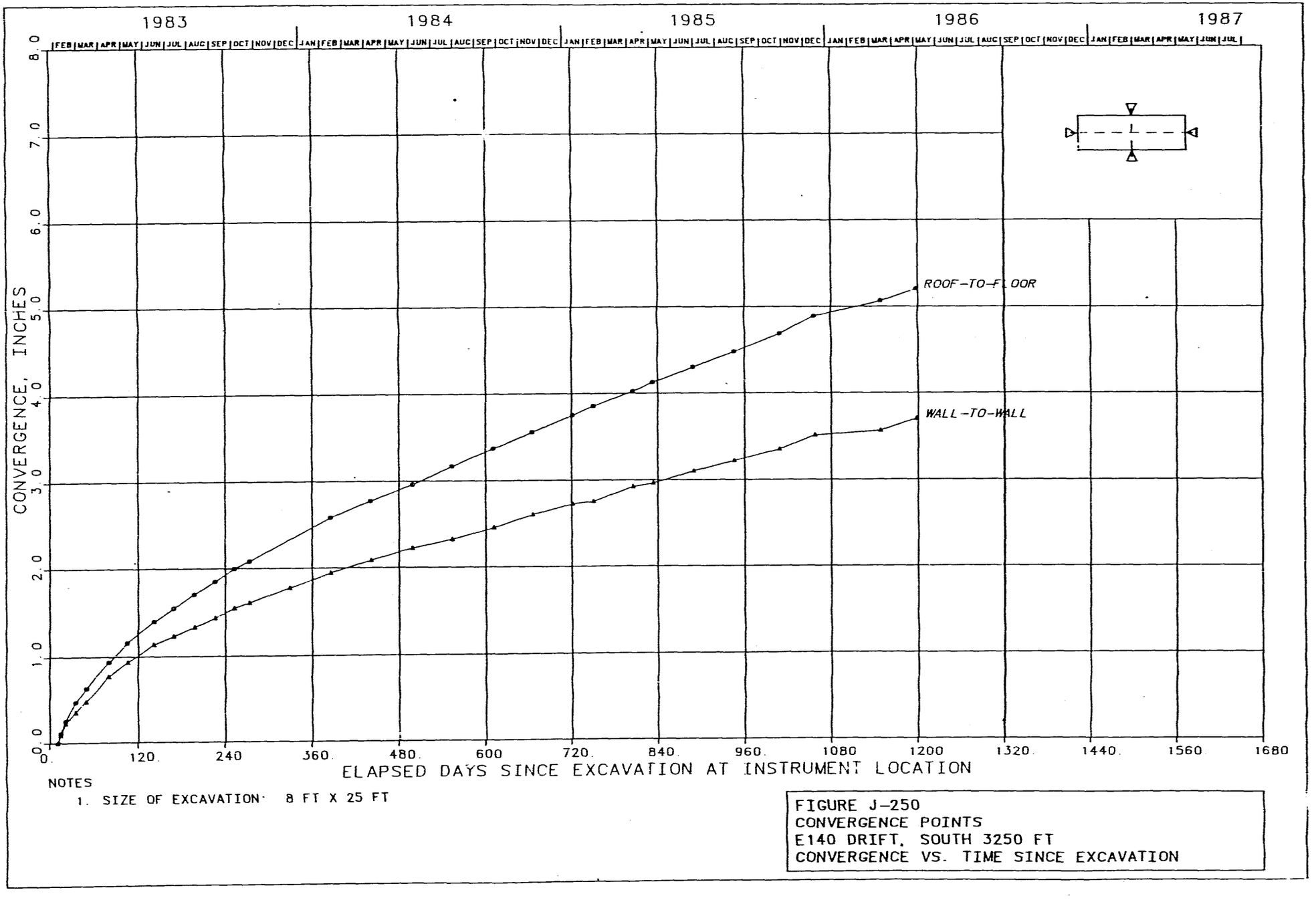
FIGURE J-248
CONVERGENCE POINTS
E140 DRIFT, SOUTH 2625 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 8 FT X 25 FT.

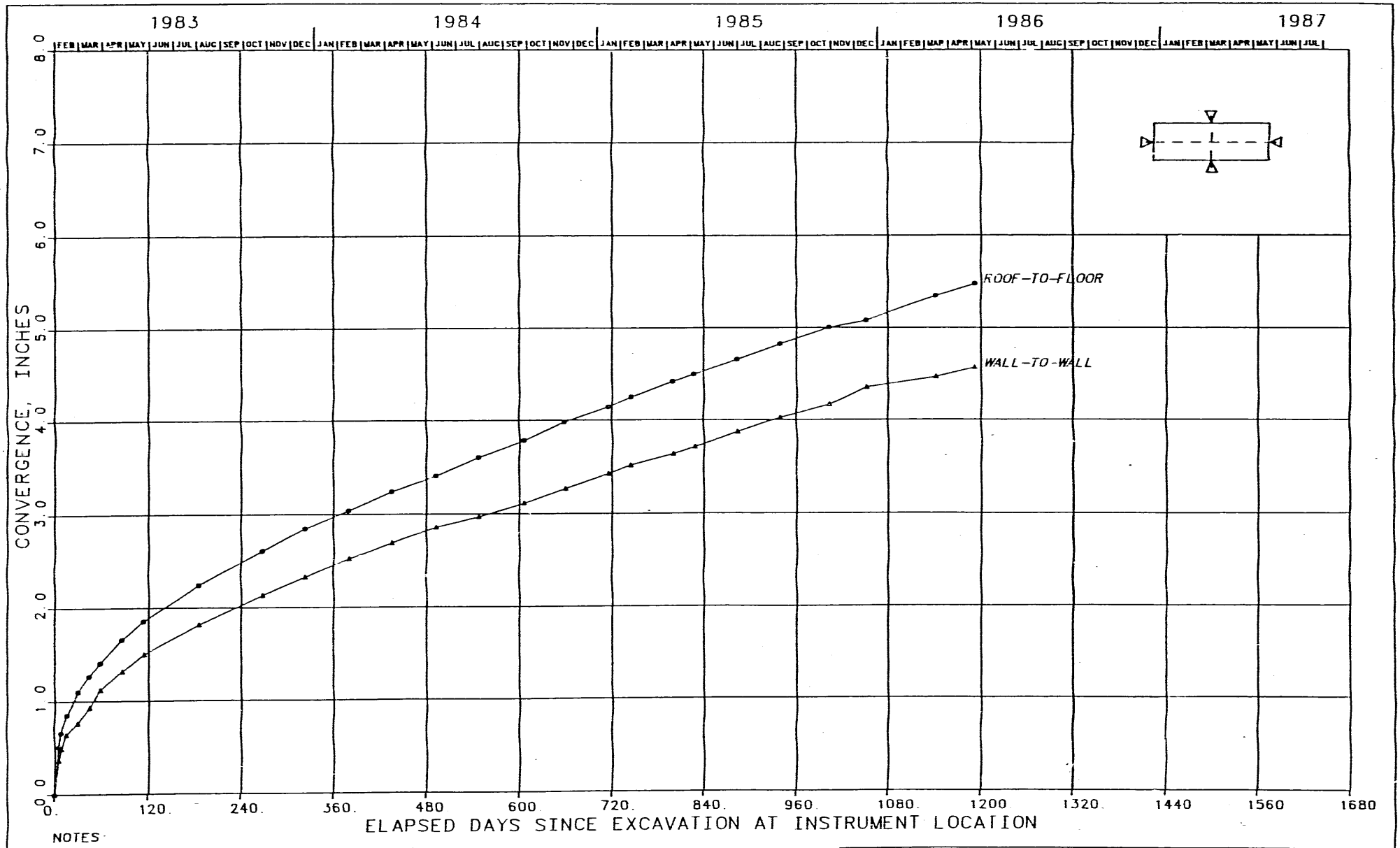
FIGURE J-249
CONVERGENCE POINTS
E140 DRIFT, SOUTH 2950 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION 8 FT X 25 FT

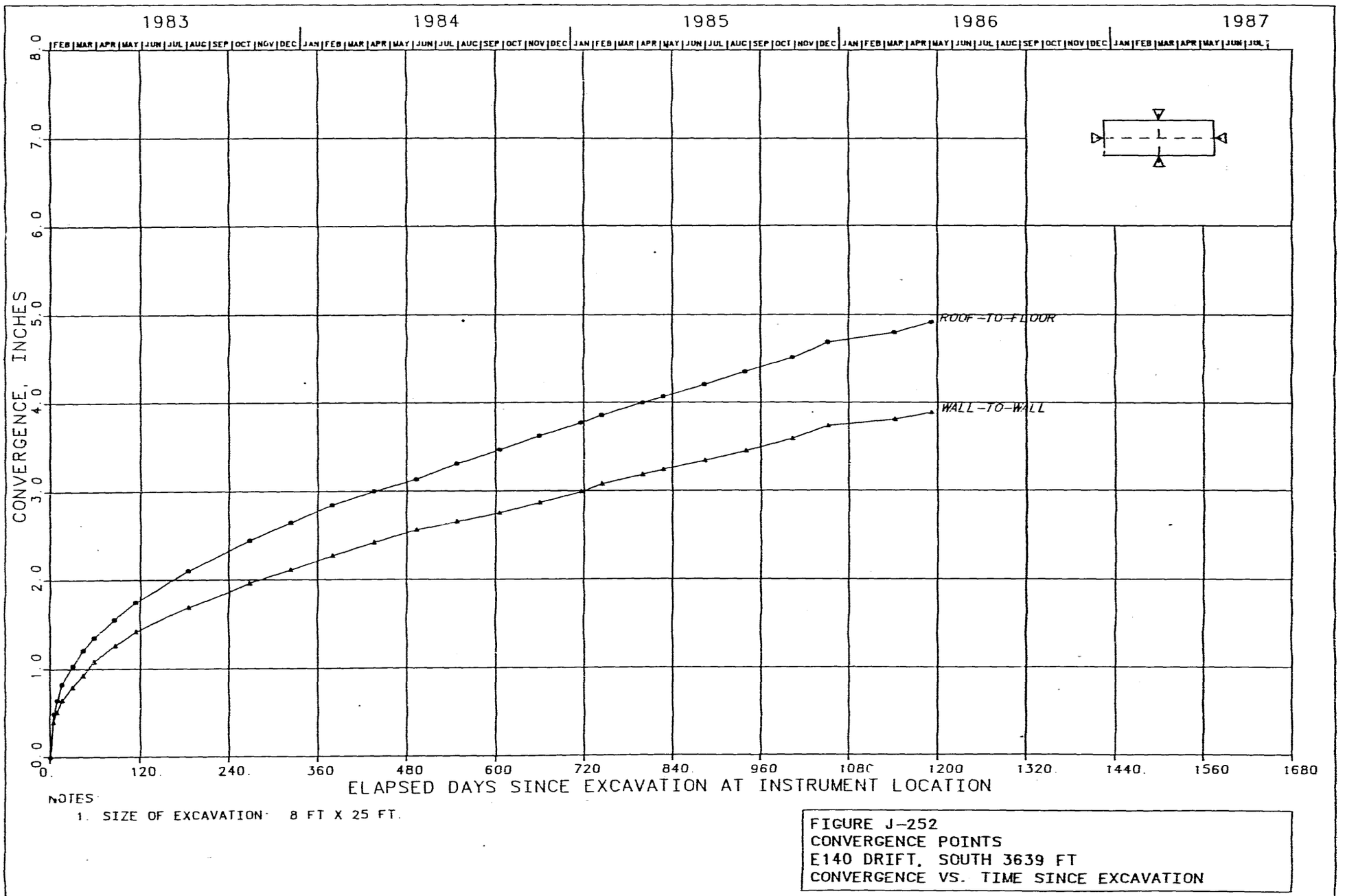
FIGURE J-250
CONVERGENCE POINTS
E140 DRIFT, SOUTH 3250 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION 8 FT X 25 FT.

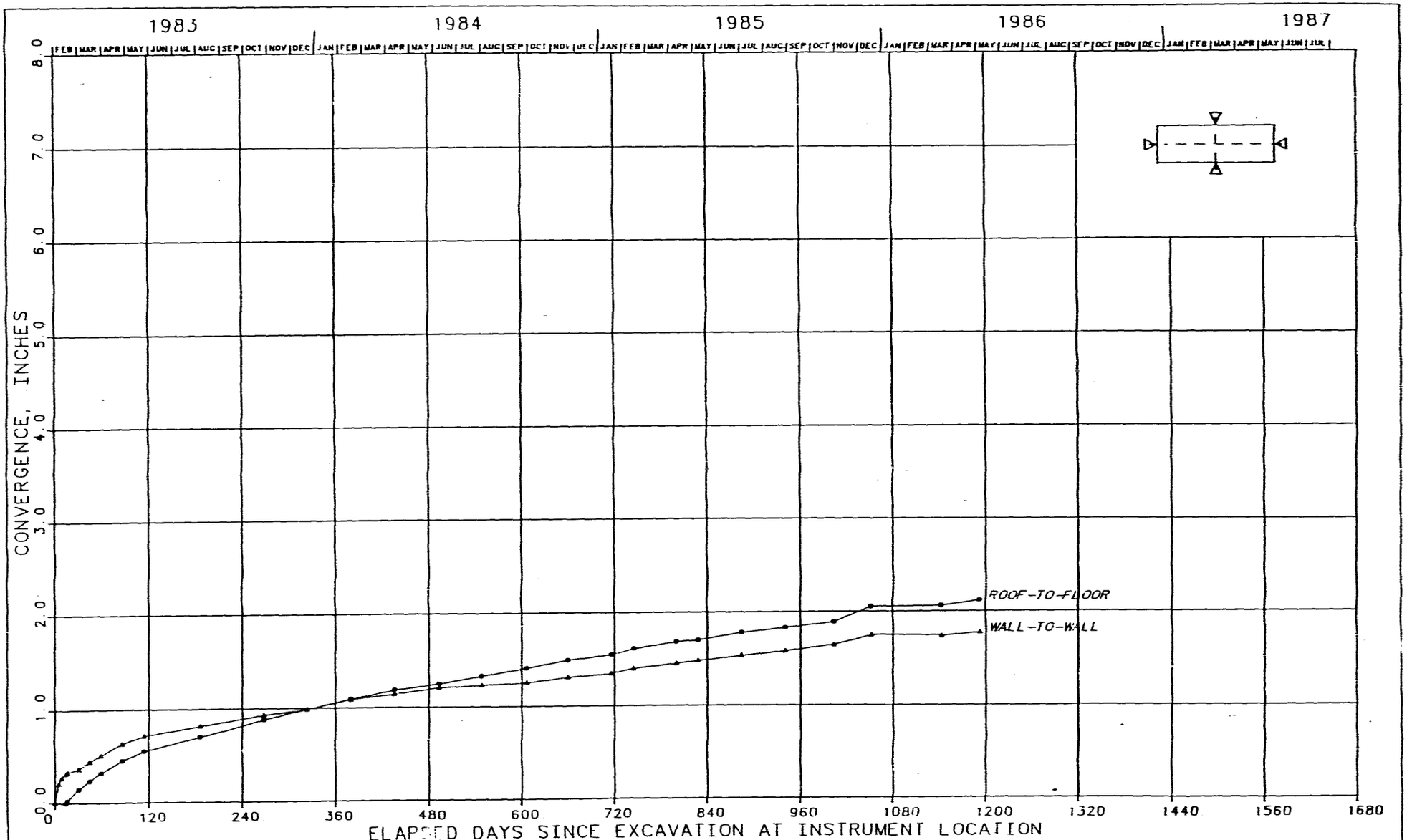
FIGURE J-251
CONVERGENCE POINTS
E140 DRIFT, SOUTH 3614 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 8 FT X 25 FT.

FIGURE J-252
CONVERGENCE POINTS
E140 DRIFT, SOUTH 3639 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION: 8 FT X 25 FT.

FIGURE J-253
CONVERGENCE POINTS
E140 DRIFT, SOUTH 3664 FT
CONVERGENCE VS. TIME SINCE EXCAVATION

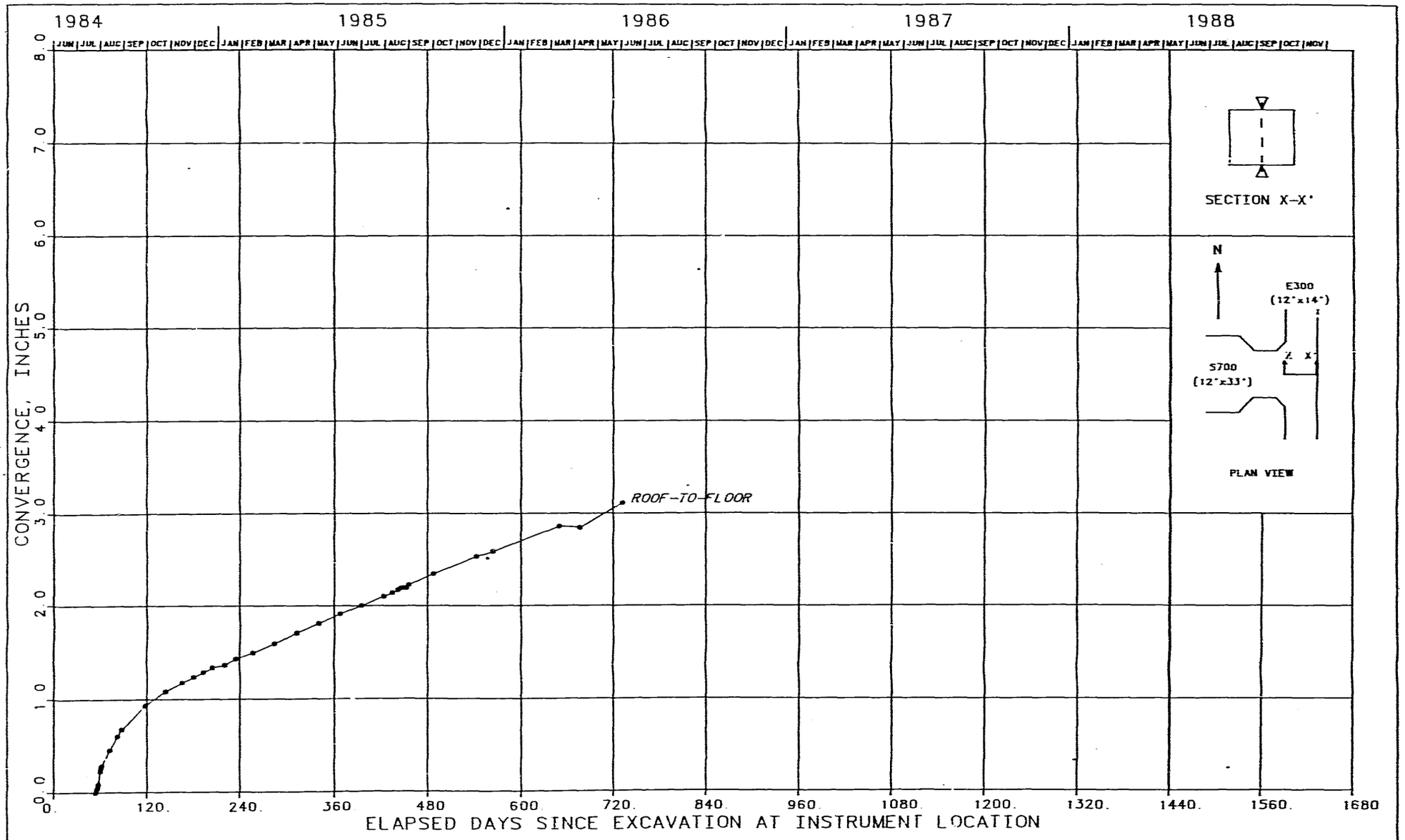
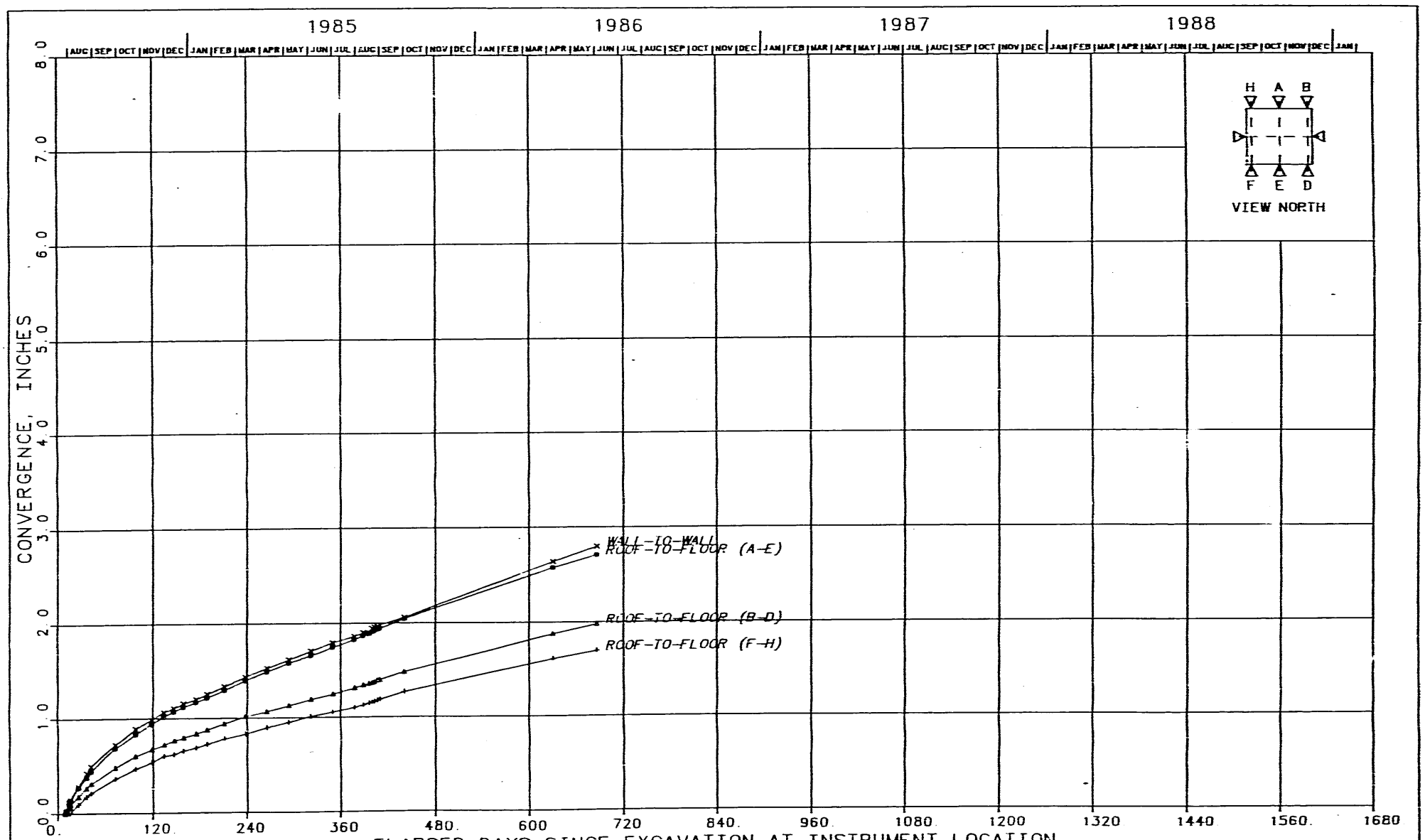


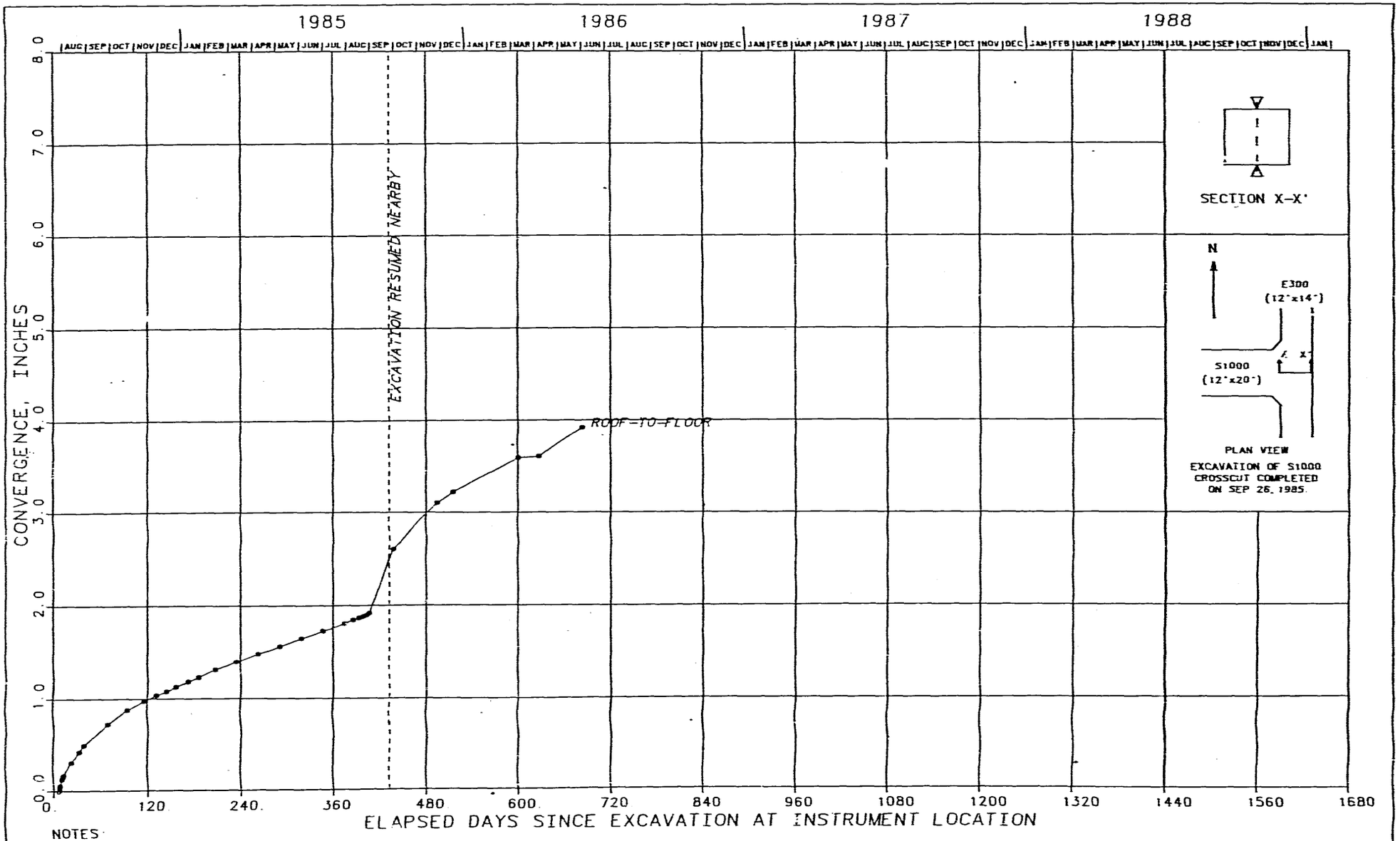
FIGURE J-254
CONVERGENCE POINTS
E300 DRIFT – S700 CROSSCUT INTERSECTION
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 14 FT.

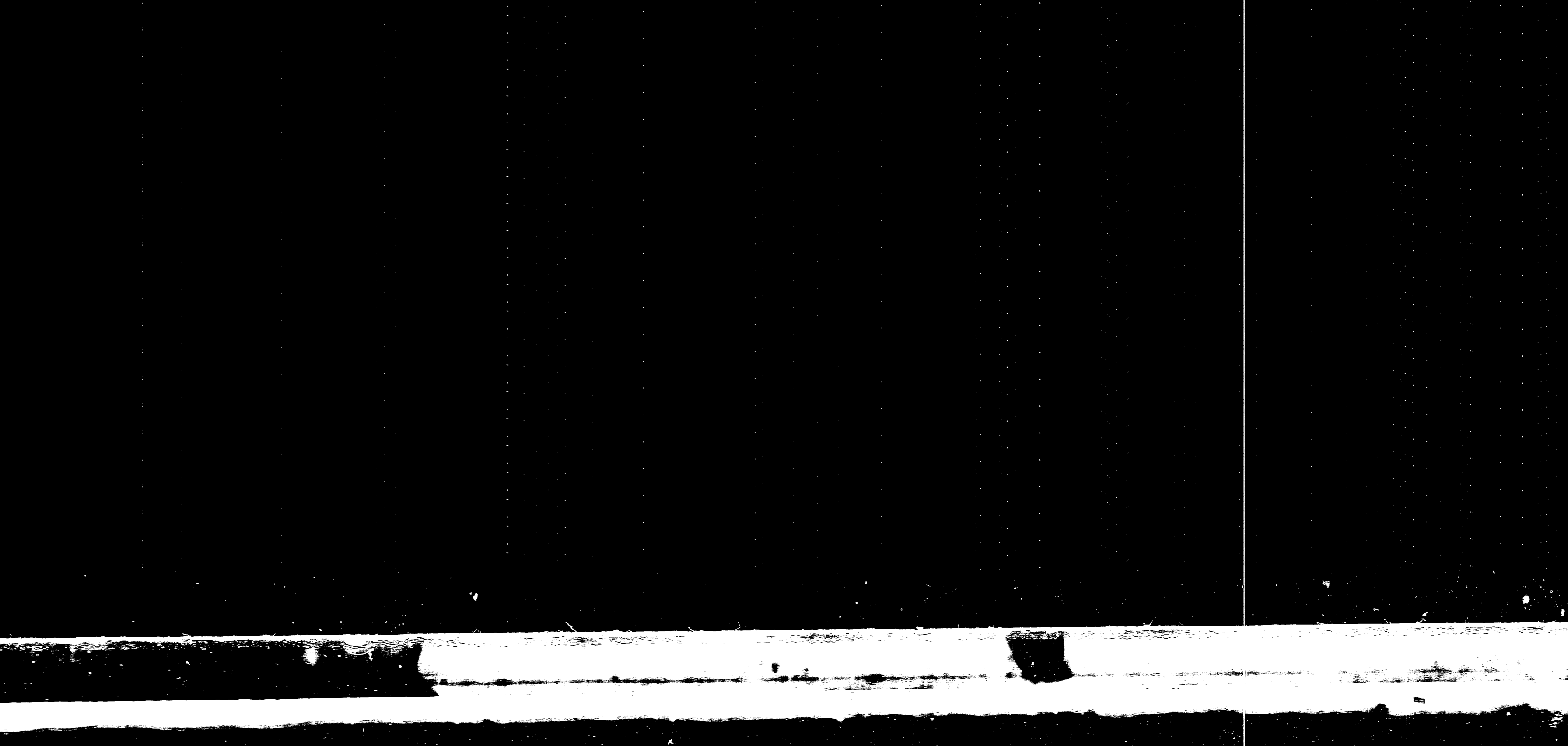
FIGURE J-255
CONVERGENCE POINTS
E300 DRIFT, SOUTH 850 FT
CONVERGENCE VS. TIME SINCE EXCAVATION

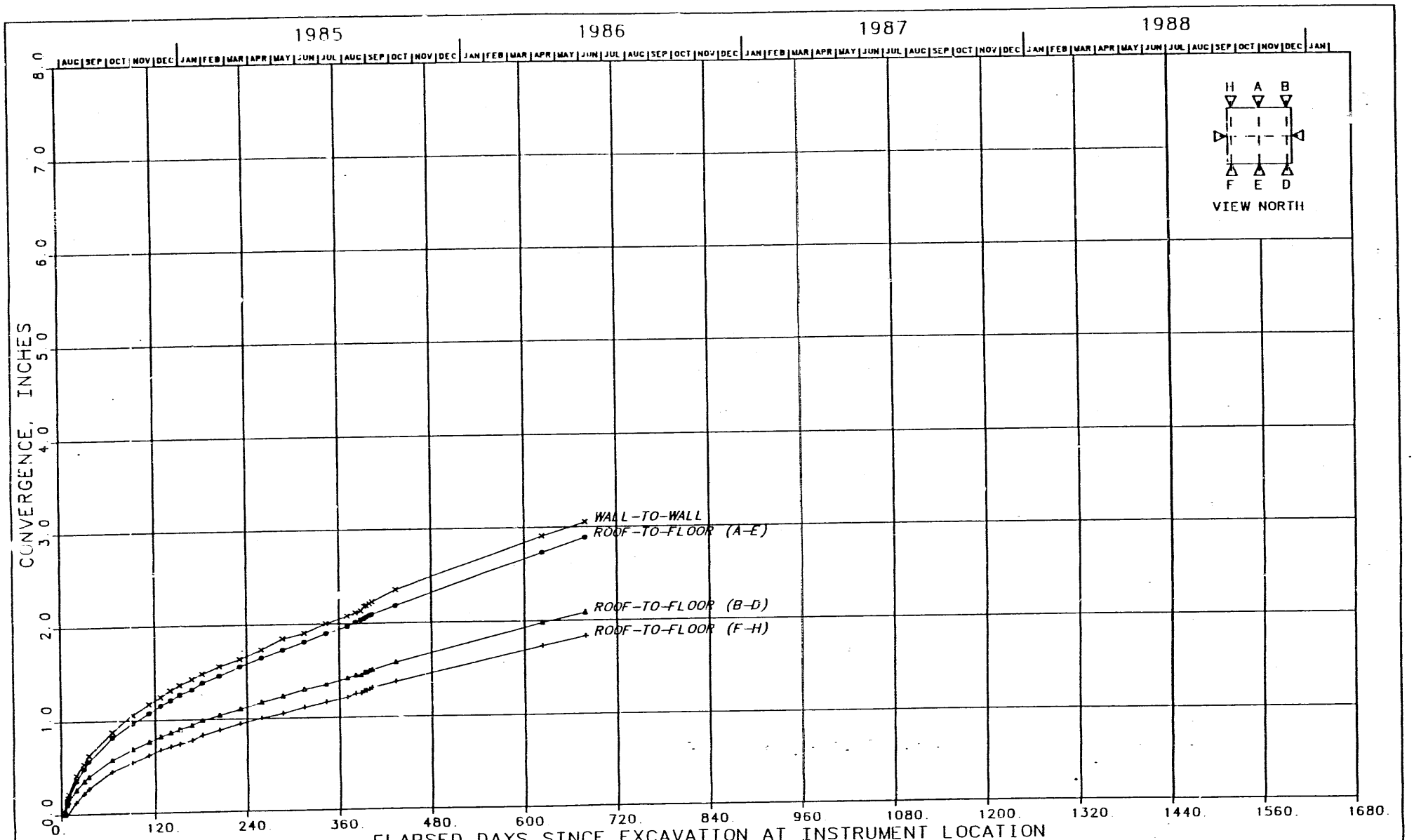


NOTES:

1. SIZE OF EXCAVATION: 12 FT X 14 FT.

FIGURE J-256
CONVERGENCE POINTS
E300 DRIFT – S1000 CROSSCUT INTERSECTION
CONVERGENCE VS. TIME SINCE EXCAVATION

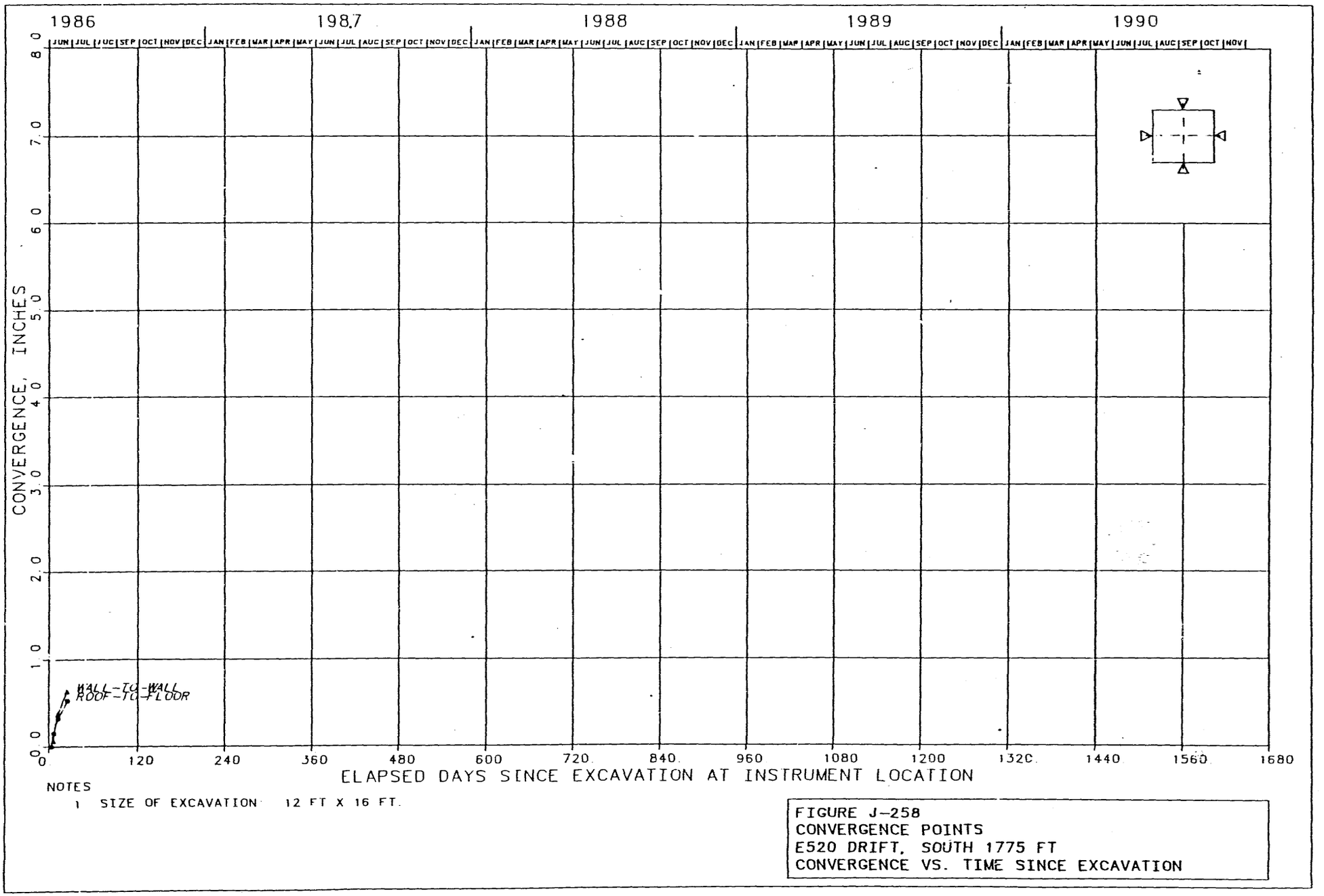




NOTES

1. SIZE OF EXCAVATION: 12 FT X 14 FT.

FIGURE J-257
CONVERGENCE POINTS
E300 DRIFT, SOUTH 1150 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1 SIZE OF EXCAVATION 12 FT X 16 FT.

FIGURE J-258
CONVERGENCE POINTS
E520 DRIFT, SOUTH 1775 FT
CONVERGENCE VS. TIME SINCE EXCAVATION

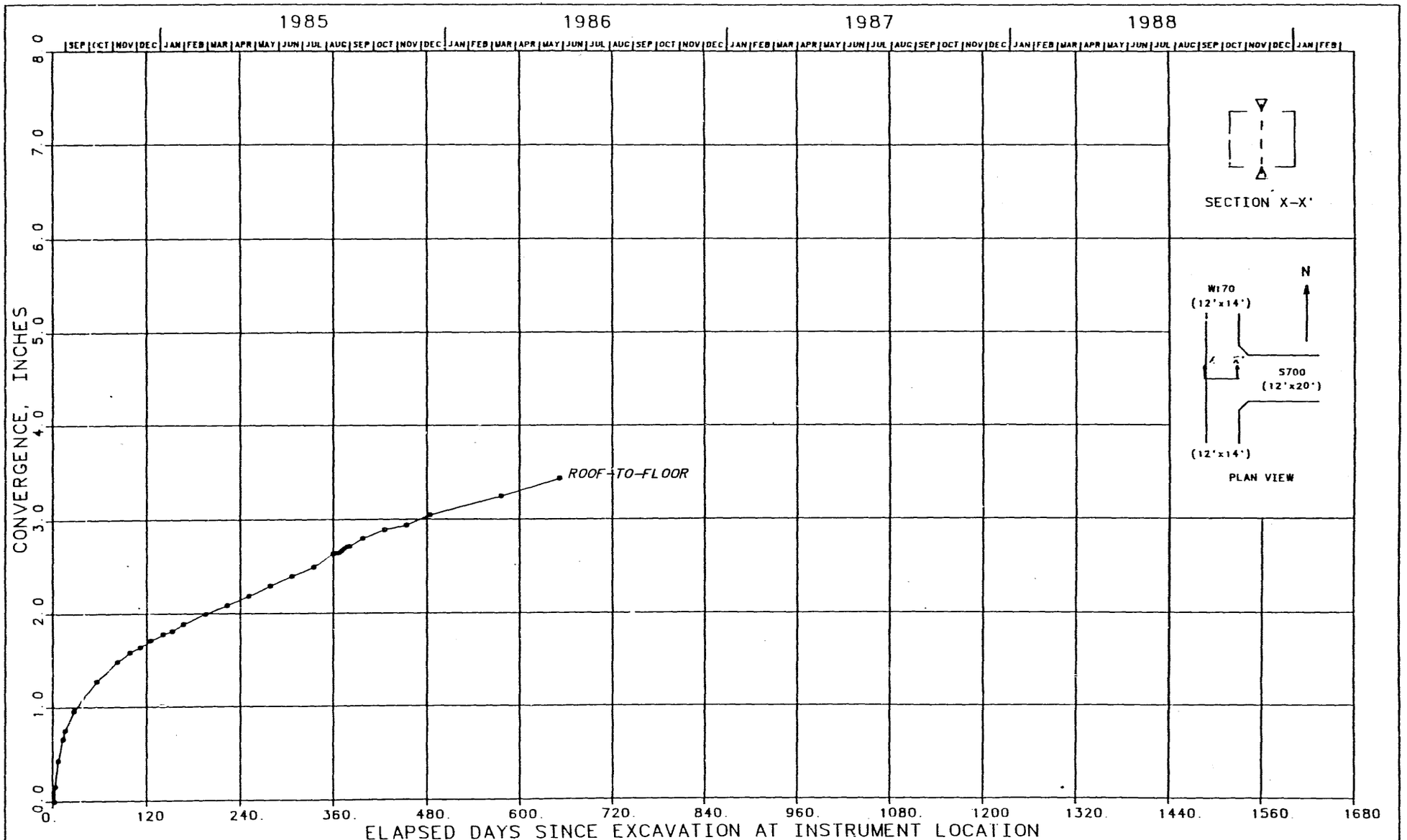
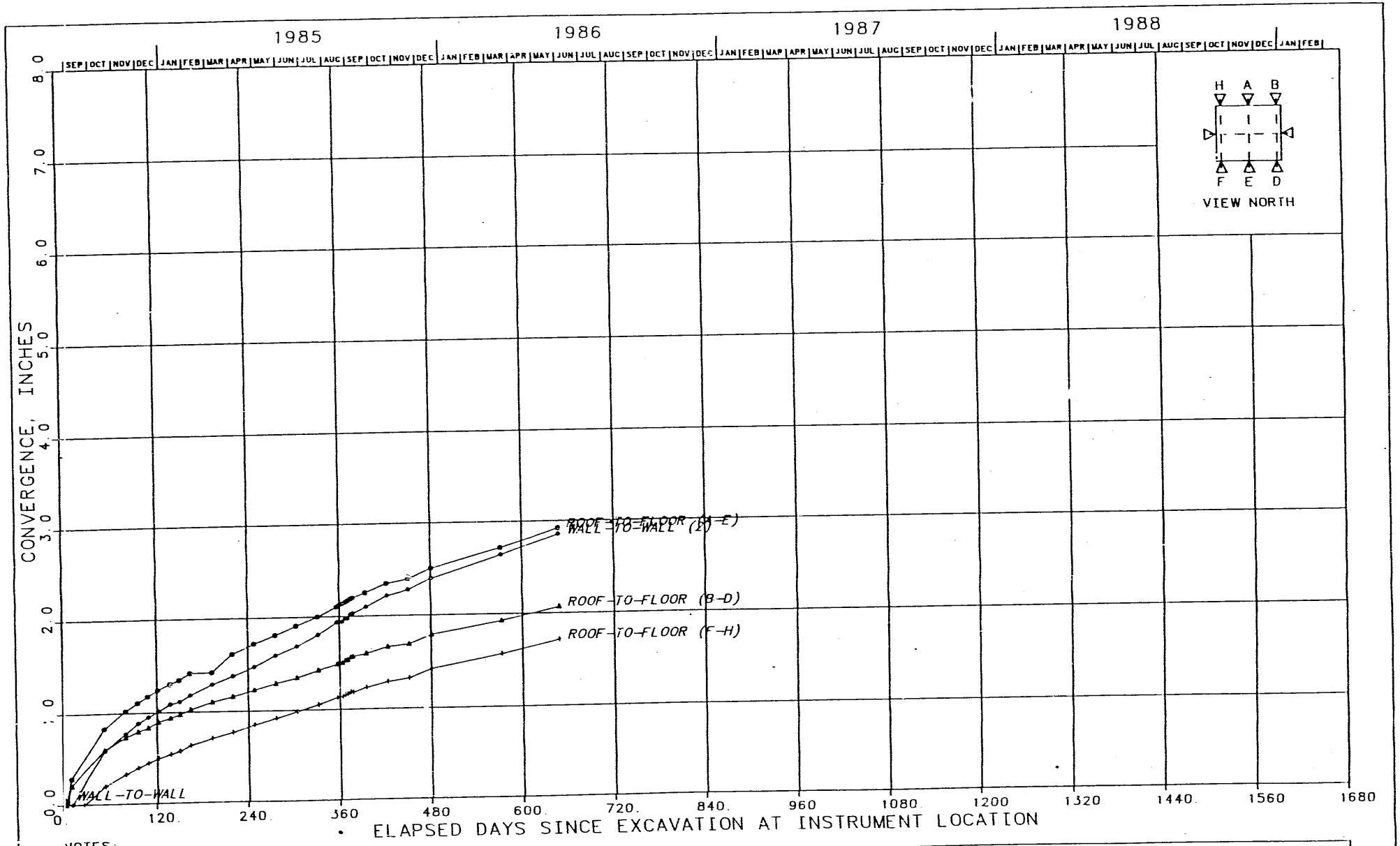


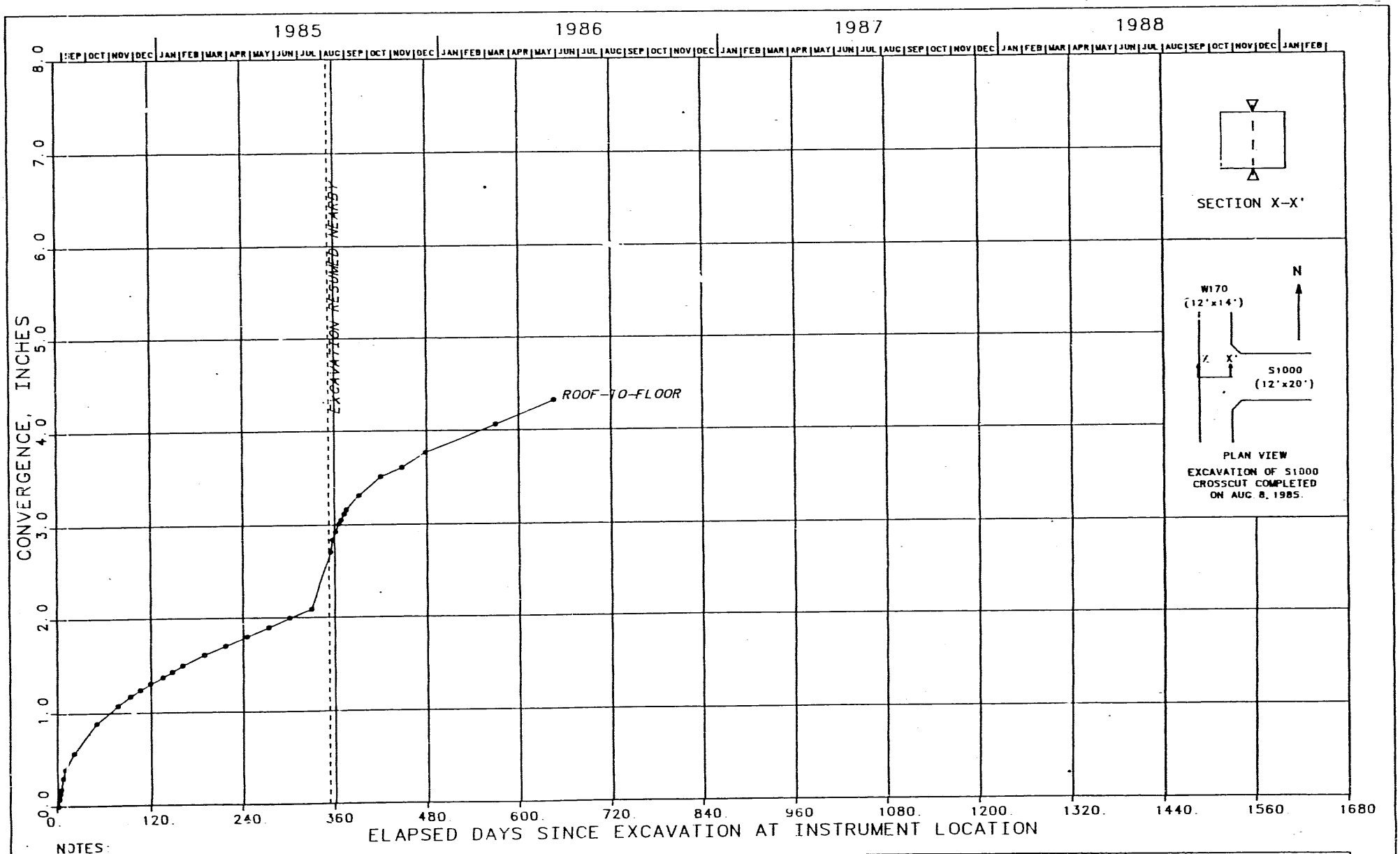
FIGURE J-259
CONVERGENCE POINTS
W170 DRIFT – S700 CROSSCUT INTERSECTION
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 14 FT

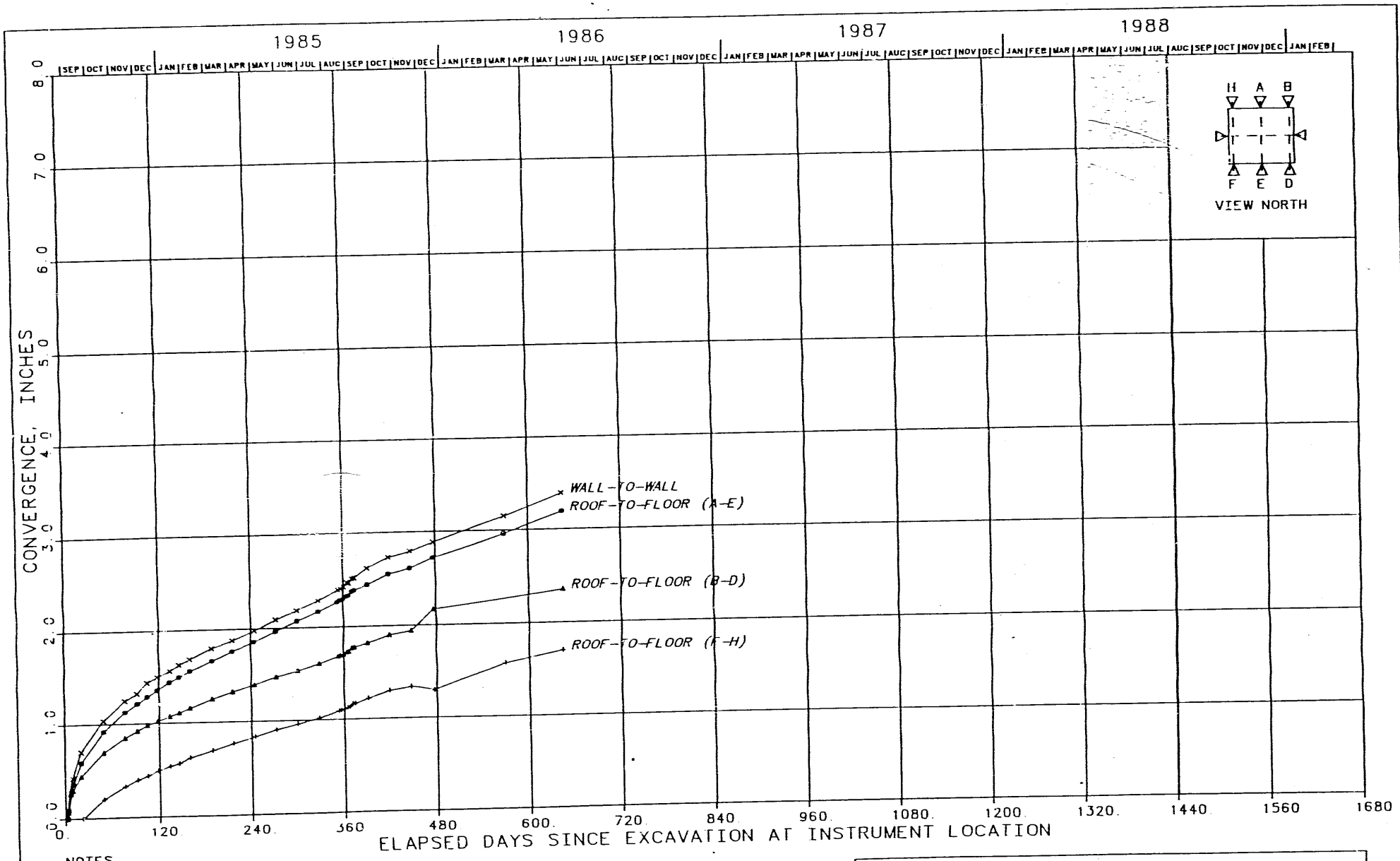
FIGURE J-260
CONVERGENCE POINTS
W170 DRIFT, SOUTH 850 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 14 FT.

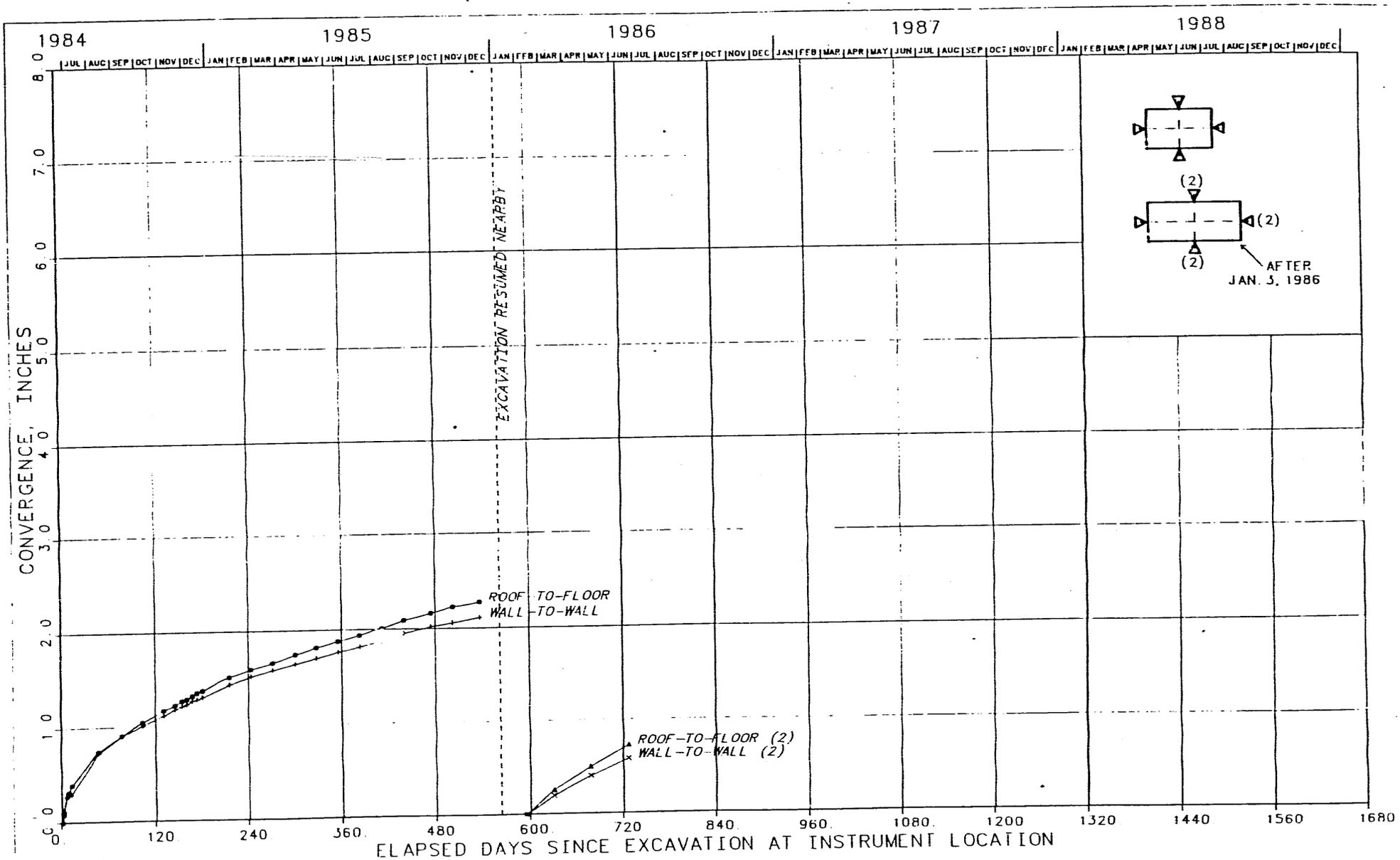
FIGURE J-261
CONVERGENCE POINTS
W170 DRIFT - S1000 CROSSCUT INTERSECTION
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION 12 FT X 14 FT.

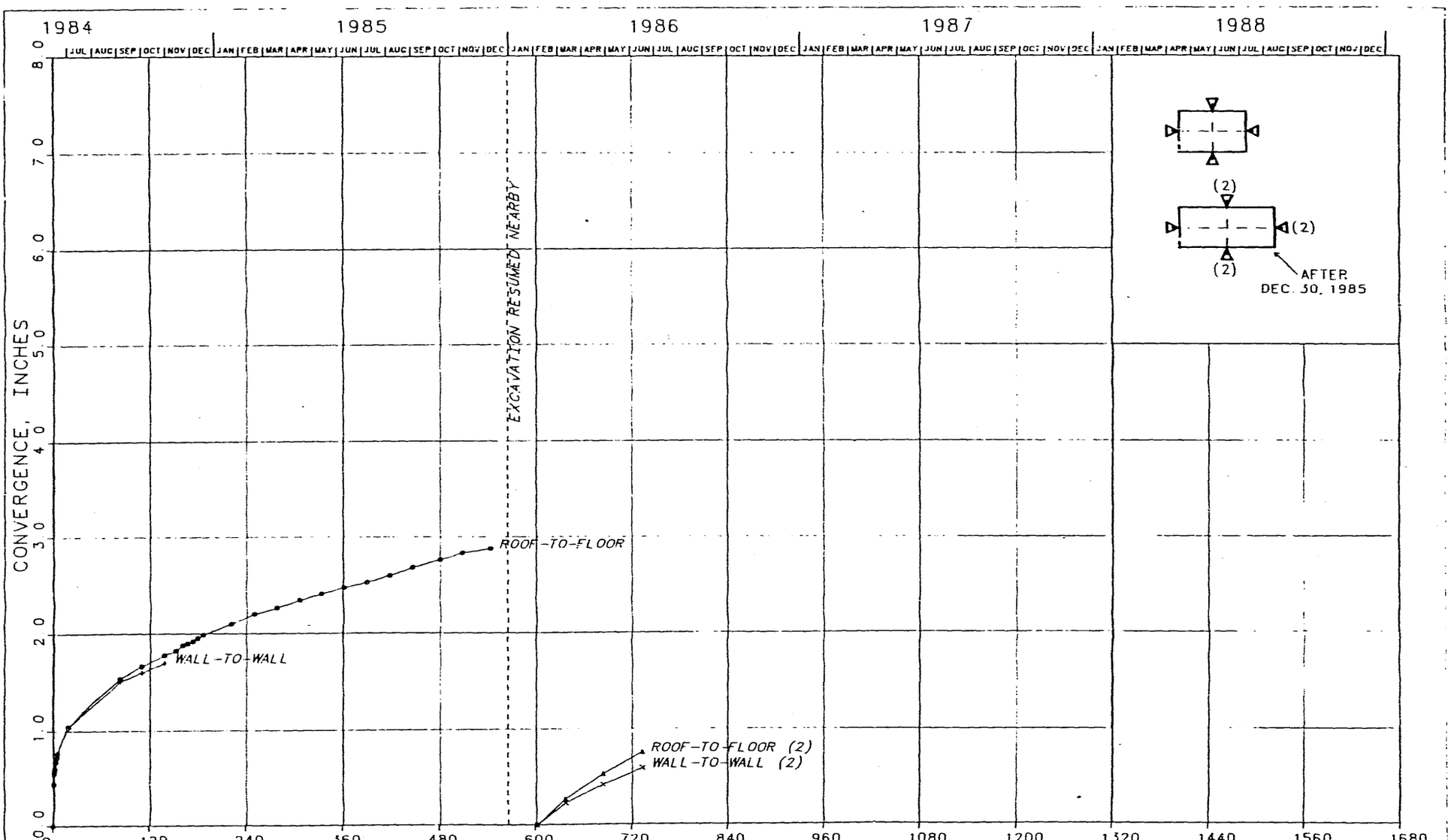
FIGURE J-262
CONVERGENCE POINTS
W170 DRIFT, SOUTH 1150 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION 8.5 FT X 20 FT.

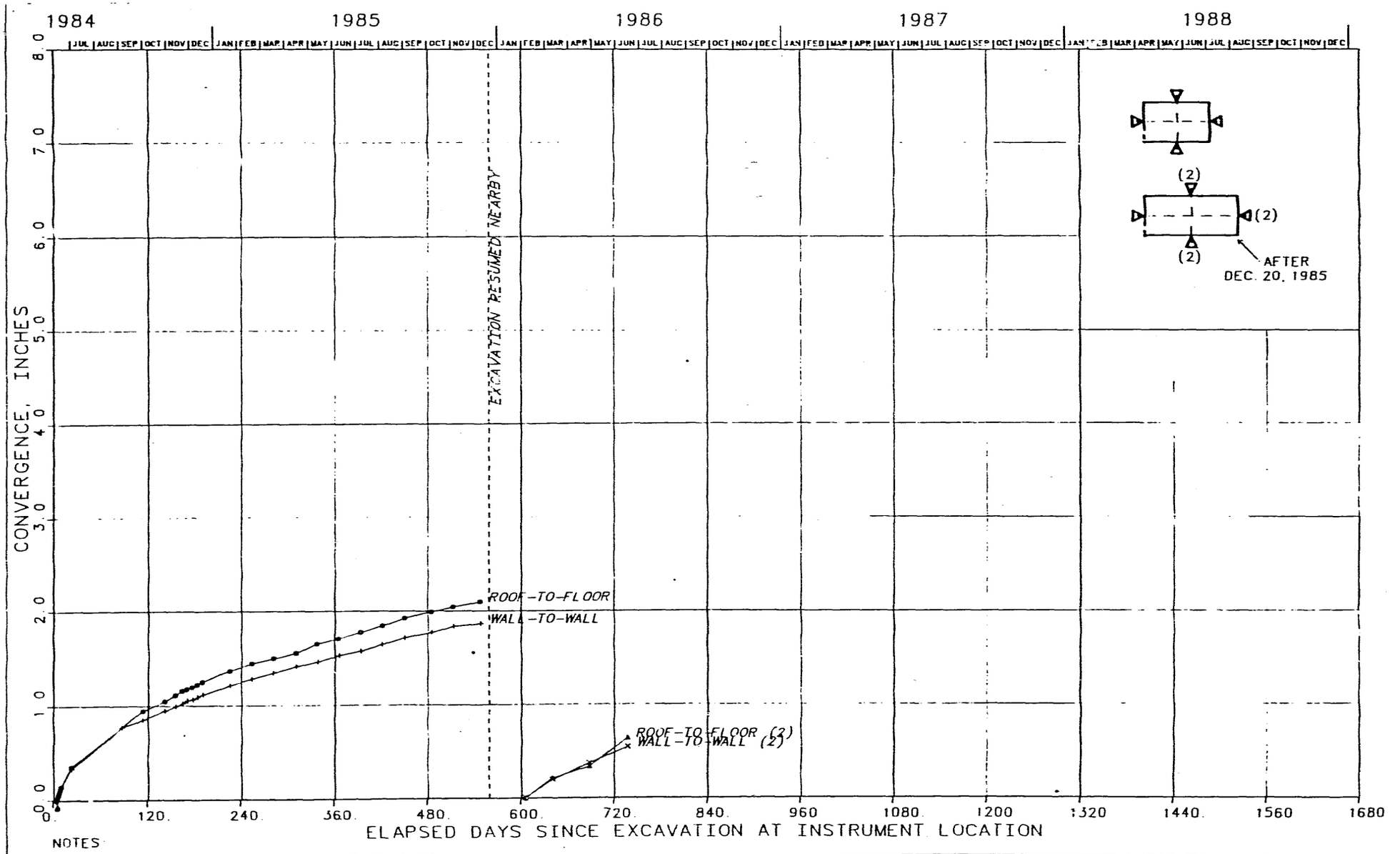
FIGURE J-263
CONVERGENCE POINTS
N1100 DRIFT, WEST 1347 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION 8.5 FT X 20 FT.

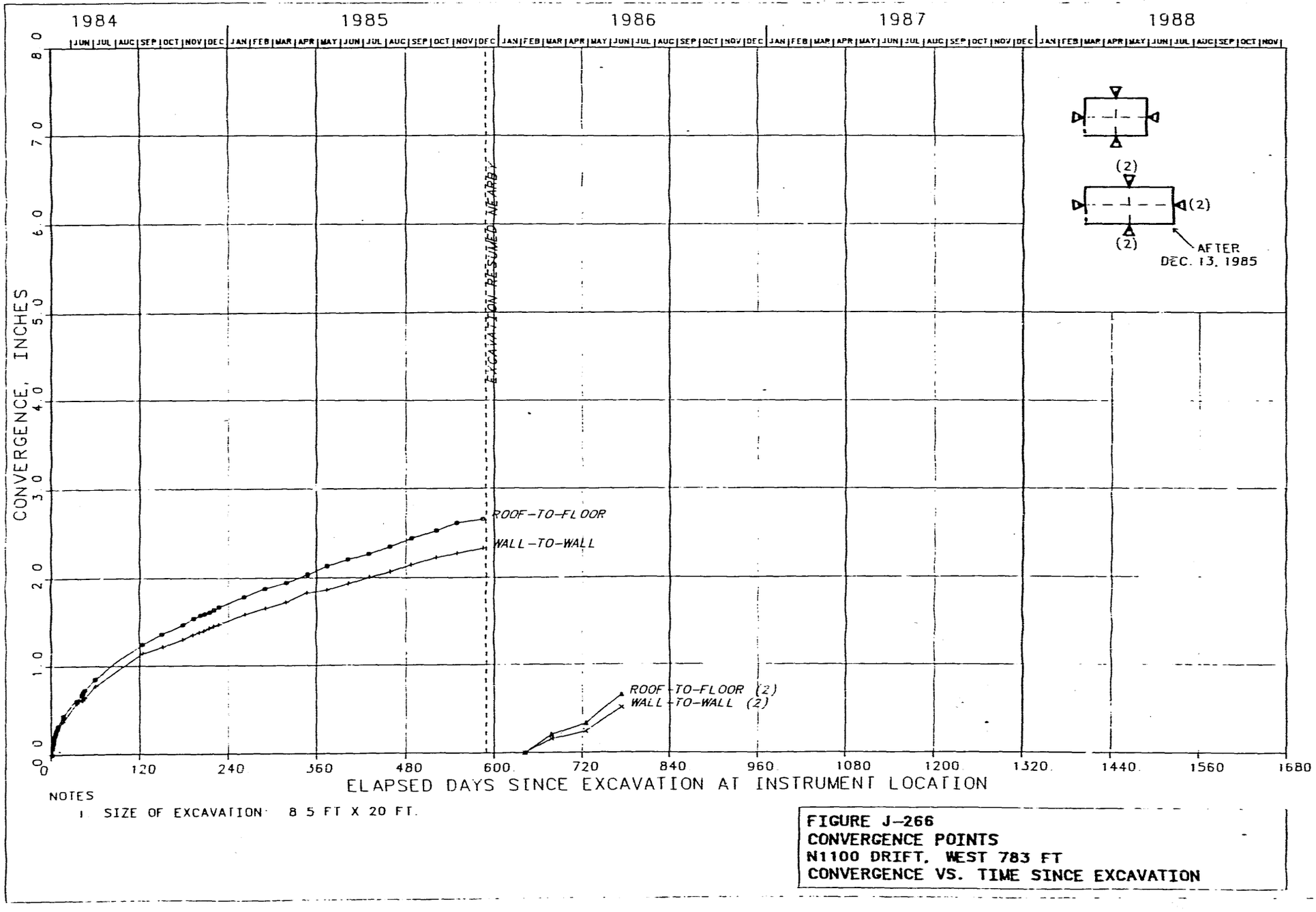
FIGURE J-264
CONVERGENCE POINTS
N1100 DRIFT, WEST 1159 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1 SIZE OF EXCAVATION: 8.5 FT X 20 FT.

FIGURE J-265
CONVERGENCE POINTS
N1100 DRIFT, WEST 951 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION 8 5 FT X 20 FT.

FIGURE J-266
CONVERGENCE POINTS
N1100 DRIFT, WEST 783 FT
CONVERGENCE VS. TIME SINCE EXCAVATION

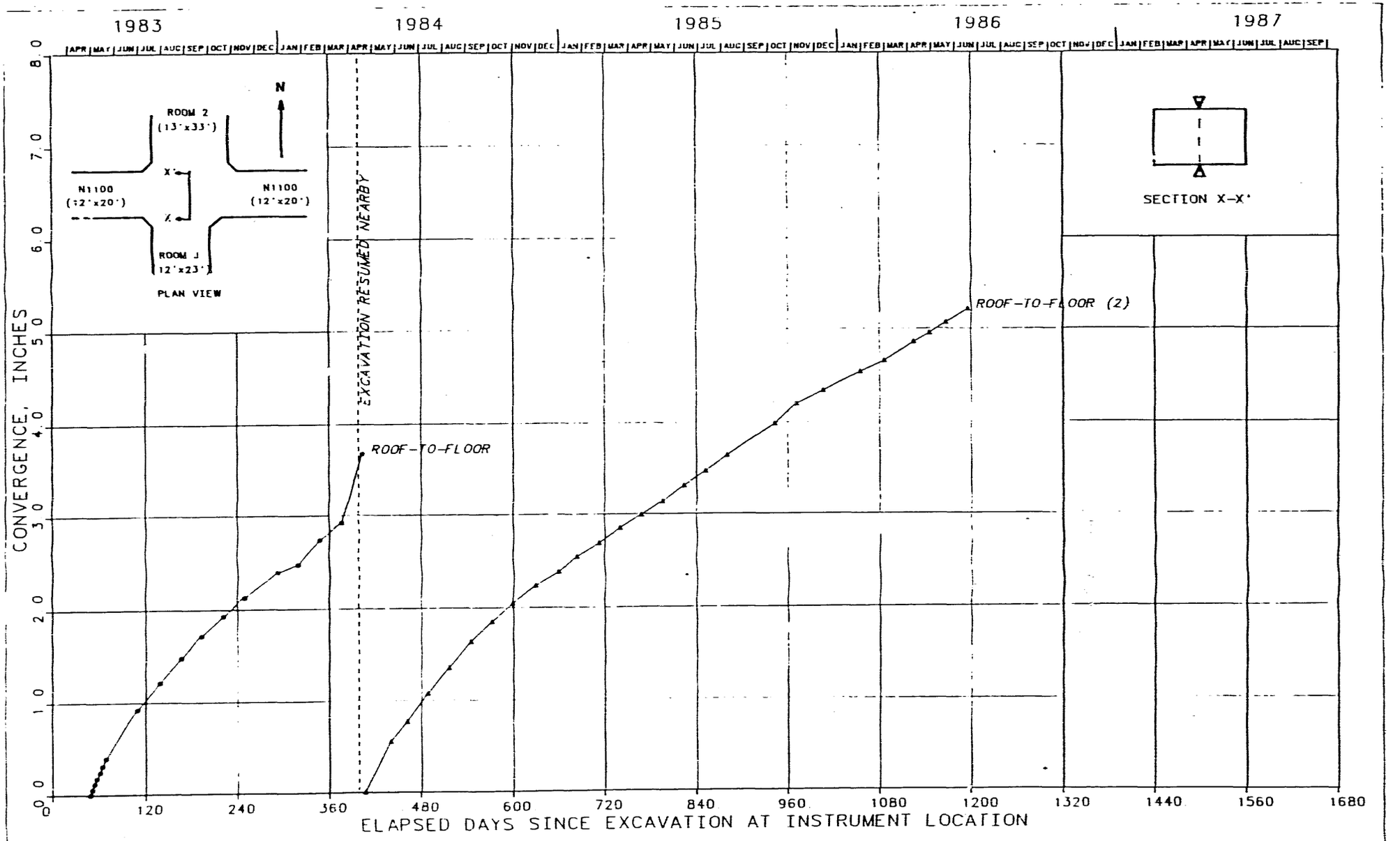
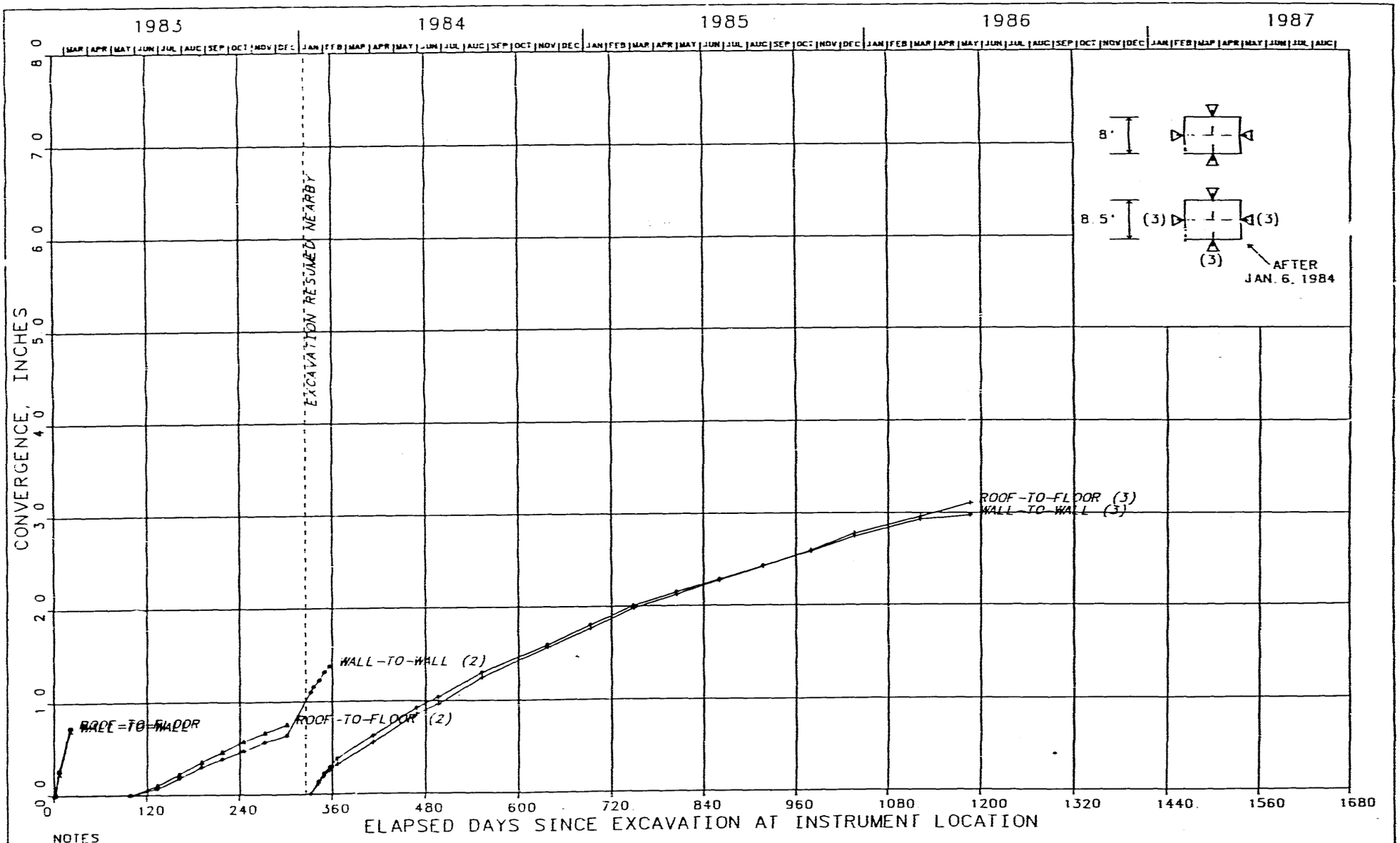


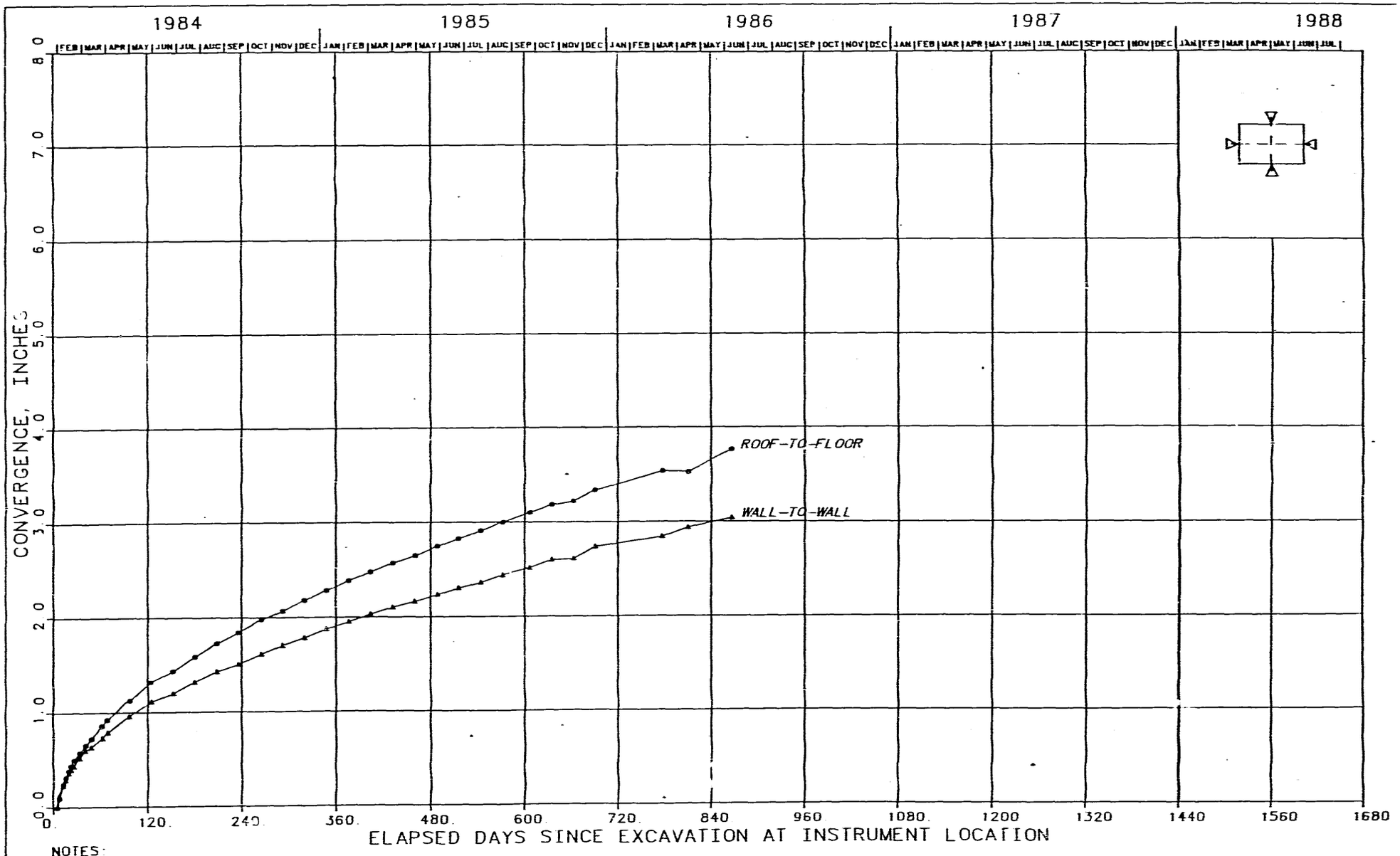
FIGURE J-267
CONVERGENCE POINTS
N1100 DRIFT – TEST ROOM 2 INTERSECTION
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION 8.5 FT X 12 FT

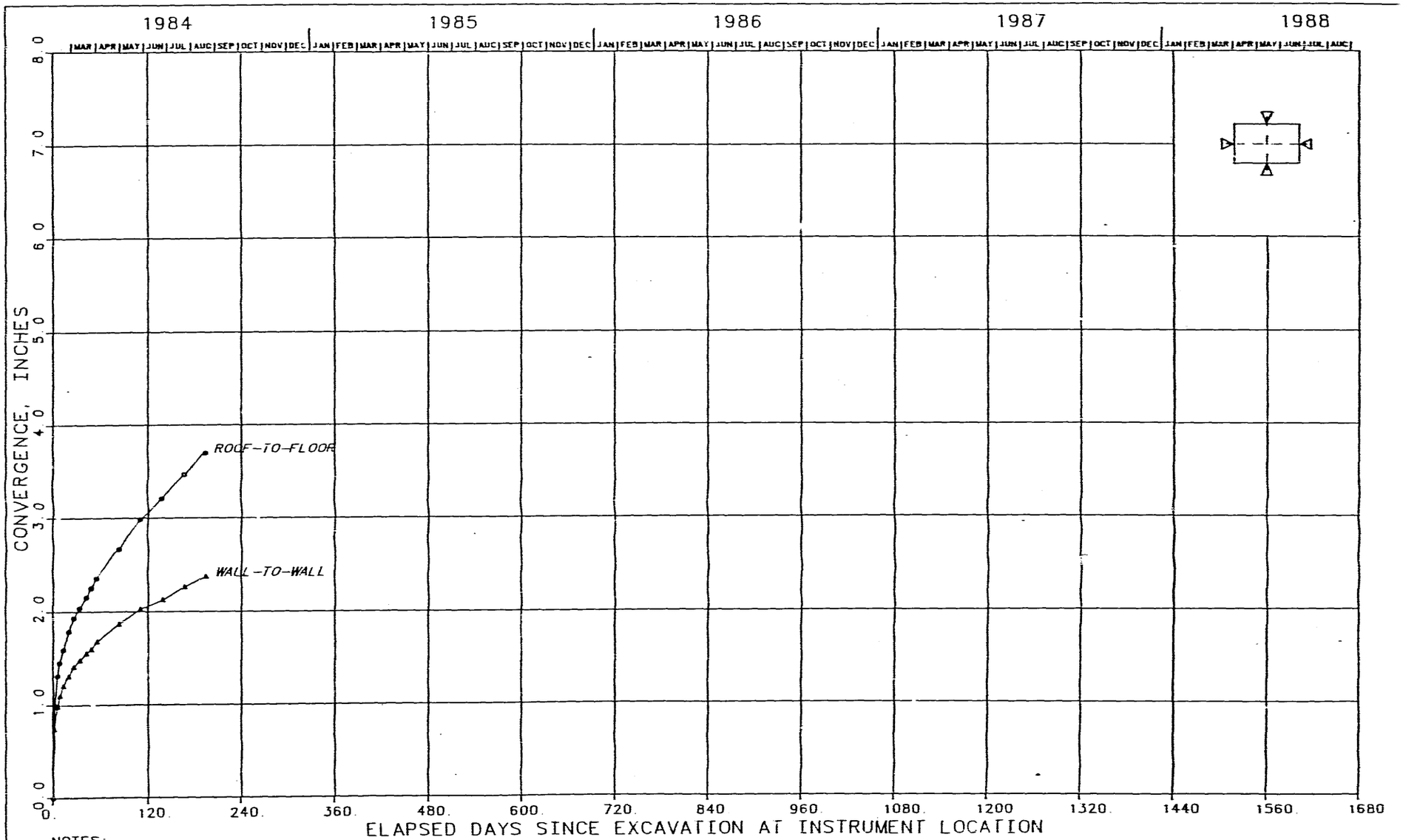
FIGURE J-268
CONVERGENCE POINTS
N1100 DRIFT, EAST 80 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 8.5 FT X 14 FT.

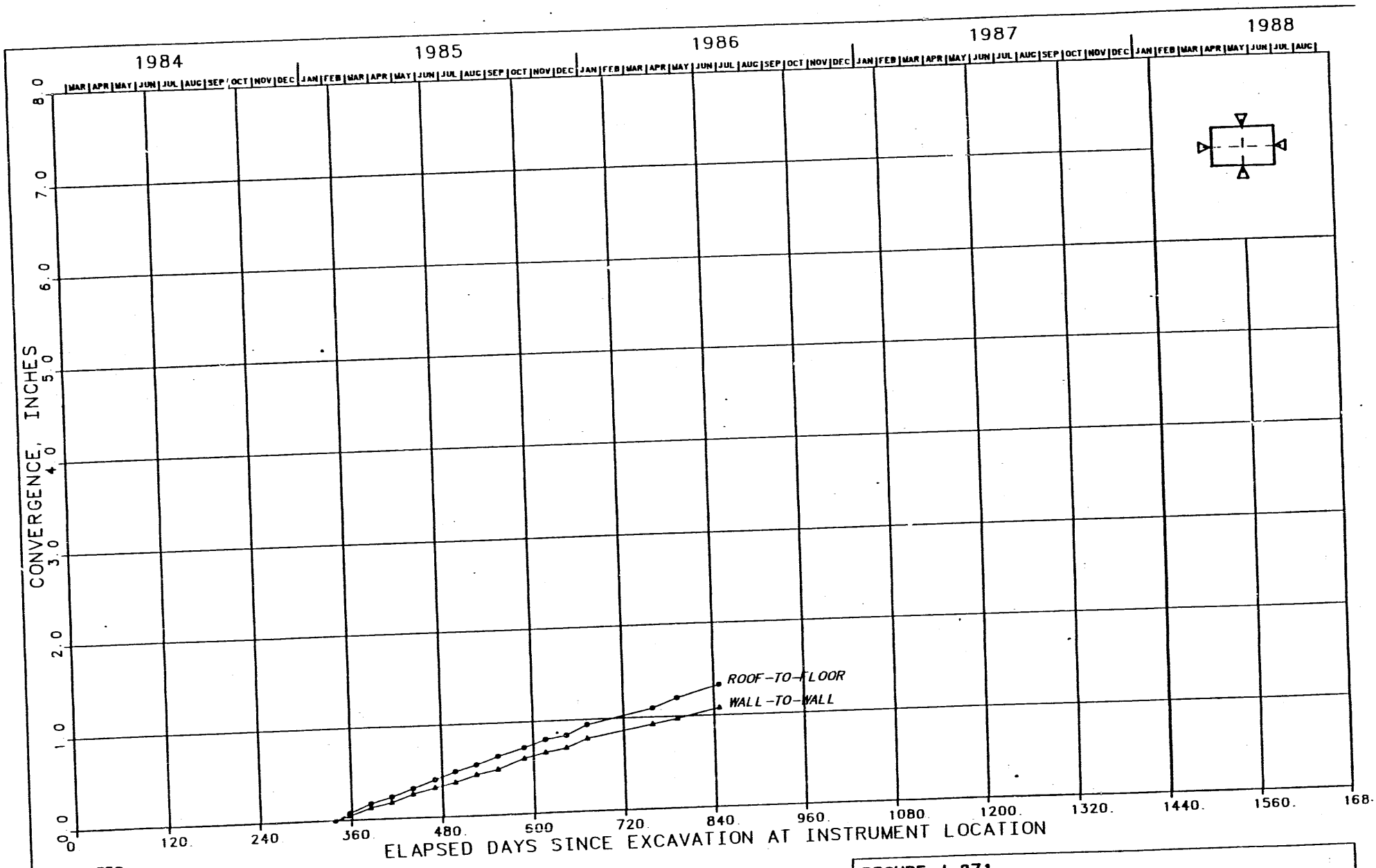
FIGURE J-269
CONVERGENCE POINTS
N1100 DRIFT, EAST 319 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

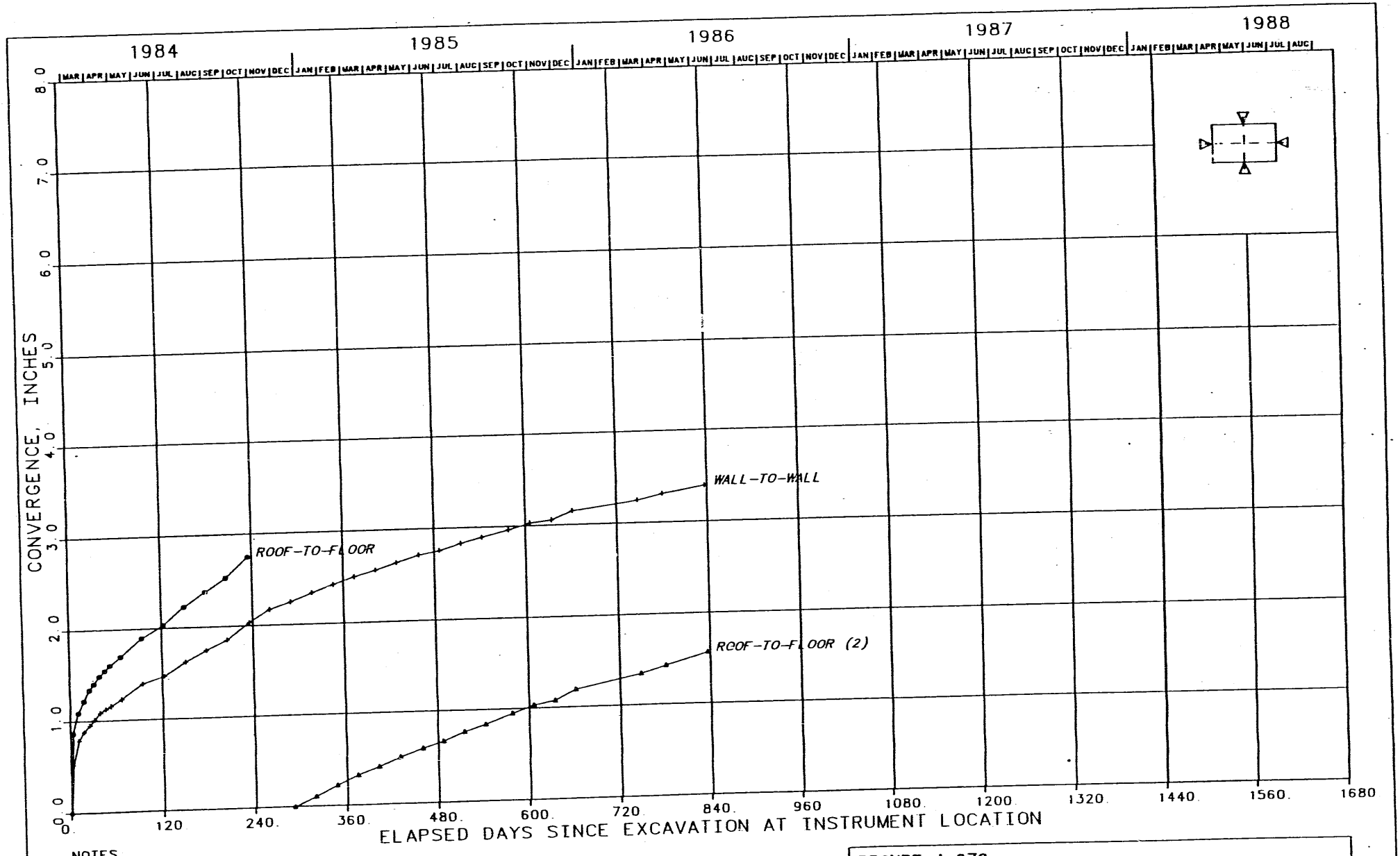
1. SIZE OF EXCAVATION: 8 5 FT X 14 FT.
2. INSTRUMENT WAS BEEN DESTROYED.

FIGURE J-270
CONVERGENCE POINTS
N1100 DRIFT, EAST 691 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:
1. SIZE OF EXCAVATION: 8.5 FT X 14 FT.

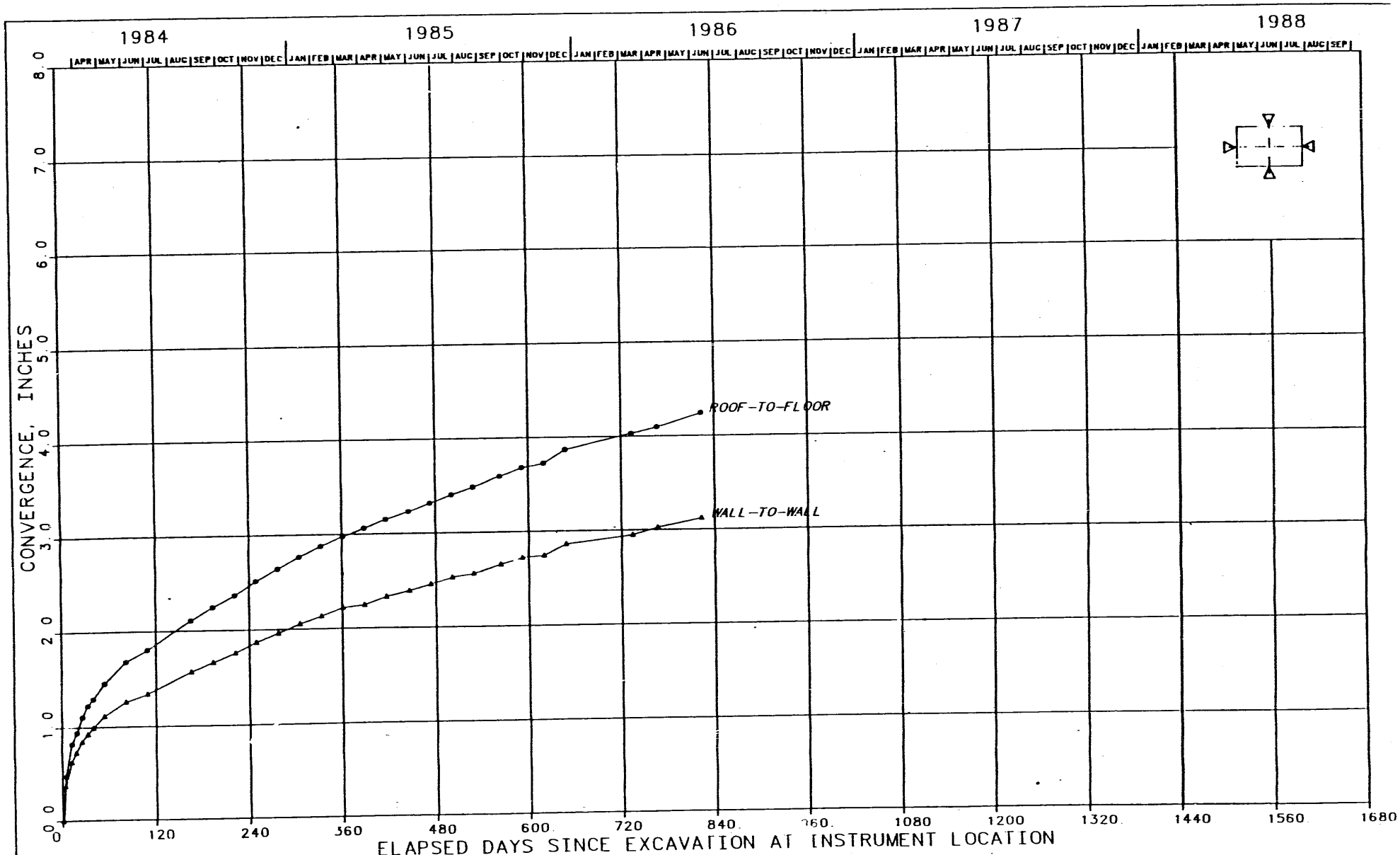
FIGURE J-271
CONVERGENCE POINTS
N1100 DRIFT, EAST 846 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION: 8.5 FT X 14 FT.

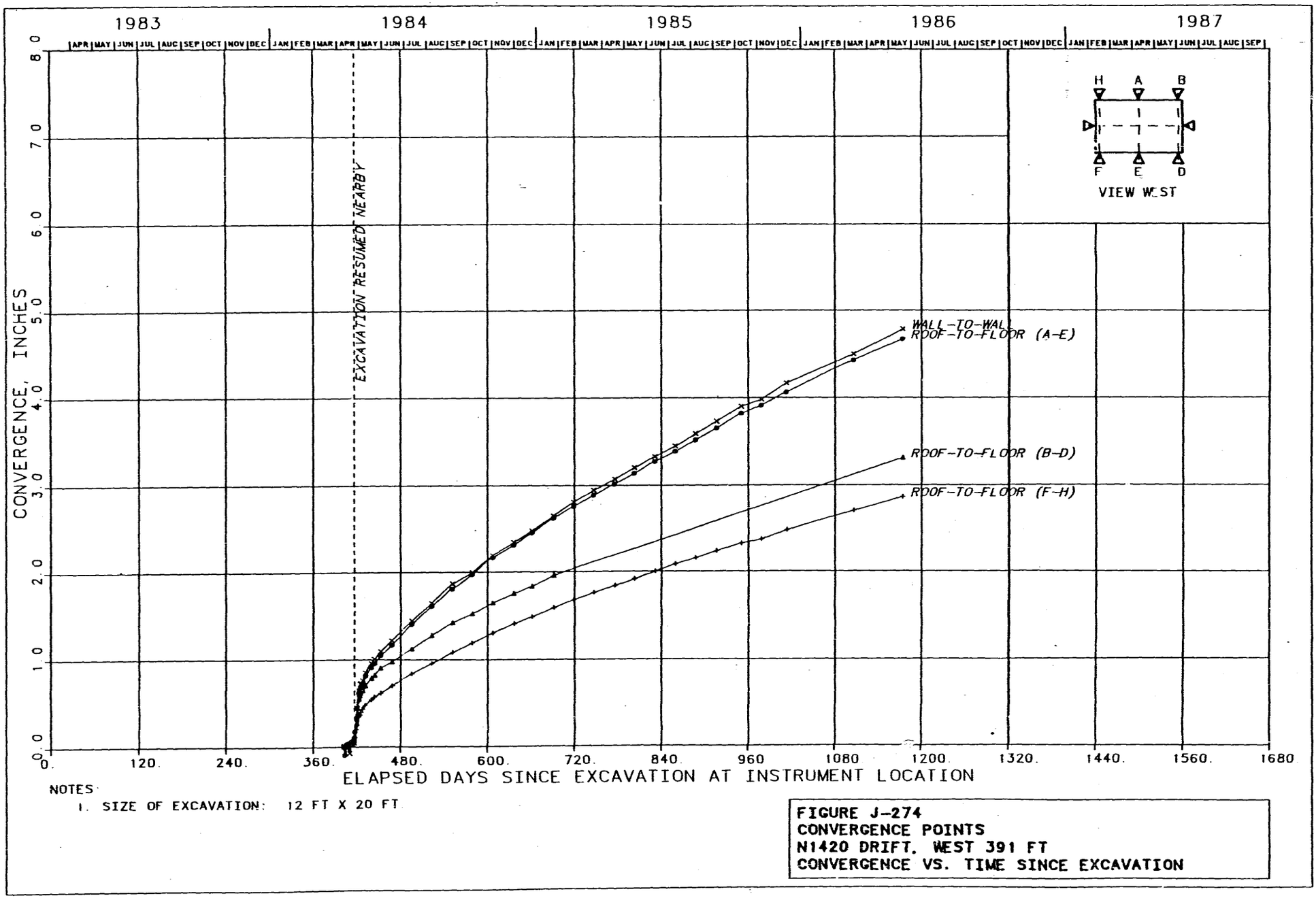
FIGURE J-272
CONVERGENCE POINTS
N1100 DRIFT, EAST 1135 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION 8 5 FT X 14 FT

FIGURE J-273
CONVERGENCE POINTS
N1100 DRIFT, EAST 1582 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 20 FT

FIGURE J-274
CONVERGENCE POINTS
N1420 DRIFT, WEST 391 FT
CONVERGENCE VS. TIME SINCE EXCAVATION

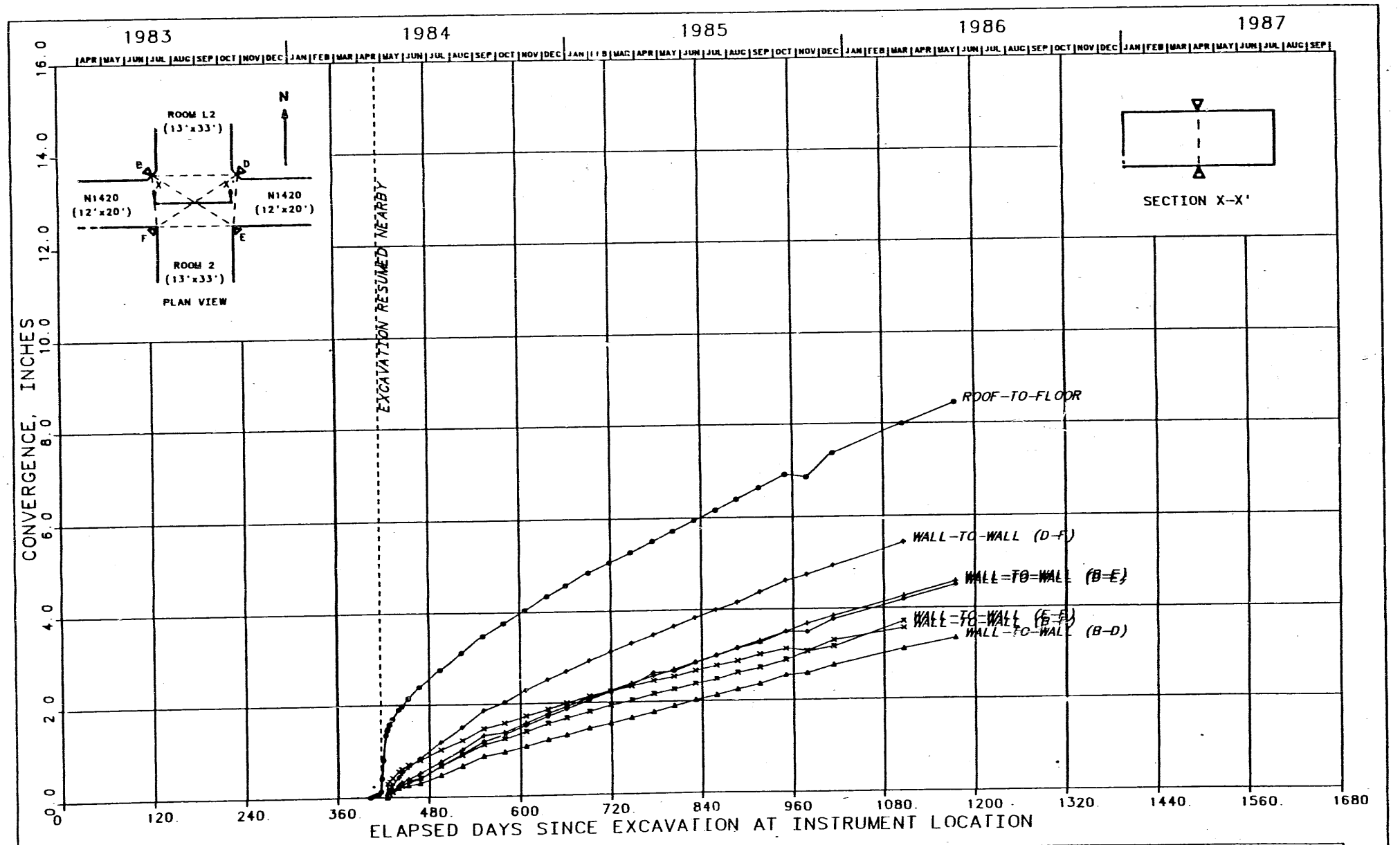
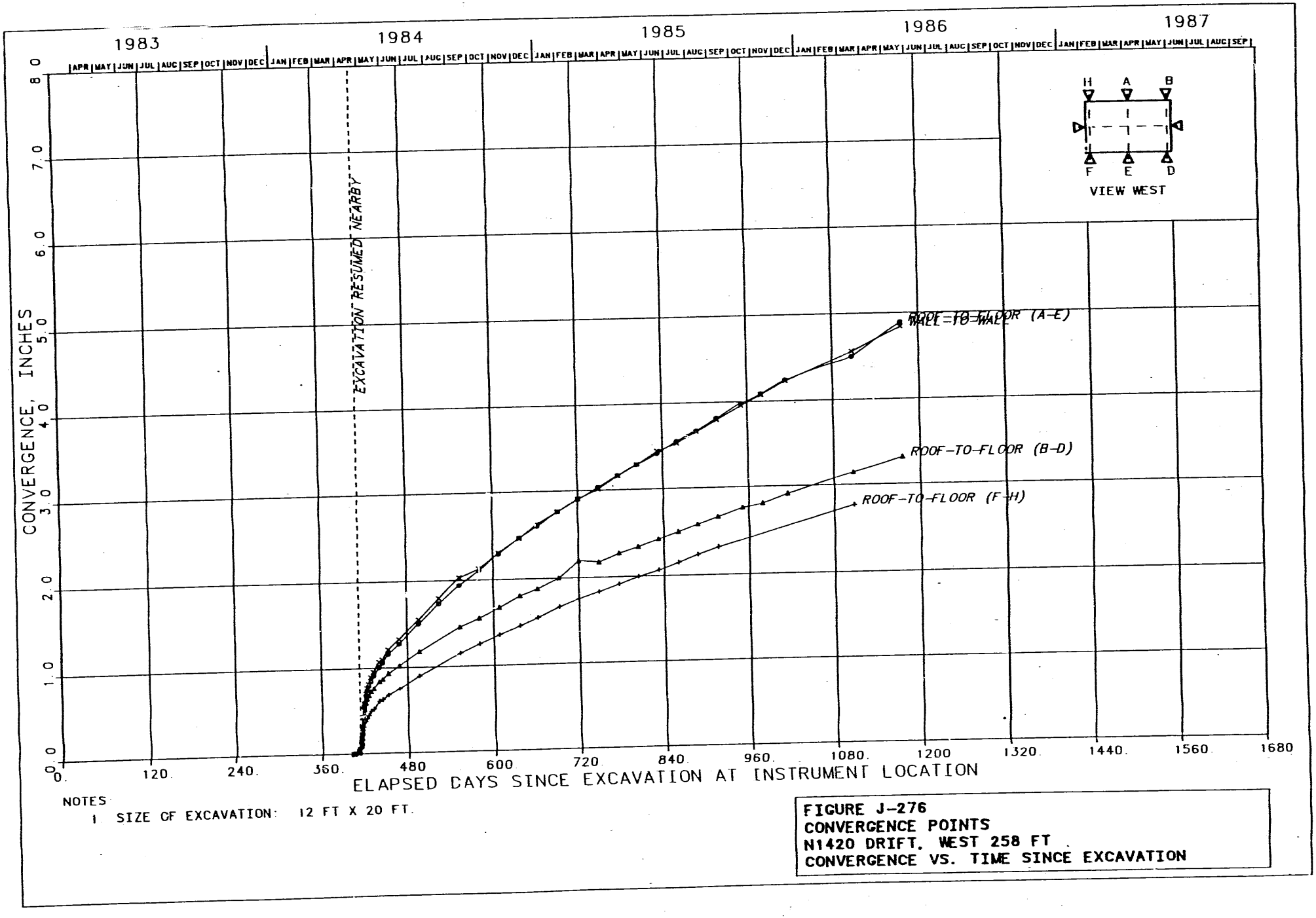


FIGURE J-275
CONVERGENCE POINTS
N1420 DRIFT – TEST ROOM 2 INTERSECTION
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1 SIZE OF EXCAVATION: 12 FT X 20 FT.

FIGURE J-276
CONVERGENCE POINTS
N1420 DRIFT, WEST 258 FT
CONVERGENCE VS. TIME SINCE EXCAVATION

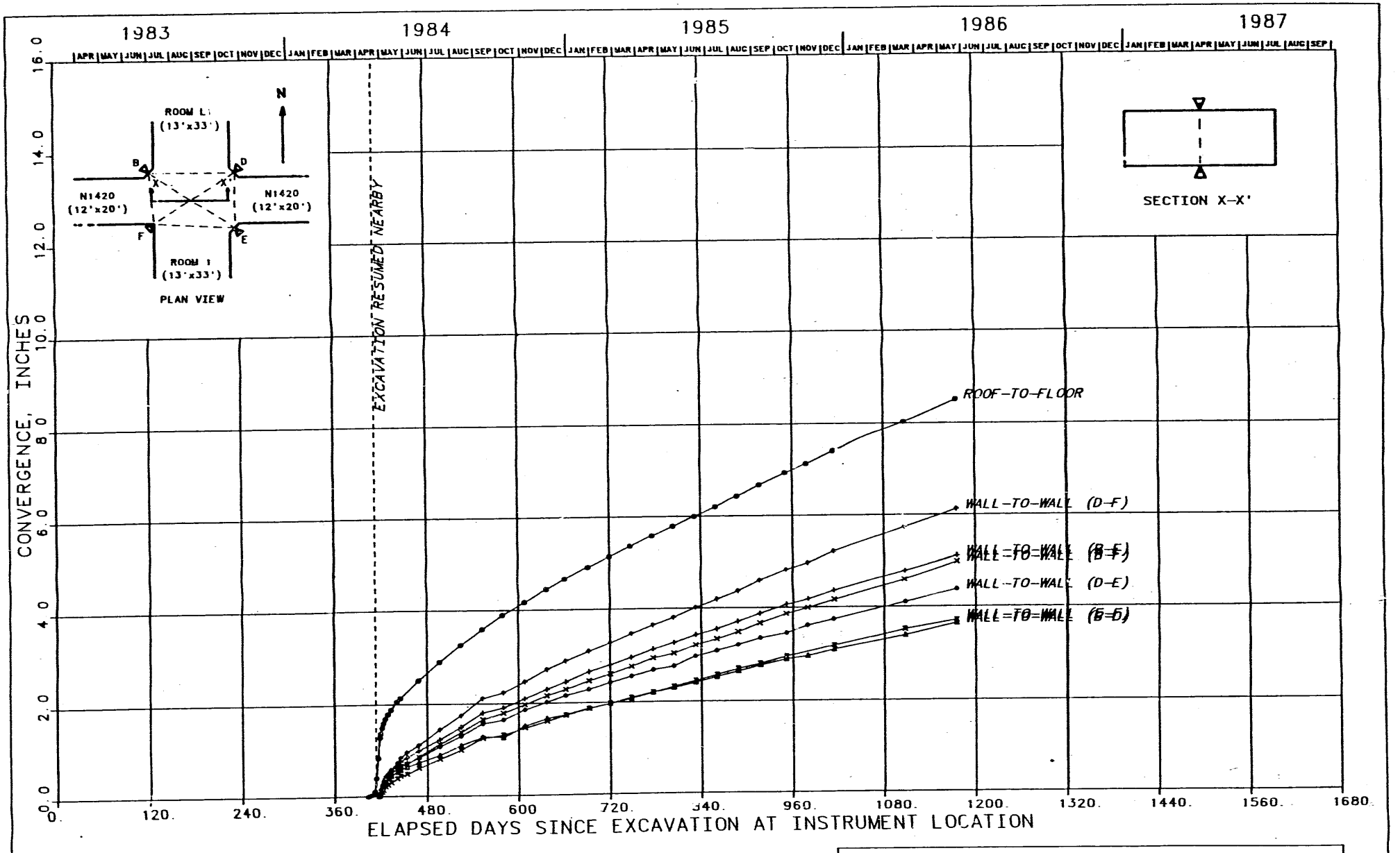
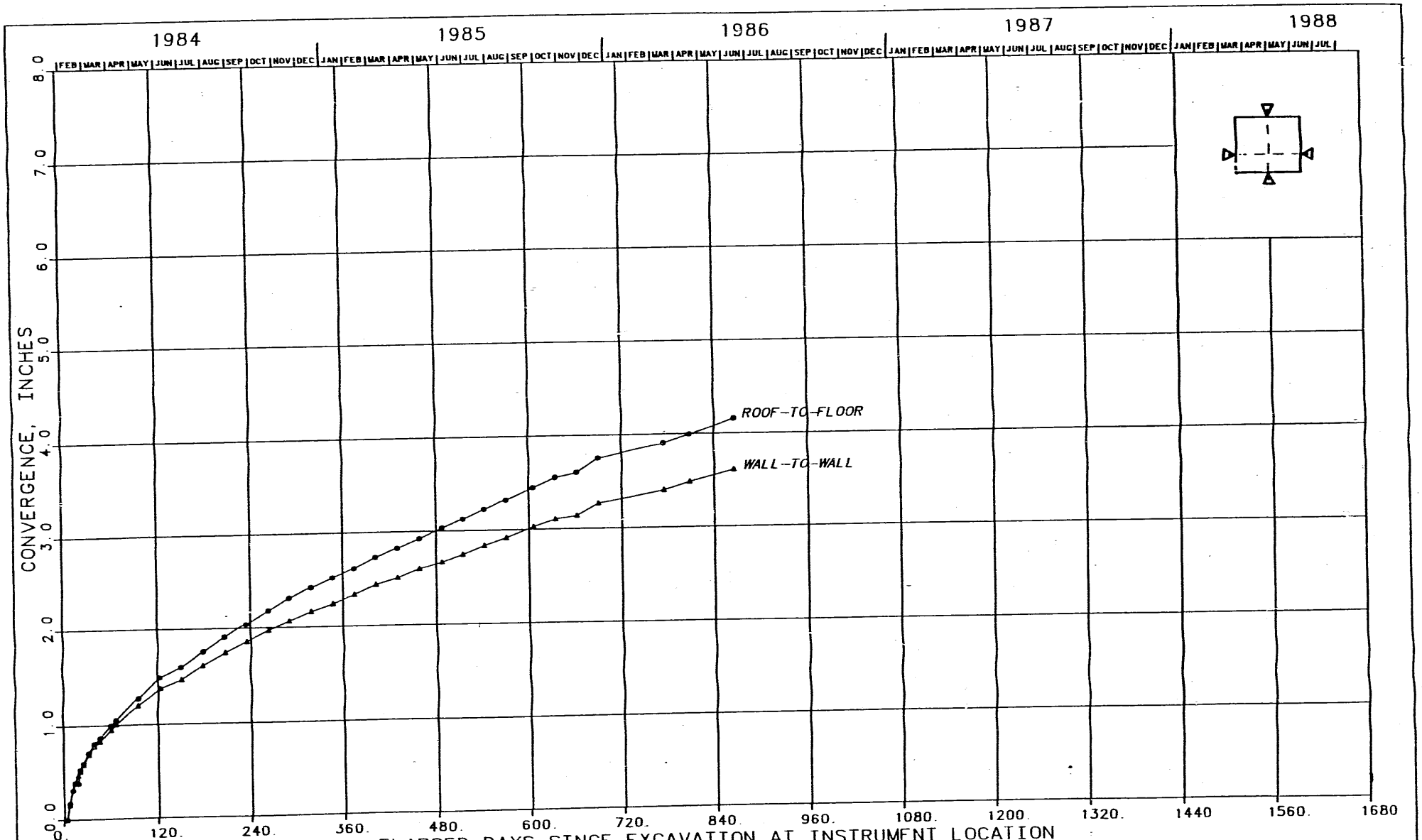


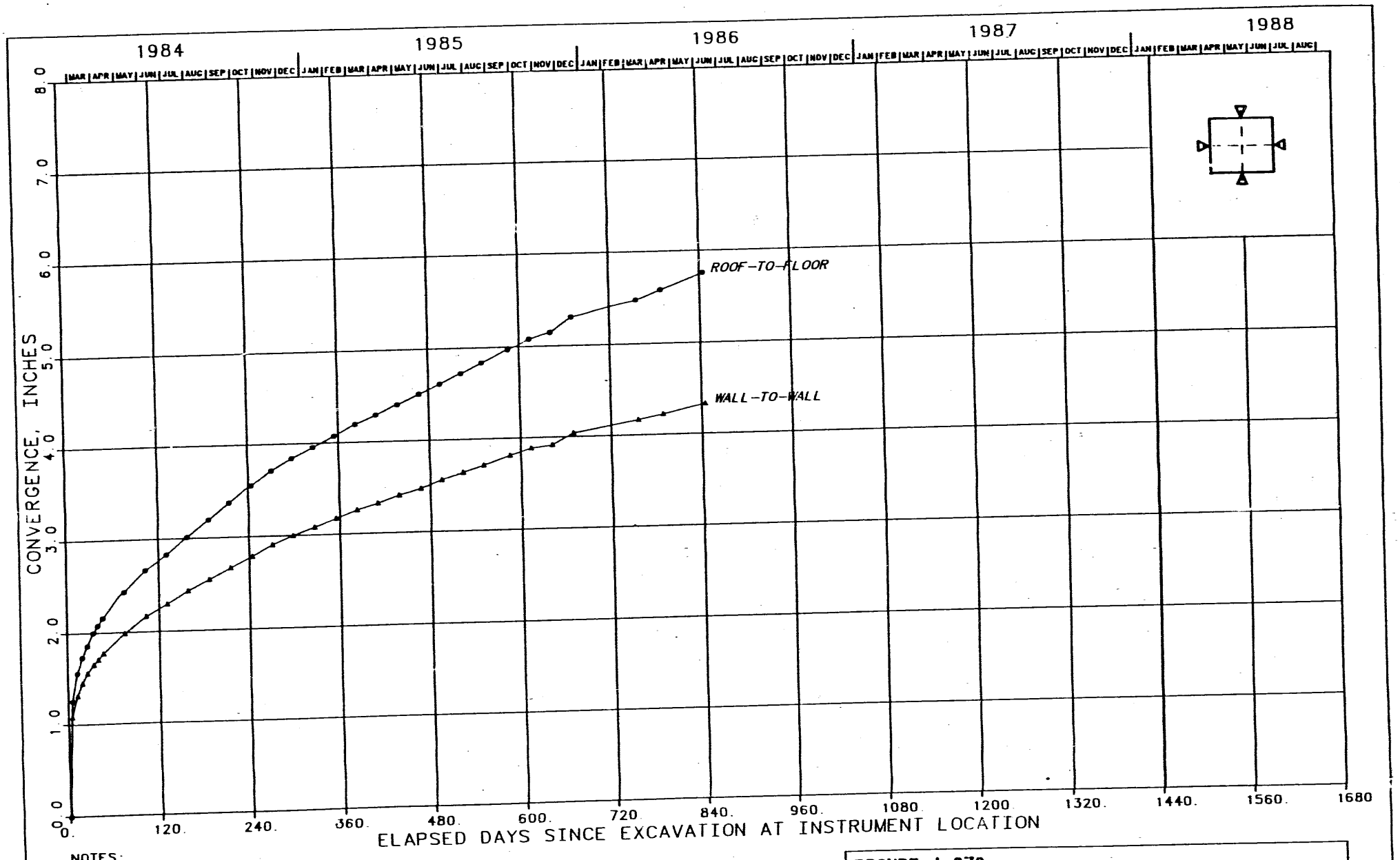
FIGURE J-277
CONVERGENCE POINTS
N1420 DRIFT – TEST ROOM 1 INTERSECTION
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 14 FT.

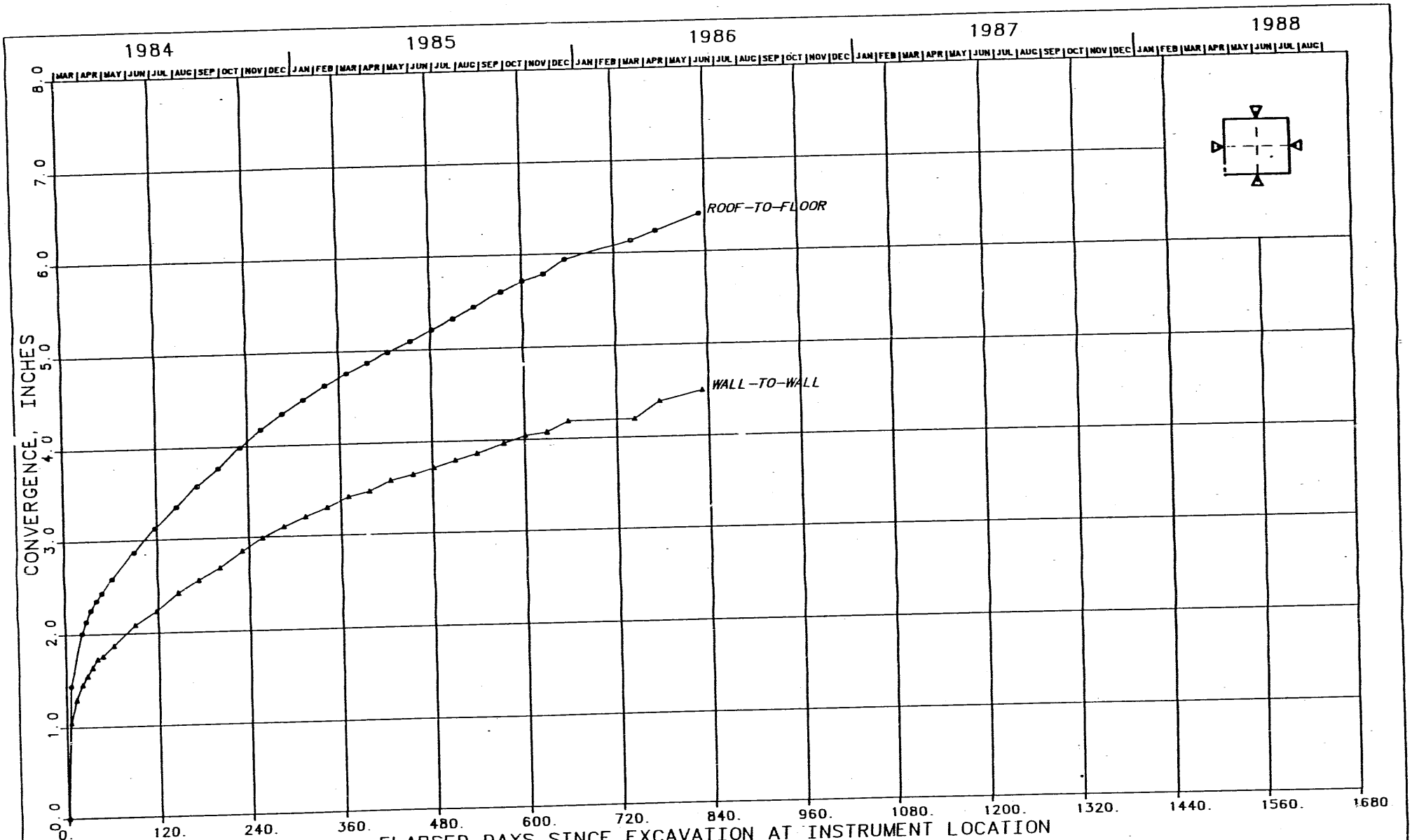
FIGURE J-278
CONVERGENCE POINTS
N1420 DRIFT, EAST 304 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 14 FT.

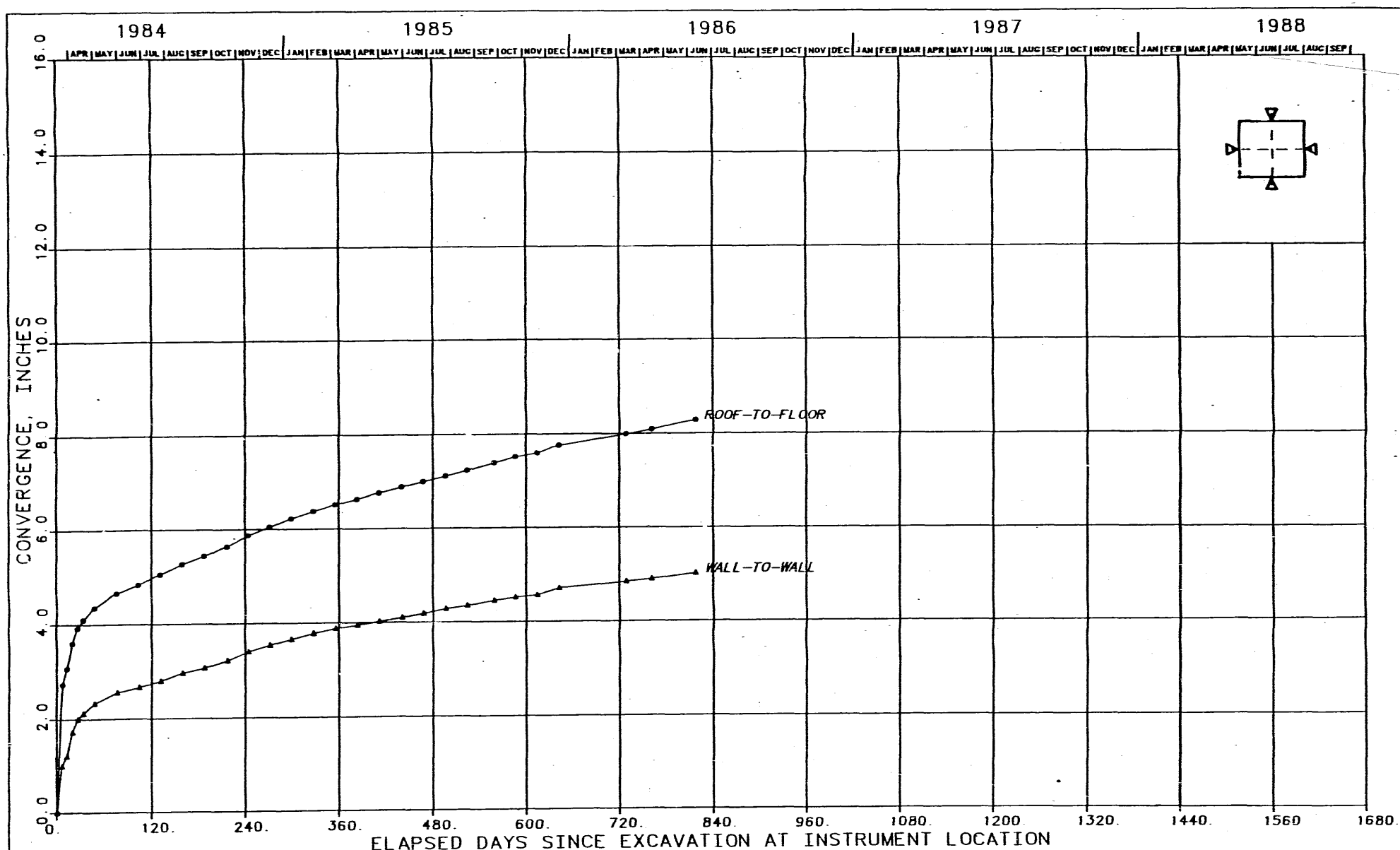
FIGURE J-279
CONVERGENCE POINTS
N1420 DRIFT, EAST 716 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 14 FT.

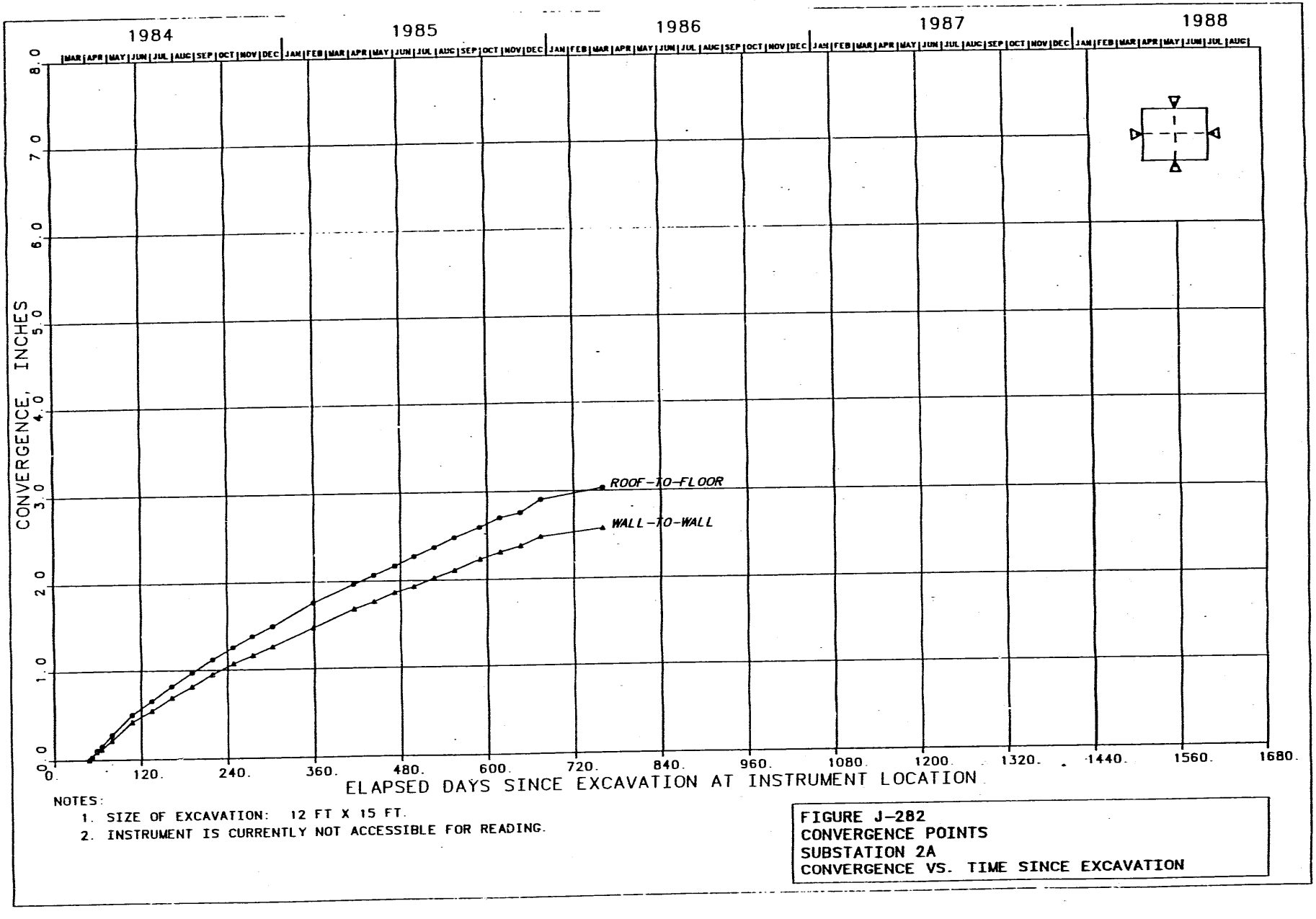
FIGURE J-280
CONVERGENCE POINTS
N1420 DRIFT, EAST 1106 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 14 FT.

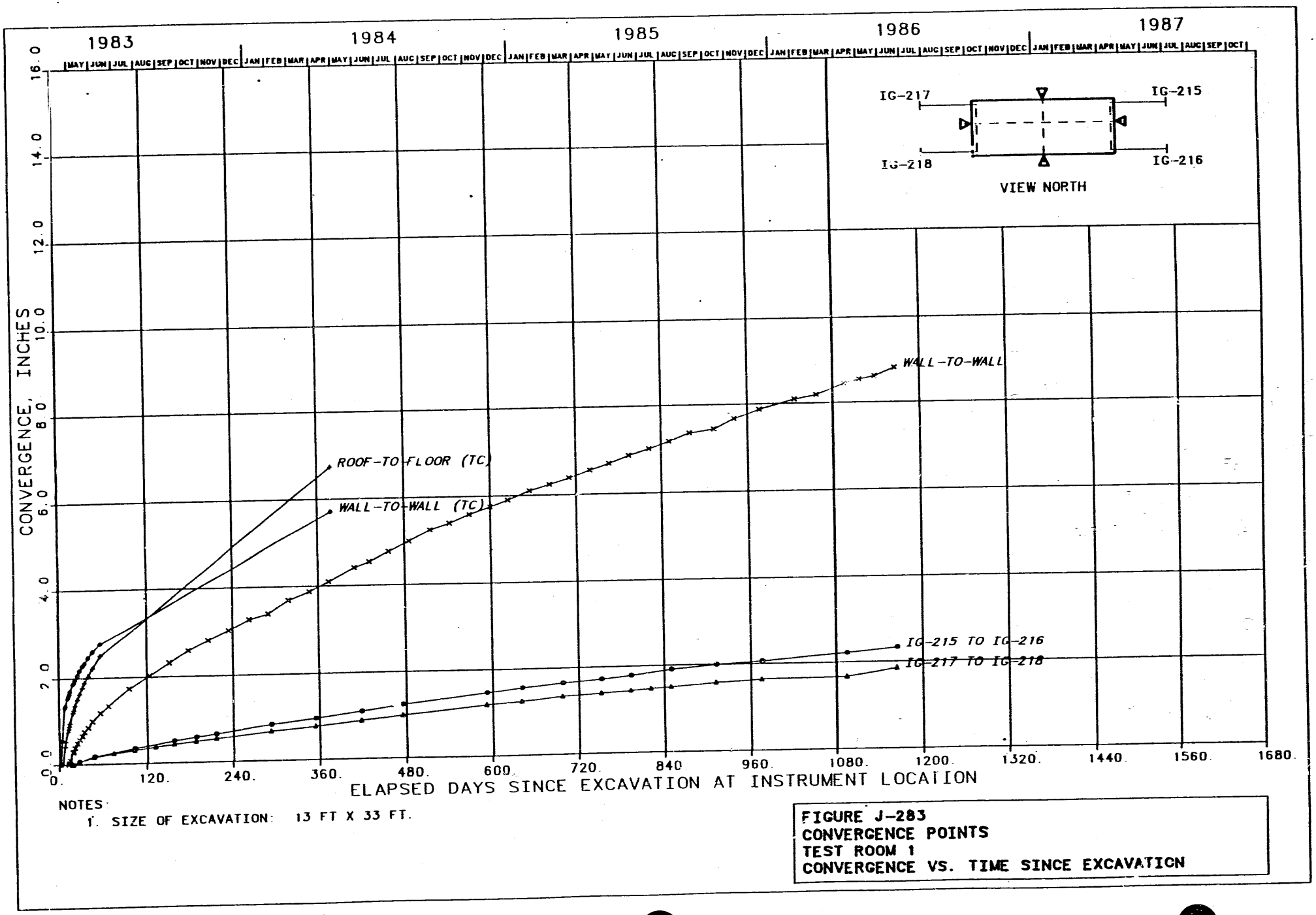
FIGURE J-281
CONVERGENCE POINTS
N1420 DRIFT, EAST 1547 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

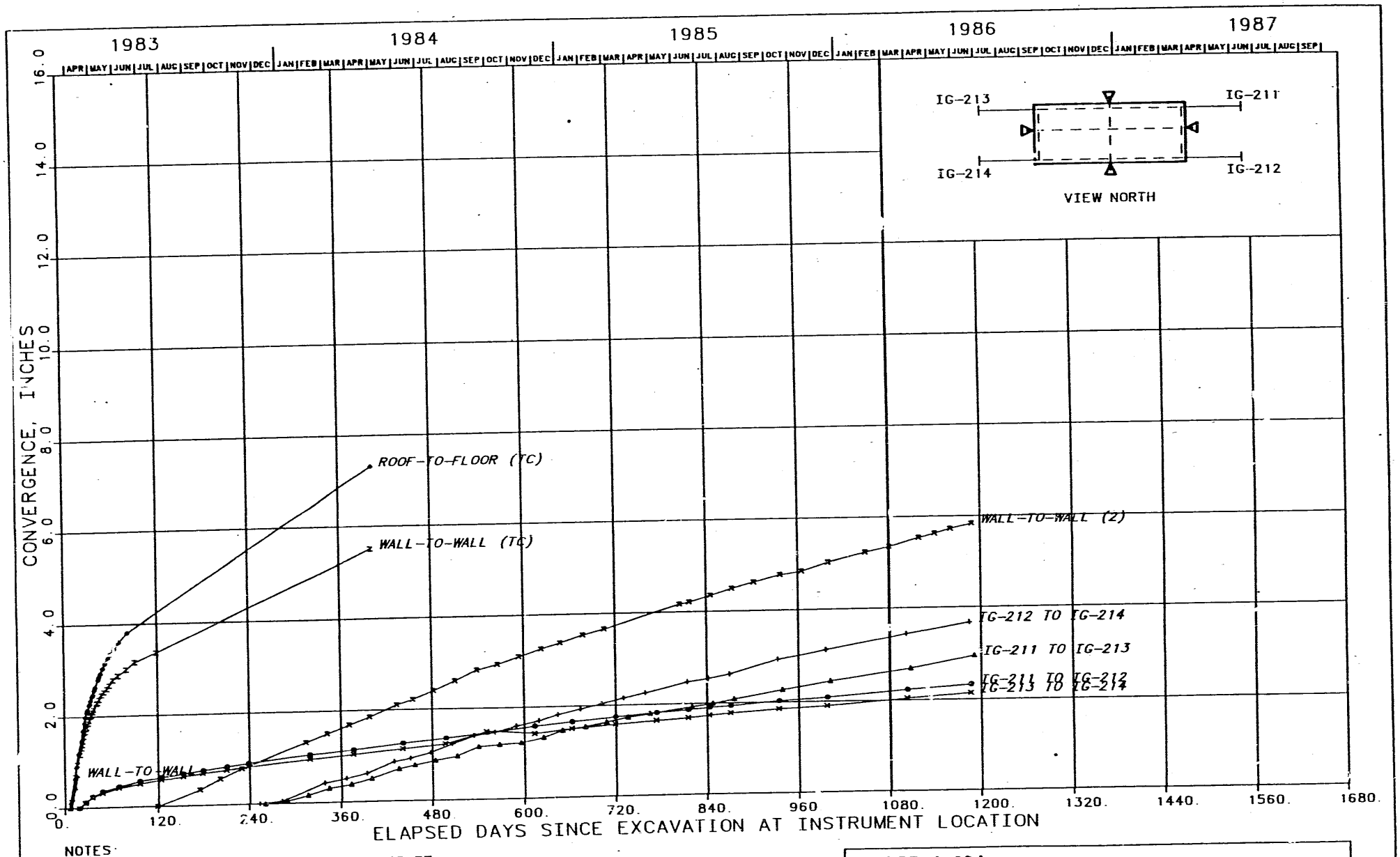
1. SIZE OF EXCAVATION: 12 FT X 15 FT.
2. INSTRUMENT IS CURRENTLY NOT ACCESSIBLE FOR READING.

FIGURE J-282
CONVERGENCE POINTS
SUBSTATION 2A
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:
1. SIZE OF EXCAVATION: 13 FT X 33 FT.

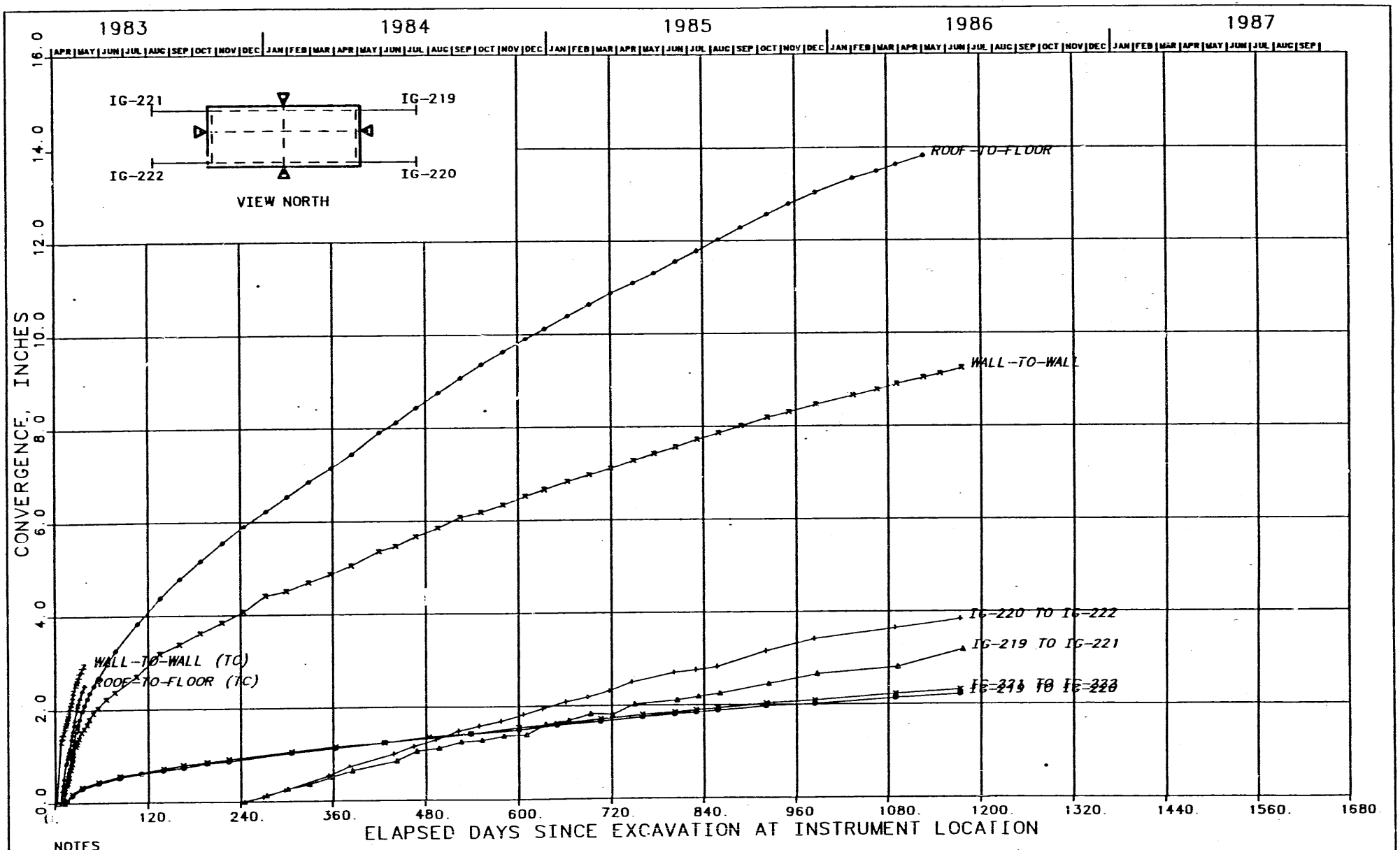
FIGURE J-283
CONVERGENCE POINTS
TEST ROOM 1
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

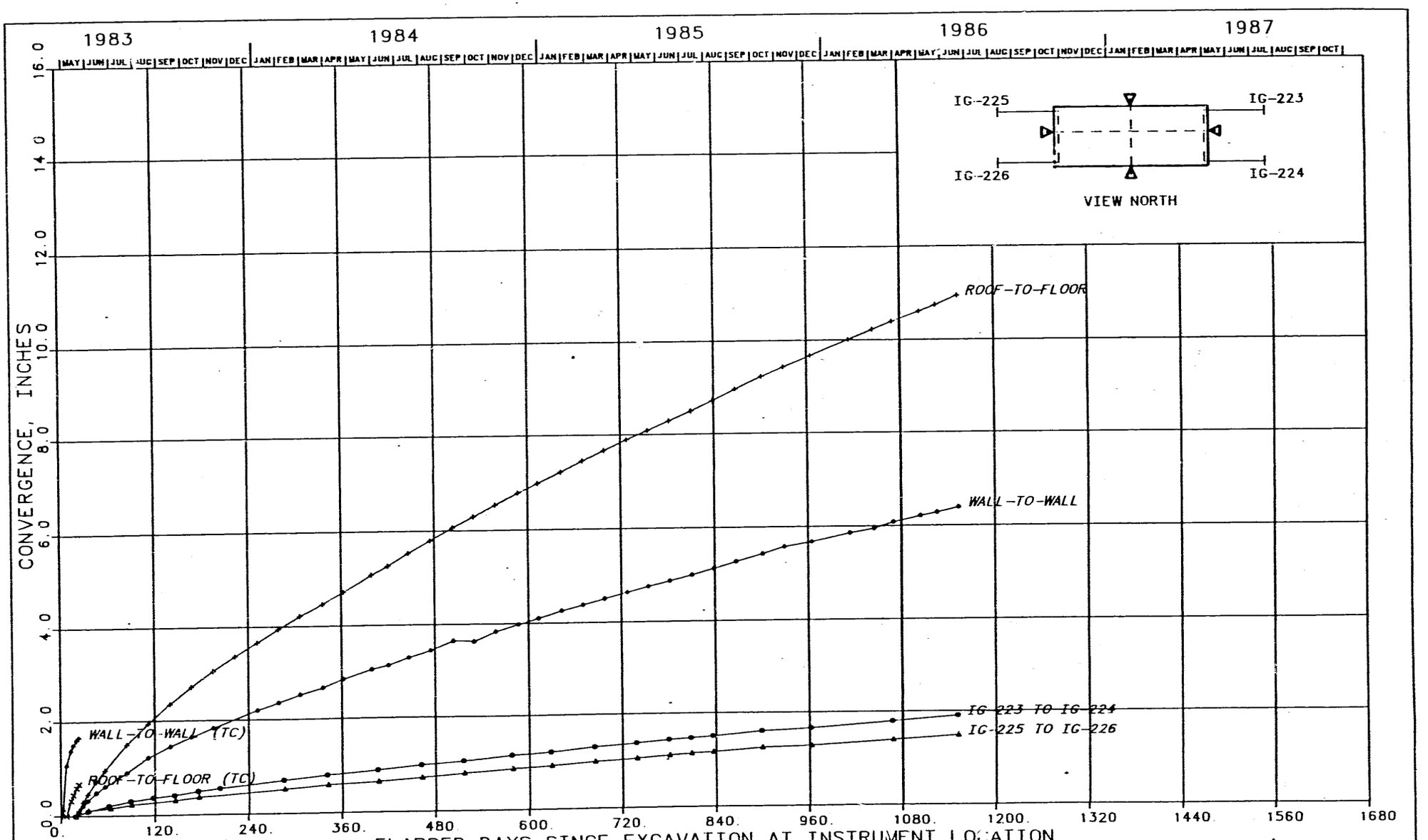
FIGURE J-284
CONVERGENCE POINTS
TEST ROOM 2
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1 SIZE OF EXCAVATION: 13 FT X 33 FT

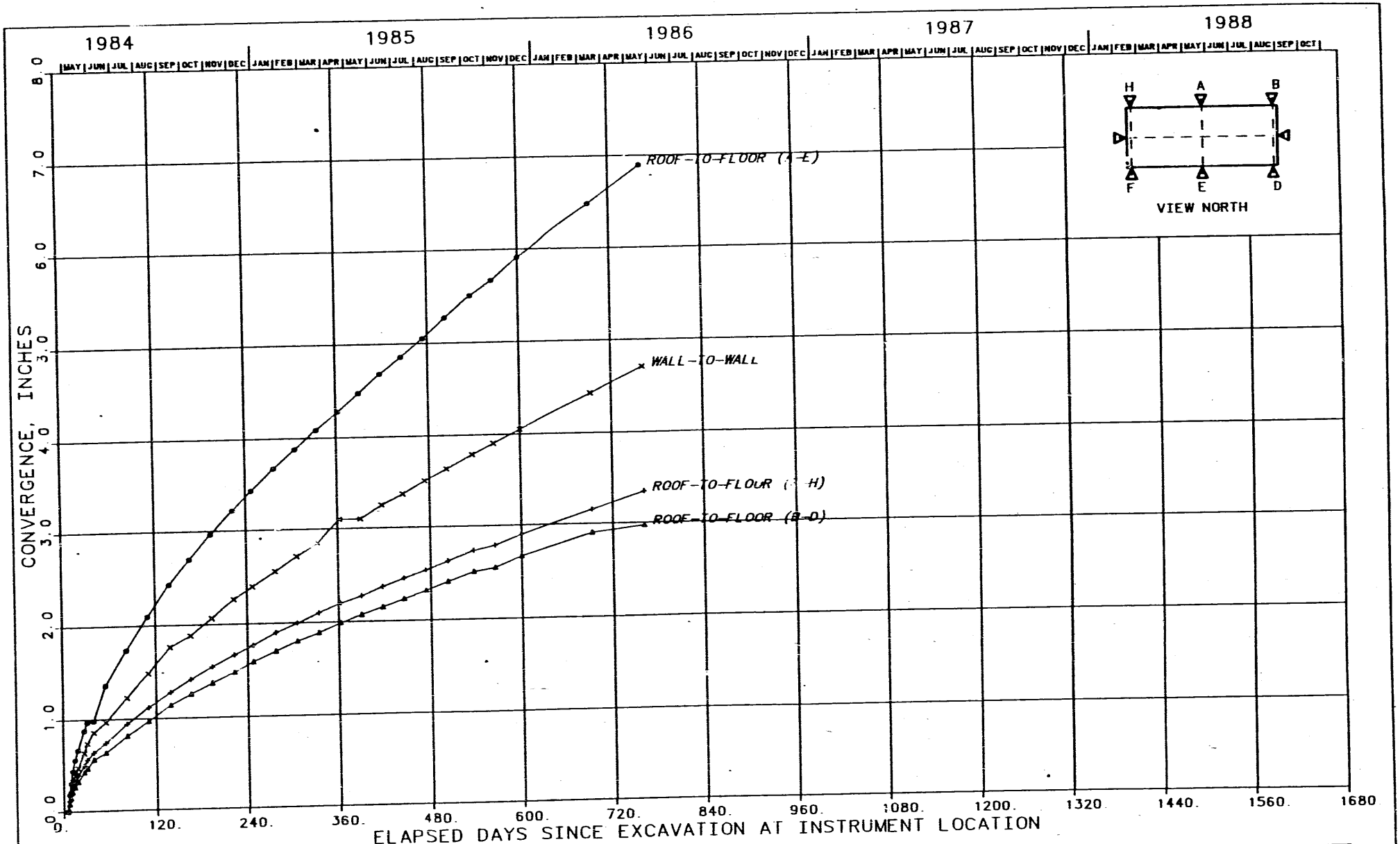
FIGURE J-285
CONVERGENCE POINTS
TEST ROOM 3
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

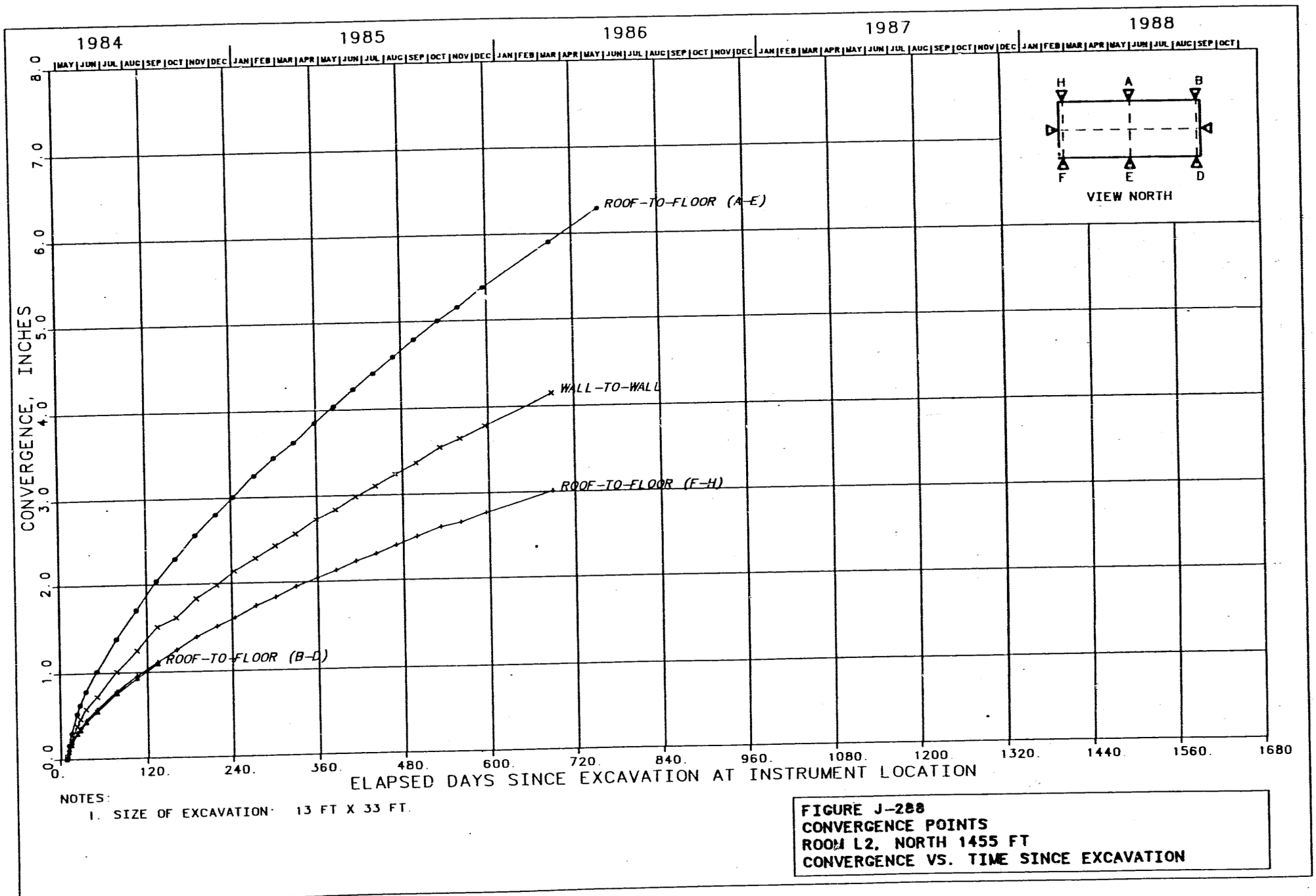
FIGURE J-296
CONVERGENCE POINTS
TEST ROOM 4
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION: 13 FT X 33 FT.

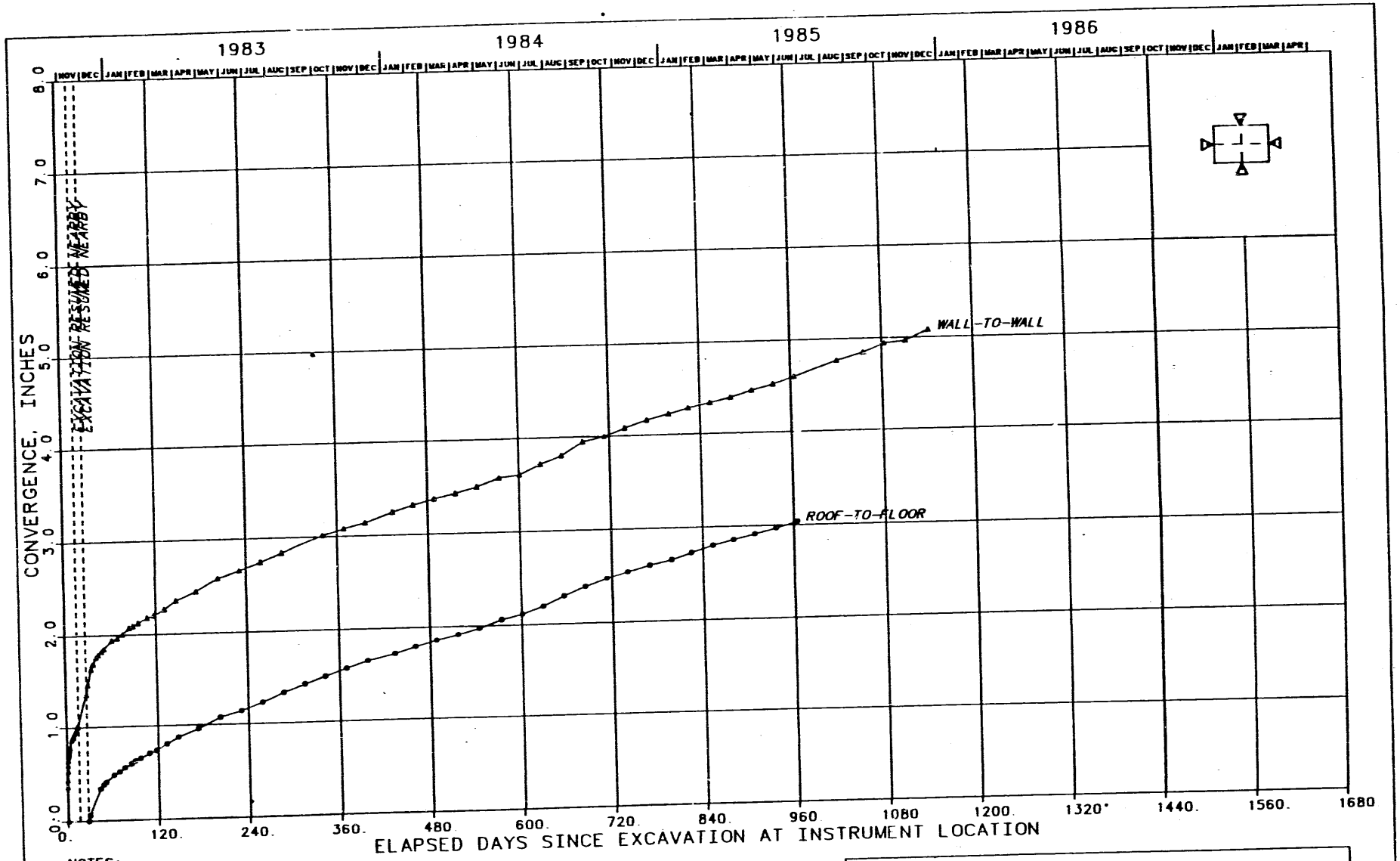
FIGURE J-287
CONVERGENCE POINTS
ROOM L1, NORTH 1455 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

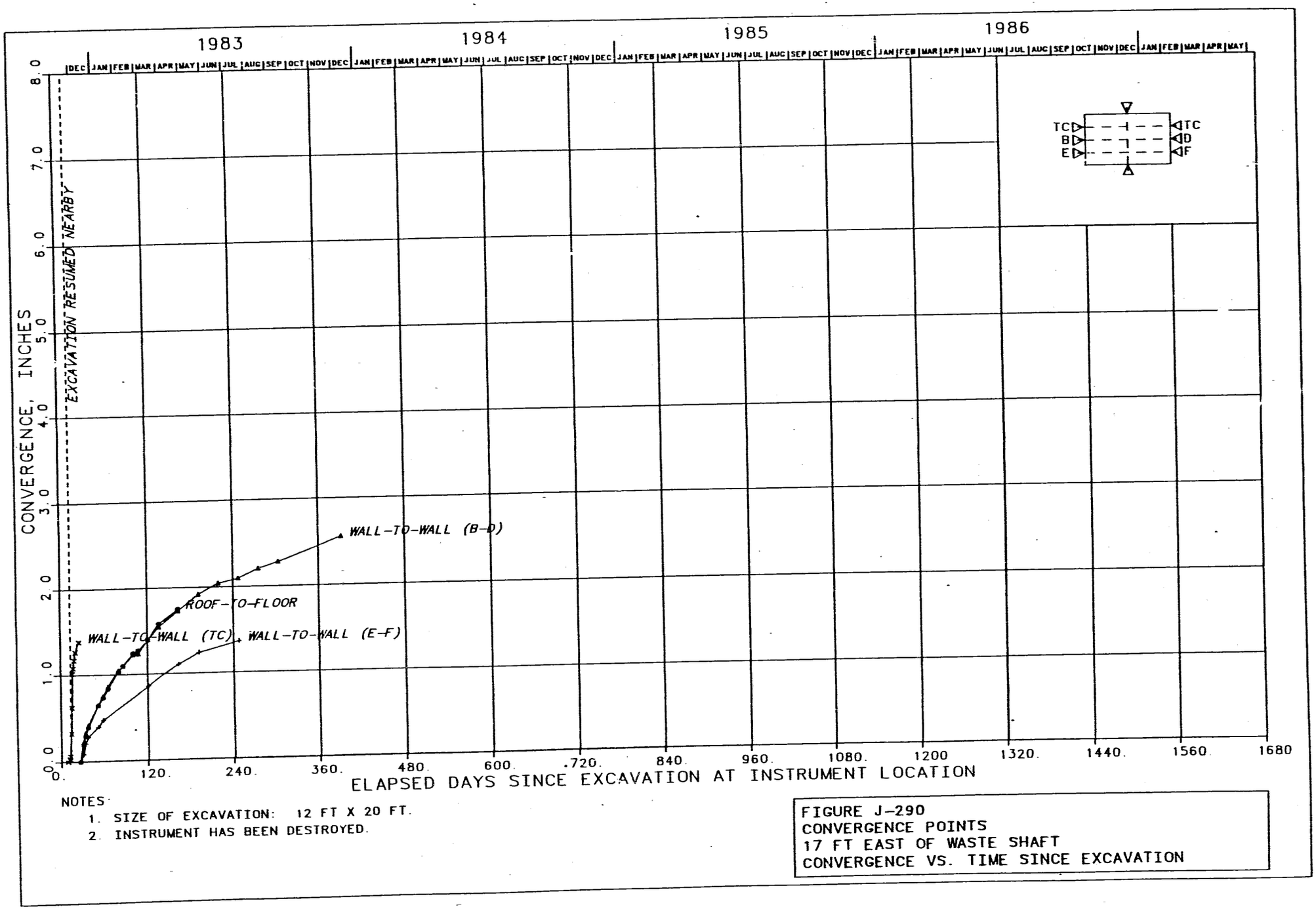
1. SIZE OF EXCAVATION: 13 FT X 33 FT.

FIGURE J-288
CONVERGENCE POINTS
ROOM L2, NORTH 1455 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:
1. SIZE OF EXCAVATION: 8 FT X 12 FT.
2. INSTRUMENT HAS BEEN DESTROYED

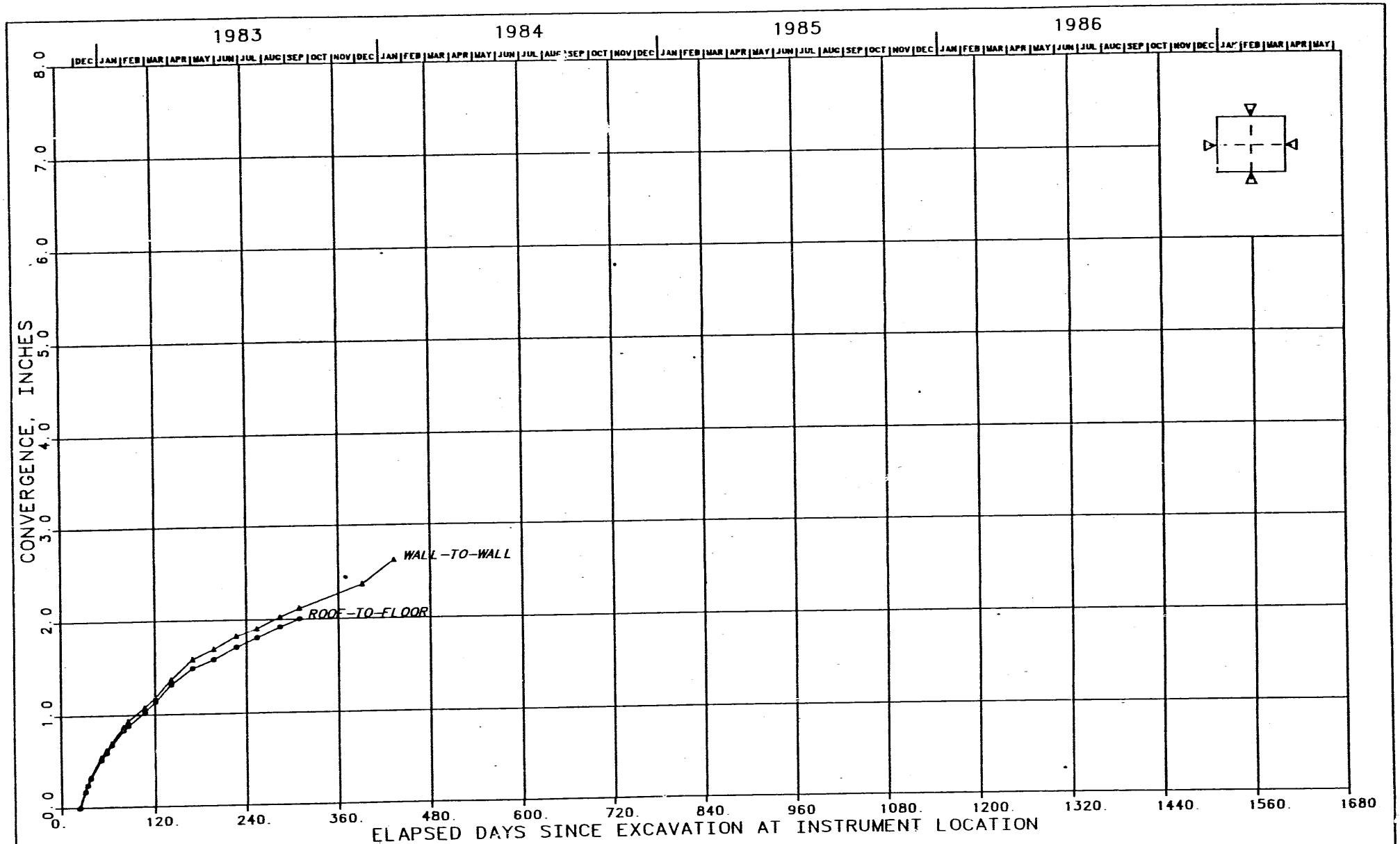
FIGURE J-289
CONVERGENCE POINTS
S90 CROSSCUT, EAST 91 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 20 FT.
2. INSTRUMENT HAS BEEN DESTROYED.

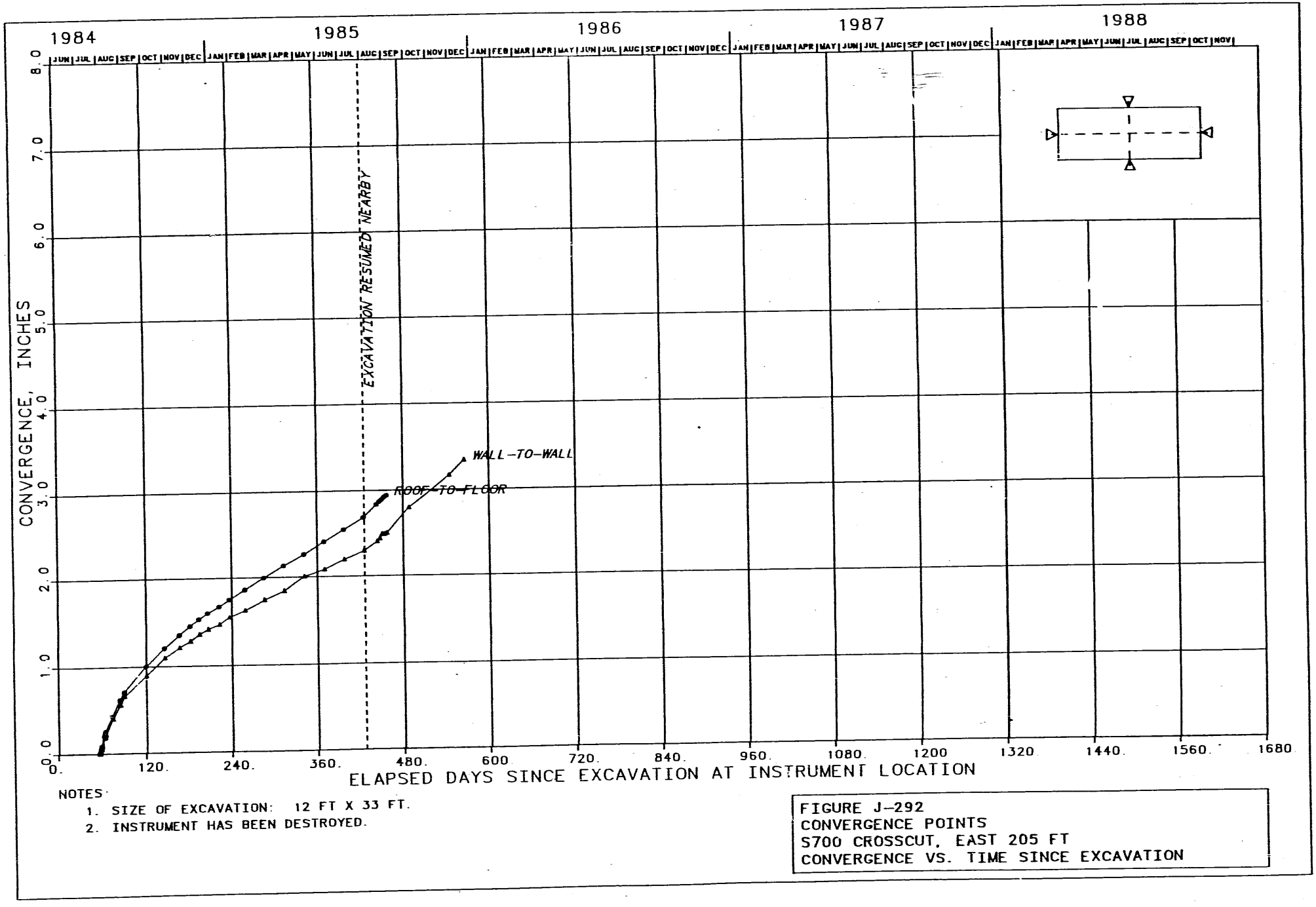
FIGURE J-290
CONVERGENCE POINTS
17 FT EAST OF WASTE SHAFT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 15 FT.
2. INSTRUMENT HAS BEEN DESTROYED.

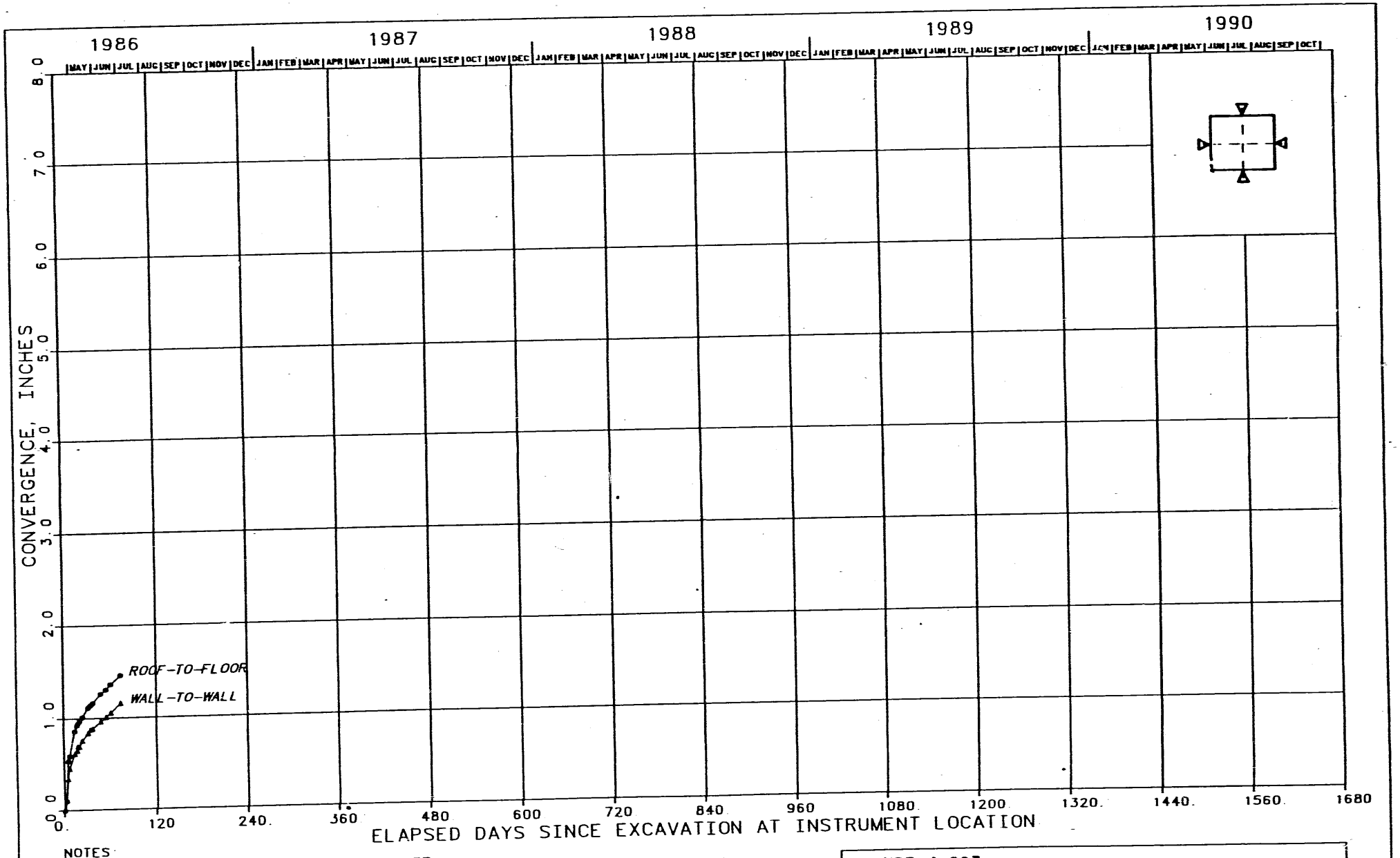
FIGURE J-291
CONVERGENCE POINTS
20 FT WEST OF WASTE SHAFT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 33 FT.
2. INSTRUMENT HAS BEEN DESTROYED.

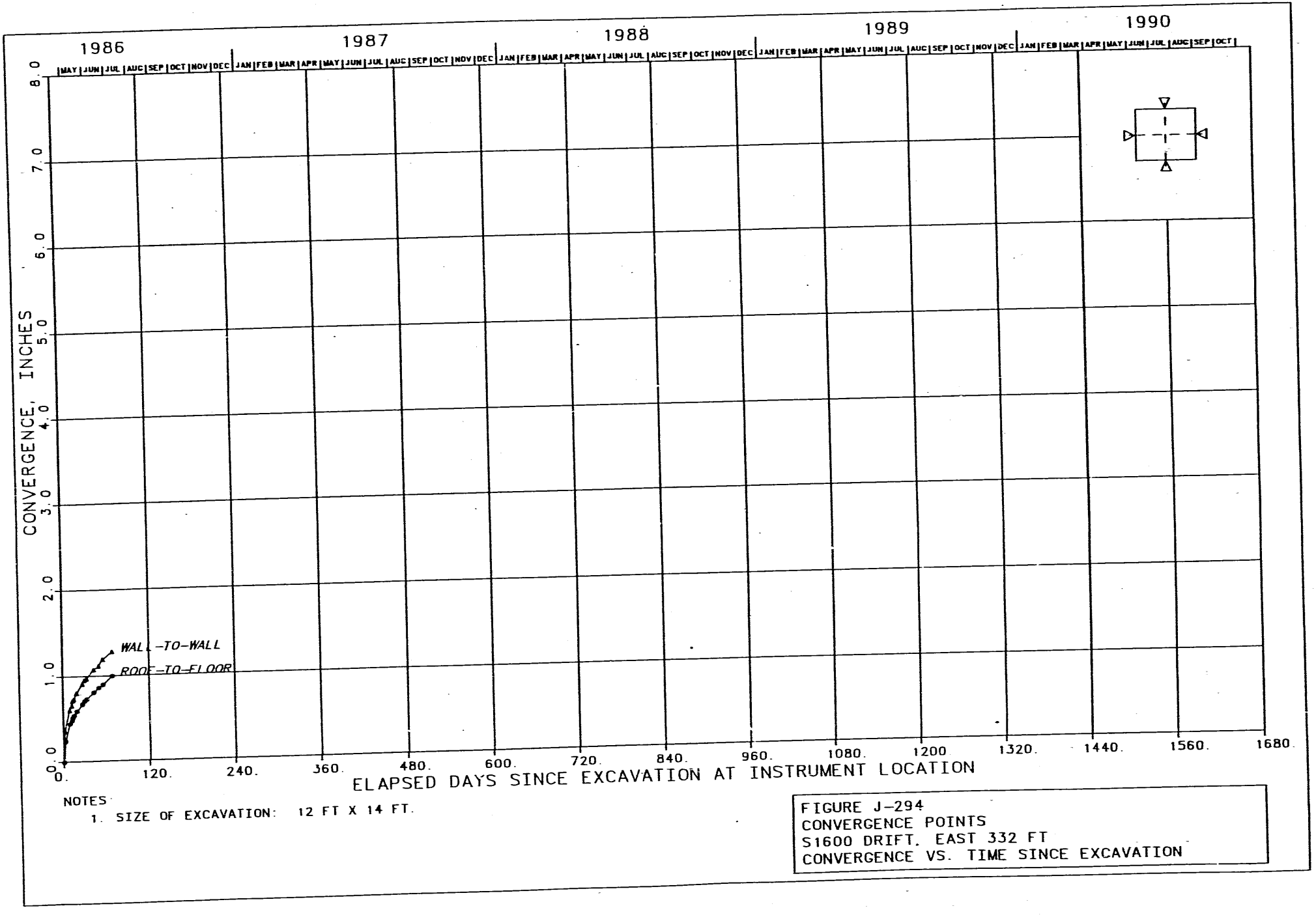
FIGURE J-292
CONVERGENCE POINTS
S700 CROSSCUT, EAST 205 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION: 12 FT X 14 FT.

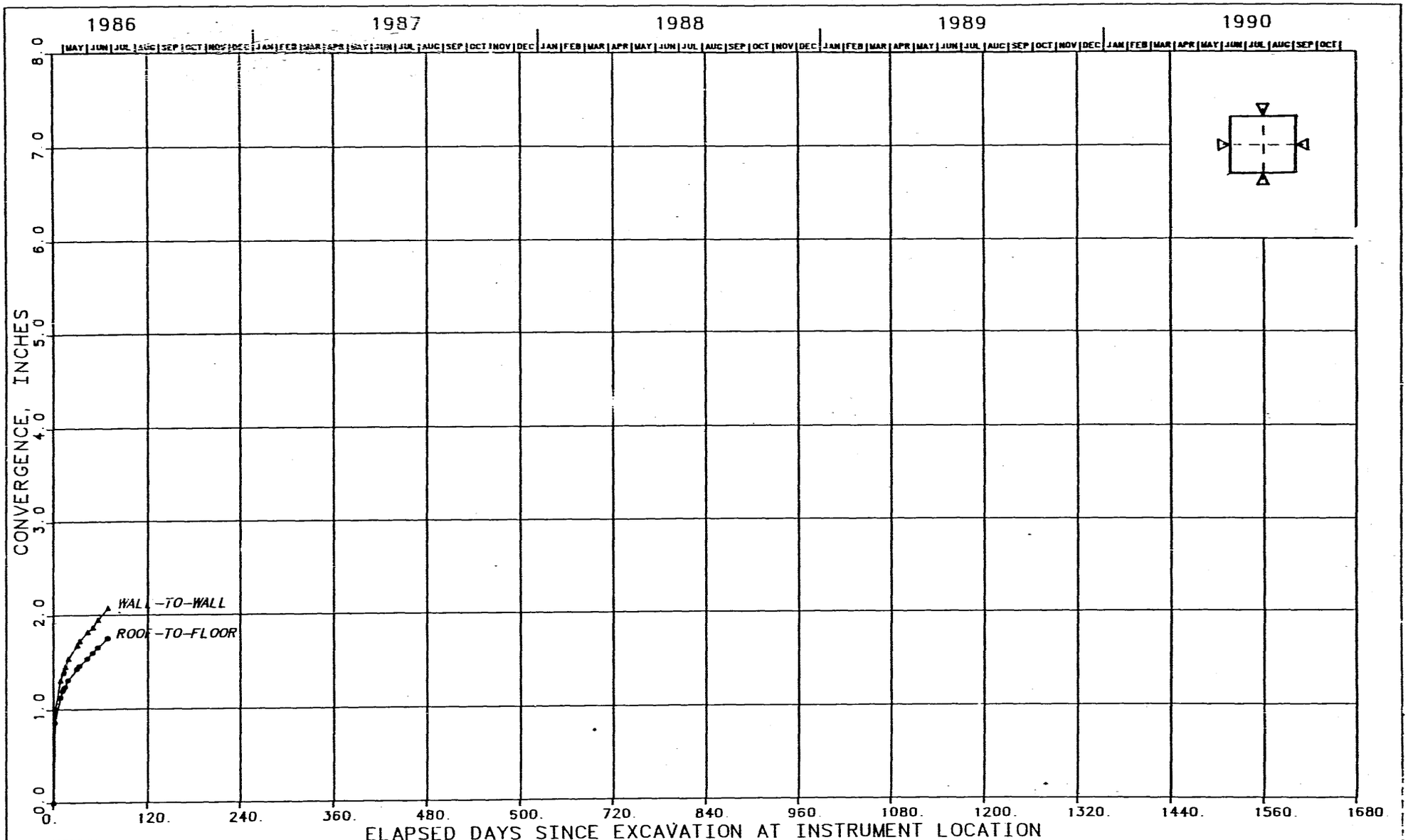
FIGURE J-293
CONVERGENCE POINTS
S1600 DRIFT, EAST 311 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION: 12 FT X 14 FT.

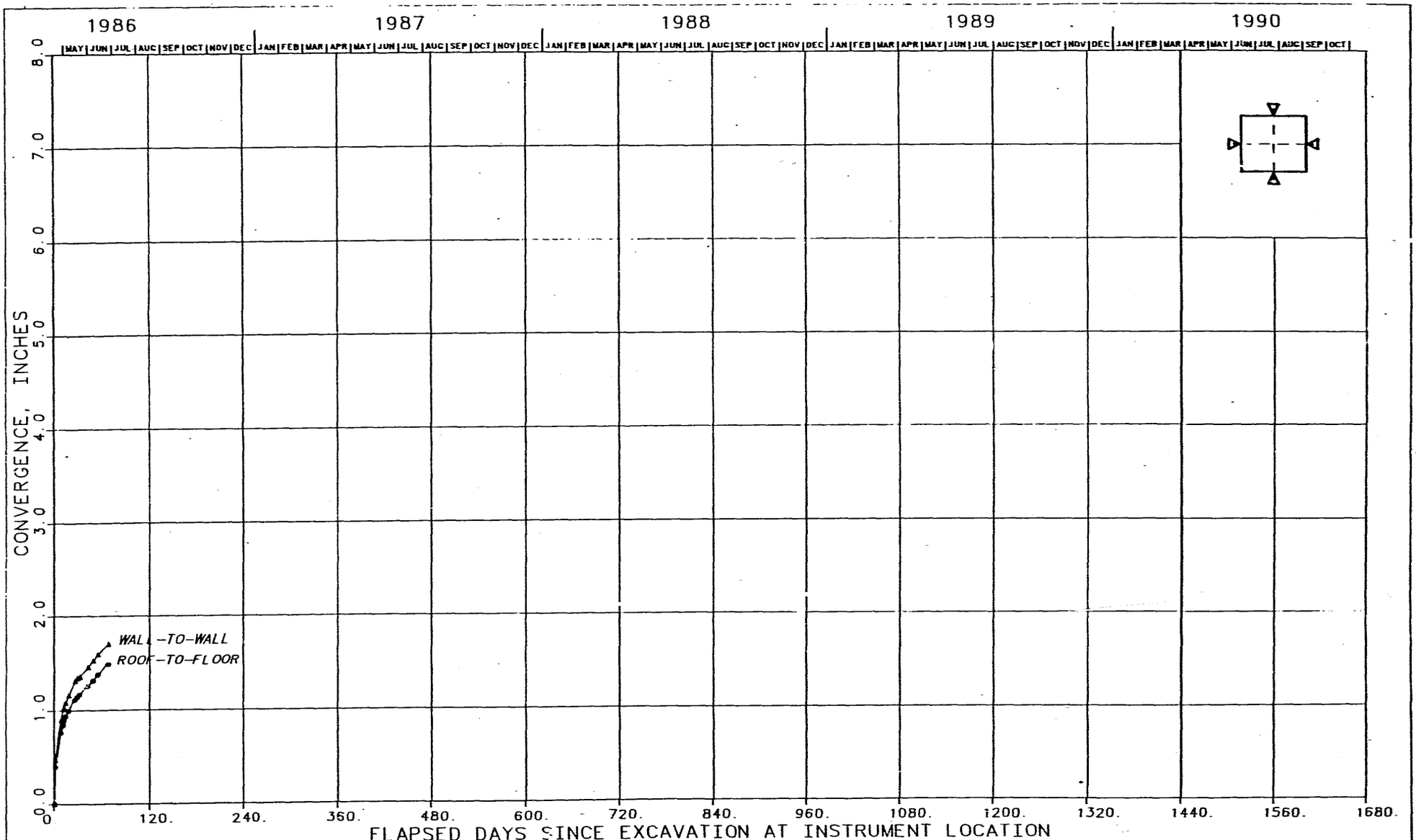
FIGURE J-294
CONVERGENCE POINTS
S1600 DRIFT. EAST 332 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 14 FT.

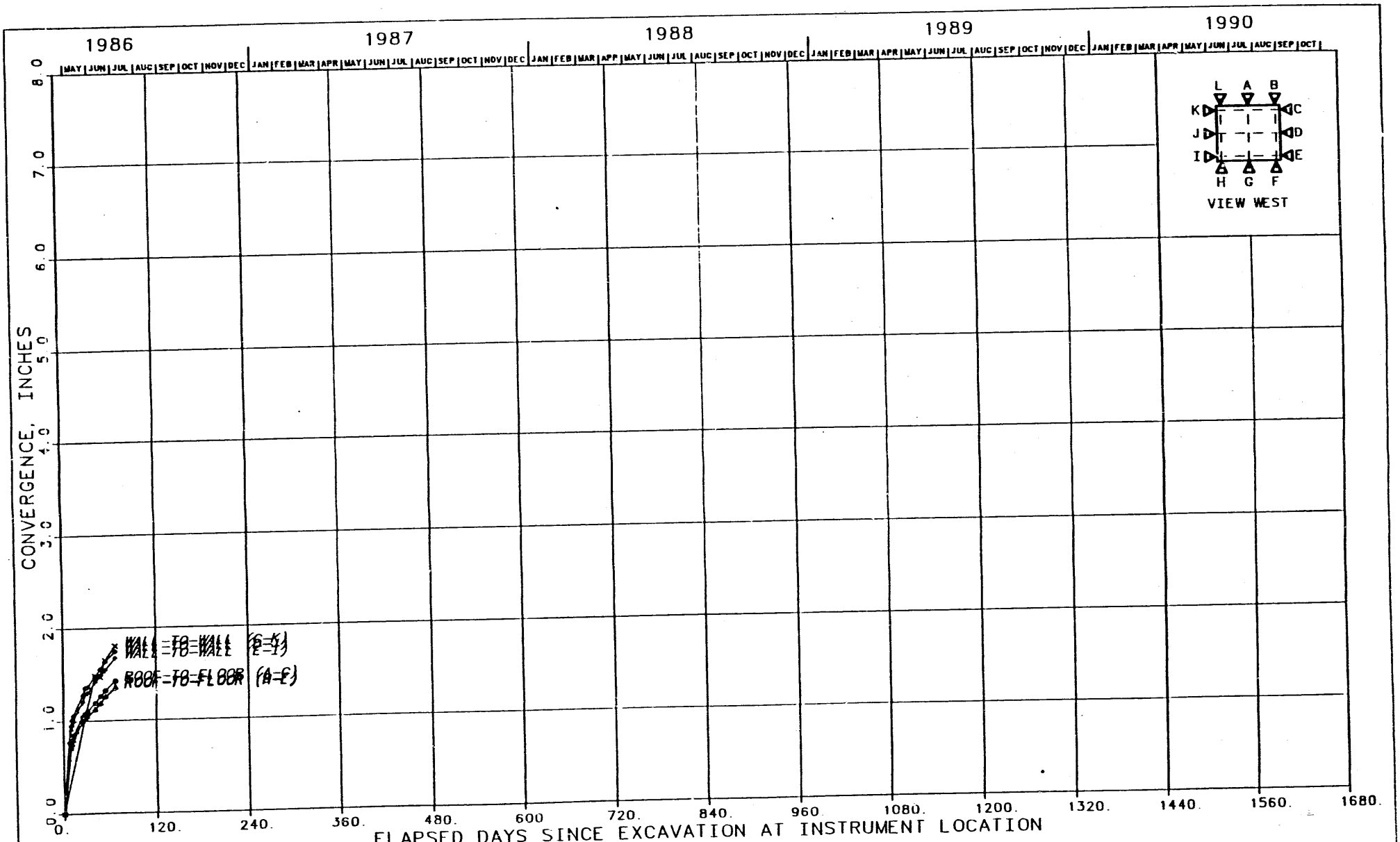
FIGURE J-295
CONVERGENCE POINTS
S1600 DRIFT, EAST 357 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 14 FT

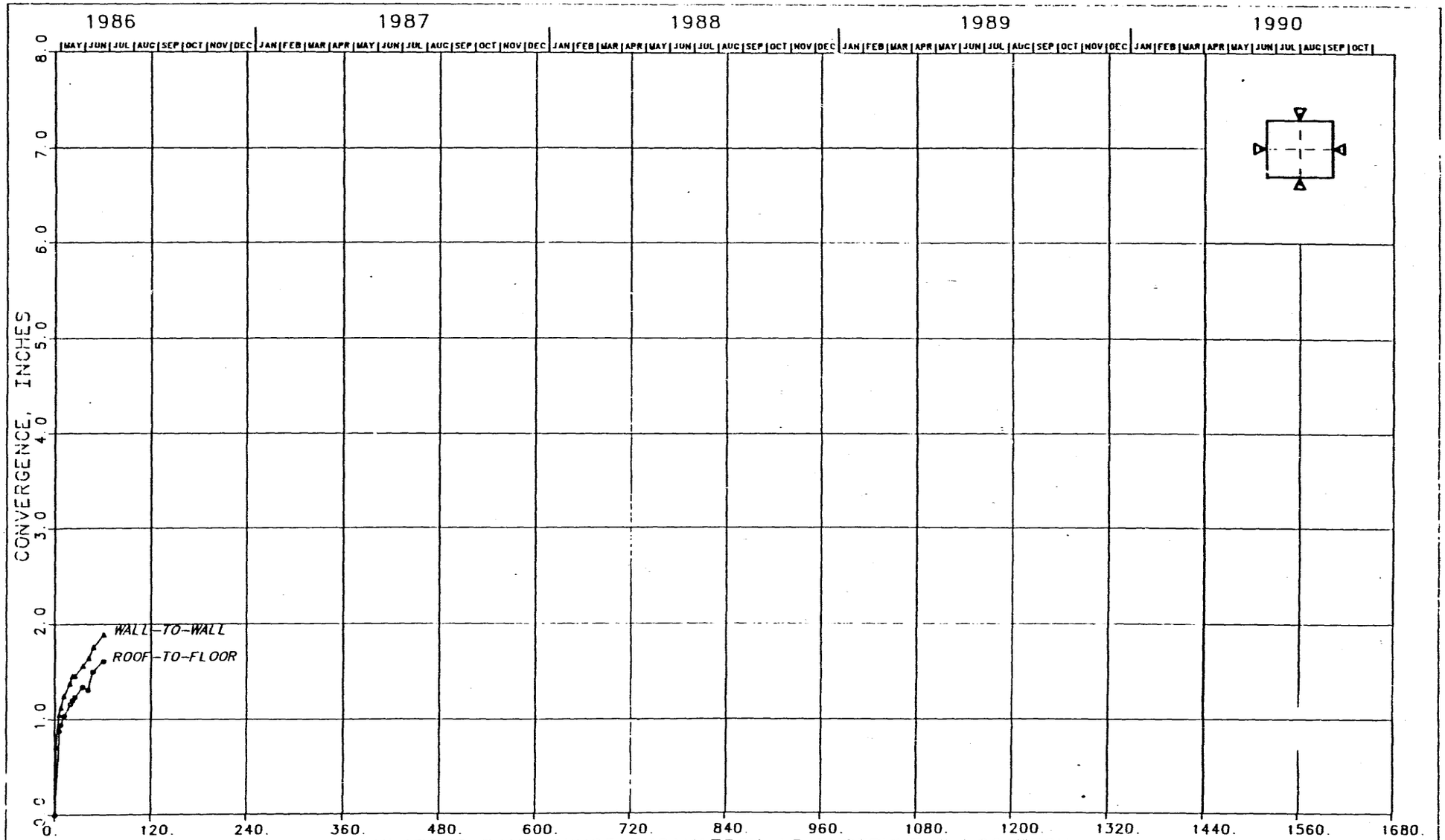
FIGURE J-295
CONVERGENCE POINTS
S1600 DRIFT, EAST 382 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 14 FT.

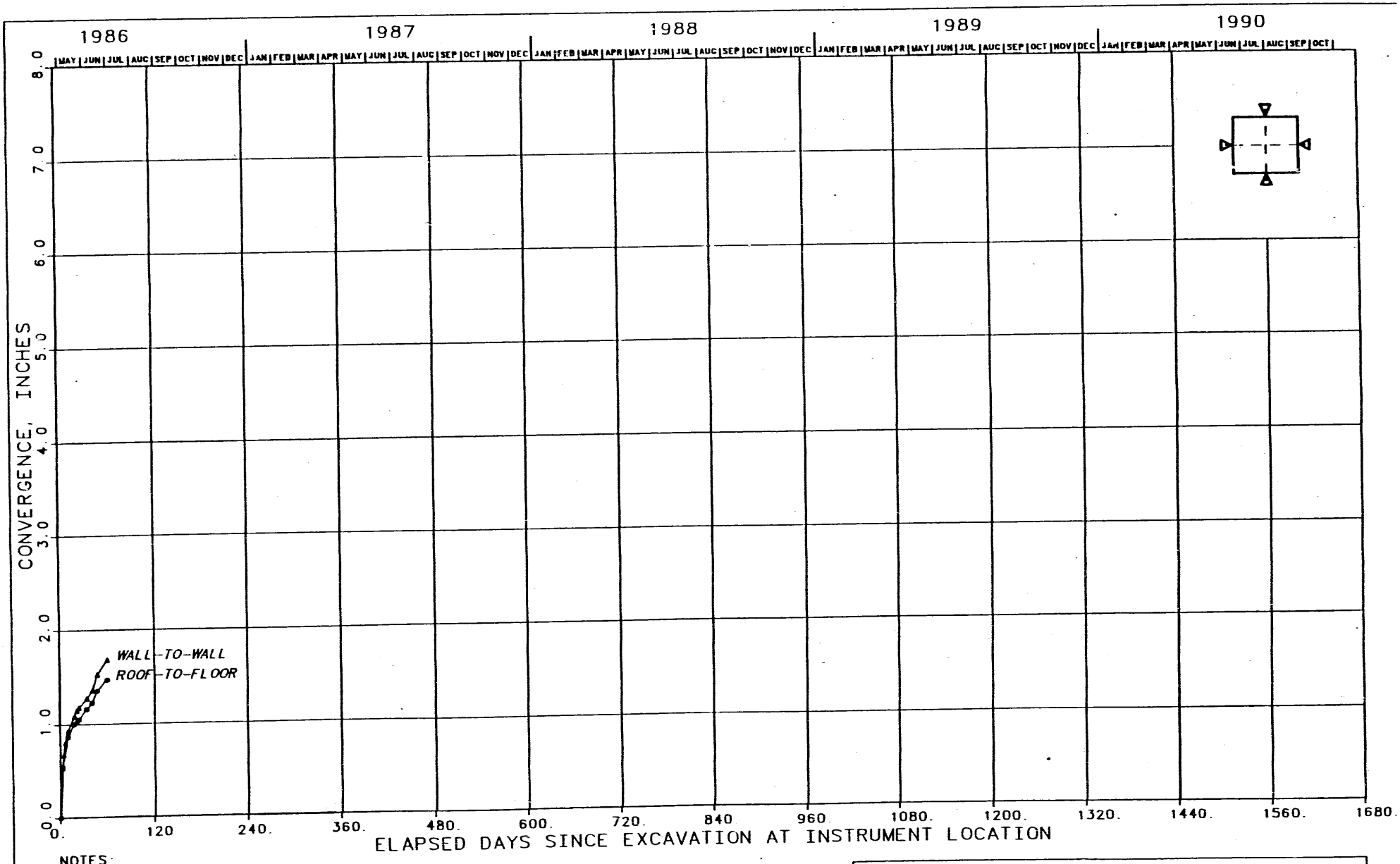
FIGURE J-297
CONVERGENCE POINTS
S1600 DRIFT, EAST 407 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 14 FT.

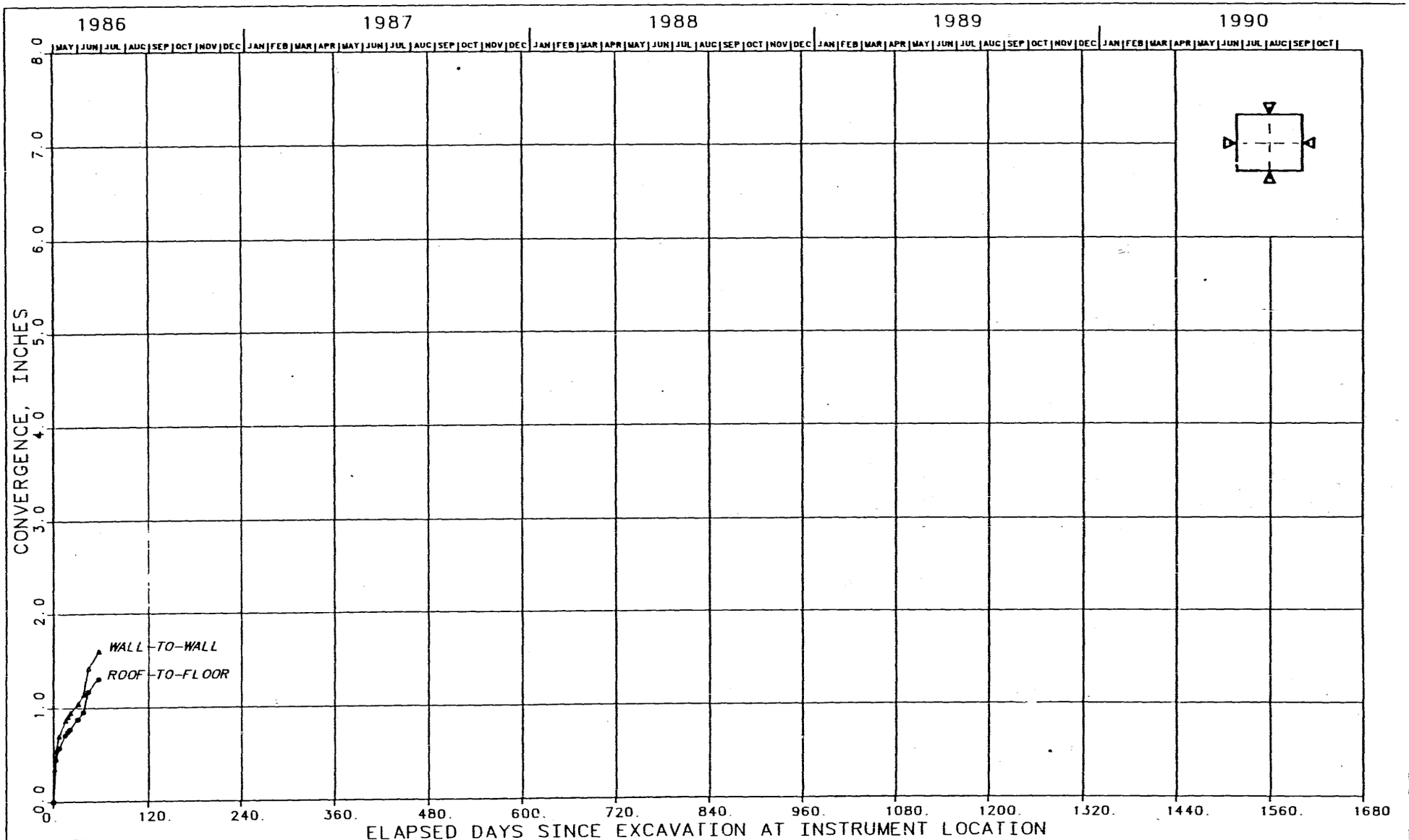
FIGURE J-298
CONVERGENCE POINTS
S1600 DRIFT, EAST 432 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 14 FT.

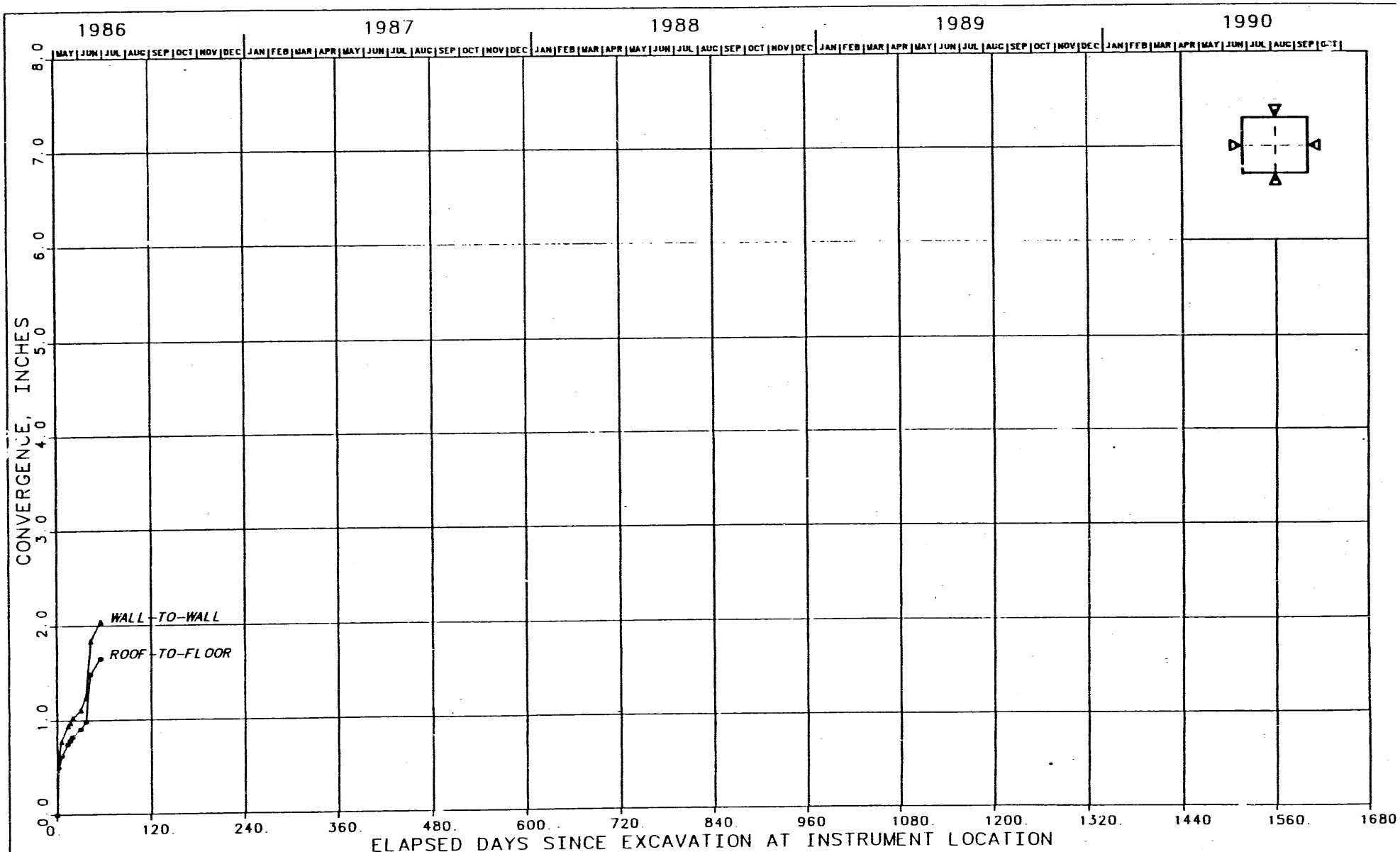
FIGURE J-299
CONVERGENCE POINTS
S1600 DRIFT, EAST 457 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION: 12 FT X 14 FT.

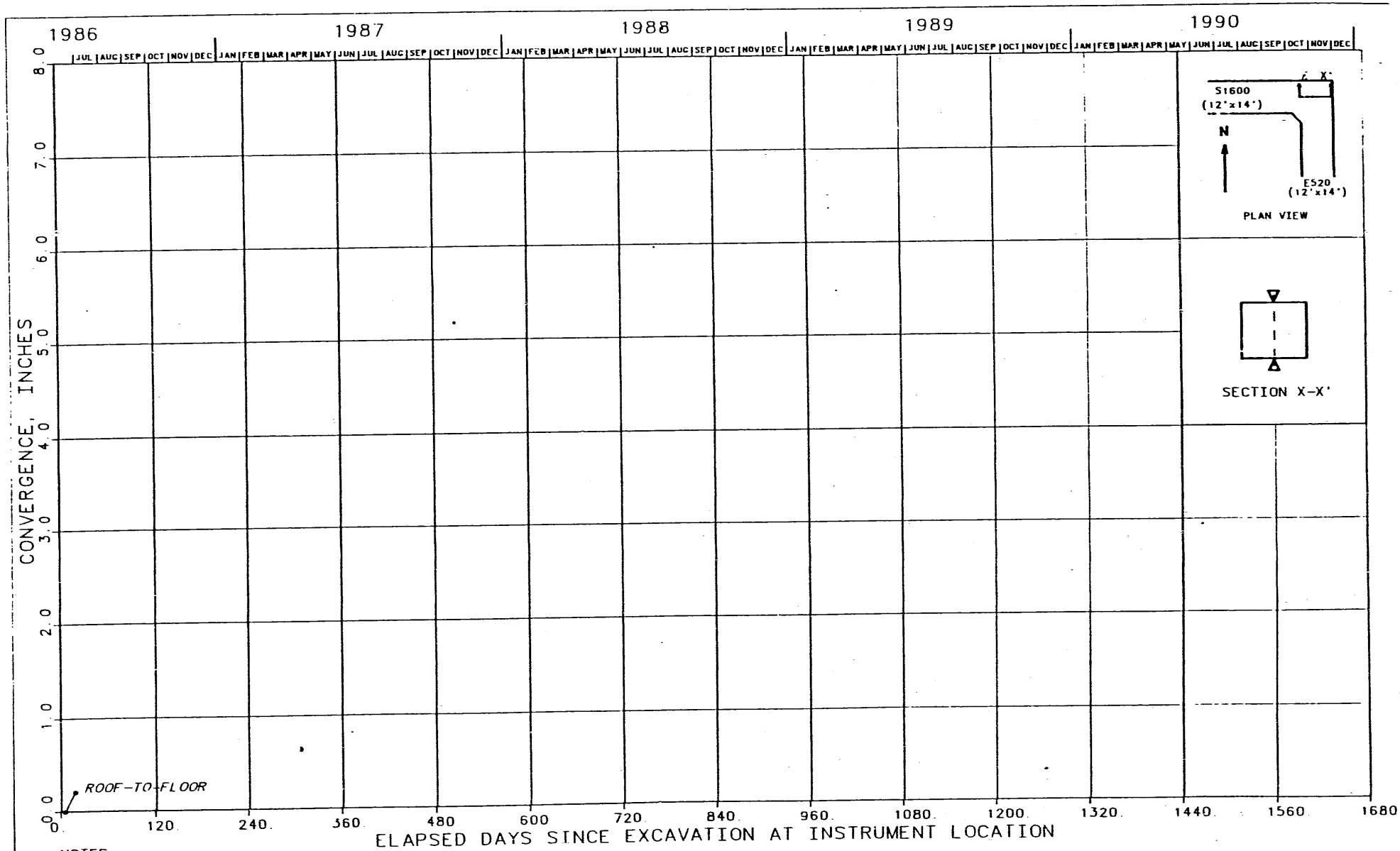
FIGURE J-300
CONVERGENCE POINTS
S1600 DRIFT, EAST 482 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 14 FT.

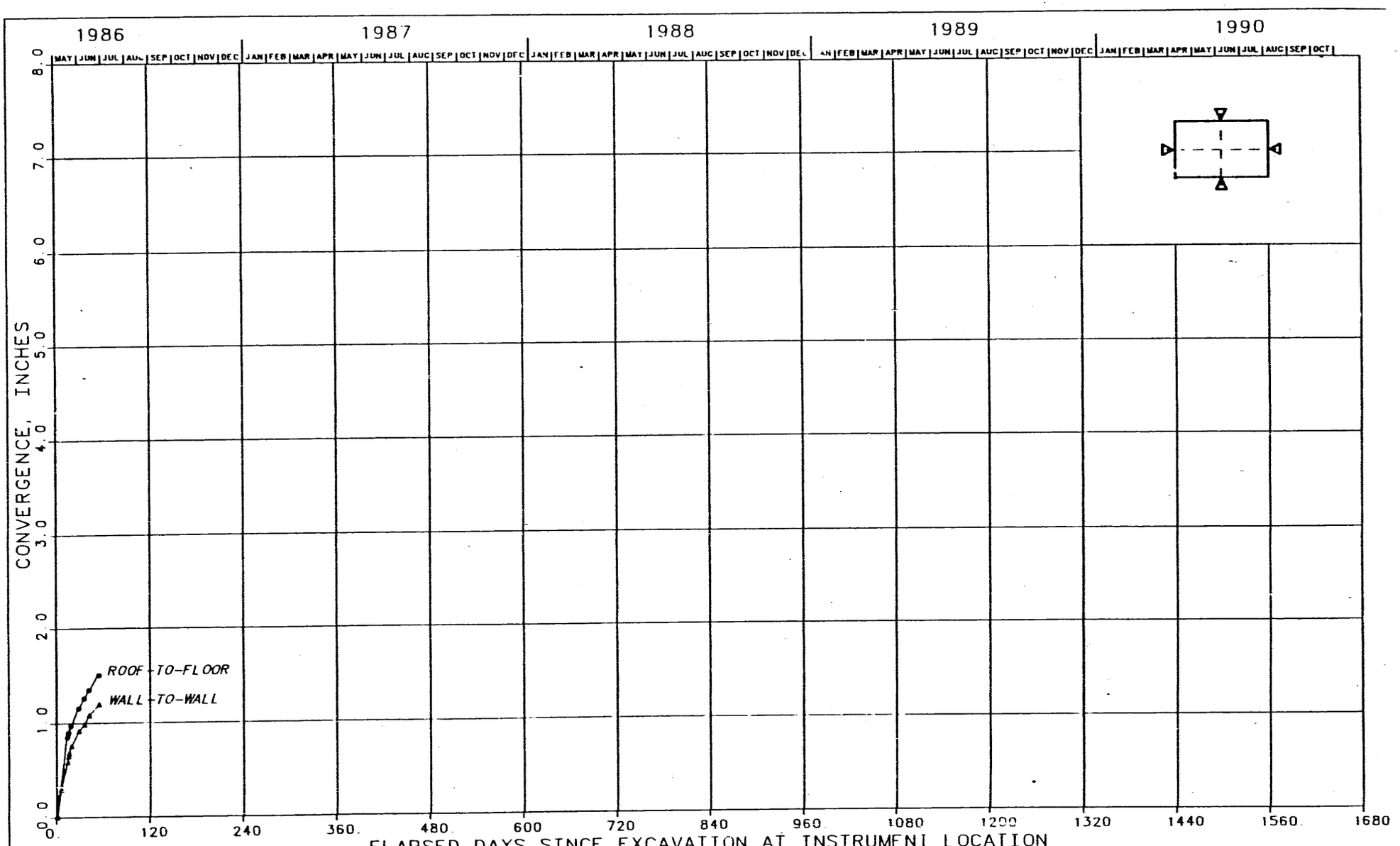
FIGURE J-301
CONVERGENCE POINTS
S1600 DRIFT, EAST 507 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION: 12 FT X 14 FT.

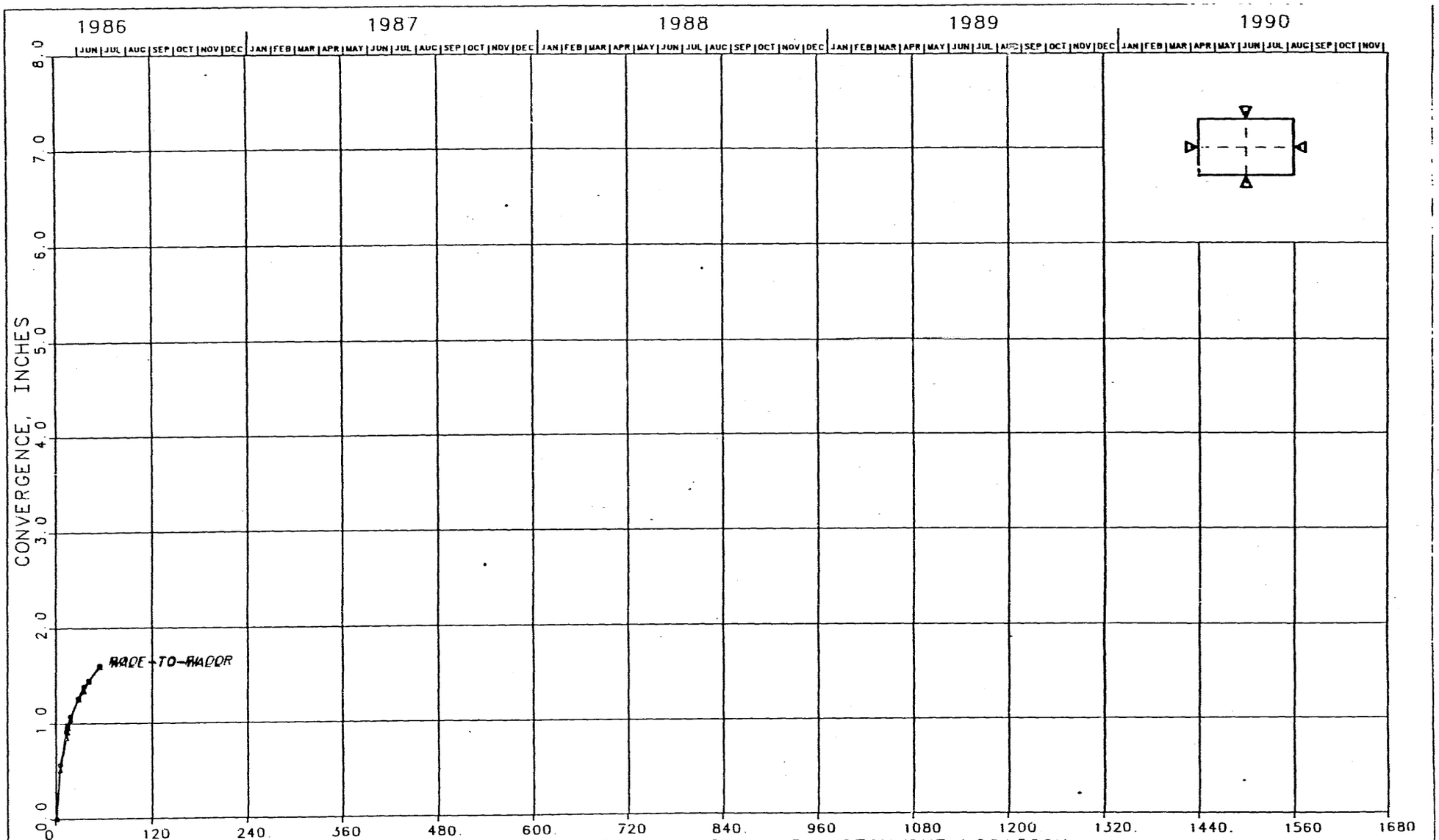
FIGURE J-302
CONVERGENCE POINTS
S1600 DRIFT, EAST 520 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1. SIZE OF EXCAVATION 12 FT X 20 FT.

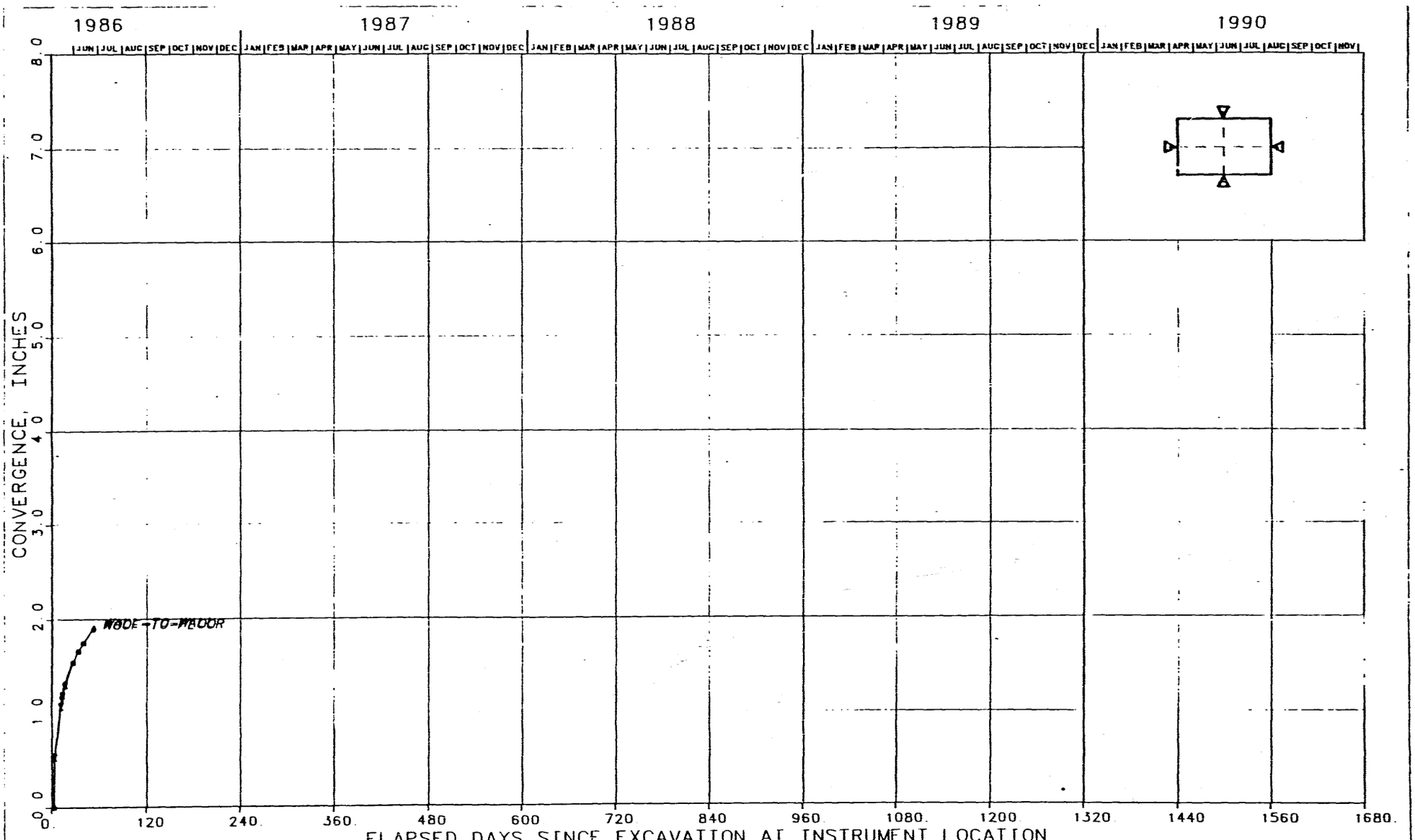
FIGURE J-303
CONVERGENCE POINTS
S1950 DRIFT, EAST 311 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION 12 FT X 20 FT

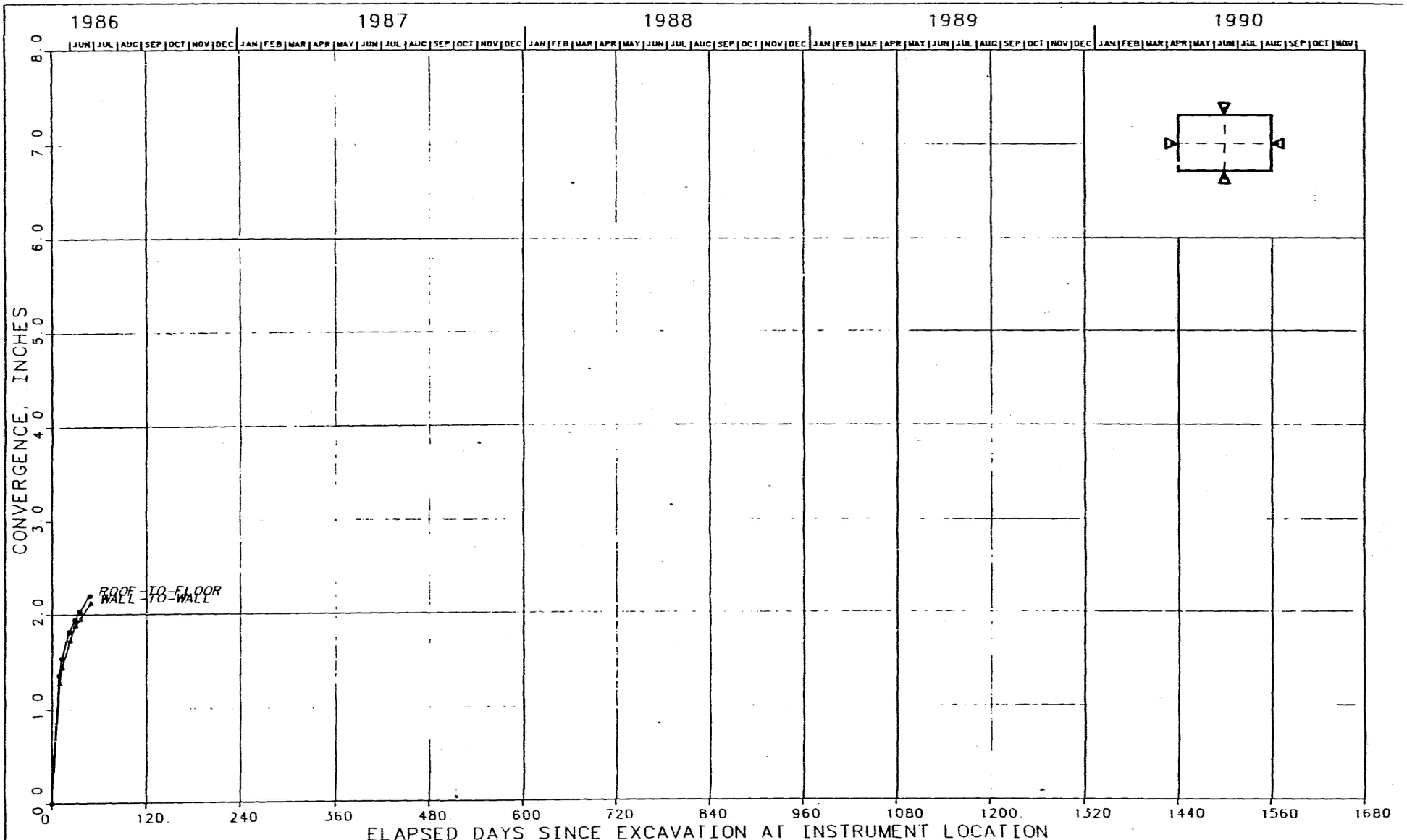
FIGURE J-304
CONVERGENCE POINTS
S1950 DRIFT, EAST 332 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION 12 FT X 20 FT

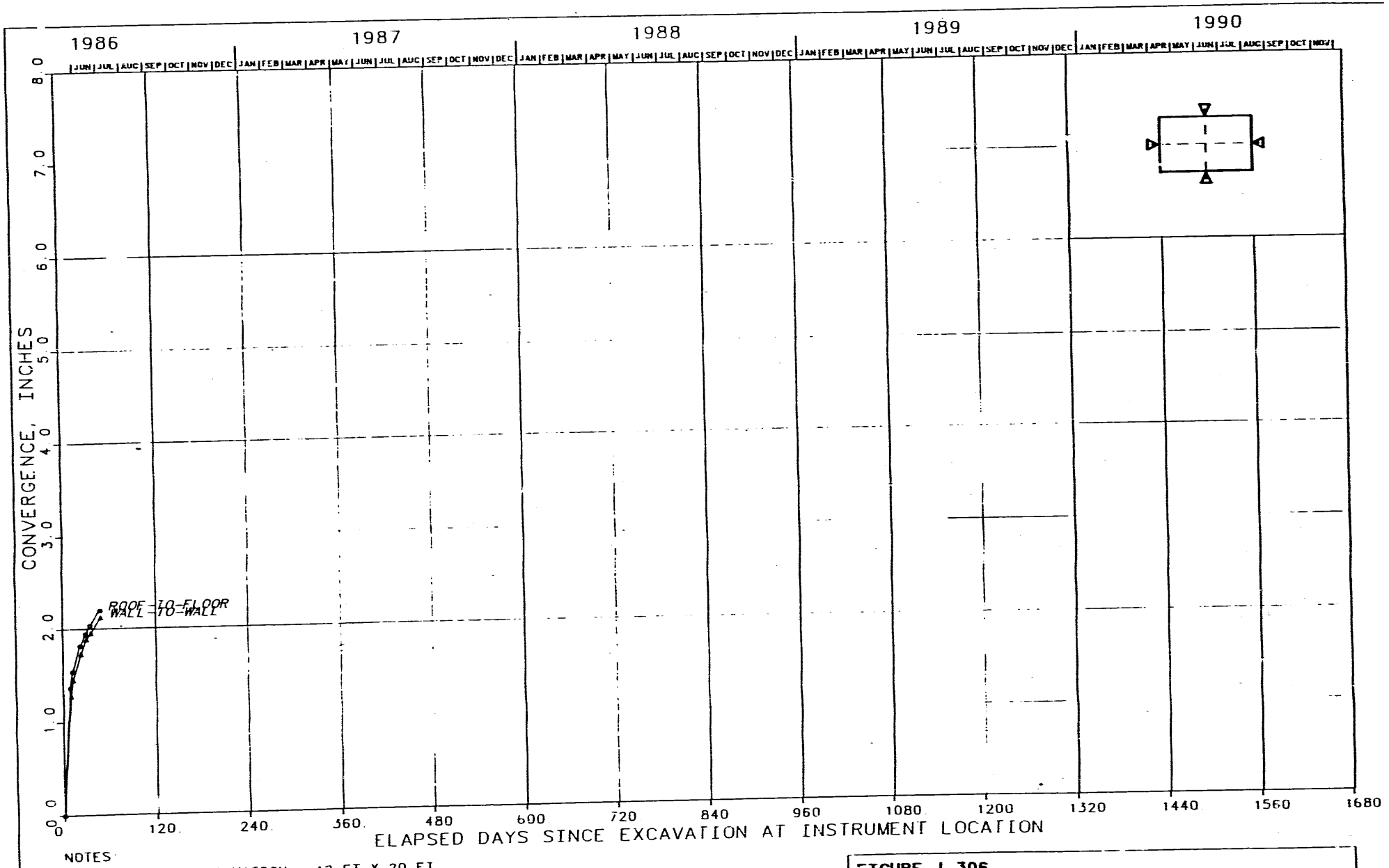
FIGURE J-305
CONVERGENCE POINTS
S1950 DRIFT, EAST 357 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1 SIZE OF EXCAVATION 12 FT X 20 FT

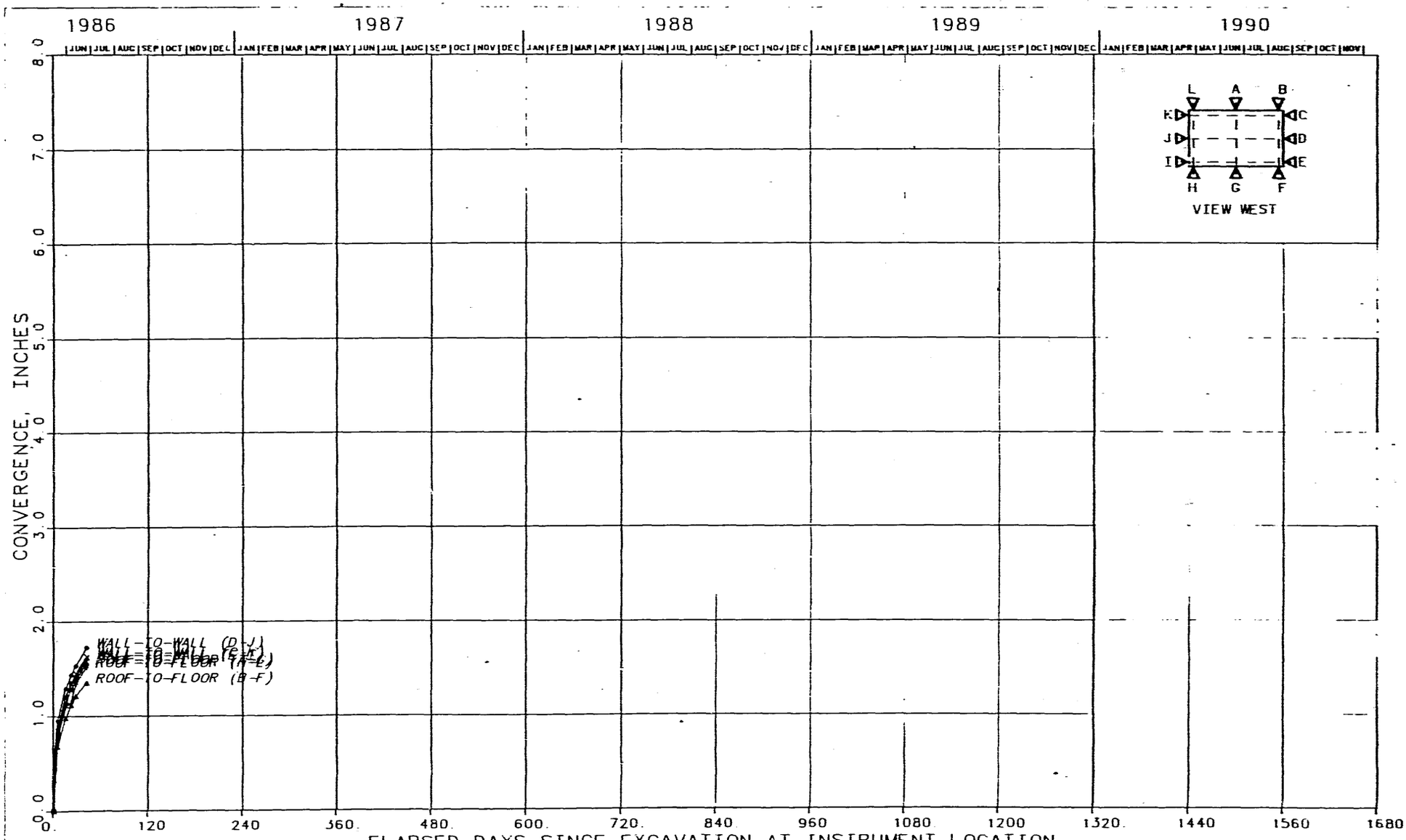
FIGURE J-306
CONVERGENCE POINTS
S1950 DRIFT, EAST 382 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES:

1 SIZE OF EXCAVATION 12 FT X 20 FT.

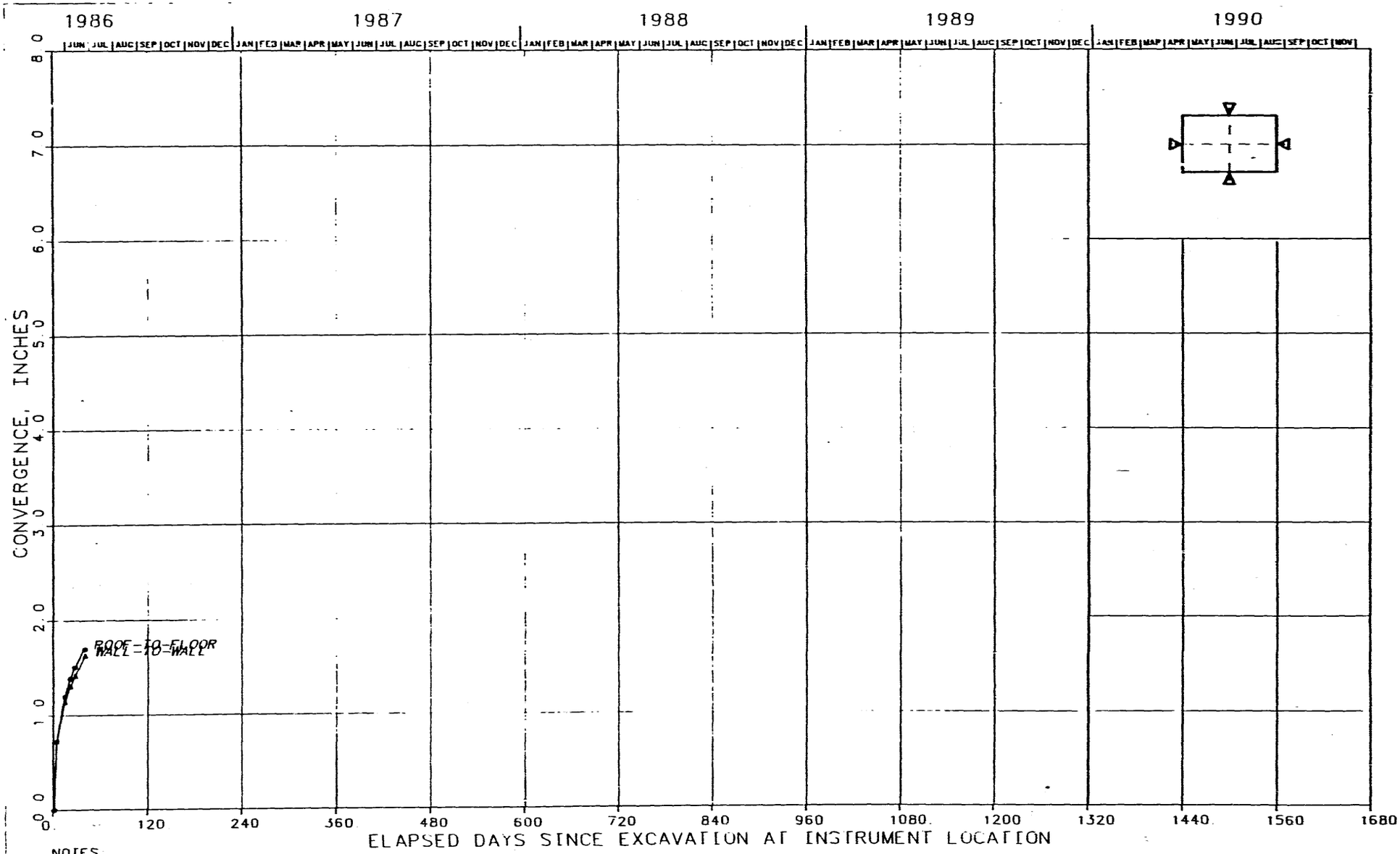
FIGURE J-306
CONVERGENCE POINTS
S1950 DRIFT, EAST 382 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION: 12 FT X 20 FT

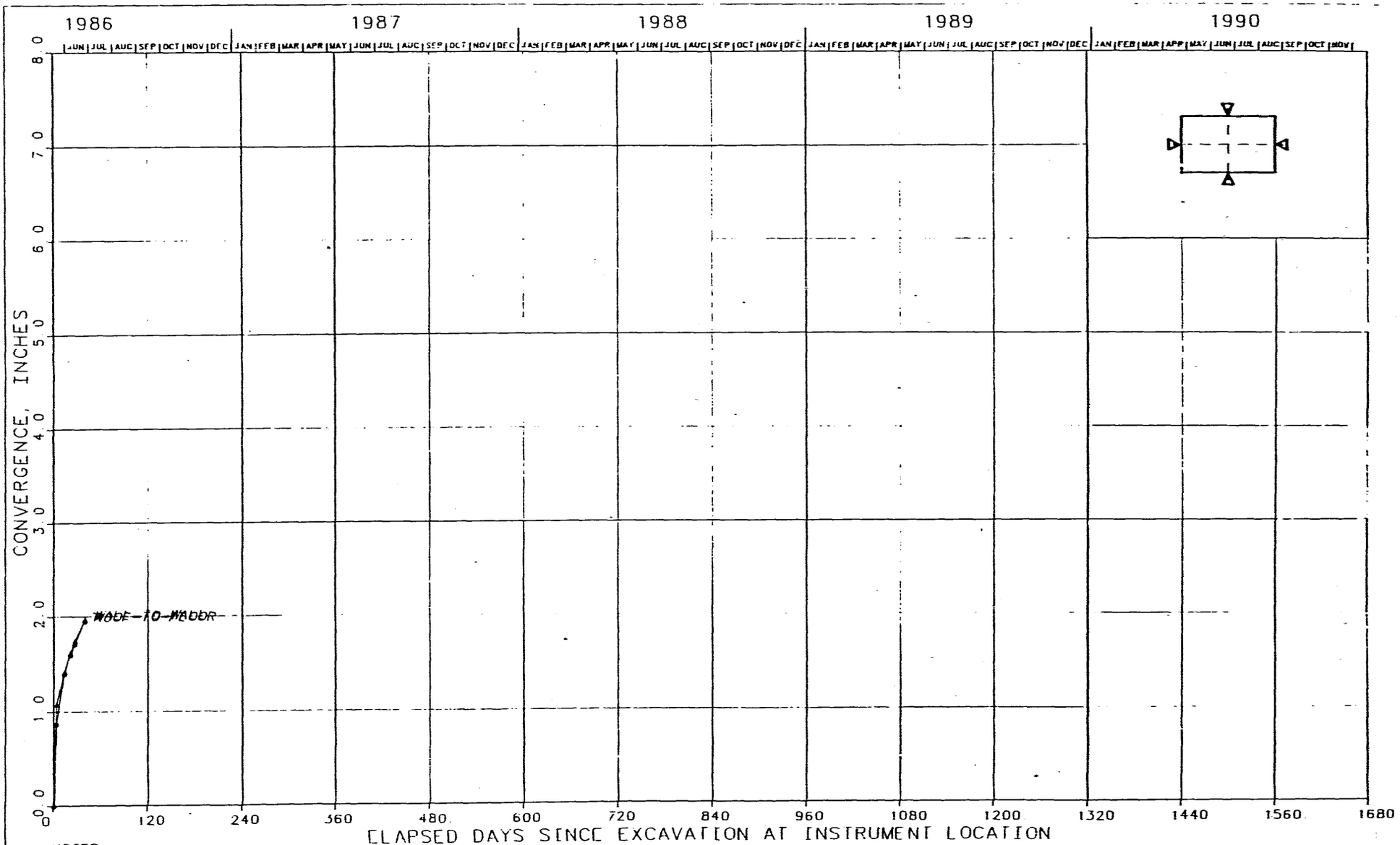
FIGURE J-307
CONVERGENCE POINTS
S1950 DRIFT, EAST 407 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1 SIZE OF EXCAVATION 12 FT X 20 FT

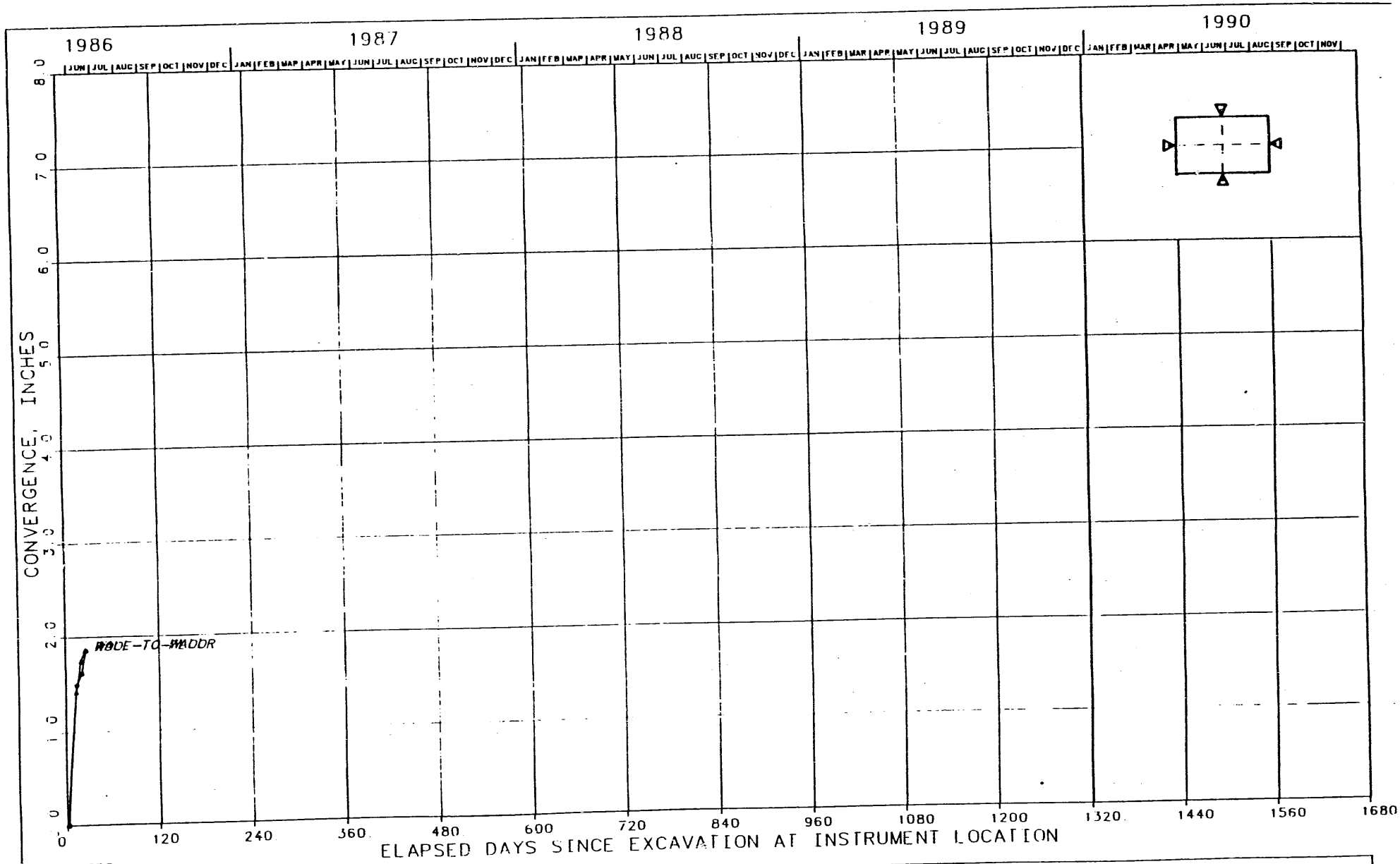
FIGURE J-308
CONVERGENCE POINTS
S1950 DRIFT, EAST 432 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION 12 FT X 20 FT

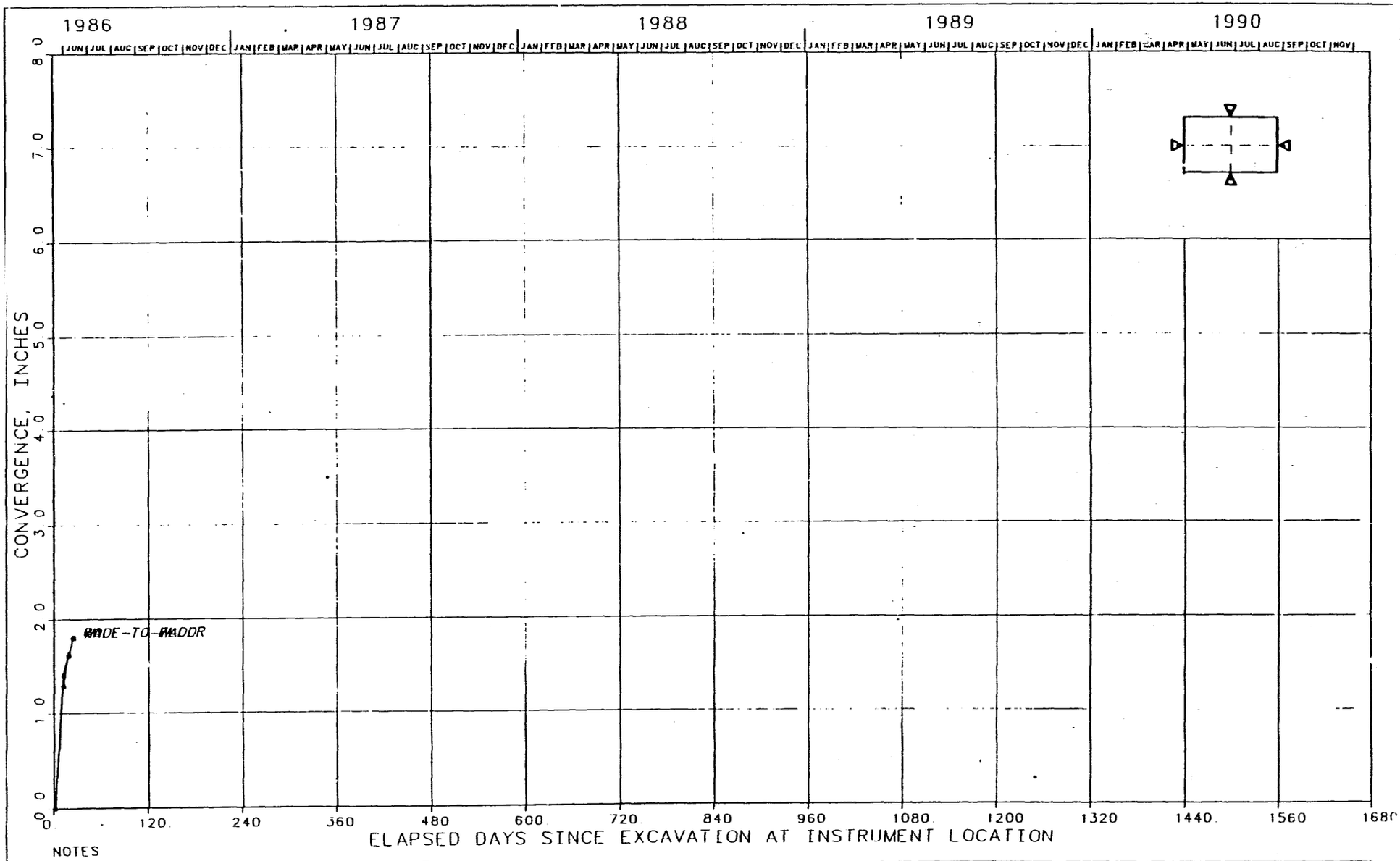
FIGURE J–309
CONVERGENCE POINTS
S1950 DRIFT, EAST 457 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1 SIZE OF EXCAVATION 12 FT X 20 FT

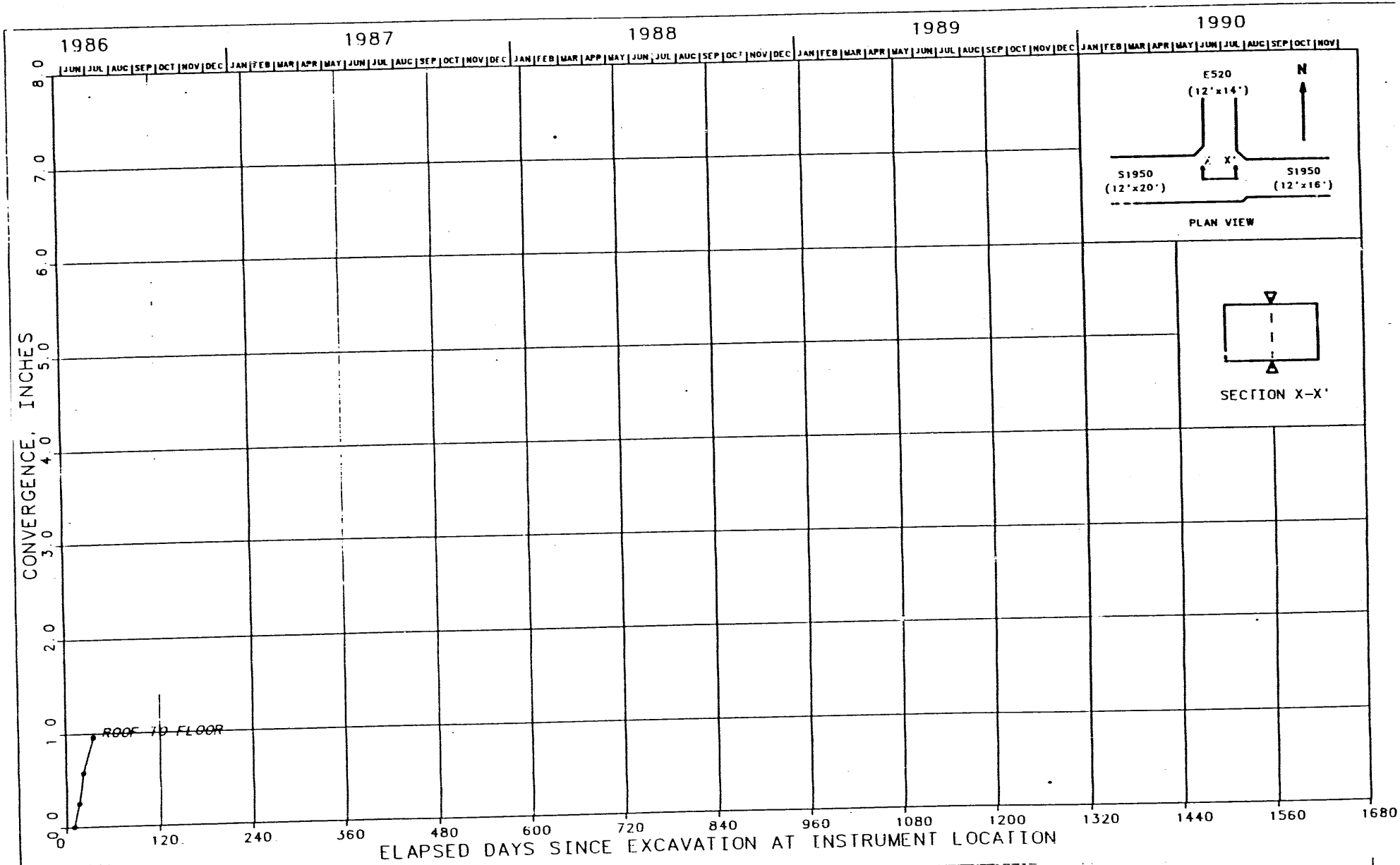
FIGURE J-310
CONVERGENCE POINTS
S1950 DRIFT, EAST 482 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION 12 FT X 20 FT

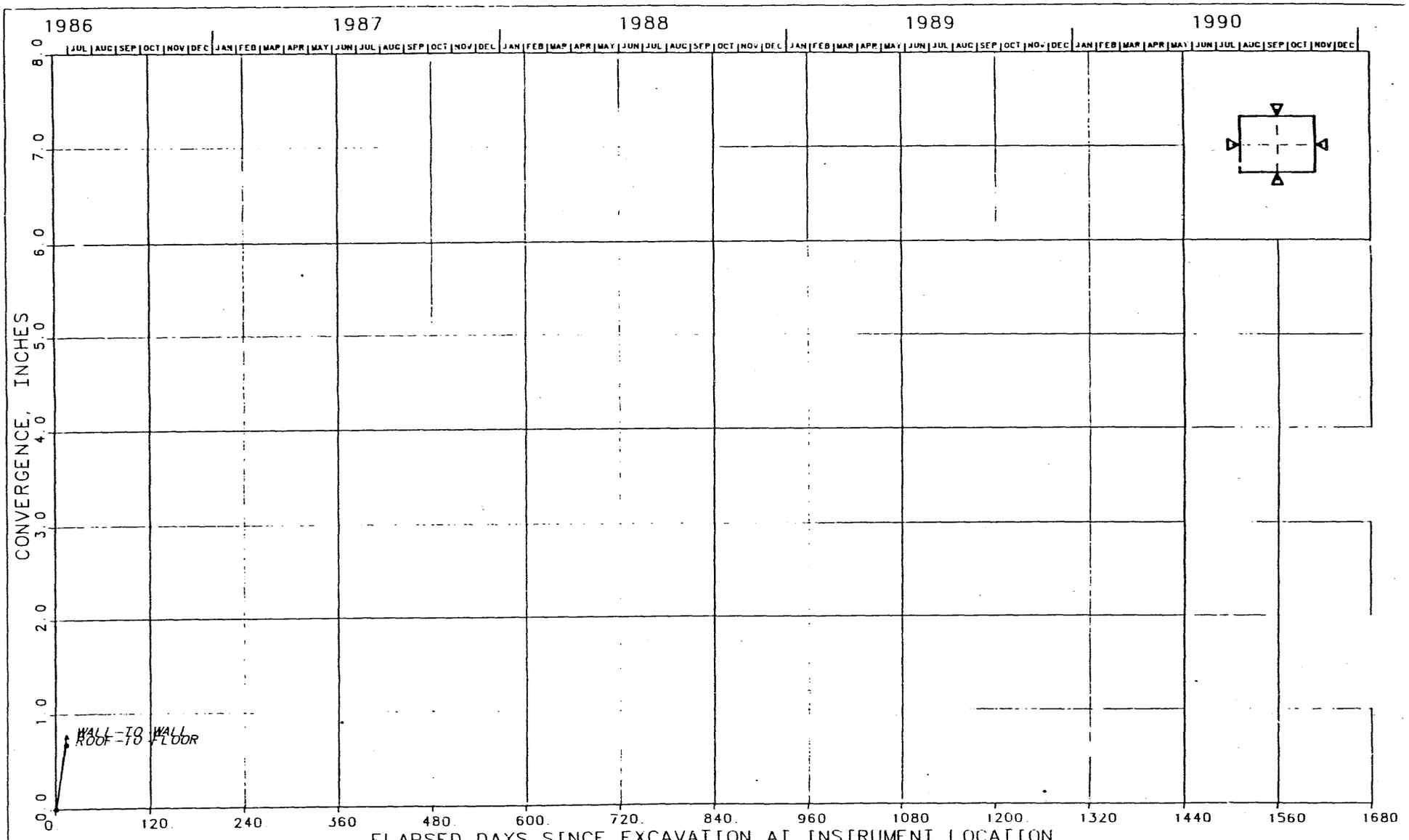
FIGURE J-311
CONVERGENCE POINTS
S1950 DRIFT, EAST 503 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1 SIZE OF EXCAVATION 12 FT X 20 FT.

FIGURE J-312
CONVERGENCE POINTS
S1950 DRIFT, EAST 523 FT
CONVERGENCE VS. TIME SINCE EXCAVATION



NOTES

1 SIZE OF EXCAVATION 12 FT X 20 FT

FIGURE J-313
CONVERGENCE POINTS
S1950 DRIFT, EAST 586 FT
CONVERGENCE VS. TIME SINCE EXCAVATION

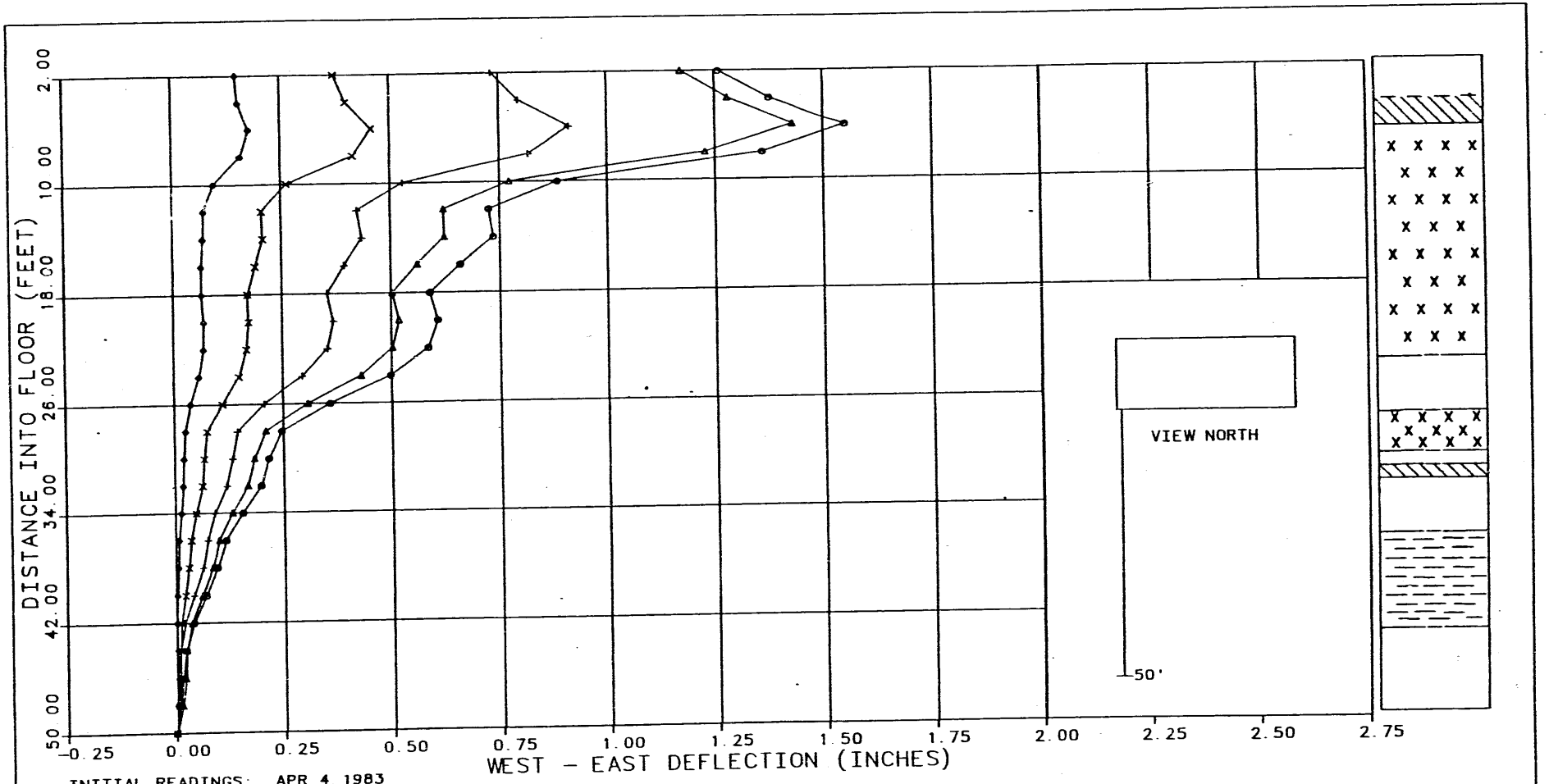


FIGURE J-314
INCLINOMETER 51X-IG-00201
TEST ROOM 2 - W FLOOR (1 FT FROM WALL)
WEST - EAST DEFLECTION

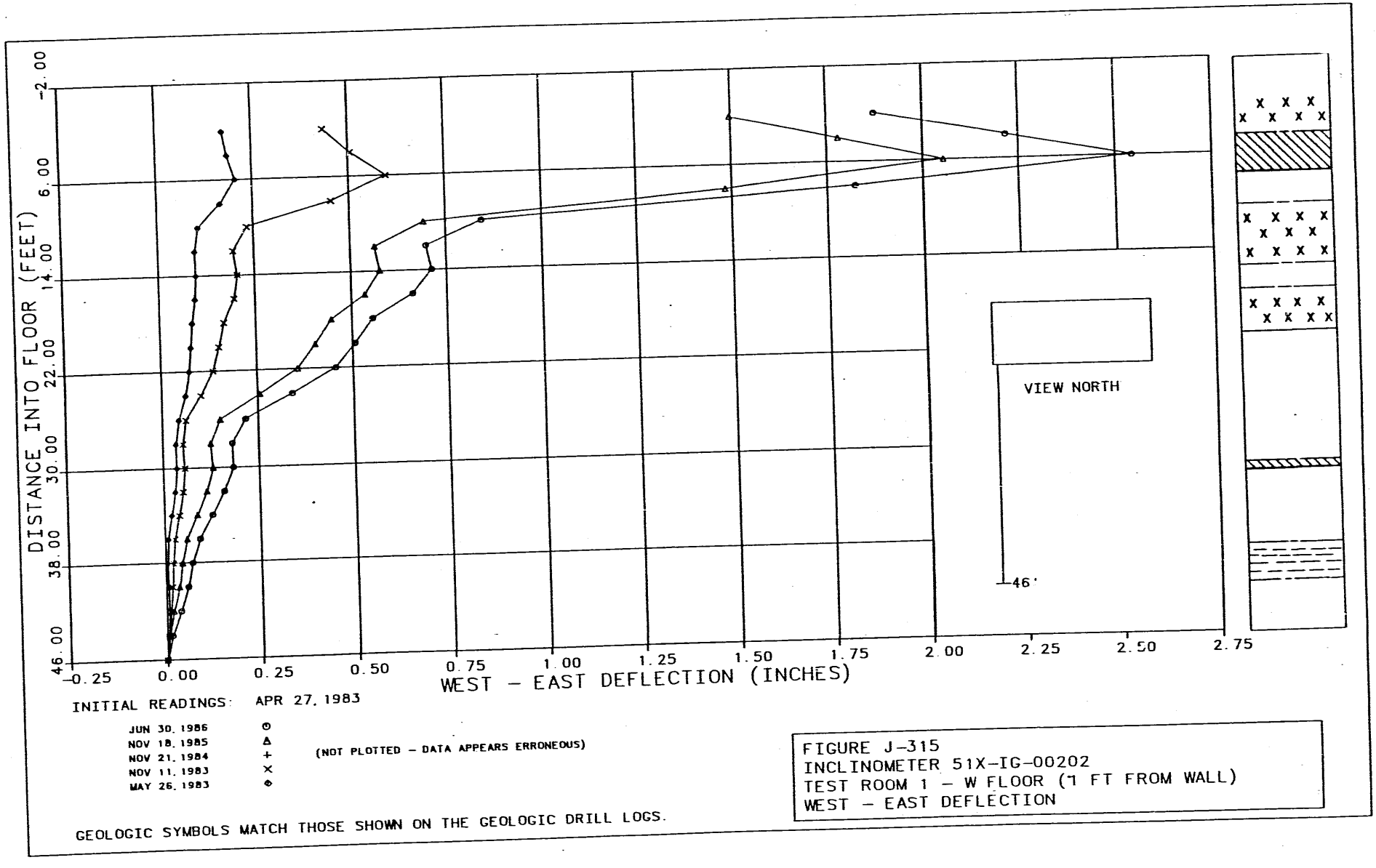


FIGURE J-315
INCLINOMETER 51X-IG-00202
TEST ROOM 1 - W FLOOR (1 FT FROM WALL)
WEST - EAST DEFLECTION

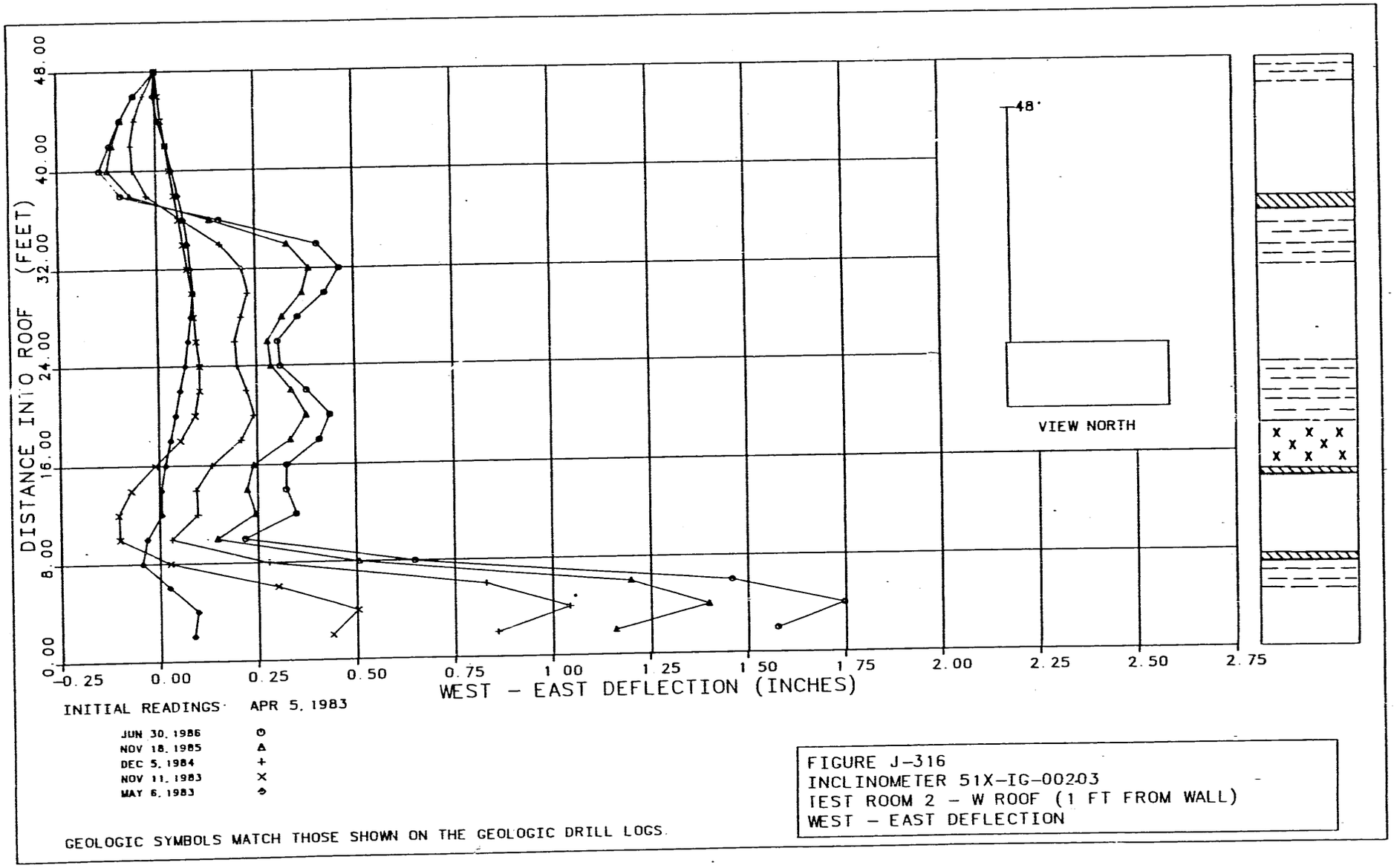


FIGURE J-316
INCLINOMETER 51X-IG-00203
TEST ROOM 2 - W ROOF (1 FT FROM WALL)
WEST - EAST DEFLECTION

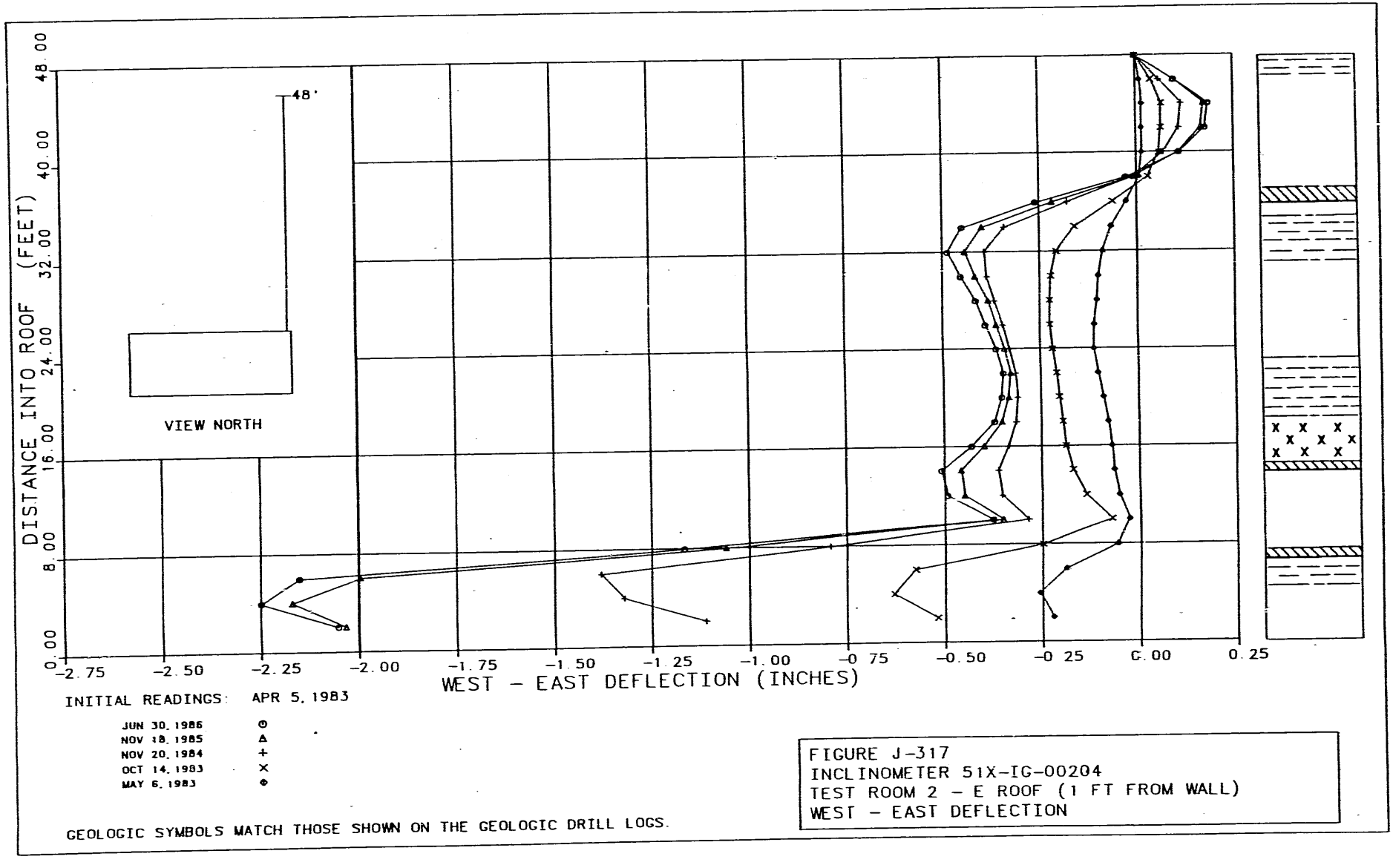


FIGURE J-317
INCLINOMETER 51X-IG-00204
TEST ROOM 2 - E ROOF (1 FT FROM WALL)
WEST - EAST DEFLECTION

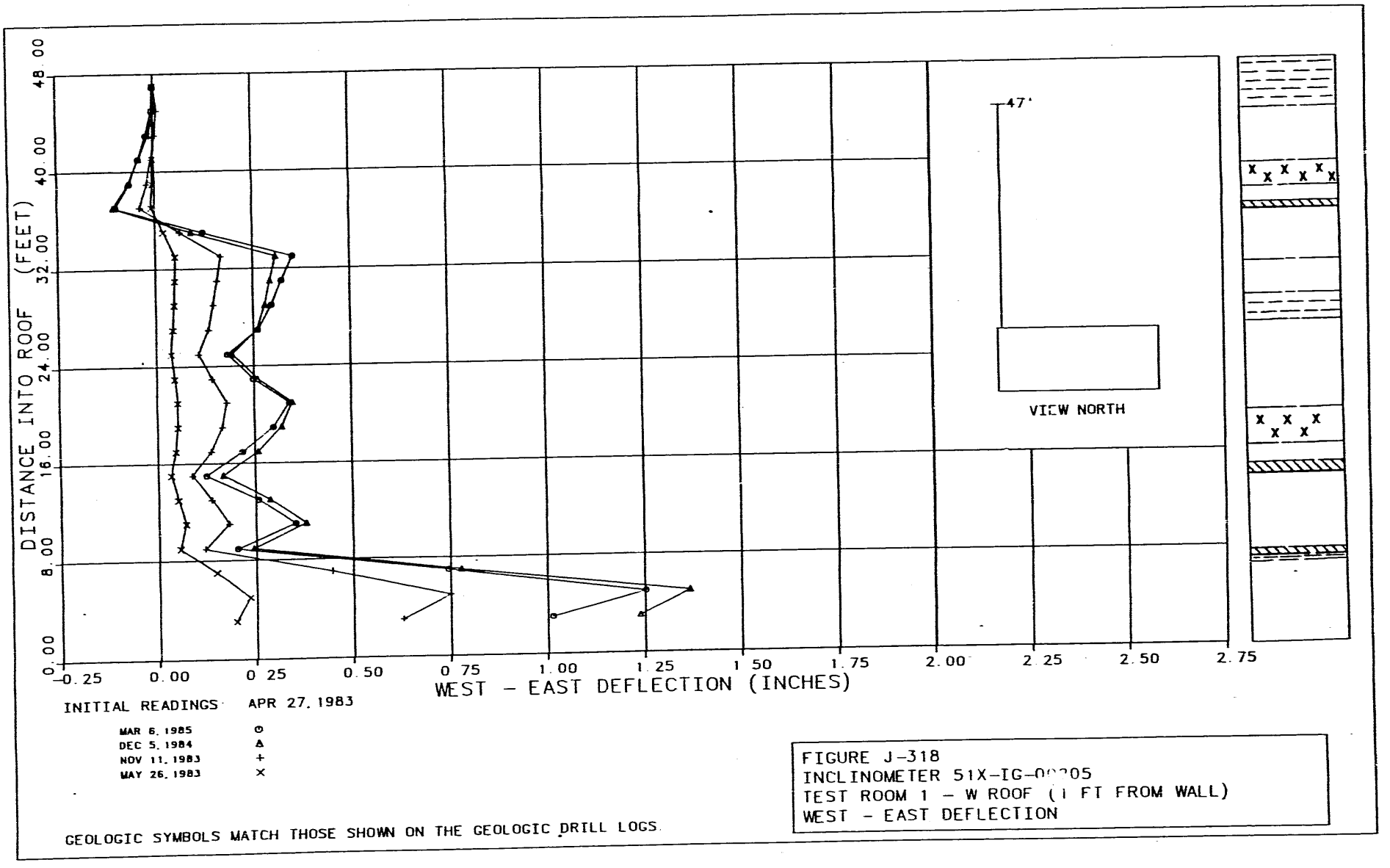


FIGURE J-318
INCLINOMETER 51X-IG-0[illegible]05
TEST ROOM 1 - W ROOF (1 FT FROM WALL)
WEST - EAST DEFLECTION

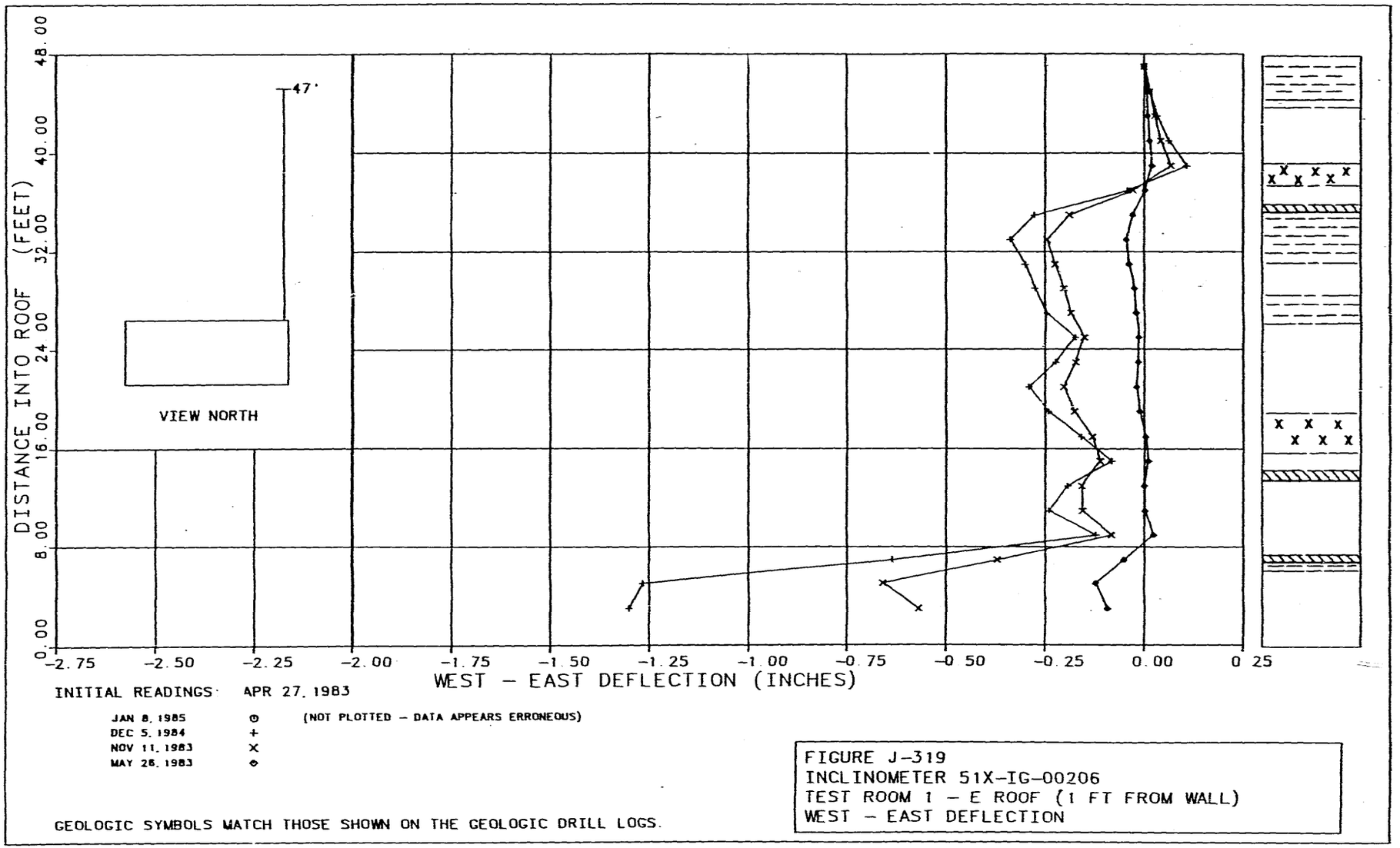


FIGURE J-319
INCLINOMETER 51X-IG-00206
TEST ROOM 1 - E ROOF (1 FT FROM WALL)
WEST - EAST DEFLECTION

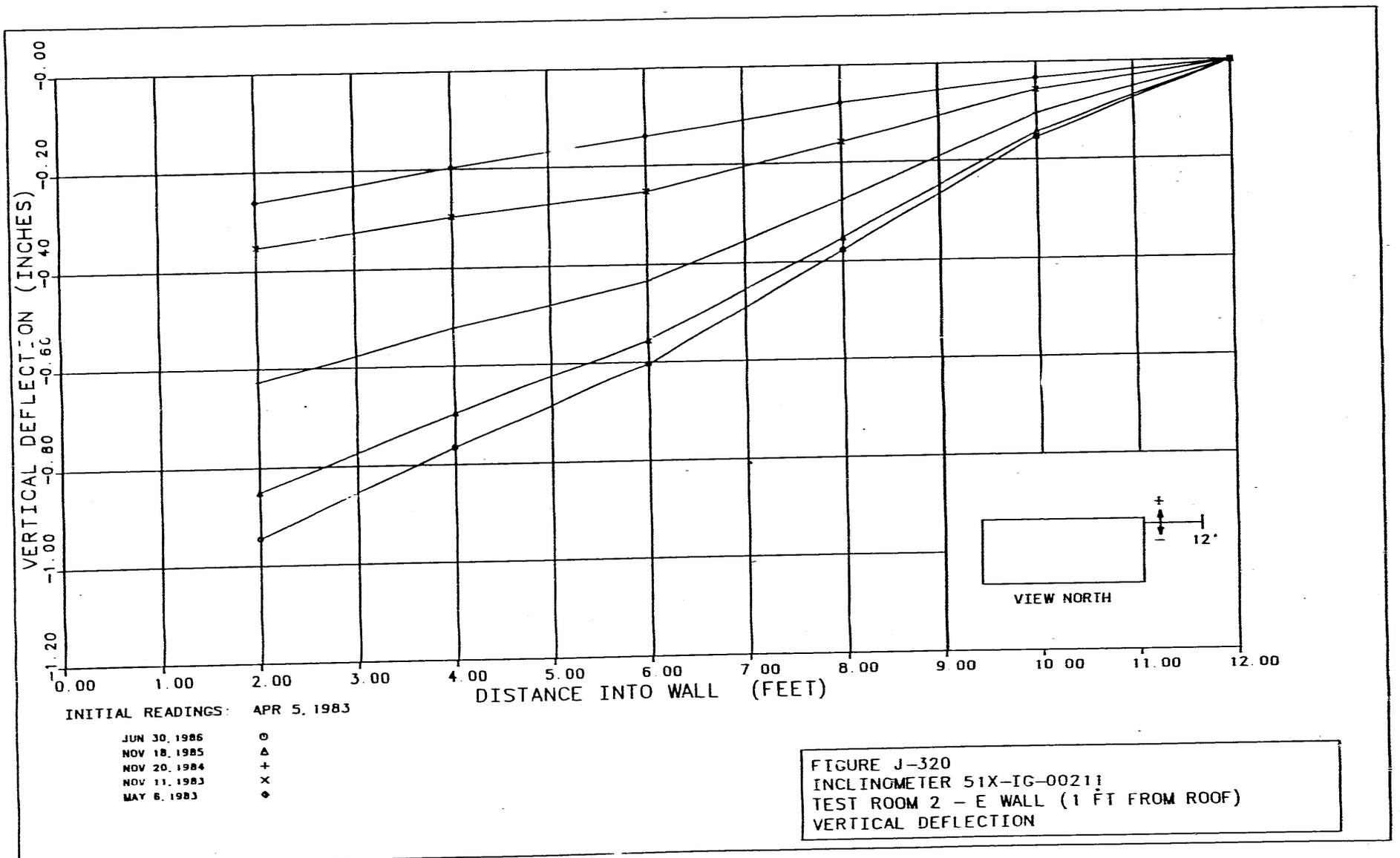


FIGURE J-320
INCLINOMETER 51X-IG-0021
TEST ROOM 2 - E WALL (1 FT FROM ROOF)
VERTICAL DEFLECTION

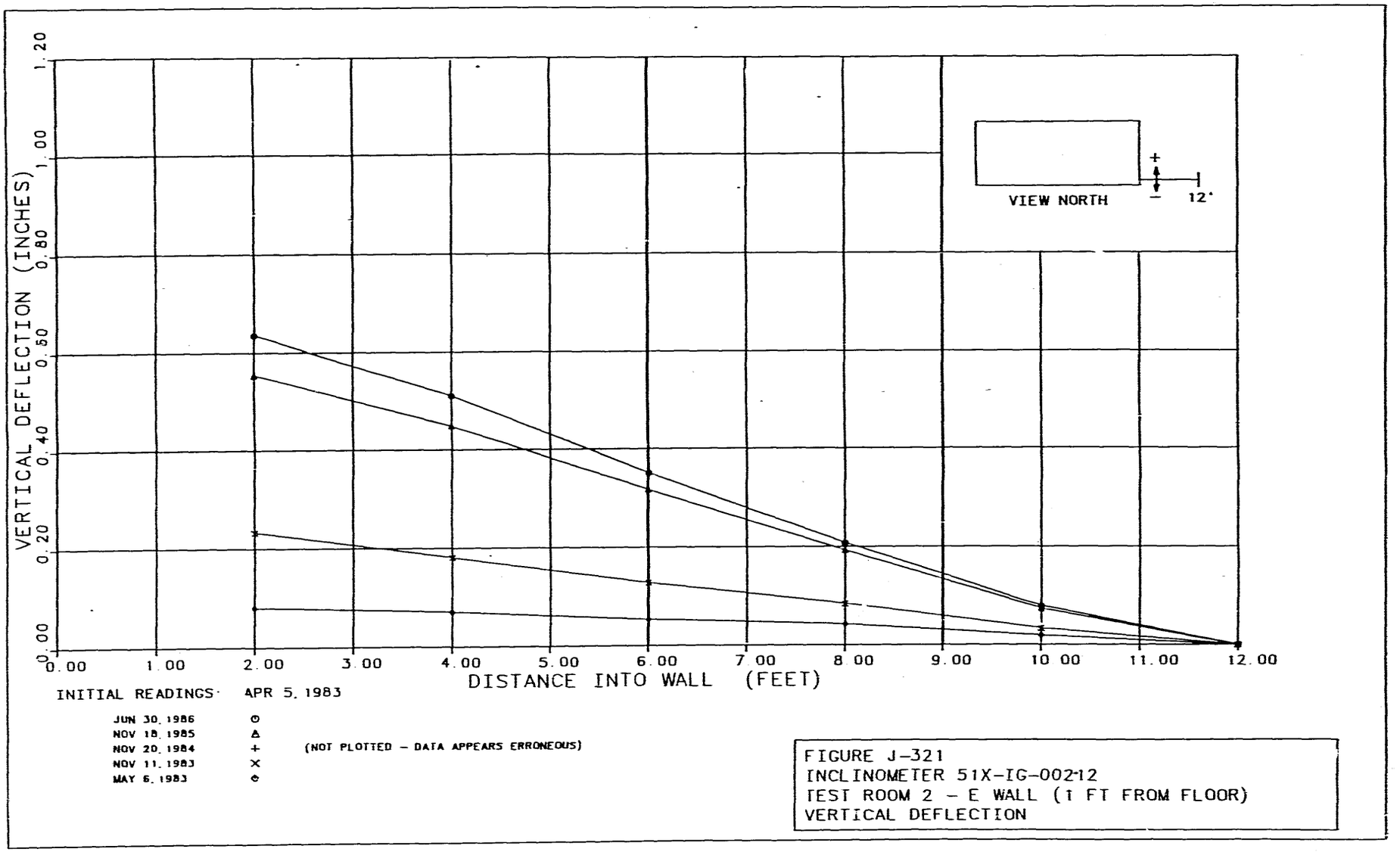


FIGURE J-321
INCLINOMETER 51X-IG-002-12
TEST ROOM 2 – E WALL (1 FT FROM FLOOR)
VERTICAL DEFLECTION

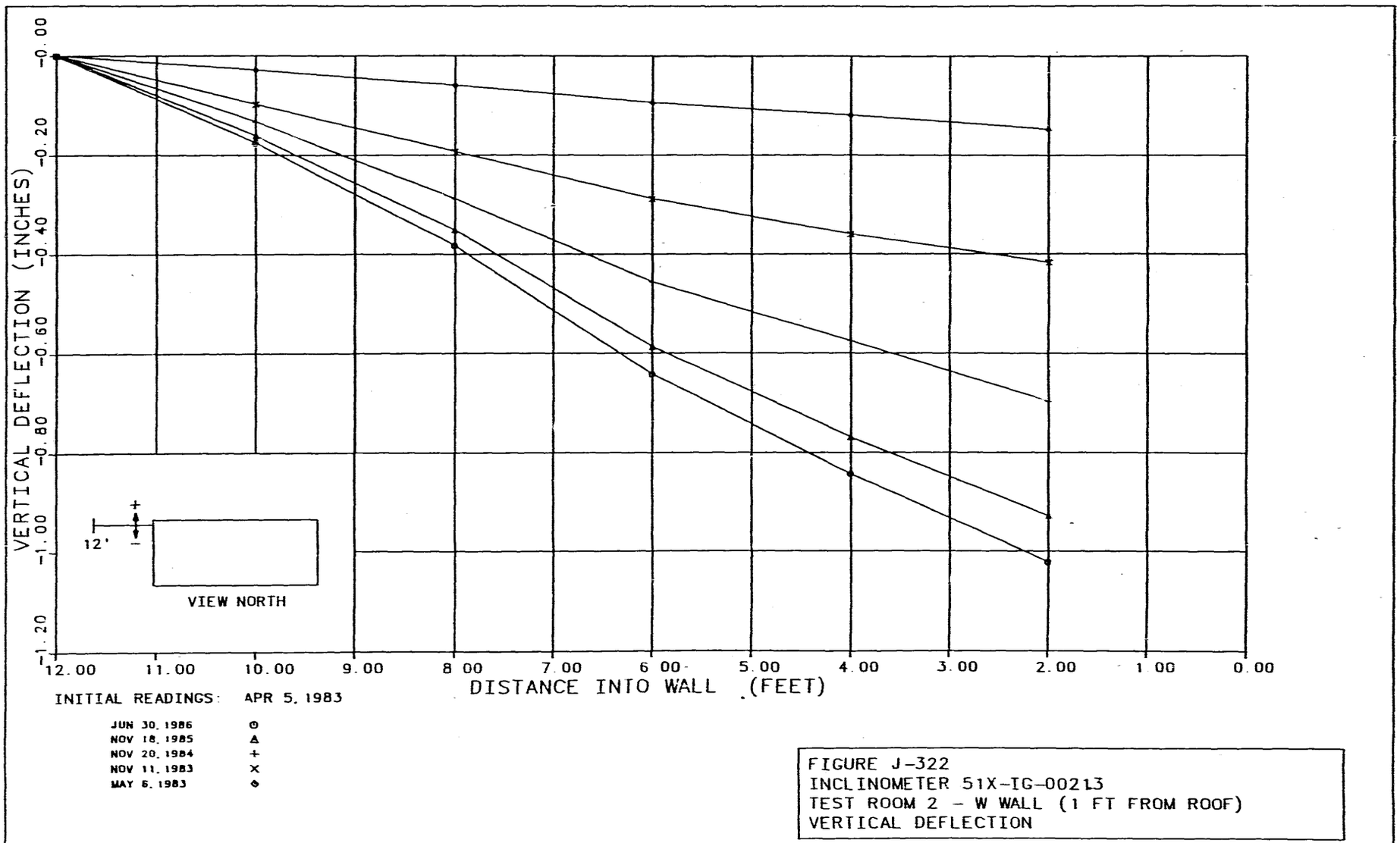


FIGURE J-322
INCLINOMETER 51X-IG-00213
TEST ROOM 2 - W WALL (1 FT FROM ROOF)
VERTICAL DEFLECTION

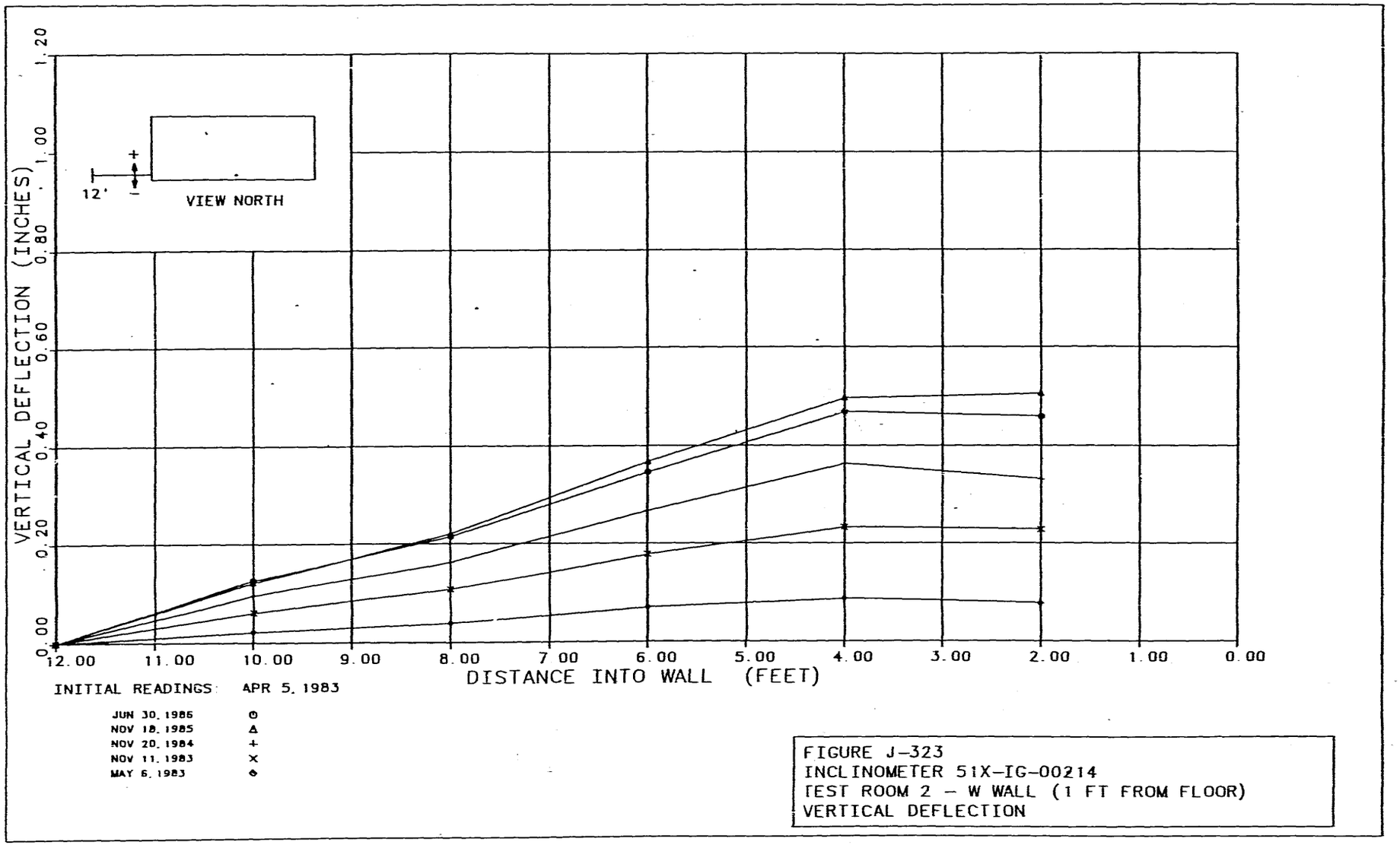


FIGURE J-323
INCLINOMETER 51X-IG-00214
TEST ROOM 2 - W WALL (1 FT FROM FLOOR)
VERTICAL DEFLECTION

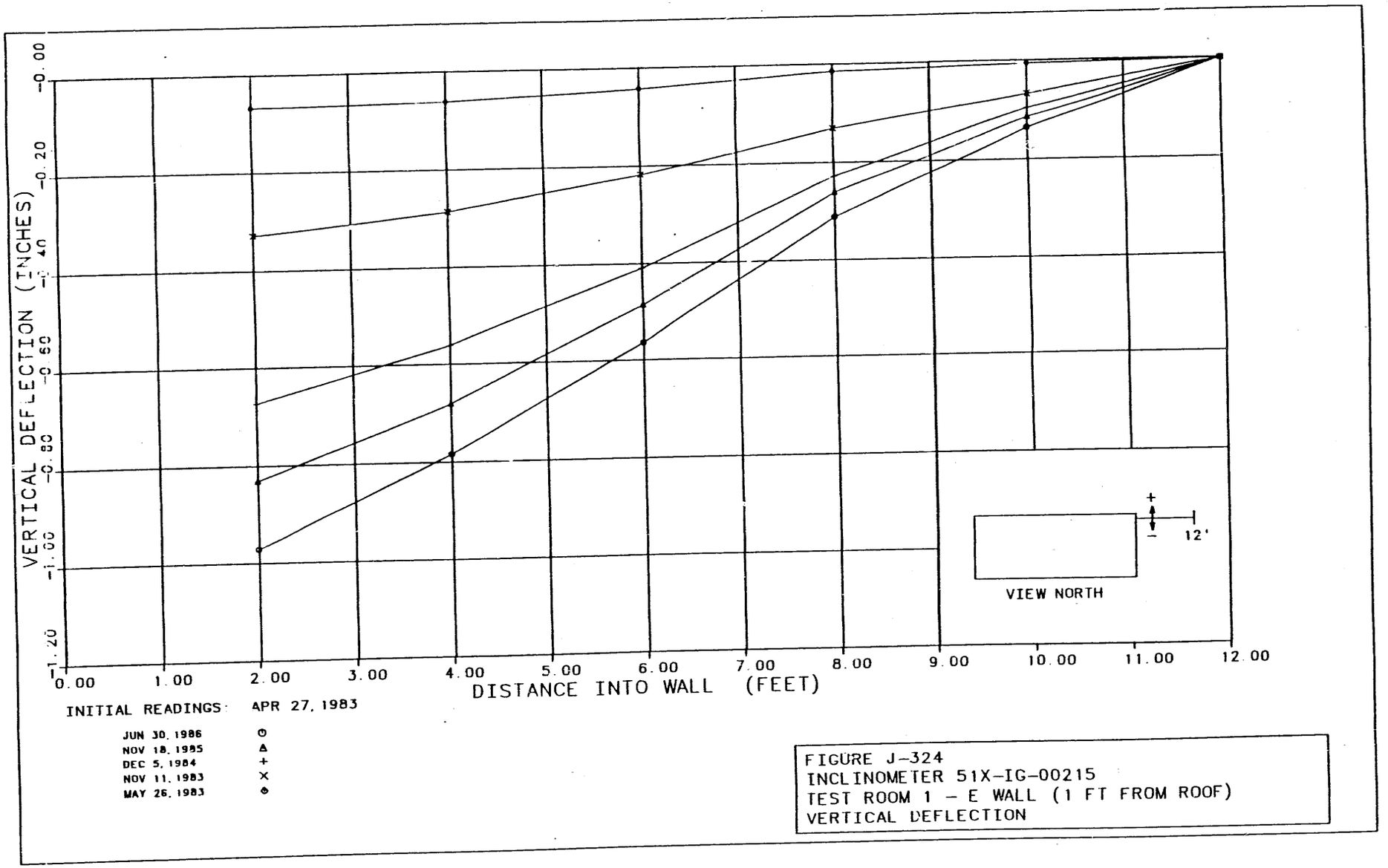


FIGURE J-324
INCLINOMETER 51X-IG-00215
TEST ROOM 1 - E WALL (1 FT FROM ROOF)
VERTICAL DEFLECTION

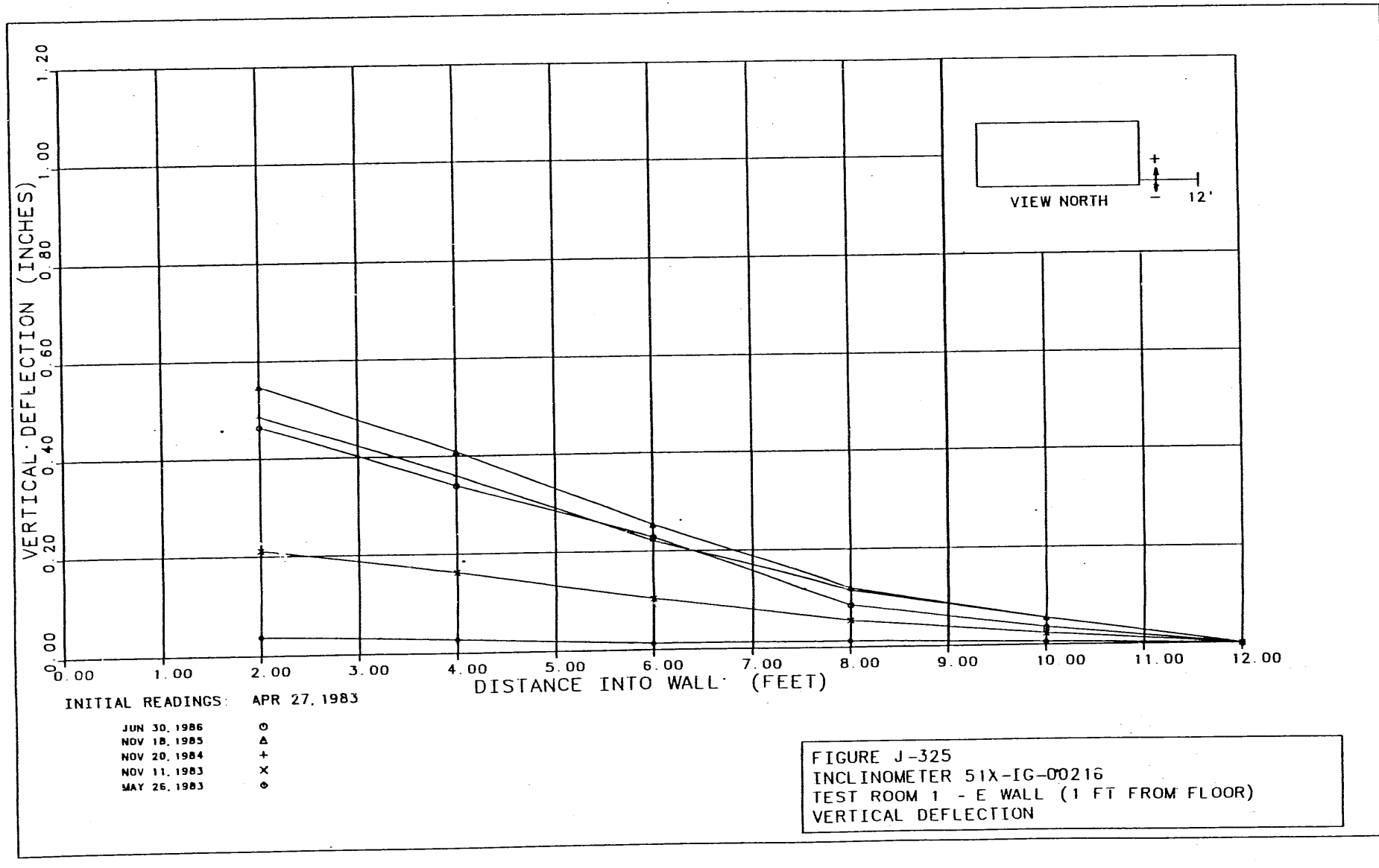


FIGURE J-325
INCLINOMETER 51X-IG-00216
TEST ROOM 1 - E WALL (1 FT FROM FLOOR)
VERTICAL DEFLECTION

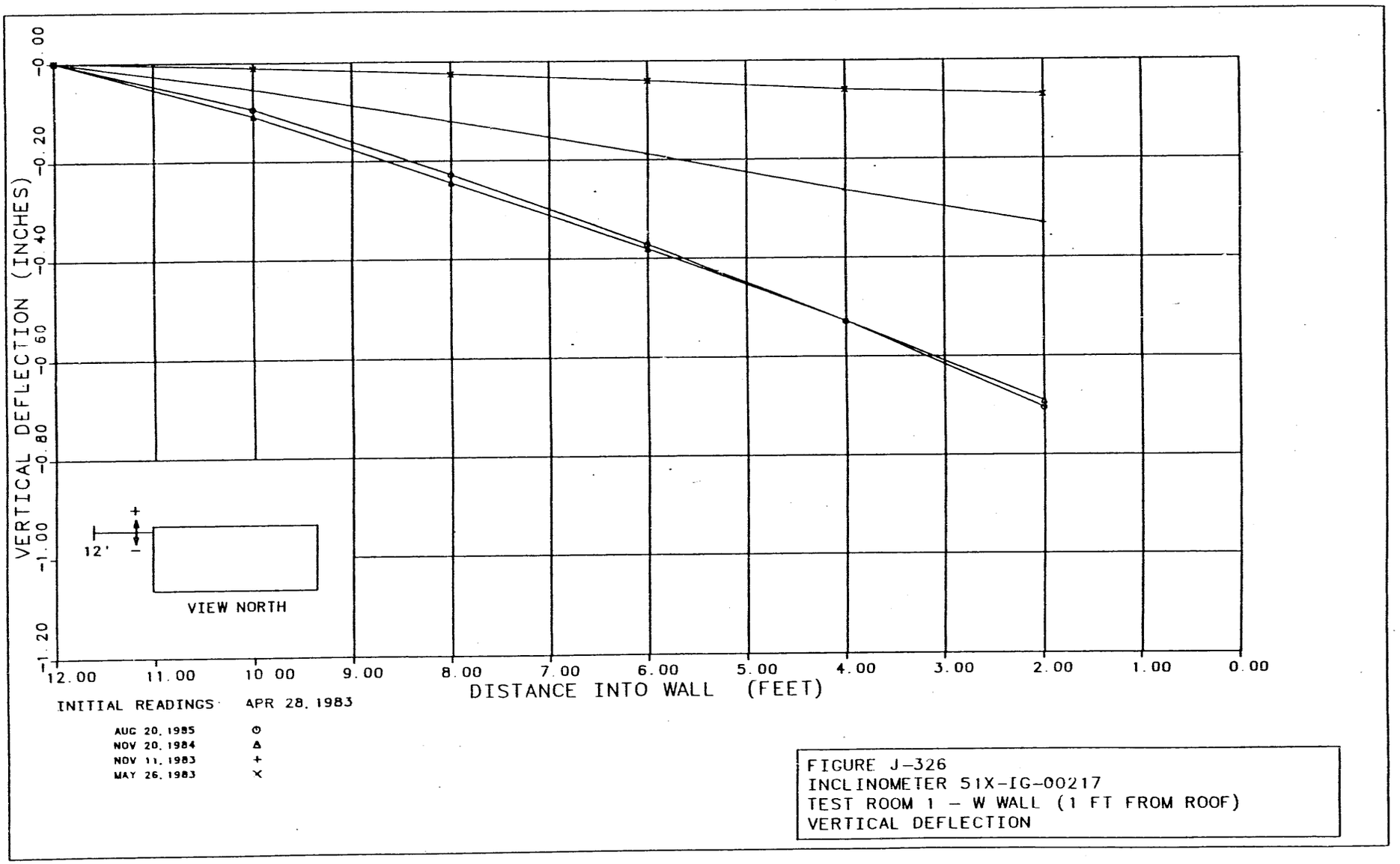


FIGURE J-326
INCLINOMETER 51X-IG-00217
TEST ROOM 1 - W WALL (1 FT FROM ROOF)
VERTICAL DEFLECTION

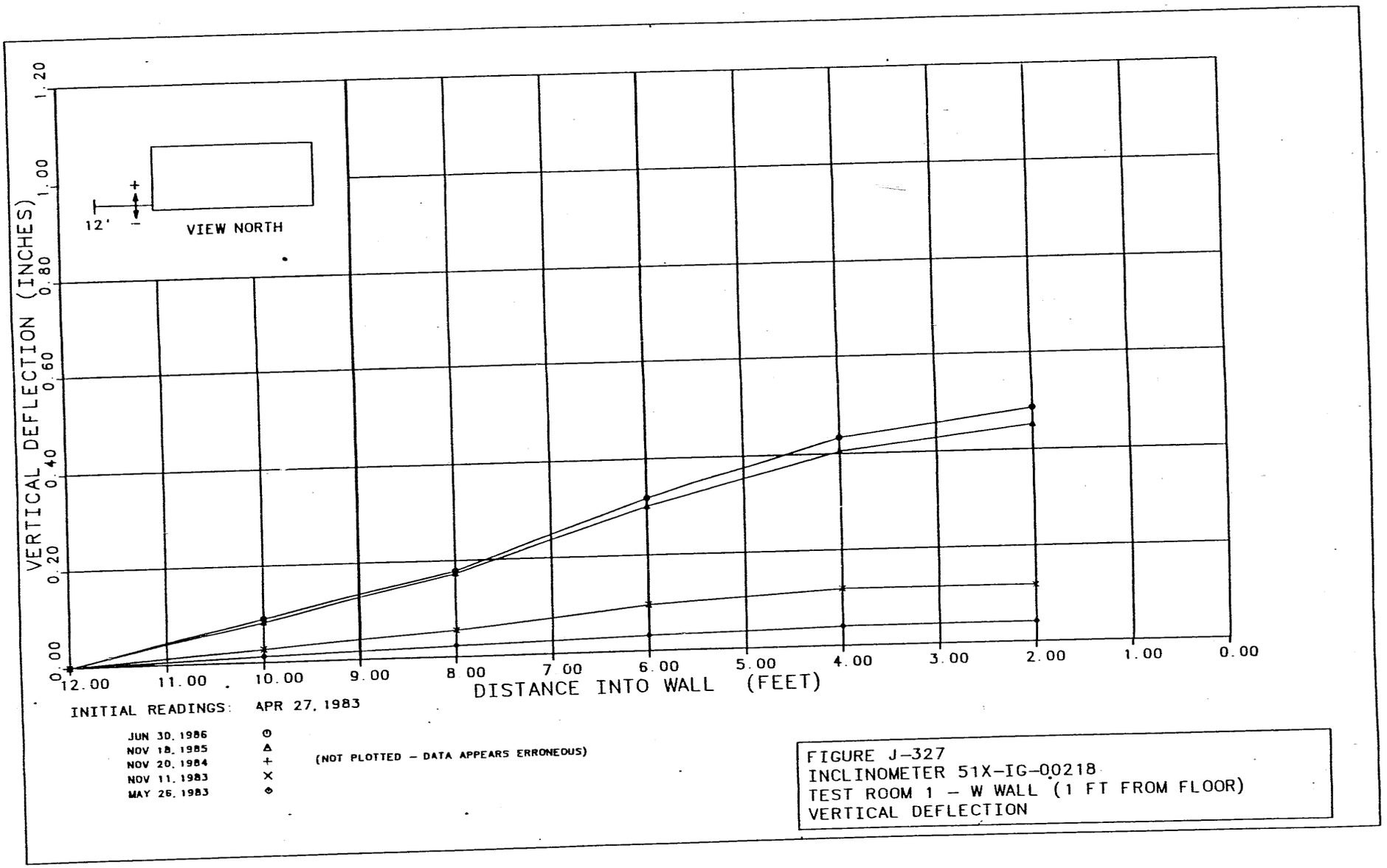


FIGURE J-327
INCLINOMETER 51X-IG-00218
TEST ROOM 1 – W WALL (1 FT FROM FLOOR)
VERTICAL DEFLECTION

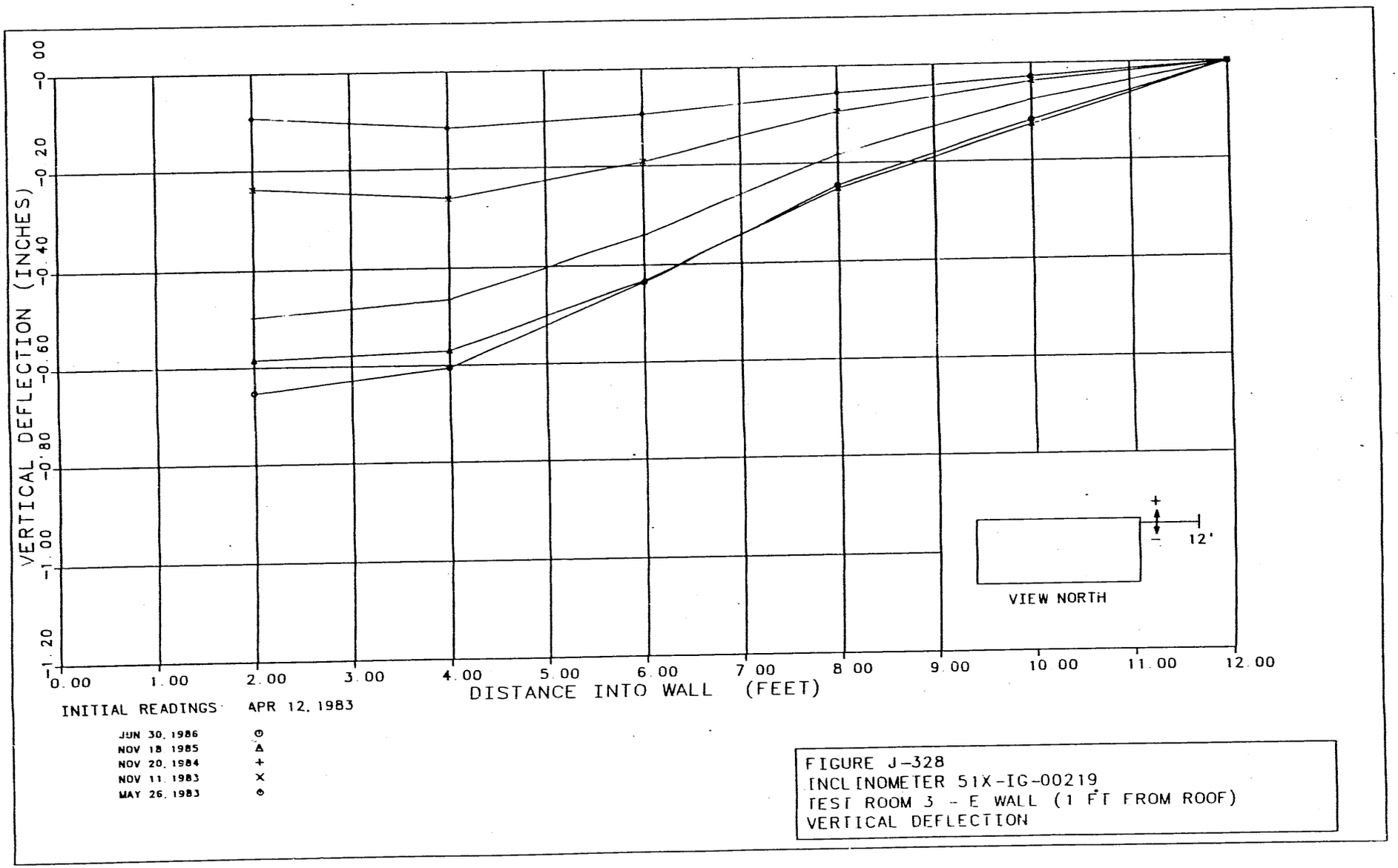


FIGURE J-328
INCLINOMETER 51X-IG-00219
TEST ROOM 3 - E WALL (1 FT FROM ROOF)
VERTICAL DEFLECTION

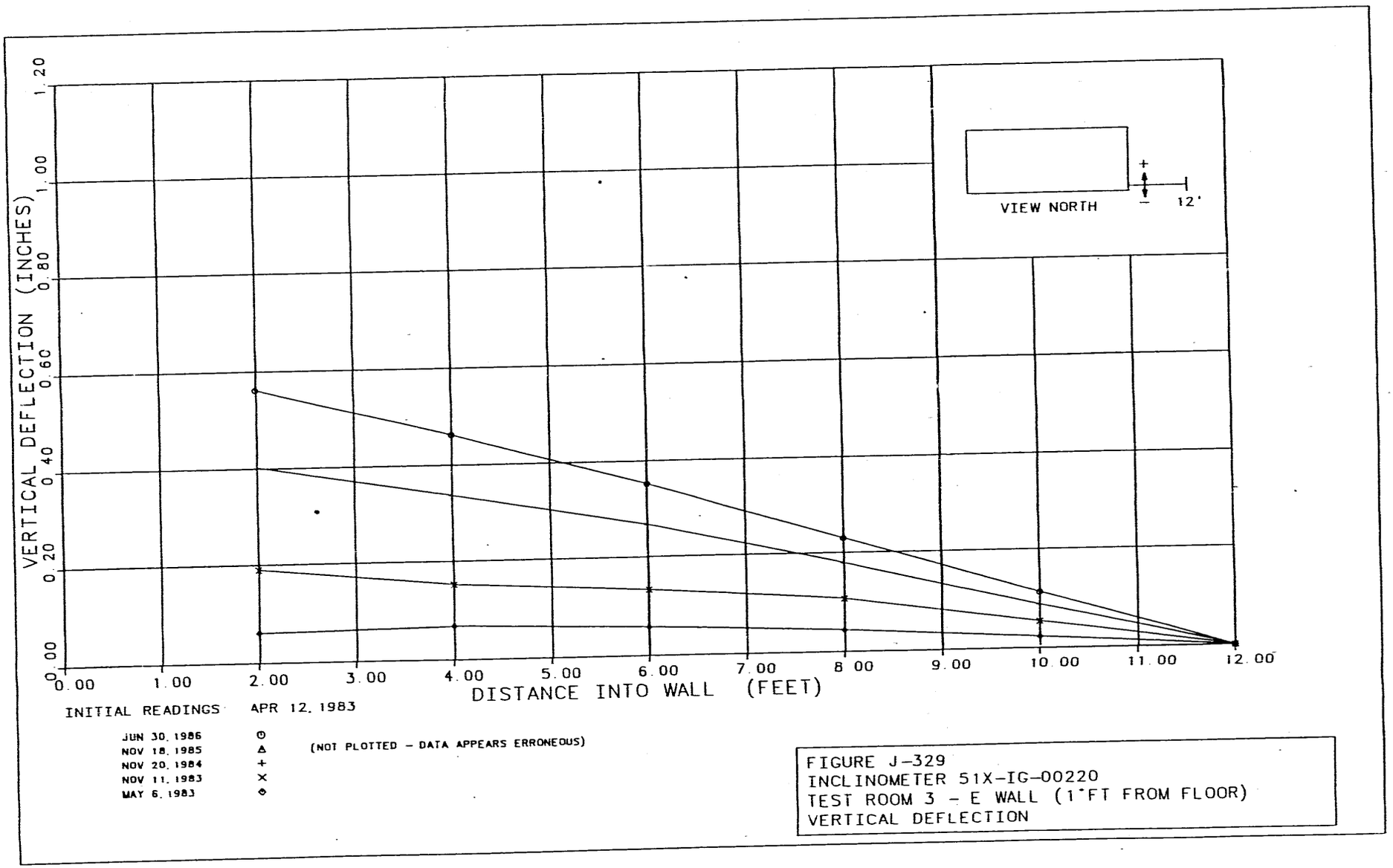


FIGURE J-329
INCLINOMETER 51X-IG-00220
TEST ROOM 3 - E WALL (1'FT FROM FLOOR)
VERTICAL DEFLECTION

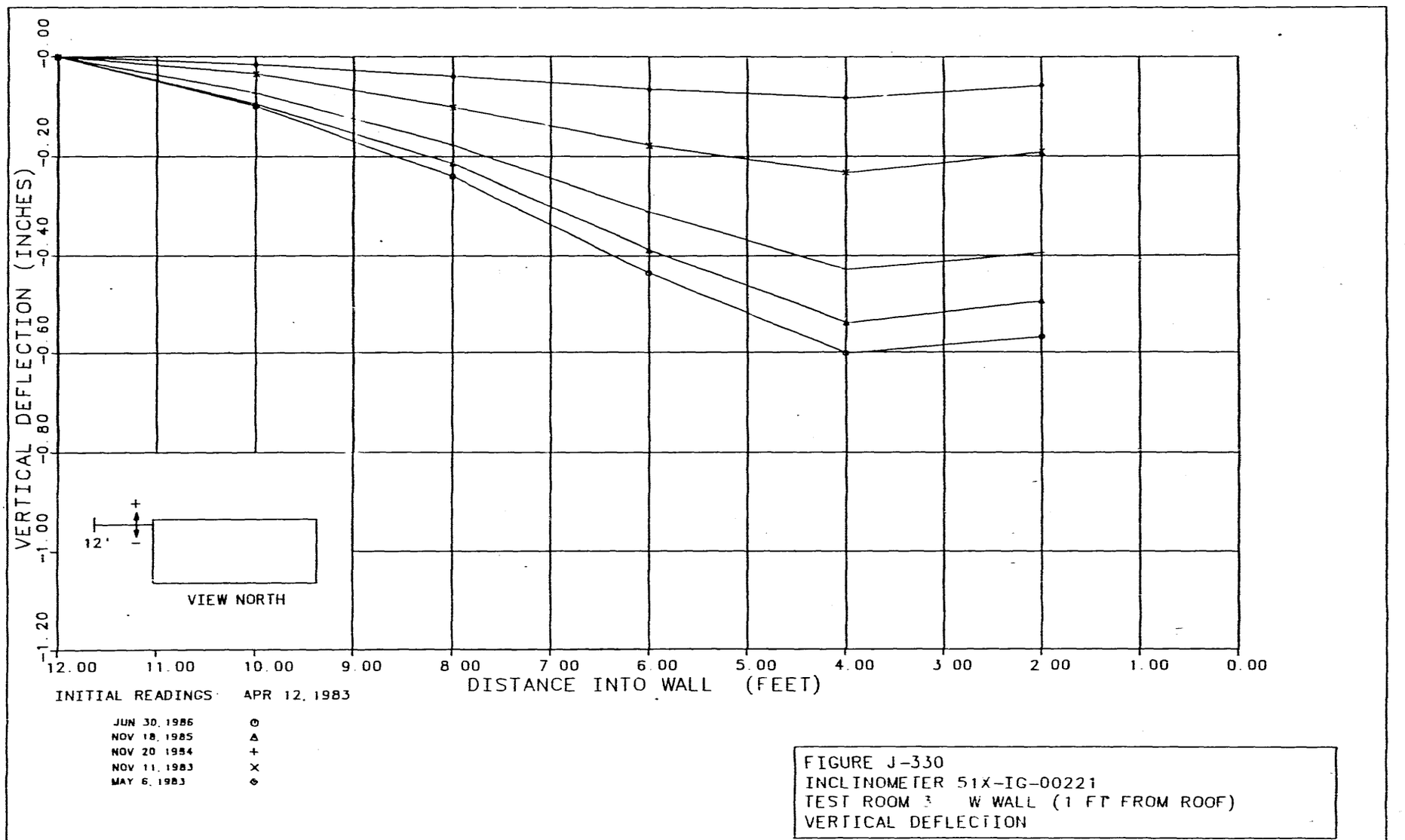


FIGURE J-330
INCLINOMETER 51X-IG-00221
TEST ROOM 3 W WALL (1 FT FROM ROOF)
VERTICAL DEFLECTION

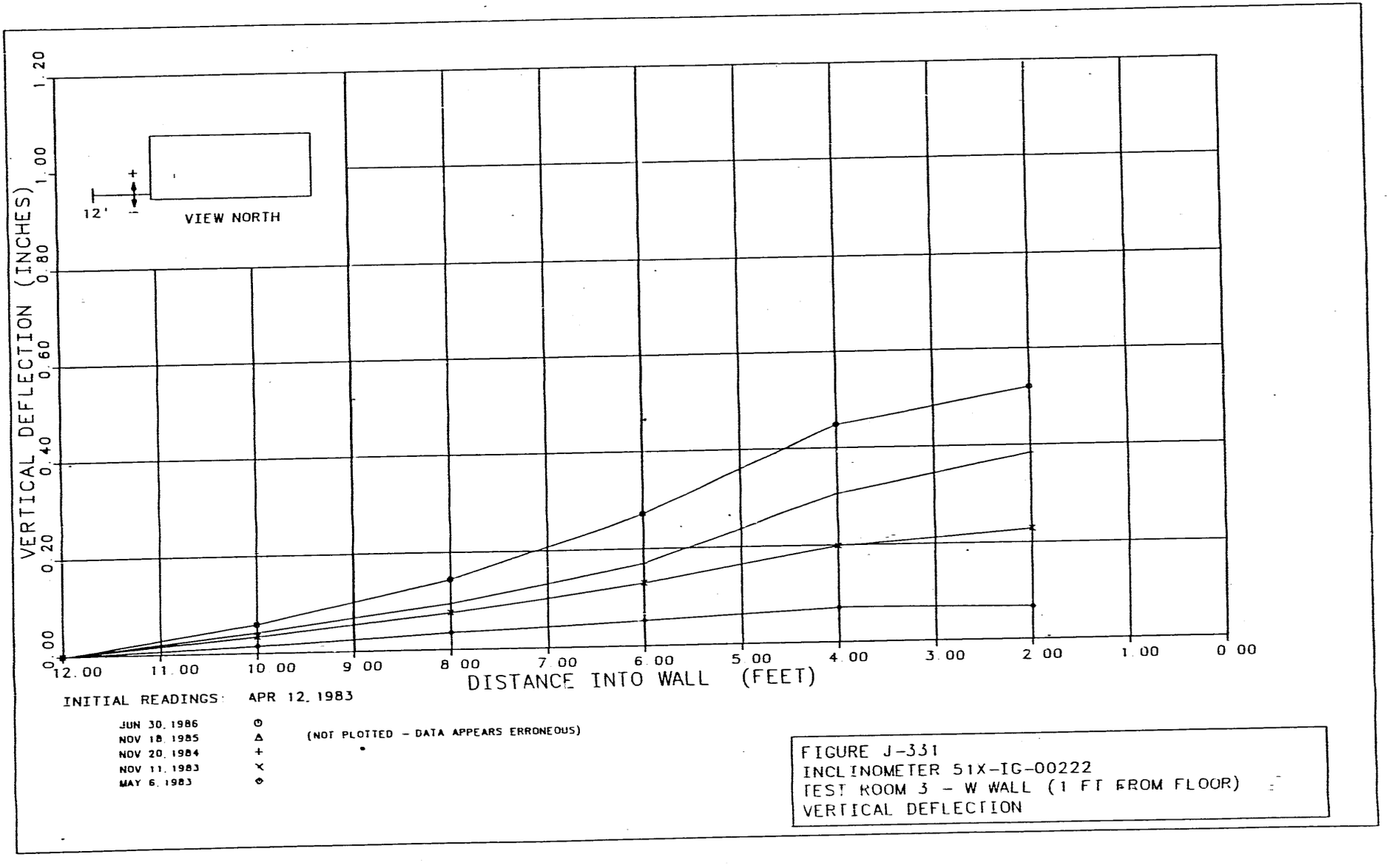


FIGURE J-331
INCLINOMETER 51X-IG-00222
TEST ROOM 3 - W WALL (1 FT FROM FLOOR)
VERTICAL DEFLECTION

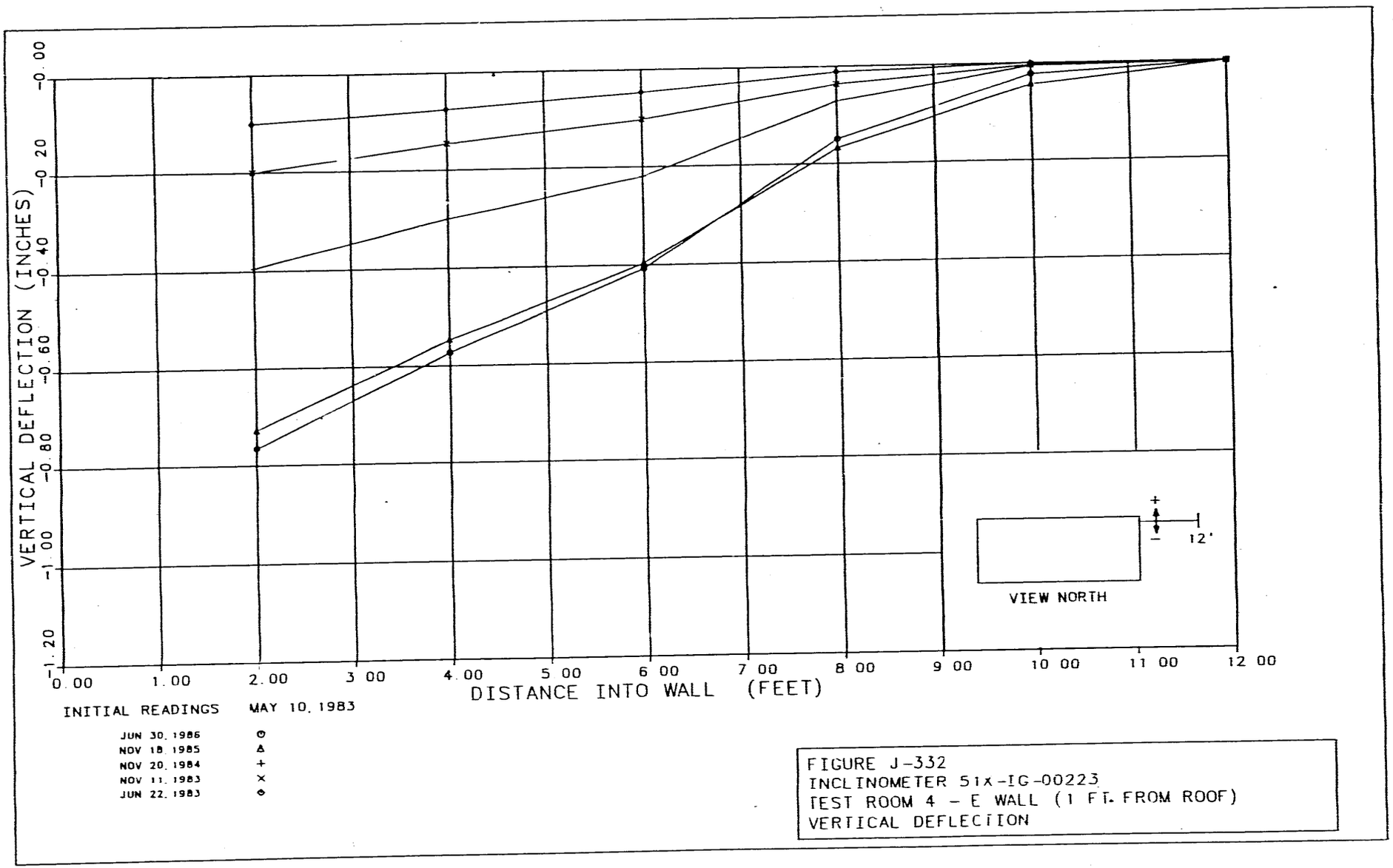


FIGURE J-332
INCLINOMETER 51X-IG-00223
TEST ROOM 4 - E WALL (1 FT. FROM ROOF)
VERTICAL DEFLECTION

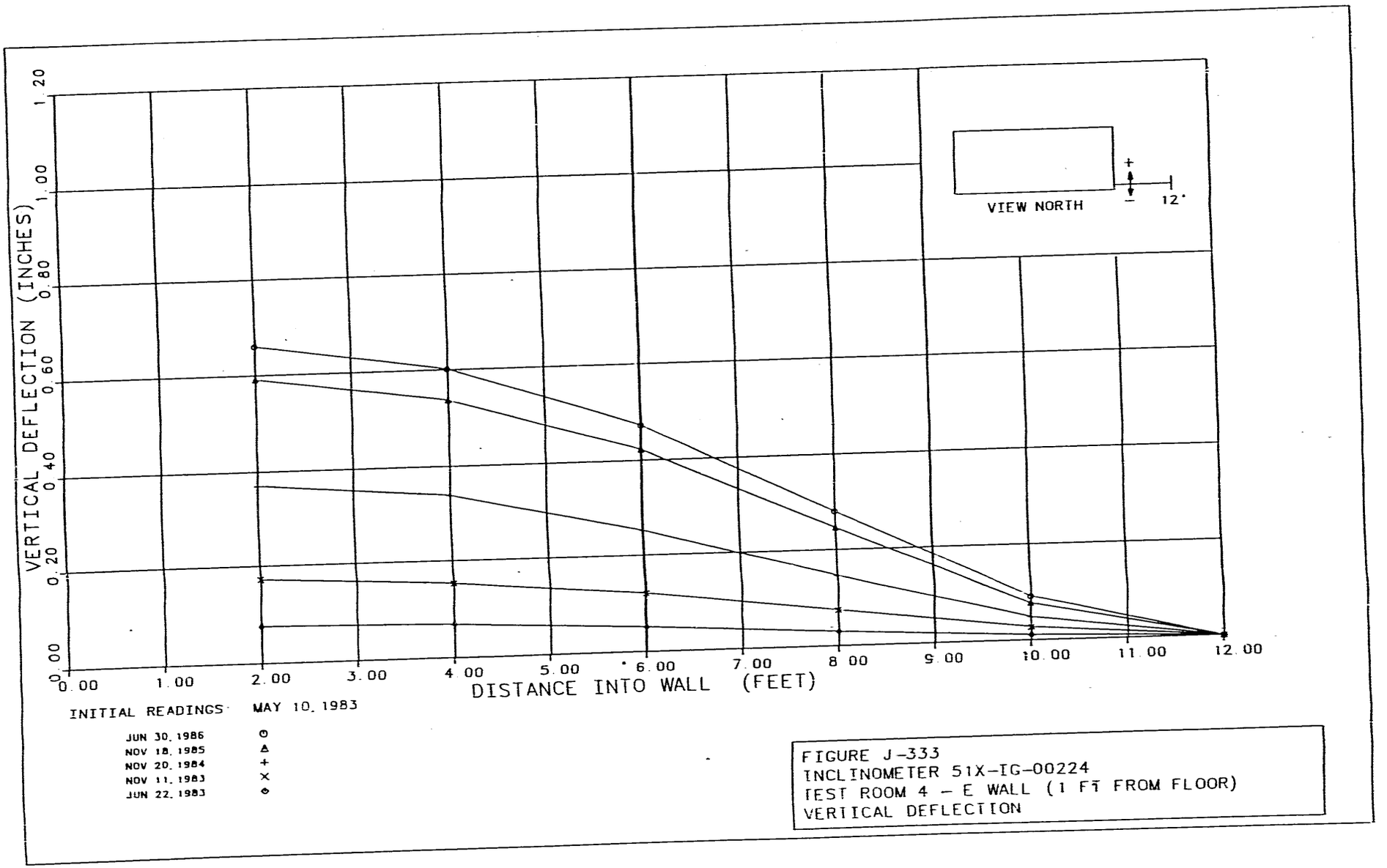


FIGURE J-333
INCLINOMETER 51X-IG-00224
TEST ROOM 4 – E WALL (1 FT FROM FLOOR)
VERTICAL DEFLECTION

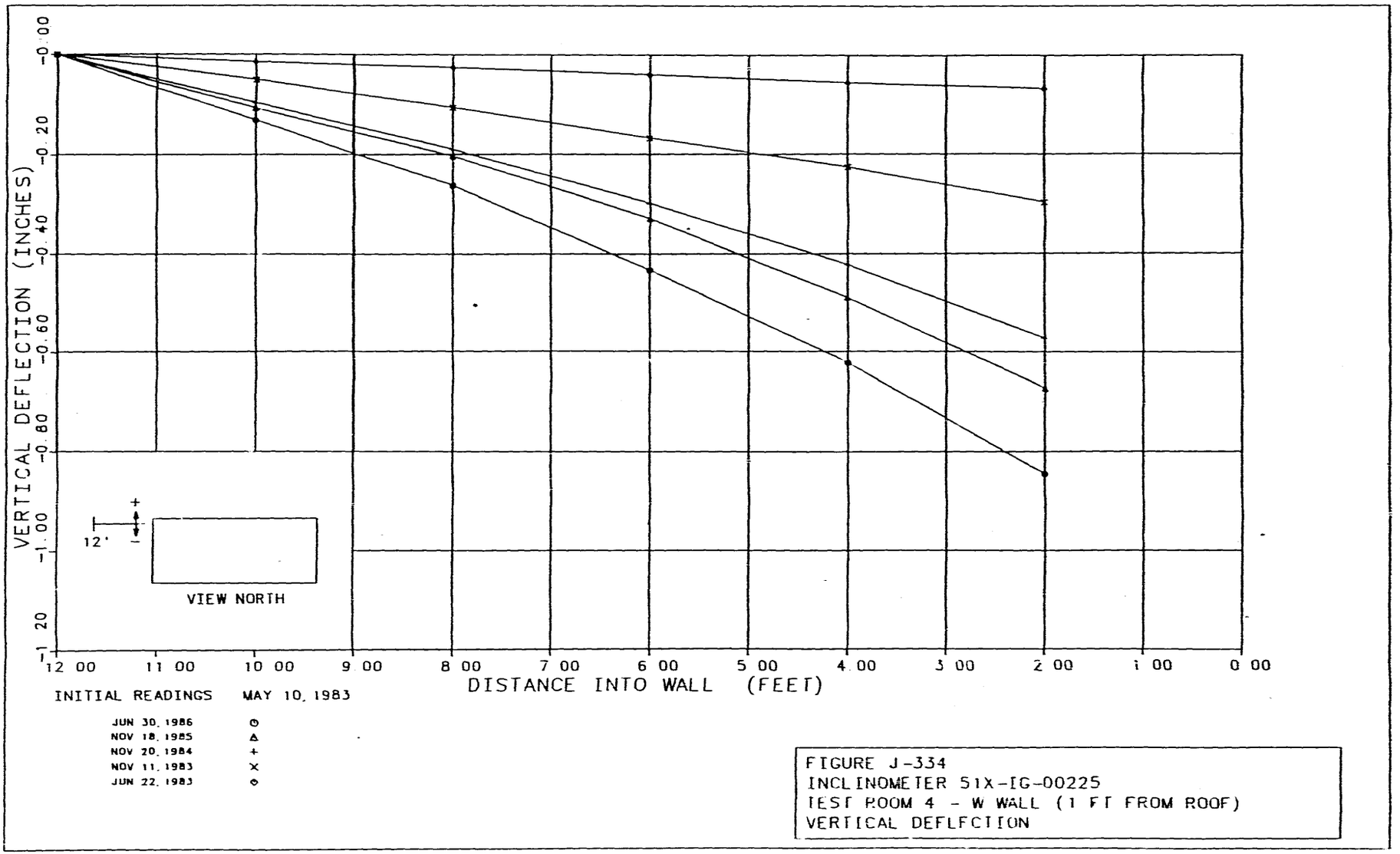


FIGURE J-334
INCLINOMETER 51X-IG-00225
TEST ROOM 4 - W WALL (1 FT FROM ROOF)
VERTICAL DEFLECTION

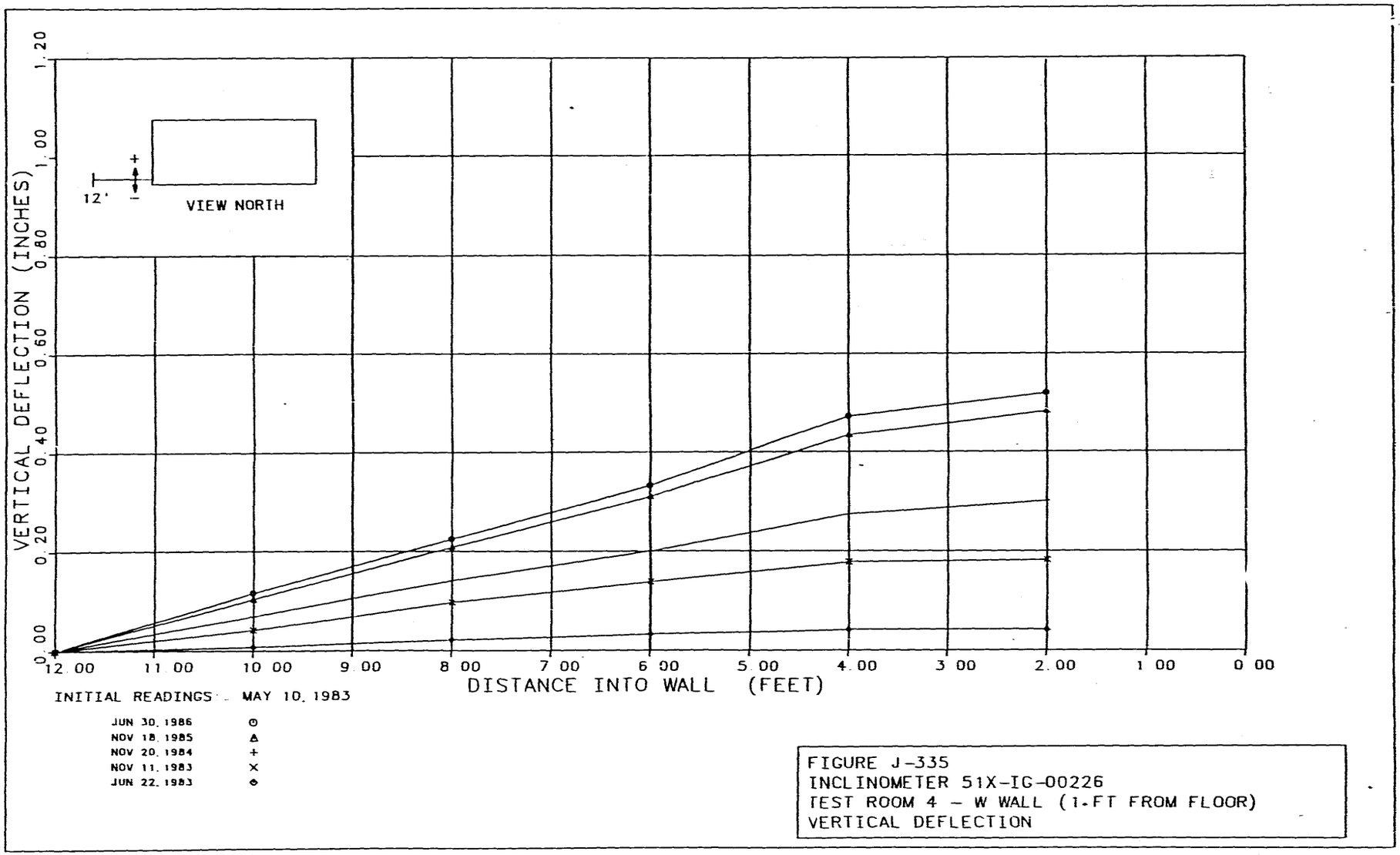


FIGURE J-335
INCLINOMETER 51X-IG-00226
TEST ROOM 4 - W WALL (1-FT FROM FLOOR)
VERTICAL DEFLECTION

APPENDIX K

ANALYTICAL DATA PLOTS

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Figure No.	Title/Description
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K-2	E140/S550
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K-4	E140/S1150
K-5	E140/S1246
K-6	E140/S1450
K-7	E140/S1879
K-8	E0/N290
K-9	E0/N626
K-10	E0/N940
K-11	E0/N1266
K-12	E140/N5
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K-14	E140/N626
K-15	E140/N1266
K-16	Test Room 1
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	Strain Versus Time Since Excavation
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K-27	Floor Extensometer 51X-GE-00250 - E140/S3045
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K-33	Floor Extensometer 51X-GE-00248 - E140/S1950
K-34	Floor Extensometer 51X-GE-00250 - E140/S3045
K-35	Roof Extensometer 51X-GE-00249 - E140/S3080

Figure No.	Title/Description
Strain Versus Time Since Excavation	
K-36	Test Room Roof Extensometers - Collar to Anchor A
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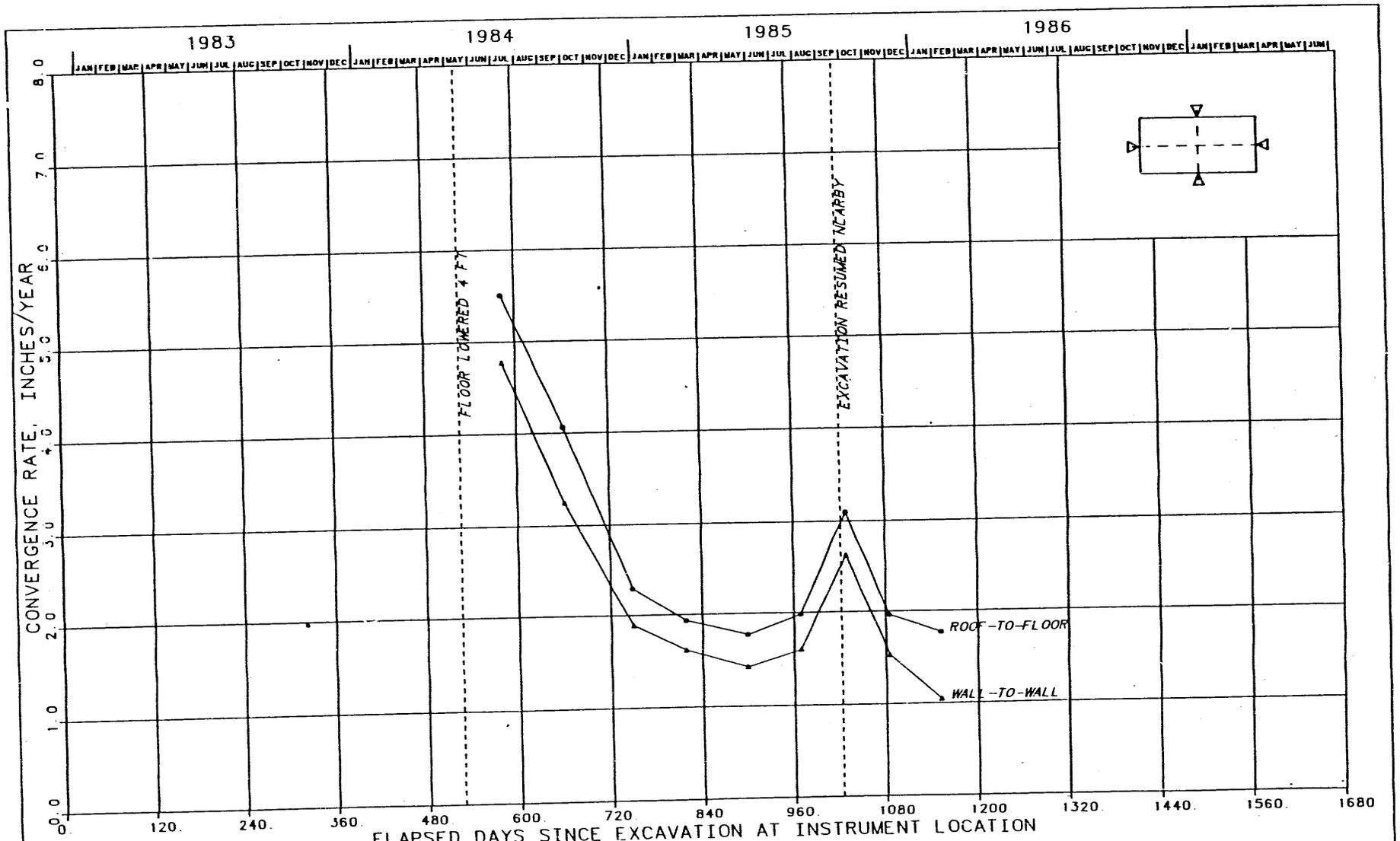
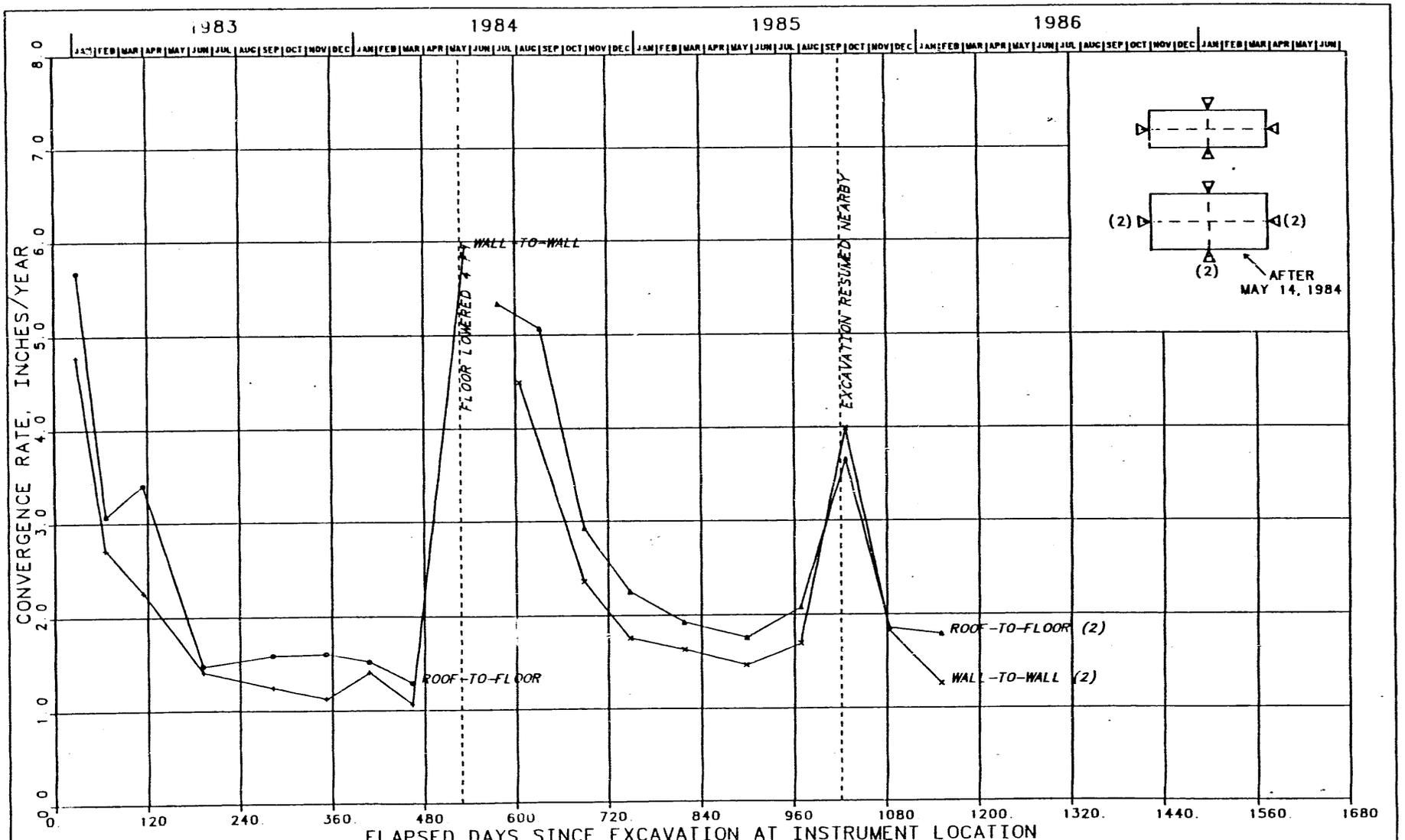


NOTES:

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.
2. SIZE OF EXCAVATION: 12 FT X 25 FT.

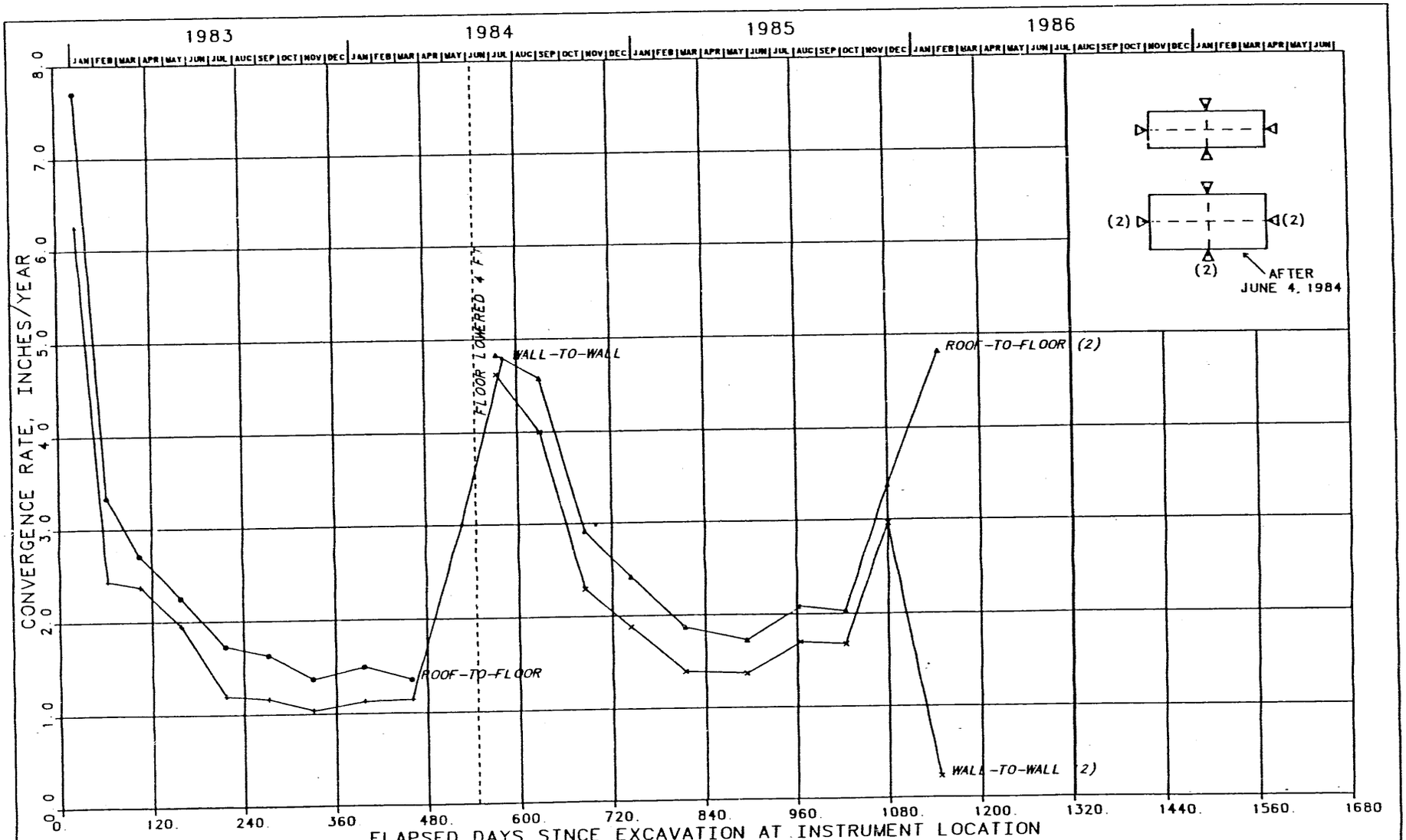
FIGURE K-1
CONVERGENCE POINTS
E140 DRIFT, SOUTH 460 FT
CONVERGENCE RATE VS. TIME SINCE EXCAVATION



NOTES

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.
2. SIZE OF EXCAVATION 12 FT X 25 FT.

FIGURE K-2
CONVERGENCE POINTS
E140 DRIFT, SOUTH 550 FT
CONVERGENCE RATE VS. TIME SINCE EXCAVATION

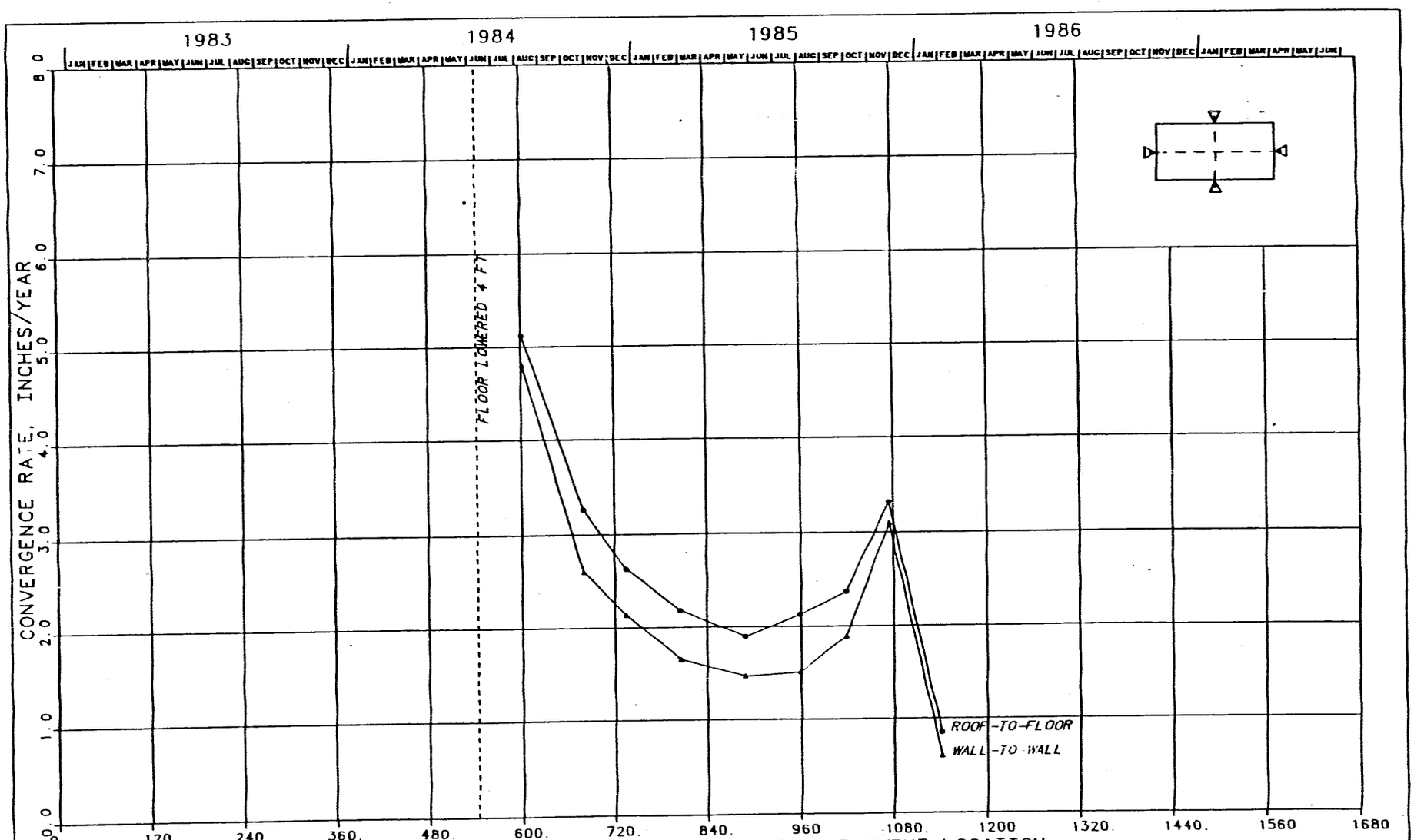


NOTES

1 RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.

2 SIZE OF EXCAVATION 12 FT X 25 FT.

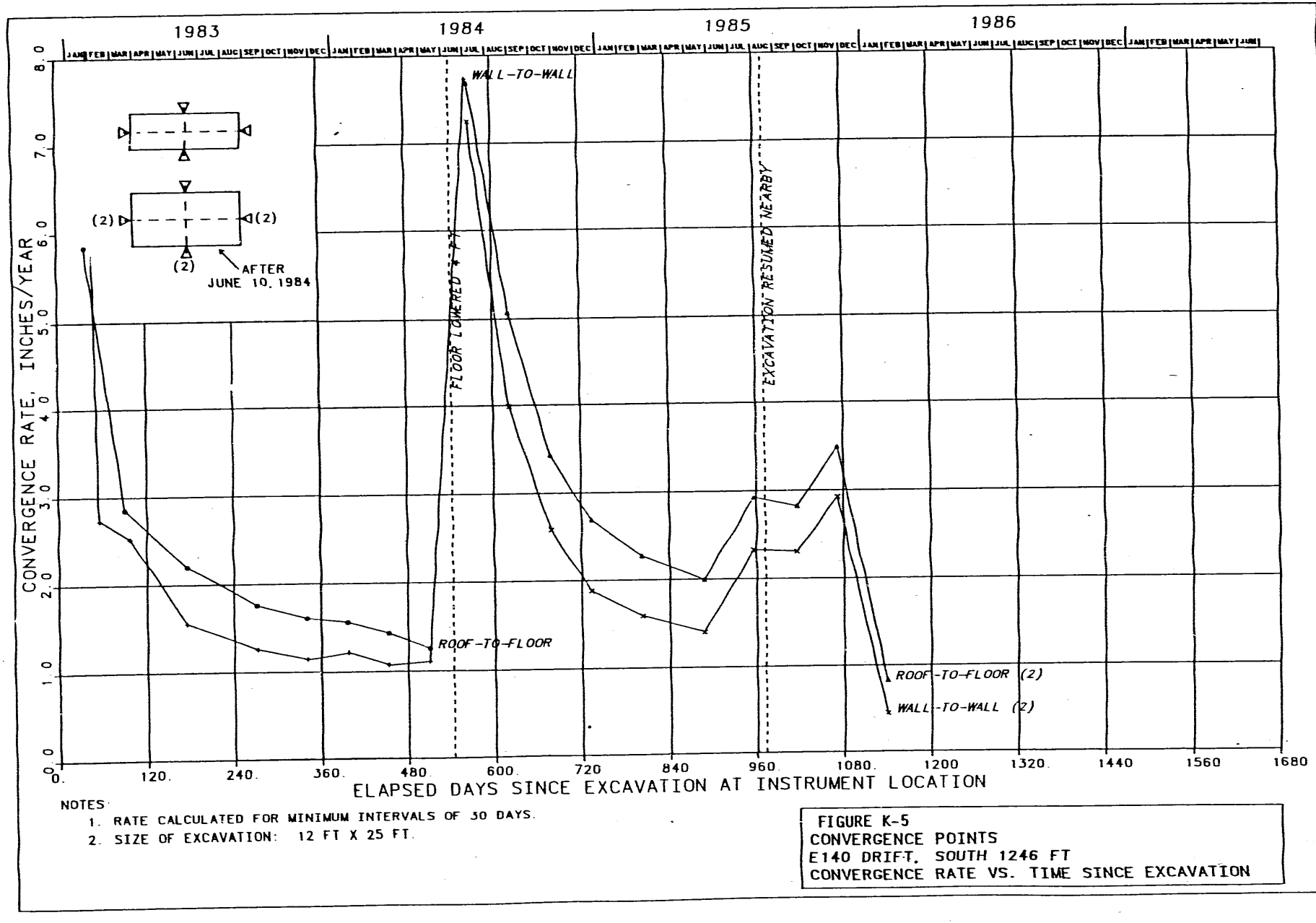
FIGURE K-3
CONVERGENCE POINTS
E140 DRIFT, SOUTH 850 FT
CONVERGENCE RATE VS. TIME SINCE EXCAVATION



NOTES:

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.
2. SIZE OF EXCAVATION: 12 FT X 25 FT.

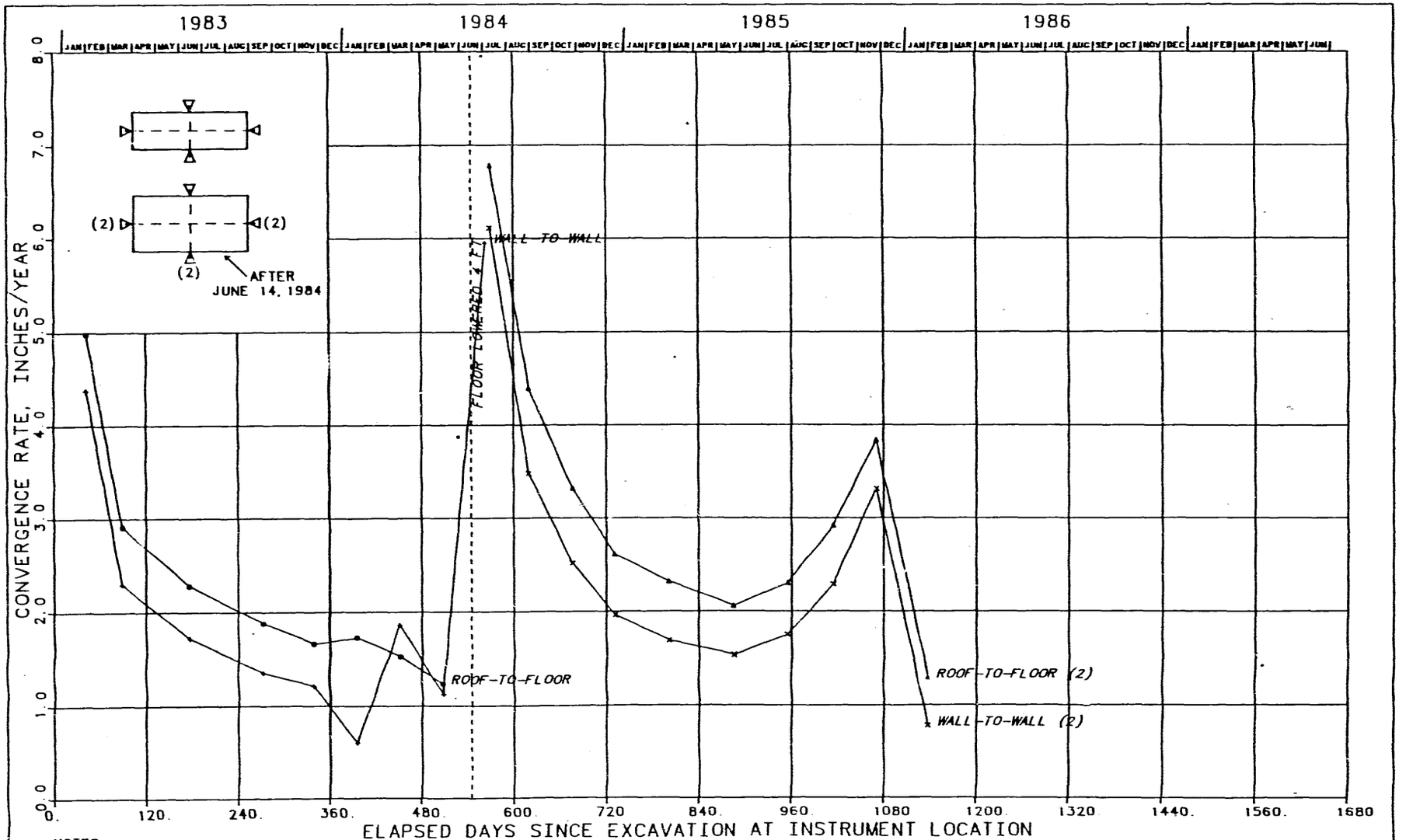
FIGURE K-4
CONVERGENCE POINTS
E140 DRIFT, SOUTH 1150 FT
CONVERGENCE RATE VS. TIME SINCE EXCAVATION



NOTES:

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.
2. SIZE OF EXCAVATION: 12 FT X 25 FT.

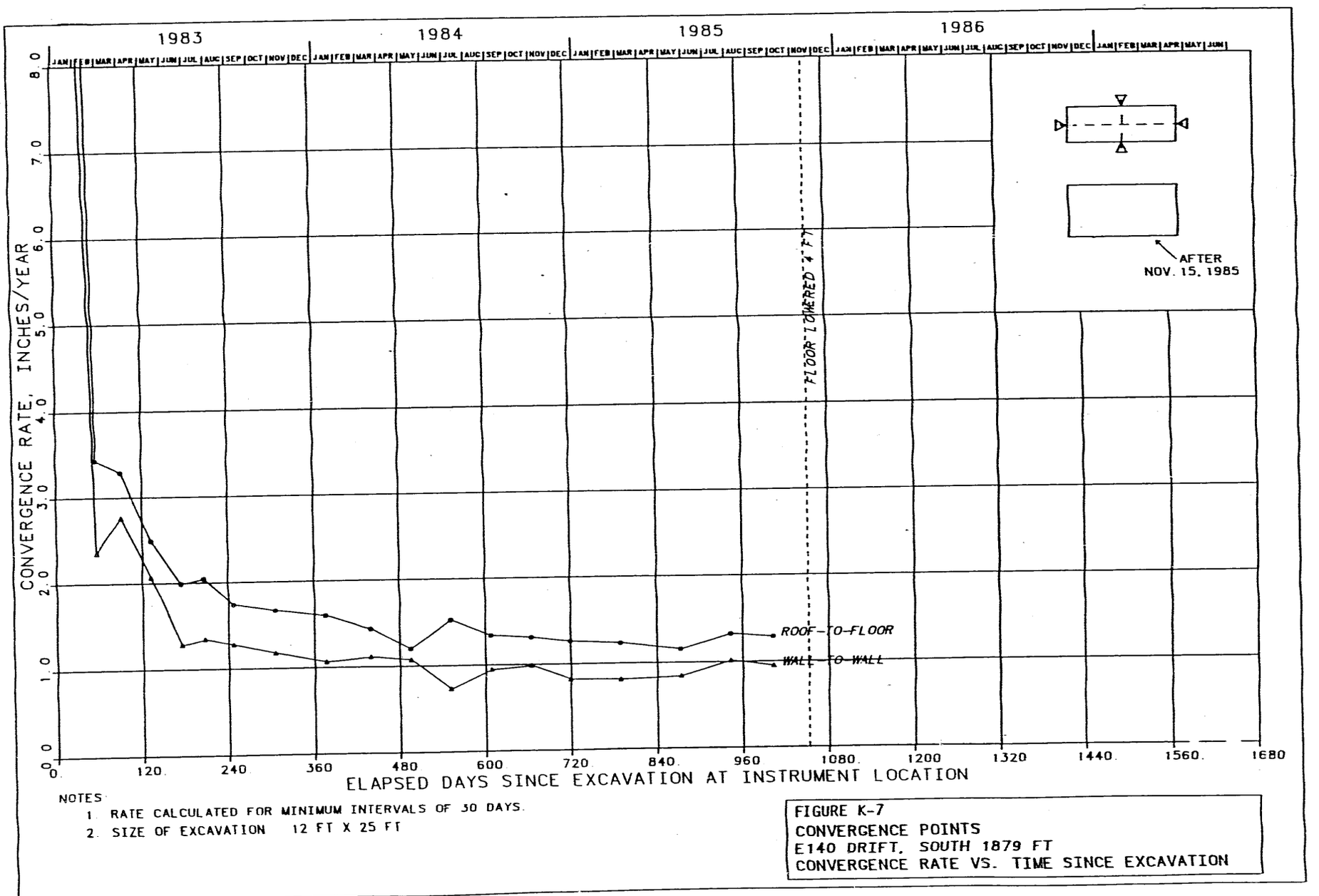
FIGURE K-5
CONVERGENCE POINTS
E140 DRIFT, SOUTH 1246 FT
CONVERGENCE RATE VS. TIME SINCE EXCAVATION



NOTES:

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.
2. SIZE OF EXCAVATION: 12 FT X 25 FT.

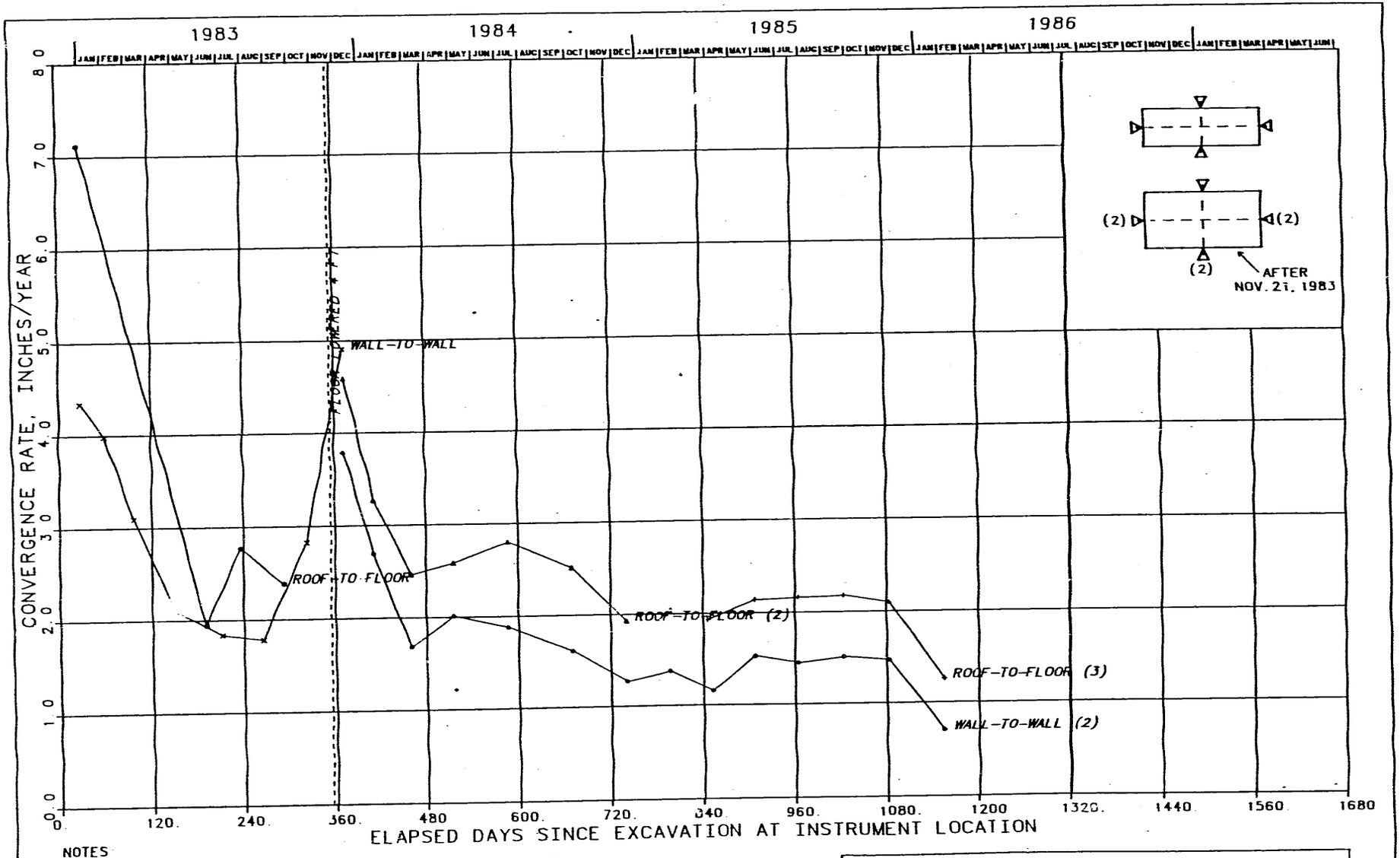
FIGURE K-6
CONVERGENCE POINTS
E140 DRIFT, SOUTH 1450 FT
CONVERGENCE RATE VS. TIME SINCE EXCAVATION



NOTES

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.
2. SIZE OF EXCAVATION 12 FT X 25 FT

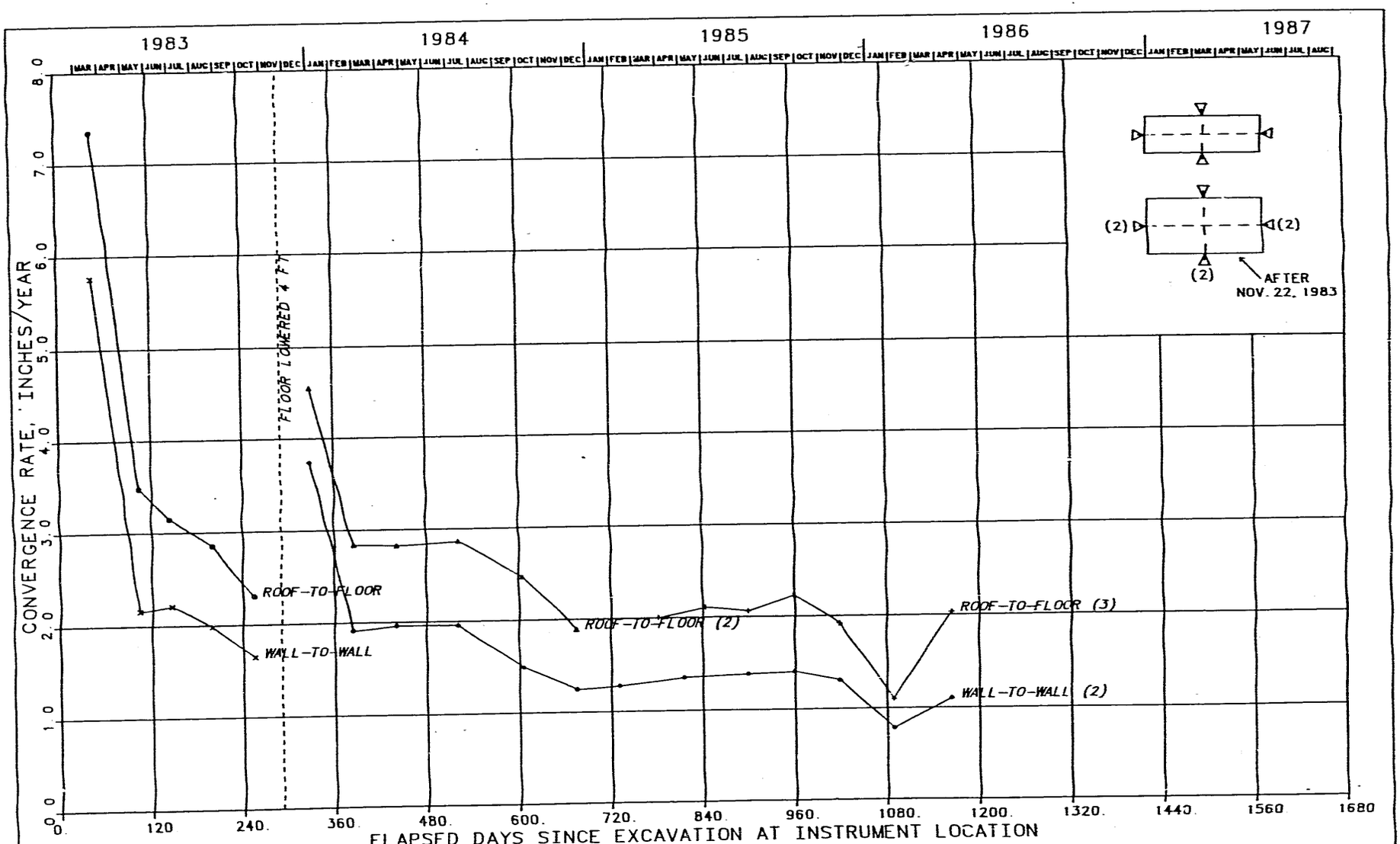
FIGURE K-7
CONVERGENCE POINTS
E140 DRIFT, SOUTH 1879 FT
CONVERGENCE RATE VS. TIME SINCE EXCAVATION



NOTES

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.
2. SIZE OF EXCAVATION: 12 FT X 25 FT.

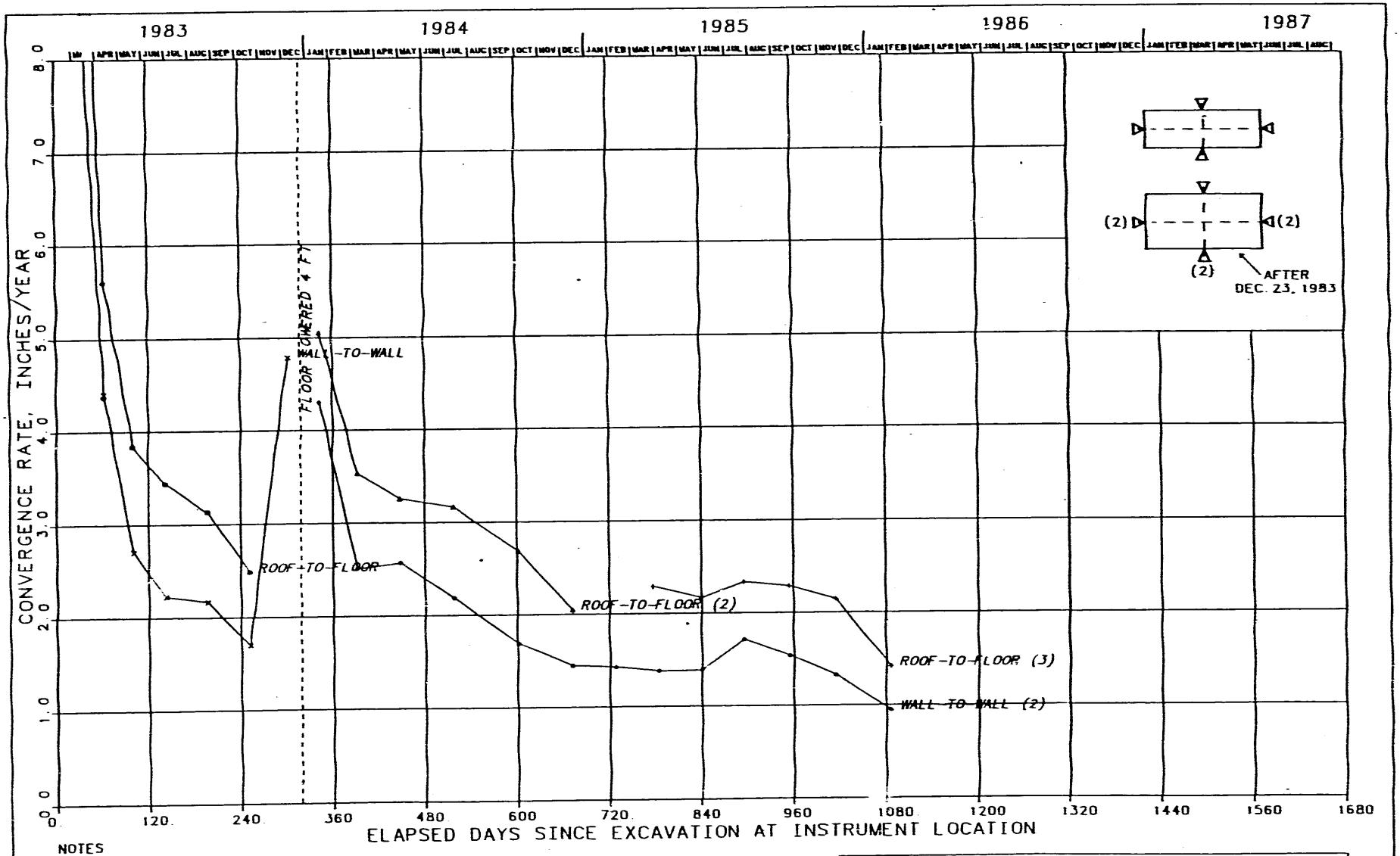
FIGURE K-8
CONVERGENCE POINTS
EO DRIFT, NORTH 290 FT
CONVERGENCE RATE VS. TIME SINCE EXCAVATION



NOTES:

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.
2. SIZE OF EXCAVATION: 12 FT X 25 FT.

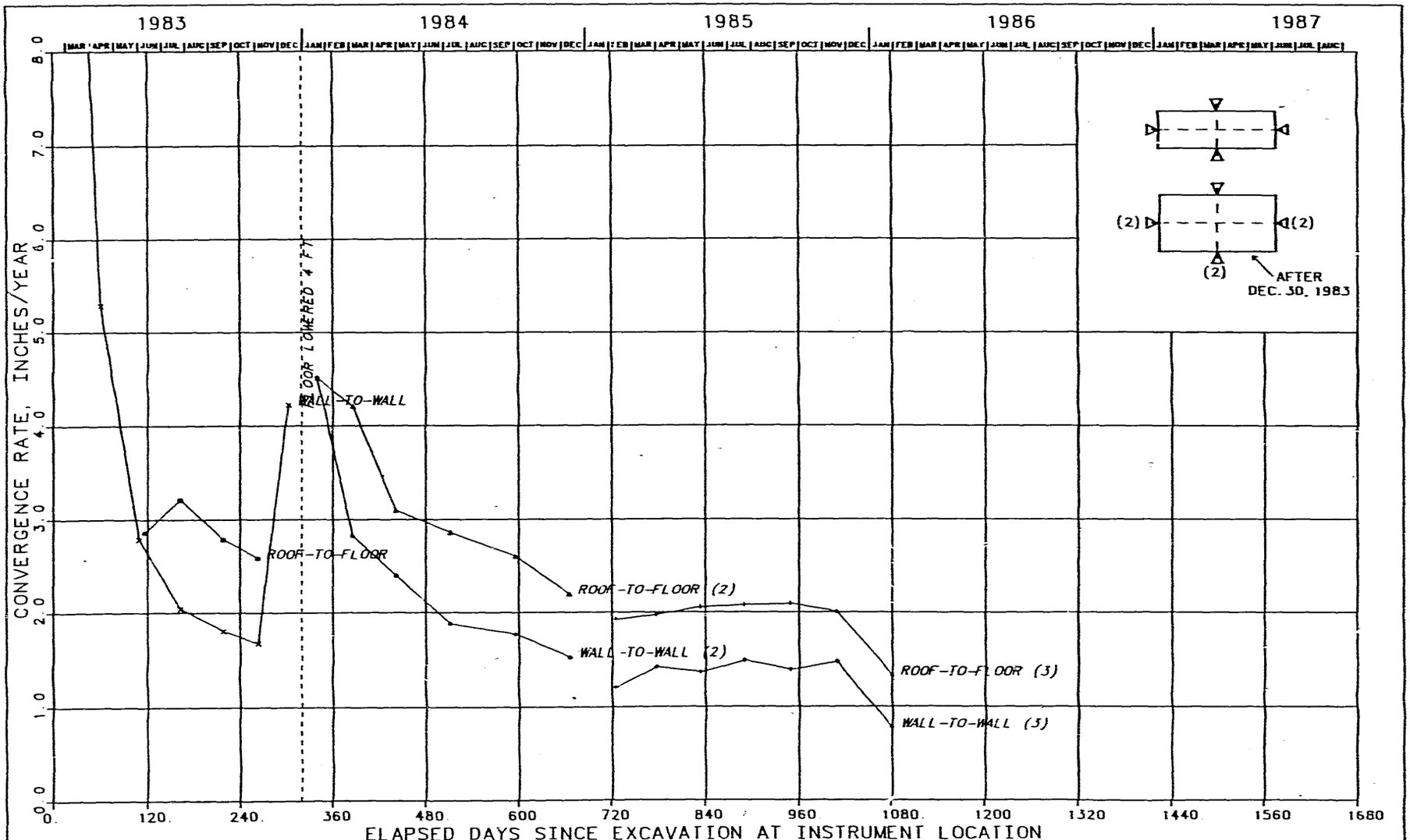
FIGURE K-9
CONVERGENCE POINTS
EO DRIFT, NORTH 626 FT
CONVERGENCE RATE VS. TIME SINCE EXCAVATION



NOTES

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.
2. SIZE OF EXCAVATION: 12 FT X 25 FT.

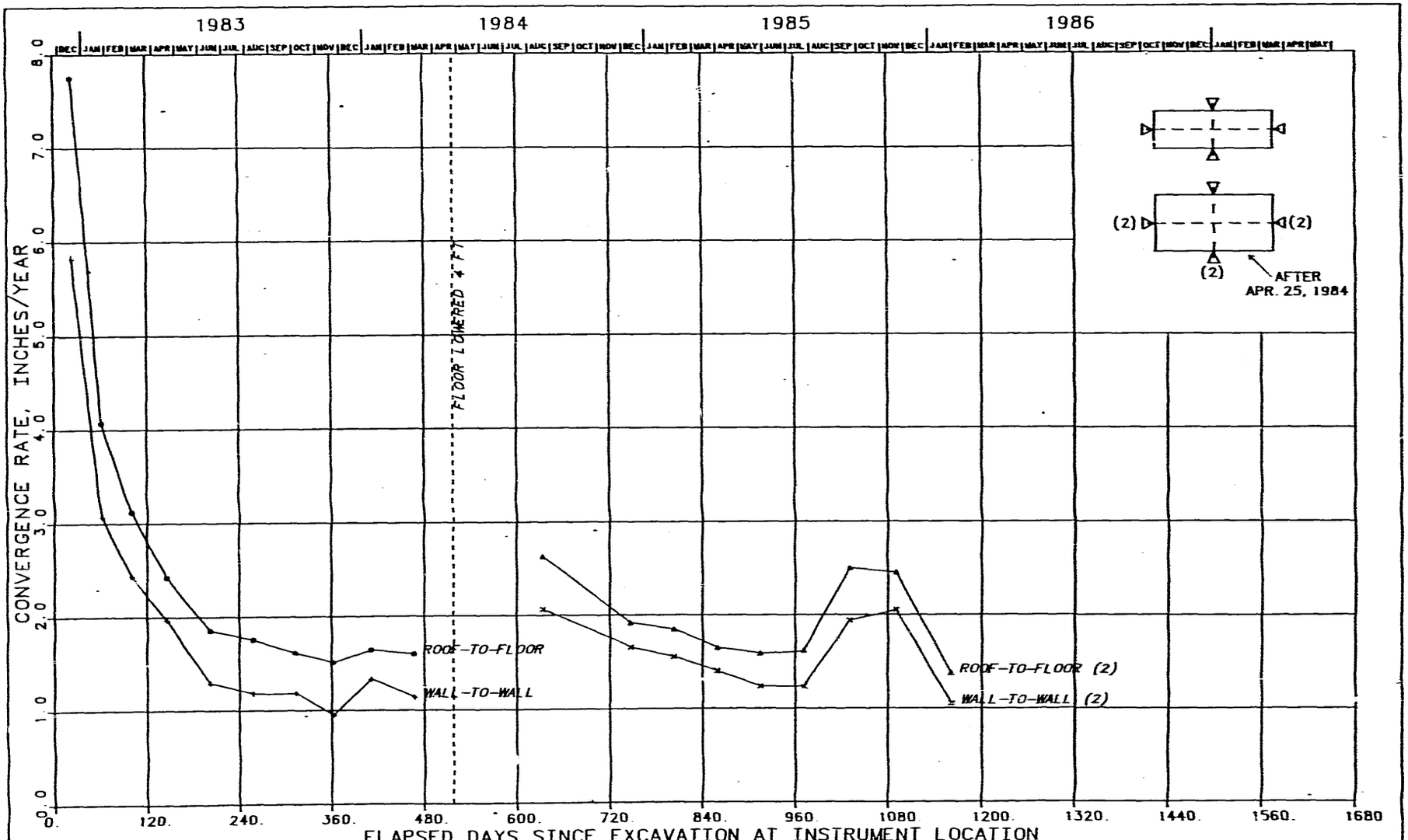
FIGURE K-10
CONVERGENCE POINTS
EO DRIFT, NORTH 940 FT
CONVERGENCE RATE VS. TIME SINCE EXCAVATION



NOTES:

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.
2. SIZE OF EXCAVATION: 12 FT X 25 FT

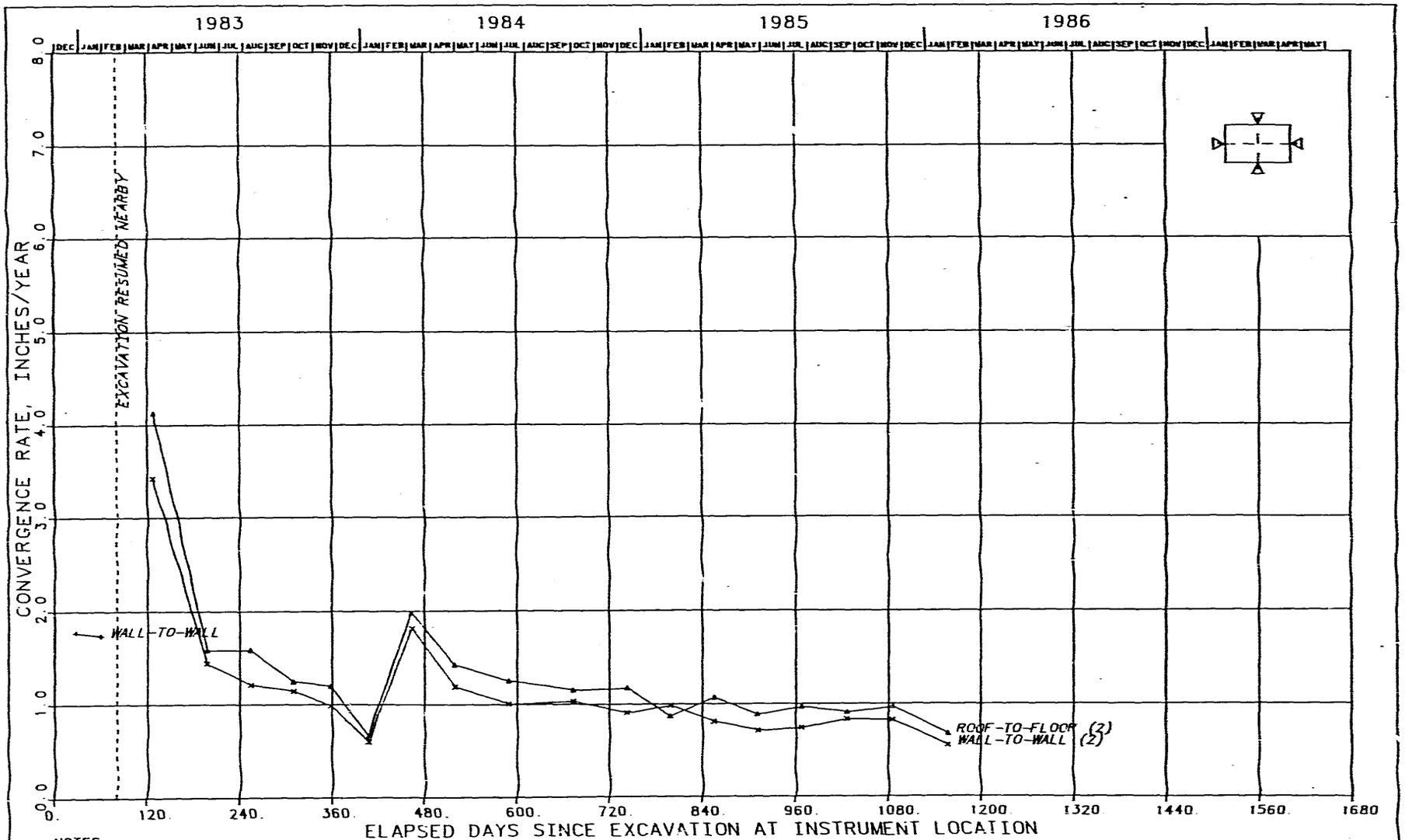
FIGURE K-11
CONVERGENCE POINTS
EO DRIFT, NORTH 1266 FT
CONVERGENCE RATE VS. TIME SINCE EXCAVATION



NOTES:

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.
2. SIZE OF EXCAVATION: 12 FT X 25 FT.

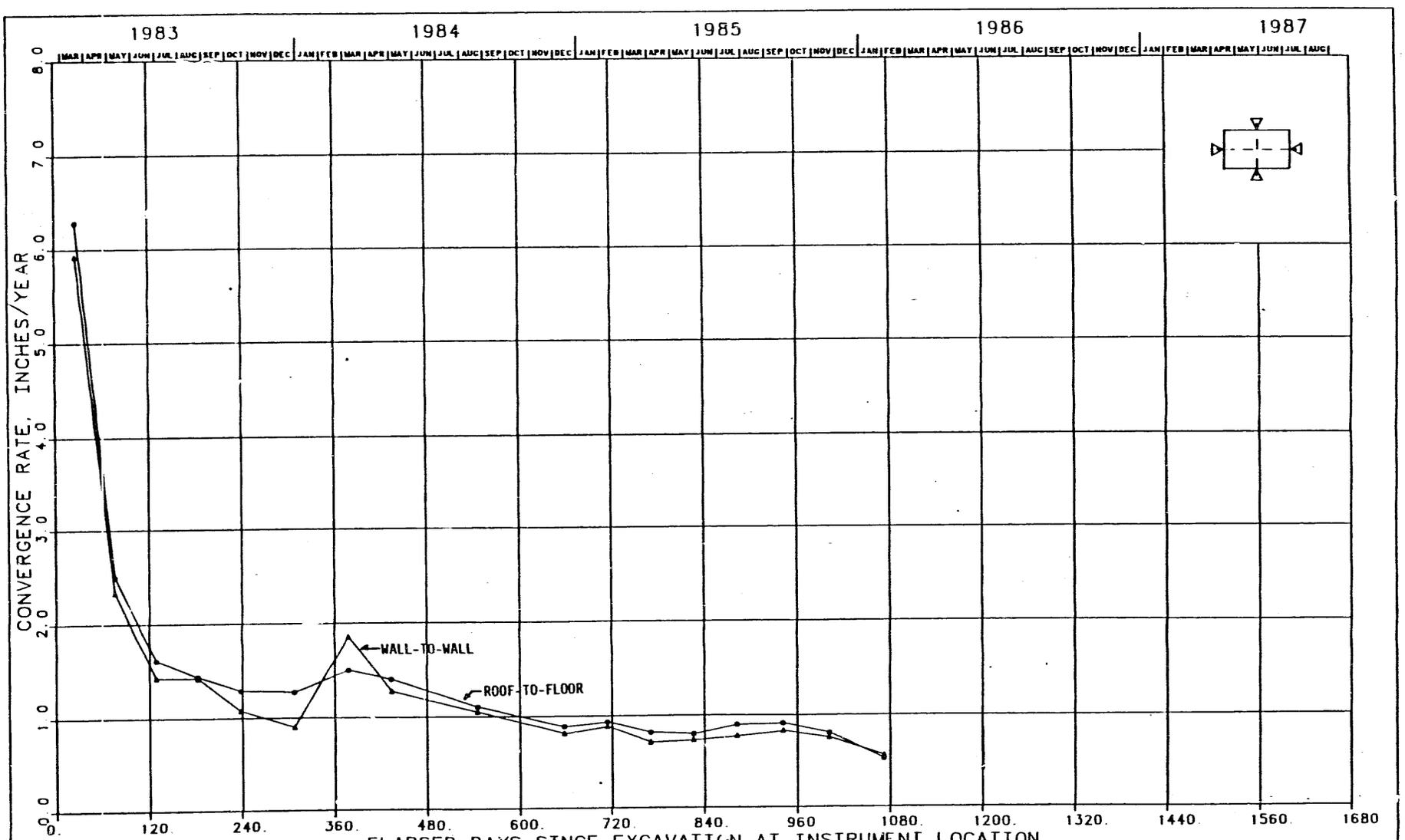
FIGURE K-12
CONVERGENCE POINTS
E140 DRIFT, NORTH 5 FT
CONVERGENCE RATE VS. TIME SINCE EXCAVATION



NOTES:

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.
2. SIZE OF EXCAVATION: 8 FT X 14 FT.

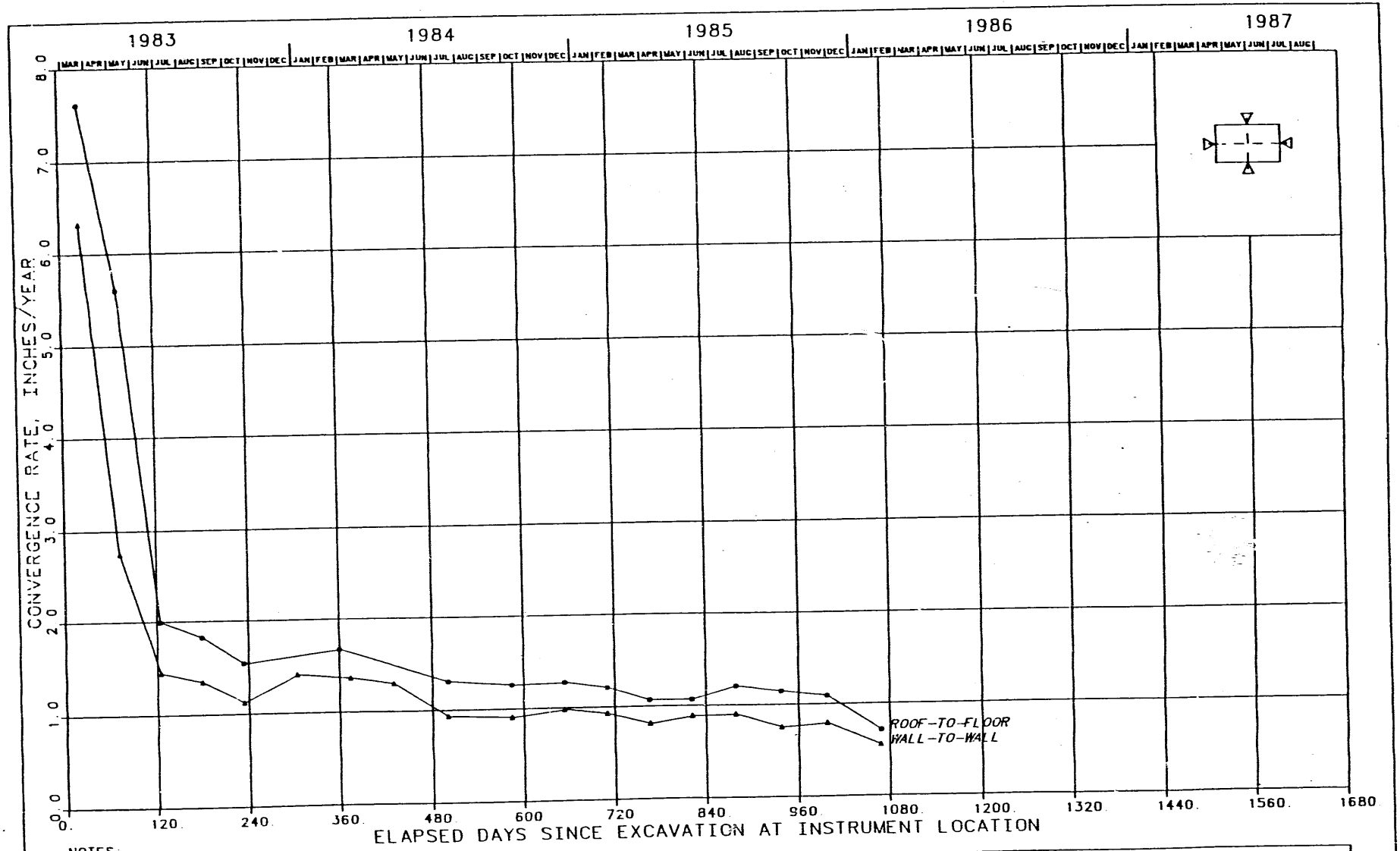
FIGURE K-13
CONVERGENCE POINTS
E140 DRIFT, NORTH 240 FT
CONVERGENCE RATE VS. TIME SINCE EXCAVATION



NOTES

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.
2. SIZE OF EXCAVATION: 8 FT X 14 FT.

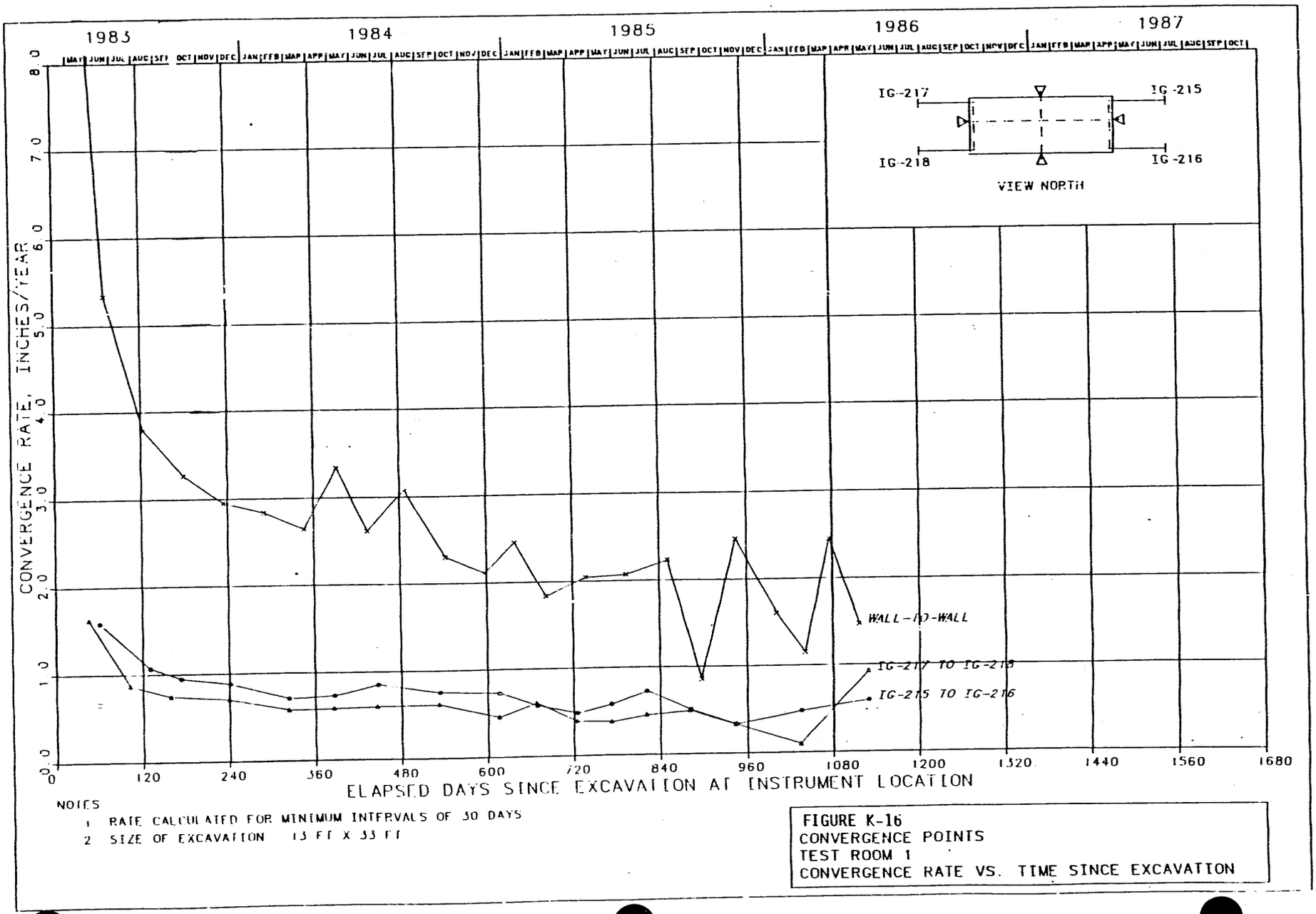
FIGURE K-14
CONVERGENCE POINTS
E140 DRIFT, NORTH 626 FT
CONVERGENCE RATE VS. TIME SINCE EXCAVATION



NOTES

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.
2. SIZE OF EXCAVATION 8 FT X 14 FT

FIGURE K-15
CONVERGENCE POINTS
E140 DRIFT, NORTH 1266 FT
CONVERGENCE RATE VS. TIME SINCE EXCAVATION

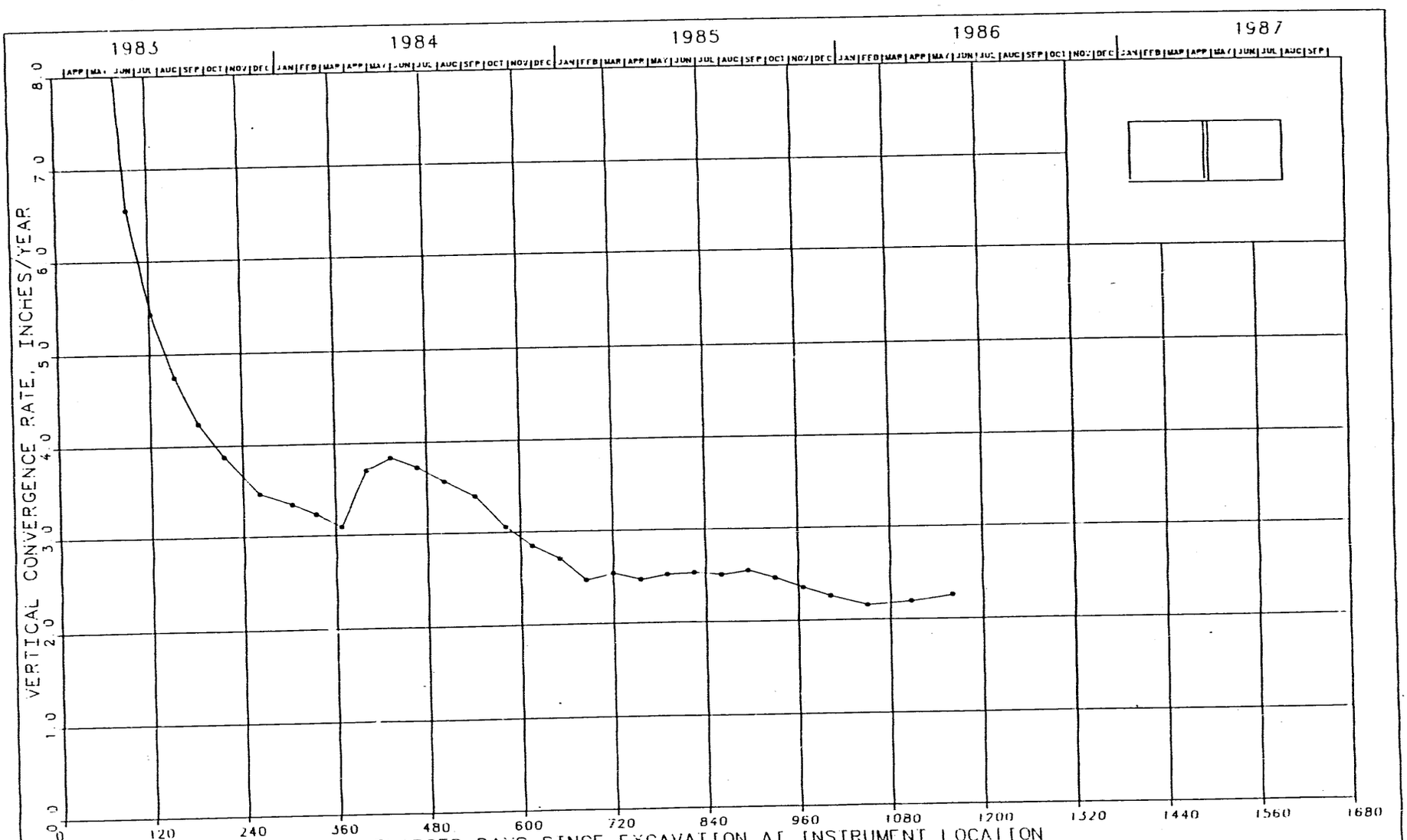


NOTES

1 RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS

2 SIZE OF EXCAVATION 13 FT X 33 FT

FIGURE K-16
CONVERGENCE POINTS
TEST ROOM 1
CONVERGENCE RATE VS. TIME SINCE EXCAVATION

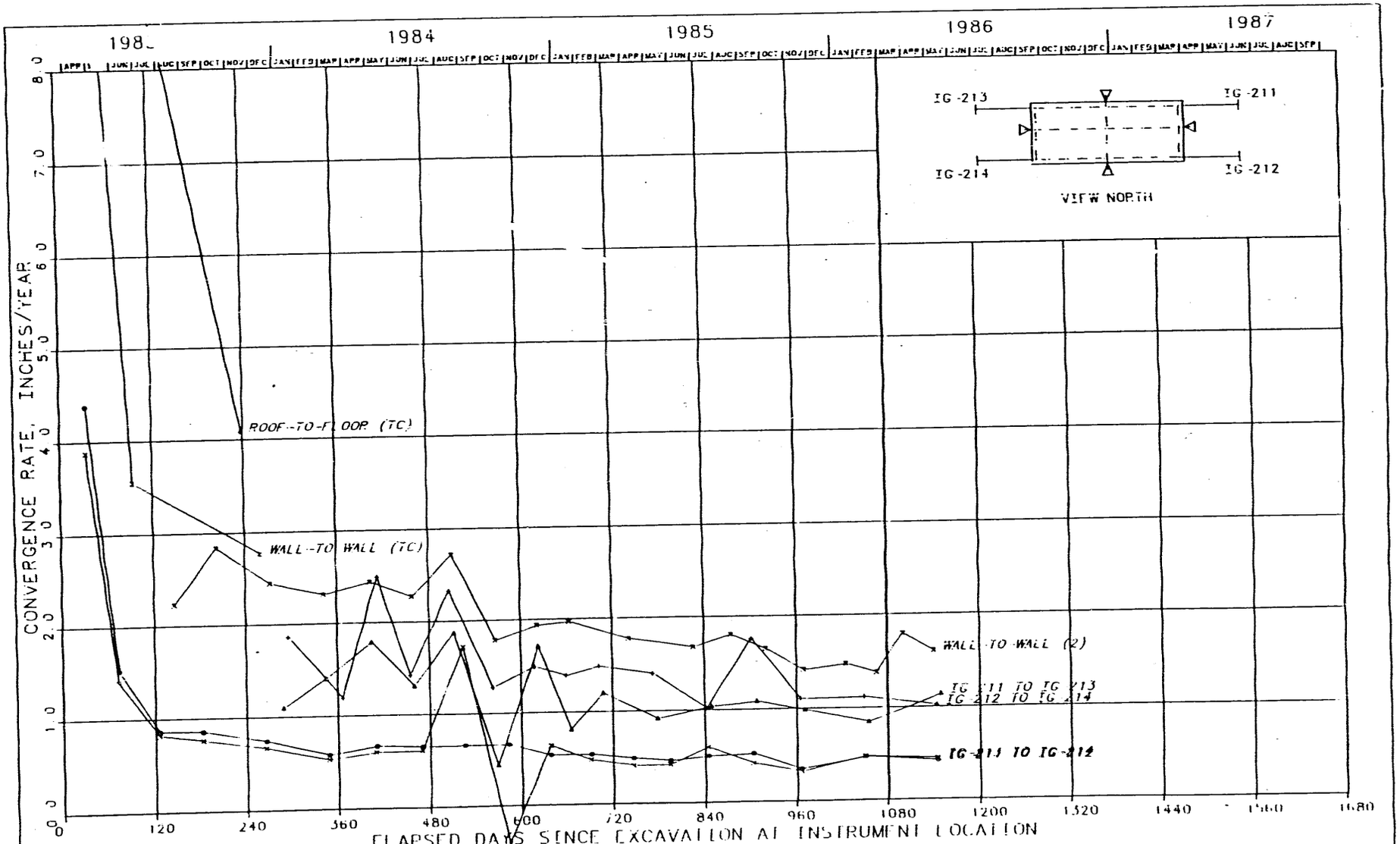


NOTES

1 RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS

2 SIZE OF EXCAVATION: 13 FT X 33 FT

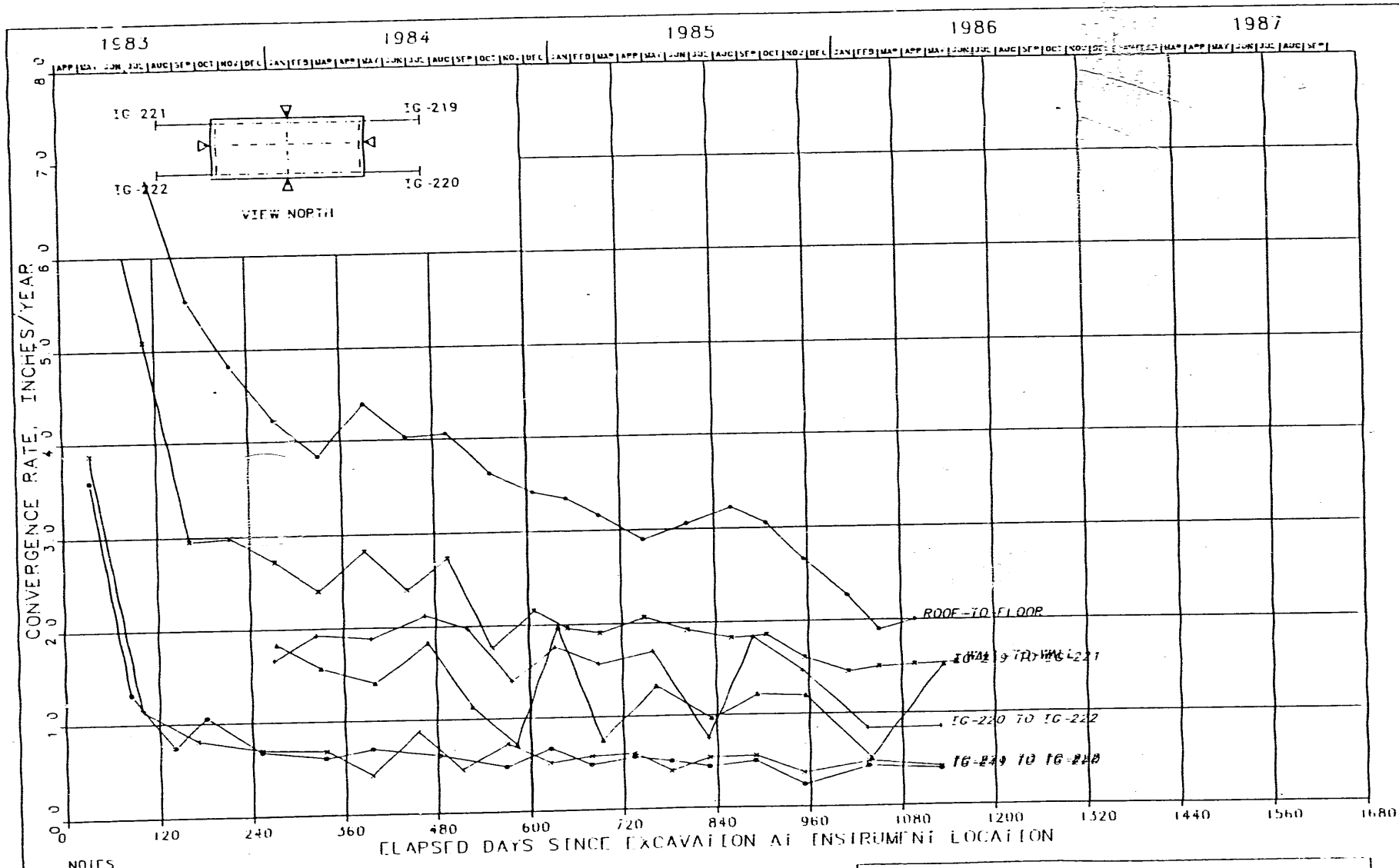
FIGURE K-17
CONVERGENCE METER 51X-CE-00201
TEST ROOM 2
CONVERGENCE RATE VS. TIME SINCE EXCAVATION



NOTES

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS
2. SIZE OF EXCAVATION 13 FT X 33 FT

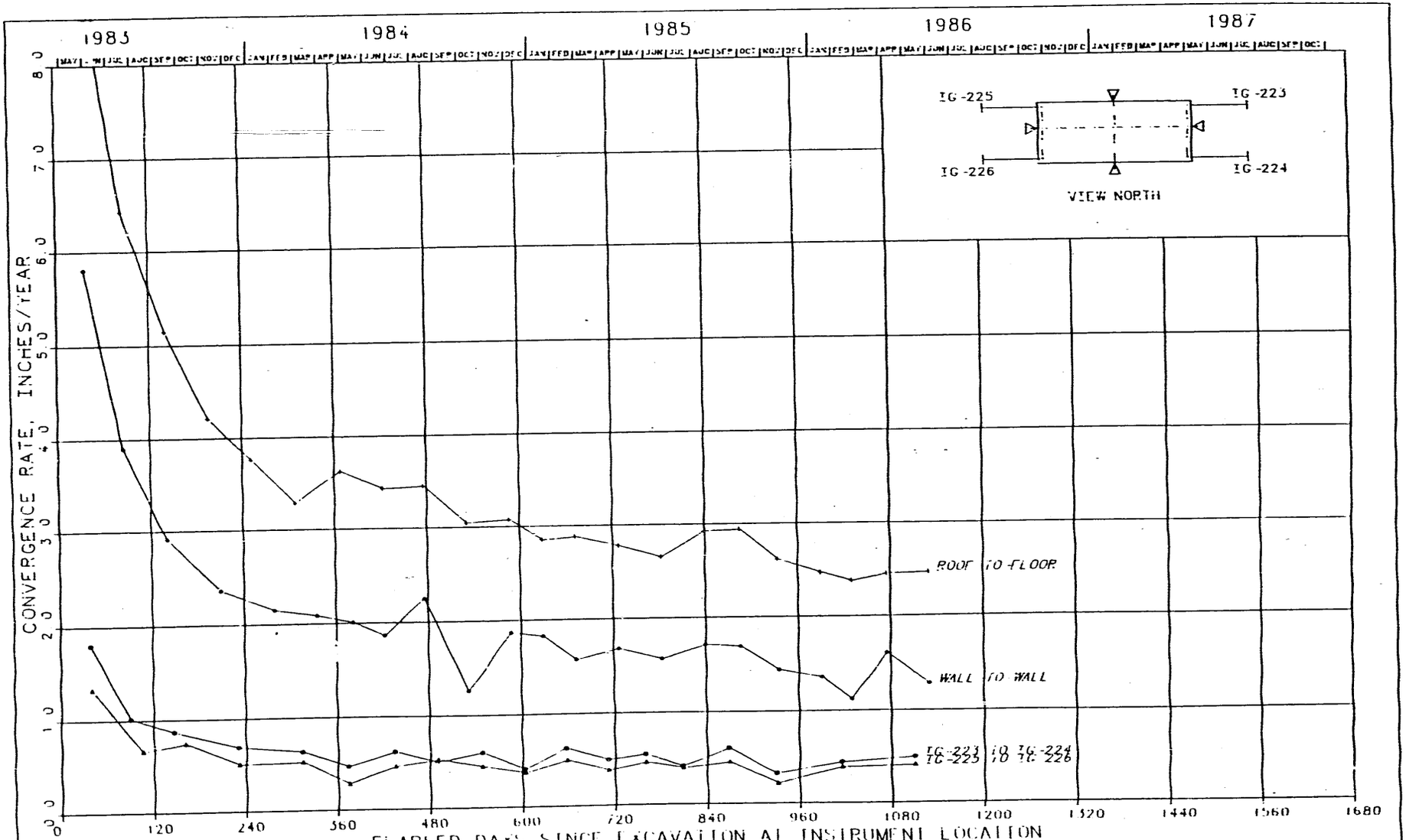
FIGURE K-18
CONVERGENCE POINTS
TEST ROOM 2
CONVERGENCE RATE VS. TIME SINCE EXCAVATION



NOTES

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS
2. SIZE OF EXCAVATION 13 FT X 33 FT

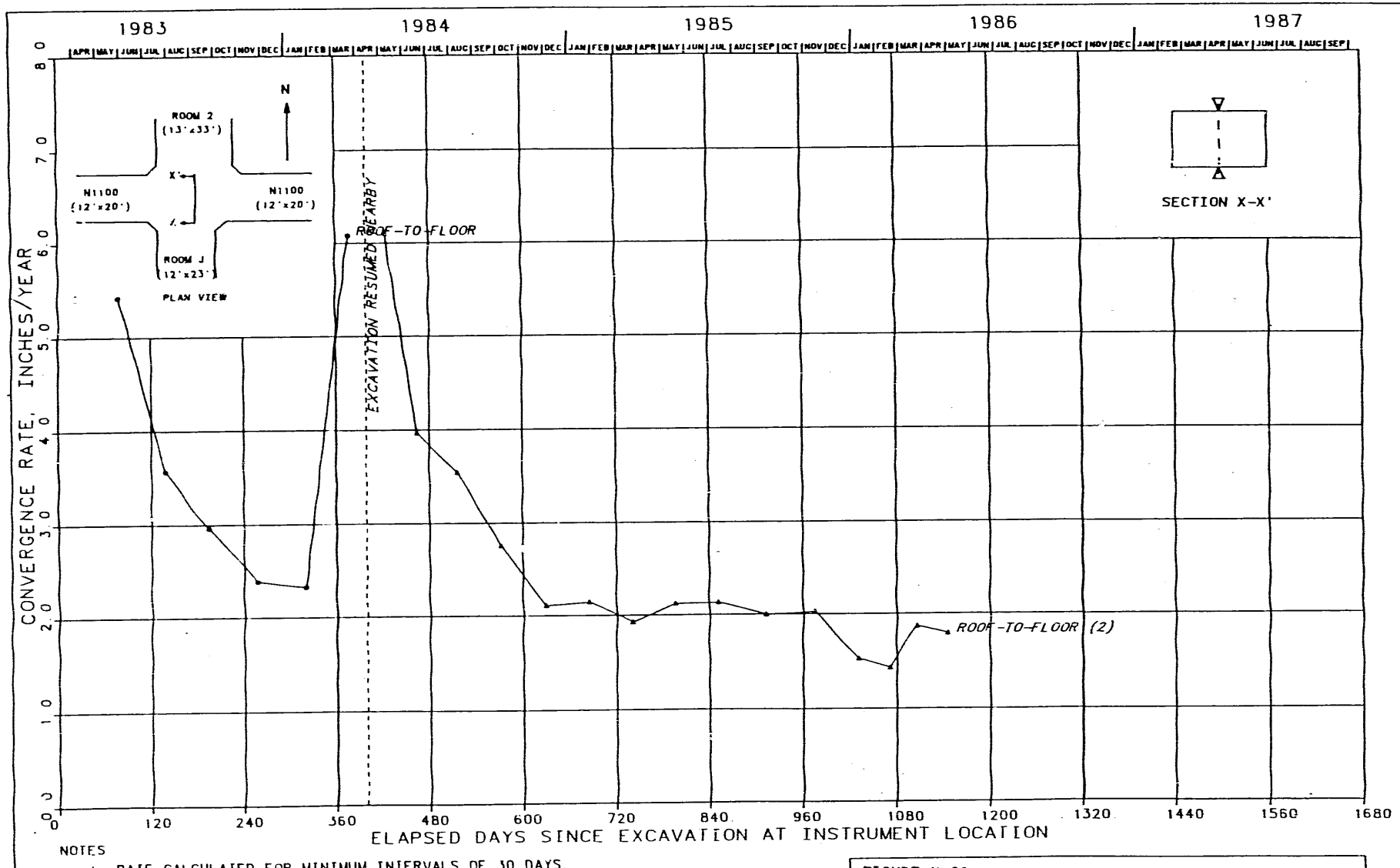
FIGURE K-19
CONVERGENCE POINTS
TEST ROOM 3
CONVERGENCE RATE VS TIME SINCE EXCAVATION



NOTES

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS
2. SIZE OF EXCAVATION 13 FT X 33 FT

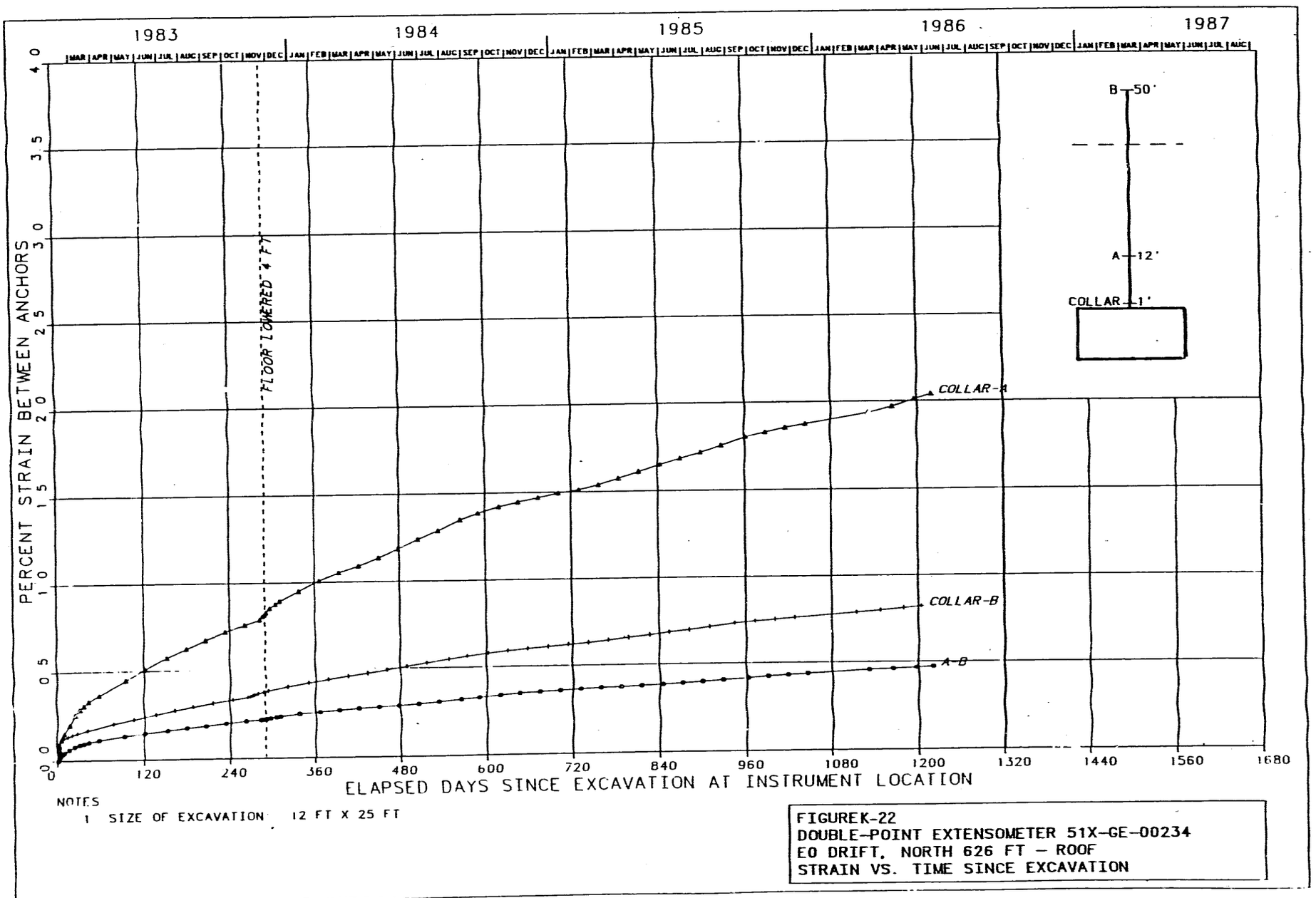
FIGURE K-20
CONVERGENCE POINTS
TEST ROOM 4
CONVERGENCE RATE VS. TIME SINCE EXCAVATION



NOTES

1 RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.

FIGURE K-21
CONVERGENCE POINTS
N1100 DRIFT – TEST ROOM 2 INTERSECTION
CONVERGENCE RATE VS. TIME SINCE EXCAVATION



NOTES

1 SIZE OF EXCAVATION 12 FT X 25 FT

FIGUREK-22
DOUBLE-POINT EXTENSOMETER 51X-GE-00234
EO DRIFT, NORTH 626 FT – ROOF
STRAIN VS. TIME SINCE EXCAVATION

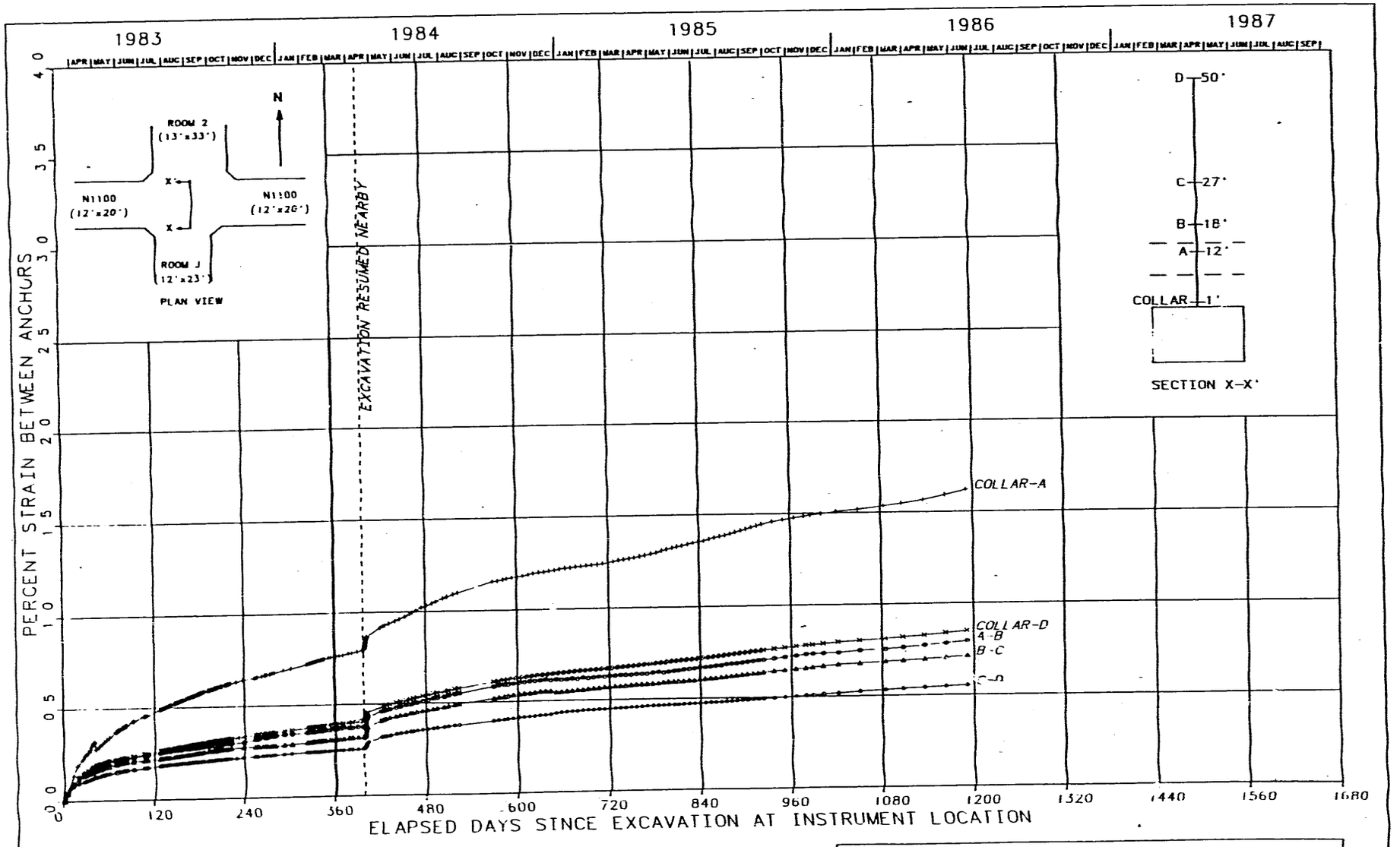


FIGURE K-23
MULTIPLE-POINT EXTENSOMETER 51X-GE-00241
N1100 - TEST ROOM 2 INTERSECTION - ROOF
STRAIN VS. TIME SINCE EXCAVATION

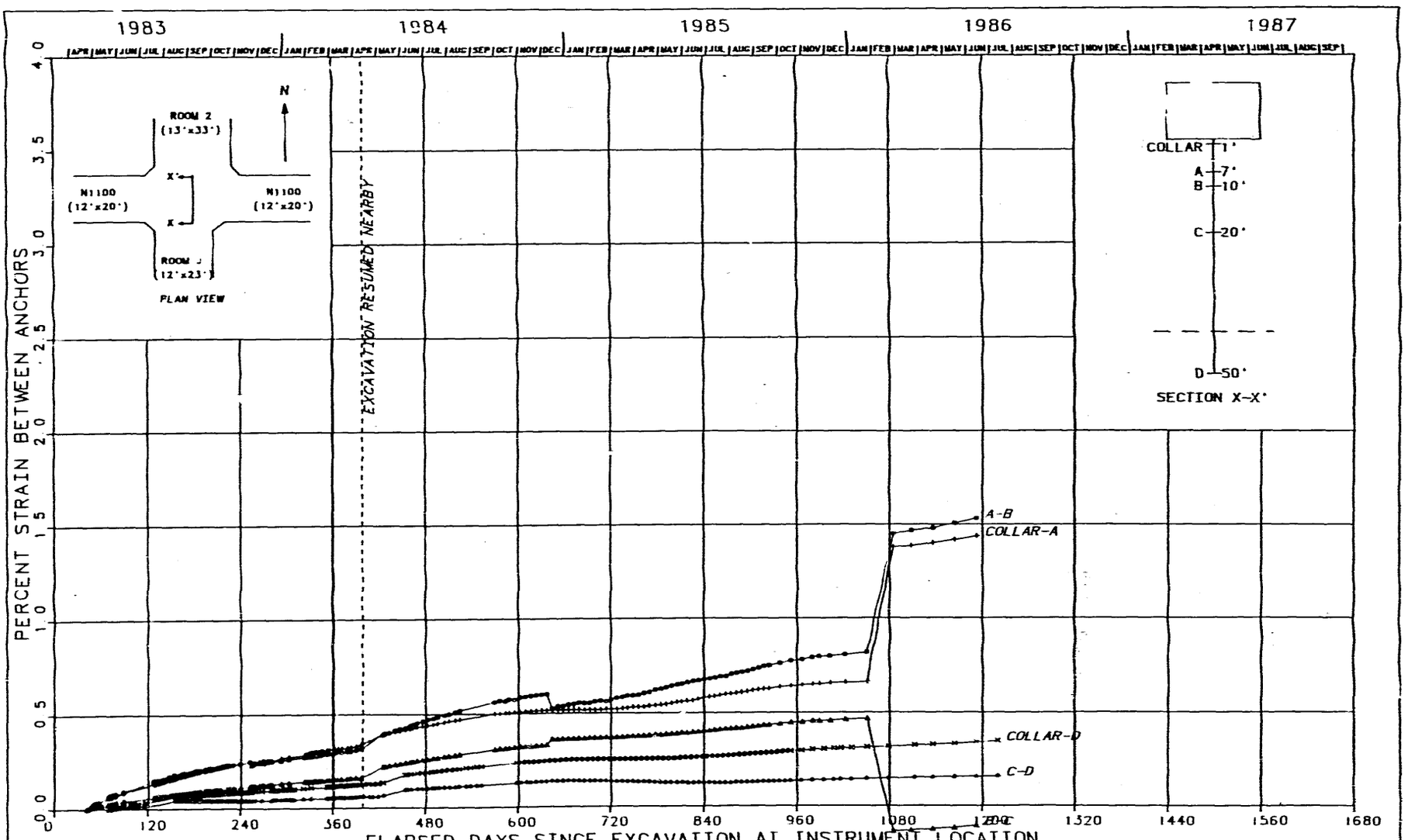
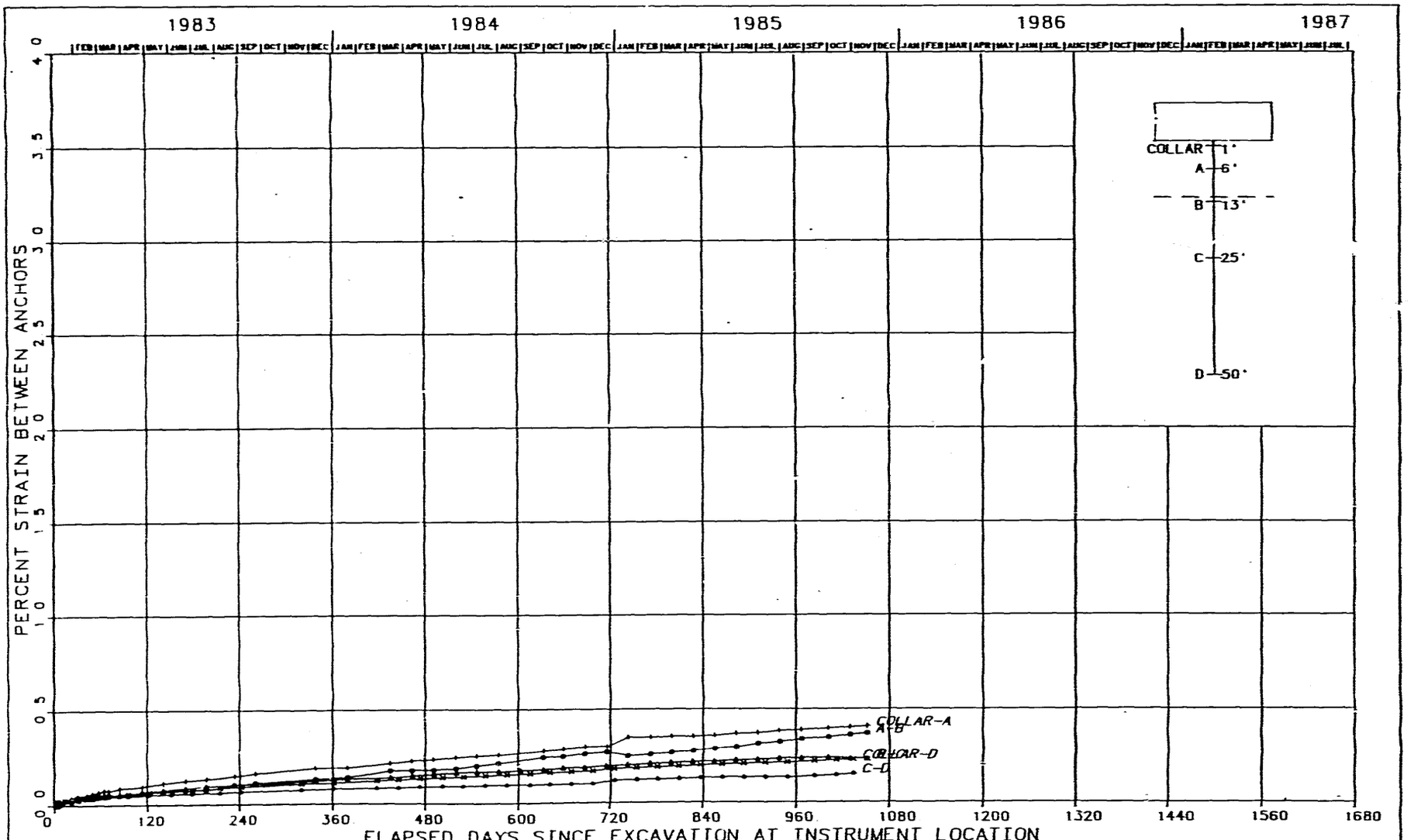


FIGURE K-24
MULTIPLE-POINT EXTENSOMETER 51X-GE-00242
N1100 – TEST ROOM 2 INTERSECTION – FLOOR
STRAIN VS. TIME SINCE EXCAVATION

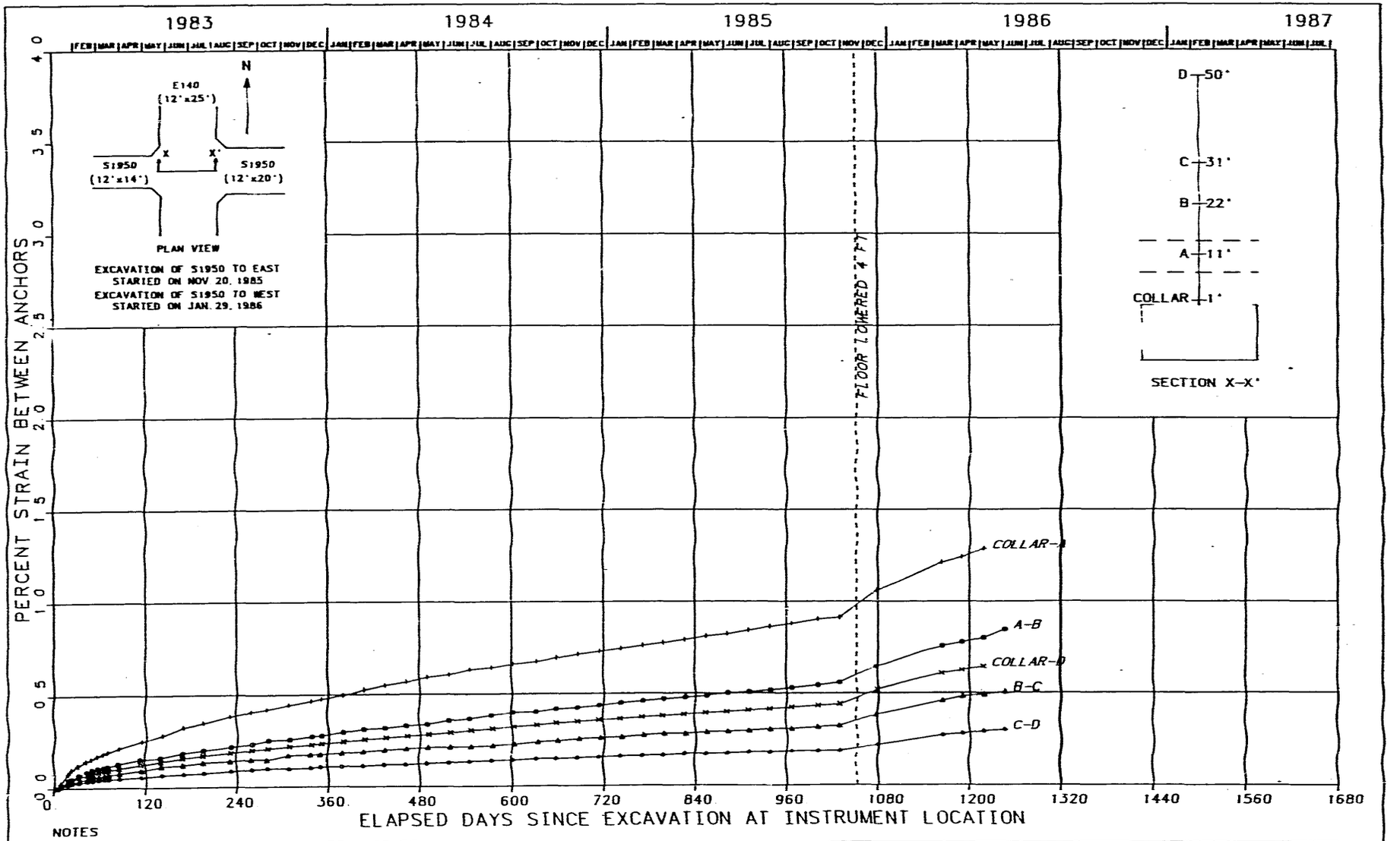


NOTES

1 SIZE OF EXCAVATION 8 FT X 25 FT

2 INSTRUMENT HAS BEEN DESTROYED

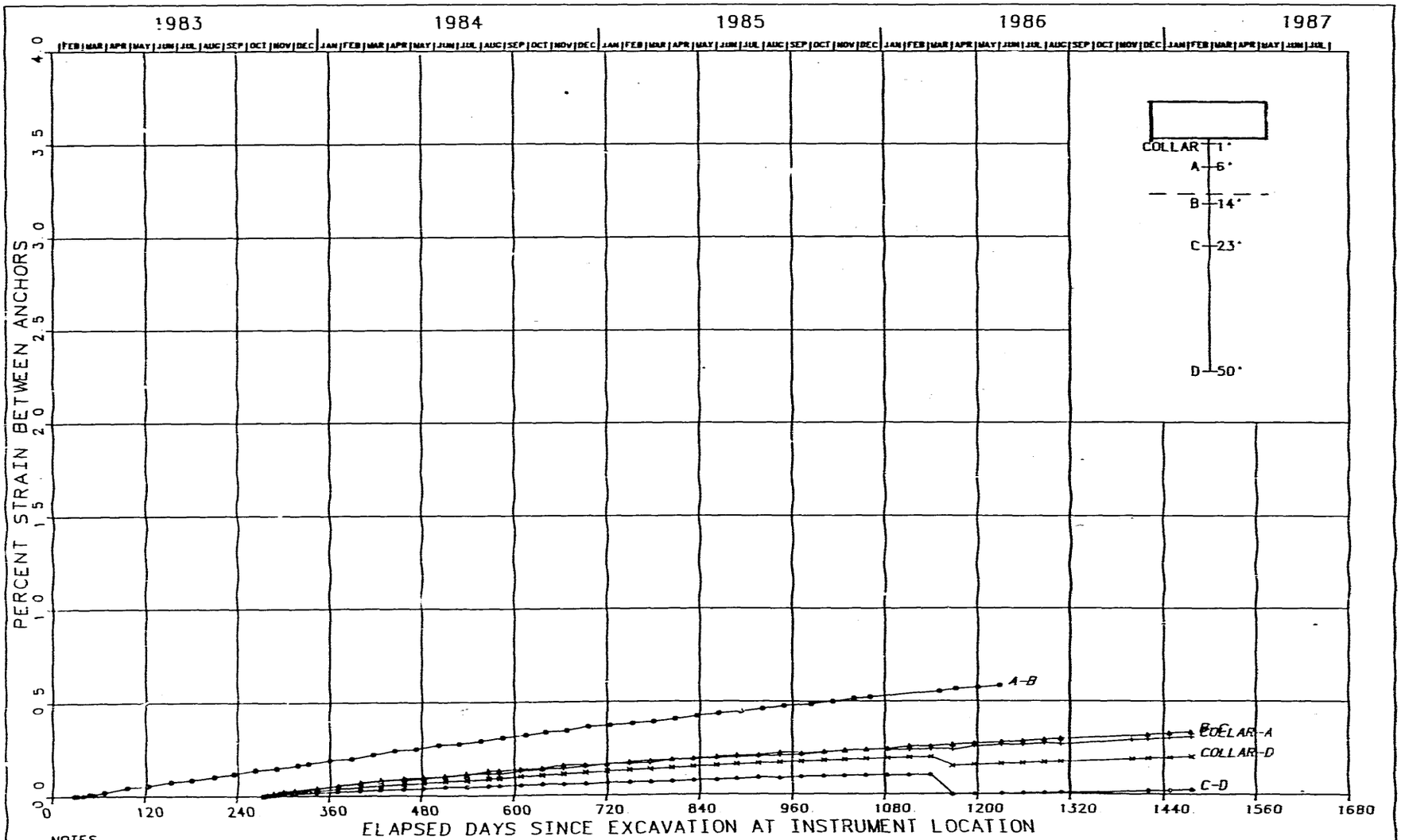
FIGURE K-26
MULTIPLE-POINT EXTENSOMETER 51X-GE-00248
E140 DRIFT, SOUTH 1950 FT - FLOOR
STRAIN VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION: 12 FT X 25 FT

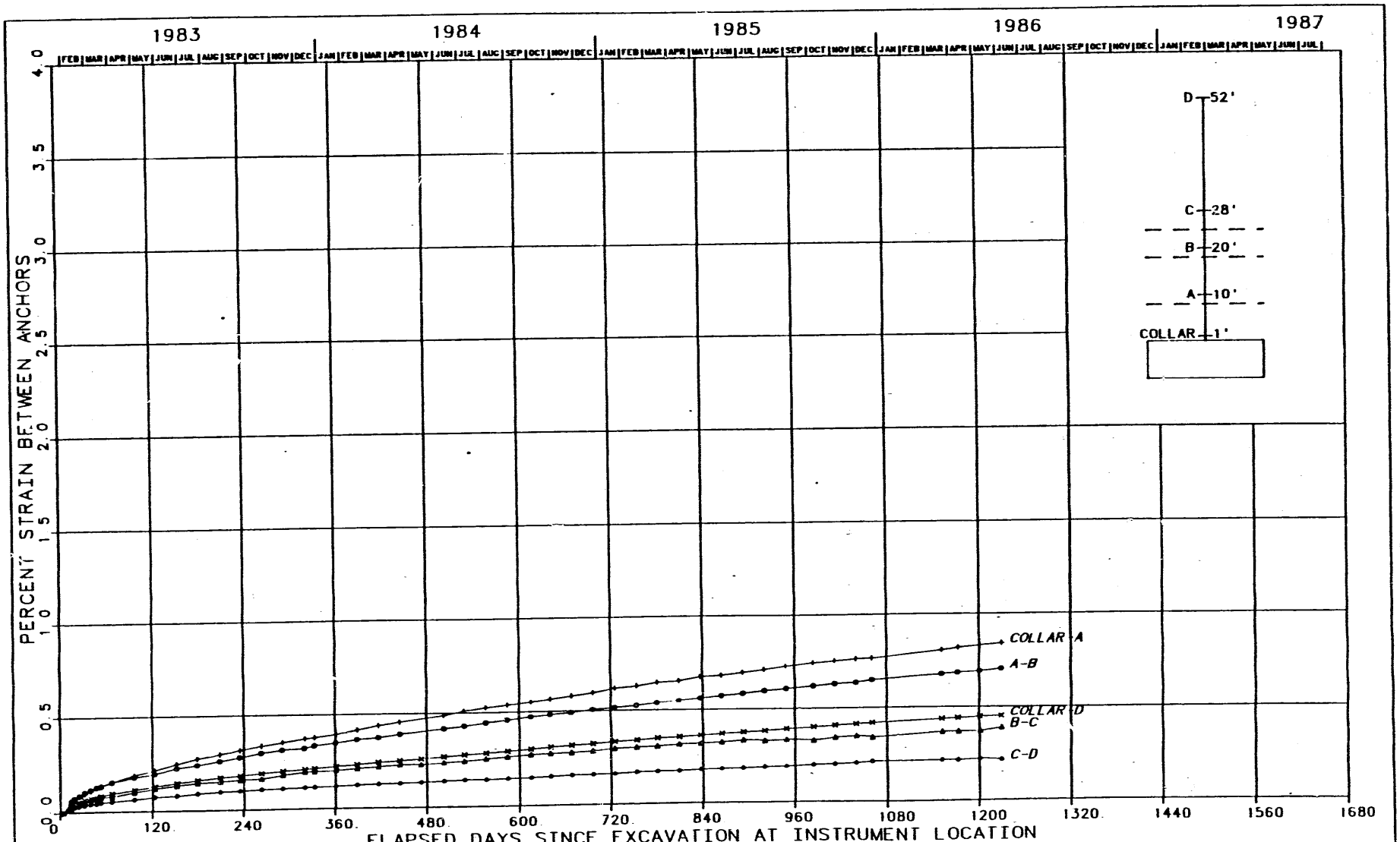
FIGURE K-25
MULTIPLE-POINT EXTENSOMETER 51X-GE-00247
E140 DRIFT, SOUTH 1950 FT – ROOF
STRAIN VS. TIME SINCE EXCAVATION



NOTES

1 SIZE OF EXCAVATION 8 FT X 25 FT

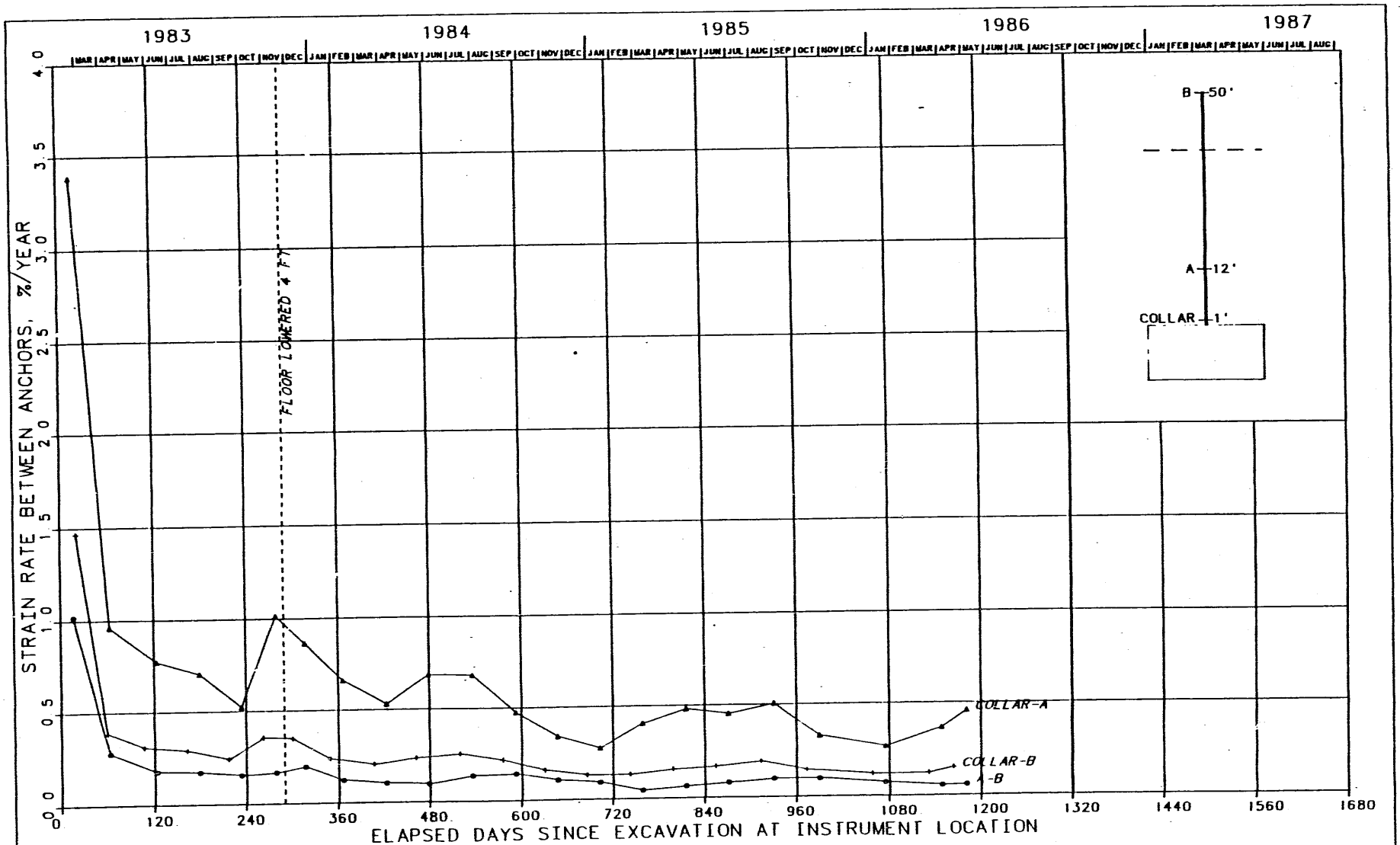
FIGURE K-27
MULTIPLE-POINT EXTENSOMETER 51X-GE-00250
E140 DRIFT, SOUTH 3045 FT - FLOOR
STRAIN VS. TIME SINCE EXCAVATION



NOTES

1. SIZE OF EXCAVATION 8 FT X 25 FT.

FIGURE K-28
MULTIPLE-POINT EXTENSOMETER 51X-GE-00249
E140 DRIFT, SOUTH 3080 FT - ROOF
STRAIN VS. TIME SINCE EXCAVATION

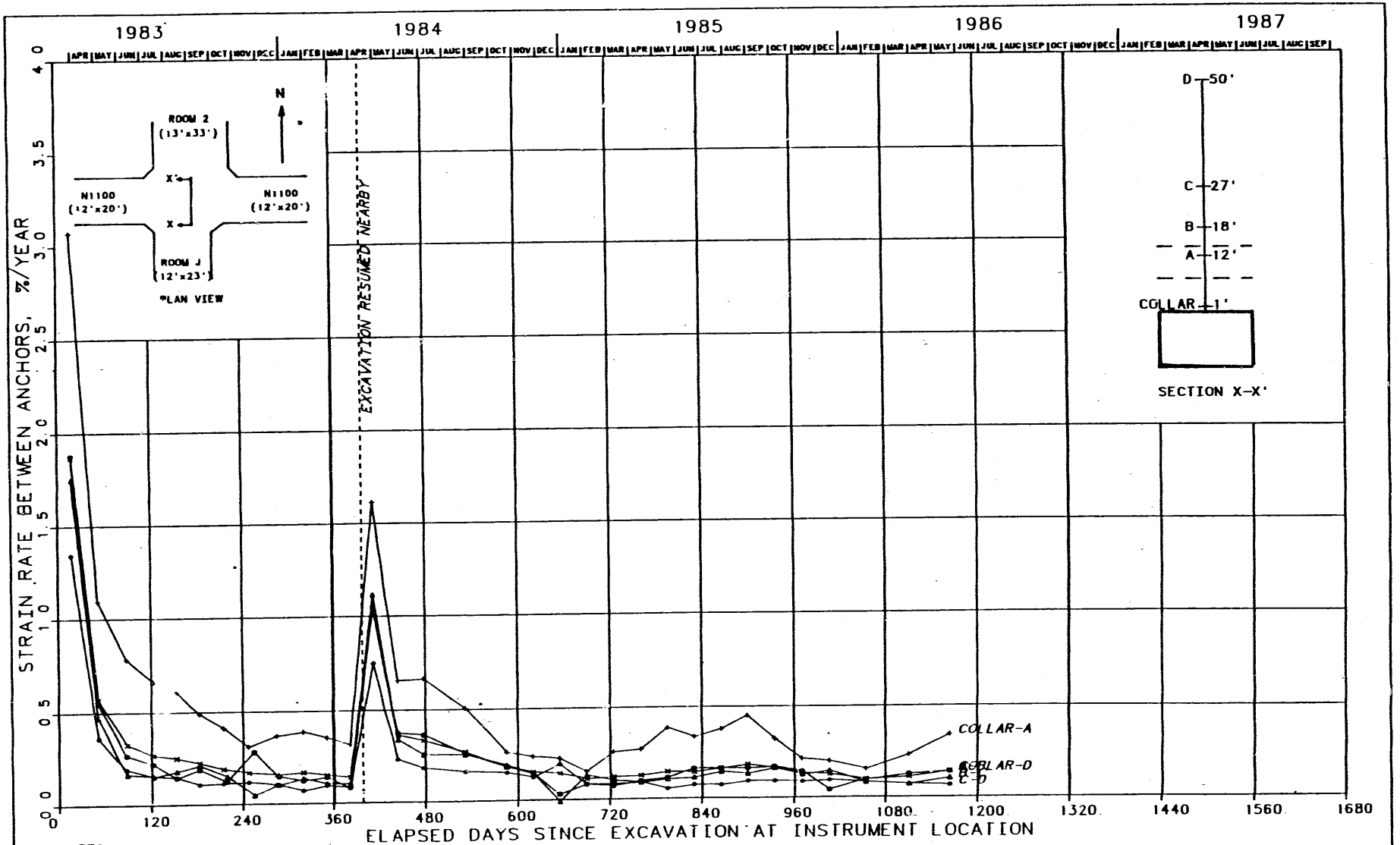


NOTES

1 RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS

2 SIZE OF EXCAVATION 12 FT X 25 FT

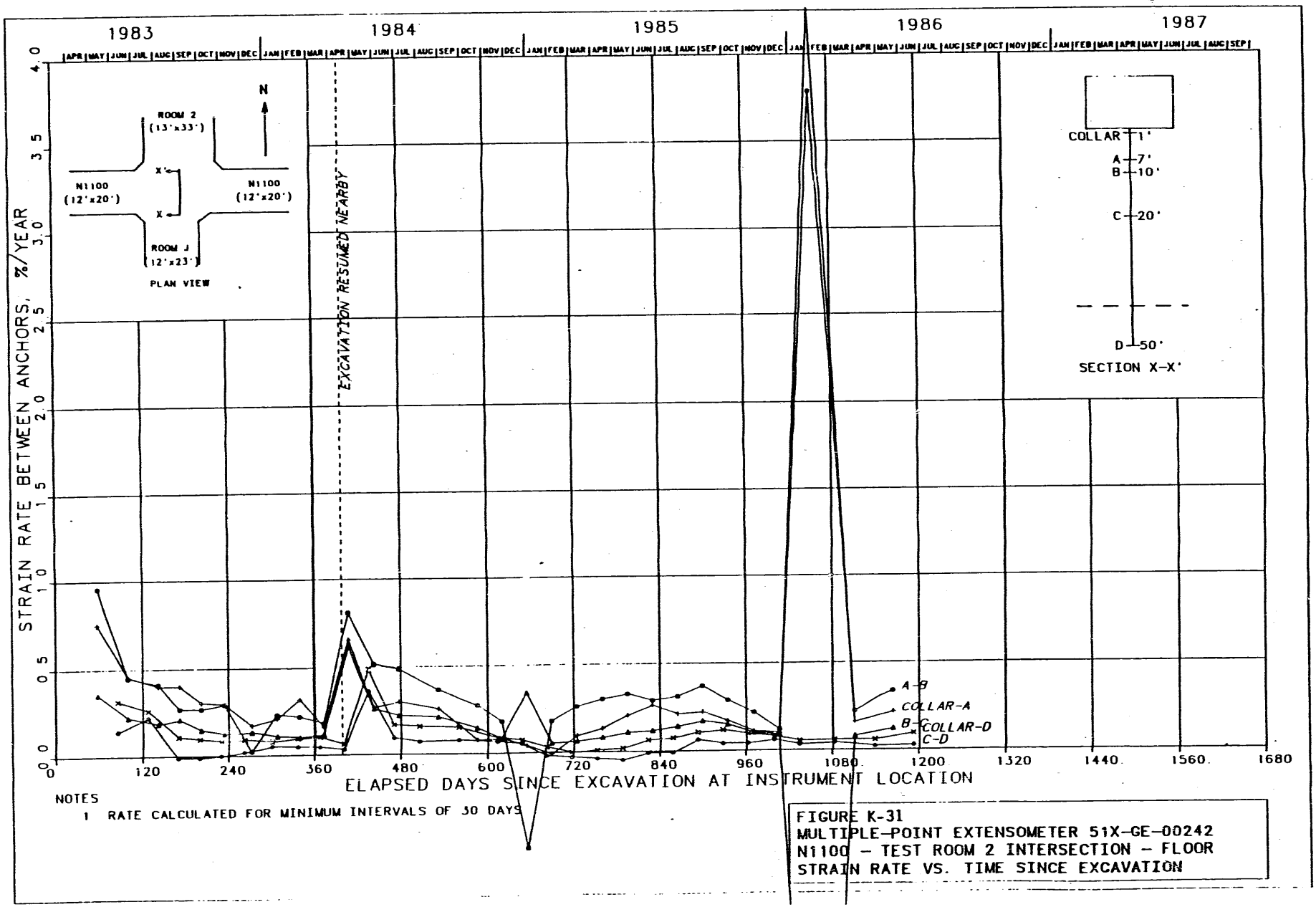
FIGURE K-29
DOUBLE-POINT EXTENSOMETER 51X-GE-00234
EO DRIFT, NORTH 626 FT – ROOF
STRAIN RATE VS. TIME SINCE EXCAVATION



NOTES

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS

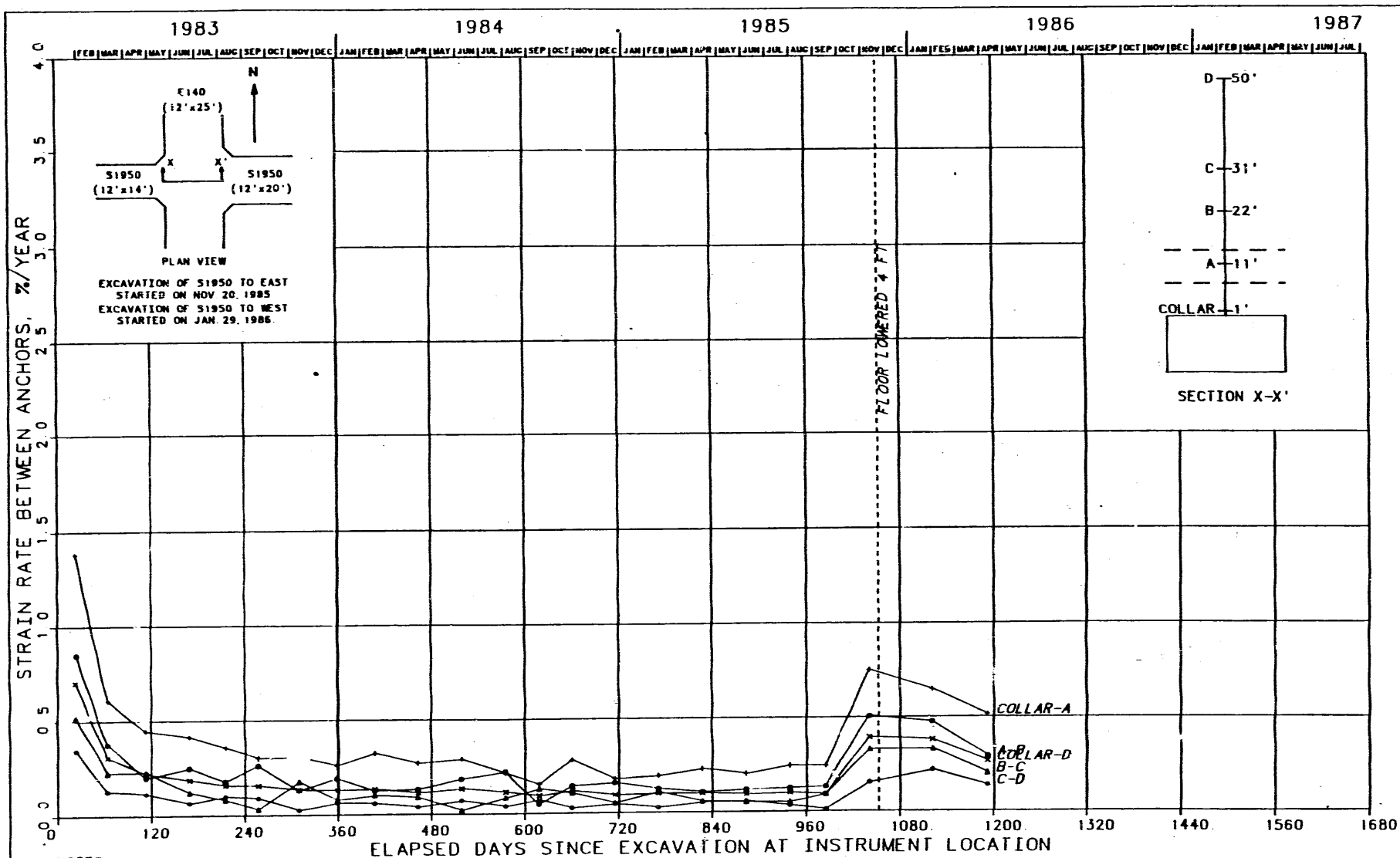
FIGURE K-30
MULTIPLE-POINT EXTENSOMETER 51X-GE-00241
N1100 – TEST ROOM 2 INTERSECTION – ROOF
STRAIN RATE VS. TIME SINCE EXCAVATION



NOTES

1 RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS

FIGURE K-31
MULTIPLE-POINT EXTENSOMETER 51X-GE-00242
N1100 - TEST ROOM 2 INTERSECTION - FLOOR
STRAIN RATE VS. TIME SINCE EXCAVATION

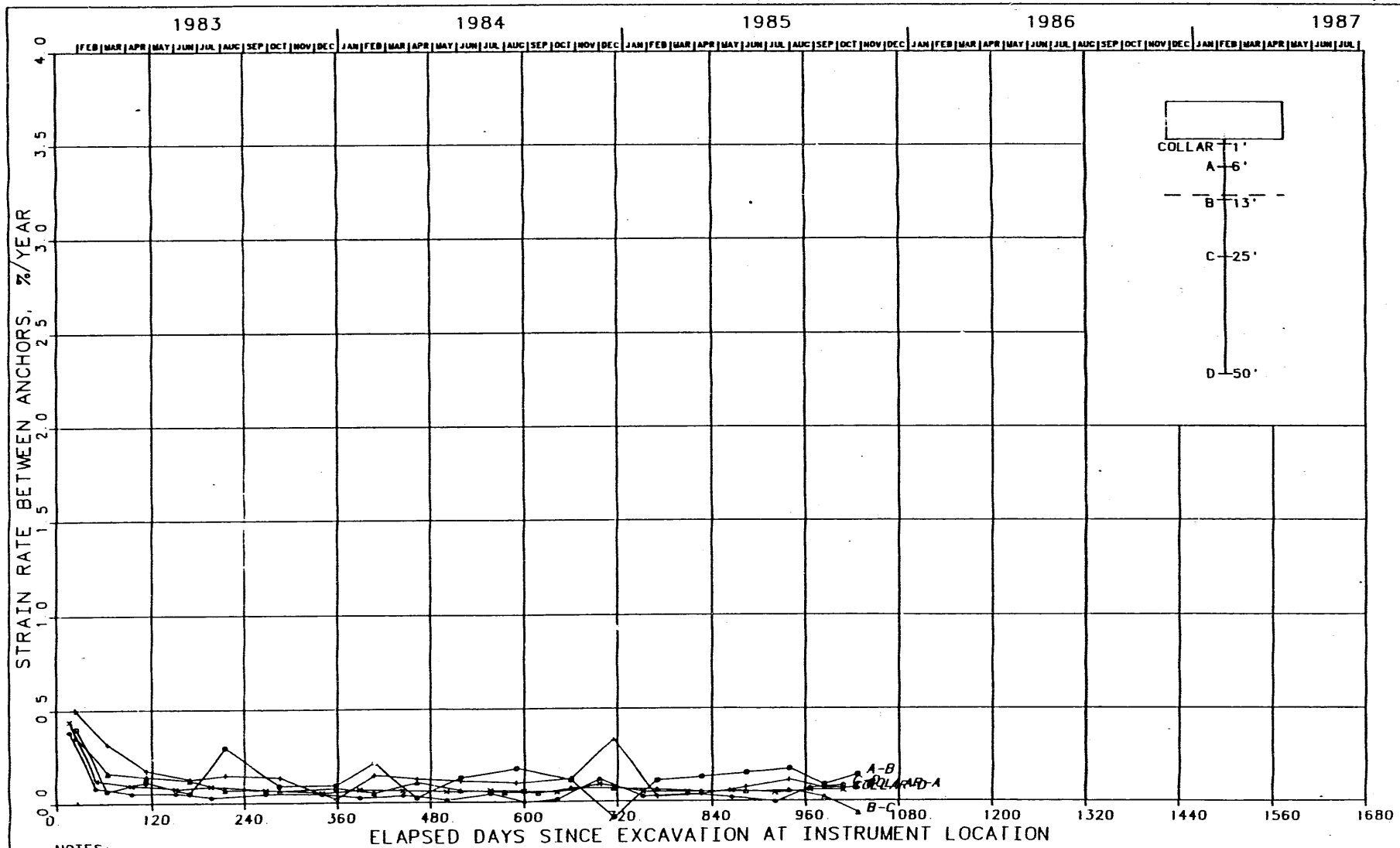


NOTES

1 RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS

2 SIZE OF EXCAVATION 12 FT X 25 FT

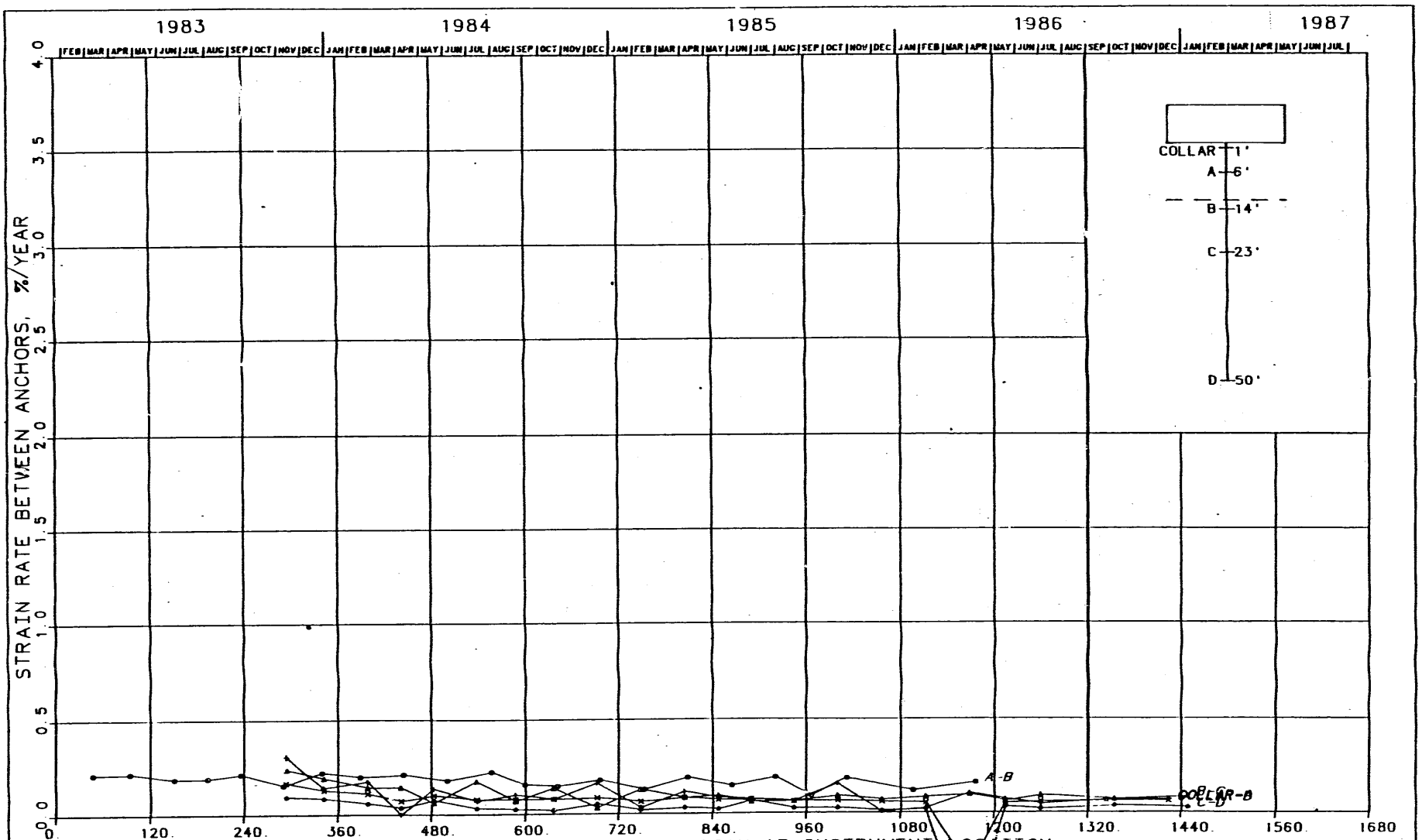
FIGURE K-32
MULTIPLE-POINT EXTENSOMETER 51X-GE-00247
E140 DRIFT, SOUTH 1950 FT – ROOF
STRAIN RATE VS. TIME SINCE EXCAVATION



NOTES

1 RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS
2. SIZE OF EXCAVATION 8 FT X 25 FT
3 INSTRUMENT HAS BEEN DESTROYED

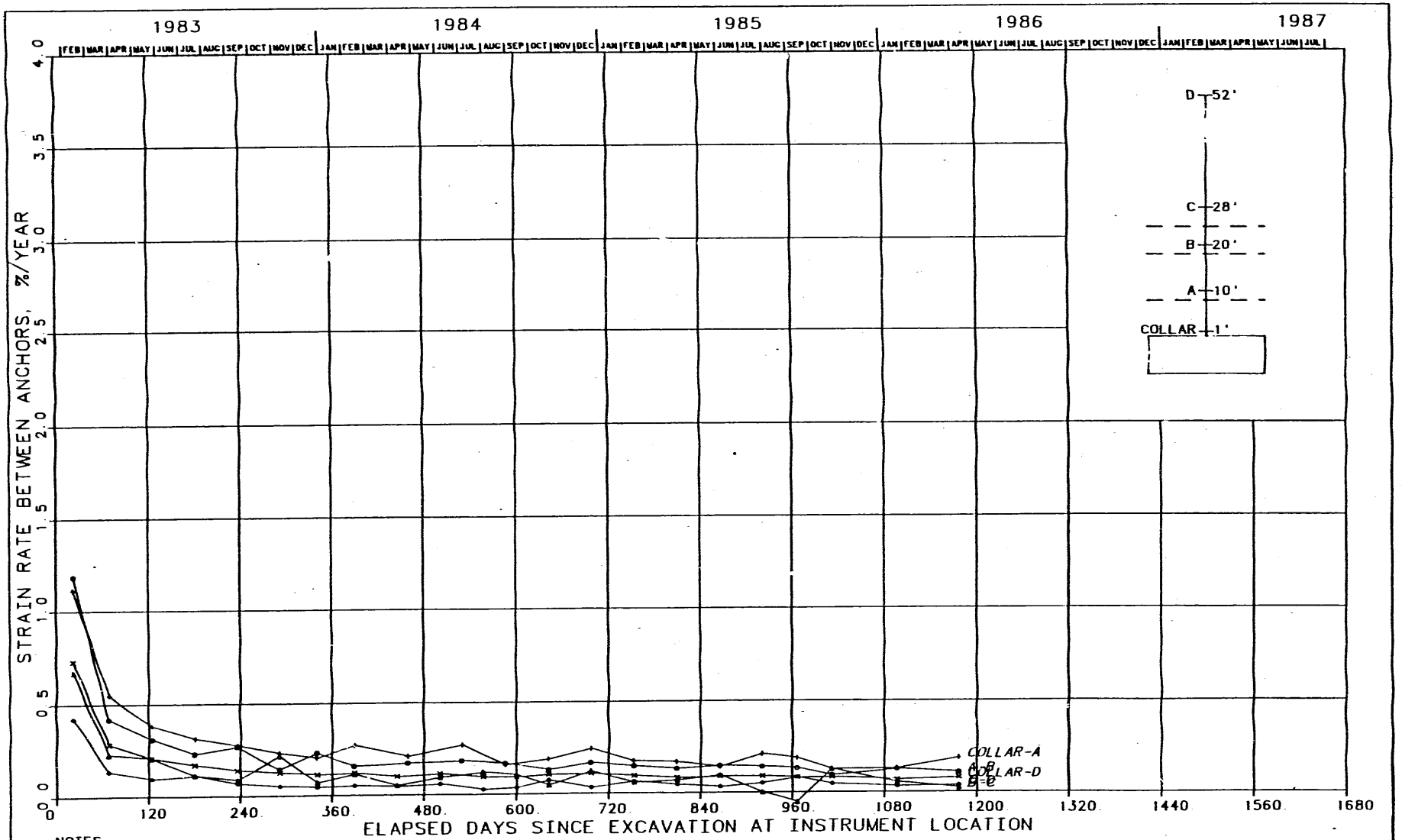
FIGURE K-33
MULTIPLE-POINT EXTENSOMETER 51X-GE-00248
E140 DRIFT, SOUTH 1950 FT - FLOOR
STRAIN RATE VS. TIME SINCE EXCAVATION



NOTES

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.
2. SIZE OF EXCAVATION 8 FT X 25 FT

FIGURE K-34
MULTIPLE-POINT EXTENSOMETER 51X-GE-00250
E140 DRIFT, SOUTH 3045 FT - FLOOR
STRAIN RATE VS. TIME SINCE EXCAVATION



NOTES

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.
2. SIZE OF EXCAVATION: 8 FT X 25 FT.

FIGURE K-35
MULTIPLE-POINT EXTENSOMETER 51X-GE-00249
E140 DRIFT, SOUTH 3080 FT – ROOF
STRAIN RATE VS. TIME SINCE EXCAVATION

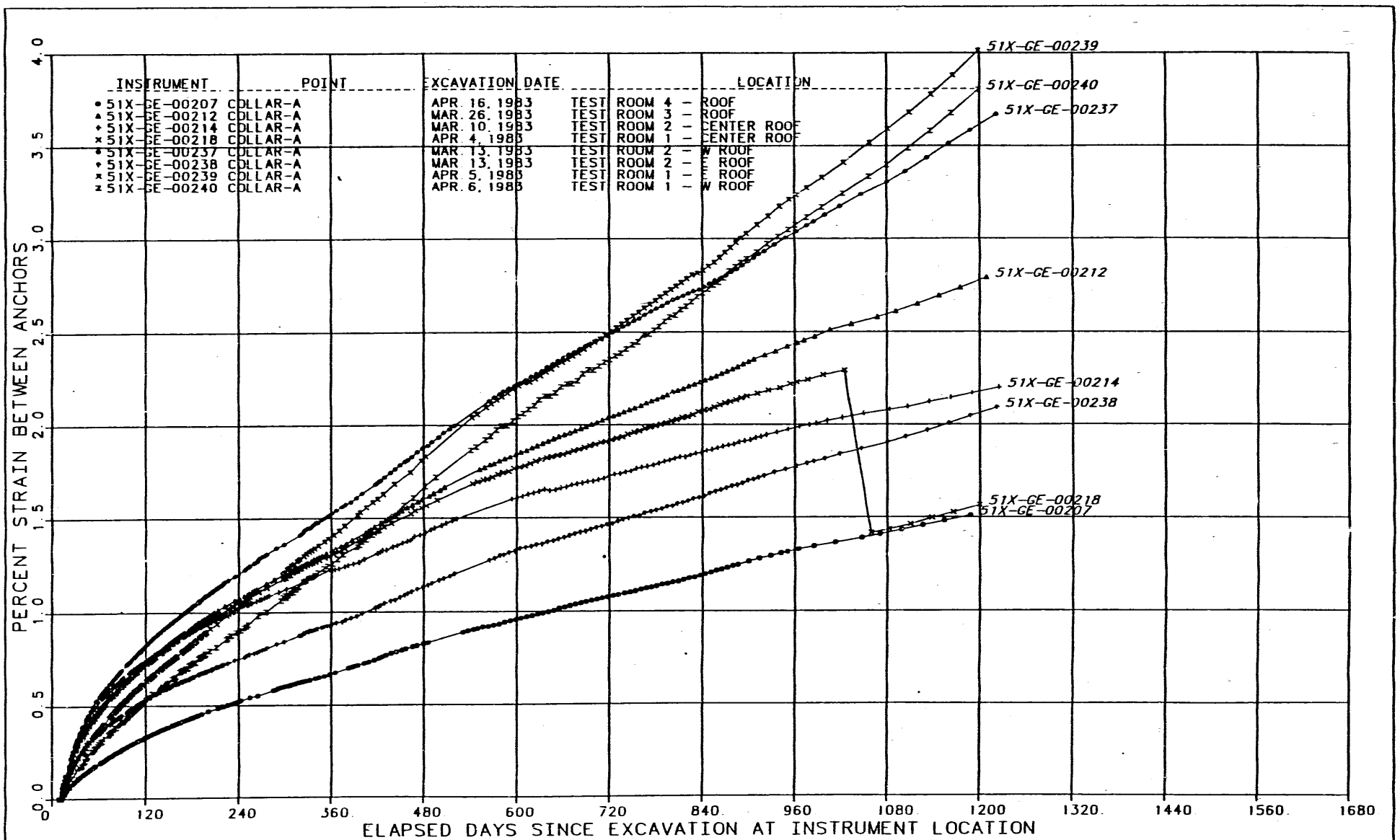


FIGURE K-36
TEST ROOM ROOF EXTENSOMETERS –
COLLAR TO ANCHOR A
STRAIN VS. TIME SINCE EXCAVATION

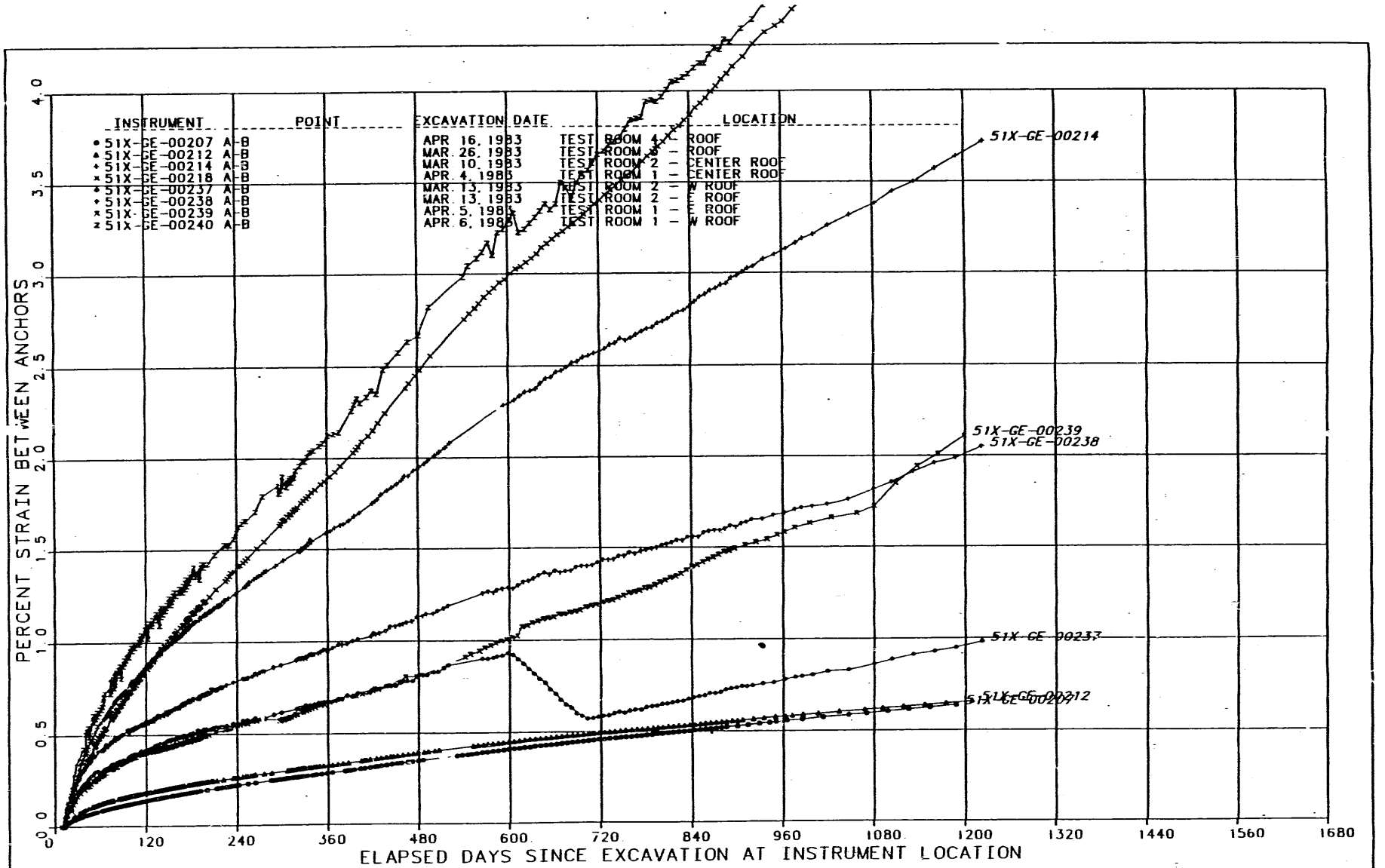


FIGURE K-37
TEST ROOM ROOF EXTENSOMETERS –
ANCHOR A TO ANCHOR B
STRAIN VS. TIME SINCE EXCAVATION

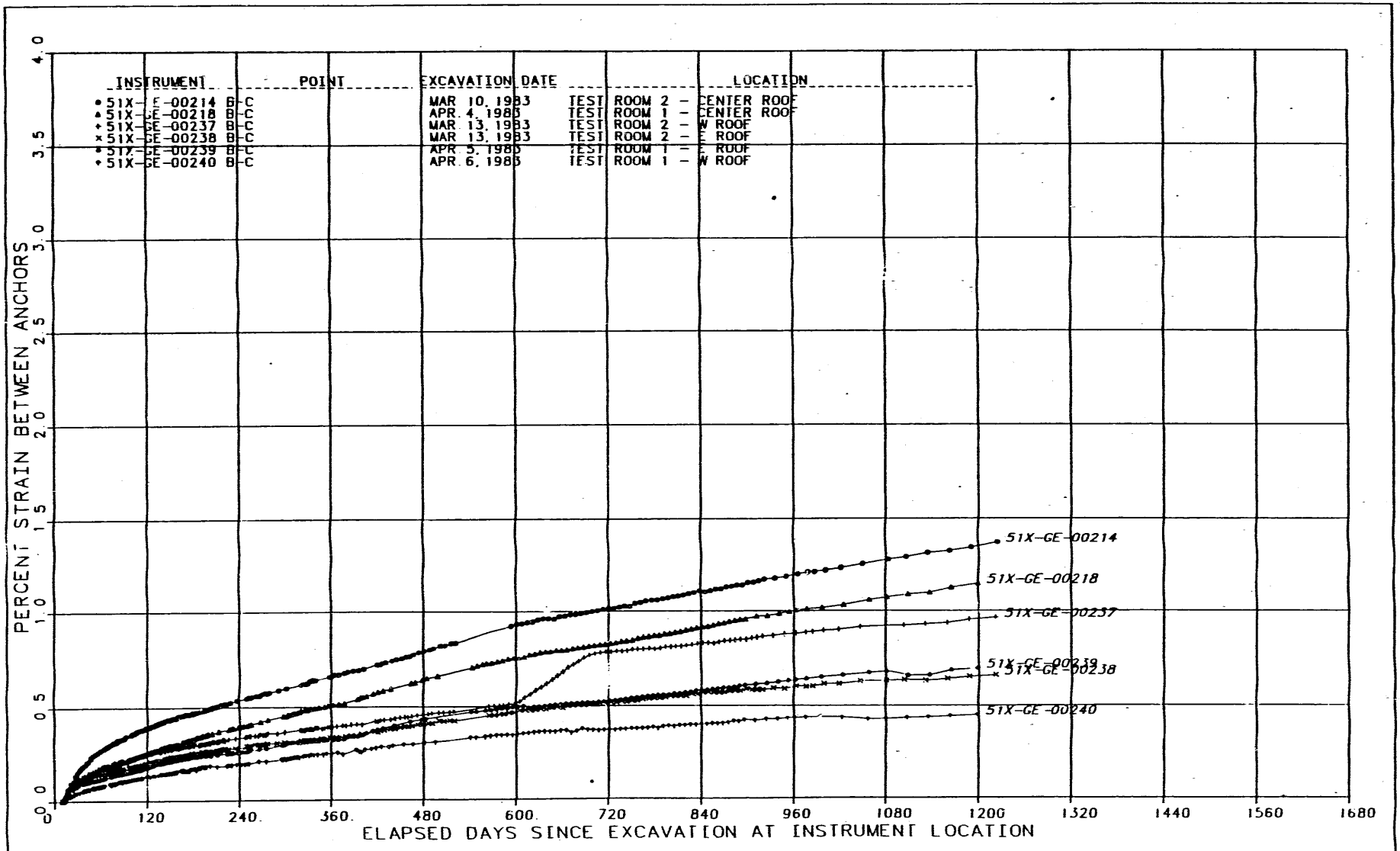


FIGURE K-38
TEST ROOM ROOF EXTENSOMETERS -
ANCHOR B TO ANCHOR C
STRAIN VS. TIME SINCE EXCAVATION

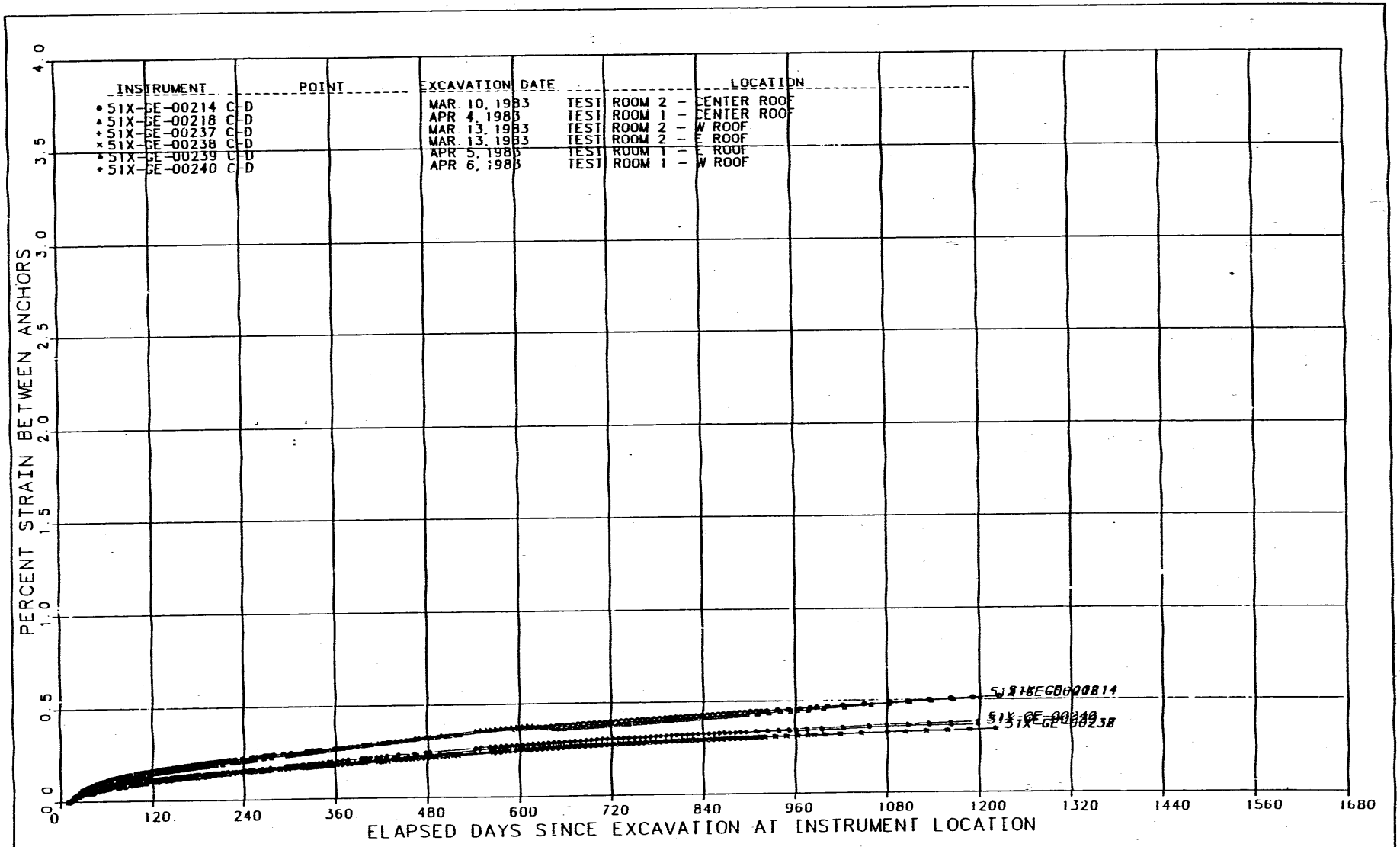


FIGURE K-39
TEST ROOM ROOF EXTENSOMETERS -
ANCHOR C TO ANCHOR D
STRAIN VS. TIME SINCE EXCAVATION

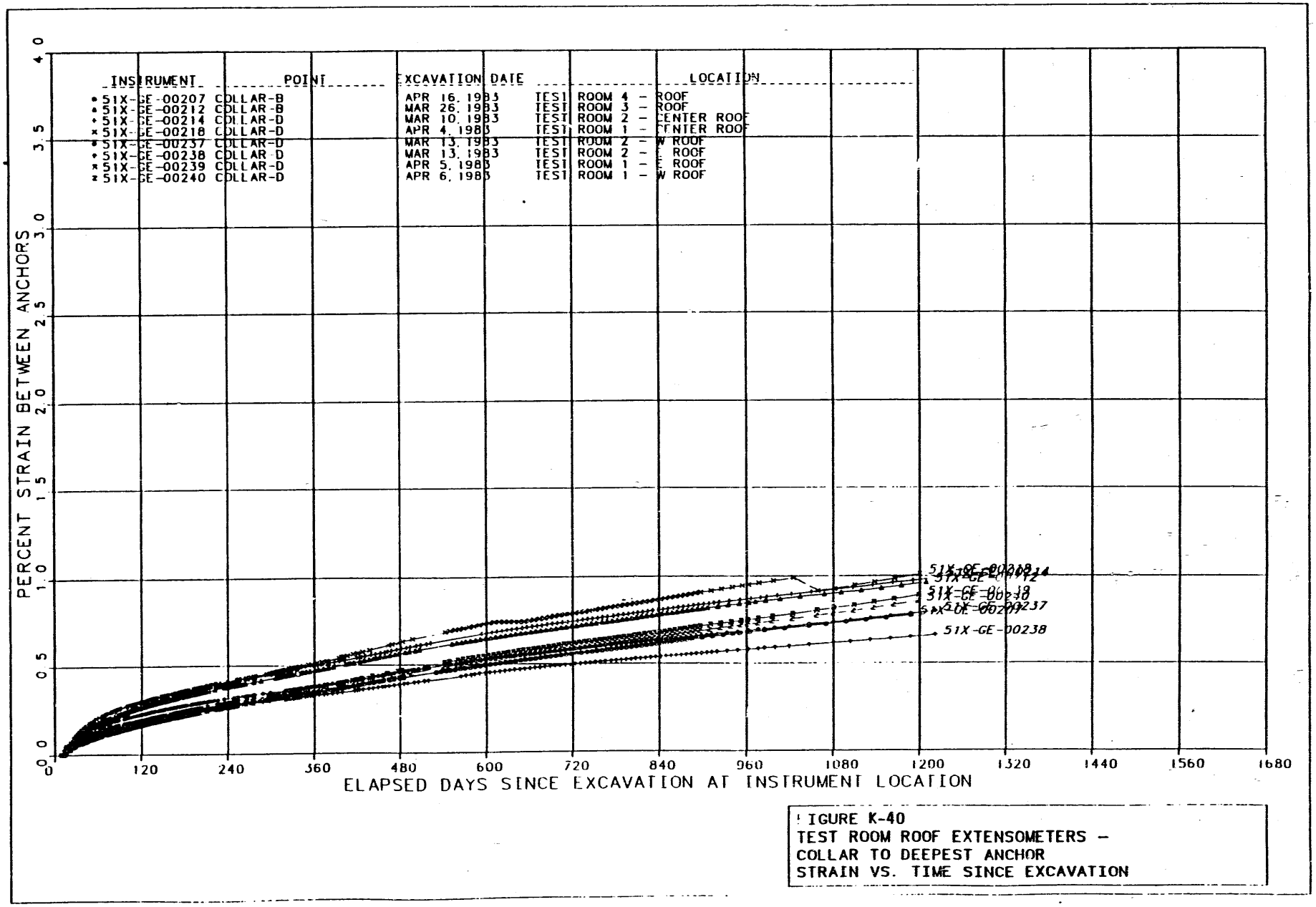


FIGURE K-40
TEST ROOM ROOF EXTENSOMETERS -
COLLAR TO DEEPEST ANCHOR
STRAIN VS. TIME SINCE EXCAVATION

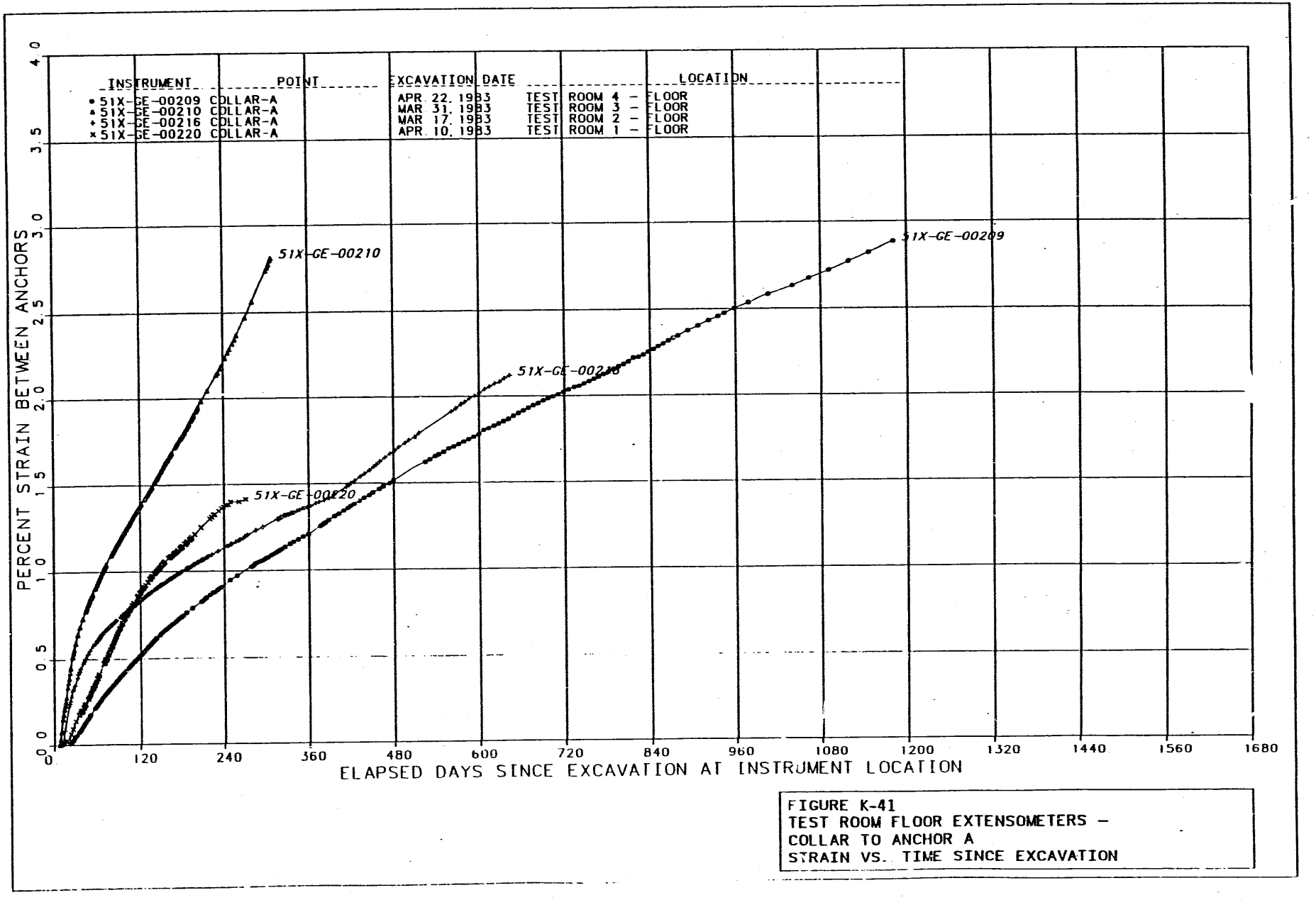


FIGURE K-41
TEST ROOM FLOOR EXTENSOMETERS -
COLLAR TO ANCHOR A
STRAIN VS. TIME SINCE EXCAVATION

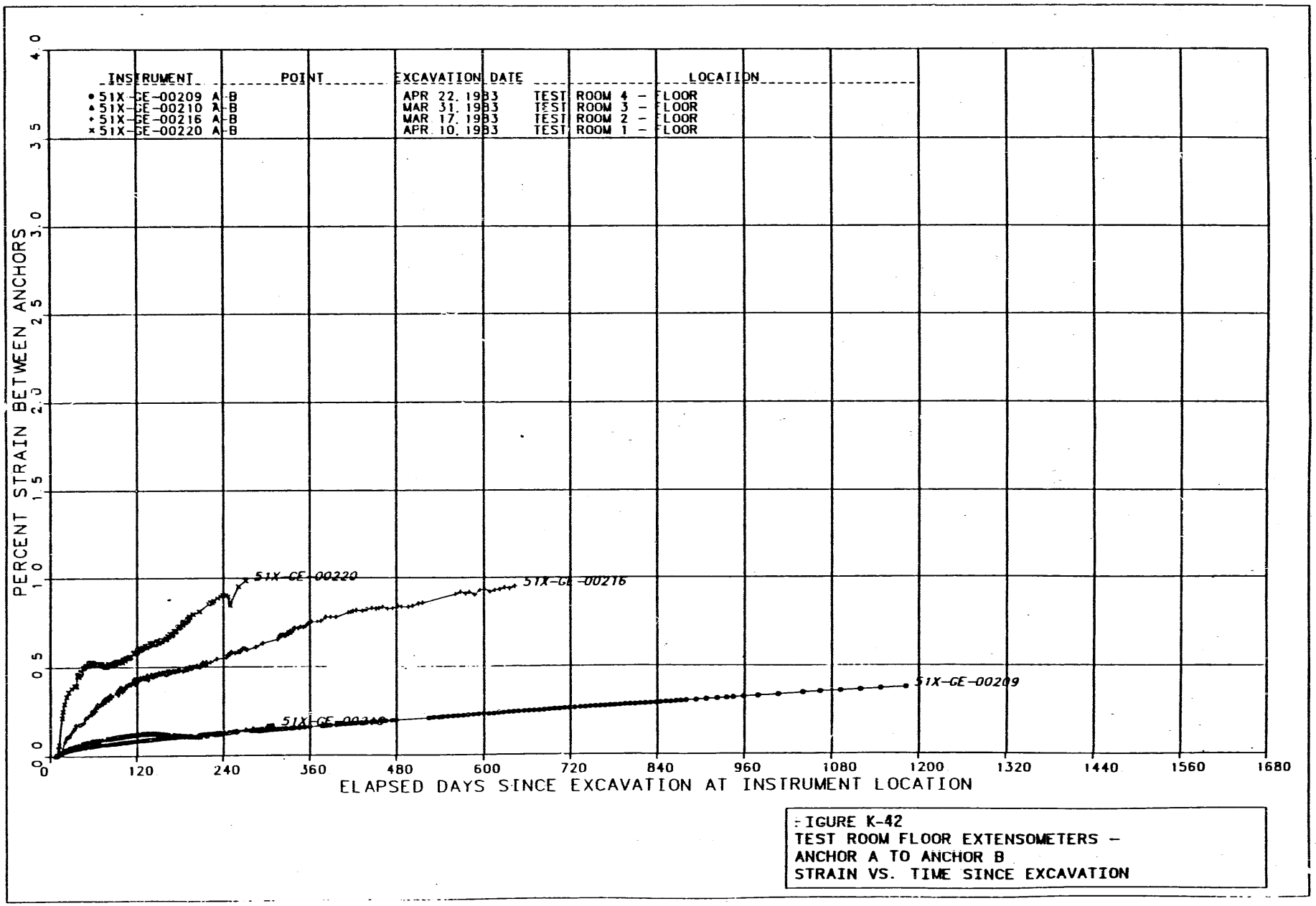


FIGURE K-42
TEST ROOM FLOOR EXTENSOMETERS -
ANCHOR A TO ANCHOR B
STRAIN VS. TIME SINCE EXCAVATION

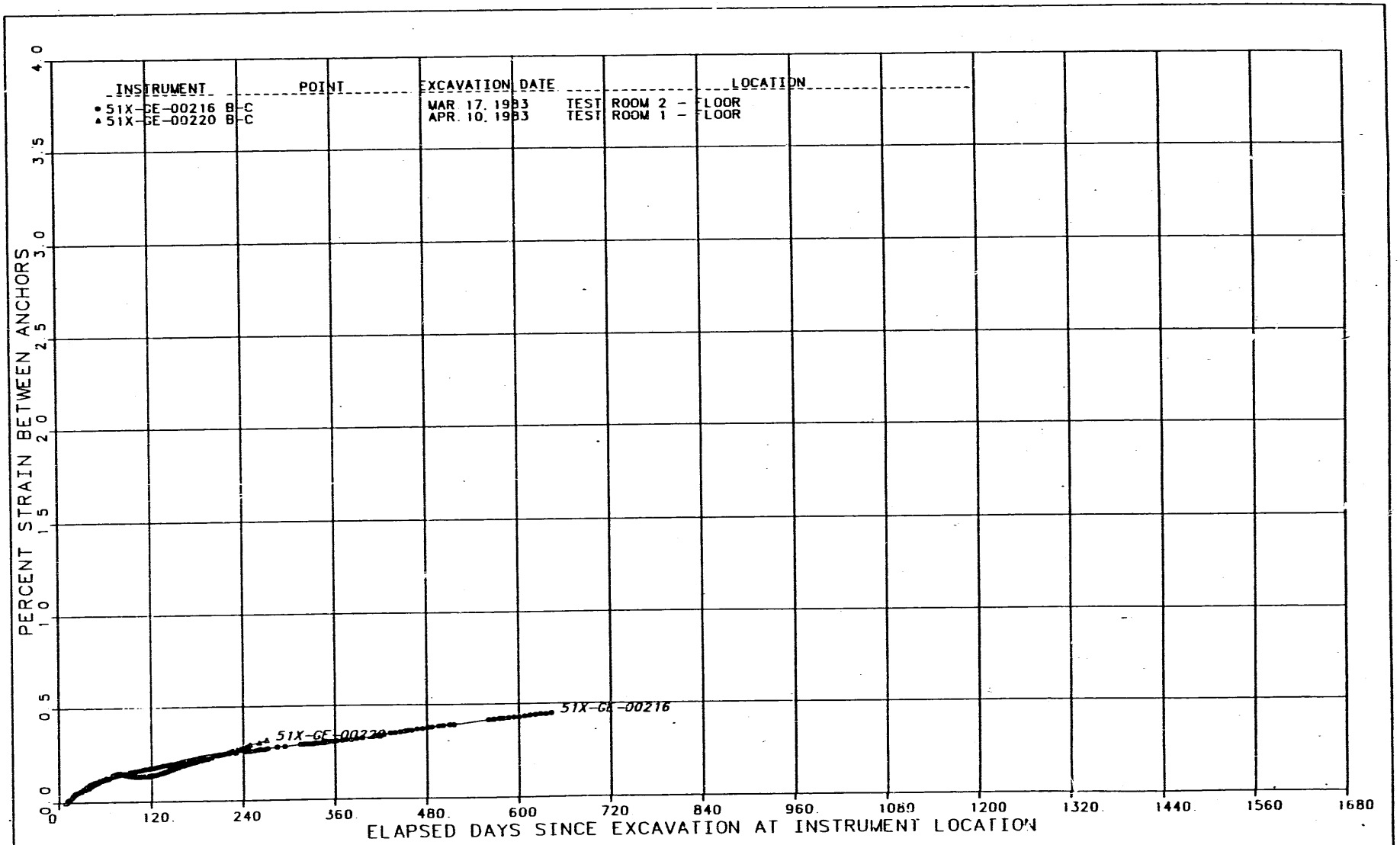


FIGURE K-43
TEST ROOM FLOOR EXTENSOMETERS -
ANCHOR B TO ANCHOR C
STRAIN VS. TIME SINCE EXCAVATION

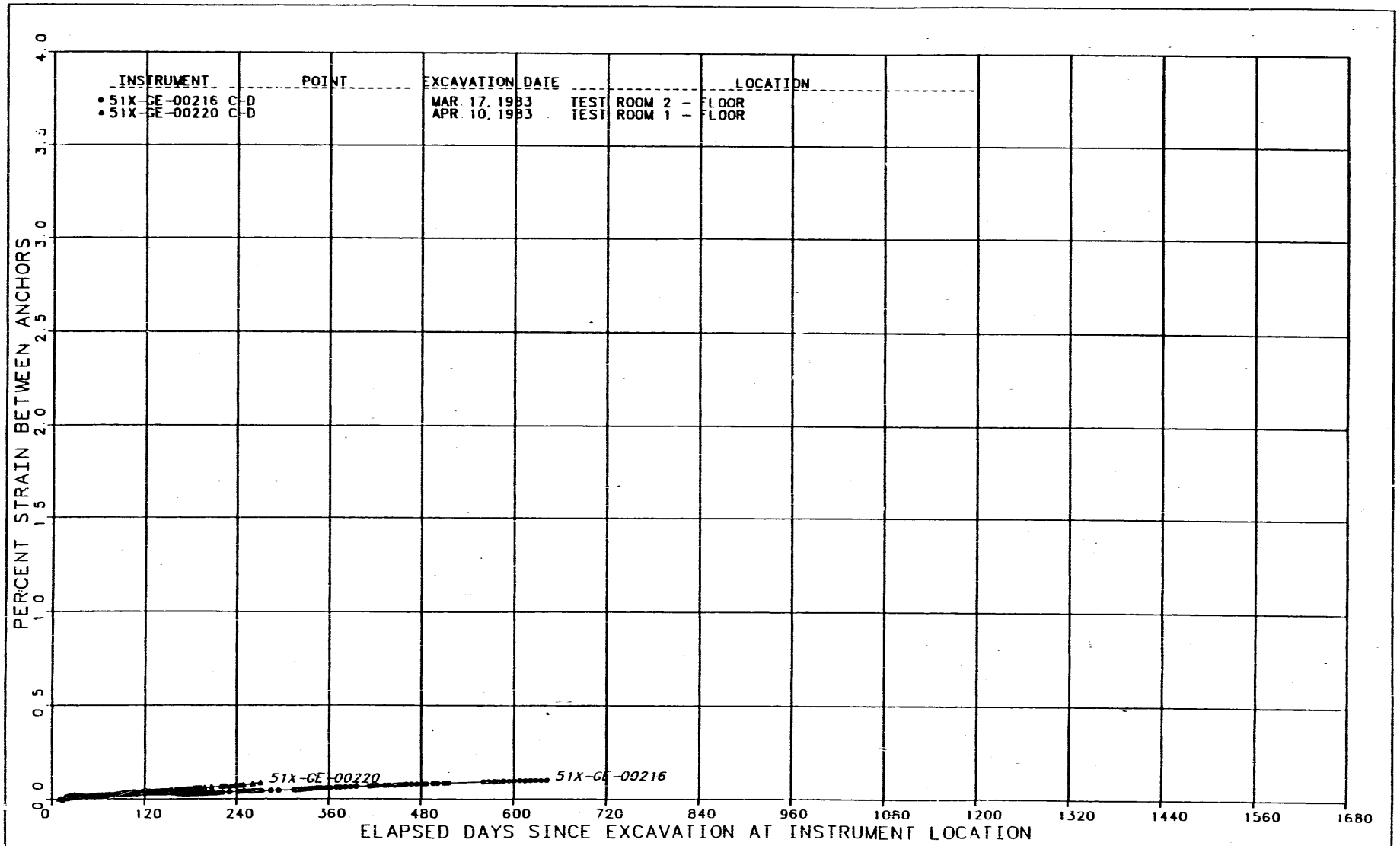


FIGURE K-44
TEST ROOM FLOOR EXTENSOMETERS -
ANCHOR C TO ANCHOR D
STRAIN VS. TIME SINCE EXCAVATION

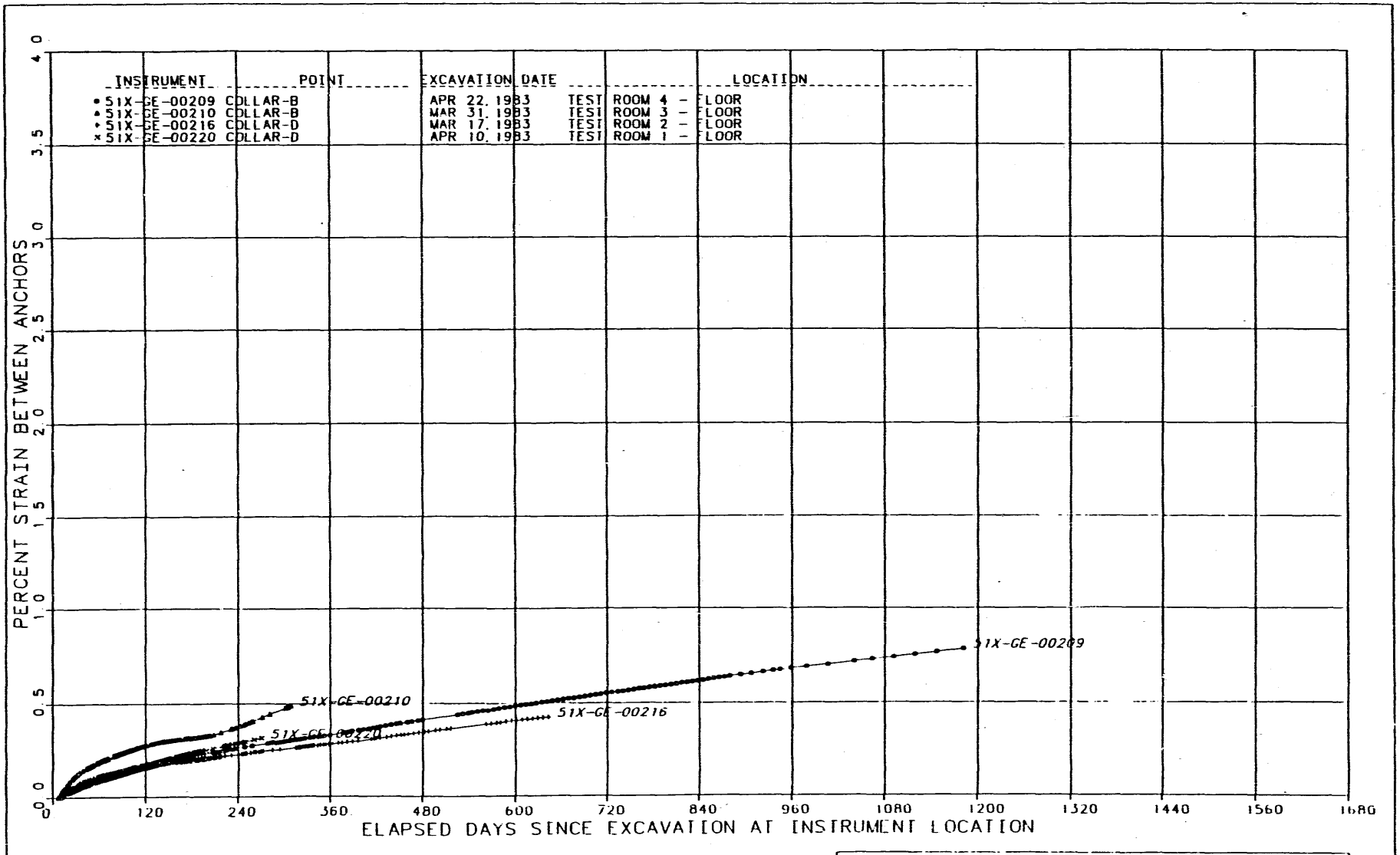
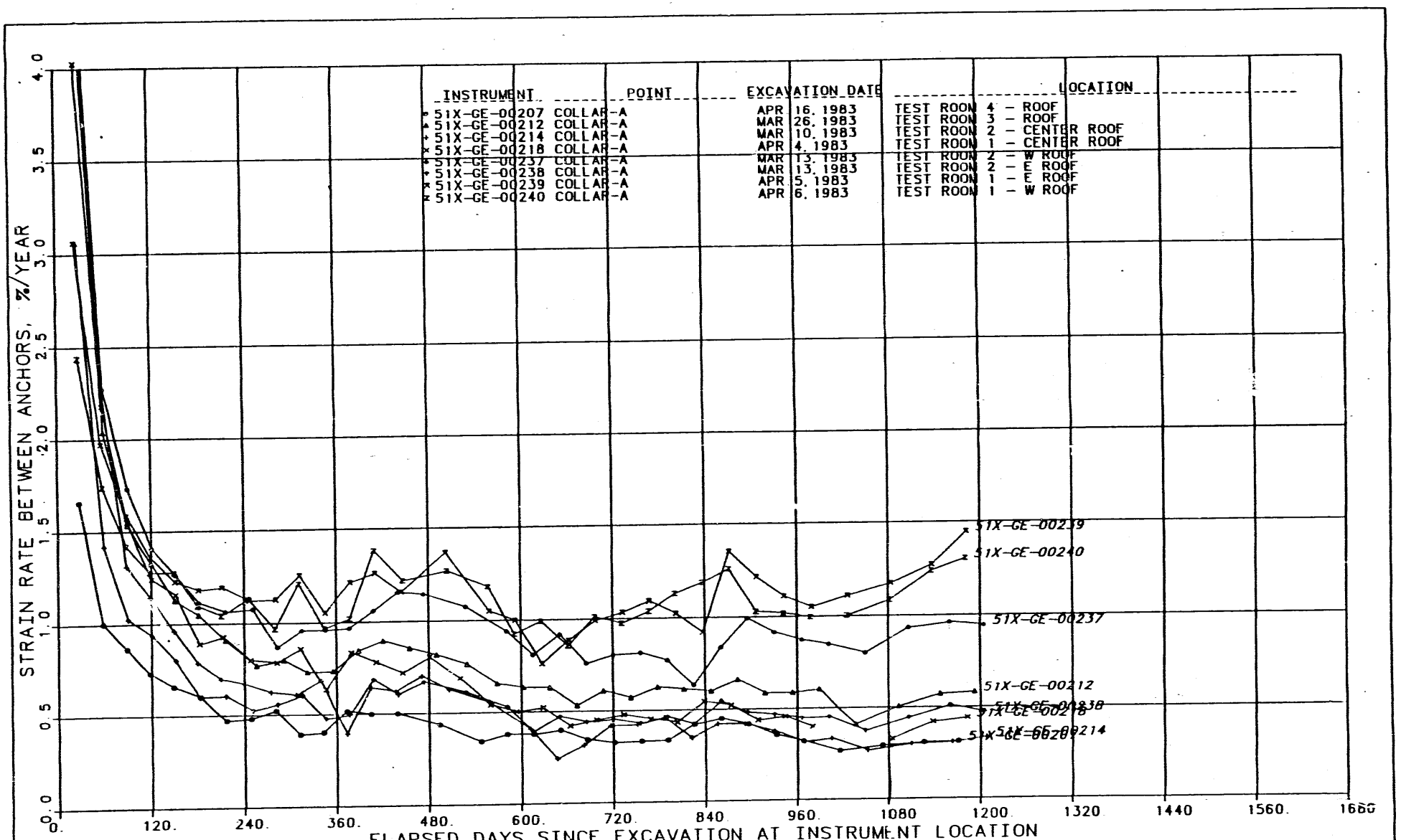


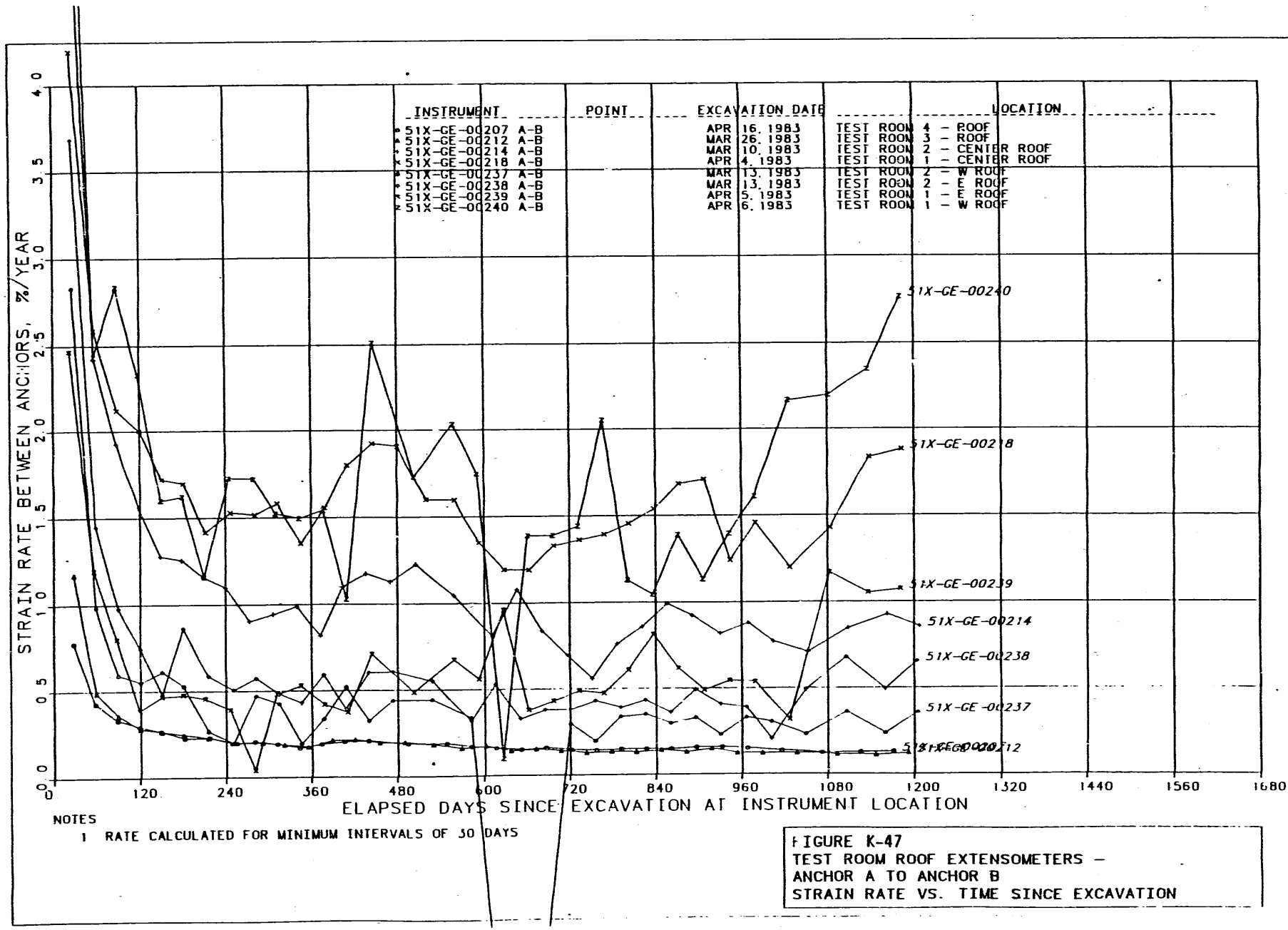
FIGURE K-45
TEST ROOM FLOOR EXTENSOMETERS -
COLLAR TO DEEPEST ANCHOR
STRAIN VS. TIME SINCE EXCAVATION



NOTES:

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.

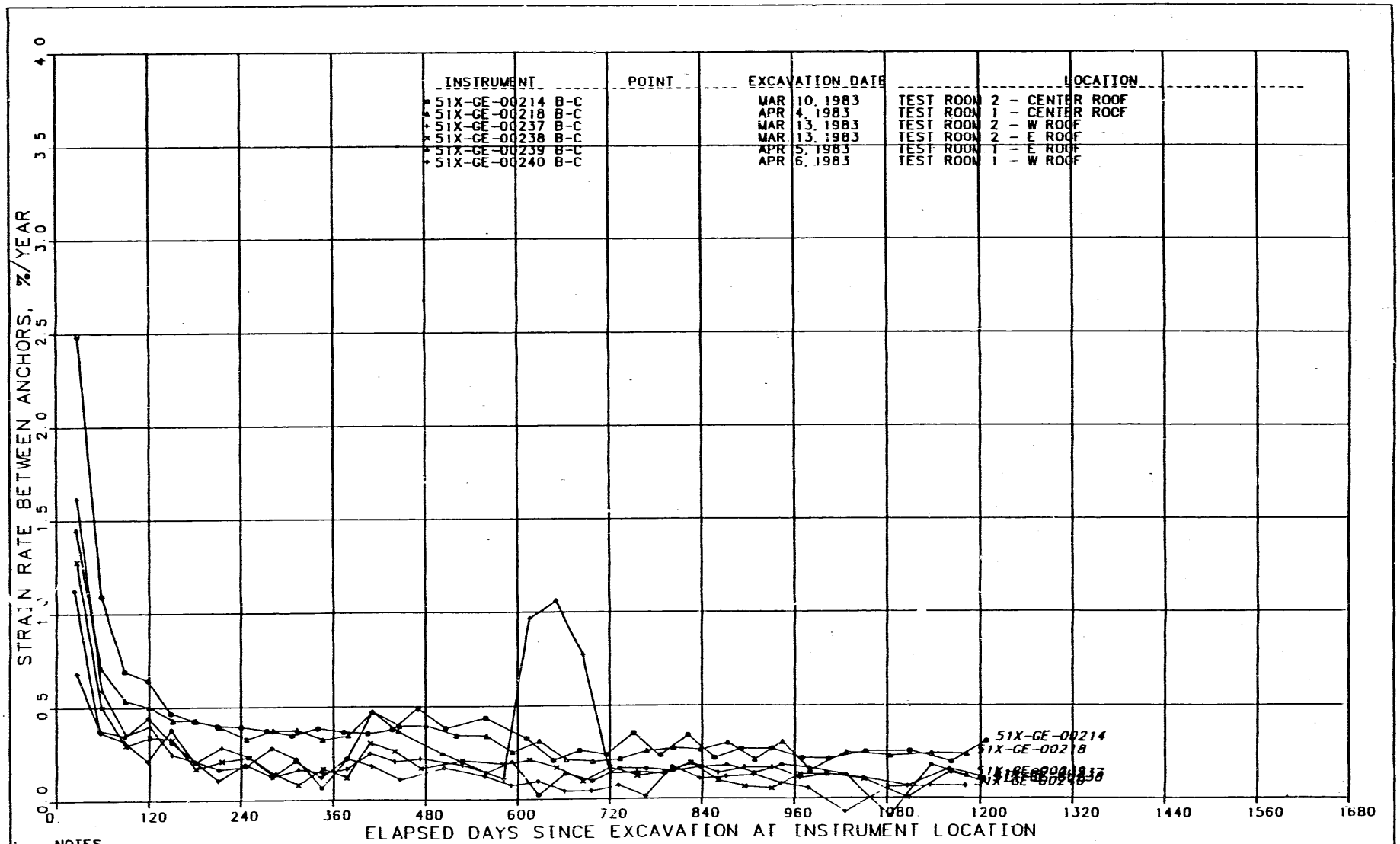
FIGURE K-46
TEST ROOM ROOF EXTENSOMETERS -
COLLAR TO ANCHOR A
STRAIN RATE VS. TIME SINCE EXCAVATION



NOTES

1 RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS

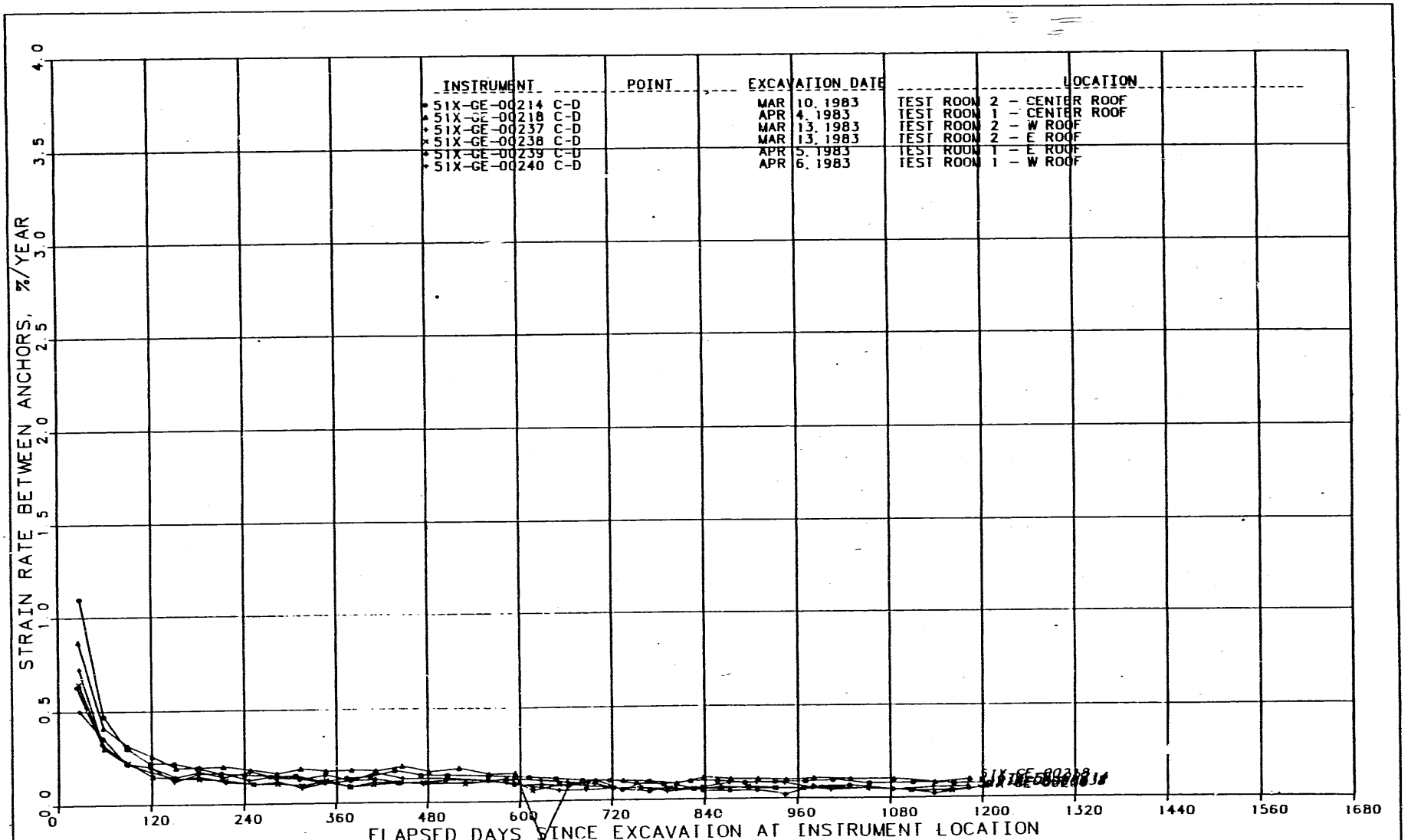
FIGURE K-47
TEST ROOM ROOF EXTENSOMETERS -
ANCHOR A TO ANCHOR B
STRAIN RATE VS. TIME SINCE EXCAVATION



NOTES

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.

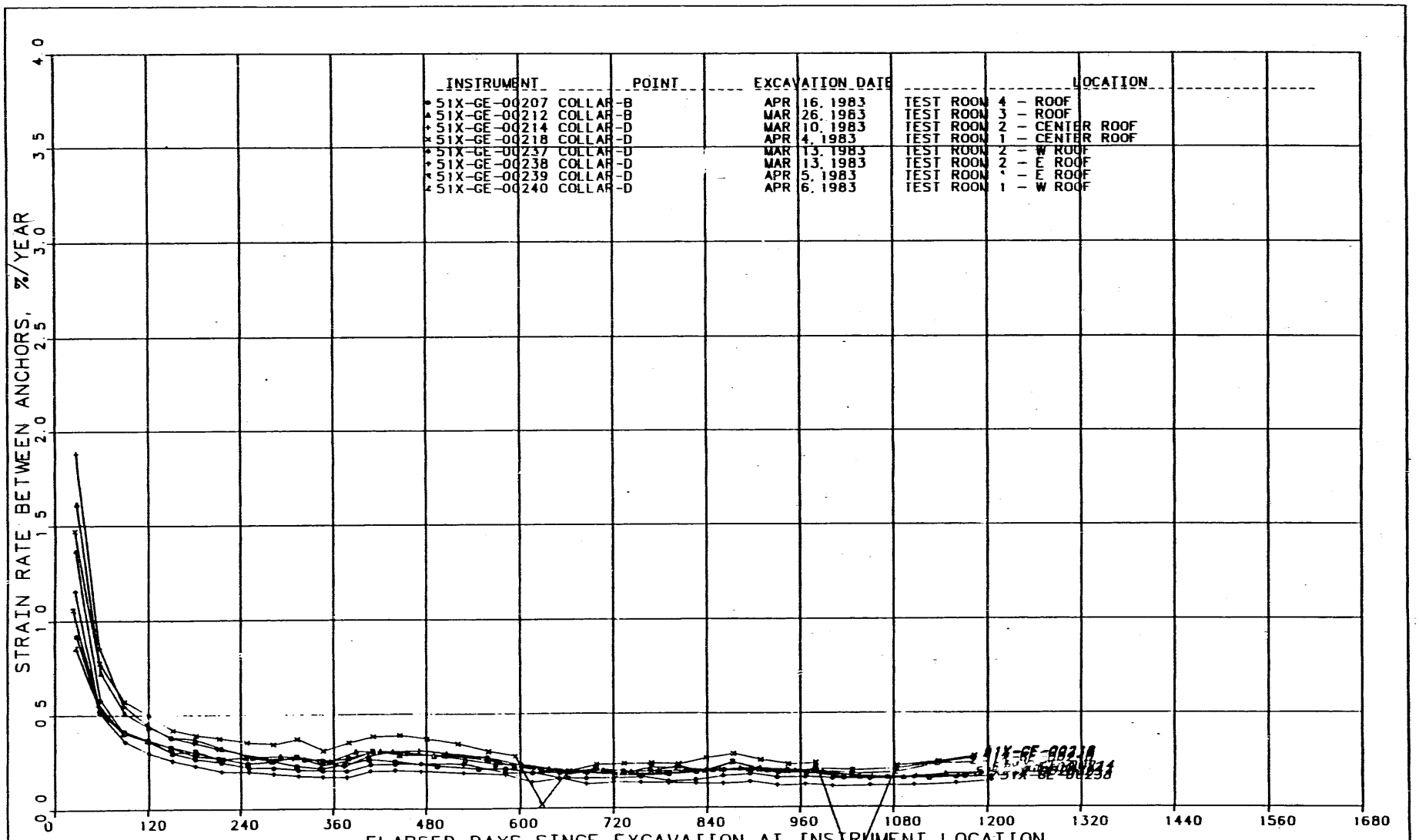
FIGURE K-48
TEST ROOM ROOF EXTENSOMETERS -
ANCHOR B TO ANCHOR C
STRAIN RATE VS. TIME SINCE EXCAVATION



NOTES

1 RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS

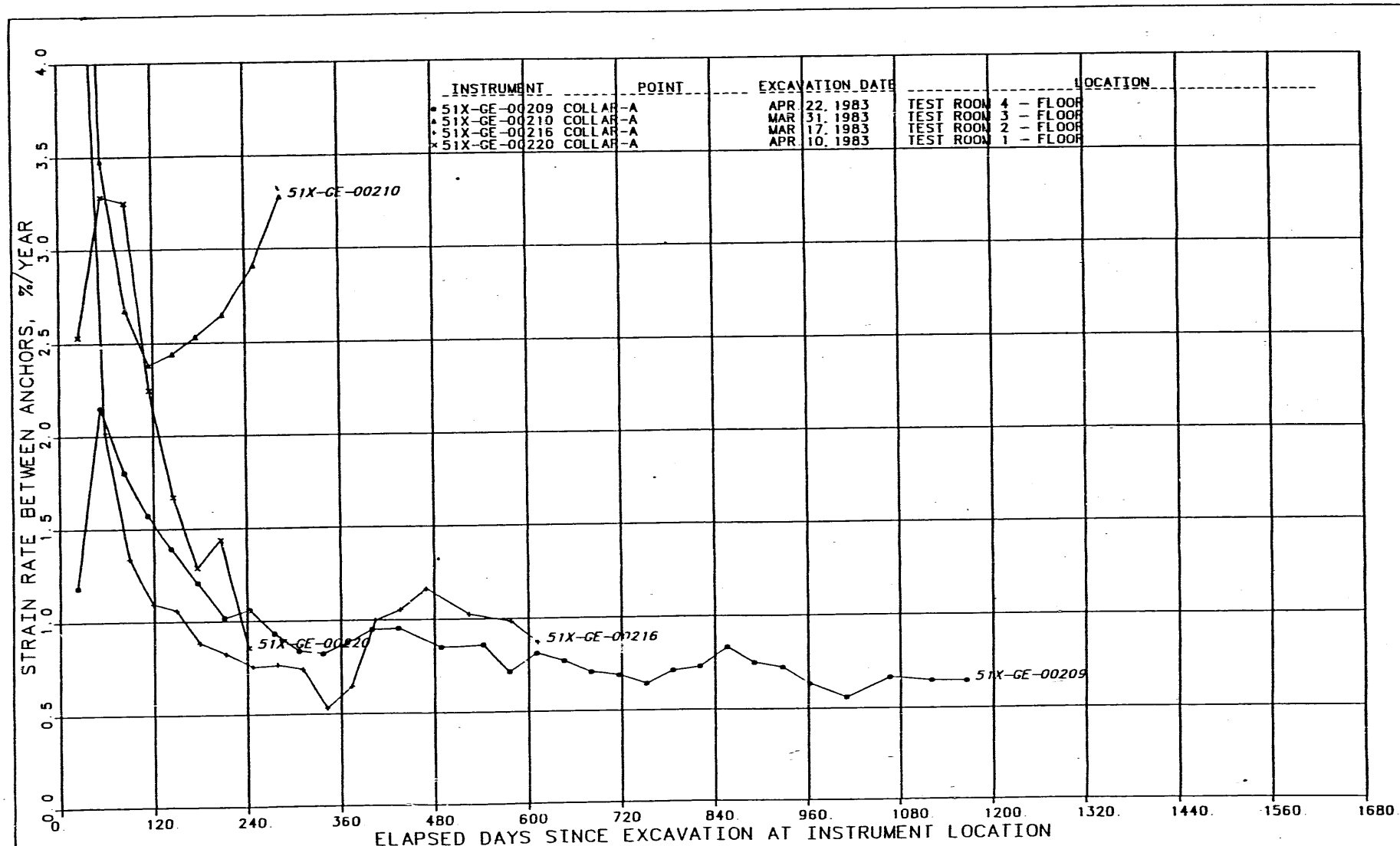
FIGURE K-49
TEST ROOM ROOF EXTENSOMETERS -
ANCHOR C TO ANCHOR D
STRAIN RATE VS. TIME SINCE EXCAVATION



NOTES

1 RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS

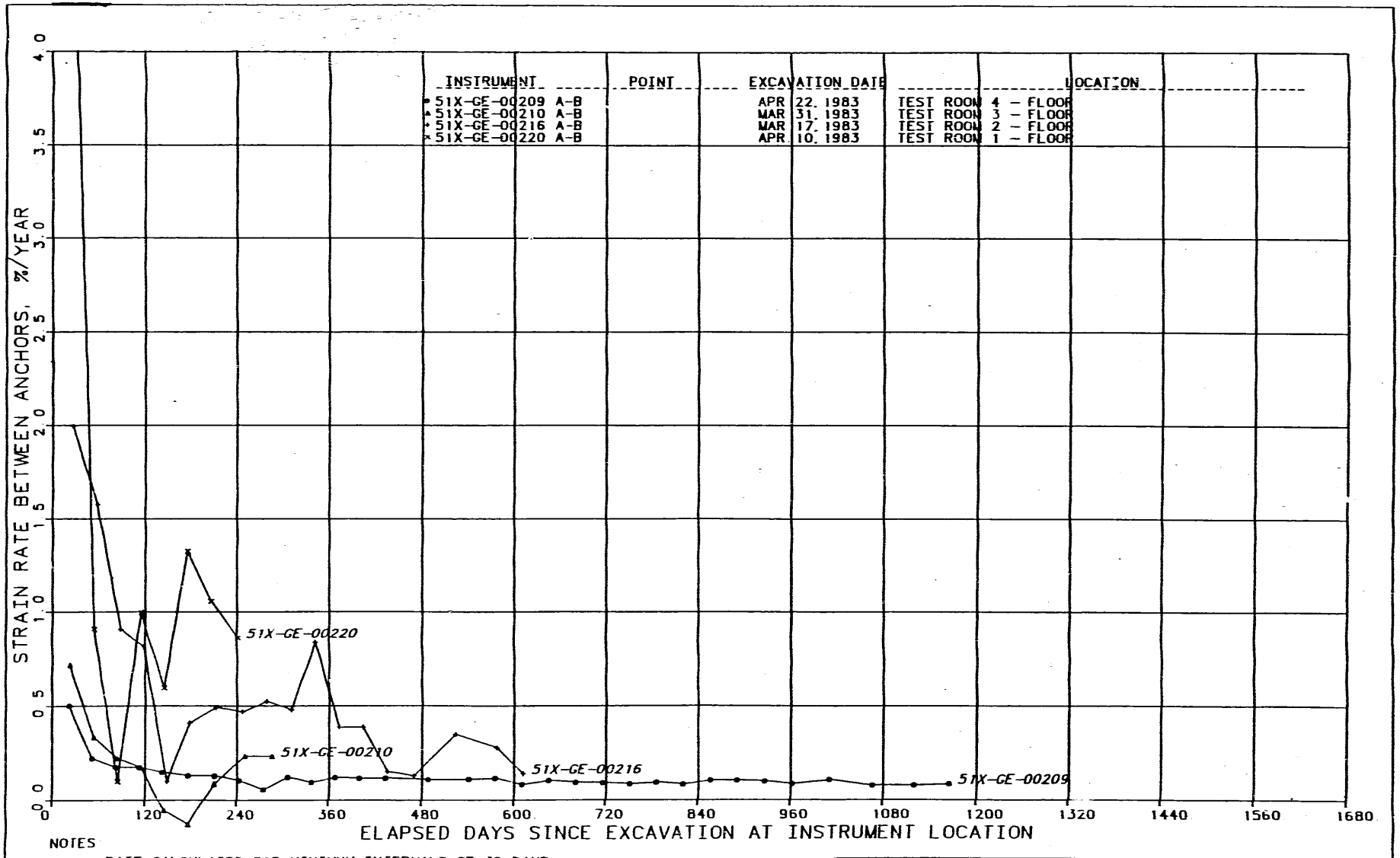
FIGURE K-50
TEST ROOM ROOF EXTENSOMETERS
COLLAR TO DEEPEST ANCHOR
STRAIN RATE VS. TIME SINCE EXCAVATION



NOTES:

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS

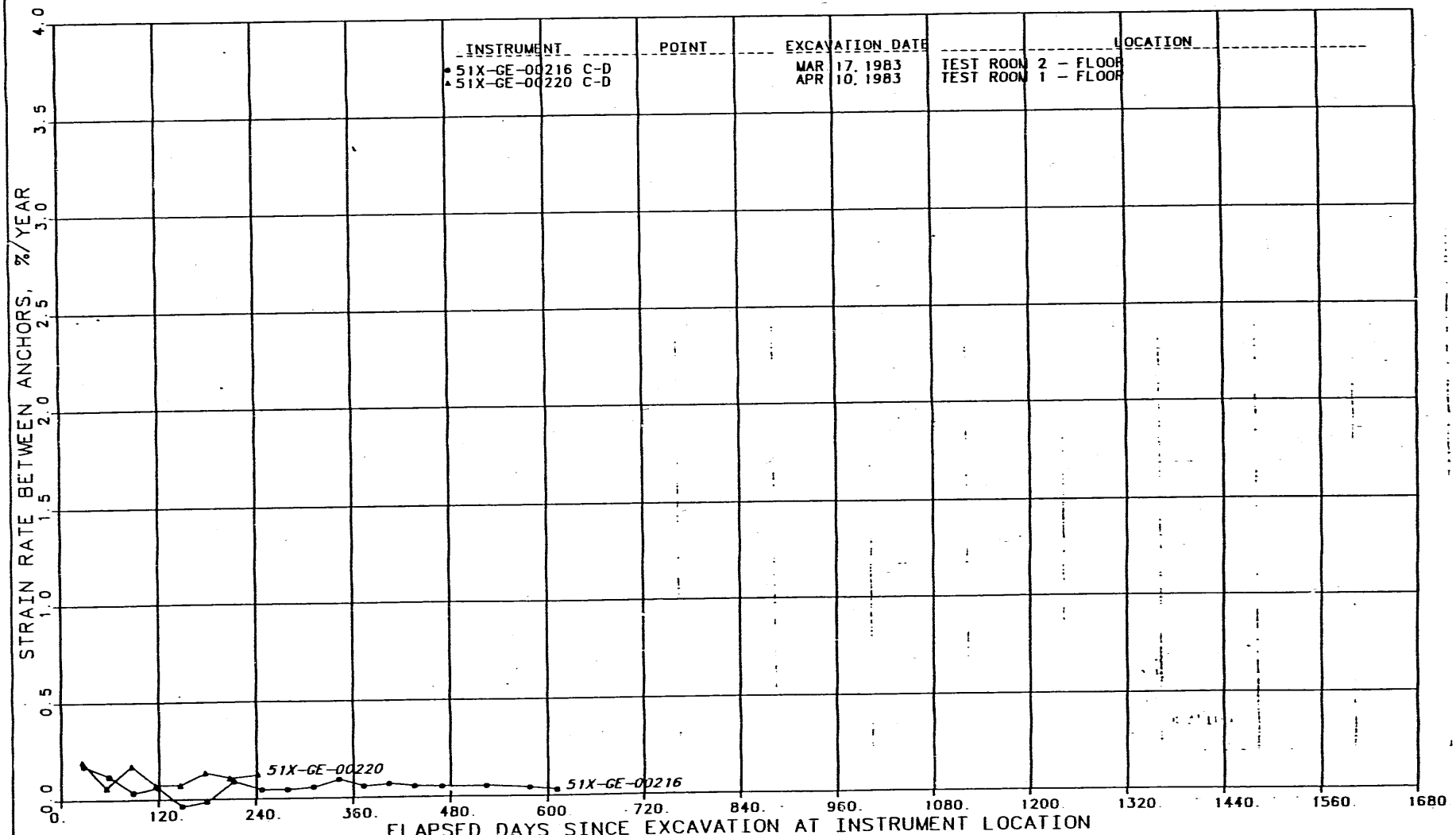
FIGURE K-51
TEST ROOM FLOOR EXTENSOMETERS -
COLLAR TO ANCHOR A
STRAIN RATE VS. TIME SINCE EXCAVATION



NOTES

1 RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS

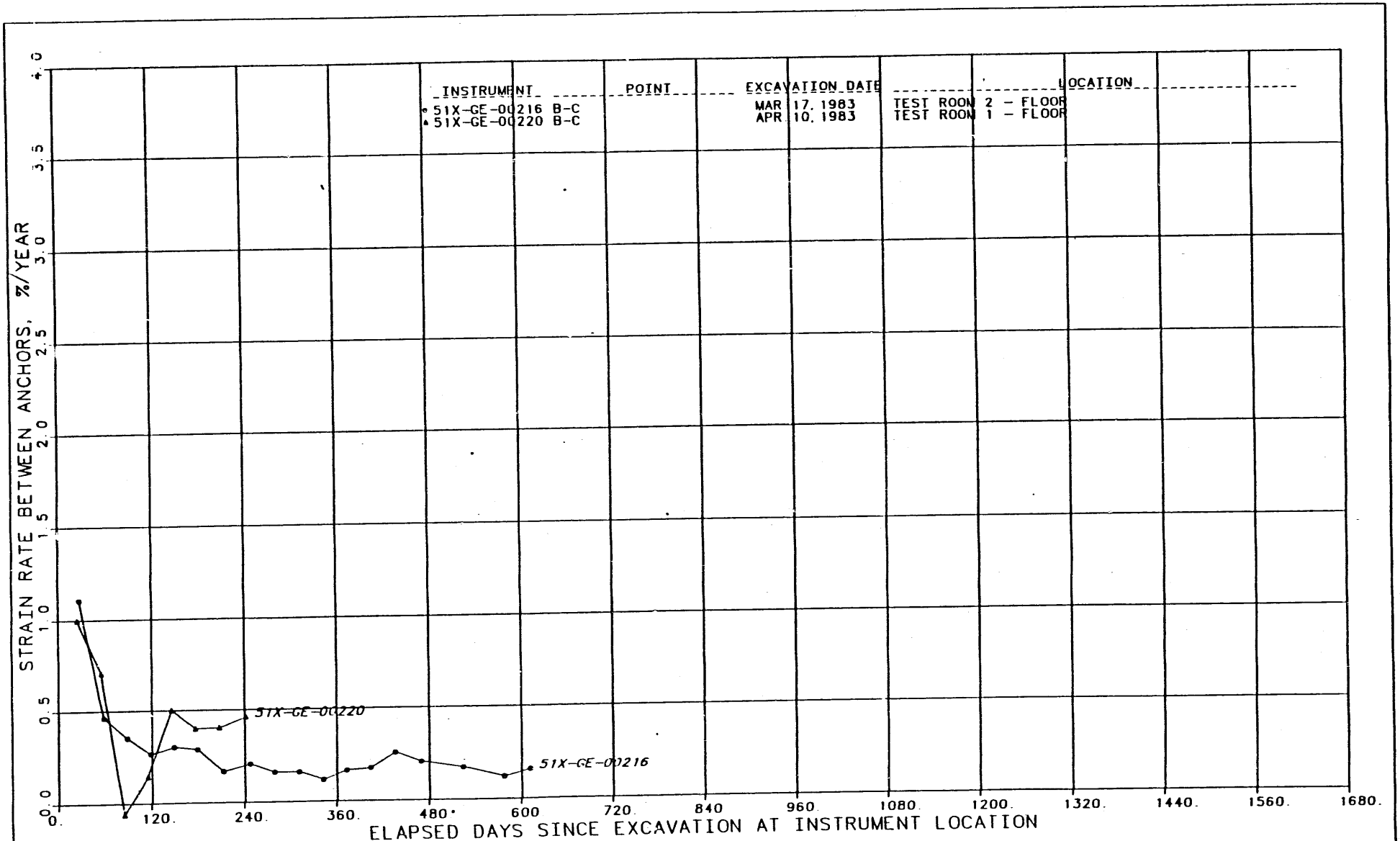
FIGURE K-52
TEST ROOM FLOOR EXTENSOMETERS -
ANCHOR A TO ANCHOR B
STRAIN RATE VS. TIME SINCE EXCAVATION



NOTES:

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.

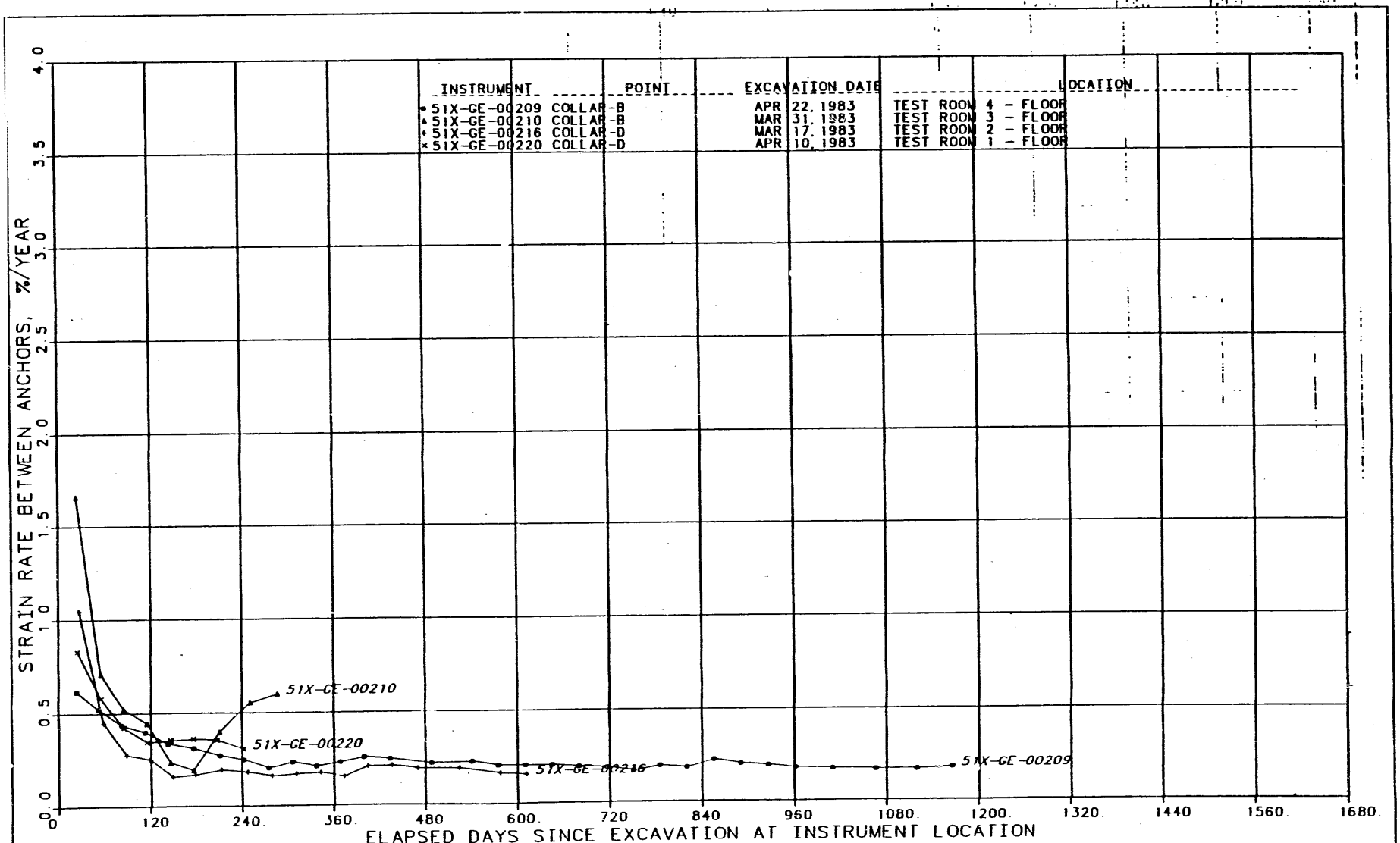
FIGURE K-54
TEST ROOM FLOOR EXTENSOMETERS -
ANCHOR C TO ANCHOR D
STRAIN RATE VS. TIME SINCE EXCAVATION



NOTES:

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS.

FIGURE K-53
TEST ROOM FLOOR EXTENSOMETERS -
ANCHOR B TO ANCHOR C
STRAIN RATE VS. TIME SINCE EXCAVATION



NOTES

1. RATE CALCULATED FOR MINIMUM INTERVALS OF 30 DAYS

FIGURE K-55
TEST ROOM FLOOR EXTENSOMETERS --
COLLAR TO DEEPEST ANCHOR
STRAIN RATE VS. TIME SINCE EXCAVATION

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Volume IV of VII

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WASTE ISOLATION PILOT PLANT

WIPP

Waste Isolation Pilot Plant

Carlsbad, New Mexico

MASTER

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APPENDIX D2

ENGINEERING DESIGN BASIS REPORTS

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Report	Seismic Evaluation Report of Underground Facilities
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SPEC. No. D-0077	VOC-10 Monitoring System
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SPEC. No. E-S-362	VOC Monitoring Station Located in the Exhaust Shaft at Station A

DESIGN CONSIDERATIONS FOR THE WASTE HOIST OF THE WASTE ISOLATION PILOT PLANT (WIPP)

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ABSTRACT

The U.S. Department of Energy is currently constructing the Waste Isolation Pilot Plant near Carlsbad, New Mexico. The full-scale pilot plant will demonstrate the feasibility of the safe disposal of defense-related nuclear waste in a bedded salt formation at a depth of 2160 feet below the surface. WIPP will provide for the permanent storage of 25,000 cu ft of remote-handled (RH) transuranic waste and 6,000,000 cu ft of contact-handled (CH) transuranic waste. The technical and operational principles of permanent isolation of defense waste in the geologic medium will also be demonstrated.

The waste containers are received in the waste handling building where inspections and mechanical processes are conducted. Then they are taken to the waste hoist tower above the waste shaft and loaded into a waste conveyance which is lowered down to the underground facility level by the waste hoist. The waste hoist and conveyance also transport underground personnel and equipment during routine operations.

This paper covers the major mechnaical/structural design considerations for the waste hoist and its hoist tower structure. The design of the hoist system components is described which includes the direct-drive friction hoist, conveyance, counterweight, ropes and guides, and the conveyance chairing device. Arrestors, crash beams and catch-gears are also discussed. The design of the hoist system and safety features incorporates state-of-the-art technology developed in the hoist and mining industry to ensure safe operation for transporting nuclear waste underground.

INTRODUCTION

In parallel with the program dealing with disposal of waste from nuclear power projects, the U.S. Department of Energy (DOE) is constructing the Waste Isolation Pilot Plant (WIPP) to demonstrate the feasibility of the safe disposal of defense-related nuclear waste in the bedded salt deposits of the Delaware Basin near Carlsbad, N.M. This full-scale pilot plant facility will provide for the permanent storage of 25,000 cu ft of remote-handled (RH) transuranic (TRU) waste and 6,000,000 cu ft of contact-handled (CH) TRU waste in deep underground salt beds. The WIPP facility will also demonstrate the technical and operational principles of permanent isolation of the defense waste in an underground salt formation. As a secondary objective, it will provide an experimental facility for the further understanding of the behavior of high-level waste in this geologic medium. This information will be useful for the future development of permanent repositories for defense and commercial nuclear waste.

The underground facility of WIPP is 2160 ft below ground and near the middle of a salt formation 2,000 ft thick. The completed facility will contain a network of access drifts and storage rooms. The underground facility is connected to the surface facilities by three vertical shafts: the waste shaft, the construction and salt-handling shaft, and the exhaust shaft.

The CH waste drums and RH waste canisters are received in separate parts of the waste handling building where inspections and mechanical processes are conducted. Then the waste containers are taken to the waste hoist tower above the waste shaft and loaded into a waste conveyance which is lowered down to the underground facility level by the waste hoist. The waste hoist and conveyance also transport underground personnel and equipment during routine operations. Thus, the waste hoist performs an important operating function of the facility.

This paper covers the major mechanical/structural design considerations for the waste hoist and its headframe structure. The design incorporates state-of-the-art technology in the hoist and mining industry to ensure safe operation for transporting nuclear waste underground. At present, the hoist and headframe are under construction with completion of the work anticipated in 1986.

GENERAL DESCRIPTION OF THE HOIST AND WASTE HOIST TOWER

The waste hoist will lower or lift the waste-carrying conveyance to or from the underground storage level, 2,160 ft below the

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surface. A tower-mounted friction hoist was designed. The direct drive hoist is mounted on a steel headframe (waste tower) over the waste shaft. The hoist headwheel is 12 ft in diameter and equipped with disc brakes. Six hoisting ropes are 1-3/8 in. in diameter, each end fastened to the conveyance and counterweight. The three tailropes are 2-½ in. in diameter. Rope guides are provided for a smooth vertical ride. At the shaft collar and underground station, spear guides are installed for accurate landing of the conveyance. The waste tower (headframe) is fabricated of structural steel and enclosed with insulated metal siding and roof decking. Deflection sheaves for the hoisting ropes are provided to minimize the diameter of the waste shaft. The waste tower and the shaft sump are furnished with wood arrestors, catch-gears, crash beams, and other safety installations. The general arrangement of the waste hoist, waste tower, and waste shaft is shown in Figs. 1 and 2. Founded on reinforced concrete collar structure, the waste tower supports the hoist equipment and also functions as a transfer station for the waste and personnel.

The conveyance and counterweight are located and dimensioned to ensure free passage during the hoist cycle in the 19 ft inner diameter waste shaft, as shown in Fig. 3. The clearance between the conveyance and the shaft wall or shaft installations is 9 in. except in the region of the fixed guides. The clearance between the conveyance and the counterweight is at least 20 in.

OPERATING DESIGN PARAMETERS

Operational design parameters for the waste hoist system are as follows:

Operating speed of conveyance	500	ft/min
Acceleration rate	1.0	ft/sec/sec
Creep speed	.67	ft/sec
Guide entry speed	4.0	ft/sec
Deceleration rate	1.0	ft/sec/sec
Rest time (minimum)	5.5	min
Conveyance weight (w/rope fittings)	33	tons
Counterweight (w/rope fittings)	52	tons
Weight of headropes	32	tons
Weight of tailropes	32	tons
Maximum design payload (RH Waste)	45	tons
Maximum payloads/8 shift normal operation	7	trips
	23	tons (lowered)
	2	trips
	45	tons (lowered)
	2	trips (manload)
	5	tons
	1	round trip empty conveyance

HOIST COMPONENTS

The major components of the WIPP waste hoist system are as follows:

- o Direct-Drive Friction Hoist
- o Conveyance
- o Counterweight
- o Hoisting Ropes and Guide Ropes
- o Conveyance/Counterweight Guides
- o Conveyance Chairing Device

Direct Drive Friction Hoist

The waste hoist is a 6 rope friction-type Koepe hoist. It is mounted on the waste tower over the waste shaft, and is directly driven by a 600 hp DC motor. The armature of

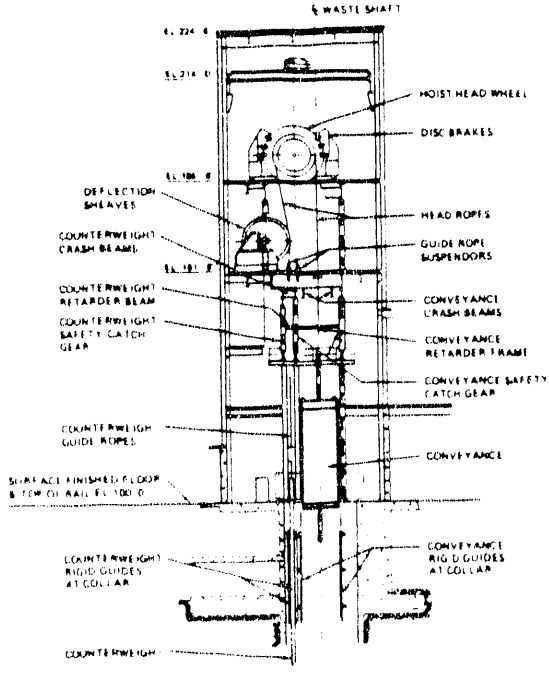

Fig. 1. General Arrangement of Waste Hoist and Headframe.

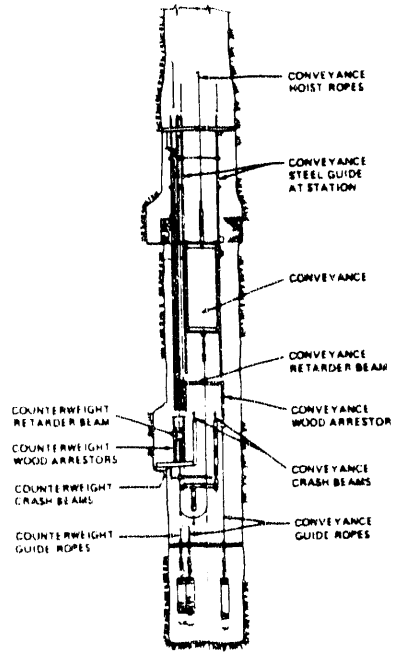

Fig. 2. General Arrangement of Waste Shaft Sump.

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the motor is directly mounted on the extension of the hoist wheel shaft. In order to ensure that the hoist support possesses adequate rigidity, and to reduce interface between the design of the headframe structure and design of the hoist, a hoist bedplate is specified to be supplied by the hoist manufacturer. The bedplate is supported on the steel floor framing by three steel bearings. The steel floor framing for the hoist machinery room is designed to provide a stiff support structure for the hoisting equipment.

Conveyance

The waste hoist conveyance has two levels. The platform level of the conveyance is used only for material transport. Approximately 15 feet above the platform level, a removable deck with wire mesh on four sides is provided. This deck has a mandoor and will be used for personnel transport.

The conveyance is a steel structure of subassemblies that are field bolted together, as shown in Fig. 4. The design of the conveyance meets the following requirements:

(1) Load Combinations: The conveyance is designed for the vertical load combination of deadload, maximum payload, and forces transmitted from the hoisting ropes and tailropes during normal operations. The allowable stresses for all the steel members and connections are limited to 25% of AISC allowable stresses[1] to allow for accelerations, decelerations, impact loading, and fatigue.

(2) Operational Condition: The conveyance is designed for horizontal loads resulting from loading and unloading the payload, and the interaction between the conveyance and rigid guides during normal operation. The magnitude of the maximum horizontal loads imposed on the conveyance is estimated to be equivalent to 0.25 g from the fixed guides in the station areas during travel and 10% of the payload during loading and unloading.

(3) Emergency Condition: In the event of emergency stops or the conveyance engaging the arrestors, all members and connections may be stressed up to full AISC allowable stresses.

(4) Accident Condition: In the unlikely event of an overtravelling conveyance crashing into the crash beams, which might result in breaking of the headropes, local yielding or buckling in the conveyance is acceptable. However, the four safety catch lugs and their support members on the conveyance must remain undistorted and operable after an ascending crash. These lugs and supports must be capable of holding a conveyance drop equivalent to 2.0 g, distributed to two lugs and two support members only.

Counterweight

The counterweight consists of steel frames. The weight compartments of the frames accepts removable steel or cast iron weights. The weight of the counterweight is approximately equal to the weight of the empty conveyance plus one-half the weight of the maximum payload. The weight of the

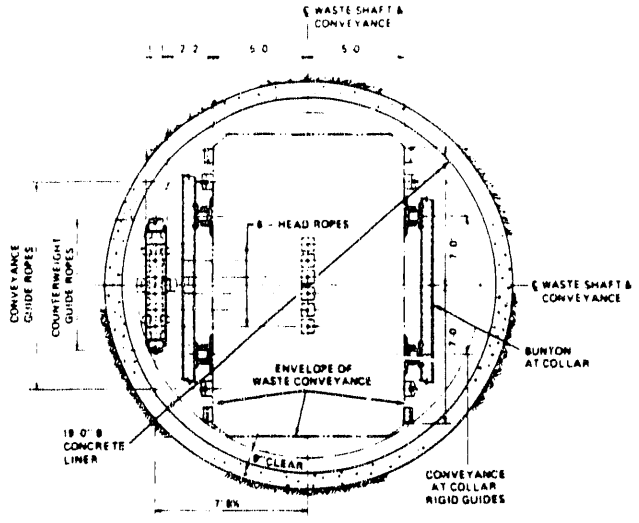

Fig. 3. Waste Shaft Cross Section.

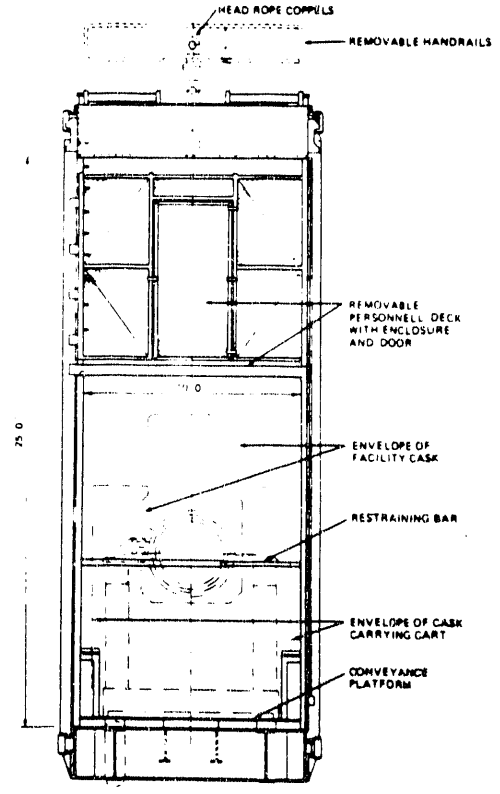

Fig. 4. Waste Conveyance.

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conveyance rope fittings and of the counterweight rope fittings is included in these weight summaries.

Hoisting Ropes and Guide Ropes

Full locked coil hoist headropes are used. Guide ropes are of half-lock coil construction. Tail ropes are a nonrotating type with a synthetic fiber core. All ropes are galvanized and fabricated with internal lubrication for corrosion protection. For fire protection only minimal manual lubrication or dressing may be applied after installation.

For the conveyance with the maximum design payload, the factor of safety of the hoisting ropes is at least 5.9 as determined by ANSI M11.1[2] according to the depth of the waste shaft, and both the hoisting ropes and tailropes have a minimum endurance limit of 400,000 loading cycles. Each guide rope has tensioning cheeseweights of at least 18,000 pounds. To reduce the tendency of the guide ropes to vibrate in unison, the amount of the tensioning load on each of the guide ropes differs by about 10%. The guide ropes have a minimum factor of safety of 5.0. The effect of the Coriolis force on the waste hoist system and specifically the lateral deflection of the guide ropes, as determined by the following formula, is considered to be negligible due to the relatively slow speed:

$$F_c = 2 \frac{W_t}{g} V w \cos e \qquad (1)$$

where F_c = Coriolis force (lb)
W_t^c = total weight of conveyance and payload (156,000 lb)
V = operating speed of conveyance (8.33 ft/sec)
w = angular velocity of earth (7.37×10^{-5} r/sec)
e = latitude of the WIPP site (33°)

The stretch and associated vibration of the head ropes under acceleration and deceleration conditions were analyzed so that the system was designed to keep the rope stretch within safe operating limits.

Conveyance/Counterweight Guides

The rigid guides are designed for a horizontal force from the conveyance or counterweight equivalent to 0.25 g. The total horizontal force from the conveyance or counterweight is distributed equally by top and bottom guide shoes only. In both the north-south and east-west directions, only two fixed guide rails are assumed to be engaged at one time.

Conveyance Chairing Device

A chairing mechanism is provided at the underground storage level station to support the conveyance during the unloading and loading of the waste or material and thus to prevent the sudden movement of the conveyance due to changes in the conveyance payload. The chairing mechanism consists of two movable structural members with pneumatic buffers. The chairing mechanism is powered by hydraulic cylinders. When a loaded conveyance is lowered and approaches the underground station at a reduced speed of 40 ft/min. it will be stopped 5 ft above the station by applying the brakes activated by a magnetic proximity switch. The chairs will be automatically moved into the chairing position under the conveyance. After the chairs are fully deployed, the conveyance will be automatically lowered at the same creep speed until it contacts the buffers. The buffers absorb the shock and slow the conveyance until the conveyance comes to rest on the chair. The hoist will continue to operate in a downward direction to raise the counterweight and release the headrope tension until about 150 percent of the hoist motor full-load torque is reached. By this chairing method, the headrope tension is reduced sufficiently to assure that the conveyance does not bounce upward when the heavy waste cask or other loads are removed from the conveyance. At this point, the current limiter will stop the hoist motor and apply hoist brakes. When this occurs, indicating lights at the storage level control station and master control station shall signal the completion of chairing and unloading may proceed.

Upon initiation of an up-travel signal, the brakes will be released, and the hoist will turn slowly to lower the counterweight and restore tension in the headropes on the conveyance side. Then the hoist can be safely accelerated to raise the conveyance. When the conveyance passes the chairing proximity switch, the chairs will be withdrawn automatically.

HOIST OPERATION, CONTROL AND SAFETY

Major components of WIPP waste hoist operational system are:

- Hoist Control System
- Brake System
- Wood arrestors
- Crash beams and catch-gears

The system is designed to provide the required operational flexibility and efficiency. Incorporated into the system are redundant features to ensure operational safety during hoist operation against overspeed and overtravel. Five levels of safety redundancy are provided. In order of their activation, in case of overspeed or overtravel, the features are 1) speed programmer and the proximity switches in the shaft, 2) the Lilly controller, 3) the track limit switches, 4) the wood arrestors, 5) the crash beams. In addition, fault detection devices are provided for all operational systems. Jamming of the conveyance or rope slip at the conveyance or rope slip at the hoist wheel is automatically detected and safety interlocks are provided for operational conditions.

Hoist Control Systems

There are four control stations for the hoist control: the master control station is

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located in the hoist control room, one local control station at the waste shaft collar, and another local control station at the underground shaft station. Furthermore, control is provided in the conveyance through an FM transmitter as shown in Fig. 5. The hoist can be operated manually or semiautomatically. When transporting waste, only the semiautomatic mode will be used. In the manual mode the hoist operation is monitored and controlled by a hoist man located at the master control station. Upon transfer of command from the master control station, the local control stations and the conveyance only operate the hoist in the semiautomatic mode. The hoist operation is continuously monitored by the central monitoring system in the WIPP central monitoring room with a local processing unit located in the hoist control room.

In the semiautomatic mode the hoist operation is monitored and controlled by a digital speed programmer connected to a hoist-driven pulse generator. It is equipped with a transmitter for depth indication and overspeed protection. It is also provided in each slowdown zone to monitor the conveyance speed and position. The speed programmer facilitates control of two different operating levels of the conveyance for transportation of materials and personnel. Figure 6 shows the speed-distance profile and control points for the semiautomatic operation.

A hoist-driven Lilly Controller (Model C) is provided to initiate an emergency stop if the conveyance should travel at 15% over the design speed at any point in the hoisting cycle, or when the conveyance is beyond the limits of normal travel.

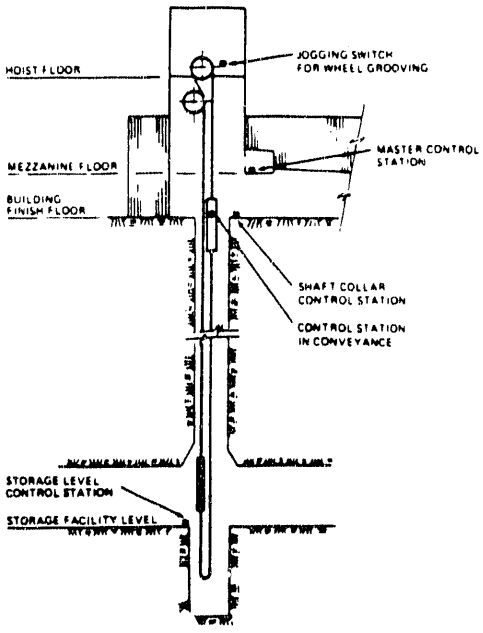

Fig. 5. Location of Hoist Control Stations.

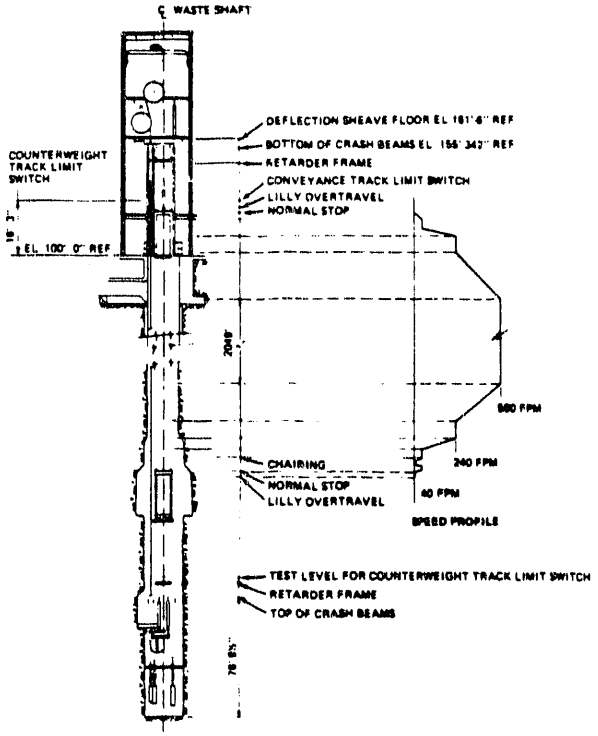

Fig. 6. Speed-Distance Profile for Semi-Automatic Operation.

Mechanical track limit switches are provided beyond the normal travelling zones which will actuate emergency stop functions on the hoist drive.

Brake System

The brakes on the hoist are sized to be capable of stopping the conveyance at a specified deceleration during operation. When the brakes are applied to the friction hoist system (Fig. 7) the equation of equilibrium can be written as follows:

$$\frac{Id_o}{r^2 g} \mp W \mp W\frac{d_o}{g} \mp W_c \mp W\frac{d_o}{c\,g} \pm (C+M) + (C+M)\frac{d_o}{g} - W + W\frac{d_o}{g} - B = 0 \qquad (2)$$

$$\text{or } B = \left(\frac{I}{r^2} + 2W + WC + C + M\right)\frac{d_o}{g} \pm (W - C - M)$$

where B = effective braking force
I = mass moment of inertia of hoist head wheel
r = radius of hoist head wheel
W = weight of the suspended ropes on one side
C = weight of conveyance
M = weight of material or men in conveyance
W_c = weight of counter weight
g = gravitational constant, 32.2 ft/sec^2
d_o = specified deceleration.

The upper sign represents the case of the ascending conveyance and the lower sign represents the case of the descending conveyance.

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The brakes are caliper type multiple disc brakes. They are operated by hydraulic cylinders and are designed to automatically apply in the event of a loss of electrical power or working fluid pressure. Furthermore, a partial failure of the brake system during an emergency is usually assumed in the design. For the WIPP waste hoist, three basic design requirements for the brakes are described as follows:

(1) In the event of a 50 percent loss of total braking effort, the remaining brake units shall be capable of retarding the conveyance at not less than 3 ft/sec^2, within the normal deceleration zone, when the maximum design payload is lowered to the maximum hoisting depth.

(2) When the conveyance carries a maximum design payload traveling at 500 ft/min, 50 percent of the total braking system shall be capable of safely stopping the conveyance within a 30-ft travel distance.

(3) During an emergency stop, with all brakes applied, deceleration of the conveyance shall not exceed 16 ft/sec^2 when personnel are carried.

These requirements determine the total braking effort (B_t) of the brake system.

Since the discs are normally built to the flanges of the hoist head wheel, the disc brake shoes and the support frames are supported by the hoist bedplate and the steel floor in the waste tower. These structural steel members are designed to accommodate the sudden exertion of forces from the brake system.

Arrestors

Overtravel arrestors are installed in the hoist tower to stop the ascending conveyance (and counterweight) in the event of an overtravel. Similarly, undertravel arrestors are installed in the shaft sump, to stop undertravel of the conveyance and counterweight. The arrestors are made of long dressed wood timbers and placed vertically. There are retarder beams resting in notches at the end of the wood arrestors. They contain deceleration knives that are forced into the arrestors when an overtraveling conveyance or counterweight strikes the retarder beams. Typical details of the wood arrestors and retarder beams are illustrated in Fig. 8.

The maximum deceleration of the ascending conveyance due to the overtravel arrestors and the brakes (if not failed) should not be greater than the gravitational acceleration g. Otherwise, the content of the conveyance will lift off the floor of the conveyance which is particularly unacceptable for the waste cask. The tail ropes will pile up under the conveyance and may then fall back with enough force to break the headropes. For the design purpose, the maximum deceleration to be imparted by the arrestors for the ascending conveyance is set at d = 30 ft/sec^2.

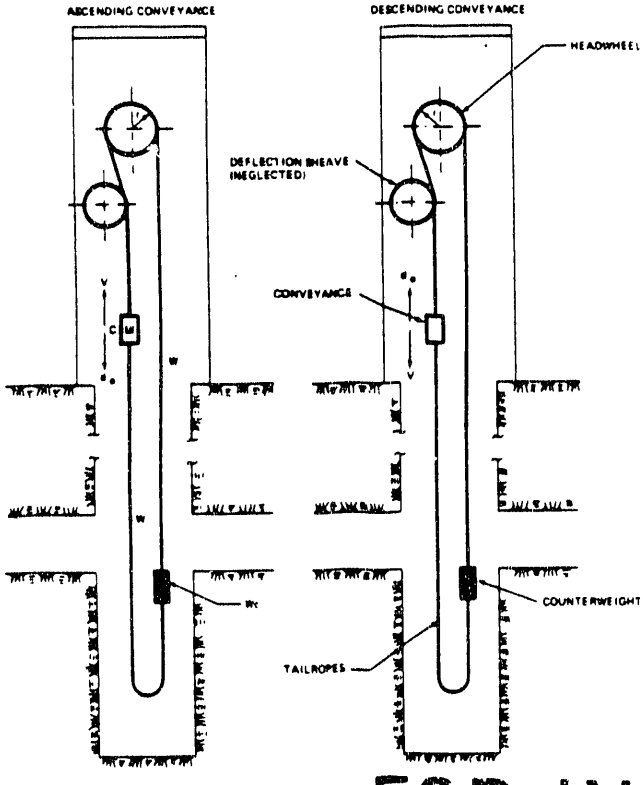

Fig. 7. Braking Effort.

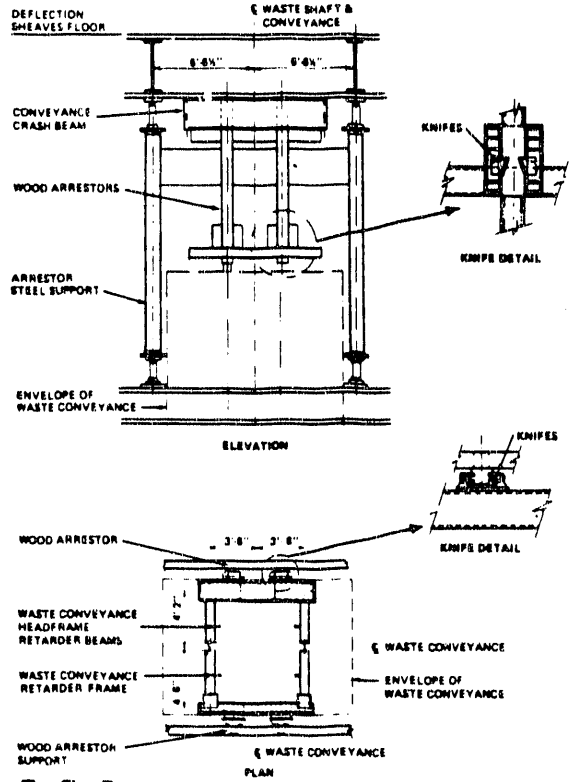

Fig. 8. Typical Details of Wood Arrestors.

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The maximum safe operating speed for handling the waste is specified as V_o = 500 ft/min, according to the rate of production. The maximum entry speed, V_e into the overtravel arrestors, could be about 15% higher. This is due to the fact that when properly adjusted, the Lilly controller should limit the hoist operating speed to 115%.

Therefore,

$$V_e = 115\% \; V_o \tag{3}$$

Then, the minimum length of the overtravel arrestors is

$$h = \frac{V_e^2}{2d} \tag{4}$$

The relative position of the overtravel arrestors in the headframe and the undertravel arrestors at the bottom of the shaft are arranged so that the descending counterweight or conveyance will enter the undertravel arrestors before the ascending conveyance or counterweight enters the overtravel arrestors (see Figs. 6 and 9). This is to ensure that the headropes at the lower end will slack and the descending counterweight or conveyance will not impose additional kinetic energy through the headrope to the ascending conveyance or counterweight during such an overtraveling situation. For an overtraveling conveyance (Fig. 9), the total retarding force, R_t, due to the brakes and arrestors can be expressed as follows:

$$R_t = \frac{I}{r^2}\frac{d}{g} + W\left(1 + \frac{d}{g}\right) - W\left(1 - \frac{d}{g}\right) - (C + M)\left(1 - \frac{d}{g}\right)$$

$$= \left(\frac{I}{r^2} + 2W\right)\frac{d}{g} - (C + M)\left(1 - \frac{d}{g}\right) \tag{5}$$

The required arrestor drag is the difference of the total retarding force and the total braking effort:

$$R_r = R_t - B_t \tag{6}$$

The governing case in this calculation is when the ascending conveyance only carries one person. The arrestor drag and the minimum arrestor length are the basic data required for the selection of overtravel arrestors for the conveyance.

Suppose the brakes failed to apply and the overtravel arrestors are solely relied upon to stop the conveyance, then the equation of equilibrium can be written as follows:

$$R_r = \left(\frac{I}{r^2} + 2W + C + M\right)\frac{d_m}{g} - (C + M) \tag{7}$$

Therefore, the minimum deceleration (due to arrestors alone) becomes:

$$d_{min} = \frac{R_r + C + M}{I/r^2 + 2W + C + M}\, g \text{ ft/sec}^2 \tag{8}$$

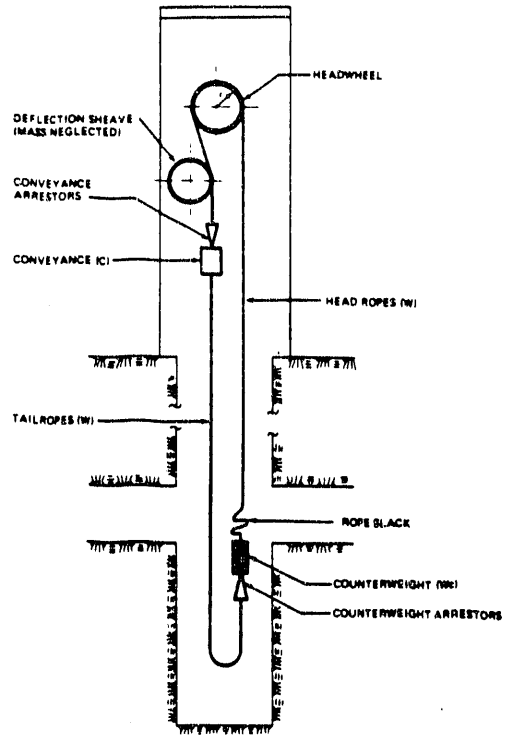

Fig. 9. Overtravel Arrestors.

The length of the conveyance overtravel arrestors, h, is checked against the safe man speed:

$$V = 2\, d_{min}\, h \times 85\% \tag{9}$$

The safe man speed may be increased to meet operational requirements by increasing the length of the overtravel arrestors.

During an undertravel, the deceleration of a descending conveyance could be larger than the gravitational acceleration without adverse effect. When men are carried, the empty conveyance may be decelerated at approximately 3.0 g. As the conveyance enters the undertravel arrestors at the bottom of the shaft, the counterweight also approaches the counterweight overtravel arrestors up in the hoist headframe. Furthermore, the conveyance is decelerated at a deceleration greater than g, and there will be slacking in the headropes above the conveyance. At this moment, the conveyance is actually isolated from the ropes and counterweight (Fig. 10). Therefore, the undertravel arrestor drag is determined by the weight of the conveyance and the maximum permissible deceleration.

$$R_r = C \times 4 \tag{10}$$

When the conveyance is loaded with payload, the maximum deceleration which the undertravel arrestor could provide is:

$$d_u = \frac{R_r}{C + M}\, g = \frac{4C}{C + M}\, g \tag{11}$$

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The undertravel arrestors should be long enough to stop a fully loaded conveyance.

$$h = \frac{V_e^2}{2d_u} \qquad (12)$$

The undertravel arrestors are supported by structural steel members which are in turn fastened to the shaft wall near the bottom. The overtravel arrestors are supported by steel members which are part of the hoist headframe. These structures are designed to be capable of resisting the arrestors' drag as calculated by the formulas shown above.

Crash Beams

The crash beam is the last line of defense against an overtraveling conveyance or counterweight crashing into the headframe or the sump structures. If the control devices such as the Lilly Controller and proximity switches as well as the brakes and overtravel arrestors should fail or partially fail, the ascending conveyance should be stopped by the crash beams before the rope attachments enter the deflection sheaves. The crash beams are located above the arrestors and below the deflection sheaves inside the hoist headframe. Normally, the crash beams are steel beams which will deform on heavy impact and absorb kinetic energy. The investigation of overtravel accidents indicates that the hoist headropes caused by the continued motion of the head ropes and hoist after the conveyance is stopped by the crash beam. Therefore, it is common practice to design the crash beams and the hoist headframe to withstand the effects of broken headropes.

If the breaking strength of the headropes is represented by P_1, the equation of equilibrium can be written as follows (Fig. 11):

$$P_1 = \frac{I}{r^2}\frac{d}{g} + P_2 \qquad (13)$$

$$\text{where } P_2 = W\left(1 + \frac{d}{g}\right)$$

The substitution leads to the deceleration of the conveyance during the impact:

$$d = \frac{P_1 - W}{I/r^2 + W} \qquad (14)$$

The rope breaking force P_1 applies as an internal force among the hoist floor, the crash beams, and the column struts between them. The crash beams themselves are subjected to direct impact of the conveyance. Due to the rarity of such a catastrophe, the crash beams are allowed to reach yield point and permanent deformation of the crash beams is expected. The deformed crash beams should be replaced after the overtravel accident. The force resulting from the change of momentum of the suspended headropes, P_2, is the net downward load on the hoist floor and on to the headframe columns. The steel hoist floor and columns are designed to withstand this load with an increase in the allowable stress due to the unlikelihood of such an event occurring.

The crash beams are also provided at the bottom of the shaft to stop the undertraveling counterweight or conveyance. Similar to the arrestors, the relative position of the crash beams is arranged in such a way that the descending counterweight or

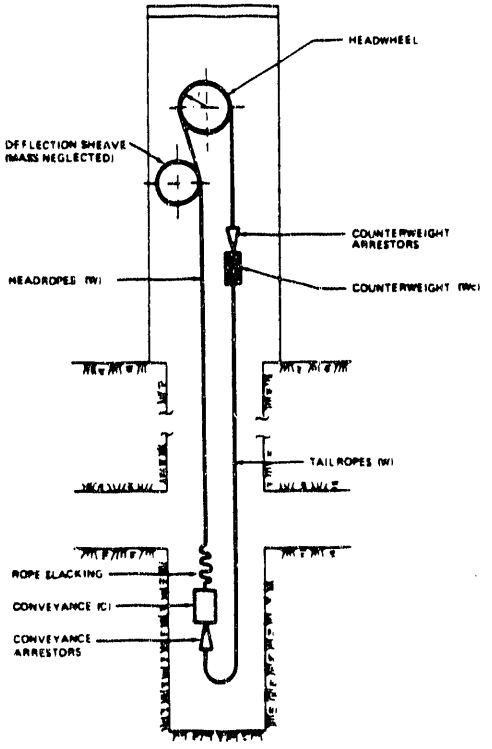

Fig. 10. Undertravel Arrestors

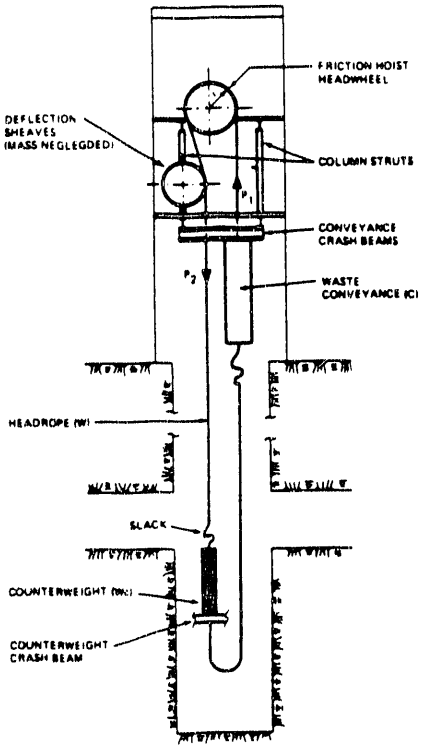

Fig. 11. Crash Beams

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conveyance will crash into the lower crash beams before the ascending conveyance or counterweight crashes into the respective crash beam in the headframe. This is to prevent an early crash or a premature rope break in the headframe.

Catch-Gears

Both the conveyance and counterweight are provided with stationary lugs that will engage the dogs of catchgear units in the waste hoist tower, if the accidental overtravel and fall-back of either should occur. This will prevent their falling down the full depth of the hoist shaft if the hoist ropes break. At its base, the catch-gear is supported by a shock absorber that fastens to the support framing. The live load transmitted to each shock absorber support member is limited to 2.0 g.

Other Safety Features

In addition to the conveyance overspeed and overtravel, jam of the conveyance at the stations or other locations will also impose a safety hazard. If a descending conveyance jams without being detected, the hoist wheel would continue to rotate, payout ropes to the top of the conveyance and lift up the tailropes. As the weight on the conveyance increases, the conveyance might unjam and suddenly drop down and thus break the headropes. In order to prevent such an accident, a trip wire is installed through the tailrope loops and linked to a magnetic switch. Should the tailrope loops be elevated because the conveyance jammed, it would trigger the wire and switch to initiate an emergency stop of the hoist. If the ascending conveyance jams without being detected, excessive pull would normally result in slippage of the headropes over the hoist headwheel. A rope-driven tachogenerator is provided near the headwheel. By comparing the voltages from the rope-driven tachogenerator and from a motor-driven tachogenerator, which is part of the speed control programmer, the rope slippage is detected and the emergency stop is initiated. In the event that the headropes are somehow caught by the headwheel during a conveyance jam, the motor torque and current would increase rapidly. A stall switch is provided for the hoist motor to limit the current to 200% of the normal load and initiate an emergency stop.

Interlocks are provided at each station level to insure that the hoist cannot be operated before the conveyance is fully loaded or unloaded.

Investigation of mine accidents indicated that most have resulted from improper operation or poor maintenance. One good example is the use of electrical jumper wires for repair. These jumpers if not removed may short-circuit the safety devices and thus enhance the possibility of an accident. Therefore, a stringent procedure for operation and maintenance is an integral part of the safety program.

CONCLUSIONS

The WIPP waste hoist is equipped with the most advanced digital control and monitoring systems available. The hoist operation is also continuously monitored by the central monitoring system. The hoist control system is provided with overspeed and overtravel protection. In addition, Lilly Controller and mechanical track limit switches are provided as redundant safety devices to prevent the conveyance from overspeeding or overtraveling. Furthermore, arrestors, crash beams, and catch-gears are installed above and below the limits of regular travel of the conveyance and arranged to prevent overtravel in the event of failure of other devices. The major components of the hoist system such as the conveyance and hoisting ropes and headframe structure are designed according to the code requirements and conservative design practice in the industry to provide ample margin of safety. It is believed that the WIPP waste hoist system satisfies the operational and safety requirements for transporting nuclear waste into the underground facility.

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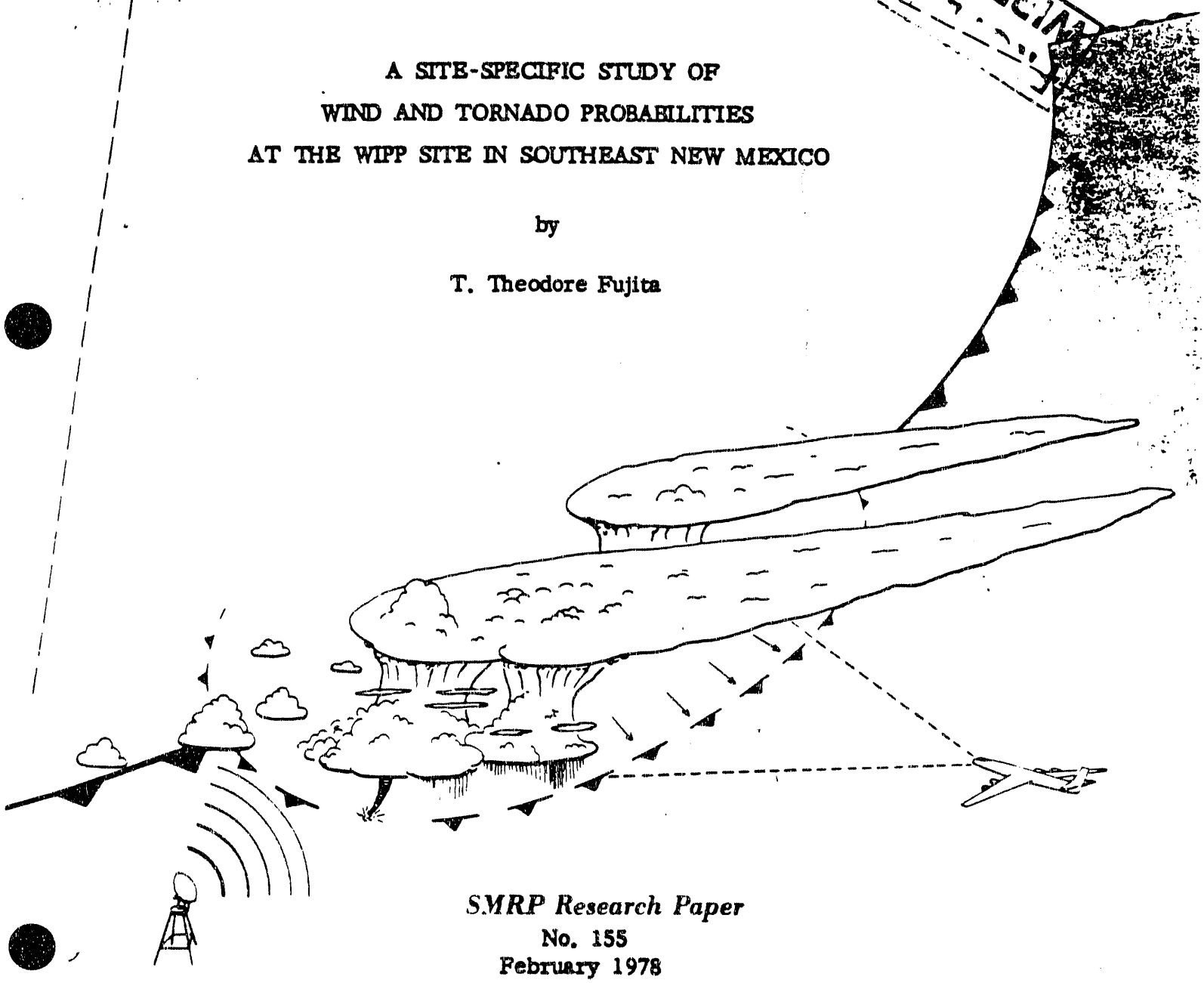
A SITE-SPECIFIC STUDY OF WIND AND TORNADO PROBABILITIES AT THE WIPP SITE IN SOUTHEAST NEW MEXICO

by

T. Theodore Fujita



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The University of Chicago

EXECUTIVE SUMMARY

Introduction

The Waste Isolation Pilot Plant (WIPP) will be the first facility designed and constructed to gather data and demonstrate, on a large scale, the feasibility of disposal of radioactive waste in bedded salt. This study was undertaken to determine the characteristics of the most severe tornado which is credible at the WIPP site. The study is based upon the reported tornado history of the Pecos River Valley watershed and the adjacent areas of west Texas and central New Mexico.

WIPP Site Location and Surrounding Areas

The proposed site for the WIPP facility lies approximately 26 miles east of the city of Carlsbad, New Mexico, in an area known as Los Medanos -- "the dunes". The surrounding area considered is the Pecos River Valley watershed extending from 30.0° N latitude to 35.5° N latitude (see Figure 1).

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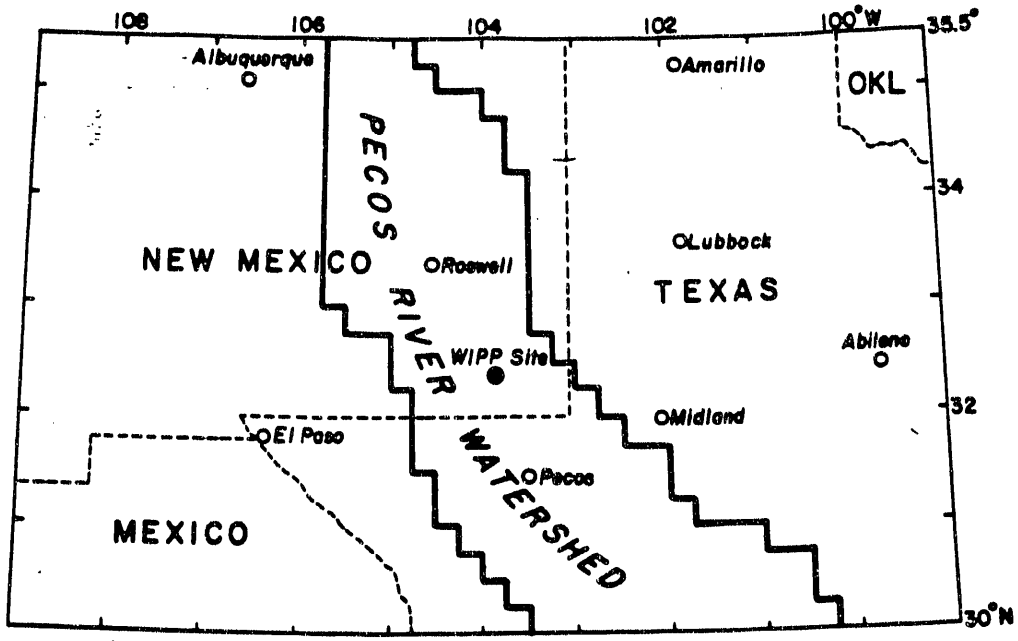

Figure I. WIPP site in Pecos River Valley watershed and surrounding areas.

Significant Assumptions

Two major difficulties were involved in assessing the tornado hazard at the site. They are: (1) the low population density within the statistical area, and (2) the rapid decrease in tornado activity as one proceeds west across eastern New Mexico. These difficulties were overcome by the adoption of following assumptions, which are believed to be conservative:

(a) The path lengths of all reported tornadoes were corrected based upon the population of the reporting location; i.e., the path length was increased for low population areas.

(b) The overall probabilities of tornado occurrences within the Pecos Valley have been applied to the WIPP site.

Site-specific Wind and Tornado Probabilities

The site-specific straight-line wind and tornado probabilities which are applicable for use in risk assessment studies relating to the WIPP operations are

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shown in Figure II. The straight-line wind probabilities were derived from climatological station data recorded at Roswell, New Mexico, Lubbock, Midland, and El Paso, Texas.

The site-specific tornado probabilities were derived using the Pecos Valley method developed by the author for this study and the DAPPLE (Damage Area Per Path LEngth) method devised by Abbey and Fujita (1975).

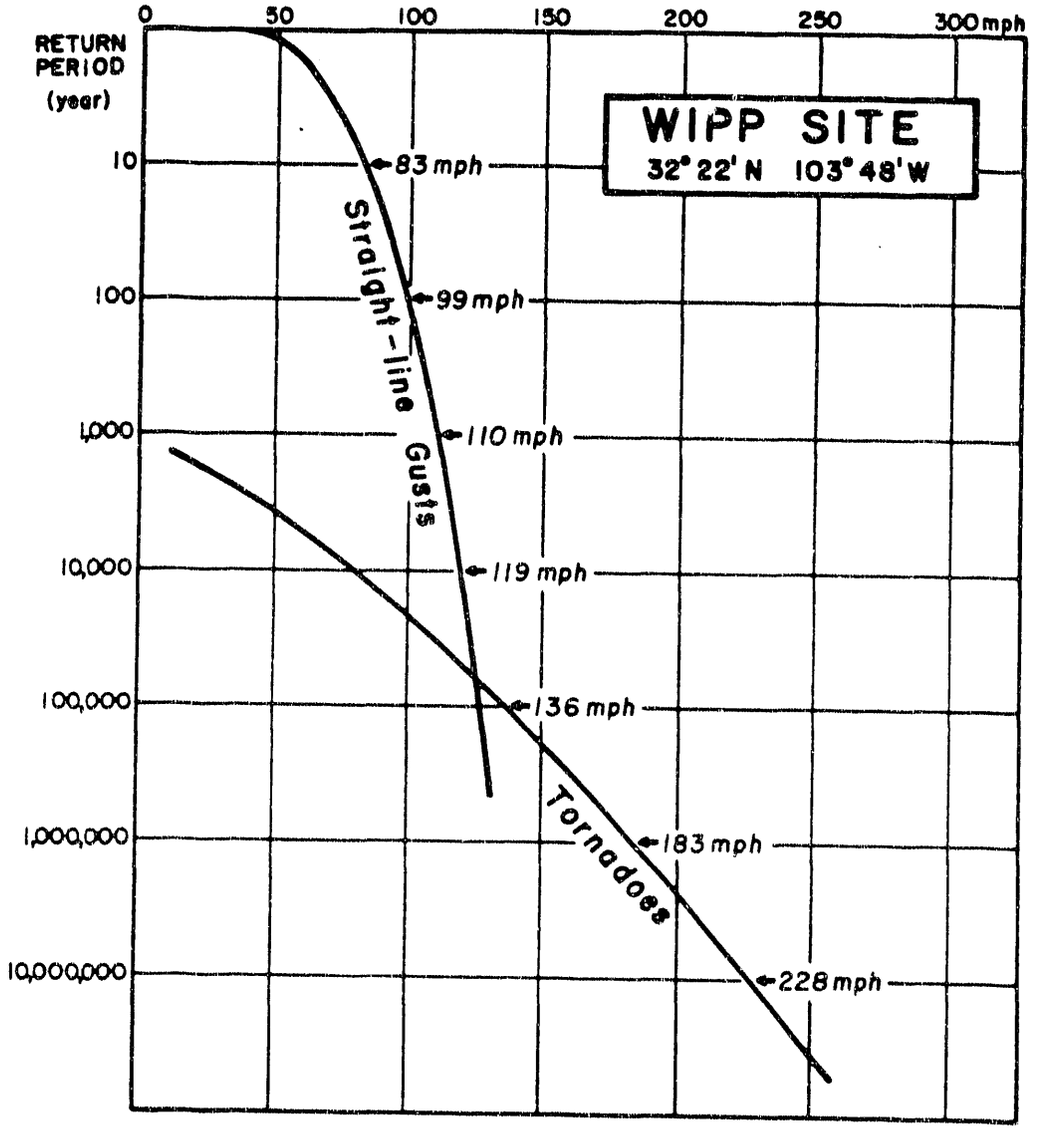

Figure II. Probabilities of straight-line winds and tornadoes at the WIPP site.

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Most Severe Credible Tornado (One in one-million-year tornado)

Based upon the results of this study, the most severe credible tornado which could be expected to occur at the WIPP site can be characterized by:

Maximum Wind Speed	183 mph
Translational Velocity	37 mph
Tangential Velocity	146 mph
Pressure Drop	0.69 psi
Rate of Pressure Drop	0.08 psi/sec
Return Period	One million years

TECHNICAL REPORT

Introduction

The Waste Isolation Pilot Plant (WIPP) site in southeast New Mexico is located at 32°22'30" N and 103°48'W with an elevation of 3,414 ft MSL.

The environmental topography of the site is shown in Figure 1 where elevations are contoured at 100' intervals. The western side of the site slopes down to the Pecos River, southeast of Carlsbad, N.M. There is a 3,800 ft hill on the east side of the site. The area under a site-specific study is hilly, but it is by no means mountainous.

Tornado risk of the southernmost Rockies was studied by Fujita (1972), who reached a conclusion that the tornado risk decreases rapidly toward the west from the Texas plains and plateau.

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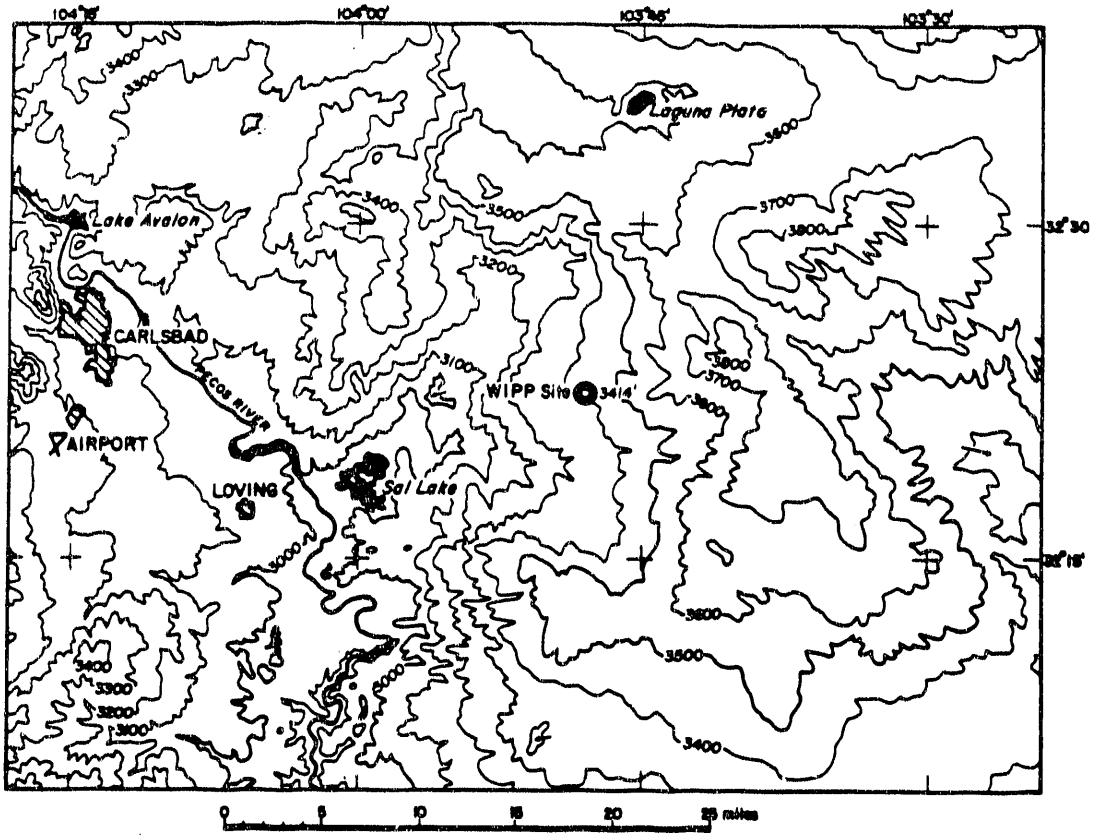

Figure 1. Location of the waste isolation pilot plant (WIPP) site, 25 miles east-southeast of Carlsbad, New Mexico. Its geographic coordinates are 32°22' 30" N and 103°48' W with elevation, 3,414ft MSL.

The WIPP site is located in a transition zone in which tornado frequency, as well as intensity, undergoes significant changes, especially with respect to elevation and longitude.

The site-specific study presented in this analysis was performed based on the DAPPLE Method of risk computations devised by Abbey and Fujita (1975). Since the environmental areas of this site are sparsely populated, the original path lengths of the tornadoes were prorated by using "correction factors" which vary with population within a 15-minute square sub-box of longitudes and latitudes.

Semi-square areas bounded by latitudes and longitudes of a specific interval are called "Marsden squares". 10°, 5°, and 1° are used to show distribution of meteorological data, especially over the oceans. The minute square used in the DAPPLE Method is called the "Sub-box".

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Probabilities of straight-line winds were also computed in an attempt to estimate the maximum windspeeds corresponding to shorter return periods or high-risk probabilities.

Results of these analyses revealed that the probabilities of straight-line winds at the WIPP site are higher than those of tornadoes when the design-basis windspeed is lower than about 125 mph or when the probabilities of interest is greater than 2×10^{-8}.

Non-tornado Wind Analysis

● Straight-line Winds

Statistics of severe local storm occurrences by Pautz (1969) revealed that the frequencies of windstorms 50 kts and greater by 2-degree square during the 13-year period, 1955 - 67, decrease westward across the state of New Mexico, from about 40 to less than 5. His statistics are based on the SELS (SEvere Local Storms) Log collected operationally at the National Severe Storms Forecast Center (NSSFC) at Kansas City, Missouri.

There are four climatological stations within a 160-mile range of the WIPP site. These stations are Roswell, N.M., Lubbock, Midland, and El Paso, Texas. According to Pautz' statistics mentioned above, it is likely that the risk of 50 kts or greater winds will decrease in the order, Lubbock (highest) to Midland to Roswell to El Paso (lowest).

The mean values of fastest-mile windspeeds, given in Table 1, from these four stations decrease, however, from El Paso (fastest) to Roswell to Lubbock to Midland (slowest). This order is entirely different from that expected from Pautz' statistics.

It is suspected that this unexpected variation of mean windspeeds is the result of anemometer environment, such as height, exposure, etc. at each climatological station.

Since the WIPP site is located near the geographic center of these four stations, an attempt was made to normalize the windspeeds from each station with

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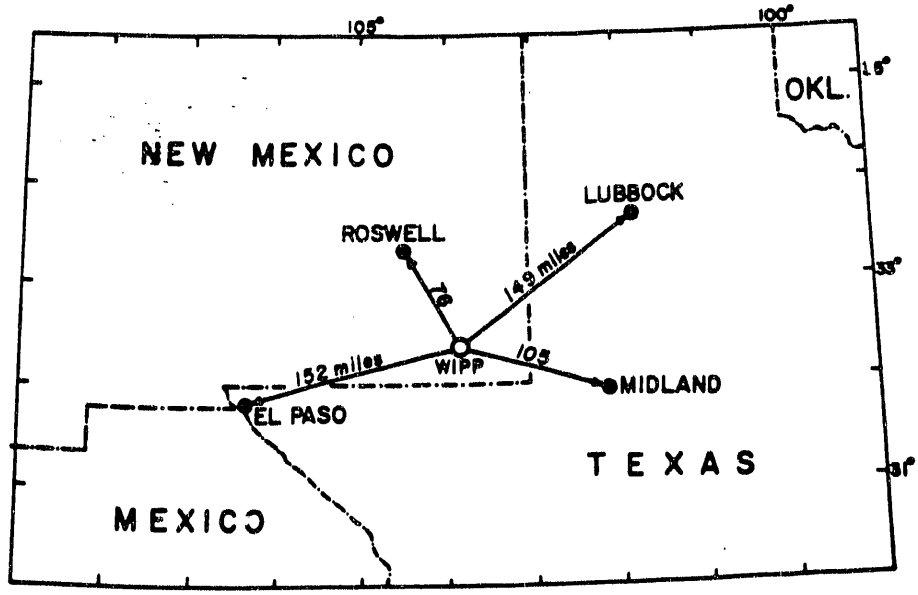

Figure 2. Distribution of four climatological stations around the WIPP site in southeastern New Mexico.

Table 1. Fastest-mile windspeed of the year at El Paso, Tex., Lubbock, Tex., Midland, Tex., and Roswell, N.M. From Climatological Data, 1950-76.

Stations	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
El Paso	70	66	59	61	66	56	57	61	66	56 mph
Lubbock	64	60	70	50	50	63	58	69	50	58
Midland	--	--	--	--	45	40	40	58	52	44
Roswell	59	61	65	75	61	73	65	72	69	68

Stations	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
El Paso	69	57	61	57	56	56	68	61	61	53 mph
Lubbock	58	52	58	52	58	59	46	44	51	44
Midland	67	44	46	49	38	41	58	44	48	41
Roswell	70	45	50	59	43	42	48	45	41	36

Stations	1970	1971	1972	1973	1974	1975	1976	Mean speeds
El Paso	66	59	57	54	59	48	42 mph	59.3 mph
Lubbock	43	40	44	51	53	53	48	53.6
Midland	39	36	41	45	44	41	40	45.3
Roswell	50	47	--	52	46	73	44	56.1

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respect to the mean speed of all four stations. Thus, the windspeeds in Table 1 were normalized by multiplying the following ratio or normalization factor applicable to each station. This normalization increases data points for statistics by the factor of 4, under the assumption that the distribution of windspeeds at these stations are more or less uniform. If not, we have to use Roswell only, because it is closest to WIPP.

$$\frac{\text{Mean of 4 stations}}{\text{Mean of El Paso}} = \frac{53.9}{59.3} = 0.91 \quad \text{(for El Paso)} \qquad (1)$$

$$\frac{\text{Mean of 4 stations}}{\text{Mean of Lubbock}} = \frac{53.9}{53.6} = 1.01 \quad \text{(for Lubbock)} \qquad (2)$$

$$\frac{\text{Mean of 4 stations}}{\text{Mean of Midland}} = \frac{53.9}{45.3} = 1.19 \quad \text{(for Midland)} \qquad (3)$$

and

$$\frac{\text{Mean of 4 stations}}{\text{Mean of Roswell}} = \frac{53.9}{56.1} = 0.96 \quad \text{(for Roswell)} \qquad (4)$$

These normalization factors along with other parameters are given in Table 2.

Windspeeds computed by multiplying each of these ratios by the fastest-mile speeds from each station are called the "normalized fastest-mile windspeeds".

Table 2. Mean windspeeds and normalization factors applicable to climatological stations in Table 1.

Stations	Distance from WIPP	Mean windspeeds	Normalization factors
El Paso	152 miles	59.3 mph	0.91
Lubbock	149	53.6	1.01
Midland	105	45.3	1.19
Roswell	76	56.1	0.96

The probabilities of the occurrence of maximum windspeeds at climatological stations should be defined differently from those of tornadoes, because windspeeds at each station are measured in time domain at a fixed point. Their spatial variations around the anemometer are usually unknown.

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For tornadoes, the National Weather Service lists all reported storms based on the best possible information. Tornadoes are listed separately, even if they occur on the same day or even one hour later, hitting the same spot again.

The maximum fastest-mile speeds are listed in "Climatological Data" by month and by year. There is no mention as to how often the maximum speed occurred within one month or one year. The period of straight-line winds, especially the ones caused by continental cyclones, are long, lasting for hours or even days. There will be numerous maxima during such a long period. We should, therefore, define the following terms:

Fastest-mile day -- the day on which the speed occurred
Fastest-mile month -- the month in which the speed occurred
Fastest-mile year -- the year in which the speed occurred

These are similar to the term

Tornado Day -- the day on which one or more tornadoes occurred.

In all of these cases, the number of occurrences of a specific event is not important.

The probability of the fastest-mile year can be computed from

$$P_s = \frac{\text{Number of fastest-mile years with specific speed and larger}}{\text{Total number of years used in statistics}} \qquad (5)$$

where P_s denotes the probability of fastest-mile years with a specific windspeed or larger.

● Probabilities of Straight-line Winds

If the causes of straight-line winds affecting the WIPP site are identical throughout the entire year, we could estimate the probability by combining all normalized wind speeds into a data set.

The number of occurrences by month, shown in Figure 3, reveals, however, that there are significant seasonal variations. The entire year was divided into two 6-month periods: April - September (warm months) and October - March (cold

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months). The former period is characterized by convective activities, spawning 93% of the annual tornadoes, while the latter, by continental cyclones with gusty winds.

Wind-direction distribution in Figure 4 show clearly a concentration of wind directions in cold months in westerly directions. During warm months, directions of strong winds spread out on both sides of the maximum frequency.

Probabilities of fastest-mile years were computed from Eq. (5) as a function of wind speeds normalized by Eqs. (1) through (4). The results in Table 3 and Figure 5 show that the maximum speeds were 72 mph in warm months and 80 mph in cold months, with the occurrence probability of 0.01 year^{-1} (return period of 100 years).

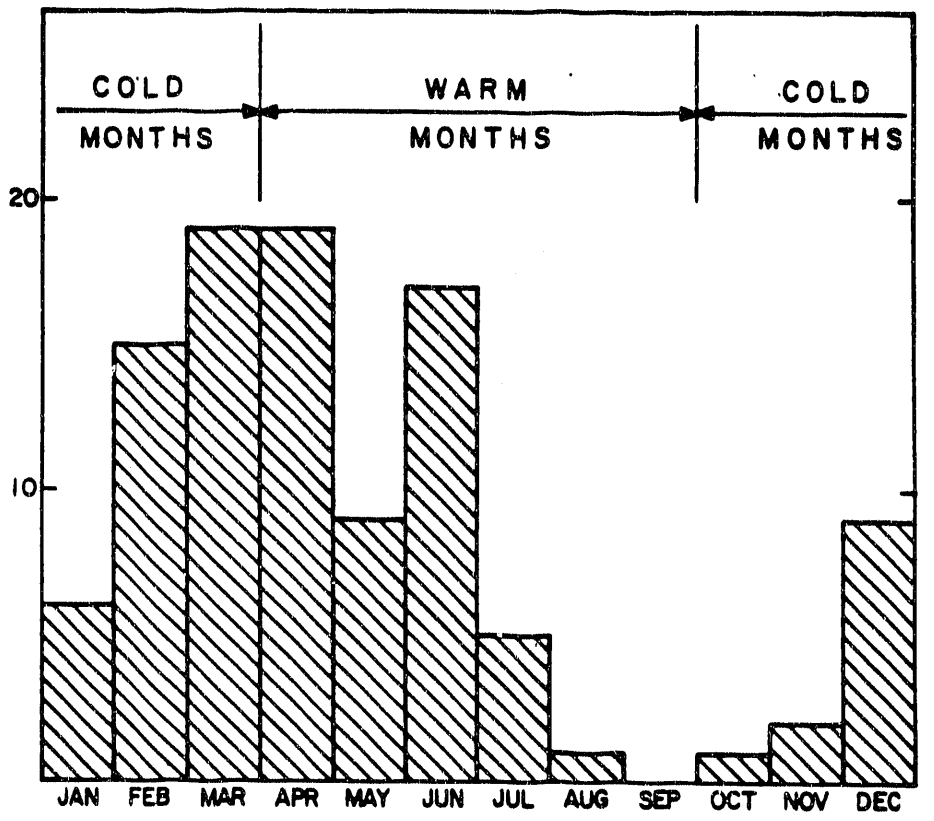

Figure 3. Frequencies of maximum fastest-mile windspeed of the year by month. For statistical purposes, one year is divided into two 6-month periods. Based on 1950-76 data from El Paso, Lubbock, Midland, and Roswell.

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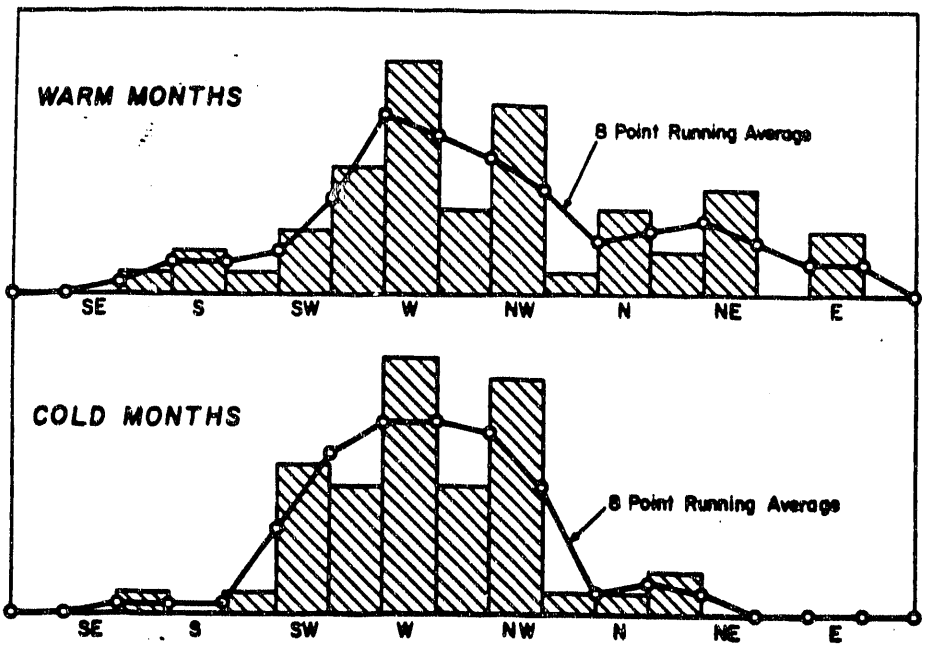

Figure 4. Distribution of the directions of fastest-mile winds of the year from El Paso, Lubbock, Midland, and Roswell, 1950-76. Since 8-point (every 45°) directions are reported more frequently than 16-point (every 22.5°) directions, curves of the 8-point running average were added in this figure.

These data points with 0.01 year^{-1} probability may not always be reliable because they represent the maximum values in 100 statistical years generated by combining four climatological stations. The normalized windspeeds are accurate, but the occurrences of windspeeds in future years are uncertain. Namely, we do not know how many years we have to wait before experiencing the same or a larger maximum windspeed. During these "waiting" years, the probability of the maximum speed decreases continuously.

As it turned out, the trends of windspeed with probability in warm and cold months are not too different from each other. It should be noted that trends are significantly different in other parts of the U.S., especially those in the Midwest.

The probabilities for two periods were combined into the all-year probability in Figure 5. The smoothed curve of the all-year probability gives 60 mph (10-year), 79 mph (100-year), and 88 mph (1,000-year return period).

It is recommended that the design-basis straight-line winds,

$$\text{Design-basis speed} = 1.25 \times \text{Fastest-mile speed} \qquad (6)$$

be used at the WIPP site.

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Table 3. Probabilities of fastest-mile windspeeds of the year obtained by combining the corrected windspeeds from four stations in Table 1.

Corrected windspeeds	Warm months (Apr - Sep)	Cold months (Oct - Mar)	All year (Jan - Dec)
35 mph	0.505	0.495	1.000
38	0.505	0.485	0.990
39	0.505	0.476	0.981
40	0.505	0.466	0.971
41	0.495	0.456	0.951
42	0.495	0.447	0.942
43	0.485	0.447	0.932
44	0.466	0.427	0.893
45	0.437	0.408	0.845
46	0.427	0.398	0.825
48	0.417	0.379	0.767
49	0.388	0.340	0.728
50	0.379	0.301	0.680
51	0.359	0.282	0.641
52	0.350	0.233	0.583
53	0.272	0.214	0.486
54	0.262	0.204	0.466
55	0.252	0.165	0.417
57	0.214	0.146	0.360
58	0.184	0.146	0.330
59	0.146	0.126	0.272
60	0.136	0.106	0.242
62	0.126	0.068	0.194
63	0.097	0.058	0.155
64	0.087	0.048	0.135
65	0.068	0.048	0.116
66	0.068	0.038	0.106
67	0.058	0.038	0.096
69	0.058	0.029	0.087
70	0.038	0.010	0.048
72	0.010	0.010	0.020
80	---	0.010	0.010

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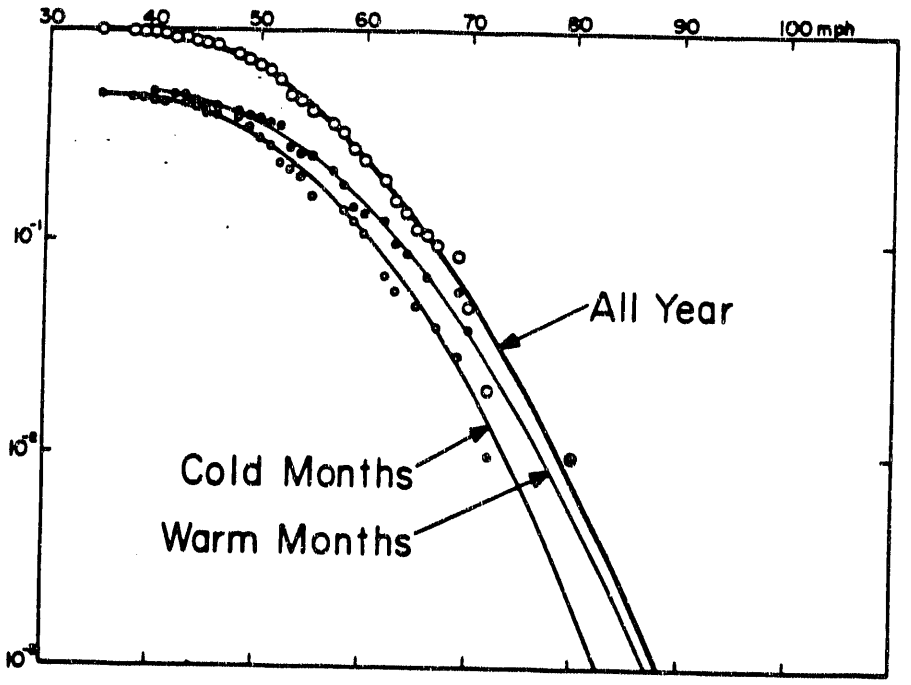

Figure 5 Probabilities of fastest-mile wind of the year obtained by combining the data from four climatological stations in Figure 2. Note that speeds in warm months increase slightly more than those in cold months.

Data Base for Tornado Study

● Reported Tornadoes in Study Area

Two major difficulties involved in assessing the tornado risk at this site are (1) low population density within statistical areas and (2) rapid decrease in tornado activities across eastern New Mexico.

It is necessary, therefore, to investigate the statistical relationship between tornado data and population before obtaining a best possible answer to this question.

As pointed out by Fujita (1972), tornado frequencies and intensities in the southernmost Rockies are influenced by topographic factors as well. Topographic factors investigated are mean height of the terrain and height variations. Since the study of the southernmost Rockies was aimed at the site-specific evaluation of the Los Alamos facilities, the statistical areas are high in elevation and large in height variations. Most of the statistical results at the Los Alamos site cannot be used

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for the WIPP site located over the terrain with low elevation and small height variations.

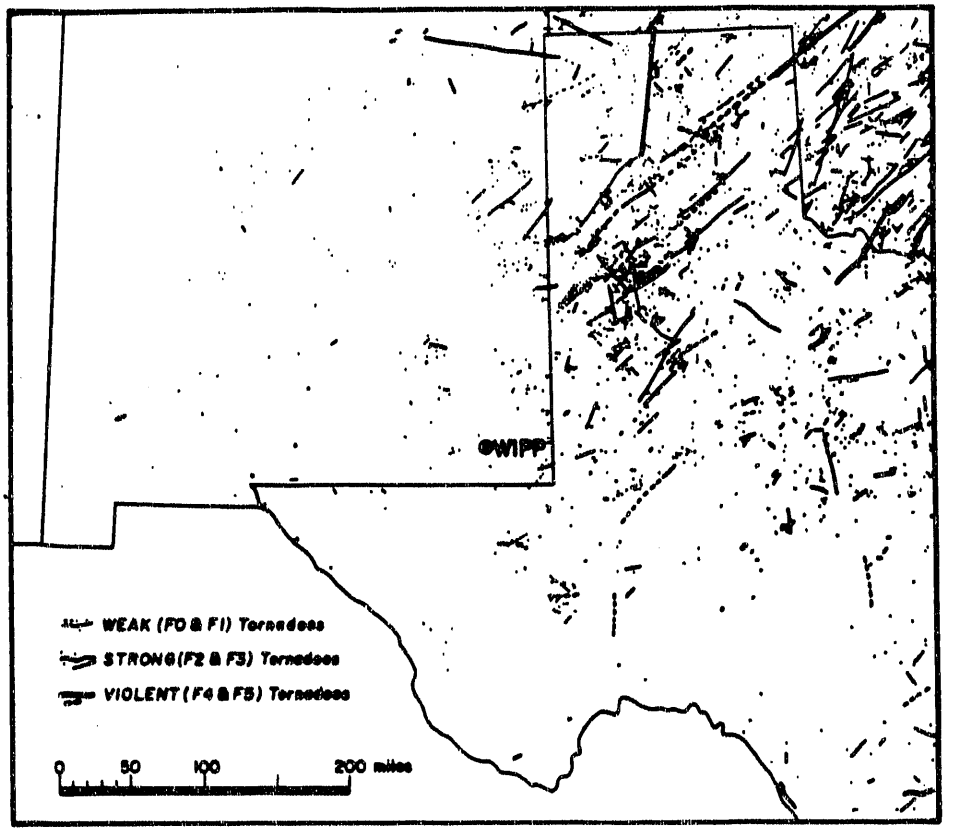

Figure 6. Distribution of tornadoes in three categories within about 300-mile range of the WIPP site. From Fujita and Pearson (1976).

● Annual and Diurnal Variations

The peak months of tornado activities within 144-mile range of the WIPP site are May and June when moist-air inflow from the Gulf generates frequent thunderstorms.

As the season progresses, moisture passes over the area, moving deep into the Rio Grande Valley and mountains. Upon the onset of the rainy season in these areas, tornado activities around the site decrease rapidly (see Figure 6).

The bi-monthly distribution of the 363 tornadoes in Figure 7 reveals a rapid decrease in the tornado frequencies during the month of June. Table 4 shows that a total of 101 tornadoes in 1950-75 occurred in June. However, 74 occurred during the first half of the month while only 27 occurred during the second half.

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Strong straight-line winds occur frequently during December through March. Occurrences of tornadoes during these months are rare, however. High winds in early spring are characterized by dust storms but rarely by tornadic storms.

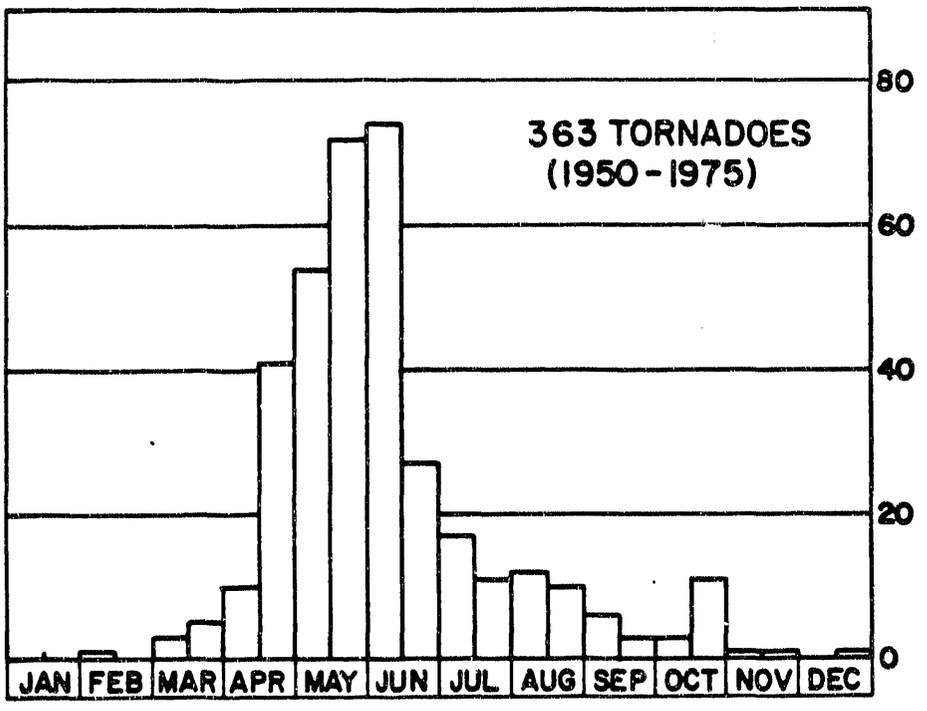

Figure 7. Frequencies of tornadoes within 144-mile range of the WIPP site by bi-month. Based on the NSSFC Tornado Tape (1977).

Table 4. Frequencies of tornadoes within 144 miles (125 n.m.) from the WIPP site. Based on 363 tornadoes in NSSFC Tape (1950-75).

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Frequencies	0	1	8	51	126	101	28	22	9	14	2	1

Diurnal variations of tornado time (touchdown) was computed based on the NSSFC Tornado Tape (1977). The results are shown in Table 5 and Figure 8.

The peak occurrence time between 2 and 4 PM MST is apparently earlier than that experienced in the Midwest. Recently, Kelly et al. (1977) obtained the peak time averaged over the entire Midwest of between 4 and 5 PM, which is one to two hours later than that around the WIPP site.

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Physical meanings of these early peak occurrences have not been fully understood. It is likely, however, that the parent clouds which spawn tornadoes near this site are, on the average, younger than those of other tornado-spawning thunderstorms. Statistics show, nonetheless, the following facts:

a. 345 tornadoes (95%) occur during the 12-hour period, 10 AM to 11 PM

b. 249 tornadoes (68%) occur during the 6-hour period, 1 PM to 7 PM

c. 153 tornadoes (42%) occur during the 3-hour period, 2 PM to 5 PM

Table 5. Frequencies of tornadoes by touch-down hour in MST. Based on 365 tornadoes with known time in NSSFC Tape (1950-76).

							AM						
Hours	12	1	2	3	4	5	6	7	8	9	10	11	12
Frequencies	2	1	1	0	1	2	1	0	0	3	5	8	13

							PM						
Hours	12	1	2	3	4	5	6	7	8	9	10	11	12
Frequencies	13	26	54	54	45	38	32	23	31	13	18	2	2

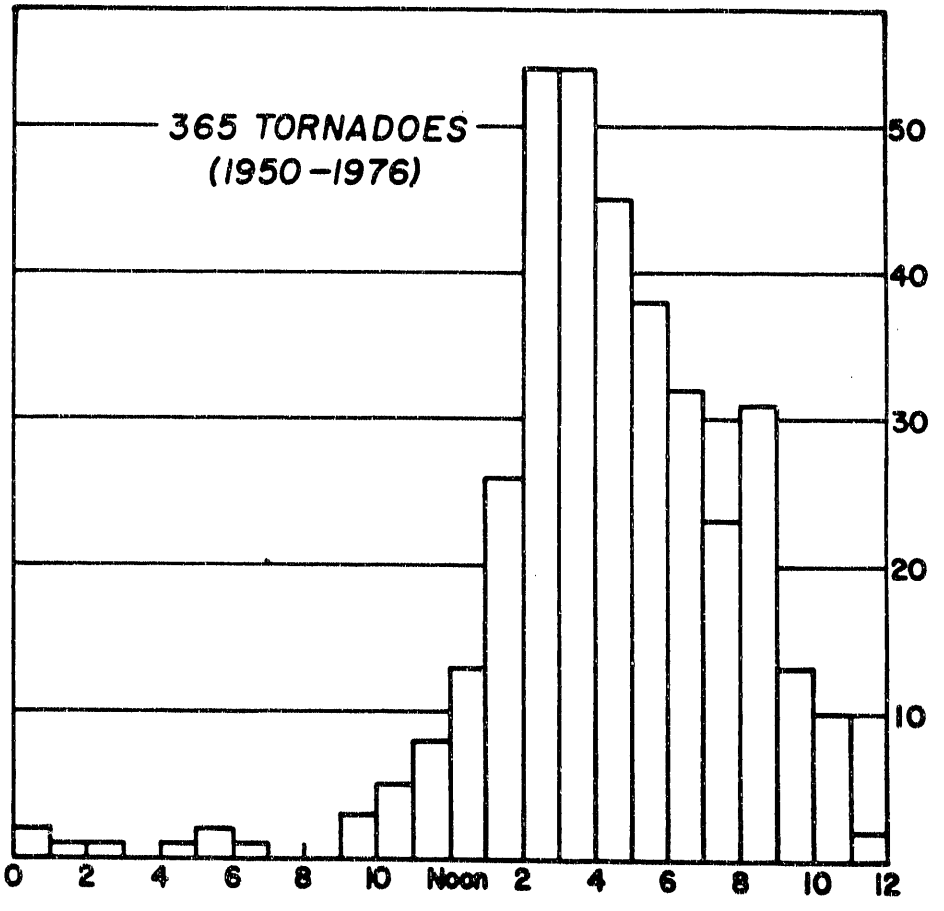

Figure 8. Diurnal variation of tornadoes within 144-mile range of the WIPP site. Note the peak occurrences between 2 and 4 PM. Time in MST.

● Path Lengths in 15 x 15 - minute Sub-boxes

The NSSFC Tornado Tape has been made and is being updated at the National Severe Storms Forecast Center (NSSFC) under the direction of Allen D. Pearson. The tape includes:

* Year, month, date, time, weather event
* Longitudes and latitudes of beginning and ending point
* Type of paths, per cent on the ground, storm types and rotational sense
* Path length and mean path width
* Fatalities, injuries, and damage class
* Affected states and counties
* FPP scale

A copy of the up-to-date tape may be obtained from Pearson.

The DAPPLE (Damage Area Per Path LEngth) tape has been made and is being updated now at the University of Chicago under the direction of T. Theodore Fujita under NRC Contract No. AT(49-24)-0239. The tape includes

* Year, month, date and time
* F scale
* Fatalities and injuries
* Affected boxes identified by 1 x 1 degree of longitude and latitude boxes, each subdivided into 15-minute sub-boxes
* Path length, path types, and direction within each sub-box

A copy of the up-to-date tape may be obtained from Fujita.

For this site-specific study, a semi-rectangular area in Figure 9 was selected. There are 22 x 40 = 880 sub-boxes (less those in Mexico) in this rectangular area.

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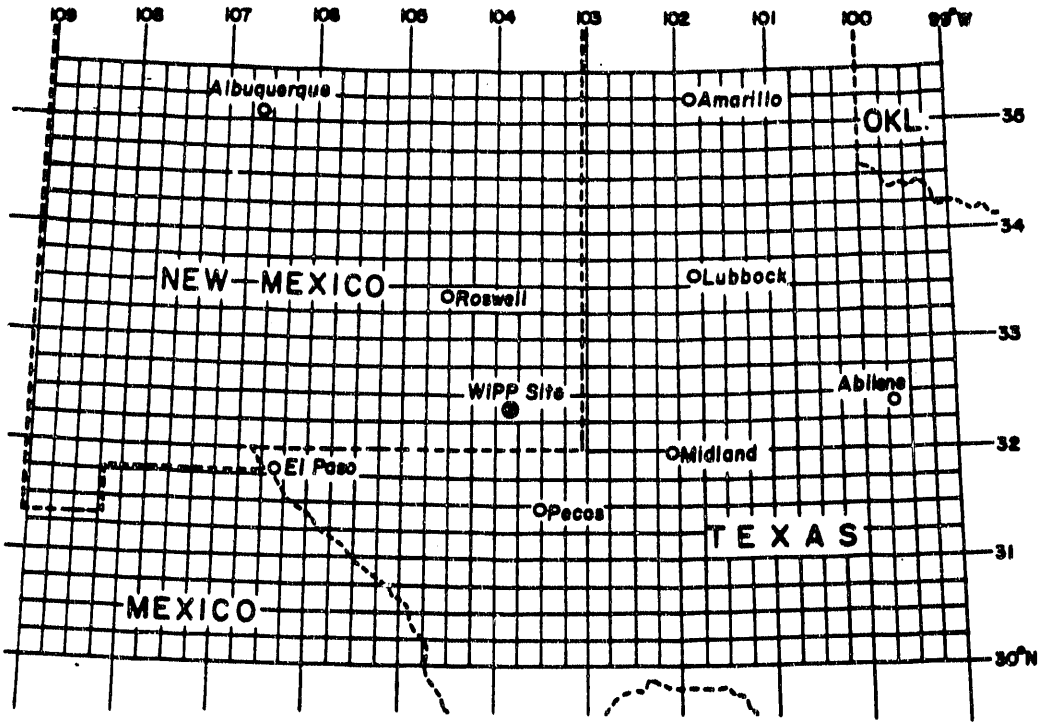

Figure 9. An area bounded by 99° and 109°W longitudes and 30° and 35.5°N latitudes which was sub-divided into 15' x 15' sub-boxes. The DAPPLE Tape lists the path length of tornadoes in each sub-box by F scale.

The DAPPLE tape was used to determine the path lengths of tornadoes in three categories within each sub-box. The three categories are

Weak tornadoes	(F0 and F1),
Strong tornadoes	(F2 and F3), and
Violent tornadoes	(F4 and F5).

The path lengths of tornadoes in three categories are given in Tables 6, 7, and 8, the area of which covers a 5 x 5 degree square which is less than that of Figure 9.

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Table 6. Path lengths of weak (F0+F1) tornadoes within 15-min sub-boxes. Longitudes and latitudes are subdivided by A(60'-45'), B(45'-30'), C(30'-15'), and D(15'-00').

(unit in miles)

		105°W				104°W				103°W				102°W				101°W			
		A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
35°	A	0	0	0	0	1	1	0	1	12	18	17	4	0	7	24	7	6	1	5	1
	B	0	0	0	0	0	0	0	1	6	5	0	13	4	23	4	6	21	2	0	4
	C	1	1	0	0	0	0	0	0	0	3	1	4	12	10	1	4	22	1	2	2
	D	0	0	1	0	2	0	0	0	0	4	7	1	1	15	10	29	9	7	5	0
						New Mexico															
34°	A	1	0	0	0	0	0	0	0	0	0	0	3	71	22	8	37	5	5	1	1
	B	0	0	0	0	0	0	0	0	0	0	0	0	7	6	5	14	20	0	6	4
	C	0	5	0	0	0	4	2	0	0	2	1	1	2	3	4	4	7	24	2	1
	D	0	0	0	0	1	0	0	0	0	1	7	0	4	1	7	11	2	10	6	1
																	Texas				
33°	A	0	0	0	0	0	1	4	0	0	1	3	1	0	7	1	0	1	0	1	0
	B	0	0	0	0	0	1	0	0	1	0	0	2	1	14	0	8	13	0	1	5
	C	0	0	0	0	0	1	1	1	●	0	0	2	6	12	1	1	9	3	1	0
	D	0	0	0	0	0	1	0	0	1	0	7	13	0	1	1	4	0	3	4	0
32°	A	0	3	0	3	0	0	0	0	1	0	4	1	1	0	3	1	2	0	0	0
	B	0	0	0	1	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	1
	C	0	0	0	0	0	0	0	0	1	7	4	2	0	0	2	0	0	0	1	0
	D	M	1	0	0	0	0	0	0	0	1	0	12	2	0	2	11	0	1	1	0
										Pecos Valley											
31°	A	M	M	0	0	0	0	0	0	0	0	0	6	3	0	0	0	0	0	0	0
	B	M	M	M	M	0	1	1	1	0	0	1	1	9	0	0	0	0	0	0	0
	C	Mexico			M	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	D	M	M	M	M	M	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0

● denotes the WIPP site and M, the sub-box in Mexico.

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Table 7. Path lengths of strong (F2+F3) tornadoes within 15-min sub-boxes. Longitudes and latitudes are subdivided by A(60'-45'), B(45'-30'), C(30'-15'), and D(15'-00')

(unit in miles)

		105°W				104°W				103°W				102°W				101°W			
		A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
35°	A	0	0	0	0	0	1	0	0	0	0	0	11	0	0	8	2	7	0	8	17
	B	0	0	0	0	0	0	0	0	0	0	7	14	0	2	16	0	1	4	11	17
	C	0	0	0	0	0	0	0	0	0	0	8	10	8	38	12	19	9	15	28	0
	D	0	0	0	0	0	0	0	0	0	0	1	4	0	1	45	30	38	7	0	0
						New Mexico															
34°	A	0	0	0	0	0	0	0	0	0	0	0	12	0	1	19	11	1	4	1	3
	B	0	0	0	0	0	0	0	0	0	0	0	0	0	9	25	1	6	8	10	0
	C	0	0	0	0	0	0	0	0	0	0	0	0	2	0	15	7	3	23	4	3
	D	0	0	0	0	0	1	0	0	0	0	0	1	1	0	3	7	8	7	1	4
																		Texas			
33°	A	1	0	0	0	0	0	0	0	0	0	2	0	0	2	0	1	0	0	0	1
	B	0	0	0	0	0	0	0	0	0	0	0	1	1	4	1	1	0	0	0	0
	C	0	0	0	0	0	0	0	0	●	0	0	0	0	0	0	0	0	1	0	1
	D	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
32°	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
	C	0	0	0	0	0	0	0	0	2	9	3	0	0	1	0	0	0	0	0	0
	D	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
										Pecos Valley											
31°	A	M	M	0	0	0	0	0	0	0	0	0	2	3	0	4	5	0	0	0	0
	B	M	M	M	M	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	2
	C	Mexico			M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	D	M	M	M	M	M	0	0	0	0	0	0	0	0	0	1	10	0	0	0	0

● denotes the WIPP site and M, the sub-box in Mexico.

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Table 8. Path lengths of violent (F4+F5) tornadoes within 15-min sub-boxes. Longitudes and latitudes are subdivided by A(60'-45'), B(45'-30'), C(30'-15'), and D(15'-00').

(unit in miles)

		105°W				104°W				103°W				102°W				101°W			
		A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
35°	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0
	D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	14	14	0	0
				New				Mexico													
34°	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	4	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0
	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
																		Texas			
33°	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	C	0	0	0	0	0	0	0	0	●	0	0	0	0	0	0	0	0	0	0	0
	D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32°	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	D	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
											Pecos		Valley								
31°	A	M	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	B	M	M	M	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	C	Mexico			M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	D	M	M	M	M	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

● denotes the WIPP site and M, the sub-box in Mexico.

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Because of the small number of violent tornadoes compared with the occurrence of strong and weak tornadoes, the stronger the tornadoes the shorter the total path mileage. The total path length of weak tornadoes in Table 6 is 914 miles, while that of strong tornadoes in Table 7 is 668 miles. The total path mileage of violent tornadoes in Table 8 turned out to be only 67 miles.

Although Tables 6, 7 and 8 include only 400 sub-boxes, tornado statistics in this paper were performed over the area of Figure 9 which is much larger than that shown in these tables.

Population Corrections

The path lengths of tornadoes by F scale in each sub-box are available in the DAPPLE tape. However, the actual population for each sub-box is not available.

A breakdown of the population into 15-minute sub-boxes was performed by

a. Obtaining county and town (city) population from the 1970 census
b. Drawing 15-minute grid on 250,000 scale U.S.G.S. map which covers the area of 1° latitude and 2° longitude
c. Placing the known population of cities and towns on the map and subtracting them from the county population
d. Distributing the balance of the population into 15-minute squares within the county, taking into consideration the distribution of communities, farm roads, and ranch houses.

This is a rather difficult and time-consuming method. However, the author found no other way except to use the original census data from the Census Bureau. This attempt, nevertheless, generated the sub-box population with estimated 50% accuracy over sparsely populated areas and with 90% accuracy in city areas.

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After completing the sub-box population, the path length of all tornadoes in each sub-box was sorted against the population to compute the mean path length within sub-boxes of various population ranges.

The results, thus obtained, are presented in Figure 10. Since the population categories were selected to be (0-200), (200-500), (500-1,000), (1,000-2,000), (2,000-3,000) ..., (10,000-20,000), (20,000-30,000) etc., both linear and log scales were used in this figure.

It is seen that the mean path length is extremely short when the population in a sub-box is less than 200. Then it increases rapidly to become more or less constant after 3,000 to 10,000 population per sub-box.

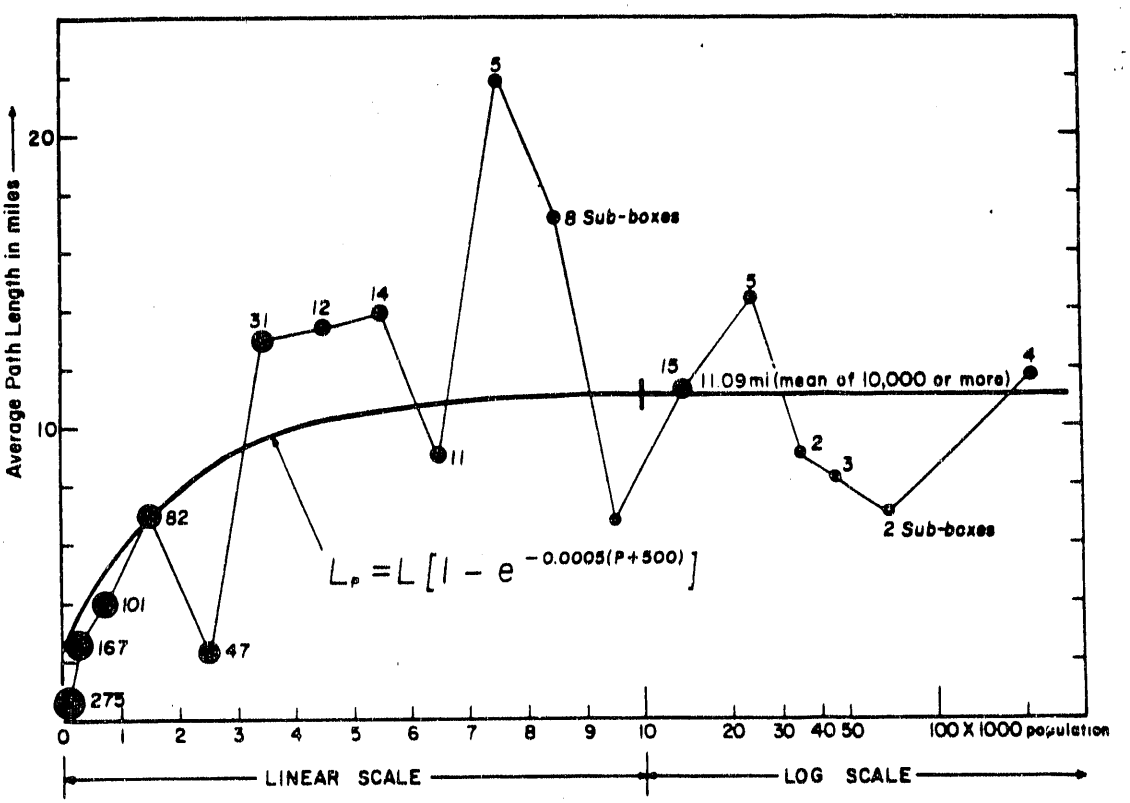

Figure 10. Average path lengths of all tornadoes plotted as a function of the population within 15-min sub-boxes. The numbers by each painted circle denote the number of sub-boxes used in compiling the statistics.

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A curve fitting was attempted, keeping in mind the ultimate use of the fitted curve for gross population correction of the path length. This is why the curve was not brought down to zero path length when the sub-box population approaches zero. The analytical equation obtained is

$$L_p = L\,[\,1 - e^{-0.0005(P+500)}\,] \tag{7}$$

where L_p denotes the "original path length" reported by the existing population; L, the "population corrected path length" reported if there were infinite population; and P, in parenthesis, the population within the sub-box. Eq. (7) shows that

$$L_p = L \text{ when } P \text{ is infinity}$$
$$\text{and} \qquad L_p = 0.221\,L \text{ when } P = 0\,, \tag{8}$$

indicating that 22% of the path length is mapped if there were no population within a sub-box. This means that tornadoes in the zero-population sub-box are assumed to be observed from outside the box and/or reported by someone who enters the sub-box later. This result suggests that the original path length must be multiplied by a correction factor in order to obtain the population corrected path length (path length which would be reported if there were infinite population).

The correction factor which is defined as the ratio, true path length divided by apparent path length, can be expressed by

$$C_p = \frac{L}{L_p} = \frac{1}{1 - e^{-0.0005(P+500)}} \tag{9}$$

where C_p is "population correction factor" which varies with P, the population. Special values of the correction factor are

$$C_p = 1 \quad \text{when } P \text{ is infinity}$$
$$C_p = 4.52 \text{ when } P = 0\,. \tag{10}$$

Shown in Figure 11 is the variation of C_p as a function of sub-box population. In view of a possibly large error in path length when the sub-box population is low, the correction factors were chosen to be coarse when population is low.

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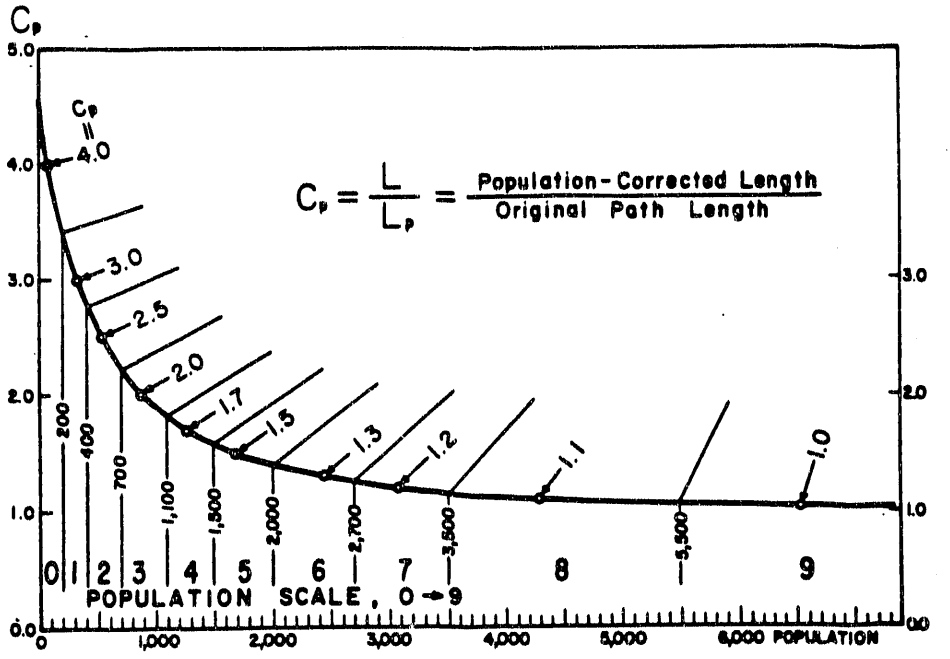

Figure 11. Variation of C_p, the population correction factor with the population scale which varies between 0 and 9.

The population scale in Table 9 was produced to result in such a variation in the correction factor. For instance, $C_p = 4.0$ is chosen when the sub-box population is less than 200 (population scale 0) while $C_p = 3.0$ applies to population scale 1 (200 to 399 population). The correction factor is designed to decrease by one-tenth when the sub-box population exceeds 2,000. Naturally, the minimum value of C_p is 1.0 which is reached when the sub-box population is 5,500 or greater.

The population scale (PS), applicable to each sub-box, is plotted in Figure 12. It should be noted that there are a large number of PS-0 sub-boxes in New Mexico and southwestern Texas. Scattered PS-0 also are found near the Oklahoma border where tornado frequencies in Figure 6 are apparently low.

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Table 9. Range of population and population correction for each population scale. Population-corrected path length is obtained as a product of original path length and C_p, the population-correction factor.

Population scale	Range of population	Population Correction factor C_p
0	0 - 199	4.0
1	200 - 399	3.0
2	400 - 699	2.5
3	700 - 1,099	2.0
4	1,100 - 1,499	1.7
5	1,500 - 1,999	1.5
6	2,000 - 2,699	1.3
7	2,700 - 3,499	1.2
8	3,500 - 5,499	1.1
9	5,500 or more	1.0

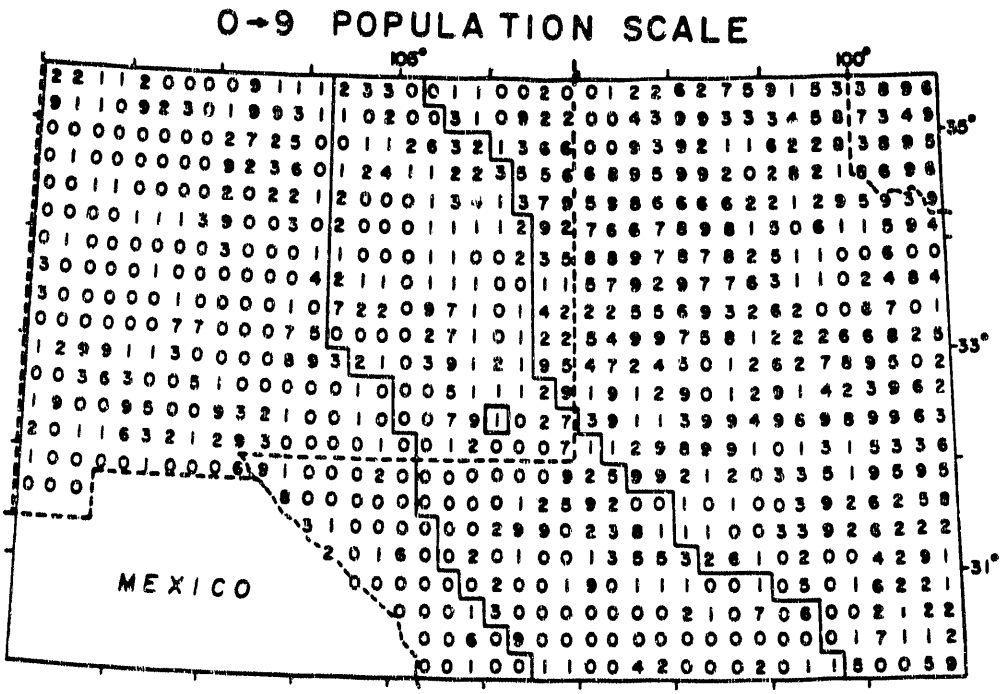

Figure 12. Distribution of population scale for 15-min. sub-boxes. No estimate of population in Mexico was attempted because no tornado reports, if any, could be obtained.

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Within the 880 sub-boxes in Figure 9, 783 are in the U.S., allowing us to make reasonable estimates of the sub-box population. Of these, 271 sub-boxes (35%) are characterized by PS-0, resulting in a serious problem in assessing the tornado risk at the WIPP site (see Table 10 and Figure 13). There are only 75 sub-boxes (less than 10%) with PS-9 (5,500 or more population). This number is considerably smaller than that in the Midwest plains where over 70% of sub-boxes are regarded as PS-9.

It should be noted, however, that the sub-boxes located both east and west of the WIPP site have significant populations. The sub-boxes to the north of the WIPP site and the sub-box containing the WIPP site are populated. The large number of zero population sub-boxes have been introduced in this model by the inclusion of southwestern Texas and the western two-thirds of New Mexico.

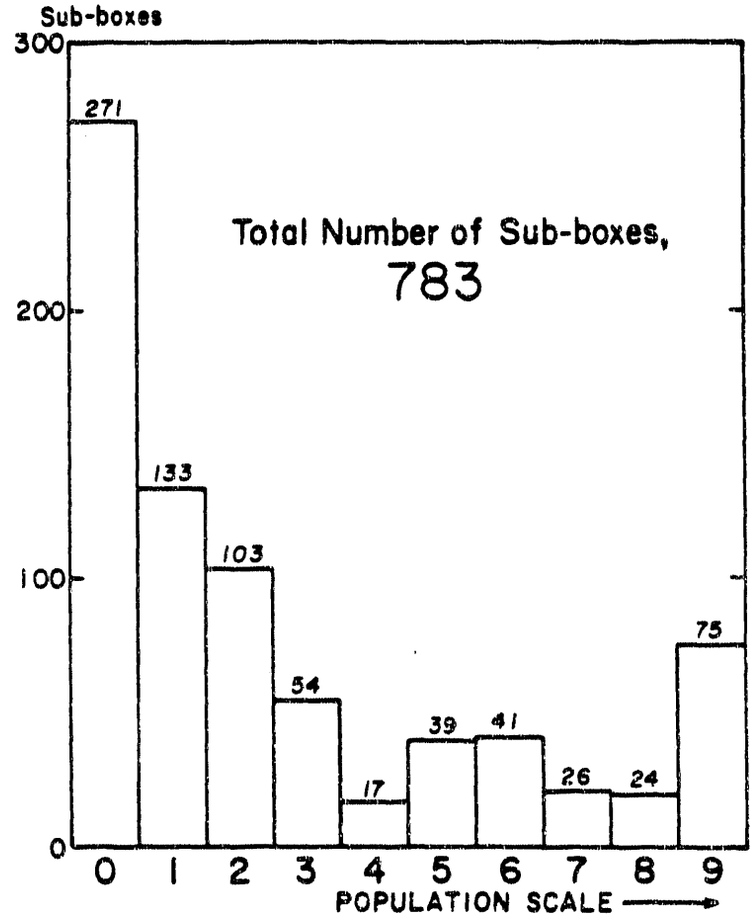

Figure 13. Number of sub-boxes shown as a function of population scale. Only 205 sub-boxes (26%) are PS-5 (1.5 population correction factor) or more.

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Table 10. Distribution of population scale within 10 x 5½ degrees of longitudes and latitudes around the WIPP site.

	Population scale (0-9)									
	0	1	2	3	4	5	6	7	8	9
Population range in each scale	200	200	300	400	400	500	700	800	2,000	infinity
Number of Sub-boxes (in %)	271 (35)	133 (17)	103 (13)	54 (7)	17 (2)	39 (5)	41 (5)	26 (3)	24 (3)	75 (10)

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● Population-corrected Path Lengths

According to above derivations, population corrections can be obtained simply through a multiplication process:

$$L = C_p L_p$$

where C_p, the correction factor is obtained from Table 9 as a function of the population scale for each sub-box.

When population-corrected lengths were plotted (Figure 14) it turned out that there were a large number of sub-boxes which would have to be left "blank" because no tornado was reported from these sub-boxes.

Can we use these blank sub-boxes as evidence of no tornado? The answer is either "yes" or "no", depending upon the population in each sub-box. If the sub-box includes sufficient population to observe tornadoes, we should use the "yes" category. If not, the answer should be the "no" category because tornadoes in a sparsely populated area may never be reported, unless meteorological methods can be advanced for identifying tornadoes at remote locations. Based on these considerations, a sub-box with "zero" path length was categorized as:

Category 1 -- Zero Path Length category if the population scale is 5 or larger. Shown with • in Figure 14, 15 and 16.

Category 2 -- Unknown Path Length category if the population scale is 4 or smaller. Sub-boxes in Figure 14, 15, and 16 are left blank.

The " zero path length" can be used as evidence of no tornado, but the "unknown path length" should be treated as if there were no data at all. The areas of the sub-box with unknown path length are thus eliminated entirely, thus regarding them as water areas or Mexican territory.

Figures 14 through 16 include concentric circles and zigzag boundaries. They are later used in assessing tornado probabilities at the WIPP site indicated by "+" symbol in these figures.

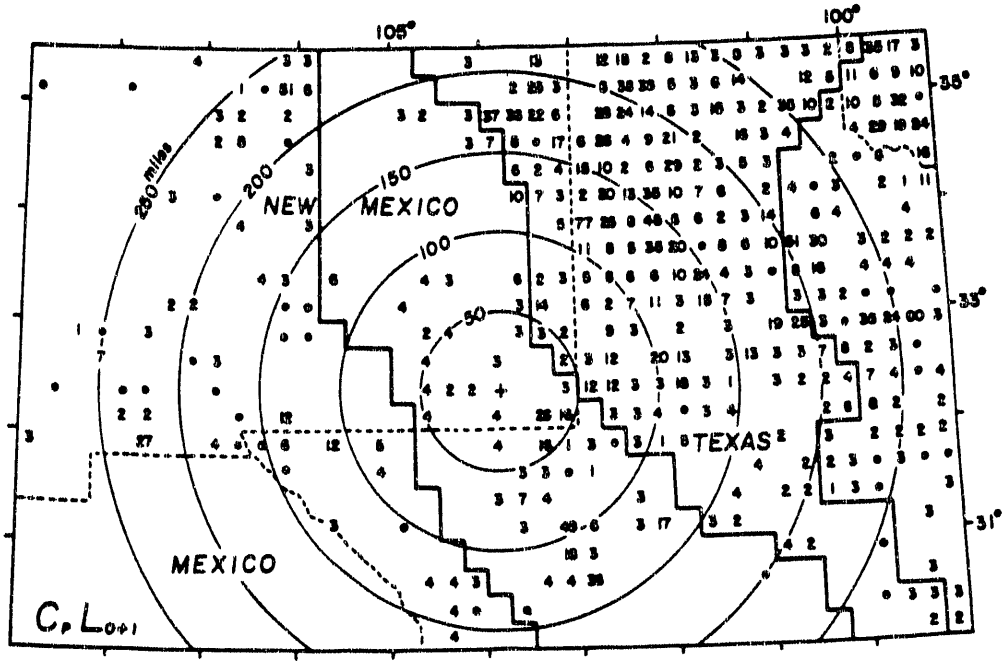

Figure 14. Population-corrected path length of Weak (F0+F1) tornadoes in miles. Sub-boxes with • are regarded as those of no tornadoes during 1950-75.

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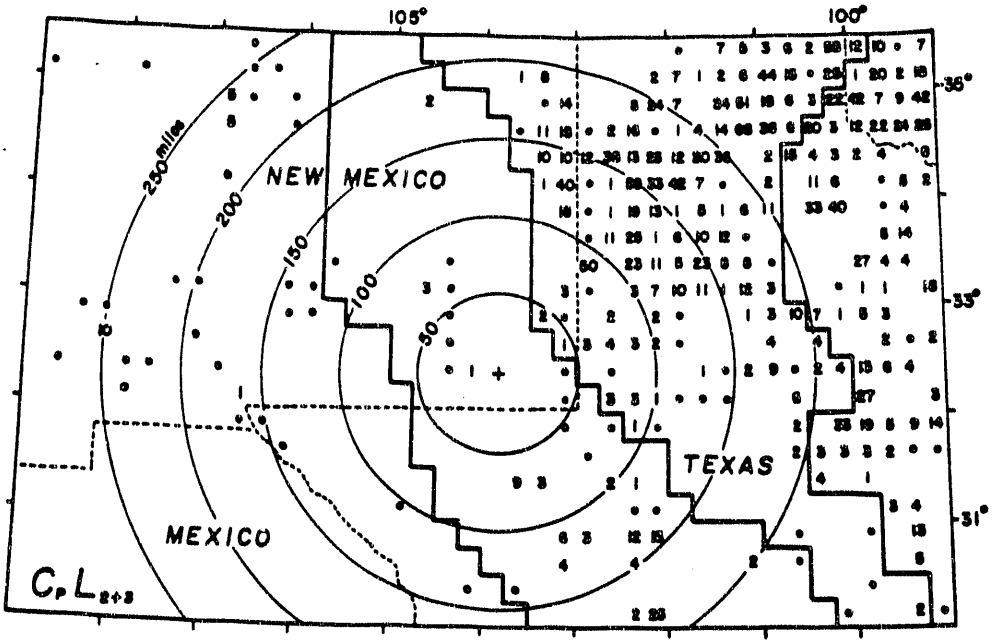

Figure 15. Population-corrected path length of Strong (F2+F3) tornadoes in miles. Sub-boxes with • are regarded as those of no tornadoes during 1950-75.

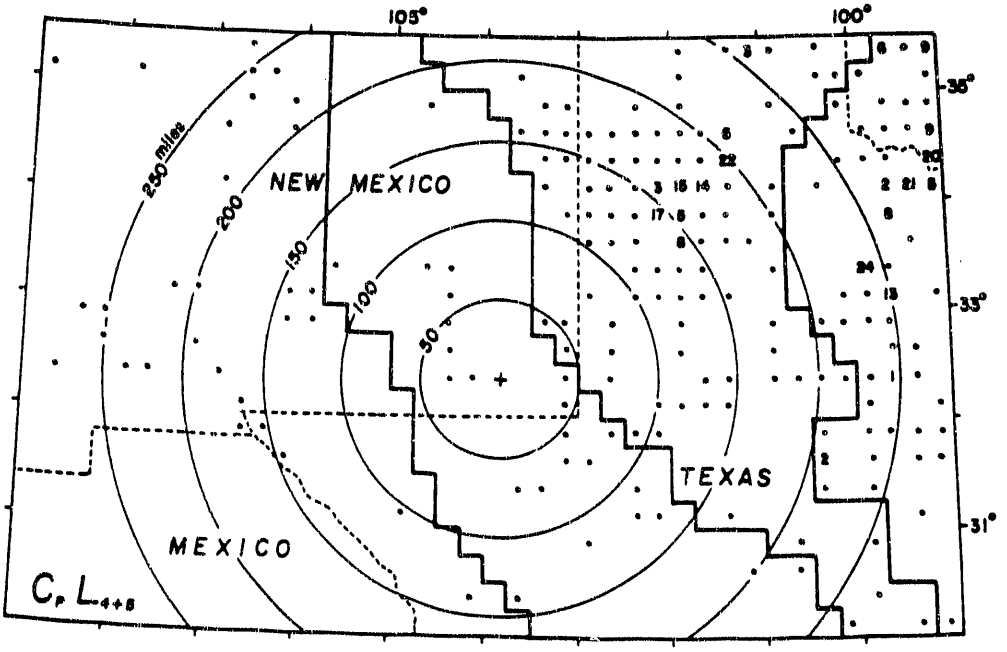

Figure 16. Population-corrected path length of Violent (F4+F5) tornadoes in miles. Sub-boxes with • are regarded as those of no tornadoes during 1950-75.

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● Computation of Probabilities by DAPPLE Method

In general, tornado probability, P_T, at a given site can be computed as the ratio,

$$P_T = \frac{\Sigma A}{B \times Y} = \frac{\text{tornado area}}{\text{land area x years}} \quad (11)$$

where ΣA denotes the total area of tornadoes inside B, the land area during Y, the number of statistical years.

Since sub-boxes in category 2 are regarded as equivalent to water areas, Eq. (11) can be modified into

$$P_T = \frac{\Sigma A}{Y \Sigma b} \quad (12)$$

where Σb is the total area of sub-boxes excluding those of category 2.

In order to obtain the probability as a function of windspeed, we have to estimate tornado areas as a function of windspeed. This can be done by applying the DAPPLE method devised by Abbey and Fujita (1975).

In their method, it is assumed that Damage Area Per Path LEngth (DAPPLE) varies with the F scale intensity of tornadoes. A set of DAPPLE curves for each F scale tornado can be obtained analytically as a function of windspeed. DAPPLE values have been computed for tornadoes divided into three categories, Weak(F0+F1), Strong(F2+F3), and Violent (F4+F5).

Available DAPPLE values, so far, are those computed from the April 3 - 4, 1974 super-outbreak. These DAPPLE values will, nevertheless, result in conservative values when applied to probability computations at most sites outside the highest tornado-risk areas.

By applying these DAPPLE values, we replace vague tornado areas with those given as functions of windspeed. For details of computation steps, see Abbey (1976). Now we express the tornado probability by

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$$P_T = \frac{1}{Y}\left(D_w \frac{\Sigma L_w}{\Sigma b_w} + D_s \frac{\Sigma L_s}{\Sigma b_s} + D_v \frac{\Sigma L_v}{\Sigma b_v} \right) \quad (13)$$

where D denotes DAPPLE value and L, path length. Suffixes, w, s, and v indicate weak, strong, and violent tornadoes, respectively. It should be noted that the DAPPLE value, D, varies with windspeed as well as three-categories of tornadoes.

The ratio of total area of one-category tornado and that of sub-boxes can be approximated by

$$PLD = \frac{\Sigma L}{\Sigma b} = \frac{\Sigma L}{n \times b} \quad (14)$$

where PLD is called the path-length density; n, the number of sub-boxes; and b, the area of each sub-box which may be assumed constant. The sub-box area, without water area in it, varies only with latitude.

At 32° 22' 30", the latitude of WIPP, b is 252 sq. mi. Between extreme latitudes of 30° N and 35.5° N, b decreases from 258 to 243 sq. mi or between +2.4% and -3.6% of the value at the WIPP latitude. In view of possible errors in tornado path lengths which, in most cases, exceed variations in b, Eq. (14) can be used unless the range of latitudes is excessive.

The path-length density in Eq. (14) is characterized by the dimension,

$$(PLD)_{dimension} = \left(\frac{mile}{mile^2}\right) = (mile^{-1}). \quad (15)$$

Now we combine Eqs. (13) and (14) into

$$P_T = (DAPPLE) \times \frac{(PLD)}{Y}, \quad (16)$$

the dimension of which is

$$(P_T)_{dimension} = \left(\frac{mi^2}{mi}\right) \times \frac{(mile^{-1})}{(year)} = (Year^{-1}). \quad (17)$$

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Probability Calculations

Probabilities by Circular-area Method

The accuracy of probability computations is dependent upon that of PLD, the path-length density. If we select a small area around the site to obtain tornado data, we will end up with a small value of ΣL divided by a small value of n. This would result in a situation to compute a value, "zero over zero" which is quite often indeterminate.

By selecting a large area around the site we definitely increase the accuracy of PLD, but the area could extend into that of non-representative tornadoes. Table 11 was prepared to show the effects of ranges upon three parameters: ΣL, the total path length; n, the number of sub-boxes; and PLD, the path-length density.

PLD of weak tornadoes increases gradually from about 20 mi^{-1} to over 30 mi^{-1} as the range increases to 250 miles. Both strong and violent tornadoes are characterized by zero PLD at the WIPP site but the values begin showing up at about 50 and 100 miles, respectively.

Table 11. Population-corrected path lengths within various ranges of the WIPP site, during the 26-year period, 1950-75. Path-length density represents the value for 26 years.

	Ranges (in miles)				
	50	100	150	200	250
WEAK (F0+F1) TORNADOES					
Total path length	94	317	948	1,570	2,203 miles
Number of sub-boxes	15	55	124	202	292 boxes
Path-length density	24.7	22.8	30.4	30.8	29.9×10^{-3} mi^{-1}
STRONG (F2+F3) TORNADOES					
Total path length	4	94	435	856	1,455 miles
Number of sub-boxes	8	31	85	144	207 boxes
Path-length density	2.0	12.1	20.3	23.6	27.9×10^{-3} mi^{-1}
VIOLENT (F4+F5) TORNADOES					
Total path length	0	0	25	62	129 miles
Number of sub-boxes	8	23	68	109	152 boxes
Path-length density	0	0	1.46	2.26	3.37×10^{-3} mi^{-1}

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Path-length densities in Table 11 were plotted as functions of the range from the WIPP site. Results in Figure 17 indicate that violent tornadoes were not reported inside the 100-mile range of the WIPP site.

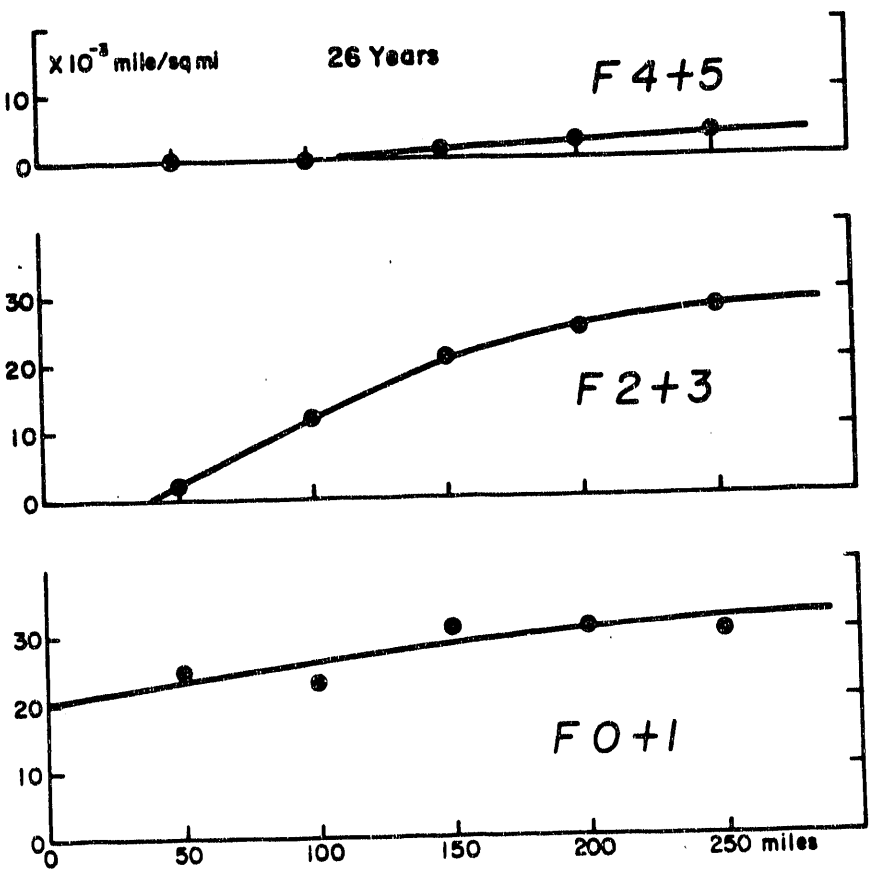

Figure 17. Variation of path-length density, PLD as a function of the ranges from the WIPP site. PLD were computed for 3-category tornadoes by varing ranges between 50 and 250 miles.

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Table 12. Path-length density within 100-mile range of the WIPP site. Smoothed value from Figure 17.

Tornado categories	Path-length densities (100 mile range) 26yrs(1950-75)	(per year)
WEAK (F0+F1)	25.6×10^{-3} mile^{-1}	0.98×10^{-3} mile^{-1} yr^{-1}
STRONG (F2+F3)	12.1×10^{-3}	0.47×10^{-3}
VIOLENT (F4+5)	0.0	0.00

Figures 14 through 16 reveal that the 50 mile range is too small to include reliable tornado data. A 150-mile range is certainly too large, thus including high-risk areas around Lubbock, Texas, which should not be extrapolated to the WIPP site based on meteorological grounds.

It is customary to use a 100-mile range of given site in computing site-specific probabilities. Because of a large gradient of PLD across the WIPP site, it is very difficult to justify the 100-mile range as the most representative range for probability computations.

Under these circumstances an attempt was made to compute probabilities within the customary 100-mile range. Path-length densities and their per-year values, thus computed, are given in Table 12.

From these figures, the tornado probabilities were computed from Eq. (16) by using DAPPLE values for every 50 mph increment of windspeed. Note that there are no violent tornadoes within the 100-mile range of the WIPP site (see Table 13).

Table 13. Probabilities of tornadoes within 100-mile range of the WIPP site. Values were computed from the path-length densities per year in Table 12.

Windspeed (mph)	WEAK TORNADOES DAPPLE	WEAK TORNADOES Probabilities	STRONG TORNADOES DAPPLE	STRONG TORNADOES Probabilities	ALL TORNADOES Probabilities
50	0.074	7.25×10^{-5} yr^{-1}	0.43	2.02×10^{-4} yr^{-1}	2.75×10^{-4} yr^{-1}
100	0.0028	2.74×10^{-6}	0.062	2.91×10^{-5}	3.18×10^{-5}
150	0.000052	5.10×10^{-8}	0.0098	4.61×10^{-6}	4.66×10^{-6}
200	0.000000	0.00	0.0012	5.64×10^{-7}	5.64×10^{-7}
250	0.000000	0.00	0.000087	4.09×10^{-8}	4.09×10^{-8}

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● Probabilities by Pecos Valley Method

An arbitrary selection of the 100-mile range discussed in the previous section resulted in a set of probabilities as a function of windspeeds. Until another method is tested these values are not justifiable because of the large PLD variations across the WIPP site.

To overcome this difficulty an independent method was devised. The statistical area was divided into four regions:

Rio Grande Valley --- Rio Grande watershed and west

Pecos Valley --- Pecos Valley watershed

Plateau --- west of the 2,000 ft contour line

Plains --- east of the 2,000 ft contour line

The boundaries of these four regions are shown in Figure 18.

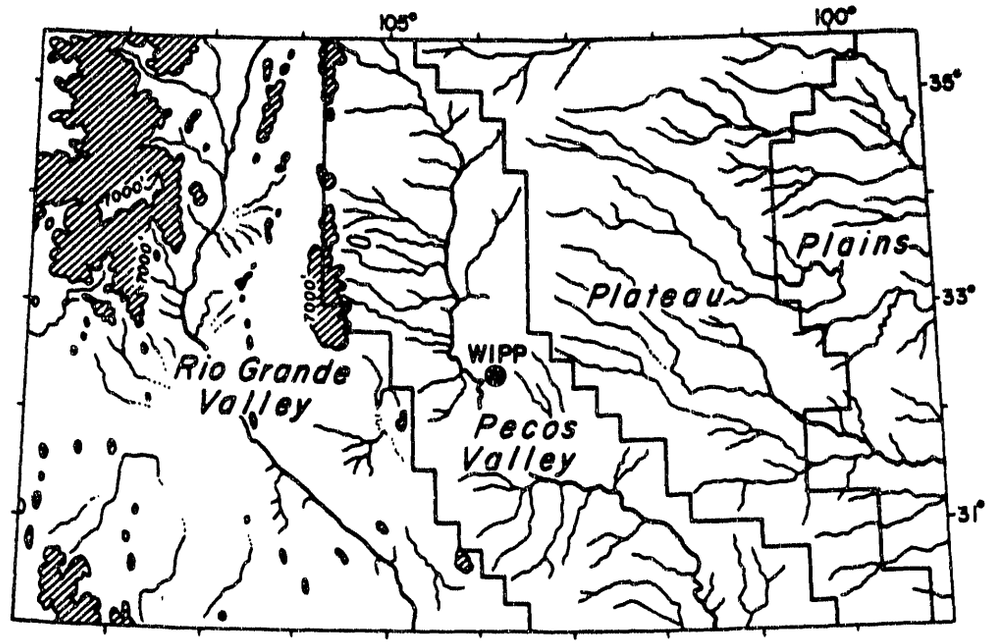

Figure 18. Four regions of different tornado characteristics. Boundaries are chosen as those of watersheds except the 2,000ft height contour was used to separate "Plateau" from "Plains".

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Normalized paths of the three-category tornadoes in Figures 14 through 16 are divided into four regions. It is seen that tornado distributions are separated by three boundaries reasonably well.

After determining the sub-boxes belonging to each region, path-length densities of the three-category tornadoes within each region were computed and plotted in Figure 19. From this figure the path length density at the WIPP site was estimated for each category of tornadoes (see Table 14).

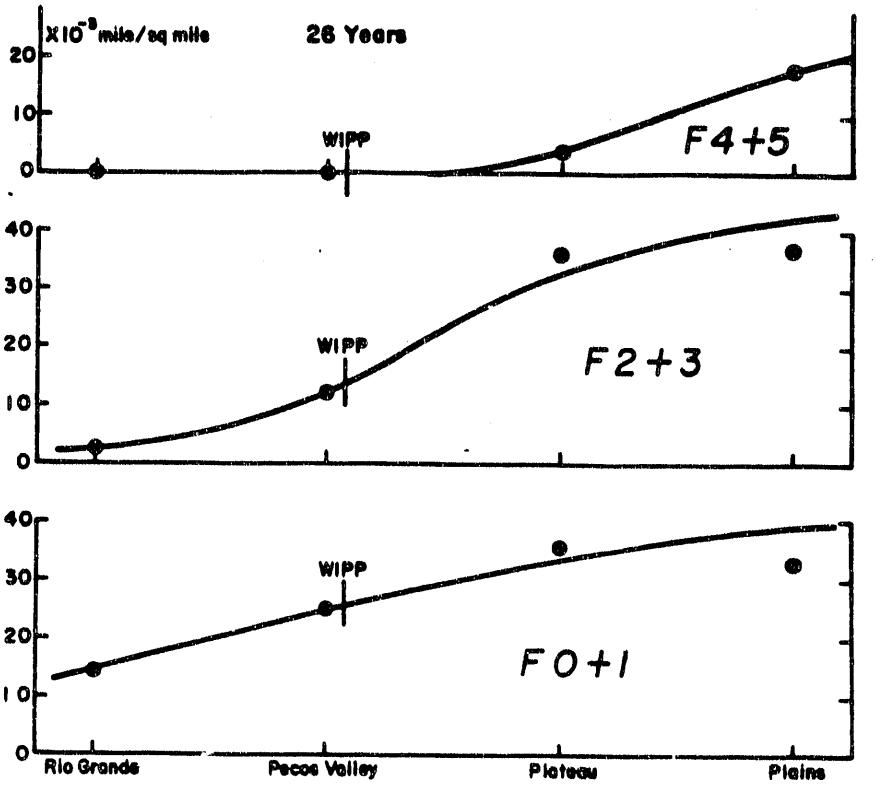

Figure 19. East-west variations of path-length densities of three-category tornadoes. The WIPP site is located to the east of the center line of Pecos Valley.

Table 14. Path-length density at the WIPP site obtained by Pecos Valley method. Values were estimated from Figure 19 by placing the site on the east side of the valley.

Tornado categories	Path-length densities at WIPP site 26yrs (1950-75)	(per year)
WEAK (F0+F1)	26.8×10^{-3} mile^{-1}	1.03×10^{-3} mile^{-1} yr^{-1}
STRONG (F2+F3)	14.3×10^{-3}	0.55×10^{-3}
VIOLENT (F4+F5)	0.0	0.00

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Then the probabilities of various windspeeds were computed from Eq. (16), using Table 14 as input data. As shown in Table 15, probabilities computed by this method (Pecos Valley method) are slightly larger than those of the 100-mile range values. If we choose either the 110- or 120-mile range, the probabilities will become very close to those obtained by the Pecos Valley method.

Table 15. Probabilities of tornadoes at the WIPP site. Values were computed from the path-length densities per year in Table 14.

Windspeed (mph)	WEAK TORNADOES DAPPLE	WEAK TORNADOES Probabilities	STRONG TORNADOES DAPPLE	STRONG TORNADOES Probabilities	ALL TORNADOES Probabilities
50	0.074	$7.62 \times 10^{-5}\ yr^{-1}$	0.43	$2.37 \times 10^{-4}\ yr^{-1}$	$3.13 \times 10^{-4}\ yr^{-1}$
100	0.0028	2.88×10^{-6}	0.062	3.41×10^{-5}	3.70×10^{-5}
150	0.000052	5.36×10^{-8}	0.0098	5.39×10^{-6}	5.44×10^{-6}
200	0.000000	0.00	0.0012	6.60×10^{-7}	6.60×10^{-7}
250	0.000000	0.00	0.000087	4.79×10^{-8}	4.79×10^{-8}

CONCLUSIONS

Probabilistic Wind Storm Model for WIPP Site

Probabilities of straight-line winds were computed by multiplying the fastest-mile winds in Table 3 by the factor of 1.25 as recommended in Eq. (6). The probability curve, thus obtained, was combined with the tornado probabilities in Table 15 obtained by the Pecos Valley method.

Two probability curves in a semi-log diagram (see Figure 20) represent the probable windspeeds at the WIPP site as a function of probabilities ranging between 10^{-1} and 10^{-7} per year.

The combined results in Table 16 reveal that the speeds of straight-line gusts are higher than those of tornadoes when probabilities are higher than about 2×10^{-5} $year^{-1}$ (return period, 50,000 years). The maximum wind speeds of tornadoes are computed to be 136, 183, and 228 mph, corresponding to 10^{-5}, 10^{-6}, and 10^{-7} $year^{-1}$ probabilities.

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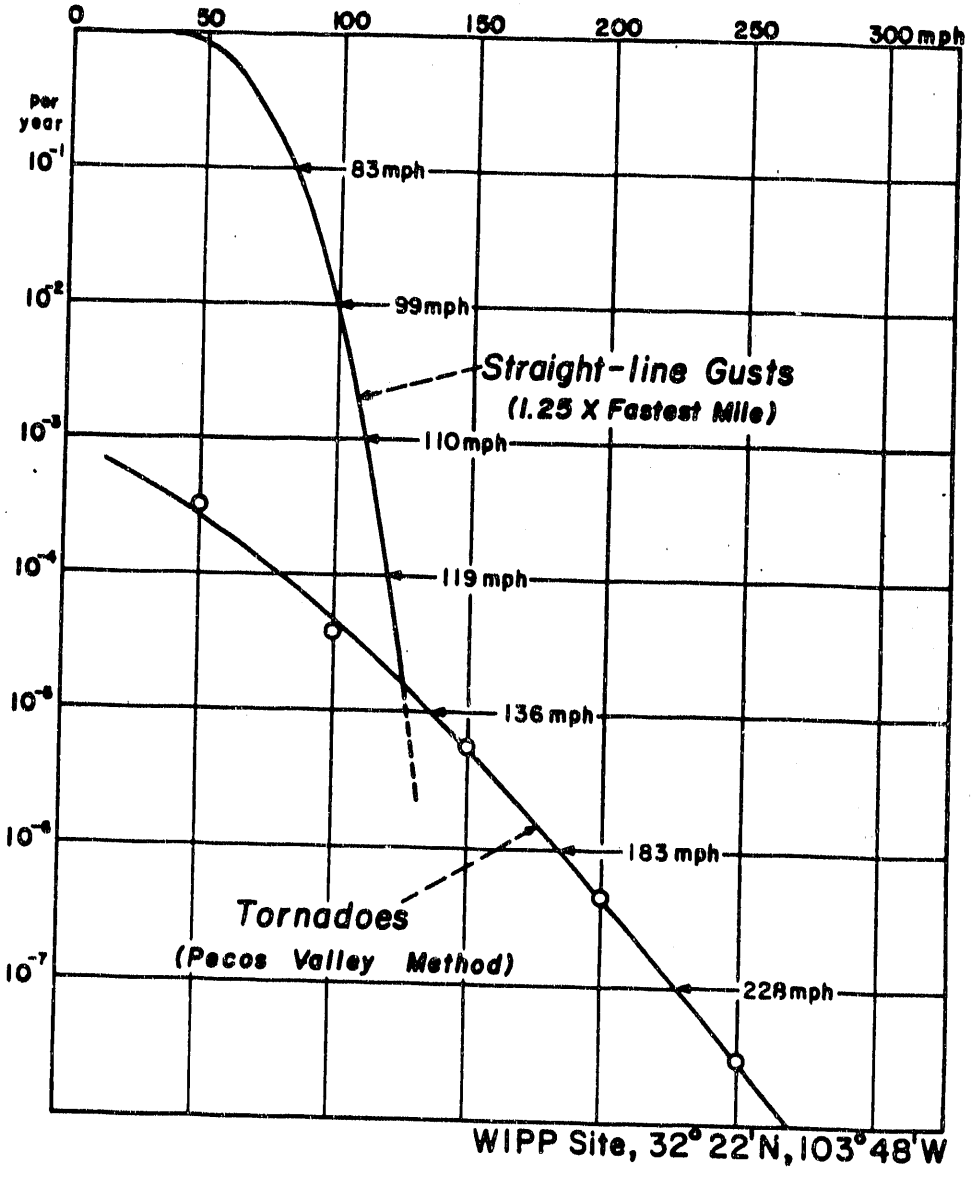

Figure 20. Probabilities of straight-line winds and tornadoes at the WIPP site located 25 miles east-southeast of Carlsbad, New Mexico.

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Table 16. Characteristics of storms corresponding to seven probabilities. Air density of the standard atmosphere at 3,414ft is 1.108 kg/m³. The radius of maximum wind was assumed 150m for computational purposes. SLG---Straight-line gust. TOR---Tornado.

	Probabilities (year^{-1})						
	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}
Wind storms	SLG	SLG	SLG	SLG	TOR	TOR	TOR
Maximum windspeeds (mph)	83	99	110	119	136	183	228
Translational vel. (mph)	--	--	--	--	27	37	46
Max. tangential vel. (mph)	--	--	--	--	109	146	182
Pressure drop (mb)	--	--	--	--	26.3	47.3	73.4
(psi)	--	--	--	--	0.38	0.69	1.06
Rate of pr. drop (mb/sec)	--	--	--	--	2.12	5.22	10.06
(psi/sec)	--	--	--	--	0.03	0.08	0.15

The maximum windspeeds of tornadoes are assumed to be the sum,

$$T_m = V_m + C \tag{18}$$

where T_m denotes the maximum total velocity (maximum windspeed); V_m, the maximum tangential velocity; and C, the translational velocity. For convenience both vertical velocity and environmental flow velocity are neglected.

For design-basis tornadoes, C is regarded as 20% of the maximum windspeed or

$$C = 0.2\ T_m \tag{19}$$

thus we have

$$V_m = 0.8\ T_m. \tag{20}$$

By assuming the radius of maximum wind to be

$$R_o = 150\ \text{m}, \tag{21}$$

we are able to estimate both the total pressure drop and the rate of pressure drop from

$$\Delta P = \rho\ V_m^2 \tag{22}$$

and

$$\frac{d}{dt}\Delta P = \frac{C}{R_o}\rho\ V_m^2 \tag{23}$$

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where ΔP denotes the deficit pressure at the vortex center and ρ, the density of air. Eq. (23) is identical to Eq. (3) of WASH-1300 by Markee et al. (1974).

Parameters computed from these equations are given in Table 16. The author recommends that these parameters be used in evaluating risks of straight-line winds and tornadoes at the WIPP site.

As shown in this table, the design-basis windspeeds increase from 83 mph to 228 mph as the probability decreases from 10^{-1} to 10^{-7} per year. Meanwhile, the type of windstorms inducing damaging winds changes from straight-line wind to tornado.

It is recommended that the level of a proper probability be selected for each structure. Then the storm type and parameters corresponding to the specific probability be used as design criteria in assessing existing structures or those to be constructed at the WIPP site.

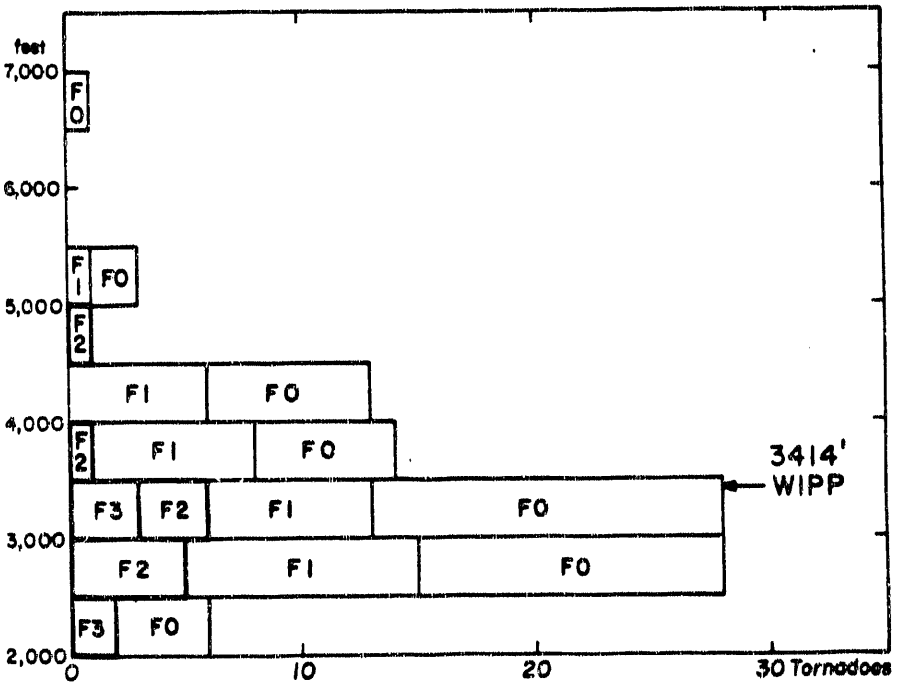

Figure 21. Frequency distribution of various F-scale tornadoes within Pecos Valley. The elevation of the WIPP site is not high enough to exclude the possibility of F3 tornado.

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NOTICE -- Development of the Design-Basis Tornado, 1978 (DBT-78) now permits us to compute improved design-basis parameters. Pages 40 and 41, with the exception of Figure 21, are to be replaced by the following text, figures, and tables.

****

Figure 20 reveals the maximum windspeeds at the WIPP site, corresponding to 10^{-1} to 10^{-7} per year probabilities. The results, also summarized in Table 16, indicate that straight-line gusts are stronger than tornado winds when probabilities are equal to or higher than 10^{-4} per year.

When probabilities are equal to or lower than 10^{-5} per year, tornadoes will induce winds higher than straight-line winds. These tornadoes are naturally characterized by both translational and swirling motions, the combination of which induces the pressure drop as well as the time rate of pressure drop. Computations of these values for design purposes require a model of design-basis tornadoes which represents conservative airflow of tornadoes.

Table 16. Maximum windspeeds and storm types corresponding to 10^{-1} to 10^{-7} per year probabilities. SLG--Straight-line gusts. TOR--Tornadoes.

	Probabilities (per year)						
	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	1
Storm types	SLG	SLG	SLG	SLG	TOR	TOR	T
Max. windspeeds (mph)	83	99	110	119	136	183	2

Under an NRC contract (Robert Abbey, contract monitor), Fujita is now in the process of improving a generalized design-basis tornado model which includes multiple vortices. The initial model was presented in the DOE sponsored Tornadoes and High Winds Workshop at Argonne National Laboratory (July 10-12, 1978).

A test application of this model to the WIPP site has been approved by the NRC contract monitor under the condition that the model be subject to necessary revisions as more tornado data become available in future years.

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The generalized design-basis tornado model (DBT-78) is characterized by the radius of outer core (R_o) and that of inner core (R_i). A horizontally-uniform vertical motion exists only inside the outer core. While the tornado rotates with its maximum tangential velocity (V_m), its center travels at translational velocity (T).

Suction vortices, assumed identical in sizes and airflow characteristics, are circular in shape, occupying the space between R_i and R_o. Each suction vortex spins around with its maximum tangential velocity ($\mathring{V}_m$) while orbiting around the tornado center at the translational velocity ($\mathring{T}$), see Figure 20A.

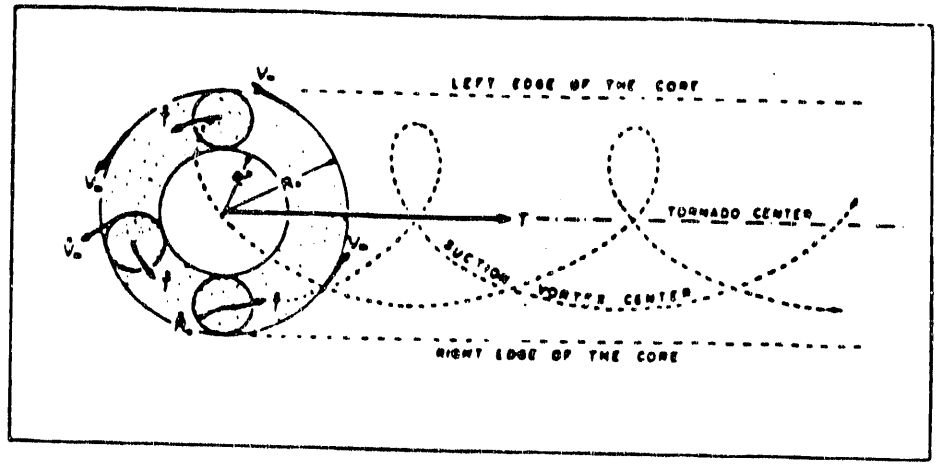

Figure 20A. Features of the design-basis tornado, 1978 (DBT-78) by Fujita, which includes suction vortices embedded inside the outer core.

Basic assumptions are summarized in Equations (18) through (30). A more complete description of DBT-78 will be available after the Second Workshop on Tornadoes and High Winds during the latter part of September, 1978.

Maximum horizontal velocity (M_H) is defined as

$$M_H = T + V_m \qquad (18$$

while the two velocities on the right side are assumed to be

$$T = 0.25\, M_H \text{ and } V_m = 0.75\, M_H . \qquad (19$$

The tornado's core radius (R_o) is assumed to increase in proportion to V_m, or

$$R_o = 0.8\, V_m \text{ (R_o in meters and V_m in mph)} \qquad (20$$

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Core radius of the embedded suction vortex is computed from

$$\dot{R}_o = \frac{1}{2}(R_o - R_o) \tag{21}$$

and the maximum tangential velocity ($\dot{V}_m$) is assumed to be one-half of V_m, or

$$\dot{V}_m = \frac{1}{2} V_m . \tag{22}$$

The maximum vertical velocity of a tornado (W_m) and of a suction vortex ($\dot{W}_m$) are computed from

$$W_m = 0.397\ V_m \quad \text{and} \quad \dot{W}_m = 0.397\ \dot{V}_m . \tag{23}$$

The translational velocity, (T), of a suction vortex around a tornado is assumed as the mean tangential velocity inside the tornado's outer core. Namely,

$$\dot{T} = \frac{1}{2} \frac{R_o + R_o}{R_o} V_m \int_0^1 h^{\frac{1}{7}}\, dh$$

$$= \frac{3}{7}\left(1 + \frac{R_o}{R_o}\right) V_m \tag{24}$$

where h denotes the normalized height above the surface. h = 1 is reached at the top of the inflow layer.

The maximum total velocity (M_T) inside the tornado is the vector sum of both horizontal and vertical velocities. The values are computed from

$$M_T^2 = (V_m + T)^2 + W_m^2 . \tag{25}$$

Inside suction vortices, the maximum total velocity ($\dot{M}_T$) includes the maximum translational velocity ($T + \dot{T}$). Thus, we write

$$\dot{M}_T^2 = (T + \dot{T} + \dot{V}_m)^2 + W_m^2 . \tag{26}$$

Numerical computations show that $\dot{M}_T$ is always larger than M_T, but their difference is negligibly small for weak tornadoes which are characterized by small core radii in this DBT-78 model.

For violent (F4 and F5) tornadoes, the difference increases to 20 to 30 mph suggesting that the maximum wind effects in suction vortices are 15 to 30% larger (see Table 17).

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Table 17. Maximum total velocities inside tornado (M_T) and those inside embedded suction vortices ($\dot{M}_T$). The highest F-scale windspeeds in tornado occur in the paths of suction vortices. $\dot{M}_T$ will, thus, represent the maximum F-scale windspeed.

F scale	$\dot{M}_T$	M_T	$\dot{M}_T - M_T$	$(\dot{M}_T/M_T)^2$	R_o
0.2	50 mph	50 mph	0.4 mph	1.02	29 m
1.7	100	97	3.1	1.07	56
2.8	150	143	7.3	1.10	82
3.8	200	187	12.7	1.14	108
4.8	250	240	19.1	1.17	132
5.7	300	274	26.2	1.20	157

The maximum pressure drop due to the tornado vortex is computed from

$$\Delta P_m = \rho V_m^2 . \qquad (2$$

Because embedded suction vortices are much smaller than their parent tornadoes we compute the maximum pressure drop due to suction vortex from

$$\Delta \dot{P}_m = \rho \dot{V}_m^2 = \tfrac{1}{4} \rho V_m^2 . \qquad (2$$

The rate of pressure drop due to tornado vortex and suction vortex are expressed, respectively, by

$$\left(\frac{d}{dt} \Delta P\right)_m = \frac{T}{R_o} \rho V_m^2 \qquad ($$

$$\left(\frac{d}{dt} \Delta \dot{P}\right)_m = \frac{T + \dot{T}}{\dot{R}_o} \rho \dot{V}_m^2 \qquad ($$

where ρ is the air density which is assumed constant for integration purposes.

Equations (18) through (30) were used in computing the design-basis tornad parameters in Table 18. The input data for three-probability tornadoes are the ma mum total windspeeds from Figure 20. These maximum windspeeds denote $\dot{M}_T$, the maximum total velocity in the path of embedded suction vortices. Table 18 sho the breakdown of the maximum total velocity into V_m, $\dot{V}_m$, T, and $\dot{T}$.

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Table 18. Characteristics of design-basis tornadoes and embedded suction vortices applicable to the WIPP site.

Design parameters	PROBABILITIES 10^{-6} year^{-1}	10^{-6} year^{-1}	10^{-7} year^{-1}
Max. total vel., $\dot{M}_T$ from Figure 20	136 mph	183 mph	228 mph
FOR TORNADOES			
Max. tang. vel., V_m	94 mph	124 mph	152 mph
Trans. velocity, T	31 mph	41 mph	51 mph
Core radius, R_o	75 m	99 m	122 m
Max. press. drop, ΔP_m	19.3 mb 0.3 psi	33.9 mb 0.5 psi	51.3 mb 0.7 psi
Max. rate of pr. drop	3.6 mb/sec 0.05 psi/sec	6.3 mb/sec 0.09 psi/sec	9.5 mb/sec 0.14 psi/sec
FOR SUCTION VORTICES			
Max. tang. vel., $\dot{V}_m$	47 mph	62 mph	76 mph
Trans. velocity, $\dot{T}$	57 mph	78 mph	99 mph
Core radius, $\dot{R}_o$	22 m	26 m	29 m
Max. press. drop, $\Delta\dot{P}_m$	4.8 mb 0.07 psi	8.4 mb 0.12 psi	12.8 mb 0.19 psi
Max. rate of pr. drop	8.6 mb/sec 0.12 psi/sec	17.4 mb/sec 0.25 psi/sec	29.6 mb/sec 0.43 psi/sec

The most important results are the large rate of pressure drop caused by fast-traveling suction vortices and the smaller amount of pressure drop due to the tornado itself. These results coincide very well with the features of tornado damage characterized by swaths of severe damages witnessed inside overall damage area.

It is recommended that a level of proper probability be selected for each structure. Then the storm type and parameters corresponding to the specific probability can be used as a design criteria in assessing existing structures or those to be constructed at the WIPP site.

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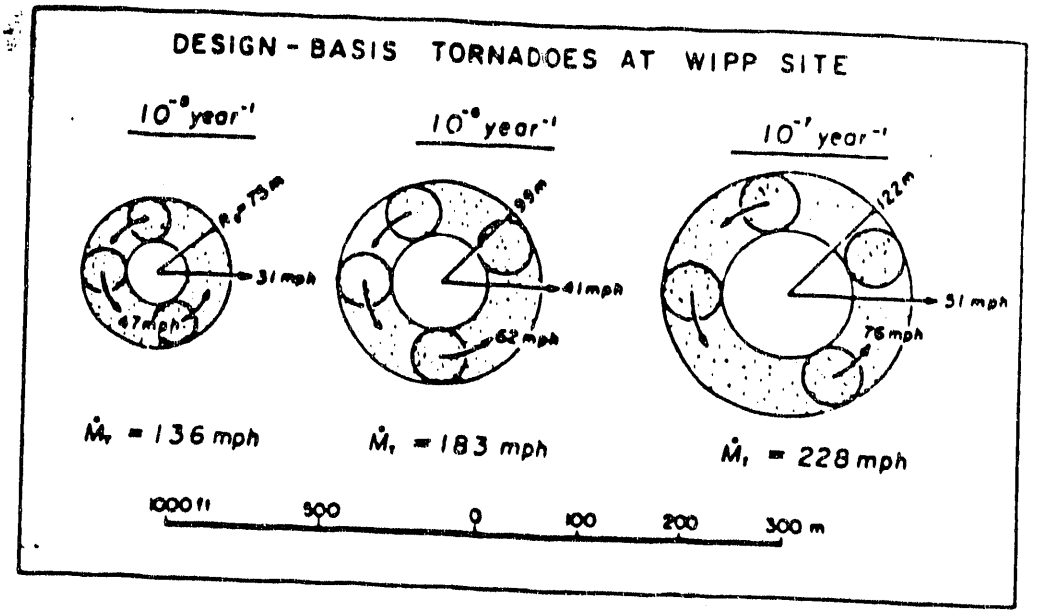

Figure 20B. Design-basis tornadoes at the WIPP site, each characterized by suction vortices orbiting around inside the outer core of the parent tornado. Core radii are proportional to the maximum tangential velocities.

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Most Severe Credible Tornado (One in one-million-year tornado)

Although the probabilities by the Pecos Valley method are reasonable, we must still consider the effects of elevation upon tornado intensities in order to determine the most severe storm which is credible at the WIPP site. For this purpose, the touchdown elevations within the Pecos Valley were obtained by plotting all reported tornadoes on 1:250,000 USGS topographic maps. Their distribution by F-scale and elevation at 500-ft intervals are presented in Figure 21.

The elevation of the WIPP site, 3,414 ft MSL, is apparently not high enough to eliminate the possibilities of F3 tornadoes. It is reasonable to select the F3 tornado as being the most severe credible tornado applicable to this site.

Acknowledgement:-

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SEISMIC EVALUATION REPORT

OF

UNDERGROUND FACILITIES

WASTE ISOLATION PILOT PLANT

SOUTHEASTERN NEW MEXICO

Backfit DCN. 012498 6/22/81
BTL 3023 to WIPP project. 6/22/81

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U.S. DEPARTMENT OF ENERGY
WASTE ISOLATION PILOT PLANT
SEISMIC EVALUATION REPORT OF UNDERGROUND FACILITIES

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(1-79) WIPP

SEISMIC EVALUATION REPORT

OF

UNDERGROUND DRIFTS FACILITIES

WASTE ISOLATION PILOT PLANT

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SEISMIC EVALUATION REPORT

OF

UNDERGROUND DRIFTS FACILITIES

WASTE ISOLATION PILOT PLANT

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1.0 INTRODUCTION

1.1 Task

The objective of this study is to determine whether the current designs for the WIPP underground facilities are adequate to withstand the effects of postulated seismic events without failure as defined by performance assessment criteria identified in this report.

The underground facilities of the Waste Isolation Pilot Plant (WIPP) are located in New Mexico salt formations. These facilities include multiple unlined drifts (unlined tunnels) 2162 feet below the surface and four vertical shafts connecting the surface facilities and the drifts. The completed shafts are lined with unreinforced concrete for the upper 820 feet of overburden and unlined for the lower 1342 feet in the salt formation.

This study evaluates the seismic structural performance of these underground facilities subjected to two postulated earthquake levels. The first is based on the requirements of the Uniform Building Code (UBC-1979) for Zone 1 and has a maximum horizontal and vertical ground acceleration of 0.05 g. The second is based on a Design Basis Earthquake (DBE, Ref. 3) with a maximum free-field horizontal and vertical ground acceleration of 0.1 g, based on a 1000-year recurrence period.

The UBC earthquake is the specified earthquake used to design the shafts and drifts. It is used to assess the structural performance with respect to personnel safety during plant operation. The DBE is the specified earthquake used to design the critical surface confinement structures and components for the WIPP. It is used in this study as an extra precaution to assess the structural performance of the shafts and drifts with respect to accessibility and retrievability under the most severe seismic event postulated for the WIPP facility.

1.2 Method

The analytical method used to evaluate the seismic structural performance was based on the following primary considerations:

(1) Two ground motion records were selected to simulate the ground motions at the site, since there is no complete recorded time history of earthquakes near the WIPP site available for

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study. These are the 1952 Kern County and 1971 San Fernando records.

(2) The study approach to obtain underground structural responses was to modify the free-field stresses/strains obtained using the computer program SHAKE with dynamic stress/-strain concentration factors.

(3) The standards used to assess structural stability of the shafts and drifts, as related to stress and strain, are the Griffith and Newmark rock failure criteria. In addition, particle velocity criterion based on observed seismic damage and calculated peak particle velocities is used to assess structural stability.

1.3 Performance Assessment Criteria

(1) For the UBC earthquake, performance assessment criterion for personnel safety is based on the capacity of the underground facilities to resist minor and moderate earthquakes without structural damage. Structural damage for this report refers to spalling and rock falls. Spalling is considered to be exfoliation of relatively thin, sharp edged pieces of rock.

(2) For the DBE, performance assessment is based on the capacity of the underground facilities to resist major earthquakes by maintaining accessibility to the underground facilities and retrievability of personnel and stored waste.

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2.0 CONCLUSIONS

2.1 Study Results

The following conclusions can be drawn from this study:

(1) For the upper portion of the shafts which are lined with unreinforced concrete:

(a) With respect to the UBC earthquake, the calculated particle velocity is less than the empirical particle velocity criterion, the calculated shear stresses are less than the Griffith stress criterion and the free-field strains are less than Newmark's strain criterion. No spalling is expected to occur as a result of the UBC earthquake and personnel safety should be maintained.

(b) With respect to the DBE, the calculated particle velocity is less than the empirical particle velocity criterion for the threshold of damage and the calculated shear stresses are less than the Griffith stress criterion. Therefore, no spalling is expected under these criteria. However, the free-field strains in the upper 200 feet of the shaft exceed the Newmark strain (spalling) criterion. Therefore, according to this criterio alone, spalling may occur in this portion of the shafts. It is not expected that drops of sufficient magnitude to cause closure or blockage of the shaft will occur. Thus, accessibility and retrievability should be maintained.

(2) For the unlined portion of the shafts and drifts, subjected to the UBC or DBE earthquake, the calculated particle velocity and free-field strains are less than the associated empirical evaluation criteria, and the dynamic stresses are only a small fraction of the static stresses. No spalling is expected to occur, provided normal required maintenance is performed. Therefore, accessibility, retrievability and personnel safety should be assured.

2.2 Recommendations

The following recommendations are made for the final analysis and detailed design of the shafts:

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(1) For the shaft key, it is expected that the relative vertical movement between the surface level and the top of the shaft key will cause stress concentrations. Therefore, there may be cracking at the transition between the relatively more rigid shaft key and the concrete lining. This area should receive special consideration in final design.

(2) For the transition of the shaft lining to the shaft collar, special consideration should be given to providing a seismic joint to accommodate the different rigidities and structural performance during ground motion.

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3.0 ASSUMPTIONS AND QUALIFICATIONS

3.1 General

The variation of earthquake ground motion response with depth is both site and earthquake dependent. The ground motion at a particular site is strongly influenced by the mechanisms of reflection, refraction, and transmission through a nonhomogeneously layered media; by surface topography; and by details of the local site geology. In addition, the frequency content of the ground motion at a particular site is strongly site dependent (Section 4.2) and the amplitudes of the input motion at the frequencies of interest may be appreciably modified by the local site conditions. Therefore the results obtained in this study are qualitative rather than quantitative.

Seismic response and analysis of underground facilities differs from surface facilities in the following ways:

(1) Underground structures have fully earth-contacted boundaries, while surface or partially embedded structures have partially ground-contacted boundaries.

(2) The seismic behavior of underground structures is not as well understood and documented by case histories as that of aboveground structures.

(3) The intensity of the underground structure responses to earth excitation is difficult to determine because it varies with the source, depth, site media, and structural characteristics.

The effects of earthquakes on facilities may generally be grouped into two categories, faulting and shaking. This study does not address the structural effects due to faulting. Geological and geophysical surveys indicate no capable faults or fissures in the area of the underground excavations.

3.2 Design Ground Motions

The DBE peak ground acceleration is defined probabilistically for a 1,000-year recurrence period. It has been estimated conservatively as 0.10 g, based on current knowledge of the geologic and dynamic characteristics of the site region. This is discussed in the WIPP SAR (Ref. 3). This definition the [illegible] for the [illegible] Nuclear

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Regulatory Commission's concept of a design basis earthquake.

The UBC recommended design levels are not directly comparable to recorded or estimated peak ground accelerations from earthquakes. However, the relationship can be derived through the Seismic Risk Map of the U.S. that is part of the UBC. This map states that for zone 1, one would expect, "Minor damage... corresponds to intensities of V and VI on the Modified Mercalli Intensity Scale (MM Scale)". These intensities may, in turn, be related to accelerations. Both Neumann (Ref. 27) and Trifunac and Brady (REf. 28) relate MM intensities to near-source accelerations. Intensity V corresponds roughly to an acceleration of 0.03 g while VI corresponds to about 0.07 g. Thus, an approximate acceleration value for UBC Zone 1 is the average of these extremes, or 0.05 g.

As a final point of interest, Figure C1-3 of ATC 3-06 (Ref. 29) shows contours of Aa (effective peak acceleration) for the U.S. The WIPP site is just outside the 0.05 g contour of the acceleration with a 90 percent chance of not occurring in a 50 year period. This is equivalent to about the 475 year event. Thus, ATC 3-06 shows that the WIPP site has a 475 year acceleration of just under 0.05 g. This is in good agreement with the mid range of the cases considered in the WIPP SAR. Figure 28-20 of that document shows a 500 year site peak dynamic acceleration of between 0.035 g and 0.07 g. Thus, the specification of a UBC equivalent site design acceleration amounts practically to the use of a 500 year rather than a 1000 year site acceleration.

3.3 Input Ground Motions

The selection of hypothetical input ground motions for seismic investigation of shafts and drifts involves careful study and comparison of earthquake and geologic dynamic characteristics. These dynamic characteristics include peak excitation, frequency content, and period of excitation. The importance of focus depth, slant distance, and magnitude of the selected earthquake should also be considered.

Two sets of ground motions records were selected, including both horizontal and vertical time histories. They represent motions of either large magnitude, distant earthquakes or small magnitude, near earthquakes; and they agree with the geologic and seismic characteristics of the site region described in Reference 3. These records are:

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(1) Kern County, California earthquake,
July 21, 1952
Station - Hollywood Storage P.E. Lot
Components - S00 W and VERT

(2) San Fernando, California earthquake,
February 9, 1971
Station - Lake Huges No. 4
Components - S 21 W and VERT

The recorded accelerograms of these earthquakes were used in the study by scaling the peak accelerations to 0.10 g and 0.05 g for both horizontal and vertical directions without modifying the time scales. The original earthquake records are shown in Figures 3-1 through 3-4. Both earthquakes occured in rock or hard stiff soil considered to be rock.

The Kern County earthquake of 1952 had a maximum ground velocity consistent with, or in fact a little greater than, the average ground velocity used in a study which forms the basis for the Nuclear Regulatory Commission's Guide 1.60, "Design Response Spectra For Seismic Design of Nuclear Power Plants." Thus, the use of the Kern County time history is considered to add to the conservatism of this study.

3.4 Physical Properties of Underground Site Media

Almost all pertinent dynamic material properties of the site media were derived from specific gravity measurements and estimates of the compressive wave (P-wave) velocities obtained from data of several bore holes at the site. Shear wave (S-wave) velocites are generally derived from the P-wave velocities and an assumed Poisson ratio of 0.30.

Other relevant properties, such as the shear modulus (G) and the constrained modulus (D), can be computed from formulas of the theory of elastic wave propagation along with known or assumed data. These are: C_s the shear wave propagation velocity, C_p the compressive wave propagation velocity, the mass density, and the Poisson ratio of the material.

Table 3-1 presents physical properties of the WIPP site geologic profile and formulas used for computation of shear and constrained moduli.

3.5 Analytical Approaches

The following assumptions were made:

(1) The underground structures such as shaft linings provide the necessary flexibility to

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prevent differential movement between the lining and the surrounding media. In other words, the structures move along with the ground media at all times, so no rock-structural interaction was considered. This is a conservative assumption.

(2) The shaft linings are fully bonded to the surrounding rock.

(3) Each stratified layer of soil or rock was assumed to be a homogeneous isotropic elastic solid.

(4) No effects of end-bearing boundaries were considered. These include shaft collars at near-surface, intersections between lined and unlined shafts, and interconnections between shafts and drifts and between drifts.

(5) No effects of multiple or interconnected shafts or drifts were considered.

(6) Frequency-independent stress concentration factors were used in the analysis and design. Thus, the ratio of wavelength to the size of cavity was not considered directly.

(7) No other structural effects that may interact with the seismic problem were considered, such as creep and high temperature in the salt and groundwater in the rock.

(8) No internal structural elements were considered in this analysis, such as fixed shaft guide supports and mechanical devices.

(9) Only vertically propagating P-waves and S-waves were considered for the shafts.

4.0 ANALYSIS

4.1 General

The problem of evaluating seismic structure performance of shafts and drifts was solved in two major steps, based on the assumptions outlined in Section 3.5.

First, an assumed unit column of underground media in a vertical direction was analyzed, under conditions that assumed that no structures or cavities were present, and subject to the prescribed earthquake excitations, free-field responses were determined using the computer program SHAKE. Using this data

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included in this report. They are similar to those of 0.1 g, but with one half the intensities.

Table 4-1 shows acceleration, velocity, and displacement at various depths for 0.1 g and 0.05 g maximum accelerations. Figures 4-6 through 4-8 represent envelopes of these peak responses. The application of the results presented in these figures and table are discussed in Sections 4.4 and 4.5.

4.3 Methods of Analyzing Underground Seismic Structural Responses

4.3.1 General

Structural effects due to ground shaking are associated with stresses resulting from the propagation of seismic elastic compressive waves (P-waves), shear waves (S-waves), and different kinds of surface waves such as Rayleigh waves (R-waves) and Love waves (L-waves). Only P-waves and S-waves were considered in this study because of the complex wave propagation phenomenon in layered elastic media.

For the analysis of the drifts, the horizontal component of the shear wave (SH) was used and for the analysis of the shafts the vertical component of the shear wave (SV) was used. P-waves propagating vertically were considered by replacing the appropriate constants (modulus and wave propagation velocity). All waves considered are sinusoidal incident waves that induce simple harmonic (steady-state) loads. Effects of surface waves were neglected.

Three types of underground structural responses due to P-waves and S-waves were examined:

(1) Flexural, representing the direct imposition of the media curvature on the structure, which must be able to absorb the resulting strains.

(2) Shearing, representing the response lag of the media to input acceleration.

(3) Extension or shortening, representing the axial deformation of the structure and the media, for which the slippage between the structure and the supporting media can be neglected under relatively small excitations.

General strain and stress formulas for these three types of responses near the opening, due to the obliquely impinging P-waves and S-waves, are briefly described in the following paragraphs.

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and applicable formulas derived from the theory of elastic wave propagation, the site media strains under earthquake excitations can be calculated.

Second, dynamic stress concentration factors (Ref. 11) of the openings were obtained to establish the maximum dynamic design stresses. An assumed unit slice between sections of the shafts or drifts was analyzed by a classical theory of elasticity. The analysis was treated as a two-dimensional plane strain problem of a defined-shape opening in an infinite elastic plate subject to simple harmonic loads.

The following sections discuss the seismic analysis of shafts and drifts, in accordance with this methodology.

4.2 Free-Field Underground Earth Responses to the Prescribed Design Ground Motions

The responses of the stratigraphic column shown in Figure 4-1 were analyzed with SHAKE. SHAKE computes the responses in a system of homogenous, viscoelastic layers of infinite horizontal extent subject only to vertically traveling waves. The maximum number of sublayers in a model is 20 and the maximum number of specified sublayers for computed motions is 15. The model chosen is shown in Figure 4-1. The program is well documented in Ref. 17.

The input motions described in Section 3.3 were applied in sublayer 2 (5 feet below the surface). The upper 820 feet of the soil-rock profile was modeled with finer mesh to accommodate the abrupt changes in physical properties of the media.

A special-purpose computer program (BASE) was developed to process response data calculated by SHAKE. BASE generates and plots the time history responses of the velocity and displacement of each sublayer by double integration of the acceleration time histories computed by SHAKE. Small errors in the initial velocity and displacement can lead to large errors in the determination of velocity and displacement time histories. Therefore, base-line correction methods were used in combination with least-square-fitting methods (Ref. 7). Figures 4-2 through 4-5 show the acceleration, velocity, and displacement time histories of sublayers 1, 10 and 20, subject to each prescribed input ground motion scaled to 0.1 g maximum peak ground acceleration. Figures for the response time histories for 0.05 g maximum peak ground acceleration have not been

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4.3.2 Free-field Strains Due to Oblique P-Waves

Figure 4-9 shows a P-wave impinging on a structure with amplitude of Yp and incident angle θ. The calculated axial, flexural, and shearing strains due to this oblique P-wave are (Ref. 23):

Axial $\varepsilon_a = \pm (V_{p\theta} \cos^2\theta)/C_p$ (4-1)

Flexural $\varepsilon_b = \pm (R A_{p\theta} \sin\theta \cos^2\theta)/C_p^2$ (4-2)

Shear $\gamma = (V_{p\theta} \sin\theta \cos\theta)/C_p$ (4-3)

From this set of equations, maximum strains due to an oblique P-wave are:

Axial $\varepsilon_a = \pm V_{p\theta}/C_p$ $\theta = 0°$ (4-4)

Flexural $\varepsilon_b = \pm 0.3849\ RA_{p\theta}/C_p^2$ $\theta = 35°16'$ (4-5)

Shear $\gamma = V_{p\theta}/2C_p$ $\theta = 45°$ (4-6)

The notations for all equations are described in Attachment 6.1.

4.3.3 Free-Field Strains Due to Oblique S-Waves

Figure 4-10 shows an S-wave impinging on a structure with an incident angle θ and excitation amplitude Ys. The axial, flexural, and shearing strains due to this oblique S-wave are:

Axial $\varepsilon_a = \pm (V_{s\theta} \sin\theta \cos\theta)/C_s$ (4-7)

Flexural $\varepsilon_b = \pm (R A_{s\theta_2} \cos^3\theta)/C_s^2$ (4-8)

Shear $\gamma = (V_{s\theta} \cos^2\theta)/C_s$ (4-9)

From this set of equations, maximum strains due to oblique S-wave are:

Axial $\varepsilon_a = \pm V_{s\theta}/2C_s$ $\theta = 45°$ (4-10)

Flexural $\varepsilon_b = \pm RA_{s\theta}/C_s^2$ $\theta = 0°$ (4-11)

Shear $\gamma = V_{s\theta}/C_s$ $\theta = 0°$ (4-12)

4.3.4 Dynamic Stress Concentration Factors

Dynamic stress concentration in an elastic media is a localized dynamic stress increment, produced by interrupted propagating seismic waves around obstacles. Obstacles that induce interruptions of wave propagation are cavities, cracks, and any rigid or flexible inclusions. Interruptions of seismic

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waves around an obstacle are mainly due to diffraction (the deviation of waves from their original path) and scattering (the outward radiation of secondary waves from the obstacle). Ref. 10 provides detailed discussions of diffraction, scattering, and dynamic stress concentrations of elastic waves.

The ratio of the dynamic stress caused by interrupted waves to the stress caused by uninterrupted waves at the same location is known as the Dynamic Stress Concentration Factor (DSCF). The DSCF generally depends on the type of seismic wave, the wave propagating medium, and the obstacle. For instance, it can vary according to the following factors:

(1) Type and predominant frequency of the incident waves

(2) Wave length

(3) Angle of incidence

(4) Physical properties of site medium

(5) Physical and geometric properties of the obstacle

Detailed discussions of the effects of these parameters on the DSCF are given in Ref. 11.

Most of the knowledge about DSCF concerns incident waves propagating in a direction that is perpendicular to the axis of the obstacle (Ref. 11). Although some analytical solutions for determining DSCF's of oblique incident plane waves can be found in Ref. 11, no detailed numerical calculations or explicit solutions are given. Moreover, in most cases, explicit solutions are given only for obstacles of circular cross sections.

However, despite this, approximate solutions for other cross sections can be reasonably obtained by incorporating appropriate shape factors into the solutions available for circular sections.

Reference 11 cites cases of incident plane P-waves (Figure 4-11) and S-waves (Figure 4-12) impinging on a circular cavity or a circular-lined cylinder in a perpendicular direction, where amplification due to dynamic effects was approximately 10 to 15 percent over static values. This suggests that dynamic amplification factors obtained for circular sections can be used for other cross sections by modifying them with appropriate shape factors.

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The following paragraphs summarize DSCF's and shape factors relevant to the design of the WIPP underground facilities.

(1) Drifts: The following equations for drifts with a rectangular shape and rounded corners assume incident waves normal to the cavity. (See Figures 4-13, 4-14, 4-15 and Paragraphs 4.3.1 and 4.5.1) (Refs. 5 and 8)

P-waves $$DSCF = K_1\left(0.6 + \left(\frac{a}{b}\right)^{2/3}\right) \qquad (4\text{-}13)$$

S-waves $$DSCF = K_2\left(0.6 + \left(\frac{a}{b}\right)^{2/3}\right) \qquad (4\text{-}14)$$

(2) Shafts: The following equations for shafts assume incident waves parallel to the cavity or lined cylinder. (See Figure 4-16 and Paragraphs 4.3.1 and 4.4.1).

(a) Unlined Shaft:

For Poisson's ratio = 0.3

P-waves $DSCF = 1.0$ (4-15)

S-waves $DSCF = K_3$ (4-16)

where $K_3 = 4.7$.

(b) Lined Shaft:

For Poisson's ratio = 0.3

P-waves $DSCF = 1.0$ (4-17)

S-waves $DSCF = K_4$ (4-18)

where K_4 is obtained from Figure 4-17 for hoop stresses.

4.4 Seismic Response of Shafts

4.4.1 Description of Shafts

There are four shafts connecting the surface facilities to the underground repository level, as shown in Figure 4-18. Each shaft was designed according to its specific function. All shafts consist of three major portions:

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(1) The concrete shaft collar near the surface (level 0'0")

(2) The portion lined with unreinforced concrete connecting the shaft collar to the top of the salt bed (level 843'0")

(3) The unlined portion from the top of the salt bed to the experimental level (level 2162'0")

Each shaft is briefly described below as follows:

(1) Waste Shaft (Figure 4-19): This shaft transports radioactive waste to the experimental level and it consists of the following parts:

(a) A concrete shaft collar located between the ground surface and level 27'9".

(b) A lined portion with an inner diameter of 19'0" consisting of the upper 537 ft with 10 inch unreinforced concrete and over break and the lower 265 ft with 18 in concrete and overbreak

(c) An unlined portion with a diameter of 20 ft.

(d) A reinforced concrete key and water ring (approximately 50 ft. long) is located at the rock and salt interface.

(2) Storage Exhaust Shaft: This shaft is for storage exhaust. Its design is similar to that of the waste shaft except for the liner, which is steel enclosed by cement grout. The liner is made of steel plate, and has a 10 ft inner diameter. The cement grout is approximately 8 inch thick plus overbreak. Circumferential steel rings are welded to the steel liner at intervals. The unlined portion of the shaft has a diameter of 11'8".

(3) Ventilation Supply and Service Shaft: This shaft is for ventilation supply and services. Its design is similar to the waste shaft design. The concrete liner has a 16'0" inner diameter and varies in nominal thickness from 8 to 14 inches plus overbreak. The unlined portion of the shaft has a diameter of 17'0".

(4) Construction Exhaust and Salt Handling Shaft: This shaft is for construction exhaust and salt handling. Again, its design is similar to the

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waste shaft design except that the concrete liner has a 14'0" inner diameter and a nominal thickness that varies from 8 to 14 inches, plus overbreak. The unlined portion of this shaft has a diameter of 15'0".

The waste shaft was selected for a typical shaft study in this report for the following reasons:

(1) Similarity of construction schemes in all vertical shafts

(2) Largest diameter in both lined and unlined portions.

4.4.2 Seismic Responses of Shafts

Since only vertically propagating P-waves and S-waves were considered in this study, dynamic stresses of vertical shafts induced by the prescribed ground motions can be determined from the equations in Section 4.3 by letting the incident angle $\theta = 0°$. Maximum response shaft strains, including dynamic stress concentration effects, can be obtained by incorporating the results of these equations as follows:

(1) Axial Strains: For lined and unlined portions, from equations 4-1 and 4-15,

$$\varepsilon_a = V_{p0}/C_p \times DSCF = V_{p0}/C_p \qquad (4\text{-}19)$$

(2) Flexural Strains: For lined portion, from equations 4-11 and 4-18,

$$\varepsilon_b = RA_{s0}/C_s^2 \times DSCF = K_4 RA_{s0}/C_s^2 \qquad (4\text{-}20)$$

For unlined portion, from equations 4-11 and 4-16,

$$\varepsilon_b = RA_{s0}/C_s^2 \times DSCF = 4.7RA_{s0}/C_s^2 \qquad (4\text{-}21)$$

(3) Shear Strains: For lined portion, from equations 4-12 and 4-18,

$$\gamma = V_{s0}/C_s \times DSCF = K_4 V_{s0}/C_s \qquad (4\text{-}22)$$

For unlined portion, from equations 4-12 and 4-16,

$$\gamma = V_{s0}/C_s \times DSCF = 4.7V_{s0}/C_s \qquad (4\text{-}23)$$

Equations 4-19 through 4-23 are used to compute the maximum response strains due to the prescribed ground motions. Results of these strains are shown

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Table 4-2. The shear wave velocity used in the program to produce these calculations is the shear wave velocity characteristic of each individual soil layer.

4.4.3 Alternate Approach

An alternate approach for determining the response shaft strains is to use the displacement response time histories of the stratigraphic column. (See Figure 4-1). In this figure, the column is analogous to a cantilever pendulum subject to the prescribed motions; and it is apparent that only shear deformations occur under the S-wave excitation (Figure 4-20a), and that only axial deformations take place under the P-wave excitation (Figure 4-20b).

For any sublayer of the stratigraphic column, maximum response strains caused by seismic wave excitations can be approximated by the strains obtained from the deformed geometries multiplied by the dynamic stress concentration factors. The response strains are described below.

(1) Axial Strain: This strain is mainly caused by P-waves or vertical motions. (See Figure 4-20b).

For any sublayer, $\varepsilon_{ai} = \Delta V_i / H_i$ (4-24)

Total axial strain stratigraphic column,

$$\varepsilon_a = \sum_i \varepsilon_{ai} = \sum_{i=1}^{n} \left(\Delta V_i / H_i \right) \quad (4\text{-}25)$$

and, $\Delta V = \sum_i \Delta V_i$ (4-26)

Maximum axial strain,

$$\left| \varepsilon_a \right|_{max} = \left| \Delta V_i / H_i \right|_{max} \quad (4\text{-}27)$$

(2) Shear Strain: This strain is mainly caused by S-waves or horizontal motions. (See Figure 4-20a).

For any sublayer, $\gamma_i = \dfrac{\Delta U_{i+1} - \Delta U_i}{H_i}$ (4-28)

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Total shear deformation of the stratigraphic column,

$$\Delta U = \sum_i \Delta U_i \qquad (4\text{-}29)$$

Maximum shear strain,

$$\left|\gamma_i\right|_{max} = \left| \frac{\Delta U_{i+1} - \Delta U_i}{H_i} \right|_{max} \qquad (4\text{-}30)$$

To calculate maximum response strains of the shafts, the dynamic stress concentration factors discussed in Paragraph 4.3.4 must be applied to the above equations. This implies no amplifications for axial strains, K_4 for shear strains of the lined portion, and K_3 for shear strains of the unlined portion.

Response strains of the shafts from the obtained displacement response time histories (Section 4.2) were calculated from equations 4-24 through 4-30. These results are presented in Table 4-3. Evaluation of structural stability of shafts from Tables 4-2 and 4-3 is presented in Section 4.6.

4.4.4 Comparison of the Two Methods

Following are some observations drawn from comparing the free-field axial strains and shear strains obtained by the dynamic theory to those obtained by the alternate deformed structure method.

(1) In general, results of these two methods agree very well in order of magnitude of the calculated strains. The alternate method shows fluctuating time responses, which reflects the local site media property changes; the dynamic theory only predicts the peak envelope of maximum responses.

(2) Peak enevelope results obtained from the dynamic theory may be sufficient for design purposes. However, the time history responses (Table 4-3) also provide valuable information relevant to the prediction of rock crack propagation and spalling.

(3) It is consistently shown in both Tables 4-2 and 4-3 that the largest axial, flexural, and shear strains are present in the upper portion of the shafts.

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4.5 Seismic Response of Drifts

4.5.1 Description of Drifts

Drifts, located on the experimental level at 2162 feet below the surface, are rectangular openings with rounded corners. The ratio of fillet radius to short dimension is approximately one to six. The typical height of drifts is 12 to 13 feet, with various widths. (See Figure 4-21 for a typical section of underground drifts). Multiple openings at the experimental level are arranged in orthogonal directions.

Rock bolts and wire mesh are used as a means of ground support in the roof and sidewalls of the drifts as required to provide structural adequacy of the rock salt locally in areas of weakness or discontinuity.

4.5.2 Seismic Responses of Drifts

Seismic responses of drifts are highly dependent on the characteristics of the ground excitations and site media, as well as on the focus depth and slant distance. The first two factors are discussed in Section 4.2. The latter two factors can be considered by evaluating the effects of shallow-near and deep-distant earthquakes.

For shallow-near earthquakes, either P-waves or S-waves may be assumed to propagate in a direction parallel to the axis of the drifts, and therefore the incident angle is $\theta = 0°$. For deep-distant earthquakes, either P-waves or S-waves may be assumed to impinge on the drifts normally at $\theta = 90°$. Based on the available seismological data in the vicinity of the WIPP site, it is reasonable to assume the incident angle is $\theta = 45°$.

At an oblique incident angle $\theta = 45°$ the earthquake would produce maximum design stresses if P-waves and S-waves propagate in the same direction. Although no numerical dynamic stress concentration factors are available for the case of incident angle $\theta = 45°$, it appears reasonable to use the DSCF's obtained in Paragraph 4.3.4. For rectangular drifts with rounded corners, the following maximum seismic responses are given:

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(1) **Axial Strains:** From equations 4-10 and 4-14,

$$\varepsilon_a = \pm(V_{s\theta}/2C_s)(DSCF) \qquad (4\text{-}31)$$

$$= \pm K_2\left(0.6 + \left(\frac{a}{b}\right)^{2/3}\right)\left(V_{s\theta}/2C_s^2\right) \qquad (4\text{-}32)$$

(2) **Flexural Strains:** From equations 4-5 and 4-13,

$$\varepsilon_b = \pm\left[(0.3849)RA_{p\theta}/C_p^2\right](DSCF)$$

$$= \pm K_1\left(0.6 + \left(\frac{a}{b}\right)^{2/3}\right)(0.3849)\left(RA_{p\theta}/C_p^2\right) \qquad (4\text{-}33)$$

(3) **Shear Strains:** From equations 4-6 and 4-13,

$$\gamma = (V_{p\theta}/2C_p)(DSCF)$$

$$= K_1\left(0.6 + \left(\frac{a}{b}\right)^{2/3}\right)\left(\frac{V_{p\theta}}{2C_p}\right) \qquad (4\text{-}34)$$

Results of maximum seismic responses of drifts calculated from equations 4-32 through 4-34 and Section 4.2 are presented in Table 4-4. The evaluation of structural stability of drifts from Table 4-4 is presented in Section 4-6.

4.6 Structural Stability Evaluation

4.6.1 Failure Theory Based on Stress

It has been shown (Ref. 8) that the Coulomb criterion, the Mohr's hypothesis, and the Griffith criterion provide the most useful theories of failure. These theories are discussed in detail in many texts of rock mechanics (Refs. 8 and 10).

The Griffith criterion is based on the premise that fracture is caused by stress concentrations at the tips of minute "Griffith cracks", which are supposed to pervade the material, and that fracture is initiated when the maximum stress near the tip of the most favorably oriented crack reaches a value characteristic of the material. In other words, the theory assumes that failure of the material, or crack propagation, takes place where the maximum tensile stress around the most dangerous crack reaches one or all of the the following conditions:

(1) Tensile conditions:

$$(\sigma_1-\sigma_2)^2 - 8T_o(\sigma_1 + \sigma_2) = 0, \text{ if } \sigma_1 + 3\sigma_2 > 0 \qquad (4\text{-}35)$$

$$2T_o(\sigma_1 + \sigma_2) = 0, \text{ if } \sigma_1 + 3\sigma_2 \leq 0 \qquad (4\text{-}36)$$

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(2) Compressive conditions:

$$\sigma_1[(\mu^2+1)^{1/2}-\mu]-\sigma_2[(\mu^2+1)^{1/2}+\mu]=4T_o\left[1+\frac{\sigma_c}{T_o}\right]^2-2\mu\sigma_c \qquad (4\text{-}37)$$

if $\sigma_c = 0$, then

$$\sigma_1[(\mu^2+1)^{1/2}-\mu]-\sigma_2[(\mu^2+1)^{1/2}+\mu]=4T_o \qquad (4\text{-}38)$$

where the notations σ_1, σ_2, T_o, μ, and σ_c are the first and second principal stresses, uniaxial tensile strenght, material internal friction coefficient, and normal stress to a crack, respectively.

The principal stresses can be determined by analyzing Mohr's Circle and are given by:

$$\sigma_1 = 1/2(\sigma_x+\sigma_y)+[\tau_{xy}^2+1/4\,(\sigma_x-\sigma_y)^2]^{1/2} \qquad (4\text{-}39)$$

$$\sigma_2 = 1/2(\sigma_x+\sigma_y)-[\tau_{xy}^2+1/4\,(\sigma_x-\sigma_y)^2]^{1/2} \qquad (4\text{-}40)$$

Note that under uniaxial stress conditions ($\sigma_2 = \sigma_3 = 0$) equation 4-35 becomes:

$$C_o = 8T_o$$

This indicates that the uniaxial compressive strength is eight times greater than the uniaxial tensile strength under the Griffith hypothesis.

Detailed studies of failure or crack propagation of rock media (Ref. 8) reveal that once failure has begun at certain values of the applied stresses, it will continue at the same, or lower, value of these stresses. In terms of the concept of cracks, this implies that as the stresses applied to the rock exceed the Griffith stresses, failure starts from the crack with the most dangerous orientation. An increase in the applied stresses is required to extend this crack.

Any stresses in excess of the Griffith stresses necessary to produce crack extension can cause the rock to partially cleave in a direction parallel to the direction of the major principal stress. As a result of this increase, failure starts from other cracks with less dangerous orientations. If this were to result in the extension of the crack in its own plane, as is the case in tension, the condition of the crack would progressively worsen. Also, the ability of a rock media containing such a crack to resist load would diminish with continued crack width. This situation is unstable, and an extension of the crack results in failure of the rock body.

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Compression Griffith crack propagation, following crack initiation, appears to be stable and does not lead to complete failure, as does the unstable propagation of Griffith cracks in tension.

In Ref. 18, Serata has cited the octahedral shearing strength for weak salt as 600 psi, and for strong salt as 750 psi. The octahedral shearing strength/stress is defined as:

$$\tau_{oct} = \frac{1}{3}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right]^{\frac{1}{2}}$$

$$= \frac{\sqrt{2}}{3}\left[\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - \sigma_1\sigma_2 - \sigma_2\sigma_3 - \sigma_3\sigma_1\right]^{\frac{1}{2}} \qquad (4\text{-}41)$$

4.6.2 Empirical Failure Criteria Based on Strain

Newmark (Ref. 9) has cited the following empirical design criteria for rocks:

(1) Minor spalls will occur up to a distance from the source at which free field strains are from 0.02 to 0.06 percent.

(2) At a distance from the source where the local compressive strain is equal to the failure strain (say a net strain of from 0.5 to 1 percent), serious damage will occur in the form of local crushing and rock drops. Although the opening may stay substantially unfilled, there will be large areas of rock drops and local crushing around the sides of the cavity.

(3) In general, the maximum local strains are about three times the free-field strains for a circular hole, and from five to six times the free-field strains for a rectangle with rounded corners.

It is recognized that different types of rock exhibit different material properties and therefore have different failure or fracture criteria. The above mentioned criteria do not attempt to determine the failure of rock salt in this study, but they do provide useful information in the evaluation of seismic performance of underground openings. Since the strength of rock salt is generally lower than for other types of rocks, like shale or dolerite (Ref. 10), it is conservatively assumed the lower bound of Newmark criteria (i.e., 0.02 percent) to be the upper bound criteria for rock salt. For the upper portion of the shafts 0.05 percent is assumed to be the spalling criteria for rock and liner.

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No other relevant empirical data or experimental information was identified in the literature survey to determine failure/fracture of salt rock in this study (Refs. 6, 13, 14, 16, 19, 20, 21).

4.6.3 Empirical Damage Criteria Based on Particle Velocity

The references discussed in this section, dealing with the response of rock tunnels to seismic and explosion induced ground motions, are not directly applicable to the shafts and drafts for the WIPP facility. This is due to differences in geology, depths of structures, orientation and direction of propogating waves, structural configurations, etc., of the WIPP and the areas studied. However, the conclusions the authors have drawn from their observations of the response of tunnels to dynamic ground motions are consistent and form the basis for a qualitative guideline for accessing structural response and explaining the good performance, relative to surface structures, of deep underground structures subjected to dynamic motions.

Although the authors refer to tunnels and do not specifically mention shafts, mine portals, surface openings for horizontal, inclined or vertical shaft passageways to the underground tunnels, are referred to.

Dowding (Ref. 24) compares observed rock tunnel responses to earthquake motions and the calculated peak ground accelerations. In all, 71 tunnels subjected to shaking and distortion located in California, Alaska, and Japan were studied. Damage, ranging from cracking to closure occurred in 41 cases studied. The majority of the tunnels were 9 to 18 ft. in diameter. Thirteen different earthquakes were involved. The Richter magnitude varied from 5.8 to 8.3 and the focal depths varied between 8 and 25 miles. Six of the earthquakes were in California, six in Japan and one in Alaska. Of the 24 tunnels where linings were described, two were unlined, two were timbered, seven were lined with brick or masonry and 13 were concrete lined.

The average depth of the rock tunnels studied was 300 ft. The median depth was 150 ft. However, the depths vary radically along the alignment from zero at the portals to 1800 ft. Portal damage was not included because of the close relationship with landsliding. The following summarized describes the relevant conclusions:

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(1) There were no reports of even falling stones in unlined tunnels up to an acceleration of .19 g and a particle velocity of 8 in/sec.

(2) Up to .25 g acceleration and 15 in/sec velocity there are only a few incidences of minor cracking in concrete lined tunnels.

(3) The report equates the "no damage zone" at .19 g acceleration with the Modified Mercalli VIII level.

(4) Comparatively, tunnels are less susceptible to damage from shaking than above-ground structures at the same intensity level as determined from surface motions.

(5) Since the variation in present attenuation relationships for surfaces motion is so large, it would seem that prediction of subsurface motions through present surface attenuation relationships in combination with deamplification factors for motions at depth would only serve to increase uncertainty.

(6) It is this deamplification effect that forms one of the lines of reasoning underlying the relative stability of tunnels with respect of surface structure.

(7) Increased damage to shallow tunnels and deamplification of Rayleigh or surface waves with depth point to increasing stability of a given diameter opening with increasing depth.

(8) During shaking, high frequency compressive waves can be reflected off the surface of the tunnel in the form of tensile waves and cause slabbing when the tensile strength of the rock mass or liner is exceeded. This is most important with the high frequency waves associated with explosives. Therefore, it is unlikely to have a predominant effect in rock tunnels stability due to earthquake shaking except at very small focal distances where higher frequencies predominate.

The results of a Bechtel study (Ref. 32) in which Dowding's work was revised to include only tunnels in rock and exclude damage to underground openings in unconsolidated materials, displacement, portal areas and those with shallow cover shows, in general, negligible damage even at accelerations exceeding 0.50 g and particle velocities exceeding 36 inches/second.

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Hendron (REf. 15) cites work done by Langefors and Kehlstrom (Ref. 26) who give particle velocity criteria for damage to tunnels in rock. A particle velocity of 12 in/sec is given as a criterion for the "fall of rock in unlined tunnels," and a particle velocity of 24 in/sec is correlated with the formation of new cracks in rock. Hendron states that these criteria are consistant with his own experience for unlined tunnels near nuclear detonations, "Unlined tunnels rarely experience visible damage at ranges when free-field ground motions are on the order of 1-2 ft/sec, unless a loosened piece of rock is detached from the roof by shaking." Hendron also synthesised the results of the explosion testing of tunnels and found that dynamic strains, calculated as a ratio of particle velocity divided by celerity for explosion induced pulses of high frequency, needed to be at least 0.0004 to cause intermittant falling of stones in an unlined, 15 ft. diameter tunnel in sandstone.

Based on Bechtel's experience, a particle velocity of 8 in/sec is a reasonable and acceptable criterion of the peak particle velocity at the threshold of damage. In view of the above referenced works, 8 in/sec is also considered to be a conservative criterion.

4.6.4 Assessment of Underground Structural Stability

Calculated strains and stresses are presented in Tables 4-5 and 4-6 for the drifts and unlined sections of the shafts respectively. The conclusions reached with respect to performance assessment, including those pertaining to the concrete lined section of the shafts, have been made based on the stress, strain and particle velocity criteria presented in Paragraphs 4.6.1, 4.6.2 and 4.6.3 as it applies to the rock and salt. The presence of the unreinforced concrete lining has not been considered in the analysis. It is recognized that the concrete lining will reduce spalling.

(1) For the maximum peak ground acceleration of 0.05 g, the free-field strains in the shaft and drifts are generally less than Newmark's strain criteria and the maximum particle velocity of 3 in/sec is less than Dowding's 8 in/sec. The combined static and dynamic shearing stresses in the lined portion of the shaft are less than the Griffith criterion and in the salt are approximately equal to or greater than the octahedral and Griffith criteria. But again, as in the case of 0.10 g below, the dynamic stresses are only a fraction of the static

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stresses. Therefore, no spalling is expected in the shafts or drifts as a result of the 0.05 g maximum acceleration design earthquake and personnel safety should be maintained.

(2) For the DBE maximum peak ground acceleration of 0.10 g:

(a) In the lined portion of the shafts the peak particle velocity does not exceed 6 in/sec. This is less than Dowding's 8 in/sec criteria, and the calculated shear stress is less than the Griffith criterion. Therefore, no spalling is expected under these criteria. The free-field strains in the upper 200 feet of rock exceed the Newmark strain criteria. However, if the apparent shear wave velocity of the material at the point where the energy is released was used in the analysis, as suggested by Newmark (Ref. 31), instead of using the shear wave velocities characteristic of each individual layer, then the free-field strains would generally not exceed the Newmark strain criteria. Blockage of the shafts is not expected. Thus, accessibility and retrievability should be maintained.

The storage exhaust shaft's steel liner offers an additional factor of safety against failure and provides an emergency escapeway.

(b) In the lower unlined portion of the shafts and drifts, the static stresses are generally much larger than the dynamic stresses, and the combined static and dynamic shearing stresses exceed the Griffith and octahedral stress criteria of the salt. However, the free-field dynamic strains are less than the Newmark criteria and the peak particle velocity below the lining is less than 5 in/sec. Therefore stress criteria alone does not appear to be adequate as a means of predicting overstressing due to dynamic ground motions. Static stresses alone appear to be of sufficient magnitude to cause cracking and spalling in the rock salt. After a state of static equilibriun is reached in the salt and periodic maintenance, such as scaling, is performed, the dynamic stresses are not

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likely to cause any additional overstressing leading to spalling. Again, accessibility and retrievability should be maintained.

(c) Flexural strains in both the unlined shaft and the drifts are small and can be neglected.

4.7 Comparison of Static and Dynamic Design Stresses

4.7.1 Static Stress Concentrations

Static stress concentrations of underground openings largely depend on the shape of openings and the Poisson's ratios of the medium. These concentrations are unlike dynamic stress concentrations that depend on opening size, shape, and other dynamic characteristics of site medium and excitation sources.

The size of the opening has relatively little effect on static stress concentrations; however, mechanical defects (faults, shear zones, joints etc.) prevent making very large openings in any rock formation.

Prior to the excavation of openings, the vertical stress on a unit horizontal section through a rock media is equal to the rock weight above this section. That is,

$$\sigma_y = \sum_i \rho_i H_i \qquad (4\text{-}42)$$

where

σ_y = vertically applied stress (also known as lithostatic stress)

ρ_i = density of i th sublayer of rocks or soils above the opening

H_i = vertical thickness of i th sublayer

Assuming linear elasticity of the medium, horizontally applied stresses are obtained with the following relationship:

$$\sigma_x = \frac{\nu}{(1 - \nu)} \sigma_y \qquad (4\text{-}43)$$

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where

σ_x = horizontal applied stress

ν = Poisson's ratio of the immediate surrounding medium of the opening

Note that this case has been reduced to a two-dimensional plane strain problem by considering the infinite length of the single opening. Critical design stress values can be obtained when vertically applied stresses and static stress concentration factors are determined.

Static stress concentrations around openings of various cross sections (circular, elliptical, ovaloid, or rectangular shapes) can be found in Refs. 5, 8, and 10. Several figures presented in Ref. 5 are reproduced to compare static and dynamic stress concentrations. Figures 4-22 through 4-25 show boundary stress concentrations for circular, elliptical, ovaloid, and rectangular cross sections, respectively. Figures 4-26 through 4-29 present critical compressive and tensile stresses for these various cross sections.

Note that the parameter M used in Ref. 5 is identical to the coefficient used in equation 4-42; thus, $M = \nu/(1-\nu)$. For design and comparison purposes, linear interpolation of various values of M (Poisson's ratio) is reasonable.

For the purposes of this report, the calculated static stresses have been assumed equal to those calculated by using equations 4-42 and 4-43 without any applied concentration factor.

4.7.2 Comparison of Static and Dynamic Design Stresses

The maximum stress concentration factors around the circular openings can be approximated by letting $\alpha_a = 0$, and $\beta_a = 0$. Probable maximum static and dynamic stress concentration factors are also shown in Figures 4-14 and 4-15.

Examination of these figures reveals that the dynamic stress concentration factors are 10 to 15 percent of the static factors in all cases. A similar conclusion can be reached in the case of a circular lined cavity as shown in Figure 4-17. Therefore, for design purposes it appears practical and justifiable to use appropriate factors of safety on static results of traditional rock mechanics.

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A detailed study of Figures 4-22 through 4-29 and of the static design stress calculation procedures (Paragraph 4.7.1) reveals that, for deep underground cavities, static concentrated stresses may be high enough to cause local rock cracking and spalling regardless of whether dynamic stresses are included or not. However, the results of studies by Bechtel (Ref. 30) indicate that in most areas at the drift level, the static stresses are significantly reduced in a relatively short period of time after excavation. This reduction is due to salt creep, relaxation, and deterioration and is influenced by items such as salt properties, room configuration and drift layout. Thus, in a material such as salt subject to creep, the relationship between the static and dynamic stresses is difficult to determine.

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6.0 ATTACHMENTS

6.1 NOTATIONS

Designation		Description
ϵ_a	=	Axial strain, in micro-strain
ϵ_b	=	Flexural strain, in micro-strain
γ	=	Shear strain, in micro-strain
C_p	=	Compressive wave velocity, ft/sec
C_s	=	Shear wave velocity, ft/sec
$V_{p\theta}$	=	Compressive wave particle velocity, in/sec Incident angle is equal to θ
$V_{s\theta}$	=	Shear wave particle velocity, in/sec Incident angle is equal to θ
$A_{p\theta}$	=	Compressive wave particle acceleration, in/sec^2 Incident angle is equal to θ
$A_{s\theta}$	=	Shear wave particle acceleration, in/sec^2 Incident angle is equal to θ
H_i	=	Thickness of sublayer i, ft
ΔU_i	=	Horizontal displacement of sublayer i, in.
ΔV_i	=	Vertical displacement of sublayer i, in.
ρ_i	=	Unit weight of sublayer i, lb/ft^3
τ_{oct}	=	Octahedral shear stress/strength, psi
$\sigma_{1,2,3}$	=	Principal stress, psi
σ_x	=	Horizontal applied stress, psi
σ_y	=	Vertical applied stress, psi
T_o	=	Uniaxial tensile strength, psi
C_o	=	Uniaxial compressive strength, psi
S_o	=	Uniaxial shearing strength, psi
ν	=	Poisson's ratio
μ	=	Material internal friction coefficient
R	=	Distance from structural axis to the boundary

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6.1 NOTATIONS

Designation		Description
ε_a	=	Axial strain, in micro-strain
ε_b	=	Flexural strain, in micro-strain
γ	=	Shear strain, in micro-strain
C_p	=	Compressive wave velocity, ft/sec
C_s	=	Shear wave velocity, ft/sec
$V_{p\theta}$	=	Compressive wave particle velocity, in/sec Incident angle is equal to θ
$V_{s\theta}$	=	Shear wave particle velocity, in/sec Incident angle is equal to θ
$A_{p\theta}$	=	Compressive wave particle acceleration, in/sec^2 Incident angle is equal to θ
$A_{s\theta}$	=	Shear wave particle acceleration, in/sec^2 Incident angle is equal to θ
H_i	=	Thickness of sublayer i, ft
ΔU_i	=	Horizontal displacement of sublayer i, in.
ΔV_i	=	Vertical displacement of sublayer i, in.
ρ_i	=	Unit weight of sublayer i, lb/ft^3
τ_{oct}	=	Octahedral shear stress/strength, psi
$\sigma_{1,2,3}$	=	Principal stress, psi
σ_x	=	Horizontal applied stress, psi
σ_y	=	Vertical applied stress, psi
T_o	=	Uniaxial tensile strength, psi
C_o	=	Uniaxial compressive strength, psi
S_o	=	Uniaxial shearing strength, psi
ν	=	Poisson's ratio
μ	=	Material internal friction coefficient
R	=	Distance from structural axis to the boundary

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of the cavity, ft.

Y_p = P-wave excitation amplitude, in.

Y_s = S-wave excitation amplitude, in.

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6.2 List of Tables

3-1 Physical Properties of the WIPP Site Geologic Profile

4-1a Peaks of Maximum Design Accelerations, Velocities, and Displacements, Horizontal Motion, Maximum Acceleration = 0.10 g

4-1b Peaks of Maximum Design Accelerations, Velocities, and Displacements, Vertical Motion, Maximum Acceleration = 0.10 g

4-1c Peaks of Maximum Design Accelerations, Velocities, and Displacements, Horizontal Motion, Maximum Accelerations = 0.05 g

4-1d Peaks of Maximum Design Accelerations, Velocities, and Displacements, Vertical Motion, Maximum Acceleration = 0.05 g

4-2a Typical Seismic Responses of Vertical Shafts for 1952 Kern County, California Earthquake, Maximum Acceleration = 0.10 g

4-2b Typical Seismic Responses of Vertical Shafts for 1952 Kern County, California Earthquake, Maximum Acceleration = 0.05 g

4-3a Seismic Responses of Vertical Shafts, 1952 Kern County, California Earthquake, Horizontal Motion (Free-Field, Alternate Solution), Maximum Acceleration = 0.10 g

4-3b Seismic Responses of Vertical Shafts, 1952 Kern County, California Earthquake, Vertical Motion (Free-Field, Alternate Solution), Maximum Acceleration = 0.10 g

4-3c Seismic Responses of Vertical Shafts, 1971 San Fernando, California Earthquake, Horizontal Motion (Free-Field, Alternate Solution), Maximum Acceleration = 0.10 g

4-3d Seismic Responses of Vertical Shafts, 1971 San Fernando, California Earthquake, Vertical Motion (Free-Field, Alternate Solution), Maximum Acceleration = 0.10 g

4-3e Seismic Responses of Vertical Shafts, 1952 Kern County, California Earthquake, Horizontal Motion (Free-Field, Alternate Solution), Maximum Acceleration = 0.05 g

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4-3f Seismic Responses of Vertical Shafts, 1952 Kern County, California Earthquake, Vertical Motion (Free-Field, Alternate Solution), Maximum Acceleration = 0.05 g

4-4a Typical Seismic Responses of Horizontal Drifts for 1952 Kern County, California Earthquake, Maximum Acceleration = 0.10 g

4-4b Typical Seismic Responses of Horizontal Drifts for 1952 Kern County, California Earthquake, Maximum Acceleration = 0.05 g

4-5a Assessment of Underground Drift Stability, Maximum Accelerator = 0.10 g

4-5b Assessment of Underground Drift Stability, Maximum Acceleration = 0.05 g

4-6a Assessment of Unlined Vertical Shaft Stability, Maximum Acceleration = 0.10 g

4-6b Assessment of Unlined Vertical Shaft Stability, Maximum Acceleration = 0.05 g

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Table 3-7

PHYSICAL PROPERTIES OF THE WIPP SITE GEOLOGIC PROFILE

Formation	Rock Type	Depth[a] Range (ft)	C_p[b] (ft/sec)	C_s[c] (ft/sec)	D[d] (10^3 lb/ft^2)	G[e] (10^3 lb/ft^2)	ρ Density (lb/ft^3)	ν (Poisson's Ratio)
	Caliche	0-5	2,650	1,300	22,180	5,340	102	0.34
Gatuna	Sandstone	5-25	3,600	2,000	41,440	12,790	103	0.28
Santa Rosa	Sandstone	25-35	4,600	2,300	84,470	21,120	129	0.33
Dewey Lake	Siltstone	35-210	6,300	2,800	167,700	33,120	156	0.38
	Siltstone	210-330	13,200	6,650	861,000	218,500	159	0.33
	Siltstone	330-400	12,200	6,150	735,500	186,900	159	0.33
	Siltstone	400-520	11,400	5,740	629,600	159,600	156	0.33
Rustler	Anhydrite	520-540	19,600	10,500	2,196,200	630,300	184	0.30
	Anhydrite	540-565	8,333	4,450	316,200	90,200	147	0.30
	Anhydrite	565-580	19,600	10,500	2,196,200	630,000	184	0.30
	Dolomite	580-605	11,000	5,880	579,200	165,200	154	0.30
	Anhydrite	605-645	19,050	10,180	2,074,600	591,600	184	0.30
	Anhydrite	645-680	16,100	8,600	1,456,700	415,400	181	0.30
	Anhydrite	680-690	8,333	4,450	316,200	90,200	147	0.30
	Dolomite	690-725	14,700	7,860	1,086,800	310,500	162	0.30
	Anhydrite	725-745	19,050	10,180	2,039,500	581,622	181	0.30
	Mudstone	745-795	13,900	7,430	842,400	240,200	140	0.30
	Mudstone	795-835	11,400	6,090	604,400	172,400	150	0.30
Salado	Halite	835-2620	14,350	8,810	850,000	320,400	133	0.30
Castile	Anhydrite	2620-	18,500	9,890	1,956,600	558,000	184	0.30

Notes: (a) Depth modeled after B-25 geologic drill log data. Datum is top of caliche at -10 ft. (Ref. 3)
(b) $C_p = (D/\rho)^{\frac{1}{2}}$ = compressive wave velocity.
(c) $C_s = (G/\rho)^{\frac{1}{2}}$ = shear wave velocity.
(d) $D = 2(1-\nu)G/(1-2\nu)$ = constrained modulus.
(e) $G = E/2(1+\nu)$ = shear modulus.

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Table 4-1a

PEAKS OF MAXIMUM DESIGN ACCELERATIONS,
VELOCITIES, AND DISPLACEMENTS
HORIZONTAL MOTION, MAX. ACCELERATION = 0.10 g
(Control Motion at 5 Ft from Ground Surface)

Sub-layer No.(a)	Depth from Ground Surface (ft)	Maximum Acceleration (in./sec/sec)		Maximum Velocity (in./sec)		Maximum Displacement (in.)	
		K.C.(b)	S.F.(c)	K.C.	S.F.	K.C.	S.F.
1	0	39.18	45.51	4.40	2.33	3.45	0.49
2	5	38.40	38.40	4.39	2.24	3.38	0.57
3	35	36.33	33.37	4.35	2.16	3.08	0.67
4	210	24.96	26.47	4.00	2.16	3.87	1.82
5	320	17.44	15.73	3.93	1.76	3.88	1.56
6	540	17.51	15.34	3.92	1.75	3.87	1.55
7	565	18.03	12.13	3.88	1.58	3.81	1.49
8	580	18.07	11.99	3.87	1.57	3.81	1.48
9	605	18.19	11.81	3.85	1.52	3.80	1.43
10	680	18.04	12.20	3.81	1.52	3.82	1.37
12	725	18.51	14.97	3.77	1.51	3.94	1.24
14	795	18.62	17.45	3.71	1.48	4.36	1.11
15	835	18.20	18.86	3.65	1.44	4.41	1.01
17	1540	18.26	14.30	3.06	0.86	6.56	1.91
19	2260	13.96	15.60	2.59	0.92	6.70	0.70
20	2620	16.93	14.79	3.17	1.05	6.42	1.25

Notes: (a) See Table 3-1 and Figure 4-1 for reference.
(b) K.C. = 1952 Kern County earthquake.
(c) S.F. = 1971 San Fernando earthquake.

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Table 4-1b

PEAKS OF MAXIMUM DESIGN ACCELERATIONS,
VELOCITIES, AND DISPLACEMENTS
VERTICAL MOTION, MAX. ACCELERATION = 0.10 g
(Control Motion at 5 Ft from Ground Surface)

Sub-layer No. (a)	Depth from Ground Surface (ft)	Maximum Acceleration (in./sec/sec)		Maximum Velocity (in./sec)		Maximum Displacement (in.)	
		K.C. (b)	S.F. (c)	K.C.	S.F.	K.C.	S.F.
1	0	38.59	39.34	5.78	1.88	4.96	0.71
2	5	38.40	38.41	5.79	1.93	5.30	1.75
3	35	38.12	36.96	5.76	1.83	5.05	0.69
4	210	32.32	19.62	5.56	1.34	5.95	0.62
5	520	25.41	11.31	5.40	1.19	6.10	0.71
6	540	25.42	11.29	5.39	1.18	6.10	0.71
7	565	26.31	10.89	5.34	1.15	6.12	0.74
8	580	26.37	10.84	5.34	1.15	6.12	0.75
9	605	26.74	11.26	5.31	1.13	6.14	0.77
10	630	26.88	11.91	5.29	1.12	6.18	0.79
12	725	26.73	12.27	5.25	1.12	6.26	0.83
14	795	26.12	11.91	5.21	1.16	6.40	0.87
15	835	25.30	11.20	5.17	1.21	6.55	0.91
17	1540	24.16	18.62	4.63	1.31	6.66	1.18
19	2260	20.54	24.14	4.53	1.17	5.07	0.51
20	2620	21.03	17.43	4.35	1.47	4.84	1.52

Notes: (a) See Table 3-1 and Figure 4-1 for reference.
(b) K.C. = 1952 Kern County earthquake.
(c) S.F. = 1971 San Fernando earthquake.

Table 4-1c

PEAKS OF MAXIMUM DESIGN ACCELERATIONS,
VELOCITIES, AND DISPLACEMENTS
HORIZONTAL MOTION, MAX. ACCELERATION = 0.05g
(Control Motion at 5 Ft from Ground Surface)

Sub-layer No.(a)	Depth from Ground Surface (ft)	Maximum Acceleration (in./sec/sec)		Maximum Velocity (in./sec)		Maximum Displacement (in.)	
		K.C.(b)	S.F.(c)	K.C.	S.F.	K.C.	S.F.
1	0	19.66	22.60	2.19	1.16	1.50	0.24
2	5	19.30	19.30	2.18	0.93	1.49	0.24
3	35	18.27	16.80	2.17	1.08	1.65	0.33
4	210	12.58	13.02	2.04	1.08	2.05	0.92
5	520	8.77	7.98	2.01	0.89	1.99	0.78
6	540	8.80	7.80	2.00	0.88	1.98	0.77
7	565	9.06	6.17	1.98	0.81	1.95	0.75
8	580	9.08	6.10	1.98	0.80	1.94	0.74
9	605	9.14	5.96	1.97	0.76	1.93	0.72
10	680	9.08	5.91	1.95	0.76	1.92	0.69
12	725	9.19	7.19	1.93	0.76	1.92	0.64
14	795	9.29	8.45	1.90	0.75	1.93	0.57
15	835	9.13	9.22	1.88	0.73	1.95	0.53
17	1540	9.16	7.33	1.56	0.43	2.45	0.96
19	2260	7.17	7.67	1.35	0.47	2.22	0.66
20	2620	7.52	5.90	1.46	0.48	2.21	0.60

Notes: (a) See Table 3-1 and Figure 4-1 for reference.
(b) K.C. = 1952 Kern County earthquake.
(c) S.F. = 1971 San Fernando earthquake.

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Table 4-14

PEAKS OF MAXIMUM DESIGN ACCELERATIONS, VELOCITIES, AND DISPLACEMENTS
VERTICAL MOTION, MAX. ACCELERATION = 0.05g
(Control Motion at 5 Ft. from Ground Surface)

Sub-layer No.(a)	Depth from Ground Surface (ft)	Maximum Acceleration (in./sec/sec)		Maximum Velocity (in./sec)		Maximum Displacement (in.)	
		K.C.(b)	S.F.(c)	K.C.	S.F.	K.C.	S.F.
1	0	19.57	20.69	2.90	0.96	3.53	0.31
2	5	19.30	19.30	2.90	1.15	3.61	0.26
3	35	18.73	16.68	2.87	0.87	3.59	0.27
4	210	12.41	10.63	2.62	0.66	3.98	0.39
5	520	11.19	7.19	2.45	0.63	3.83	0.54
6	540	11.07	7.16	2.45	0.63	3.80	0.54
7	565	9.96	6.37	2.41	0.59	3.63	0.46
8	580	9.94	6.27	2.41	0.59	3.61	0.45
9	605	9.72	5.47	2.43	0.58	3.51	0.38
10	680	9.71	5.99	2.44	0.59	3.51	0.29
12	725	9.73	6.32	2.46	0.59	3.56	0.24
14	795	9.22	6.22	2.45	0.59	3.58	0.28
15	835	9.59	7.65	2.43	0.58	3.58	0.31
17	1540	8.96	5.74	2.11	0.57	3.50	0.30
19	2260	9.26	5.96	2.05	0.46	3.51	0.26
20	2620	9.80	7.36	2.01	0.44	3.62	0.91

Notes: (a) See Table 3-1 and Figure 4-1 for reference.
(b) K.C. = 1952 Kern County earthquake.
(c) S.F. = 1971 San Fernando earthquake.

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Table 4-2a

TYPICAL SEISMIC RESPONSES OF VERTICAL SHAFTS FOR 1952
KERN COUNTY, CALIF., EARTHQUAKE
MAX. ACCELERATION = 0.10 g

Sublayer No.	Depth From Ground Surface (ft)	1	2	3	4	5	6	7	8	9	10
		V_p (in./sec)	V_s (in./sec)	A_s (in./sec^2)	DSCF (Eq. 4-15, 4-17)	Axial Strain ($\times 10^{-6}$)	DSCF (Eqs. 4-16, 4-18)	Flexural Strain ($\times 10^{-6}$)	DSCF (Eqs. 4-16, 4-18)	Shear Strain ($\times 10^{-6}$)	Shaft Liner
											Lined Shaft: D$_{Diam.}$ = 19'0" / 20'0"
											D$_{Diam.}$ = 19'0" 18" Concrete Liner
											D$_{Diam.}$ = 19'0" 10" Concrete Liner
1	0	5.78	4.40	39.18	1.0	182	4.2	84	4.2	1186	
2	5	5.79	4.39	38.40	1.0	134	4.2	35	4.2	768	
3	35	5.76	4.35	36.33	1.0	104	4.2	25	4.2	663	
4	210	5.56	4.00	24.96	1.0	74	4.2	12	4.2	500	
5	520	5.40	3.93	17.44	1.0	37	4.2	17	4.2	224	
6	540	5.39	3.92	17.31	1.0	23	4.2	1	4.2	131	
7	565	5.34	3.88	18.03	1.0	53	4.0	3	4.0	191	
8	580	5.36	3.87	16.07	1.0	23	4.0	1	4.0	123	
9	605	5.31	3.85	18.19	1.0	40	4.0	2	4.0	218	
10	680	5.29	3.81	18.04	1.0	25	4.0	1	4.0	135	
12	725	5.25	3.77	18.51	1.0	30	4.0	1	4.0	160	
14	795	5.21	3.71	18.62	1.0	31	4.0	1	4.0	166	
15	835	5.17	3.65	18.20	1.0	38	4.0	1	4.0	200	
17	1545	4.63	3.06	18.26	1.0	27	4.7	1	4.7	136	
19	2260	4.53	2.59	13.96	1.0	26	4.7	1	4.7	115	
20	2620	4.35	3.17	16.93	1.0	20	4.7	1	4.7	126	

Notes: a Refer to Section 4.4.2 for detailed equations.
b Typical vertical shaft is waste shaft.

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Table 4-2b

TYPICAL SEISMIC RESPONSES OF VERTICAL SHAFTS FOR 1952
KERN COUNTY, CALIF., EARTHQUAKE
MAX. ACCELERATION = 0.05 g

Sublayer No.	Depth From Ground Surface (ft)	1	2	3	4	5	6	7	8	9	10
		V_p (in./sec)	V_s (in./sec)	A_s (in/sec^2)	DCF (Eq. 4-15, 4-17)	Axial Strain ($\times 10^{-6}$)	DSCF (Eqs. 4-16, 4-18)	Flexural Strain ($\times 10^{-6}$)	DSCF (Eqs. 4-16, 4-18)	Shear Strain ($\times 10^{-6}$)	Shaft Liner
1	0	2.40	2.19	19.66	1.0	91	4.2	42	4.2	590	Lined Shaft: Diam. = 19'0" 30" Concrete Liner
2	5	2.90	2.18	19.30	1.0	67	4.2	17	4.2	382	
3	35	2.87	2.17	18.27	1.0	38	4.2	8	4.2	271	
4	210	2.62	2.04	12.58	1.0	17	4.2	1	4.2	107	
5	520	2.43	2.01	8.77	1.0	10	4.2	1	4.2	67	
6	540	2.45	2.00	8.80	1.0	15	4.2	2	4.2	157	
7	565	2.41	1.98	9.06	1.0	10	4.0	1	4.0	268	
8	580	2.41	1.98	9.08	1.0	16	4.0	1	4.0	515	
9	605	2.43	1.97	9.14	1.0	11	4.0	1	4.0	65	
10	680	2.44	1.95	9.08	1.0	24	4.0	1	4.0	145	
12	725	2.46	1.93	9.19	1.0	11	4.0	1	4.0	63	
14	795	2.45	1.90	9.29	1.0	18	4.0	1	4.0	104	
15	835	2.43	1.88	9.13	1.0	14	4.0	1	4.0	71	
17	1540	2.11	1.56	9.16	1.0	12	4.7	1	4.7	69	Lined Shaft: Diam. = 19'0" 18" Concrete Liner
19	2260	2.05	1.35	7.17	1.0	12	4.7	1	4.7	60	
20	2620	2.01	1.46	7.52	1.0	9	4.7	1	4.7	298	Unlined: Diam. = 20'0"

Notes: a Refer to Section 4.4.2 for detailed equations.
a Typical vertical shaft is waste shaft.

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Table 4-3a

SEISMIC RESPONSES OF VERTICAL SHAFTS, 1952 KERN COUNTY EARTHQUAKE, HORIZONTAL MOTION

(FREE-FIELD, ALTERNATE SOLUTION)

MAX. ACCELERATION = 0.10 g

Sub-Layer No.	Depth Ground from Surface (ft)	Δℓ (ft)	Peak Displ. at t=10.48 Sec (in.)	Shear Strain γ_1 ($\times10^{-6}$)	Peak Displ. at t=14.88 Sec (in.)	Shear Strain γ_2 ($\times10^{-6}$)	Peak Displ. at t=22.44 Sec (in.)	Shear Strain γ_3 ($\times10^{-6}$)	Peak Displ. at t=27.16 Sec (in.)	Shear Strain γ_4 ($\times10^{-6}$)	Peak Displ. at t=32.28 Sec (in.)	Shear Strain γ_5 ($\times10^{-6}$)	Peak Displ. at t=35.92 Sec (in.)	Shear Strain γ_6 ($\times10^{-6}$)
1	0		-0.8078		-1.1646		-1.1473		-1.50753		+1.5964		-3.4414	
2	5	5	-0.8438	-600	-1.2026	-630	-1.1693	-367	-1.5094	-31	+1.6292	-547	-3.3824	+1083
3	35	30	-1.0165	-480	-1.3837	-504	-1.2762	-272	-1.51945	-28	+1.7867	-436	-3.0762	+850
4	210	175	-1.8056	-376	-2.2155	-396	-1.7586	-230	-1.57103	-25	+2.5081	-344	-1.6308	+ 688
5	320	310	-1.79103	+ 4	-2.2087	+ 2	-1.7427	+ 4	-1.5797	- 2	+2.4979	+ 3	-1.5991	+ 102
6	540	20	-1.7881	+ 12	-2.2057	+ 13	-1.7405	+ 9	-1.5796	0	+2.4953	+ 11	-1.6028	- 15
7	565	25	-1.7630	+ 84	-2.1814	+ 81	-1.7234	+ 57	-1.5805	- 3	+2.4728	+ 75	-1.6312	- 95
8	580	15	-1.7615	+ 8	-2.1801	+ 7	-1.7223	+ 6	-1.5805	0	+2.4715	+ 7	-1.6325	- 7
9	605	25	-1.7546	+ 23	-2.1738	+ 21	-1.7168	+ 18	-1.5811	- 2	+2.4652	+ 21	-1.6359	- 11
10	680	75	-1.7618	- 8	-2.1820	- 9	-1.7198	- 3	-1.5822	- 1	+2.4716	- 7	-1.6147	+ 24
12	725	45	-1.7947	- 61	-2.1179	- 66	-1.7382	- 36	-1.5354	- 6	+2.5015	- 55	-1.5411	+ 136
14	795	70	-1.8571	- 76	-2.2840	- 79	-1.7743	- 43	-1.5899	- 5	+2.5578	- 67	-1.4139	+ 151
15	835	40	-1.8311	+ 54	-2.3620	-163	-1.8173	- 83	-1.5951	-11	+2.6243	-139	-1.2660	+ 308
17	1540	705	-2.5466	- 85	-3.0018	- 76	-2.1578	- 40	-1.6225	- 3	+3.1763	- 65	+0.0417	+ 145
19	2260	720	-2.4975	+ 6	-2.9706	+ 4	-2.0407	+ 14	-1.5912	+ 4	+3.1313	+ 5	+0.2720	- 27
20	2620	360	-2.3623	+ 31	-2.8448	+ 29	-1.8981	+ 33	-1.5659	+ 6	+3.0085	+ 28	+0.2025	+ 16

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Table 4-3b

SEISMIC RESPONSES OF VERTICAL SHAFTS, 1952 KERN COUNTY EARTHQUAKE, VERTICAL MOTION
(FREE-FIELD, ALTERNATE SOLUTION)
MAX. ACCELERATION = 0.10g

Sub-Layer No.	Depth Ground from Surface (ft)	Δh (ft)	Displ. at t=24.46 Sec (in.)	Axial Strain ε_{a1} ($\times 10^{-6}$)	Displ. at t=32.40 Sec (in.)	Axial Strain ε_{a2} ($\times 10^{-6}$)	Displ. at t=36.66 Sec (in.)	Axial Strain ε_{a3} ($\times 10^{-6}$)
1	0		-4.0375		+4.9598		-4.8882	
2	5	5	-3.9372	+1672	+4.8051	+2578	-5.3028	-6910
3	35	30	-3.9992	-172	+4.9004	-264	-5.0448	+716
4	210	175	-3.7749	+ 107	+4.5564	+ 164	-5.9449	- 429
5	520	310	-3.7329	+ 11	+4.4914	+ 17	-6.0918	- 39
6	540	20	-3.7325	+ 2	+4.4905	+ 4	-6.0928	- 4
7	565	25	-3.7263	- 21	+4.4806	+ 33	-6.1115	- 62
8	580	15	-3.7253	+ 6	+4.4793	+ 7	-6.1140	- 14
9	605	25	-3.7197	+ 19	+4.4705	+ 29	-6.1328	- 63
10	680	75	-3.7104	+ 10	+4.4560	+ 16	-6.1664	- 37
12	725	45	-3.6902	+ 37	+4.4240	+ 59	-6.2422	- 144
14	795	70	-3.6603	+ 35	+4.3774	+ 55	-6.3561	- 136
15	835	40	-3.6270	+ 69	+4.3257	+ 108	-6.4833	- 265
17	1540	705	-3.5788	+ 6	+4.2371	+ 10	-6.5282	- 5
19	2260	720	-3.8777	- 35	+4.6818	- 51	-5.0589	+ 170
20	2620	360	-3.9016	- 6	+4.7069	- 6	-4.8185	+ 56

FOR INFORMATION ONLY

Table 4-3c

SEISMIC RESPONSES OF VERTICAL SHAFTS, 1971 SAN FERNANDO EARTHQUAKE, HORIZONTAL MOTION
(FREE-FIELD, ALTERNATE SOLUTION)
MAX. ACCELERATION = 0.10 g

Sub-Layer No.	Depth from Ground Surface (ft)	Δℓ (ft)	Displ. at t=9.40 Sec (in.)	Shear Strain γ_1 ($\times 10^{-6}$)	Displ. at t=11.32 Sec (in.)	Shear Strain γ_2 ($\times 10^{-6}$)	Displ. at t=13.84 Sec (in.)	Shear Strain γ_3 ($\times 10^{-6}$)
1	0		-0.4866		+0.4167		-0.4020	
2	5	5	-0.5221	-592	+0.3758	+682	-0.4439	-698
3	35	30	-0.5915	-192	+0.2946	+226	-0.5272	-232
4	210	175	-0.89904	-146	-0.08167	+101	-0.9077	-181
5	520	310	-0.82023	+ 21	+0.00194	+ 21	-0.81953	+ 24
6	540	20	-0.82023	0	+0.00194	0	-0.81773	+268
7	563	23	-0.79965	+ 69	+0.02427	- 74	-0.79362	+ 74
8	580	15	-0.7978	+ 10	+0.02629	- 11	-0.7934	+ 12
9	605	25	-0.7833	+ 49	+0.04204	- 53	-0.7767	+ 56
10	680	75	-0.7635	+ 22	+0.06376	- 24	-0.7535	+ 26
12	725	45	-0.72664	+ 68	+0.10393	- 74	-0.7106	+ 79
14	795	70	-0.6878	+ 46	+0.1457	- 50	-0.6657	+ 53
15	835	40	-0.6575	+ 63	+0.1777	- 67	-0.6306	+ 73
17	1540	705	-0.8994	- 29	-0.12203	+ 7	-0.91675	- 34
19	2260	720	-0.5543	+ 40	+0.2554	- 15	-0.4945	+ 49
20	2620	360	-0.7100	- 55	+0.0708	+ 43	-0.6702	- 41

FOR INFORMATION ONLY

Table 4-3d

SEISMIC RESPONSES OF VERTICAL SHAFTS, 1971 SAN FERNANDO EARTHQUAKE, VERTICAL MOTION
(FREE-FIELD, ALTERNATE SOLUTION)
MAX. ACCELERATION = 0.10g

Sub-Layer No.	Depth from Ground Surface (ft)	ΔH (ft)	Displ. at t=3.60 Sec (in.)	Axial Strain ϵ_{a1} ($\times 10^{-6}$)	Displ. at t=14.30 Sec (in.)	Axial Strain ϵ_{a2} ($\times 10^{-6}$)	Displ. at t=17.30 Sec (in.)	Axial Strain ϵ_{a3} ($\times 10^{-6}$)
1	0		-0.5707		-0.4594		+0.3249	
2	5	5	-0.5397	+517	-0.3977	+1028	+0.3819	-1000
3	35	30	-0.5669	-72	-0.4529	-154	+0.3308	+142
4	210	175	-0.5471	+ 9	-0.4260	+ 13	+0.3536	- 11
5	520	310	-0.5526	- 1	-0.4555	- 8	+0.3239	+ 8
6	540	20	-0.5530	- 2	-0.4569	- 6	+0.3226	+ 5
7	565	25	-0.5561	- 10	-0.4681	- 37	+0.3115	+ 70
8	580	15	-0.5564	- 20	-0.4694	- 7	+0.3103	+ 7
9	605	25	-0.5581	- 6	-0.4760	+ 22	+0.3037	+ 22
10	680	75	-0.5601	- 2	-0.4831	- 8	+0.2968	+ 8
12	725	45	-0.5633	- 6	-0.4939	- 20	+0.2861	+ 20
14	795	70	-0.5670	- 4	-0.5069	- 15	+0.2732	+ 15
15	835	40	-0.570	- 6	-0.5195	- 26	+0.2608	+ 26
17	1540	705	-0.5948	- 3	-0.6028	- 10	+0.1706	+ 11
19	2260	720	-0.6236	+ 20	-0.2290	+ 43	+0.5021	- 38
20	2620	360	-0.6387	- 50	-0.7026	- 110	+0.0519	+ 104

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Table 4-3e

SEISMIC RESPONSES OF VERTICAL SHAFTS, 1952 KERN COUNTY EARTHQUAKE, HORIZONTAL MOTION

(FREE-FIELD, ALTERNATE SOLUTION)

MAX. ACCELERATION = 0.01g

Sub-Layer No.	Depth Ground from Surface (ft)	Δh (ft)	Displ. at t=10.48 Sec (in.)	Shear Strain γ_1 ($\times 10^{-6}$)	Displ. at t=14.88 Sec (in.)	Shear Strain γ_2 ($\times 10^{-6}$)	Displ. at t=22.44 Sec (in.)	Shear Strain γ_3 ($\times 10^{-6}$)	Displ. at t=27.16 Sec (in.)	Shear Strain γ_4 ($\times 10^{-6}$)	Displ. at t=32.28 Sec (in.)	Shear Strain γ_5 ($\times 10^{-6}$)	Displ. at t=35.92 Sec (in.)	Shear Strain γ_6 ($\times 10^{-6}$)
1	0		0.8294		0.8103		-0.7429		0.9441		-1.3822		1.01095	
2	5	5	0.8179	192	0.8048	25	-0.7373	93	0.9527	143	-1.4912	183	1.0238	281
3	35	30	0.7135	384	0.6599	414	-0.9036	462	0.7874	439	-1.6463	431	0.8935	360
4	210	175	0.3803	59	0.2289	265	-1.3518	313	0.3363	215	-2.045	+190	0.5496	164
5	520	310	0.4928	- 6	0.2734	- 12	-1.2908	- 16	0.3796	- 12	-1.9861	- 16	0.5792	- 8
6	540	20	0.4055	- 11	0.27764	- 18	-1.2857	- 21	0.3840	- 18	-1.9815	- 19	0.5820	- 12
7	565	25	0.4265	- 76	0.3093	-106	-1.2487	-123	0.4163	-108	-1.9462	-116	0.6061	- 80
8	580	15	0.4277	7	0.3113	- 11	-1.2463	- 13	0.4182	- 11	-1.9439	- 13	0.6075	- 8
9	605	25	0.4369	- 31	0.3241	- 49	-1.2285	- 59	0.42315	- 50	-1.9269	- 57	0.6185	- 37
10	680	75	0.4395	- 3	0.3319	- 6	-1.2204	- 9	0.4388	- 6	-1.9182	- 10	0.6228	- 5
12	725	45	0.4339	10	0.3283	7	-1.2217	3	0.4336	58	-1.9178	- 1	0.6183	8
14	795	70	0.4143	23	0.3078	25	-1.2408	23	0.4109	27	-1.9319	17	0.6016	28
15	835	40	0.3902	50	0.2802	56	-1.2656	52	0.3821	60	-1.9522	42	0.5793	44
17	1540	705	0.1338	38	-0.0033	34	-1.5206	30	0.0610	36	-2.1461	23	0.3543	27
19	2260	720	0.1107	3	0.0130	2	-1.4206	- 12	0.1173	- 25	-1.9963	- 17	0.3806	- 3
20	2620	360	0.0816	7	-0.0109	6	-1.4080	- 29	0.1068	2	-1.9601	- 8	0.3709	2

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Table 4-3f

SEISMIC RESPONSES OF VERTICAL SHAFTS, 1952 KERN COUNTY EARTHQUAKE, VERTICAL MOTION
(FREE-FIELD, ALTERNATE SOLUTION)
MAX. ACCELERATION = 0.05g

Sub-Layer No.	Depth Ground from Surface (ft)	Δh (ft)	Displ. at t=24.46 Sec (in.)	Axial Strain ϵ_{a1} ($\times 10^{-6}$)	Displ. at t=32.48 Sec (in.)	Axial Strain ϵ_{a2} ($\times 10^{-6}$)	Displ. at t=36.66 Sec (in.)	Axial Strain ϵ_{a3} ($\times 10^{-6}$)
1	0		-2.8566		3.4277		-3.5266	
2	5	5	-2.6085	4135	3.6082	3008	-3.4125	1902
3	25	20	-2.6044	11	3.5910	48	-3.4416	79
4	215	175	-1.9750	300	3.9834	187	-3.2287	101
5	530	510	-2.1951	59	3.8251	43	-3.3013	20
6	548	20	-2.2230	116	3.8065	78	-3.3118	40
7	565	25	-2.5006	925	3.6216	616	-3.4042	311
8	580	15	-2.5242	131	3.6034	90	-3.4126	48
9	605	25	-2.6762	507	3.5043	337	-3.4637	170
10	680	75	-2.8024	140	3.4198	94	-3.5056	47
12	725	45	-2.9475	269	3.2797	1185	-3.5344	90
14	795	70	-3.0156	81	3.2721	586	-3.5766	26
15	825	40	-3.0310	32	3.2573	30	-3.5811	9
17	1540	705	-2.5717	54	3.4948	28	-3.4193	19
19	2260	720	-2.7634	22	3.2910	25	-3.4764	6
20	2620	360	-3.1274	84	2.9934	399	-3.5918	27

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Table 4-4a

TYPICAL SEISMIC RESPONSES OF HORIZONTAL DRIFTS FOR 1952 KERN COUNTY, CALIF. EARTHQUAKE (a)

MAX. ACCELERATION = 0.10 g

Drift Geometry a/b	1	2	3	4	5	6	7	8	9	10
	V_p (in./sec)	V_s (in./sec)	A_{po} (in/sec^2)	DSCF Eq. 4-14	Axial Strain ($\times 10^{-6}$)	DSCF Eq. 4-13	Flexural Strain ($\times 10^{-6}$)	DSCF Eq. 4-13	Shear Strain ($\times 10^{-6}$)	$R = \sqrt{a^2 + b^2}_{(ft)}$
1	4.53	2.59	20.54	7.52	92	6.48	1	6.48	59	$\sqrt{6^2 + 6^2} = 8.5$
2	4.53	2.59	20.54	10.30	126	6.14	1	6.14	81	$\sqrt{6^2 + 12^2} = 13.4$
3	4.53	2.59	20.54	12.63	155	7.53	1	7.53	100	$\sqrt{6^2 + 18^2} = 14.0$
4	4.53	2.59	20.54	14.72	181	8.77	0	8.77	116	$\sqrt{6^2 + 24^2} = 24.7$

Note: (a) Refer to Section 4.5.2 for detailed equations.

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Table 4-4b

TYPICAL SEISMIC RESPONSES OF HORIZONTAL DRIFTS FOR 1952 KERN COUNTY, CALIF. EARTHQUAKE (a)

MAX. ACCELERATION 0.05g

Drift Geometry a/b	1 V_p (in./sec)	2 V_s (in./sec)	3 A_{po} (in/sec^2)	4 DSCF Eq. 4-14	5 Axial Strain ($\times 10^{-6}$)	6 DSCF Eq. 4-13	7 Flexural Strain ($\times 10^{-6}$)	8 DSCF Eq. 4-13	9 Shear Strain ($\times 10^{-6}$)	10 $R = \sqrt{a^2 + b^2}$ (ft)
1	2.05	1.35	7.17	7.52	48	4.48	1	4.48	27	$\sqrt{6^2 + 6^2} = 8.5$
2	2.05	1.35	7.17	10.30	66	6.14	1	6.14	37	$\sqrt{6^2 + 12^2} = 13.4$
3	2.05	1.35	7.17	12.63	81	7.53	1	7.53	46	$\sqrt{6^2 + 18^2} = 14.0$
4	2.05	1.35	7.17	14.72	94	8.77	1	8.77	53	$\sqrt{6^2 + 24^2} = 24.7$

Note: (a) Refer to Section 4.5.2 for detailed equations.

FOR INFORMATION ONLY

Table 4-5a

ASSESSMENT OF UNDERGROUND DRIFT STABILITY

MAX. ACCELERATION = 0.10 g

Drift Geometry a/b	Axial Strain ϵ_a ($\times 10^{-6}$)	Flexural Strain ϵ_b ($\times 10^{-6}$)	Shear Strain γ ($\times 10^{-6}$)	STATIC $\sigma_y = E p_1 B_1$ Eq 4-42 (psi)	STATIC $\sigma_x = \frac{\nu}{1-\nu}\sigma_y$ Eq 4-43 (psi)	DYNAMIC $\sigma_x = \pm E \epsilon_a$ (psi)	DYNAMIC $\tau_{xy} = G\gamma$ (psi)	STATIC PLUS DYNAMIC σ_y (psi)	STATIC PLUS DYNAMIC σ_x (psi)	STATIC PLUS DYNAMIC τ_{xy} (psi)	σ_1 Eq 4-39 (psi)	σ_2 Eq 4-40 (psi)	τ_{oct} [a] Eq 4-41 <600 (psi)	T_o [b] Eq 4-38 <375 (psi)
1	92	1	59	-2115	-906	± 532	± 131	-2115	-374 -1438	± 131	-364 -1414	-2125 -2139	928 888	804
2	126	1	81	-2115	-906	± 729	± 180	-2115	-177 -1635	± 180	-160 -1575	-2132 -2175	970 917	839
3	155	1	100	-2115	-906	± 897	± 227	-2115	-9 -1803	± 222	+14 -1688	-2138 -2230	1011 950	868

NOTE: (a) Assumed octahedral shearing strength is 600 psi, as per Serata, Paragraph 4.6.1
(b) Assumed tensile strength of salt based on $C_o = 8T_o$, where C_o = 3000 psi, Paragraph 4.6.1

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Table 4-5b

ASSESSMENT OF UNDERGROUND DRIFT STABILITY

MAX. ACCELERATION = 0.05 g

Drift Geometry a/b	Axial Strain ϵ_a ($\times 10^{-6}$)	Flexural Strain ϵ_b ($\times 10^{-6}$)	Shear Strain γ ($\times 10^{-6}$)	STATIC $\sigma_y = \sum p_i H_i$ Eq 4-42 (psi)	STATIC $\sigma_x = \frac{\nu}{1-\nu}\sigma_y$ Eq 4-43 (psi)	DYNAMIC $\sigma_x = E\epsilon_a$ (psi)	DYNAMIC $\tau_{xy} = G\gamma$ (psi)	STATIC PLUS DYNAMIC σ_y (psi)	STATIC PLUS DYNAMIC σ_x (psi)	STATIC PLUS DYNAMIC τ_{xy} (psi)	σ_1 Eq 4-39 (psi)	σ_2 Eq 4-40 (psi)	τ_{oct} (a) Eq 4-41 <600 (psi)	τ_o (b) Eq 4-38 <375 (psi)
1	48	1	27	-2115	-906	± 278	± 60	-2115	-628 -1184	± 60	-626	-2117	888	760
2	66	1	37	-2115	-906	± 382	± 82	-2115	-524 -1288	± 82	-520	-2119	902	778
3	81	1	46	-2115	-906	± 469	± 102	-2115	-437 -1375	± 102	-431	-2121	904	792

NOTE: (a) Assumed octahedral shearing strength is 600 psi, as per Serata, Paragraph 4.6.1
(b) Assumed tensile strength of salt based or $C_o = 8T_o$, where C_o = 3000 psi, Paragraph 4.6.1

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Table 4-6 a

ASSESSMENT OF UNLINED VERTICAL SHAFT STABILITY

MAX. ACCELERATION = 0.10 g

Shaft Elevation Below Ground Surface (ft)	Axial Strain ϵ_a ($\times 10^{-6}$)	Flexural Strain ϵ_b ($\times 10^{-6}$)	Shear Strain γ ($\times 10^{-6}$)	STATIC STRESS $\sigma_y = \Sigma D_i H_i$ Eq 4-42 (psi)	STATIC STRESS $\sigma_x = \frac{\upsilon}{1-\upsilon}\sigma_y$ Eq 4-43 (psi)	DYNAMIC STRESS $\sigma_y = D\epsilon_a$ (psi)	DYNAMIC STRESS $\tau_{xy} = G\gamma$ (psi)	STATIC PLUS DYNAMIC σ_y (psi)	STATIC PLUS DYNAMIC σ_x (psi)	STATIC PLUS DYNAMIC τ_{xy} (psi)	σ_1 Eq 4-39 (psi)	σ_2 Eq 4-40 (psi)	τ_{oct}[a] Eq 4-41 $\leq$ 600 (psi)	τ_o [b] Eq 4-38 $\leq$ 375 (psi)
35	104	25	662	- 27	- 13	± 61	± 97	-88	-13	± 97	53	-155	± 64	+72
210	74	12	500	-192	-118	± 94	± 115	-286	-118	± 115	-60	-344	±150	+131
520	37	17	224	-632	-262	± 212	± 248	-744	-262	± 248	-157	-849	± 369	+323
605	40	2	218	-629	-270	± 167	± 250	-796	-270	± 250	-170	-896	± 389	+340
835	38	1	200	-889	-381	± 160	± 239	-1049	-381	± 239	-304	-1126	± 476	+413
1540	27	1	136	-1527	-654	± 160	± 303	-1687	-654	± 303	-572	-1769	737	+627
2162	26	1	115	-2115	-906	± 153	± 256	-2268	-906	± 256	-860	-2315	955	+804

NOTE: (a) Octahedral shearing strength of the rock and salt assumed to be 600 psi, see note (a), Table 4-5a.
(b) Assumed internal friction coefficient = 0.5 (Ref. 8).
Tensile strength of salt assumed to be 375 psi, see note (b), Table 4-5a.

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Table 4-6 b

ASSESSMENT OF UNLINED VERTICAL SHAFT STABILITY

MAX. ACCELERATION = 0.05 g

Shaft Elevation Below Ground Surface (ft)	Axial Strain ϵ_a ($\times 10^{-6}$)	Flexural Strain ϵ_b ($\times 10^{-6}$)	Shear Strain γ ($\times 10^{-6}$)	STATIC STRESS $\sigma_y = \Sigma b_i H_i$ Eq 4-42 (psi)	STATIC STRESS $\sigma_x = \frac{\nu}{1-\nu}\sigma_y$ Eq 4-43 (psi)	DYNAMIC STRESS $\sigma_y = D\epsilon_a$ (psi)	DYNAMIC STRESS $\tau_{xy} = G\gamma$ (psi)	STATIC PLUS DYNAMIC σ_y (psi)	STATIC PLUS DYNAMIC σ_x (psi)	STATIC PLUS DYNAMIC τ_{xy} (psi)	σ_1 Eq 4-39 (psi)	σ_2 Eq 4-40 (psi)	τ_{oct} (a) Eq 4-41 $\leq$ 600 (psi)	τ_o (b) Eq 4-38 $\leq$ 375 (psi)
35	38	8	271	-27	-13	±26	±40	-53	-13	±40	12	-78	± 23	+34
210	17	1	107	-192	-118	±20	±25	-212	-118	±25	-112	-218	± 89	+72
520	10	1	67	-532	-262	±44	±74	-576	-262	±74	-254	-593	± 244	+204
605	11	1	65	-629	-270	±44	±75	-673	-270	±75	-257	-687	± 283	+241
835	14	1	71	-889	-381	±59	±85	-948	-381	±85	-369	-961	± 396	+335
1540	12	1	69	-1527	-654	±71	±154	-1598	-654	±154	-630	-1622	668	+519
2162	12	1	60	-2115	-906	±71	±134	-2186	-906	±134	-892	-2200	903	+753

NOTE: (a) Octahedral shearing strength of rock and salt assumed to be 600 psi, see note (a), Table 4-5a.
(b) Assumed internal friction coefficient $\mu = 0.5$ (Ref. 8).
Tensile strength of salt assumed to be 375 psi, see note (b), Table 4-5a.

6.3 List of Figures

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Figure No.	Description
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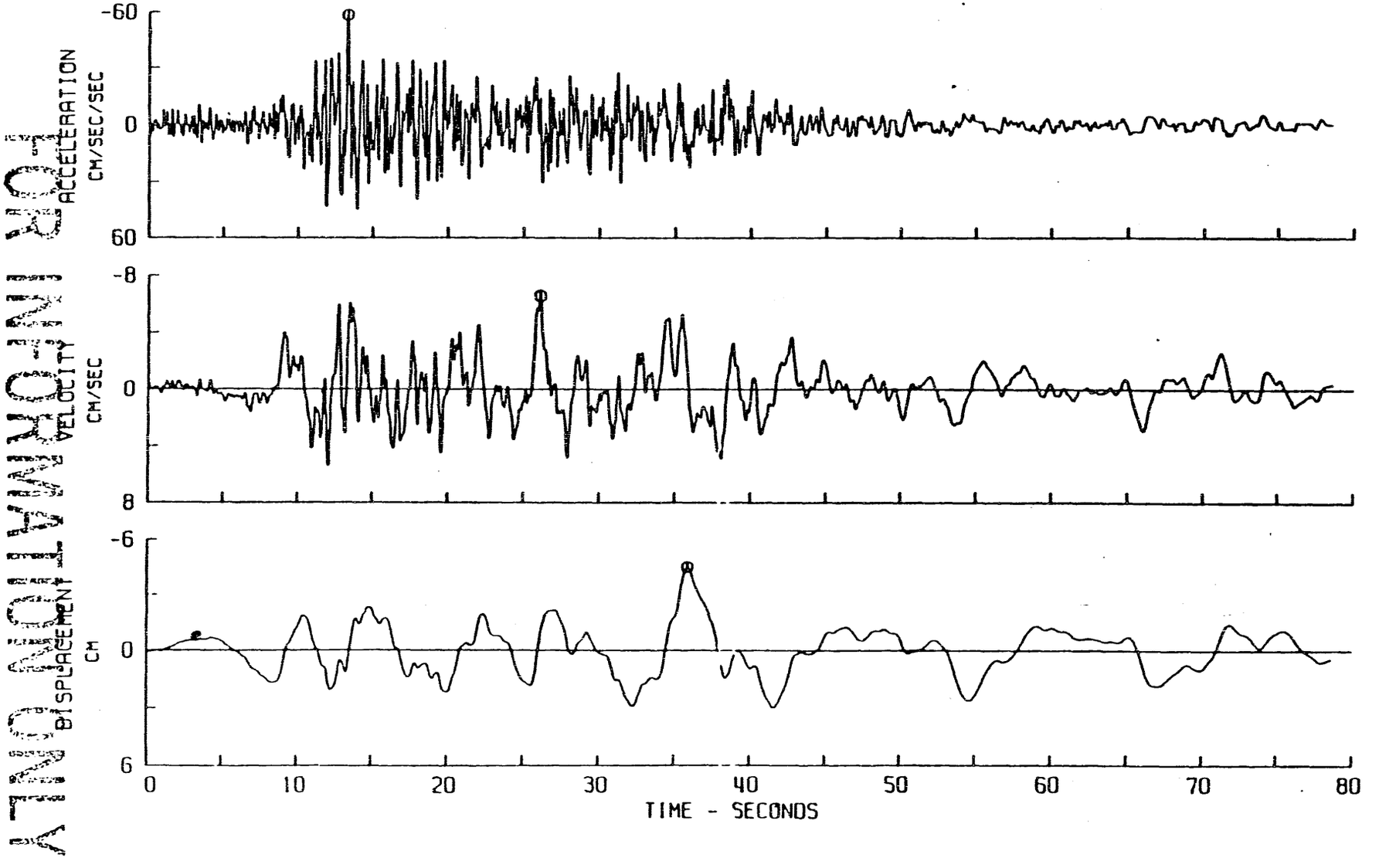


FIGURE 3-1 KERN COUNTY, CALIFORNIA EARTHQUAKE JULY 21, 1952 - 0453 PDT

IIA007 52.006.0 HOLLYWOOD STORAGE P.E. LOT COMP S00W

⊙ PEAK VALUES : ACCEL = -58.1 CM/SEC/SEC VELOCITY = -6.6 CM/SEC DISPL = -4.5 CM

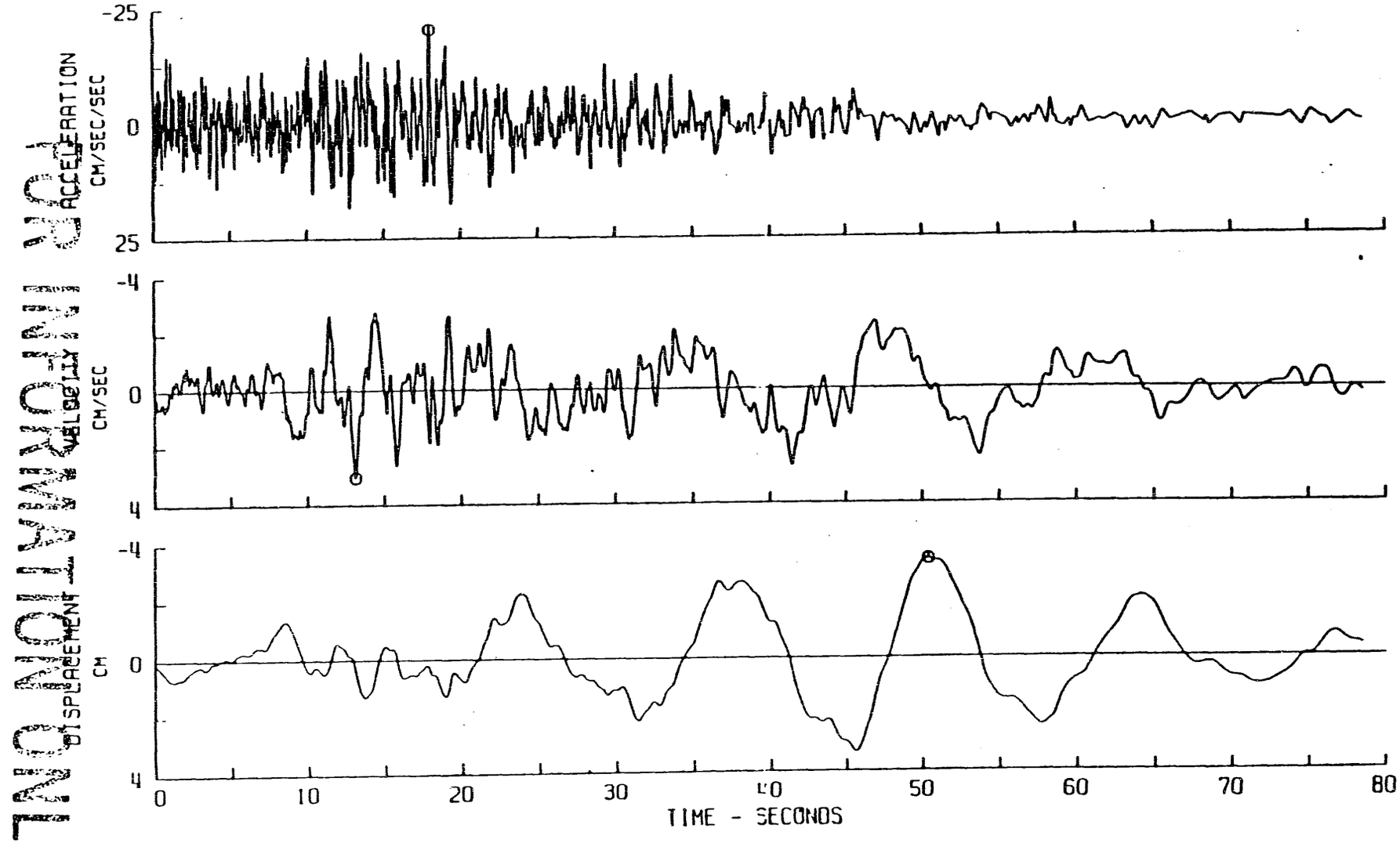


FIGURE 3-2 KERN COUNTY, CALIFORNIA EARTHQUAKE JULY 21, 1952 - 0453 PDT

1 1A007 52.006.0 HOLLYWOOD STORAGE P.E. LOT COMP VERT

⊙ PEAK VALUES : ACCEL = -20.3 CM/SEC/SEC VELOCITY = 3.0 CM/SEC DISPL = -3.4 CM

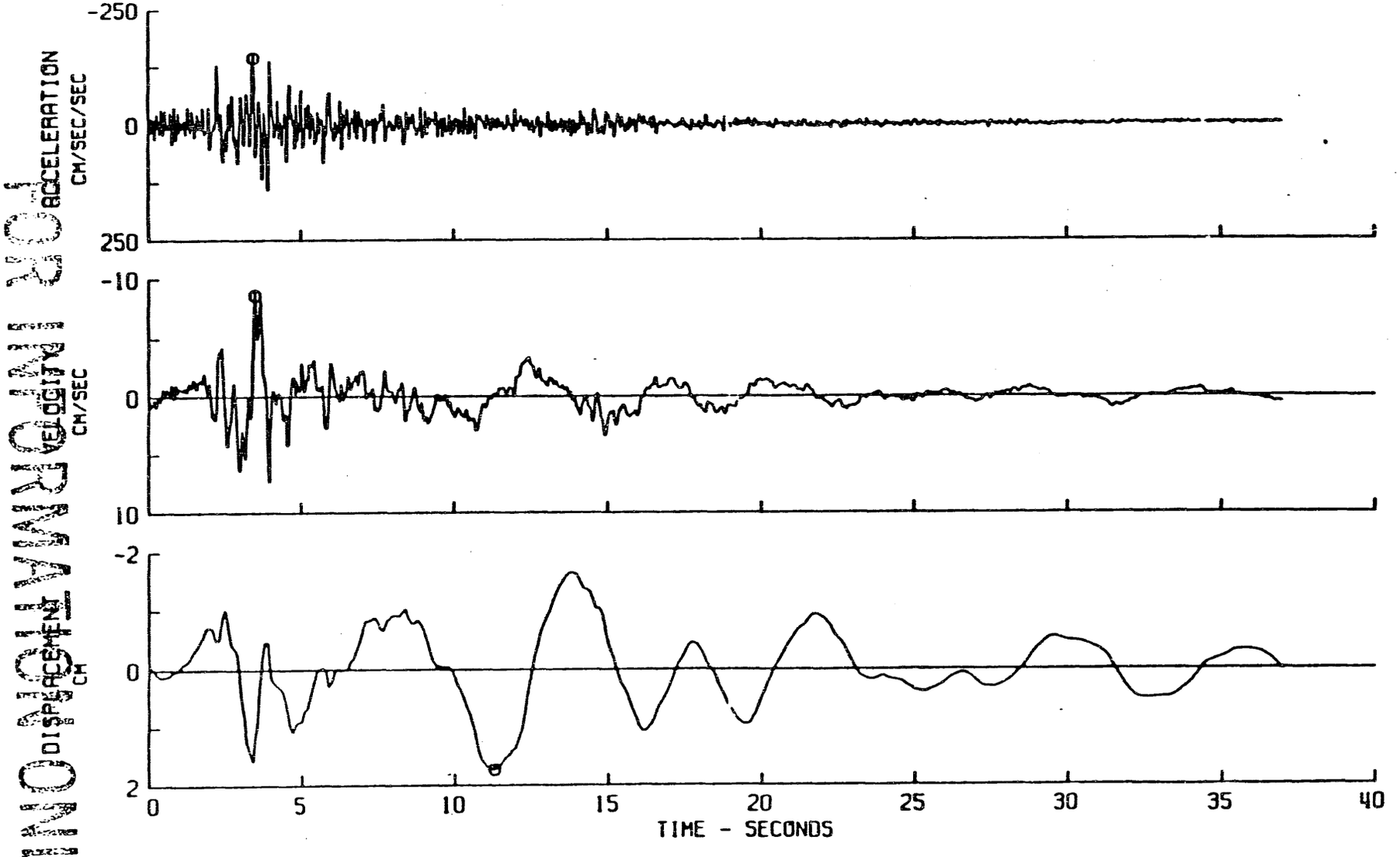


FIGURE 3-3 SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

11J142 71.065.0 LAKE HUGHES, ARRAY STATION 4, CAL. COMP S21W

⊙ PEAK VALUES : ACCEL = -183.5 CM/SEC/SEC VELOCITY = -8.6 CM/SEC DISPL = 1.7 CM

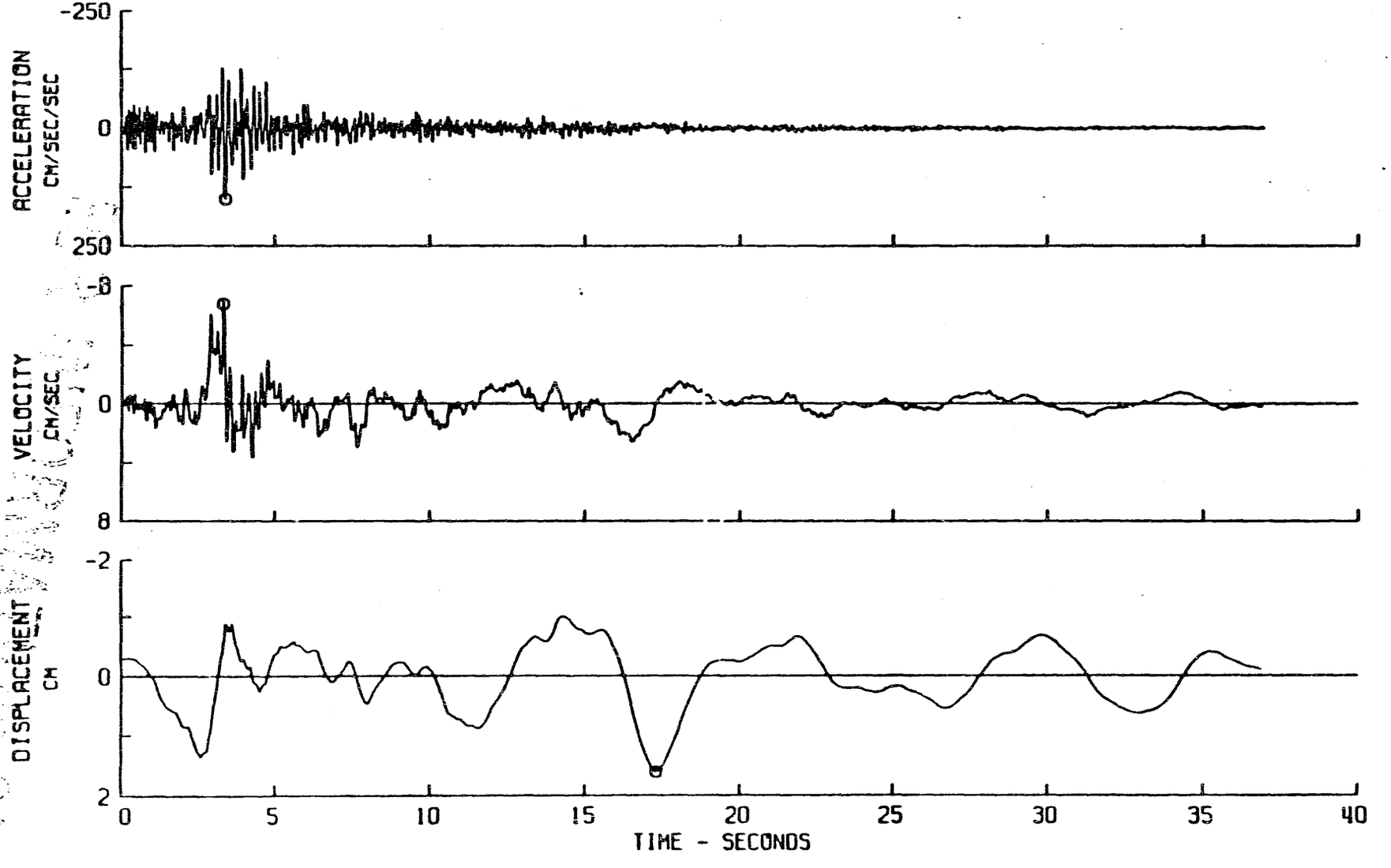


FIGURE 3-4 SAN FERNANDO EARTHQUAKE FEB 9. 1971 - 0600 PST

1IJ142 71.065.0 LAKE HUGHES. ARRAY STATION 4. CAL. COMP DOWN

⊙ PEAK VALUES : ACCEL = 150.8 CM/SEC/SEC VELOCITY = -6.8 CM/SEC DISPL = 1.6 CM

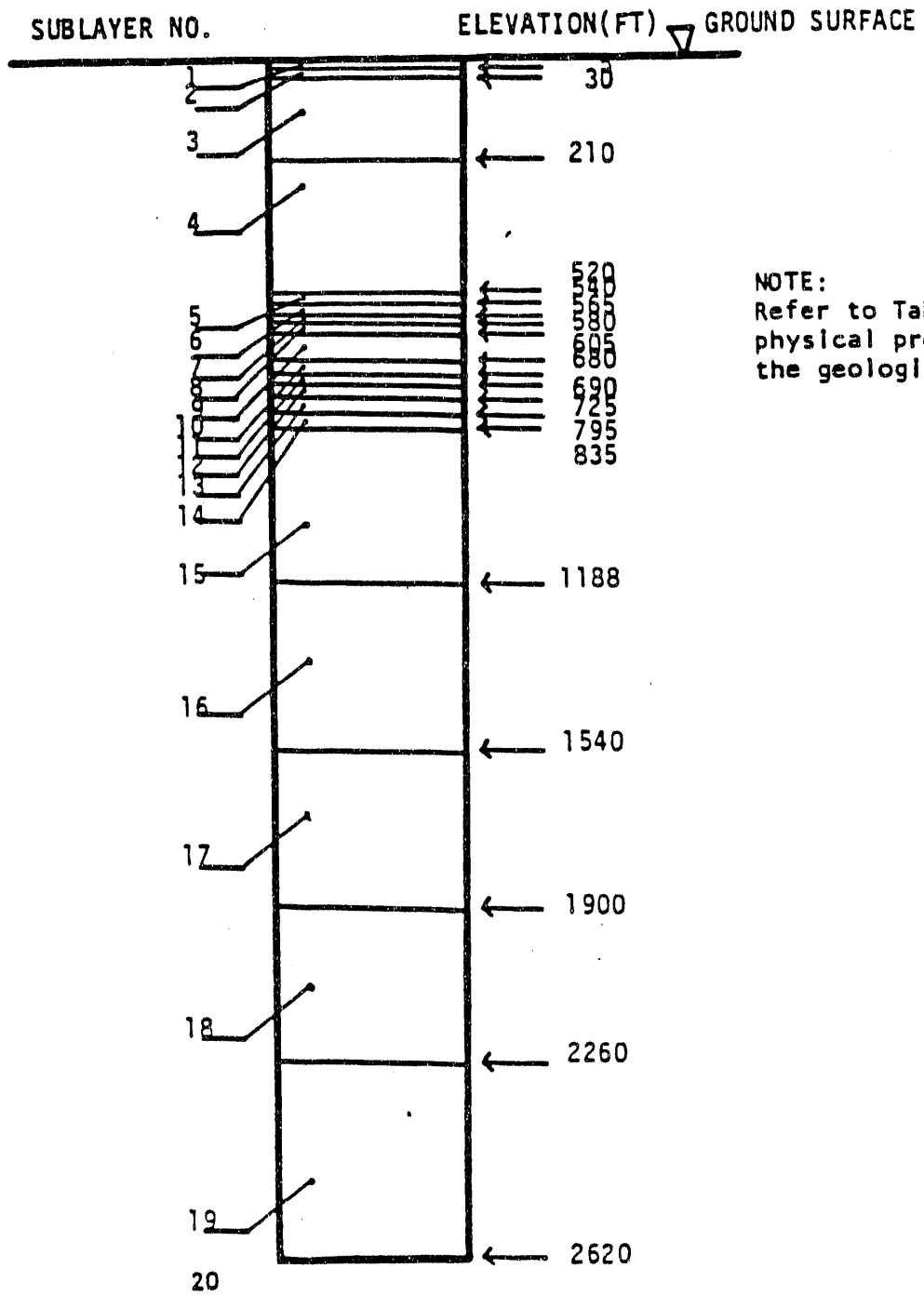


FIGURE 4-1 STRATIGRAPHIC COLUMN OF THE WIPP SITE MEDIA

FOR INFORMATION ONLY

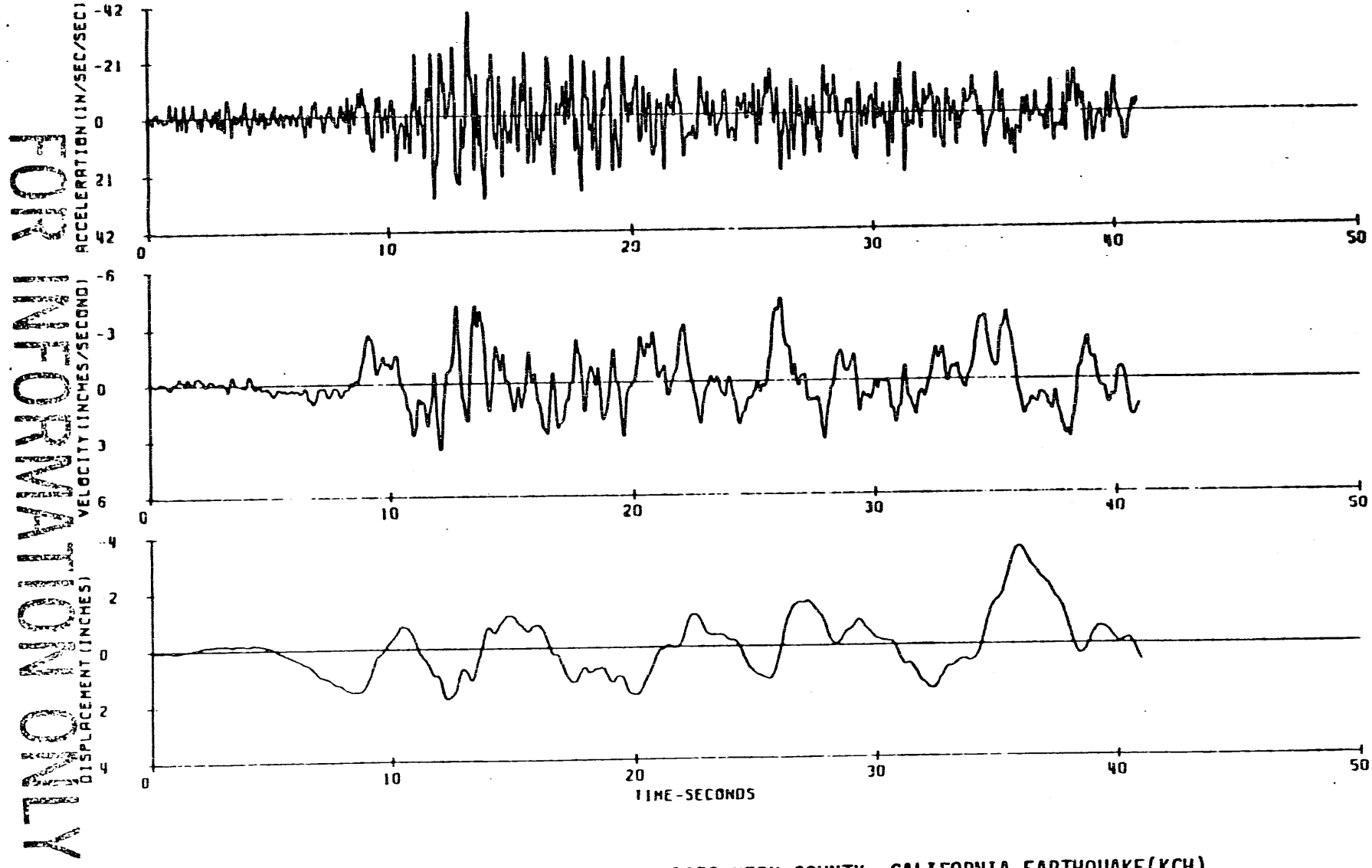


FIGURE 4-2(a) TIME HISTORY RESPONSES- 1952 KERN COUNTY, CALIFORNIA EARTHQUAKE(KCH)
HORIZONTAL MOTION- SUBLAYER 1

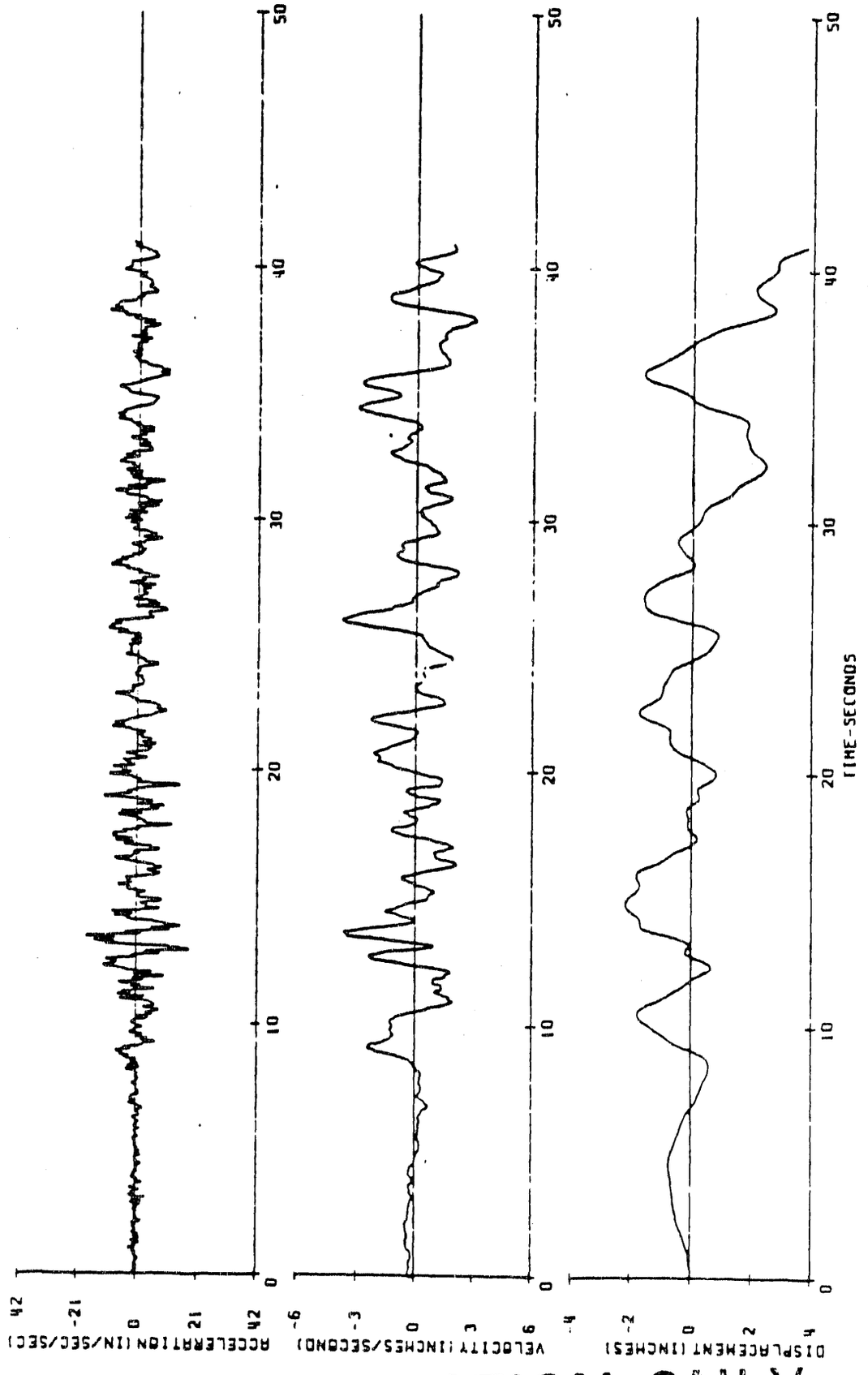


FIGURE 4-2(b) KCH- SUBLAYER 10

FOR INFORMATION ONLY

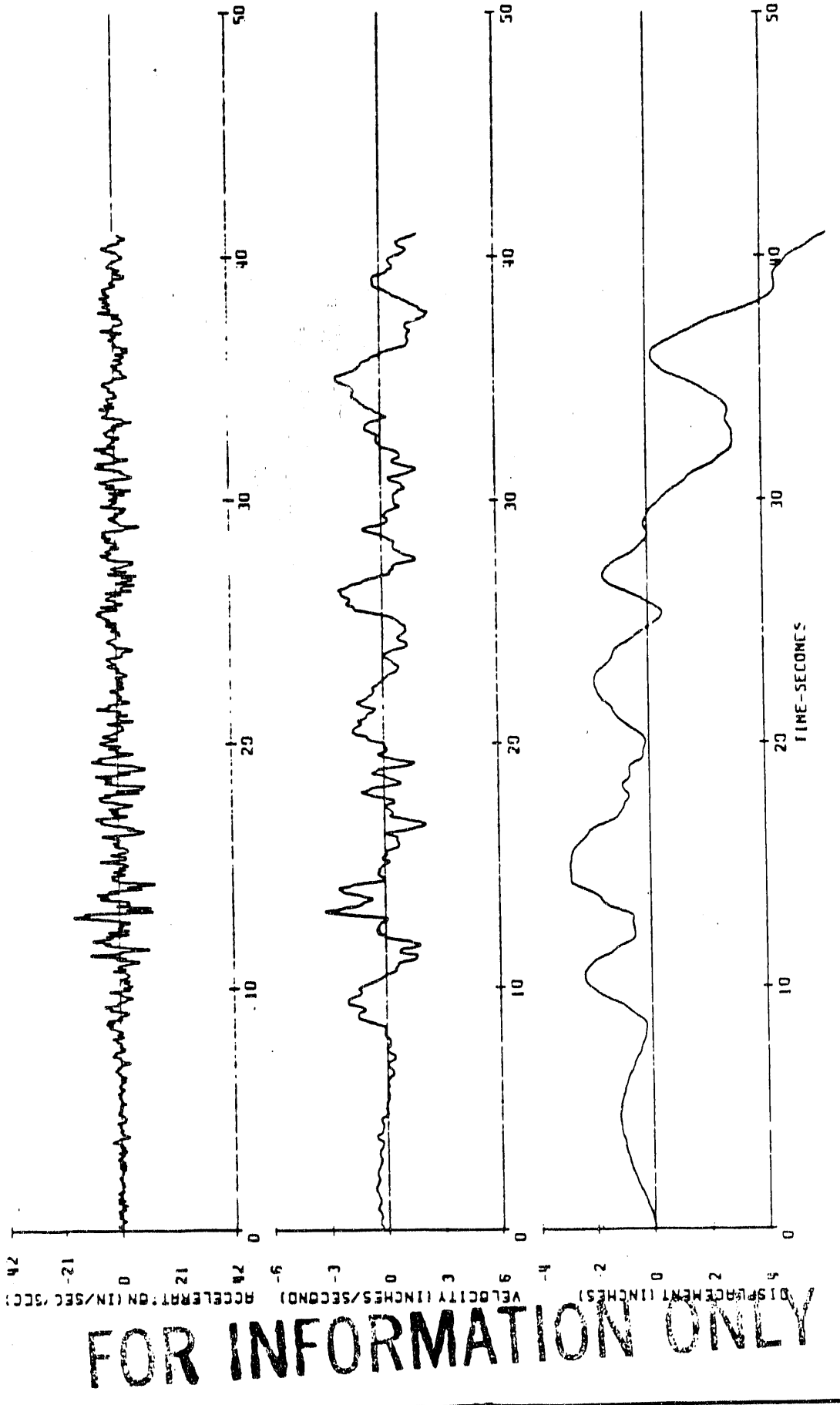


FIGURE 4-2(c) KCH- SUBLAYER 20

FOR INFORMATION ONLY

NOT MEASUREMENT QUALITY INFORMATION

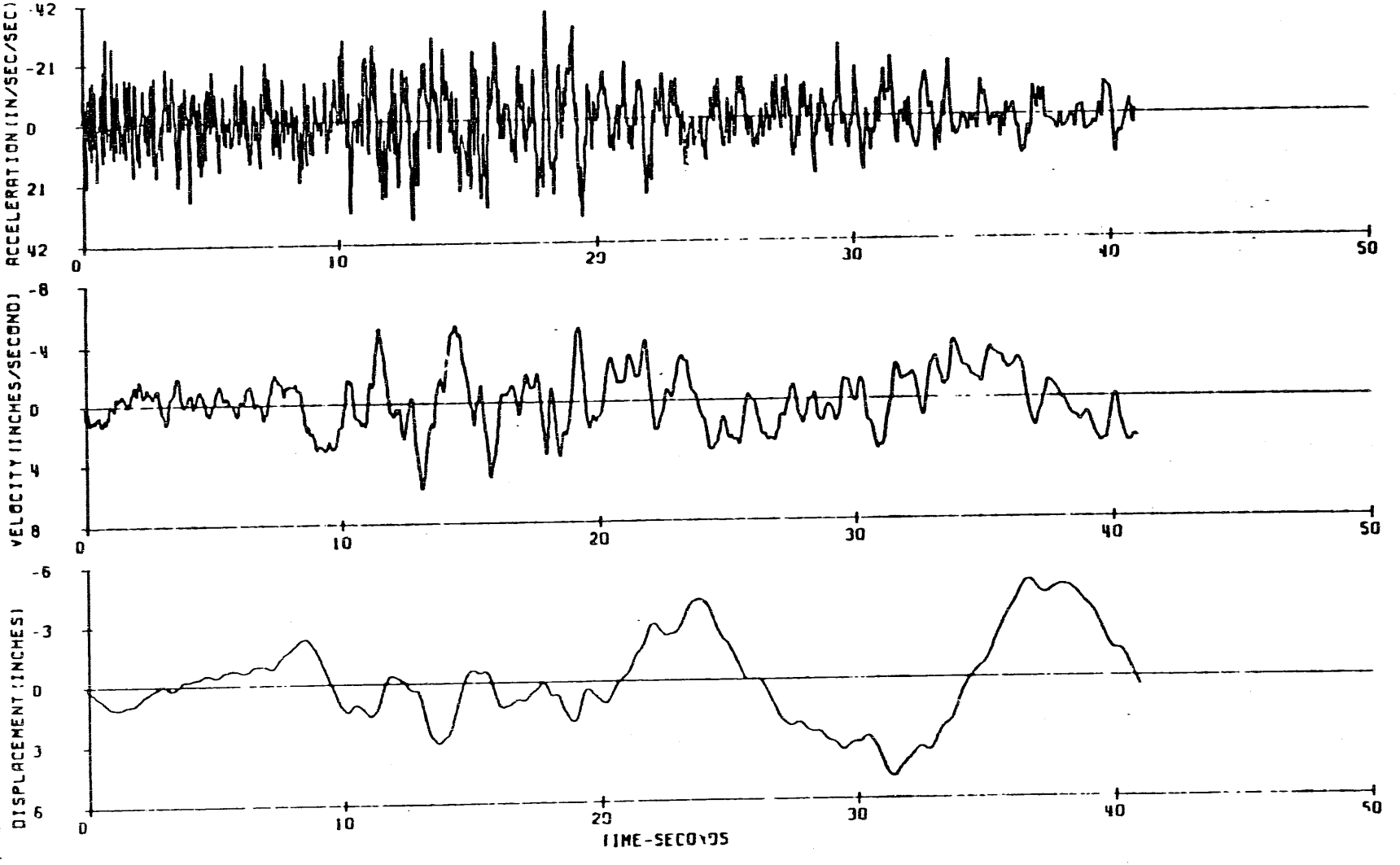


FIGURE 4-3(a) TIME HISTORY RESPONSES- 1952 KERN COUNTY, CALIFORNIA EARTHQUAKE(KCV)
VERTICAL MOTION- SUBLAYER 1

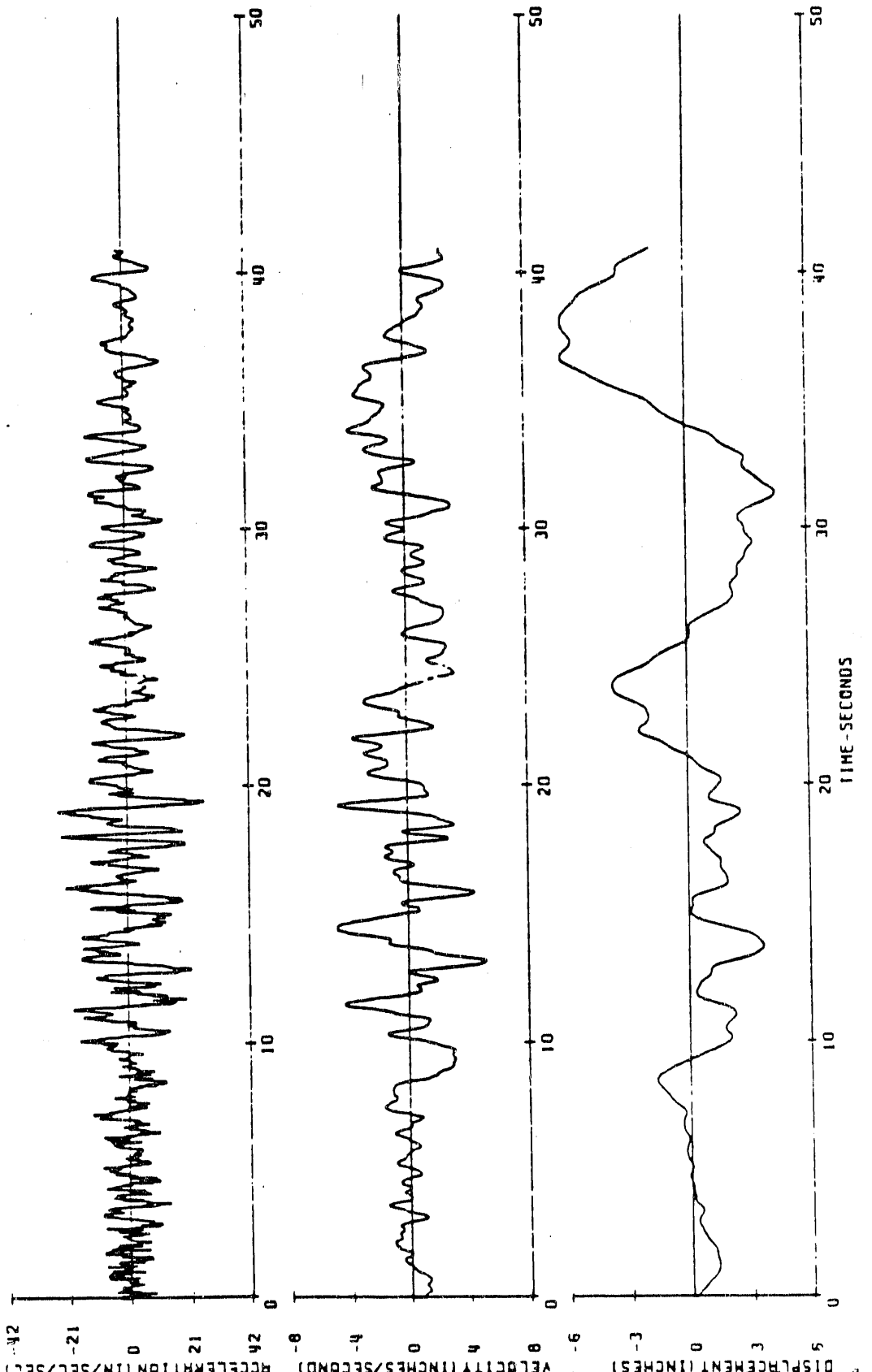


FIGURE 4-3(b) KCV- SUBLAYER 10

FOR INFORMATION ONLY

FOR INFORMATION ONLY

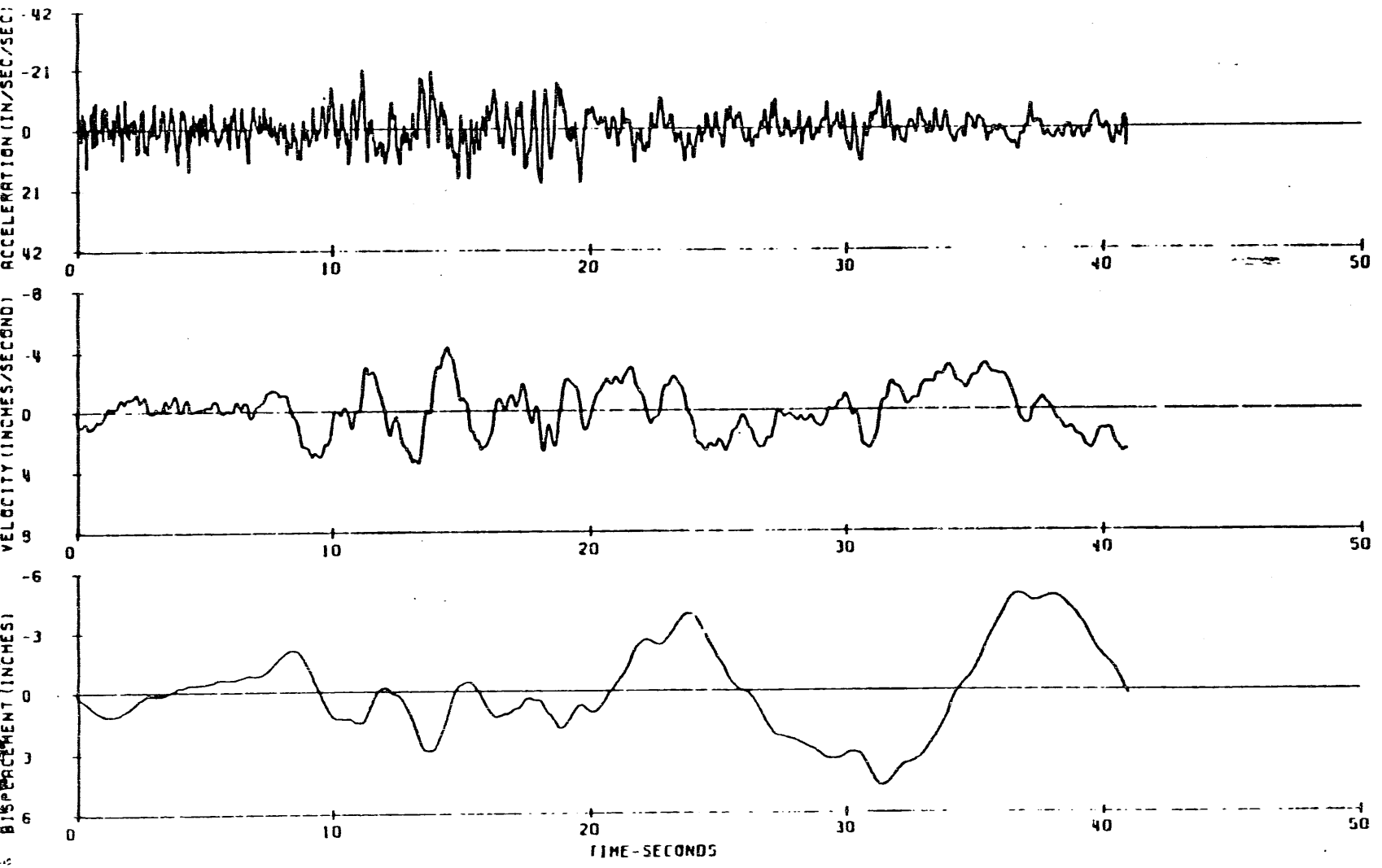


FIGURE 4-3(c) KCV- SUBLAYER 20

FOR INFORMATION ONLY

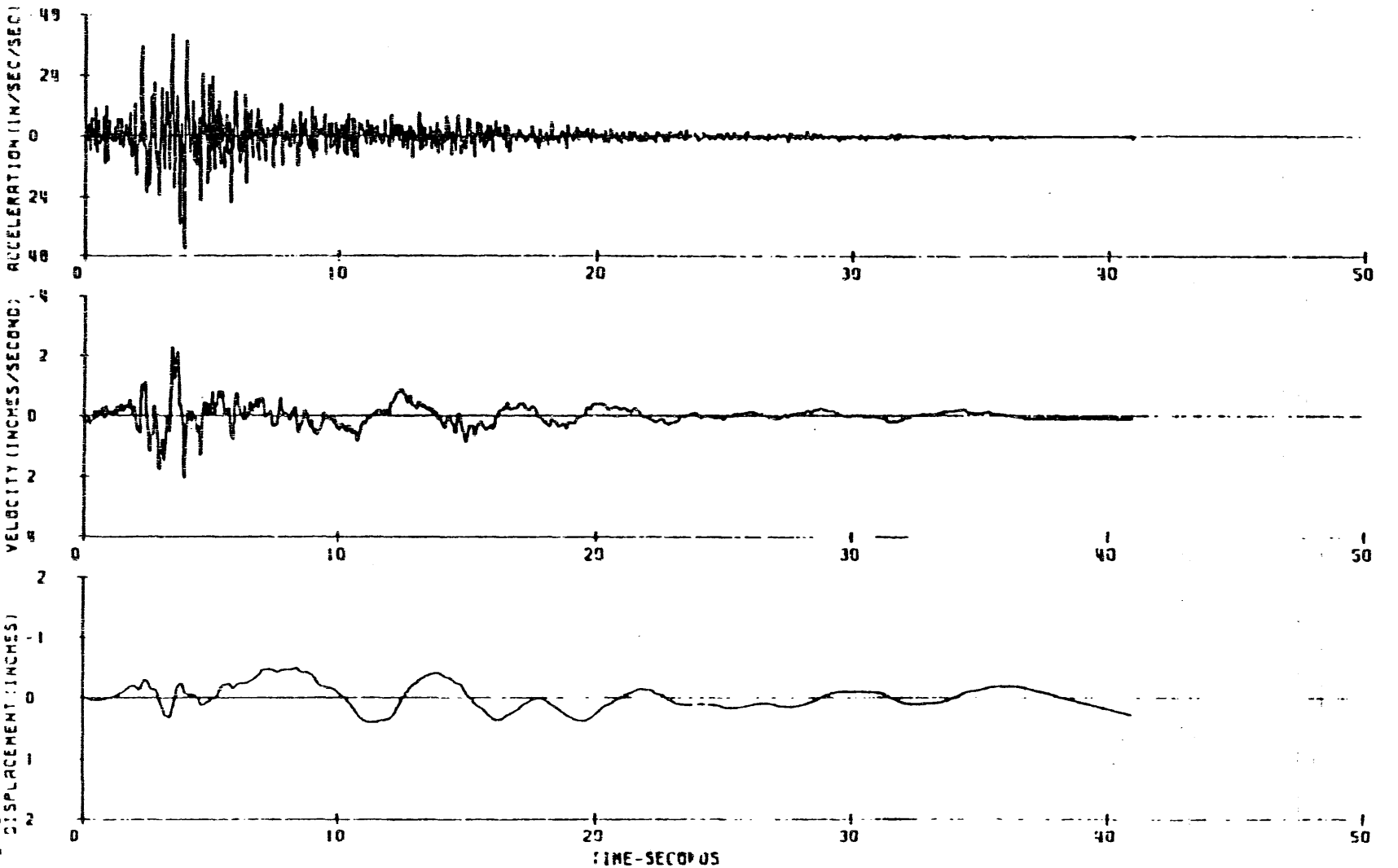


FIGURE 4-4(a) TIME HISTORY RESPONSES- 1971 SAN FERNANDO, CALIFORNIA EARTHQUAKE(SFH)
HORIZONTAL MOTION- SUBLAYER 1

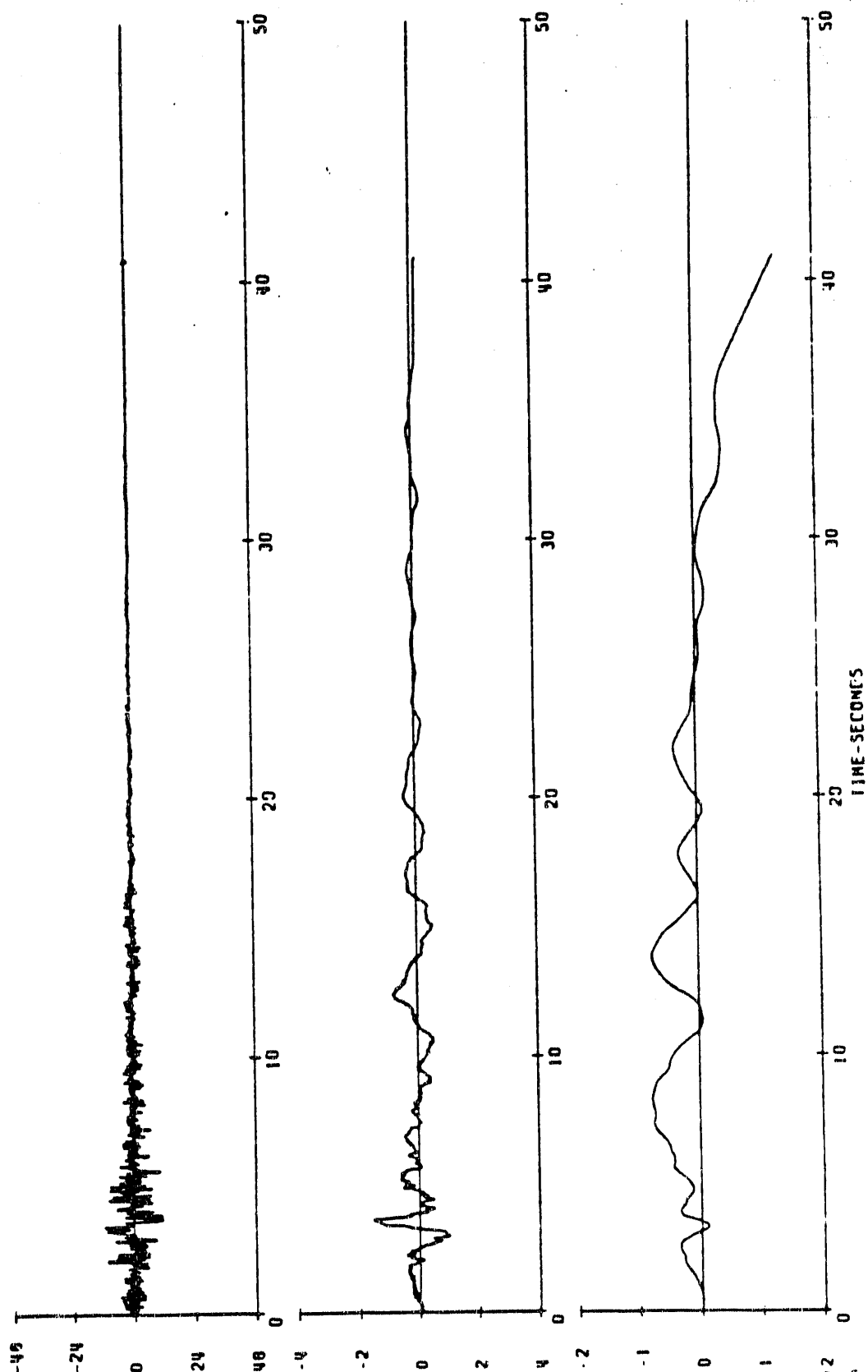


FIGURE 4-4(b) SFH- SUBLAYER 10

FOR INFORMATION ONLY

DOCUMENT NO. 76D10AA-000 REV. 0 SHEET 74 OF 98

NO INFORMATION

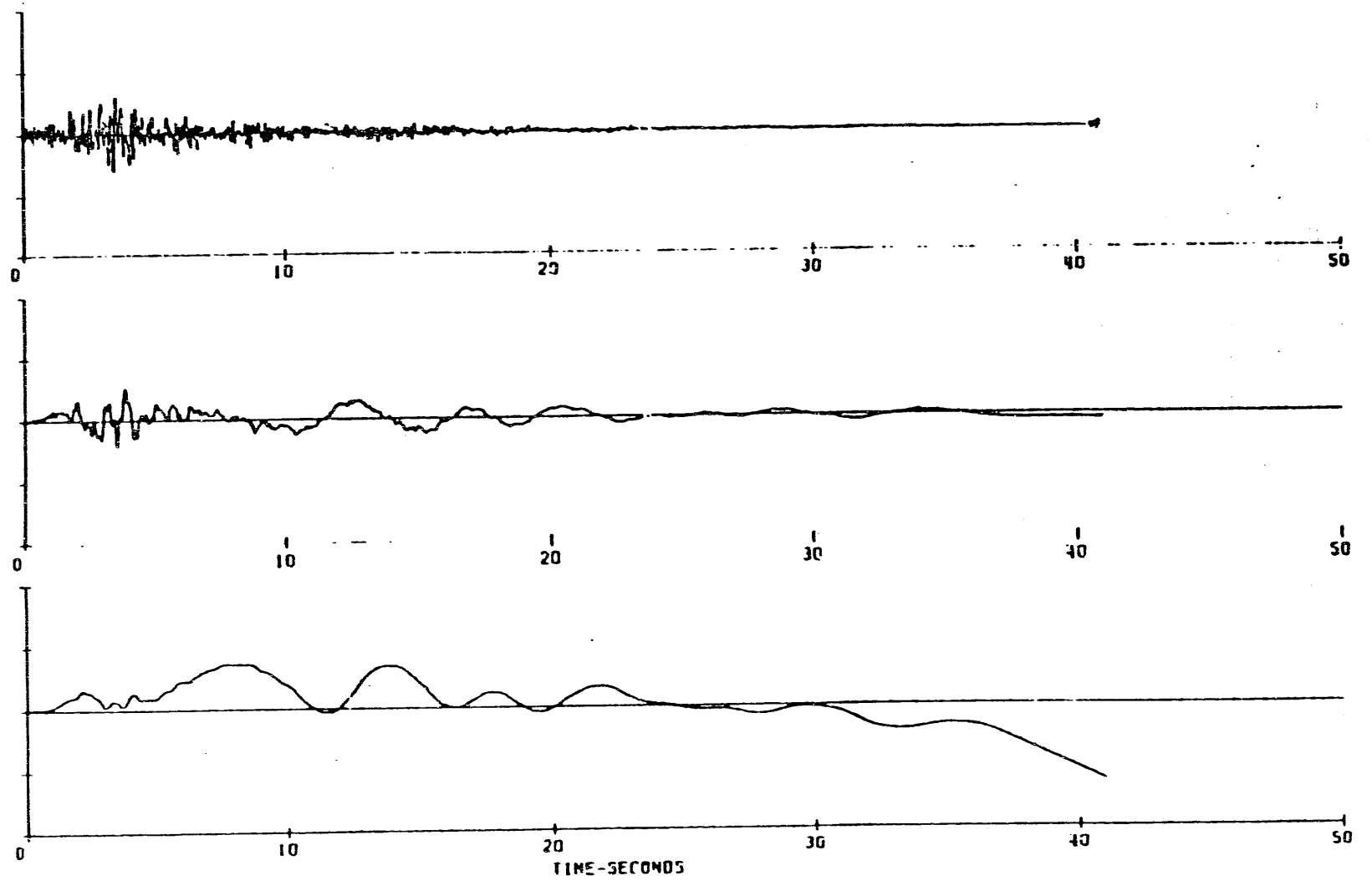


FIGURE 4-4($_c$) SFH- SUBLAYER 20

UNCONTROLLED DOCUMENT

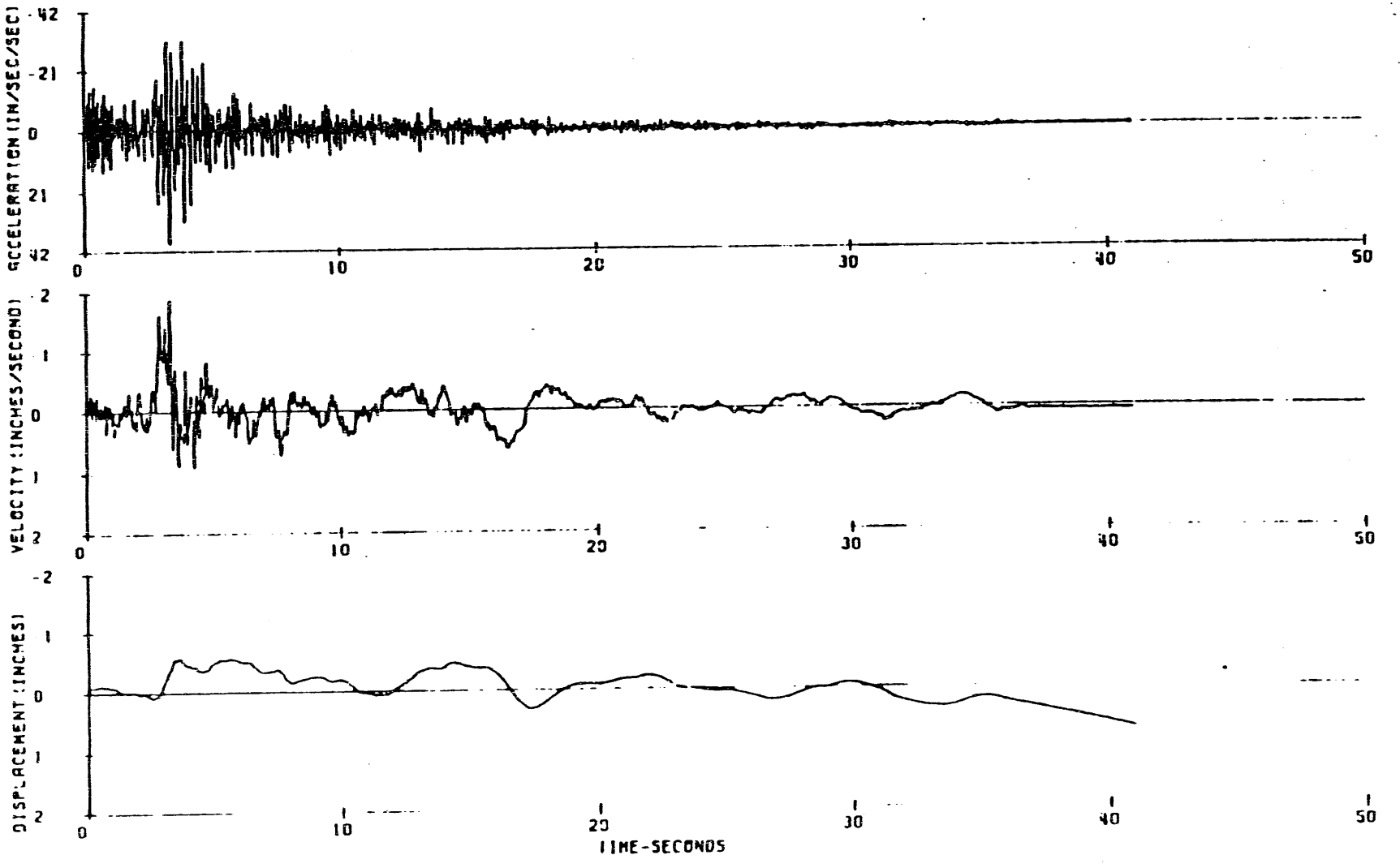


FIGURE 4-5(a) TIME HISTORY RESPONSES- 1971 SAN FERNANDO, CALIFORNIA EARTHQUAKE(SFV)
VERTICAL MOTION- SUBLAYER 1

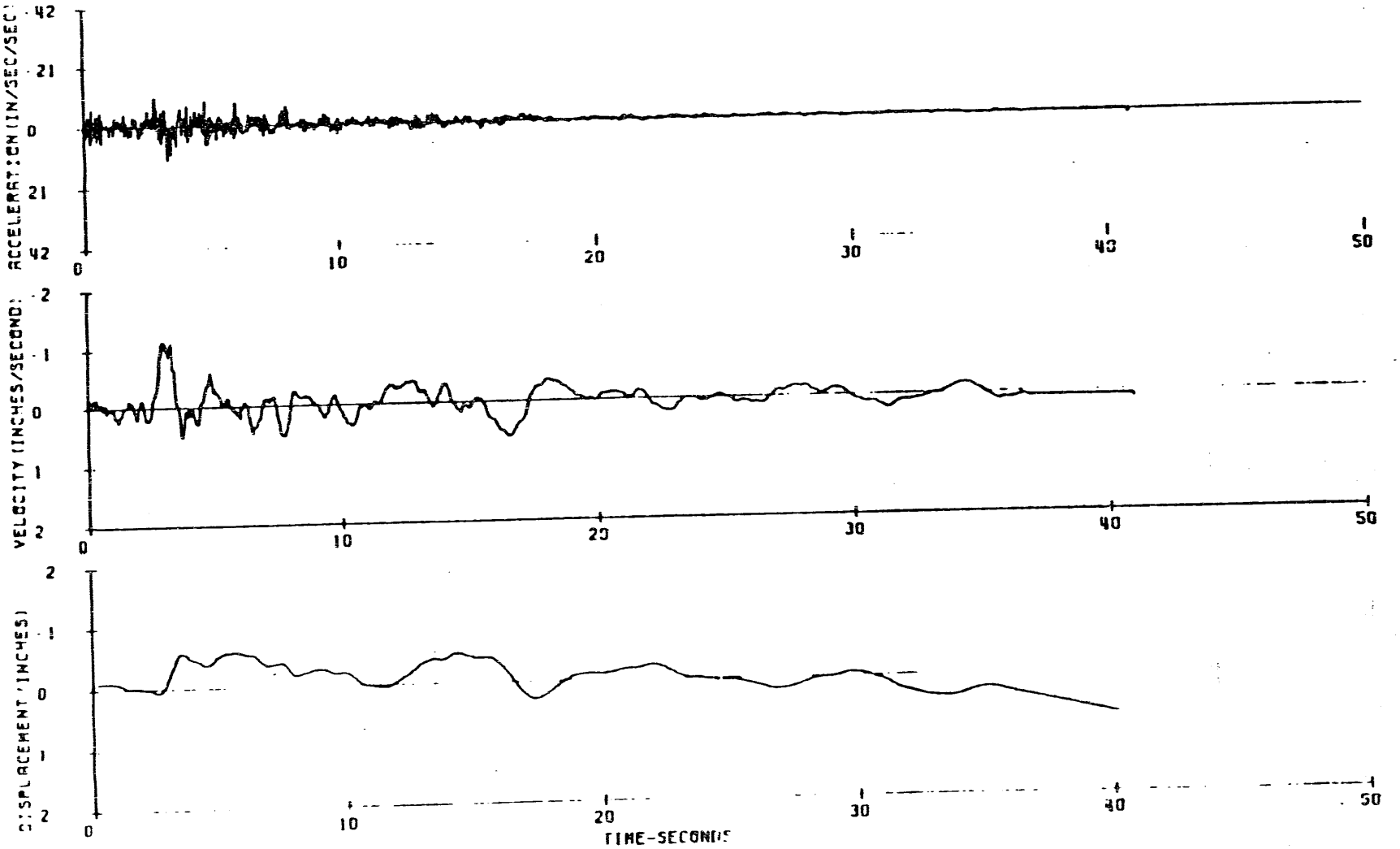


FIGURE 4-5(b) SFV- SUBLAYER 10

CONFORMATION ONLY

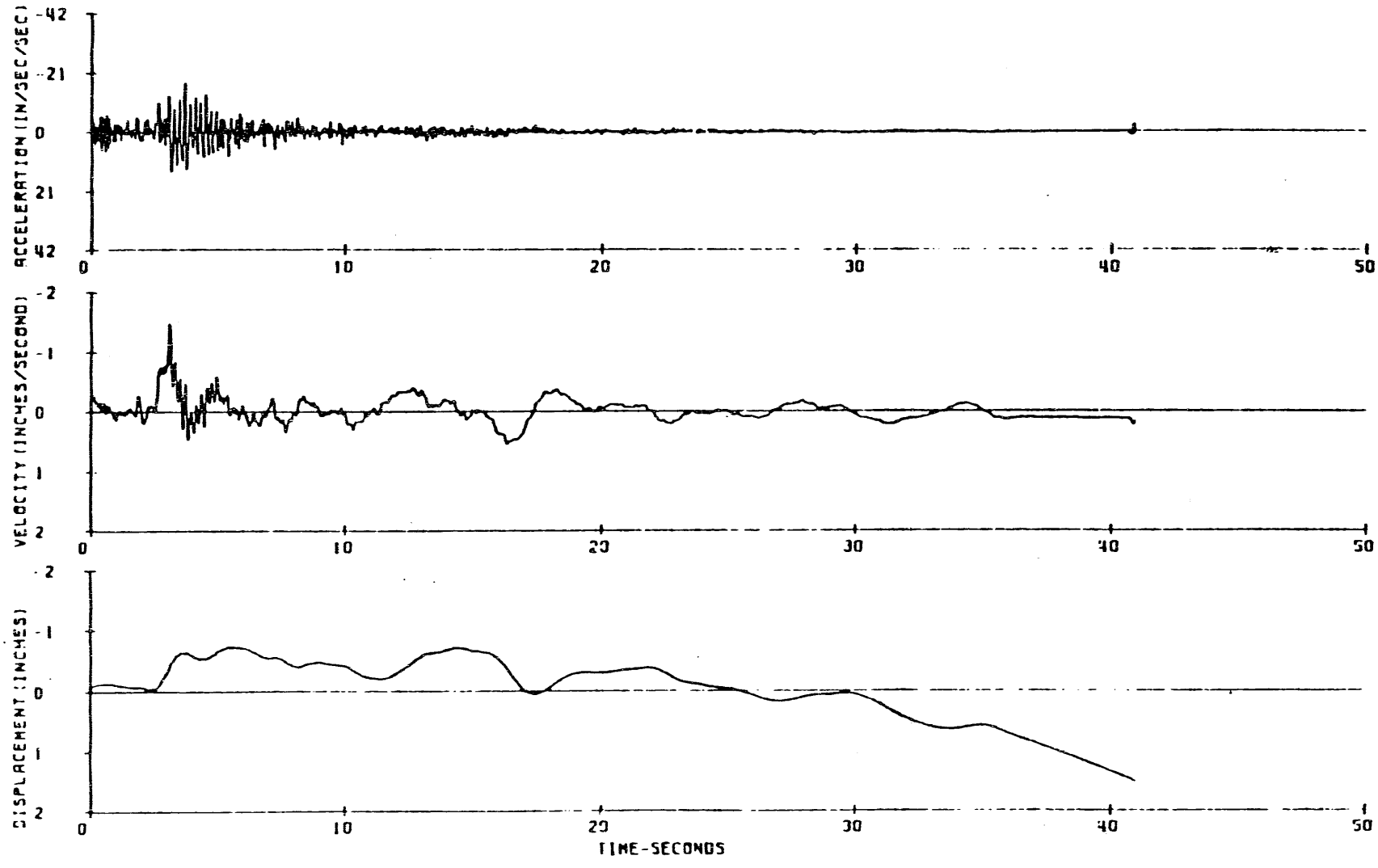


FIGURE 4-5(c) SFV- SUBLAYER 20

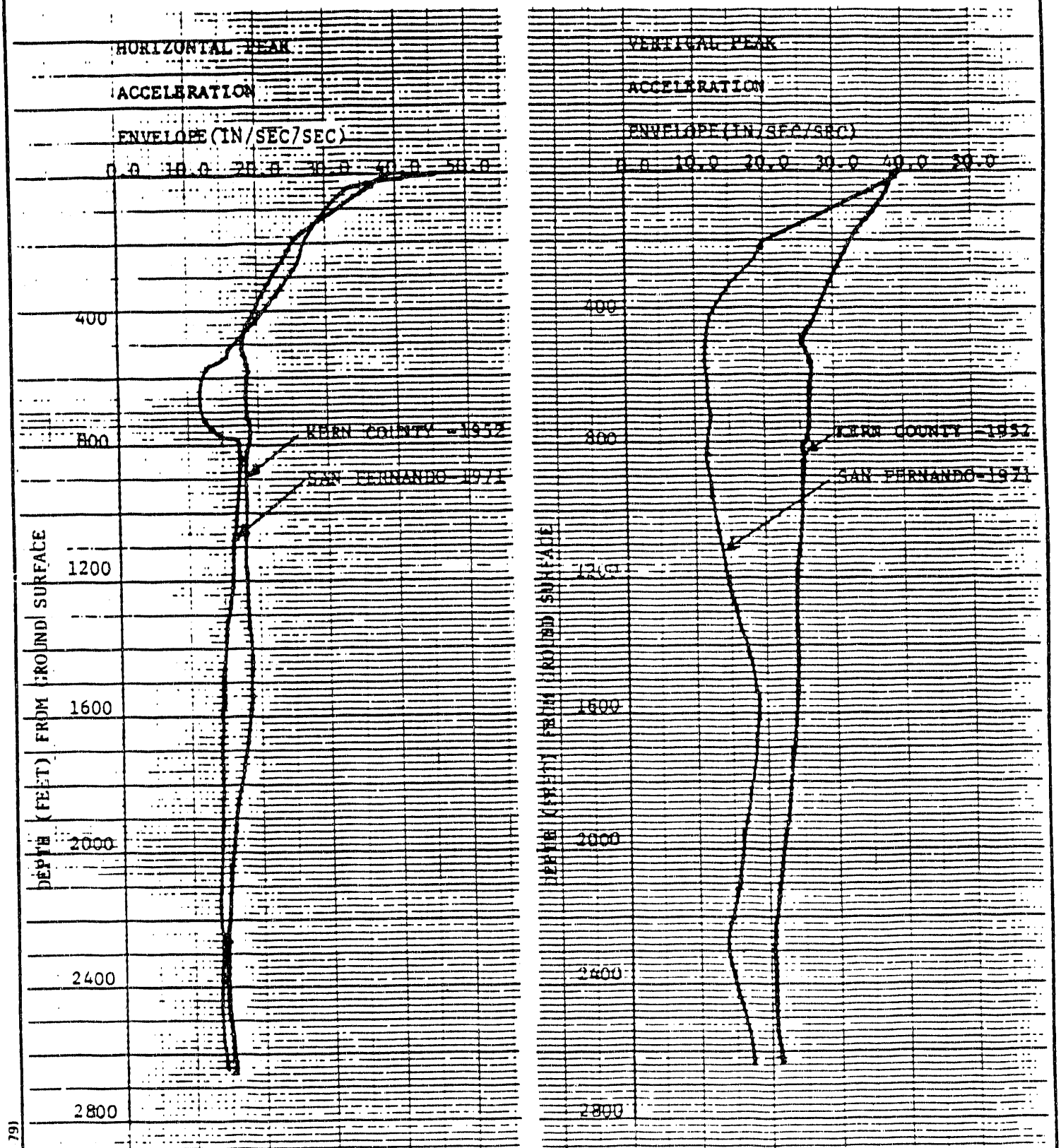


FIGURE 4-6a PEAK ACCELERATION ENVELOPES

MAX. ACCELERATION 0.40g

FOR INFORMATION ONLY

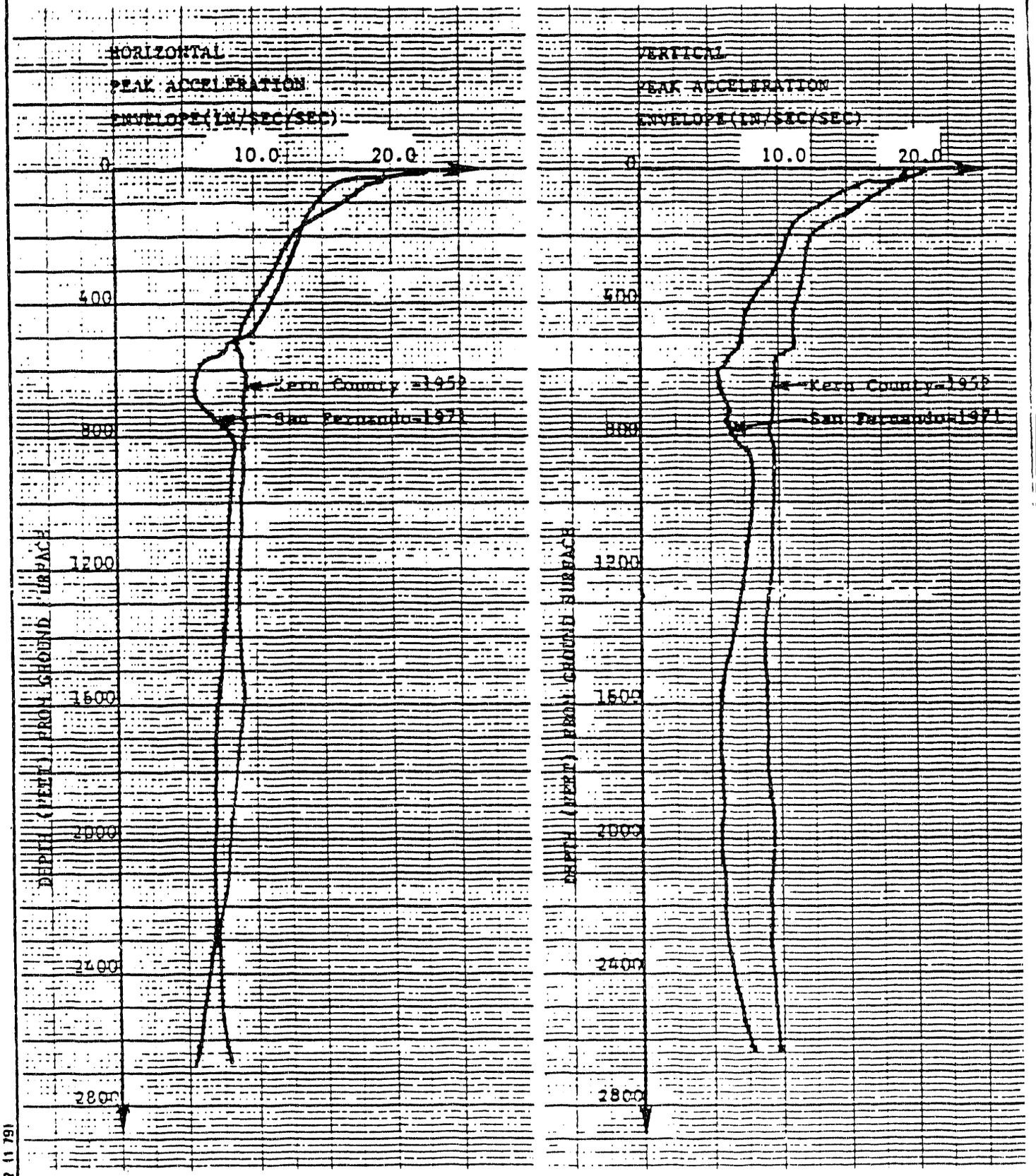


FIGURE 4-6b PEAK ACCELERATION ENVELOPES

MAX. ACCELERATION 0.206g

FOR INFORMATION ONLY

WIPP ENG-1.2 (1-79)

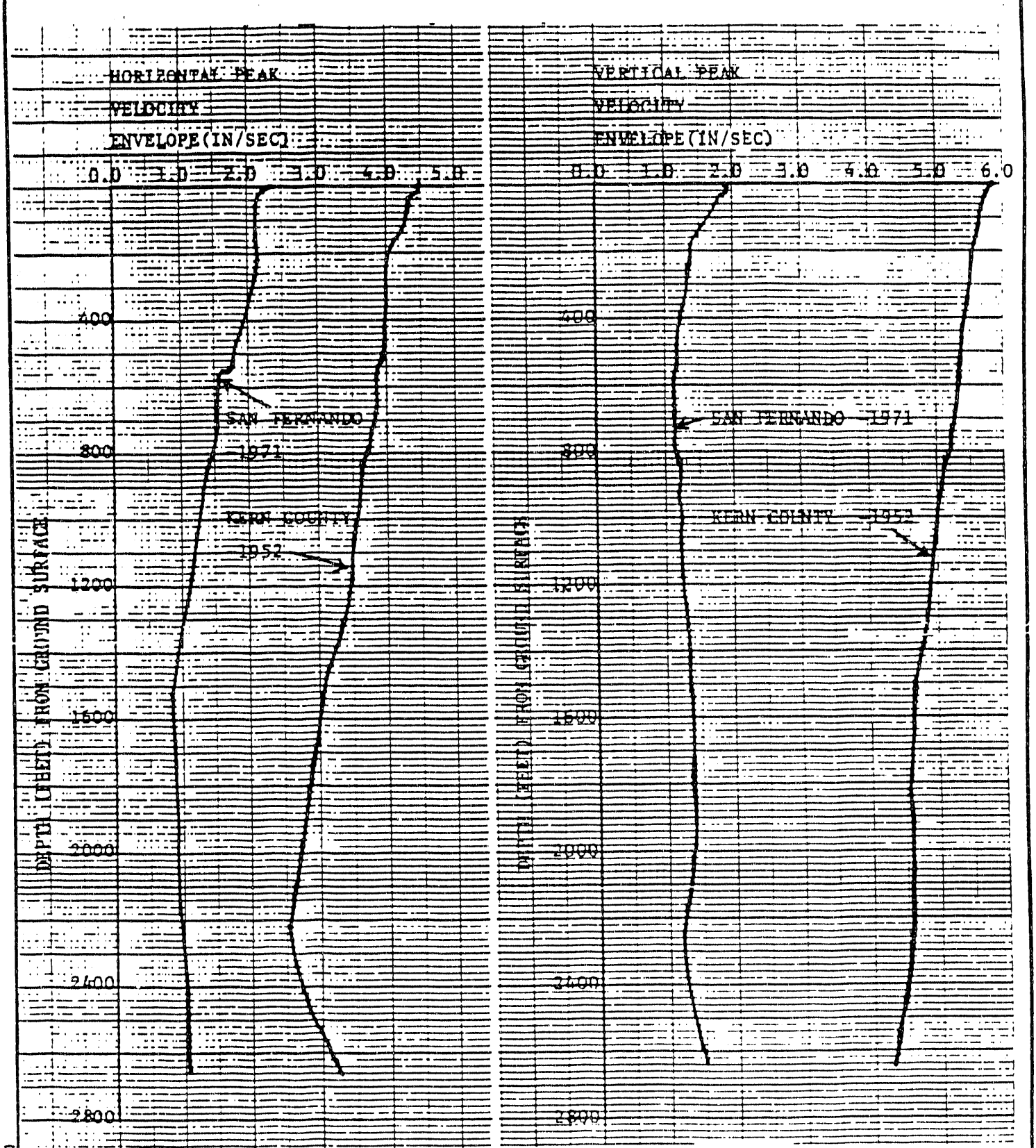


FIGURE 4-7a PEAK VELOCITY ENVELOPES

MAX. ACCELERATION = 0.10g

FOR INFORMATION ONLY

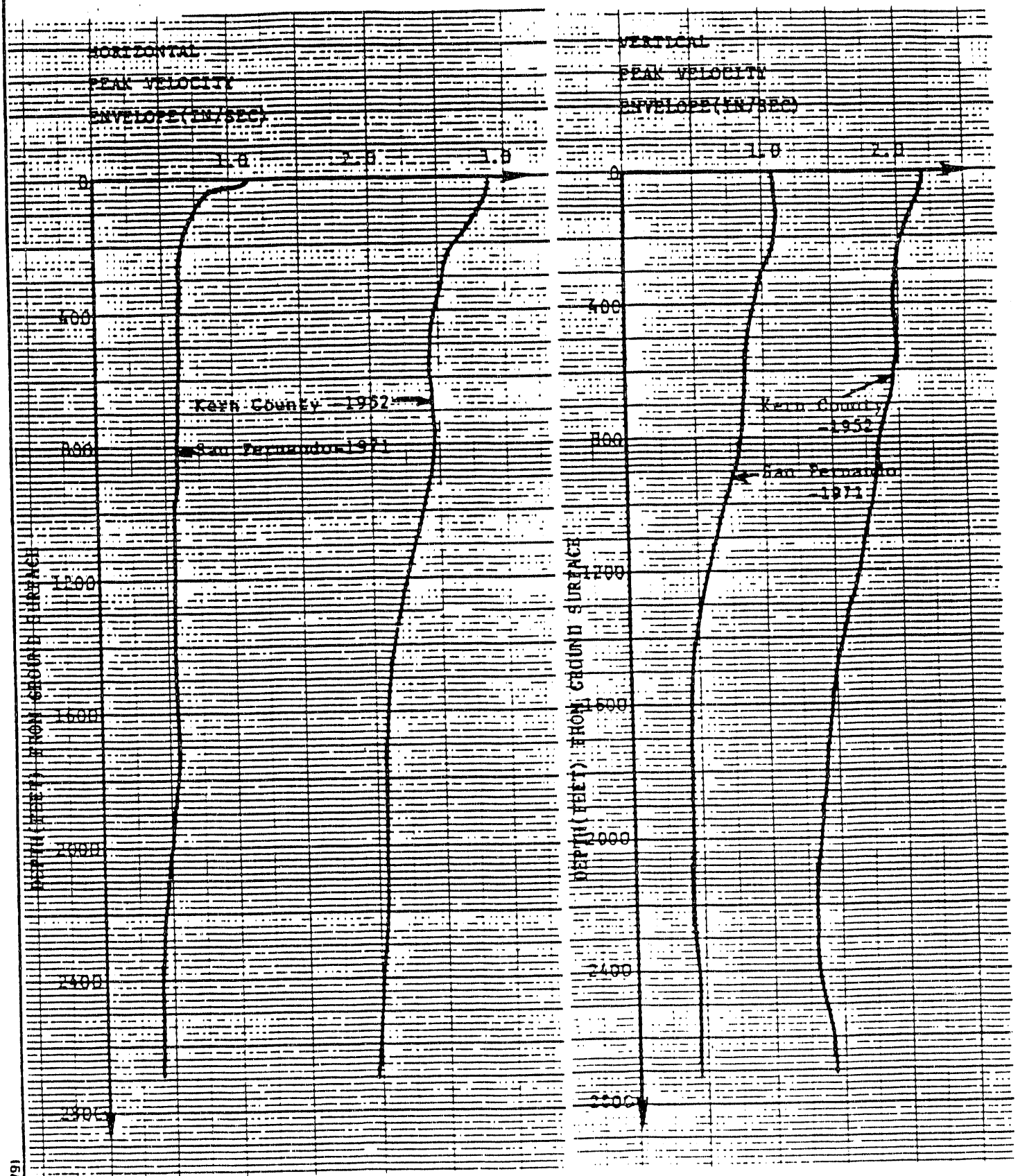


FIGURE 4-7b PEAK VELOCITY ENVELOPES

MAX. ACCELERATION 0.05g

FOR INFORMATION ONLY

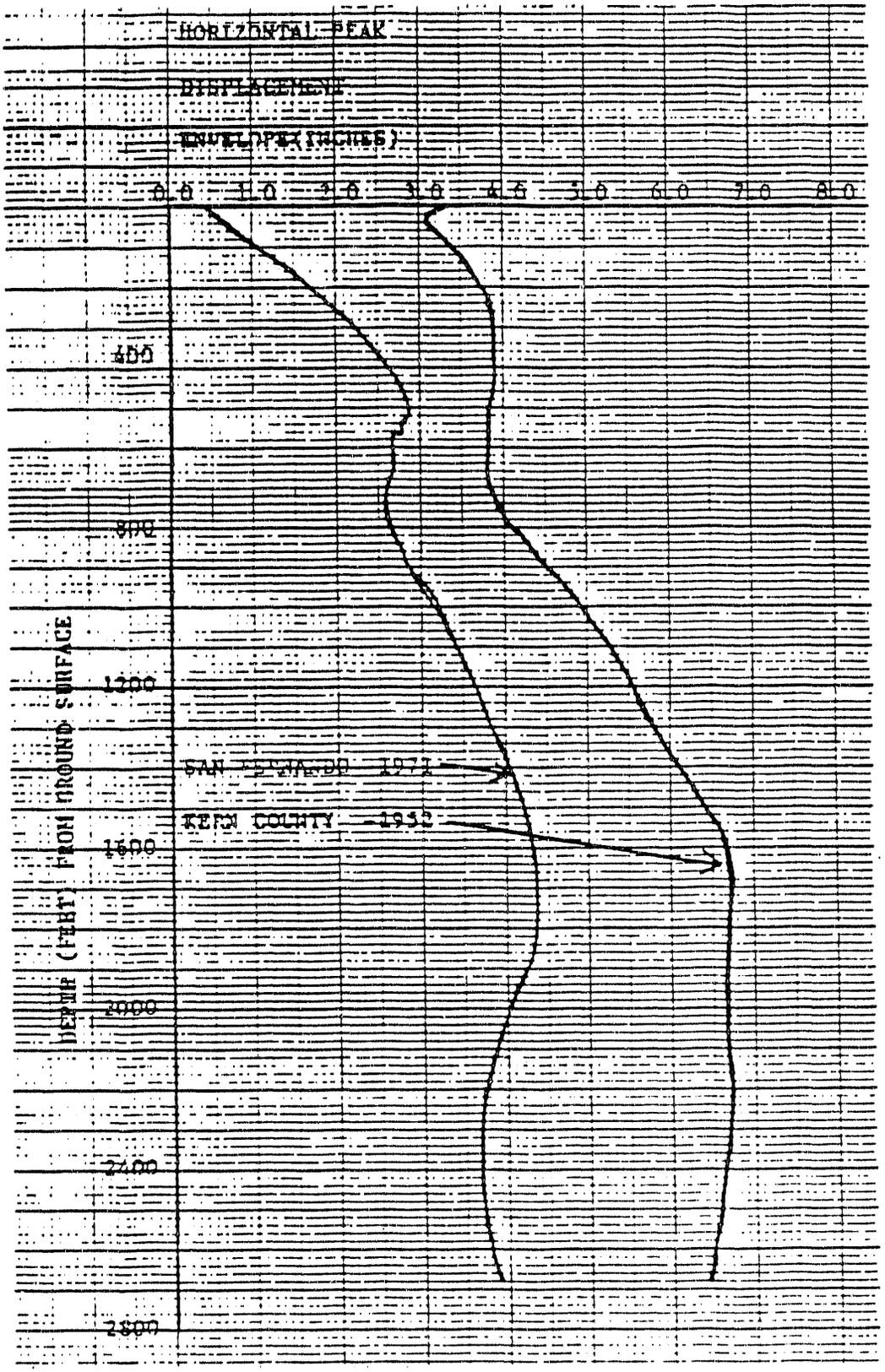


FIGURE 4-8 PEAK DISPLACEMENT ENVELOPES
MAX. ACCELERATION 0.10g

FOR INFORMATION ONLY

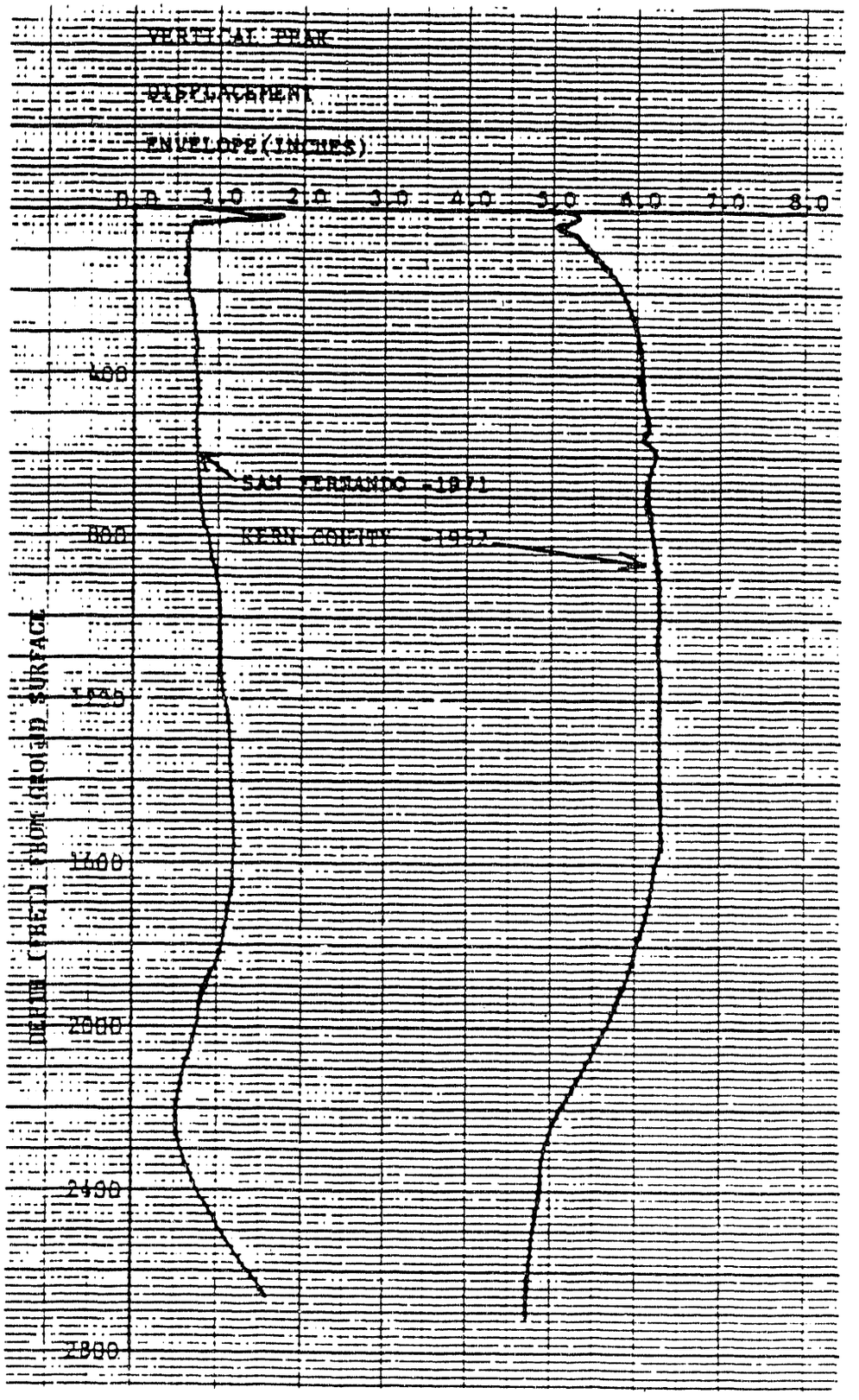


FIGURE 4-8 PEAK DISPLACEMENT ENVELOPES
MAX. ACCELERATION = 0.10g

FOR INFORMATION ONLY

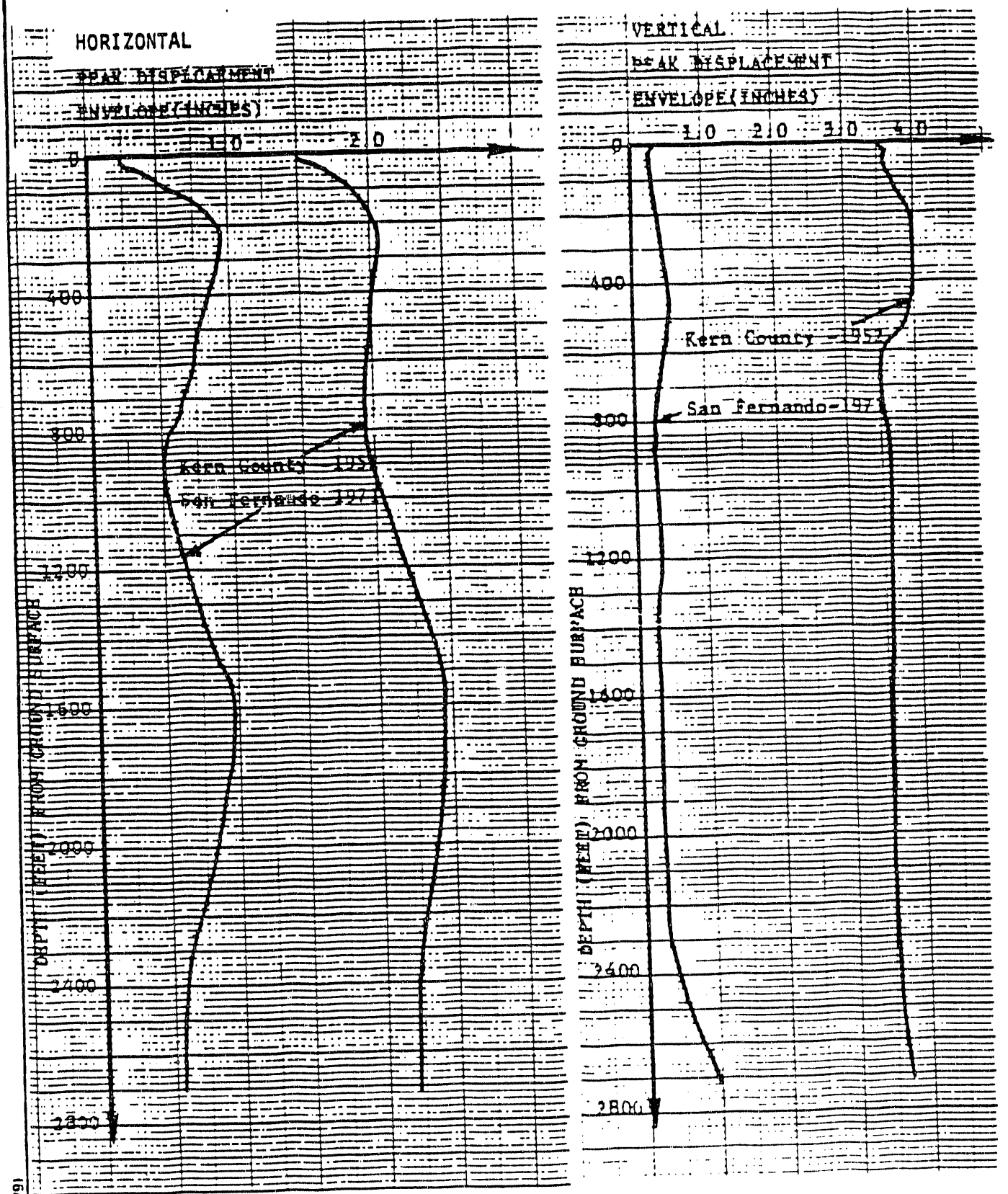
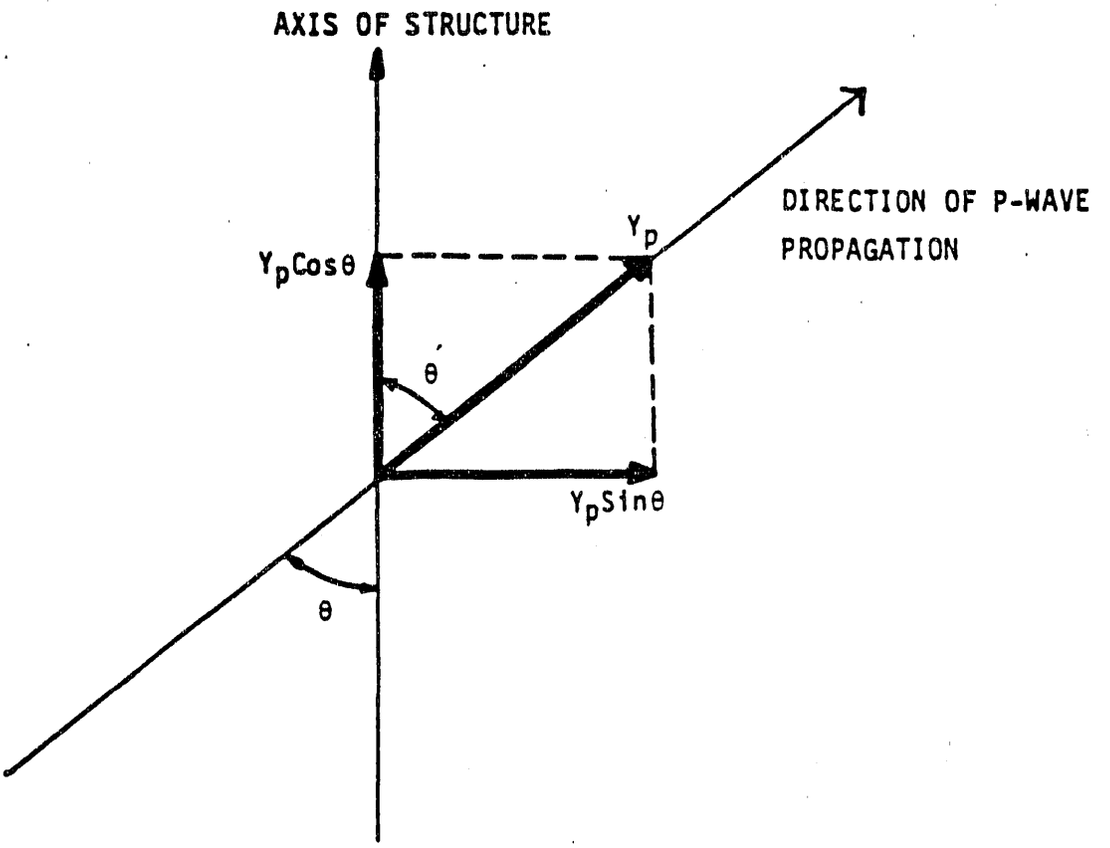


FIGURE 4-8c PEAK DISPLACEMENT ENVELOPES

MAX. ACCELERATION 0.05g

FOR INFORMATION ONLY



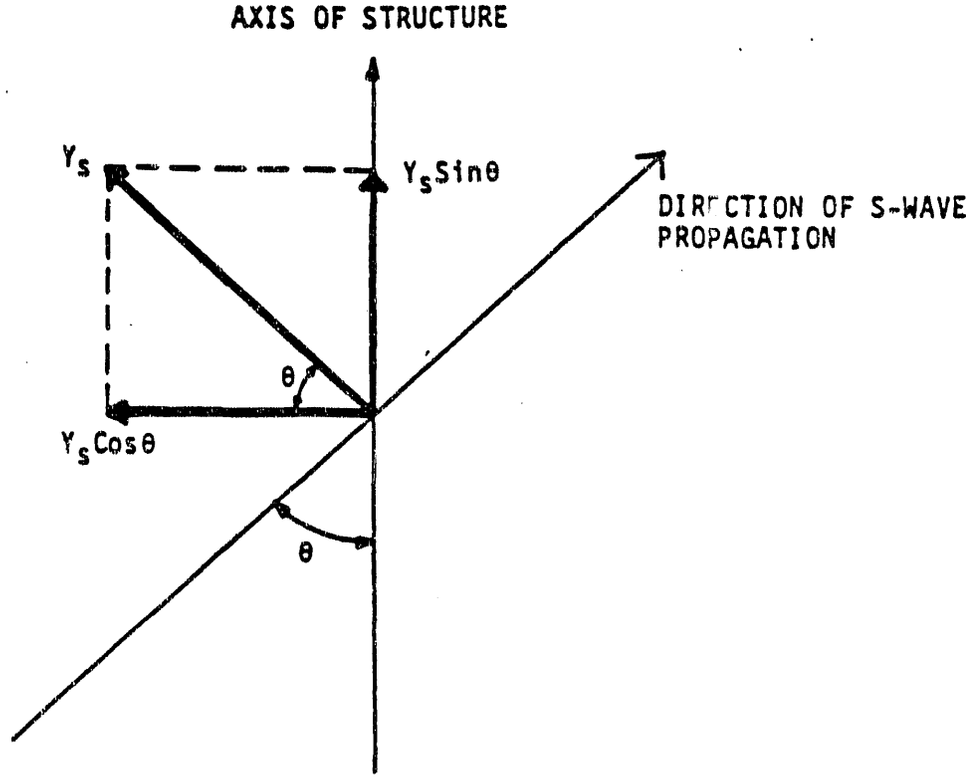
WHERE:

θ = INCIDENT ANGLE
Y_p = PARTICLE EXCITATION AMPLITUDE
C_p = WAVE VELOCITY
$Y_p Cos\theta$ = APPARENT COMPRESSIVE WAVE
$Y_p Sin\theta$ = APPARENT SHEAR WAVE

FIGURE 4-9 OBLIQUE IMPINGING P-WAVES

WIPP ENG-12 (1-79)

FOR INFORMATION ONLY



WHERE:

θ = INCIDENT ANGLE

Y_S = PARTICLE EXCITATION AMPLITUDE

C_S = WAVE VELOCITY

$Y_S Cos\theta$ = APPARENT SHEAR(SH) WAVE

$Y_S Sin\theta$ = APPARENT COMPRESSIVE(SV) WAVE

FIGURE 4-10 OBLIQUE IMPINGING S-WAVES

WIPP ENG-1 2 (1 79)

FOR INFORMATION ONLY

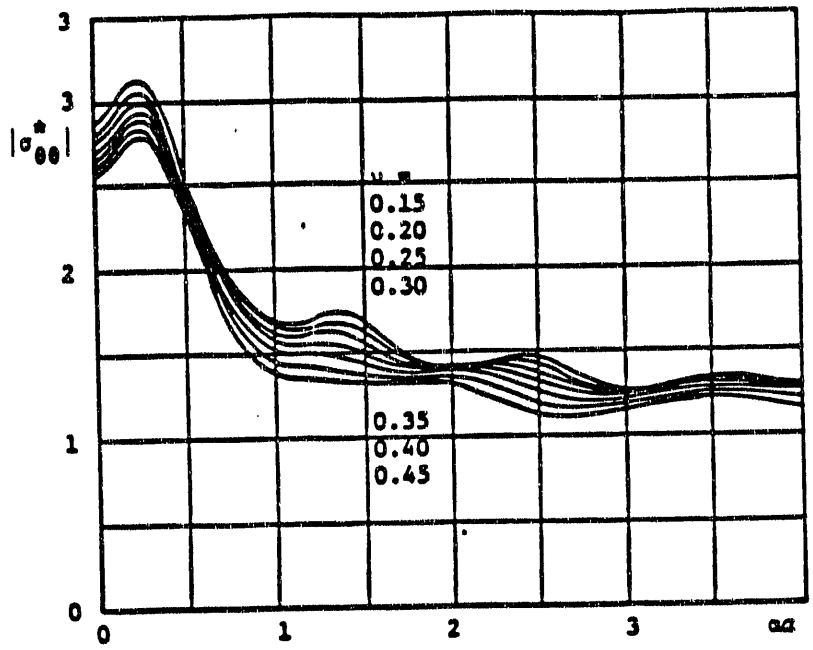


FIG. 4-11 *The Maximum Dynamic Stress Concentration Factors (Absolute Values of $\sigma_{\theta\theta}/\sigma_o$ at $\theta = \pi/2$)*

WHERE: $|\sigma_{\theta\theta}^*|$ = DYNAMIC HOOP STRESS CONCENTRATION FACTOR

$\sigma_{\theta\theta}$ = DYNAMIC HOOP STRESS AT A SPECIFIC LOCATION

σ_o = STATIC HOOP STRESS AT SAME SPECIFIC LOCATION

αa = COMPRESSIVE WAVE NUMBER

βa = SHEAR WAVE NUMBER

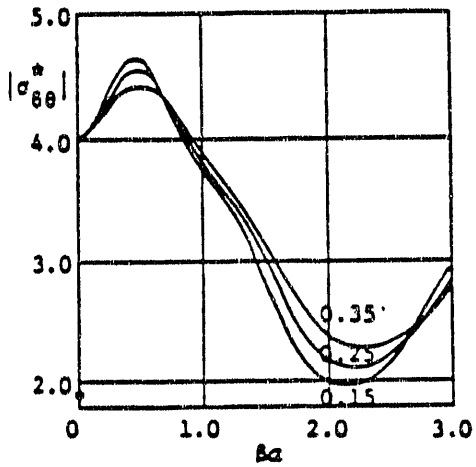


FIG. 4-12(a) $|\sigma^*_{\theta\theta}|$ *Versus βa for Various ν at $\theta = \pi/4$ (Cavity)*

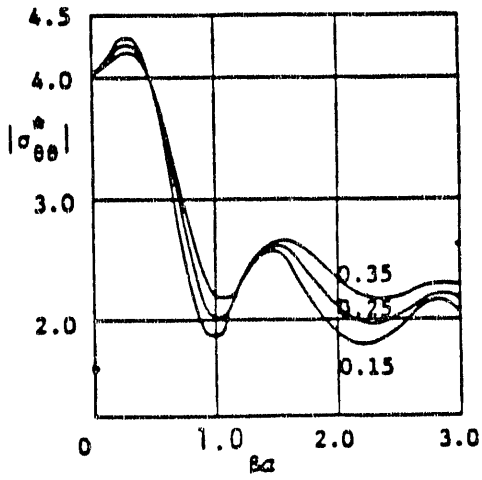


FIG. 4-12(b) $|\sigma^*_{\theta\theta}|$ *Versus βa for Various ν at $\theta = 3\pi/4$ (Cavity)*

FOR INFORMATION ONLY

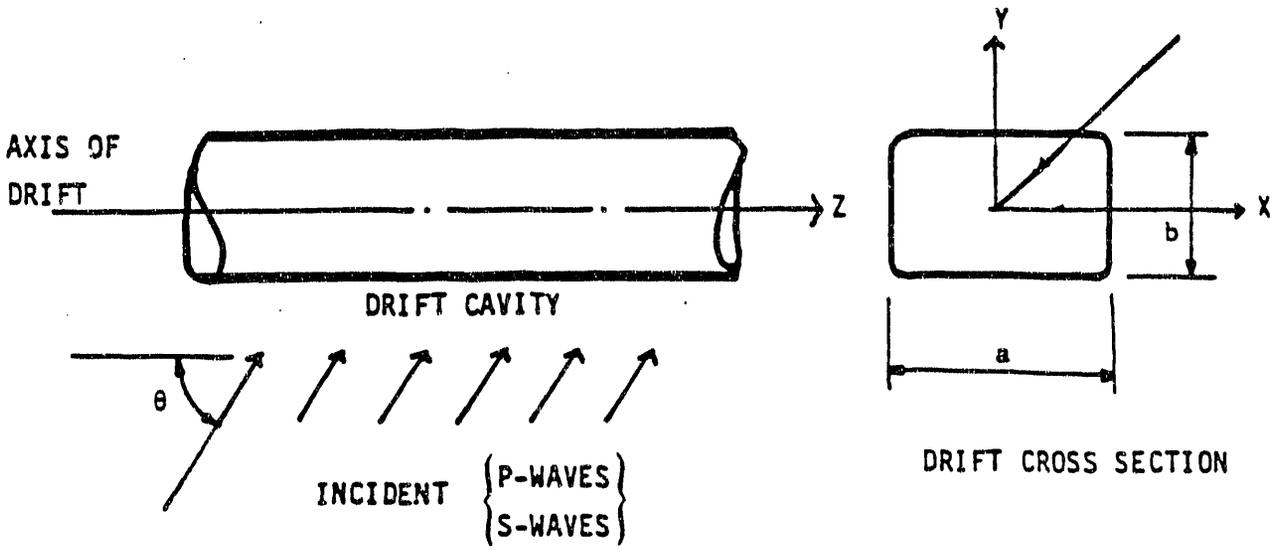


FIGURE 4-13 UNDERGROUND DRIFTS SUBJECT TO EARTHQUAKE WAVES

WIPP ENG-1 2 (1-79)

FOR INFORMATION ONLY

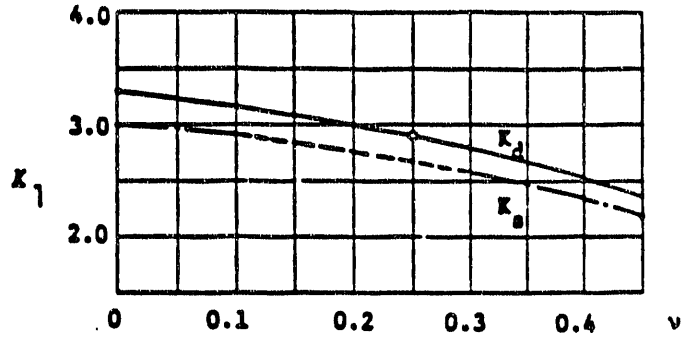


FIG. 4-14 *Dynamic and Static Stress Concentration Factors for Cylindrical Cavity Versus Poisson Ratio (Compressional Wave)*

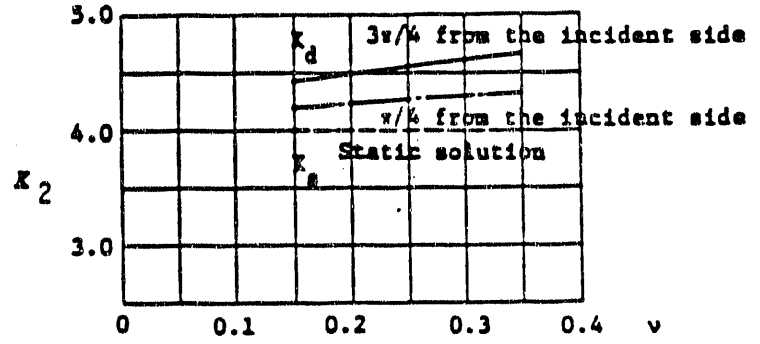


FIG. 4-15 *Dynamic and Static Stress Concentration Factors for Cylindrical Cavity Versus Poisson Ratio (Shear Wave)*

WIPP FIG-1.2 (1.79)

FOR INFORMATION ONLY

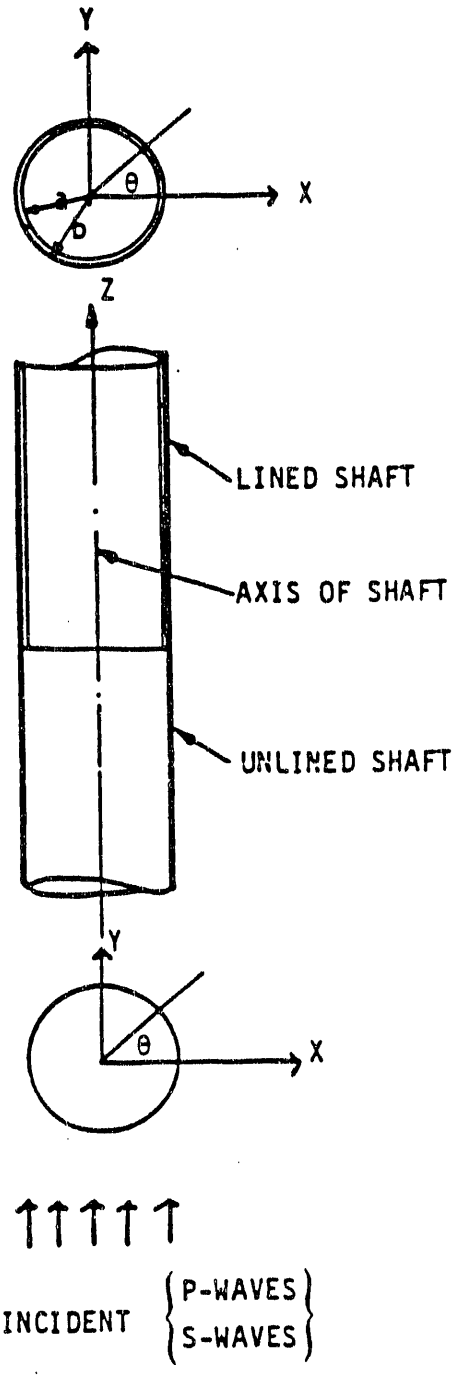


FIGURE 4-16 VERTICAL SHAFTS SUBJECT TO EARTHQUAKE WAVES

FOR INFORMATION ONLY

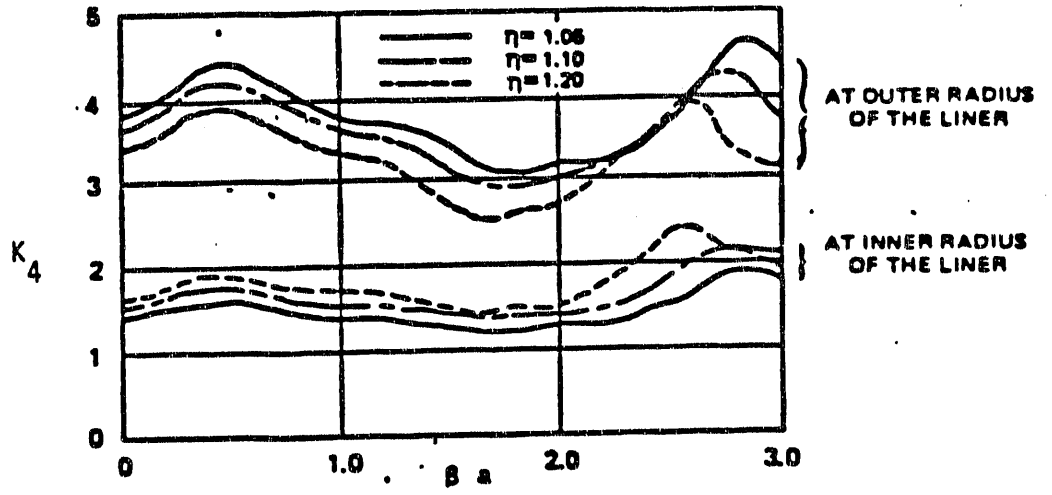


FIG. 4-17 MAXIMUM DIMENSIONLESS TANGENTIAL STRESSES VERSUS β a AND VARIOUS η

WHERE:

βa = SHEAR WAVE NUMBER

η = b/a RATIO OF OUTER RADIUS TO INNER RADIUS OF LINERS

FOR INFORMATION ONLY

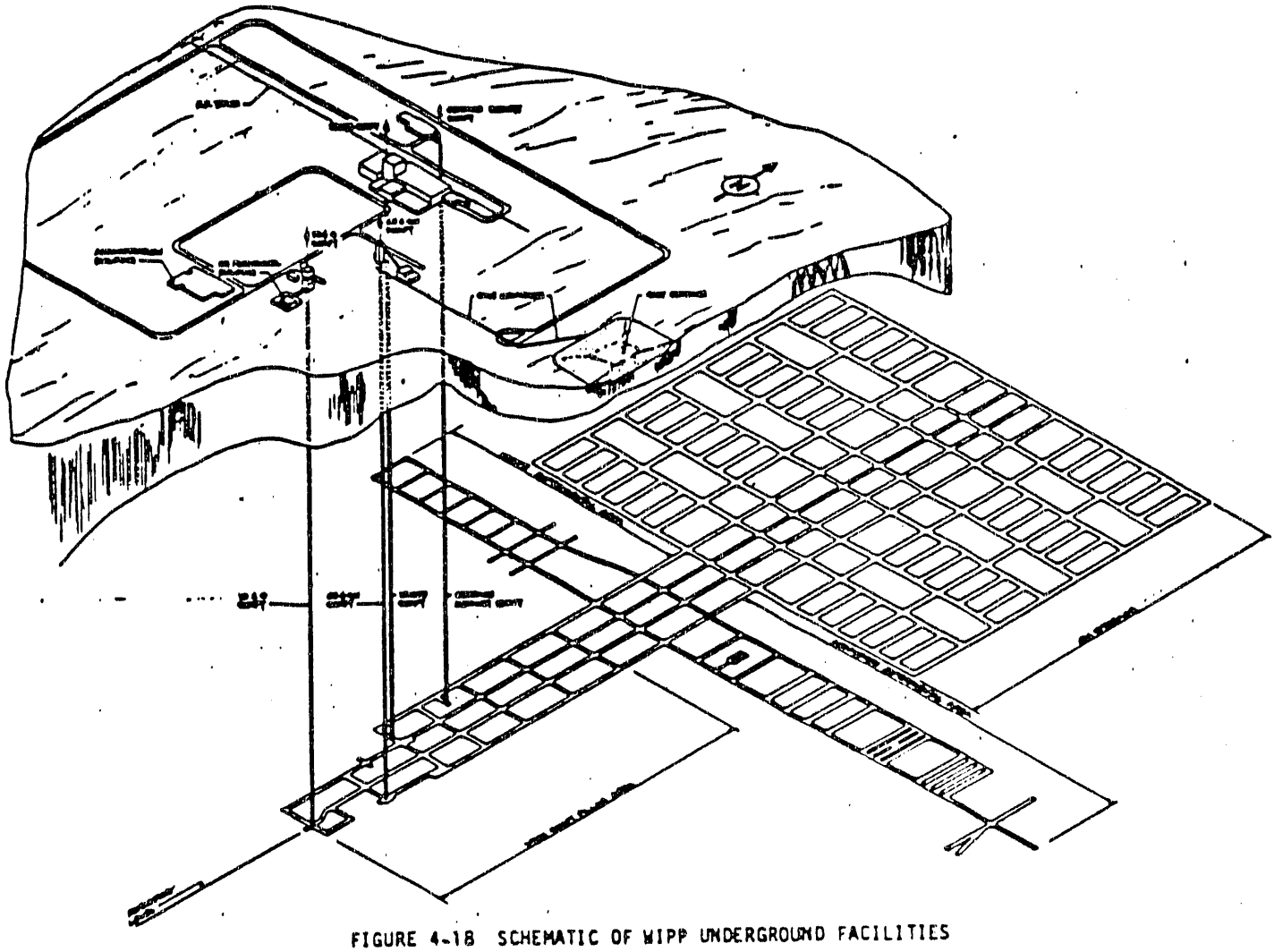
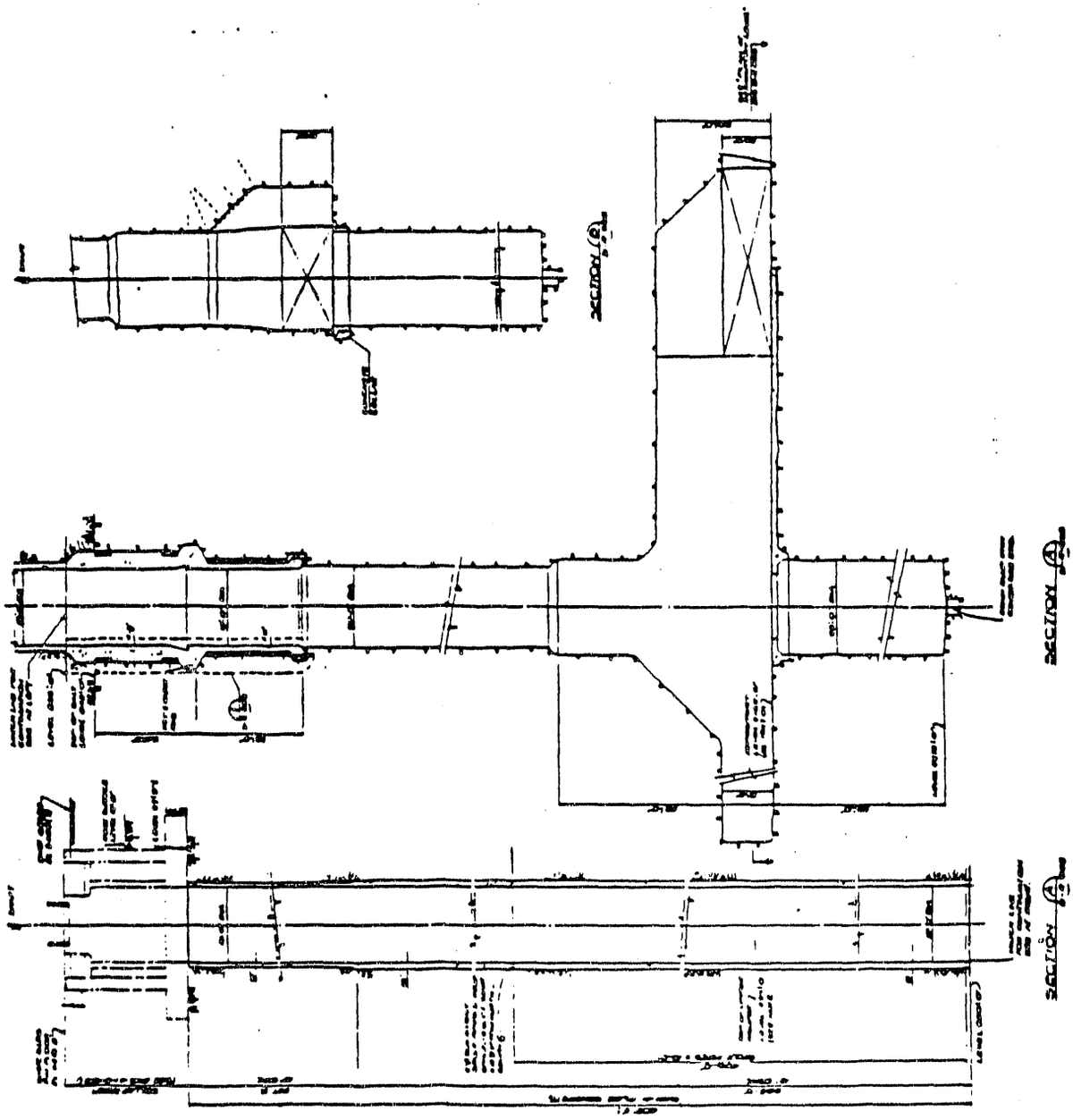


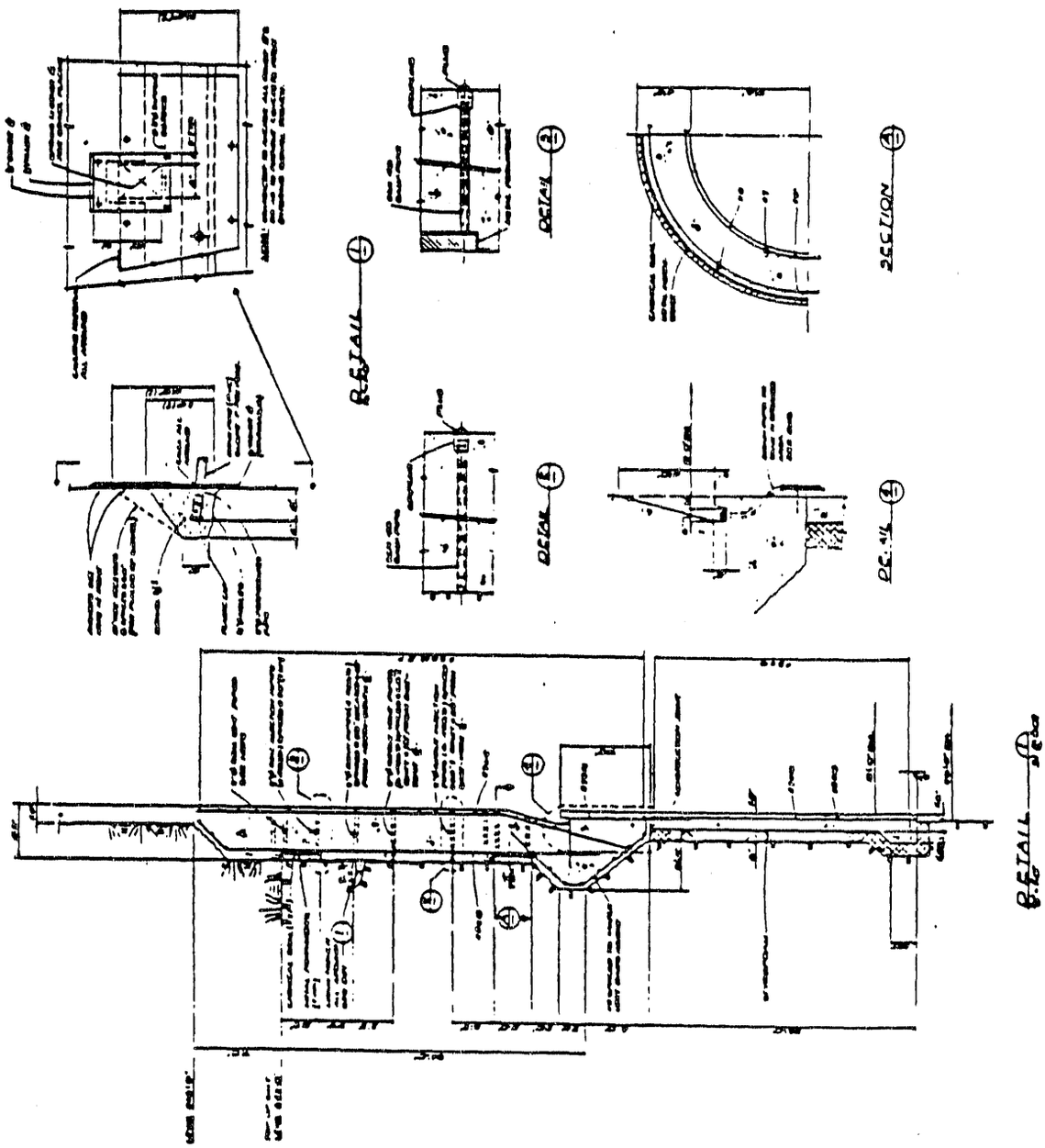
FIGURE 4-18 SCHEMATIC OF WIPP UNDERGROUND FACILITIES

R INFORMATION ONLY



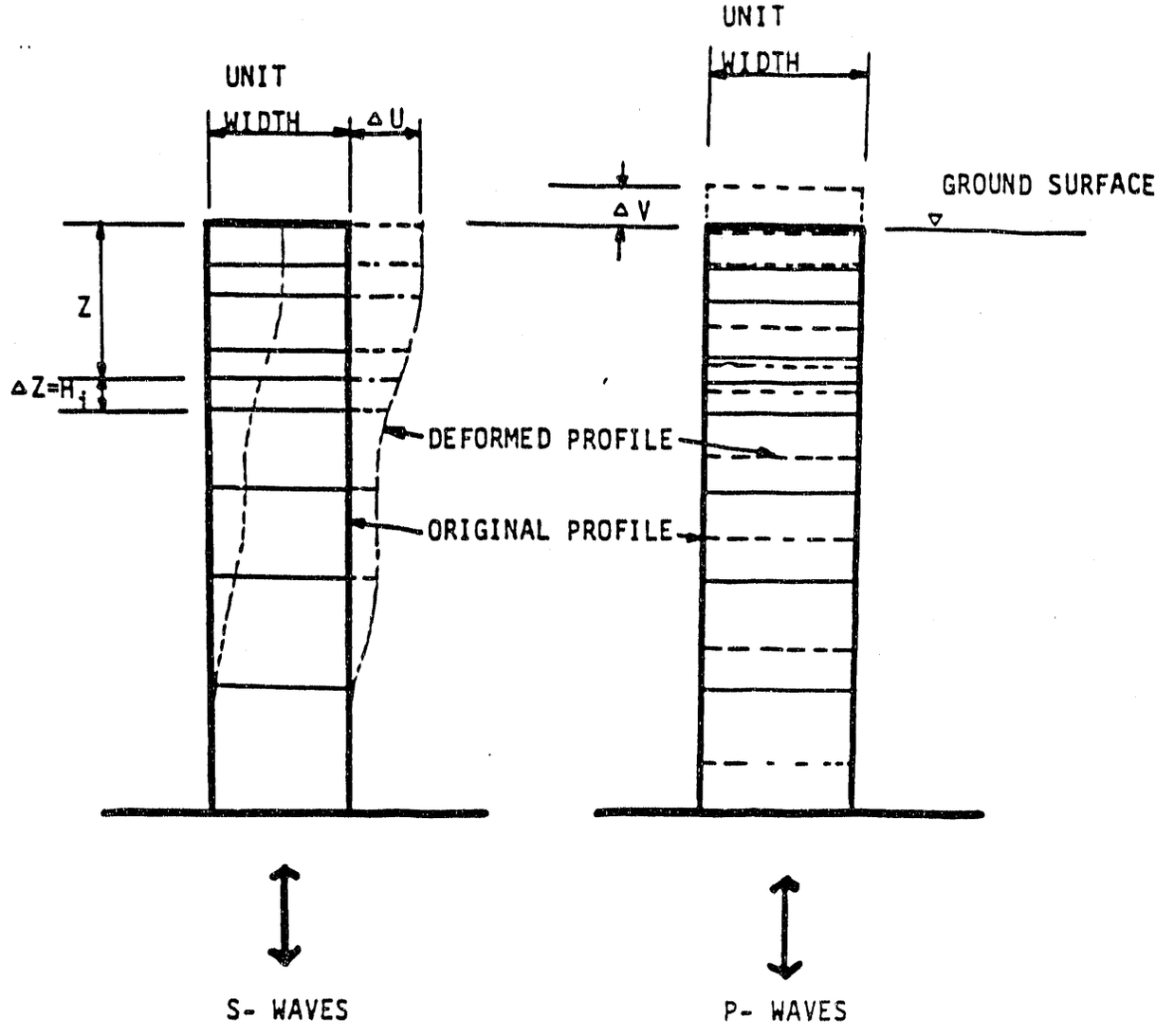
FOR INFORMATION ONLY

FIGURE 4-19 DETAILS OF THE WASTE SHAFT



FOR INFORMATION ONLY

FIGURE 4-19 (Cont'd)

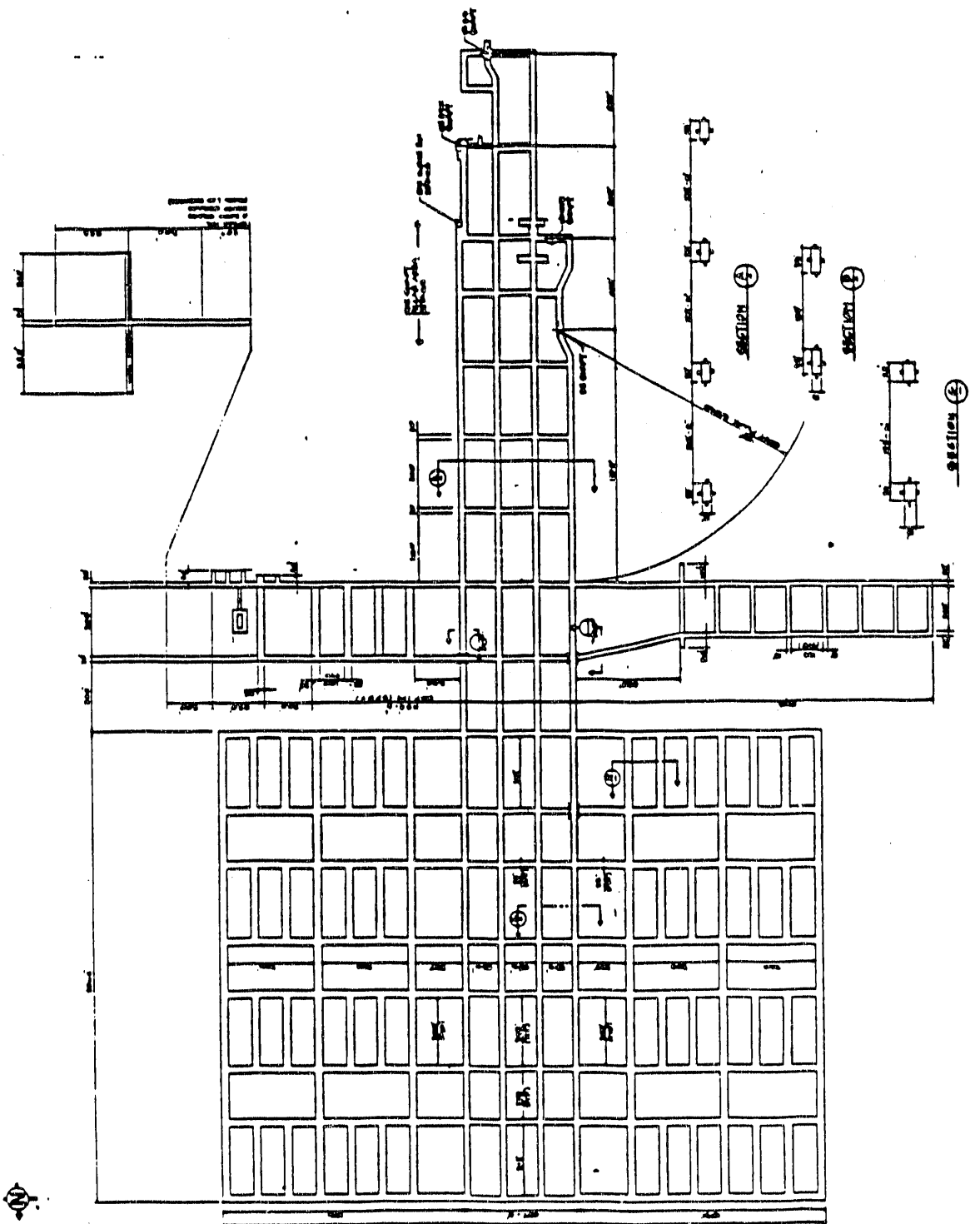


(a) HORIZONTAL EARTHQUAKE (b) VERTICAL EARTHQUAKE

FIGURE 4-20 ORIGINAL AND DEFORMED STRATIGRAPHIC COLUMN

FOR INFORMATION ONLY

WIPP ENG-1.2 (1 79)



FOR INFORMATION ONLY

FIGURE 4-21 SCHEMATIC OF TYPICAL SECTION OF UNDERGROUND DRIFTS

WIPP ENG-1 2 (1 79)

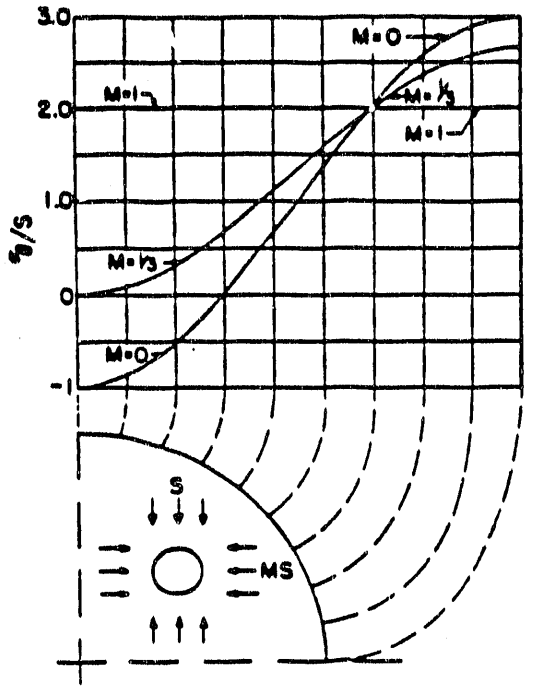


FIG. 4-22 *Boundary stress concentration for circular tunnels*

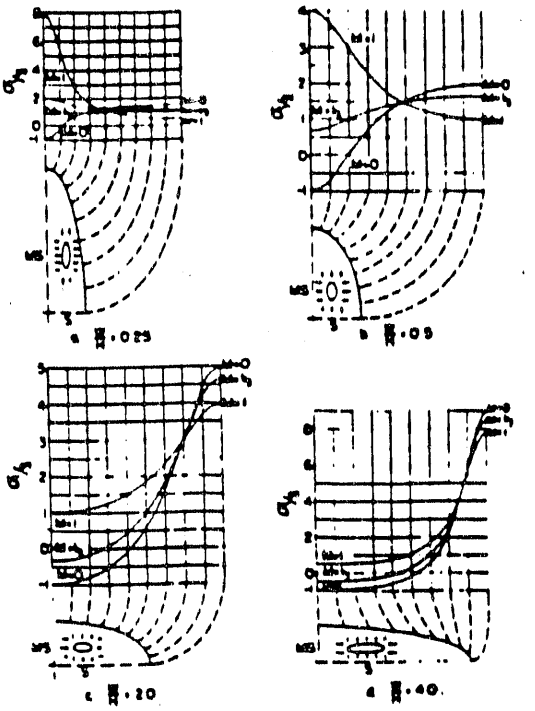


FIG. 4-23 *Boundary stress concentration for elliptical tunnels*

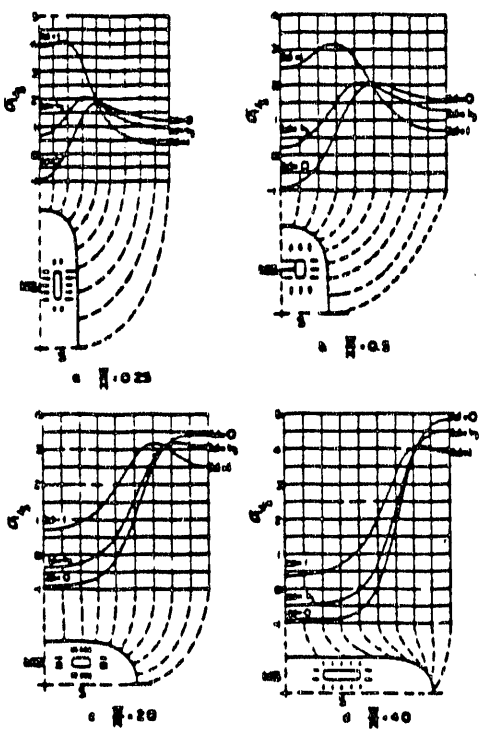


FIG. 4-24 *Boundary stress concentration for ovaloidal tunnels*

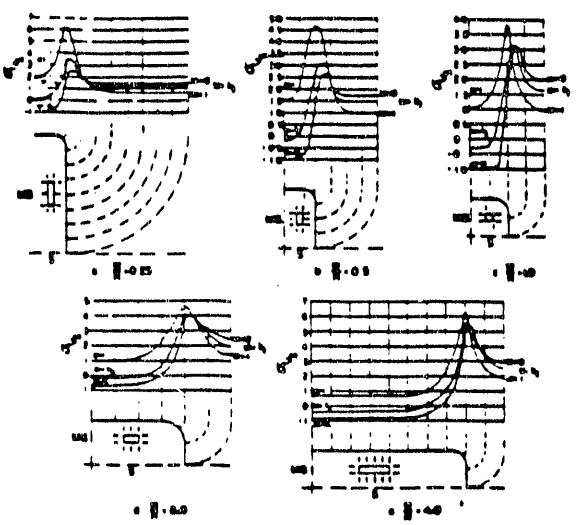


FIG. 4-25 *Boundary stress concentration for rectangular tunnels with rounded corners. Ratio of fillet radius to short dimension = 1/6*

FOR INFORMATION ONLY

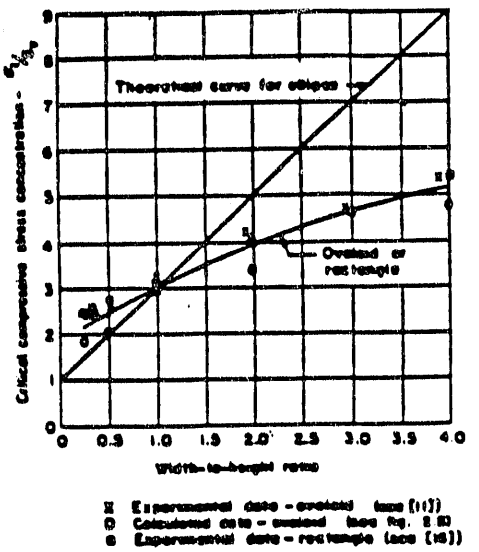


FIG. 4-26 *Critical compressive stress concentration for tunnels of various cross sections, unidirectional stress field.* $S_h = S_v$, $S_h = 0$

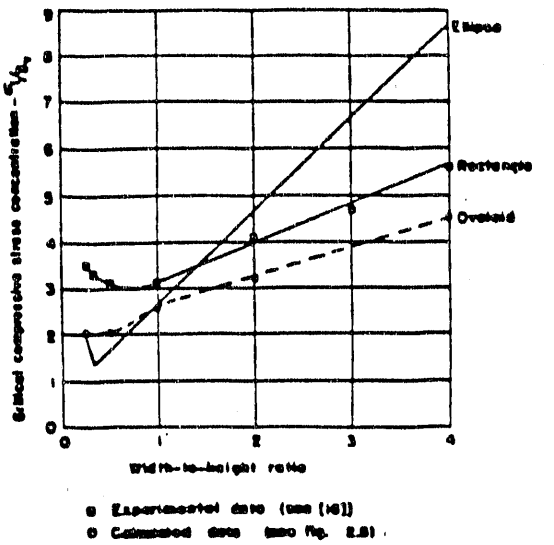


FIG. 4-27 *Critical compressive stress concentration for tunnels of various cross sections, two-directional stress field.* $S_h = 1/3\ S_v$

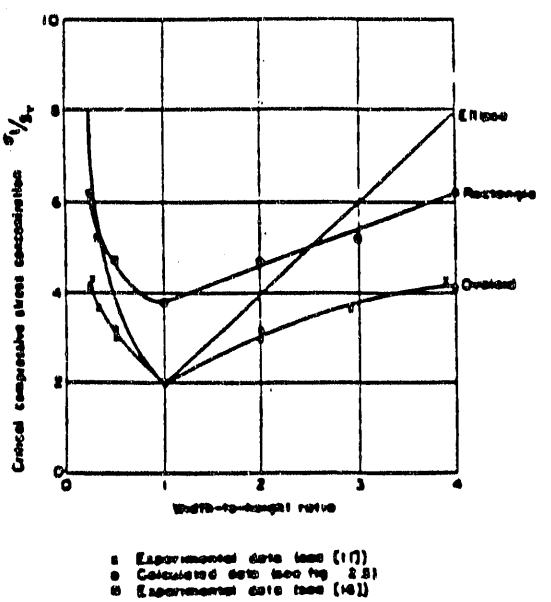


FIG. 4-28 *Critical compressive stress concentration for tunnels of various cross sections, hydrostatic stress field.* $S_h = S_v$

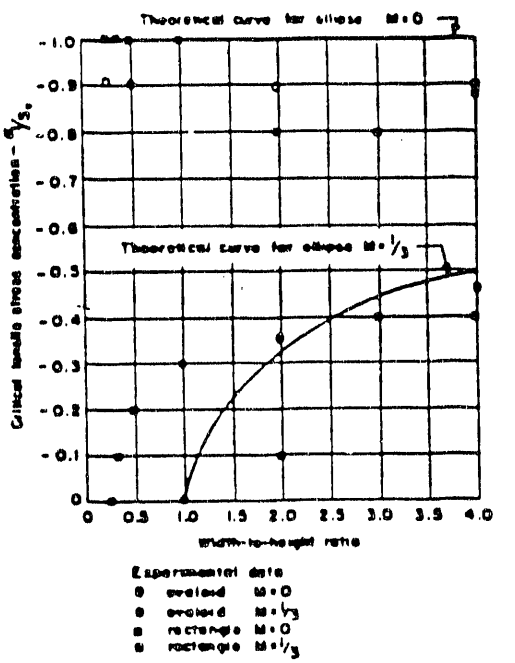


FIG. 4-29 *Critical tensile stress concentration for tunnels of various cross sections, two types of stress fields.* $M = 0$, $M = 1/3$

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C Fitzgabriele 1.22.82

CALC. NO.	CS-41-D-006
DESIGN CLASS	II
SHEET NO.	1 OF 6

NUCLEAR FUEL OPERATIONS

CALCULATION SHEET

BECHTEL JOB 12484
DEPARTMENT OF ENERGY
WASTE ISOLATION PILOT PLANT

STATEMENT OF PROBLEM
ANALYSIS OF WIND LOADS FOR WASTE HANDLING BUILDING

SAR CHECKED ✓ SAR CHANGE REQ'D N/A SAR CHANGE REQUEST MADE ______

SOURCE OF DATA
1 ANSI A58.1-1972
2
3

SOURCE OF FORMULAS & REFERENCES
1
2

TITLE OF COMPUTER PROGRAM(S) USED

COMPUTER PROGRAM(S) VERIFICATION

TYPE OF CALCULATION PRELIM. ______ FINAL ✓ SUPERSEDES CALC. NO. ______

SUPERSEDED ______

REFERENCES P & ID/DWG. NO./REV. NO. ENTITLED

FOR INFORMATION ONLY

REV.	DESCRIPTION	BY	DATE	CHK'D	DATE	APPR'D	DATE
△							
△							
△	ISSUED FOR TITLE II	CD	9.22.82	[illegible]	9.29.82	[illegible]	11/10/82

RECORD OF ISSUES

C Delaabreele 1.22.82

JOB NO.	12484
CALC. NO.	CS-91-0-006
SHEET NO.	2 OF 6
REV. NO.	0
CHECKED BY	G.K DATE 9-82

NUCLEAR FUEL OPERATIONS

CALCULATION SHEET

NOTE: ALL ELEVATIONS SHOWN ARE APPROXIMATE TAS

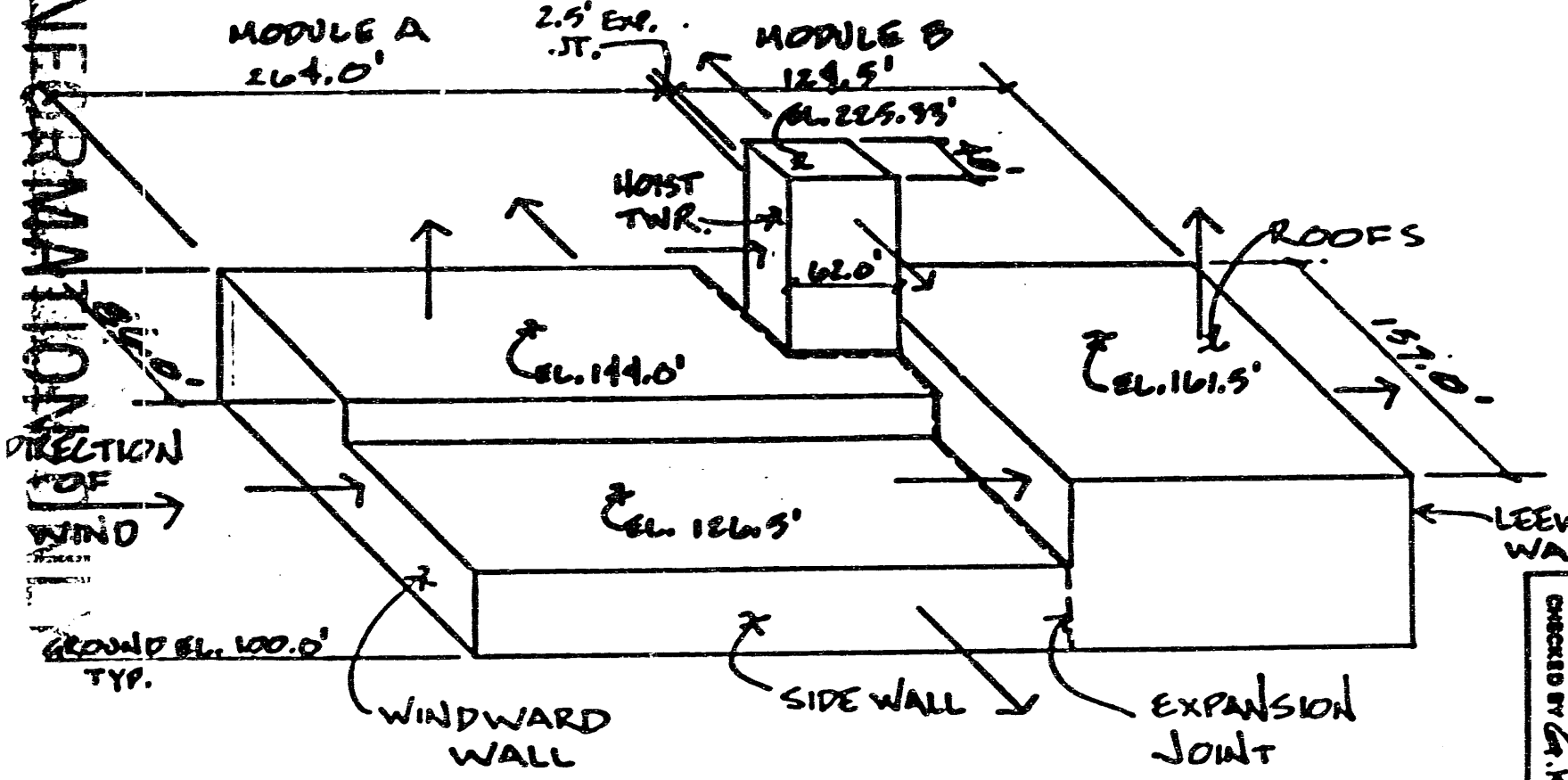
FOR INFORMATION ONLY

NOTE: ALL ELEVATIONS SHOWN ARE APPROXIMATE T.O.S.

Height of Wall / Least Width: MODULE A = 44.0'/171.0' = 0.26 < 2.5

MODULE B = 61.5'/124.5' = 0.49 < 2.5

HOIST TOWER = 125.33'/40.0' = 3.13 > 2.5



WASTE HANDLING BLDG

E-W WIND

CALCULATION SHEET

NUCLEAR FUEL OPERATIONS

C. Blakeslee 1.22.82

JOB NO. 12484	
CALC. NO. CS-41-D-006	
SHEET NO. 3 OF 6	
REV. NO. 0	
CHECKED BY G.K DATE 9-82	

C. Orlando 1.22.82

JOB NO.	12484
CALC. NO.	C9-91-D-006
SHEET NO.	4 OF 6
REV. NO.	0
CHECKED BY	G.K DATE 1-82

NUCLEAR FUEL OPERATIONS

CALCULATION SHEET

WIND LOADS:

WIND SPEED = 110 MPH DESIGN BASIS D-76-D-01 REV.7 # 3.1.7

DESIGN WIND PRESSURE FOR SURFACE FACILITIES - EXPOSURE C:

WIND SPEED	110 MPH		
WIND PRESSURE	q_p (PSF)	q_p (PSF)	q_m (PSF)
LESS THAN 30'	32	46	31
30' TO 50'	43	49	34
50' TO 75'	48	55	38
75' TO 125'	53	59	44

ANSI A58.1-72 TABLES 5, 6 & 12

EXTERNAL PRESSURE COEFFICIENTS - ANCI A58.1-72 TABLE 7 & # 6.5.3.2.1

OVERALL BLDG. / MODULE A / MODULE B:

WINDWARD WALL	$C_p = 0.8$
LEEWARD WALL	$C_p = -0.5$
SIDE WALLS	$C_p = -0.7$
ROOF	$C_p = -0.7$

HOIST TOWER:

WINDWARD WALL	$C_p = 0.8$
LEEWARD WALL	$C_p = -0.6$
SIDE WALLS	$C_p = -0.7$
ROOF	$C_p = -0.8$

INTERNAL PRESSURE COEFFICIENTS - ANSI A58.1-72 TABLE 11

ASSUME ALL OPENINGS (WINDOWS, DOORS, LOUVERS) WILL BE DESIGNED TO RESIST $P = q_p C_p - q_m C_{pi}$ $\therefore n = 0$

$C_{pi} = \pm 0.3$

FOR INFORMATION ONLY

[illegible] 9.22.82

JOB NO.	12686
CALC. NO.	CS-41-D-006
SHEET NO.	5 OF 6
REV. NO.	0
CHECKED BY	G.K DATE 9.82

NUCLEAR FUEL OPERATIONS

CALCULATION SHEET

DESIGN WIND PRESSURES

OVERALL BLDG., MODULE A & MODULE B WIND IN N-S OR E-W DIRECTION

DESIGN WIND PRESS. HT. \ WALL	P = $q_F C_p - q_H C_{pi}$ (PSF)			
	WINDWARD	LEEWARD	SIDE	ROOF
LESS THAN 30'	34.9	-25.3	-31.7	-31.7
30' TO 50'	44.6	-31.7	-40.3	-40.3
50' TO 75'	49.8	-35.4	-45.0	-45.0
75' TO 125'	55.6	-39.7	-50.3	-50.3

(FOR MODULES A & B DESIGN PRESSURE WILL BE 0.0 BELOW EXP. JT.)

HOIST TOWER WIND IN N-S OR E-W DIRECTION

DESIGN WIND PRESS. HT \ WALL	P = $q_F C_p - q_H C_{pi}$ (PSF)			
	WINDWARD	LEEWARD	SIDE	ROOF
LESS THAN 30'	34.9	-28.5	-31.7	-34.9
30' TO 50'	44.6	-36.0	-40.3	-44.6
50' TO 75'	49.8	-40.2	-45.0	-49.8
75' TO 125'	55.6	-45.0	-50.3	-55.6

GIRTS, PURLINS & SPANDRELS W/ TRIBUTARY AREA < 200 SF

DESIGN WIND PRESS. HT \ WALL	P = $q_F C_p - q_H C_{pi}$ (PSF)	
	WINDWARD	SIDES & ROOF
LESS THAN 30'	46.1	-41.5
30' TO 50'	49.4	-44.5
50' TO 75'	53.8	-48.5
75' TO 125'	60.4	-54.5

LOCAL PEAK EXTERNAL PRESSURES

C_p (RIDGES & EAVES) = -2.4 ANSI A58.1-72 TABLE 10

C_p (CORNERS-ROOF) = -5.0

C_p (CORNERS-WALL) = -2.0

DESIGN WIND PRESS. HT \ SECTION	P_1 = -2.4 q_F	P_2 = -5.0 q_F	P_3 = -2.0 q_F
	EAVES	ROOF CNRS.	WALL CNRS.
LESS THAN 30'	-76.8	-160.0	-64.0
30' TO 50'	-103.2	-215.0	-86.0
50' TO 75'	-115.2	-240.0	-96.0
75' TO 125'	[illegible]	[illegible]	-106.0

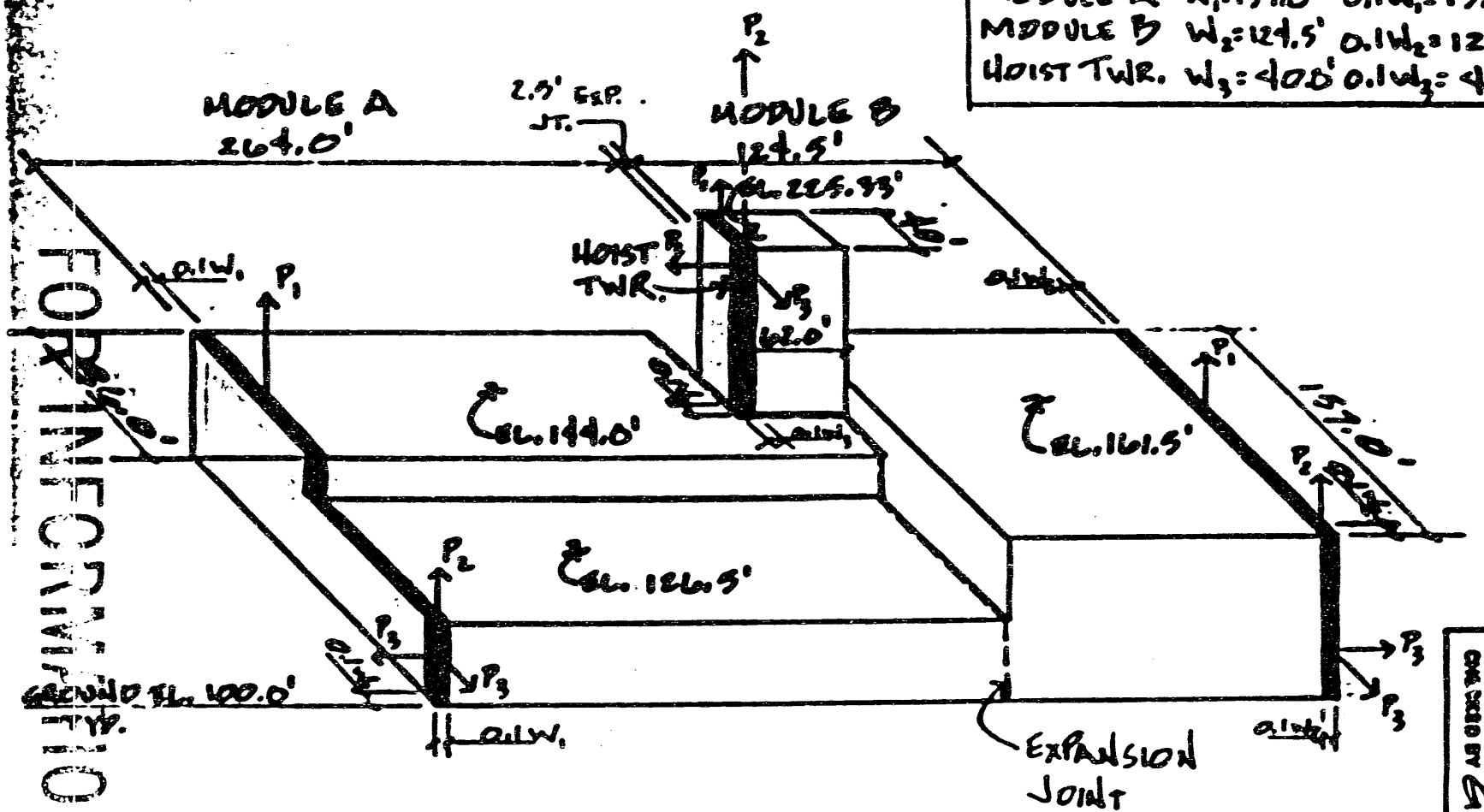
FOR INFORMATION ONLY

NOTE: ALL ELEVATIONS SHOWN ARE APPROXIMATE TOS.

NUCLEAR FUEL OPERATIONS

CALCULATION SHEET

LEAST WIDTHS		
MODULE A	W_1 = 157.0'	$0.1W_1$ = 15.7'
MODULE B	W_2 = 124.5'	$0.1W_2$ = 12.45'
HOIST TWR.	W_3 = 40.0'	$0.1W_3$ = 4.0'



WASTE HANDLING BUILDING

LOCAL PEAK EXTERNAL PRESSURES

JOB NO.	12000
CALC. NO.	03-41-0006
SHEET NO.	6 OF 6
REV. NO.	0
ORIGINATED BY	G. KRAFT 9-82

C. Pittsville 1.22.82

FOR INFORMATION ONLY

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entitled CALC CS-41-S-006 Rev 0

which were forwarded to Micrographics on Microfilm Service Order number 126202

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Signed _____ Camera Operator Date 11-12-92 Camera Type TDC

FOR INFORMATION ONLY

BLDG NO: 11A FD
HVAC. 3-17-83

C DeGabriele 7.22.82

CALC. NO.	CS-41-0-007
DESIGN CLASS	II
SHEET NO.	1 OF 8

NUCLEAR FUEL OPERATIONS

CALCULATION SHEET

BECHTEL JOB 13484
DEPARTMENT OF ENERGY
WASTE ISOLATION PILOT PLANT

STATEMENT OF PROBLEM

ANALYSIS OF TORNADO LOADS FOR WASTE HANDLING BLDG.

SAR CHECKED ✓ SAR CHANGE REQ'D. N/A SAR CHANGE REQUEST MADE _____

SOURCE OF DATA
1. DESIGN BASIS D-76-D-03 REV. 6
2. 12484-SK-41-G-926 REV. A
3. 12484-SK-41-G-927 REV. A

SOURCE OF FORMULAS & REFERENCES
1. ANSI A58.1-1972
2. BC-TOP-3-A

TITLE OF COMPUTER PROGRAM(S) USED

COMPUTER PROGRAM(S) VERIFICATION

TYPE OF CALCULATION: PRELIM. _____ FINAL ✓ SUPERSEDES CALC. NO. _____

SUPERSEDED _____

REFERENCES	P & ID/DWG. NO./REV. NO.	ENTITLED

REV.	DESCRIPTION	BY	DATE	CHK'D	DATE	APP'D	DATE
A	ISSUED FOR TITLE II	QDM	9.17.82	G.KM	9.29.82	OW	11/30/83

RECORD OF ISSUES

FOR INFORMATION ONLY

C. DiGabriele 7.22.82

JOB NO.	12484
CALC. NO.	CS-41-D-007
SHEET NO.	2 OF 8
REV. NO.	0
CHECKED BY	E.I.K DATE 9.82

NUCLEAR FUEL OPERATIONS

CALCULATION SHEET

TORNADO LOADINGS :

DESIGN PARAMETERS DESIGN BASIS D-76-D-03 REV. 6 P 3.1

MAX. WIND SPEED	183 MPH
TRANSLATIONAL VELOCITY	41 MPH
TANGENTIAL VELOCITY	124 MPH
PRESSURE DROP	0.5 PSI
RATE OF PRESSURE DROP	0.09 PSI/SEC
RETURN PERIOD	1×10^6 YRS
RADIUS OF MAXIMUM WIND	325 FT

VELOCITY PRESSURE AT RADIUS OF MAXIMUM WIND

$P_{MAX} = 0.00256\, V^2_{MAX}$ BC-TOP-3-A P 3.5.1.1 EQ. 3-8

$P_{MAX} = 0.00256\,(183)^2$

$P_{MAX} = 85.73$ PSF

OVERALL BLDG. E-W TORNADO WIND

$L = 157.0'$ $L/R_M = 157/325 = 0.48$

$C_S = 0.79$ BC-TOP-3-A FIG. 3-3

$q_M = q_P = C_S P_{MAX}$ BC-TOP-3-A EQ. 3-7

$q_M = q_P = 0.79\,(85.73)$ SEE NOTE!

$q_M = q_P = 67.72$ PSF

N-S TORNADO WIND

$L = 391.0'$ $L/R_M = 391.0/325 = 1.20$

$C_S = 0.58$ BC-TOP-3-A FIG. 3-3

$q_M = q_P = 0.58\,(85.73)$

$q_M = q_P = 49.72$ PSF

NOTE: ASSUME RELATIVE UNIFORM SIZE AND DISTRIBUTION OF OPENINGS AROUND BUILDING PERIMETER.

FOR INFORMATION ONLY

C. DiGabriele 7.22.82

JOB NO.	12484
CALC. NO.	CS-41-O-007
SHEET NO.	3 OF 8
REV. NO.	O
CHECKED BY	G.K DATE 7-82

NUCLEAR FUEL OPERATIONS

CALCULATION SHEET

MODULE A N-S TORNADO WIND

$L = 264.0'$ $L/R_M = 264/325 = 0.81$

$C_s = 0.68$ BC-TOP-3-A FIG. 3-3

$q_M = q_F = 0.68\ (85.7\#)$

$q_M = q_F = 58.3$ PSF

E-W TORNADO WIND

SAME AS OVERALL BLDG.

MODULE B N-S TORNADO WIND

$L = 124.5'$ $L/R_M = 124.5/325 = 0.38$

$C_s = 0.83$ BC-TOP-3-A FIG. 3-3

$q_M = q_F = 0.83\ (85.7\#)$

$q_M = q_F = 71.16$ PSF

E-W TORNADO WIND

SAME AS OVERALL BLDG.

HOIST TOWER N-S TORNADO WIND

$L = 62.0'$ $L/R_M = 62/325 = 0.19$

$C_s = 0.91$ BC-TOP-3-A FIG. 3-3

$q_M = q_F = 0.91\ (85.7\#)$

$q_M = q_F = 78.01$ PSF

E-W TORNADO WIND

$L = 40.0'$ $L/R_M = 40/325 = 0.12$

BC-TOP-3-A FIG. 3-3

$C_s = 0.94$

$q_M = q_F = 0.94\ (85.7\#)$

$q_M = q_F = 80.59$ PSF

FOR INFORMATION ONLY

C. DeGabriele 7.22.82

JOB NO.	12484
CALC. NO.	CS-41-D-007
SHEET NO.	4 OF 8
REV. NO.	0
CHECKED BY	E.K DATE 9-82

NUCLEAR FUEL OPERATIONS

CALCULATION SHEET

EXTERNAL PRESSURE COEFFICIENTS ANSI A58.1-72 TABLE 7 & SP 5.3.2.1

OVERALL BLDG / MODULE A / MODULE B:	WINDWARD WALL	$C_p = 0.8$
	LEEWARD WALL	$C_p = -0.5$
	SIDEWALLS	$C_p = -0.7$
	ROOF	$C_p = -0.7$
HOIST TOWER:	WINDWARD WALL	$C_p = 0.8$
	LEEWARD WALL	$C_p = -0.6$
	SIDEWALLS	$C_p = -0.7$
	ROOF	$C_p = -0.8$

INTERNAL PRESSURE COEFFICIENTS ANSI A58.1-72 TABLE II

ASSUME ALL OPENINGS (DOORS, WINDOWS, LOUVERS) WILL BE DESIGNED TO RESIST $P = q_p C_p - q_h C_{pi}$ $\therefore \eta = 0$

$C_{pi} = \pm 0.3$

MAXIMUM TORNADO DIFFERENTIAL PRESSURE

$W_p = +0.5$ PSI

$W_p = -72.0$ PSF

DESIGN TORNADO WIND PRESSURES

OVERALL BLDG. WIND IN N-S OR S-N DIRECTION

DESIGN WIND PRESS. $P = q_h C_p - q_h C_{pi} \cdot W_w$				
W_w \ WALL	WINDWARD	LEEWARD	SIDE	ROOF
$W_w = W_H$ (PSF)	53.7	-32.5	-49.7	-49.7
$W_w = W_p$ (PSF)	-72.0	-72.0	-72.0	-72.0
$W_w = W_H + 0.5 W_p$ (PSF)	18.7	-75.5	-85.7	-85.7

FOR INFORMATION ONLY

CALCULATION SHEET

NUCLEAR FUEL OPERATIONS

JOB NO.	[illegible]
CALC. NO.	CS-41-D-007
SHEET NO.	5 OF 8
REV. NO.	0
CHECKED BY	G.K DATE 9-82

OVERALL BLDG. WIND IN E-W OR W-E DIRECTION

DESIGN WIND PRESS.	$P = q_F C_p - q_H C_{pi} = W_W$			
W_x \ WALL	WINDWARD	LEEWARD	SIDE	ROOF
$W_1 = W_W$ (PSF)	74.5	-54.2	-67.7	-67.7
$W_2 = W_P$ (PSF)	-72.0	-72.0	-72.0	-72.0
$W_3 = W_W + .5W_P$ (PSF)	38.5	-90.2	-103.7	-103.7

MODULE A WIND IN N-S OR S-N DIRECTION

DESIGN WIND PRESS.	$P = q_F C_p - q_H C_{pi} = W_W$			
W_x \ WALL	WINDWARD	LEEWARD	SIDE	ROOF
$W_1 = W_W$ (PSF)	64.1	-46.6	-58.3	-58.3
$W_2 = W_P$ (PSF)	-72.0	-72.0	-72.0	-72.0
$W_3 = W_W + .5W_P$ (PSF)	28.1	-82.6	-94.3	-94.3

MODULE A WIND IN E-W DIRECTION

DESIGN WIND PRESS.	$P = q_F C_p - q_H C_{pi} = W_W$			
W_x \ WALL	WINDWARD*	LEEWARD	SIDE	ROOF
$W_1 = W_W$ (PSF)	0.0	-54.2	-67.7	-67.7
$W_2 = W_P$ (PSF)	0.0	-72.0	-72.0	-72.0
$W_3 = W_W + .5W_P$ (PSF)	0.0	-90.2	-103.7	-103.7

* EXPANS JOINT

MODULE A WIND IN W-E DIRECTION

DESIGN WIND PRESS.	$P = q_F C_p - q_H C_{pi} = W_W$			
W_x \ WALL	WINDWARD	LEEWARD*	SIDE	ROOF
$W_1 = W_W$ (PSF)	74.5	-54.2	-67.7	-67.7
$W_2 = W_P$ (PSF)	-72.0	-72.0	-72.0	-72.0
$W_3 = W_W + .5W_P$ (PSF)	38.5	-90.2	-103.7	-103.7

* EXPANS JOINT

MODULE B WIND IN N-S OR S-N DIRECTION

DESIGN WIND PRESS.	$P = q_F C_p - q_H C_{pi} = W_W$			
W_x \ WALL	WINDWARD	LEEWARD	SIDE	ROOF
$W_1 = W_W$ (PSF)	78.3	-56.9	-71.2	-71.2
$W_2 = W_P$ (PSF)	-72.0	-72.0	-72.0	-72.0
$W_3 = W_W + .5W_P$ (PSF)	42.3	-92.9	-107.2	-107.2

FOR INFORMATION ONLY

C DiGiambrcle 7.22.82

JOB NO.	12484
CALC. NO.	CS-410-007
SHEET NO.	6 OF 8
REV. NO.	0
CHECKED BY	G.K DATE 7-82

NUCLEAR FUEL OPERATIONS

CALCULATION SHEET

MODULE B WIND IN E-W DIRECTION

DESIGN WIND PRESS. $P = q_p C_p - q_m C_{pi} = W_N$				
W_N \ WALL	WINDWARD	LEEWARD *	SIDE	ROOF
$W_N = W_N$ (PSF)	79.5	-54.2	-67.7	-67.7
$W_N = W_P$ (PSF)	-72.0	-72.0	-72.0	-72.0
$W_N = W_{wind} \cdot S_{NP}$ (PSF)	38.5	-90.2	-103.7	-103.7

* EXPANSION JOINT

MODULE B WIND IN W-E DIRECTION

DESIGN WIND PRESS. $P = q_p C_p - q_m C_{pi} = W_N$				
W_N \ WALL	WINDWARD *	LEEWARD	SIDE	ROOF
$W_N = W_N$ (PSF)	79.5	-54.2	-67.7	-67.7
$W_N = W_P$ (PSF)	-72.0	-72.0	-72.0	-72.0
$W_N = W_{wind} \cdot S_{NP}$ (PSF)	38.5	-90.2	-103.7	-103.7

* EXPANSION JOINT

HOIST TOWER WIND IN N-S OR S-N DIRECTION

DESIGN WIND PRESS. $P = q_p C_p - q_m C_{pi} = W_N$				
W_N \ WALL	WINDWARD	LEEWARD	SIDE	ROOF
$W_N = W_N$ (PSF)	85.0	-70.2	-78.0	-85.8
$W_N = W_P$ (PSF)	-72.0	-72.0	-72.0	-72.0
$W_N = W_{wind} \cdot S_{NP}$ (PSF)	99.8	-106.2	-114.0	-121.8

HOIST TOWER WIND IN E-W OR W-E DIRECTION

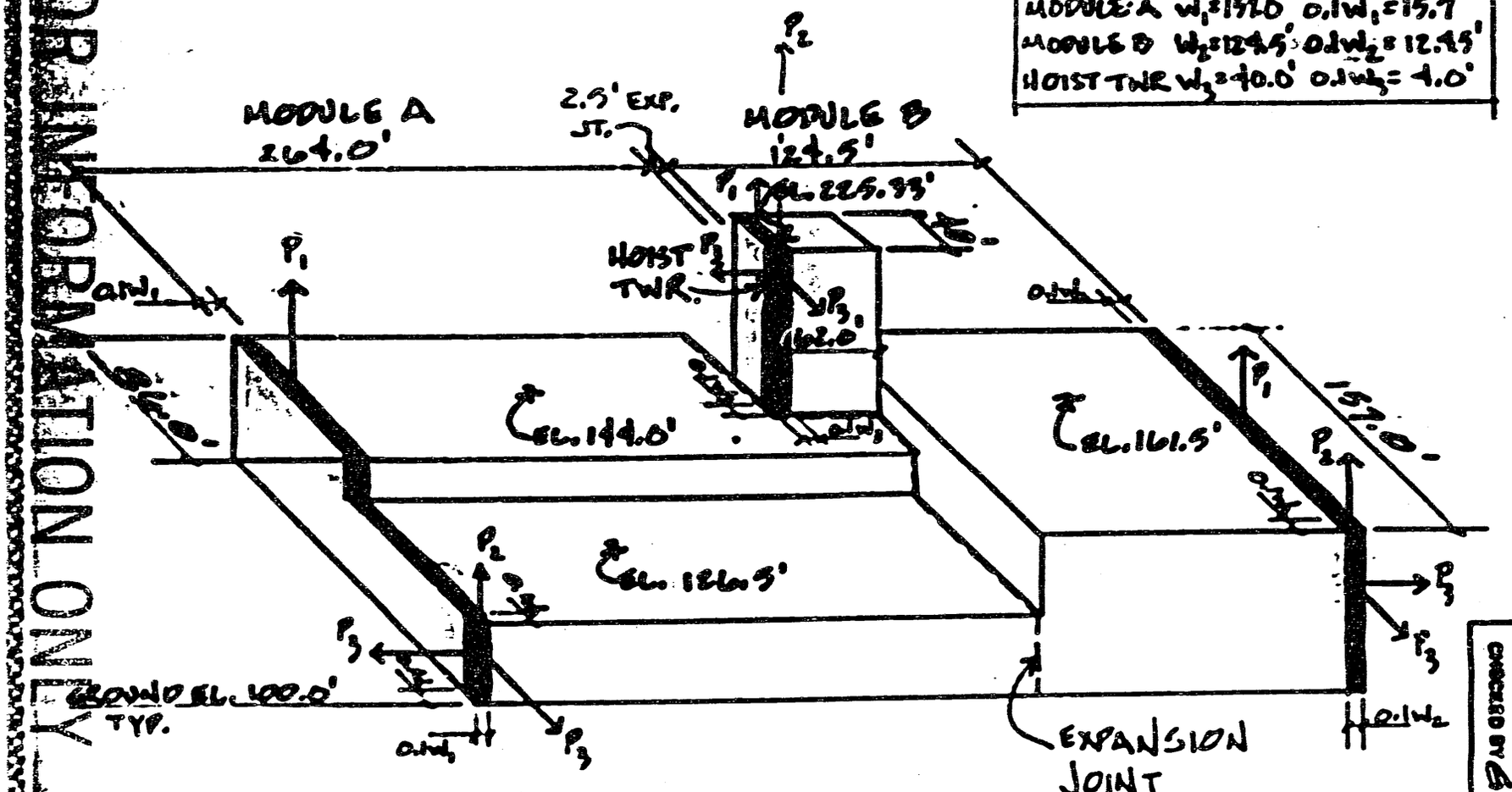
DESIGN WIND PRESS. $P = q_p C_p - q_m C_{pi} = W_N$				
W_N \ WALL	WINDWARD	LEEWARD	SIDE	ROOF
$W_N = W_N$ (PSF)	88.6	-72.5	-80.6	-88.6
$W_N = W_P$ (PSF)	-72.0	-72.0	-72.0	-72.0
$W_N = W_{wind} \cdot S_{NP}$ (PSF)	52.6	-108.5	-116.6	-124.6

FOR INFORMATION ONLY

NOTE: ALL ELEVATIONS SHOWN ARE APPROXIMATE T.O.S.

LEAST WIDTHS

MODULE A	$W_1 = 151.0'$	$0.1W_1 = 15.1'$
MODULE B	$W_2 = 124.5'$	$0.1W_2 = 12.45'$
HOIST TWR	$W_3 = 40.0'$	$0.1W_3 = 4.0'$



WASTE HANDLING BUILDING

LOCAL PEAK EXTERNAL PRESSURES

C. Pellerite 1.22.82

JOB NO.	12404
CALC. NO.	CG-41-D-007
SHEET NO.	7 OF 8
REV. NO.	0
CHECKED BY	G.K. DATE 1/82

NUCLEAR FUEL OPERATIONS

CALCULATION SHEET

FOR INFORMATION ONLY

C. DeGabriele 1.22.82

JOB NO.	12484
CALC. NO.	CS-41-0-007
SHEET NO.	8 OF 8
REV. NO.	0
CHECKED BY	G.K. DATE 1-82

NUCLEAR FUEL OPERATIONS

CALCULATION SHEET

LOCAL PEAK EXTERNAL PRESSURES

COEFFICIENTS ANSI A58.1-72 TABLE 10

C_p (RIDGES & EAVES) = -2.4

C_p (CORNERS - ROOF) = -5.0

C_p (CORNERS - WALL) = -2.0

DESIGN LOCAL PRESSURES = $C_p q_F$

DESIGN WIND PRESS. / SECTION AREA	$P_1 = -2.4\ q_F$ EAVES	$P_2 = -5.0\ q_F$ ROOF CNRS	$P_3 = -2.0\ q_F$ WALL CNRS
OVERALL BLDG.	-162.5	-338.6	-135.4
MODULE A	-162.5	-338.6	-135.4
MODULE B	-170.8	-355.8	-142.3
HOIST TOWER	-193.4	-403.0	-161.2

FOR INFORMATION ONLY

SPEC. NO. D-0077
REVISION NO. 4
REVISION DATE 9/18/91
EM05

VOC-10 MONITORING SYSTEM

WASTE ISOLATION PILOT PLANT

Westinghouse Electric Corporation
Carlsbad, New Mexico 88220

FOR INFORMATION ONLY

USE BLACK INK

ENGINEERING CHANGE ORDER

1. **ECO No.:** 5267
CC&D Review: [illegible]

Initials

Posted

2. **Impact Level** 1 ☐ 2 ☒ 3 ☐ 4 ☐

3. **System:** EM05 Equipment No.: _____ Building: UG

4. Associated Documents.
PWR M12071
ECP _____
P.O. _____
Others _____

5. **Document Type:**
Drawing W05-L-0002-W2, W05-J-0022-W ☒
Specification D-0077 ☒
Vendor Data ☐
SDD ☐
Others _____

6. **Title of Change:** Spiked Matrix Duplicate Sampling Routine

7. **Originator:** (print) Brian W. King | Ext. No.: 8793 | Department: Elec. Eng. | Date: 7-26-91

8. **Cognizant Engineer:** (print) J.R. Stroble

9. **Description of Change:**

① Add Definitions to section 1.2 of D-0077 to include "Matrix Duplicate Sampling" and "Spiked Matrix Duplicate Sampling". (see Design Document change sheet for wording.)
② Add a paragraph to section 3.2 of D-0077 to cover process control requirements for "Spiked Matrix Duplicate sampling" routines. This should be added after paragraph 8 of section 3.2. (see Design Document change sheet for wording.)
③ Change Occurances of the wording "duplicate, concurrent" found in Section 3.2, paragraph 8 to read "Matrix Duplicate".
④ Change wire destination annotations on drawing W05-L-0002-W2 in quadrant E-7+8 that reads "Audit Sample Routine Pushbutton" to read " and in quadrant F-4 that reads "Audit sample Routine started" to change to "spiked Matrix Duplicate Pushbutton" and "spiked Matrix Duplicate sampling started".
BIL 7-26-91

Yes ☐ No ☒ Component indices change required (if yes, attach sheets)

☒ 9a Drawing Change Sheet attached
☒ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

See ECO continuation sheet for Item # 5

10. Yes ☐ No ☒ **MODIFICATION IN PROGRESS**
☐ Modification complete: _____ (Signature / Date)
ECO will be incorporated after M.I.P. signed complete
☐ Change drawing per as-built markup dated: _____
☒ Change drawing per ECO-provided data
☐ Temporary modification

11. **Design Verification Requirements:** (per WP 09-018) EDT No.: _____

JAD 1. Requirements satisfied by review/approval of design document
_____ 2. Independent review
_____ 3. Alternate calculations
_____ 4. Development testing
_____ 5. Design review
_____ 6. Other: _____

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12. **Addendum Sheet added:** _____ (Signature / Date)

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WASTE ISOLATION PILOT PLANT

SPECIFICATION D-0077
ENGINEERING DESIGN SPECIFICATIONS FOR VOC-10 MONITORING SYSTEM

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Attachment	Title
A	VOC Monitoring System, P&I Diagram
B	Technical Validation of Design
C	VOC System Tolerances

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1.0 SCOPE

1.1 Description of Work

This design specification is for the sampling of volatile organic compounds (VOC) which may be emitted from the test waste bins to the mine ventilation system. The test waste bins are to be placed underground in Rooms 1 and 2 of Panel 1. The design concept of the VOC Sampling System presented in the VOC Monitoring Plan, Waste Isolation Pilot Plant (WIPP) was prepared jointly by Waste Isolation Division (WID) Environmental Permitting Group, Electrical Engineering, Radioactive Waste Handling Engineering, and IT Corporation. This design accomplishes the objective of the VOC Monitoring Plan, meets the design interfacing requirements of the waste bins, and meets the requirements identified in the EPA Federal Register, Vol. 55, No. 220 dated 11/14/90.

1.2 Definitions

The following definitions clarify certain terminology that might not be readily understandable to the reader.

Bin - Specially designed, transportable, sealed metal box equipped with sampling ports and instrumentation, and containing specially packaged and prepared TRU waste.

Matrix Duplicate Sampling - A sampling event where the sampler unit simultaneously fills two sample canisters.

PLC - Programmable Logic Controller

Sorption System - A bed of activated carbon acting as an adsorbent for VOCs.

Spiked Matrix Duplicate Sampling - The act of sampling a known volume of gas with known concentrations of five target VOC's in a Matrix Duplicate Sample canister.

Suppliers - All vendors supplying any equipment or part thereof for the VOC monitoring system.

VOC - Volatile Organic Compound

VOST - Volatile Organic Sampling Train

1.3 System Purpose and Design Objectives

The main purpose of the VOC Monitoring System is to fulfil the requirements of 40 CFR 268.6, which allows the disposal of wastes otherwise prohibited from land disposal, only if a demonstration can be made that, to a reasonable degree of certainty, there will be no migration of hazardous constituents in excess of any health based criteria from the disposal unit for as long as the waste remains hazardous. Certain VOCs are considered to be hazardous constituents and therefore a monitoring program needs to be implemented at the WIPP facility which is capable of detecting releases of VOC from the in-experiments and conclusively providing evidence of the migration of VOCs from the WIPP to concentrations

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exceeding health-based criteria. Thus, a VOC Monitoring System is absolutely mandatory to enable the WIPP No-Migration Variance Determination to fulfill the requirements of 40 CFR 268.6. Additional VOC monitoring will be performed to quantify background concentrations and to monitor emissions from other test programs. This will be addressed in a separate specification.

The primary objectives of the monitoring design are:

a. To successfully demonstrate that there is no migration of specific VOC target compounds above any health-based criteria in the ventilation exhaust airstream.

b. To provide data for validation of the proposed monitoring method for the WIPP operational phase.

However, in the course of accomplishing the above objectives, the design also needs to satisfactorily meet the following criteria for the test bin interface:

a. The VOC monitoring system should have no impact on the gas analyses, control, or release of gases from the bin experiments, as described in the Test Plan and Test Plan Addendum (Section 2.3).

b. Each bin shall exhaust into a volume at approximately atmospheric pressure.

c. The volume shall be large enough to accept approximately 2 liters of gas per minute per bin. The gas will be released from the bin at a maximum pressure of 0.5 psig.

d. The volume shall be available for venting each bin at any time.

e. The system volume shall attach only to the bin outlet tube/pipe.

1.4 System Description

Figure 1 shows a one-line representative illustration of the VOC 10 Bin-Scale Test Monitoring System. The system essentially consists of the waste bins, the manifold, a Helium make-up gas subsystem, the sorption unit, and the sampler units. The following subsections describe the various components and their operations in more detail.

1.4.1 Manifold

The manifold is constructed of stainless steel tubing. All gaseous flow from each bin will be directed through a riser and into the manifold. The manifold volume will be approximately 440 liters. This volume and the control scheme will be sufficient to maintain stability, given the bin worst case gas generation calculations. The bins worst case discharge volume has been calculated to be 139 liters per day based on 76 bins (see Attachment B).

1.4.2 Helium Make-Up Gas Subsystem

The make-up gas used will be Ultra High Purity (UHP) research grade (99.9999 percent) helium with total impurities less than one part per million and neon

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less than one part per million. The helium make-up gas subsystem consists of a helium supply tank, a pressure regulator, a flow meter and an air operated flow control valve. The configuration of this equipment shall be such that the flow from the helium supply bottle can be regulated and monitored. The PLC will control the pressure by determining when the manifold requires the addition of helium and will actuate the air operated flow control valve accordingly.

1.4.3 Carbon Sorption Unit

All gaseous flow from the manifold will be directed through a carbon sorption unit. The sorption unit will consist of a main carbon bed and a series of Volatile Organic Sampling Train (VOST) tubes connected in parallel.

The main carbon bed shall be constructed of a 6" O.D. tube packed with 26.4 lb/ ft^3 of carbon and fitted with 20 mesh steel screen on both ends. The VOST tubes will consist of three smaller tubes, in series with each other, packed with approximately 8 grams of carbon material identical to that found in the main carbon bed. The sorption unit's piping will be configured so that gaseous flow from the manifold may be directed either through the main carbon bed or the VOST tubes via three way hand operated valves. One placed at the inlet and the outlet of the sorption unit. At specified times, and when the bins start to generate gas, flow will be directed through the VOST loop for a predetermined test period. The duration of the test period will be determined by the amount of carbon in the tubes and the quantity of gas anticipated to flow through them during this time. The flow will then be redirected through the main carbon bed, the VOST tubes disconnected from the loop and sent to an independent laboratory for analysis. This analysis of the VOST tubes will provide data as to the validity of the sizing of the main carbon bed.

1.4.4 VOC Sampler Unit

The VOC sampler will use four 6 liter passivated stainless steel canisters to obtain regular samples of the gas exiting the carbon sorption unit. Each canister will be filled in a 24 hour period by sampling at regular intervals and directing a portion of the gas to one of the sample canisters. The PLC will control the filling of each canister and operate the appropriate solenoid diversion valves to start filling the next canister as each canister is filled.

1.5 System Operation

As shown in Figure 1, all bins discharge into a manifold of approximately 440 liters by volume. The bins are configured such that when the internal pressure reaches 0.5 psid a relief valve will open. This valve will remain open for two minutes and close, leaving the bin pressure at approximately 0.4 psid. (Actual bin configuration and operation are described in detail in a Sandia National Laboratories Test Plan: WIPP Bin-Scale CH TRU Waste Tests and its addendum labeled SAN90-2082, dated December, 1990.) After a period of time (detailed in Section 3.2) or if the manifold pressure reaches a predetermined limit (detailed in Section 3.2.2) the PLC will start the sample pump and pull the gas through the Carbon Sorption Unit. After the gas is "scrubbed" of VOCs by passing through the carbon sorption unit, it will flow into the sampler where a portion of the flow will be directed into a sampler canister for collection (and subsequent testing) and the remainder exhausted into the ventilation system.

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The PLC will be programmed to operate the sampler and associated valves. The mass flow meter in the sampler and manifold pressure signals will be continuously monitored by the PLC. This will allow the PLC to maintain continuous control as the system dynamics dictate. The manifold pressure will be maintained at approximately atmospheric pressure.

During sampler operation, there will be a reduction of pressure in the manifold. This reduction in pressure will be sensed by the differential pressure transducer. If at the end of the sampler cycle, the manifold is below 0.0 psig, the PLC will open the helium make-up gas flow control valve and hold it open until the system returns to equilibrium.

1.6 Program Responsibility

The responsibilities associated with the design, installation, and operation of the VOC Monitoring System are as follows:

Sandia National Laboratories (SNL) will have full responsibility for the bin pressure release manifold argon purge system and oxygen gettering system. Westinghouse Corporation will have full responsibility for the VOC manifold system which includes all the components of the sampling system with the exception of the VOST tubes. IT Corporation is responsible for designing the VOST tubes. Westinghouse-WID personnel will be responsible for operating and maintaining these units.

2.0 APPLICABLE DOCUMENTS

2.1 Order of Precedence

Unless otherwise specified for the VOC Monitoring System, this design specification shall take precedence over any of the documents listed in this section. Specific interfaces are noted elsewhere.

a. WP 02-10, WIPP VOC Monitoring Program Manual, (Draft)

2.2 Codes, Standards, and Practices

The following codes, standards, and practices shall be considered a part of this specification. Unless otherwise stated, the latest revision of each document shall apply.

American National Standards Institute

ANSI/ASME NQA-1 Quality Assurance Program for Nuclear Facilities

American Society for Testing and Materials

ASTM A269 Seamless and Welded Austenitic Stainless Steel Tubing for General Service

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Code of Federal Regulations

Title 29, Part 1910 (29 CFR 1910)	Occupational Safety and Health Administration Standards (OSHA)

U.S. Environmental Protection Agency

SW-846	Test Methods for Evaluating Solid Waste, Physical/ Chemical Methods, Third Edition (1986)
Compendium Method TO-14	The Determination of Volatile Organic Compounds (VOC) in Ambient Air Using SUMMA Passivated Canister Sampling and Gas Chromatographic Analyses, May 1988

National Fire Protection Association

NFPA 70	National Electric Code

WID Specifications and Procedures

E-P-242	Basic Electrical Material and Methods
E-P-243	Conduit and Fittings
E-P-244	Terminations
E-P-245	Cable (600V)
E-P-247	Grounding
E-P-309	Instruments Cabinets and Panels
E-Q-281	Instrumentation Cables
WP 09-021	Equipment Numbering

2.3 Reference Documents

The following document shall be considered a part of this specification. Unless otherwise stated, the latest version shall apply.

Test Plan: WIPP Bin-Scale CH TRU Waste Tests, M. A. Molecke, Sandia National Laboratories, Albuquerque, New Mexico, January, 1990 and addendum labeled SAN90-2082 dated December, 1990.

VOC Monitoring Plan Waste Isolation Pilot Plant, IT Corporation dated December 1, 1990.

Formulas for calculations come from the following reference documents:

Flow of Fluid Through Valves, Fittings, and Pipes, Crane Technical Paper No. 410

Handbook of Chemistry and Physics, Weast

Standard Handbook for Mechanical Engineers, Baumeister & Marks

Technical Data Handbook, Hartford Steam Boiler Inspection and Insurance Co.

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3.0 DESIGN REQUIREMENTS

This section describes the requirements for the design, maintenance, personnel protection, material fabrication, packaging, and shipping, and also presents a failure analysis.

3.1 General Requirements

The design of the monitoring system shall to the maximum extent possible: 1) be based on existing technology, maximizing the use of standard available components, and standard design and construction for the service specified; 2) be engineered, designed, built, and/or finally assembled by the organizations listed in Section 1.6; 3) conform to this specification; 4) comply with recognized industrial standards and practices; and 5) be of sound quality.

Safety features shall be incorporated to provide for personnel protection during testing, installation, and system operation.

There is a possibility that the gas atmosphere within the test bins may contain small amounts of radioactivity coming from the waste contained in the waste bins. The design of these bins is required to provide for adequate particulate filtering of all gas lines which come from the bins.

All materials of construction will be suitable for use in the WIPP salt mine and capable of performing their intended functions over the duration of the bin experiments.

The manifold system must be closed to the atmosphere and controlled at atmospheric pressure. The sample system will sample all gasses released from the bins or the helium make-up system. The sample rate will be adjustable to accommodate all scenarios of sampling requirements. The sample rate, under normal operation, will support the gas generation calculated by the worst case scenarios and achieve normal sample requirements.

Alarm conditions, which impact operability, will be indicated on the surface in the Central Monitoring Room (CMR). A two level alarm, with priority, will be used to notify of an impending emergency situation or an emergency situation. An impending emergency situation will be one in which an abnormal condition has occurred or is occurring that will not detrimentally effect system operation or does not require immediate attention. This impending emergency situation alarm will be low priority. An emergency situation will be one in which an abnormal condition or a system failure has occurred in which the system's ability to control manifold pressure has failed. This emergency situation requires immediate attention and will be high priority.

Manifold pressure will be read by the pressure differential transducer and controlled by the PLC to satisfy normal operation conditions as well as abnormal conditions.

The helium system will be controlled by the PLC to maintain manifold pressure. The status of the helium flow control valve will be monitored by the system.

The PLC will be an integral part of system sampling and control. It is therefore required that there be at least one complete spare PLC system on hand at all

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times. These units shall have sufficient capabilities to monitor and act on all required digital and analog signals, and have the ability to be expanded for future requirements. The I/O cards that are to be used in the PLC shall have the quick disconnect type terminal board on the face of the cards to minimize down time in the event of card failure. The system will have the capability of being programmed on-line and off-line by; hand-held programmer and through the use of a portable Personal Computer (PC) with the proper programming software and cabling. The unit shall have a battery integral to the processor that is capable of maintaining the integrity of the CPU's program during a power failure, and that battery shall be replaced annually. Rack slot fillers are required for all empty I/O slots. The I/O modules shall be of sufficient current carrying capacity to meet the requirements of the field and local devices. Below are listed the minimum requirements for each module type:

Digital Input Modules - Nominal 120 VAC input range with ten percent over and under range input capabilities. Provide 1000 volts RMS minimum optical isolation between field devices and logic circuitry of PLC.

Digital Output Modules - Nominal 120 VAC output range. Each channel must be isolated from the other. Provide 1000 volts RMS minimum optical isolation between field devices and logic circuitry of PLC. Must provide 2.0 amperes (internally fused) output capacity per channel.

Analog Input Modules - Must be capable of accepting a -10 to +10 VDC input range. Minimum resolution of 25 mV per bit (least significant bit). Provide 1000 volts RMS minimum isolation between field devices and logic circuitry of PLC.

3.2 Process Control Requirements

The VOC sampling system design shall satisfy all the requirements of the test bin interface as mentioned in Section 1.3. This design satisfactorily meets the criteria mentioned in Section 1.3, and the technical validation is presented in Attachment B. The technical validation conclusively proves that the monitoring system will have no impact on the bin experiments.

The following calculations provide the technical basis on which the systems control scheme is based. The value of worst case bin gas generation was taken from the first two documents listed in Section 2.3.

1. Worst case per bin gas generation per year is = 670 liters.
2. 670 liters/year *76 bins = 50,920 liters/year.
3. (50,920 liters/year) / 365 days = 139.5 liters/day.
4. (139.5 liters/day) / (60 minutes * 24 hours) = 0.0969 liters/minute.
5. Manifold volume = 440 liters.
6. .0969 liters/minute will raise manifold pressure by .1 psig in 30.9 minutes.

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7. The sample pump discharges approximately three liters/minute when operating with a 20 psig back pressure. Therefore the pump will decrease the pressure in the manifold .1 psig after approximately one minute of operation.

The sample pump will be turned on by the PLC once every 30 minutes for a duration of one minute. This will cause the pump to run for a total of 48 minutes over a 24 hour period, pumping a total of 144 liters of gas from the manifold. This will ensure that a volume greater than worst case bin gas generation is discharged from the manifold every day based on calculation #3 and #7. Also because the pump is cycled every 30 minutes, the manifold pressure will never exceed .1 psig during worst case bin gas generation based on calculation #6.

The sampler unit will divert 12 liters of this total daily flow to a sample bottle. 12 liters will fill one sample bottle to a two atmosphere capacity. To accomplish this 250 milliliters of the sampler pump's output will be sent to a sample canister (250 milliliters/minute * 48 minutes = 12 liters). The remainder of the sampler pump flow will be exhausted to the ventilation system.

Calculations #3 and #7 dictate that during worst case bin gas generation, the manifold pressure will be returned to approximately atmospheric every 30 minutes. In actuality the bins will probably generate little if any gas, leaving the manifold pressure somewhere between 0.0 psig and +0.1 psig over a 30 minute period. Now, when the sampler pump runs for its one minute cycle, decreasing the manifold pressure by 0.1 psig (calculation #7), the resultant pressure at the end of that cycle will be between -0.1 psig to 0.0 psig. When this is the case, the PLC (which constantly monitors the manifold pressure via the PDT cell) will open the helium flow control valve to bring the manifold back up to equilibrium. Once the manifold pressure is sensed as being at approximately 0.00 psig, the PLC will close the helium flow control valve and continue to monitor the system until the next cycle is scheduled to start.

Each of the four sample canister solenoid valves will have an associated push button and status light on the control cabinet. Each light and push button will be labeled and numbered in succession to reflect the order in which the bottles will be filled. When the fourth bottle is filled the PLC will then cycle back to start filling the first bottle again. As each bottle is being filled, the PLC will flash the corresponding light to alert the operator that the solenoid valve for that bottle is open. Once the bottle is determined to be full, the PLC will stop flashing the light and hold that light on steady. This will alert the operator that bottle corresponding to that light is full, the solenoid valve is closed and the bottle is ready for removal. Once the bottle is removed and a new bottle is placed on that sample port, the operator will depress the push button corresponding to that bottle, informing the PLC that the bottle is available for filling.

If the operator wishes to stop the filling of a bottle that is currently being filled, he may, at any time, depress the push button corresponding to that bottle. The PLC will then close the respective solenoid and proceed to fill the next available bottle.

This system will also be capable of taking a Matrix Duplicate sample when necessary. This will be achieved by the operator placing the sample canister previous to the canister that is currently being filled. The PLC will fill each

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canister in sequence, i.e. #1, #2, #3, #4, back to #1, #2, and so on. If the PLC was presently filling canister #4, the operator would place the duplicate sample canister at position #3. If the PLC was presently filling canister #1, the operator would place the Matrix Duplicate canister at position #4, and so on.) The operator will then be required to depress the button for that canister and hold that button until the light starts to flash. This will take approximately 15 seconds during which time the light will come on steady warning the operator that he is about to initiate a sample cycle on a bottle. This is done to ensure that a solenoid valve is not inadvertently opened without a bottle being attached.

The system shall be capable of allowing a Spike Matrix duplicate sample to be taken. The system will be required to be able to perform a ten minute purge on an operator selected sample canister port. The system shall also have the ability to suspend it's control over the sampler unit allowing the operator to control the sampler unit remotely. There shall be a Spike Matrix status light on the control panel that will inform the operator as to the mode of operation that the system is in. If the status light is off, that will indicate that the system is in it's normal or Matrix Duplicate mode of operation. If the status light is on steady that will indicate that the system is performing a ten minute purge on the operator selected sample bottle port. A Spike Matrix flashing status light will indicate that the system has suspended it's control over the sampler unit to allow for remote operation. The operator will also have a Spike Matrix pushbutton to initiate a ten minute purge and the suspended mode of operation. If the status light is off and this pushbutton is depressed, the system will suspend it's control over the sampler unit and the Spike Matrix status light will flash. When the operator is ready to perform a ten minute purge, he will depress the sample bottle pushbutton corresponding to the sample bottle connection port that the purge is to be performed on. The operator will then be able to depress the Spiked Matrix pushbutton to allow the system to start the purge cycle. After the ten minute purge is complete, the Spiked Matrix status light will again start to flash, denoting that the system has again suspended it's control over the sampler unit. During this time the sampler unit may be disconnected from the system and the sampler may be operated by means of a remote control unit. Once the operator has completed his work he will depress the Spike Matrix pushbutton again, returning the system back to a normal mode of operation.

3.2.1 Normal Operation

When the system is operating normally, the PLC will control the process and maintain status lights for operator interface. Software status may be checked by use of a hand-held programmer or a portable PC.

3.2.2 Abnormal Operation

High priority and low priority alarms will be sent to the CMR by the PLC. There will also be a local alarm light found on the control cabinet that will flash on either of the two priority alarms. The operator may distinguish which priority condition has caused the local alarm by contacting the CMR. However, the CMR will not be able to distinguish the cause of the alarm, a system diagnosis must be performed to reveal this. Any alarm condition must be reset at the control cabinet via the Alarm Reset push button thereby also clearing the alarms sent to

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the CMR. The PLC will not allow the local alarm to be reset until the fault has been corrected.

The PLC will maintain the VOC monitoring system in all control modes. If the system approaches overpressurization, +0.3 psig, a high priority alarm will be sent to the CMR. If an under pressurization of the manifold occurs, -0.3 psig, (i.e. pump running too long), the sampler unit will be disabled and the high priority alarm will be activated.

The PLC will also monitor various parts of the system's activities for abnormalities and malfunctions. The sample pump's motor current will be monitored via a current transformer (CT), for an over-current or an under-current condition. If the sample pump draws more current than 1.9 amperes, the sampler unit will be disabled and a high priority alarm activated. If the sample pump is in an under-current condition, less than 0.2 amperes, the PLC will assume the motor is not running, disable the sampler unit and activate the high priority alarm.

The position of the helium flow control valve will be monitored by the PLC. If the PLC has requested the valve to open and it has not opened in a 2.0 second time period, the high priority alarm will sound and the sampler will not be allowed to cycle as long as the manifold pressure is below 0.0 psig. If the helium valve is called to close by the PLC and does not do so in a 2.0 second time period, the high priority alarm will sound. If this condition is sensed the PLC will enable the sampler unit to run as necessary to ensure that the manifold pressure does not exceed +0.4 psig.

The mass flow meter that measures the flow to the sample canisters is monitored by the PLC. If the sampler unit is called to run and this measured flow deviates plus or minus 100 milliliters per minute from the expected flow, (250 milliliters per minute), the low priority alarm will be activated. If a "no flow" condition is sensed by the PLC and the sampler unit has been called to run, the sampler unit will be disabled and the high priority alarm will be activated.

An alarm will also be generated if the PLC has determined that there are not any more available bottles to be filled. If the last bottle is being filled and the PLC senses that there are not any more available bottles, the PLC will activate the low priority alarm. If the PLC has finished filling the last bottle, and it senses that there are not any more available bottles to fill, the PLC will activate the high priority alarm.

3.2.3 Sampler Unit Restart

As stated in Section 3.2.1, the PLC has a battery that will ensure that the program is not lost during a power failure. This battery will also enable the PLC to retain the accumulated values in all of its timers and counters. The PLC will therefore resume its action from where it left off when the power was lost.

3.2.4 Sample System Certification

The sample system will be certified "clean" of VOCs. This will be accomplished by laboratory analysis of an initial samples taken once the system is operational.

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Subsequent certifications will be performed by obtaining a system sample by injecting a known gas into the system and having that sample analyzed. If the analysis shows that the system requires further inspection and/or cleaning, that will be performed by sending the system to an independent laboratory for recertification. Operability of all components, within this document's tolerances, will be ensured by the laboratory before the equipment is returned to the site.

3.3 Instrumentation Requirements

A mass flow meter is required to measure the total flow out of the system. The total flow from the system is required to determine concentration of detectable compounds in the sample canister. By rationing, the amount of compounds in the total mine ventilation flow can be calculated. A record of the mass flow must be made and is required by paragraph 6.1.5.2 of the VOC Monitoring Plan.

A record of the measured system pressure shall be made on the local chart recorder. These data are required in order to have information on the system operation. This will give an indication of the amount of bin gas generation, show when a part fails, and show the effects of valve operation and helium gas injection.

A current transmitter will be used to monitor the sampler motor current. The transmitter will be used to track pump performance. Transmitter output will be monitored by the PLC and recorded by the chart recorder.

The records will be kept by strip chart recorder. The recorder shall be capable of keeping the record for several weeks without replacing the paper. A spare channel shall be provided.

An enclosure is required for the electronic instruments. The enclosure shall be large enough to house the PLC, chart recorder, amplifiers for mass flow and DPT, current indicators, and other components, as required. The enclosure shall be corrosion resistant and equipped with a fan and filters to cool the instruments and keep dust out.

Air to operate the valves will be obtained from the plant air system. To assure that the air is clean and at the right pressure, a drier and a pressure regulator will be provided.

3.4 Maintenance Requirements

The pressure in the helium cylinder shall be checked regularly to ensure there is adequate helium for normal operation. If the pressure falls below 50 psig, the cylinder shall be replaced with a full cylinder.

Maintenance for the remainder of the system will consist of component replacement with a few exceptions. On the valves the seals can be replaced as well as some other parts which may wear. Pens and chart paper will be replaced as they are needed.

The carbon sorption bed is expected to be replaced once a year. A greater or lesser frequency will be determined from the VOST tube measurements.

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3.5 Electrical Power Requirements

A 110/120 VAC, 15 ampere, 60 Hz power supply will be adequate for operating all the units which need electrical power. Upon failure of site power, the surface diesel back-up power system would be energized, supplying power to this system. Extended loss of power would be covered in Section 3.6, Failure Analysis.

3.6 Failure Analysis

The PLC will maintain the VMS in all control modes. If the system approaches overpressurization, an alarm will be sent to the CMR. If pressure continues to increase, a mechanical pressure relief valve will open at .8 psig. If underpressurization occurs as the result of the pump running too long, the PLC will send an alarm and disable the pump. A loss of power underground will cause an undervoltage trip, which will be reset manually from the surface. A diesel back-up generator will be able to supply power for an extended period to Room 1 in the event of an extended power outage.

3.7 Personnel Requirements

Specific Westinghouse personnel will be trained in the operation and maintenance of the system.

3.8 Material Requirements

The material chosen for all piping and instrumentation is stainless steel. Although there is an abundance of chlorine in the mine atmosphere, there is no high temperature or high stress environment for this system. For this application, which requires a five-year lifetime, 316 stainless steel is acceptable.

All stainless steel fittings and valves will be ordered with the requirement that they be cleaned to ensure that they are VOC free. The stainless steel tubing will be passivated or be of chromatographic quality.

3.9 Fabrication Requirements

The only special fabrication requirements for assembly of the whole system on the site is that the fabrication personnel be trained in installation of the fittings. The system shall be assembled on the site using standard maintenance tools except for a hydraulic swaging unit required for one-inch and two-inch tubing connections.

4.0 FIELD EXECUTION

4.1 System Installation

The overall VOC sampling system including all instrumentation and piping downstream of bin relief valves shall be installed according to work instructions prepared by Westinghouse. All work activity will use WID procedures.

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4.2 Field Inspection and Testing

Two types of tests shall be performed by the organizations responsible for parts of the monitoring system as mentioned in Section 1.6.

4.2.1 Leak Test

A leak test on the manifold piping shall be performed in accordance with work instructions prepared by Westinghouse.

4.2.2 Startup Test

An acceptance test shall be conducted to demonstrate that all design operating criteria have been met and the monitoring system performs satisfactorily with respect to meeting design objectives mentioned in Section 1.3.

4.3 Personnel Training

All associated personnel shall undergo special training to become familiar with the system, know the operating manuals for various equipment, and learn the steps to be taken during failure scenarios. All personnel directly involved with the operation and maintenance of this system shall be trained to understand and deal with the hazardous nature of VOCs.

5.0 QUALITY ASSURANCE REQUIREMENTS

In addition to adhering to all WID procedures and/or procedures approved by WID, the following procedures shall be followed:

1. Pressure and leak test results shall be documented in a report.

2. Acceptance test results shall be documented in a Startup Report.

3. Any changes to the design shall be verified through a design review process by individuals excluding those who prepared the original design.

4. All test procedures and conditions shall be established jointly by Westinghouse, IT Corporation and Sandia National Laboratories to their mutual satisfaction.

5. Review and approval procedures will involve all contractors as appropriate.

6. Samples shall be taken, handled, and analyzed in accordance with requirements specified in the WIPP VOC Monitoring Program Manual, WP 02-10.

7. The testing specified in Section 4.2 shall be witnessed by WID QA.

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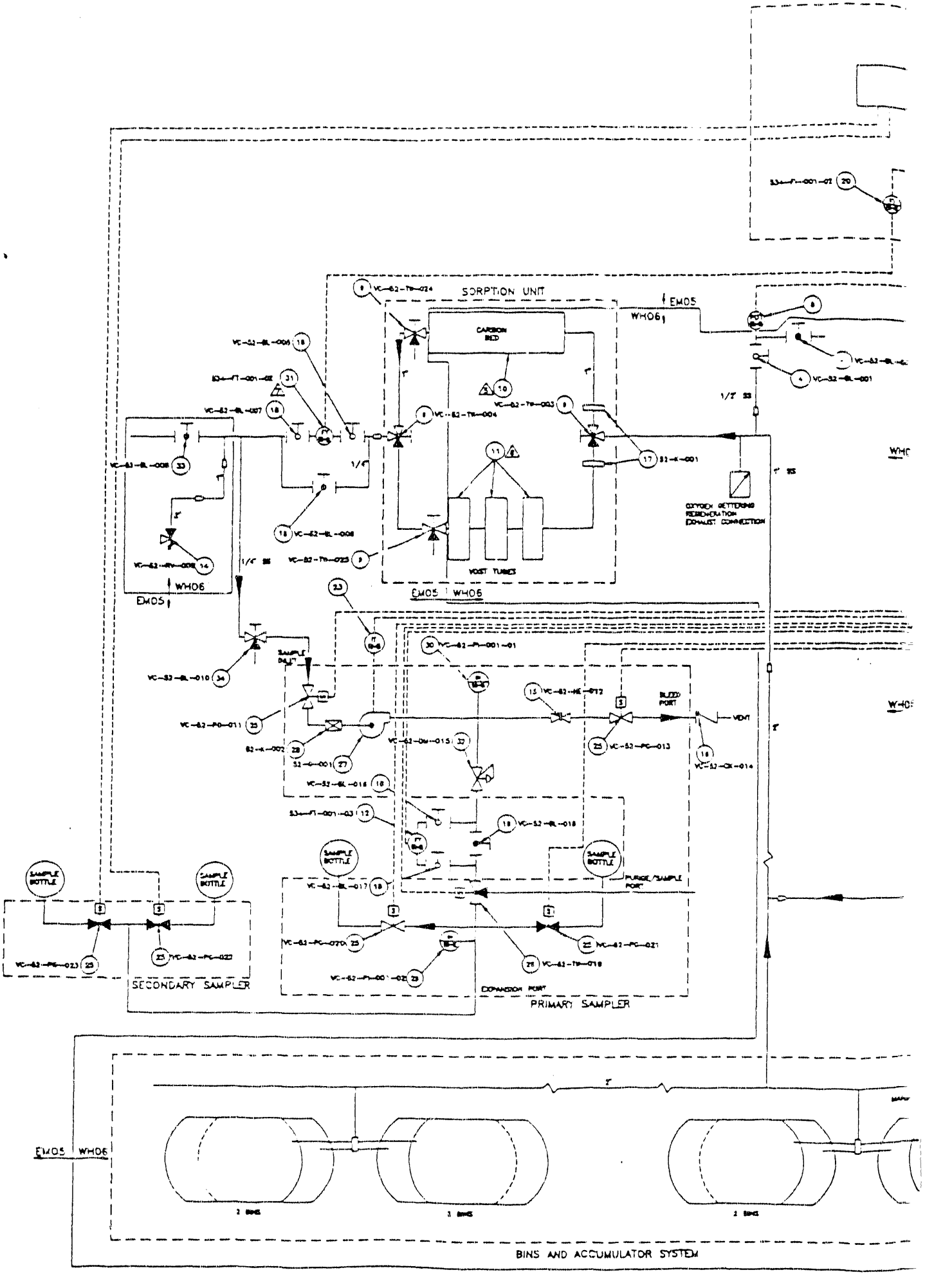
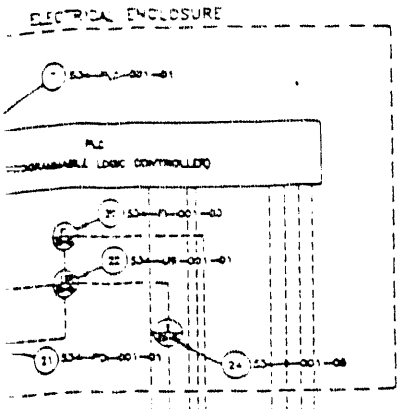

SORPTION UNIT
CARBON BED
VOST TUBES
EMO5 WHO6
SECONDARY SAMPLER
PRIMARY SAMPLER
SAMPLE BOTTLE
PURGE/SAMPLE PORT
BLEED PORT
VENT
EXPANSION PORT
OXYGEN GETTERING REGENERATION EXHAUST CONNECTION
BINS AND ACCUMULATOR SYSTEM

ATTACHMENT A
Page 1 of 1



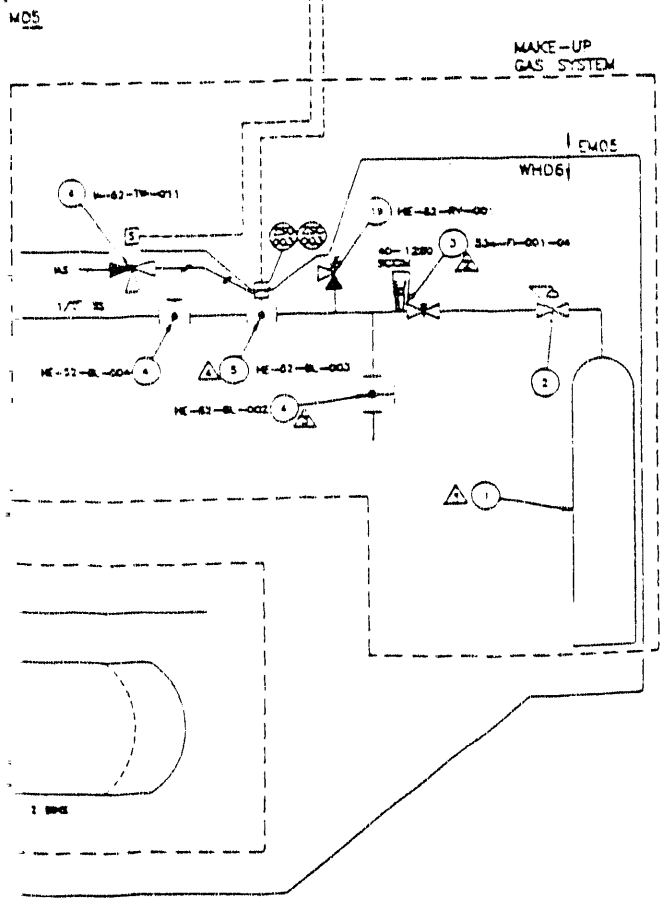
ITEM	QTY	PART NUMBER/DESCRIPTION	REC'D	MATL SPEC
	1	CYLINDER, 80L		SCOTT SPECIAL
	2	REGULATOR, HELIUM, 1ST STAGE	51-18-680	SCOTT
	3	FLOW METER, VARIABLE AREA, 0-60 TO 0-6 SCCM	51-313-1	SCOTT
	4	VALVE, BALL, 1/8" 2-WAY MANUALLY OPERATED	SS-6BG	WHITEY
	5	VALVE, BALL, 1/8" 3-WAY AIR-OPERATED, NC	SS-43TBG-33C	WHITEY
	6	VALVE, SOLENOID 3-WAY NC	071327052702	ASCO
	7	CONTROLLER, PROGRAMMABLE LOGIC "PLC"	90-30/331	GENERAL ELECTRIC
	8	TRANSDUCER, PRESSURE DIFFERENTIAL, 0-100mm H2O	2230D-00100A2B	MKS
	9	VALVE, BALL, 1/8" 3-WAY MANUALLY OPERATED	32-43XT318-T18	WHITEY
	10	BCL CARBON SORPTION		CALGON, TYPE BPL CARBON
	11	VOST TUBES		ANALYTICAL LABORATORY
	12	METER, MASS FLOW 0-500 SCCM	1559AC-00050-SV	MKS
	13	VALVE, BALL 1/8" 2-WAY AIR OPERATED NO	SS-43TXB-33D	WHITEY
	14	VENT, EMERGENCY RELIEF 7" WIDE LOADED CLAMPING	2300-02-44-1000	GROTH
	15	VALVE, METERING MICROMETER HANDLE	SS-22RS4	WHITEY
	16	VALVE, CHECK 1/8" IN-LINE	SS-4C-1/3	NUPRO
2	17	HOUSING, FILTER 47MM	2220	BIO-MAN
6	18	VALVE, BALL 1/8" 2-WAY MANUAL	SS-42TS4	WHITEY
	19	VALVE, 1/8" IN-LINE, 0.6 PSI	SS-4L3S4	NUPRO
	20	INDICATOR/AMPLIFIER, FLOW	TYPE 246	MKS
	21	INDICATOR, AMPLIFIER, PRESSURE	TYPE PDR-C-2C	MKS
	22	CHART RECORDER, 8CH DIGITAL SIGNAL	DPR 3000-8J	HONEYWELL
	23	CURRENT TRANSMITTER	IACT	MOORE IND.
	24	CURRENT INDICATOR	1015-P71	WALKER/SIGN
4	25	VALVE, SOLENOID 1/8" NPT, 115VAC	SERIES 40, 2-WAY	EDMOD
	26	VALVE, SOLENOID 1/8" NPT 115VAC	SERIES 4C, 3-WAY	EDMOD
	27	PUMP, DIAPHRAGM	UNOBBV1	KNF NEUBERGER
	28	FILTER, INLINE 1/8 MICRON	SS-4F-1/8	NUPRO
	29	INDICATOR, SAMPLE PRESSURE	10109	SPAN INSTRUMENTS
	30	INDICATOR, PUMP PRESSURE	21-0119-01	SPAN INSTRUMENTS
	31	METER, MASS FLOW 0-5000 SCCM	1558C-05000-SV	MKS
	32	CONTROLLER, FLOW	5C4233 PMK	MONIFLOW
	33	VALVE, BALL 1/4" MANUAL 3-WAY	SS-43TS4	WHITEY
	34	VALVE, BALL 1/4" MANUAL 3-WAY	SS-43XS4	WHITEY

REFERENCE DRAWINGS

69m-SCALE TESTS ROOM 1 LAYOUT	52-9-001-9
69m-SCALE TESTS VOC MONITORING AND HELIUM STATION DETAILS	53-4-003-9

LEGEND:

- INSTRUMENT AIR SUPPLY
- PNEUMATIC LINES
- ELECTRICAL LINES
- WHO6 WASTE HANDLING ENGINEERING
- EMO5 ELECTRICAL ENGINEERING



NOTES:

1. 99.9999% PURE, TOTAL IMPURITIES <1 PPM, THC <0.1 PPM, H2O <1 PPM.
2. ROTAMETER, SCOTT MODEL 82-31-S----1 WITH 150MM TUBE, 4.3-43 SCCM HELIUM (CALIBRATION REQUIRED WITH UNITS), INLET PRESSURE SET AT 10 PSIG.
3. HELIUM SERVICE, 0 TO 30 PSIG, STANDARD HANDLE.
4. 80 PSIG (MIN.) AIR MOUNTING KIT: MS-MB-62, HELIUM LEAK TEST, LIMIT SWITCH KIT: MS-LSH-A1-131.
5. 1/8" INCH O.D. STAINLESS STEEL PIPE WITH 0.25" WALL THICKNESS, LENGTH, 6.15 FEET PACKED WITH 28.4 LBS. OF ACTIVATED CARBON, (ORDERING INFORMATION PROVIDED ACCESSORY ITEMS).
6. VOST TUBES PROVIDED BY ANALYTICAL LABORATORY.
7. 0-50 SCCM MKS MODEL 1559AC.
8. REMOVED
9. REMOVED
10. MODIFY INC. P/N ACT/0-5A/4-20mA/117VAC/TDL/PM

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TECHNICAL VALIDATION OF DESIGN

This attachment will demonstrate that the VOC Monitoring System will have no impact on the ability of the bins to release generated gasses.

Impact of VOC Monitoring Design on Bins

Any potential impact or interference with the bin experiments has been overcome by using a manifold between bins and the VOC Monitoring System. The manifold will be of sufficient volume to accumulate all gasses expected to be generated in one day, worst case scenario. The manifold is of 2.00" OD 316 stainless steel tubing.

The calculations are as follows:

Reference CH TRU Test Plan dated 1-90

Gas released from bins = 670 l/yr each

Gas released per bin per day = $\frac{670}{365}$ = 1.835 l/day

76 bins in Room 1 76(1.835) = 139.46 l/day total gas generation worst case

From the above calculations the manifold should be of a volume at least equal to 139.46 liter. For ease of calculations liters will be converted to ft^3.

1 liter = .3531 ft^3 139.46L(.03531) = 4.924 ft^3

To determine the manifold volume the following calculations are used.

The I.D. of 2.00" OD tubing is:

2.00" OD - 2(0.188 wall thickness) = 1.624" ID

The manifold consists of 1044 ft of 2.00" tubing

3 (212 ft runs)	=	636 ft	
38 (9 ft risers)	=	342 ft	(for 76 bins)
2 (33 ft runs)	=	66 ft	
		1044 ft	

Volume is calculated as shown below:

Va - volume total in ft^3
r - radius of tubing
L - length of tubing in ft

$Va = \pi r^2 L = \pi(.812 \text{ in})^2 ((1044 \text{ ft})(12 \text{ in/ft}))$
$= \pi(.812 \text{ in})^2 (12528 \text{ in}) = 25950.377 \text{ in}^3$

$\frac{25950 \text{ in}^3}{1728 (\text{in}^3/\text{ft}^3)} = 15.017 \text{ ft}^3$ 15.017 ft^3 (28.32 liters/ft^3) = 425.281 liters

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From the above calculations it can be seen that the manifold volume is sufficient to both accommodate worst case bin gas generation and dampen any pressure spikes that might be developed.

Minimum manifold volume to accept worst case gas generation is 139.46 liters. Actual manifold volume is 425.281 liters.

The large manifold volume will ensure that the suction of the small diaphragm pump will not be felt by the bin relief valves. In addition the sorption chamber will act as a buffer or snubber to prevent the manifold from sensing any pressure deviations caused by the stroke of the diaphragm pump.

The preceding calculations are based on 2.00" tubing upstream of the sorption unit. This is the large volume chamber that the bins will initially discharge into. For purposes of this attachment, this volume of tubing is referred to as the manifold. To fully understand the control scheme, as dictated by system dynamics, total system volume will now be calculated.

2.00" tubing in the manifold	- 1044 ft.	=	425.281 liters
Additional 2.00" tubing in system	- 2 ft.	=	.815 liters
1.00" tubing in system	- 10 ft.	=	.869 liters
1/2" tubing in system	- 3 ft.	=	.087 liters
1/4" tubing in system	- 10 ft.	=	.053 liters
Total volume of tubing	-		427.105 liters

Volume of the sorption unit is as follows:

6.33 ft. in length = 75.96 in.
6.00 in. OD - 2(.250 wall thickness) = 5.50 in I.D.

$Va = \pi r^2 L \qquad \pi(2.75)^2\ 75.96 = 1804.680\ in^3$

$\frac{1804.680\ in^3}{1728\ (in^3/ft^3)} = 1.044\ ft^3 \qquad 1.044\ ft^3(28.32\ liters/ft^3) = 29.566\ liters$

We know the volume of carbon in the filter to be 13.90 liters. (VOC Monitoring Plan dated December, 1990 by IT Corporation.)

29.566 liters
-13.900 liters (VOC Monitoring Plan, pg. 21)
15.666 liters volume available in sorption unit

427.105 liters
+ 15.666 liters
442.771 liters total volume in the system. For clarification this total volume will be referred to as accumulator volume.

Pressure Drop Due to Helium Flow

The helium used as a make-up/transport gas will only flow through a portion of the 2.00" tubing. The 38 nine ft risers will not have helium flow through them. In addition flow will be divided between 2 of the 212 ft runs. So for purposes

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of these calculations 424 ft will be used as a representative number. The flow rate generated by the sample pump will be approximately 3000 ml/min. To determine the pressure drop in the accumulator due to this flow rate the following calculations are used: (First the mean velocity will be calculated.)

V - mean velocity of flow in ft per min
qm - rate of flow in cubic ft per min at standard flow conditions
A - cross sectional area of tubing in square ft
d - internal tubing diameter in inches

The formula for velocity is:

$$V = \frac{qm}{A}$$

$1\ ml = 3.5315 \times 10^{-5}\ ft^3$ $\quad$ $3000\ ml/m\ (3.5315 \times 10^{-5}\ ft^3) = .016\ ft^3/min$

$qm = .016\ ft^3/min$

$$A = \frac{\pi d^2}{4} \qquad \frac{\pi(1.624)^2}{4} = 2.071\ in.^2 = .0144\ ft^2 \qquad A = .014\ ft^2$$

$$V = \frac{.016\ ft^3/min}{.014\ ft^2} = 1.143\ ft\ per\ min$$

Using the velocity determined from above, an approximation of the pressure drop due to helium flow through 424 ft of 2.00" tubing can be calculated. Helium at 3000 ft above sea level and 68 degrees fahrenheit has a kinematic viscosity (ν) of $1.2566 \times 10^{-3}\ ft^2/sec$. To determine this pressure drop due to friction the Reynolds number first must be calculated.

Re - Reynolds number
D - internal diameter of pipe in ft
v - mean velocity in ft per sec
ν - kinematic viscosity, square ft per sec

$$Re = \frac{Dv}{\nu} \qquad D = \frac{1.624\ in}{12} = .135\ ft$$

$$v = \frac{1.143\ ft\ per\ min}{60} = .019\ ft\ per\ sec$$

$$\nu = 1.2566 \times 10^{-3}\ ft^2/sec$$

$$Re = \frac{.135\ ft(.019\ ft/sec)}{1.2566 \times 10^{-3}\ ft^2/sec} = 2.052$$

A Reynolds number of less than 2000 indicates a laminar flow condition and implies very low friction losses. With a Reynolds number as low as 2.052 an essentially frictionless flow can be assumed. However, pressure loss will be calculated using this number.

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The friction factor for laminar flow is calculated as follows:

f - friction factor
Re - Reynolds number

$$f = \frac{64}{Re} = \frac{64}{2.052} = 31.189$$

Darcy's formula provides the general equation for pressure drop.

h_L - loss of static pressure head due to flow of fluid, in ft. of fluid
f - friction factor
L - length of tubing in ft.
v^2 - mean velocity of flow in ft. per sec. squared
D - internal diameter of pipe, in ft.
g - acceleration of gravity (32.2 ft. per sec. per sec.)

Darcy's formula is $h_L = \frac{fLv^2}{D2g}$ 1 ft H_2O = .434 psig

$$\frac{31.189(424 \text{ ft})(.019 \text{ ft/sec})^2}{(.135 \text{ ft})(32.2)2} (.434 \text{ psig}) = .238 \text{ psig pressure drop}$$

Actual pressure drop through the carbon sorption chamber is estimated to be .072 psig. Combine this estimated pressure drop with the calculated pressure drop through the tubing and it becomes evident that the helium make-up system can easily overcome the effects.

.238 psig +.072 psig = .31 psig

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VOC SYSTEM TOLERANCES

Pressure

Pump start .1 psig ± .05 psig
High pressure alarm - .3 psig ± .05 psig
Low pressure alarm - -.3 psig ± .05 psig
Pump discharge pressure - 20 psig ± 1 psig

Flow

Sample flow - 250 ml/m ± 20 ml/m

Current Alarms

Pump overcurrent - 1.9a ± .1a
Pump undercurrent - .2a ± .1a

Priority 1	Over/under pressure
	Over/under pump current
	Helium FCV failure
	No flow
	No bottle
Priority 2	Mass flow
	On last bottle

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SPEC. NO. E-S-357
REVISION NO. 0
REVISION DATE 9-04-91
= EM05

VOC MONITORING STATIONS LOCATED IN PANEL 1

WASTE ISOLATION PILOT PLANT

Westinghouse Electric Corporation
Carlsbad, New Mexico 88220

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ENGINEERING CHANGE ORDER
(USE BLACK INK)

(1) CC&D REVIEW [signature]

ECO- 4713

(2) IMPACT LEVEL
☐ LEVEL-1 ☐ LEVEL-3
☒ LEVEL-2
(SEE SIDE 2 FOR APPROVALS)

(3) SYS/EQUIP NO./BLDG
EMOS

(4) ASSOCIATED DOCUMENTS
030 _____
RELATED ECO _____
EDT _____
P.O. _____

(5) DOCUMENT NO.
DRAWING ☐
SPEC ☒
O&M MANUAL ☐
SDD ☐
E-S-327

(6) SHEET
—

(7) REVISION ADVANCED
FROM 0 TO —
FROM — TO —

(8) DOCUMENT TITLE
ENGINEERING DESIGN SPECIFICATIONS FOR V.C MONITORING LOCATED IN PANEL 1

(9) DESCRIPTION OF CHANGE
Equipment specifications for VOC Monitoring Station located in Panel 1.

Y/N
☐ ☒ ELECTRICAL LOAD LIST (25-X-001-W)
☐ ☒ PANEL SCHEDULE (INCLUDE MARK-UP)

☐ YES ☒ NO
**** MODIFICATION IN PROGRESS
(ECO NOT TO BE INCORPORATED)

☐ MODIFICATION COMPLETE _____
(ECO RELEASED FOR INCORPORATION)

(10) JUSTIFICATION
Need for equipment specification.

SEP 1991
COMPLETE
SK

(11) ORIGINATOR (PRINT)	(12) PHONE	(13) ORGANIZATION	(14) DATE
SHANE THOMPSON	8373	ELECTRICAL ENGINEERING	7/5/90

(15) COG. ENGINEER (PRINT)	(12) PHONE	(16) DRAFTING REQUIRED DATE
NONE		—

WP FORM 1200A; REVISED 3/8/90

(Side 1)

U.S. DEPARTMENT OF ENERGY
WASTE ISOLATION PILOT PLANT

SPECIFICATION E-S-357
ENGINEERING DESIGN SPECIFICATIONS FOR VOC MONITORING STATIONS LOCATED IN PANEL 1

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SPECIFICATION E-S-357
ENGINEERING DESIGN SPECIFICATIONS FOR VOC
MONITORING STATIONS LOCATED IN PANEL 1

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SPECIFICATION E-S-357
ENGINEERING DESIGN SPECIFICATIONS FOR VOC
MONITORING STATIONS LOCATED IN PANEL 1

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B	Copy of Meeting Minutes Dated 4/3/90	2

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1.0 SCOPE

1.1 Description of Work

This design specification is for the monitoring of volatile organic compounds (VOCs) at two locations; Panel 1-Room 1 (S1950) and Panel 1-Room 1 (S1600). These two locations are shown in Figure 1 as Station VOC-8, and Station VOC-9. The design is based on the concept presented in the VOC Monitoring Plan, Waste Isolation Pilot Plant prepared by International Technology Corporation of Albuquerque, New Mexico, dated January 1990. It meets the sampling requirements outlined in the VOC Monitoring Plan and accomplishes the objective of satisfactory monitoring of VOCs at the aforementioned sampling locations.

1.2 Definitions

The following definitions clarify certain terminology contained in this document.

Volatile Organic Compound (VOC) - Organic compounds having saturated vapor pressures at 25°C, greater than 10^{-1} mm Hg.

Sampler and Accessories - Air sampler unit with all the supporting items required for its installation and operation (as described in a later section).

Secondary Module - Unit containing two sampling canisters used to increase sampling capacity of the air sampler unit.

Suppliers - All vendors supplying any equipment or part thereof for the sampler and accessories.

1.3 System Purpose and Design Objectives

The main purpose of the VOC Monitoring System is to fulfill the requirements of 40 CFR 268.6, which allows the disposal wastes otherwise prohibited from land disposal only if a demonstration can be made that, to a reasonable degree of certainty, there will be no migration of hazardous constituents from the disposal unit for as long as the wastes remain hazardous. VOCs are considered as hazardous constituents, and therefore a monitoring program will be implemented at the WIPP facility which is capable of detecting releases of VOCs from the bin and alcove experiments and conclusively providing evidence of no-migration of VOCs from the WIPP in concentrations exceeding health-based criteria. Thus, a VOC Monitoring System is mandatory to enable the WIPP No-Migration Variance Petition to fulfill the requirements to 40 CRF 268.6.

The specific purpose of air sampling at these two locations is described below:

a. Station VOC-8 will monitor VOC target compound concentrations at Panel 1-Room 1 (S1950) in order to measure the background concentration of VOCs already existing in the ambient air drawn into Panel 1 in the underground. Monitoring background concentrations at the air intake shaft collar area is not sufficient because certain lubricants, solvents, etc. (unrelated to the waste, but used in the WIPP underground) may also release additional VOCs to the repository atmosphere.

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b. Station VOC-9 will be deployed downstream in the Panel 1-Room 1 (S1600) passageway and will monitor any VOC emissions potentially released from any leaks in the bin or alcove ducting systems. Subtraction of the VOC target compound concentrations measured by Station VOC-8 from those measured in Station VOC-9 will yield an estimate of VOCs released from the bin rooms and alcoves through leaks in the ducting system.

1.4 System Description

The two sampling locations are shown in the general layout of VOC Monitoring System Locations in Figure 1. This section describes the components of each sampling station and their precise location within the repository. The sampling system includes the primary sampler with all controls and the secondary module. The secondary module is used for increasing sampling capacity, and for extended automated sampling up to four days (if necessary, during weekends, holidays, etc.).

1.4.1 Panel 1 Air Intake and Outlet (Stations VOC-8 and VOC-9)

The components of Stations VOC-8 and VOC-9 as well as their arrangement are shown in Figure 2.

As shown in Figure 2, Stations VOC-8 and VOC-9 are recessed in the ribs. The sampler and the secondary sampling module are housed within a stainless steel shelter box, and the entire system is kept within the recess excavated in the ribs as shown in Sections A-A, and B-B. The size of the recess is approximately 75" x 70" x 30", and the size of the shelter box is 65" x 30" x 18" without the supporting legs. A clearance space of approximately 10 inches has been maintained between the shelter box and the walls of the recess to facilitate easy dismantling of the system, if and when necessary. The sampler shelter box must be kept within the wall recess to ensure that the sampling station does not interfere with normal traffic, ventilation, or become damaged.

The assembly of the sampler and the secondary sampling module within the shelter box is shown in Figure 3 with the shelter doors kept open. The primary sampler and the secondary module are roughly of the same size (20" x 18.5" x 10"), and sit side by side within the shelter box. Clearance of 5" between the samplers, and at least 10" between the samplers and the shelter box provide for adequate ventilation, connection of fittings, and for easy access during routine service or maintenance. Once the samplers are in place inside the shelter box with all inlet and outlet lines properly connected, the shelter doors will be kept closed. The doors will be weather stripped to prevent any dirt or salt particulates from entering the protective shelter and damaging the sampling system or its parts. Flexible stainless steel metal hoses inserted through 3/4-inch holes drilled through the sides of the shelter box provide connection to the sampler inlet and outlet. The 1/4-inch flexible metal hoses will be inserted into the shelter box through a 1/4-inch opening in a 3/4-inch rubber grommet mounted on the shelter box. This will provide a reasonable tight seal in order to prevent any salt dust from flowing through the 3/4-inch hole. An exhaust fan mounted on the inside of the shelter box ensures that adequate air circulation takes place around the samplers for dissipation of heat generated from valves and sampler pump operation. An air

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filter mounted on the shelter box side opposite to that of the exhaust fan, ensures that air drawn in by the exhaust fan will not contain any salt dust from the drift.

The tubing interconnections between the primary sampler and the secondary sampling module are shown in Figure 4. The primary sampler has one inlet for sampling and three pathways for exit air in the form of bleed air, purge air, and a connection port for expansion. All connections are made by flexible stainless steel metal hoses for ease of assembly, and also to facilitate easy dismantling whenever needed. The expansion port is used to connect the secondary module. The bleed air is taken out through a flexible stainless steel metal hose out of the shelter box. No fittings are necessary on the purge air connection because the low flow rate of purge air will be easily withdrawn by the exhaust fan. Detailed description of the sampling unit is discussed later in this section.

The layout of tubing inlet and outlet from the sampling stations are shown in Figure 5. The flexible metal hose connected to the sampler inlet in Figure 4 is taken out through the 3/4-inch hole on the shelter box side and supported on the drift wall by means of a supporting bracket. Thereafter, 1/4-inch straight tubing is connected to the flexible metal hose and is made to project three feet into the drift passageway at a height of approximately nine feet from the drift floor, and flagged for easy identification. The outlet side does not have any need to exhaust away from the drift walls. Therefore, the flexible metal hose from the secondary sampler outlet is withdrawn through the 3/4-inch hold in the shelter box. It is then supported on the drift wall with six feet of straight tubing added so that the exhaust air is downstream enough not to be recycled back into the sampling system.

The VOC sampling unit is shown in Figure 6. It is essentially an automated four canister air sampler with the capacity to fill four 6-liter sample canisters. The sampler can collect up to four samples in 6-liter sampling containers (two in the primary sampler and two in the secondary module) using separate timing channels for each container. The sampling pump and the inlet and bleed air solenoid valves are operated by the third timing channel. A proprietary design feature allows operation by the third timing channel. A proprietary design feature allows separation of the three-way solenoid valve for both the purge mode and actual sample collection. The unit will be operated from a 120V AC power supply. Under normal operating conditions, the sampler utilized normally closed solenoid valves that are energized and remain energized in their open position. The valves do become warm but do not pose a fire hazard. All pneumatic and electronic components are housed in the control module and are accessible either from the control panel or upon removal of the control module from the container housing.

Details of the sampling method and frequency of sampling are provided in the document "VOC Monitoring Plan" listed in Section 2.0.

The sampler will also have a real-time clock which will have the provision of shutting off if a power failure occurs. Thus, in case of a power failure going undetected for any length of time, the real-time clock will give an indication of how many of the 24 hours of required sampling were actually carried out. Once this is known, adjustments will be made to compensate for the lost time.

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1.5 System Operation

Once the system has been properly assembled, the only operating component is the sampler itself as shown in Figure 6. The sampler is set for a sampling cycle by plugging the unit into an available 120V AC power outlet. The actual clock time is set first and then the unit is programmed for the sample collection of as many as four canisters. The sample collection into container number one is operated by timing channel number one, and the corresponding sample collection into container number two is operated by timing channel number two. Timing channel number three operates the sampling pump and the inlet and bleed air solenoid valves which open and remain open whenever the sampling pump is operating. The secondary module also has a three-channel timer for similar purposes.

The seven-day, three-channel digital timer allows independent control of the sampling pump with the inlet and bleed air solenoid valves, and dedicated timing of each of the two sampling channels. The three-way purge solenoid valve is operated separately by each sampling channel. The timer has a battery backup for memory, large LC display, and is easily programmable.

Purge air flow exits via the three-way solenoid valve purge port on top of the control panel. This port is also used to set the flow and to calibrate the flow controller. When sampling into container number one or number two begins, the sample air flow is diverted into the sampling container at the flow that has been set by the flow controller. The bleed air adjustment, and the related pump head pressure (read by the 0-30 psig pressure gauge) are controlled by the needle valve located on the upper right side of the control panel. The flow adjustment is done via the set screw on the tamper proof flow controller located on the upper left side of the control panel. The inlet plug, bleed air, and purge air plugs are removed prior to sampling. The sampling containers located in the bottom case are connected to the solenoid valve outlets labeled sample #1 and sample #2 with the connecting tubes supplied with the sampler. The digital timer LED lights up when a given channel is in use. The sampling container valves should be open prior to the beginning of the sampling cycle.

After completing the sampling cycle the container valves are closed using extension handles. The connecting tubes are disconnected and the sampling containers removed and replaced with new ones.

1.6 Program Responsibility

The responsibilities (see Attachment B, Meeting Minutes, 4/3/90) associated with the design, installation, and operation of the sampler and accessories are as follows:

a. Systems Design - WID/IT will provide technical support to Regulatory and Environmental Programs.

b. Systems Installation - Facilities Engineering will provide the required support for installation of the VOC monitoring systems.

c. Systems Operation - Operation and maintenance of VOC monitoring systems.

FOR INFORMATION ONLY

1. Surface sample collection will be performed by Facilities Operations Technicians.

2. Underground sample collection will be performed by a Waste Handling Operations Technician.

3. Handling and storage of used and new canisters, and shipment of canisters to off-site laboratory for analyses will be performed by an Environmental Monitoring Technician.

d. Program Management and receipt of analytical data from the laboratory will be performed by the Environmental Compliance Section of Regulatory and Environmental Programs.

2.0 APPLICABLE DOCUMENTS

2.1 Order of Precedence

Unless otherwise specified, this design specification shall take precedence over any of the documents listed in this section.

2.2 Codes, Standards, and Practices

The following codes, standards, and practices shall be considered a part of this specification. Unless otherwise stated, the latest revision of each document shall apply.

ASTM	American Society for Testing Materials, ASTM A269
SW846	EPA and RCRA Sampling Standards
Compendium Method TO-14	EPA Procedure for VOC sampling

2.3 Reference Documents

The following documents shall be considered a part of this specification. Unless otherwise stated, the latest version of each shall apply.

VOC Monitoring Plan, Waste Isolation Pilot Plant, DOE, January 1990

WP-090-21, WIPP Equipment Numbering Procedure

Specification No. D-0077, Engineering Design Specification for VOC Monitoring System, March 8, 1990

3.0 DESIGN REQUIREMENTS

This section describes the requirements for the design, maintenance, personnel, material fabrication, packaging, shipping, and handling.

FOR INFORMATION ONLY

3.1 General Requirements

The design of the system shall be to the maximum extent possible: 1) be based on existing technology, maximizing the use of standard available components and standard design and construction for the service specified; 2) be engineered, designed, built and/or finally assembled by the organizations listed in Section 1.6; 3) conform to this specification; 4) comply with recognized industrial standards and practices; and 5) be of sound quality.

Any filters connected upstream of the sampler inlet shall not absorb or remove component gases like volatile organic compounds.

All materials of construction for the sampler and its accessories need to be suitable for use in the WIPP underground environment and for performing their intended functions over the duration of the test phase.

3.2 Instrumentation and Control Requirements

All the equipment required as shown in Figures 3 through 12 are listed in Table 1 in Attachment A. Unless otherwise specified, any original equipment listed can be substituted with an equivalent. Table 1 also lists the costs and delivery time for each item. In some cases the total number of items have been multiplied by two account for the two sampling locations.

3.3 Maintenance Requirements

The sampling personnel will have complete responsibility for routine sampler maintenance. This includes but is not limited to replacement of damaged or malfunctioning parts, filter changes, leak testing, and any minor cleaning. All major cleaning and sampler cleanliness certification will be the responsibility of the laboratory contracted for post-sampling analytical procedures.

Two complete spare units and a spare parts inventory will be maintained on-site to minimize down time due to malfunction of any sampler.

The sampling system at each location will include sufficient collection canisters (approximately 20) so that any delays due to laboratory turn around time and canister cleaning and certification will not result in canister shortages.

3.4 Electrical Requirements

A 110/120 VAC, 60 Hz, 15A power supply is required for operating the sampler. Therefore, appropriate power outlets are required in the vicinity of both sampling locations described earlier.

3.5 Personnel Requirements

During installation, skilled personnel will be required to drill and excavate the small cavities in the repository walls to accommodate the sampler and its accessories.

Once in operation, the system can be programmed to be completely automatic except for routine maintenance checks and canister changeout. Once a sampling

FOR INFORMATION ONLY

program is stored in memory, that control program will be executed until it is changed, cancelled, or a complete power loss occurs.

3.6 Material Requirements

All piping and instrumentation will be made of stainless steel. The possibility of associated stress corrosion cracking is remote due to the nonexistence of a high temperature and/or a high stress environment.

All stainless steel tubing and piping shall be cleaned by the following procedure. The tubing shall be cleaned (passivated) be a nitric/hydrofluoric acid wash at a maximum temperature of 130°F and a minimum temperature of 70°F for 10 to 15 minutes. The solution shall be made to the following concentrations: nitric acid (HNO_3) at 12 percent or 0.5 percent by volume; hydrofluoric acid (HF) at 3 percent or 5 percent be volume. To inhibit the solution, 7 to 10 grams per liter of iron may be added. The acid wash shall be followed immediately with a demineralized water wash until the solution indicates a neutral pH. (Reference: MIL-T-23226E Tube and Pipe, Corrosion Resistant Steel, Seamless.)

Westinghouse Quality Assurance shall witness cleaning of the tubing. The supplier shall notify WID when they are ready to perform the cleaning process.

3.7 Fabrication Requirements

The recessed area in the ribs will be mined and leveled to accommodate the placement of the sampler shelter as shown in the design in Figure 2. The shelter box shall be fabricated according to Figures 7 through 12. No other special fabrication requirements are necessary. The entire system excluding the SIS Model TGS-2/A samplers shall be assembled on-site using standard maintenance tools.

3.8 Packaging, Shipping, and Handling Requirements

In general, all suppliers shall ensure that the components are packaged and shipped such that they do not suffer any damage during shipment. All suppliers will be responsible for any damage to components prior to installation.

Any tubing should be cleaned prior to packaging and shipment. All grease and foreign substances shall be removed using the procedures described in Section 3.6.

The suppliers shall ship the components to the address provided in the purchase order.

Each crate or package shall be marked with ink, paint, or other indelible material to indicate the equipment number, purchase order number, and description of the equipment. Weight, center of gravity, and lifting points of packages shall be clearly marked for fragile or heavy materials.

The suppliers shall assure that the size, weight, and configuration of components shipped will fit within the WIPP C&SH shaft engineering access requirements and requirements for transportation in the WIPP facility.

FOR INFORMATION ONLY

4.0 FIELD EXECUTION

4.1 System Installation

The sampling systems shall be installed according to work instruction prepared by the Westinghouse Environmental and Regulatory Compliance Section in conformance with the responsibilities outlined in Section 1.6.

In addition, the following procedure will also be followed:

a. Prior to use, the sampler collection units must be laboratory certified to demonstrate that they are free of any contamination.

b. Prior to initiation of sampling, a Standard Operating Procedure (SOP) will be prepared by the contracted laboratory to describe the cleaning and certification procedures for the sampling units both before and after each sampling usage.

c. The system will be tested for leaks using a leak detector system similar to Snoop. Any detected leads will be appropriately rectified.

d. A performance test shall be carried out after complete installation of the system to the satisfaction of the responsible party listed in Section 1.6.

4.2 Personnel Training

All sampling personnel shall undergo special training to become familiarized with the system, the standard operating procedures, and all emergency procedures wherever applicable. They should also be trained to understand the hazardous nature of VOCs.

5.0 QUALITY ASSURANCE REQUIREMENTS

All procedures will adhere to the Quality Assurance Project Plan (QAPP) which is presently under preparation. In addition, the following procedures will be followed:

a. All QA procedures already in place at the WIPP site will be strictly followed.

b. All QA procedures will be consistent with the QA objectives outlined in the VOC Monitoring Plan document mentioned in Section 2.3.

*349+

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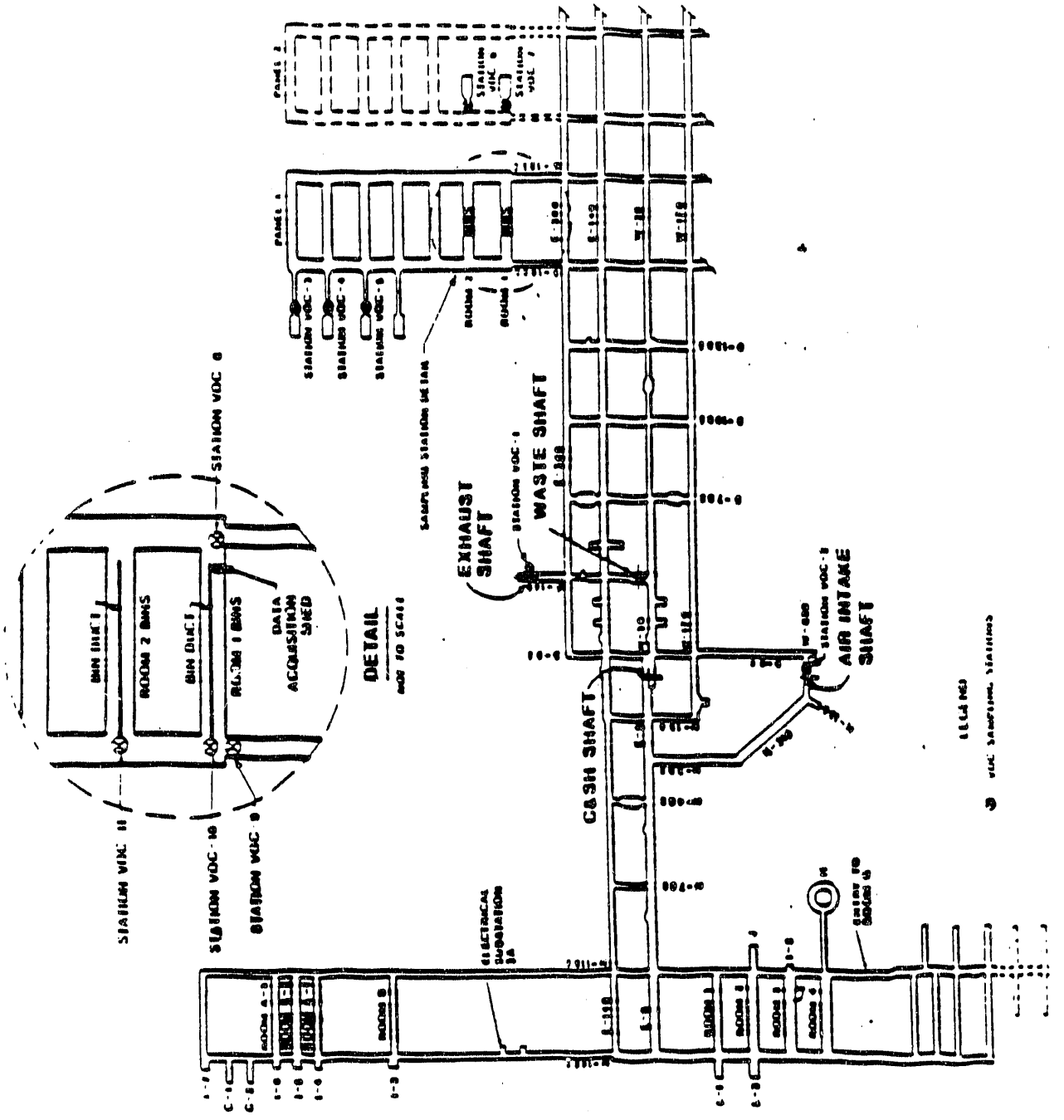
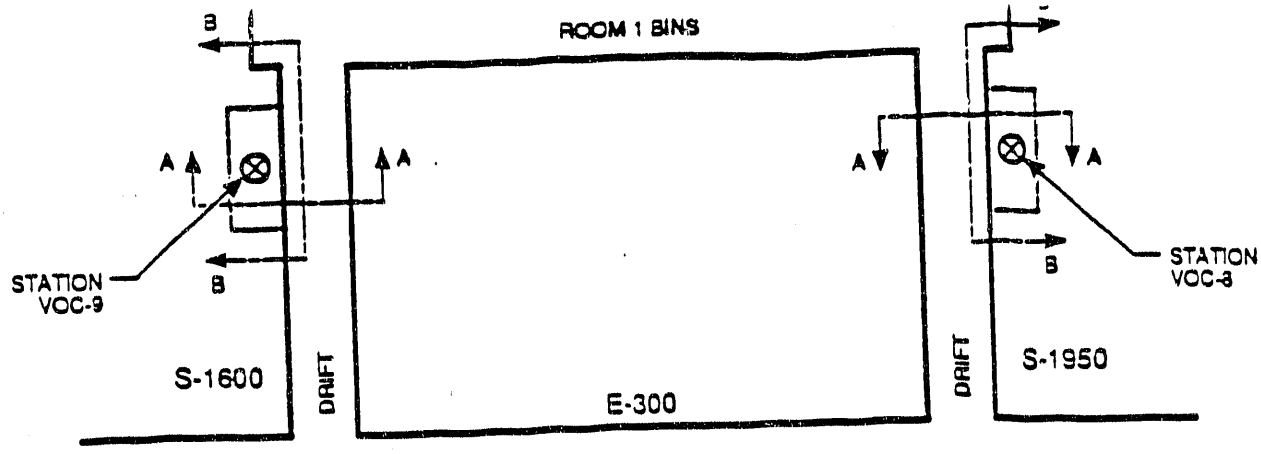
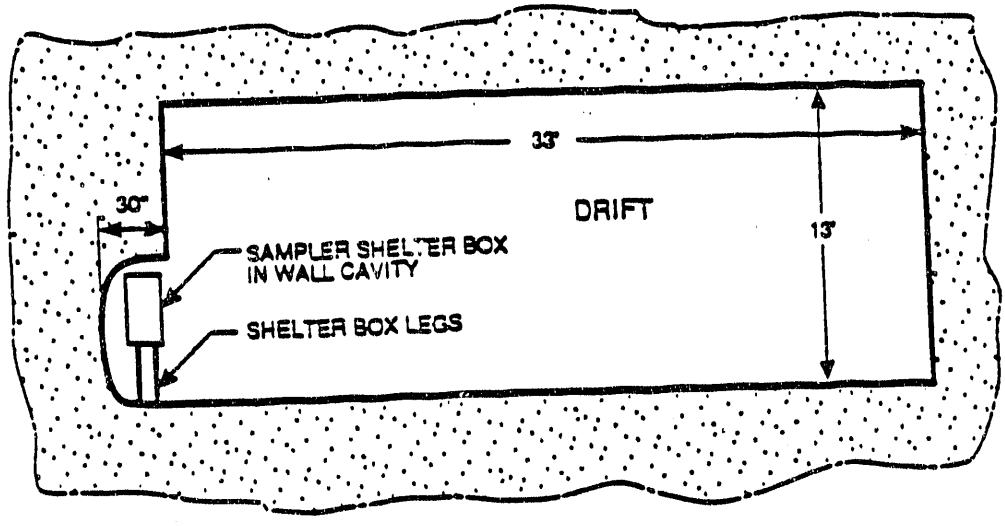


FIGURE 1. Schematic Diagram of VOC Sampling Stations

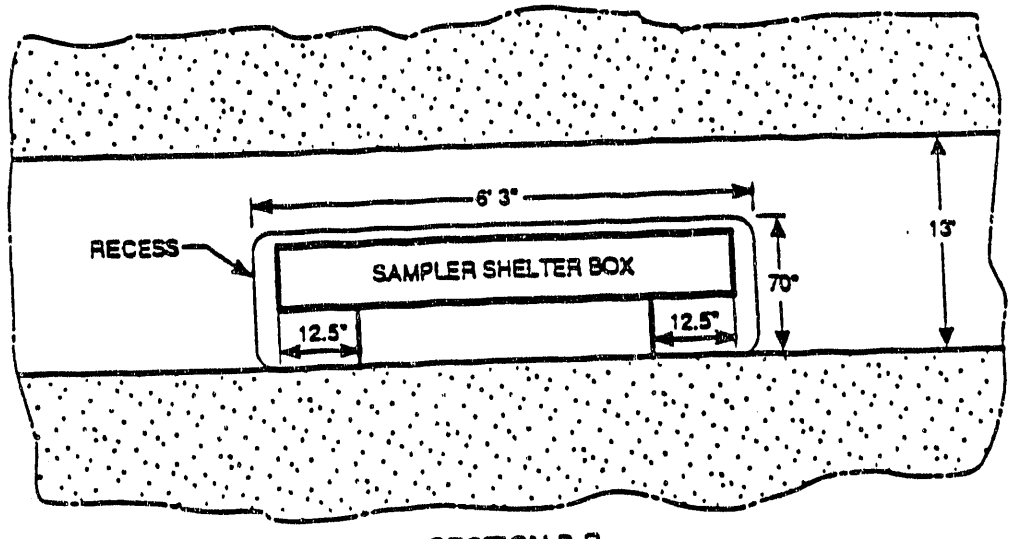
FOR INFORMATION ONLY



NOT TO SCALE



SECTION A-A



SECTION B-B

FIGURE 2. Layout and Construction Drawing for Sampling Stations VOC-8 and VOC-9

FOR INFORMATION ONLY

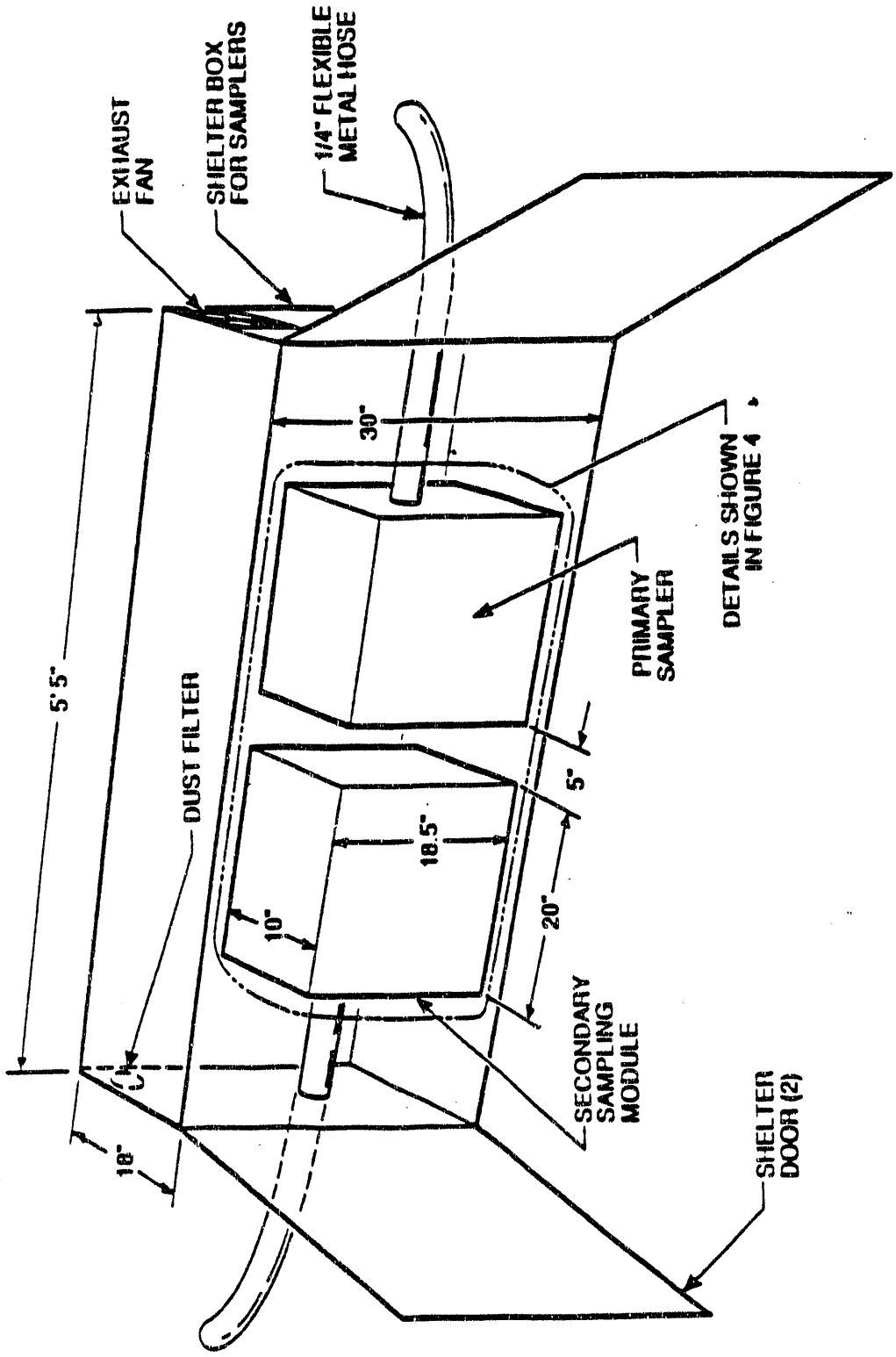


FIGURE 3. Sampler Shelter Box with Samplers Inside*
*(Shelter Box Legs Not Shown)

FOR INFORMATION ONLY

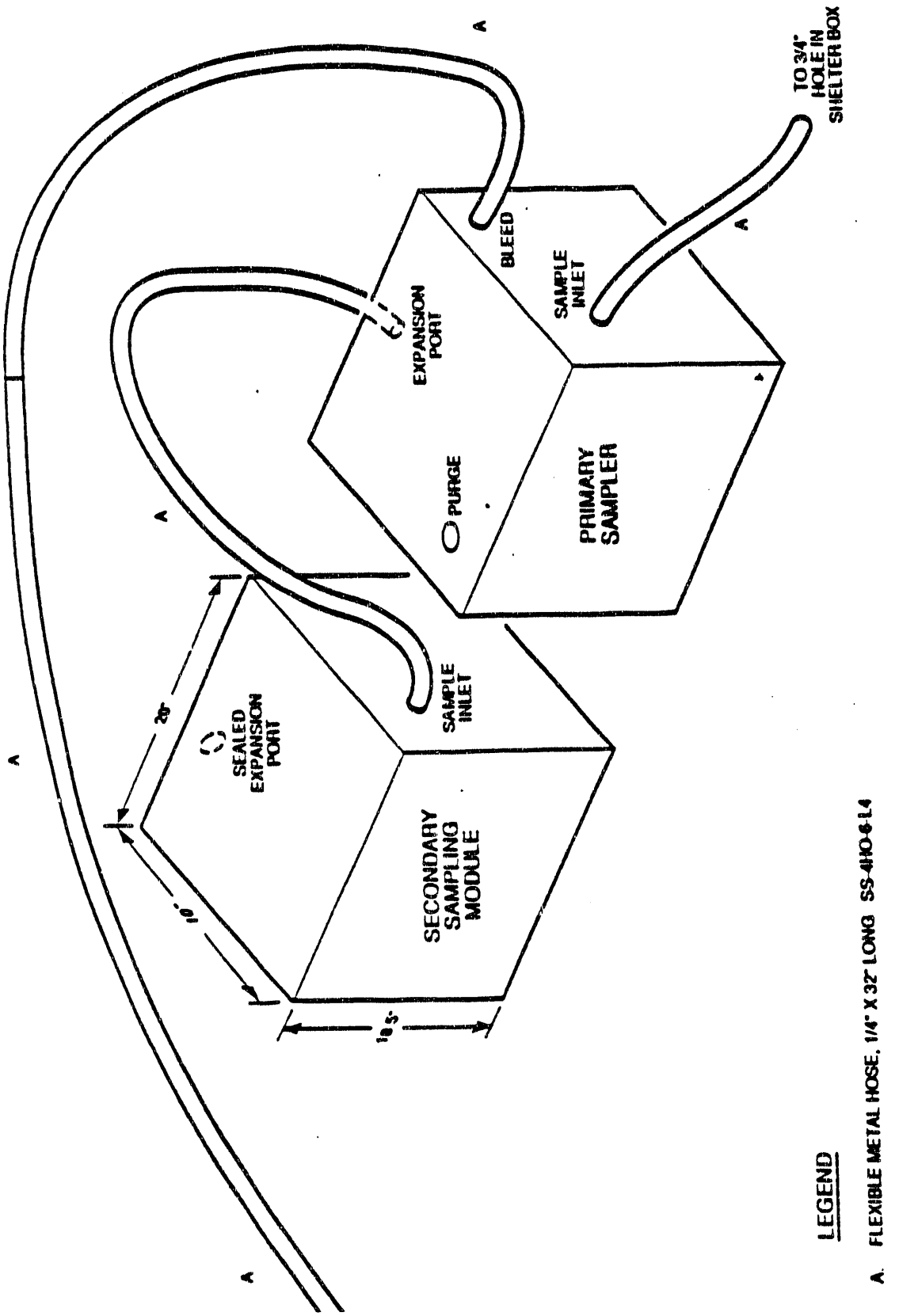
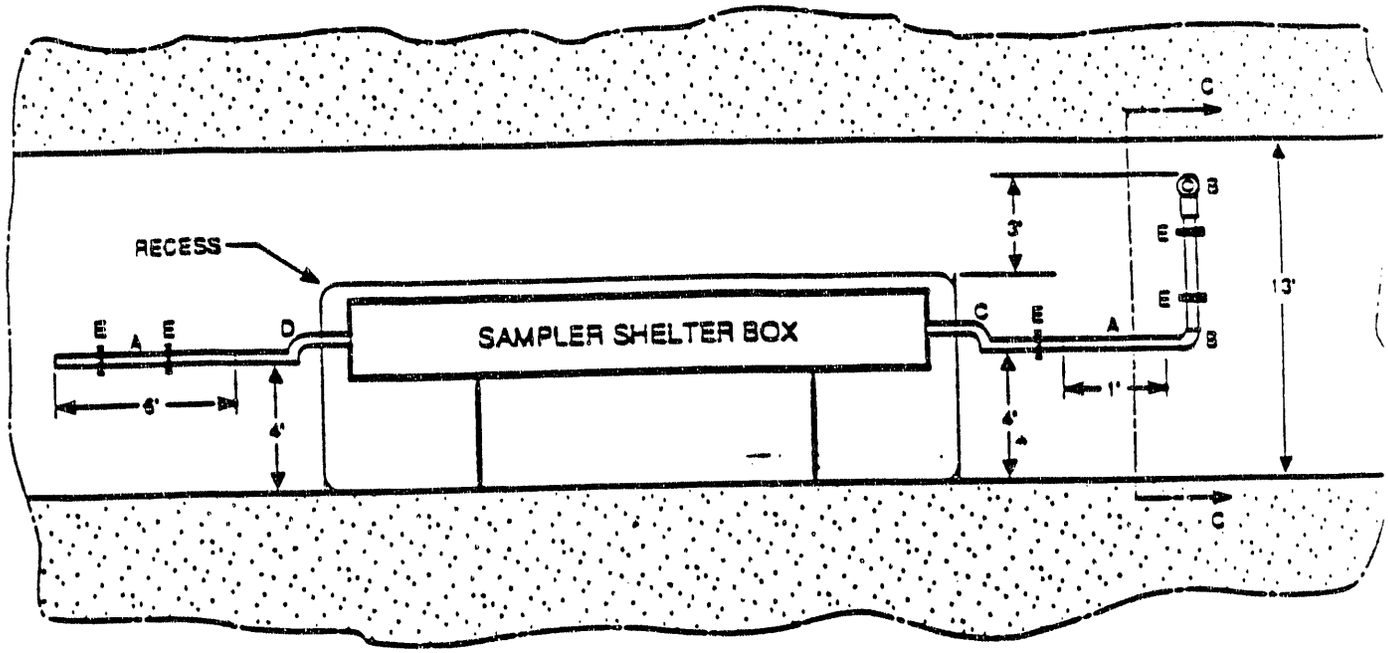


FIGURE 4. Tubing Interconnections Between Primary Sampler and Secondary Module

FOR INFORMATION ONLY



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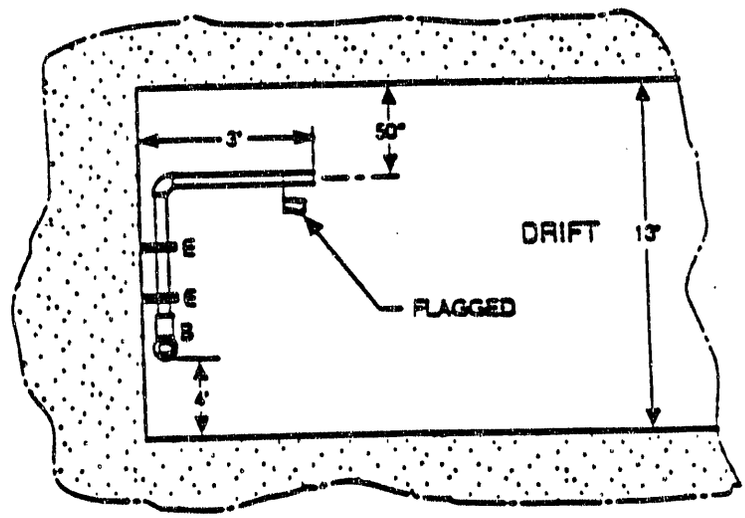


SECTION C-C

LEGEND

A. 1/4" O.D. X 0.028" WALL STAINLESS STEEL TUBE ASTM A269
B. SWAGELOK 1/4" UNION ELBOW SS-400-9
C. FLEXIBLE METAL HOSE, INLET SIDE, 1/4" X 32" LONG, SWAGELOK SS-4HO-6-L4
D. FLEXIBLE METAL HOSE, OUTLET SIDE, 1/4" X 32" LONG, SWAGELOK SS-4HO-6-L4
E. METAL FRAMING CHANNEL, B-LINE SYSTEMS, B22SH

FIGURE 5. Layout of Tubing Inlet and Outlet From Sampling Station

FOR INFORMATION ONLY

SAMPLER
TGS-2/A

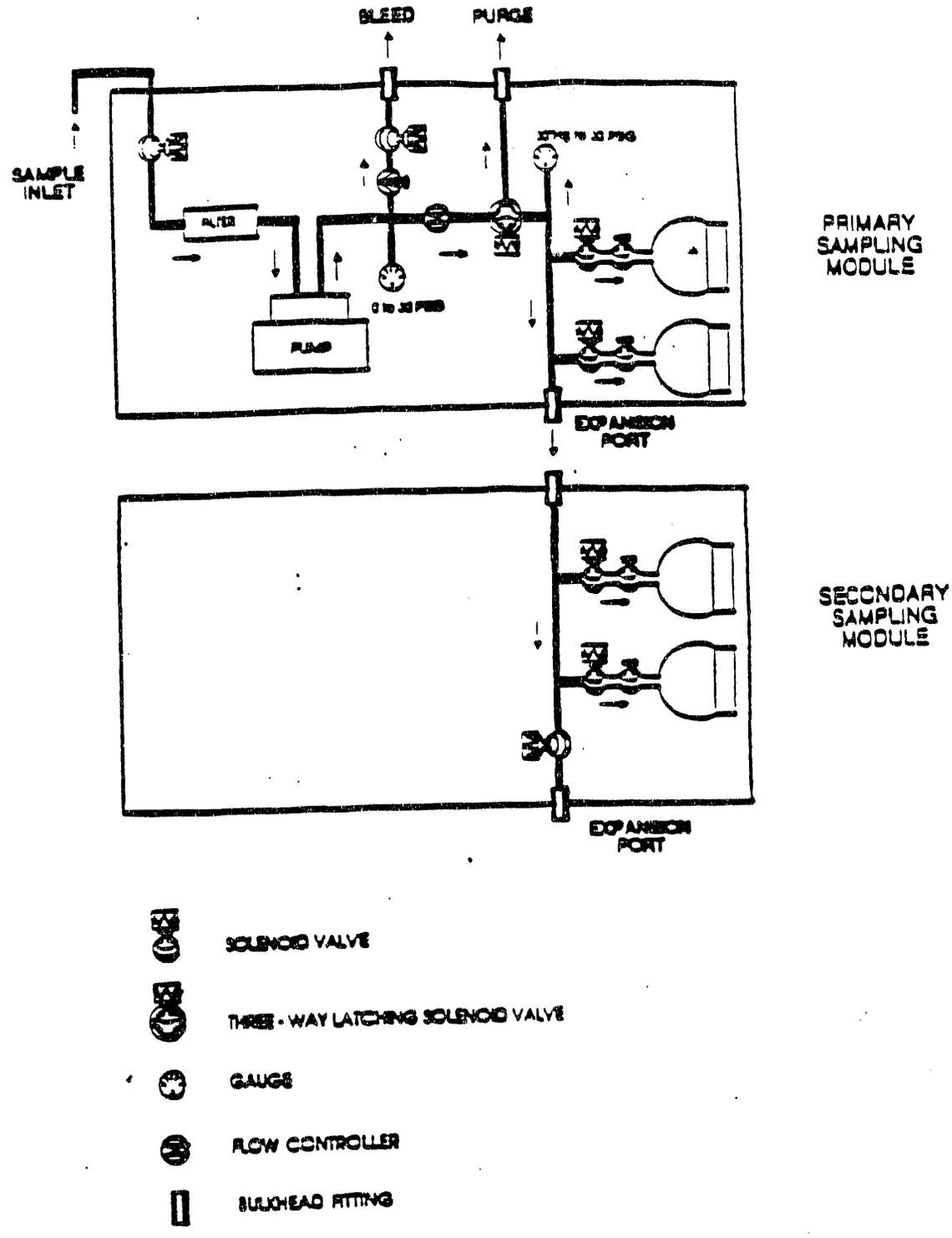
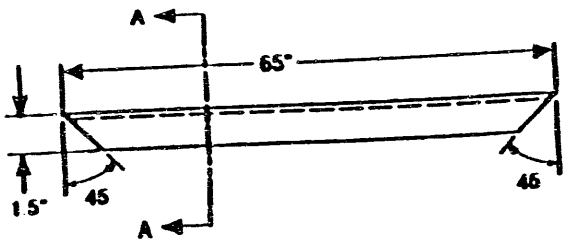


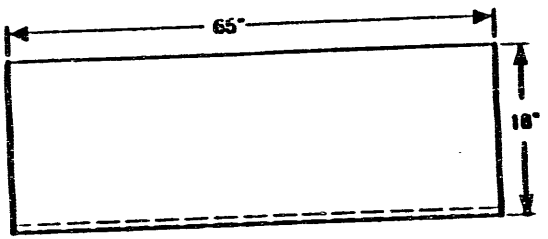
FIGURE 6. Air Sampler Unit

FOR INFORMATION ONLY

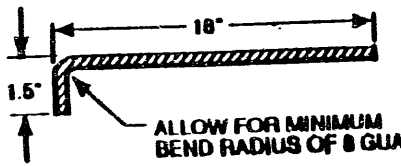


FRONT VIEW

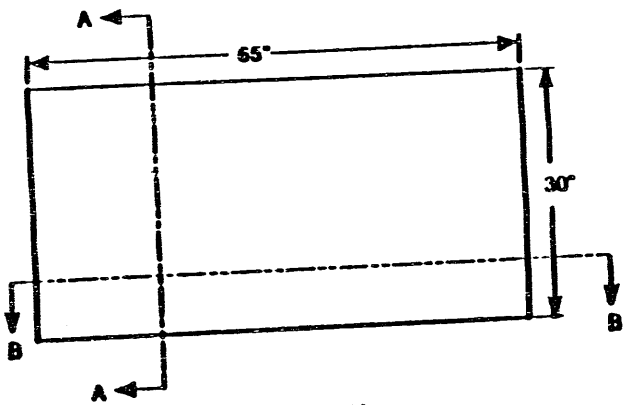
SHELTER BOX TOP



TOP VIEW

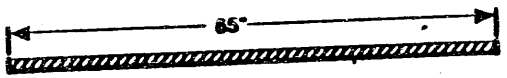


SECTION A-A



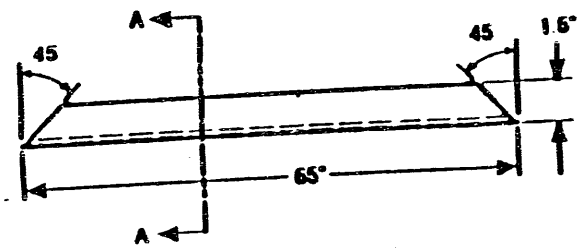
FRONT VIEW

SHELTER BOX BACK



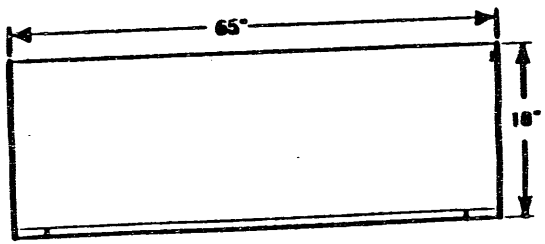
SECTION B-B

SECTION A-A

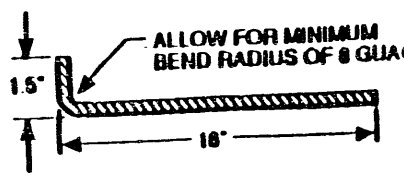


FRONT VIEW

SHELTER BOX BOTTOM



TOP VIEW



SECTION A-A

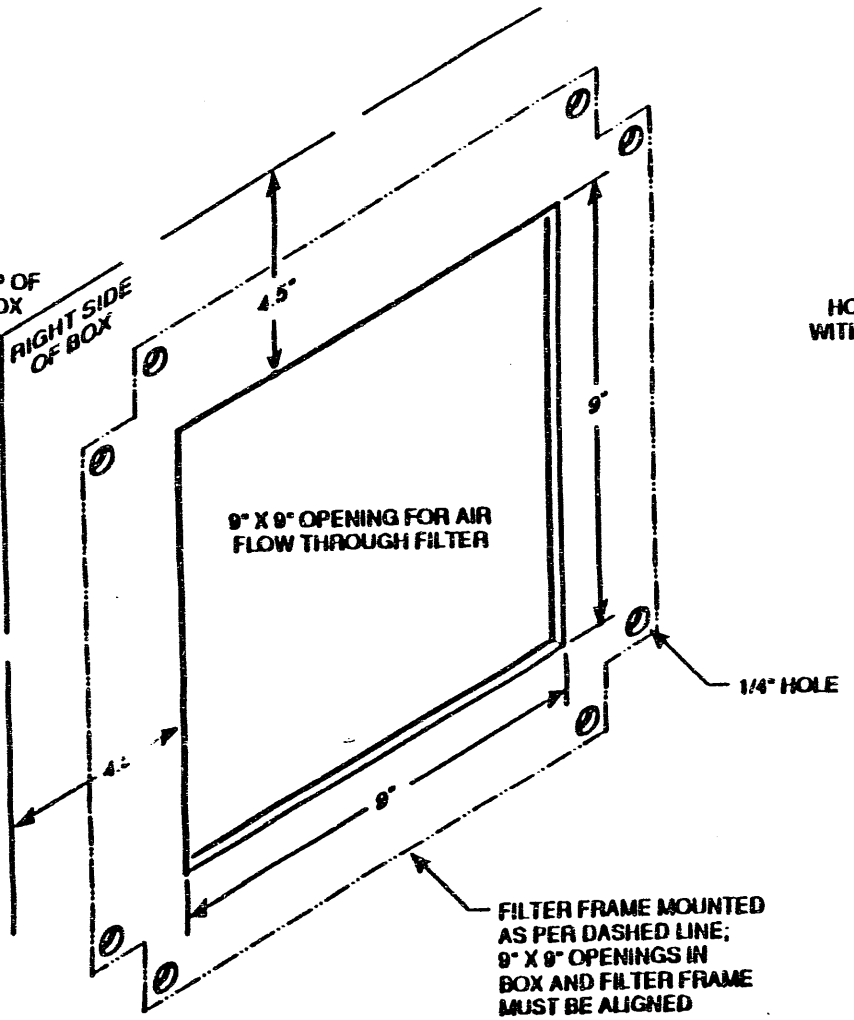
NOTES: 1 NOT TO SCALE
2 ALL PARTS FABRICATED FROM SS 316, 8 GAUGE

FIGURE 7. Fabrication Drawing for Sampler Shelter Box (Components - Top, Back, and Bottom)

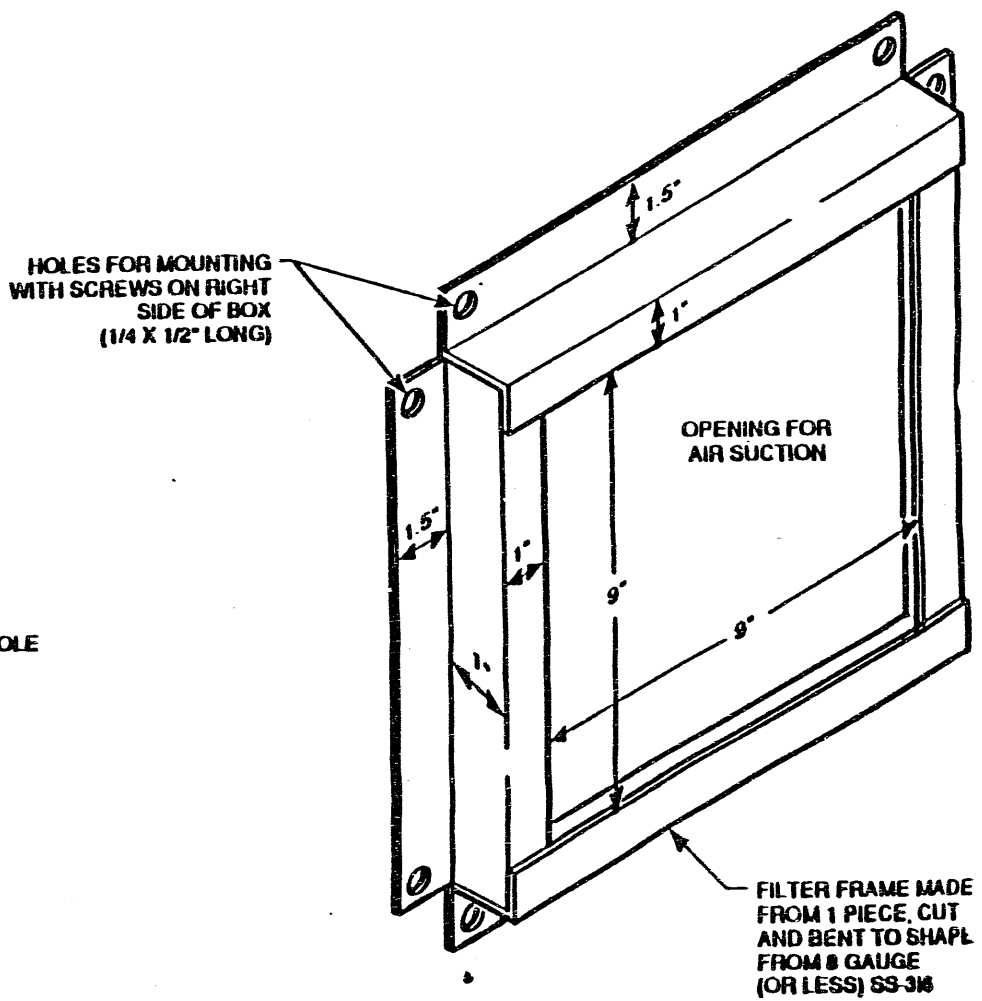
FOR INFORMATION ONLY
EPA-135-K
Rev. 0

FIGURE 8. Fabrication Drawing for Sampler Shelter Box
(Components - Left and Right Side)

FOR INFORMATION ONLY



SHELTER BOX (RIGHT SIDE)



FILTER FRAME

FIGURE 9. Details of Filter Frame and Associated Mounting

FOR INFORMATION ONLY

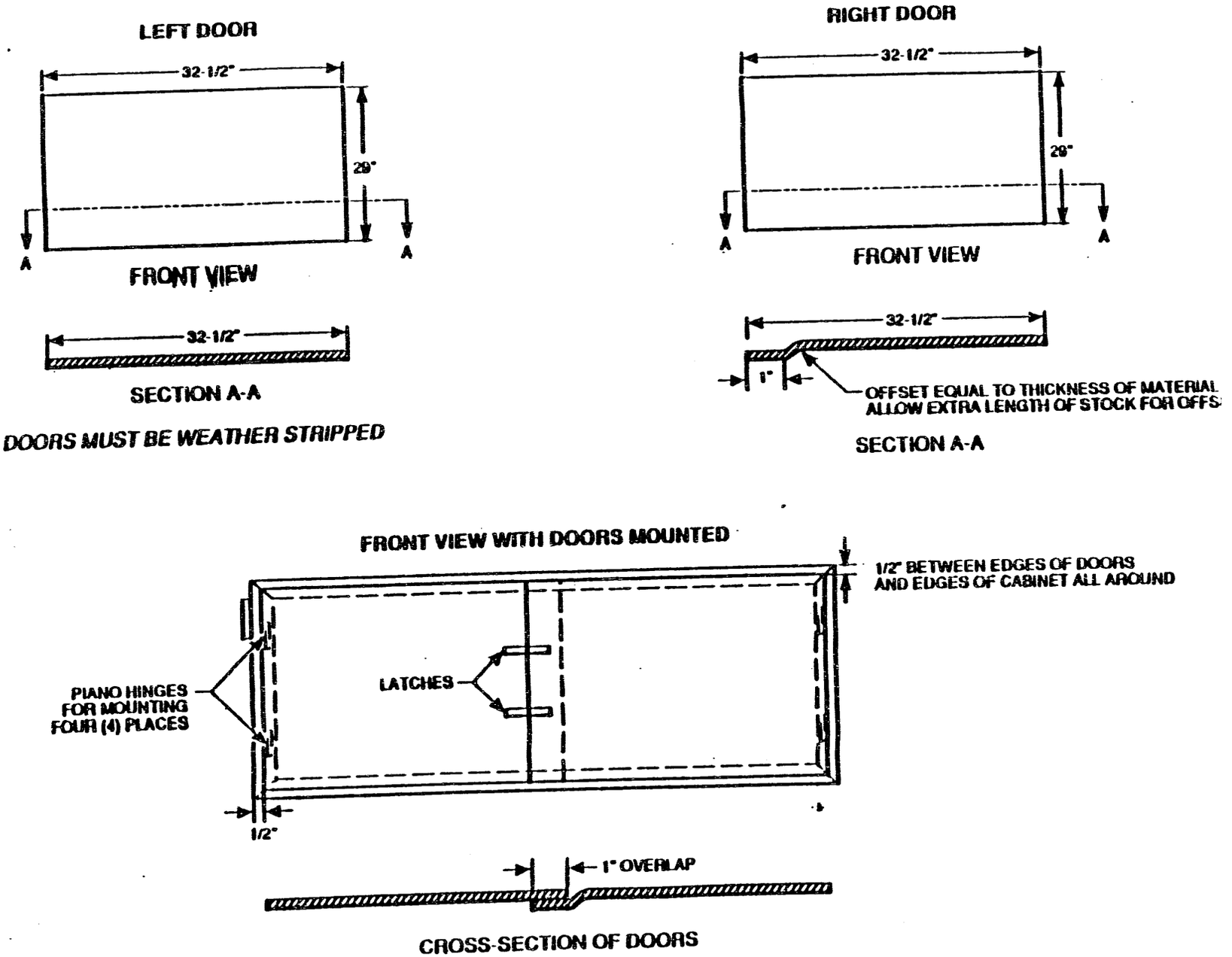


FIGURE 10. Fabrication and Mounting Drawing for Shelter Box Doors

NOTES: 1 NOT TO SCALE
2 ALL PARTS FABRICATED FROM SS 316, 8 GAUGE

FOR INFORMATION ONLY

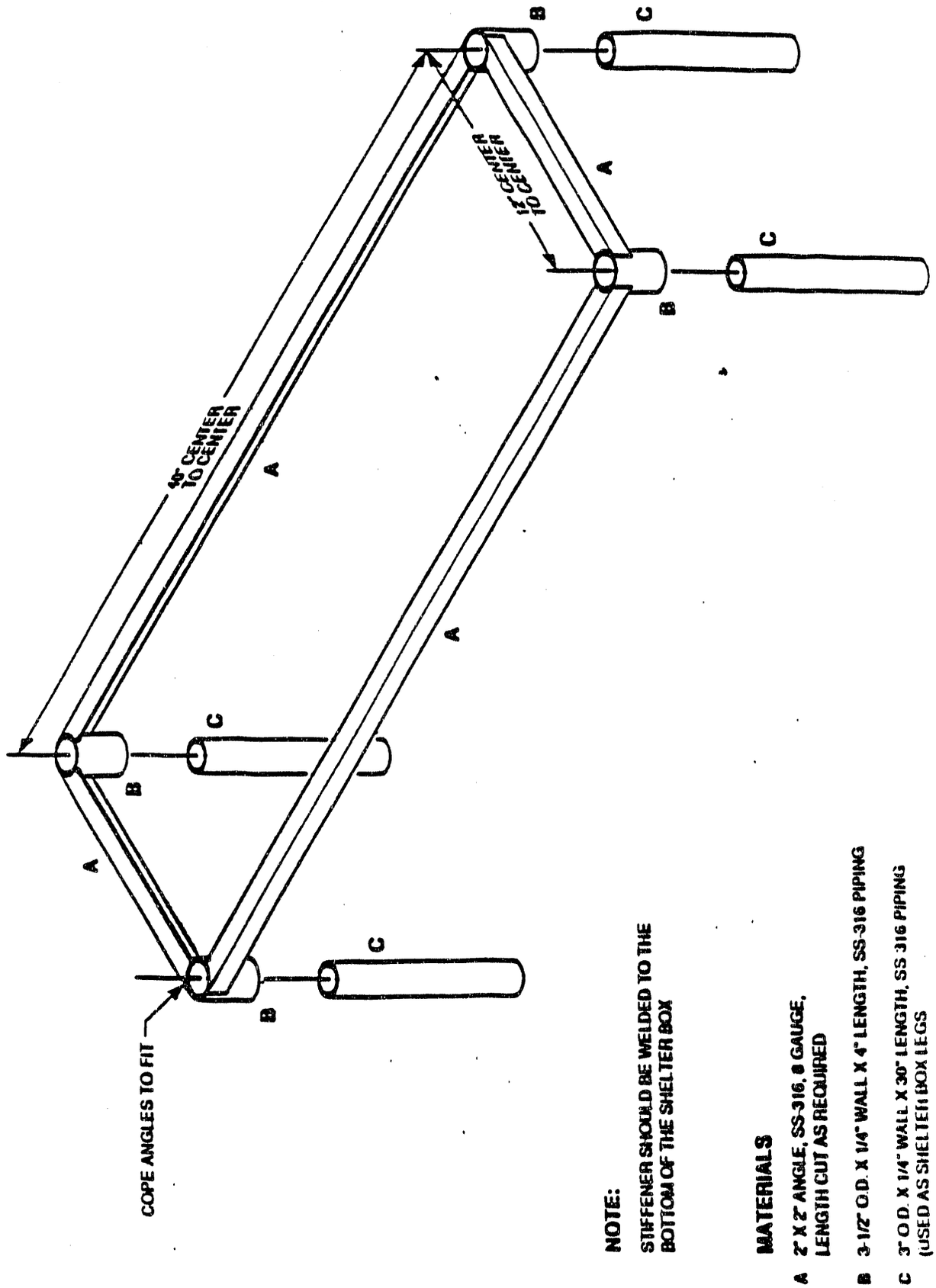


FIGURE 11. Fabrication Drawing for Shelter Box Leg Stiffener

FOR INFORMATION ONLY

NOTES:

1. NOT TO SCALE
2. ALL SHEET STOCK PARTS FABRICATED FROM SS-316, 8 GAUGE

WELDING PROCEDURE

1) TACK WELD TOP, BOTTOM, BACK, AND BOTH SIDES TO FORM OVERALL BOX FRAME.
2) WELD ALL ADJACENT EDGES.
3) WELD LEG STIFFENER AT BOTTOM.

FIGURE 12. Assembled View of Shelter Box (Shown Without Legs)

FOR INFORMATION ONLY

Table 1

EQUIPMENT COST AND DELIVERY INFORMATION

Item	Quantity at Unit Price	Total Cost
Air Sampler, SIS Model TGS-2/A together with Secondary Sampling Module	2 at $9,000.00 (These samplers have been ordered by Purchase Requisition No. 41205)	$18,000.00
Shelter Box, 65" x 18" x 30", stainless steel, fabricated	2 at $1,773.00	$ 3,546.00
Exhaust Fan Dayton, Model 2C634	2 at $67.69	$ 135.38
Flexible Metal Hose, 1/4 x 32 Swagelok, SS-4HO-6-L4	12 at $110.60	$ 1,327.20
1/4 Union Elbow, Swagelok, SS-400-4	4 at $27.25	$ 109.00
Brackets for Wall Mounting, B-Line Systems, Formed Channel, B22SH	50 ft. at $1.60	$ 80.00
1/4 O.D. x 0.028 Wall 316 Stainless Steel Tubing, ASTM A269, Degreased, Solvent Free, ends capped for shipping	40 ft. at $3.94	$ 157.60
Disposable Glass Fiber Air Filters, Size 10" x 10"	1 dozen at $15.22	$ 15.22
3/4" Rubber Grommet	10 at $_____	$_____
1" Rubber Grommet	5 at $_____	$_____

Delivery Schedules

The first three items on the list will take 3 to 4 weeks. All other items will be available within 1 week.

FOR INFORMATION ONLY

MEETING MINUTES

Name	Organization	Attendees Plus
W. P. Poirier	WID	L. R. Fitch
C. E. Conway	WID	T. W. Halverson
S. C. Cooper	WID	R. Kuginskie
L. Frank	WID	J. R. Walls
J. J. Garcia	RWHE	O. L. Cordes
R. F. Kehrman	WID	T. F. Kocialski
C. R. Kelley	WID	L. L. Reed
M. W. King	RWHE	
R. J. Rodriguez	RWHE	
S. C. Sethi	RWHE	

Prepared By: Sethi — Date: 4/3/90

Subject or Purpose of Meeting: VOC MONITORING SYSTEM - OPERATION & STAFFING — Location: SCR — Date: 4/2/90

Item Number	Discussions or Resolutions	Action By	Date
	This meeting was called to assign responsibilities for operating and maintaining the VOC Monitoring System and establish staffing requirements (Ref. Letter no. HA:90:7096 of March 15, 1990). It resulted in the following decisions:		
1	PWR's (030s) on all VOC Monitors required, both on surface and underground, will be issued by R. F. Kehrman. Does not need to include Panel 1 Room 1.	Kehrman	
2	Facilities Engineering shall provide the required support for installation of the VOC Monitors. RWHE is already working on the Room 1-Panel 1 VOC Monitoring System.	Kocialski	
3	In addition to Room 1-Panel 1 VOC Monitors, RWHE will also procure all other monitors with two spare units.	Garcia	
4	Evaluation shall be performed by Mr. Kehrman's group on: a) The need for providing an alarm or alarms in the CMR in case of failure of any of the VOC Monitors. b) Required corrective action in case of failure of VOC Monitors individually and collectively.	Kehrman	

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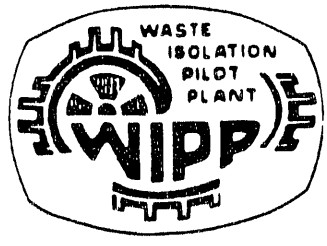
MEETING MINUTES
(Continued)

Item Number		Action By	Date
	c) Possibility of establishing a temporary on-site gas analysis facility.		
	d) Establishing the appropriate number of sampling bottles required.		
5.	Waste Handling Operations will be responsible for operating and maintaining the VOC Monitoring System. Sampling bottles shall be collected by Waste Handling Operations in accordance with approved procedures (to be developed) and delivered to Mr. Kehrman's group for analysis. Mr. Kehrman will coordinate collection and transmittal of all test results.	Kuginskie/ Kehrman	
6.	The system shall provide for automatic collection of samples for up to 4 days to allow week-end and holiday coverage.	Garcia	
7.	a) Waste Handling Ops. shall determine staffing requirements and identify appropriate training for operating and maintenance personnel.	Kuginskie	
	b) Regulatory & Environmental Programs will have a Systems Expert.	Kehrman	
	c) Engineering will assign a Cognizant Engineer responsible for the system.	Halverson	

SPEC. NO. E-S-362
REVISION NO. 0
REVISION DATE 10-10-90
SYSTEM EM05

VOC MONITORING STATION LOCATED IN THE EXHAUST SHAFT AT STATION A



WASTE ISOLATION PILOT PLANT

Westinghouse Electric Corporation
Carlsbad, New Mexico 88220

FOR INFORMATION ONLY

ENGINEERING CHANGE ORDER
(USE BLACK INK)

(1) CC&D REVIEW [X]

ECO- 4767

(2) IMPACT LEVEL
- [ ] LEVEL-1
- [ ] LEVEL-3
- [X] LEVEL-2

(SEE SIDE 2 FOR APPROVALS)

(3) SYS/EQUIP NO./BLDG
EM05

(4) ASSOCIATED DOCUMENTS
030 _____
RELATED ECO _____
EDT _____
P.O. _____

(5) DOCUMENT NO.
- DRAWING [ ]
- SPEC [X]
- O&M MANUAL [ ]
- SDD [ ]

E-S- 3622

(6) SHEET
—

(7) REVISION ADVANCED
FROM Draft TO 0
FROM ____ TO ____

(8) DOCUMENT TITLE
ENGINEERING DESIGN SPECIFICATIONS FOR THE VOC MONITORING STATION LOCATED IN THE EXHAUST SHAFT AT STATION A.

(9) DESCRIPTION OF CHANGE
Equipment specification for the VOC Monitoring Station located in the Exhaust Shaft at Station A.

Y/N
- [ ] [X] ELECTRICAL LOAD LIST (25-X-001-W)
- [ ] [X] PANEL SCHEDULE (INCLUDE MARK-UP)

- [ ] YES [X] NO

**** MODIFICATION IN PROGRESS
(ECO NOT TO BE INCORPORATED)

- [ ] MODIFICATION COMPLETE _____
(ECO RELEASED FOR INCORPORATION)

(10) JUSTIFICATION
Need for equipment specification.

(11) ORIGINATOR (PRINT)	(12) PHONE	(13) ORGANIZATION	(14) DATE
Shane Thompson	8373	EE	7/5/90

(15) COG. ENGINEER (PRINT)	(12) PHONE	(16) DRAFTING REQUIRED DATE
NONE		

FOR INFORMATION ONLY

U.S. DEPARTMENT OF ENERGY
WASTE ISOLATION PILOT PLANT

SPECIFICATION E-S-362
ENGINEERING DESIGN SPECIFICATIONS FOR THE VOC MONITORING STATION LOCATED IN THE EXHAUST SHAFT AT STATION A

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	1.3 System Purpose and Design Objectives	1
	1.4 System Description	2
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List of Attachments

Attachment	Title
A	Table 1. Equipment Cost and Delivery Information
B	Copy of Meeting Minutes Dated 4/3/90

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1.0 SCOPE

1.1 Description of Work

This design specification is for the monitoring of volatile organic compounds (VOCs) in the exhaust shaft at Station A. This location is shown in Figure 1 as Station VOC-1. The design is based on the concept presented in the VOC Monitoring Plan, Waste Isolation Pilot Plant (WIPP) prepared by International Technology Corporation of Albuquerque, New Mexico, dated January 1990. It meets the sampling requirements outlined in the VOC Monitoring Plan and accomplishes the objective of satisfactory monitoring of VOCs at the repository unit boundary.

1.2 Definitions

The following definitions clarify certain terminology contained in this document.

Sampler and Accessories - Air sampler unit with all the supporting items required for its installation and operation (as described in a later section).

Secondary Module - Unit containing two sampling canisters used to increase sampling capacity of the air sampler unit.

Suppliers - All vendors supplying any equipment or part thereof for the sampler
and accessories.

Volatile Organic Compound (VOC) - Organic compounds having saturated vapor pressures at 25° C, greater than 10^{-1} mm Hg.

1.3 System Purpose and Design Objectives

The main purpose of the VOC Monitoring System is to fulfill the requirements of 40 CRF 268.6, which allows the disposal of wastes otherwise prohibited from land disposal only if a demonstration can be made that, to a reasonable degree of certainty, there will be no-migration of hazardous constituents from the disposal unit for as long as the wastes remain hazardous. VOCs are considered as hazardous constituents, and therefore a monitoring program will be implemented at the WIPP facility which is capable of detecting releases of VOCs from the bin and alcove experiments and conclusively providing evidence of no-migration of VOCs from the WIPP in concentrations exceeding health-based criteria. Thus, a VOC Monitoring System is mandatory to enable the WIPP No-Migration Variance Petition to fulfill the requirements of 40 CFR 268.6.

The specific purpose of air sampling at this location is described below:

- Station VOC-1 will be deployed at Station A in the exhaust shaft area to monitor detectable quantities of the target compounds in the air which will be exhausted into the ambient atmosphere outside of the facility at WIPP. Monitoring at the exhaust shaft is required to demonstrate no-migration of VOCs from the waste stored underground at the WIPP. This will be demonstrated by quantitatively showing that the concentrations of these compounds leaving the exhaust shaft are

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not greater than background concentrations resulting from sources other than the waste stored underground.

1.4 System Description

The sampling location is shown in the general layout of VOC Monitoring System locations in Figure 1. This section describes the components of this sampling stations and its precise location at the WIPP facility. The sampling system includes only the primary sampler with all controls and does not require the secondary sampling module. The secondary module is used for increasing sampling capacity, and for extended automated sampling up to four days (if necessary, during weekends, holidays, etc.). Station VOC-1 will be sampled only once per week and does not require extended sampling capabilities. However, the sampling system design will allow for the expansion of sampling capabilities if becomes desirable in the future.

1.4.1 Exhaust Shaft at Station A (Station VOC-1)

The assembly of the sampler and a potential secondary sampling module in Station A at the exhaust shaft will not require a protective shelter box. The primary sampler and the secondary module are roughly of the same size (20"x18.5"x 10"), and will sit side by side behind the existing location of Skid A. It is anticipated at this time that the sampling unit(s) will sit on the floor against the back wall of Station A. The protective structure now housing the monitoring equipment in Station A is climate controlled and protected from the weather, dust, and moisture. No additional protection for the sampling equipment is required.

The tubing interconnections between the primary sampler and a potential secondary sampling module are shown in Figure 2. The primary sampler has one inlet for sampling and three pathways for exit air in the form of bleed air, purge air, and a connection port for expansion. All connections are made by flexible stainless steel metal hoses for ease of assembly, and also to facilitate easy dismantling whenever needed. The expansion port is used to connect the main sampling unit to the secondary module if desired. The bleed air is taken out of the main sampler through a flexible stainless steel metal hose and is routed back to the exhaust air stream of the sampling system of Skid A. No fittings are necessary on the purge air connection. The purge air out connection will be capped after flow to the sample canister loop has been adjusted to the desired volume using the mass-flow controller. Detailed description of the sampling unit is discussed later in this section.

The layout of tubing inlet and outlet from the sampler to Skid A is shown in Figure 3. The sampler inlet line will be attached using a Swagelok T just upstream of the vacuum pump now installed in Skid A. Air will be drawn into the sampler from the airstream that is now monitored by Skid A in Station A at the exhaust shaft. The outlet airflow from the bleed port on the VOC sampler will be routed back to the exhaust airstream on the downstream side of the vacuum pump.

The VOC sampling unit is shown in Figure 4. It is essentially an automated two canister air sampler with the capacity for four 6-liter sample canisters to be filled when the secondary sampling module is utilized. The sampler can collect up to four samples in 6-liter sampling containers (two in the primary sampler and two in the secondary module) using separate timing channels for

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each container. The sampling pump and the inlet and bleed air solenoid valves are operated by the third timing channel. A proprietary design feature allows operation of the three-way solenoid valve for both the purge mode and actual sample collection. The unit will be operated from a 120V AC power supply. Under normal operating conditions, the sampler utilized normally closed solenoid valves that are energized and remain energized in their open position. The valves do become warm but do not pose a fire hazard. All pneumatic and electronic components are housed in the control module and are accessible either from the control panel or upon removal of the control module from the container housing.

Details of the sampling method and frequency of sampling are provided in the document "VOC Monitoring Plan" listed in Section 2.0.

The sampler will also have a real-time clock which will have the provision of shutting off if a power failure occurs. Thus, in case of a power failure going undetected for any length of time, the real-time clock will give an indication of how many of the 24 hours of required sampling were actually carried out. Once this is known adjustment will be made to compensate for the lost time.

1.5 System Operation

Once the system has been properly assembled, the only operating component is the sampler itself as shown in Figure 4. The sampler is set for a sampling cycle by plugging the unit into an available 120V AC power outlet. The actual clock time is set first and then the unit is programmed for the sample collection of as many as four canisters. The sample collection into container #1 is operated by timing channel #1, and the corresponding sample collection into container #2 is operated by timing channel #2. Timing channel #3 operated the sampling pump and the inlet and bleed air solenoid valves which open and remain open whenever the sampling pump is operating. The secondary module also has a three-channel timer for similar purposes if needed.

The seven-day, three-channel digital timer allows independent control of the sampling pump with the inlet and bleed air solenoid valves, and dedicated timing of each of the two sampling channels. The three-way purge solenoid valve is operated separately by each sampling channel. The time has a battery backup for memory, large LC display, and is easily programmable.

Purge air flow exits via the three-way solenoid valve purge port on top of the control panel. This port is also used to set the flow and to calibrate the flow controller. When the sampling into container #1 or #2 begins, the sample air flow is diverted into the sampling container at the flow that has been set by the flow controller. The bleed air adjustment, and the related pump head pressure (read by the 0-30 psig pressure gauge) are controlled by the needle valve located on the upper right side of the control panel. The flow adjustment is done via the set screw on the tamper proof flow controller located on the upper left side of the control panel. The inlet bleed air and purge air plugs are removed prior to sampling. After the sampling flow rate is adjusted, the plug or cap for the purge air port will be reinstalled to prevent any air from being discharged to the atmosphere in Station A. The sampling containers located in the bottom case are connected to the solenoid valve outlets labeled sample #1 and sample #2 with the connecting tubes supplied with the sampler. The digital timer LED lights up when a given

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channel is in use. The sampling container valves should be open prior to the beginning of the sampling cycle.

After completing the sampling cycle the container valves are closed using extension handles. The connecting tubes are disconnected and the sampling containers removed and replaced with new ones.

1.6 Program Responsibility

The responsibilities (see Attachment B, Meeting Minutes, 4/3/90) associated with the design, installation, and operation of the sampler and accessories are as follows:

- Systems Design - Waste Isolation Division/International Technology Corporation (WID/IT) will provide technical support to Regulatory and Environmental Programs.
- Systems Installation - Facilities Engineering will provide the required support for installation of the VOC monitoring systems.
- Systems Operation - Operation and maintenance of VOC monitoring systems:
    - Surface sample collection at Station VOC-1 will be performed by Waste Handling Operations Technicians.
    - Underground sample collection will be performed by a Waste Handling Operations Technician.
    - Handling and storage of used and new canisters, and shipment of canisters to an off-site laboratory for analyses will be performed by an Environmental Monitoring Technician.
- Program Management and receipt of analytical data from the laboratory will be performed by the Environmental Compliance Section of Regulatory and Environmental Programs.

2.0 APPLICABLE DOCUMENTS

2.1 Order of Precedence

Unless otherwise specified, this design specification shall take precedence over any of the documents listed in this section.

2.2 Codes, Standards, and Practices

The following codes, standards, and practices shall be considered a part of this specification. Unless otherwise stated, the latest revision of each document shall apply.

ASTM A269	American Society for Testing Materials
SW846	EPA and RCRA Sampling Standards

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Compendium
Method TO-14 EPA Procedure for VOC Sampling

2.3 Reference Documents

The following documents shall be considered a part of this specification. Unless otherwise stated, the latest version of each shall apply.

	VOC Monitoring Plan, Waste Isolation Pilot Plant, DOE, January 1990
WP 090-21	WIPP Equipment Numbering Procedure
D-0077	Engineering Design Specification for VOC Monitoring System, March 8, 1990.

3.0 DESIGN REQUIREMENTS

This section describes the requirements for the design, maintenance, personnel,
material fabrication, packaging, shipping, and handling.

3.1 General Requirements

The design of the system shall be to the maximum extent possible: 1) be based on existing technology, maximizing the use of standard available components and standard design and construction for the service specified; 2) be engineered, designed, built, and/or finally assembled by the organizations listed in Section 1.6; 3) conform to this specification; 4) comply with recognized industrial standards and practices; and 5) be of sound quality.

Any filters connected upstream of the sampler inlet shall not absorb or remove component gases like VOCs.

All materials of construction for the sampler and its accessories need to be suitable for use in the WIPP underground environment and for performing their intended functions over the duration of the test phase.

3.2 Instrumentation and Control Requirements

All the equipment required as shown in Figures 2 through 4 are listed in Table 1 in Attachment A. Unless otherwise specified, any original equipment listed can be substituted with an equivalent. Table 1 also lists the costs and delivery time for each item.

3.3 Maintenance Requirements

The sampling personnel will have complete responsibility for routine sampler maintenance. This includes but is not limited to replacement of damaged or malfunctioning parts, filter changes, leak testing, and any minor cleaning. All major cleaning and sampler cleanliness certification will be the responsibility of the laboratory contracted for post-sampling analytical procedures.

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Two complete spare units and a spare parts inventory will be maintained on site to minimize down time due to malfunction of any sampler.

The sampling system at this location will include sufficient collection canisters (approximately ten) so that any delays due to laboratory turn around time and canister cleaning and certification will not result in canister shortages.

3.4 Electrical Requirements

A 110/120 VAC 60 Hz, 15A power supply is required for operating the sampler. Therefore, appropriate power outlets are required in the vicinity of the exhaust shaft sampling location.

3.5 Personnel Requirements

Trained personnel will be required to operate sampling equipment, maintain and repair equipment, and to collect quality assurances and other air samples.

Once in routine operation, the system can be programmed to be completely automatic except for routine maintenance checks and canister changeout. Once a sampling program is stored in memory, that control program will be executed until it is changed, canceled, or a complete power loss occurs.

3.6 Material Requirements

All piping and instrumentation will be made of stainless steel. The possibility of associated stress corrosion cracking is remote due to the nonexistence of a high temperature and/or a high stress environment.

All stainless steel tubing and piping shall be cleaned by the following procedure. The tubing shall be cleaned (passivated) by a nitric/hydrofluoric acid wash at a maximum temperature of 130°F and a minimum temperature of 70°F for 10 to 15 minutes. The solution shall be made to the following concentrations: nitric acid (HNO_3) at 12 percent or 0.5 percent by volume; hydrofluoric acid (HF) at 3 percent or 5 percent by volume. To inhibit the solution, 7 to 10 grams per liter of iron may be added. The acid wash shall be followed immediately with a demineralized water wash until the solution indicates a neutral pH. (Reference: MIL-T-23226E Tube and Pipe, Corrosion Resistant Steel, Seamless.)

Westinghouse Quality Assurance shall witness cleaning of the tubing. The supplier shall notify WID when they are ready to perform the cleaning process.

3.7 Fabrication Requirements

There are no special fabrication requirements for the VOC monitoring system to be installed in Station A. The only requirement is attachment of the sampling inlet and outlet tubing to the existing monitoring equipment on Skid A in Station A.

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3.8 Packaging, Shipping, and Handling Requirements

In general, all suppliers shall ensure that the components are packaged and shipped such that they do not suffer any damage during shipment. All suppliers
will be responsible for any damage to components prior to installation.

Any tubing should be cleaned prior to packaging and shipment. All grease and foreign substances shall be removed using the procedures described in Section 3.6.

The suppliers shall ship the components to the address provided in the purchase
order.

Each crate or package shall be marked with ink, paint, or other indelible material to indicate the equipment number, purchase order number, and description of the equipment. Weight, center of gravity, and lifting points of packages shall be clearly marked for fragile or heavy materials.

4.0 FIELD EXECUTION

4.1 System Installation

The sampling system shall be installed according to work instructions prepared by the Westinghouse Environmental and Regulatory Compliance Section in conformance with the responsibilities outlined in Section 1.6.

In addition, the following procedure will also be followed:

- Prior to use, the sample collection unit must be laboratory certified to demonstrate that they are free of contamination.
- Prior to initiation of sampling, Standard Operating Procedures (SOPs) will be prepared by the contracted laboratory to describe the cleaning and certification procedures for the sampling units and sample canisters both before and after each sampling usage.
- The sampling system will be tested for leaks using a leak detector system similar to Snoop. Any detected leaks will be appropriately rectified.
- A performance test shall be carried out after complete installation of the system to the satisfaction of the responsible party listed in Section 1.6.

4.2 Personnel Training

All sampling personnel shall undergo special training to become familiar with the system, the standard operating procedures, and all emergency procedures wherever applicable. They should also be trained to understand the hazardous nature of VOCs and the sensitive nature of the TO-14 sampling method.

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5.0 QUALITY ASSURANCE REQUIREMENTS

All procedures will adhere to the Quality Assurance Project Plan (QAPP) which is presently under preparation. In addition, the following procedures will be followed:

- All Quality Assurance procedures already in place at the WIPP site will be strictly followed.
- All Quality Assurance procedures will be consistent with the Quality Assurance objectives outlined in the VOC Monitoring Plan document mentioned in Section 2.3.

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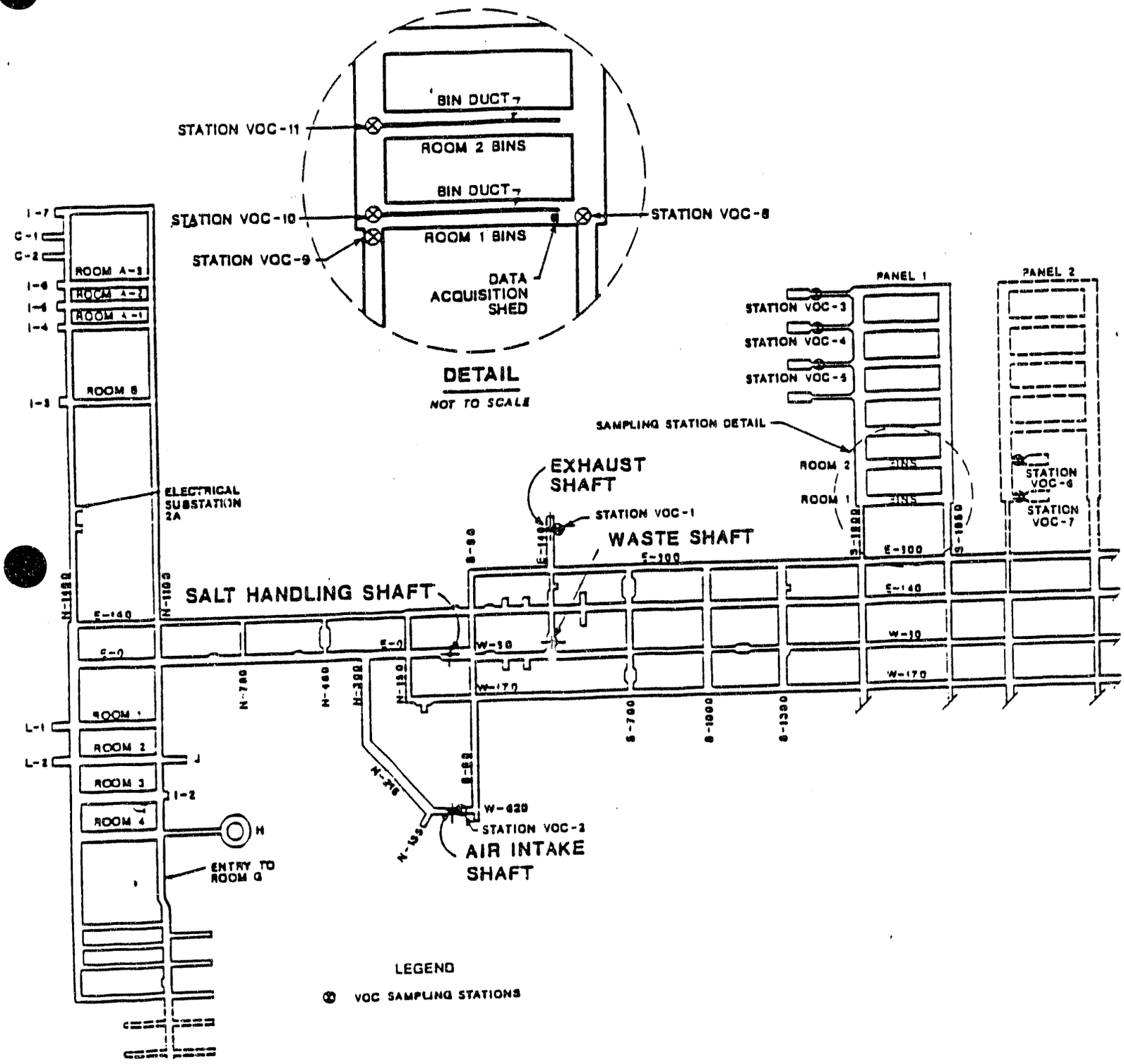

FIGURE 1. Schematic Diagram for VOC Sampling Stations

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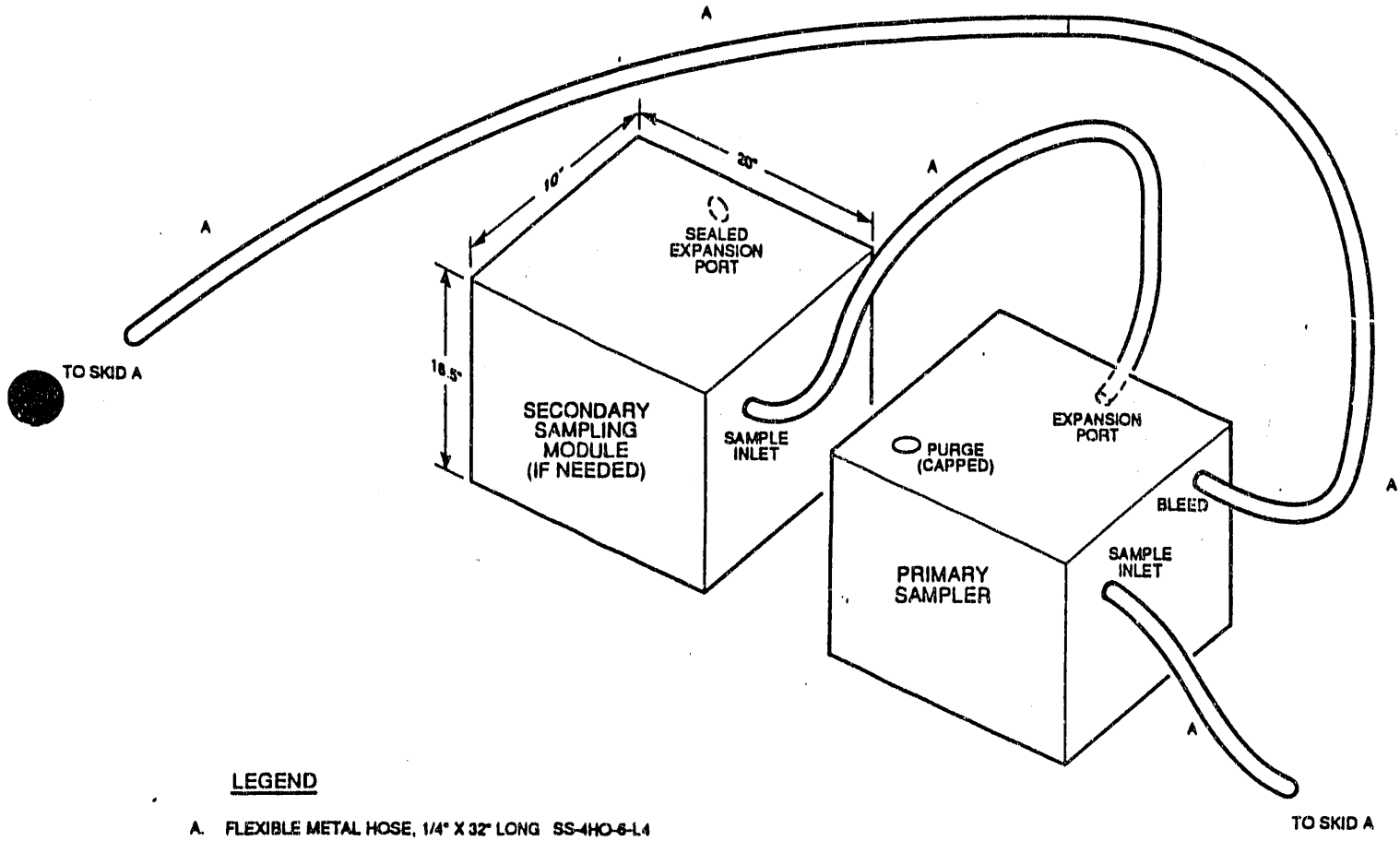

LEGEND

A. FLEXIBLE METAL HOSE, 1/4" X 32" LONG SS-4HO-6-L4

FIGURE 2. Tubing Interconnections Between Primary Sampler and Secondary Module

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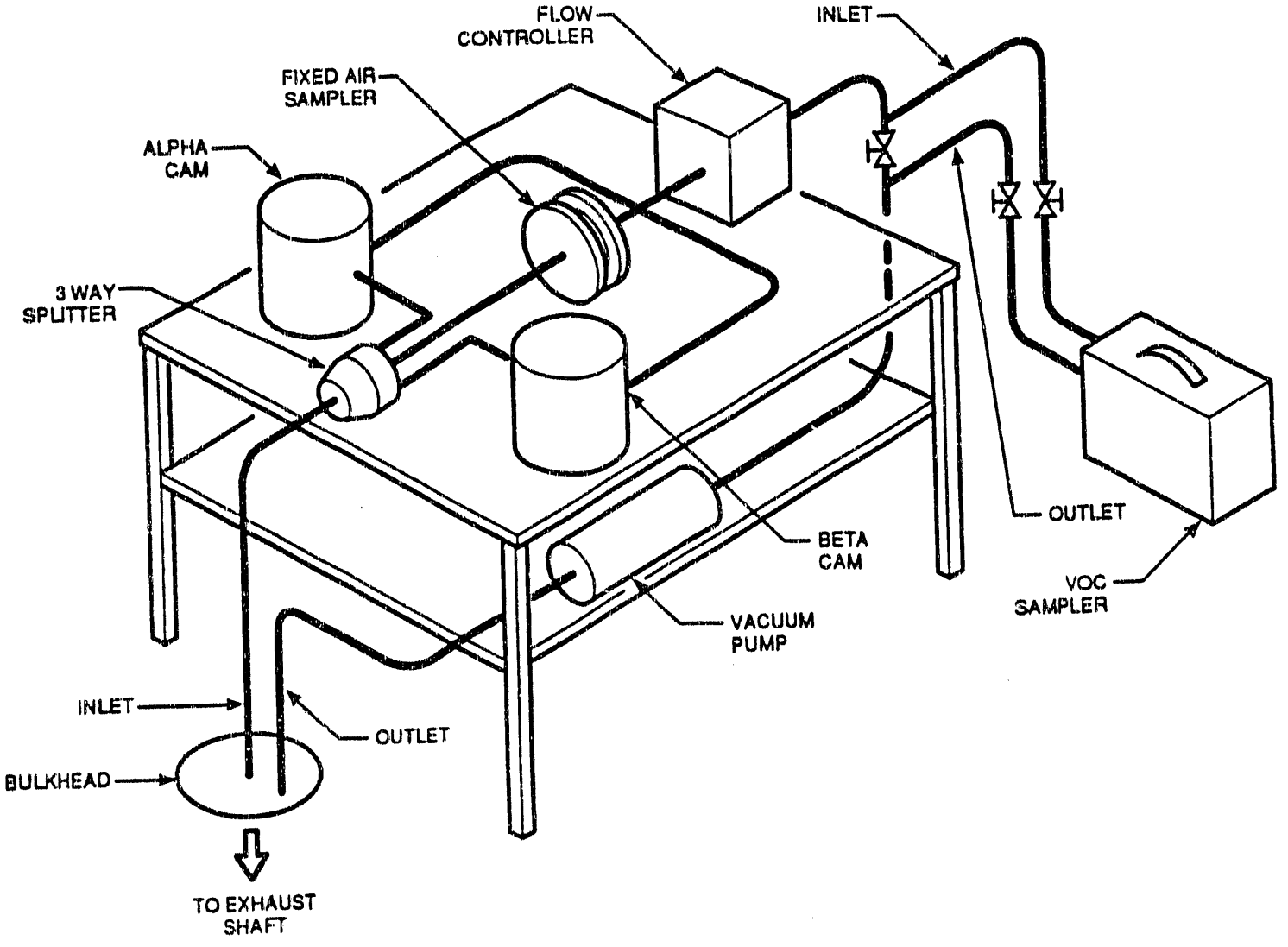

FIGURE 3. Layout of Tubing Inlet and Outlet From the Sampling Unit to Skid A in Station A

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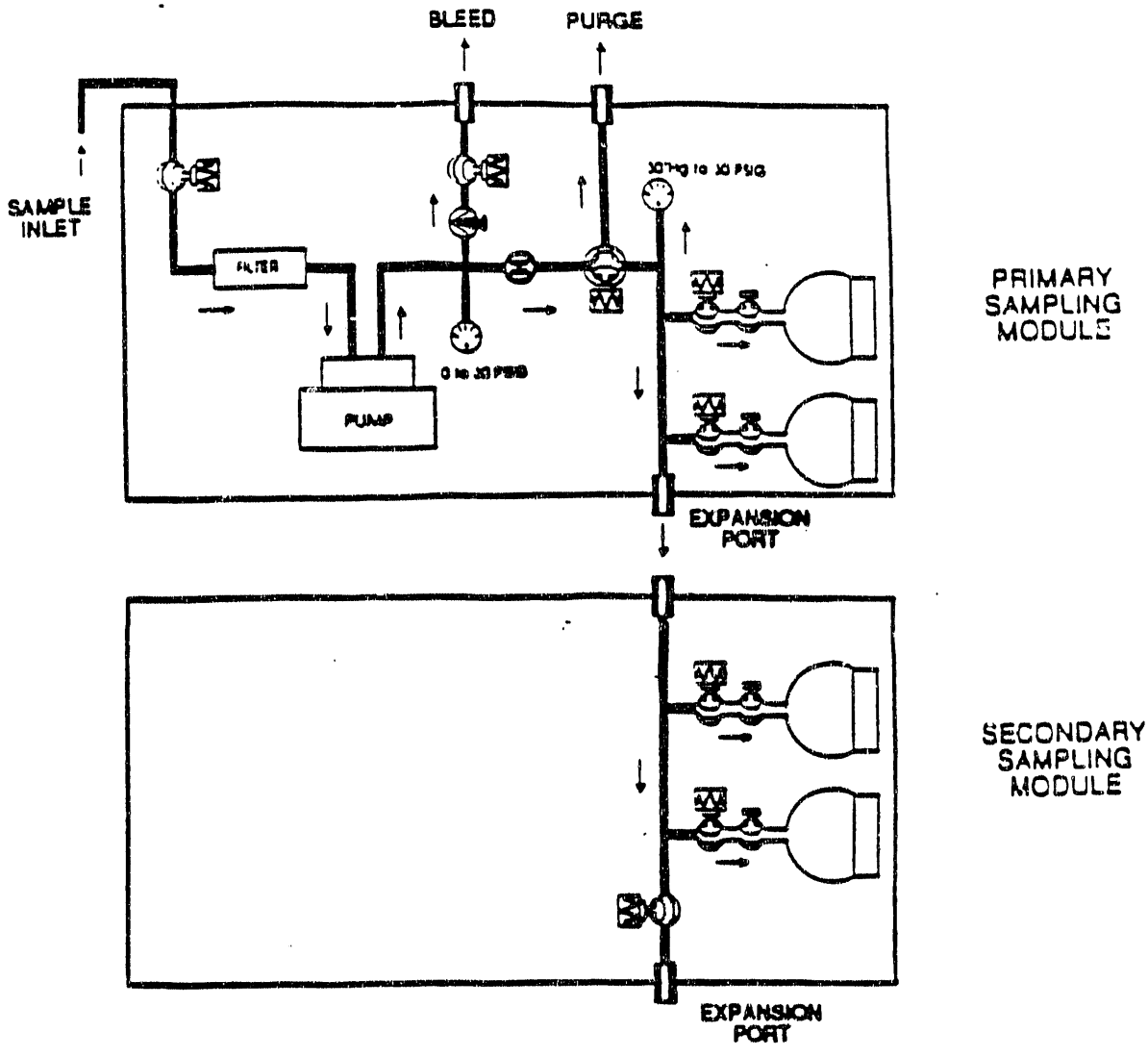

FIGURE 4 Air Sampler Unit

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Table 1

EQUIPMENT COST AND DELIVERY INFORMATION

Item	Quantity at Unit Price	Total Cost
Air sampler, SIS Model TGS-2/A together with secondary sampling module	1 at $9,000.00 (These samplers have been ordered by Purchase Requisition No. 41205.)	$9,000.00
Flexible metal hose, 1/4 x 32 Swagelok, SS-4HO-6-L4	4 at $110.60	$442.40
1/4 union elbow, Swagelok, SS-400-4	4 at $27.25	$109.00
1/4 O.D. x 0.028 Wall 316 stainless steel tubing, ASTM A269, degreased, solvent free, ends capped for shipping	15 feet at $3.94	$59.10
Delivery Schedules The first item on the list will take 3 to 4 weeks for delivery. All other items will be available within 1 week.		

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Meeting Minutes

MEETING MINUTES

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Attendees		Distribution
Name	Organization	Attendees Plus
W. P. Poirier	WID	L. R. Fitch
C. E. Conway	WID	T. W. Halverson
S. C. Cooper	WID	R. Kuginskie
L. Frank	WID	J. R. Walls
J. J. Garcia	RWHE	O. L. Cordes
R. F. Kehrman	WID	T. F. Kocialski
C. R. Kelley	WID	L. L. Reed
M. W. King	RWHE	
R. J. Rodriquez	RWHE	
S. C. Sethi	RWHE	

Prepared By	Date
Sethi	4/3/90

Subject or Purpose of Meeting	Location	Date
VOC MONITORING SYSTEM - OPERATION & STAFFING	SCR	4/2/90

Item Number	Disucssions or Resolutions	Action By	Date
	This meeting was called to assign responsibilities for operating and maintaining the VOC Monitoring System and establish staffing requirements (Ref. Letter no. HA:90:7096 of March 15, 1990). It resulted in the following decisions:		
1.	PWR's (030s) on all VOC Monitors required, both on surface and underground, will be issued by R. F. Kehrman. Does not need to include Panel 1 Room 1.	Kehrman	
2.	Facilities Engineering shall provide the required support for installation of the VOC Monitors. RWHE is already working on the Room 1-Panel 1 VOC Monitoring System.	Kocialski	
3.	In addition to Room 1-Panel 1 VOC Monitors, RWHE will also procure all other monitors with two spare units.	Garcia	
4.	Evaluation shall be performed by Mr. Kehrman's group on: a) The need for providing an alarm or alarms in the CMR in case of failure of any of the VOC Monitors. b) Required corrective action in case of failure of VOC Monitors individually and collectively.	Kehrman	

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MEETING MINUTES

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Item Number		Action By	Date
	c) Possibility of establishing a temporary on-site gas analysis facility. d) Establishing the appropriate number of sampling bottles required.		
5.	Waste Handling Operations will be responsible for operating and maintaining the VOC Monitoring System. Sampling bottles shall be collected by Waste Handling Operations in accordance with approved procedures (to be developed) and delivered to Mr. Kehrman's group for analysis. Mr. Kehrman will coordinate collection and transmittal of all test results.	Kuginskie/ Kehrman	
6.	The system shall provide for automatic collection of samples for up to 4 days to allow week-end and holiday coverage.	Garcia	
7.	a) Waste Handling Ops. shall determine staffing requirements and identify appropriate training for operating and maintenance personnel.	Kuginskie	
	b) Regulatory & Environmental Programs will have a Systems Expert.	Kehrman	
8.	c) Engineering will assign a Cognizant Engineer responsible for the system.	Halverson	

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APPENDIX D3

DETAILED PLANS AND DRAWINGS

CONTENTS OF APPENDIX D3

Drawing or Report Number	Title
DOE-WIPP 91-059 (Report)	WIPP Underground Storage Area, Panel 1, Room 1
WP-04-ED1341 (Report)	Site Backup Power System
23-C-001-022	Project Location Maps
23-C-003-003	North Access Road, Orientation Plan (Sh 01 of 02)
23-C-004-003	North Access Road, Orientation Plan (Sh 02 of 02)
23-C-014-003	Access Roads, Details
23-C-161-05A	Access Railroad, Plan & Profile
24-C-140-022	Site Work, Finish Grading & Paving, Overall Plan
24-C-145-022	Site Work, Finish Grading and Paving Plan
24-C-147-022	Site Work, Fencing Plan
24-C-149-022	Site Work, Finish Grading and Paving Sections & Details
25-J-015-W1	Yard Electrical, Area Sub No 3 and On Site Power, 480V SWGR 25P-SWG04/3, Electrical Diagrams & Details
25-J-020-W1	WIPP Site Primary Power Distribution-One Line Diagram
25-J-020-W6	Selected Load System Operations-Surface & U/G
25-F-003-W	Yard Piping - Fire Water System Plan
41-F-082-014	Waste Handling Building 411, Fire Protection Floor Plan (Sh 1 of 4)
41-F-087-014	Waste Handling Building 411, Firewater Collection System, Flow Diagram
41-S-003-W1	Waste Handling Building 411, Fire Protection Sprinkler System P&ID
41-S-003-W2	Waste Handling Building 411, Fire Protection Sprinkler System P&ID
41-S-003-W3	Waste Handling Building 411, Fire Protection Sprinkler System P&ID
41-S-003-W4	Waste Handling Building 411, Fire Protection Sprinkler System P&ID

[1]Unless otherwise specified.

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Drawing or Report Number	Title
53-S-002-W	Underground Fuel Stations 1 & 2, Dry Chemical Fire Suppression Systems P&ID
53-J-039-W	Underground Utilities, Fire Panel 534-FP-0320
53-J-040-W	Underground Utilities, Fire Panel 534-FP-14001
53-J-041-W	Underground Utilities, Fire Panel 534-FP-14002
53-J-042-W	Underground Utilities, Fire Panel 534-FP-00601
53-J-051-W	Underground Utilities, Fire Panel 534-FP-033
53-J-054-W	Underground Utilities, Fire Panel 534-FP-0315
41-E-008-019	Exhaust Filter Building No. 413, Architectural, Plan Elevation & Schedules
41-F-026-019	Exhaust Filter Building 413, Underground Exhaust System, Flow Diagram
41-D-002-014	Waste Handling Building 411, Foundation Plan
41-D-003-014	Waste Handling Building 411, Foundation Plan
41-D-006-014	Waste Handling Building 411, Ground Floor Slab, Plan El. 100'-0"
41-D-010-014	Waste Handling Building 411, Foundation Details
41-D-016-014	Waste Handling Building 411, Hoist Tower Foundation, Plans El. 76'-0" & 89'-0"
41-D-017-014	Waste Handling Building 411, Hoist Tower Floor Slab, Plan El. 100'-0"
41-D-117-014	Waste Handling Building 411, Steel Framing, Elevation Line F
41-D-118-014	Waste Handling Building 411, Steel Framing, Elevation Line "E"
41-D-119-014	Waste Handling Building 411, Steel Framing, Elevation Lines 3, 5, and 7
41-E-003-014	Waste Handling Building No. 411, Architectural, C.H. Area-Plan at El. 100'0"
41-E-005-014	Waste Handling Building No. 411, Architectural, RH Area - Plan at El. 100'-0"
41-E-006-014	Waste Handling Building No. 411, Architectural, Mech. Equip. Rm. Plan at El. 123'-0"

[1]Unless otherwise specified.

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Drawing or Report Number	Title
41-E-063-014	Waste Handling Building 411, Architectural, Plans at Tower
41-F-022-014	Waste Handling Building 411, CH Area HVAC, Flow Diagram
41-F-025-W	TRUPACT Dock Vacuum/Monitoring, Equipment Location, Drawing Equipment No. 41-D-047
41-A-001-W	Exhaust Filter Bldg 413, Underground Exhaust and Ventilation System P&ID
41-B-001-W1	Waste Handling Bldg 411, CH Area HVAC Piping and Instrument Diagram
41-B-001-W2	Waste Handling Bldg 411, CH Area HVAC Piping and Instrument Diagram
41-B-001-W3	Waste Handling Bldg 411, CH Area HVAC Piping and Instrument Diagram
41-B-003-W	Exhaust Filter Bldg 413, HVAC System Piping & Instrument Diagram
31-R-001-O1D	Waste Shaft 311, Shaft Development Sections
31-R-002-O1D	Waste Shaft 311, Shaft Lining and Key, Section and Details
31-R-006-O1D	Waste Shaft 311, Geomechanical Instrumentations, Installation Details
35-R-001-01D	Exhaust Shaft 351, Shaft Development, Plan, Sections and Detail
35-R-004-01D	Exhaust Shaft 351, General Arrangement, Plans and Sections
41-D-011-W	Waste Handling Facilities, Facility Pallet Assembly, Eqpt. No. 52-Z-002- C,D
165-F-001-W	TRUPACT II Standard Waste Box Assembly
54-W-001-W	Underground Mine, Ventilation System
54-W-002-W	Underground Ventilation Plan, Waste Handling Mode
54-W-004-W	Underground Ventilation Plan, Filtration Mode
54-W-009-W	Underground Mine Plan, Shaft and Drift Dimensions
24-D-001-W	Tech Devel. Trailer, Base for Radio Antenna Tower
73-E-001-W	Underground Utilities, Evacuation Warning Layout (2 sheets)
73-J-010-W	Underground Utilities,Public Address System Layout

[1]Unless otherwise specified.

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Drawing or Report Number	Title
73-J-011-W	Underground Utilities, Mine Paging System Layout
73-J-014-W	Surface Layout, Plant Communications
73-J-025-W	Public Address and Intercom, Block Diagram and Master Control Console Wiring Diagram 73-P-006
51-W-102-W	Underground Development
54-D-003-W1	Supplementary Roof Support, Room 1, Panel 1 General Arrangement
54-D-003-W2	Supplementary Roof Support, Room 1, Panel 1 Steel Set Locations & Details
54-D-003-W3	Supplementary Roof Support, Room 1, Panel 1 Steel Set Fabrication
54-D-003-W4	Supplementary Roof Support Room 1, Panel 1 Cross Section
54-D-003-W5	Supplementary Roof Support Room 1, Panel 1, Wire Mesh and Lacing Detail
412-F-017-W	Bin-Scale Tests, Dry Test Bin Details (2 sheets)
412-N-002-W	Bin-Scale Tests, Dry Test Bin Assembly
412-N-009-W	Bin Scale Tests, SWB Lid Modification for RCB Lid Assembly and Details
52-L-001-W	Bin-Scale Tests, VOC Monitoring System P & I Diagram
52-L-002-W1	Bin-Scale Tests, VOC Monitoring and Helium Stations, Details
52-L-002-W2	Bin-Scale Tests, VOC Monitoring and Helium Stations, Details
52-L-002-W3	Bin-Scale Tests, VOC Monitoring and Helium Stations, Details
52-L-002-W4	Bin-Scale Tests, VOC Monitoring and Helium Stations, Details
52-L-002-W5	Bin-Scale Tests, VOC Monitoring and Helium Stations, Details
52-L-002-W6	Bin-Scale Tests, VOC Monitoring and Helium Stations, Details
52-L-002-W7	Bin-Scale Tests, VOC Monitoring and Helium Stations, Details
52-L-002-W8	Bin-Scale Tests, VOC Monitoring and Helium Stations, Details
52-L-002-W9	Bin-Scale Tests, VOC Monitoring and Helium Stations, Details
52-L-002-W10	Bin-Scale Tests, VOC Monitoring and Helium Stations, Details

[1]Unless otherwise specified.

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Drawing or Report Number	Title
105-F-013-W	VOC (10) Monitoring System, Air Sampler Unit Assembly 105-S-008
412-M-003-W	Bin-Scale Tests, VOC Monitoring System, Carbon Sorption System

[1]Unless otherwise specified.

DOE/WIPP 91-057
Revision 0

Waste Isolation Pilot Plant
Supplementary Roof Support System
Underground Storage Area
Panel 1, Room 1

October 1991

Waste Isolation Pilot Plant

1091W:00002

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WASTE ISOLATION PILOT PLANT
SUPPLEMENTARY ROOF SUPPORT SYSTEM
UNDERGROUND STORAGE AREA
PANEL 1, ROOM 1

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1.0 EXECUTIVE SUMMARY

WIPP is designed to provide a full-scale facility to demonstrate the technical and operational principles for permanent isolation of defense-generated transuranic waste. It is also designed to provide a facility in which studies and experiments can be conducted.

Dry Bin-Scale Tests are being planned as a portion of the WIPP Test Phase Performance Assessment Program described in the WIPP Test Phase Plan: Performance Assessment (DOE 1990 b). These Tests are anticipated to be conducted for a period of up to seven years. Room 1 of Panel 1 of the Underground Storage Area is to be used as the location of the Bin Scale Tests to investigate the generation of gas from the waste that is proposed to be stored at the WIPP in the near future.

The original design for the waste storage rooms in Panel 1 provided for a limited period of time during which to mine the openings and to emplace waste. Room 1 was scheduled to be filled in fewer than five years before being sealed. Initially mined to rough dimensions in 1986, Room 1 was later mined to finished dimensions in 1988. Information obtained from the Site and Preliminary Design Validation (SPDV) program indicates that the rooms in Panel 1 should remain stable without ground support and that creep closure would not adversely affect equipment clearances during at least five years following excavation.

The demonstration phase was later deferred and an experimental program including Bin Scale Tests was added for Panel 1. Delays in the test schedule have revised the date for first waste receipt. Therefore, based on the timing and scope of the test phase, an additional seven years of useful life may be required to complete the tests in Room 1, Panel 1.

To assess the long term stability of Panel 1, a panel of geotechnical experts was convened in April, 1991. The final report of the panel was issued on June 5, 1991. The panel agreed that the WIPP geotechnical monitoring program as used in the SPDV Test Rooms is adequate to provide early warning of deteriorating conditions in Panel 1. The panel reviewed the design and stability of the rooms in Panel 1 and concluded that these rooms could be expected to provide a useful life of at least seven years from the time of excavation (up to 11 years with a decreasing level of confidence) with routine maintenance (DOE, 1991). However, the panel also agreed that ground support measures could be used that would allow the Bin Scale Tests to be carried to completion. The test period as currently defined is up to seven years, thus requiring a room life of up to 12 years from when the room was mined. The following options or their combinations recommended by the Expert Panel have been evaluated to extend the life of Room 1 of Panel 1 and to provide added confidence in its ability to support the test program:

- Relying on the currently installed rock bolt system and upgrading, if necessary, based on the results of the geomechanical monitoring program.
- A ground support system using resin anchored rock bolts.
- Interlaced grout anchored wire cables and wire mesh to control rock falls.
- Cutting slots in the back and/or floor to relieve the lateral stresses.

- Yielding support system such as timber cribs or steel yielding supports.
- Roof truss system.
- Mine new rooms.

In order to extend the life of Room 1, Panel 1, a ground support system needs to consider the past history of Room 1, the on-going deformations in the room, and the potential roof failure mode. Also, the support system must be designed to accommodate the bins and test equipment, including forklift access for bin installation and subsequent monitoring activities.

To be acceptable, the ground support system must:

- Be capable of fully supporting the anticipated roof wedge such as that produced in SPDV Room 1.
- Be capable of yielding in a manner which would accommodate the future closure and deformation of the roof rock.
- Accommodate the bin scale equipment, including forklifts and ancillary equipment.
- Extend the life of Room 1 to allow completion of the experiments, for an additional period of up to seven years (from July 1991).

The initial roof support concept developed for Room 1 of Panel 1 involved timber "crib sets" with interconnected steel beams. After further analysis, timber crib supports were abandoned in favor of yieldable roof supports which would provide more uniform roof support. These supports consisted of resin anchored steel rock bolts and steel cross beams, with yielding steel columns as commonly used in the coal mining industry. More importantly, the rock bolts could be continuously monitored using load cells and adjusted to accommodate further room creep.

As the design process proceeded, it became clear that the majority of the load would be carried by the rock bolts. The yielding columns were therefore eliminated. The steel beam was modified from an initial I beam configuration to an inverted channel, thus eliminating the complex attachment plate structure needed for the I beam.

The final roof support design contained in this document consists of 8.23m (27 feet) long 15 x 40 steel channel support sets installed laterally across Room 1 on 2.44m (8 feet) to 3.05m (10 foot) centers. Each channel set is divided into three nine foot long segments which are bolted together in place using connecting plates. Each support set is secured by eleven 3.96m (13 feet) long Dywidag steel tendons (anchor bolts) that are resin anchored in relatively stable ground above the Anhydrite "b" clay horizon. The channel support anchor bolts are designed so that their loads can be monitored and adjusted to accommodate continuing roof deformation. To allow for differential lateral deformations, each tendon is located in an oversized .076m (3 inch) diameter hole which extends from the hole collar to the Anhydrite "b" clay horizon.

The area between the channel support sets is covered by a network of steel wire lacing cables underneath a mat of steel welded wire mesh and expanded metal. This mat is held in place by the channel support sections. Its function is to contain loose rock in between the channel support sets.

Chainlink wire mesh pinned to the ribs (sidewalls), is provided to contain any minor spalling down to approximately 2.13m (7 feet) above the floor.

A conservative approach has been used throughout the design process. Areas where this has been done include the following:

- A minimum .76m (3 foot) grouted bolt length has been used where tests have shown 18 inches to be sufficient.
- The manufacturer's minimum yield load has been used for bolt design - tests give results 22-28% higher.
- The support effect of the existing 3.04m (10 feet) mechanically anchored rockbolts and the meshing and lacing has been disregarded.
- The wedge-shaped salt beam has inherent strength which has been disregarded.

As designed, the supplementary roof support system incorporates the four acceptance criteria stated above as well as five out of the seven Expert Panel recommendations. The support system can also be installed concurrently with bin operations. Figure 1-1 provides an isometric view of the support system for Room 1, Panel 1.

The geomechanical monitoring system represents an integral part of the roof support system design. The monitoring system is designed to monitor loads on each rock bolt, measure continuing creep and deformation in and around the room, identify stress loads on the rock and deflections of the steel channel supports.

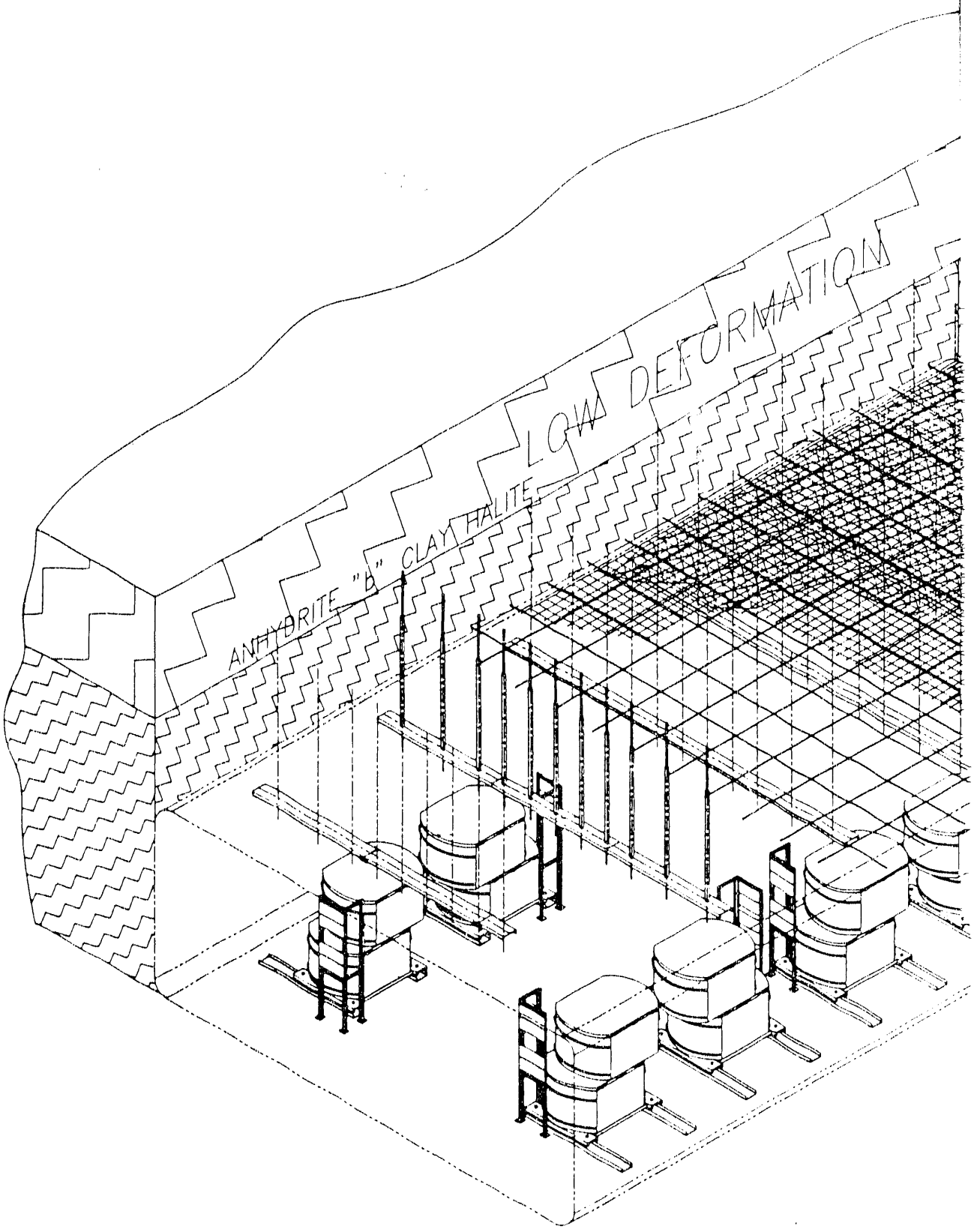
The monitoring system allows for adjustment of loads in the rock bolts to accommodate room creep and to provide early indication of any unusual closure activity.

The test bins, within the standard waste boxes, are stacked two high along the ribs of the test room. The spacing is sufficient to allow personnel access between the bins for ground support installation, inspection, and routine ground control maintenance tasks.

In addition to the monitoring program, a testing program was implemented to confirm the validity of rock anchor calculations and installation procedures.

The testing program included destructive testing of rock anchors and a mock-up installation of a portion of the entire system.

The WIPP is committed to safely providing long term roof support.


LOW DEFORMATION
ANHYDRITE "B"
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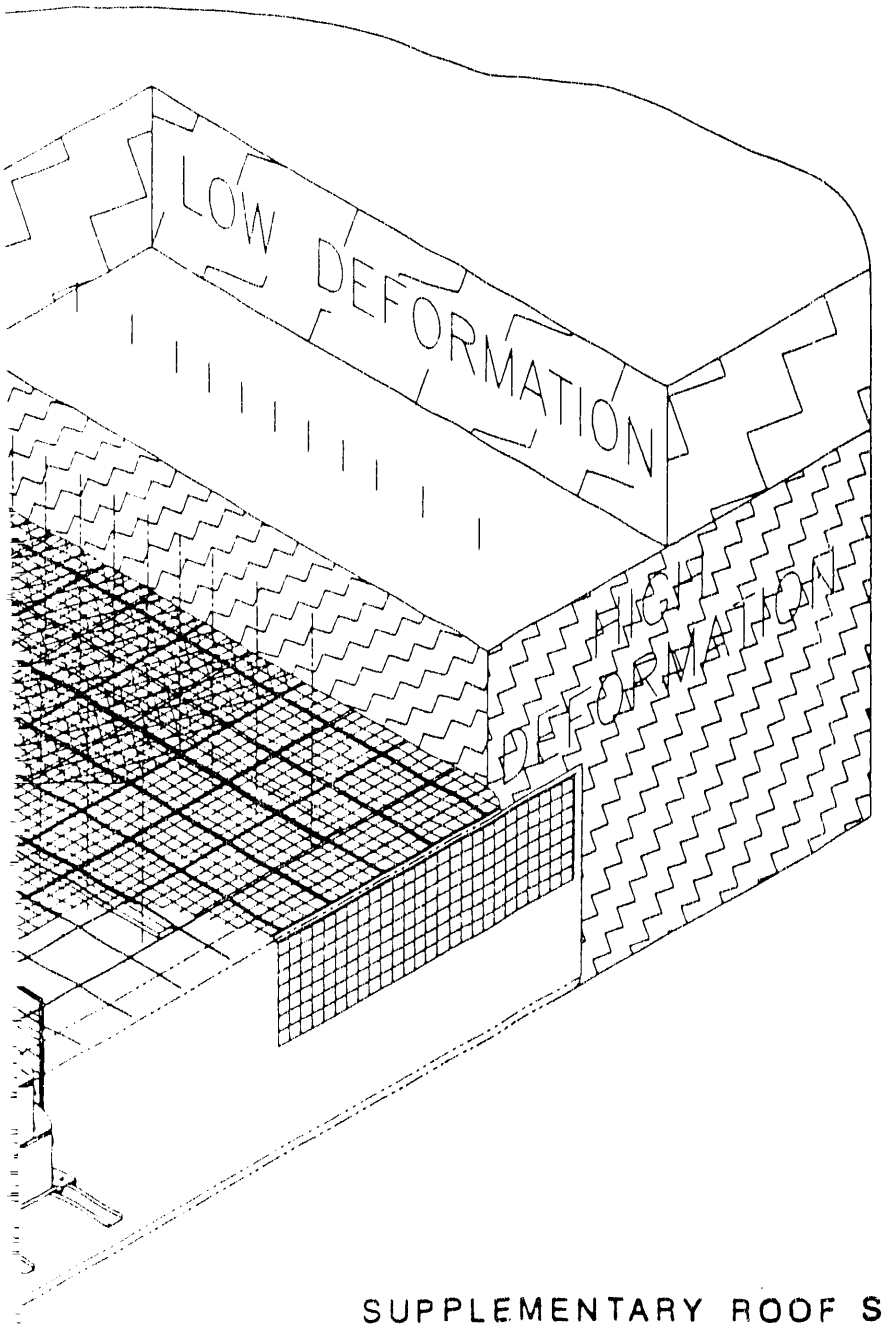


SUPPLEMENTARY ROOF SUPPORT SYSTEM
UNDERGROUND STORAGE AREA
PANEL 1, ROOM 1

FIGURE 1-1. Isometric View Room 1, Panel 1, Supplementary Roof Support System

2.0 INTRODUCTION

WIPP is designed to provide a full-scale facility to demonstrate the technical and operational principles for permanent isolation of defense-generated transuranic waste. It is also designed to provide a facility in which studies and experiments can be conducted.

Bin Scale Tests are being planned as part of the WIPP Test Phase Performance Assessment Program described in the WIPP Test Phase Plan: Performance Assessment (DOE 1990 b). These Tests are anticipated to be conducted over a period of up to seven years.

Room 1 of Panel 1 of the Underground Storage Area is to be used as the location of the Bin-Scale Tests to investigate the generation of gas from the waste that is proposed to be stored at the WIPP in the near future.

The original design for the waste storage rooms in Panel 1 provided for a limited period of time during which to mine the openings and to emplace waste. Room 1 was initially mined to rough dimensions in 1986. Information obtained from the Site and Preliminary Design Validation (SPDV) program showed that the rooms would remain stable without ground support and that creep closure would not adversely affect equipment clearances during at least five years following excavation.

The demonstration phase was later deferred and an experimental program including Bin Scale Tests was added for Panel 1. Delays in the test schedule have revised the date for first waste receipt. Therefore, based on the timing and scope of the test phase, up to seven years of useful life are required to complete the tests in Room 1, Panel 1. This document presents the design for a supplementary roof support system for Room 1 of Panel 1 of the Underground Storage Area. System design and its implementation process is presented in Figure 2-1.

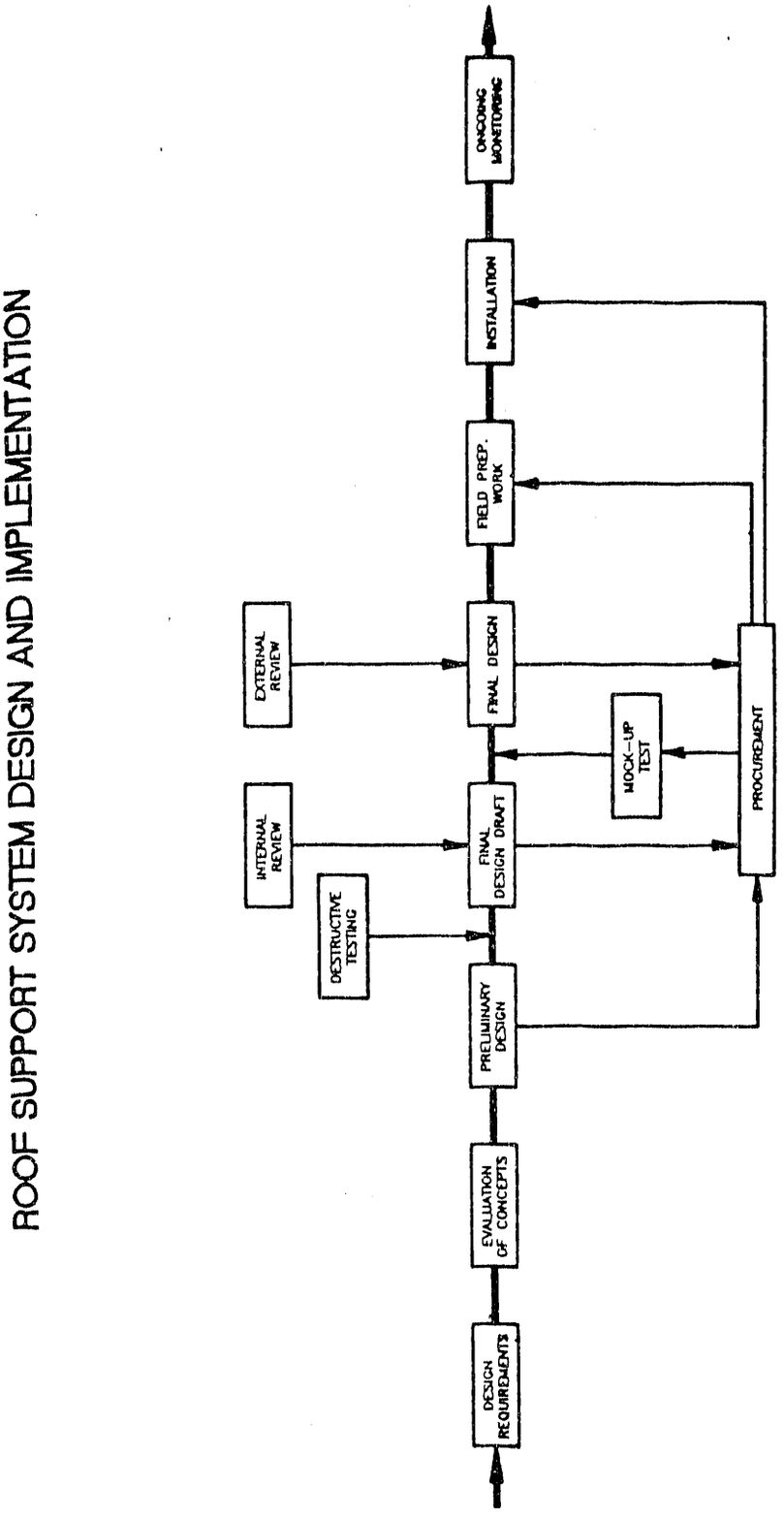


FIGURE 2-1. Roof Support System Design and Implementation
Room 1, Panel 1

3.0 DESIGN REQUIREMENTS

3.1 DESIGN CRITERIA/CONSIDERATIONS

The support system must be designed to accommodate the following criteria:

1) Provide a suitable supplementary roof support system to ensure that the Bin Scale Tests conducted in Room 1, Panel 1, of the Underground Storage Area will not be interrupted during the seven year period starting July 1991.

2) The basic design parameters are determined by geotechnical considerations such as the age of Room 1, existing and future ground deformations in and around Room 1, and the prevailing stratigraphy and stress conditions.

3) The support system takes cognizance of the recommendations of the Geotechnical Expert Panel.

4) The support system takes cognizance of Design Spec. No. D-0087.

3.2 DESIGN SPECIFICATIONS

Design specifications are contained in Document entitled "Design Spec., No. D-0087, Supplementary Roof Support for Room 1 of Panel 1."

3.3 DESIGN BASES

The Supplementary Roof Support System for Panel 1, Room 1, is a yieldable type support that consists of evenly spaced sets of 15 x 40 inverted steel channel sections supported by eleven rock anchors.

The design for the Supplementary Roof Support System for Room 1, Panel 1, is based on the following:

3.3.1 General

- The support system is able to be installed concurrently with bin operations.
- Safe access is provided for a minimum of seven years from July 1991.
- A minimum access height of 3.45m (11 feet, 4 inches), is provided after seven years.
- Support installation procedures take into account working within RMA boundaries.
- Corrosion is a non-impactive factor for the duration of the system installation, based on experience gained at the WIPP and in the potash basin mines.
- Because of accessibility limitations and RMA requirements during the testing program, only the center portion of Room 1 located between the ventilation bulkheads has been considered in this supplementary roof

support design. Roof control for the remainder of the room will be addressed elsewhere at a later date.

3.3.2 Rock Mechanics

- The zone of rock between Anhydrite "b" and Anhydrite "a" is sufficiently stable to provide a good anchoring base for the support system rock anchors.
- Horizontal and vertical virgin stresses are equal at the repository horizon of 655m (2,150 feet).
- The geology and stratigraphy at Room 1, Panel 1, are similar to those in the SPDV Test Room area.
- Observations and measurements from the SPDV Test Rooms will be used as the bases for describing the deformation mechanisms occurring in Room 1, Panel 1.
- Creep deformations arise from differential stresses created as a result of excavating an opening of the given shape.
- Low-angle shear fractures will occur in the immediate roof rock, and once these have formed, roof movements into the excavation are increasingly associated with gravity rather than salt creep.
- The supplementary support system accommodates past and future room deformations.
- The roof failure mode is expected to be that of a detaching wedge, triangular in section, 10m (33 feet) wide and 2.13m (7 feet) high at the center. However, the design will accommodate, as a worst-case scenario, a rectangular section 33 feet wide and 7 feet high.
- The density of the immediate roof rock above Room 1, Panel 1, is 2,160 kg/m^3 (135 pound per $foot^3$) for all calculations.
- The rock anchor holes have a 7.6mm (3 inch) reamed-out section below the grouted portion that will be sufficient to prevent shearing of the tendons that may arise from differential lateral deformations that might take place in the roof rock.
- The roof expansion between the anchor horizon and hole collar is assumed to be 38mm (1.5 inch) per year.
- The maximum lateral differential deformation below Anhydrite "b" is assumed to be 12mm (0.5 inch).

3.3.3 System Design

- The system of rock anchors consist of resin grouted rock anchors, grade 60 steel, anchored above Anhydrite "b" horizon.
- Minimum resin bond length between anchor and salt is 0.91m (3 feet).
- The steel channel set assembly would act as a surface plate system that:

- Is capable of accommodating the design load
- Is capable of accommodating monitoring devices that would allow continuous monitoring of bolt load
- Allows detensioning of anchor loads as and when required
- Assists in distributing the load between bolts
- Is capable of supporting the lacing and meshing.

- Each rock bolt anchor extends downwards through the channel section plate for a distance of 18 inches to provide for a downward adjustment life of seven years. This accommodates the expected 38mm (1.5 inches) per year of roof expansion as well as the bearing plates and load cell assembly. If required, couplings will provide for additional adjustment.
- Rock spalling in between sets is controlled by a system of wire mesh and lacing.
- Floor maintenance will be carried out as and when required.
- The transverse 16 mm (5/8 inch) diameter wire lacing ropes will be adjustable.
- Rib spalling that may occur is contained by a wire mesh system that extends down to a height of approximately 2.1m (7 feet) above the floor.
- No stability problems are expected from fracturing of the ribs, based on experience gained at the WIPP since the opening of the project.

3.3.4 Installation and Maintenance

- The bolt loads are readjusted when the load on a bolt reaches 1.1 times the design load.
- Existing 3.04m (10 foot) rockbolts may be removed in order to facilitate installation of the supplemental rockbolt supports.
- Existing instrumentation fixtures, installed cables, and piping will be relocated to the sides of the room to avoid damage during system installation and maintenance.
- Rock anchor holes will be drilled vertically with a tolerance of $\pm$ 2 degrees measured in such a way that the ends of the holes will not be closer than 0.5m (20 inches).
- Drilling tolerance for the depth of the hole is $\pm$ 25mm (1 inch).

3.3.5 Testing and Monitoring

- A complete full-scale mock-up test will be carried out in Room 2. This will have at least five channel sets.

- Quality control and creep tests will be carried out on each bolt. The test load will be taken to 1.33 times the maximum design load.
- The monitored data from Room 1 will be evaluated on an ongoing basis.
- The design loads for the rockbolts and associated anchoring system have been confirmed by the destructive tests that have been conducted.
- The geomechanical monitoring system is designed as an integral part of the support system and will:
  - Monitor the load on every rockbolt
  - Measure ongoing creep and deformation
  - Allow an assessment of the length of room life that might be obtained beyond seven years.

4.0 SYSTEM DESIGN

4.1. GEOLOGY AND ROCK MECHANICS

4.1.1 Rock Mechanics

Much of the understanding regarding the performance of excavations in salt at the WIPP has been gained from observations taken in the Site and Preliminary Design Validation (SPDV) Test Rooms. The case study presented by the roof fall in SPDV Test Room 1, together with numerical modelling results, provides the information for defining the size and shape of the rock wedge that must be supported by roof support system. This is assumed to have a triangular cross-section as shown in Figure 4-1.

The virgin in-situ stresses are one of the basic determining factors governing the rate of deformation in and around the mined opening.

The initial stress state at the repository horizon is established from Heims Rule for weak rocks (Hoek and Brown, 1980). This rule establishes the vertical stress as dependent on the depth of overburden and its average density, and the horizontal stresses to be equal to the vertical stress. Taking the average density for the overburden at the WIPP site as 2160 kg/m^3 (135 pound/foot^3), the initial stresses at the repository horizon are about 2000 psi.

When a room is excavated in salt, the local virgin in-situ stress field is disturbed. The immediate initial response of the rock is to set up stress as if it were in an elastic rock, the so-called "time zero" response. Differential stresses are created around the excavation and it is these stress differences that drive the subsequent creep deformations that result in closure of the room.

With time, the stresses close to the excavation are relieved by creep of the salt into the excavation. Shear stresses develop at the strata interfaces due to the differences in the mechanical properties of the different rock types and lead to slippage at these contacts and eventually to bed separation. The presence of these strata interfaces further leads to the concentration of lateral stresses in the roof and floor beams leading ultimately to the development of low angle shear fractures. Once the shear fractures have developed, roof movements in an excavation are increasingly associated more with gravity effects than with salt creep. At this stage there are two processes at work in the strata above the excavation. These are:

- Creep of the salt - Salt creep is still occurring in the competent salt above the rock wedge and above the ribs.

- Kinematic movement of the immediate rock due to gravity - The rock wedge, if it is unsupported, will move down under its own weight. Figure 4-1.

Inclinometer measurements, in vertical and horizontal boreholes, give the horizontal and vertical deflections of these boreholes in the rooms roof and ribs respectively. The effect of the 2.13m (7 foot) clay seam can clearly be seen as a large relative horizontal difference in the movement of the salt immediately below the clay seam.

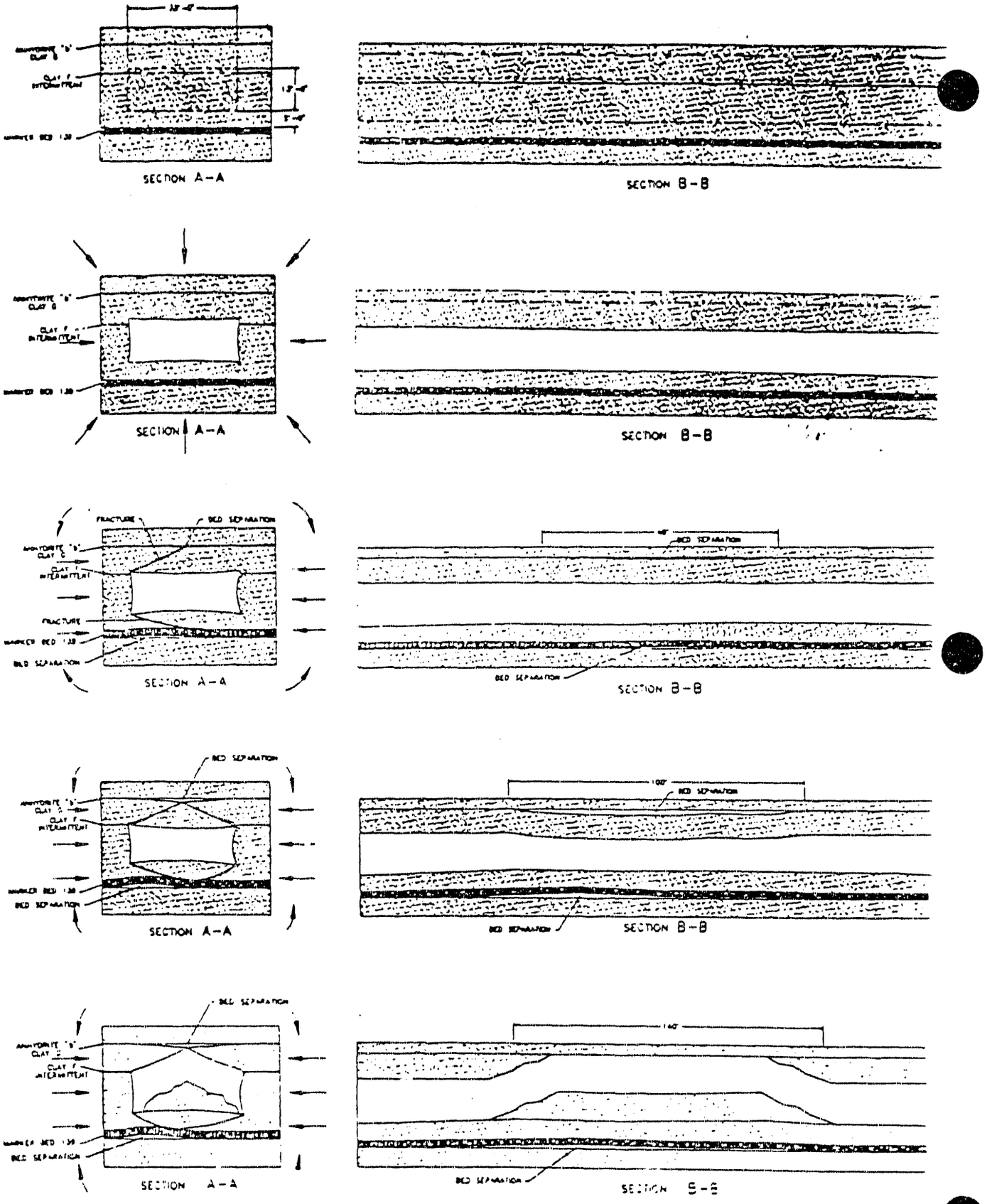


FIGURE 4-1. Kinematic Movement of the Rock Wedge

Extensometers located in the roof, ribs and floor measure the extensions at different distances along the lengths of their boreholes. Closure meters measure the closure of the rooms, either between roof and floor or rib to rib. A composite picture of how the rock is deforming and moving into the excavated room is obtained when inclinometer, extensometer, and closure measurements are put together. The Expert Panel unanimously agreed that the mechanism of deformation at Room 1, Panel 1 would be very similar to that experienced at the SPDV Test Rooms. For further detailed discussion and information on Geology and Rock Mechanics at WIPP, refer to Appendix A.

4.1.2 Stratigraphy

The proposed underground storage facility is located 655m (2,150 feet) below the surface in bedded salt of the Permian Salado Formation. This formation consists primarily of halite, argillaceous halite, minor anhydrite, and minor polyhalitic units. Over 365m (1,200 feet) of impermeable evaporitic deposits separate the facility horizon from the first overlying sedimentary rocks and 620m (2,034 feet) of evaporites lie below the facility horizon and provide a barrier to Permian limestones and sandstones. Figure 4-2.

The facility horizon lies within a 12m (39.4 feet) thick unit consisting of halite, argillaceous halite, and polyhalitic halite (Figure 4-3). A thin, 0.3m (.98 feet) to 0.5m (1.64 feet) thick layer consisting of anhydrite and polyhalite, and identified as Marker Bed 139 lies about 1.5m (4.92 feet) below the floor level. Anhydrite beds (less than 10mm [.03 feet] thick), called anhydrite "a" and "b" occur about 4m (13.12 feet) and 2m (6.56 feet) above the roof. Thin clay seams called Clay G and Clay H are associated with the bottom of these beds. In addition, an intermittent thin clay layer identified as Clay F is found in the immediate roof of excavations.

The anhydrite and clay layers have a significant impact on the mechanical performance of excavations. The clay layers provide interfaces along which slip can occur whereas the thick layers can provide a stiff anhydrite band within the strata sequence that does not deform plastically with time. For further detailed discussion and information on Geology at the WIPP, refer to Appendix A.

4.1.3 Vertical Movements

The vertical movement that the roof support must accommodate are a combination of salt creep, dilation of the salt due to fracture development, and gravity effects once fractures have formed.

The total roof expansion that has to be accommodated has been taken as 38mm (1.5 inches) per year at midspan.

4.1.4 Lateral Movements

Lateral displacements occur at strata interfaces and within the immediate roof beam where discrete fractures have formed. These lateral differential displacements have been observed up to 15m (50 feet) into the roof at strata changes particularly the clay/salt contacts. The largest shifts are found at the clay/salt contact below the Anhydrite "b" layer. Lateral shifts can also be expected within the immediate roof beam where fractures form. The support system has been designed to accommodate a lateral shift of 12mm (.5 inch) per year and bed separation of 25mm (1 inch) per year at the clay/salt contact below the Anhydrite "b" layer once the bond at the interface is disrupted.

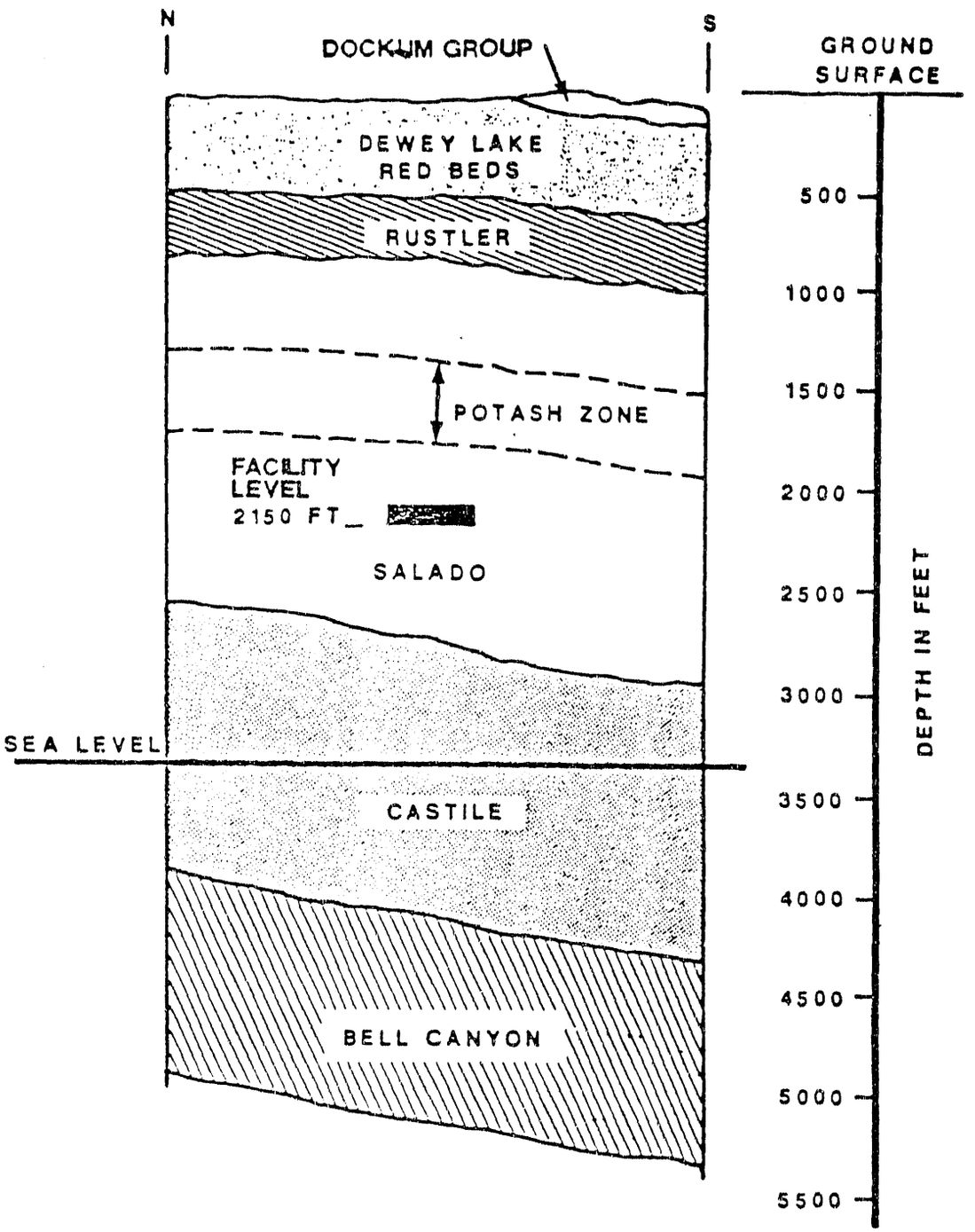


FIGURE 4-2. Generalized Site Stratigraphy

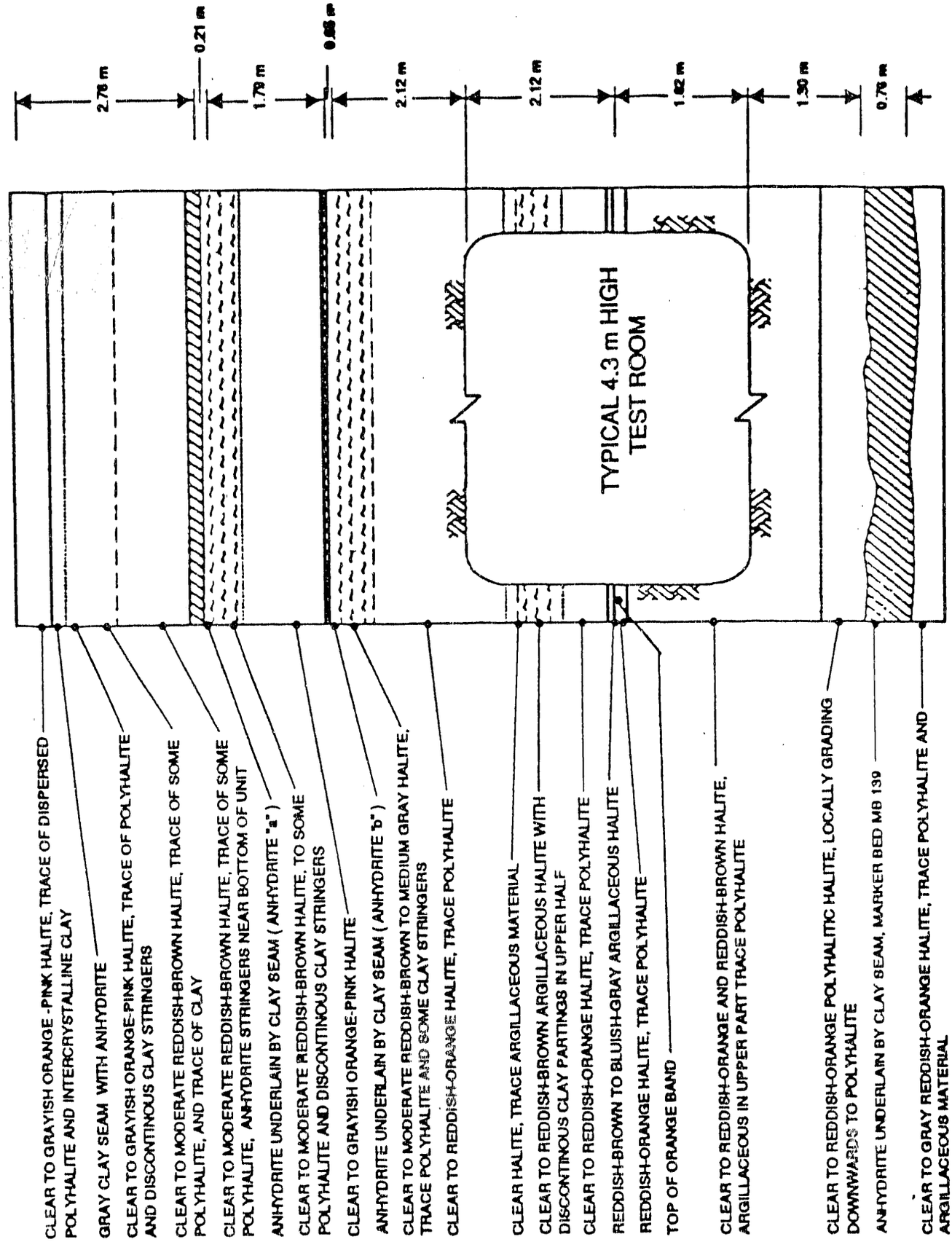


FIGURE 4-3. Stratigraphy of the WIPP Repository Horizon

4.1.5 Anchor Horizon

The zone in which rock anchors were to be installed had to satisfy three main criteria:

- It had to be relatively stable, in that the creep deformations occurring in it should be low.
- The effect of installing anchors in it should not induce loading conditions that would increase the creep deformations significantly or reduce the overall strata stability at that horizon.
- Penetration of roof stratigraphy should be kept to a minimum.

The reasons for going into the zone above Anhydrite "b" can be summarized as follows:

- Rock mechanics data from extensometers, inclinometers and borehole surveys have shown that the zone above Anhydrite "b" is relatively stable. This was in part due to the fact that the well-defined clay seam associated with Anhydrite "b" served to concentrate differential stresses in the immediate roof rock below Anhydrite "b". The reason for this phenomenon arose from the inability of the clay seam to sustain shear stress.
- Large numbers of 3.04 m (10 feet) mechanically anchored rock bolts had been installed at a fairly precisely defined horizon, some .91m (3 feet) above Anhydrite "b". After more than two years of installation, during which time the rock bolts were known to have developed load, there was no evidence from rock mechanics measurements of roof strata deformations that this concentration of anchoring load was causing any separation to occur.
- Sandia National Laboratory has a requirement that Anhydrite "a" should not be penetrated if this can be avoided.
- No separation has been observed to date across the Anhydrite "a" layer.
- The difficulties involved in drilling, reaming, and installing the grout anchored rockbolts increase rapidly with depth. In order to meet the required design requirements with a high degree of confidence the anchor horizon chosen is that above Anhydrite "b".

4.2 CONCEPTUAL DESIGN

Room 1 of Panel 1 is currently five years old and must remain accessible for an additional seven years in order to support the Bin Scale Testing program without interruption. In order to extend the life of Room 1, a supplementary roof support system has been developed to minimize the possibility of any roof fall during testing.

On February 4, 1991, a substantial section of roof fell in Room 1 of the SPDV area. Geotechnical instrumentation had indicated accelerated room closure rates for some time, and the roof fall had been anticipated for several months. At that time, the room had been open for almost eight years. The four SPDV rooms had been mined to exactly the same dimensions as the waste storage (and disposal)

rooms 91.4m (300 feet) long, 10.05m (33 feet) wide, 3.96m (13 feet) high in Panel 1, in order to simulate, monitor, and study their behavior in response to lithostatic (overburden) pressure over time. No ground support, such as rock bolts, had been installed.

In response to the roof fall in SPDV Room 1 and to assess the long-term stability of Panel 1, Westinghouse convened a panel of geotechnical experts in April 1991. The final report of this panel was released on June 5, 1991. The expert panel agreed that the WIPP geotechnical monitoring program as used in the SPDV Test Rooms is an adequate tool for giving early warning of deteriorating conditions in Panel 1. Based on collected geotechnical monitoring data, panel members concluded that the rooms in the panel are likely to have a total life of seven to eleven years from the time of excavation using the currently installed roof support system, consisting of 3.04m (10 feet) long mechanically anchored rock bolts. Mining of Room 1, Panel 1, began during the second half of 1986. Therefore, as of July 1991, the remaining life of Room 1 is anticipated to be between two and six years. However, the panel agreed that measures could be taken in Panel 1 that would give a reasonable assurance that the Bin Scale Tests could be carried out to completion. In order to carry out the Bin Scale Tests, a solution to the support problem had to be found to extend the required life of Panel 1 for up to seven years. The expert panel suggested alternative actions which included use of the following:

- The use of full column resin or resin anchor bolts;
- Grout anchored cable with lacing and wire mesh;
- Slotting and/or relief entries;
- Yielding support;
- Rely on currently installed support and upgrade when necessary;
- Roof trusses;
- Mining new rooms.

They also indicated that the measures should be augmented by a monitoring program that would regularly assess the geomechanical conditions and that maintenance should be carried out as a routine activity in the rooms as they aged.

The WIPP project has evaluated the support systems suggested by the Geotechnical Expert Panel.

The initial evaluations looked at support systems (wooden cribs, wooden cribs with steel beams) that could be installed within the room and would provide a passive support as the rock deforms into the room. These systems were eventually abandoned because they interfered with the functional use of the room largely as a result of the physical size of the supports. They limited the number of bins that could be placed in the rooms and more importantly, the support could not be placed where it was most needed (i.e., midspan where the largest loads are developing) without eliminating equipment access to the bin locations.

Another form, a yielding support system, was then considered. This eliminated any need for bin removal and provided a more uniform support of the roof strata. The yielding system consisted of deep grout anchored rock bolts supporting a

steel cross beam with supplemental support being provided by yielding steel columns. The beam anchor bolts were designed so that their loads could be continually monitored and adjusted to accommodate room deformation by lowering the beam. As the design process became more detailed, it became clear that the major share of the load was carried by the beam support bolts; the yielding columns were in fact unnecessary and were therefore eliminated from the design. The beam itself was also modified from an initial I-beam to a more structurally convenient inverted channel section. This eliminated complex attachment plate structures needed for the I-beam suspension system. Any roof rock spalling between the steel sets is contained by a network of steel wire rope lacing underneath a mat of steel meshing and expanded metal.

As designed, roof support for Room 1, Panel 1, is providing the following:

- Progressive support of the detaching triangular wedge of roof rock as it develops.
- Containment of the detaching wedge of roof rock and safe control of the rate at which the detaching section moves downward based on the creep rate produced by the roof strata above.
- Accommodation of lateral movements in the roof strata above.

Throughout the design process, a conservative approach was used. The design is largely based on the room deformations and subsequent roof fall that took place in SPDV Test Room 1, which is seen as a worst case scenario. Previous resin grout anchor tests have shown that an eighteen inch bond length of grout would be sufficient, whereas a minimum .91m (3 feet) bond length is used in this design. The rock bolt design is based on the manufacturer's minimum yield strength of 209,000N (47.4 kips), whereas the destructive tests carried out in Room 2, Panel 2 gave actual minimum yield strengths 22% to 26% higher. A continuous channel section beam is used where individual plates would have been sufficient. Very little support capability has been assigned to the meshing and lacing, whereas it is certain that this will be capable of a considerable load carrying capacity. No strength has been assigned to the wedge-shaped rock salt beam formed as a result of roof fracture formation. It will have an inherent strength, this effect being enhanced by the existing 3.04m (10 foot) mechanically anchored rockbolts as well as the steel meshing and lacing. The existing system of 3.04m (10 foot) mechanically anchored rockbolts, installed on a 1.2m (4 foot) by 1.5m (5 foot) spacing have considerable load bearing capability which has been disregarded in the design.

The net effect of all the above factors when added together means that the design is very conservative, thus reducing the risk of potential failures.

4.3 DESIGN DESCRIPTION

The yielding roof support system for Room 1 of Panel 1 is designed to contain and support the detaching load while allowing it to be lowered. The system is not designed in any way to prevent the creep of rock into the room. The roof support consists of 27 steel channel support sets installed laterally across the room on 2.37m (7.8 feet) to 3.04m (10 foot) centers. The actual location of the channel sets will be determined in the field during their installation based on the location of the existing roof bolts which are installed on a 1.2m (4 foot) by 1.5m (5 foot) pattern. This is to minimize interference with the existing roof bolts.

Each support set is secured by 11 Dwyidag steel tendons (anchor bolts) that are 4.0m (13 feet) long. The resin grouted anchor bolts are anchored in between the Anhydrite "a" and the Anhydrite "b" horizons. The channel support anchor bolts are designed so the load of each bolt can be monitored and adjusted to accommodate continuous roof deformation. System adjustment is accomplished by keeping the tension on each anchor bolt within the design limits which are calculated to support the detaching load. Once the tension in the anchor bolt reaches the design limits, the bolt load is then relieved. Each anchor bolt extends .46m (18 inches) below the roof to accommodate downward movement of the roof due to creep. Roof strata extension measurements have shown that the anchor bolts will have to accommodate approximately 38mm (1.5 inches) of movement per year. To allow for differences in lateral deformations, each tendon is located in an oversized .08m (3 inch) diameter hole extending from the hole collar to the Anhydrite "b" clay horizon.

In order to cater for the possibility of shear and bending at Anhydrite "b" exceeding these limits, a set of five test anchors and four observation holes will be installed in Room 2 as a part of a mock-up. Periodic proof testing of the test anchors would be conducted when observations indicate that shearing and bending of the anchors are occurring.

The roof area between the channel sets is covered by a network of steel wire lacing cables underneath a mat of steel wire mesh and expanded metal. This mat is held in place by the channel support sets. Its function is to contain any rock spalling in between the channel support sets.

4.3.1 Steel Channels

Each roof support set consists of a structural steel channel placed with the web flat against the roof, running across the room (rib to rib) and 11 rock anchor bolts. The set is designed to accommodate the triangularly distributed wedge load. Eleven rock anchor bolts are required to support the channel. In the unlikely event that the roof detaches as a rectangular shaped section, the anchor capacities are sufficient to cater for this extra load.

The support channel is a 15 x 40 channel section 8.2m (27 feet) long. Each channel set consists of three 2.7m (9 foot) long sections connected together with four .19m (7.5 inch) by .08m (3 inch) splice plates. Two of these splice plates are welded to each end of the section center. The other channel is then connected by a .02m (.625 inch) bolt passing through the un-welded end of the plate and through the flange. The plates are placed on the outside of each flange and have a .04m (1.5 inch) long slot in which the bolt passes through; this allows for a small horizontal movement in each of the sections without affecting its performance. The channel has been divided in to three equal sections for ease of transport and installation.

The rock anchors are fastened through the centerline of each channel. The anchors are spaced every .61m (2 feet) in the middle of the room and every .76m (2.5 feet) or .91m (3 feet) near the ribs. Each rock anchor passes through a .04m (1.5 inch) diameter hole in the channel which allows for a .006m (.25 inch) tolerance in placing the anchors in the salt.

Each rockbolt will be tested to ensure its quality of installation. These tests are described in section 6.1.2.

Detailed channel support calculations are given in Appendix "C".

4.3.2 Rockbolts

The rock anchors that support the roof load are the most critical element of the design. The rockbolts are 4.0m (13 feet) long threaded No. 8 Dywidag rods with a 209,000N (47,400 pound) minimum yield strength. The rock anchors are inserted 3.5m (11.5 feet) into the roof and anchored between Anhydrite "a" and Anhydrite "b" horizons. The rock anchors are anchored by resin which bonds at least .91m (3 feet) of the bolt to the salt using one .84m (33 inch) long resin cartridge. Each rockbolt extends .46m (18 inches) below the roof to allow the back to expand downwards while supporting the load.

Since the assumed pattern of the detaching load is uneven, the design tension in each rockbolt is different. However, the suspension capacity of the rockbolts is such that all bolts can handle the maximum load which would be the case if the detached wedge was rectangular in section. Each anchor is to be monitored to ensure that the nuts are relieved before the tension rises above the designed limit. Further details regarding the design of the rockbolts are provided in Appendix "C".

4.3.3 Wire Mesh and Lacing

A mat of wire mesh and lacing is installed between the channel sets. The primary function of the mesh and lacing is to keep small pieces of salt from falling down from the roof. The lacing is made of .02m (.625 inch) diameter wire ropes placed not more than .91m (3 feet) apart in both the longitudinal and transverse directions. Above this, a layer of .10 x .10m (4 inch x 4 inch) welded wire mesh is placed. And lastly, a 10 gauge small aperture expanded metal is placed against the salt.

The transverse wire lacing ropes are approximately 9.1m (30 feet) long and extend from rib to rib. Each rope is anchored in place by 2.4m (8 feet) resin anchored rockbolt. For ease of channel installation, the wire mesh and expanded metal are temporarily attached to the existing 3.0m (10 foot) roof bolts and/or Hilti bolts.

4.3.4 Rib Support

The fracturing which is occurring in the ribs along potential failure planes, is similar to those in the roof. However, based on experience elsewhere at the WIPP, this fracturing is not expected to result in any serious stability problems over the anticipated working life of Room 1. Small scale flaking and peeling off of small pieces of rock will take place, these being expected to have a nuisance value as well as posing something of a threat to installed piping and cabling.

Wire mesh is therefore extended from the end of the channels in the roof, around the corners, and down the rib to a height of approximately 2.13m (7 feet) above floor level. This extra wire meshing is pinned to the wall with 1.2m (4 feet) mechanical rock bolts. The mesh and bolts do not prevent the flaking from occurring but contain it and allow subsequent removal and maintenance. This is standard practice in the WIPP underground to accommodate rib spalling.

4.4 DESIGN CALCULATIONS

Detailed design calculation for the Room 1 of Panel 1 roof support system are included in Appendix "C".

5.0 DESIGN IMPLEMENTATION

5.1 SURVEYING AND MARKING

The locations of currently installed rock bolts, and instrumentation equipment that may interfere with support installation has been accurately surveyed and is shown on a map of Room 1 (Drawing No. 54-D-003-W1 and 54-D-003-W2). These drawings will be used to locate the positions of the channel support sets and their associated rock anchors. Roof profiles will be determined at each channel support set location. Once the channel set locations have been plotted on the room map, they will be transferred underground and marked on the roof and ribs of the room. Individual rock anchor holes will then be accurately marked to determine precise locations of the anchor bolts. Experience has shown that a minimum accuracy of ± .063m (.25 inch) will be achieved while marking the positions of the boreholes.

5.2 RELOCATION OF INSTRUMENTATION, CABLES AND PIPING

Any damage to the existing instrumentation installations consisting of electric cables, gas piping, distribution boxes and lighting fixtures must be avoided during installation of the support system. For that reason, the suspended cabling will be moved to the side of the room and attached to the rib, and the piping will be lowered. Relocation of these fixtures will not affect the testing and monitoring program. Conveyor belting suspended from the rib will also be used to provide additional protection to the existing equipment.

5.3 SYSTEM INSTALLATION

5.3.1 Rock Drilling

5.3.1.1 Steel Channel Anchor Bolts

Each channel set has been designed for 11 bolt anchor holes which are to be installed vertically. It is required that all bolt anchor holes are drilled tc a specified depth of 3.55m (11.5 feet), measured from the hole collar. An allowable vertical alignment tolerance of 2 degrees and a depth tolerance of .025m (1 inch) are expected. Deviations of anchor bolt holes are to be addressed on a hole-by-hole basis so that the distance apart at hole ends will not be less than 20 inches. In order to achieve the specified vertical tolerance, collaring alignment holes are required. The holes shall be drilled as accurately as possible to vertical and to a minimum depth of .076m (3 inches). After completing the collar alignment drilling, a .035m (1.375 inch) diameter pilot holes of the correct length will be drilled. These will then be reamed to .076m (3 inch) diameter to a depth of approximately 2.13m (7 feet). To ensure that there is an acceptable annulus in the anchorage zone, all .035m (1.375 inch) ±0.030 diameter finishing bits will be properly gauged. Drawing No. 54-D-003-W2 provides details of the drilled hole.

5.3.1.2 Cable Lacing Anchors

The support system requires that lacing across the room width and length be terminated with resin grouted rock anchors and be provided with means for tensioning the cables. Lacing cable termination anchors will consist of a truss plate fastened to the roof by a .016m (5/8 inch) diameter and 2.4m (8 feet) long resin grouted bar. An adjustable eyebolt will pass through a truss plate and the

lacing cable will be terminated through this eyebolt as shown on Drawing No. 54-5-003-W5. The termination anchor holes will be drilled at 45° angle to a depth of 2.4m (8 feet) with drilling accuracy of ±.025m (1 inch). Drilling detail for lacing holes anchors are shown on Drawing No. 54-5-0003-W4.

5.3.1.3 Rib Support Anchors

The rib anchors are installed to hold the chainlink wire mesh against the rib from the top corner down to approximately 2.13m (7 feet) above the floor. The chainlink meshing is installed to support small pieces of loose or broken salt. Chainlink meshing is currently used at the WIPP as a standard practice for rib maintenance underground. The rib anchors are standard 1.22m (4 feet) long mechanical anchors. Rib support anchor holes are drilled on approximately 1.52m (5 foot) pattern and are 1.22m (4 feet) deep to accommodate the anchors.

5.3.1.4 Recovery Operations

In the event that drilling tolerances or anchorage capacities are not met, the hole depth will be extended an additional .91m (3 feet). The anchor will be reinstalled at this depth.

5.3.2 Installation Sequence

5.3.2.1 Steel Anchor Bolts

Installation of the roof support system in Room 1, Panel 1, will commence with drilling of the steel channel anchor holes and installation of Dywidag anchor bolts.

Correct installation of the Dywidag anchors is critical to the whole support system. The minimum bond length of .91m (3 feet) is required in order to maintain design load capacity of the support system. This has been confirmed by the destructive tests described in Appendix B of this report. A minimum of .457m (18 inches) of the anchor bolt measured from the hole collar will protrude from the mouth of the drill hole. Both the Dywidag tendons and the resin will be installed according to the manufacturers specifications. Following anchor installation, each bolt will be quality checked to confirm its anchorage capacity. Details regarding quality control testing are included in Section 6.1.2.

5.3.2.2 Wire Mesh and Lacing

The wire mesh and lacing will be installed after testing of the anchor bolts is completed and advanced enough to provide adequate working space for wire mesh hanging operations. This would allow for simultaneous installation of wire mesh, cable lacing, and drilling of anchor holes. The wire mesh system consists of two layers, a layer of .10m x .10m (4 inch x 4 inch) welded wire mesh and another layer of expanded metal which is installed directly against the salt and above the welded wire mesh layer.

Both layers are attached to the existing 3.04m (10 foot) rock bolt plates in order to provide temporary suspension until the lacing and channel supports are finally installed. Drawing No. 54-D-003-W5 shows the installation detail of the meshing and lacing. The wire lacing rope will be doubled back through one of the eyebolts attached to the anchor plate, and the free end clamped with three crosby clamps. The loose end will then be passed through the opposite eyebolt and snug

tensioned by means of a come-along and clamped with three crosby clamps. The transverse lacing will be installed before the longitudinal ropes.

5.3.2.3 Steel Channel Sets

The .381m (15 inch) by 177.92N (40 pound) channel steel set will be installed in three 2.74m (9 foot) long sections with the flanges down. Each section will be joined in place by the splice plates located along the flanges. An .356m (14 inch) wide by 2.743m (9 foot) long by .0191m (.75 inch) thick treated plywood gasket will be placed on top of the channel with .038m (1.5 inch) holes drilled to coincide with the hole pattern of the channel. The plywood gasket will first be fitted over the anchor bolt ends, thus forcing them to be correctly aligned before installation of the steel channel is attempted. The steel channel sections will be installed next, by passing the protruding Dywidag anchor ends through the .0381m (1.5 inch) pre-drilled holes. The final step will be the installation of the fastening nut assemblies, together with their associated plates and load cells. Drawing No. 54-D-003-W3 shows the channel support details. A setting load of 4448.22N (1000 pound) will be applied to the anchors. Steel spacers will be used to ensure contact at the rock anchor positions.

5.3.2.4 Rib Support

Installation of the rib support system will commence with drilling of the rib anchor holes followed by hanging of the chainlink mesh together with anchor installation. Approved current WIPP installation procedures for rib bolting will be followed.

Since the rib support system is intended for protection against small scale flaking and peeling of small rock which are of nuisance value, its installation sequence will depend more on convenience than on a rigid schedule.

6.0 TESTING AND MONITORING

The most important component of the roof support system described herein is the rock anchor system. After each Dywidag rock anchor is grouted, both in the mock-up test as well as during actual Room 1 installations, the rock anchors will be subjected to performance tests. The testing will be carried out using as a guideline the specifications laid down in "Recommendations For Prestressed Rock And Soil Anchors", 1989, produced by the Post-Tensioning Institute of Phoenix, Arizona.

Monitoring of the loads on the rock anchors will be done during the test phase as well as prior to the actual installations. The information will be used to determine when and by how much the loads should be adjusted in order to keep pace with the deformation of the salt rock into the room. In addition to monitoring rock anchor loads, deformations in and around the room as well as deflections of the supporting channels will also be monitored. These measurements will enable a clear picture of the room stability to be obtained.

Three inch diameter, 12 foot long observation holes will be installed to monitor the development of shear offsets within the immediate roof, particularly in relation to the potential impact of such shearing on rock bolt performance. Any instrumentation that is destroyed or becomes defective during the operation of Room 1 will be replaced.

6.1 TESTING

6.1.1 Mock-up Test

A mock-up test will be performed in Room 2 of Panel 1 and will include installation of five complete channel sets. The objectives of the mock-up tests are as follows:

- Provide information necessary to evaluate existing equipment;
- Establish practical and safe installation procedures;
- Install and test monitoring equipment;
- Check the performance of the overall system as well as individual components;
- Establish procedures for rock anchor performance tests, and ensure that personnel are proficient in the use of these tests.

6.1.2 Quality Control Testing

The purpose of Quality Control testing is to ensure that every rock anchor installed is capable of handling at least 1.1 times the maximum design load. Because of the large number of bolts (approximately 300) to be installed, these tests have to be done as quickly as possible.

After a rock anchor has been installed for a minimum of 8 hours, it will be loaded to 26 kips (1.1 times the design load). The loading arrangement is shown in Drawing No. 54-D-003-W2. The load will be measured by the load cell and conveniently displayed during loading. After reaching 26 kips, the nut will be

tightened and the loading ram removed. The load will be continually monitored for a minimum of 1 hour to check whether there is any loss of load due to creep. If there is a load loss, the load will be reapplied and monitored. This will be repeated until all "slack" in the system has been removed, or the rock anchor installation is deemed to be unsatisfactory. Recovery operations as detailed in Section 5.3.1.4 may then be instituted. The above procedure may be modified based on field experience.

6.1.3 Destructive Tests

The main component of the support system described in this design document is the rock anchor system.

The primary emphasis of the anchorage system testing program is to guard against the most probable modes of movement that may lead to its failure. The importance of field validation tests of the anchorage system has been recognized as essential to the success of the whole support system.

The rock anchor system was tested by loading correctly installed bolts to destruction. These destructive tests determined that the anchorage capacity of the No. 8 Dywidag rockbolts tested in Room 2 of Panel 1, are equal or greater than guaranteed manufacturers specification of (47.4 KIPS) yield load or (71.1 KIPS) of ultimate load used for support system design. Details of the tests and the results obtained are given in Appendix B.

6.2 MONITORING

Since the support system will be adjusted during its operational life, it is essential to ensure that the loads on the anchors do not exceed the working loads specified by the design. The two main parts of the monitoring program will be observations of room performance and of support performance.

Room stability will be determined from data that will establish the rock mechanics performance of the excavations in terms of room closure, rock deformations in and around rooms, the development of fractures and bed separation at strata interfaces.

The support system performance will be determined from tests that will provide input data from field tests for the design, from tests to prove quality during installation, and from a program that will monitor loads that develop in the rock anchors and on the lacing during the working life of the support. The evaluation of the rock mechanics data characterizing room performance and of the support performance data will establish the effectiveness of the support system. A description of the Geomechanical Monitoring Program including specifications for the instruments is given in Appendix "D".

6.2.1 Geotechnical Monitoring

Geomechanical instrumentation can adequately establish the performance of excavations at the WIPP and provide adequate warning of deteriorating conditions. This has been demonstrated by the early warnings provided in SPDV Test Room 1 prior to its roof fall, and was confirmed by the views expressed by the Geotechnical Expert Panel convened to establish an estimate of the life of Panel 1 (US DOE, 1991 91-023). The geomechanical instrumentation for Room 1, Panel 1, has been upgraded based on a monitoring program presented to the

Geotechnical Expert Panel (US DOE, 1991 91-023). The basis of the revised monitoring program is:

- The measurement of deformations across the Anhydrite "a" and "b" layers in the roof in order to assess the development of bed separations at these strata interfaces.

- The measurement of room closure in order to assess the development of closure rates that exceed bounding levels and to establish the development of asymmetric room closure that may be an indication of fracture development along one rib and rotation of the roof slab. These measurements will be made by convergence measurements of roof/floor and wall/wall closure.

- The observation of conditions in the roof in observation boreholes in order to establish the extent of fracturing and bed separation.

- The measurement of lateral deformations within the pillars to establish the competency of the pillars. These measurements will be made by means of borehole extensometers.

6.2.2 Support System Monitoring

Monitoring of the support system under working conditions in the field is an integral element to ensure its successful performance. The monitoring program consists of measurement of:

- The load that develops in each rock anchor. This provides the basis for adjusting the tension on the anchor so that the load build-up does not exceed the design limits of 1.1 times the design load while accommodating the continued movements of the salt. The load will be measured by means of load cells located at the anchor nut.

- The load that develops on the lacing and mesh. This will be evaluated over selected lengths of the room. The load will be measured by means of hydraulic flat jacks located at cross-over points of the lacing.

- The extension of the cables due to the development of the load due to the detaching wedge. The cable deformation will be measured by means of a calibrated standard length and dial indicator.

- The deflection of the channel support arising from the action of the rock anchor supports and the load transferred by the lacing and meshing. The deflection will be measured by precise surveying techniques.

The purpose of the monitoring of lacing and meshing loads and extensions is to gather information for later analysis. Initially, the monitoring will be carried out daily but this frequency will be adjusted as data becomes available on the load changes with time. The measurement frequency will be based on observing load changes equivalent to 2 percent of maximum working load. The measurements of the loads will be compared with the criteria presented in Appendix "D" to establish when loads in the rock anchors must be adjusted, and the extent of that adjustment:

It should be noted that these criteria are preliminary. Field tests and analytical computations will be performed in order to more effectively define these criteria and the method of load adjustment that will be based on them.

The criteria and the adjustment to the loads will be reviewed as data becomes available and may be changed to be more effective. The process by which these factors become adjusted will require approval by the manager of Engineering for the Managing and Operating Contractor with concurrence from the managers of Operations and Safety.

6.2.3 Instrumentation

Geomechanical Instrumentation installed in Room 1 of Panel 1 will include:

- Beam support rock bolt load cells - Rock bolt load cells will be used to monitor the axial loading on the rock bolts. Loads on the cells are measured by means of resistance strain gages bonded to the cell in a full bridge configuration. The load cells are capable of monitoring loads of up to 444,800N (50 tons) with an approximate instrument sensitivity of 88.9N (20 pounds). In order to maximize the adjustment range of the support system, a low profile type cell will be used.

- Pressure cells or flat jacks - will be used to monitor loading on the cable lacing and mesh as a result of creep displacement. Pressure cells will be constructed of stainless steel and be capable of monitoring the range from 0 to 70 MPa (0 to 10,000 psi) with sensitivity of 0.4 per cent.

- Extensometers - Five borehole extensometers are installed in Panel 1, Room 1, to monitor rock mass deformation adjacent to the excavation. Three extensometers are installed in the roof to monitor possible bed separation within the roof beam. These extensometers are installed along the centerline in the middle at approximately 1/4 length locations of the room. Horizontal extensometers are installed in each wall at the center of the room.

- Convergence points - Convergence measurements will be taken from installed convergence points throughout the room. These measurements are used to determine the amount and rate of closure at selected points. Monitoring of horizontal and vertical convergence will allow for a comparison of the performance of the support system in response to the actual room closure.

- Level survey - Changes in elevation will be monitored at selected locations along the support beams and the rock surface. The elevation surveys will identify areas of differential movement which, in addition to the results from installed geomechanical instrumentation, will establish the response of the system to creep closure.

Due to the large number of instruments, a data acquisition system will be installed. This system will be capable of monitoring up to 330 resistance strain gaged rock bolt load cells. The data loggers will be incorporated into the Geomechanical Instrumentation System which will allow for timely monitoring and reporting.

7.0 ADDITIONAL REQUIREMENTS

Quality of installation and monitoring is of key importance to the successful performance of the support system.

- In order to provide continuity to all the activities and assure future system performance a Project Control Group shall be assembled to oversee all installation and monitoring activities. This group shall include representatives from Mine Engineering, Geotechnical Engineering, Mine Operations, Quality Control, Safety and an outside project consultant.

- Collected monitoring data shall be routinely reviewed and results compared with design parameters.

- Periodic progress reviews shall be conducted to evaluate system performance and to define possible changes to the system not foreseen during design stage.

- Possible further testing might be required to define performance of individual components.

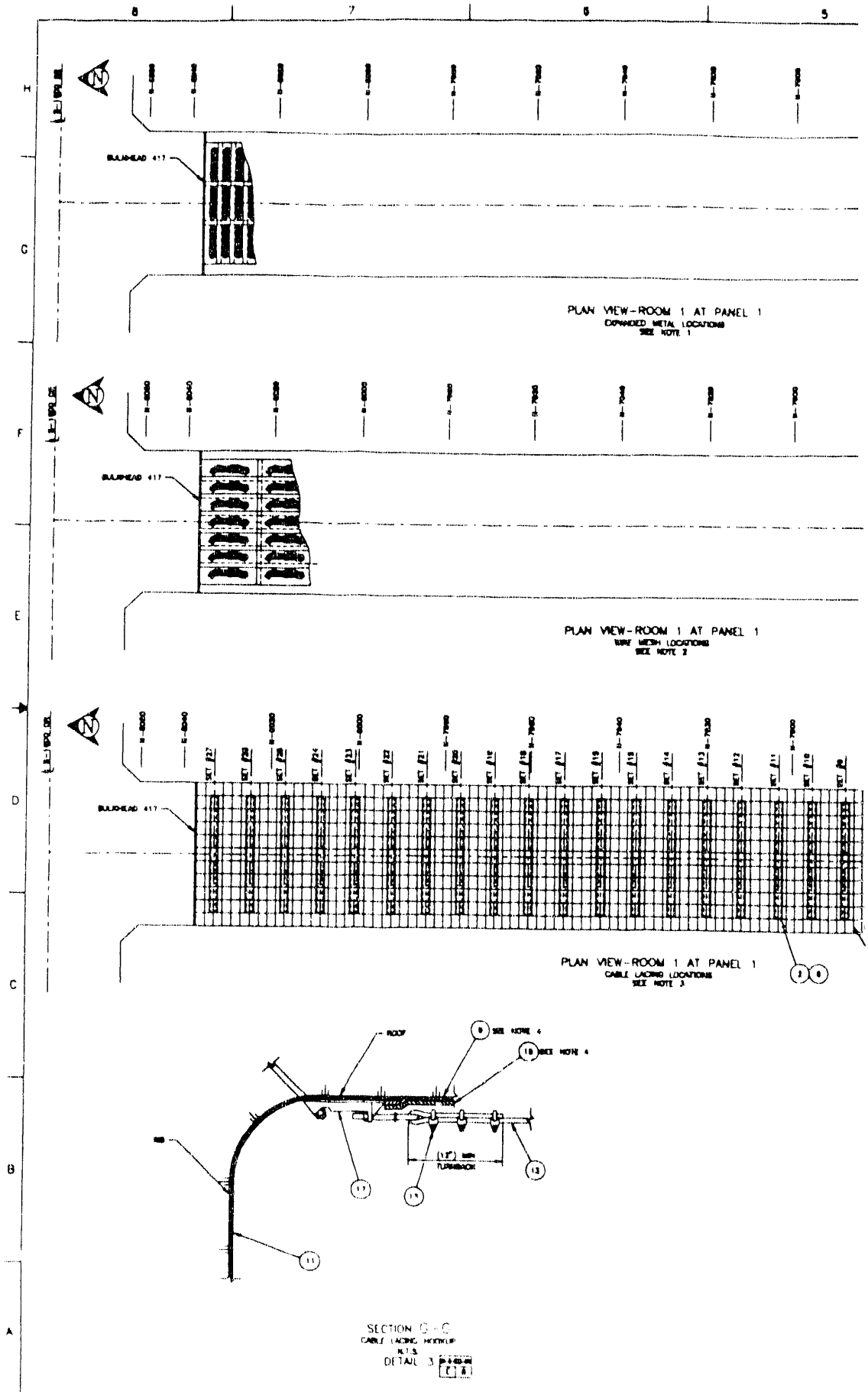
- Further steps shall be taken to develop and validate a mathematical or numerical model which would more easily describe the behavior of the support system.

02080

WASTE ISOLATION PILOT PLANT
SUPPLEMENTARY ROOF SUPPORT SYSTEM

DRAWINGS

Westinghouse Electric Corporation
Waste Isolation Division
Carlsbad, New Mexico
October 1991


8
7
6
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G
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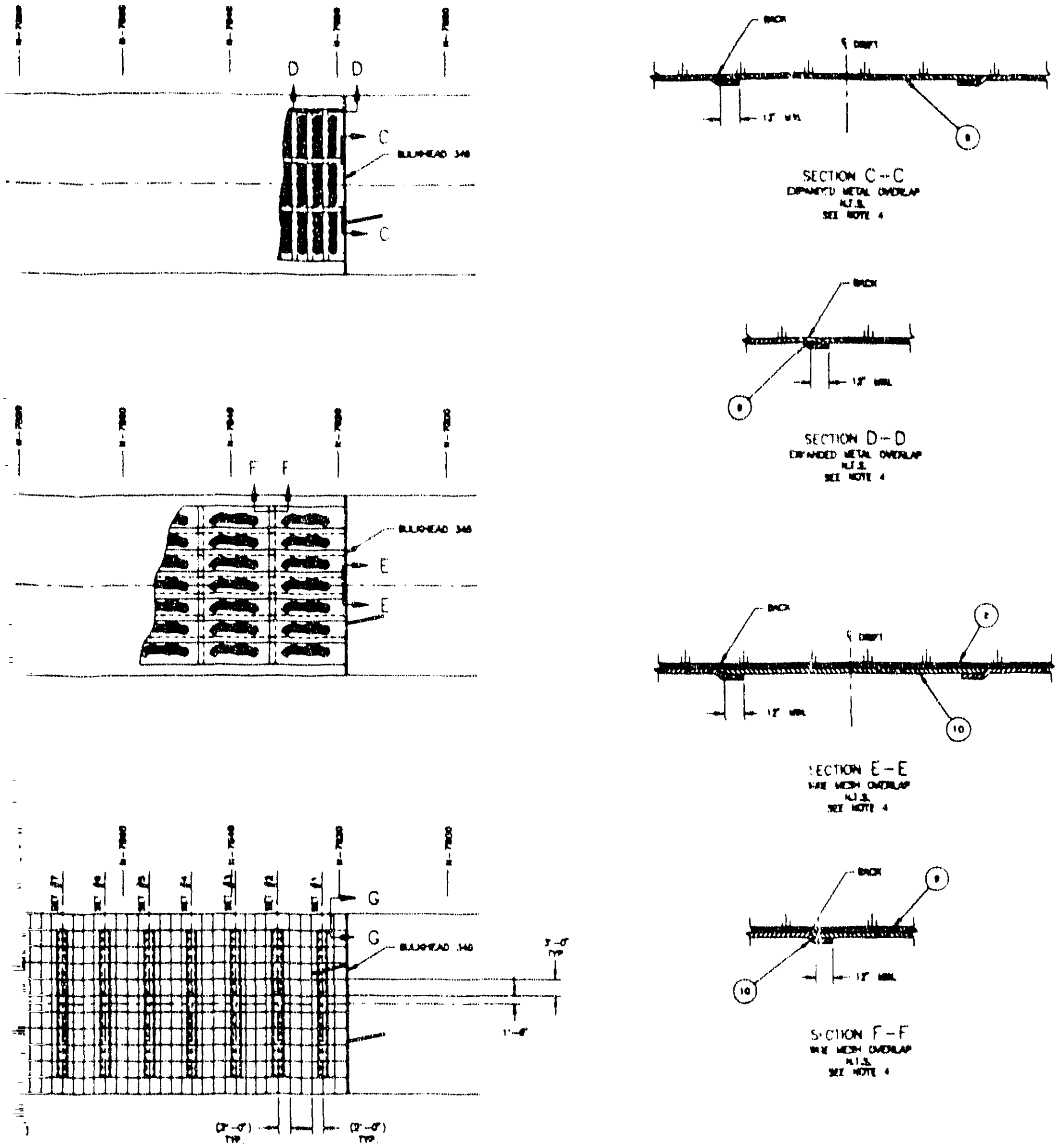
C
B
A
BULKHEAD 417
PLAN VIEW - ROOM 1 AT PANEL 1
EXPANDED METAL LOCATIONS
SEE NOTE 1
PLAN VIEW - ROOM 1 AT PANEL 1
SEE NOTE 2
PLAN VIEW - ROOM 1 AT PANEL 1
CABLE LACING LOCATIONS
SEE NOTE 3
ROOF
SEE NOTE 4
SECTION C - C
CABLE LACING HOOKUP
N.T.S.
DETAIL 3



NOTES:

1. PLACEMENT OF EXPANDED METAL TO BE DETERMINED IN FIELD.
2. LOCATION OF WIRE MESH SHEETS TO BE DETERMINED IN FIELD.
3. LOCATION OF CABLE LACING TO BE DETERMINED IN FIELD.
4. EXPANDED METAL AND WIRE MESH OVERLAPPING EXAGGERATED. ACTUAL FIELD INSTALLATION MAY VARY.

U.S. DEPARTMENT OF ENERGY

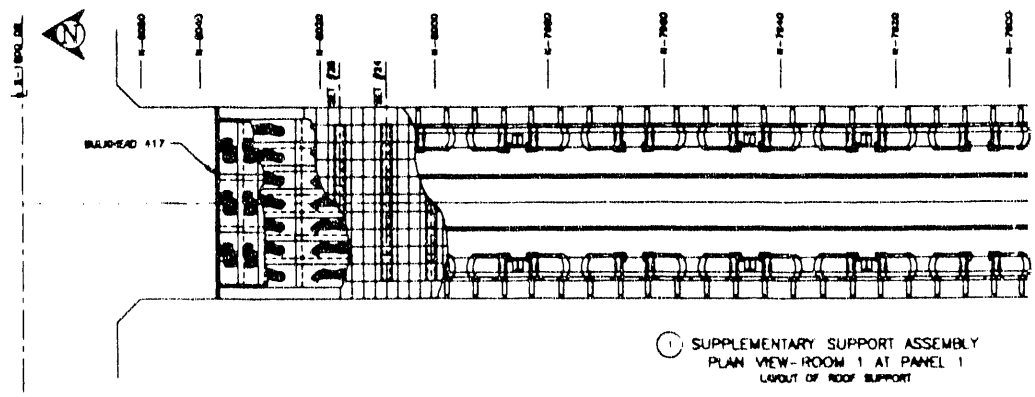
Westinghouse Waste Isolation Division

Waste Isolation Pilot Plant

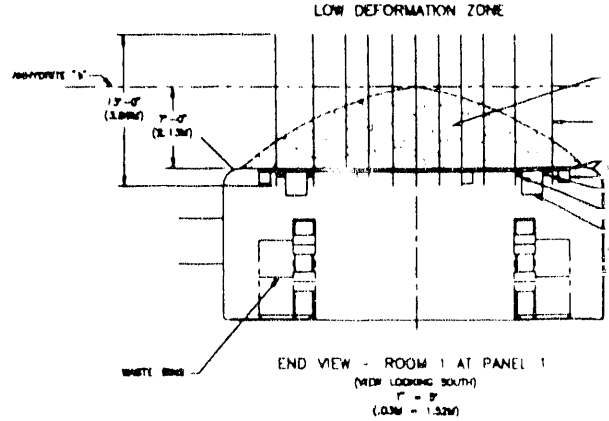
CARLSBAD, NEW MEXICO

SUPPLEMENTARY ROOF SUPPORT
ROOM 1, PANEL 1
WIRE MESH & LACING DETAILS

AU02 | 54-D-003-W5

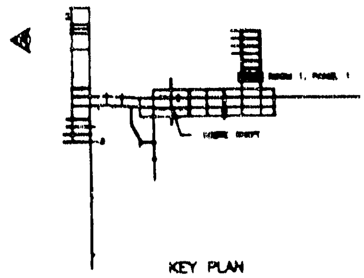


① SUPPLEMENTARY SUPPORT ASSEMBLY
PLAN VIEW - ROOM 1 AT PANEL 1
LAYOUT OF ROOF SUPPORT



END VIEW - ROOM 1 AT PANEL 1
(VIEW LOOKING SOUTH)

LIST OF MATERIAL											
QTY REQ			ITEM NO.	ORDERING INFORMATION	NOTE	DRAWING NO. OR PART NO.	MATERIAL SPECIFICATION				
[illegible]	[illegible]	[illegible]					MAT'L	STD	NUMBER	COMP	FORM
		-	1	ENHANCED ROOF SUPPORT ASSEMBLY		[illegible]					
	-	AR	2	STEEL SET ASSEMBLY		[illegible]					
-	1		3	STEEL SET CENTER PIECE ASSEMBLY		[illegible]					
4			4	BAR, FLAT .38 THK STK	A		CS	ASTM	A36		
1	2		5	CHANNEL, C15X40	A		CS	ASTM	A36		
	4		6	BOLT, .63-11 UNC-2A X 2.50 LG, HEX HEAD	B	91247A708	CS	ASTM	A325		
	4		7	NUT, .63-11 UNC-2B, HEX HEAD	B	90473A036	CS	ASTM	A563		
		AR	8	PLYWOOD, .75 THK STK 4'X10' SHT	F		CDX				
		AR	9	METAL, EXPANDED 10 GA 4'X10' SHT	G		CS				
		AR	10	WIRE, MESH .25 W/4X4 OPENINGS 5'X14' SHT	G		CS				
		AR	11	FENCING, CHAINLINK 9 GA	H		GAL	ASTM	A392		
		AR	12	CABLE, ∅.63 6X25 IWRC	B	3405T15					
		AR	13	CLAMP, CABLE	B	3468T18					
		AR	14	ROCKBOLT, 13' LONG	D						
		AR	15	ROCKBOLT, 4' LONG	D						
		AR	16	PLATE, STEEL 8X8X.50 THK STK	D		CS				
		AR	17	PLATE, TRUSS	C						
		AR	18	LOADCELL							
		AR	19	RESIN, EPOXY	E	3212H80					
	8		20	WASHER, FLAT .63	B	91880A035	CS	ASTM	F436		



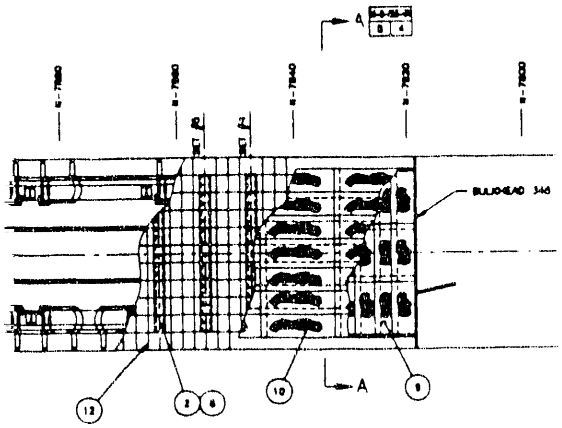
KEY PLAN

REFERENCE DRAWINGS

BIN-SCALE TESTING PANEL 1 ROOM 1 POWER AND LIGHTING	53-J-053-W
UNDERGROUND MINING PANEL 1-PROFILES ALONG ROOM 1 AND S1800 (R)	51-W-080-W
BIN-SCALE TESTS VOC MONITORING AND HELIUM STATION, DETAILS	53-L-003-W
BIN-SCALE TESTS ROOM 1 LAYOUT	53-W-001-W

SUPPLIERS:

A. RYERSON OR APPROVED EQUAL
B. McMASTER-CARR OR APPROVED EQUAL
C. JENNMAR CORP. OR APPROVED EQUAL
D. DYWIDAG OR APPROVED EQUAL
E. CELTITE OR APPROVED EQUAL
F. TEXAS LUMBER OR APPROVED EQUAL
G. RAYNELL OR APPROVED EQUAL
H. ACME FENCE OR APPROVED EQUAL



DETACHING WEDGE

CHANNEL SUPPORT ANCHORS

CABLE LACING ANCHORS

CHANNEL

LIGHTING (EXIST)

POWER CABLE (EXIST)

SANDIA MESSENGER CABLE (EXIST)

SANDIA INSTRUMENT BOX (EXIST)

RIB ANCHORS

MESH

REV	ISSUE DESCRIPTION	DATE	DATE	DATE	DATE		

U.S. DEPARTMENT OF ENERGY

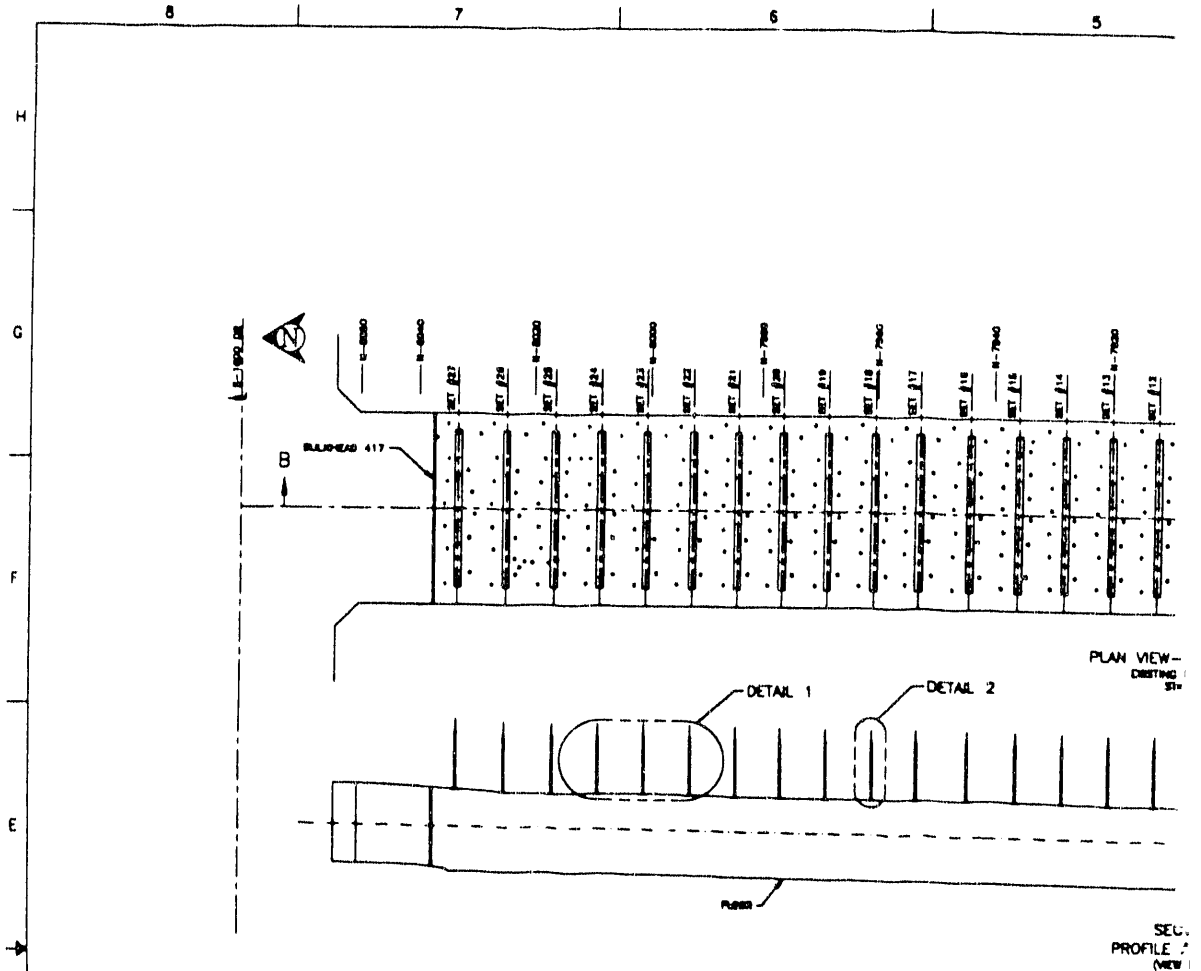
Westinghouse Waste Isolation Division

Waste Isolation Pilot Plant

CARLSBAD, NEW MEXICO

SUPPLEMENTARY ROOF SUPPORT
ROOM 1, PANEL 1
GENERAL ARRANGEMENT

AU06 54-D-003 W1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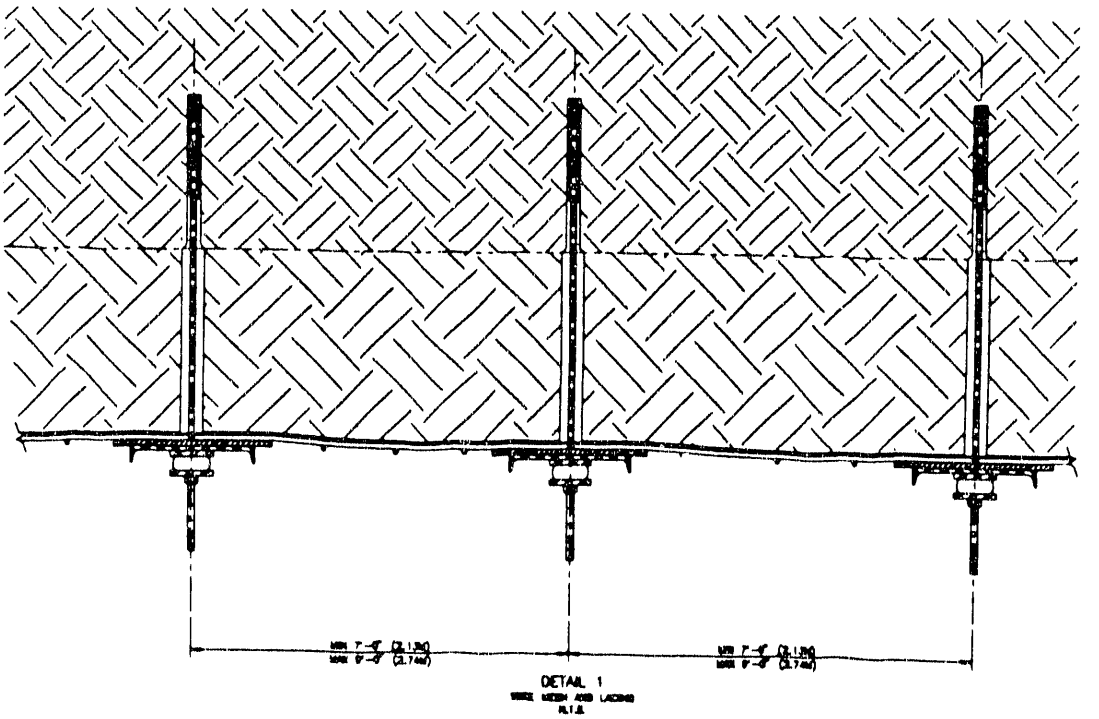
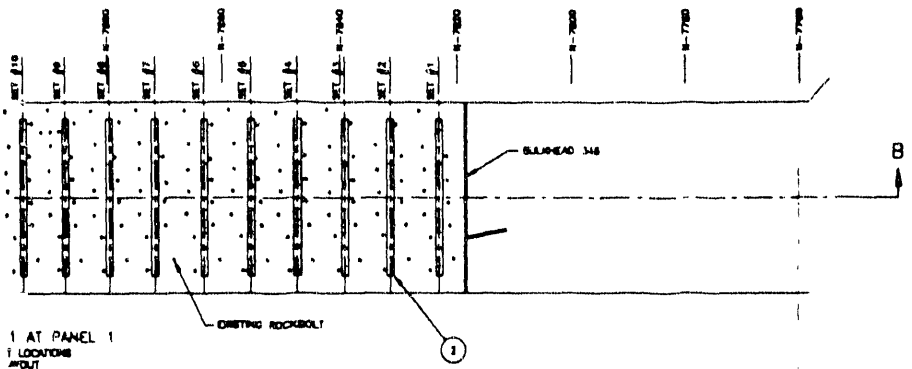
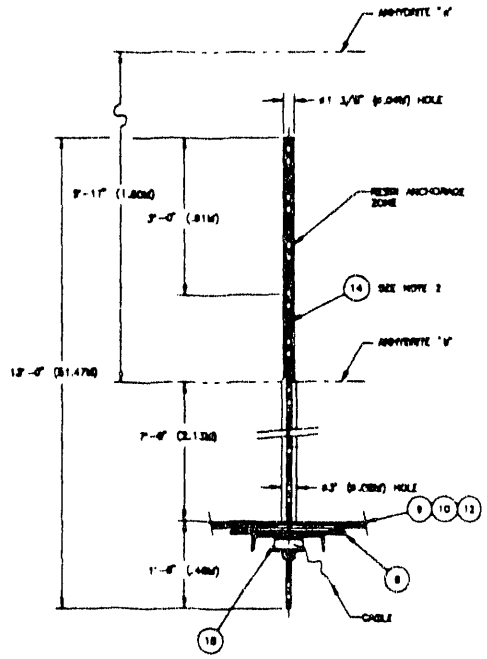
BULKHEAD 417
DETAIL 1
DETAIL 2
PLAN VIEW–
SEC
PROFILE


DETAIL 1



1 AT PANEL 1
T LOCATIONS
APOUT
1

B
T CENTER
(EAST)



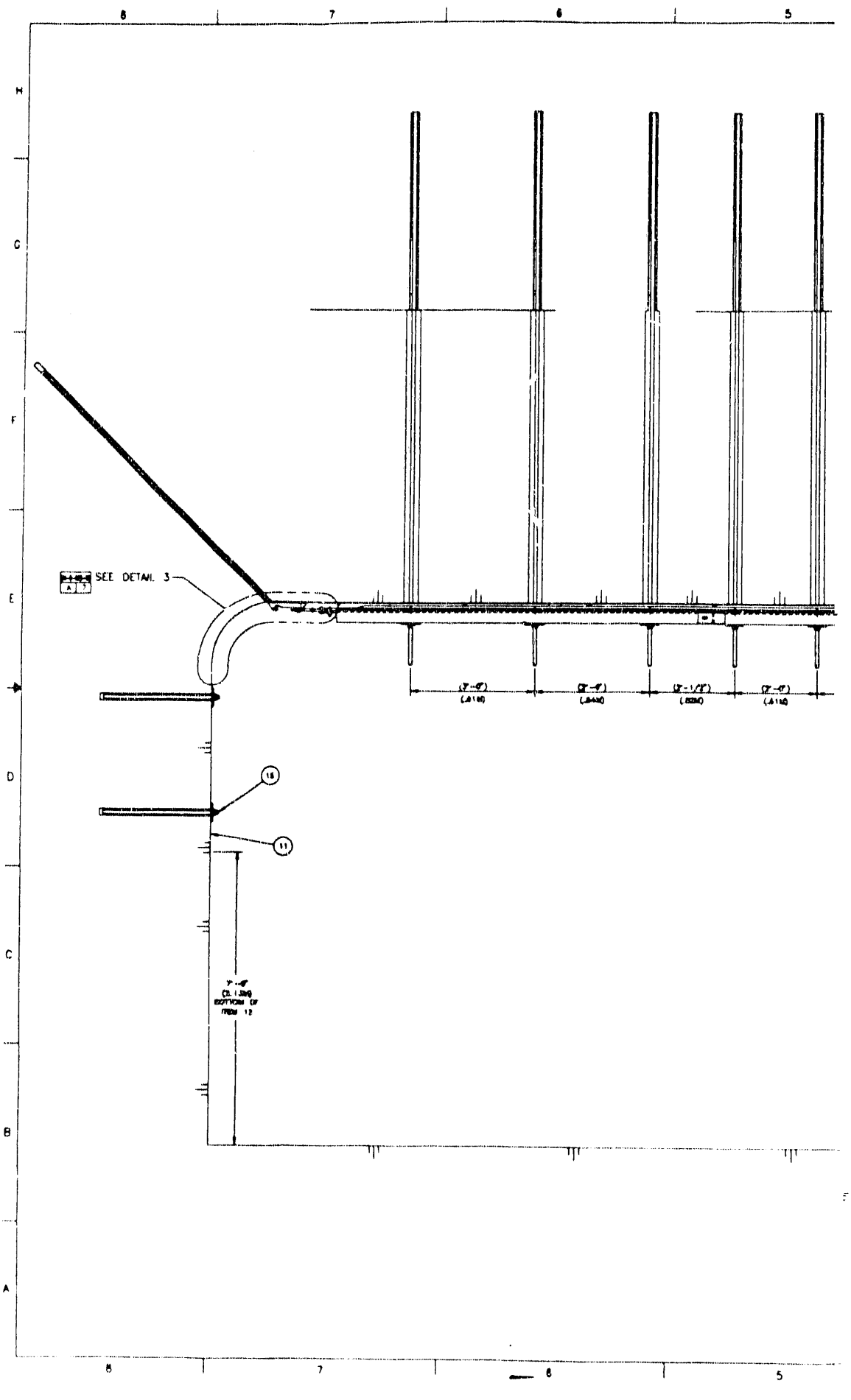
DETAIL 2
ROCKBOLT INSTALLATION & ASSEMBLY
N.T.S.

NOTES:
1. LOCATION OF STEEL SETS (ITEM 1) TO BE DETERMINED IN FIELD.
2. INSTALL ROCKBOLTS (ITEM 14) PER MANUFACTURERS INSTRUCTIONS.

U.S. DEPARTMENT OF ENERGY
Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant

SUPPLEMENTARY ROOF SUPPORT
ROOM 1, PANEL 1
STEEL SET LOCATIONS & DETAILS

AU06 | 54-D-003-W2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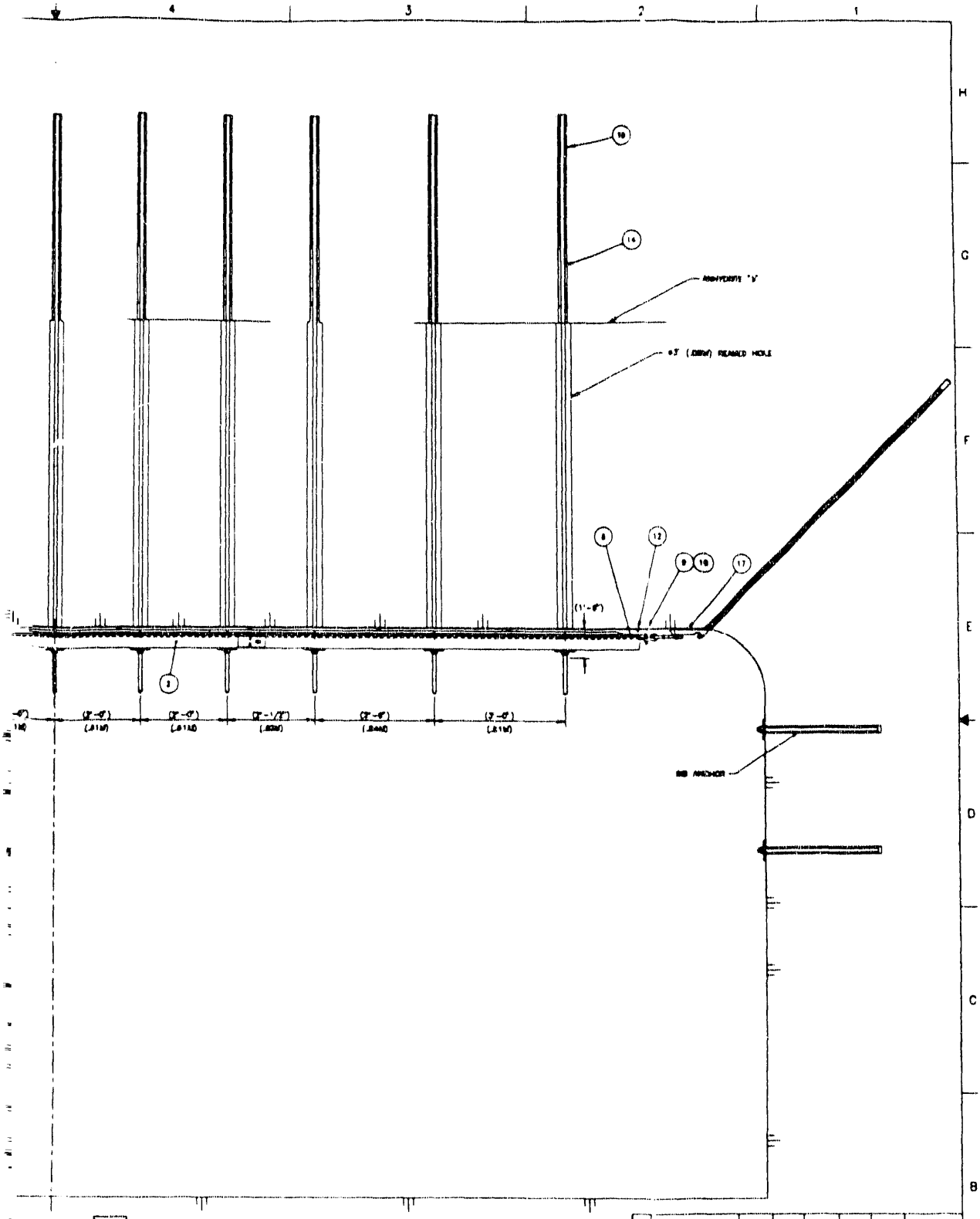
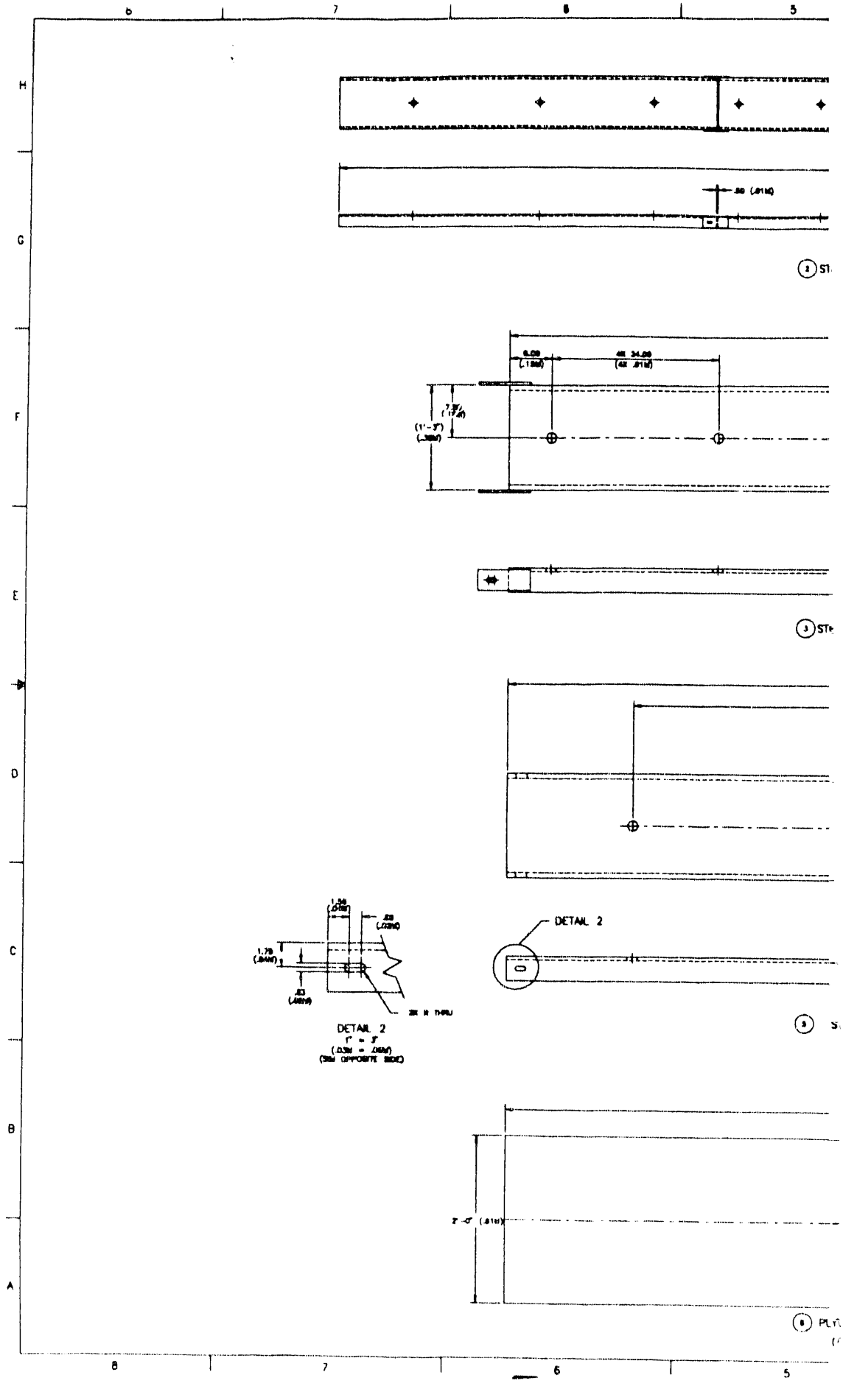


ECTION A – A
M 1 AT PANEL 1
EW LOOKING SOUTH)
STEEL SUPPORT

U.S. DEPARTMENT OF ENERGY
Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant

SUPPLEMENTARY ROOF SUPPORT
ROOM 1, PANEL 1
ROOM 1 CROSS SECTION

AUQE | 54 - D - 003 - W4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DETAIL 2
DETAIL 2
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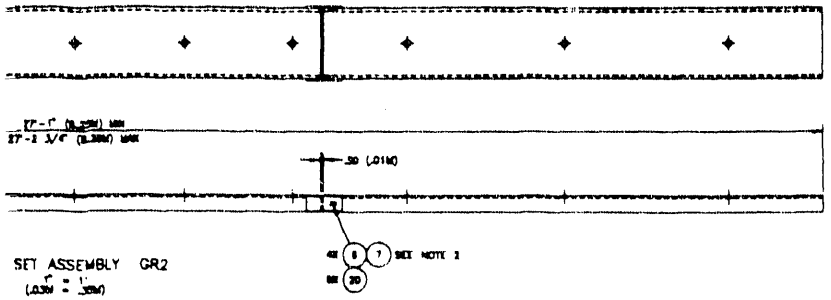
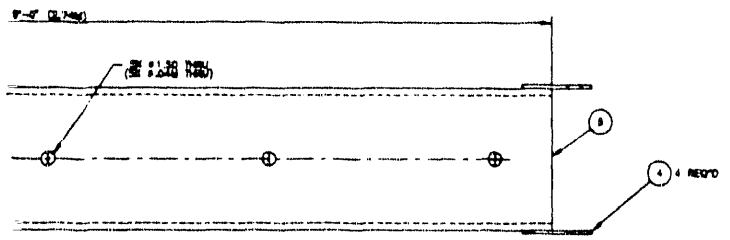
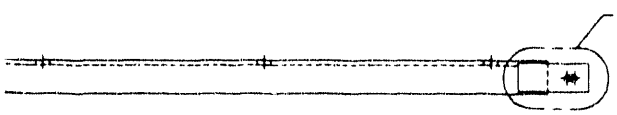
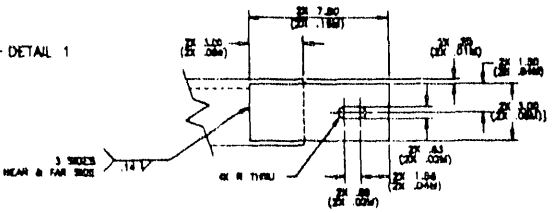


SET ASSEMBLY GR2

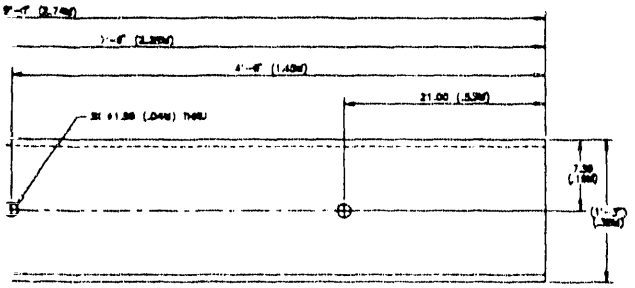


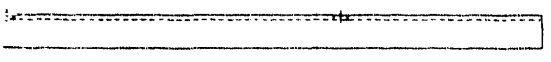


SET CENTER PIECE ASSEMBLY GR3

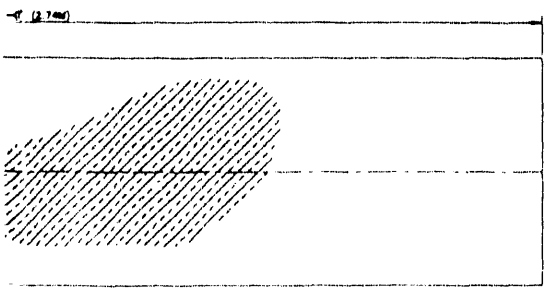


DETAIL 1





SET END PIECE



D STRIP

NOTES:

1. USE ITEMS 3 AND 5 AS A TEMPLATE TO DRILL HOLES IN ITEM 6.
2. FINGER TIGHTEN ITEMS 6 AND 7 UPON INSTALLATION.

U.S. DEPARTMENT OF ENERGY

Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant

SUPPLEMENTARY ROOF SUPPORT
ROOM 1, PANEL 1
STEEL SET FABRICATION

AV02 | 54-D-003-W3

WASTE ISOLATION PILOT PLANT
SUPPLEMENTARY ROOF SUPPORT SYSTEM

APPENDIX A
Geology and Rock Mechanics

Westinghouse Electric Corporation
Waste Isolation Division
Carlsbad, New Mexico
October 1991

WASTE ISOLATION PILOT PLANT
SUPPLEMENTARY ROOF SUPPORT SYSTEM

APPENDIX A
Geology and Rock Mechanics

Westinghouse Electric Corporation
Waste Isolation Division
Carlsbad, New Mexico
October 1991

GEOTECHNICAL DESIGN SUMMARY REPORT

FOR ROOF SUPPORT SYSTEM IN ROOM 1, PANEL 1

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3.0 Properties of Rocks at Repository Horizon

4.0 In Situ Stress Regime

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5.2 Rock Deformations About Room

5.3 Stresses Around Room

6.0 Performance Requirements for Support System

6.1 Performance

6.2 Geotechnical Design Basis for the Roof Support System for Room 1, Panel 1

6.2.1 Rockload To Be Supported

6.2.2 Vertical Movements

6.2.3 Lateral Movements

1.0 INTRODUCTION

The purpose of this report is to provide the geotechnical basis for the design of a system to support the rock in the roof of Room 1, Panel 1. The system must ensure that the room meets the functional requirements necessary to support its use as an underground laboratory for the study of gas generation from CH TRU radioactive waste (Molecke, 1990). This research program, called the Bin Scale Testing Program, is under development at the present time and the experiments are expected to start in the second half of 1991. Room 1 of Panel 1 is currently 5 years old and must remain accessible for a further 7 years in order to support the bin scale testing program.

The Geotechnical Design Summary Report interprets the geologic and rock mechanics data presented in the annual Geotechnical Field Data and Analysis Reports (US DOE, 1991a; US DOE, 1990) and other occasional reports (US DOE, 1991b) and presents the geotechnical assumptions that have been made for the design. The geotechnical investigations at the WIPP are comprehensive and provide detailed information on the site conditions that is not typically available for an engineering design. This has enabled a phenomenological model to be established that explains the performance of openings. This model establishes the mechanisms that must be addressed by the design of the support system in order to control the roof conditions in Room 1, Panel 1.

Following the collapse on February 4th, 1991 of the roof in the Site and Preliminary Design Validation (SPDV) Test Room 1 that confirmed the concerns raised by the Geotechnical Engineering Section concerning the capability to maintain the Panel 1 room for the period of the bin scale tests, a panel of Geotechnical experts was formed to evaluate the life expectancy of the underground room in which the tests will take place. The panel concluded that if no additional remedial measures were taken, the rooms in Panel 1 are likely to have a total life of seven to eleven years from the time of excavation using the currently installed roof support system, consisting of rockbolts. Mining of Room 1, Panel 1 began during the second half of 1986. Therefore the remaining life of this room is anticipated to be between two and six years (US DOE, 1991b). The most current geotechnical field data from this room does not indicate that its geomechanical performance differs significantly from that observed in SPDV Test Room 1. On this basis, the remaining life for Room 1 as currently supported is about two to three years.

The panel members agreed that measures could be taken that would provide reasonable assurance that the bin scale tests could be carried out to completion in Panel 1. They suggested a number of alternative actions that could be taken and recommended that the WIPP project evaluate the alternatives and select one, or a combination, of measures that would assure continued use of the rooms over the period of the tests. They also indicated that the measures should be augmented by a monitoring program that would regularly assess the geomechanical conditions and that maintenance should be carried out as a routine activity in the rooms as they aged.

2.0 STRATIGRAPHY OF REPOSITORY HORIZON

The proposed underground storage facility is located 655m (2150 feet) below the surface in bedded salt of the Permian Salado Formation. A generalized stratigraphy showing the facility level is given in Figure 2.1. Over 300m (1000 feet) of impermeable evaporitic deposits separate the facility horizon from the overlying sedimentary rocks and 620m (2000 feet) of evaporites lie below the facility horizon and provide a barrier to Permian limestones and sandstones.

Halite is the most abundant mineral in the Salado and occurs in thick beds intercalated with thinner beds of polyhalite and anhydrite. Salado halite is rarely pure and usually contains trace and minor amounts of foreign material including clay, anhydrite and polyhalite. Halite crystal size and morphology vary considerably, and various large and small scale sedimentary features are abundant throughout out all of the Salado Salt. A detailed discussion of the Geology of the Salado formation can be found in the Geologic Mapping of the Air Intake Shaft at the Waste Isolation Pilot Plant (U. S. DOE, 1991c).

The facility horizon lies within a 12m (40 feet) thick unit consisting of halite, argillaceous halite, and polyhalitic halite. Figure 2.2 identifies the typical geology within this unit. Observations indicate that these geologic conditions are consistent across the site at the repository horizon. Figure 2.3 a, b, and c provide the stratigraphy exposed in Room 1, Panel 1.

A 0.5m (20 inches) to 0.8m (32 inches) thick persistent bed of sulfate (anhydrite and polyhalite), identified as Marker Bed 139 lies about 1.5m (5 feet) below the floor level. Considerable lateral variability in composition and thickness exists within this sulfate bed at both the regional and repository scale. The variability in thickness is associated with the top of the deposit and undulations up to 150mm (6 inches) have been observed in 100mm (4 inch) diameter bore (Holt, 1991). The bottom of the Marker Bed is sub horizontal and is underlain by Clay "E".

Anhydrite beds, called Anhydrites "a" and "b" occur about 4m (13 feet) and 2m (6.5 feet) above the roof. Thin clay seams called Clay G and Clay H are associated with the bottom of these beds. In addition, a thin clay layer identified as Clay F is found intermittently in the immediate roof of excavations.

The Marker Bed 139 and the clay layers can have a significant impact on the mechanical performance of excavations. The clay layers provide surfaces along which slip can occur whereas the Marker Bed acts as a unit that does not deform plastically with time. In addition, the undulating nature of the top of the Marker bed will resist shear movements along the interface with the overlying salt.

3.0 PROPERTIES OF ROCKS AT REPOSITORY HORIZON

The reference material properties for the repository horizon rocks are provided in Table 3.1. These properties are based on laboratory tests carried out during the site characterization phase of the WIPP Project (Krieg, 1983). The tests have demonstrated the range of mechanical properties associated with the WIPP strata, and in particular have defined the time dependent behavior of the salt.

Salt is a material that flows when subject to high confining pressures and deviatoric stress conditions. This behavior has long been recognized in the mining industry (Baar, 1977; Dreyer, 1981) and considerable efforts have been made to characterize this response from laboratory creep tests. However, extensive experience within the mining industry has demonstrated the difficulties involved in establishing in situ performance based on the laboratory characterization of salt creep (Baar, 1977).

TABLE 3.1
ROCK PROPERTIES OF THE REPOSITORY HORIZON

	DIMENSIONS	SALT	ANHYDRITE	POLYHALITE
THERMAL PROPERTIES				
Thermal Conductivity	W/(m.K)	5.0	4.7	1.4
Specific Heat	J/(kg.K)	860	860	860
Coefficient of Linear Expansion	K^{-1}	45.0E-6	20-E6	24E-6
MECHANICAL PROPERTIES				
Young's Modulus	Pa	3.1E+10	7.5E+10	5.5E+10
Poisson's Ratio	dimensionless	0.25	0.35	0.36
Bulk Modulus	Pa	2.1E+10	6.3E+10	6.6E+10
Shear Modulus	Pa	1.2E+10	2.8E+10	2.0E+10
Density	Mg/m^3	2.3	2.3	2.3

PROPERTIES FOR SECONDARY CREEP FOR SALT

$$\dot{\epsilon} = D\,\bar{\sigma}^{n} e^{-Q/RT}$$

Where: $\dot{\epsilon}$ = effective creep strain rate

$\bar{\sigma}$ = effective stress

T = temperature in degrees Kelvin
D, n are empirical constants

$D = 5.79E\text{-}36\ Pa^{-4.9}/sec$
$n = 4.9$
$Q/R = 6060\ K$

Where: Q = the effective activation energy for salt, (cal/mole)
R = the universal gas constant, (cal/mole.K)

Further explanation of the definitions for effective creep strain rate and effective stress are provided in DOE-WIPP-86-010, the Design Validation Final Report, Appendix C.

Reference parameter values are based on:

Branstetter, L.J., "Second Reference Calculation for the WIPP" SAND83-2461, Sandia National Laboratories Albuquerque, New Mexico.

Krieg, R. D., Reference Stratigraphy and Rock Properties for the Waste Isolation Pilot Plant (WIPP) Project" SAND83-1908, Sandia National Laboratories, Albuquerque, New Mexico.

The mechanical response of the salt at the WIPP has been characterized by a steady state creep law that was developed in the early 1980's by laboratory creep tests on the Salado salt (Hansen, 1979; Hansen and Mellegard, 1979; Herrmann et al, 1980). This constitutive law relates creep strains to stress and temperature. The relationship ignores transient creep effects that will influence early time deformations and does not include dilation of the salt that will occur when the rock is subject to deviatoric stresses and low confining pressures. The steady state creep law has been used in the model studies to establish predictions of the structural performance of the openings.

Field observations at the WIPP (Cook and Roggenthen, 1991) and in the Carlsbad Potash Basin (Greenwald and Howarth, 1938) have shown that the brittle behavior of salt under deviatoric stresses with low confinement can be a significant factor contributing to the mechanical performance close to excavations. This brittle behavior of salt is generally not characterized by laboratory studies, and therefore, the constitutive law developed to define the creep behavior of salt at the WIPP does not include fracture development or rock dilation. The evaluation of performance must take into consideration the limitations of the constitutive law applied to the salt. Provided that these limitations are understood, and the structural responses of other stratigraphic zones are properly modelled, it will be possible to establish useful models with which to predict the structural performance of excavations at the WIPP.

4.0 IN SITU STRESS REGIME

The initial stress state at the repository horizon is established from Helms Rule for weak rocks (Hoek and Brown, 1980). This rule establishes the vertical stress as dependent on the depth of overburden and its average density, and the horizontal stresses to be equal to the vertical stress. Taking the average density for the overburden at the WIPP site as 2130 kg/m^3 (135 lb/ft^3), the initial stresses at the repository horizon are about 14 MPa (2000 psi).

Measurements of virgin in situ stress in salt are difficult to achieve since the measuring techniques assume that rock behaves in an elastic manner (Hoek and Brown, 1980) whereas salt deforms plastically. However, hydraulic fracturing tests have been carried out in boreholes in salt at the WIPP in order to estimate the stresses (Wawersik and Stone, 1986). Although data interpretation was difficult, it was concluded that the virgin in situ stress state at the WIPP is approximately uniform in all directions and that the stress magnitudes correspond to the weight of the overburden. This conclusion confirms, the assumptions used for design purposes at the WIPP Project (US DOE, 1986).

5.0 STRUCTURAL RESPONSE OF EXCAVATED ROOM

Field observations form the basis for a phenomenological model of the structural performance of the underground excavations. This performance is best characterized by data from the SPDV Test Room Panel. These test rooms are among the oldest excavations underground, having been constructed in March and April, 1983. The rooms have the same size and shape as those in the proposed waste storage panels and are located at the same geologic horizon. They are relatively large excavations with each room having a nominal height of 3.95m,(13 feet) width of 10m (33 feet), and a length of 91m (300 feet). The rooms are separated by 30m (100 feet) wide pillars. This configuration results in an extraction ratio in the Test Room panel of about 25 percent. The rooms were excavated in order to confirm the geology, validate design assumptions for the underground, and provide data, where necessary for revision of the design.

TABLE 5.1

CLOSURE RATES BY TIME SINCE EXCAVATION
VERTICAL CONVERGENCE DATA

ROOM	DATE OF EXCAVATION AT INSTRUMENT	EXCAVATION COMPLETED TO FINAL DIMENSIONS	YEAR							
			0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
PANEL 1:										
ROOM 1	JUNE 1986	AUGUST 1986	4.13	4.26	4.60	3.24	(3.57)			
ROOM 2	MARCH 1987	MARCH 1988	3.02	6.71	3.33	2.26				
ROOM 3	FEBRUARY 1987	MARCH 1988	1.60	9.85	3.34	2.71				
ROOM 4	FEBRUARY 1988	MARCH 1988	8.33	3.14	2.56					
ROOM 5	FEBRUARY 1988	MARCH 1988	9.19	2.76	2.28					
ROOM 6	FEBRUARY 1988	MAY 1988	8.36	3.41	2.76					
ROOM 7	MARCH 1988	MARCH 1988	9.26	3.22	2.70					
SPDV:										
ROOM 1	APRIL 1983	APRIL 1983	6.79	3.75	2.93	2.88	2.85	3.36	4.70	12.77
ROOM 2	MARCH 1983	MARCH 1983	7.69	3.16	2.39	2.19	2.14	2.33	2.74	2.87
ROOM 3	MARCH 1983	MARCH 1983	7.59	3.65	2.64					
ROOM 4	APRIL 1983	APRIL 1983	5.70	3.18	2.65	2.33	2.13	2.33	2.42	2.31

Notes: Closure rates in inches/year.
Year is determined from date of excavation at instrument.
( ) Estimated based on less than one full year of data.

Observations of the performance of these rooms have been routinely made over the past eight years. They have established room performance in terms of room closure, rock movements and the development of fractures in the immediate vicinity of openings (US DOE, 1989; US DOE, 1990; Cook and Roggenthen, 1991). SPDV Test Room 1 has provided the most complete picture of the structural performance of an excavation. Measurements were taken in this room over a period of almost eight years, from immediately following its excavation until a major roof fall occurred. Different stages in the performance of the room can be related to its roof/floor closure history (see Figure 5.1). Other rooms are showing the same general behavior but none others (outside of the SNL experimental area where different conditions exist) have yet failed. SPDV Test Room 1 provides the most detailed example of the performance that can be expected from other rooms having similar geometries.

In addition, numerical analyses have been carried out to evaluate the structural performance in terms of stress and strain redistribution taking place about excavations with time. The analyses have used the near repository horizon stratigraphy described in Section 2.0 and the mechanical properties of the rock types provided in Section 3.0. Of particular significance to the interpretation of the model, are:

- the time dependent relationship governing the mechanical response of the salt
- the properties that control bed separations at the strata interfaces

The field observations and the numerical analyses have been used to develop a model of the mechanisms that occur in the roof of an excavation with time. The model is primarily based on the performance monitored in SPDV Test Room 1. Its various stages are shown in Figure 5.2. The field and analytical data supporting this phenomenological model are given in the following sections of the report.

It is expected that rooms having a geometry similar to the SPDV Test Rooms and the waste storage rooms will eventually pass through all the stages identified in Figure 5.2 unless remedial actions are taken to control roof deterioration and roof movements. The roof support system for Room 1, Panel 1 is based on the control of the conditions identified by the model.

5.1 ROOM DEFORMATION

Rooms with similar geometries have shown relatively consistent deformation characteristics. Although actual magnitudes of the room closures show a range of values. The variability in the closure rates is demonstrated in Table 5.1 which lists rates of closure at mid room, mid span for the SPDV Test Rooms and the rooms in Panel 1 all of which have similar geometries. The highest closure rates appear to be related to the rooms closest to the barrier pillars and are lower in the middle of panels and at the solid abutments. At present, no correlation has been established between closure rate and variables such as excavation sequence and variations in stratigraphy that might explain these differences.

The changes in roof profile have been correlated with time, based on data from SPDV Test Room 1. The room deformation is initially symmetrical about the room center but after about five years, the roof/floor closure, become assymmetric with one side closing faster than the other side. This behavior identified from SPDV Test Room 1 has been measured in other locations within the facility, and may be considered typical of the performance in the wider spanned excavations at the WIPP.

5.2 ROCK DEFORMATIONS ABOUT ROOM

FIELD DATA

Deformation measurements show that the rock mass deforms with time and that rock movements generally reduce with distance from an excavation surface although this behavior is modified at strata interfaces. Movements occur both normal and parallel to excavation surfaces. In particular, the Anhydrite 'b' in the roof and the Marker Bed 139 in the floor are associated with relatively large vertical and lateral deformations. Typical inclinometer data from a room cross section are shown in Figure 5.3 covering the period from 1983 to 1987. Figure 5.4 provides the data for roof extensometers.

Bed separation has been identified at the Anhydrite 'b' in the roof after approximately three years. Vertical separation at the clay/salt interface beneath the anhydrite 'b' appears to increase at a rate of about 25mm per year once the bond across the interface is broken.

The geotechnical data show that the roof and floor of an excavation act as a series of flexing beams separated by zones or planes across which lateral differential movement occurs. This is largest at the Anhydrite 'b' but does occur at other horizons above and below the excavations in association with strata interfaces, generally clay/salt interfaces. Lateral shifts in the roof indicate that beam flexure was still occurring at a depth of 15m. In the floor, deflections were not as pronounced, and have largely disappeared at a depth of 15m. Differential lateral movements of about 12 mm per year have been measured in the immediate roof beam, five years after excavation. These rates of movement have been confirmed by the monitoring of lateral displacements in old excavations (U.S. DOE, 1991a). Rock deformations about a room also is governed by fracture development. The typical fracture development observed in the wide excavations is shown in Figure 5.5. The most significant fractures are low angled shear fractures develop at the rib/roof interface of excavations. In SPDV Test Room 1, these fractures became sufficiently persistent and continuous that a detached wedge formed in the roof of SPDV Test Room 1. This wedge fell eight years after the excavation of the room. Precise surveys of the roof in SPDV Test Room 1 following the rock fall are shown in Figure 5.6 and indicate the geometry of the roof cross-sections to be arch shaped. The condition of the roof in Room 1, Panel 1 is shown in Figure 5.7 as of the summer 1991.

MODEL DATA

Roof/floor closure for the model is compared with the field data in Figure 5.8. Roof/floor closure rate is 0.1 m per year (4 inches per year) and does not vary significantly with time. This is probably due to the limitations of the steady state of the creep law used for the calculations. A more sophisticated constitutive law that includes transient creep effects has been developed by SNL and would provide a more accurate simulation of the early time performance of the excavations.

Bed separation provided by the model at the Anhydrite 'b' level indicate that the separation is at a maximum above the mid span of the excavation and increases at about 12mm per year. The model is compared with the field data in Figure 5.8b. The model also shows that bed separation is occurring at the clay beneath the Anhydrite 'a' layer. This is not consistent with the field observations which do not indicate bed separation at this level. Further investigations of the performance at this layer are required.

The shear strains are shown in Figure 5.9. They build up with time as creep occurs under relatively constant compressive stress in the immediate roof beam and the contours of effective strains indicate potential failure planes. These planes are consistent with the fracture development that occurs in the roof of excavations with time.

5.3 STRESSES AROUND ROOM

Prior to excavation, the strata at the repository horizon are subject to an in situ stress field that is uniform in all directions and has a value of about 14MPa (2000 psi) which is equivalent to the overburden loading. Immediately the excavation is made, the stresses adjust to an elastic distribution. Of particular importance are the high shear stress concentrations that develop in the corners of the excavation (Miller, 1991). These may provide incipient fracturing that later develop into discrete fracture planes. With time, the stresses in the immediate vicinity of the excavation reduce due to stress relief as the salt moves into the opening. The excavation disturbs the stresses and the redistribution continues over time dependent properties of the salt. The principal maximum and minimum stresses induced at 0, 3 and 5 years following excavation are shown in Figures 5.10 and 5.11. These plots indicate the changes in stress that take place with time.

The influence of the stratigraphy on the stress distributions is evident immediately that the excavation is formed. The Marker Bed 139 modifies the structural performance of the floor and the anhydrite 'b' effects the stress distribution in the roof.

In the floor, the Marker Bed 139 acts as a stiff unit which does not exhibit time dependent behavior. The variable elevation in the upper boundary of the Marker Bed indicates that a high resistance to shear movements at this boundary develops. These immediate effects were also observed in numerical analyses presented by Mckinnon (U.S. DOE 1991b) at the Geotechnical Expert Panel Meeting The salt above and below the Marker Bed will deform with time and depending on the slippage between the salt and the anhydrite will maintain high compressive stress into the Marker Bed. These high stresses may cause brittle fracture of the Marker Bed 139 and its failure which would result in floor heave.

The clay beneath the anhydrite 'b' introduces a plane of low frictional resistance into the strata sequence. The plane will not support shear stresses, and this isolates the immediate roof beam. The plastic flow of the clay ensures that high shear stresses cannot develop at the interface and the low bond strength between the clay and the salt leads to separation at the interface. Once the immediate roof beam becomes isolated, the lateral movements of the pillars maintain the lateral stresses in the beam. With time, the shear strains build up in the beam and eventually result in the development of failure along particular surfaces. This failure initially occurs at room mid length. The localized failure relieves the lateral stresses in the beam. However, due to the continued lateral creep of the salt, the roof beam continues to be subject to compressive stress. The failures propagate in the longitudinal direction, gravity effects take over, and the weight of the unsupported section of the roof spanning increases. At some critical length, the strength of the beam cross section is exceeded and the roof falls as a unit.

6.0 PERFORMANCE REQUIREMENTS FOR SUPPORT SYSTEM

A geotechnical design basis has been developed from the discussions presented in Section 5. The design provides a system support of the roof in Room 1, Panel 1 to meet the functional requirements described in Section 6.1. The geotechnical design basis is as follows:

- The support system shall support the weight of the detached rock wedge that forms in the roof as a result of the development of low angled fractures from the ribs.
- The support system shall accommodate vertical movements of the roof that include both differential and total displacements.
- The support system shall accommodate lateral shifts

These requirements are discussed in the following sections in terms of the bounding values that encompass the conditions expected to be encountered in the field.

ROCKLOAD TO BE SUPPORTED

The weight of the detached rock wedge that forms in the roof depends on the orientation of the fractures that develop. The estimate is based on the observations of the rock fall geometry seen in SPDV Test Room 1 and the interpretation contours of shear strain in the roof (Miller, 1991). The wedge geometry consists of an arched or triangular shape that forms from low angled fractures starting at the the ribs whose propagation is bounded and controlled by the bed separation occurring at the Anhydrite 'b'.

VERTICAL MOVEMENTS

The vertical movements that the roof must accommodate are a combination of salt creep, dilation of the salt due to fracture development, and gravity effects once fractures have formed.

The total displacement has been taken as 38mm per year (1.5 inches per year) vertical lowering of the roof at midspan. The differential movement is taken as the difference between displacement of the roof at mid span and that close to the ribs. The differential movement to be accommodated by the design has been taken as a maximum of 25mm per year (1 inch per year). Roof displacements are not always a maximum at mid span. Once fracturing becomes visible in the roof along one rib, then the field data shows that the roof deforms asymmetrical with one side lowering more rapidly than mid span or the other side.

LATERAL MOVEMENTS

The lateral displacements occur at strata interfaces and within the immediate roof beam where discrete fractures have formed. These lateral shifts may be associated with the widening of fracture apertures and bed separation. The lateral differential displacements have been observed up to 15m (50 feet) into the roof at strata changes particularly the clay/salt contacts. The largest shifts are found at the clay/salt contact below the Anhydrite 'b' layer. Lateral shifts can also be expected within the immediate roof beam where fractures form. The support system should be designed to accommodate a lateral shift of 12mm per year (0.5 inches per year) and bed separation of 25mm per year (1 inch per year) at the clay/salt contact below the Anhydrite 'b' layer once the bond at the interface is disrupted.

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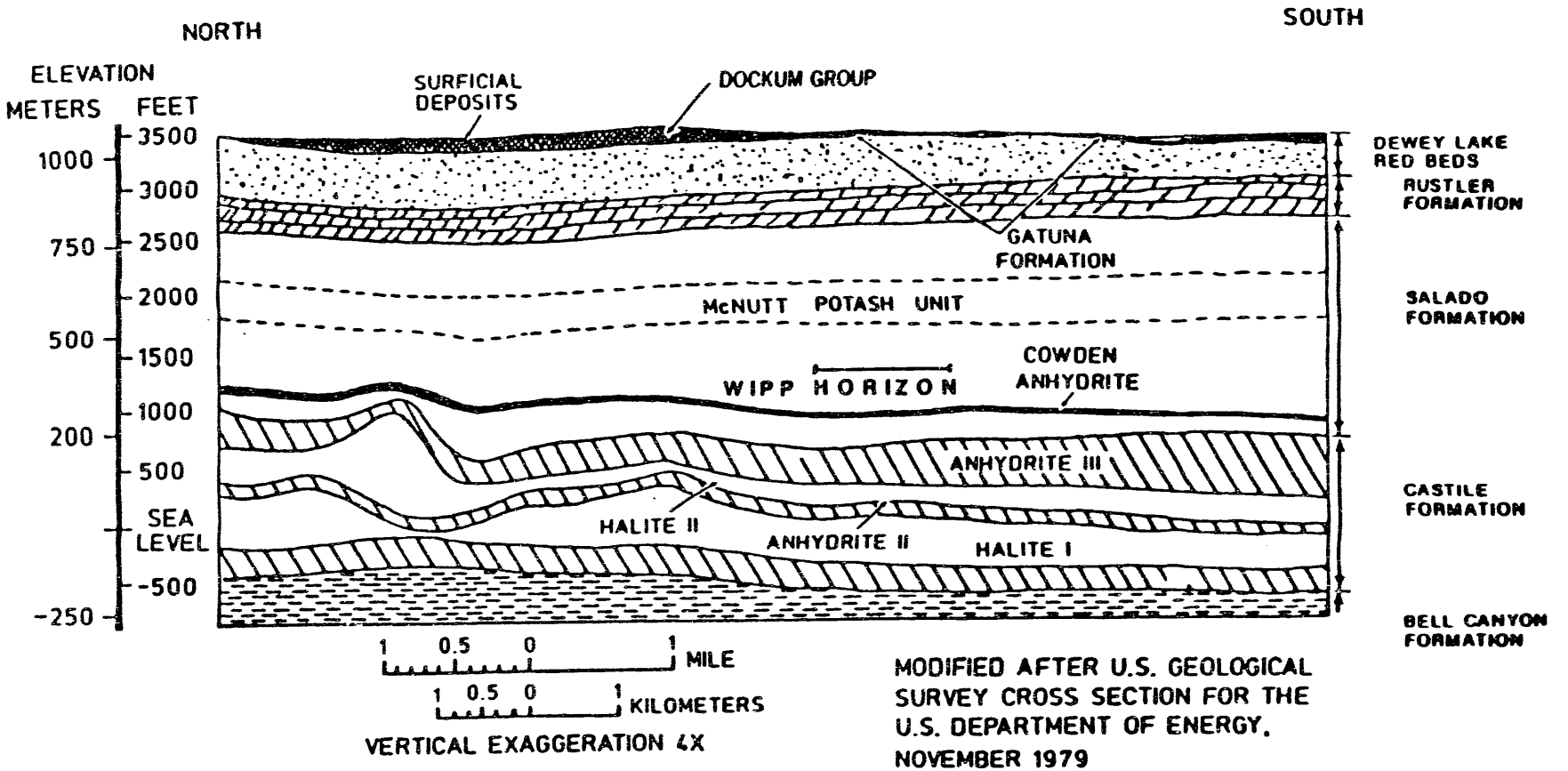

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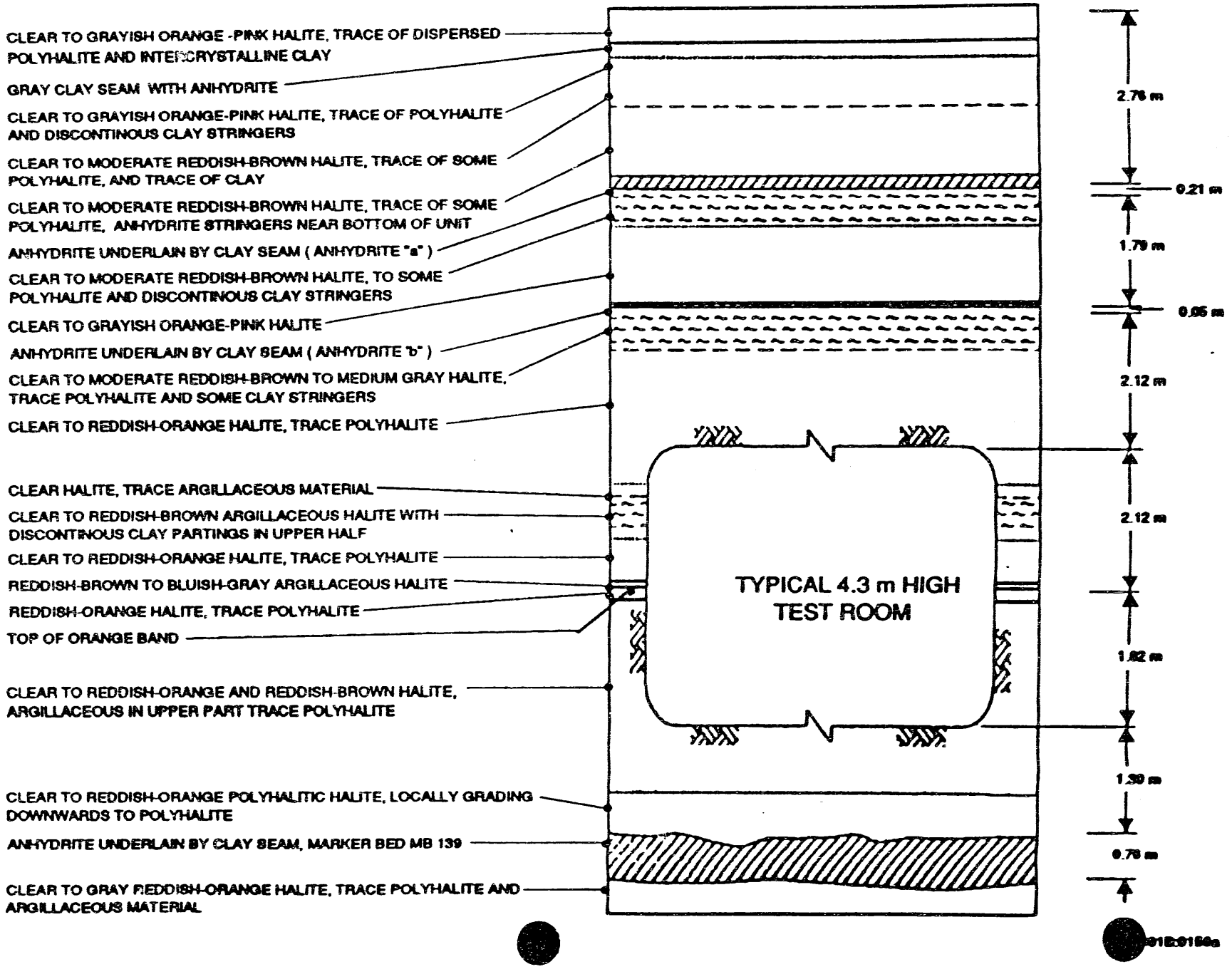

CLEAR TO GRAYISH ORANGE -PINK HALITE, TRACE OF DISPERSED POLYHALITE AND INTERCRYSTALLINE CLAY
GRAY CLAY SEAM WITH ANHYDRITE
CLEAR TO GRAYISH ORANGE-PINK HALITE, TRACE OF POLYHALITE AND DISCONTINOUS CLAY STRINGERS
CLEAR TO MODERATE REDDISH-BROWN HALITE, TRACE OF SOME POLYHALITE, AND TRACE OF CLAY
CLEAR TO MODERATE REDDISH-BROWN HALITE, TRACE OF SOME POLYHALITE, ANHYDRITE STRINGERS NEAR BOTTOM OF UNIT
ANHYDRITE UNDERLAIN BY CLAY SEAM (ANHYDRITE "a")
CLEAR TO MODERATE REDDISH-BROWN HALITE, TO SOME POLYHALITE AND DISCONTINOUS CLAY STRINGERS
CLEAR TO GRAYISH ORANGE-PINK HALITE
ANHYDRITE UNDERLAIN BY CLAY SEAM (ANHYDRITE "b")
CLEAR TO MODERATE REDDISH-BROWN TO MEDIUM GRAY HALITE, TRACE POLYHALITE AND SOME CLAY STRINGERS
CLEAR TO REDDISH-ORANGE HALITE, TRACE POLYHALITE
CLEAR HALITE, TRACE ARGILLACEOUS MATERIAL
CLEAR TO REDDISH-BROWN ARGILLACEOUS HALITE WITH DISCONTINOUS CLAY PARTINGS IN UPPER HALF
CLEAR TO REDDISH-ORANGE HALITE, TRACE POLYHALITE
REDDISH-BROWN TO BLUISH-GRAY ARGILLACEOUS HALITE
REDDISH-ORANGE HALITE, TRACE POLYHALITE
TOP OF ORANGE BAND
CLEAR TO REDDISH-ORANGE AND REDDISH-BROWN HALITE, ARGILLACEOUS IN UPPER PART TRACE POLYHALITE
CLEAR TO REDDISH-ORANGE POLYHALITIC HALITE, LOCALLY GRADING DOWNWARDS TO POLYHALITE
ANHYDRITE UNDERLAIN BY CLAY SEAM, MARKER BED MB 139
CLEAR TO GRAY REDDISH-ORANGE HALITE, TRACE POLYHALITE AND ARGILLACEOUS MATERIAL
TYPICAL 4.3 m HIGH TEST ROOM
2.76 m
0.21 m
1.79 m
0.05 m
2.12 m
2.12 m
1.82 m
1.30 m
0.78 m

FIGURE 2.3a GEOLOGIC CROSS-SECTION OF PANEL 1, ROOM 1
View West

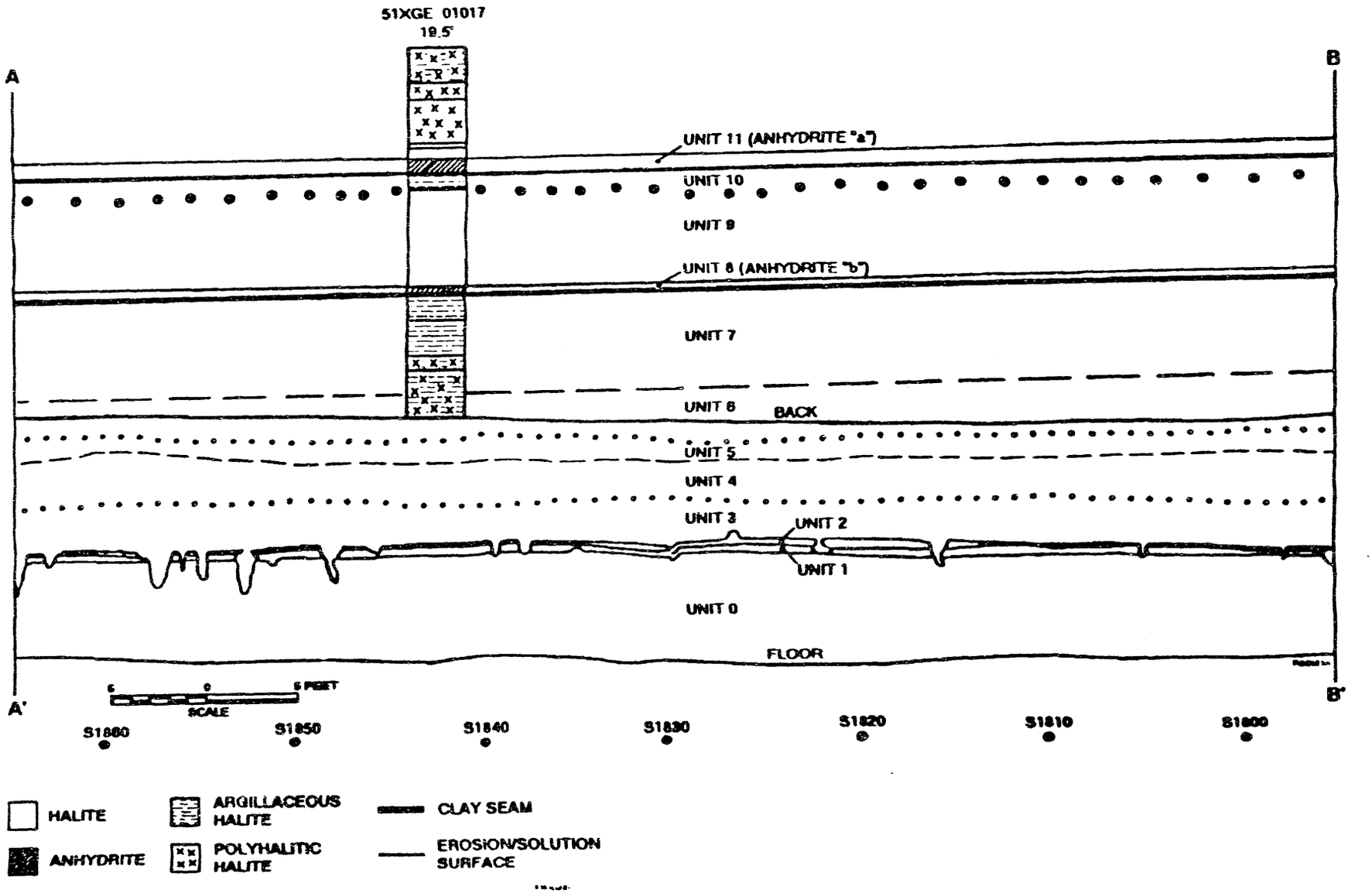


FIGURE 2.3b GEOLOGIC CROSS-SECTION OF PANEL 1, ROOM 1
View West

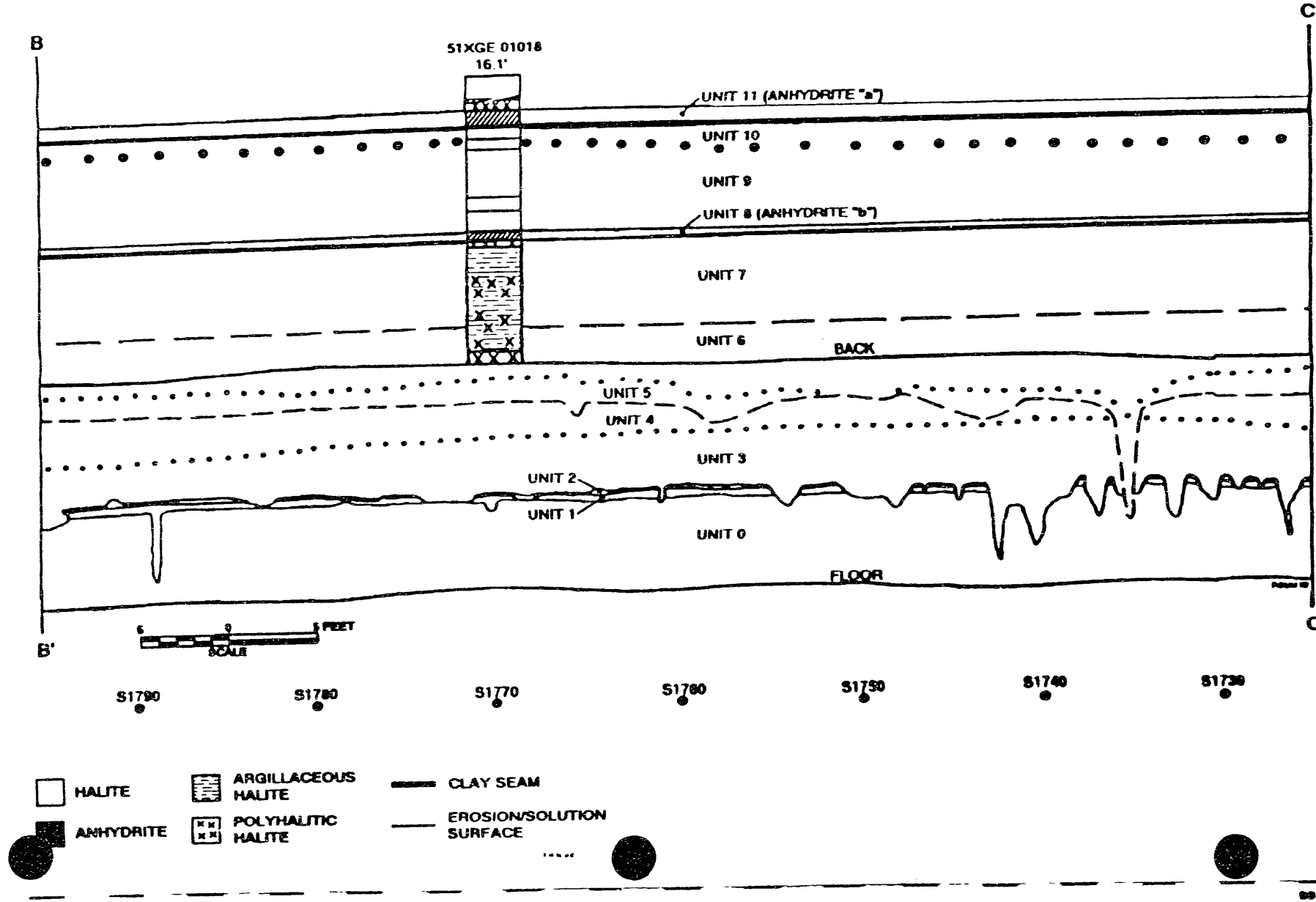
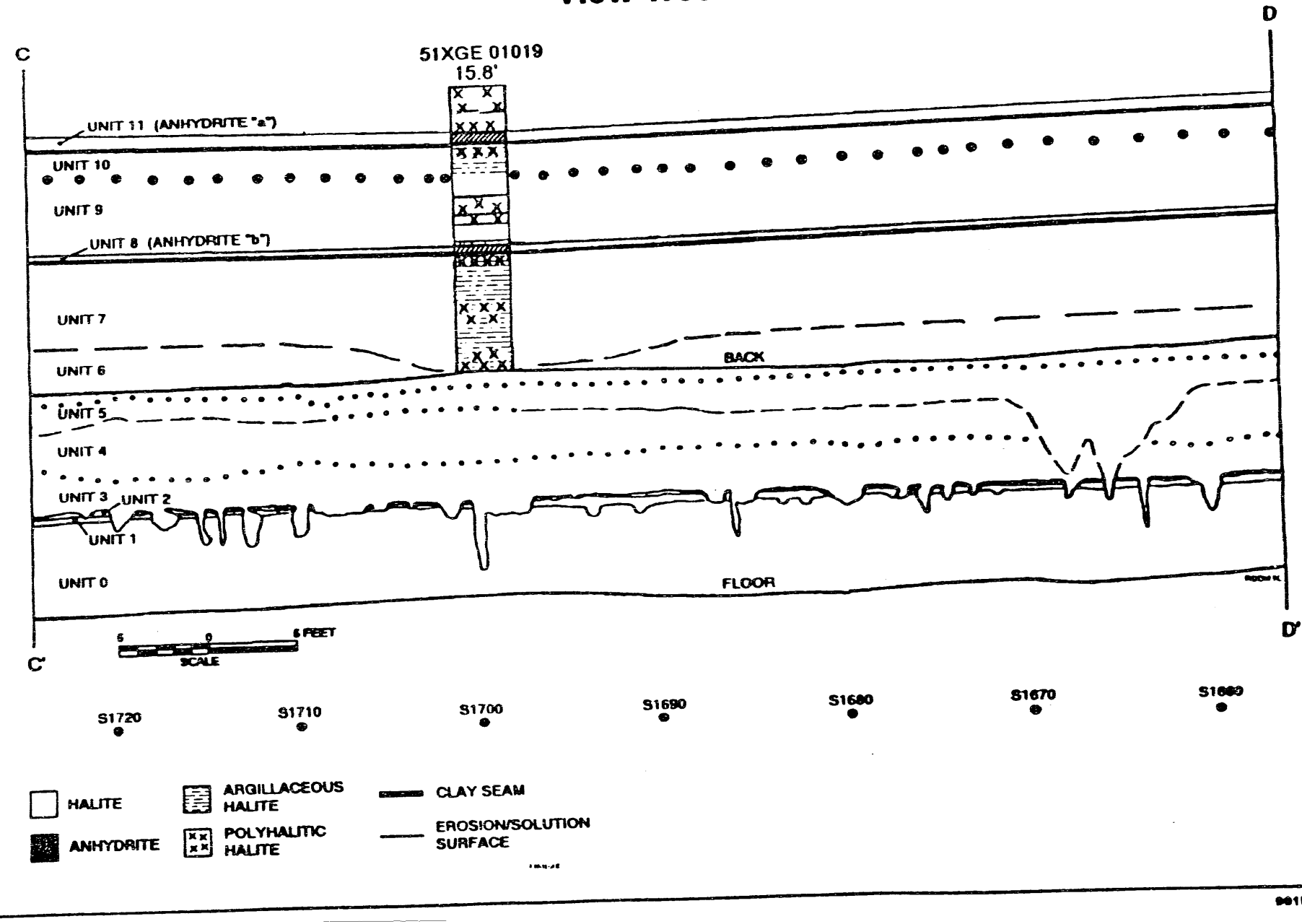
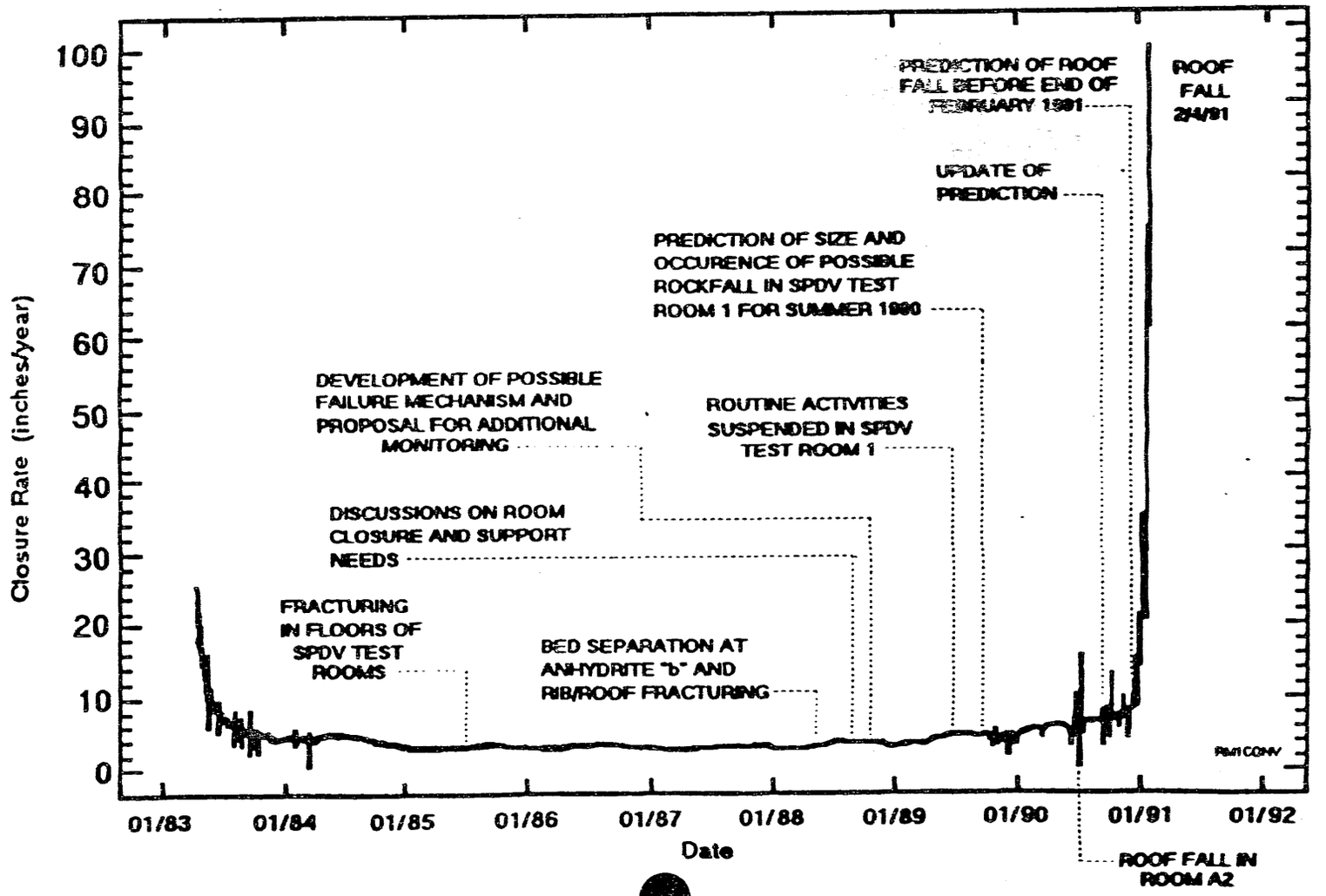


FIGURE 2.3c GEOLOGIC CROSS-SECTION OF PANEL 1, ROOM 1
View West



SPDV Test Room 1 Convergence Date
Combination of Instr. 8001 and 14001



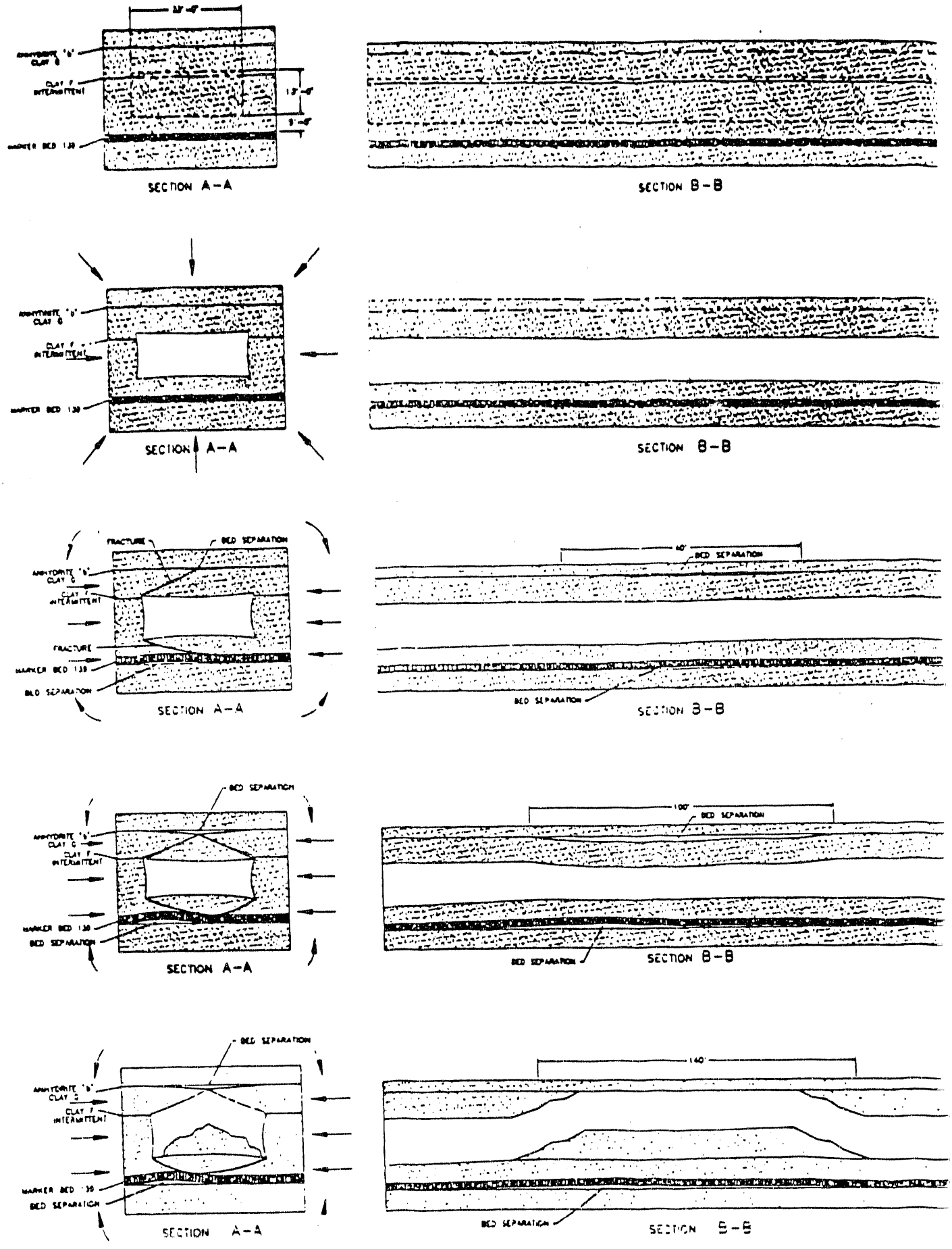
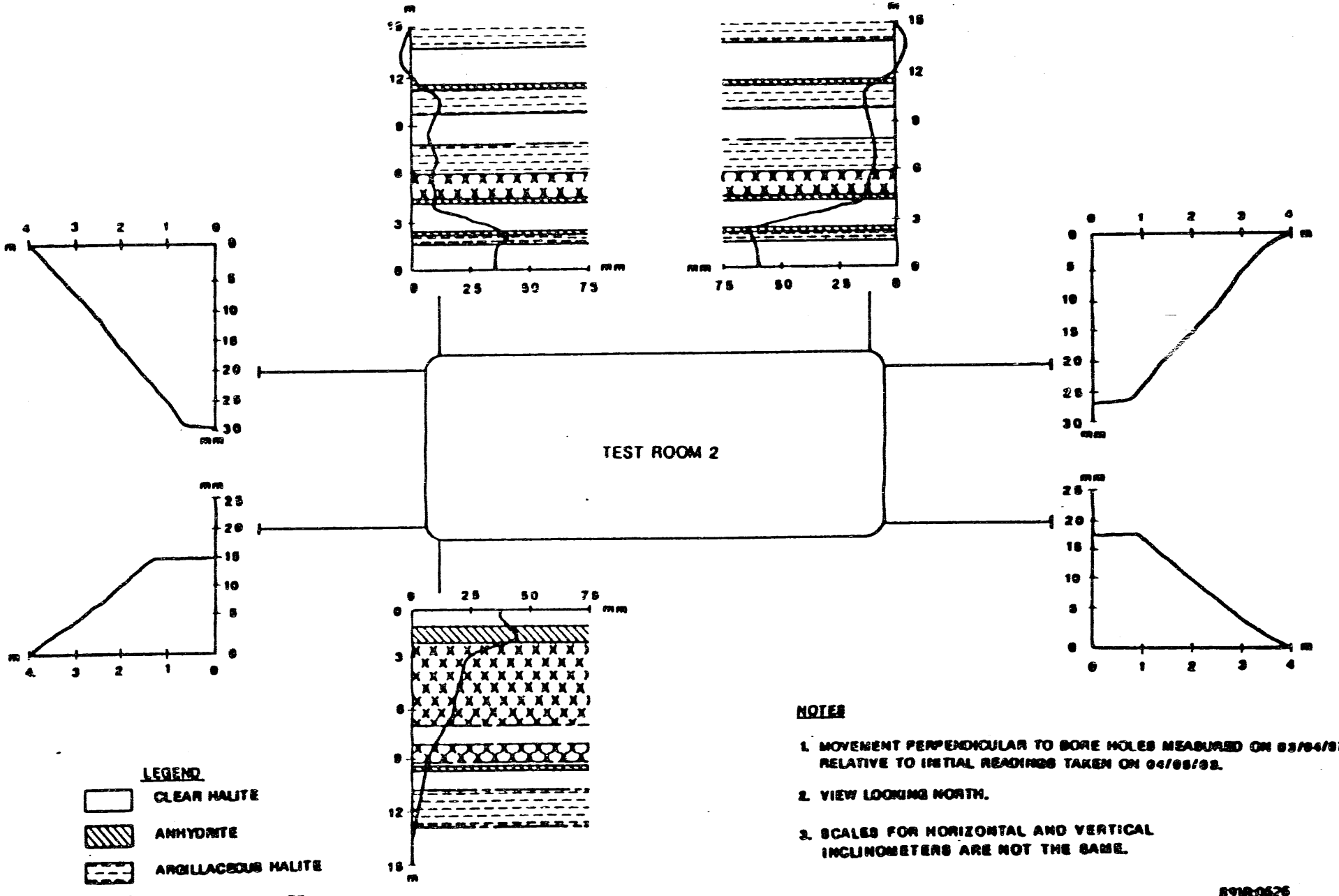


FIGURE 5.2 PHENOMENOLOGICAL MODEL OF ROOF FALL DEVELOPMENT



NOTES

1. MOVEMENT PERPENDICULAR TO BORE HOLES MEASURED ON 03/04/97 RELATIVE TO INITIAL READINGS TAKEN ON 04/09/92.
2. VIEW LOOKING NORTH.
3. SCALES FOR HORIZONTAL AND VERTICAL INCLINOMETERS ARE NOT THE SAME.

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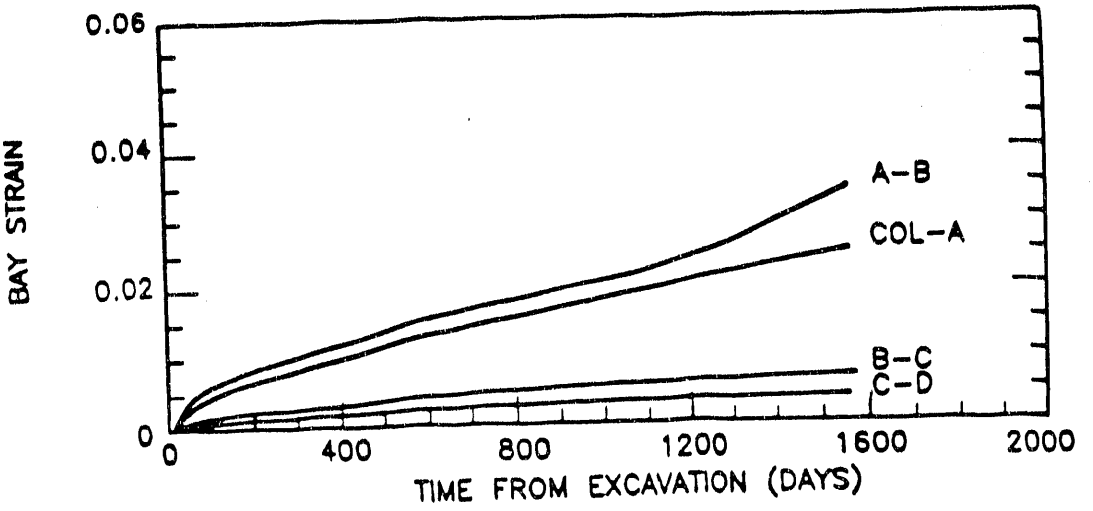
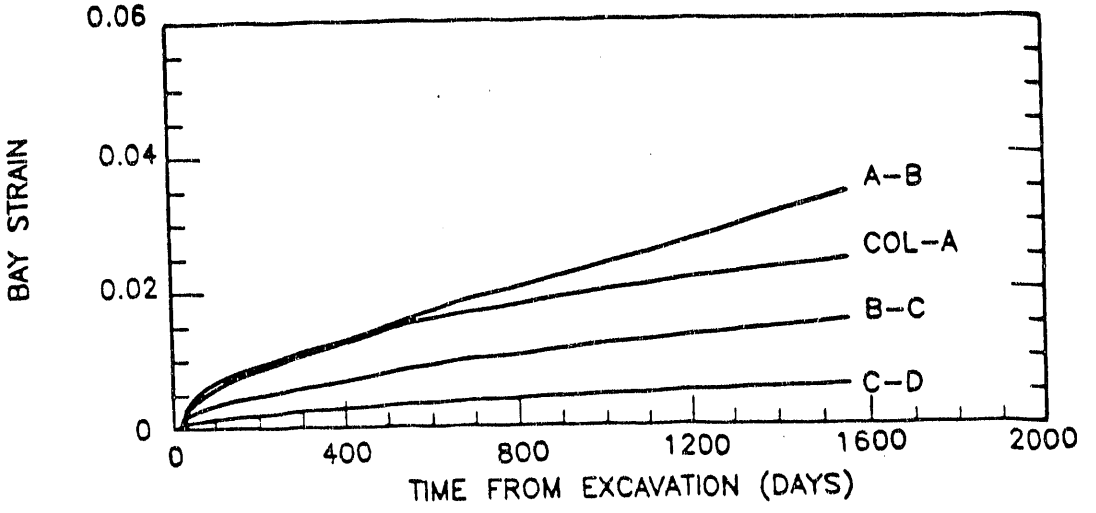
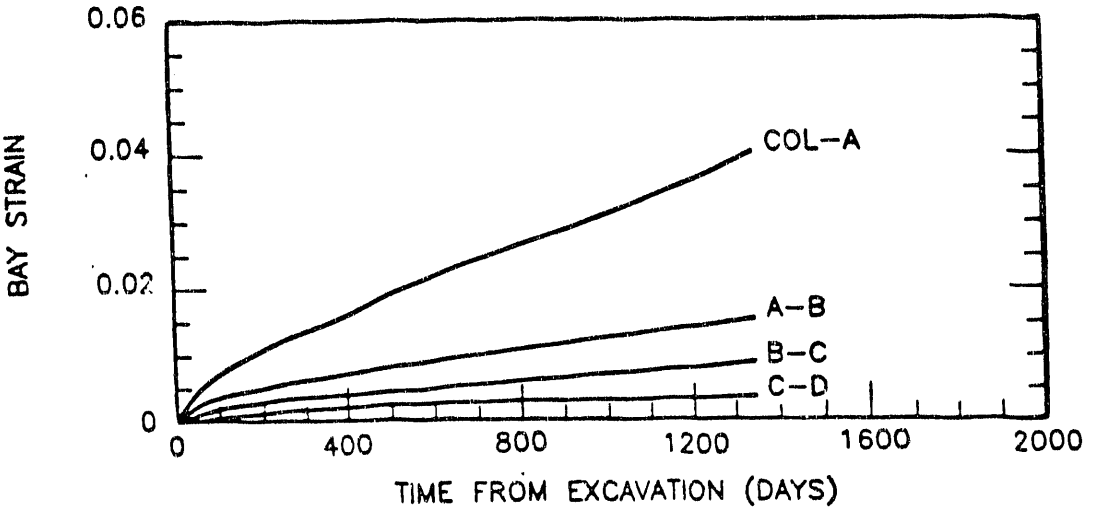


c. EAST ROOF
EXTENSOMETE
51X GE-002



b. MID ROOF
EXTENSOMETE
51X GE-002



a. WEST ROOF
EXTENSOMET
51X GE-002

12908:0

Figure 5.4 Extensometer Data from SPDV Test Rooms

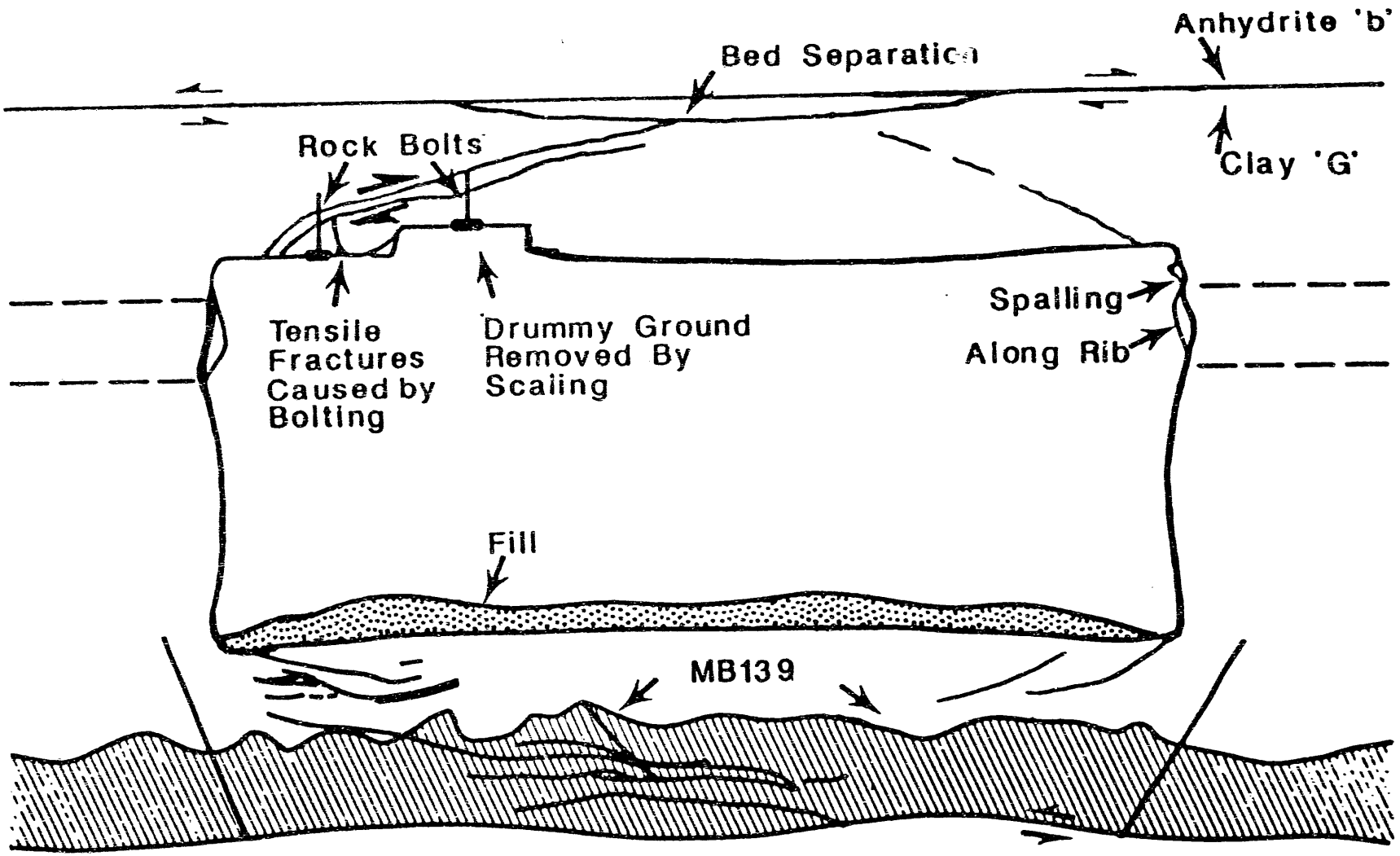
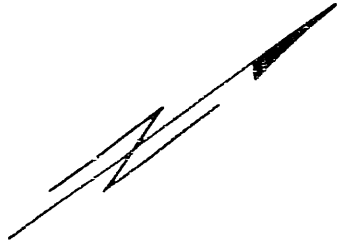


Figure 5.5 Patterns of Fracturing (Idealized excavation effects modified from Borns & Stormont, 1987)



Station: N-1372 Max height n/a

Station: N-1362 Max height n/a

Station N-1352 Max. height: 3.8'

Station N-1342 Max. height: 3.6'

Station N-1332 Max. height: 3.6'

Station N-1322 Max. height 5.2'

Station N-1312 Max height 6.7'

Station N-1302 Max height 6.9'

Station N-1292 Max height 6.25'

Station N-1282 Max. height: 6.25'

Station N-1272 Max. height: 6.25'

Station N-1262 Max height: 4.2'

Station N-1252 Max height: 1.7'

Station N-1242 Max height: 1.7'

Station N-1232 Max. height: 2.0'

Station N-1222 Max height 2.1'

Station N-1212 Max height n/a

SPDV TEST ROOM 1
BACK CAVITY

CROSS-SECTIONED VIEW

Fall Date 02/04/91

(Drawing Not To Scale)

FIGURE 5.2

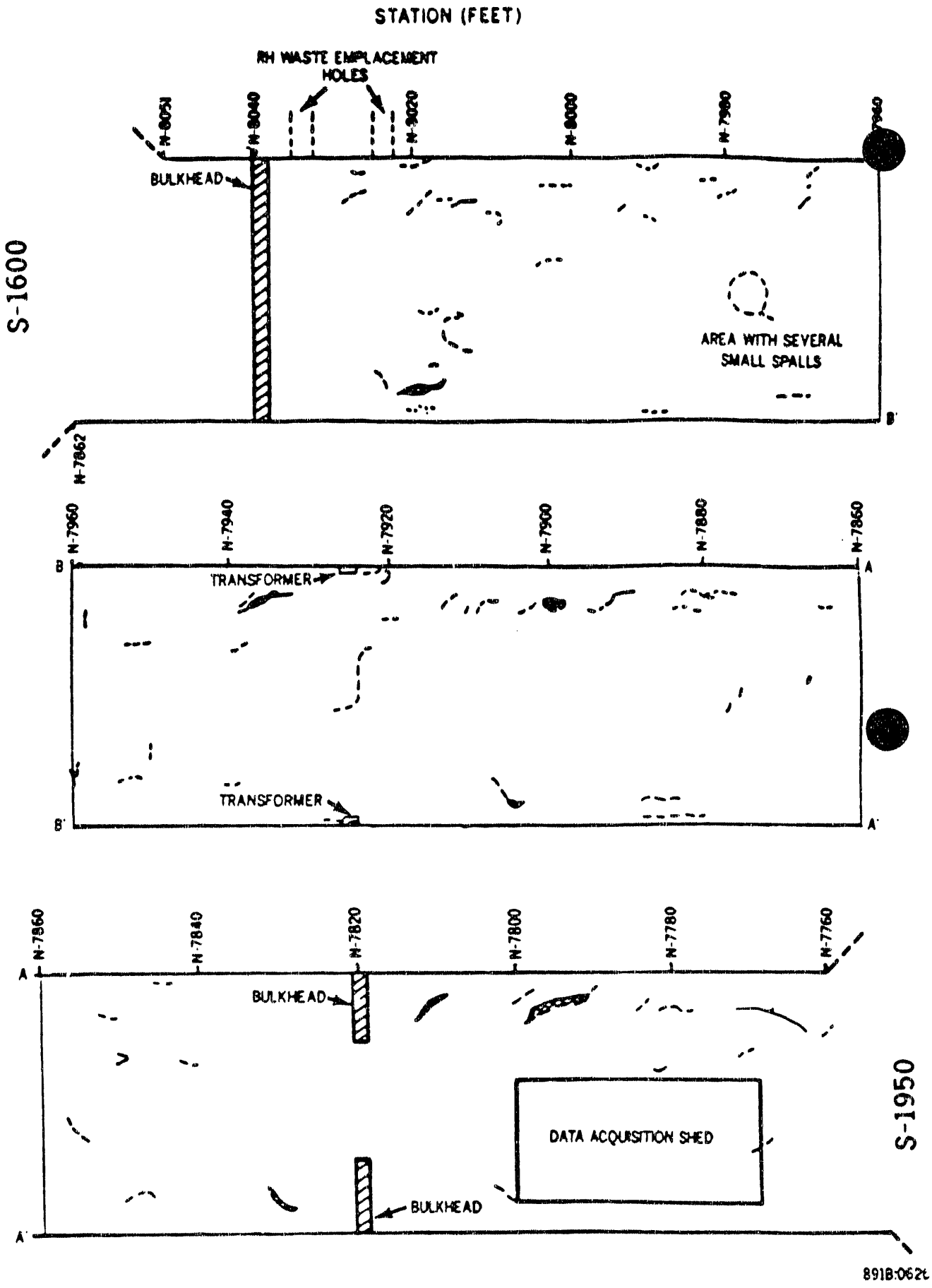
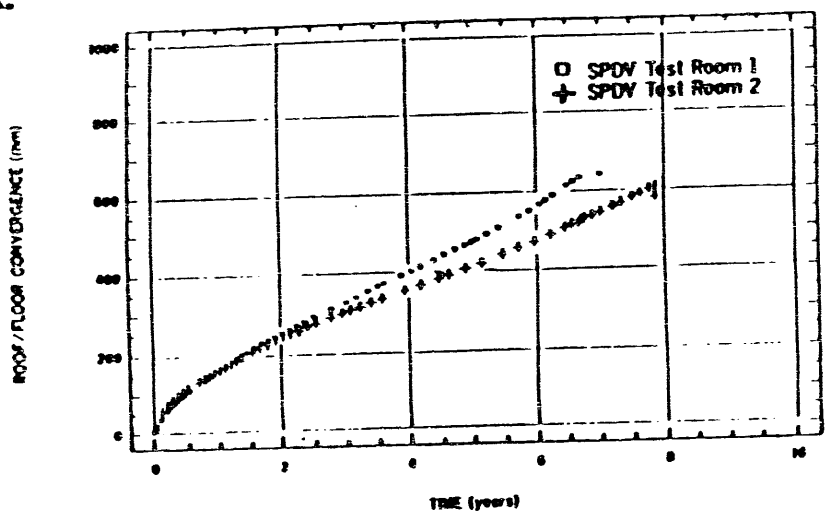


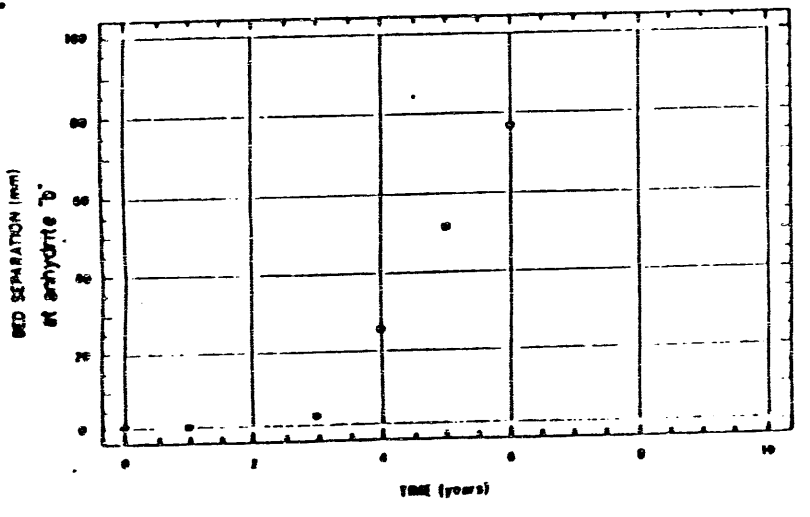
Figure 5.7 Back Fractures, Panel 1, Room 1 mapped on 2/12/91

FIELD MEASUREMENTS

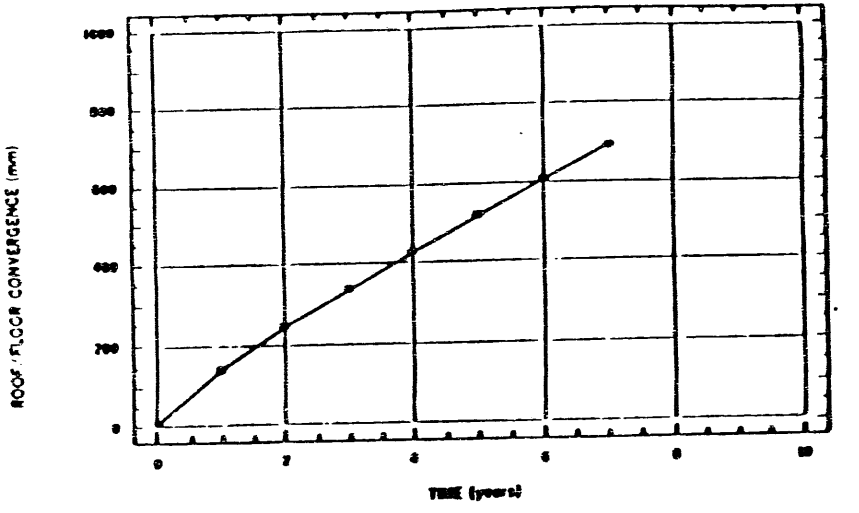
a.

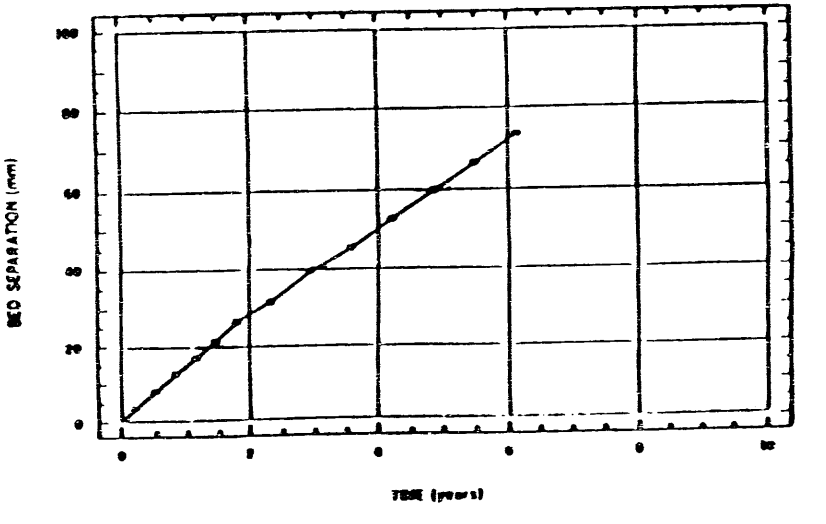


b.



MODEL RESULTS





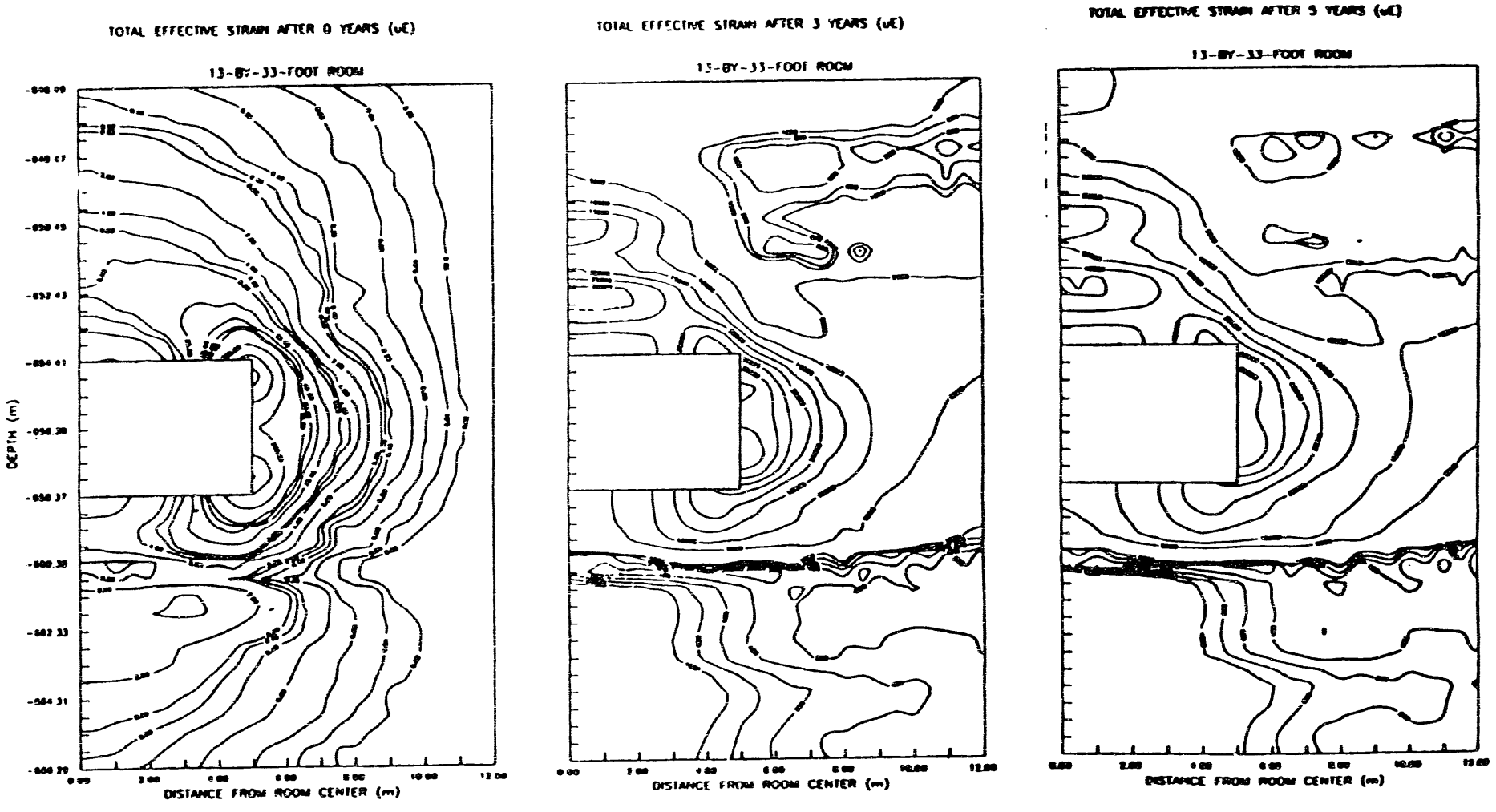


FIGURE 5.9 CONTOURS OF EFFECTIVE STRAIN FOR MODEL OF 33 FEET WIDE B[illegible]3 FEET HIGH ROOM.

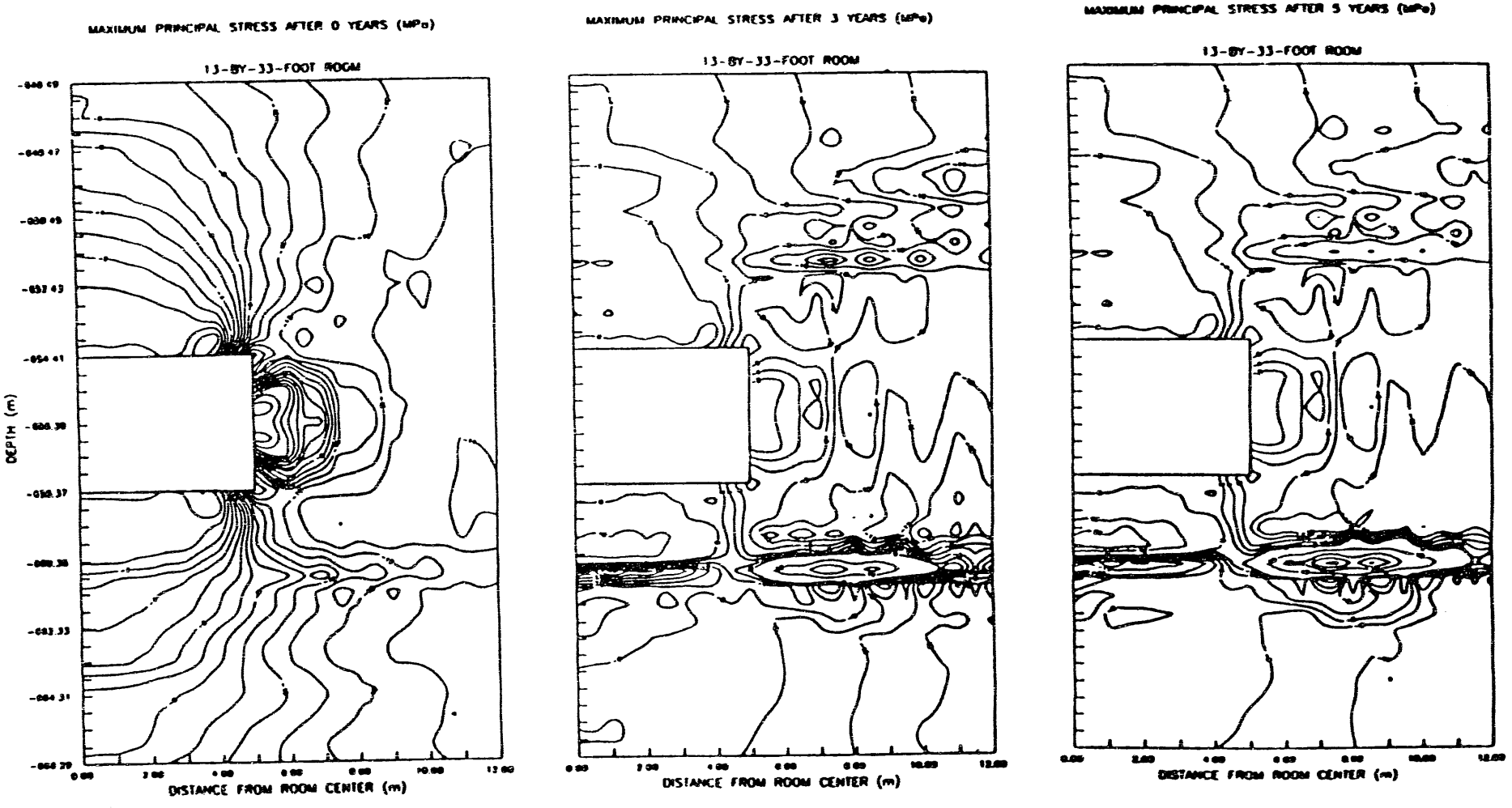


FIGURE 5.10 CONTOURS OF MAXIMUM PRINCIPAL STRESS FOR MODEL OF 33 FEET WIDE BY 13 FEET HIGH ROOM.

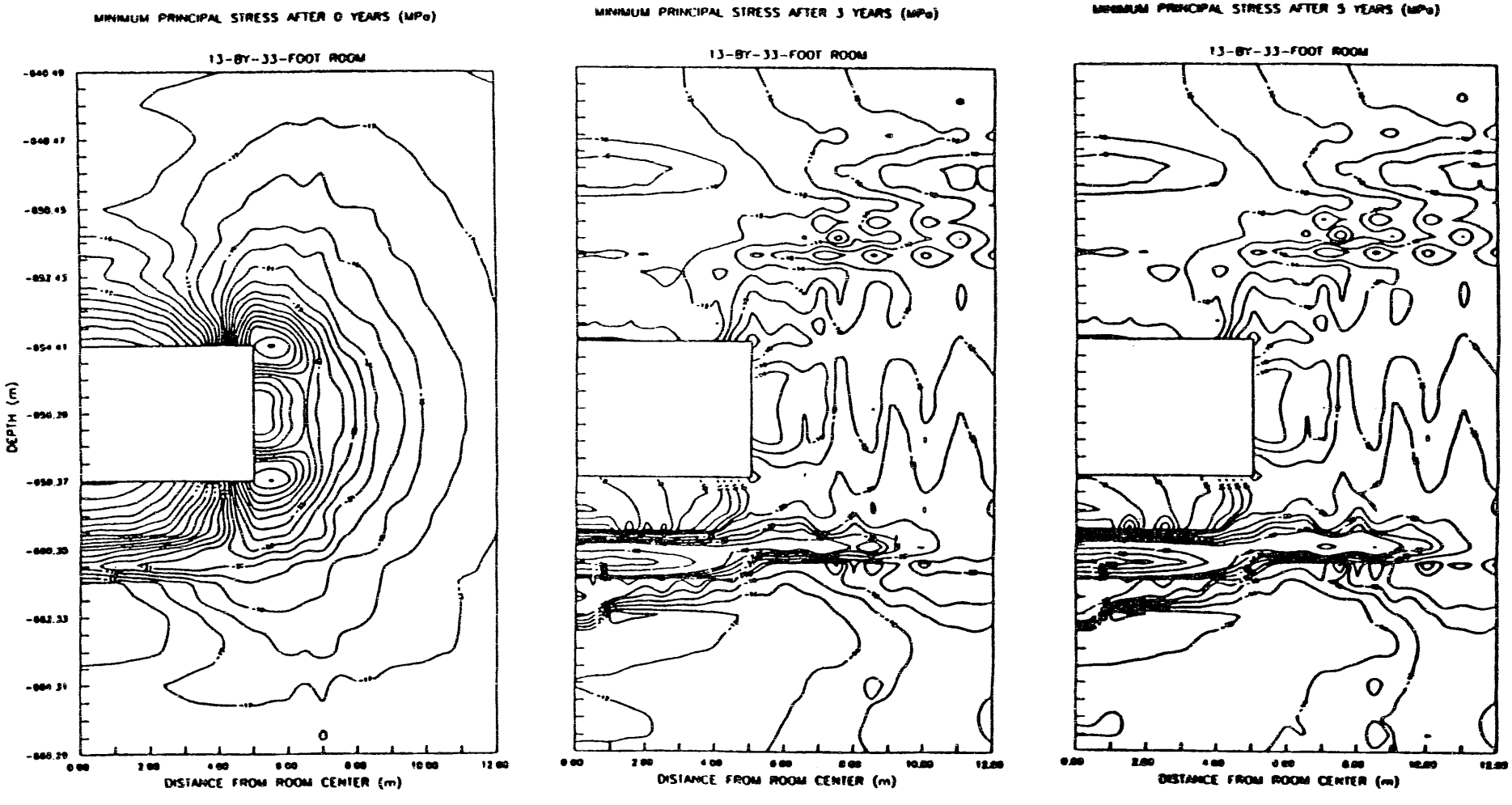


FIGURE 5.11 CONTOURS OF MINIMUM PRINCIPAL STRESS FOR MODEL OF 33 FEET WIDE BY 13 FEET HIGH ROOM.

WASTE ISOLATION PILOT PLANT
SUPPLEMENTARY ROOF SUPPORT SYSTEM

APPENDIX B
Destructive Tests

Westinghouse Electric Corporation
Waste Isolation Division
Carlsbad, New Mexico
October 1991

INTERNATIONAL MINING SERVICES INC.
RETYPED FAX RECEIVED FROM HAMISH MILLER

CONCLUSIONS FROM DESTRUCTIVE ROCKBOLT TESTS

The curves of load vs. extension were plotted for the 10 rockbolts that were tested to "failure". The points beyond which non-linear behavior occurred, were noted and these values are given in Table 1 below.

TABLE 1

TEST NO.	"YIELD" LOAD X 1,000 LB	BOLT STRESS AT "YIELD" PSI X 1,000
1	58.045	73.475
2	58.045	73.475
3	56.81	71.911
4	56.81	71.911
5	60.52	76.608
6	58.045	73.475
7	58.045	73.475
8	58.045	73.475
9	58.045	73.475
10	58.045	73.475

NOTE: "Yield" represents the point on the LOAD-EXTENSION curves where the curve departed from linearity. (see attached test results). The manufacturers of the Dywidag bolts give the "Yield Load" as 47.4 KIPS, which with a cross-sectional area of 0.79 sq. ins., gives a yield stress of 60,000 psi.

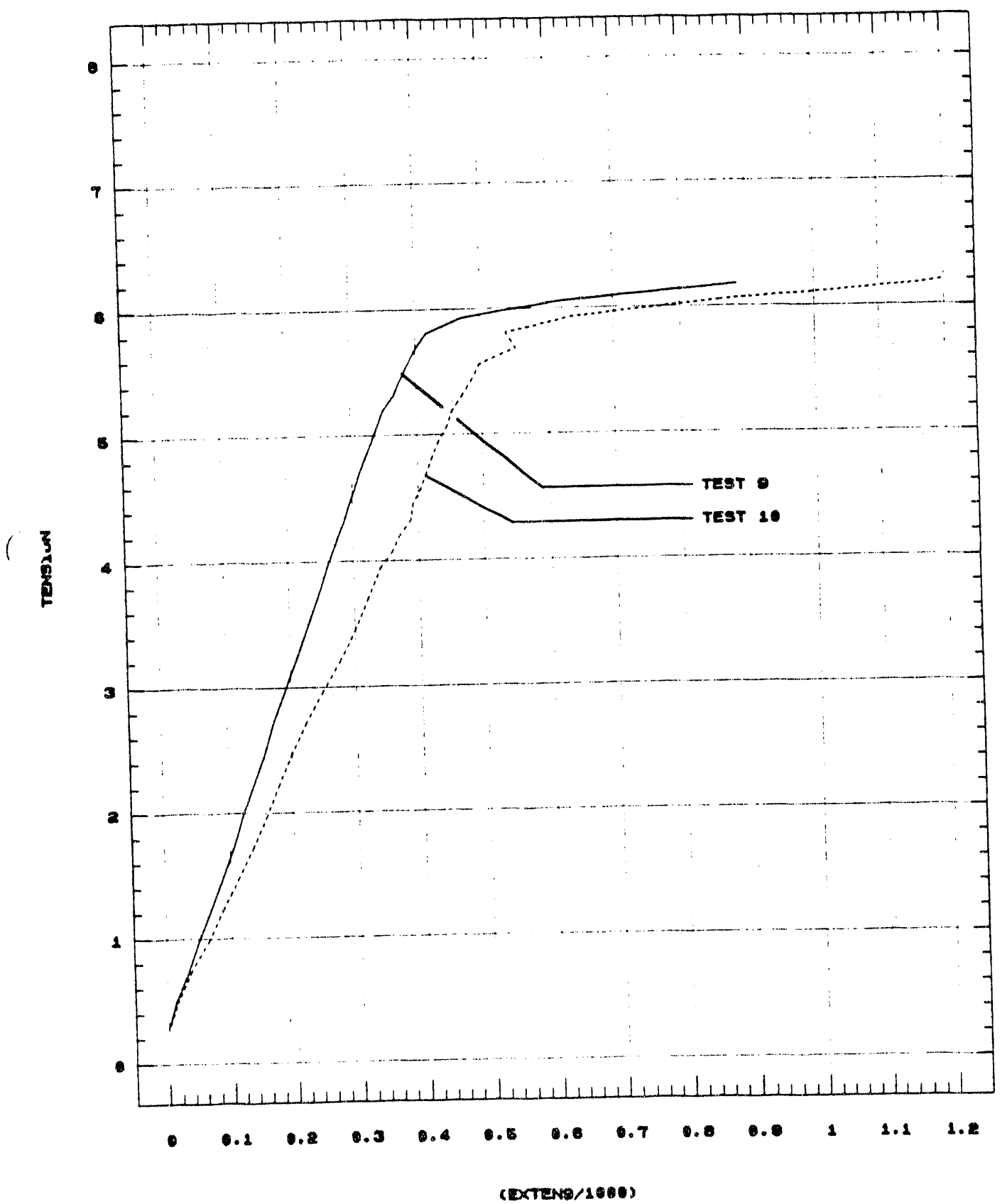
The results thus indicate that the mode of failure is that of bolt yield and not failure of the resin anchor bond.

There are slight indications of non-linearity in some of the test results, but it is felt that these are due to deformations of the plate and the "bedding-in" of the plate on the salt.

The test "yield" stresses are between 22% and 28% higher than the ASTM yield stress of 60,000 psi.

BOLT TENSION VERSUS EXTENSION

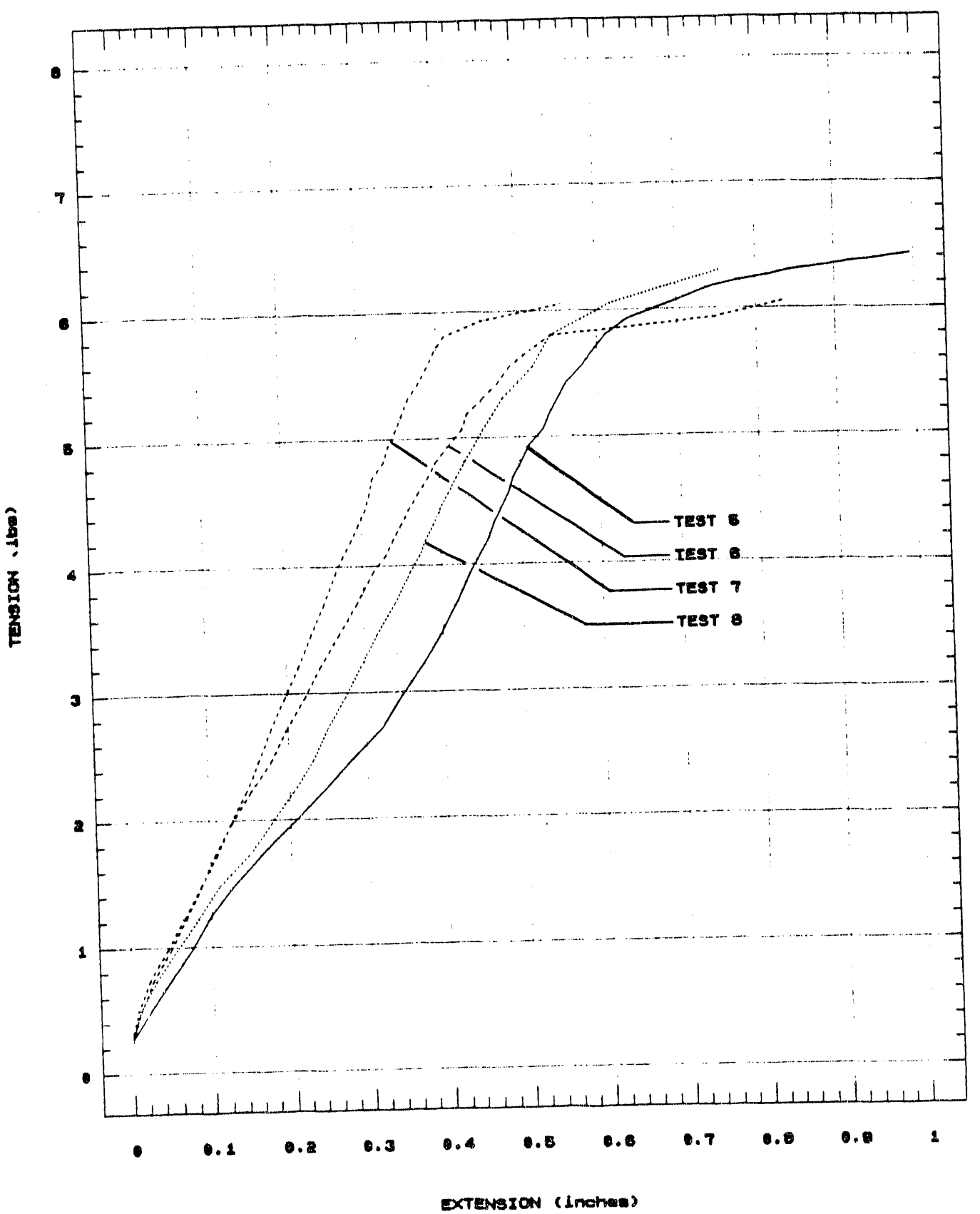
ROOM 2 PANEL 1



2 AND 3 DAYS CURE

BOLT TENSION VERSUS EXTENSION

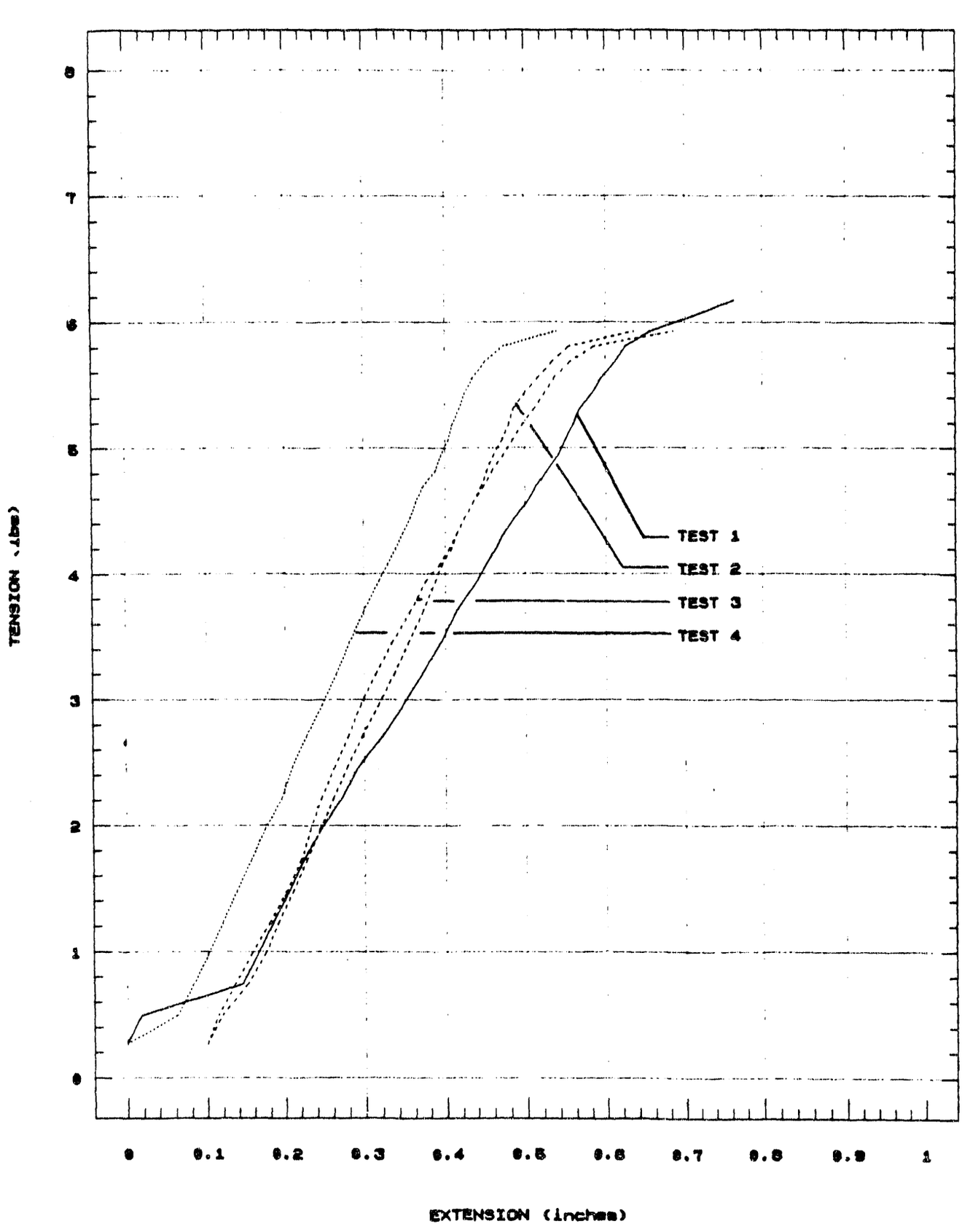
ROOM 2 PANEL 1



28 HOURS CURE

BOLT TENSION VERSUS EXTENSION

ROOM 2 PANEL 1



25 HOURS CURE

Test 10

ROCK BOLT CERTIFICATION TEST DATA SHEET

Mine - WIPP Rock - HALITE Rock Bolt No. PT081391-7 Hole Location PANEL 1-ROOM 2

Hole Length - 11'-7" Dia. - @ Anchor GAUGED /@ midpoint N/A /@ collar N/A
Orientation - VERT. (5° TOLERANCE) SMOOTH

Bolt Grade - GR60 Length - 13'-0" Diameter - #8

Shell Manufacturer - N/A Model - N/A Diameter - N/A
Length - N/A

Resin Manufacturer - CELTITE Model - H20.0204 Diameter - 1¼"
Length - 12" No. Cartridges - 3

Installation Date - 08/13/91 Time - 11:16 AM Torque - N/A ft/lb

Test Date - 08/16/91 Time - 1:05 PM Torque - N/A ft/lb
Test Jack - RC-60-CH 5.5A. Test Pump - RC-60-CH 5.5 SN 23886
Dial Indicator - AMES CD-0040 Calibrated - DUE 10-4-91
Pressure Gauge - U.S. GAGE DS1 # 001 Calibrated - 08/06/91

~~Pump~~ PSI x 100 Pressure	Bolt LBS Tension	Extensometer Reading	Displacement	Remarks
2	2470	0.000		
4	4940	0.015		
6	7410	0.035		
8	9880	0.056		
10	12350	0.088		
12	14820	0.112		
14	~~17290~~	0.138		17290 lbs
16	19760	0.159		
18	22,230	0.179		
20	24,700	0.199		
22	27,170	0.228		
24	29,640	0.250		
26	32,110	0.278		
28	34,580	0.301		
30	37,050	0.322		
32	39,520	0.341		
33	40,755	0.353		
34	41,990	0.370		
35	43,225	0.380		
36	44,460	0.391		
37	45,695	0.405		
38	46,930	0.918		
39	48,165	0.421		
40	49,400	0.431		
41	50,635	0.445		
42	51,870	0.454		
43	53,105	0.470		
44	54,340	0.485		
45	55,575	0.497		
46	56,810	0.511		
47	58,045	0.536		Bled To 4600 PSI
48	XXX	0.636		REMOVE DIAL INDICATOR
49		0.862		ATTEMPT 4800 Bled To 4800
50		1.171		AT 4700 Holding 4800 59,280
51		1.333		AT 5000 Holding 4900 60,515
52		1.714		AT 5200 Holding 5100 62,985
53			RAM 2¾	AT 5400 Holding 5300 65,455
				AT 5600 Holding 5500 67,925

TERMINATED TEST 1:40

Test Results - ACCEPTED Maximum Pull Force - 69,160#
Displacement at Maximum Pull Force - APPROX. 2.65 in.
Nature of Failure/Yield - BOLT YIELD @ 5600 PSIG
Other Remarks - @ 73.5 HOURS AFTER INSTALLATION
Tested By - D. Belluscio Approved By - P.K. Broadman

Test 10

Page 2 of 2

ROCK BOLT CERTIFICATION TEST
DATA SHEET

Rock Bolt No. PT081391-7

Mine _____ Rock _____ Hole Location PANEL - ROOM 17

Hole Length - ____ Dia. - @ Anchor _____/@ midpoint _____/@ collar ____
Orientation - _____

Bolt Grade - _____ Length - _____ Diameter - _____

Shell Manufacturer - _____ Model - _____ Diameter - _____
Length - _____

Resin Manufacturer - _____ Model - _____ Diameter - _____
Length - _____ No. Cartridges - _____

Installation Date - _____ Time - _____ Torque - _____ ft/lb

Test Date - _____ Time - _____ Torque - _____ ft/lb
Test Jack - _____ Test Pump - _____
Dial Indicator - _____ Calibrated - _____
Pressure Gauge - _____ Calibrated - _____

Pump Pressure	Bolt Tension	Extenso-meter Reading	Displace ment	Remarks
~~54~~ 55 ~~56~~ 57			Ram 1.98	AT 5800 Holding AT 5800/2 loop / 69,000

Test ~~Results~~ _____ Maximum Pull Force - _____
Displacement at Maximum Pull Force - _____
Nature of Failure/Yield - _____
Other Remarks _____
Tested By - D. Bellmont Approved By - [illegible]

UNDERGROUND DRILLING HOLE FIELD DATA SHEET

Date: 8/13/91

Room/Drift: ROOM 2 - PANEL 1

Purpose of Hole: PULL TEST: DESTRUCTIVE (PWR 120197)
P+081391-7

Location: N. END 4" W Rib @ 45-50 FT. FROM N. BULKHEAD

Depth at Completion: 11'-7"

Diameter: 1 3/8" ϕ

Approximate Collar Coordinates

Vertical Angle: VERT. (5° TOLERANCE)

Direction/Azimuth:

Remarks: RESIN/ROCK ANCHOR TEST AT 1:05 PM (
AND COMPLETED AT 2:00 PM FOR
CERTIFICATION.

Signature/Department: D. Ballmann 8/16/91

ROCK BOLT CERTIFICATION TEST DATA SHEET

Mine WIPP Rock HALITE Rock Bolt No. PTOB1391-6
Hole Location PANEL 1 - ROOM 2

Hole Length - 11'-7" Dia. - @ Anchor GAUGED /@ midpoint N/A /@ collar N/A
Orientation - VERT. (5° TOLERANCE) SMOOTH

Bolt Grade - GR60 Length - 12'-11 7/8" Diameter - #8

Shell Manufacturer - N/A Model - N/A Diameter - N/A
Length - N/A

Resin Manufacturer - CELTITE Model - HRD-0204 Diameter - 1¼"
Length - 12" No. Cartridges - 3

Installation Date - 08/13/91 Time - 11:04 AM Torque - N/A ft/lb

Test Date - 8/15/91 Time - 12:50 PM Torque - N/A ft/lb
Test Jack - RC-60-CH 95A Test Pump - RC-60-CH 9.5 SN 25836
Dial Indicator - AMES CD-0040 Calibrated - DUE 10-4-91
Pressure Gauge - U.S. GAUGE DSI # 001 Calibrated - 08/06/91

PSI X 100 Pump Pressure	Bolt Tension LBS	Extensometer Reading	Displacement	Remarks
2	2470	0.000		
4	4940	0.012		
6	7410	0.032		
8	9880	0.050		
10	12,350	0.070		
12	14,820	0.088		
14	17,290	0.105		
16	19,760	0.121		
18	22,230	0.140		
20	24,700	0.158		
22	27,170	0.178		
24	29,640	0.150		
26	32,110	0.207		
28	34,580	0.226		
30	37,050	0.244		
32	39,520	0.265		
33	40,755	0.269		
34	41,990	0.278		
35	43,225	0.288		
36	44,460	0.295		
37	45,695	0.309		
38	46,930	0.311		
39	48,165	0.321		
40	49,400	0.331		
41	50,635	0.340		
42	51,870	0.349		
43	53,105	0.365		
44	54,340	0.373		
45	55,575	0.387		
46	56,810	0.399		
47	58,045	0.416		
47.88	59,280	0.470		W/L Bled TO 9600 PSI REMOVE DIAL INDICATOR PSI/LBS
48	60,515	0.616		Bled TO 4700 PSI APPROX 5 MIN. Bled TO 4600 PSI REMOVED DIAL INDICATOR *
49		0.886 *		BOLT YIELD @ 248000
50				
51				
52				
53				TERMINATED TEST @ 1:20 PM

Test Results - ACCEPTED Maximum Pull Force W/L 59,280 LBS 64,220 LBS
Displacement at Maximum Pull Force - APPROX .886 IN
Nature of Failure/Yield - BOLT YIELD @ 248000 PSI 8.16.91
Other Remarks @ 12.5 HRS AFTER INSTALLATION: HOLD AT
Tested By - A. VERMEAU Approved By - [signature]

ROCK BOLT CERTIFICATION TEST DATA SHEET

Mine _____ Rock _____ Rock Bolt No. PT081391-6 Hole Location _____

Hole Length - _____ Dia. - @ Anchor _____ /@ midpoint _____ /@ collar _____
Orientation - _____

Bolt Grade - _____ Length - _____ Diameter - _____

Shell Manufacturer - _____ Model - _____ Diameter - _____
Length - _____

Resin Manufacturer - _____ Model - _____ Diameter - _____
Length - _____ No. Cartridges - _____

Installation Date - _____ Time - _____ Torque - _____ ft/lb

Test Date - _____ Time - _____ Torque - _____ ft/lb
Test Jack _____ Test Pump - _____
Dial Indicator - _____ Calibrated - _____
Pressure Gauge - _____ Calibrated - _____

Pump Pressure	Bolt Tension	Extenso-meter Reading	Displace ment	Remarks
54 53 52 51				Comments → 11:30 PM
			4900	Holding AT 4900 PSI 1½" RAM 59250# 11:35 PM
			5000	Holding AT 4700 PSI 1⅝" RAM 60315# 1:40 PM
			5200	Holding AT 5000 PSI 1¾" RAM 61150# 1:46 PM
			5200	Holding AT 5000 PSI 1¾" RAM 61750# 2:00 PM
			5200 5000	Holding AT 5100 PSI 1⅞" RAM 62486 2:07 PM
			5500	Holding AT 5300 PSI 2" RAM 64200# 2:13 PM
			5500	Holding AT 5300 PSI 2⅛" RAM 65455# 2:25 PM
			5600	Holding AT 5400 PSI 2¼" RAM 66690# 2:33
			5700	Holding AT 5500 PSI 2⅜" RAM 67425# 2:40
			5800	Holding AT 5600 PSI 2½" RAM 69160# 2:45
			5800	Holding AT 5700 PSI 2⅝" RAM 70??
			08/16/91	BLED TO 5200 PSI 12:40 PM 64250# MAX PULL FORCE

Test Results - _____ Maximum Pull Force - _____
Displacement at Maximum Pull Force _____
Nature of Failure/Yield - _____
Other Remarks _____
Tested By - R. Patterson Approved By - D.K.R.

UNDERGROUND DRILLING HOLE FIELD DATA SHEET

Date: 8/13/91

Room/Drift: PANEL 1 - ROOM 2

Purpose of Hole: PULL TEST: DESTRUCTIVE (PWR120177)
PT081391-6

Location: N END 4+/W RIB & 36-40 FT. FROM N. BULKHEAD

Depth at Completion: 11'-7"

Diameter: 1 3/8" ϕ COMPLETION

Approximate Collar Coordinates

Vertical Angle:

Direction/Azimuth: VERT. (5° TOLERANCE)

Remarks: RESIN / ROCK ANCHOR TEST AT 12:50 PM
AND COMPLETED AT 2:45 PM FOR
CERTIFICATION.

Signature/Department: D. Ballmann 8/15/91

ROCK BOLT CERTIFICATION TEST
DATA SHEET

Mine WIPP Rock HALITE Rock Bolt No. PTDB1391-1 Hole Location PANEL - ROOM 2

Hole Length - 11.58" Dia. - @ Anchor GAUGED /@ midpoint N/A /@ collar N/A
Orientation - VERTICAL (5° TOLERANCE) SMOOTH

Bolt Grade - GR60 Length - 13'-0" Diameter - #8

Shell Manufacturer - N/A Model - N/A Diameter - N/A
Length - N/A

Resin Manufacturer - CELTITE Model - HDD-0204 Diameter - 1¼"
Length - 12" No. Cartridges - 3

Installation Date - 08/13/91 Time - 10:16 AM Torque - N/A ft/lb

Test Date - 8/14/91 Time - 11:30 AM Torque - N/A ft/lb
Test Jack - RC-60-CH95A Test Pump - RC-60-HP3 SN# 23836
Dial Indicator - AMES 4027 CD-0040 Calibrated - BUS 10-14-91
Pressure Gauge - USAGES PSI #001 Calibrated - 08-06-91

PSI Pump Pressure	LBS Bolt Tension	Extenso-meter Reading	Displace ment	Remarks
200	2470	0.000	8/14/91	
400	4940	0.062		
600	7410	0.082		
800	9880	0.102		
1000	12350	0.120		
1200	14820	0.138		
1400	17290	0.157		
1600	19760	0.176		
1800	22230	0.194		
2000	24700	0.210		
2200	27170	0.229		
2400	29640	0.248		
2600	32110	0.266		
2800	34580	0.282		
3000	37050	0.300		
3200	39,520	0.318		
3300	40755	0.328		
3400	41990	0.338		
3500	43225	0.347		
3600	44460	0.356		
3700	45695	0.363		
3800	46930	0.372		
3900	48165	0.388		HOLD 1 MIN - BLEED SLOWLY TO 3900
4000	49400	0.349	8/14/91	
4100	50635	0.404		
4200	51870	0.409		
4300	53105	0.419		
4400	54340	0.425		
4500	55575	0.435		
4600	56810	0.451		HELD - BLED BACK TO 4600 B.Y.
4700	58045	0.474		REMOVED DIAL INDICATOR PM 8/14/91
4800	59280	0.539		ATTEMPTED 4900 BLED TO 4700
4900				REMOVED DIAL INDICATOR
5000				HELD FOR 5 MIN. BLED TO 4900
5100				PUMPED 4800 PSI HELD AT 4800
5200				WOULD NOT GO TO 4900
5300				TEST TERMINATED @ 12:05 PM

Test Results - ACCEPTED Maximum Pull Force - 59280 #
Displacement at Maximum Pull Force - .589 in.
Nature of Failure/Yield - Bolt YIELD 4600 PSI to 4700 PSI
Other Remarks - @ 29.3 HRS AFTER INSTALLATION
Tested By - D. Ballinger Approved By - R.E. Beauheim

UNDERGROUND DRILLING HOLE FIELD DATA SHEET

Date: 8/13/91

Room/Drift: PANEL 1 - ROOM 2

Purpose of Hole: PULL TEST: DESTRUCTIVE (PWR 120177)
PTOB1391-1

Location: N. END APPROX 4' W/E DX/S.1841 ROOM ℄ APPROX. 4-6 FT FROM BULKHEAD

Depth at Completion: 11'-7"

Diameter: 1-3/8" ℄ COMPLETION

Approximate Collar Coordinates

Vertical Angle: VERT. (5° TOLERANCE)

Direction/Azimuth:

Remarks: RESIN/ROCK ANCHOR TESTED AT 11:30 am COMPLETED AT 12:05 PM
FOR CERTIFICATION.

Signature/Department: D. Dallmann 8/14/91

ROCK BOLT CERTIFICATION TEST
DATA SHEET

Rock Bolt No. PTOB1591-2

Mine WIPP Rock HALITE Hole Location PANEL 1 - ROOM 2

Hole Length - 11.58' Dia. - @ Anchor GAUGED /@ midpoint N/A /@ collar N/A
Orientation - VERTICAL (.5° TOLERANCE) SMOOTH

Bolt Grade - GR60 Length - 13'-0" Diameter - #8

Shell Manufacturer - N/A Model - N/A Diameter - N/A
Length - N/A

Resin Manufacturer - CELTITE Model - H90-0204 Diameter - 1 1/4"
Length - 12" No. Cartridges - 3

Installation Date - 08/13/91 Time - 10:31 AM Torque - N/A ft/lb

Test Date - 8/14/91 Time - 1:37 PM Torque - N/A ~~ft/lb~~ in/lb
Test Jack - RC-60-CH 9.5A Test Pump - RC-60-CH 9.5 SN 250686 138A
Dial Indicator - AMES 4122 CD-0040 Calibrated - PMS 10.4.91
Pressure Gauge - ~~USG~~ PSI #0001 Calibrated - 08-06-91

Pump Pressure (PSI X100)	Bolt Tension (LBS)	Extensometer Reading	Displacement	Remarks
2	2470	0.000		
4	4940	0.023		
6	7410	0.049		
8	9880	0.075		
10	12350	0.098		
12	14820	0.128		
14	17290	0.169		
16	19760	0.204		
18	22230	0.248		
20	24700	0.291		
22	27170	0.320		
24	29640	0.345		
26	32110	0.373		
28	34580	0.398		
30	37050	0.418		
32	39520	0.435		
33	40755	0.447		
34	41990	0.456		
35	43225	0.466		
36	44460	0.475		
37	45695	0.485		
38	46930	0.491		
39	48165	0.502		
40	49400	0.512		
41	50635	0.520		
42	51870	0.535		
43	53105	0.550		
44	54340	0.560		
45	55575	0.575		
46	56810	0.595		
47	58045	0.611		REMOVE DIAL INDICATOR
48	59280	0.635		BLEED TO 4700 PSI
49		0.652		HOLD TO 4700 PSI 2 min
50	09/13/14/91	0.745		
51		0.946		
52				BLEED TO 4500 PSI
53		0.996		TERMINATE TEST 1:55 PM

Test Results - ACCEPTED Maximum Pull Force - 59280 lb
Displacement at Maximum Pull Force - 0.996 in.
Nature of Failure/Yield - BOLT YIELD AT 1 4800 PSI
Other Remarks 32 ft 27.1 HRS AFTER INSTALLATION
Tested By - A. Ballmann Approved By - R.K. Rauch

UNDERGROUND DRILLING HOLE FIELD DATA SHEET

Date: 8/13/91

Room/Drift: PANEL 1 - ROOM 2

Purpose of Hole: PULL TEST: DESTRUCTIVE (PWR 12017T)
PT081391-2

Location: N. END APPOX 4' W OF ROOM 2 APPROX 12 FEET FROM N. BULKHEAD

Depth at Completion: 11'-7"

Diameter: 1 3/8" ϕ COMPLETION

Approximate Collar Coordinates

Vertical Angle: VERT. (5° TOLERANCE)

Direction/Azimuth:

Remarks: RESIN/ROCK ANCHOR TESTED AT 1:37 PM
AND COMPLETED AT 1:55 PM FOR
CERTIFICATION

Signature/Department: D Ballweber 8/14/91

ROCK BOLT CERTIFICATION TEST
DATA SHEET

Mine WIPP Rock HALITE Rock Bolt No. PTCB1391-3 Hole Location PANEL 1 - ROOM 2

Hole Length - 11'7" Dia. - @ Anchor GAUGED /@ midpoint N/A /@ collar N/A
Orientation - VERTICAL (5° TOLERANCE) SMOOTH

Bolt Grade - GR 60 Length - 13'-0" Diameter - #8

Shell Manufacturer - N/A Model - N/A Diameter - N/A
Length - N/A

Resin Manufacturer - CELTITE Model - H30-0204 Diameter - 1¼"
Length - 12" No. Cartridges - 3

Installation Date - 08/13/91 Time - 10:41 Torque - N/A ft/lb

Test Date - 08/13/91 Time - 2:00 PM Torque - N/A ft/lb
Test Jack - RC-60-CH 9.5A Test Pump - RC-60 & CH95 SN 79886 231%
Dial Indicator - AMES CD-0040 Calibrated - DLR 10-9-91
Pressure Gauge - US GAUGE DSI # 001 Calibrated - 08-06-91

Pump Pressure (DSI x100)	Bolt Tension (LBS)	Extensometer Reading	Displacement	Remarks
2	2670	0.000		
4	4940	0.011		
6	7410	0.028		
8	9880	0.050		
10	12350	0.069		
12	14820	0.085		
14	17290	0.106		
16	19760	0.127		
18	22230	0.151		
20	24700	0.173		
22	27170	0.199		
24	29640	0.222		
26	32110	0.244		
28	34580	0.268		
30	37050	0.292		
32	39520	0.313		
33	40755	0.325		
34	41990	0.335		
35	43225	0.350		
36	44460	0.360		
37	45695	0.372		
38	46930	0.385		
39	48166	0.396		BLEED TO 3800 PSI
40	49400	0.413		
41	50635	0.424		
42	51870	0.435		
43	53105	0.456		
44	54340	0.475		
45	55575	0.499		
46	56810	0.519		
47	58045	0.544		BLEED TO 4600 PSI REMOVE DIAL INDICATORS
48		0.743		BLEED TO 4600 PSI
49		0.839		Accepted 4900 Bleed to 4700 PSI
50				
51				
52				
53				TERMINATE TEST 2:15 PM

Test Results - ACCEPTED Maximum Pull Force - 58045#
Displacement at Maximum Pull Force - 0.839 in.
Nature of Failure/Yield - Bar Yield 4700 PSI
Other Remarks - 27.3 Hrs AFTER INSTALLATION
Tested By - D. Ballmann Approved By - [signature]

UNDERGROUND DRILLING HOLE FIELD DATA SHEET

Date: 8/13/91

Room/Drift: PANEL 1 - ROOM 2

Purpose of Hole: PULL TEST: DESTRUCTIVE (PWR 12017)
PT081391-3

Location: N. END APPROX 4'+/- W ROOM ℄ APPROX. 15 FT FROM BULKHEAD

Depth at Completion: 11'-7"

Diameter: 1-3/8" ϕ COMPLETION

Approximate Collar Coordinates

Vertical Angle: VERT. (5° TOLERANCE)

Direction/Azimuth:

Remarks: RESIN/ROCK ANCHOR TEST AT 2:00 pm AND COMPLETED AT 2:
FOR CERTIFICATION

Signature/Department: D. Ballmaier 8/14/91

ROCK BOLT CERTIFICATION TEST
DATA SHEET

Mine WIPP Rock HALITE Rock Bolt No. PT091391-4
Hole Location PANEL 1 - ROOM 2

Hole Length - 11'-7" Dia. - @ Anchor GAUGED /@ midpoint N/A /@ collar N/A
Orientation - VERT. (5° TOLERANCE) SMOOTH

Bolt Grade - GR 60 Length - 13'-0" Diameter - #8

Shell Manufacturer - N/A Model - N/A Diameter - N/A
Length - N/A

Resin Manufacturer - CELLITE Model - H90-0204 Diameter - 1¼"
Length - _____ No. Cartridges - _____

Installation Date - 08/13/91 Time - 10:51 am Torque - N/A ft/lb

Test Date - 08/14/91 Time - 2:25 PM Torque - N/A DB 8/14/91 ft/lb
Test Jack - RC-60-CH-9.5A Test Pump - PC-60-9.5 SN 23686 23586
Dial Indicator - AMES CD-0040 Calibrated - DUE 10-8-91
Pressure Gauge - LG GAGE 0-5M ± 0.01 Calibrated - 08/06/91 DB 8/13/91
08/06/91

PSI X 100 Pump Pressure	LBS Bolt Tension	Extenso-meter Reading	Displace ment	Remarks
2 DB 8/14/91	2470	0.009		
4	4940	0.007		
6	7410	0.023		
8	9880	0.046		
10	12350	0.067		
12	14820	0.087		
14	17290	0.109		
16	19760	0.126		
18	22230	0.146		
20	24700	0.162		
22	27170	0.179		
24	29640	0.197		
26	32110	0.215		
28	34580	0.232		
30	37050	0.250		
32	39520	0.266		
33	40755	0.275		
34	41990	0.286		
35	43225	0.295		
36	44460	0.306		
37	45695	0.311		
38	46930	0.315		
39	48165	0.330		
40	49400	0.336		
41	50635	0.346		
42	51870	0.354		
43	53340	0.362		
44	54575	0.375		
45	55810	0.386		
46	56810	0.396		BOLT TO 4600 PSI REMOVE DIAL INDICATOR
47	58045	0.410		
48 DB 8/14/91		0.456		BLED TO 4700 PSI
49		0.556		
50				
51				
52				
53				TERMINATE TEST 2:35

Test Results - ACCEPTED Maximum Pull Force - 58045 #
Displacement at Maximum Pull Force - 0.556
Nature of Failure/Yield - BOLT YIELD @ 4700 PSI
Other Remarks - N/A
Tested By - D. Gallegos Approved By - T.E. Thompson

UNDERGROUND DRILLING HOLE FIELD DATA SHEET

Date: 8/13/91

Room/Drift: PANEL 1 - ROOM 2

Purpose of Hole: PULL TEST : DESTRUCTIVE (PWR 12-7T)
PT 081391-4

Location: N. END 4th W Room & APPROX. 28-30 FT FROM W. BULKHEAD

Depth at Completion: 11'-7"

Diameter: 13/8" ϕ COMPLETION

Approximate Collar Coordinates

Vertical Angle: VERT. (5° TOLERANCE)

Direction/Azimuth:

Remarks: RESIN/ROCK ANCHOR TEST AT 2:25 PM
AND COMPLETED AT 2:35 PM FOR CERTIFICATION.

Signature/Department: D. Dalhaim 8/14/91

ROCK BOLT CERTIFICATION TEST
DATA SHEET

Mine WIPP Rock HALITE Rock Bolt No. PTC91391-5 Hole Location PANEL 1-ROOM 2

Hole Length - 11'-7" Dia. - @ Anchor GAUGED /@ midpoint N/A /@ collar N/A
Orientation - VERT. (5° TOLERANCE) SMOOTH

Bolt Grade - GR60 Length - 13'-0" Diameter - #8

Shell Manufacturer - N/A Model - N/A Diameter - N/A
Length - N/A

Resin Manufacturer - CELTITE Model - H90 .02gal Diameter - 1¼"
Length - 12" No. Cartridges - 3

Installation Date - 08/13/91 Time - 10:54 AM Torque - N/A ft/lb

Test Date - 08/14/91 Time - 2:38 PM Torque - N/A ft/lb
Test Jack - RC-60-CN 9.5A Test Pump - RC-60-CN 9.5 SN 23886
Dial Indicator - ALMES CD-0040 Calibrated - DUE 10-4-91
Pressure Gauge - US GAGE DSI #001 Calibrated - 08/06/91

PSI x100 Pump Pressure	LBS Bolt Tension	Extenso-meter Reading	Displace ment	Remarks
2	2470	0.009		
4	4940	0.020		
6	7410	0.038		
8	9880	0.058		
10	12350	0.084		
12	14820	0.111		
14	17290	0.145		
16	19760	0.177		
18	22230	0.206		
20	24700	0.231		
22	27170	0.251		
24	29640	0.274		
26	32110	0.295		
28	34580	0.316		
30	37050	0.340		
32	39520	0.360		
33	40755	0.372		
34	41990	0.380		
35	43225	0.391		
36	44460	0.400		
37	45695	0.411		
38	46930	0.421		
39	48165	0.432		
40	49400	0.448		
41	50635	0.455		
42	51870	0.468		
43	53105	0.480		
44	54240	0.497		
45	55575	0.518		
46	56810	0.536		
47	58045	0.542		
48	59280	0.580		
49	60515	0.616		Bled TO 4800 PSI
50	8/14/91	0.685		Bled TO 4800 PSI
51		0.735		
52				
53				TAKEN OUT TEST 2:55 PM

Test Results - ACCEPTED Maximum Pull Force - 60515#
Displacement at Maximum Pull Force - 0.255
Nature of Failure/Yield - BOLT YIELD @ 4700 PSIG
Other Remarks - N/A
Tested By - D. Balthaser Approved By - T.E. Bruce

UNDERGROUND DRILLING HOLE FIELD DATA SHEET

Date: 8/13/91

Room/Drift: PANEL 1 - ROOM 2

Purpose of Hole: PULL TEST: DESTRUCTIVE (PWR 12017T)
PT081391-5

Location: N. END 4th W ROOM & 30-35 FT. FROM N. BULKHEAD

Depth at Completion: 11'-7"

Diameter: 1 3/8" ϕ COMPLETION

Approximate Collar Coordinates

Vertical Angle: VERT. (5° TOLERANCE)

Direction/Azimuth:

Remarks: RESIN/ROCK ANCHOR TEST AT 2:38 PM
AND COMPLETED AT 2:55 PM FOR
CERTIFICATION.

Signature/Department: D. Sullivan 8/14/91

ROCK BOLT CERTIFICATION TEST DATA SHEET

Mine WIPP Rock HALITE Rock Bolt No. PT-B0091-1 Hole Location PANEL 1 - ROOM 2

Hole Length - 11.5B Dia. - @ Anchor GAUGED/@ midpoint N/A /@ collar N/A
Orientation - VERTICAL (5° TOLERANCE) SMOOTH

Bolt Grade - GR 60 Length - 13'-0 1/4" Diameter - #8

Shell Manufacturer - N/A Model - N/A Diameter - N/A
Length - N/A

Resin Manufacturer - CELTITE Model - H90-0204 Diameter - 1 1/4" (32mm)
Length - 12" No. Cartridges - 3

Installation Date - 08/08/91 Time - 12:46 pm Torque - N/A ft/lb

Test Date - 08/09/91 Time - 1:45 pm Torque - N/A ft/lb
Test Jack - RC-60-CH2.5A Test Pump - PE-60-CH2.5A
Dial Indicator - AMES 4822 SN-0060 Calibrated - 10-4-91 DUE
Pressure Gauge - 42 GAGE PSI Calibrated - 8-6-91

Pump Psi Pressure	LBS Bolt Tension	Extensometer Reading	Displacement	Remarks
200	2470	0.000		
400	4940	0.017		
600	7410	0.144		
800	9880	0.165		
1000	12350	0.184		
1200	14820	0.205		
1400	17290	0.225		
1600	19760	0.246		
1800	22230	0.272		
2000	24700	0.293		
2200	27170	0.322		BLED TO APPROX. 2100
2400	29640	0.343		NC IG - P6
2600	32110	0.371		
2800	34580	0.394		
3000	37050	0.414		
3200	39520	0.441		BLED BACK TO 3100 AFTER 2 MIN.
[illegible]	[illegible]	0.464		* MISSED READING AT 3300 PSI
[illegible]				
[illegible]				
[illegible]				
3500	43225	0.474		HELD AT 2 MIN.
3600	44460	0.487		BLED BACK 3500 PSI AFTER 2 MIN
3700	45695	0.502		
3800	46930	0.513		* PLATE AT BACK DEFORMING
3900	48165	0.527		BLED TO 3800 AFTER 2 MIN.
4000	49400	0.540		HOLDING 4000 AFTER 2 MIN BLED 3900 AFTER 5 MIN.
4100	50635	0.549		BLED TO 4000 AFTER 2 MIN
4200	51870	0.559		HOLDING AFTER 2 MIN
4300	53105	0.567		BLED TO 4200 HELD AT 4200 AFTER 5 MIN
4400	54340	0.583		HOLDING AFTER 2 MIN
4500	55575	0.594		HOLDING AFTER 2 MIN
4600	56810	0.612		HOLDING BLED SLIGHTLY
4700	58045	0.626		HOLDING AFTER 2 MIN
4800	59280	0.657		HOLD BLED TO 4700 AFTER 2 MIN
4900		0.712		ATTEMPT TO GO TO 5000
		0.765		BLED BACK TO 4800

Test Results - ACCEPTED Maximum Pull Force @ 59280#
Displacement at Maximum Pull Force - 0.765 in. @ 0.842 in.
Nature of Failure/Yield - BOLT YIELD 4900 PSI 4860 PSI
Other Remarks - CONTINUED PULL ON 8/12/91 TO 6700 PSI with approx 1.3" elongation (approx 10 tons)
Tested By - D. Waltman Approved By - [illegible]

ROCK BOLT CERTIFICATION TEST DATA SHEET

page 2 of 2

Mine WIPP Rock HALITE Rock Bolt No. PTBB0891-1 Hole Location

Hole Length - ____ Dia. - @ Anchor ____ /@ midpoint ____ /@ collar ____
Orientation - ____

Bolt Grade - ____ Length - ____ Diameter - ____

Shell Manufacturer - ____ Model - ____ Diameter - ____
Length - ____

Resin Manufacturer - ____ Model - ____ Diameter - ____
Length - ____ No. Cartridges - ____

Installation Date - ____ Time - ____ Torque - ____ ft/lb

Test Date - ____ Time - ____ Torque - ____ ft/lb
Test Jack - ____ Test Pump - ____
Dial Indicator - ____ Calibrated - ____
Pressure Gauge - ____ Calibrated - ____

Pump Psi Pressure	Bolt Tension	Extenso-meter Reading	Displace ment	Remarks
~~5000~~		0.842		ATTEMPTED 5000 PSI - BLEEDS BACK TO 4800
				BOLT YIELD - ~~NATURE OF FAILURE~~ 10/8/91
				TEST TERMINATED 2:30 pm

Test Results - ____ Maximum Pull Force - ____
Displacement at Maximum Pull Force - ____
Nature of Failure/Yield - ____
Other Remarks - ____
Tested By - D. Bellamy Approved By - R.E. Beauheim

UNDERGROUND DRILLING HOLE FIELD DATA SHEET

Date: 08/08/91

Room/Drift: PANEL 1 - ROOM 2

Purpose of Hole: PULL TEST : DESTRUCTIVE (PWR 12017T-PT080891-1)

Location: NORTH END: APPROX. 4'1" E OF ROOM 2 & APPROX. 10' FROM NORTH BULKHEAD

Depth at Completion: 11'-6.5" (+1" -0) 11'-6.5"

Diameter: 1 3/8 COMPLETION

Approximate Collar Coordinates

Vertical Angle: VERTICAL (5° TOLERANCE

Direction/Azimuth:

Remarks: BOLT ROCK/RESIN ANCHORS TESTED ON 8.9.91 AT 1:45 TEST COMPLETED 2:30 pm FOR CERTIFICATION.

Signature/Department: D. Ballenait / Mine Engineering

ROCK BOLT CERTIFICATION TEST
DATA SHEET

Mine WIPP Rock HALITE Rock Bolt No. PTDB0891-2 Hole Location PANEL 1 · ROOM 2

Hole Length - 11.5' Dia. - @ Anchor GAUGED @ midpoint N/A /@ collar N/A
Orientation - VERTICAL (5° TOLERANCE) SMOOTH

Bolt Grade - GR60 Length - 13'-0 1/4" Diameter - #8

Shell Manufacturer - N/A Model - N/A Diameter - N/A
Length - N/A

Resin Manufacturer - CELTITE Model - H90-0204 Diameter - 1 1/4" (32mm)
Length - 12" No. Cartridges - 3

Installation Date - 08/08/91 Time - 1:13 pm Torque - N/A ft/lb

Test Date - 08/09/91 Time - 2:56 pm 08/09/91 AM Torque - N/A ft/lb
Test Jack - RC-60-CH-25 Test Pump - RC-60-CK9.5 23886
Dial Indicator - AMES 4322 CD-0040 Calibrated - 10-4-91 DJB
Pressure Gauge - U.S. GAGE PSI±001 Calibrated - 8-6-91

Pump Pressure PSI	~~Bolt Tension~~ ST. ROD	~~Extenso meter~~ A SS ROD Reading	~~Displace ment~~ TENSION LBS	Remarks
200	0.100	0.100 8.9.91	2470	
400	0.118	0.100 8.9.91	4940	
600	0.151	0.100 8.9.91	7410	
800	0.174	0.100 8.9.91	9880	
1000	0.191	0.100 8.9.91	12350	
1200	0.211		14820	
1400	0.229		17290	
1600	0.245		19760	
1800	0.262		22230	
2000	0.279		24700	
2200	0.299		27170	
2400	0.317		29640	
2600	0.336		32110	
2800	0.354		34580	
3000	0.372		37050	
39,520# 3200	0.388		39520	HOLD FOR 2 MIN - 3000 TO 3200 PSI
3300	0.396		40755	HELD AT 3300
3400	0.406		41990	HOLDING AFTER 2 MIN.
3500	0.415		43225	PS 8/9/91
* 3600	0.425	0.326 X	44460	ADJUST TO 0.326
3700		0.337	45695	GAUGE CAME OFF BOLT
3800		0.349	46930	PLATE AT BACK DEFORMED
3900		0.354	48165	
4000		0.362	49400	HELD FOR 2 MIN. BLED TO 3900
4100		0.373	50635	
4200		0.381	51870	
4300		0.387	53105	
4400		0.400	54340	
4500		0.417	55575	
4600		0.434	56810	
4700		0.455 PS	58045	
~~4800~~		0.530 8.9.91		BOLT YIELD - PUMP BLEEDS TO 4700: BACK @ 4600 0.577 AT 4200 PSI
				TEST TERMINATED @ 3:05 pm PS 8/9/91

Test Results - ACCEPTED Maximum Pull Force - ~~56810~~ 58045#
Displacement at Maximum Pull Force - 0.530 in.
Nature of Failure/Yield - BOLT YIELD (APPROX.) PS 8-9-91 AM 8-4-91 47000 psi
Other Remarks - 24 HOURS AFTER INSTALLATION
Tested By - A. Baltimore Approved By - L.E. Brandshaw

UNDERGROUND DRILLING HOLE FIELD DATA SHEET

Date: 08/08/91

Room/Drift: PANEL 1 - ROOM 2

Purpose of Hole: PULL TEST : DESTRUCTIVE (PWR 12017T)
PTOB0891-2

Location: NORTH END: APPROX. 4' E OF ROOM ℄ APPROX. 15' FROM NORTH BULKHEAD

Depth at Completion: 11'-6" (+1" -0") 11'-7"

Diameter: 1-3/8" COMPLETION

Approximate Collar Coordinates

Vertical Angle: VERTICAL (5° TOLERANCE)

Direction/Azimuth:

Remarks: ROCK/RESIN ANCHOR TESTED ON 8.9.91 AT ~~3:05~~ 2:55 pm.
COMPLETED AT ≈ 3:05 pm FOR CERTIFICATION.

Signature/Department: D. Galbraith / Mine Engineering

ROCK BOLT CERTIFICATION TEST
DATA SHEET

Mine WIPP Rock HALITE Rock Bolt No. PTOBOD91-3
Hole Location PANEL 1 · ROOM 2

Hole Length - 11.5' Dia. - @ Anchor GAUGED /@ midpoint N/A /@ collar N/A
Orientation - VERTICAL (5° TOLERANCE) SMOOTH

Bolt Grade - GR60 Length - 13'-0 1/4" Diameter - #8

Shell Manufacturer - N/A Model - N/A Diameter - N/A
Length - N/A

Resin Manufacturer - CELTITE Model - H90 -0204 Diameter - 1 1/4" (32 mm)
Length - 12" No. Cartridges - 3

Installation Date - 08/08/91 Time - 1:46 pm Torque - N/A ft/lb

Test Date - 08/09/91 Time - 3:30 pm Torque - N/A ft/lb
Test Jack - RC-60-CH95A Test Pump - RC-60.H95 28886
Dial Indicator - ASTEC 4822 CD-0040 Calibrated - 10-4-91 BLUE
Pressure Gauge - 4" GAUGE DS1#001 Calibrated - 9-6-91

PSI Pump Pressure	LBS Bolt Tension	Extensometer Reading	Displacement	Remarks
200	2470	0.100		
400	4940	0.113		
600	7410	0.135		
800	9880	0.157		
1000	12350	0.180		
1200	14820	0.202		
1400	17290	0.222		
1600	19760	0.238		
1900	23230	0.247		
2000	24700	0.263		
2200	27170	0.281		
2400	29640	0.296		
2600	32110	0.314		
2800	34580	0.334		
3000	37050	0.356		
3200	39520	0.376		HELD 30 SEC/MIN. 3000
3300	40755	0.393		HOLDING
3400	41990	0.405		
3500	43225	0.415		HOLDING AFTER 1 MIN
3600	44460	0.425		HOLDING
3700	45695	0.436		HOLDING AFTER 1 MIN.
3800	46930	0.449		
3900	48165	0.460		
4000	49400	0.473		
4100	50635	0.485		
4200	51870	0.497		HOLDING AFTER 1 MIN
4300	53105	0.511		
4400	54340	0.524		HOLDING AFTER 1 MIN.
4500	55575	0.536		HOLDING
4600	56810	0.555		HELD FOR 2 MIN BLED TO 4500 #
4700	58045	0.585		HELD 1 MIN. BB 4600 # PLATE DEFORM.
4800	59280	0.686		BOLT YIELD - FAILURE APPARENT
4800 ATTEMPTED				CONTINUE LOADING PUMPING
				DEF. .686 AT 4600 GAUGE
				.702 AT 4600 READING
				TEST TERMINATED @ 3:45 PM

39,520 #

Test Results - ACCEPTED Maximum Pull/Force - 58045 #
Displacement at Maximum Pull Force - 0.686 IN 0.702 IN
Nature of Failure/Yield - BOLT YIELD @ 4700 psi (58045 lbs) APPARENT
Other Remarks - @ 24 HOURS AFTER INSTALLATION
Tested By - D. Ballinger Approved By - T.F.A.

UNDERGROUND DRILLING HOLE FIELD DATA SHEET

Date: 08/08/91

Room/Drift: PANEL 1 - ROOM 2

Purpose of Hole: PULL TEST: DESTRUCTIVE (PWR 12017T)
PT080891-3

Location: NORTH END: APPROX. 4' E OF ROOM ℄ APPROX. 20-25 FT FROM NORTH BULKHEAD

Depth at Completion: 11'-6" (+1" -0) 11'-7"

Diameter: 1-3/8" COMPLETION

Approximate Collar Coordinates

Vertical Angle: VERTICAL (5° TOLERANCE)

Direction/Azimuth:

Remarks: ROOF/REBAR ANCHOR TESTED ON 8.9.91 AT 3:30 pm.
COMPLETED AT 3:45 pm FOR CERTIFICATION

Signature/Department: D. Gallerani / Mine Engineering

WORK CHANGE NOTICE

1. WCN No.: 1	2. Critical System Yes ☐ No ☑	
3. Work Request: 12017-T	4. Originated By / Phone No.: T.F. BROCKMAN 8304 Date: 8/7/91	5. Incorporated By / Phone No.: T.F. BROCKMAN 8304 Date: 8/7/91

6. DESCRIPTION OF CHANGE (Print or Type Proposed Change)

Page	Step or Paragraph	Instructions: Rewrite Paragraph Changes, Draw Illustration Changes
ATTACHMENT 6		CHANGE LARGE REAMED HOLE FROM 3" TO 3-4".
5	7.2.4b	CHANGE LOAD FROM 1,000# TO 200 P.S.I.
5	7.2.6	CHANGE ALL REFFERENCE OF 1,000# TO READ 200 P.S.I.
5	7.2.7b	CHANGE 40,000# TO READ 3,200 P.S.I.
5	7.2.7	CHANGE 500# TO READ APPROXIMATELY 100 P.S.I.

7. Reason for Change:

TO ACCOMODATE FOR AVAILABLE EQUIPMENT. CHANGE DOES NOT AFFECT SCOPE NOR INTENT OR DESIGN

8. DESIGN CLASSIFICATION

☑ Class II or IIIA ☑ Class IIIB or Non-Facility

9. Required Approval

Signature	Date
PIC All Classes M. Campbell	8/8/91
Originator All Classes T.F. Brockman	8/7/91
Safety As Required T.F. Brockman	8/8/91
Quality Assurance II or IIIA	8/8/91
Cognizant Engineer II or IIIA for J.A. GONZALES D. Gallegos	8/7/91
Cognizant Operations Mgr. All Classes T.F. Brockman	8/7/91
Other	
Other	

DESTRUCTIVE TESTING OF RESIN ANCHORS

1.0 SCOPE

A representative sample of resin anchored Dywidag tendons will be pull tested to destruction. This will be achieved by installing the rock anchors in Room 2, Panel 1 in conditions as similar to those in Room 1 as possible. The results will be used as basic input data in the design of the supplemental support system proposed for Room 1, Panel 1.

2.0 OBJECTIVES

The objectives of the destructive testing are expected to yield results that:

- o provide data on both the mode and load at failure of the halite/resin/tendon bond.
- o establish the allowable design load for the rock anchor system.

In addition, other in situ tests are expected to provide results that:

- o check for interaction effects between rock anchors.
- o provide short term creep response of the rock anchor system.

3.0 SAFETY REQUIREMENTS

3.1 Personnel Safety - All personnel participating in or observing destructive testing shall be properly equipped.

3.2 For the safety of observers, personnel not actively participating in the destructive testing are requested to stay outside the designated work area. The boundary for a designated work area is to be established at least fifty (50) feet away.

3.3 During the performance of the destructive tests, safety chain or cables shall be attached to each item of test equipment weighing more than 10 lbs. that may be violently released or fall as a result of testing.

4.0 TEST MATERIALS

4.1 Resin: Celtite Lockset Polyester Resin Cartridge
High Viscosity, Code (H)
Gel Time, Two-to-Four Minutes Code (90) 0204 DG 8.1.91
Cartridge, 3212

QA Verification: KA Lacy

For additional information refer to Attachments 1, 2, and 3 for Material Safety Data Sheets, installation instructions, and product information.

4.2 Tendons: Dywidag Post-Tensioning System
#8 THREADBAR (LHT), ASTM A615 GR 60
FULL LOAD ANCHOR NUTS FOR GRADE 60 THREADBAR

QA Verification: KA Lacy

For additional information refer to Attachments 4 and 5.

5.0 TEST EQUIPMENT AND TEST REQUIREMENTS

5.1 A minimum of ten (10) rock anchors shall be installed, and loaded to failure. Initially, only one set (of five) rock anchor installations shall be tested in any given twenty-four (24) hours. The load will be recorded all the way to failure.

5.1.1 The failure mode is to be determined by pulling tendons completely of the hole.

5.1.2 For the purpose of destructive testing, failure is defined as an increasing or continuous deformation with no increase of the applied load.

5.2 There is to be a waiting period of at least twenty-four (24) hours between resin/anchor activation and the commencement of destructive testing. The waiting period assures that the resin has cured and is approaching ultimate strength. Fully cured resin develops compressive strength of 14,000 psi and tensile strength of 5,000 psi or more.

QA Verification: Mike Lacy

5.3 The testing equipment includes a hydraulic ram with a 60 ton capacity, a pressure gauge readable in 200 psi increments, and a dial indicator gauge for measuring deformation in increments of 0.001 inch. Rock/resin anchor deformation will be measured by means of the dial indicator.

QA Verification: Mike Lacy

5.4 Installation of properly calibrated Geotechnical instrumentation may be used where required.

5.5 All instruments and devices used for measuring or recording loads or deformation during the test shall have been properly calibrated with tags affixed indicating calibration due date.

QA Verification: Mike Logan

6.0 DRILLING AND ANCHOR/RESIN INSTALLATION INSTRUCTIONS

6.1 Drill each test hole as per Attachment 6 in accordance with applicable sections as prescribed in WP 04-220 and provided by factory representative's instructions.

6.1.1 Test hole locations shall have not less than four (4) feet spacings.

6.1.2 The 1-3/8 inch diameter bits shall be gauged prior to drilling above Anhydrite "b". Gauging assures the annular tolerance needed for a minimum bond length of three (3) feet.

6.1.3 Holes shall be drilled to a depth of 11 feet 6 inches with 1 inch tolerance, for test purposes only.

6.1.4 The perpendicular hole tolerance shall be 5 degrees as shown on Attachment 6.

6.2 Initially, only one set (of five) rock anchor installations shall be tested in any given twenty-four (24) hours. This may be changed subject to improved installation performance gained by experience and signed by cognizant engineer or his designee.

6.3 Resin and threadbar will be installed in accordance with the manufacturers' recommendations. A manufacturer's representative will be present during resin/anchor installation and destructive testing.

6.4 Insert required number of resin cartridges (3 minimum) through plastic or steel pipe and fed into the end of the hole. The resin is then followed by the threadbar with spin adapter.

Care must be taken to avoid rupturing the resin cartridges.

6.5 Start rotation at about 50 rpm or more and gradually insert the threadbar bolt into the resin cartridge to rupture the cartridge. *

6.5.1 Advance threadbar bolt at an approximate rate of 2 to 4 inches per second or as recommended by the factory representative.

* DUE TO AVAILABLE EQUIPMENT AND PER CONTRACT THE BAR IS TO BE INSERTED TO FULL DEPTH

6.5.2 Hold bolt in the hole and hold until the resin sets, approximately for two (2) to four (4) minutes.

6.5.3 Threadbar should have approximately eighteen (18) inches of thread protruding from the hole in its final position.

6.5.4 Thorough mixing of the resin ingredients is essential.

6.6 There is to be a waiting period of at least twenty-four (24) hours between resin/anchor activation and destructive testing.

A waiting period assures that the resin has cured and is approaching its ultimate strength. When fully cured, the resin develops a compressive strength of 14,000 psi and tensile strength of 5,000 psi or more.

QA Verification: Mike Bogan

7.0 FULL TEST INSTRUCTIONS

7.1 Preparation for tests

7.1.1 All instruments and devices used for measuring or recording loads or deformation during the testing shall have been properly calibrated with tags affixed indicating calibration due date.

7.1.2 Prepare data sheets. Applicable information and test data shall be recorded on data sheets, Attachment 7. See Section 8 for QA verification.

7.1.2.1 Record at least the following: rock bolt number (i. e., PTmmddyy-#); mine; rock type; hole location; orientation; hole length and diameter; bolt grade, length, and diameter; installation date and time; test date and time; resin type, manufacturer, number of resin cartridges; and, identify test equipment by serial number and indicate calibration due date.

7.1.2.2 Measure the hole length and record.

7.1.2.3 When testing is complete, submit the data sheet to Mine Engineering.

7.1.2.4 When testing is complete, submit WP Form 2014 to Mine Engineering, Attachment 8.

7.1.2.5 Mark the final depth of the threadbar at 11 feet 6 inches with 1 inch tolerance from the anchor end and record.

7.1.2.6 Estimate hole orientation and roughness (i.e., vertical and smooth) and record.

7.2 PULL TEST

7.2.1 Install a bearing plate against the rock followed by placing the ram over the threadbar followed by another bearing plate and load cell and bearing plate, and finally torque the anchor nut.

The anchor nut shall be tightened to the manufacturer's recommended torque values (150 ft-lbs to 300 ft-lbs).

7.2.1.1 Fasten safety chain or cable to all equipment weighing more than 10 lbs and anchor to adjacent rock bolt plates.

7.2.2 The ram alignment should be near parallel to the axis of the tested bolt and within the limits allowed by the installation.

7.2.3 Make hose connections from the hydraulic pump to the ram.

7.2.4 a Make load cell and other instrumentation connections to data logger.

7.2.4 b Apply 1,000 lb load on the ram to eliminate apparatus slack.

7.2.5 Attach a magnet mounted dial indicator gauge on the ram with the point set in place on the bolt or to a fixed reference point in the salt. Adjust the dial indicator gauge to zero.

7.2.6 Test loading shall continue to be applied starting with 1,000 lbs and increased by 1,000 lb increments up to 40,000 lbs. Loads are to be held for approximately one (1) minute before recording the load and deformation data. Record the test data, Attachment 7.

7.2.7 From 40,000 lbs, the load shall be applied in 500 lb increments. While approaching failure, data readings may be taken more often.

7.2.8 Testing the resin/rock anchor to failure is the acceptance criteria. The test is accepted as complete at failure.

7.2.8.1 For the purpose of destructive testing, failure is defined as an increasing or continuous deformation with no increase of the applied load.

7.2.9 Terminate testing.

7.2.10 Remove equipment and pull bolt from hole, if possible

7.2.11 Continue testing of the next installation.

8.0 TEST DATA, ILLUSTRATIONS AND REPORTS

8.1 The data sheet form (Attachment 7) shall be filled out for each test bolt installation. The data sheet shall be keyed to match the rock anchor pull test number (PTmmddyy-#).

QA Verification: Mike Rogers

8.2 Each test shall be identified by rock anchor number and plotted on an appropriate scale. Each data point shall be plotted with the horizontal (x) axis showing displacement while the vertical (y) axis indicates load.

8.3 Photographs of a typical rock anchor installation shall be referenced to the rock anchor test number.

8.4 A report shall be prepared by Mine Engineering summarizing the test results and certifying the installation procedures and resin/rock anchors that have been tested and approved for installation at the WIPP.

8.5 The results will be used as basic input data in the design of the supplemental support system proposed for Room 1, Panel 1.

CONCURRENCE BY:

D. Galbraith

D. Galbraith, Senior Engineer
Mine Engineering

Chi Chung / J. Gonz 8/7/91

J. A. Gonzalez, Cognizant Engineer
Mine Engineering

P.F. Brandenburg 8/7/91

S. C Sethi, Manager
Mine Engineering

MATERIAL SAFETY DATA SHEET

SECTION 1 - PRODUCT IDENTIFICATION AND USE

MANUFACTURER: CELTITE TECHNIK USA
150 CARLEY COURT
GEORGETOWN, KY 40324
(502) 863 - 6800

CANADIAN CONTACT: FOSECO CANADA INC.
GUELPH, ONTARIO

MANUFACTURERS IDENTIFICATION CODE:
20,35,37,40,45,50,70,90,0204,0510,1530
PRODUCT NAME: LOKSET POLYESTER RESIN CARTRIDGE
CHEMICAL FAMILY: Polyester Resin & Catalyst
PRODUCT USE: Anchoring Compound
WHMIS CLASSIFICATION: Class D, Division 2A; Class B, Division 3

SECTION 2 - HAZARDOUS INGREDIENTS

INGREDIENT	%	ACGIH/OSHA TLV TWA	ACGIH/OSHA TLV STEL	ACGIH/OSHA TLV CARC	NTP CARC	IARC CARC
Polyester resin CAS# N.R.	10-30	N.E.	N.E.	NO	NO	NO
Styrene monomer CAS# 100-42-5	5-10	50P	100P	NO	NO	2B
Benzoyl Peroxide CAS# 94-36-0	.5-1.5	5M	N.E.	NO	NO	NO
Calcium Carbonate CAS# 471-34-1	60-100	N.A.	N.E.	NO	NO	NO
Propylene Glycol CAS# 57-55-6	.5-1.5	N.E.	N.E.	NO	NO	NO

units - P suffix denotes PPM and M suffix denotes mg/m3
m suffix denotes mppcf and c suffix denotes ceiling value
N.A.- Not Applicable N.E.- Not Established N.D.- Not Determined
CARC- Carcinogen N.D.F.- No Data Found N.R.- Not Reported
NOTE: See SUPPLEMENT for SARA Section 313 reporting information.

This document is prepared pursuant to the OSHA Hazard Communication Standard (29 CFR 1910.1200) and the Canadian Workplace Hazardous Materials System (WHMIS). In addition, other ingredients not 'Hazardous' per these standards may be listed.

SECTION 3 - PHYSICAL DATA

APPEARANCE: Tan or black resin mortar and white paste catalyst in plastic package.
ODOR: N.A.
ODOR THRESHOLD: 0.1 ppm as Styrene
PERCENT VOLATILE: 11
SOLUBILITY IN WATER: N.A.
VAPOR PRESSURE(mmHg): 4.5 @ 20C(Styrene)SPECIFIC GRAVITY: 1.75-1.85
VAPOR DENSITY: 3.6 as Styrene
EVAPORATION RATE: N.D.
BOILING POINT: 293F
FREEZING POINT: N.D.
pH: Acidic
COEF. OF WATER/OIL DISTRIBUTION: N
PHYSICAL HAZARDS: Organic peroxide; Combustible Liquid

ATTACHMENT 1

SECTION 7 - PREVENTIVE MEASURE

SPECIAL PROTECTION INFORMATION:
RESPIRATORY: Use MSHA (NIOSH) approved respirator if application produces vapors, mists, or fumes above the TLV.
VENTILATION: Adequate to prevent vapor build-up above the TLV.
PROTECTIVE GLOVES: Chemical resistant polyethylene or equivalent.
EYE PROTECTION: Safety glasses or goggles as required to prevent eye contamination.
OTHER: Use protective clothing to minimize contact with skin. Wash contaminated clothing before reuse.

SPILL OR LEAK PROCEDURES:
SPILL: Ventilate area. Remove all sources of ignition. Absorb with inert material and collect.
WASTE DISPOSAL METHOD: Dispose of in accordance with Federal, State, and local regulations.
STORAGE: For maximum shelf-life avoid storage in direct sunlight, elevated temperatures or near sources of heat such as steam pipes and radiators. Store in a cool, dry well-ventilated area.
OTHER: Since the product is a sealed cartridge, handling hazards are minimal unless product is damaged or misused.
SHIPPING INFORMATION: Not Applicable

SECTION 8 - FIRST AID MEASURES

EYES - Flush with water for at least 15 min. Consult a physician.
SKIN - Wash thoroughly with soap and water.
INGESTION - Consult a physician immediately.
INHALATION - Remove to fresh air if effects occur. Call a physician if effects persist.

SECTION 9 - PREPARATION DATE OF MSDS

Revision date: 12/11/89
Previous revision date: 01/01/89
For further information contact: Leo Hickam
Phone number: (502) 863 - 6800

SUPPLEMENT:

HAZARDOUS INGREDIENTS Continued...

The following chemicals are subject to the reporting requirements of Section 313 of Title III of the Superfund Amendments and Reauthorizati Act of 1986 (SARA) and 40 CFR Part 372.

Chemical Name	CAS#	Maximum % by Weight
Benzoyl Peroxide	94-36-0	1.5%
Styrene	100-42-5	10.0%

Dy/G. Sealy & G. Greenfield Celtite
GEORGETOWN, KY : 150 CARLEY CT. 40324
502/863-6800
PRINCETON, WV: Rogers St. & Caperton Ave. 24740 304-425-7501
GRAND JUNCTION, CO. 1440 Winters Ave. 81501 303-245-4007

INSTALLATION INSTRUCTIONS FOR CELTITE RESIN CARTRIDGES

1. Measure and mark drill steel 1" longer than bolt length. Note: The bore hole should be shortened accordingly when headers or thick plates are used.

2. Insert required number of cartridges and place bolt into the base of the hole behind the resin.

3. With the head of the bolt placed firmly in the chuck of the bolter or in a spin-in wrench, push the bolt into the hole. Slow rotation is recommended but not required for adequate mixing.

4. When the bolt reaches just below the roof, stop upward movement and spin the bolt rapidly for five to ten seconds. (See note for stoper.)

5. Stop rotation and push the bolt upward with the full thrust from the machine and hold until the resin sets.

6. If the bolt tends to drop out of the hole after the chuck or adapter is removed, simply push it back up into the hole and hold until the resin sets.

7. NEVER re-rotate the bolt after the final spin, as damage to the partially-set resin may occur.

8. Always wear safety glasses or eye shields when installing resin bolts.

9. To achieve maximum performance, selection of bolt diameter, cartridge type and related hole diameter are very important. Celtite® technical representatives are available to assist in the selection of the correct combination of components, based on specific applications.

10. Note for stoper: Contact Celtite® technical representative.

11. For applications other than fully grouted bolts, Celtite® technical representatives will instruct mine personnel in correct installation procedure.

12. Cartridges should be stored in a cool, well-ventilated and dry area away from direct sunlight. High temperature conditions can reduce shelf life of cartridges. Stock rotation is recommended so that oldest stock is used first.

CAUTION: Do not open or puncture cartridges. Contents of cartridges may cause mild irritation and should be avoided. Eye protection should always be used when bolting. If resin contacts the eyes, flush immediately with water for at least 15 minutes. Call a physician.

We believe that the information contained herein (which supersedes all previous information on this subject) is true and reliable. We cannot be held responsible for any loss, injury, or damage resulting from its use, as, of necessity, the information given is of a general nature, so that users are advised to consult us about their specific problems.

Celtite® warrants that its products, at the time of shipment, conform to the applicable descriptions herein and are free from defects in materials and workmanship. NO OTHER WARRANTY, WHETHER EXPRESS, IMPLIED OR STATUTORY, INCLUDING ANY WARRANT OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, SHALL EXIST IN CONNECTION WITH THE SALE OR USE OF ANY CELTITE® PRODUCT, AND ALL SUCH WARRANTIES ARE HEREBY EXPRESSLY EXCLUDED.

IN NO EVENT SHALL CELTITE® BE LIABLE FOR INJURY TO PERSON OR PROPERTY, LOSS OF BUSINESS OR PROFIT ON ANY OTHER DIRECT, INDIRECT, INCIDENTAL, SPECIAL OR CONSEQUENTIAL DAMAGES.

U.S. Patent Nos. 3731791, 3915297 Canada No. 872075 Other World Patents

00-00-03
04-22-88

ATTACHMENT 2

The Lokset® Polyester Resin Cartridge Anchor System

This system's simplicity of application enables bolts of various lengths to be anchored and grouted in one easy operation, with no need for injection equipment.

The Celtite Technik system consists of an easily handled "cartridge," containing a highly reinforced polyester resin component, together with its catalyst, in accurately measured quantities. The components are isolated from each other by a *physical-chemical barrier* which prevents reaction between the components until required. The cartridges are sausage-shaped and designed for rapid insertion into a range of bore hole sizes, where they may be readily pushed to the extremity at any angle above or below the horizon. Therefore, optimum bolt anchorage in a wide range of rock or concrete strengths is easily achieved simply by adjusting the length of the resin anchor zone.

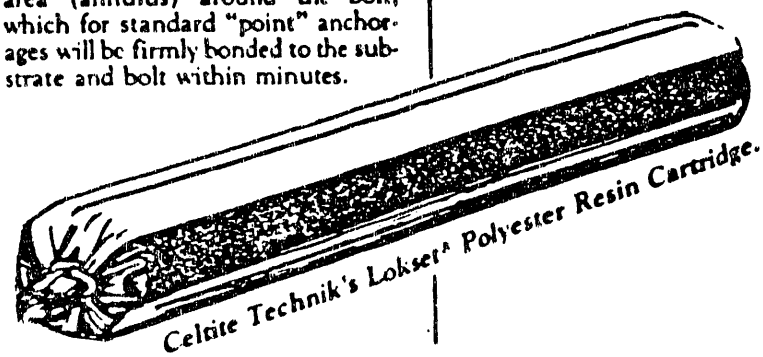
No reaction takes place until the roof or rockbolt is rotated through the cartridge, mixing the components and initiating the curing action. The chemical nature (thixotropy) of the Lockset® cartridge allows the contents to be easily mixed yet minimizes resin displacement after mixing is complete.

The mixed resin totally fills the area (annulus) around the bolt, which for standard "point" anchorages will be firmly bonded to the substrate and bolt within minutes.

The setting time of the resin components can be controlled. A combination of fast and slow-setting cartridges makes possible the simultaneous operation of anchoring, grouting and tensioning a rockbolt. The simplicity of this method of anchoring/grouting eliminates the need for cumbersome injection equipment.

APPLICATIONS

- Rock bolting in mines and tunnels.
- Permanent rock reinforcement on highway rock cuts, dams and underground rock structures (power-houses and machinery galleries).
- Integral ties between reinforced concrete and rock faces above or below water.
- Vibration resistant anchorages for attachment of "critical" equipment to concrete or rock.
- Anchorage for electrical transmission towers.
- Uplift anchorages for near surface structures.
- Immediate post-tensioning of steel reinforcements in rock or concrete structures.



Celtite Technik's Lokset® Polyester Resin Cartridge.

ADVANTAGES

Accuracy. All Anchorages can now be accurately designed with Celtite Technik resins having reproducible strength characteristics.

Speed. The fast-gelling Lokset® resins enable rapid installation to be carried out, a significant advantage in the area of tunnel bolting and rock slope stabilization. Application of load can be completed within minutes.

Permanence. The resins protect the embedded bolt from corrosion due to acid-bearing water, sea or ground water. Atmosphere is precluded from the bore hole, preventing further deterioration of the strata.

Safety. Millions of Lokset® resin anchors are used every year for critical jobs such as roof support or permanent rock reinforcement in mines, tunnels and foundations.

Vibration. Celtite Technik anchors are not affected by vibration and require *no* retensioning even after close proximity blasting.

Stress-free. No internal stresses are set up in the rock or concrete by resin anchors.

TECHNICAL SERVICE

Celtite Technik is available to discuss with you both installation techniques and the selection of proper Lokset® cartridges for your project. Our field representatives are ready to review your applications and help you to develop successful, economical anchoring systems.

ATTACHMENT 3

Anchoring

INTRODUCTION

Installation of Celtite Technik polyester resin cartridges in rock and concrete have ranged from application of short 3/4-inch rebar "starter bars" into concrete to 1 3/8" diameter bolts for rock reinforcement, measuring 55' in length, weighing over 300 pounds and fully embedded in resin!

ANCHORAGE STRENGTHS

To achieve maximum anchorage strength between bolt and concrete or rock, the difference in diameter between hole and bolt should be kept to a minimum. This also insures better mixing of both catalyst and resin.

Standard Rebar or Threadbar bolts (conforming to ASTM A-615 specifications) are used without further refinement. Deformations on the bar serve to effectively mix the cartridge components during the "spin-in" or insertion cycle. (SEE BOLT SELECTION ON PAGE 6).

Spin adaptors are available from several manufacturers. *Consult CELTITE® TECHNIK for source information.*

UNDERWATER ANCHORAGES

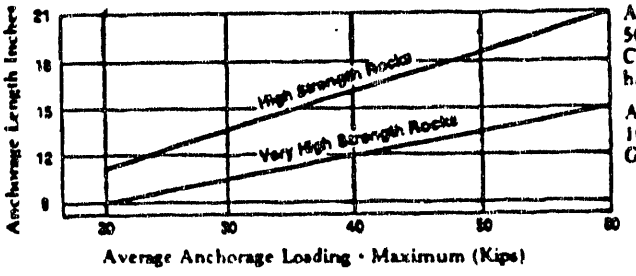
Lokset® cartridges can be applied in underwater anchorage applications over 24 inches in length, in both concrete and rock. *Consult CELTITE® TECHNIK for your specific job requirements.*

APPLICATION EQUIPMENT

The hole-drilling equipment mentioned in this brochure is generally suitable for spinning in bolts. This equipment should be rotary percussive and have provision for independent rotation to maintain 100 rpm under load. Under no circumstances should the bolt be simply pushed through the resin cartridges as improper mixing can result, providing for possible anchorage failure.

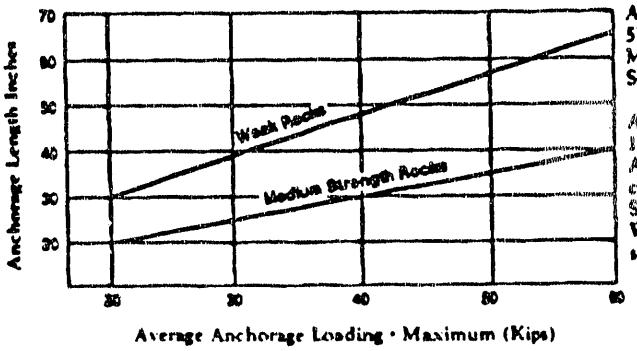
RESIN ANCHORAGE CHARTS

Typical anchorage loadings* in rock for point anchored rockbolts used in accordance with the manufacturer's recommendations. Intended as a guide for site trials, which will establish the working specifications in the actual ground conditions. **Shown in Kips (1000 lbs. = 1 Kip).*



Avg. 7000 PSI
50 MN/m²
Carboniferous
hard limestone

Avg. 14000 PSI
100 MN/m²
Granites

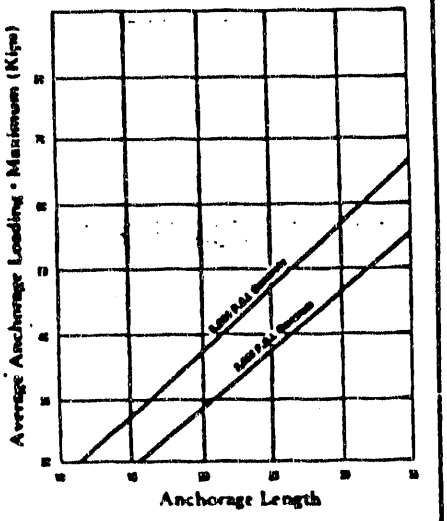


Avg. 750 PSI
5MN/m²
Mudstone
Siltstone

Avg. 2000 PSI
14 MN/m²
Average
coal measure
Sandstone
Weak compacted
shales

Rock strengths are in uniaxial compression terms. Information based on trials conducted by Imperial College, London (1970), J. A. Franklin, B.S.C., M.Sc., Ph.D, D.I.C.

Average Strength vs. Bond Length (Concrete)



Packaging.

Order Code (1)	Cartridge Diameter (inches)	Pieces Per Carton	Weight Per Carton
2312	15/16	50	27.5 lbs.
2812	1 1/8	35	29.5 lbs.
3212	1 1/4	25	26.5 lbs.
3512	1 3/8	20	26.0 lbs.
4012	1 9/16	16	27.0 lbs.
4512	1 3/4	12	25.0 lbs.

Minimum shipment; single full cartons.
A full pallet contains 75 cartons of standard 12-inch cartridges.
(1) Do not forget to specify gel time (see description section on page 5).

STORAGE PROCEDURES

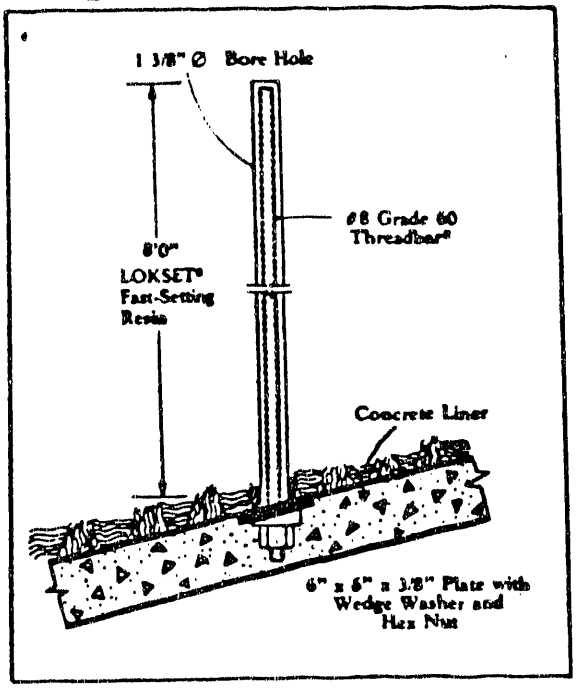
Lokset® cartridges should be stored in a cool, well-ventilated and dry area away from direct sunlight. High temperature conditions can reduce shelf life. Cartridges stored in extreme temperatures should be "normalized" at 50-70°F for at least two days prior to use to provide the expected gel time.

Pallets should not be stacked. Stock rotation is recommended so that the oldest stock is used first.

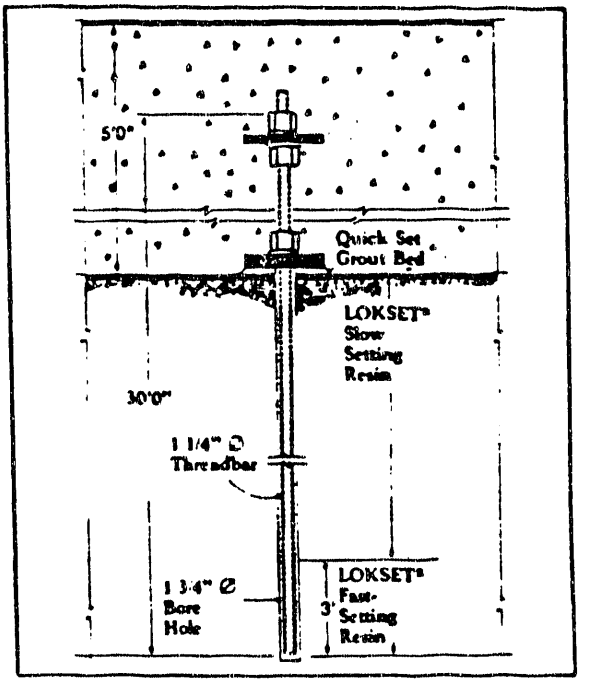
SAFE HANDLING PROCEDURES

REFER TO THE MATERIAL SAFETY DATA SHEET. Do not open or puncture cartridges prior to insertion. Contents of cartridges may cause mild irritation and contact should be avoided. Use in adequately ventilated area. Avoid prolonged inhalation of vapor. Eye protection should always be used when bolting. If resin contacts the eyes, flush immediately with water for at least 15 minutes. Seek medical attention.

Typical Lokset® resin anchor applications



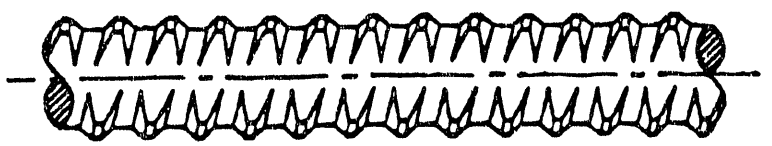
Roof bolts in diversion tunnel.
Paintsville Lake Dam, Kentucky.
Army Corps of Engineers, Huntington District.



Stilling Basin Rock Anchors.
Smithland Dam, Ohio River.
Army Corps of Engineers, Nashville District.

The illustrations on page 3 and the engineering drawings above are reprinted courtesy of Dywidag Systems International, Lemont, Illinois.

LEFT HAND THREAD



PHYSICAL PROPERTIES	
EFFECTIVE AREA:	0.79 SQ.IN.
ULTIMATE STRENGTH:	90 KSI
ULTIMATE LOAD:	71.1 KIPS
YIELD LOAD:	47.4 KIPS
WEIGHT:	2.67 LBS./FT.
MAX. BAR Ø INCL. RIBS:	1.12 IN.
AVERAGE CORE Ø:	0.95 IN.
PITCH:	0.492 IN.

ATTACHMENT 4

DYWIDAG POST-TENSIONING SYSTEMS

[redacted]

DATE: 08-29-90 DRAWN: C. MALECKI APPROVED:

DIMENSIONS: INCH/mm
mm FOR REFERENCE ONLY

TOLERANCES:
± .02
UNLESS NOTED

MATERIAL:
ASTM A615, GR 60

SCALE
NTS

REV.	DATE	NAME

DRAWING
BOSJO

DYWIDAG SYSTEMS INTERNATIONAL U.S.A., INC.

TABLE: COMPARISON OF BAR MECHANICAL PROPERTIES

Bar Size/Grade ASTM	#7/GR 60 A 615			#7/GR 75 F 432			#8/GR 60 A615		
	Yield (kips)	Tensile (kips)	Elong. (%)	Yield (kips)	Tensile (kips)	Elong. (%)	Yield (kips)	Tensile (kips)	Elong. (%)
Guaranteed per ASTM	36	54	8	45	60	8	47.4	71.1	8
Avg. actual per mill cert.	42	65	12	47	72	9	55	83	13

6/24/91

ATTACHMENT 4.1

Heat # B-42323

Size #8 Sq.

Grade 7432-55

Date Rolled 5/3/90

P.O.

M.O. #

NORTH STAR STEEL MINNESOTA

P.O. Box 64186
1678 Red Rock Road
Saint Paul, Minnesota 55164

CERTIFIED TEST REPORT

CHEMICAL ANALYSIS

C	MN	P	S	SI	SN	CU	NI	CR	MO	CB	V
.43	.98	.043	.039	.22	.017	.42	.13	.16	.032	.019	

AL				

JOMINY END-QUENCH HARDENABILITY RESULTS (HRc)

J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11	J12

J13	J14	J15	J16	J18	J20	J22	J24	J26	J28	J30	J32

PHYSICAL TEST REPORT

SPECIMEN AREA (in²)	YIELD KIPS	YIELD N.S.I.	TENSILE KIPS	TENSILE N.S.I.	GAUGE LENGTH (in)	% ELONG	BEND	% R.A.	Specification/Grade
.79	54.9	69.3	88.6	112.2	8.0	13.7	OK		7432-55
.79	54.8	69.4	83.6	105.8	8.0	13.7	OK		9606

Grain Size: Cleanliness:

Macro Etch: Specification: Results:

Impact Test	Temp (F)	ft./lb.	% Shear*	% L.E.*

* By specification or request only

This material has been produced and tested in accordance with the requirements of applicable specifications unless otherwise listed below. We hereby certify that the above test results are representative of those contained in the records of the company.

Any modification to this certification is prohibited by North Star Steel Minnesota without the expressed written consent of North Star Steel Minnesota negates the validity of this test report.

North Star Steel Minnesota is not responsible for the suitability of this material to meet specific applications.

SIGNED

5/3/90

DATE

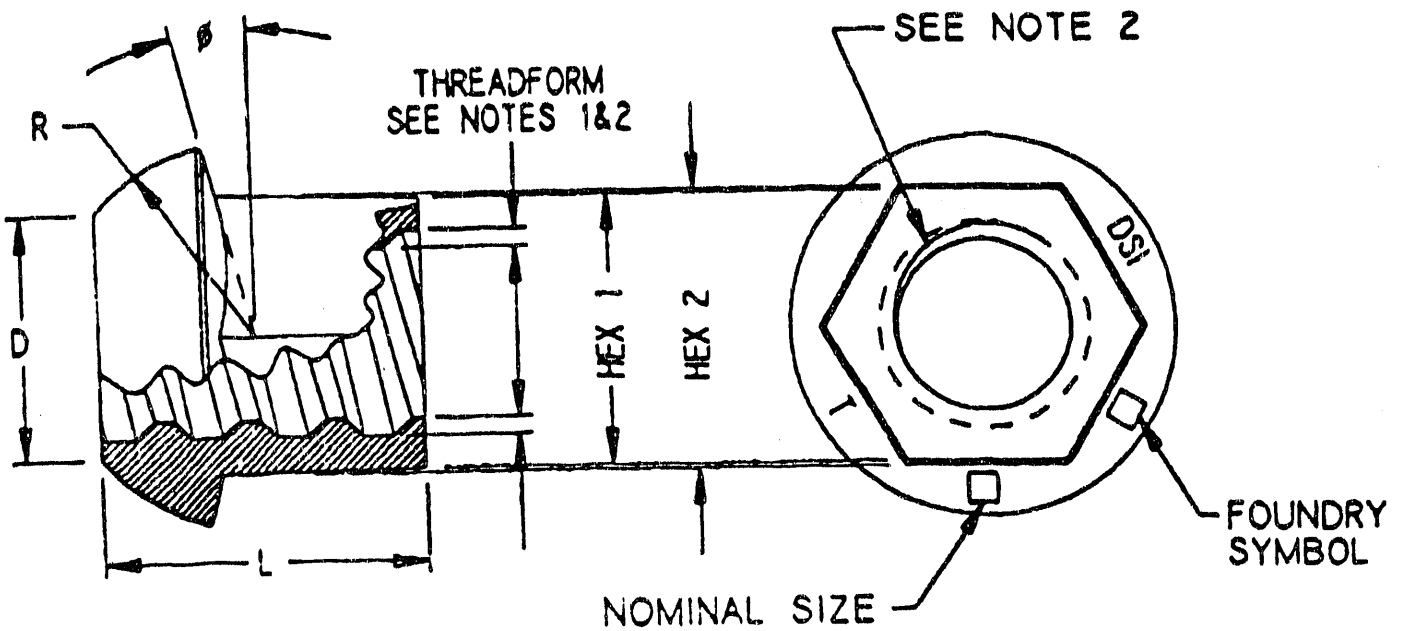
SWORN AND SUBSCRIBED TO BEFORE ME

THIS _____ DAY _____

_____
NOTARY PUBLIC

MY COMMISSION EXPIRES _____

THIS CERTIFICATE IS NOTORIZED ONLY WHEN REQUESTED.



NOMINAL SIZE		#6	20mm	#7	[redacted]	#9	#10	#11
PART NUMBER		B06U28810	B20U28810	B07U28810	B08U28810	B09U28810	B10U28810	B11U28810
L (IN./mm)		1.375/34.9	1.625/41.3	1.625/41.3	1.750/44.5	2.125/54.0	2.250/57.2	2.625/66.7
HEX 1 (IN./mm)								
HEX 2 (IN./mm)		1.250/31.8	1.375/34.9	1.375/34.9	1.500/38.1	1.688/42.9	1.813/46.0	2.063/52.4
R (IN./mm)		0.865/22.0	1.000/25.4	1.000/25.4	1.120/28.4	1.250/31.8	1.419/36.0	1.530/38.9
D (IN./mm)		1.063/27.0	1.188/30.2	1.188/30.2	1.313/33.4	1.438/36.5	1.641/41.7	1.821/46.3
Ø DEG.		14	14	14	14	14	14	14
THREADFORM: 8341/		743	785	744	745	746	747	724
MINOR Ø	MIN. (IN./mm)	0.730/18.5	.782/19.9	0.858/21.7	0.974/24.7	1.096/27.8	1.238/31.4	1.406/35.7
	MAX. (IN./mm)	0.742/18.8	.794/20.2	0.868/22.0	0.986/25.0	1.108/28.1	1.252/31.8	1.420/36.1
WEIGHT LBS		0.27	0.54	0.5	0.72	0.89	1.20	1.77

PRELIMINARY

4 → L FOR #11, AND WEIGHTS FOR #9, #10 & #11 CHANGED.

MATERIAL:

AUSTEMPERED DUCTILE IRON OR CAST STEEL
MIN. YIELD: 100 KSI
MIN. TENS: 120 KSI
MIN. EL. IN 2": 6%

TOLERANCES:

FOR HEX1, HEX2, R, D: +0/-0.040"

FOR L: +0.125/-0"

FOR Ø: ±1°

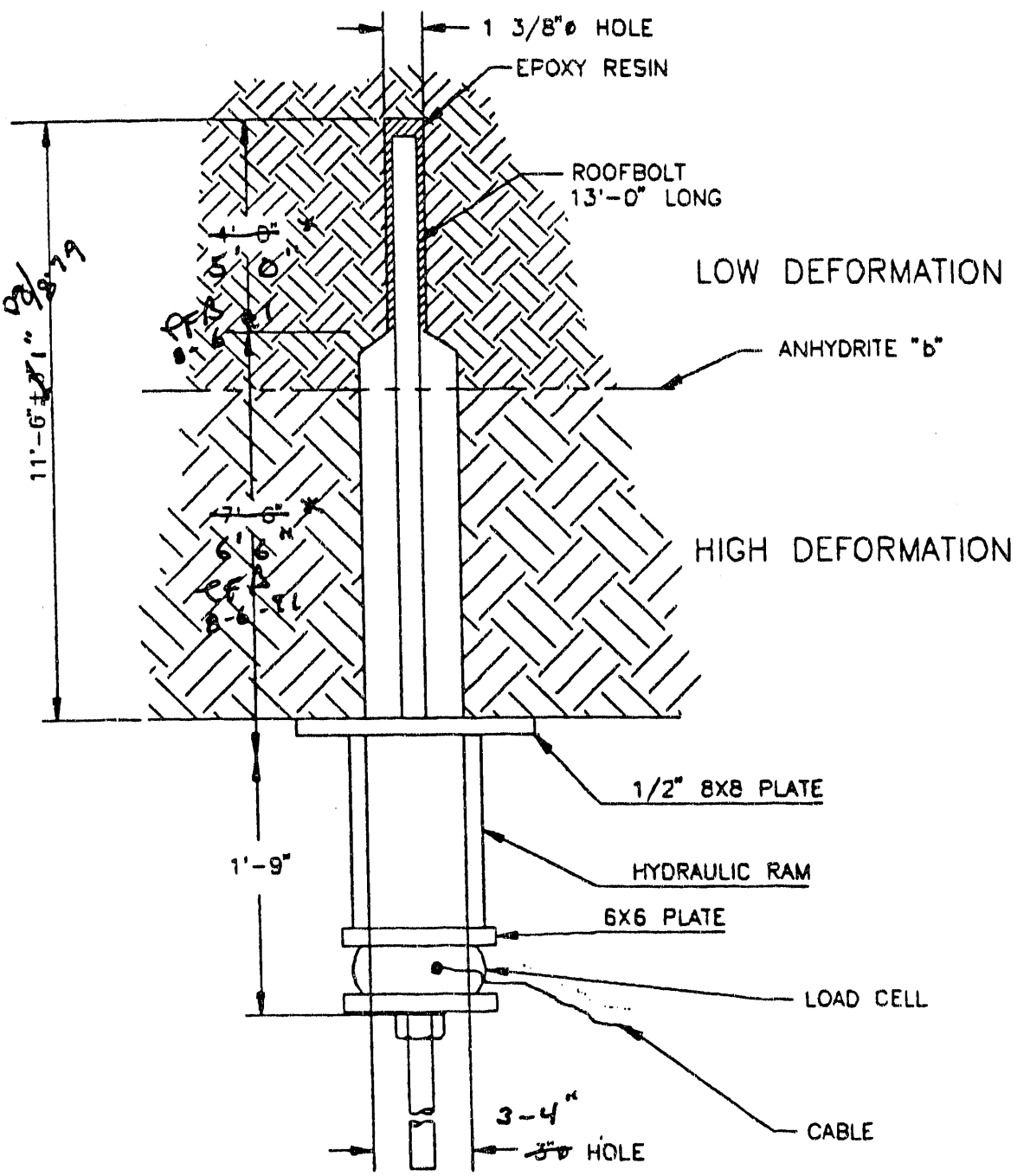
NOTES:

1. THREADFORM AS SPECIFIED WITH EXCEPTION OF MINOR DIAMETER (MINOR Ø) WHICH IS SPECIFIED IN TABLE.
2. AT BOTH ENDS OF NUT THREADFORM IS MODIFIED OVER LAST 1/2 TURN AS FOLLOWS: MINOR Ø OPENS UP TO MAJOR Ø AT CONSTANT RADIUS.

ATTACHMENT 5

DYWIDAG POST-TENSIONING SYSTEMS	DIMENSIONS: INCH/mm mm FOR REFERENCE ONLY	REV.	DATE	NAME	DRAWING N
		1	02-20-90	K.L.	B00U28
		2	09-01-90	K.L.	
		3	09-25-90	K.L.	
FULL LOAD ANCHOR NUTS FOR GRADE 60 THREADBAR		4	01-29-91	K.L.	
	MATERIAL: SEE ABOVE	SCALE 1:1 FOR #7			

* CHANGE MADE DUE TO AVAILABLE EQUIPMENT
CRB
8/6/91



ROOFBOLT DETAIL
VERTICAL ALIGNMENT (TOL. 5°)

ATTACHMENT 6

ROCK BOLT CERTIFICATION TEST DATA SHEET

Mine _____ Rock _____ Rock Bolt No. _____ Hole Location _____

Hole Length - ____ Dia. - @ Anchor _____/@ midpoint_____/@ collar ____
Orientation - _____

Bolt Grade - _____ Length - _____ Diameter - _____

Shell Manufacturer - _____ Model - _____ Diameter - _____
Length - _____

Resin Manufacturer - _____ Model - _____ Diameter - _____
Length - _____ No. Cartridges - _____

Installation Date - _____ Time - _____ Torque - _____ ft/lb

Test Date - _____ Time - _____ Torque - _____ ft/lb
Test Jack - _____ Test Pump - _____
Dial Indicator - _____ Calibrated - _____
Pressure Gauge - _____ Calibrated - _____

Pump Pressure	Bolt Tension	Extenso-meter Reading	Displace ment	Remarks

Test Results - _____ Maximum Pull Force - _____
Displacement at Maximum Pull Force - _____
Nature of Failure/Yield - _____
Other Remarks - _____
Tested By - _____ Approved By - _____

ATTACHMENT 7

UNDERGROUND DRILLING HOLE FIELD DATA SHEET

Date: _____

Room/Drift: _____

Purpose of Hole: _____

_____

_____

_____

_____

_____

_____

Location: _____

Depth at Completion: _____

Diameter: _____

Approximate Collar Coordinates _____

Vertical Angle: _____

Direction/Azimuth: _____

Remarks: _____

_____

_____

_____

Signature/Department: _____

WP Form 2014; 10/15/90
Page 1 of 1

10/1:

WASTE ISOLATION PILOT PLANT
SUPPLEMENTARY ROOF SUPPORT SYSTEM

APPENDIX C
Support System Design

Westinghouse Electric Corporation
Waste Isolation Division
Carlsbad, New Mexico
October 1991

03-13-91 4:10P

Check print #2

WESTINGHOUSE WASTE ISOLATION DIVISION

TITLE: BOLT WORKING LOAD FOR 10' x 2' SPACING			PAGE 1 OF 3
PROJECT	AUTHOR C. FRANCKE DATE 9/5/91	CHK'D BY J.R. Tyburski DATE 9/6/91	CHK'D BY DATE
SD	CALC NO	FILE NO	

PROBLEM: DETERMINE THE MAXIMUM WORKING LOAD ON A BOLT IN A 2' x 10' SPACING.

ASSUMPTIONS:

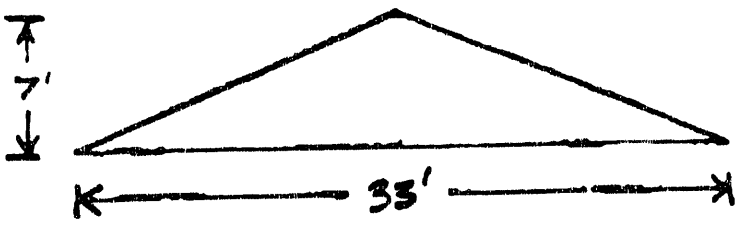
1) DENSITY OF WIPP SALT = 135 lb/ft³ = 2.17 gm/cm³ (DOC# ~~D-W-~~ D-BI-W-01, Rev 6)
2) THE ROCK REQUIRING SUPPORT IS DELINEATED BY AN ISOCELES TRIANGLE WITH ITS APEX AT CLAY G AND ITS BASE AT THE ROOF. THE HEIGHT OF THE TRIANGLE IS 7' (DISTANCE FROM ROOF TO CLAY G). THE BASE OF THE TRIANGLE IS 33' (WIDTH OF THE ROOM).
3) THE ROCKBOLT PATTERN SPACING WILL BE 2' ACROSS THE WIDTH OF THE ROOM AND 10' ALONG THE LENGTH OF THE ROOM.

METHOD: THE MAXIMUM VOLUME OF ROCK SUPPORTED BY EACH BOLT WILL BE CALCULATED AND MULTIPLIED BY THE DENSITY OF THE ROCK TO DETERMINE THE LOAD ON THE BOLT.

CALCULATIONS:

THE FOLLOWING DIAGRAM ILLUSTRATES THE DIMENSIONS OF THE ROCK REQUIRING SUPPORT.

CROSS-SECTION VIEW



TITLE:	REV NO:	AUTHOR	DATE	CHK'D BY	DATE

WESTINGHOUSE FORM 0000-0

TITLE			PAGE 2 OF 3
BOLT WORKING LOAD FOR 10' x 2' SPACING			
PROJECT	AUTHOR C. FRANCKE DATE 9/5/91	CHK'D BY JRTybrick DATE 9/6/91	CHK'D BY DATE
S.O.	CALC NO	FILE NO	GROUP

CALCULATIONS (CONT'D)

VOLUME OF ROCK

THE VOLUME OF ROCK SUPPORTED BY A BOLT IS DETERMINED BY THE FOLLOWING EQUATION:

$$V = s_L s_w t$$

WHERE V = VOLUME OF ROCK TO BE SUPPORTED

s_L = SPACING OF BOLTS IN THE LONG DIMENSION

s_w = SPACING OF BOLTS IN THE SHORT DIMENSION

t = THICKNESS OF ROCK TO BE SUPPORTED

THE VALUE OF "t" FOR A PARTICULAR BOLT IS THE AVERAGE THICKNESS OF THE ROCK ALONG A LINE "s_w" LONG CENTERED ON THE BOLT. THE MAXIMUM WORKING LOAD WILL BE AT THE CENTER OF THE SPAN WHERE $t = 7'$.

$$V = (10')(2')(7')$$

$$V = 140\ ft^3$$

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WESTINGHOUSE WASTE ISOLATION DIVISION

TITLE: BOLT WORKING LOAD FOR 10' x 2' SPACING — PAGE 3 OF

PROJECT	AUTHOR	DATE	CHK'D BY	DATE	CHK'D BY
	C. FRANCKE 9/8/91				
S.O.	CALC NO		FILE NO		GROUP

CALCULATIONS: (CONT'D)

WORKING LOAD

THE WEIGHT OF THE ROCK SUPPORTED BY A BOL
IS DETERMINED BY THE FOLLOWING EQUATION:

$$W = \rho V$$

WHERE: W = WEIGHT OF ROCK (WORKING LOA
ρ = DENSITY OF ROCK
V = VOLUME OF ROCK

Checker Note:
Sale density changed to that used in the "Design Basis" report for consistency

$$W = (195\ lb/ft^3)(.140\ ft^3)$$

$$W = 18.9\ kip = 84.1\ kN$$

DISCUSSION:

THE MAXIMUM LOAD ON A BOLT IN THE PROPOSED 2'x10' LAYOUT WILL BE ~~20~~ 18.9 kip.

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WESTINGHOUSE FORM 6025DA

FROM "DESIGN BASIS - UNDERGROUND EXCAVATIONS" BECHTEL
DOC. # D-51-W-01

3.1.9 Excavation shall permit early installation and start up of experiments in one of more rooms while excavation continues in the remainder of the experimental areas. The design shall permit access to, and utilization of, both waste and nonwaste experimental areas.

3.2 Configuration and Essential Features

3.2.1 General Location Underground

All depths assume ERDA No. 9 drill hole surface elevation as datum. This is 3409 ft above mean sea level.

The storage area floor is approx. 2,150 ft below the ground surface. The final level of the excavations shall be as determined by the contracting officer. All excavations shall be parallel to the existing bedding planes within allowable tolerances. To the extent practical, a marker bed in the excavation rib will be defined as the reference plane from which the excavation shall be continued. In addition, holes shall be drilled into the floor and roof of the excavation for determination of the location of Marker Bed - 139 and the clay seams above the roof. Coring of these holes shall begin before the continuous miner advances more than 250 feet from the location.

Based on the existing, the average dip of the sedimentary beds in the underground areas will be approximately 2 percent to the south east.

3.2.2 Salt Composition and Density

The halite is relatively free of impurities with the exception of occasional thin but separate layers of lightly interspersed argillaceous materials (up to 4%) and of polyhalite (less than 1%). Halite is also widely interbedded with layers of anhydrite ranging from a few inches to several feet in thickness. The overall moisture content is 0.4%.

For purposes of excavation calculations, the salt in place is assumed to have a density of 135 lb /cu ft (1.8225 tons/cu yd).

3.2.3 Creep Allowance

Excavation dimensions shall include an allowance for salt creep of 1 ft in the vertical dimension and nine inches in the required width of all rooms.

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TITLE: FACTOR OF SAFETY - BOLT TENDON FAILURE				PAGE 1 OF 2
PROJECT	AUTHOR C. FRANCKE DATE 9/6/91	CHK'D BY JR Tyburski DATE 9/6/91	CHK'D BY DATE	
CO	CALC NO	FILE NO	GROUP	

PROBLEM: DETERMINE THE FACTOR OF SAFETY (FOS) OF ROCKBOLTS AGAINST TENDON FAILURE.

ASSUMPTIONS:

1) THE TENDON IS EXPECTED TO BE GRADE 60 STEEL WHICH MEETS ASTM STANDARD A615 (REF. 2).
2) THE MAXIMUM WORKING LOAD ON THE TENDON IS 18.9 kip (84.1 KN).
3) THE MINIMUM (GUARANTEED) ULTIMATE TENSILE STRENGTH OF THE TENDON IS 90,000 psi (REF. 2).
4) THE TENDON IS 1" DIAMETER. Value we verify

REFERENCES:

1) PTI (Post-Tensioning Institute), 1986, Recommendations for Prestressing Rock and Soil Anchors.
2) ASTM Standard A615.

METHOD:

THE WORKING LOAD ON THE TENDON IS CALCULATED.

CALCULATIONS:

THE MAXIMUM LOAD THAT THE TENDON CAN SUPPORT IS DETERMINED BY MULTIPLYING THE ULTIMATE TENSILE STRENGTH OF THE TENDON BY THE CROSS-SECTIONAL AREA OF THE TENDON.

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TITLE: FACTOR OF SAFETY - BOLT TENDON FAILURE				PAGE 2 OF 2
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WBS	CALC NO	FILE NO	GROUP	

CALCULATIONS (CONT'D)

$$P_t = T_t \pi d_t^2/4$$

WHERE: P_t = MAXIMUM ALLOWED WORKING LOAD
T_t = ULTIMATE TENSILE STRENGTH OF TENDON
d_t = DIAMETER OF TENDON

$$P_t = (90\ kip/in^2)\,\pi\,(1\ in)^2/4$$
$$P_t = 70.7\ kip$$

FACTOR OF SAFETY

$$F_{of}S = \frac{\text{MAXIMUM ALLOWED TENSILE STRESS}}{\text{ACTUAL WORKING LOAD}}$$

$$F_{of}S = 70.7\ kip / 18.9\ kip$$

$$F_{of}S = 3.7$$

DISCUSSION:

ACCORDING TO THE PTI RECOMMENDATIONS (REF 1): "The tendon size is determined such that the design load for the anchor does not exceed 60% of the guaranteed ultimate strength of the tendon." THIS WOULD BE EQUIVALENT TO A $F_{of}S$ OF 1.7 (i.e. 1/0.6 = 1.7). ~~NORMALLY~~, IN OTHER WORDS, THE WORKING LOAD SHOULD NOT EXCEED $0.6 * P_t$ = 42.4 kip, WHICH IT DOES NOT. NORMALLY, ONE ONE DETERMINE A DESIRED SAFETY FACTOR, SUCH AS 1.7, AND DETERMIN THE REQUIRED BOLT DIAMETER. IN THIS CALCULATIO THE SAFETY FACTOR WAS NOT CALCULATED UNTI THE END SINCE BOLT DIAMETER AND LOAD WERE K

Checker Note: Agree, however when evaluating the FofS we should use 60% of Ult. or May Allowed Tensile Stress 42.4/18.9 or 2.2 which is still greater than 1.7 i.e. reference

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ASTM A615 90 ■ 0759510 0035993 2 ■

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Designation: A 615 – 90

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American Association State Highway and Transportation Officials Standard
AASHTO No. M 31

Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement[1]

This standard is issued under the fixed designation A 615; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This specification has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This specification covers deformed and plain billet-steel concrete-reinforcement bars in cut lengths or coils. A deformed bar is defined as a bar that is intended for use as reinforcement in reinforced concrete construction. The surface of the bar is provided with lugs or protrusions (hereinafter called *deformations*) which inhibit longitudinal movement of the bar relative to the concrete which surrounds the bar in such construction and conform to the provisions of this specification. The standard sizes and dimensions of deformed bars and their number designations shall be those listed in Table I.

NOTE 1—For coils of deformed bars, the capacity of industrial equipment limits the maximum bar size that can be straightened.

1.2 Bars are of three minimum yield levels: namely, 40 000, 60 000, and 75 000 psi, designated as Grade 40, Grade 60, and Grade 75, respectively.

1.3 Hot-rolled plain rounds, in sizes up to and including 2 in. in diameter in coils or cut lengths, when specified for dowels, spirals and structural ties or supports shall be furnished under this specification in Grade 40, Grade 60, and Grade 75 (Note 2). For bending properties, test provisions of the nearest nominal diameter deformed bar size shall apply. These requirements providing for deformations and marking shall not be applicable.

1.4 The weldability of the steel is not part of this specification.

NOTE 2—The weight for plain rounds smaller than ¼ in. in diameter shall be computed on the basis of the size in Specification A 615.

NOTE 3—A complete metric companion to Specification A 615 has been developed—A 615M; therefore, no metric equivalents are presented in this specification.

2. Referenced Documents

2.1 *ASTM Standards:*
A 370 Methods and Definitions for Mechanical Testing of Steel Products[2]
A 510 Specification for General Requirements for Wire Rods and Coarse Round Wire, Carbon Steel[2]
A 700 Practices for Packaging, Marking, and Loading Methods for Steel Products for Domestic Shipment[3]
E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[4]

2.2 *U.S. Military Standards:*
MIL-STD-129 Marking for Shipment and Storage[5]
MIL-STD-163 Steel Mill Products Preparation for Shipment and Storage[5]

2.3 *U.S. Federal Standard:*
Fed. Std. No. 123 Marking for Shipment (Civil Agencies)[5]

3. Ordering Information

3.1 Orders for material under this specification should include the following information:
3.1.1 Quantity (weight),
3.1.2 Name of material (deformed and plain billet-steel bars for concrete reinforcement),
3.1.3 Size,
3.1.4 Cut lengths or coils,
3.1.5 Deformed or plain,
3.1.6 Grade,
3.1.7 Packaging (see Section 19),
3.1.8 ASTM designation and year of issue, and
3.1.9 Certified mill test reports (if desired).

NOTE 4—A typical ordering description is as follows: 20 tons deformed and plain billet-steel bars for concrete reinforcement, No. 3 40 (5) in. long, deformed, Grade 40, in secured lots, to ASTM A 615 – —. Certified mill test reports are required.

4. Material and Manufacture

4.1 The bars shall be rolled from properly identified heats of mold cast or strand cast steel using the open-hearth, basic-oxygen, or electric-furnace process.

5. Chemical Composition

5.1 An analysis of each heat of steel shall be made by the manufacturer from test samples taken preferably during the pouring of the heats. The percentages of carbon, manganese, phosphorus, and sulfur shall be determined. The phosphorus content thus determined shall not exceed 0.06 %.

5.2 The chemical composition thus determined shall be reported on request to the purchaser or his representative.

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[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.05 on Steel Reinforcement.

Current edition approved Apr. 27, 1990. Published June 1990. Originally published as A 615 – 68. Last previous edition A 615 – 89.

[2] *Annual Book of ASTM Standards*, Vol 01.04.

[3] *Annual Book of ASTM Standards*, Vol 15.09.

[4] *Annual Book of ASTM Standards*, Vol 14.02.

[5] Available from Naval Publications and Forms Center, 5801 Tabor Ave., Philadelphia, PA 19120.

TABLE 1 Deformed Bar Designation Numbers, Nominal Weights, Nominal Dimensions, and Deformation Requirements

Bar Designation No.[B]	Nominal Weight lb/ft	Nominal Dimensions[A]			Deformation Requirements, in.		
		Diameter in.	Cross-Sectional Area in.²	Perimeter in.	Maximum Average Spacing	Minimum Average Height	Maximum Gap (Chord of 12½% of Nominal Perimeter)
3	0.376	0.375	0.11	1.178	0.262	0.015	0.143
4	0.668	0.500	0.20	1.571	0.350	0.020	0.191
5	1.043	0.625	0.31	1.963	0.437	0.028	0.239
6	1.502	0.750	0.44	2.356	0.525	0.038	0.286
7	2.044	0.875	0.60	2.749	0.612	0.044	0.334
8	2.670	1.000	0.79	3.142	0.700	0.050	0.383
9	3.400	1.128	1.00	3.544	0.790	0.056	0.431
10	4.303	1.270	1.27	3.990	0.849	0.064	0.487
11	5.313	1.410	1.56	4.430	0.987	0.071	0.540
14	7.65	1.693	2.25	5.32	1.185	0.085	0.648
18	13.60	2.257	4.00	7.09	1.58	0.102	0.864

[A] The nominal dimensions of a deformed bar are equivalent to those of a plain round bar having the same weight per foot as the deformed bar.
[B] Bar numbers are based on the number of eighths of an inch included in the nominal diameter of the bars.

5.3 An analysis may be made by the purchaser from finished bars. The phosphorus content thus determined shall not exceed that specified in 5.1 by more than 25 %.

6. Requirements for Deformations

6.1 Deformations shall be spaced along the bar at substantially uniform distances. The deformations on opposite sides of the bar shall be similar in size and shape.

6.2 The deformations shall be placed with respect to the axis of the bar so that the included angle is not less than 45°. Where the line of deformations forms an included angle with the axis of the bar of from 45 to 70° inclusive, the deformations shall alternately reverse in direction on each side, or those on one side shall be reversed in direction from those on the opposite side. Where the line of deformation is over 70°, a reversal in direction is not required.

6.3 The average spacing or distance between deformations on each side of the bar shall not exceed seven tenths of the nominal diameter of the bar.

6.4 The overall length of deformations shall be such that the gap between the ends of the deformations on opposite sides of the bar shall not exceed 12½ % of the nominal perimeter of the bar. Where the ends terminate in a longitudinal rib, the width of the longitudinal rib shall be considered the gap. Where more than two longitudinal ribs are involved, the total width of all longitudinal ribs shall not exceed 25 % of the nominal perimeter of the bar, furthermore, the summation of gaps shall not exceed 25 % of the nominal perimeter of the bar. The nominal perimeter of the bar shall be 3.14 times the nominal diameter.

TABLE 2 Tensile Requirements

	Grade 40[A]	Grade 60	Grade 75[B]
Tensile strength, min, psi	70 000	90 000	100 000
Yield strength, min, psi	40 000	60 000	75 000
Elongation in 8 in., min, %, Bar No.			
3	11	9	
4 & 5	12	9	
6		8	
7		7	
8		7	4
9, 10, 11, 14, 18			

[A] Grade 40 bars are furnished only in sizes 3 through 6.
[B] Grade 75 bars are furnished only in sizes 11, 14, and 18.

6.5 The spacing, height, and gap of deformations shall conform to the requirements prescribed in Table 1.

7. Measurements of Deformations

7.1 The average spacing of deformations shall be determined by dividing a measured length of the bar specimen by the number of individual deformations and fractional parts of deformations on any one side of the bar specimen. A measured length of the bar specimen shall be considered the distance from a point on a deformation to a corresponding point on any other deformation on the same side of the bar. Spacing measurements shall not be made over a bar area containing bar marking symbols involving letters or numbers.

7.2 The average height of deformations shall be determined from measurements made on not less than two typical deformations. Determinations shall be based on three measurements per deformation, one at the center of the overall length and the other two at the quarter points of the overall length.

7.3 Insufficient height, insufficient circumferential coverage, or excessive spacing of deformations shall not constitute cause for rejection unless it has been clearly established by determinations on each lot (Note 5) tested that typical deformation height, gap, or spacing do not conform to the minimum requirements prescribed in Section 6. No rejection may be made on the basis of measurements if fewer than ten adjacent deformations on each side of the bar are measured.

NOTE 5—A lot is defined as all the bars of one bar number and pattern of deformation contained in an individual shipping release or shipping order.

8. Tensile Requirements

8.1 The material, as represented by the test specimens, shall conform to the requirements for tensile properties prescribed in Table 2.

8.2 The yield point or yield strength shall be determined by one of the following methods:

8.2.1 The yield point shall be determined by drop of the beam or halt in the gage of the testing machine.

8.2.2 Where the steel tested does not have a well defined yield point, the yield strength shall be determined at extension under load using an autographic diagram method or an

TABLE 3 Bend Test Requirements

Bar Designation No.	Pin Diameter for Bend Tests[A]		
	Grade 40	Grade 60	Grade 75
3, 4, 5	3½ d[B]	3½ d	
6	5 d	5 d	
7, 8		5 d	
9, 10		7 d	
11		7 d	9 d
14, 18		9 d	11 d

[A] Test bends 180° unless noted otherwise.
[B] d = nominal diameter of specimen.

extensometer as described in 13.1.2 and 13.1.3 of Methods and Definitions A 370. The extension under load shall be 0.005 in./in. of gage length (0.5 %) for Grade 40 and Grade 60 and shall be 0.0035 in./in. of gage length (0.35 %) for Grade 75. When material is furnished in coils, the test sample must be straightened prior to placing it in the jaws of the tensile machine (see Note 6).

8.3 The percentage of elongation shall be as prescribed in Table 2.

NOTE 6—Straightening should be done carefully to avoid the formation of local sharp bends and to minimize cold work. Insufficient straightening prior to attaching the extensometer can result in lower-than-actual yield strength readings.

9. Bending Requirements

9.1 The bend-test specimen shall withstand being bent around a pin without cracking on the outside of the bent portion. The requirements for degree of bending and sizes of pins are prescribed in Table 3.

9.2 The bend test shall be made on specimens of sufficient length to ensure free bending and with apparatus which provides:

9.2.1 Continuous and uniform application of force throughout the duration of the bending operation.

9.2.2 Unrestricted movement of the specimen at points of contact with the apparatus and bending around a pin free to rotate.

9.2.3 Close wrapping of the specimen around the pin during the bending operation.

9.3 Other acceptable more severe methods of bend testing, such as placing a specimen across two pins free to rotate and applying the bending force with a fixed pin, may be used. When failures occur under more severe methods, retests shall be permitted under the bend test method prescribed in 9.2.

10. Permissible Variation in Weight

10.1 The permissible variation shall not exceed 6 % under nominal weight, except for bars smaller than ¾ in. plain round, the permissible variation in weight shall be computed upon the basis of the permissible variation in diameter in Specification A 510. Reinforcing bars are evaluated on the basis of nominal weights. In no case shall the overweight of any bar be the cause for rejection.

10.2 The specified limit of variation shall be evaluated in accordance with Practice E 29 (rounding method).

11. Finish

11.1 The bars shall be free of detrimental surface imperfections.

11.2 Rust, seams, surface irregularities, or mill scale shall not be cause for rejection, provided the weight, dimensions, cross-sectional area, and tensile properties of a hand wire brushed test specimen are not less than the requirements of this specification.

11.3 Surface imperfections other than those specified in 11.2 shall be considered detrimental when specimens containing such imperfections fail to conform to either tensile or bending requirements.

12. Test Specimens

12.1 Tension test specimens shall be the full section of the bar as rolled. The unit stress determination shall be based on the nominal bar area.

12.2 The bend test specimens shall be the full section of the bar as rolled.

13. Number of Tests

13.1 For bar sizes No. 3 to 11, inclusive, one tension test and one bend test shall be made of the largest size rolled from each heat. If, however, material from one heat differs by three or more designation numbers, one tension and one bend test shall be made from both the highest and lowest designation number of the deformed bars rolled.

13.2 In the case of Nos. 14 and 18 bars, one tension test and one bend test shall be made of each size rolled from each heat.

14. Retests

14.1 If any tensile property of any tension test specimen is less than that specified, and any part of the fracture is outside the middle third of the gage length, as indicated by scribe scratches marked on the specimen before testing, a retest shall be allowed.

14.2 If the results of an original tension specimen fail to meet the specified minimum requirements and are within 2000 psi of the required tensile strength, within 1000 psi of the required yield point, or within two percentage units of the required elongation, a retest shall be permitted on two random specimens for each original tension specimen failure from the lot. If all results of these retest specimens meet the specified requirements, the lot shall be accepted.

14.3 If a bend test fails for reasons other than mechanical reasons or flaws in the specimen as described in 14.4 and 14.5, a retest shall be permitted on two random specimens from the same lot. If the results of both test specimens meet the specified requirements, the lot shall be accepted. The retest shall be performed on test specimens that are at a temperature but not less than 60°F.

14.4 If any test specimen fails because of mechanical reasons such as failure of testing equipment or improper specimen preparation, it may be discarded and another specimen taken.

14.5 If any test specimen develops flaws, it may be discarded and another specimen of the same size bar from the same heat substituted.

15. Inspection

15.1 The inspector representing the purchaser shall have free entry, at all times while work on the contract of purchaser is being performed, to all parts of the manufac-

er's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy him that the material is being furnished in accordance with this specification. All tests except product analysis and inspection, shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

15.2 *For Government Procurement Only*—Except as otherwise specified in the contract, the contractor is responsible for the performance of all inspection and test requirements specified herein and may use his own or any other suitable facilities for the performance of the inspection and test requirements specified herein, unless disapproved by the purchaser at the time of purchase. The purchaser shall have the right to perform any of the inspections and tests at the same frequency as set forth in this specification, where such inspections are deemed necessary to assure that material conforms to prescribed requirements.

16. Rejection

16.1 Unless otherwise specified, any rejection based on tests made in accordance with 5.3, shall be reported to the manufacturer within 5 working days from the receipt of samples by the purchaser.

16.2 Material that shows injurious defects subsequent to its acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified.

17. Rehearing

17.1 Samples tested in accordance with 5.3 that represent rejected material shall be preserved for 2 weeks from the date rejection is reported to the manufacturer. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

18. Marking

18.1 When loaded for mill shipment, bars shall be properly separated and tagged with the manufacturer's heat or test identification number.

18.2 Each producer shall identify the symbols of his marking system.

18.3 All bars produced to this specification, except plain round bars which shall be tagged for grade, shall be identified by a distinguishing set of marks legibly rolled onto the surface of one side of the bar to denote in the following order:

18.3.1 *Point of Origin*—Letter or symbol established as the producer's mill designation.

18.3.2 *Size Designation*—Arabic number corresponding to bar designation number of Table 1.

18.3.3 *Type of Steel*—Letter *S* indicating that the bar was produced to this specification.

18.3.4 *Minimum Yield Designation*—For Grade 60 bars, either the number 60 or a single continuous longitudinal line through at least 5 spaces offset from the center of the bar side. For Grade 75 bars, either the number 75 or two continuous longitudinal lines through at least 5 spaces offset each direction from the center of the bar. (No marking designation for Grade 40 bars.)

19. Packaging

19.1 When specified in the purchase order, packaging shall be in accordance with the procedures in Practices A 700.

19.2 *For Government Procurement Only*—When specified in the contract or order, and for direct procurement by or direct shipment to the U.S. government, material shall be preserved, packaged, and packed in accordance with the requirements of MIL-STD-163. The applicable levels shall be as specified in the contract. Marking for shipment of such material shall be in accordance with Fed. Std. No. 123 for civil agencies and MIL-STD-129 for military agencies.

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WESTINGHOUSE WASTE ISOLATION DIVISION

TITLE: FACTOR OF SAFETY - ANCHOR BOND				PAGE 1 OF 3
PROJECT	AUTHOR / DATE: C FRANCKE 9/5/91	CHK'D BY / DATE: J R Tyburski 9/4/91	CHK'D BY / DATE	
WBS	CALC NO.	FILE NO.	GROUP	

PROBLEM: DETERMINE FACTOR OF SAFETY (FofS) FOR A RESIN ANCHOR BOND TO SALT VS. WORKING LOAD ON THE ANCHOR.

ASSUMPTIONS:

1.) MAXIMUM WORKING LOAD ON THE ANCHOR IS 18.9 kip (84.1 kN).
2.) FIXED ANCHOR LENGTH IS 3' (0.91 m).
3.) AVERAGE HOLE (AND ANCHOR) DIAMETER IS 1 3/8" (0.035 m).
4.) UNCONFINED COMPRESSIVE STRENGTH (UCS) OF WIPP SALT IS TAKEN AS 25 MPa. (SEE DISCUSSION).

See Below

REFERENCES:

1.) G.S. Littlejohn and D.A. Bruce, "Rock Anchors - State of the Art - Part 1: Design", Ground Engineering, May 1975.
2.) PTI (Post-Tensioning Institute), Recommendations for Prestressed Rock and Soil Anchors, 1986.
3.) BSI (British Standards Institute), BSI 8081, "British Standard Code of Practice for Ground Anchorages", 1989.
4.) SAND 78-1596, Geologic Characterization Report, Powers et al.

METHOD: THE ULTIMATE ANCHOR LOAD IS CALCULATED BASED ON THE SIZE OF THE ANCHOR AND THE ANCHOR BOND STRENGTH.

For most elastic rocks using the higher UCS value from lab testing may be appropriate, however, because the strength of salt is time dependent, I'm not certain this is a conservative approach. The original checker comment (using 1 N/mm^2) was to use a lower value. This needs to be discussed. A reasonable field test to evaluate time dependent slippage might need be developed for confirmation.

REV NO	REV DATE	AUTHOR	DATE	CHK'D BY	DATE	CHK'D BY	DAT

WESTINGHOUSE WASTE ISOLATION DIVISION

TITLE: FACTOR OF SAFETY - ANCHOR BOND			PAGE 2 OF 3
PROJECT	AUTHOR / DATE: C. FRANCIS 4/5/91	CHK'D BY / DATE: J.R. Tyburski 4/5/91	CHK'D BY / DATE
SO	CALC NO	FILE NO	GROUP

CALCULATIONS:

ACCORDING TO REF 2., THE ULTIMATE ANCHOR LOAD IS CALCULATED AS FOLLOWS:

$$P_a = \pi d_a L_a \tau$$

WHERE: P_a = LOAD TO CAUSE BOND FAILURE
d_a = EFFECTIVE ANCHOR DIAMETER
L_a = FIXED ANCHOR LENGTH
τ = WORKING BOND STRENGTH

REF 2 FURTHER STATES THAT, IN THE ABSENCE OF PULL TEST DATA ON BOND STRENGTH, τ CAN BE ESTIMATED AS 1/10 OF THE UCS OF THE ROCK. THEREFORE:

$$\tau = 0.1\,(UCS)$$
$$= 0.1\,(25\,MPa)$$
$$\tau = 2.5\,MPa = 2500\,kN/m^2$$

This does not address the lack of relevant data, as suggested by L. Hoek & Bruce.

τ IS OFTEN REDUCED TO 1/3 τ TO ADD A SAFETY FACTOR. THIS WILL NOT BE DONE HERE BECAUSE THE 1/3τ VALUE IS USED TO DETERMINE (DESIGN) ANCHOR LENGTH OR DIAMETER. SINCE ANCHOR LENGTH & DIAMETER ARE PRE-DETERMINED, THE FULL VALUE OF τ IS USED SO THAT THE REAL SAFETY FACTOR CAN BE DETERMINED.

THE LOAD TO CAUSE BOND FAILURE IS THEN:

$$P_a = \pi(0.05m \times 0.91m \times 2500\,kN/m^2)$$
$$P_a = 230\,kN = 56\,kip$$

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WESTINGHOUSE WASTE ISOLATION DIVISION

TITLE: FACTOR OF SAFETY - ANCHOR BOND				PAGE 3 OF 3
PROJECT	AUTHOR / DATE: C. Brucks 9/6/91	CHK'D BY / DATE: J R Tyburski 9/6/91	CHK'D BY / DATE	
WA	CALC NO.	FILE NO	GROUP	

CALCULATIONS (CONT'D)

FACTOR OF SAFETY - ANCHOR BOND

$$FofS = \frac{\text{LOAD CAUSING FAILURE}}{\text{WORKING LOAD}}$$

$$FofS = 56\ \text{kip} / 18.9\ \text{kip} = 3.0$$

DISCUSSION

RECOMMENDED SAFETY FACTORS FOR ANCHOR BOND RANGE FROM 1.5 TO 4, DEPENDING ON ROCK TYPE AND APPLICATION (REF 1, 2, 3). SAFETY FACTOR IS NORMALLY INTRODUCED INTO THE CALCULATION BY REDUCING τ, WORKING BOND STRENGTH, TO 25% TO 50% OF THE ULTIMATE BOND STRENGTH (REF. 2). THIS WOULD BE EQUIVALENT TO A SAFETY FACTOR OF 2 TO 4. AS IS EXPLAINED ON PAGE 2 OF THIS CALC, τ WAS NOT REDUCED SO THAT THE TRUE FACTOR OF SAFETY COULD BE DETERMINED.

See Comment pg 1 of 3

THE VALUE USED FOR UNCONFINED COMPRESSIVE STRENGTH (UCS) IS BASED ON LABORATORY TESTING (REF. 4) AND ENGINEERING JUDGEMENT. BECAUSE UCS VALUES FROM LAB TESTING USUALLY UNDERESTIMATE THE IN SITU STRENGTH, THE HIGHEST VALUE FROM REF 4 WAS USED.

THE 3' FIXED ANCHOR LENGTH PROVIDES AN ACCEPTABLE FACTOR OF SAFETY AGAINST FAILURE OF THE ANCHOR BOND.

THE ABOVE ASSUMPTIONS WILL BE VERIFIED BY FIELD TESTING.

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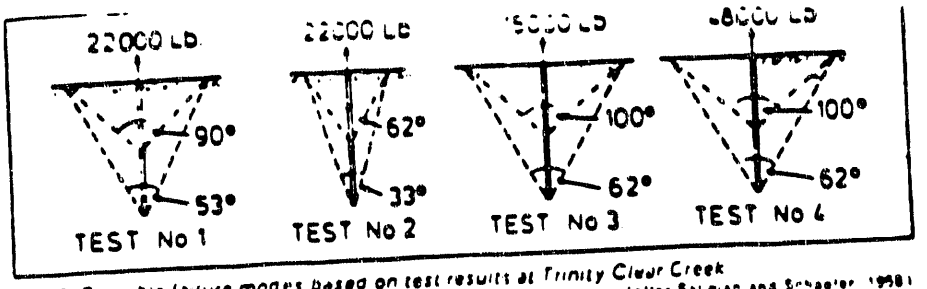

Fig 3 Possible failure modes based on test results at Trinity Clear Creek (after Saliman and Schaefer 1968)

pos by Littlejohn and Truman-Davies (1974) where 20 CaN anchors were spaced at 1m centres. Another method to dissipate load within the rock mass is simply to install anchors at different inclinations as in the design by Solétanche (1968) for the Zardesas Dam, Algeria. In some other countries a minimum distance between anchors is stipulated. Broms (1968), reviewing Swedish practice, confirmed a minimum spacing of 2.5m, whilst the Czech Standard (1974) recommends 1.5m, one consideration being to reduce "interhole grouting", although this phenomenon is not necessarily a disadvantage in practice.

It is noteworthy that these guide rules or approaches are based on experience and engineering judgement, and not on an intimate knowledge of stress distribution around the anchor.

Remarks

With regard to uplift capacity no experimental or practical evidence and only very little theoretical data substantiate the methods currently used (Table I) to calculate the ultimate resistance to pull-out of individual, or groups of anchors. Indeed, there would appear to be results (Saliman and Schaefer (1968) and Brown (1970)) which indicate that failure in a rock mass does not generally occur in the form of an inverted 90 deg cone or wedge. However it is reassuring to know that most designs are likely to be conservative in adopting a cone method with no allowance for the shear strength of the rock mass.

Nevertheless, some standardisation on safety factors for temporary and permanent anchors is desirable together with agreement on what allowances should be made for surcharge due to unconsolidated overburden and the effect of upper layers of weathered rock.

In general, effort should now be expended, in the form of field testing in a wide range of rock materials and masses which have been carefully classified, in order to study the shape and position of the rock zones mobilised at failure. Such programmes should accommodate single anchors and groups tested over a range of inclinations. Only in this way can anchor design in relation to overall stability be optimised both technically and economically.

BOND BETWEEN CEMENT GROUT AND ROCK

Introduction

Most designs to date concerning straight shaft fixed anchors have been successfully based on the assumption of uniform bond distribution over the fixed anchor surface area. In other words it has been generally accepted that the bond developed is merely a function of fixed anchor dimensions and applied load.

However, recent experimental and theoretical analyses have indicated that the character of the bond to the rock is more complex, and reflects additional parameters which often give rise to a markedly non-uniform stress distribution. Thus, in many cases the assumed mechanism of load transfer in the fixed anchor zone may be grossly inaccurate. For example, the situation could well arise where, for a high capacity anchor, the level of bond stress at the loaded (or proximal) end may be extremely high, possibly approaching failure, whereas the more distal parts of the fixed anchor may in effect be redundant. Clearly, such a situation will have a bearing on overall stability analyses, the interpretation of anchor extensions, and long-term creep behaviour.

Design criteria are reviewed relating to the magnitude and distribution of bond fixed anchor dimensions, and factors of safety. For comparison, the results of relevant theoretical and experimental investigations are presented.

The straight shaft anchor relies on the development of bond or shear in the region of the rock/grout interface, and as described by Littlejohn (1972) it is usual in Britain to assume an equivalent uniform distribution of bond stress along the fixed anchor. Thus the anchor load, P, is related to the fixed anchor design by the equation

$$P = \pi d L \tau \qquad (1)$$

where L = fixed anchor length
d = effective anchor diameter
τ = working bond stress

This approach is used in many countries e.g. France (Fargeot, 1972), Italy (Mascardi, 1973) Canada (Coates, 1970) and USA (White, 1973).

The rule is based on the following simple assumptions

(i) Transfer of the load from the fixed anchor to the rock occurs by a uniformly distributed stress acting over the whole of the curved surface of the fixed anchor.

(ii) The diameter of the borehole and the fixed anchor are identical.

(iii) Failure takes place by sliding at the rock/grout interface (smooth borehole) or by shearing adjacent to the rock/grout interface in weaker medium (rough borehole).

(iv) There are no discontinuities or inherent weakness planes along which failure can be induced, and

(v) There is no local debonding at the grout/rock interface.

Where shear strength tests are carried out on representative samples of the rock mass, the maximum average working bond stress at the rock/grout interface should not exceed the minimum shear strength divided by the relevant safety factor (normally not less than 2). This approach applies primarily to soft rocks where the uniaxial compressive strength (UCS) is less than 7N/mm², and in which the holes have been drilled using a rotary percussive technique. In the absence of shear strength data or field pull-out tests, Littlejohn (1972) states that the ultimate bond stress is often taken as one-tenth of the uniaxial compressive strength of massive rock (100 per cent core recovery) up to a maximum value of 4.2N mm², assuming that the crushing strength of the cement grout is equal to or greater than 42N mm². Applying an apparent safety factor of 3 or more, which is conservative bearing in mind the lack of relevant data, the wor

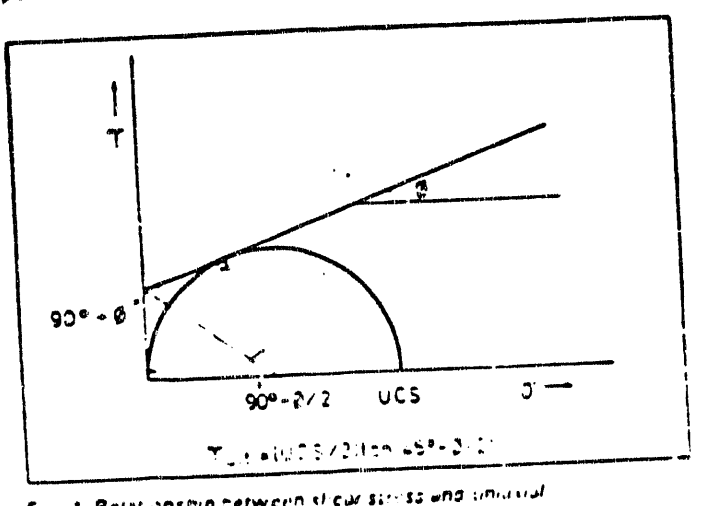

Fig 4 Relationship between shear stress and uniaxial compressive strength

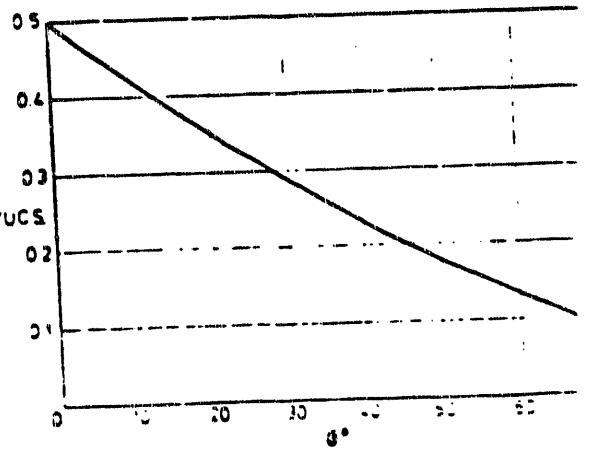

Fig 5 Effect of ø on τult UCS ratio

... bond stress ... therefore limited to ... N/mm².

In this connection it is noteworthy that Coates (1970) allows a maximum working bond of 2.45N/mm² but with a safety factor of 1.75 which indicates a value of τ_{ult} of 4.3N/mm². In some rocks, particularly granular, weathered varieties with a relatively low c value the assumption that τ_{ult} equals 10 per cent rock UCS may lead to an artifically low estimate of shear strength (Figs 4 and 5). In such cases the assumption that τ_{ult} equals 20-35 per cent UCS may be justified.

As a guide to specialists, bond values, as recommended throughout the world for wide range of igneous, metamorphic and sedimentary rocks, are presented in Table III. Where included, the factor of safety relates to the ultimate and working bond values calculated assuming uniform bond distribution. It is common to find that the magnitude of bond is simply assessed by experienced engineers: the value adopted for working bond stress often lies in the range 0.35 to 1.4N/mm². Koch (1972) suggests bond stresses in this range for weak, medium and strong rock (Table III), and the Australian Code CA 35—1973 states that a value of 1.05N/mm² has been used in a wide range of igneous and sedimentary rocks, but confirms that site testing has permitted bond values of up to 2.1 N/mm² to be employed.

In this connection the draft Czech Standard (1974) concludes that since the estimation of bond magnitude and distribution is a complex problem, field anchor tests should always be conducted to confirm bond values in design, as there is no efficient or reliable alternative. Certainly, a common procedure amongst anchor designers is to arrive at estimates of permissible working bond values by factoring the value of the average ultimate bond calculated from test anchors, when available. Usually the recommended safety factor ranges from 2 to 3, but is frequently lower in very competent rocks, and higher in weaker, fissured, or weathered variations.

The degree of weathering of the rock is

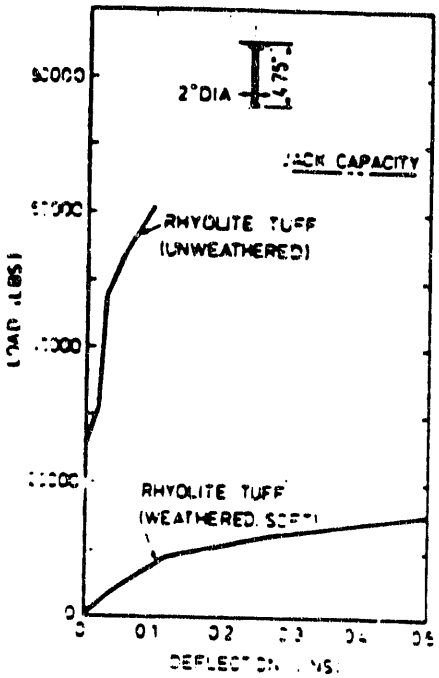

Fig 5 Effect of weathering at Currecanti Midway Transmission Line

(after Sallman and Schaefer, 1968)

TABLE III—ROCK GROUT BOND VALUES WHICH HAVE BEEN RECOMMENDED FOR DESIGN

Rock type	Working bond (N/mm²)	Ultimate bond (N/mm²)	Factor of safety	Source
Igneous				
Medium hard basalt		5.73	3.4	India—Rao (1968)
Weathered granite		1.90-2.90		Japan—Suzuki et al (197
Basalt	1.21-1.38	3.44	2.8-3.2	Britain—Weston Jones (
Granite	1.38-1.55	4.83	3.1-3.5	Britain—Weston Jones (
Serpentine	0.45-0.69	1.55	3.4-3.7	Britain—Weston Jones (
Dolerite & basalt		1.72-3.10	1.5-2.5	USA—PCI (1976)
Metamorphic				
Metamorphic schist	0.70	2.80	4.0	USA—White (1971)
Slate & hard shale		1.93-3.38	1.5-2.5	USA—PCI (1976)
Calcareous sediments				
Limestone	1.00	3.83	3.4	Switzerland—Lizzatti (1965)
Chalk—Grades I-III	0.014 N/SPT = blows 0.3m	0.22-1.07	1.5-3.0 (Temporary) 3.0-4.0 (Permanent)	Britain—Littlejohn (1970)
Yesterday limestone	0.83-0.97	2.76	2.8-3.2	Britain—Weston Jones (
Chalk limestone	0.86-1.00	2.76	2.8-3.2	Britain—Weston Jones (
Soft limestone		1.03-1.52	1.5-2.5	USA—PCI (1976)
Dolomitic limestone		1.38-2.07	1.5-2.5	USA—PCI (1976)
Arenaceous sediments				
Hard coarse-grained sandstone	2.46		1.75	Canada—Coates (1970)
Weathered sandstone		0.69-0.86	3.0	New Zealand—Lee (1977)
Well cemented mudstones		0.69	2.0-2.5	New Zealand—Lee (1977)
Softer sandstone	0.60		3.0	Britain—Littlejohn (1972)
Softer sandstone (UCS > 2.0N/mm²)	0.60		3.0	Britain—Littlejohn (1972)
Hard fine sandstone	0.69-0.83	2.24	2.7-3.3	Britain—Weston Jones (
Sandstone		0.83-1.79	1.5-2.5	USA—PCI (1976)
Argillaceous sediments				
Keuper marl		0.17-0.28 (C_u 0.48)	3.0	Britain—Littlejohn (1970) C_u undrained cohesion
Weak shale		0.35		Canada—Golder Brawner (
Soft sandstone & shale	0.10-0.14	0.37	2.7-3.7	Britain—Weston Jones (
Soft shale		0.21-0.83	1.5-2.5	USA—PCI (1976)
General				
Competent rock (where UCS > 20N/mm²)	Uniaxial compressive strength—30 up to a maximum value of 1.4N/mm²)	Uniaxial compressive strength—70 up to a maximum value of (4.2N/mm²)	3	Britain—Littlejohn (1972)
Weak rock	0.35-0.70			Australia—Koch (1972)
Medium rock	0.70-1.05			
Strong rock	1.05-1.40			
Wide variety of igneous and metamorphic rocks	1.05		2	Australia—Standard CA35
Wide variety of rocks	0.98			France—Fargeot (1972)
	0.90			Switzerland—Wa[illegible]
	0.70			Switzerland—Co[illegible]
		1.20-2.50		Switzerland—Co[illegible]
	0.70		2-2.5 (Temporary) 3 (Permanent)	Italy—Mascardi (1972)
	0.69	2.76	4	Canada—Golder Brawner
	1.4	4.2	3	USA—White (1971)
		15-20 per cent of grout crushing strength	3	Australia—Longworth (19[illegible]
Concrete		1.38-2.76	1.5-2.5	USA—PCI (1976)

TABLE IV—ROCK/GROUT BOND VALUES WHICH HAVE SEEN EMPLOYED PRACTICE

Rock type	Working bond (N/mm²)	Test bond (N/mm²)	Ultimate bond (N/mm²)	α_s (test)	α_s (ultimate)	Source
Igneous						
Basalt	1.93		6.37		3.3	Britain—Parker (1958)
Basalt	1.10	3.80				USA—Eberhardt & Veltrop (1[illegible]
Tuff	0.80					France—Cambefort (1966)
Basalt	0.83	0.72				Britain—Cementation (1962)
Granite	1.56	1.72				Britain—Cementation (1962)
Dolerite	1.56	1.72				Britain—Cementation (1962)
Very fissured felsite	1.56	1.72				Britain—Cementation (1962)
Very hard dolerite	1.56	1.72				Britain—Cementation (1962)
Hard granite	1.56	1.72				Britain—Cementation (1962)
Basalt & tuff	1.56	1.72				Britain—Cementation (1962)
Granodiorite	1.09					Britain—Cementation (1962)
Shattered basalt		1.01				Britain—Cementation (1962)
Decomposed granite		1.24				UEC—Sallman & Schaefer (1968)
Flow breccia		0.83				USA—Sallman & Schaefer (1968)
Mylonitised porphyrite	0.32-0.67					USA—Sallman & Schaefer (1968)
Fractured diorite	0.95					Switzerland—Descoeudres (1[illegible]
Granite	0.83	0.81				Switzerland—Descoeudres (1[illegible]
						Canada—Barron et al (1[illegible]
Metamorphic						
Schist	0.31					
All types	1.20					Switzerland—Lizzatti (1965)
Weathered fractured quartzite	1.56	1.72		1.1		Britain—Cementation (1962)
Blue schist	1.32	1.67		1.1		
Weak meta sediments	1.10	1.23		1.1		Britain—Cementation (1962)
Slate	0.43					Britain—Cementation (1962)
Decomposed greywacke	1.57	1.73		1.1		Britain—Cementation (1962)
[illegible]	0.35-0.39					Britain—Cementation (1962)
Fractured quartzite	0.51					
Weathered meta tuff		0.25				
Greywacke	0.34					
Quartzite	0.91-1.20	1.02-1.72		1.1		Britain—Cementation (1962)
Metagneiss	0.35					Britain—Cementation (1962)

Rock	Working bond (N/mm)	Test bond (N/mm)	Ultimate bond (N/mm)	ϕ_s (test)	ϕ_s (estimate)	Source
Metamorphic—contd.						
Bernese schist	0 05					Italy—Berardi (1972)
Quartzitic schist	0 10					Italy—Berardi (1972)
Argillaceous & calcareous schist	0 63					Italy—Berardi (1972)
Slate	0 96	1 24		1 3		Switzerland—Meschler & Matt (1974)
Highly metasediments	0 84	1 08		1 3		USA—Bure (1972)
Slate & greywacke	1 08	1 40		1 3		Germany—Anon (1972)
Various metasediments						Germany—Abraham & Portig (1973)
Micaschist & phyllite gneiss	0 53	0 83		1 5		USA—Nicholson Anchorage Co Ltd (1973)
Slate	0 60	0 90	1 80	1 5	3 0	Britain—Littlejohn & Truman Davies (1974)
Sound Micaschist	1 74	2 16				USA—Feld & White (1974)
Micaschist	0 83-0 14			1 24		USA—Feld & White (1974)
Very clayey gneiss & mud band	0 07					USA—Feld & White (1974)
Carbonate sediments						
Loam/limestone		0 63				Italy—Berardi (1980)
Fissured limestone & intercalations	1 08	1 19		1 1		Britain—Cementation Co Ltd (1962)
Limestone	0 85					Switzerland—Muller (1966)
Poor limestone	0 32					France—Henniequin & Combeforr (1966)
Massive limestone	0 39-0 78					France—Henniequin & Combeforr (1966)
Karstic limestone	0 54					France—Henniequin & Combeforr (1966)
Tertiary limestone	1 00		2 63		2 8	Switzerland—Lesinger & Co Ltd (1966)
Limestone			4 55-4 85		-	Switzerland—Ruttner (1968)
Marly limestone	0 03-0 07 (average) 0 21-0 38 (measured)					Italy—Berardi (1967)
Limestone			0 27			USA—Salmon & Schaefer (1968)
Limestone	0 28					Italy—Berardi (1969)
Dolomitic limestone			1 80			Canada—Brown (1970)
Marly limestone	0 39-0 94					Italy—Berardi (1972)
Limestone	0 26					Italy—Berardi (1972)
Limestone/ puddingstone	0 44					France—Soletanche Co Ltd (1968)
Limestone	1 18	1 42		1 2		USA—Bure (1972)
Chalk			0 70			Britain—Associated Tunnelling Co Ltd (1973)
Dolomite		1 86				Canada—Golder Brawner (1973)
Dolomitic siltstone	0 43					USA—White (1973)
Limestone & marly bands	0 37	0 55		1 5		Italy—Mongilardi (1972)
Arenaceous sediments						
Sandstone	1 44	1 58		1 1		Britain—Morris & Garrett (1956)
Hard sandstone	1 42	1 56		1 1		Britain—Cementation Co Ltd (1962)
Bunter sandstone	0 95	0 98		1 03		Britain—Cementation Co Ltd (1962)
Sandstone	0 76	0 84		1 1		Britain—Cementation Co Ltd (1962)
Sandstone	0 74					Czechoslovakia—Hobst (1968)
Sandstone	0 31	0 40	1 73	1 29	5 6	USA—Dressel (1970)
Sandstone	0 80					USA—Thompson (1970)
Poor sandstone	0 40					Germany—Brunner (1970)
Good sandstone	1 14					Germany—Brunner (1970)
Sandstone & Breccia	0 38					France—Soletanche (1968)
Sandstone		0 95				Australia—Williams et al (1972)
Bunter sandstone	0 60	1 20	-	2 0		Britain—Littlejohn (1973)
Sandstone	1 17					Australia—McLeod & Hoadley (1974)
Argillaceous sediments						
Shale	0 62					Canada—Juergens (1965)
Marl	0 10	0 28		2 8		Italy—Berardi (1967)
Shale	0 30		0 63		2 1	Canada—Hanna & Seaton (1967)
Very weathered shale			0 38			USA—Salmon & Schaefer (1968)
Shale	0 13-0 24					USA—Kotelain (1970)
Grey siltstone	0 62					Britain—Universal Anchorage Co Ltd (1971)
Clay marl	0 14-0 24	0 21-0 38		1 5		Germany—Schwarz (1972)
Shale	0 62					Canada—Mollos te et al (1972)
Argillite	0 62					Canada—Golder Brawner (1973)
Mudstone	0 63	0 88		1 4		Australia—McLeod & Hoadley (1974)
Miscellaneous						
Bedded sandstone & shale	0 25-0 90					Italy—Beemonte (1981)
Porous, sound gossamer	1 57	1 72		1 1		Britain—Cementation Co Ltd (1962)
Shale & sandstone	0 07	0 10		1 5		USA—Reti (1964)
Soft rocks	0 75					Sweden—Nordin (1966)
Sandstone & shale	1 82					Poland—Bujak et al (1967)
Siltstone & mudstone	1 65					Australia—Maddox et al (1967)
Fractured rock (75 per cent shale)						
Poor			0 24			USA—Salmon & Schaefer (1968)
Average			0 35			USA—Salmon & Schaefer (1968)
Good			0 76			USA—Salmon & Schaefer (1968)
Limestone & clay breccia	0 20-0 28					Italy—Berardi (1972)

a major factor which affects not only the ultimate bond but also the load-deflection characteristics. Fig. 6 shows the results produced by test anchors in rhyolite tuff, of both sound and weathered varieties. No data are provided on grout or rock strengths but it is significant that the equivalent uniform bond stress at maximum jack capacity is sensibly 0·1 N/mm². For design in soft or weathered rocks there are signs that the standard penetration test is being further exploited. For example, Suzuki *et al* (1972) state that for weathered granite the magnitude of the bond can be determined from the equation

$$\tau_{ult} = 0.007N - 0.12 \text{ (N/mm}^2\text{)}$$

where N = number of blows per 0·3m ..... (2)

Similarly, Littlejohn (1970) illustrates a correlation between N and ultimate bond

for stiff, hard clays as follows

$$\tau_{ult} = 0.01N \text{ (N/mm}^2\text{)}$$

In grades III, II and I of chalk he observed a range of τ_{ult} of 0·21–1·07N/m based on test anchors pulled to failure.

Although it would appear from evide presented in subsequent sections that assumptions made in relation to unifo bond distribution are not strictly accur it is noteworthy that few failures are countered at the rock grout interface new designs are often based on the s cessful completion of former proje that is, former working bond values re-employed or slightly modified dep ing on the judgement of the designer.

Table IV contains data abstracted f reports of rock anchor contracts throu out the world. In addition to the work test, and ultimate bond values, the m sured and designed safety factors are vided where available. In certain cases fixed anchor diameter has been inferred facilitate analysis of the data, as pointed

It will be noted that, even for one r type, the magnitude of bond used in p tice is extremely variable. There are m reasons for this, the most important which are:

(*i*) Different designers use different b values and safety factors, which may related to type of anchor and extent of anchor testing programme.

(*ii*) "Standard" values for a certain type have often been modified to re local peculiarities or irregularities of geology.

(*iii*) Factors related to the construc techniques e.g. drilling method, flus procedure, and grout pressure will ence the results obtained. (The effec these aspects will be discussed in Par Construction.)

On the whole however, it would ap that the bond values employed are to gree consistent with rock type and petency.

Fixed anchor dimensions

The recommendations made by va engineers with respect to length of anchor are presented in Table V. Under tain conditions it is recognised that shorter lengths would suffice, even the application of a generous fact safety. However, for a very short a the effect of any sudden drop in quality along the anchorage zone, a constructional errors or inefficie could induce a serious decrease in anchor's capacity.

With regard to the choice of anch meter several considerations may be into account:

(*i*) Type and size of tendon.

(*ii*) The relation of diameter to per area of fixed anchor and hen anchor capacity, assuming u bond.

(*iii*) Ratio of steel area to cross-se area of borehole for efficient bo tribution and corrosion protect

(*iv*) Drilling method and rig to be and

(*v*) Nature of rock in the anchor zo presence of unconsolidated burden, if any.

The authors find from a survey eral hundred commercial anchor that no direct relationship may be ved bearing in mind the range of types but that most anchors con the trend indicated in Table VI

RECOMMENDATIONS

3.2.3 Factors of Safety

The design load P for the anchor equals the maximum anticipated load applied to the anchor times the factor of safety used in the design of the anchored structure The value of the factor of safety depends upon the type of application the degree of uncertainty in the design of the structure and the risk

COMMENTARY

The engineer should not compound various factors of safety when designing an anchored structure The uncertainty and risk associated with the work should be the criteria to determine engineering design capacities and the engineer adds a separate factor of safety to the applied loads the design capacities are low and the anchor test load the actual factor of safety for the anchor will have been compounded resulting in an overly conservative design

3.2.4 Anchor Tendon Design

The tendon size is determined such that the design load for the anchor does not exceed 60 percent of the guaranteed ultimate tensile strength (GUTS) of the tendon The lock off load which shall be determined by the design engineer may be larger or smaller than the design load The recommendations for corrosion protection given in Section 6 0 Corrosion Protection shall be considered

The load in an anchor tendon may either increase or decrease with time depending on the behavior of the structure

3.2.5 Free Stressing Length

The free stressing length should not be less than 15 feet [4 572m]

The minimum stressing length recommended is to prevent significant reductions in transfer load due to stressing anchorage losses or movement

3.2.6 Bond Length

The bond length can be estimated by the following equation

$$Lb = \frac{P}{\pi \cdot d \cdot r_w}$$

Where

- Lb = bond length
- P = design load for the anchor
- π = 3.14
- d = diameter of the drill hole
- r_w = working bond stress in the interface between rock and grout

The bond length normally is not less than 10 feet For normal applications the bond between the tendon and anchor grout is not critical

Pull-out tests may be used to determine the ultimate insitu bond stress between the rock and the anchor grout Pull-out tests usually require that the tendon capacity be increased or the bond length reduced in order to fail the anchor Pull-out test should not be required if the anchors are tested as described in Section 3 5

The working bond stress used to determine the bond length is normally 25 to 50 percent of the ultimate bond stress

When selecting the working bond stress the engineer should consider the critical nature of the anchor application variations in the rock properties and the installation procedures

The ultimate bond stress depends on the

1 Shear strength of the rock

2 Discontinuities in the rock mass

"British Standard Code of practice for Ground Anchorages" British Standards Institute, 1989

Table 25. Rock/grout bond values which have been recommended for design after Littlejohn and Bruce (1977)

Rock type	Working bond N/mm²	Ultimate bond N/mm²	Load factor of safety	Source
Igneous				
Medium hard basalt		0.73	3.4	India Rao (1964)
Weathered granite		1.50 to 2.50		Japan Suzuki et al (1972)
Basalt	1.21 to 1.39	3.86	2.8 to 3.2	Britain Wycliffe-Jones (1974)
Granite	1.38 to 1.55	4.83	3.1 to 3.5	Britain Wycliffe-Jones (1974)
Serpentine	0.45 to 0.59	1.55	2.6 to 3.5	Britain Wycliffe-Jones (1974)
Granite and basalt		1.72 to 3.10	1.5 to 2.5	USA PCI (1974)
Metamorphic				
Manhattan schist	0.70	2.80	4.0	USA White (1973)
Slate and hard shale		2.83 to 1.38	1.5 to 2.5	USA PCI (1974)
Calcareous sediments				
Limestone	1.00	2.83	2.8	Switzerland Lesinger (1968)
Chalk – Grades I - III	0.01 N (N = SPT n blows/0.3 m)	0.22 to 1.07	1.5 to 2.0 (Temporary) 3.0 to 4.0 (Permanent)	Britain Littlejohn (1970)
Tertiary limestone	0.83 to 0.97	2.76	2.9 to 3.3	Britain Wycliffe-Jones (1974)
Chalk limestone	0.86 to 1.00	2.76	2.8 to 3.2	Britain Wycliffe-Jones (1974)
Soft limestone		1.03 to 1.52	1.5 to 2.5	USA PCI (1974)
Dolomitic limestone		1.38 to 2.07	1.5 to 2.5	USA PCI (1974)
Arenaceous sediments				
Hard coarse-grained sandstone	2.45		1.75	Canada Coates (1970)
Weathered sandstone		0.69 to 0.85	3.0	New Zealand Irwin (1971)
Well-cemented mudstones		0.69	2.0 to 2.5	New Zealand Irwin (1971)
Bunter sandstone	0.40		3.0	Britain Littlejohn (1973)
Bunter sandstone (ultimate compressive stress > 2.0 N/mm²)	0.60		3.0	Britain Littlejohn (1973)
Hard fine sandstone	0.69 to 0.83	2.24	2.7 to 3.3	Britain Wycliffe-Jones (1974)
Sandstone		0.83 to 1.73	1.5 to 2.5	USA PCI (1974)
Argillaceous sediments				
Keuper marl		0.17 to 0.35 (0.45 C_u)	3.0	Britain Littlejohn (1973) C_u = undrained cohesion
Weak shale		0.35		Canada Golder Brawner (1973)
Soft sandstone and shale	0.10 to 0.11	0.37	2.0 to 3.0	Britain Wycliffe-Jones (1974)
Soft shale		0.21 to 0.83	1.5 to 2.5	USA PCI (1974)
General				
Competent rock (where ultimate compressive stress > 20 N/mm²)	Uniaxial compressive strength ÷ 30 up to a maximum value of 1.4 N/mm²	Uniaxial compressive strength ÷ 10 up to a maximum value of 4.2 N/mm²	3	Britain Littlejohn (1972)
Weak rock	0.35 to 0.70	–	–	Australia Koch (1972)
Medium rock	0.70 to 1.05			
Strong rock	1.05 to 1.40			
Wide variety of igneous and metamorphic rocks	1.05		3	Australia Standard CA35 (1973)

Table 25. concluded

Rock type	Working bond	Ultimate bond	Load factor of safety	Source
	N/mm²	N/mm²		
Wide variety of rocks	0·98			
	0·50			France Forgeot (1972)
	0·70			Switzerland Walther (1969)
		1·20 to 2·50		Switzerland Comte (1965)
	1·70		2 to 2·5 (Temporary)	Switzerland Comte (1971)
			3 (Permanent)	Italy Mascardi (1973)
	0·69	2·76	4	
	1·4	6·2	3	Canada Golder Brawner (1973)
		15 % to 20 % of grout crushing strength	3	USA White (1973)
				Australia Longworth (1971)
Concrete		1·38 to 2·76	1·5 to 2·5	USA PCI (1974)

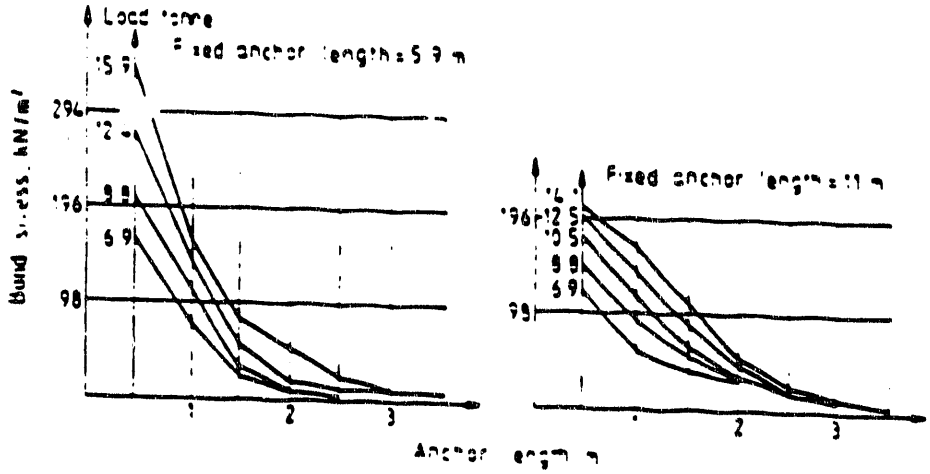

Figure 56. Distribution of bond along fixed anchor length (after Berardi (1967))

For compact sandy gravel ($\phi' = 40°$) at Vauxhall Bridge, London and compact dune sand ($\phi' = 35°$) at Ardeer, Scotland values of β equal to 101 and 31 have been measured in the field (Littlejohn 1970) which are in good agreement with respective values of 99 and 35 estimated from figure 6

The value of A depends to a large extent on construction technique and for the type B anchorage relevant to equation (3) value of 1·7 and 1·4 have been recorded in compact sandy gravel ($\phi' = 40°$) and compact dune sand ($\phi' = 35°$) respectively (Littlejohn 1970)

Littlejohn (1970) estimated for equation (3) that A lay in the range of 1 to 2 but that if the soil was not compacted or displaced during the casing installation and no residual grout pressure was left at the fixed anchor grout soil interface on completion of the injection A might reduce to a value approximating to K_o. In light of experience, this reduction is now considered unduly pessimistic since even with tremie grouting the full hydrostatic head of the grout is applied at the anchor interface, which creates a contact pressure greater than $K_o \sigma'_v$ in normally consolidated ground

As a consequence, even for the tremie grouting method it is difficult to envisage a value of A less than 1 for design purposes

TITLE: FACTOR OF SAFETY - WEDGE PULLOUT			PAGE 1 OF 4
PROJECT	AUTHOR: C. FRANKE 9/5/91	CHK'D BY: J.R. Tyler 9/6/91	CHK'D BY / DATE
SO	CALC NO	FILE NO	GROUP

PROBLEM: DETERMINE THE FACTOR OF SAFETY (F of S) AGAINST PULLOUT OF A ROCK WEDGE BY A ROCKBOLT.

ASSUMPTIONS:

1) THE GEOMETRY OF THE WEDGE IS AS SHOWN ON THE SKETCH ON PAGE 2.
2) COHESION OF SALT IS C = 1000psi = 6.89 MPa (REF 1)
3) DENSITY OF WIPP SALT, ρ = 135 lb/ft³ (REF 2)

REFERENCES:

1) SAND 78-1596, "Geological Characterization Report", Powers, et al, 1978.
2) D-51-W-01, "Design Basis - Underground Excavations" Bechtel

METHOD: THE SHEAR RESISTANCE OF THE WEDGE ABOVE CLAY G AND THE WEIGHT OF THE WEDGE ARE COMPARED.

THE SHEAR STRENGTH OF SALT WILL BE TAKEN AS EQUAL TO THE COHESION. THIS IS A VERY CONSERVATIVE VALUE SINCE

$$T = C + \sigma \tan\phi \qquad \text{(REF 1)}$$

WHERE T IS THE SHEAR STRENGTH, σ IS NORMAL FORCE (i.e. UCS for MAXIMUM) AND ϕ IS THE FRICTION ANGLE.

General Comment: I don't know that this calculation is significant to a bolt in salt.

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WESTINGHOUSE WASTE ISOLATION DIVISION

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W U	CALC NO		FILE NO		GROUP	

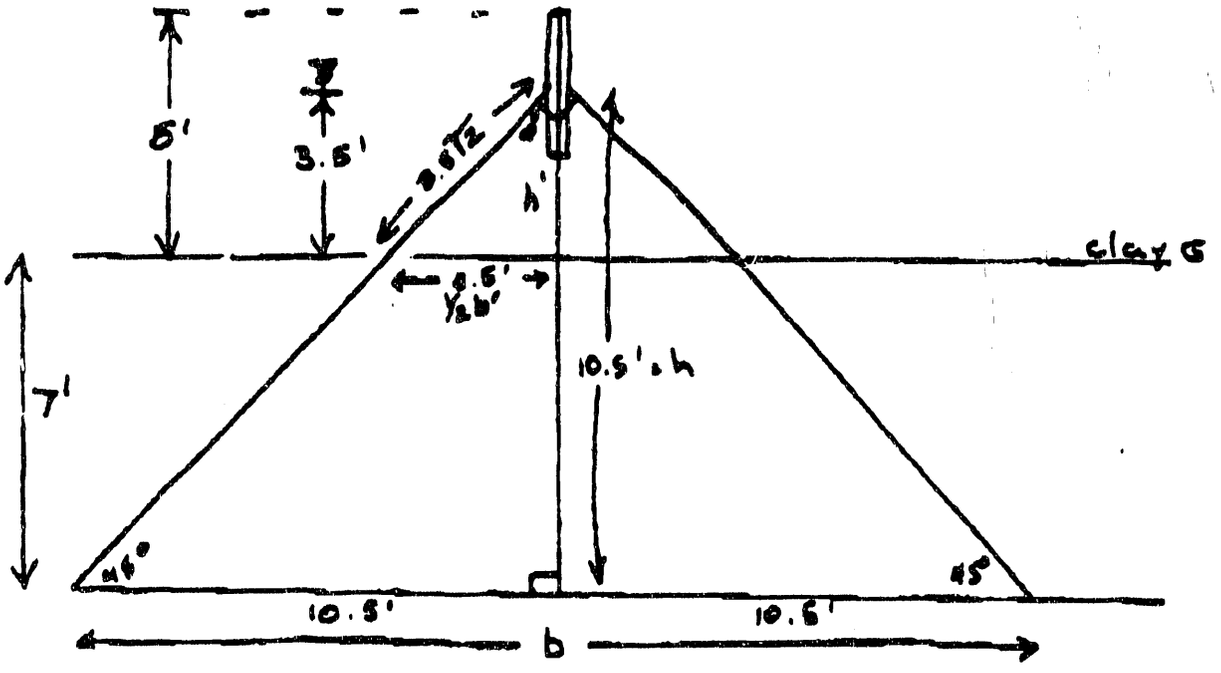

FIG. 1

W = WIDTH = 33'

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TITLE: FACTOR OF SAFETY - WEDGE PULLOUT				PAGE 3 OF 4
PROJECT	AUTHOR C. FRANCKE DATE 9/8/81	CHK'D BY J.R. Tyburski DATE 9/9/81	CHK'D BY	DATE
WBS	CALC NO	FILE NO	GROUP	

CALCULATIONS:

WEIGHT OF WEDGE

$$W = \tfrac{1}{2} b h w \rho$$

WHERE W = WEIGHT OF WEDGE
ρ = DENSITY OF SALT
b, h, w ARE BY FIGURE 1.

$$W = \tfrac{1}{2}(21' \times 10.5' \times 35')(135\ lb/ft^3)$$

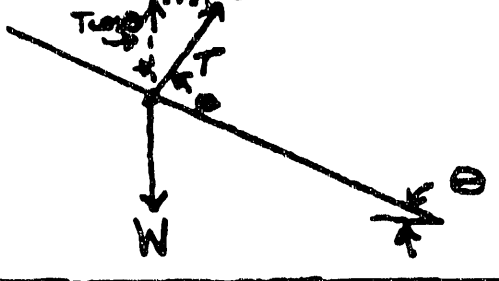
$$W = 491\ kip = 2.18\ MN$$

SHEAR RESISTANCE OF SMALL WEDGE

$$S = AT\cos\theta$$
$$= [\tfrac{1}{2} b'h' + 2 \cdot 2 \cdot \sqrt{2}\, h'w]\, T\cos\theta$$

WHERE: S = SHEAR RESISTANCE OF SMALL WEDGE
T = SHEAR STRENGTH OF ROCK
b', h', w ARE BY FIGURE 1
θ = ANGLE OF WEDGE FRACTURE

THE DIAGRAM BELOW ILLUSTRATES THE FORCES INVOLVED:



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TITLE: FACTOR OF SAFETY - WEDGE PULLOUT				PAGE 4 OF 4
ORIGIN	ORIGINATOR / DATE: C. FRANCKE 9/5/91	CHK'D BY / DATE: J R Tyburski 9/4/91	CHK'D BY	DATE
S U	CALC NO.	FILE NO	GROUP	

CALCULATIONS: (CONT'D)

SHEAR RESISTANCE OF WEDGE (CONT'D)

$$S = [\tfrac{1}{2}(7'X9.5')(2) + (2X\tfrac{1}{2}X9.5'X33')]T\cos\Theta)$$
$$S = (351\ ft^2 X \frac{144\ in^2}{1\ ft^2} X 1000 psi)\cos\Theta$$
$$S = (50,544\ kip)\cos\Theta$$

$$\tan\Theta = \frac{7'}{\frac{1}{2}(66')}$$

$$\Theta = 23°$$

$$S = (50,544\ kip)\cos 23°$$
$$S = 46,530\ kip$$

FACTOR OF SAFETY

$$F.of\ S = \frac{46,530\ kip}{491\ kip} = 95$$

DISCUSSION:

THE CALCULATED F.of S IS QUITE ADEQUATE

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WESTINGHOUSE FORM 6X628A

"Geological Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico" SAND78-1976 Powers, e

stress space (σ,T) where σ and T denote normal and shear stresses, and an envelope is drawn tangent to the circles representing the ultimate shear stress of any value of confining pressure.

When the data from Tables 9.2.4-1 and 9.2.4-2 are plotted, three Mohr's circles which are normal for SENM rock salt are obtained in Figure 9.2.4-2A in stress space (σ,T) . The ultimate stresses can be approximated by a straight line (Coulomb) envelope of the form $T = C + \sigma \tan \phi$. In conventional engineering terminology, C is called the cohesion and ϕ, the angle of internal friction. In this case, at ambient temperatures, rock salt from the 2,700 foot level has an apparent cohesion of approximately 1,000 psi and an angle of internal friction of 33°. Similar data for other rocks are being used for mine pillar design. However, it should be recognized that the validity of these ultimate stress analyses rests on two assumptions: (1) failure is independent of the intermediate principal stress, and (2) failure is defined solely in terms of stresses and independent of strain, strain rate and time. Both of these assumptions are currently being evaluated for rock salt.

In contrast to other rocks, it is important to remember that rock salt undergoes large deformations long before the ultimate stress is reached. Since these deformations can exceed 15% even at ambient temperature, it is conceivable that a practial failure condition might incorporate a maximum deformation criterion. To illustrate this case, a Coulomb envelope was constructed (Figure 9.2.4-2B) which defines the stress magnitudes at an arbitrarily chosen constant value of strain ($\varepsilon_1 = 2.5\%$). This value is the average strain at the ultimate stress of samples tested in uniaxial compression at ambient temperature and a loading rate of 30 psi/min. It can be seen that Figure 9.2.4-2B is different from the ultimate stress envelope in Figure 9.2.4-2A. Clearly, the shapes of the Mohr envelopes are highly dependent on failure criteria. The values obtained also depend on the manner in which the Mohr's envelope is drawn. In Figure 9.2.4-2A, a "best fit" straight line tangent to the circles was drawn; while in B, a parabola was drawn tangent to the circles.

APPENDIX C - CHANNEL SUPPORT DESIGN

The final design of the steel beam support system was the result of an evolutionary process that started by considering an I beam. The original concept called for an I beam that would be held in place by eight rock anchors and four yieldable steel posts. This design had several difficulties with it:

- Each I beam would weigh about 2,000 pounds, making the installation process difficult and potentially dangerous.
- The supporting rock anchors could not be attached to the centerline of the I beam. Instead, the rock anchors would have to be attached by means of a separate plate to the flanges of the I beam. This would have generated excess moments in the beam as well as introducing torque forces, which would have been difficult to calculate.
- The yieldable posts would have been difficult to test, and as they were not performing any function that the rock anchors could not provide, they were eliminated from the design.

The final design calls for a 15 x 40 channel with 11 rock anchors that are fastened through the centerline of the channel.

The channel will be made of three 9 foot sections bolted together with four 7.5 inch by 3 inch splice plates which allow for greater ease in the handling and placement of the channel.

The beam has been designed to accommodate the unequal distribution of the rock load, and the rock anchors will be tensioned to account for the fact that most of the detached load is in the middle of the room.

The support channel design calculations are given below.

WESTINGHOUSE WASTE ISOLATION DIVISION
CALCULATION COVER SHEET

System:	AUOO
PWR:	N/A

Design Class:	III-A.
Sheet No.:	1 of 9
Ref. EDT:	NEA

FSAR Checked: ✓ FSAR Change Required: yes

DOE Order 6430.1A Checked: ✓

Source of Data: 1. Geotech. Expert Report - WIPP, June 1991
2. —
3. —

Source of Formulas and References: AISC - Manual of Steel Construction
Blodget - Design of Weldments

Type of Calculation: Prelim.: _____ Final: ✓

References: Westinghouse Drawings

P&ID/Dwg. No./Rev.: 54-D003-W1, -W2, -W3, -W4, -W5

Entitled: Supplementary Roof Support, Room 1, Panel 1 General Arrangement, Sections and Details

RECORD OF ISSUES

Rev.	Description	By	Date	Chk'd	Date	App'd	Date
0	Issued for external review	JHK	9/7/91	HS	9/6/91	MJP	9/6/91

491B:9

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Data and assumptions for the below calculations:

1. Density of salt material is 135 lb/ft as per Design Basis - U/G Excavations, D-51-W-01, page 6.
2. The total load overburden is based on 10 ft spacing of the rows of Rock Bolts in the longitudinal direction of the room.
3. Triangular distribution of the load is assumed across the width of the room (33'-0).
4. Material of the Rock Bolts is as per ASTM A 615 - Grade 60. Yield stress Fy = 60 000 psi, allowable working

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stress in tension $F_t = 0.60\,F_y =$

$= 36000$ psi. (See PTI-1986).

5. Allowable load on the Rock Bolt is

$P_W = A \times F_t = 0.79 \times 36.0 = \underline{28.4^k}$

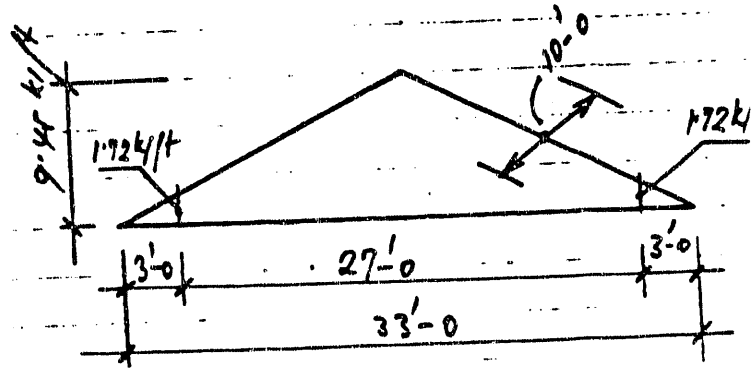
Triangular load:

Weight of the overburden

$w = \left(\frac{1}{2} 10.0 \times 33.0 \times 7.0\right) \times 135\ ^{lb}/_{ft^3} = \underline{156000\ lb.}$

Load per linear foot across the

room $q = \dfrac{2 \times 156.0}{33.0} = \underline{9.45\ k/ft}$



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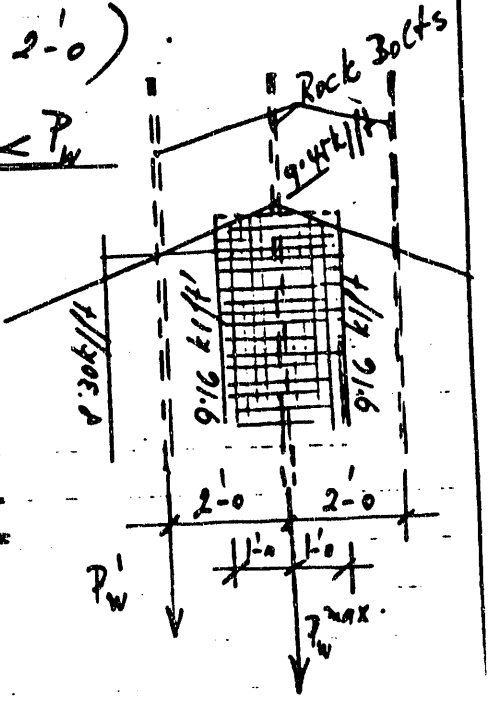
Load on the critical Rock Bolt @ center of the room: (spacing @ 2'-0)

$P_W^{max.} = 2'o \times 9.16 = \underline{18.33^k < P_W}$



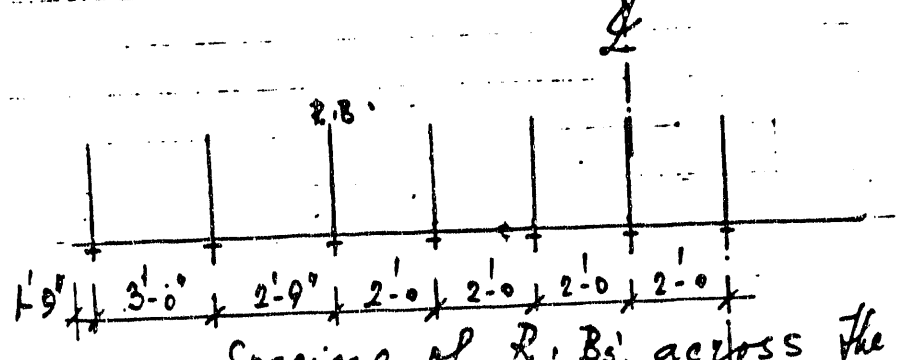
Adjacent Rock Bolt:

$P_W' = 2'o \times 8.30 = \underline{16.6^k}$

In case the center R.B. fails half of the load i.e $\frac{1}{2}$ 18.33 k. = 9.16 k will be taken by the adjacent R.B.

$2P_W = 16.6 + 9.16 = \underline{25.76^k < P_W = 28.4^k}$ – see page 3

$\Rightarrow$ no overloading occurs.



Spacing of R.Bs. across the room

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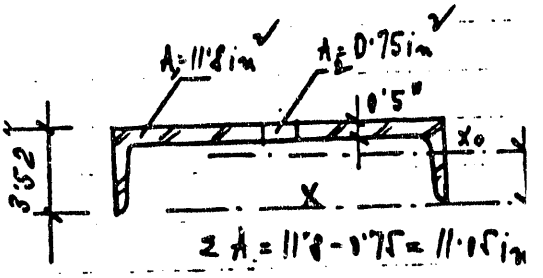
Check of stress in the channel form bending. (C15x40; S = 3.37 in³).

Assume conservatively $M = 1/10\, w l^2$

$M_{\ell} = 1/10 \times 8.9 \times 2.0^2 = 3.56$ k/ft ~ @ center of the room

$\sigma = \frac{3.56 \times 12}{3.37} = 12.676$ psi < σ_{allow}.

Section modulus "S" of the C15x40 with a ϕ1.5" hole.



Static moment M_x:

11.8 x 2.74 ..... 32.33 in³

- 0.75 x 3.27 ..... - 2.45

$M_x = 29.88$ in³

$x_0 = \frac{M_x}{A_0} = \frac{29.88}{11.05} = 2.70$ in

$I = I_0 + A_1 x_1 - I_\phi - A_2 x_2 = 9.23 + 11.8 \times 0.043^2 -$

$- 1/12 \times 1.5 \times 0.5^3 - 0.75 \times 0.82^2 = \underline{8.71 \text{ in}^4}$

$S = \frac{I}{C} = \frac{8.71}{2.70} = \underline{3.21 \text{ in}^3}$

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Check new stress in the [15 (see page 5)

$M = 3.56$ k-ft $\Rightarrow \sigma = \frac{3.56 \times 12}{3.21} = 13.308$ psi $< \sigma_{all}$

Shear in the web:

$P_w^{max.} = 18.33^K$

$A_{req.} = \frac{18330}{14000} = 1.31 \text{ in}^2$

$r_{req.} = \frac{1.31}{1.5 \times 2\pi} = 0.42$ in $\Rightarrow r_{used} = 1.00 > 0.42$

Use ϕ 2" washer under the rock bolt (see below 2 5½ x 5

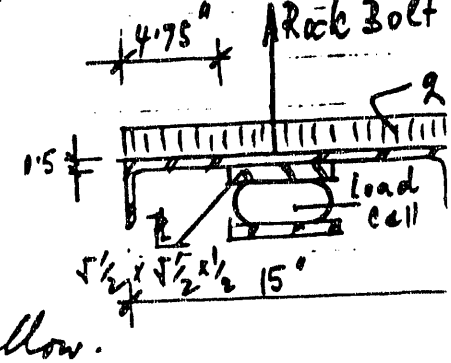
Bending of the [15 perpendicular to the length of the beam @ sag

$f = \frac{2P_w}{15.0 \times 24"} = \frac{28400}{15 \times 24} =$

$= 78.9$ psi

$M = \frac{1}{2} 78.9 \times 4.75^2 = 890$ lb. in

$\sigma = \frac{890}{1.042} = 27192$ psi $< \sigma_{allow.}$



$S = \frac{1}{6} 1.0 \times 0.5^2 = 1.0$

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Shear (in the 11" web) (along the ℄ perimeter)

$A = 4 \times 5.5 \times 0.5 = 11 \text{ in}^2$

$\tau = \frac{28400.0}{11.0} = 2582 \text{ psi} < \tau_{allow} = 14000 \text{ psi}$

Combined stress: (bending + shear)

$$\left(\frac{f_b}{F_{cr}}\right)^2 + \left(\frac{\tau}{\tau_{cr}}\right)^2 \leq 1$$

$$\left(\frac{21.19}{23.76}\right)^2 + \left(\frac{2.58}{14.0}\right)^2 = 0.795 + 1.033 = 0.928 < 1.0$$

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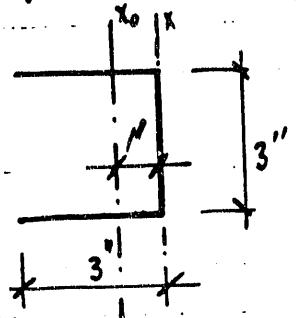
Design of splice :

- assumed as a flexible pin, allowing small horizontal movement

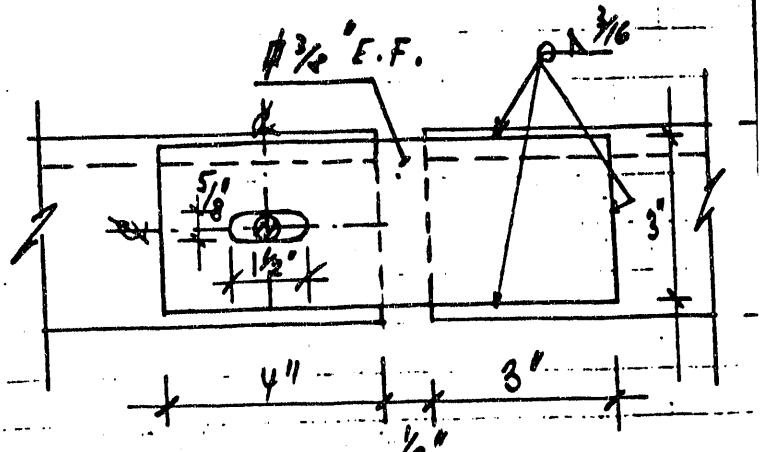
C.G. of the weld:



$S_{M_x} = 2x(3 \times 1.5) = 9 in$

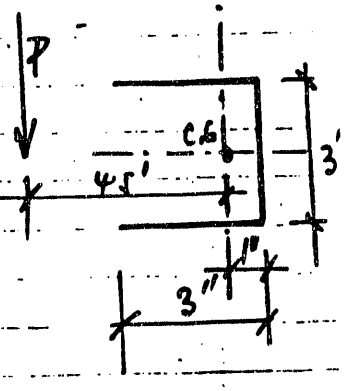
$L = 3 \times 3 = 9 in$

$x_0 = \frac{9.0}{9.0} = 1"$



Design of the weld:

See table XXIII, page 4-90 AISC.



$k = 1.0 \quad a = 1.5$

$l = 3" \quad P = 5.66^k$

$C = 0.775$

$$D = \frac{P}{C C_1 l} = \frac{5.66^k}{0.775 \times 1.0 \times 3.0} = 2.43$$

Use 3/16 weld

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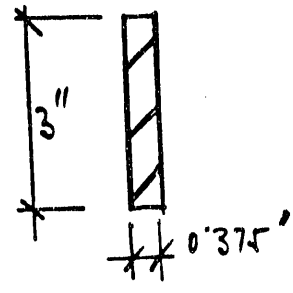
Splice plate - stresses from bending and shear.

Assume ℔ 3/8" thick

Moment: me plate

$M = \frac{1}{2}\sqrt{}\cdot 66 \times 2\cdot\sqrt{} = 707\sqrt{}$ in-lb



$\sigma = \frac{707\sqrt{}\cdot 0}{0\cdot\sqrt{}62} = 12\sqrt{}89$ psi => ok

$S = \frac{1}{6} 0\cdot 37\sqrt{} \times 3\cdot 0^2 =$

$= 0\cdot\sqrt{}62$ in^3

Shear:

$\tau = \frac{\frac{1}{2}\sqrt{}660}{3 \times 0\cdot 37\sqrt{}} = 2\sqrt{}1\sqrt{}$ psi < 14000

Combined stress:

$\left(\frac{12\sqrt{}89}{23760}\right)^2 + \left(\frac{2\sqrt{}1\sqrt{}}{14000}\right)^2 = 0\cdot 28 + 0\cdot 03 = 0\cdot 31 < 1\cdot 0 \Rightarrow$ OK

Bolt at the sliding end.

$\tau = \frac{\frac{1}{2}\sqrt{}\cdot 66}{0\cdot 306} = 9\cdot 2\sqrt{}$ ksi

Assume ϕ 5/8"

$A = 3\cdot 14 \times 0\cdot 31^2 =$

$= 0\cdot 306$ in^2

Use Bolts A 32$\sqrt{}$ ($F_v = 17\cdot\sqrt{}$ ksi)

Finger tight.

REV. NO.	REV. DATE	AUTHOR	DATE	CHK'D. BY	DATE	CHK'D. BY	DAT

WASTE ISOLATION PILOT PLANT
SUPPLEMENTARY ROOF SUPPORT SYSTEM

APPENDIX D
Geomechanical Monitoring Program

Westinghouse Electric Corporation
Waste Isolation Division
Carlsbad, New Mexico
October 1991

GEOTECHNICAL MONITORING PROGRAM

FOR ROOF SUPPORT SYSTEM IN ROOM 1, PANEL 1

GEOTECHNICAL MONITORING PROGRAM
FOR ROOF SUPPORT SYSTEM IN ROOM 1, PANEL 1

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1.0 INTRODUCTION

A system to support the roof in Room 1, Panel 1 has been designed on the basis of the rock mechanics data that is given in Appendix A. The design itself, is presented in Chapter 4 Support System, Underground Storage Area, Panel 1, Room 1. The support system accommodates a controlled yield of the roof rock as the creep of the salt takes place. The success of the planned system relies heavily on a monitoring program that will determine not only the geomechanical performance of the room but will also assess the structural performance of the support system.

The support system is designed to carry the dead weight of a rock wedge that is forming in the roof of Room 1. The development of this wedge has been established from the rock fall that occurred in SPDV Test Room 1 and from observations of fracture development in other parts of the underground facility. The wedge is not yet fully formed but experience in would indicate that it will form within the next 7 years in Room 1, Panel 1 unless fracture development in the roof can be controlled. The support system in Room 1 has two purposes. It is designed to minimize the development and propagation of roof fractures thereby, ensuring that the rock remains self supporting for as long as possible, and secondly the system must have a capacity to carry the dead weight of the rock wedge once it forms in the roof while accommodating both vertical and lateral displacements due to far field creep effects.

The geotechnical monitoring program will establish the loads that are developing in the support and the deformations of the rock that are taking place around the room. The geotechnical data will be used to ensure that the support system is performing in a controlled manner and to establish the load adjustments required to the support system in order to accommodate the creep movements of the salt, and to confirm that room performance remains within satisfactory bounds. Geomechanical monitoring of a room can give indications of its deterioration. Monitoring of the performance of excavations at the WIPP has already provided early identification of such conditions. SPDV Test Room 1 showed evidence of worsening conditions at least 3 years prior to the roof failure in that room. In addition, the Geotechnical Expert Panel has expressed confidence that instrumentation in Panel 1 can give adequate notification of deteriorating conditions (US DOE, 1991).

This plan describes the geotechnical monitoring program that will be implemented to evaluate both the room performance and the performance of the support system. The plan describes the instrumentation that will be installed in the room, and it discusses the criteria that will be applied to ensure that the support system is adjusted in a controlled manner and that room performance remains satisfactory. It should be noted that as more data becomes available, especially on the interaction of the support with the room, then the criteria that are the basis for adjusting the loads on the support may require modification.

The plan has been developed and will be implemented in accordance with the general requirements for the control of test activities as described in the Geotechnical Engineering Program Plan (Westinghouse, 1991a). The Geotechnical Engineering Program Plan supports the Quality Assurance Program implemented at the site (Westinghouse, 1991b) and covers the eighteen criteria that are defined in the Quality Assurance Program for Nuclear Facilities (ANSI/ASME NQA-1-1989).

2.0 MONITORING OF ROOM PERFORMANCE

The program for monitoring room performance has already been developed and implemented in Room 1, Panel 1. The basis for the monitoring is that the measurements and observations are simple to make; that minimal maintenance of instrumentation is required; that instrumentation is easily replaced if it malfunctions; and that conditions throughout the room are known. The data should provide data on geomechanical performance features that have been identified elsewhere in the underground facility, especially in the SPDV Test Rooms as features that should be compared with other data collected at the site. Room performance is being characterized from the following:

- The development of bed separations and lateral shifts at the interfaces of the salt and the clays underlying the anhydrites "a" and "b".
- The establishment of the room closure rates and determination if they are accelerating with time or exceeding expected rates.
- The assessment of the behavior of the pillars.
- The assessment of fracture development in the roof and floor.

The instrumentation in Room 1, Panel 1 was upgraded during the summer of 1991 from the original monitoring program established for the panel in 1988. At that time, limitations were imposed on penetrations through the Anhydrite "b" in the roof. These limitations were in effect for waste storage considerations and no longer apply to the use of the room as the location for the bin scale tests. Roof conditions are now assessed from observation boreholes and from extensometer measurements. Measurements of room closure, rock displacements and observations of fracture development in the immediate roof beam can now be made and used to evaluate the performance of the room. The upgraded monitoring program was presented to the Geotechnical Expert Panel who considered that it was adequate to determine deterioration within the room and could provide early warning of deteriorating conditions in the room (US DOE, 1991).

The location of the instrumentation monitoring room performance is shown in Figure 2-1. The specifications for the instruments are given in Table 2.1. A summary of the installation requirements including tolerances, workmanship and national codes and standards that the instrumentation monitoring system must meet are given in Appendix A. Figures 2-2 and 2-3 provide the instrumentation cabling layout for the convergence meters and extensometers respectively.

2.1 Room Convergence Measurements

Vertical and horizontal convergence stations will be installed at seven cross sections throughout the room to monitor roof/floor and wall/wall room closure. The locations for the instruments are provided in Figure 2-1. At each cross section, roof/floor convergence will be measured at mid span and at room quarter points and wall/wall convergence will be measured at mid wall height. The convergence measurements will establish the rates of room closure for comparison with predicted rates and will be evaluated to determine asymmetric roof/floor closure of the room.

Each convergence station will consist of a mechanical anchor fixed about 150 mm below the rock surface. Details of a typical convergence anchor installation are given in Figure 2-4. An extensometer consisting of a wire or tape stretched under a constant tension and an accurate distance measuring device is attached between the anchors . Changes in length between the anchors will be monitored periodically to determine room closure. The convergence measurements can be made manually or remotely. For manual measurements the extensometer is put in place only for a reading and is subsequently removed. For the remote readings, the extensometer remains in position and the manual extensometer measuring device is replaced by a electronic device capable of measuring length changes. In Room 1, a potentiometer readout with a range of 36 inches will be used where remote readings can be obtained. Remote readings cannot be made at all locations because the permanent installation of wires across the room will interfere with access into the room.

2.2 Extensometer Measurements

Borehole extensometers will be installed in the roof and the walls of Room 1. Roof extensometers will monitor bed separations at anhydrites "a" and "b", and dilation and creep movements within the immediate roof beam of salt. Wall extensometers will monitor the lateral deformations within the pillars.

Within each borehole, five measuring points will be anchored to the rock to monitor rock movements towards the room. Details of a typical borehole extensometer installation are shown in Figure 2-5. In the roof holes, the anchors are nominally fixed at depths into the hole of 0, 2m (6.5 feet), 2.3m (7.5 feet), 4m (13 feet), and 4.3m (14 feet), for the purpose of monitoring bed separation across the anhydrites "a" and "b". In the wall holes, the anchors are fixed at depths of 0, 1.5m (5 feet), 3m (10 feet), 4.6m (15 feet), 7.6m (25 feet) and 15m (50 feet). The specifications for the drilling of boreholes, the installation of extensometers and for the instruments are given in Table 2.2.

Calibration of the measuring device for the multiple point extensometers will be carried out either by the manufacturer or by the Site Calibration Laboratory. Calibration will be traceable to National Institute of Standards and Testing (NIST).

Readings will either be taken manually with a readout device provided by the manufacturer or will be performed remotely through the automatic data acquisition system that is maintained in the underground. Measuring frequency, once the room is in use as a laboratory for the bin scale tests will be carried out every week. This frequency may be adjusted to meet any changes that develop.

2.3 Survey Measurements

Survey measurements will be made in the room by the surveyors from Mine Engineering. These measurements will be used to separate roof and floor deformations. The measurements will be taken on a routine basis, probably at intervals of about 3 months.

2.4 Fracture Mapping of Observation Boreholes

Three observation boreholes have been drilled into the roof of Room 1, Panel 1. Additional boreholes will be installed at the existing locations to monitor the behavior of the roof cross-section. Observations of bed separation and lateral

strata shifts will be made on a routine basis at intervals of about 3 months. The boreholes will be monitored using a scratch probe that has been used for the Excavation Effect Program (U.S. DOE, 1986). The holes can also be viewed with a borehole camera if the fractures require visual observation.

In addition, the boreholes for the rock anchors will be observed for fractures immediately following their drilling. This will be carried out using the scratch probe and the borehole camera.

2.5 Data Acquisition

The instrumentation monitoring room performance, is currently read manually. Conversion to remote reading of instrumentation is planned. This conversion will take place once the data acquisition system for the monitoring of the support system is installed in the room. It may not be practical to convert all the instrumentation to remote readings. The roof extensometers will be converted to remote reading. The ancillary equipment to allow remote reading of the quarter point convergence stations will be installed but a final decision on installation of the wires will depend on establishing that they will not be damaged by personnel maintaining or sampling the bins. The roof/floor convergence stations at midspan i.e. down the middle of the central access way and the wall/wall convergence stations will not be monitored remotely as they would interfere with access.

Remote instrumentation will be monitored from a data logger located in an alcove in S1950 of Panel 1 between Rooms 4 and 5. The data logger is part of the Geomechanical Instrumentation System installed in the underground. The system is controlled from a computer located on the surface. The data logger that will be used to remotely read the instrumentation monitoring room performance in Room 1 is already in place. The specifications to which the datalogger is manufactured are provided in Appendix A.

The results from the instrumentation in the room will be evaluated on a continuous basis. Documentation of the results will be provided annually in the Geotechnical Field Data and Analysis Reports.

3.0 MONITORING OF SUPPORT SYSTEM PERFORMANCE

The monitoring of the support system performance provides an assessment of the manner in which the support is controlling roof movements including the breakup of the immediate roof. The monitoring program in Room 1, Panel 1 will evaluate the following:

- The performance of the structural system that supports the roof.
- The load that develops in each rock anchor for the purpose of adjusting loads so that the build up is controlled in a consistent manner.

The basis for the instrumentation will be that the measurements are simple; that instrumentation is easily replaced if it malfunctions; and that the performance of each anchor can be continuously monitored and readily compared with performance of other anchors. The instrumentation layout for monitoring the

support system performance is provided in Figure 2-6. Cabling layouts are provided in Figures 2-7, 2-8, and 2-9.

The most important of these measurements are those that determine the anchor loads. These measurements will be used to adjust the anchors to ensure that they are not stressed beyond the allowable working stresses and that the roof is lowered in a controlled manner that accommodates the continued creep of the solid salt.

The measurements of cable elongation and pressures developing on the sheeting will be taken to determine how these components of the support system are performing. No adjustments are planned on the basis of these measurements. However, if they show load buildup, additional actions may be considered. It is not expected that breakup of the roof rock will be excessive, it appears more likely that the rock will remain primarily self supporting until the detached wedge in the roof fully forms. It is not expected that this will occur within the next two years based on the experience obtained from SPDV Test Room 1 Therefore, it is not believed that loads approaching the full weight of the detached wedge will develop on the expanded metal sheeting and the cables.

3.1 Rockbolt Load Cells

The rockbolt load cells will monitor the axial loading on the rock anchors. The measurements will be made on each anchor and will be the basis for adjusting the load on each anchor, should an adjustment become necessary.

Each load cell consists of a cylindrical body with a central annulus for the rock anchor. The load measuring element is a spool of high strength steel or aluminum on which electrical resistance strain gauges are bonded in a full bridge configuration that provides temperature stability and compensates for off center loading. A steel outer cover and O ring seals protect the strain gauges from mechanical damage and water penetration.

The load cells shall have sufficient capacity to measure up to 50 kips with a sensitivity of 0.02 kips. In order to maximize the vertical adjustment on the tendons, the height of the load cells shall not exceed 75 mm. The typical load cell installation is shown in Figure 2-10.

3.2 Pressure Cells

Pressure Cells will monitor the pressures that develop between the expanded metal sheeting and the salt roof. The measurements will be made in selected areas within the room that are expected to have the greatest roof movements and hence, be more susceptible to the development of loads due to the breakup of the immediate roof rock. Typical pressure cell installation is shown in Figure 2-11.

Each pressure cell is manufactured from two steel plates welded together. The space between the two plates is filled with de-aired antifreeze solution or hydraulic fluid and is connected via a high-pressure stainless steel tube to a pressure gage and/or pressure transducer. A pump is used to inflate the pressure cell and press the cell against the rock. A change in load on the cell will cause a deflection of the diaphragm which results in a change in the fluid pressure. The pressure cells, in Room 1, will be installed between the rock and the mesh to monitor the pressure distribution on the cable lacing and mesh.

The pressure cells will be constructed from corrosion resistant materials such as stainless steel. The pressure cell can be modified for remote monitoring by replacing the pressure gage with or adding a pressure transducer.

The pressure cells will be placed between the rock surface and support mesh. An important factor to take into consideration when installing a pressure cell is to ensure good contact with the surrounding material and to avoid localized or point loading of the cell. To avoid point loading, each pressure cell will be encapsulated with a concrete based grout. After the grout has set up, the pressure cell will be placed between two steel plates in order to evenly distribute the load on it. The pressure cells will be pumped up so that the cell is completely filled with fluid.

Pressure in the cells will be monitored using pressure gages. Monitoring of the pressure cells can be changed from manually read to remotely read with the addition of a pressure transducer to the cell.

3.3 Cable Elongation

Crack meters will monitor the elongation of the cables that support the mesh and expanded metal sheeting. The measurements will be made at selected sections within the room that are expected to have the largest deformations and subsequently load the mesh an cables. Typical crack meter installation is shown in Figure 2-12.

3.4 Data Acquisition System

The data acquisition system shall provide for remote multiplexing of the load cells at locations within the room. The data acquisition system shall be capable of handling the required number of multiplexers. The data acquisition system shall be configured to monitor 33 rows of load cells, each row containing 11 loads cells.

The data logger will consist of a programmable controller, switching units, and a readout device. To prevent thermal deterioration, the switching units must multiplex all signal functions for each instrument. Continuous connection to a constant-voltage power bus is not allowed.

The data logger will include a Racal-Vadic Model VA1251G/K modem for data link connection to the surface data logging computer.

To facilitate compatibility with existing GIS equipment, existing communication parameters, protocol, and programming must be incorporated into the data logging components.

A Racal-Vadic Modem Model VA1251G/K will exchange ASCII character data over the datalink cable via the following parameters:

- Baud Rate - 300
- Parity - Even
- Stop Bits - One
- Word Length - Seven Bits

The two panel switches on the Racal-Vadic Modem are to be set as follows:

- Analog/Digital Loopback - OFF
- Transmit Reversal - OFF

The modem's RS-232 interface will connect with the supplier-provided control units to ensure proper data communications.

The surface datalogging computer has been programmed to communicate with all underground control units through an exchange of ASCII character data. The computer sends a two character address sequence down the datalink cable through the surface modem. Each control unit then demodulates the character sequence through its modem. Each control unit is uniquely programmed (via a PROM chip) to respond to its own address sequence. Upon receipt of its address sequence, each control unit will poll its instruments, perform any necessary data reduction, and send instrument readings through the modem as a string of ASCII characters.

4.0 ADJUSTMENT OF SUPPORT SYSTEM

The anchors will be set to a nominal load of 500 kg (1000 lb) after proof testing to 1.33 times their working load. The purpose of the preload is to ensure that the lacing and meshing under the channel is secured firmly in position. As the loads change they will be compared with an estimate of conditions. There are two cases to be considered. These are the control of load during the detachment of the wedge when the full loads have not developed and the case when the wedge has detached and the working loads have been reached and any continued build up would be dependent on the creep of the solid salt onto the wedge that creates a stress build up in the support system that must be relieved by the controlled yield of the support.

Initially, the roof will be self supporting as the fractures will not have developed sufficiently to define a detached wedge. It is likely that this condition will be maintained for a period of years, especially if the bolting systems are able to reduce the widening and propagation of the fractures that do develop. However, for worst case conditions, it will be assumed that fractures will propagate and that gradually the degree of self support of the roof will be lost. As this occurs, the rock anchors will provide increasing roof support and loads will build up in the anchors. Once the roof wedge becomes detached, then the rock anchors will be fully supporting the wedge and will have reached their working loads. Control of anchor loads must consider the adjustments needed during load build up when the wedge is not fully detached and load distributions may not be as expected, and those required once the wedge has detached and is subject to both vertical and lateral movements due to the creep of the solid salt.

In addition, the wedge shape must be taken into account when estimating the adjustments that must be made to the anchor loads. Two possible geometric shapes have been proposed to define the wedge that develops in the roof of excavations. A triangular distribution identified from visual observation of the roof fall in SPDV Test Room 1, and a parabolic distribution based on survey data of the roof of the room after the fall. For the purpose of assessing the adjustments to the anchors in Room 1, both distributions will be compared with the field data to determine which is more appropriate. The comparison will be carried out on a row by row basis and also over time since the geometry of the wedge may depend on

location within the room and load distribution within a row of anchors may change with time as fractures develop.

4.1 Criteria for Load Adjustment

The preliminary criteria for adjusting the loads in the anchors are as follows for the two cases that have been identified:

CASE 1: Load distribution below Maximum Working Load

This case will occur as the load develops from the nominally applied loads due to the increasing support provided to the wedge as the fractures develop. During this stage it is not obvious precisely how the loads will build up, but it is expected that they will develop slowly because the rock is still self supporting. Based on these assumptions, the following criteria will be applied to load adjustments for a row during the build up to maximum working loads:

- No adjustments will be considered necessary to a row of anchors until the load in one anchor exceeds 27.5 MPa (4 kips.)

- If the load distribution within a row of anchors is consistent with a triangular or a parabolic load distribution, then no adjustment is necessary. Consistent is taken to mean, variations from the load distribution of less than 20 percent for all anchors in the row.

- If the loading for a row of anchors is consistent with a triangular or a parabolic distribution but with a variation from 20 to 25 percent for an individual anchor, then no adjustment is necessary, but an analysis shall be made to establish the rate of load increase for all anchors within the row and to estimate whether the variation is increasing and the time that it will take to reach a value of 25 percent above the remainder of the distribution.

- If the load distribution for a row of anchors is consistent with a triangular or a parabolic load distribution but with a variation of 25 percent for an individual anchor, then an adjustment to that anchor will be carried out. The load on the anchor will be reduced by not more than 50 percent.

- If the load in one anchor exceeds 27.5 MPa (4 kips) and the load distribution within the row is not consistent with either a triangular or a parabolic distribution, then a study will be carried out to establish whether an alternative plausible load distribution can be established. If this is possible, then this distribution will be used to determine the adjustment to the anchor load.

For example, if the loads develop on one side of the room due to asymmetric room closure, then an asymmetric load distribution may be found to be a more appropriate basis for load redistribution.

CASE 2: Load Distribution at Maximum Working Loads

Load distribution at maximum working load is considered to have developed when controlled adjustment of a row of bolts cannot reduce the anchor loads below

levels that are consistent with the weight of a detached rock wedge. Once this stage has been reached, then the following criteria will be used to adjust the anchors in each row:

- If the measured load in an anchor is 10 percent or more over the allowable working load for that anchor, an adjustment to the load will be made. The load on the anchor will be reduced by not more than 50% of its allowable working load.

- If the load distribution does not conform with a triangular or parabolic distribution, a study will be carried out to determine whether the measured distribution is reasonable and can be explained in terms of a geometric wedge shape that is appropriate.

These criteria are based on our expectation of the performance of the roof rock and of the support system and their interaction. A mock up demonstration is planned in another room in Panel 1. During the demonstration, loads in the anchors will be adjusted to establish the effects of changing loads by a controlled amount on the loads that develop on nearby bolts. Should the data from the demonstration indicate that the criteria do not provide adequate control for support system adjustments, then alternative criteria will be developed. The application of the modified criteria to the adjustment of the support system in Room 1 will require the approval of the Manager of Engineering for the Managing and Operating Contractor for the WIPP with concurrence from the Managers of Operations, Safety, and Quality Assurance.

4.2 ANALYTICAL EVALUATION FOR LOAD ADJUSTMENTS

In parallel with the monitoring of actual loads in the rock anchors, a study will be carried out to determine the load transfer that can occur between anchors. The study will include field tests and analytical computations. The field tests will investigate how load changes in one bolt affect adjacent bolts. Computational analyses will look at load transfer effects between bolts. These studies will be completed before adjustments to anchor loads are required in Room 1, Panel 1.

Computer simulations will assess the effects of adjusting the loads within the tendons . This will be done on a row basis, since the available software codes are based on two dimensional modelling. This assumes that interaction effects between rows spaced nominally 10 feet apart will not be significant. The codes that will be used are VISCOT, a finite element code and FLAC, a finite difference code. Both codes were developed for the structural analysis of geologic media. The VISCOT code which is a version of a publicly available code originally developed by Owen and Hinton (1980) was modified for used in the Salt Repository Program for the disposal of high level radioactive wastes. The FLAC code (ITASCA, 1991) is a proprietary code developed by ITASCA, Inc. to simulate the behavior of geotechnical materials which may undergo plastic flow.

The codes will be used to determine interaction effects between bolts supporting the isolated rock wedge. They will establish if adjusting the load in one anchor within a row will change the loads in other bolts within the row and by how much. They will also assess whether asymmetric load distributions can develop due to lateral or differential vertical displacements of the salt and how these effects can be compensated for or minimized by adjusting the anchor loads.

A preliminary assessment of load redistribution has been carried our using VISCOT. For the case of the fully detached wedge reduction is bolt loading of will be redistributed among the other bolts in a row without overloading of any bolt. The redistributions for a number of cases are shown in Figures 4-1. It should be noted that the study of bolt load adjustment will be an ongoing activity and that field data will be assessed to determine the effectiveness of the analytical evaluations for load adjustments.

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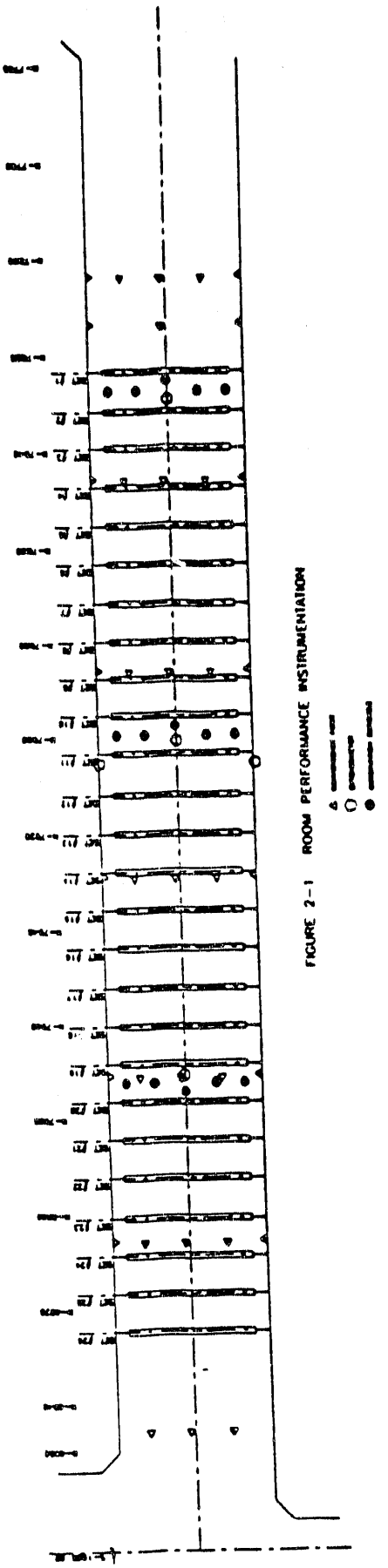


FIGURE 2-1. Room Performance Instrumentation

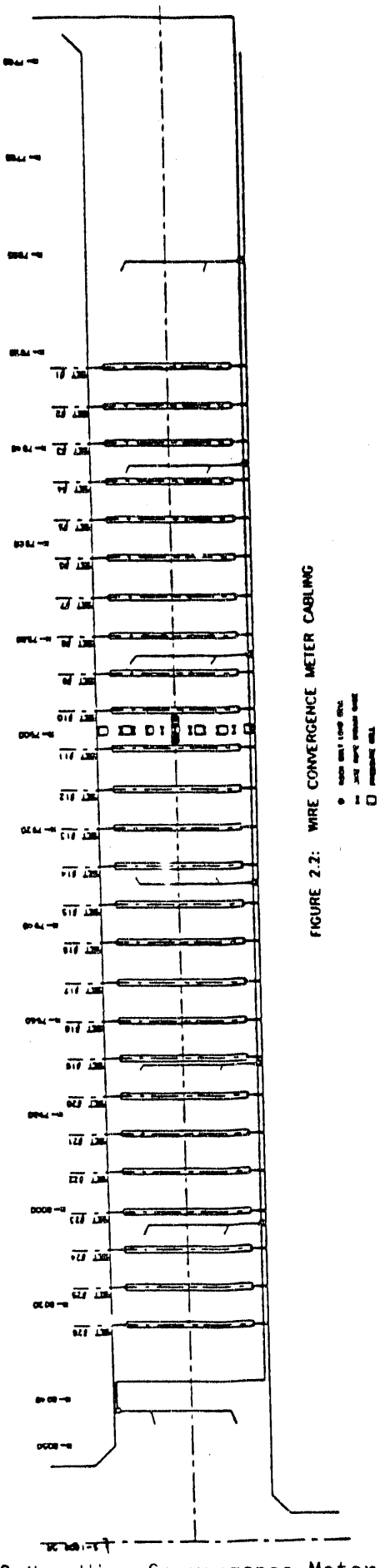


FIGURE 2-2. Wire Convergence Meter Cabling

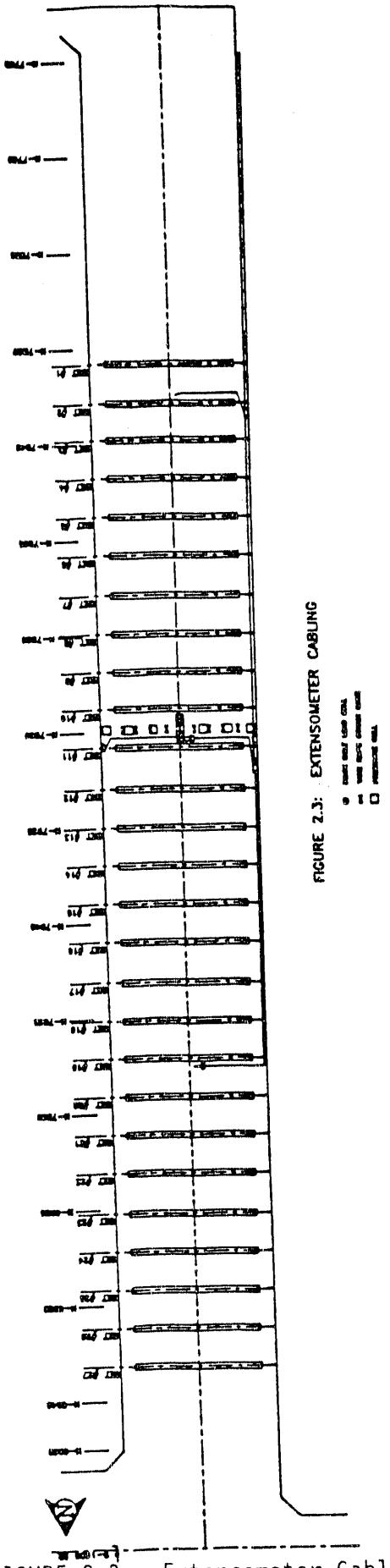
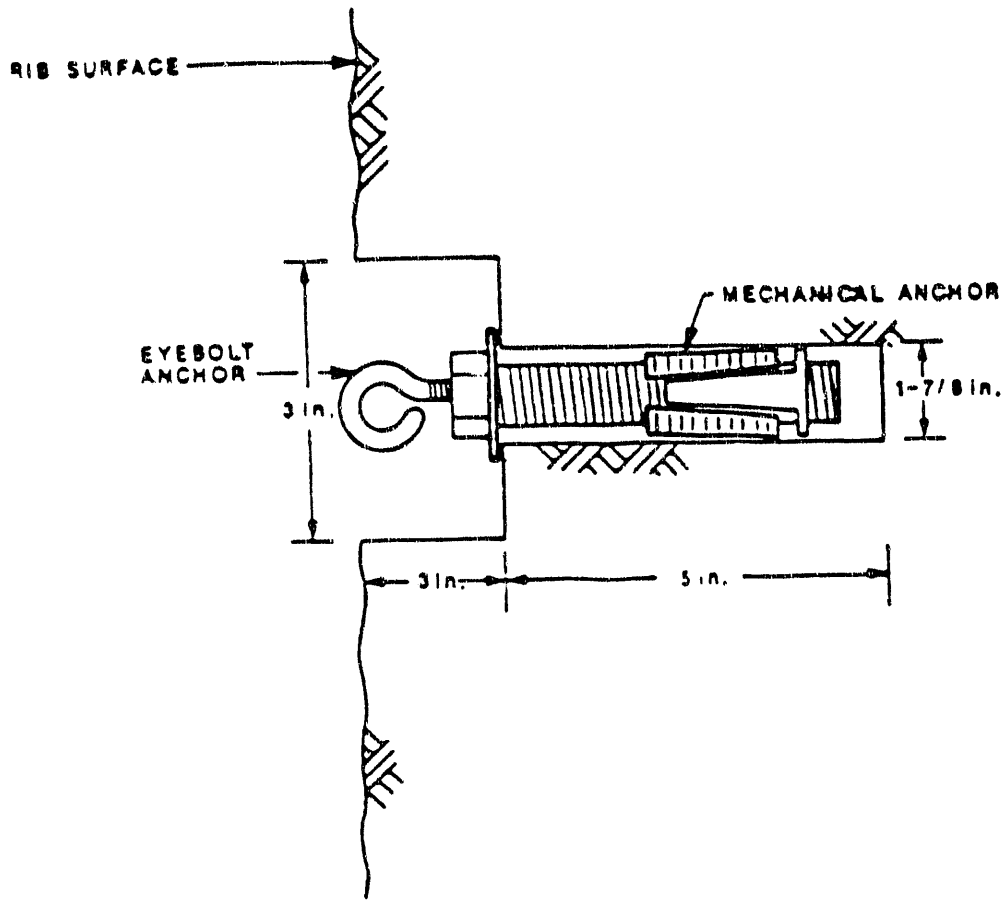


FIGURE 2-3. Extensometer Cabling



Note: • *Floor installations may be recessed greater than 3 in. and protected with coverplate.*

• *Dimensions approximate*

FIGURE 2-4. Typical Radial Convergence Point

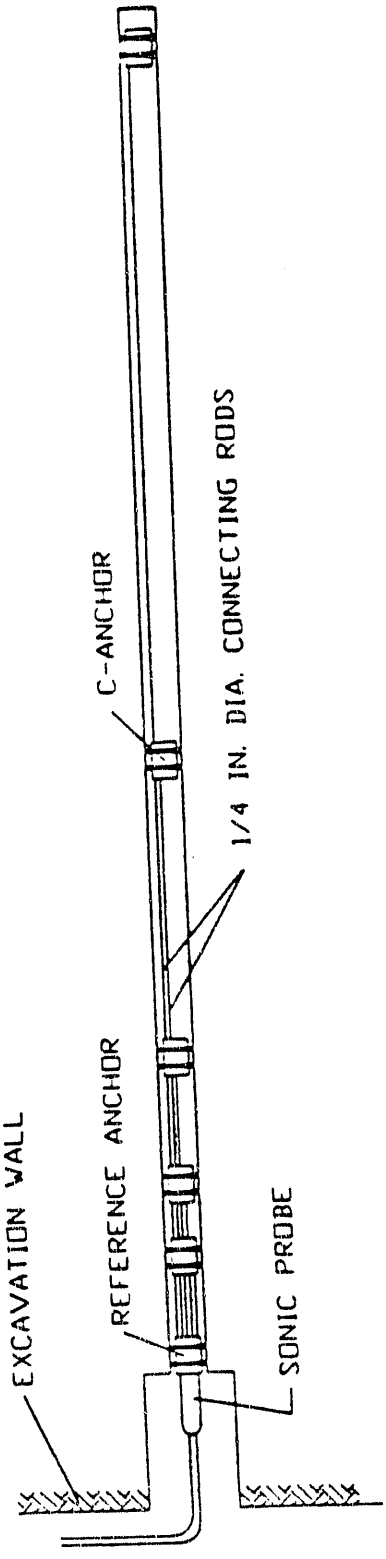


FIGURE 2-5. Typical Rod-Type Extensometer Installation

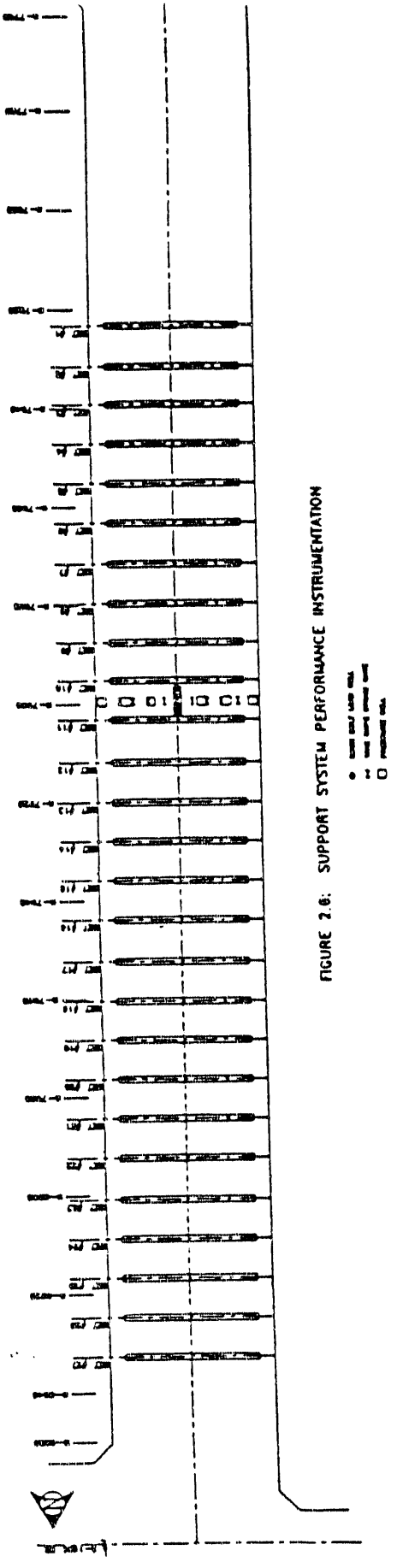


FIGURE 2-6. Support System Performance Instrumentation

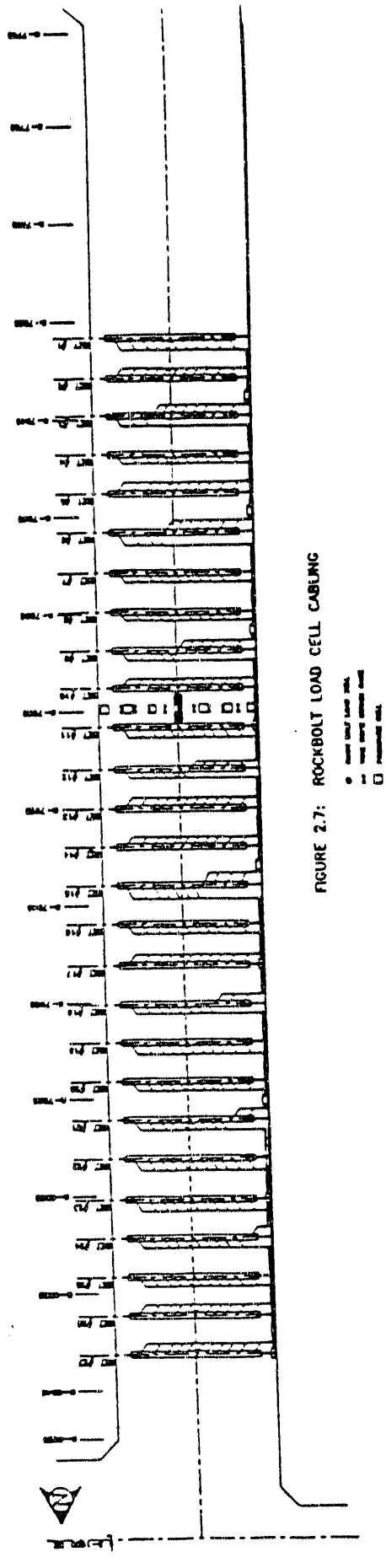


FIGURE 2-7. Rockbolt Load Cell Cabling

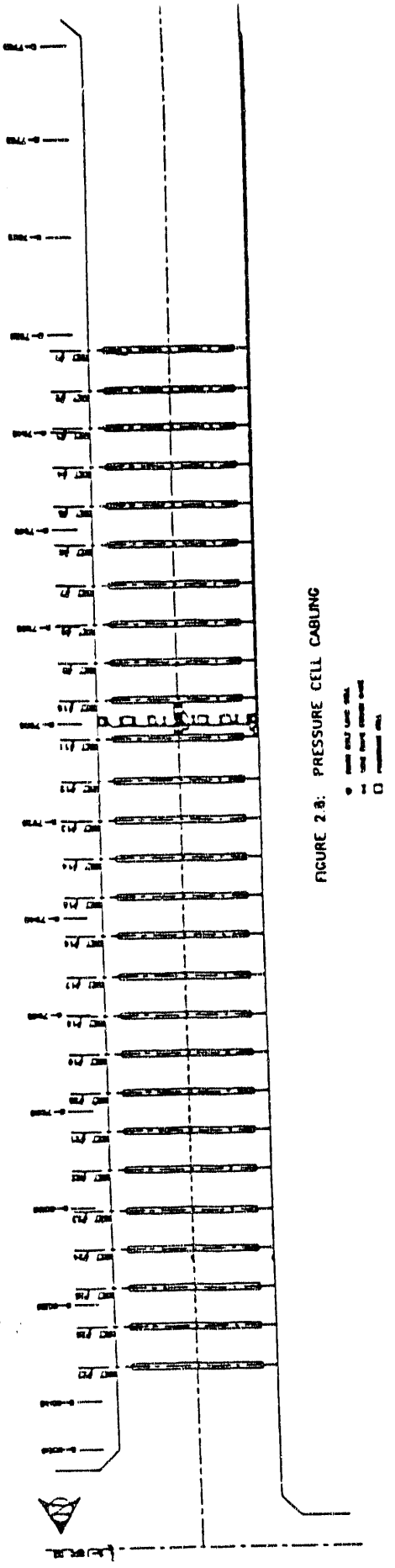


FIGURE 2-8. Pressure Cell Cabling

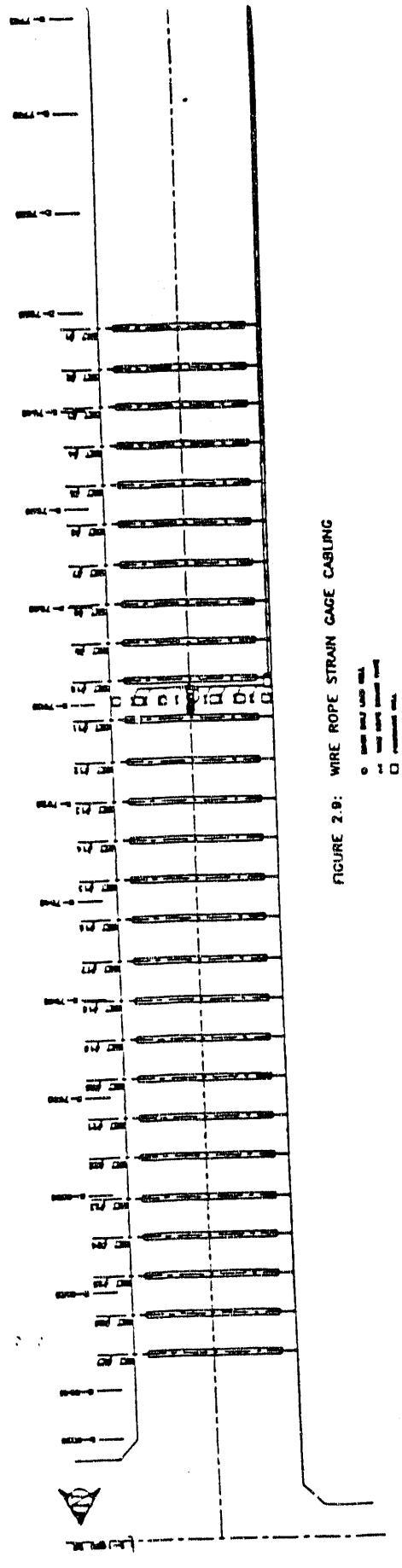


FIGURE 2-9. Wire Rope Strain Gage Cabling

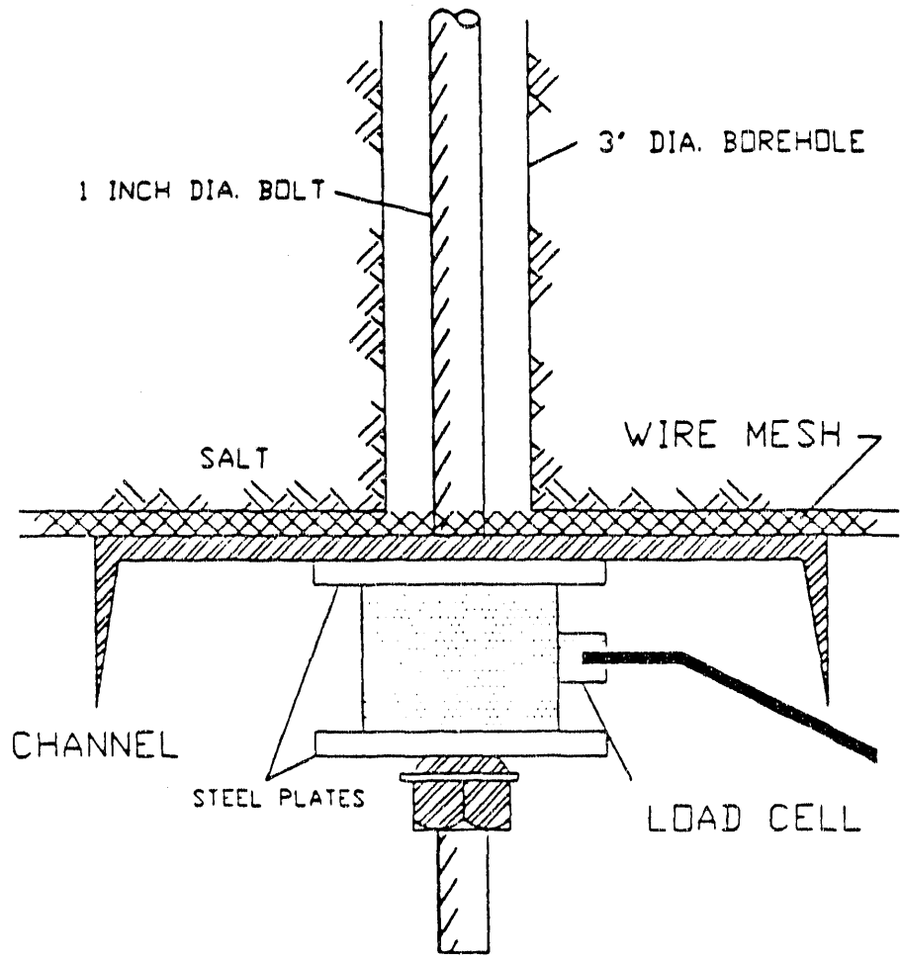


FIGURE 2-10. Typical Load Cell Installation

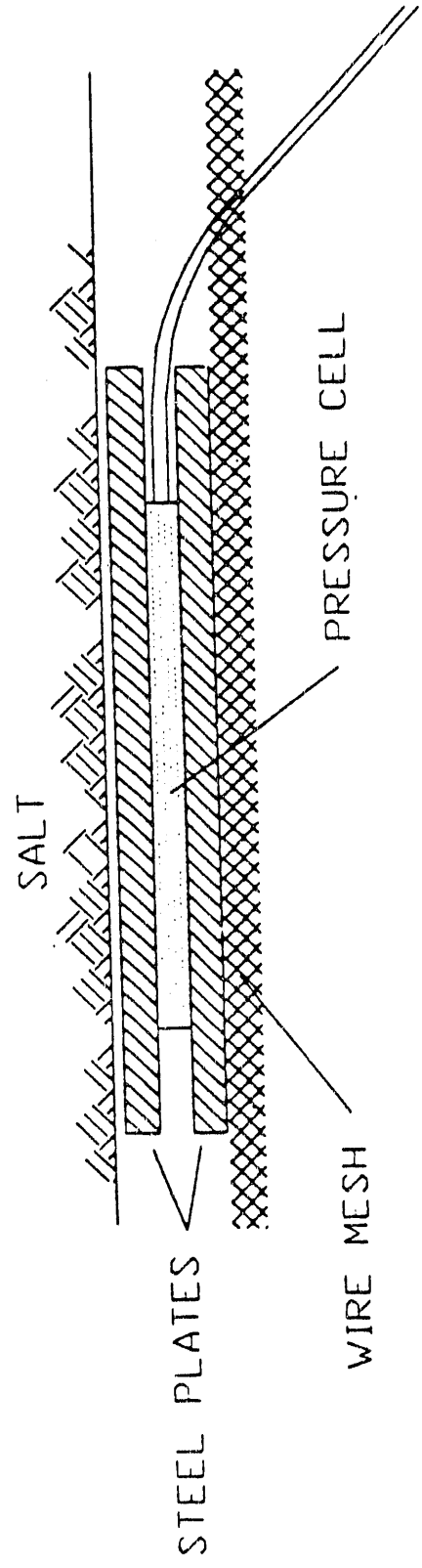


FIGURE 2-11. Typical Pressure Cell Installation

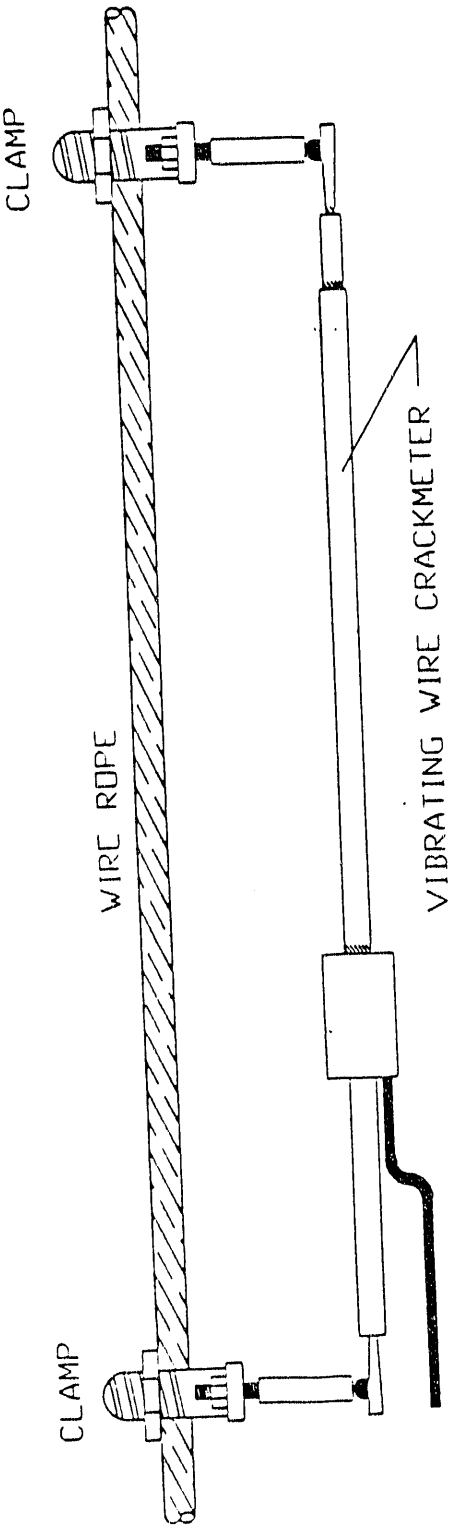


FIGURE 2-12. Typical Crackmeter Installation

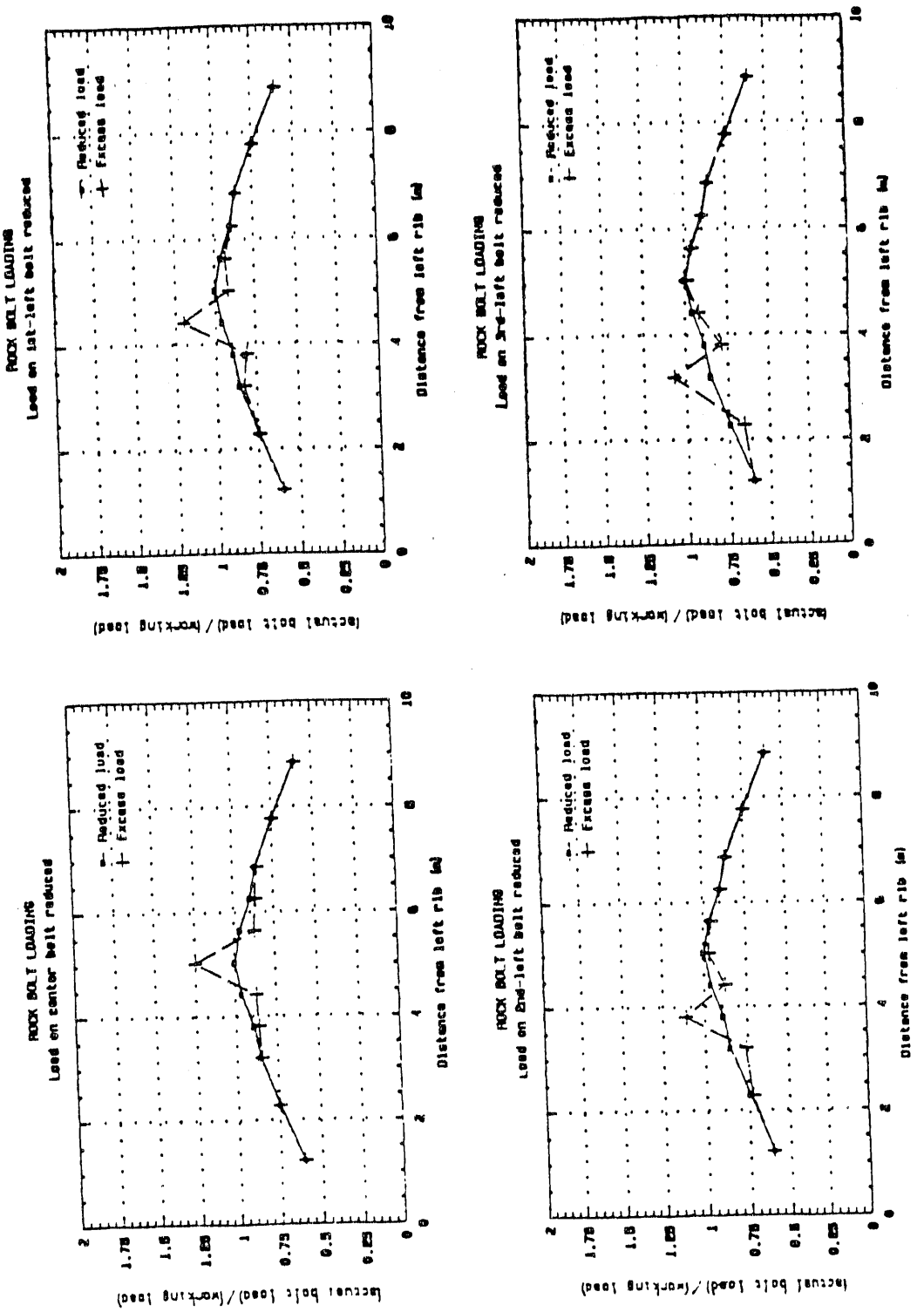


FIGURE 4-1. Rock Bolt Loading Redistribution

Table 2-1

PANEL 1 ROOM 1
GEOMECHANICAL INSTRUMENTATION SPECIFICATIONS

TABLE 2.1

PANEL 1 ROOM 1
GEOMECHANICAL INSTRUMENTATION SPECIFICATIONS

Instrument Type	Measured	Range	Precision	Accuracy	Method
Borehole Extensometers	Cumulative Deformation	0-2 in.	+/- 0.001 in.	+/- 0.001 in.	Sonic Probe
Convergence Points	Cumulative Deformation	2-50 ft.	+/- 0.001 in.	+/-0.005 in.	Tape Extensometer
Convergence Meters Wire	Cumulative Deformation	0-3 ft.	+/- 0.004 in.	+/- 0.032 in.	Rotary Potentiometer
Rockbolt Load Cells	Load	0-50 tons	+/- 40 lbs	+/- 40 lbs	Strain Gage
Earth Pressure Cells	Lithostatic Pressure	0-10 psi	+/- 0.05 psi	+/- 0.05 psi	Vibrating Wire
Crackmeters	Cumulative Strain	0-4 in.	+/- 0.0008 in.	+/- 0.004 in.	Vibrating Wire

APPENDIX A

GEOMECHANICAL INSTRUMENTATION SYSTEM SPECIFICATIONS

MATERIALS/INSTALLATION	SPECIFICATION
CABINET DESIGN AND PERFORMANCE	Specification No.E-P-309 1. Cabinets shall be wall-mounted Maintenance to wall. Maintenance on wall-mounted cabinets shall be from the front. 2. Cabinet enclosures shall be NEMA Type 4X enclosures. 3. Interface cabinets shall be fitted with flame-resistant gaskets and tamperproof screws. 4. All controls,instruments, and devices shall be shown on the contract drawings. 5. Cabinets shall have their identification permanently marked on the cabinet or panel structure immediately adjacent to their location. Identification shall be clearly visible.
INSTRUMENTATION CABLES	Specification No.E-Q-281 1. Cable shall be suitable for use in dry and wet location, capable of continous operation temperature of 90 degrees Celsius. It shall be UL-listed as Type TC cable in accordance with NFPA 70, Article 340. 2. Cable shall be rated for 300V or 600V insulation, single- or multiple-twisted pairs. 3. Each conductor shall be tinned, soft or annealed copper, Class B seven-strand concentric in accordance with ASTM B 33 and ASTM B 8, Size No. 16 AWG for single pairs and No. 20 AWG for multiple pairs.
INSTRUMENTATION CABLES	4. Cable shields for single-twisted pairs shall be mede of aluminum taps wrapped around the conductor and the tinned stranded copper drain wire. 5. Shielding for multiple shielded pairs shall consist of a group shield wrapped around each pair and drain wire and an overall cable shield wrapped around the whole cable assembly and drain wire. 6. Conductor identification shall be by color codes in accordance with NEMA WC 30.

MATERIALS/INSTALLATION	SPECIFICATION
INSTRUMENTATION CABLES	7. Insulation and Jacket For U/G installatins the following materials are approed for use for cable insulation and jacketing as designated below: 1. Jacketing: CPE - Chlorinated Polyethylene CSP - Chororsulphonated Polyethylene - Neoprene 2. Insulation: EPR - Ethylene Propylene Rubber PPE - Polypropylene Ethylene XLPE - Crosslink Polyefin (Polyethylene) EPDM - Ethylene Propylene Diene Monomer 8. All wires and cables shall be identified at junction boxes and cabinets with wire and cable marker indicating the instrument number of the wired device.
TERMINAL BLOCKS & STRIPS	Specification No.E-P-244 1. Terminal blocks shall be surface-mounted, molded plastic screw-terminals, barrier type, capable of accepting No. 20 through No. 12 AWG wire terminated with solderless ring-tongue compression-type lugs. An 8-inch horizontal clear gap shall be provided between adjacent columns.

MATERIALS/INSTALLATION	SPECIFICATION
	2. Thirty percent unused spare terminals shall be provided for each group of terminal blocks. 3. Terminal blocks shall be grouped by circuit type and segregated according to circuit voltage and destination of field wiring. 4. Not more than wires shall be connected to any one terminal point. 5. Terminal strips for powere connections shall be fitted with covers to minimize shock hazards. 6. Each teminal block marking strip shall be identified. Identification of terminal blocks and terminal points shall be alphanumeric, with each terminal block having unique identifying letters and each terminal point to identify instrument input.
GROUNDING	Specification No.E-P-247 1. Instrument cases, relays, and other switching devices shall be grounded to the cabinet or panel steel structure through theri mounting screws. Additional grounding shall not be required. 2. For each instrument circuit with a definite ground at the cabinet or panel, a single wire shall be run independently to the applicable ground bus and fastened thereto with a drilled-and-tapped connection, or on a terminal board for wall-mounted cabinets. Each ground point shall be readily accessible for removal, testing, and replacements. 3. Signal cable shielding and grounding requirements shall be included in the wiring diagrams.
FUNCTIONS OF TYPICAL INTERFACE DEVICES	1. Control Unit: When the control unit is activated by the communication controller, either locally or remotely by the GIS Data Logger, it shall, in turn, activate the readout unit and switching module simultaneously to read

MATERIALS/INSTALLATION	SPECIFICATION

all the sensors and transmit the output of the readout unit to the GIS Data Logger. When the last connected sensor has been read, the unit shall deactivate itself.

2. Switching Module: Sequentially connects the readout unit to the sensors, enabling each one to be read.

3. Remote Reaout/Polling Unit: When the readout unit connected to particular sensor, the readout unit shall energize the sensor, receive its measurement, display the reading, and the transmit the reading to the communication controller through the signal converter.

4. Signal Converter: If the ouput from the readout unit is not in conformance with EIA RS-232-C and ANSI X3.4, a signal converter shall be furnished to generate a serial ASCII signal. The signal converter shall be either an internal subsystem in the control unit or an external unit.

5. Communication Controller: Under the control of the GIS Data Logger, the Communication Controller shall activate the remote readout/polling unit to start the data transmission and deactivated the remote readout/polling unit when data transmission in complete.

FUNCTIONS OF TYPICAL INTERFACES DEVICES

When interrogated by the GIS Data Logger, the Communication Controller shall be able to handle the malfunction or failur of the interface devices. The Communication Controller shall modulate and demodulate the signal for the data link cable/

RECORD OF REVISION

Rev./PCN No.	Reason for Revision/Change
0	New procedure written from WP 04-110/WP 04-1NO042

INFORMATION ONLY

TECHNICAL REVIEW ORGANIZATIONS (check as applicable)

Facility Operations	X	Mining Operations	N/A	Engineering	X	Radiological Engineering	N/A
Underground Operations	X	Hoisting Operations	N/A	Quality Assurance	N/A	Environmental	N/A
Waste Handling Operations	N/A	Safety	N/A	Regulatory Assurance	N/A	Sandia National Laboratories	N/A

Initiated By: Bert E. Markillie (Name) 3/26/91 (Date)

OPSRC Approval: [Signature] (Signature) 4/17/91 (Date)

Approved By: [Signature] (Signature) 4-17-91 (Date)

Effective Date: 04/17/91

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1.0 PURPOSE and SCOPE

1.1 The purpose of this procedure is to provide instructions for Facility Operations to operate the Site Back Up Power System during loss of (Utility Power) Public Service Power at the Waste Isolation Pilot Plant (WIPP).

1.2 The scope of this procedure includes safe operation of the following:

- The Site Back Up Power System during loss of (Utility Power) Public Service Power
- Alternatives for energizing the site with and without the Plant Sub buses

2.0 REFERENCES

2.1 BASELINE DOCUMENTS

25-J-020-W, (Sheets 1-9) WIPP Site Primary Power Distribution - One Line Diagram

2.2 REFERENCED DOCUMENTS

- WP 04-ED1021, Site Surface Electrical Distribution System
- WP 04-ED1221, Operation of Site Surface Electrical Distribution Breakers
- WP 04-ED1301, Operation of Diesel Generator No. 1
- WP 04-ED1321, Operation of Diesel Generator No. 2
- WP 04-ED1621, Normal Underground Electrical Distribution Lineups

3.0 DEFINITIONS

3.1 ACRONYMS

- CAM - Continuous Air Monitor
- CB - Circuit Breaker
- CMRO - Central Monitoring Room Operator
- DG - Diesel Generator
- LIS - Load Interrupter Switch

- OPS - Operations
- PS - Plant Sub
- SUB - Substation
- U/G - Underground
- VIS - Vacuum Interrupter Switch

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4.0 EQUIPMENT LIST

NONE

5.0 PRECAUTIONS AND LIMITATIONS

5.1 High Voltage is present in switches and breakers; use CAUTION when positioning these devices.

5.2 LIS(s) **SHALL** NOT be operated from CLOSED to OPEN position with a connected load.

5.3 Under NO circumstances **SHALL** an attempt be made to override or defeat KEY interlocks without Engineering concurrence.

5.4 Operation of Site CBs **SHALL** be performed in accordance with WP 04-ED1221.

5.5 U/G Switching and lineups **SHALL** be performed by Procedure WP 04-ED1621.

5.6 Breaker and system interlocks **SHALL** NOT be relied upon for safe operation of site Electrical Systems.

5.7 Utility Sub CB-1 **SHALL NOT** be CLOSED paralleling 1 or 2 diesel generators with Utility Power.

5.8 The sequence of CB operation **OR** substation energization will be at the FOSS's discretion.

5.9 Any CB or switch which is Danger Tagged or Locked Out **SHALL NOT** be operated.

5.10 When starting or energizing equipment identified in this procedure use the specific procedure for that equipment.

5.11 Inspect for missing or improperly installed panels, doors or hardware.

5.12 Inspect relays for flags and ground loss indications (95 relay light normally ON).

5.12.1 DO NOT CLOSE a CB that has a flag.

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5.12.2 **DO NOT** energize equipment being served by the tripped CB with a flag.

5.12.3 Notify the FOSS of any relay flags found.

5.12.4 Reset relay flags after Maintenance and Engineering concur, with the exceptions of the following:

A) When a 27 (under voltage) relay flag and a 86 (lockout) relay flag are BOTH present due to a known power outage,
AND
NO other flags are present.

B) Make only one attempt to RESET 86 (lockout) relay.

C) When an 81 (Under Frequency) relay flag is present, due to a known power outage.

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5.12.5 Plant Sub 13.8 Kv breakers feeding U/G will NOT CLOSE if the U/G 13.8 Kv switchgear panel is OPEN. This will cause the 95 (ground check) relay light on corresponding PS CB to be OFF.

5.13 The performance of this procedure requires coordinated activities between Surface Facility Operations and U/G Operations. The Central Monitoring Room Operator (CMRO) will be the contact point and coordinate these activities.

5.14 Perform Section(s) of procedure as directed by the FOSS.

6.0 INITIAL CONDITIONS

None

7.0 PROCEDURE

7.1 ENERGIZING SITE WITH BACKUP POWER USING 13.8 Kv CABLES (NOT using PS).

7.1.1 **IF** U/G is manned,
THEN notify U/G Ops VIA CMRO to align the U/G for receiving power from the Exhaust Shaft Feeder,
AND
Configure for one (1) 860 fan in filtration.

7.1.2 Verify Utility Sub CB-1 is OPEN.

NOTE: Attachment 1 **SHALL** be completed in conjunction with Steps 7.1.3 through 7.1.19.

7.1.3 Reduce loads per Attachment 1.

7.1.4 Start Diesel Generator No.1
OR
No. 2.

7.1.5 Verify the following Plant Sub CBs are OPEN:

- CB-10
- CB-1
- CB-2
- CB-3
- CB-4
- CB-9
- CB-5
- CB-6
- CB-7
- CB-8

7.1.6 Verify SB Air Compressors 45-G-400A/B are OFF at control panel.

7.1.7 Verify SB Air Compressors 45-G-403A/B are OFF at control panel.

7.1.8 Verify Air Compressors 41-G-021A/B are OFF at control panel(s).

7.1.9 Verify Chilled Water Pumps 41-B-891A/B are OFF at control panel.

7.1.10 Line Up Sub 2 by verifying the following:

A) OPEN Sub 2 LIS 25P-SW15/2A.

B) CLOSE Sub 2 LIS 25P-SW15/2B.

C) CLOSE Sub 2 CB-1 Main Breaker.

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D) CLOSE Sub 2 CB-2.
Water Chiller, 41-B-890A.

E) CLOSE Sub 2 CB-3.
Air Handling Unit CH Area, 41-B-812.

F) CLOSE Sub 2 CB-4.
Air Handling Unit CH Area, 41-B-813.

G) CLOSE Sub 2 CB-5.
WHB Overpack, 41P-MCC04/5.

H) CLOSE Sub 2 CB-6.
Water Chiller, 41-B-890B.

I) OPEN Sub 2 CB-7 (Spare).

J) CLOSE Sub 2 CB-8.
Mech. Equip. Room WHB, 41P-DP04/3.

7.1.11 OPEN Sub 4 CB-1 Main Breaker.

7.1.12 Line Up Sub 6 by verifying the following:

A) OPEN Sub 6 LIS 25P-SW15/6A.

B) CLOSE Sub 6 LIS 25P-SW15/6B.

C) CLOSE Sub 6 CB-1 Main Breaker.

D) OPEN Sub 6 CB-2.
Switchrack 7, 24P-SWRO4/7.

E) CLOSE Sub 6 CB-3.
Hoist, 33P-HMO4/1.

F) OPEN Sub 6 CB-4 (Spare).

G) CLOSE Sub 6 CB-5.
Switchrack, 33P-SWRO4/1.

7.1.13 Line Up SB Sub by verifying the following:

A) OPEN SB Sub LIS 45P-SW15/1A.

B) CLOSE SB Sub LIS 45P-SW15/1B.

C) CLOSE SB Sub CB-1 Main Breaker.

D) CLOSE SB Sub CB-2.
Elect. Equip. Room SB, 45P-MCC04/4.

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E) CLOSE SB Sub CB-3.
Mech. Equip. Room WHB,
41P-MCC04/6.

F) CLOSE SB Sub CB-4.
Hoist Control Room WHB,
31P-MCC04/1.

G) Verify SB Sub CB-5 is OPEN and LOCKED.
Tie to Sub 3 CB-1.

7.1.14 Line Up Sub 1 by verifying the following:

A) CLOSE Sub 1 LIS 25P-SW15/1B2.

B) CLOSE Sub 1 LIS 25P-SW15/1B1.
Tie To Sub 3 Top Side of the
LIS 25P-SW15/3B.

C) CLOSE Sub 1 CB-1 Main Breaker.

D) CLOSE Sub 1 CB-2.
SB, 45P-MCC04/3.

E) CLOSE Sub 1 CB-3.
RH Waste Area, 41P-MCC04/1.

F) CLOSE Sub 1 CB-4.
Operating Gallery,
41P-MCC04/2.

G) CLOSE Sub 1 CB-5.
Mech. Equip. Room WHB,
41P-MCC04/3.

H) CLOSE Sub 1 CB-6.
Air Handling Unit RH Area,
41-B-803.

I) CLOSE Sub 1 CB-7.
Air Handling Unit RH Area,
41-B-804.

J) Verify Sub 1 CB-8 is OPEN and LOCKED.
Tie to Sub 3 CB-18.

K) CLOSE Sub 1 CB-9.
Bldgs 482, 41P-MPC03/3
and EOC 462, 45P-DP04/27.

7.1.15 Verify CLOSED LIS 25P-SW15/11 Exhaust Shaft Feeder.

7.1.16 Line UP Sub 3 by verifying the following:

A) CLOSE Sub 3 LIS 25P-SW15/3A.

B) CLOSE Sub 3 LIS 25P-SW15/3B.

C) OPEN SUB 3 CB-8 Main Breaker.

D) OPEN Sub 3 CB-10 Main Breaker.

E) OPEN Sub 3 CB-5.
EFB, 41P-MCC04/7.

F) OPEN Sub 3 CB-6.
Safety and Emergency Bldg.,
45P-DP04/25A and 45P-DP04/25B.

G) OPEN Sub 3 CB-12.
Engineering Bldg. 486
45P-DP04/50.

H) OPEN Sub 3 CB-13.
Switchrack 6, 25P-SWR04/6.

I) Verify Sub 3 CB-1 is OPEN and LOCKED.
Tie CB to SB Sub CB-5.

J) Verify Sub 3 CB-18 is OPEN and LOCKED.
Tie to Sub 1 CB-8.

K) CLOSE either Sub 3 CB-7 if DG 1 is operating,
OR
CB-11 if DG 2 is operating.

L) CLOSE locally Sub 3 CB-9 tie breaker between Sub 3 Buses A and B.

M) CLOSE Sub 3 CB-5.
EFB, 41P-MCC04/7.

7.1.17 **IF** U/G is manned,
THEN notify U/G Ops VIA CMRO that Exhaust Shaft Feeder can be energized.

7.1.18 CLOSE SUB 3 CB-8 Main Breaker, energizing Exhaust Shaft Feeder.

7.1.19 Verify Attachment 1 is complete.

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7.1.20 CLOSE Sub 3 CB-10 Main Breaker energizing Subs 1, 2, 6 and SB.

7.1.21 Start Air Compressor 41-G-021A
OR
41-G-021B.

7.1.22 Start EFB Air Compressors 41-G-022A
AND
41-G-022B (as required).

7.1.23 Verify LPUs 835 and 836 are operational.

7.1.24 Verify UPSs 335 and 336 are operating with invertor supplying load.

7.1.25 Start the Underground Ventilation and Filtration System (UVFS) in accordance with WP 04-VU1001.

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7.1.26 Start the following:

- Start Vacuum Pump 41-G-040A
OR
41-G-040B
- Start Vacuum Pump 41-G-040C
OR
41-G-040D
- Start WHB Exhaust Fan(s) as directed by the FOSS
- Start SB Zone 6 HVAC

7.1.27 **IF** <900 Kw on operating DG,
THEN AIS Hoisting operation may begin as required.

7.1.28 Perform load reduction list Attachment 2 as required.

7.1.29 Perform the following:

- Shut down EFB Air Compressors 41-G-022A
AND
41-G-022B
- Verify Diesel Fire Pump Shut down MODE switch in AUTO/TEST position.

7.1.30 At the completion of hoisting, pick up available perimeter lighting.

7.1.31 Experimental loads and additional equipment may be energized at the direction of the FOSS.

7.2 RETURNING SITE TO UTILITY POWER.

7.2.1 **IF** U/G is manned,
THEN notify U/G Ops VIA CMRO that Exhaust Shaft Feeder is being de-energized.

7.2.2 Shut down filtration.

7.2.3 Shut down operating fan 41-B-860A
OR
41-B-860B
OR
41-B-860C.

7.2.4 Shut down the following:

- Shut down operating Air Compressor
  41-G-021A
  OR
  41-G-021B
- Shut down operating Vacuum Pumps
- Shut down operating WHB Exh. Fan(s)
- Shut down Zone 6 SB HVAC

7.2.5 OPEN Sub 3 CB-8, Main Breaker de-energizing Exhaust Shaft Feeder.

7.2.6 OPEN Sub 3 CB-10 Main Breaker de-energizing Subs 1, 2, 6 and SB.

7.2.7 OPEN Sub 3 CB-5.
EFB, 41P-MCC04/7.

7.2.8 OPEN Sub 3 CB-9.
Tie Breaker.

7.2.9 OPEN either Sub 3 CB-7 if DG 1 is operating,
OR
CB-11 if DG 2 is operating.

7.2.10 Shut down operating DG No.1
OR
DG No. 2.

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7.2.11 Realign substation CBs and LISs in accordance with procedure WP 04-ED1021.

7.3 OPTION 1 ENERGIZING SITE WITH BACKUP POWER, USING PS.

7.3.1 **IF** U/G is manned,
THEN notify U/G Ops VIA CMRO to align the U/G for receiving power from the Exhaust Shaft Feeder,
AND
Configure for one (1) 860 fan in filtration.

7.3.2 Verify Utility Sub CB-1 is OPEN.

NOTE: Attachment 1 **SHALL** be completed in conjunction with Steps 7.3.3 through 7.3.22. PCN 00-01

7.3.3 Reduce loads per Attachment 1.

7.3.4 Start Diesel Generator No.1
OR
No. 2.

7.3.5 Verify the following Plant Sub CBs are OPEN:

- CB-10
- CB-1
- CB-2
- CB-3
- CB-4
- CB-9
- CB-5
- CB-6
- CB-7
- CB-8

7.3.6 **IF** Sullair Air Compressors are NOT to be operated, skip Step 7.3.7 and proceed to Step 7.3.8.

7.3.7 Perform the following lineup:

A) Verify Sullair Air Compressors 45-G-009
AND
45-G-010 are OFF at control panel(s).

B) Verify Sullair Air Dryer 45-K-001 is OFF at control panel.

C) CLOSE Sub 5 LIS 25P-SW15/5.

D) CLOSE Sub 5 CB-1 Main Breaker.

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E) OPEN Sub 5 CB-2.
Switchrack 1, 24P-SWR04/1.

F) OPEN Sub 5 CB-3.
Salt Handling Hoist House.

G) OPEN Sub 5 CB-4.
Switchrack 2, 24P-SWR04/2.

H) OPEN Sub 5 CB-5.
38P-DP04/1.

I) OPEN Sub 5 CB-6 (Spare).

J) OPEN Sub 5 CB-7 (Spare).

K) OPEN Sub 5 CB-8.
Switchrack 3, 24P-SWR04/3.

L) OPEN Sub 5 CB-9.
Bldg 485, 45P-MPC04/1.

M) OPEN Sub 5 CB-10.
Perimeter & Street Lights.

N) OPEN Sub 5 CB-11.
Switchrack 8, 24P-SWR04/8.

O) OPEN Sub 5 CB-13.
Switchrack 9, 24P-SWR04/9.

P) CLOSE Sub 5 CB-14.
Compressor, 45-G-010.

Q) CLOSE Sub 5 CB-15.
Compressor, 45-G-009.

7.3.8 Verify SB Air Compressors 45-G-400A/B are OFF at control panel.

7.3.9 Verify SB Air Compressors 45-G-403A/B are OFF at control panel.

7.3.10 Verify Air Compressors 41-G-021A/B are OFF at control panel(s).

7.3.11 Verify Chilled Water Pumps 41-B-891A/B are OFF at control panel.

7.3.12 OPEN Sub 4 CB-1 Main Breaker.

7.3.13 Verify CLOSED LIS 31P-SW15/1 Waste Shaft Feeder.

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7.3.14 Verify CLOSED VIS 25P-VIS15/11 Exhaust Shaft Feeder.

7.3.15 Line UP Sub 3 by verifying the following:

A) CLOSE Sub 3 LIS 25P-SW15/3A.

B) CLOSE Sub 3 LIS 25P-SW15/3B.

C) OPEN Sub 3 CB-8 Main Breaker.

D) OPEN Sub 3 CB-10 Main Breaker.

E) OPEN Sub 3 CB-5.
EFB, 41P-MCC04/7.

F) OPEN Sub 3 CB-6.
Safety and Emergency Bldg.
45P-DP04/25A and 45P-DP04/25B.

G) OPEN Sub 3 CB-12.
Engineering Bldg. 486
45P-DP04/50.

H) OPEN Sub 3 CB-13.
Switchrack 6, 25P-SWR04/6.

I) Verify Sub 3 CB-1 is OPEN and LOCKED.
Tie CB to SB Sub CB-5.

J) Verify Sub 3 CB-18 is OPEN and LOCKED.
Tie CB to Sub 1 CB-8.

K) CLOSE either Sub 3 CB-7 if DG 1 is operating,
OR
CB-11 if DG 2 is operating.

L) CLOSE locally Sub 3 CB-9 tie breaker between Sub 3 Buses A and B.

M) CLOSE Sub 3 CB-5.
EFB, 41P-MCC04/7.

7.3.16 **IF** U/G is manned,
THEN notify U/G Ops VIA CMRO that U/G Feeders can be energized.

7.3.17 CLOSE Sub 3 CB-8 Main Breaker Energizing Exhaust Shaft Feeder.

7.3.18 Start EFB Air Compressors 41-G-022A
AND
41-G-022B (as required).

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7.3.19 Verify LPUs 835 and 836 are operational.

7.3.20 Verify UPSs 335 and 336 are operating with invertor supplying load.

7.3.21 Start the UVFS in accordance with WP 04-VU1001.

7.3.22 Verify Attachment 1 is complete.

PCN 00-01

7.3.23 CLOSE Sub 3 CB-10 Main Breaker energizing SB Sub and Waste Hoist Sub.

7.3.24 Verify OPEN PS CB-9.
Buses A & B tie breaker.

7.3.25 CLOSE PS CB-4.
Energizing PS Bus A.

7.3.26 CLOSE PS CB-3.
Energizing Subs 2 and 6.

7.3.27 CLOSE PS CB-2.
Salt Handling Shaft Feeder.

7.3.28 CLOSE PS CB-7.
Energizing PS Bus B.

7.3.29 CLOSE PS CB-6.
Energizing Sub 1.

7.3.30 CLOSE PS CB-5.
Waste Shaft Feeder.

7.3.31 CLOSE PS CB-8 **IF** Sullair Air Compressor is to be operated.

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7.3.32 Start the following:

- Start one Air Compressor 41-G-021A
  OR
  41-G-021B
  OR
  41-G-009
  OR
  41-G-010
- Start Vacuum Pump 41-G-040A
  OR
  41-G-040B
- Start Vacuum Pump 41-G-040C
  OR
  41-G-040D
- Start WHB Exhaust Fan(s) as directed by the FOSS
- Start SB Zone 6 HVAC

7.3.33 **IF** <900 Kw on operating DG,
THEN AIS Hoisting operation may begin as required.

7.3.34 Perform load reduction list Attachment 2 as required.

7.3.35 Perform the following:

- Shut down EFB Air Compressors 41-G-022A
  AND
  41-G-022B
- Verify Diesel Fire Pump Shut down MODE switch in AUTO/TEST position

7.3.36 At the completion of hoisting, pick up perimeter lighting.

7.3.37 Experimental loads and additional equipment may be energized at the direction of the FOSS.

7.4 RETURNING SITE TO UTILITY POWER AFTER PERFORMING OPTION 1.

7.4.1 **IF** U/G is manned,
THEN notify U/G Ops VIA CMRO that U/G Feeders are being de-energized.

7.4.2 Shut down filtration.

7.4.3 Shut down operating fan 41-B-860A
OR
41-B-860B
OR
41-B-860C.

7.4.4 Shut down the following:

- Shut down operating Air Compressor
  41-G-021A
  OR
  41-G-021B
  OR
  41-G-009
  OR
  41-G-010
- Shut down operating Vacuum Pumps
- Shut down operating WHB Exhaust Fan(s)
- Shut down Zone 6 SB HVAC

7.4.5 OPEN the following PS CBs:

- CB-2
- CB-3
- CB-4
- CB-5
- CB-6
- CB-7
- CB-8 (If CB was closed)

7.4.6 OPEN Sub 3 CB-8 Main Breaker de-energizing Exhaust Shaft Feeder.

7.4.7 OPEN Sub 3 CB-10 de-energizing SB and Waste Hoist Sub.

7.4.8 OPEN Sub 3 CB-5.
EFB, 41P-MCC04/7.

7.4.9 OPEN Sub 3 CB-9.
Tie Breaker.

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7.4.10 OPEN either Sub 3 CB-7 if DG 1 is operating,
OR
CB-11 if DG 2 is operating.

7.4.11 Shut down operating DG No.1
OR
DG No. 2.

7.4.12 Realign substation CBs and LISs in accordance with procedure WP 04-ED1021.

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7.5 OPTION 2 ENERGIZING SITE WITH BACKUP POWER, USING PS BUS A.

A) **IF** U/G is manned,
THEN notify U/G Ops VIA CMRO to align the U/G for receiving power from the Exhaust Shaft Feeder
AND
Salt Handling Shaft Feeder
AND
Configure for one (1) 860 fan in filtration.

PCN 00-03

7.5.1 Verify Utility Sub CB-1 is OPEN.

NOTE: Attachment 1 **SHALL** be completed in conjunction with Steps 7.5.2 through 7.5.19.

PCN 00-01

7.5.2 Reduce loads per Attachment 1.

7.5.3 Start Diesel Generator No.1
OR
No. 2.

7.5.4 Verify the following Plant Sub CBs are OPEN:

- CB-10
- CB-1
- CB-2
- CB-3
- CB-4
- CB-9
- CB-5
- CB-6
- CB-7
- CB-8

7.5.5 Verify SB Air Compressors 45-G-400A/B are OFF at control panel.

7.5.6 Verify SB Air Compressors 45-G-403A/B are OFF at control panel.

7.5.7 Verify Air Compressors 41-G-021A/B are OFF at control panel(s).

7.5.8 Verify Chilled Water Pumps 41-B-891A/B are OFF at control panel.

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7.5.9 Line Up Sub 2 by verifying the following:

A) OPEN Sub 2 LIS 25P-SW15/2B.

B) CLOSE Sub 2 LIS 25P-SW15/2A.

C) CLOSE Sub 2 CB-1 Main Breaker.

D) CLOSE Sub 2 CB-2.
Water Chiller, 41-B-890A.

E) CLOSE Sub 2 CB-3.
Air Handling Unit CH Area, 41-B-812.

F) CLOSE Sub 2 CB-4.
Air Handling Unit CH Area, 41-B-813.

G) CLOSE Sub 2 CB-5.
WHB Overpack, 41P-MCC04/5.

H) CLOSE Sub 2 CB-6.
Water Chiller, 41-B-890B.

I) OPEN Sub 2 CB-7 (Spare).

J) CLOSE Sub 2 CB-8.
Mech. Equip. Room WHB, 41P-DP04/3.

7.5.10 OPEN Sub 4 CB-1 Main Breaker.

7.5.11 Line Up Sub 6 by verifying the following:

A) OPEN Sub 6 LIS 25P-SW15/6B.

B) CLOSE Sub 6 LIS 25P-SW15/6A.

C) CLOSE Sub 6 CB-1 Main Breaker.

D) OPEN Sub 6 CB-2.
Switchrack 7, 24P-SWR04/7.

E) CLOSE Sub 6 CB-3.
Hoist, 33P-HM04/1.

F) OPEN Sub 6 CB-4 (Spare).

G) CLOSE Sub 6 CB-5.
Switchrack, 33P-SWR04/1.

7.5.12 Line Up SB Sub by verifying the following:

A) OPEN SB Sub LIS 45P-SW15/1B.

B) CLOSE SB Sub LIS 45P-SW15/1A.

C) CLOSE SB Sub CB-1 Main Breaker.

D) CLOSE SB Sub CB-2.
Elect. Equip. Room SB,
45P-MCC04/4.

E) CLOSE SB Sub CB-3.
Mech. Equip. Room WHB,
41P-MCC04/6.

F) CLOSE SB Sub CB-4.
Hoist Control Room WHB,
31P-MCC04/1.

G) Verify SB Sub CB-5 is OPEN and LOCKED.
Tie CB to Sub 3 CB-1.

7.5.13 Line Up Sub 1 by verifying the following:

A) Verify Sub 1 LIS 25P-SW15/1B1 is OPEN.

B) OPEN Sub 1 LIS 25P-SW15/1B2.

C) OPEN Sub 1 CB-1 Main Breaker.

D) CLOSE Sub 1 CB-2.
SB, 45P-MCC04/3.

E) CLOSE Sub 1 CB-3.
RH Waste Area, 41P-MCC04/1.

F) CLOSE Sub 1 CB-4.
Operating Gallery, WHB
41P-MCC04/2.

G) CLOSE Sub 1 CB-5.
Mech. Equip. Room WHB,
41P-MCC04/3.

H) CLOSE Sub 1 CB-6.
Air Handling Unit RH Area,
41-B-803.

I) CLOSE Sub 1 CB-7.
Air Handling Unit RH Area,
41-B-804.

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J) UNLOCK and CLOSE Sub 1 CB-8.
Tie to Sub 3 CB-18.

K) CLOSE Sub 1 CB-9.
Bldgs 482, 41P-MPC03/3
and EOC 462, 45P-DP04/27.

PCN 00-02

7.5.14 Verify CLOSED VIS 25P-VIS15/11 Exhaust Shaft Feeder.

7.5.15 Line Up Sub 3 by verifying the following:

A) **IF** U/G is manned,
THEN notify U/G Ops VIA CMRO that U/G Feeders can be energized.

B) OPEN Sub 3 LIS 25P-SW15/3B.

C) CLOSE Sub 3 LIS 25P-SW15/3A.

D) OPEN Sub 3 CB-8 Main Breaker.

E) OPEN Sub 3 CB-9.
Tie Breaker.

F) OPEN Sub 3 CB-10 Main Breaker.

G) OPEN Sub 3 CB-5.
EFB, 41P-MCC04/7.

H) OPEN Sub 3 CB-6.
Safety and Emergency Bldg.
45P-DP04/25A and 45P-DP04/25B.

I) OPEN Sub 3 CB-12.
Engineering Bldg. 486,
45P-DP04/50.

J) OPEN Sub 3 CB-13.
Switchrack 6, 25P-SWR04/6.

K) Verify Sub 3 CB-1 is OPEN and LOCKED.
Tie CB to SB Sub CB-5.

L) UNLOCK and CLOSE Sub 3 CB-18.
Tie to Sub 1 CB-8.

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M) CLOSE either Sub 3 CB-7 if DG 1 is operating,
OR
CB-11 if DG 2 is operating.

N) CLOSE locally Sub 3 CB-9 tie breaker between Sub 3 Buses A and B.

O) CLOSE Sub 3 CB-5.
EFB, 41P-MCC04/7.

P) Start EFB Air Compressors 41-G-022A
AND
41-G-022B (as required).

7.5.16 Verify LPUs 835 and 836 are operational.

7.5.17 Verify UPSs 335 and 336 are operating with invertor supplying load.

PCN 00-01

7.5.18 Start the UVFS in accordance with WP 04-VU1001.

7.5.19 Verify Attachment 1 is complete.

7.5.20 **IF** U/G is manned,
THEN notify U/G Ops VIA CMRO that U/G Exhaust Shaft and Salt Handling Shaft Feeders can be energized.

7.5.21 CLOSE Sub 3 CB-8 energizing SB Sub, Waste Hoist Sub and Exhaust Shaft Feeder.

7.5.22 CLOSE PS CB-4.
Energizing PS Bus A.

7.5.23 CLOSE PS CB-3 energizing Subs 2 and 6.

7.5.24 CLOSE PS CB-2 Salt Handling Shaft Feeder.

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7.5.25 Start the following:

- Start Air Compressor 41-G-021A
  OR
  41-G-021B
- Start Vacuum Pump 41-G-040A
  OR
  41-G-040B
- Start Vacuum Pump 41-G-040C
  OR
  41-G-040D
- Start WHB Exhaust Fan(s) as directed by the FOSS
- Start SB Zone 6 HVAC

7.5.26 **IF** <900 Kw on operating DG,
THEN AIS Hoisting operation may begin as required.

7.5.27 Perform load reduction list per Attachment 2, as required.

7.5.28 Perform the following:

- Shut down EFB Air Compressors 41-G-022A
  AND
  41-G-022B (as required).
- Verify Diesel Fire Pump Shut down MODE switch in AUTO/TEST position.

7.5.29 At the completion of hoisting, pick up perimeter lighting.

7.5.30 Experimental loads and additional equipment may be energized at the direction of the FOSS.

7.6 RETURNING SITE TO UTILITY POWER AFTER PERFORMING OPTION 2.

7.6.1 **IF** U/G is manned,
THEN notify U/G Ops VIA CMRO that U/G Feeders are being de-energized.

7.6.2 OPEN PS CB-2 Salt Shaft Feeder.

7.6.3 Shut down filtration.

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7.6.4 Shut down operating fan 41-B-860A
OR
41-B-860B
OR
41-B-860C.

7.6.5 Shut down Air Compressor 41-G-021A
OR
41-G-021B.

7.6.6 OPEN PS CB-3 de-energizing Subs 2 and 6.

7.6.7 Shut down the following:

- Shut down operating Vacuum Pumps
- Shut down operating WHB Exh. Fan(s)
- Shut down Zone 6 SB HVAC
- OPEN PS CB-4 de-energizing PS Bus A

7.6.8 OPEN Sub 3 CB-8 Main Breaker de-energizing SB Sub, Waste Hoist Sub and Exhaust Shaft Feeder.

7.6.~~9~~ OPEN Sub 3 CB-5.
EFB, 41P-MCC04/7.

7.6.10 OPEN Sub CB-9.
Tie Breaker.

7.6.11 OPEN either Sub 3 CB-7 if DG 1 is operating,
OR
CB-11 if DG 2 is operating.

7.6.12 Shut down operating DG No. 1
OR
DG No. 2.

7.6.13 Realign substation CBs and LISs in accordance with procedure WP 04-ED1021.

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7.7 OPTION 3 ENERGIZING SITE WITH BACKUP POWER, USING PS BUS B.

7.7.1 **IF** U/G is manned,
THEN notify U/G Ops VIA CMRO to align the U/G for receiving power from the Waste Shaft Feeder,
AND
Configure for one (1) 860 fan in filtration.

7.7.2 Verify Utility Sub CB-1 is OPEN.

NOTE: Attachment 1 **SHALL** be completed in conjunction with Steps 7.7.3 through 7.7.20.

7.7.3 Reduce loads per Attachment 1.

7.7.4 Start Diesel Generator No.1
OR
No. 2.

7.7.5 Verify the following Plant Sub CBs are OPEN:

- CB-10
- CB-1
- CB-2
- CB-3
- CB-4
- CB-9
- CB-5
- CB-6
- CB-7
- CB-8

7.7.6 **IF** Sullair Air Compressors are NOT to be operated, skip Step 7.7.7 and proceed to Step 7.7.12.

7.7.7 Perform the following lineup:

A) Verify Sullair Air Compressors 45-G-009
AND
45-G-010 are OFF at control panel(s).

B) Verify Sullair Air Dryer 45-K-001 is OFF at control panel.

C) CLOSE Sub 5 LIS 25P-SW15/5.

D) CLOSE Sub 5 CB-1 Main Breaker.

E) OPEN Sub 5 CB-2.
Switchrack 1, 24P-SWR04/1.

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F) OPEN Sub 5 CB-3.
Salt Handling Hoist House.

G) OPEN Sub 5 CB-4.
Switchrack 2, 24P-SWR04/2.

H) OPEN Sub 5 CB-5.
38P-DP04/1.

I) OPEN Sub 5 CB-6 (Spare).

J) OPEN Sub 5 CB-7 (Spare).

K) OPEN Sub 5 CB-8.
Switchrack 3, 24P-SWR04/3.

L) OPEN Sub 5 CB-9.
Bldg 485, 45P-MPC04/1.

M) OPEN Sub 5 CB-10.
Perimeter & Street Lights.

N) OPEN Sub 5 CB-11.
Switchrack 8, 24P-SWR04/8.

O) OPEN Sub 5 CB-13.
Switchrack 9, 24P-SWR04/9.

P) CLOSE Sub 5 CB-14.
Compressor, 45-G-010.

Q) CLOSE Sub 5 CB-15.
Compressor, 45-G-009.

7.7.8 Verify SB Air Compressors 45-G-400A/B are OFF at control panel.

7.7.9 Verify SB Air Compressors 45-G-403A/B are OFF at control panel.

7.7.10 Verify Air Compressors 41-G-021A/B are OFF at control panel(s).

7.7.11 Verify Chilled Water Pumps 41-B-891A/B are OFF at control panel.

7.7.12 Line Up Sub 2 by verifying the following:

A) OPEN Sub 2 LIS 25P-SW15/2A.

B) CLOSE Sub 2 LIS 25P-SW15/2B.

C) CLOSE Sub 2 CB-1 Main Breaker.

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D) CLOSE Sub 2 CB-2.
Water Chiller 41-B-890A.

E) CLOSE Sub 2 CB-3.
Air Handling Unit CH Area,
41-B-812.

F) CLOSE Sub 2 CB-4.
Air Handling Unit CH Area,
41-B-813.

G) CLOSE Sub 2 CB-5.
WHB Overpack, 41P-MCC04/5.

H) CLOSE Sub 2 CB-6.
Water Chiller, 41-B-890B.

I) OPEN Sub 2 CB-7 (Spare).

J) CLOSE Sub 2 CB-8.
Mech. Equip. Room, 41P-DP04/3.

7.7.13 OPEN Sub 4 CB-1 Main Breaker.

7.7.14 Line Up Sub 6 by verifying the following:

A) OPEN Sub 6 LIS 25P-SW15/6A.

B) CLOSE Sub 6 LIS 25P-SW15/6B.

C) CLOSE Sub 6 CB-1 Main Breaker.

D) OPEN Sub 6 CB-2.
Switchrack 7, 24P-SWR04/7.

E) CLOSE Sub 6 CB-3.
Hoist, 33P-HM04/1.

F) OPEN Sub 6 CB-4 (Spare).

G) CLOSE Sub 6 CB-5.
Switchrack, 33P-SWR04/1.

7.7.15 Line Up SB Sub by verifying the following:

A) OPEN SB Sub LIS 45P-SW15/1A.

B) CLOSE SB Sub LIS 45P-SW15/1B.

C) CLOSE SB Sub CB-1 Main Breaker.

D) CLOSE SB Sub CB-2.
Elect. Equip. Room SB,
45P-MCC04/4.

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E) CLOSE SB Sub CB-3.
Mech. Equip. Room WHB,
41P-MCC04/6.

F) CLOSE SB Sub CB-4.
Hoist Control Room WHB,
31P-MCC04/1.

G) Verify SB Sub CB-5 is OPEN and LOCKED.
Tie CB to Sub 3 CB-1.

7.7.16 Verify CLOSED LIS 31P-SW15/1 Waste Shaft Feeder.

7.7.17 Line Up Sub 1 by verifying the following:

A) Verify LIS 25P-SW15/1B1 is OPEN.

B) CLOSE LIS 25P-SW15/1B2.

C) CLOSE Sub 1 CB-1 Main Breaker.

D) CLOSE Sub 1 CB-2.
SB, 45P-MCC04/3.

E) CLOSE Sub 1 CB-3.
RH Waste Area, 41P-MCC04/1.

F) CLOSE Sub 1 CB-4.
Operating Gallery, WHB.
41P-MCC04/2.

G) CLOSE Sub 1 CB-5.
Mech. Equip. Room WHB,
41P-MCC04/3.

H) CLOSE Sub 1 CB-6
Air Handling Unit RH Area,
41-B-803.

I) CLOSE Sub 1 CB-7.
Air Handling Unit RH Area,
41-B-804.

J) Verify Sub 1 CB-8 is OPEN and LOCKED.
Tie to Sub 3 CB-18.

K) CLOSE Sub 1 CB-9.
Bldgs 482, 41P-MPC03/3
and EOC 462, 45P-DP04/27.

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7.7.18 Line Up Sub 3 by verifying the following:

A) OPEN Sub 3 LIS 25P-SW15/3A.

B) CLOSE Sub 3 LIS 25P-SW15/3B.

C) OPEN Sub 3 CB-8 Main Breaker.

D) OPEN Sub 3 CB-10 Main Breaker.

E) OPEN Sub 3 CB-5.
EFB, 41P-MCC04/7.

F) OPEN Sub 3 CB-6.
Safety and Emergency Bldg.
45P-DP04/25A and 45P-DP04/25B.

G) OPEN Sub 3 CB-12.
Engineering Bldg. 486
45P-DP04/50.

H) OPEN Sub 3 CB-13.
Switchrack 6, 25P-SWR04/6.

I) Verify Sub 3 CB-1 is OPEN and LOCKED.
Tie to SB Sub CB-5.

J) Verify Sub 3 CB-18 is OPEN and LOCKED.
Tie CB to Sub 1 CB-8.

K) CLOSE either Sub 3 CB-7 if DG 1 is operating,
OR
CB-11 if DG 2 is operating.

L) CLOSE locally Sub 3 CB-9 tie breaker between Sub 3 Buses A and B.

M) CLOSE Sub 3 CB-5.
EFB, 41P-MCC04/7.

7.7.19 Start EFB Air Compressors 41-G-022A
AND
41-G-022B (as required).

7.7.20 Verify Attachment 1 is complete.

7.7.21 CLOSE Sub 3 CB-10 Main Breaker energizing SB Sub and Waste Hoist Sub.

7.7.22 CLOSE PS CB-7.
Energizing PS Bus B.

7.7.23 CLOSE PS CB-6 energizing Subs 1, 2 and 6.

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7.7.24 **IF** U/G is manned,
THEN notify U/G Ops VIA CMRO to align the U/G for receiving power from the Waste Shaft Feeder.

7.7.25 CLOSE PS CB-5 Waste Shaft Feeder.

7.7.26 Verify LPUs 835 and 836 are operational.

7.7.27 Verify UPSs 335 and 336 are operating with invertor supplying load.

PCN 00-01

7.7.28 Start the UVFS in accordance with WP 04-VU1001.

7.7.29 CLOSE PS CB-8 **IF** Sullair air compressors are to be operated.

7.7.30 Start the following:

- Start Air Compressor 41-G-021A
  OR
  41-G-021B
  OR
  41-G-009
  OR
  41-G-010

- Start Vacuum Pump 41-G-040A
  OR
  41-G-040B

- Start Vacuum Pump 41-G-040C
  OR
  41-G-040D

- Start WHB Exhaust Fan(s) as directed by the FOSS.

- Start SB Zone 6 HVAC

7.7.31 **IF** <900 Kw on operating DG,
THEN AIS Hoisting operation may begin as required.

7.7.32 Perform load reduction list per Attachment 2, as required.

7.7.33 Perform the following:

- Shut down EFB Air Compressors 41-G-022A
  AND
  41-G-022B
- Verify Diesel Fire Pump Shut down MODE switch in AUTO/TEST position

7.7.34 At the completion of hoisting, pick up perimeter lighting.

7.7.35 Experimental loads and additional equipment may be energized at the direction of the FOSS.

7.8 RETURNING SITE TO UTILITY POWER AFTER PERFORMING OPTION 3.

7.8.1 **IF** U/G is manned,
THEN notify U/G Ops VIA CMRO that Waste Shaft Feeder is being de-energized.

7.8.2 Verify OPEN PS CB-5 Waste Shaft Feeder.

7.8.3 Shut down operating fan 41-B-860A
OR
41-B-860B
OR
41-B-860C.

7.8.4 Shut down filtration.

7.8.5 Shut down Air Compressor 41-G-021A
OR
41-G-021B.

7.8.6 Shut down the following:

- Shut down operating Vacuum Pumps
- Shut down operating WHB Exh. Fan(s)
- Shut down Zone 6 SB HVAC

7.8.7 OPEN PS CB-6 de-energizing Subs 1 and 6.

7.8.8 OPEN PS CB-7 de-energizing PS Bus B.

7.8.9 OPEN Sub 3 CB-10 Main Breaker de-energizing Sub 2, 4, SB Sub and Waste Handling Sub.

7.8.10 OPEN Sub 3 CB-5.
EFB, 41P-MCC04/7.

7.8.11 OPEN Sub 3 CB-9.
Tie Breaker.

7.8.12 OPEN either Sub 3 CB-7 if DG 1 is operating,
OR
CB-11 if DG 2 is operating.

7.8.13 Shut down operating DG No.1
OR
DG No. 2.

7.8.14 Realign substation CBs in accordance with procedure WP 04-ED1021.

7.9 OPTION 4 ENERGIZING PS BUSES USING PS TIE CB-9.

NOTE: This note applies to Option 4. Option 4 **MAY BE** used with Options 2 or 3.

7.9.1 PS tie breaker CB-9 **MAY BE** used if the following conditions exist.

A) Both PS Buses are in a condition to be energized.

B) PS CB-9 can be CLOSED **IF ONE** or more of the following CBs or LISs are open:

1) Sub 3 CB-10.
2) Sub 3 CB-9.
3) Sub 3 CB-8.
4) PS CB-7.
5) PS CB-4.
6) Sub 3 LIS 25P-SW15/3B.
7) Sub 3 LIS 25P-SW15/3A.

7.9.2 CLOSE PS CB-9.
Tie Breaker.

7.9.3 At the direction of the FOSS available PS CBs **MAY BE** operated.

8.0 REVIEW

None

9.0 RECORDS

No Quality Assurance records are generated by this procedure.

ATTACHMENT 1

BACKUP POWER LOAD LIST

NOTE: De-energize Attachment 1 in any order or concurrently if desired.

1.0 SB Elevator at 45P-DP04/2 (Room 226).

2.0 SB HVAC System at the Local Control Panels.

3.0 WHB HVAC System at the Local Control Panels.

4.0 Vacuum Pumps 41-G-040A, B, C & D at the Local Control Panel.

5.0 WHB Lighting Panels at 41P-MCC04/6.

6.0 Forklift Battery Recharging Station Dist. Panel 41P-DP04/21 at 41P-MCC04/5.

7.0 Perimeter Lights in 45P-LP04/5 CB 8/10, 16/18, 22/24 and 21/23 (Overpack & Repair Room).

8.0 Trupact Maintenance Facility 41P-DP04/4 at 41P-MCC04/5.

9.0 Safety Building Chiller 45-E-646 at Local Control Panel.

10.0 Engineering Building Chiller 45-E-407 at Local Control Panel.

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ATTACHMENT 2

ADDITIONAL LOAD REDUCTION LIST

NOTE: De-energize Attachment 2 in any order or concurrently if desired.

1.0 SB Water Heater 45-E-402 at 45P-DP04/1 (RM 116).

2.0 SB Lighting Panels at 45P-DP04/1 (RM 116).

3.0 SB Cart Chargers at 45P-DP03/11 CB26, 32 and 36 (RM 116).

4.0 WHB Mech. Room Unit Heaters 904, 905, 906, 907 and 908 at 41P-DP04/3.

5.0 CH Area Unit Heaters 935, 938, 939 and 941 at 41P-MCC04/5.

6.0 Met Tower At 41P-MCC04/7 (EFB).

7.0 Perimeter Lighting at 41P-LP04/11 CB-8/10 and CB-9/11 (EFB).

INFORMATION ONLY

CONTROLLED COPY

DOE/WIPP 91-005

Revision 1.0

Received OSTI

JUN 0 5 1992

Resource Conservation and Recovery Act Part B Permit Application

Volume V of VII

DISCLAIMER

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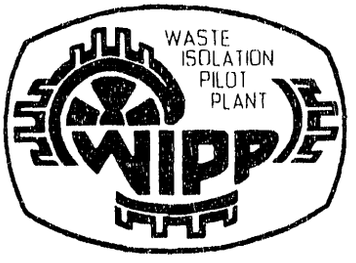

AC04-86AL31950

Waste Isolation Pilot Plant

Carlsbad, New Mexico

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

ENGINEERING CHANGE ORDERS

1736
2450
3378
3690
4048
4127
4463
4983
4996
5022
5071
5166
5189
5204
5206
5292
5294
5299
5315
5353
5513
5532
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5625
5674
5723
5741
5746
5776
5821
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5866
5873
5893

DOE/WIPP--91-005-Vol.5-Rev.10

DE92 014821

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

31R 002 010

NF 8-007

ENGINEERING FILE ROOM COPY

ECO# 1736 SUPERSEDES ECO # _____

TYPE REG. ✓ ACT. ___ DESIGN CLASS III R QA CODE 1 ___ 2 ✓ 3 ___

DOCUMENT # 3[illegible] REV. ___ DATE _____ EWP # _____

TITLE OF CHANGE Waste Shaft Key Sect... Lower Tell-Tales

COST ESTIMATE REQUIRED: YES ___ NO ✓ COST ESTIMATE IS _____

COST ACCOUNT # — SYSTEM/FACILITY Waste Shaft

SCHEDULE IMPACT —

DETAIL DESCRIPTION OF CHANGE: Use continuation sheets as necessary, list affected documents and note total number of pages on page one.

This is a request to show as-built dimensions of Waste shaft key with the addition of 8 tell-tales below 2551 Chemical Seal. This print will be used as proposed for EWP 31-4-0368 PRE-GROUT INSPECTION.

CANCELLED
[illegible] 19 March 92
[illegible] 3/19/92
EWP 31-4-0368 was cancelled 7/17/87

Affected Related Drawing(s)
31-R-002-0110 Rev 4/ page 59

Drawing(s) to be "As-Built"

JUSTIFICATION OF CHANGE

To monitor lower Chemical Seal

APPROVALS/DATE

*Originator [signature] 12-23 QA _____
*Cog. Engr. [signature] 12-23 Safety _____
*Cog. Mgr. [signature] for T. Dillon 12/23/91 Other _____
* MINIMUM APPROVAL

FINAL DISPOSITION

Cog Engr. _____ Date _____
Signature verifies that all requirements of the ECO have been completed including any items checked at the right.

Drawing(s) As-Built _____
Document Changes Completed _____
Other _____

Form 1200

41D017014

ENGINEERING CHANGE ORDER
WP 9-007

Page 1 of 1

ECO# 2450 SUPERSEDES ECO # _____
TYPE REG. X ACT. ___ DESIGN CLASS III.4 QA CODE 1 X 2 ___ 3 ___

DOCUMENT # 1351-S REV. ___ DATE 5-2-88 ENP/0308 88-C619
TITLE OF CHANGE WEST WASTE SHAFT STATION GATE SWITCHES

COST ESTIMATE REQUIRED: YES ___ NO X COST ESTIMATE IS _____
COST ACCOUNT # _____ SYSTEM/FACILITY WASTE SHAFT STATION
SCHEDULE IMPACT _____

DETAIL DESCRIPTION OF CHANGE: Use continuation sheets as necessary, list affected documents and note total number of pages on page one.

--PROVIDE A SKETCH NUMBER AND ADD THE ATTACHED SKETCH TO ENGINEERING FILES.

ALSO ADD THIS DETAIL ~~ADDED~~ TO DWGS 31-S-002-017 AND 41-D-017 REFERENCING THIS SKETCH ~~AS FOLLOWS:~~

~~-FOR TYPICAL GATE SWITCH IDENTIFICATION A~~
~~SPECIFIC STATION WEST GATE DETAILS SEE~~
SKETCH NO. ___

Affected Related Drawing(s)	Drawing(s) to be "As-Built"
	31-S-002
	41-D-017

JUSTIFICATION OF CHANGE

SAFETY SYSTEM INTERLOCK

APPROVALS/DATE

*Originator	[signature]	QA	[signature] 5/2/88
*Cog. Engr.	[signature] 5-2-55	Safety	[signature] 5/2/88
*Cog. Mgr.	[signature] 5/1/88	Other	[signature]

* MINIMUM APPROVAL

FINAL DISPOSITION

Cog Engr. _____ Date ___
Signature verifies that all requirements of the ECO have been completed including any items checked at the right.

Drawing(s) As-Built ___
Document Changes Completed ___
Other ___

Form 1200 A

Dravo
Denver Operating Center

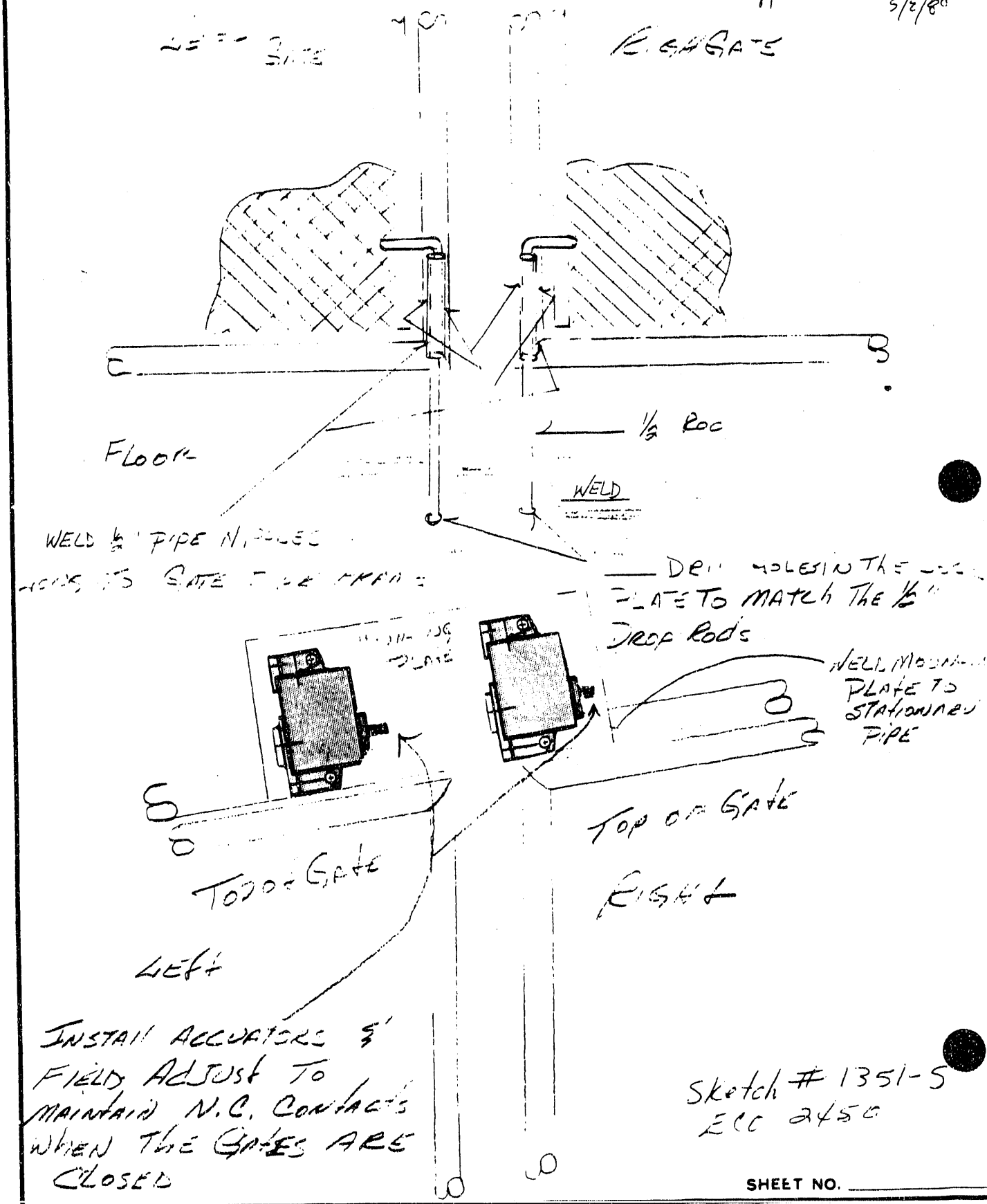
ENGINEERING COMPUTATIONS

EST NO. _____
CONT NO. _____
DIVISION _____

COMPANY _____
LOCATION _____
DESCRIPTION _____

DATE _____
DR _____ CH _____
REF _____

Approved: RTV: dmT
5/2/80



INSTALL ACCUATORS & FIELD ADJUST TO MAINTAIN N.C. CONTACTS WHEN THE GATES ARE CLOSED

Sketch # 1351-5
ECC 2456

SHEET NO. _____

EC-555

24147022

ENGINEERING CHANGE ORDER

(USE BLACK INK OR FELT TIP PEN)

(1) E&RTS REVIEW [signature]

ECO- 3378

(2) IMPACT LEVEL	(3) BLDG/SYS/EQUIP NO.	(4) RELATED CHANGE NO.
☐ LEVEL-1 ☒ LEVEL-3 ☐ LEVEL-2 (SEE SIDE 2 FOR APPROVALS)	CCP-22	130-871431

(5) DOCUMENT NO.	(6) SHEET	(7) REV.	(8) TITLE OF CHANGE
See bellow	-	-	Site Roads and Grading

(9) DESCRIPTION OF CHANGE

"As built" drawings drawn by the contractor. ~~Incorporate into Eng. Title.~~ JWK 04/3/89

Incorporate as built changes in to CCP-22 drawings as per drawing index 76-B-147-022

Also incorporate any applicable changes to affected related dwgs. A list of those drawings to be attached to this ECO before completion 4-4-89 J Sikkema

(10) JUSTIFICATION

Requirement of the contract.

(11) COST ESTIMATE	(12) SCHEDULE IMPACT
N.A.	none

(13) ORIGINATOR	(14) PHONE	(15) ORGANIZATION	(16) DATE
J. Kowalski	8167	F.E.	04/3/89

(17) RELATED CHANGES: INDICATE THE DOCUMENTS, DRAWINGS, INSTRUCTIONS OR PROCEDURES (OTHER THAN THE DRAWINGS OR DOCUMENTS IDENTIFIED IN EITHER 5 OR 9) THAT WILL BE AFFECTED BY THE CHANGE DESCRIBED IN BLOCK 9. ENTER THE DOCUMENT NUMBER(S) IN BLOCK 18.

YES	NO		YES	NO	
☐	☒	1. CONCEPTUAL DESIGN REPORT	☐	☒	13. TRAINING MANUAL
☐	☒	2. EQUIPMENT SPECS.	☐	☒	14. OPERATING INSTRUCTIONS
☐	☒	3. DESIGN SPECS.	☐	☒	15. OPERATING PROCEDURES
☐	☒	4. VENDOR DATA	☐	☒	16. SPARES/MULTIPLE UNIT LISTINGS
☐	☒	5. O&M MANUAL	☐	☒	17. TEST PROCEDURES/SPECS.
☐	☒	6. FSAR/SAR	☐	☒	18. COMPONENT INDICES
☐	☒	7. SEISMIC/STRESS ANALYSIS	☐	☒	19. ASME CODED ITEMS
☐	☒	8. STRESS/DESIGN REPORT	☐	☒	20. HUMAN FACTOR CONSIDERATIONS
☐	☒	9. INTERFACE CONTROL DWGS.	☐	☒	21. PROCUREMENT SPECS.
☐	☒	10. CALIBRATION PROCEDURES	☐	☒	22. COMPUTER SOFTWARE
☐	☒	11. INSTALLATION PROCEDURES	☐	☒	23. ELECTRIC CIRCUIT SCHEDULE
☐	☒	12. MAINTENANCE PROCEDURES	☐	☒	24. ICRS PROCEDURES

(18) RELATED DOCUMENT NO.; INSTRUCTION NO.; DRAWING NO.; IDENTIFIED IN BLOCK 17. (DESIGN DOCUMENTS LISTED IN BLOCK 18 WILL NOT BE INCORPORATED BY THIS ECO)

DOCUMENT NO./REV.	INSTRUCTION/PROCEDURE NO.	DWG. SHT. REV.

(19) DISTRIBUTION

NAME	ORG.

(20) SIGNATURE REQUIREMENTS

IMPACT LEVEL

☐ PRE-OPS TEST/OPS
☐ DESIGN/FAB./CONST.

3	A	COG. ENGINEER
	A	COG. ENGR. MGR.
	R	Q.A.
		DOE
2	R	SAFETY
1		DEPT. MGR.
		OPERATIONS
		CONST. MGT.
		SECURITY
		OTHER

KEY
A=APPR.
R=REVIEW
PR=POST REVIEW, I=INFORMATION

(21) ACTIONS REQUIRED TO IMPLEMENT CHANGES

- incorporate dwgs into Eng. File System

(Side 2)

ENGINEERING CHANGE ORDER CONTINUATION SHEET	DOCUMENT NO.	DATE	ECO 3378

✓ 25-J-533-009
✓ 25-J-531-009
✓ 25-J-530-009
25-C-046-010
25-C-045-010

3378

24-C-001-022 completed 4/4/89
24-C-140-022 completed 4/17/89
24-C-008-W completed 4/06/89
24-C-010-W Compl. 12/21/89
24-C-143-022 completed 4/12/89
24-C-145-022 completed 4/13/89
24-C-146-022 Complete 4/3
24-C-147-022

25-C-045-010
24-C-013-W
~~25-C-046-010~~ complete w 24-C-013-W
25-J-530-009 completed 4/2/89
25-J-531-009 complete 4/17/89
25-J-533-009 Complete 4/3

REV	DATE	ISSUE DESCRIPTION	BY	ENG	ECO	EWP
C	9/9/88	REVISED PER ECO	S.G.	JHK	2839	88-3792
B	6/2/88	REVISED PER ECO	TRA	JHK	2580	24-2-0406
A	2/24/88	APPROVED FOR USE	DEG	JHK	2282	24-2-0406
–	2/5/88	ISSUE FOR REVIEW	DEG	JHK	2282	24-2-0406

DFTG D. GREEN 2/5/88

CHKR. [illegible] 2/10/88

COG. ENG [illegible] 2/10/88

COG. MGR [illegible] 2/10/88

Q.A. [illegible]

SAFETY [illegible] 2/10/88

APPD [illegible] 2/10/88

APPD

DFTG. MGR [illegible]

DOE

SCALE 1"=20'

U.S. DEPARTMENT OF ENERGY

Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

SITE WORK
FINISH GRADING AND PAVING PLAN

DWG. NO. 24-C-010-W

REV. C

SH. 1 OF 2

ENGINEERING CHANGE ORDER
ADDENDUM SHEET

1. Addendum Sheet to ECO Number: 3378 Drawing Number: 25-C-045-010

2. Description of change:

DRAWING 25-C-045-010 HAS BEEN REMOVED FROM THE ACTIVE DRAWING REGISTER (ECO 5235). THEREFORE, DELETE THE REQUIREMENT TO REVISE THIS DRAWING AND CLOSE ECO 3378. AS IT RELATES TO 25-C-045-010.

3. Approvals

Cognizant Engineer:	Signature	Date 7/15/91
CC&D Mgr. /Desig. Rep.:	Signature	Date 7/16/91
Other Approval:	Signature	Date
Other Approval::	Signature	Date

1290:B0009

24 C 149 022

ENGINEERING CHANGE ORDER
(USE BLACK INK)

(1) E&RTS REVIEW Illegible

ECO- 3690

(2) IMPACT LEVEL
☐ LEVEL-1 ☒ LEVEL-3
☐ LEVEL-2
(SEE SIDE 2 FOR APPROVALS)

(3) BLDG/SYS/EQUIP NO.
Site 1255.1 #2

(4) ASSOCIATED DOCUMENTS
030/EWP M4108Q
RELATED ECO ~
EDT
P.O.

(5) DOCUMENT NO.
See below

(6) SHEET
N/A

(7) REVISION ADVANCED
FROM D TO E

(8) DOCUMENT TITLE
Finish Grading and Paving

(9) DESCRIPTION OF CHANGE

Incorporate changes as per attachment and engineering instructions.

Dwg. 24-C-143. Rev. D
24-C-146. Rev. D
24-C-149. Rev. D

(10) JUSTIFICATION

Erosion of unpaved area constitute a safety concern for the diesel generators operator.

(11) COST ESTIMATE
N. A.

(12) SCHEDULE IMPACT
by 07/31/89

(13) ORGINATOR	(14) PHONE	(15) ORGANIZATION	(16) DATE
J. Kowalski	8167	F. E.	07/13/89

WP Form 1200A. revised 2/89

(Side 1)

(17) RELATED CHANGES: INDICATE THE DOCUMENTS, INSTRUCTIONS OR PROCEDURES (OTHER THAN THE DRAWINGS OR DOCUMENTS IDENTIFIED IN EITHER 5 OR 9) THAT WILL BE AFFECTED BY THE CHANGE DESCRIBED IN BLOCK 9. ENTER THE DOCUMENT NUMBER(S) IN BLOCK 18.

YES	NO	N/A		YES	NO	N/A	
☐	☒	☐	1. CONCEPTUAL DESIGN REPORT	☐	☒	☐	14. OPERATING INSTRUCTIONS
☐	☒	☐	2. EQUIPMENT SPECS.	☐	☒	☐	15. OPERATING PROCEDURES
☐	☒	☐	3. DESIGN SPECS.	☐	☒	☐	16. SPARES/MULTIPLE UNIT LISTINGS
☐	☒	☐	4. VENDOR DATA	☐	☒	☐	17. TEST PROCEDURES/SPECS.
☐	☒	☐	5. O&M MANUAL	☐	☒	☐	18. COMPONENT INDICES
☐	☒	☐	6. FSAR/SAR	☐	☒	☐	19. ASME CODED ITEMS
☐	☒	☐	7. SEISMIC/STRESS ANALYSIS	☐	☒	☐	20. HUMAN FACTOR CONSIDERATIONS
☐	☒	☐	8. STRESS/DESIGN REPORT	☐	☒	☐	21. PROCUREMENT SPECS.
☐	☒	☐	9. INTERFACE CONTROL DWGS.	☐	☒	☐	22. COMPUTER SOFTWARE
☐	☒	☐	10. CALIBRATION PROCEDURES	☐	☒	☐	23. ELECTRIC CIRCUIT SCHEDULE
☐	☒	☐	11. INSTALLATION PROCEDURES	☐	☒	☐	24. ICRS PROCEDURES
☐	☒	☐	12. MAINTENANCE PROCEDURES	☐	☒	☐	25. ELECTRICAL LOAD LIST (25-X-001-W)
☐	☒	☐	13. TRAINING MANUAL				

(18) RELATED DOCUMENT NO.; INSTRUCTION NO.; IDENTIFIED IN BLOCK 17. (DESIGN DOCUMENTS LISTED IN BLOCK 18 WILLNOT BE INCORPORATED BY THIS ECO).

DOCUMENT NO./REVISION	

(19) DISTRIBUTION

NAME	ORG.

(20) SIGNATURE REQUIREMENTS

☐ PRE-OPS TEST/OPS
☐ DESIGN/FAB./CONST.

KEY
A=APPR.
R=REVIEW

A	COG. ENGINEER	J. Howard 7/13/89
A	COG. ENGR. MGR.	for G. Becker
R	Q.A.	7/7/89
	DOE	
	SAFETY	
	DEPT. MGR.	
	OPERATIONS	
	CONST. MGT.	
	SECURITY	
	OTHER	

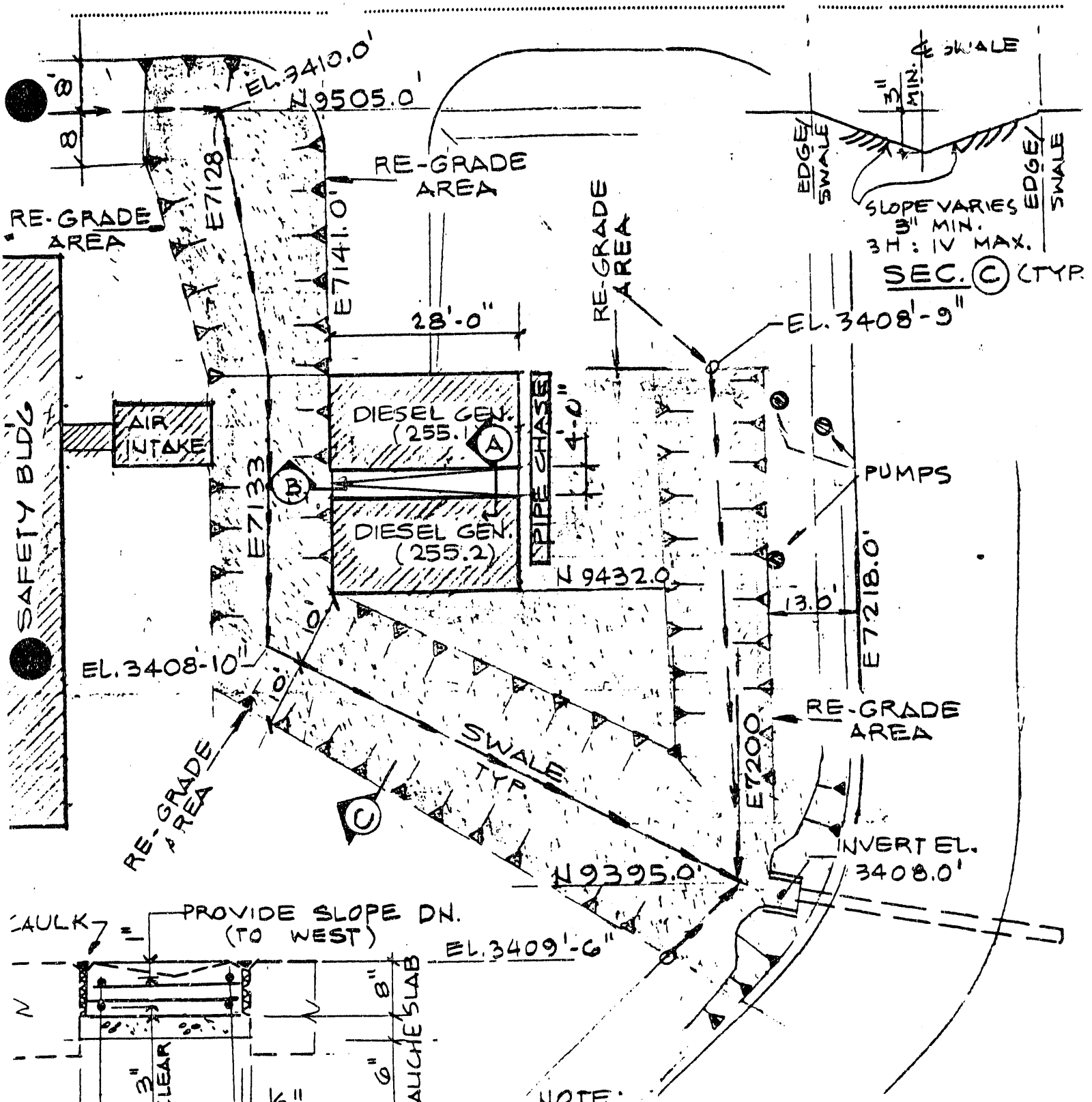
(21) DESIGN VERIFICATION REQUIREMENTS

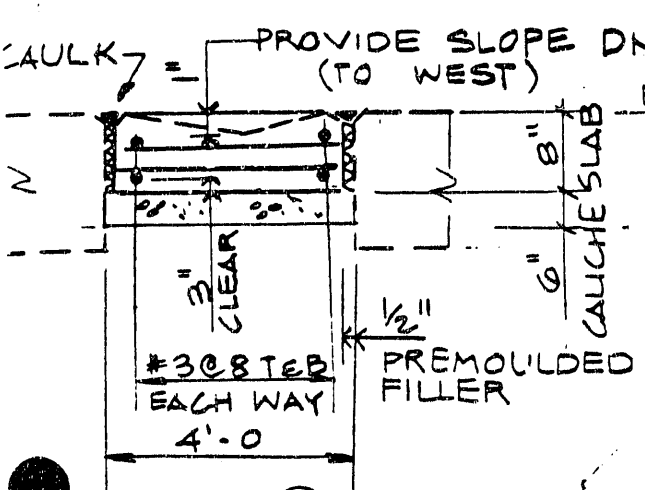
For James For G. Becker 1. REQUIREMENTS SATISFIED BY REVIEW/APPROVAL OF DESIGN DOCUMENT
2. INDEPENDENT REVIEW
3. ALTERNATE CALCULATIONS
4. DEVELOPMENT TESTING
5. DESIGN REVIEW
6. OTHER _____

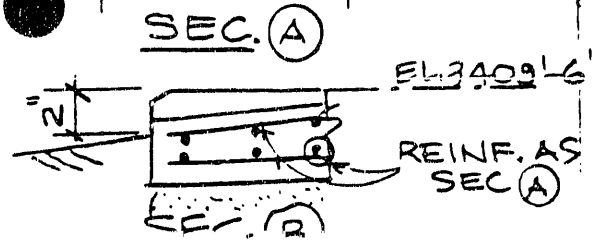
EDT# _____

BY S.K.13 DATE 7/12/89 SUBJECT ..... SHEET NO. 1 OF 1

CHKD. BY ..... DATE ..... JOB NO. .....







NOTE:

1. PROVIDE CONC. WALKWAY BTWN EXIST. FTG'S, WITH SLOPED; INVERTED TOP, AS SHOWN ON PLAN & SEC.

2. RE-GRADE AREA (SHOWN SHADED)

REF. SPEC:

E-Z-261	EARTHWORK	REV.1
E-Z-204	REINF. STEEL	REV.4
E-Z-205	FORM & PLACING CONC.	REV.6

24C140 022

PAGE 1 OF 2

ENGINEERING CHANGE ORDER
(USE BLACK INK)

(1) CCB REVIEW ~~N/A~~

ECO- 4048

(2) IMPACT LEVEL
☐ LEVEL-1 ☒ LEVEL-3
☐ LEVEL-2
(SEE SIDE 2 FOR APPROVALS)

(3) SYS/EQUIP NO./BLDG
Facility # 474

(4) ASSOCIATED DOCUMENTS
030 M-414-2
RELATED ECO —
EDT
P.O.

(5) DOCUMENT NO.
DRAWING ☒
SPEC ☐
O&M MANUAL ☐
SDD ☐
SEE BLOCK (9)

(6) SHEET

(7) REVISION ADVANCED
FROM ____ TO ____
FROM ____ TO ____

(8) DOCUMENT TITLE
HAZARDOUS MATERIAL STORAGE AREA

(9) DESCRIPTION OF CHANGE

Y/N
☐ ☒ ELECTRICAL LOAD LIST (25-X-001-W)
☐ ☒ PANEL SCHEDULE (INCLUDE MARK-UP)

Incorporate the new facility configuration on the following drawings: 24-C-CC1-022 Rev F
24-C-140-022 Rev. G.
24-C-145-022 Rev. G.
For information use the set of drawings as produced by the AE Assoc - final issue.

☒ YES ☐ NO
**** MODIFICATION IN PROGRESS
(ECO NOT TO BE INCORPORATED)
☒ MODIFICATION COMPLETE VHK 1/30/91
(ECO RELEASED FOR INCORPORATION)

(10) JUSTIFICATION
New facility, need to update plant layout

(11) ORIGINATOR (PRINT)	(12) PHONE	(13) ORGANIZATION	(14) DATE
J Kowalski	8167	Fac. Eng.	12/20/90
(15) COG. ENGINEER (PRINT)	(12) PHONE	(16) DRAFTING REQUIRED DATE	
— " —	— " —	New	

WP FORM 1200A; REVISED 10/89

(Side 1)

(17) RELATED CHANGES: INDICATE THE DOCUMENTS, INSTRUCTIONS OR PROCEDURES (OTHER THAN THE DRAWINGS OR DOCUMENTS IDENTIFIED IN EITHER 8 OR 9) THAT WILL BE AFFECTED BY THE CHANGE DESCRIBED IN BLOCK 9. ENTER THE DOCUMENT NUMBER(S) IN BLOCK 18.

YES	NO	N/A		YES	NO	N/A	
☐	☒	☐	1. CONCEPTUAL DESIGN REPORT	☐	☒	☐	10. TRAINING MANUAL
☐	☒	☐	2. VENDOR DATA (WP 09-025)	☐	☒	☐	11. OPERATING PROCEDURES
☐	☒	☐	3. FSAR	☐	☒	☐	12. SPARES/MULTIPLE UNIT LISTINGS
☐	☒	☐	4. SEISMIC/STRESS ANALYSIS	☐	☒	☐	13. DO SPARES NEED MODIFIED
☐	☒	☐	5. DESIGN REPORT	☐	☒	☐	14. TEST PROCEDURES/SPECS.
☐	☒	☐	6. INTERFACE CONTROL DWGS.	☐	☒	☐	15. COMPONENT INDICES
☐	☒	☐	7. CALIBRATION PROCEDURES	☐	☒	☐	16. ASME CODED ITEMS
☐	☒	☐	8. INSTALLATION PROCEDURES	☐	☒	☐	17. HUMAN FACTOR CONSIDERATIONS
☐	☒	☐	9. MAINTAINANCE PROCEDURES	☐	☒	☐	18. COMPUTER SOFTWARE

(18) RELATED DOCUMENT NO.; INSTRUCTION NO.; IDENTIFIED IN BLOCK 17 (CHANGES TO DOCUMENTS LISTED IN BLOCK 18 WILL NOT BE INCOPRORATED BY THIS ECO).

DOCUMENT NO./REVISION	

(19) DISTRIBUTION

NAME	ORG.

(20) SIGNATURE REQUIREMENTS

KEY
A=APPR.
R=REVIEW

ECO # 4048

A	COG. ENGINEER	[signature]	12/20/89
A	COG. ENGR. MGR.	[signature]	12/20/89
R	Q.A.	[signature]	12-21-89
	DOE		
	SAFETY		
	DEPT. MGR.		
	OPERATIONS		
	SECURITY		

(21) DESIGN VERIFICATION REQUIREMENTS (PER WP 09-018)

Sup

1. REQUIREMENTS SATISFIED BY REVIEW/APPROVAL OF DESIGN DOCUMENT
2. INDEPENDENT REVIEW
3. ALTERNATE CALCULATIONS
4. DEVELOPMENT TESTING
5. DESIGN REVIEW
6. OTHER _____

EDT# _____

ENGINEERING CHANGE ORDER
(USE BLACK INK)

(1) CC&D REVIEW TMS

ECO- 4127

(2) IMPACT LEVEL
☐ LEVEL-1 ☐ LEVEL-3
☑ LEVEL-2 Des. Class III A.
(SEE SIDE 2 FOR APPROVALS)

(3) SYS/EQUIP NO./BLDG
HV01/41-B-012/411

(4) ASSOCIATED DOCUMENTS
030 _____
RELATED ECO -3628; 3850
EDT _____
P.O. _____

(5) DOCUMENT NO.
DRAWING ☑
SPEC ☐
O&M MANUAL ☐
SDD ☐
41-B-002-W
41-F-022-014 SH. 1&2
41-F-022-014 SH. 2&2
~~41-G-305-014~~ ~~41-B-001-014~~

(6) SHEET

(7) REVISION ADVANCED
FROM ____ TO ____
FROM ____ TO ____

(8) DOCUMENT TITLE
Interface ductwork between Trupact Hood Vent sys. and CH area HVAC sys.

(9) DESCRIPTION OF CHANGE 41-B-001-W

Y/N
☐ ☒ ELECTRICAL LOAD LIST (25-X-001-W)
☐ ☒ PANEL SCHEDULE (INCLUDE MARK-UP)

Prepare design/drawings for HVAC ductwork that will interface with the Trupact Hood Vent system.

New drawings 41-B-002-W
41-B _____

(Continued on Page 3)

☑ YES ☐ NO
**** MODIFICATION IN PROGRESS
(ECO NOT TO BE INCORPORATED)

☑ MODIFICATION COMPLETE
(ECO RELEASED FOR INCORPORATION)

(10) JUSTIFICATION To provide ductwork connections between the Trupact Hood Vent System and existing CH area HVAC system (HV01) exhaust ductwork.

(11) ORIGINATOR (PRINT)	(12) PHONE	(13) ORGANIZATION	(14) DATE
K. EALDEN	8174	F.A.C.E.	30 Jan. '90.

(15) COG. ENGINEER (PRINT)	(12) PHONE	(16) DRAFTING REQUIRED DATE
K-EALDEN	8174	9 Feb. '90.

(17) RELATED CHANGES: INDICATE THE DOCUMENTS, INSTRUCTIONS OR PROCEDURES (OTHER THAN THE DRAWINGS OR DOCUMENTS IDENTIFIED IN EITHER 5 OR 9) THAT WILL BE AFFECTED BY THE CHANGE DESCRIBED IN BLOCK 9. ENTER THE DOCUMENT NUMBER(S) IN BLOCK 18.

YES	NO	N/A		YES	NO	N/A	
☐	☑	☐	1. CONCEPTUAL DESIGN REPORT	☐	☑	☐	10. TRAINING MANUAL
☑	☐	☐	2. VENDOR DATA (WP 09-025)	☑	☐	☐	11. OPERATING PROCEDURES
☐	☑	☐	3. FSAR	☑	☐	☐	12. SPARES/MULTIPLE UNIT LISTINGS
☐	☑	☐	4. SEISMIC/STRESS ANALYSIS	☐	☑	☐	13. DO SPARES NEED MODIFIED
☐	☑	☐	5. DESIGN REPORT	☑	☐	☐	14. TEST PROCEDURES/SPECS.
☐	☑	☐	6. INTERFACE CONTROL DWGS.	☐	☑	☐	15. COMPONENT INDICES
☐	☑	☐	7. CALIBRATION PROCEDURES	☐	☑	☐	16. ASME CODED ITEMS
☑	☐	☐	8. INSTALLATION PROCEDURES	☐	☑	☐	17. HUMAN FACTOR CONSIDERATIONS
☑	☐	☐	9. MAINTAINANCE PROCEDURES	☐	☑	☐	18. COMPUTER SOFTWARE

(18) RELATED DOCUMENT NO.; INSTRUCTION NO.; IDENTIFIED IN BLOCK 17. (CHANGES TO DOCUMENTS LISTED IN BLOCK 18 WILL NOT BE INCOPRORATED BY THIS ECO).

DOCUMENT NO./REVISION	

(19) DISTRIBUTION

NAME	ORG.
L. Jackson	R.W.H.E.
W. Bridges	Fac. Ops.
D. Schoen	Maint.

(20) SIGNATURE REQUIREMENTS

KEY
A=APPR.
R=REVIEW

ECO # 4127

A	COG. ENGINEER	30 Jan. '90.
A	COG. ENGR. MGR.	
A	Q.A.	3-1-90
A	DOE	6 Mar 90
R	SAFETY	3/7/90
	DEPT. MGR.	
R	OPERATIONS	3/6/9
	SECURITY	

(21) DESIGN VERIFICATION REQUIREMENTS (PER WP 09-018)

WP
1. REQUIREMENTS SATISFIED BY REVIEW/APPROVAL OF DESIGN DOCUMENT
2. INDEPENDENT REVIEW — See Attachment B.
3. ALTERNATE CALCULATIONS
4. DEVELOPMENT TESTING
5. DESIGN REVIEW
6. OTHER _____

EDT# E90-021.

(9) Description of change (continued)

Scope

A Hood Vent System is being implemented at each Trupact dock, see ECO-3850 and specification D-0070. The purpose of this ECO is to provide the design and drawings required to implement the Inlet Manifold Duct and the ductwork interface between the Trupact Hood Vent System fans and the existing CH area HVAC exhaust duct.

Description

The basic design has been provided by the Hood Vent System supplier, EDS. See Attachment A for a copy of their preliminary design information and calculations.

The design information contained in Attachment A has been used to produce the ductwork layout shown in the sketches on pages 4 through 17. These sketches are to be the basis of new drawing 41-B-002-W.

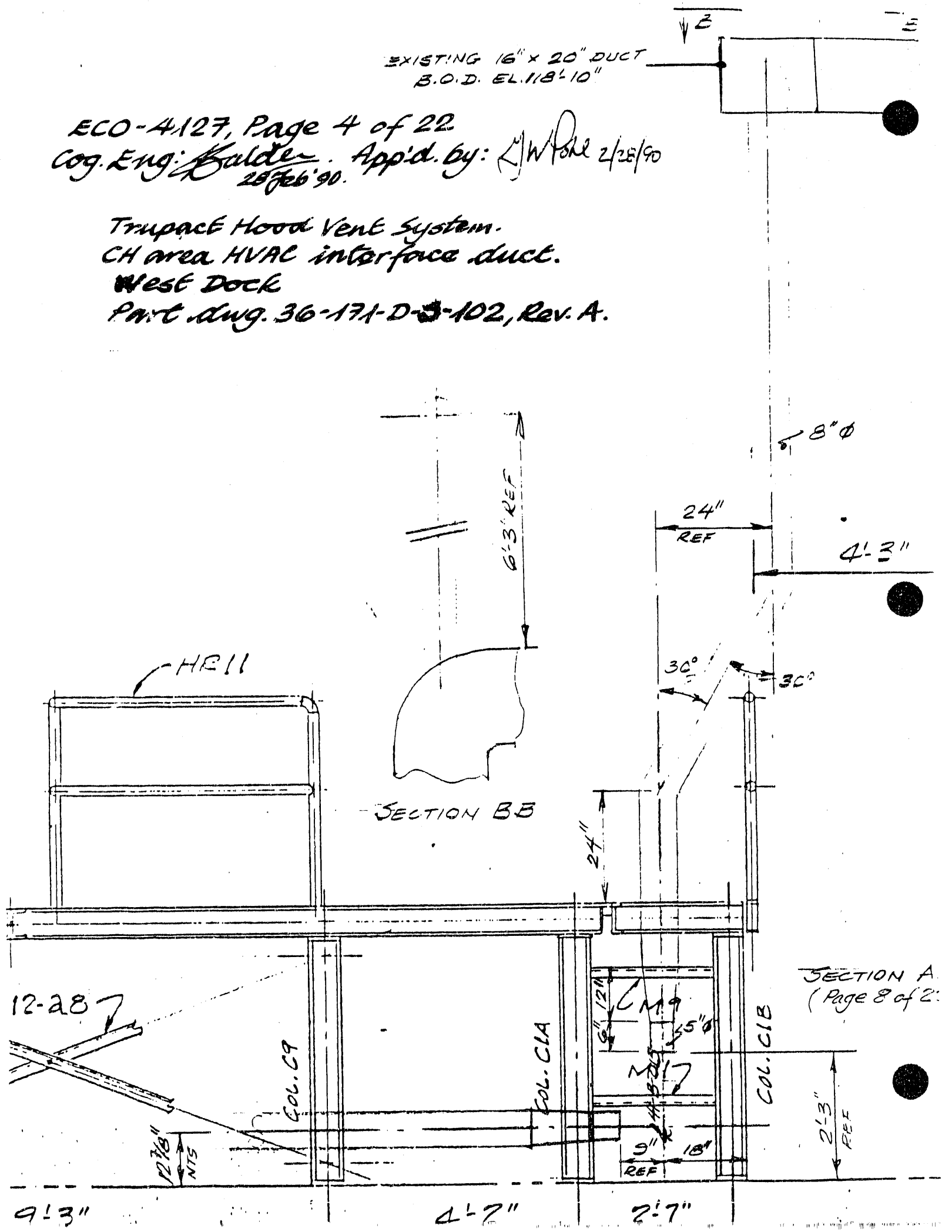
The sketch on page 18 is to be used to create a new flow diagram for the additions to the CH area HVAC system, 41-F-022-014, Sht. 2 of 2. Existing flow diagram 41-F-022-014 to be labelled Sht. 1 of 2 and is to be revised to show the changes required by pages 19 and 20.

The sketch on page 21 shows the new automatic dampers that are to be installed in the CH area HVAC system exhaust duct. Drawing 41-G-305-014, Rev. D is to be revised accordingly.

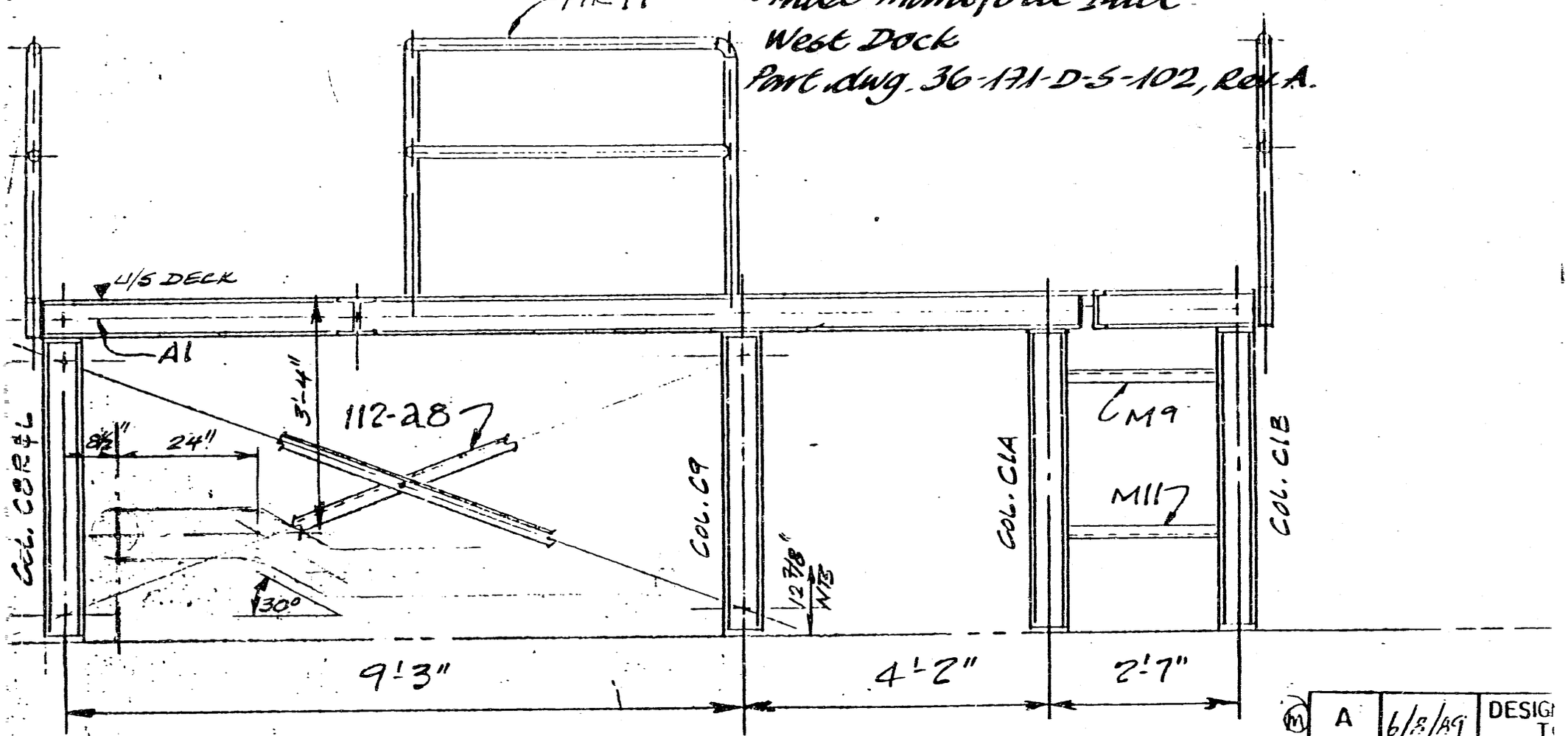
The sketch on page 22 shows the revisions that are required to P. & I. D. 41-F-059-014, Rev. E.

ECO-4127, Page 4 of 22
Cog. Eng: Balde 28 Feb '90. App'd. by: J W Pohl 2/25/90

Trupace Hood Vent System.
CH area HVAC interface duct.
West Dock
Part dwg. 36-171-D-3-102, Rev. A.



Tripact Hood Vent System
~ Inlet Manifold Duct
West Dock
Part dwg. 36-171-D-5-102, Rev A.



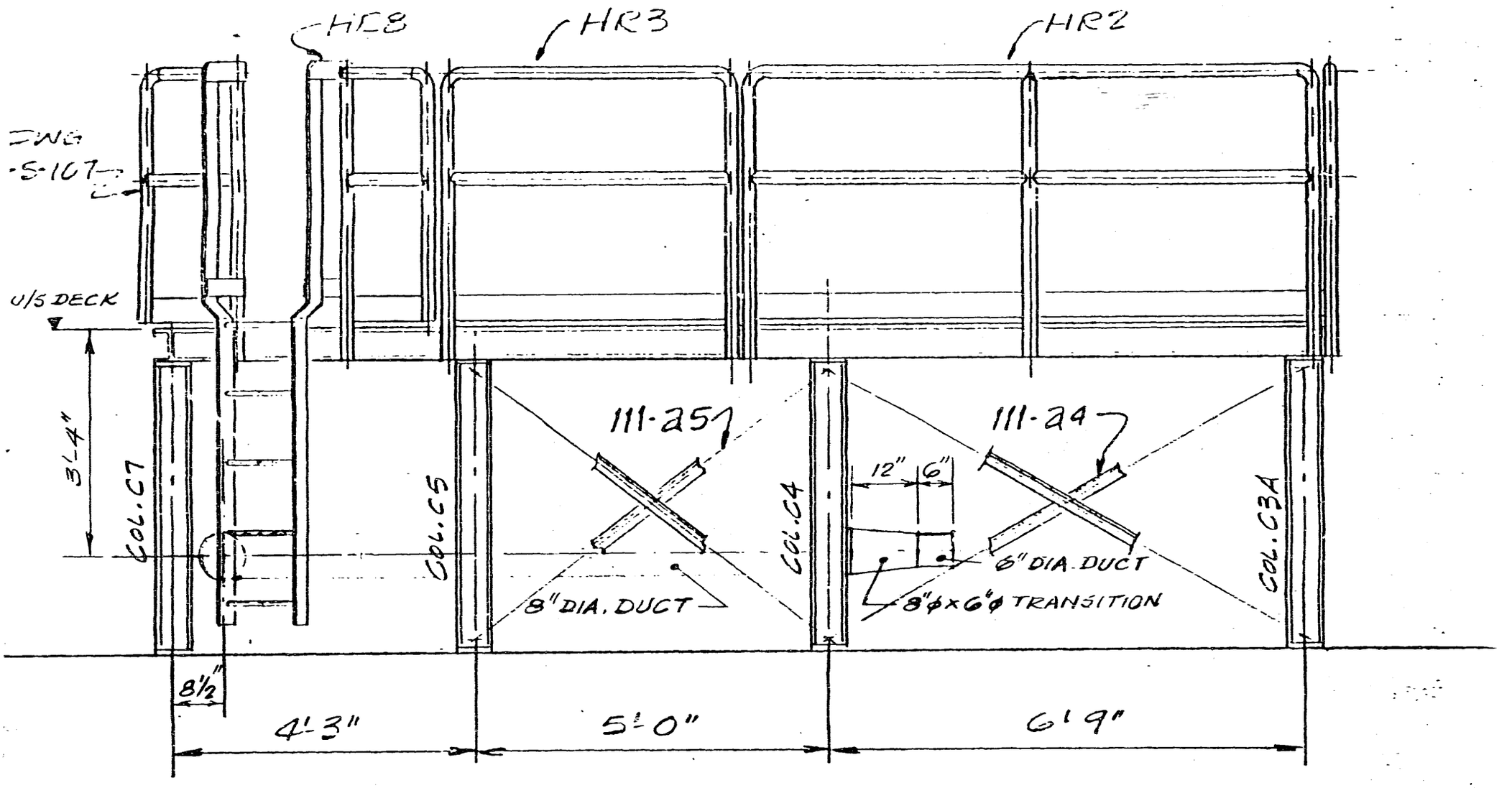
SECTION (D/101)

SECTION CC
(Page 10 of 22)

REV	DATE	DESIGN
A	6/8/89	

A	AS BUIL
NO	

ECO-4127, Page 5 of 22.
Cog. Eng.: [illegible] 28 Feb 90
App'd. by: [illegible] 4/25/90



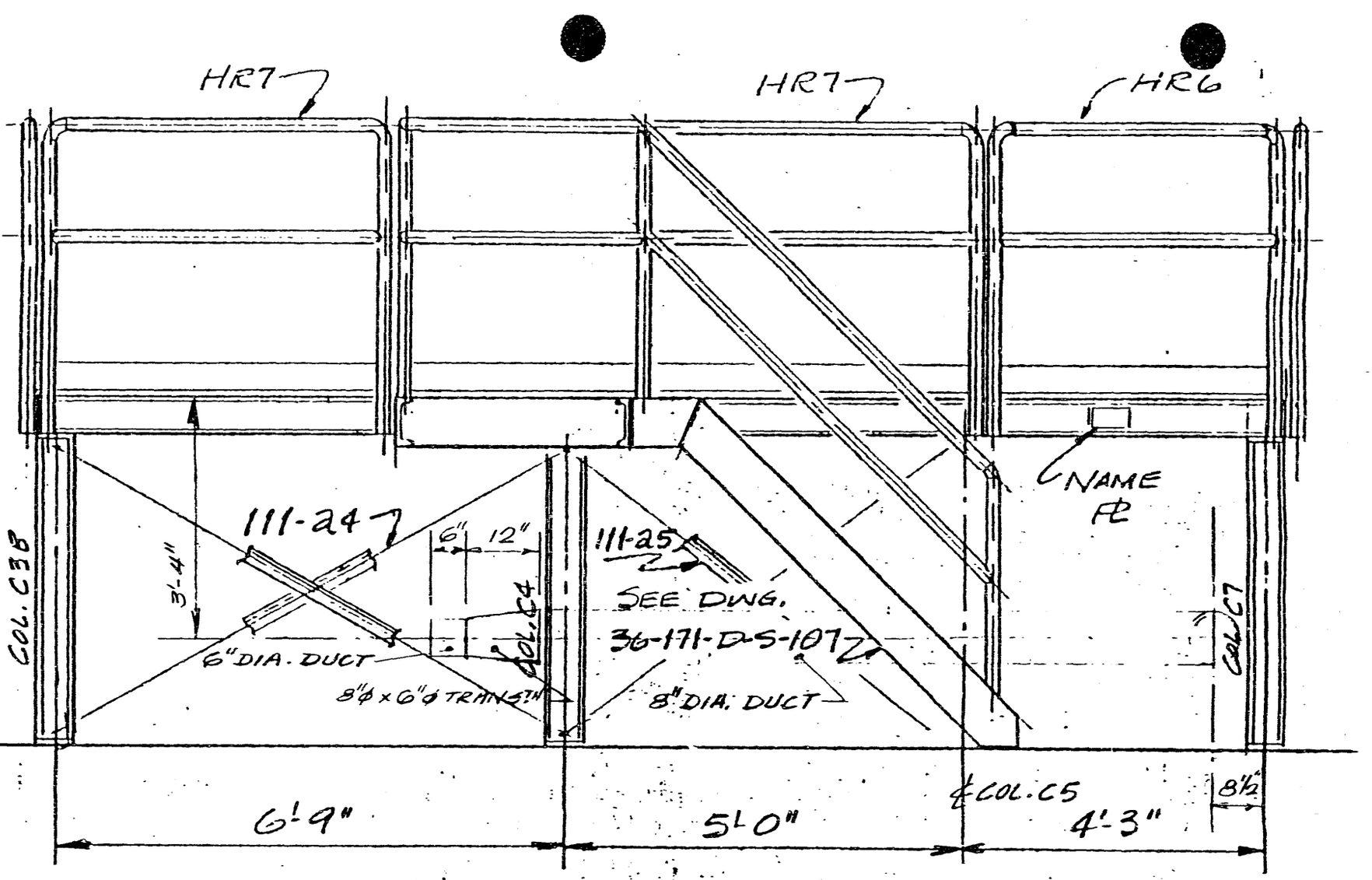
SECTION DD
(Page 10 of 22)

SECTION C/101

Trupact Hood Vent System
- Inlet Manifold Duct.
West Dock

Cog. Eng.: [illegible] - 6 Feb. '90.
Appd. by: Gwfoke 2/13/90
ECO-4127, Page 6 of 22.

Part dwg. 36-171-D-S-102, Rev. A.

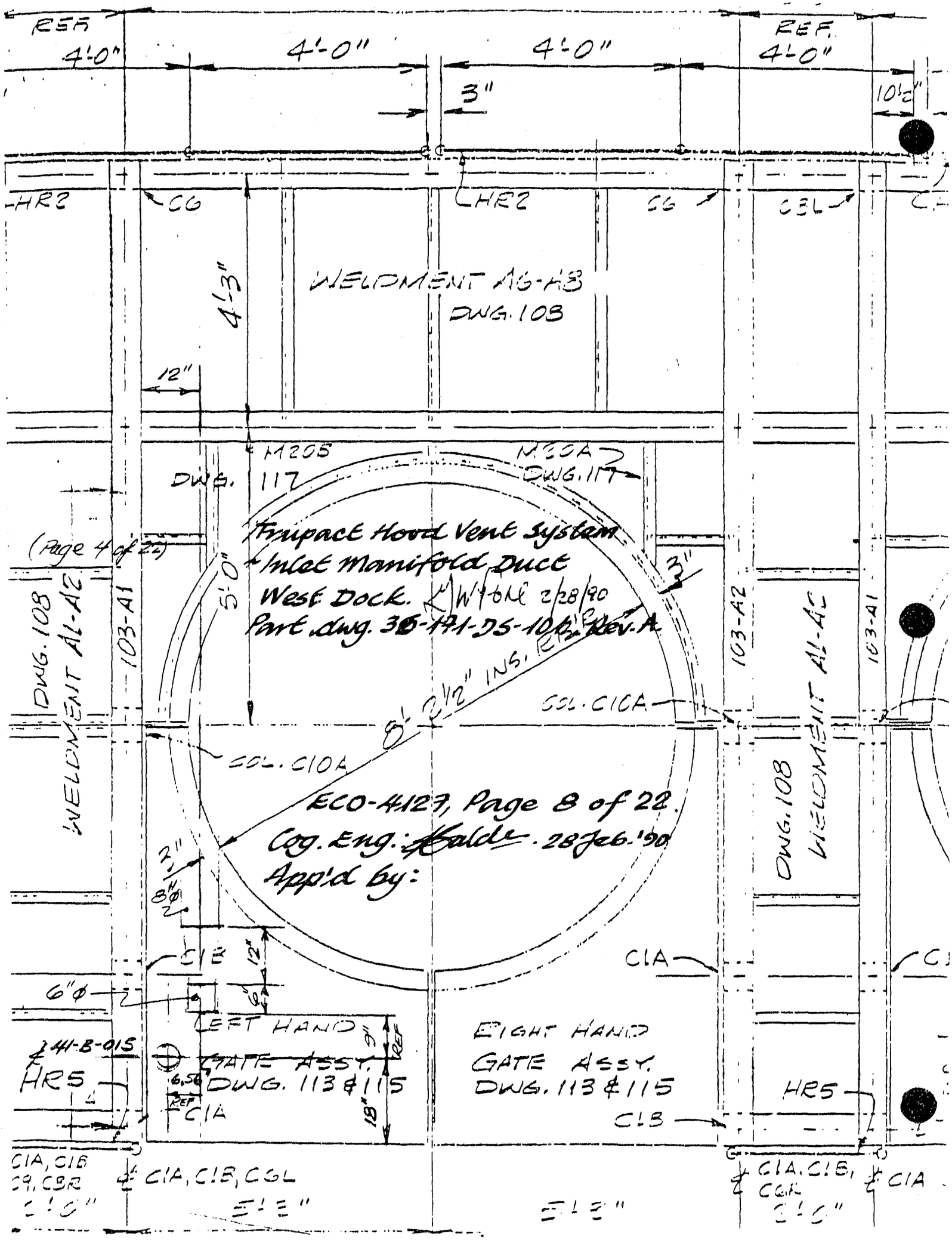


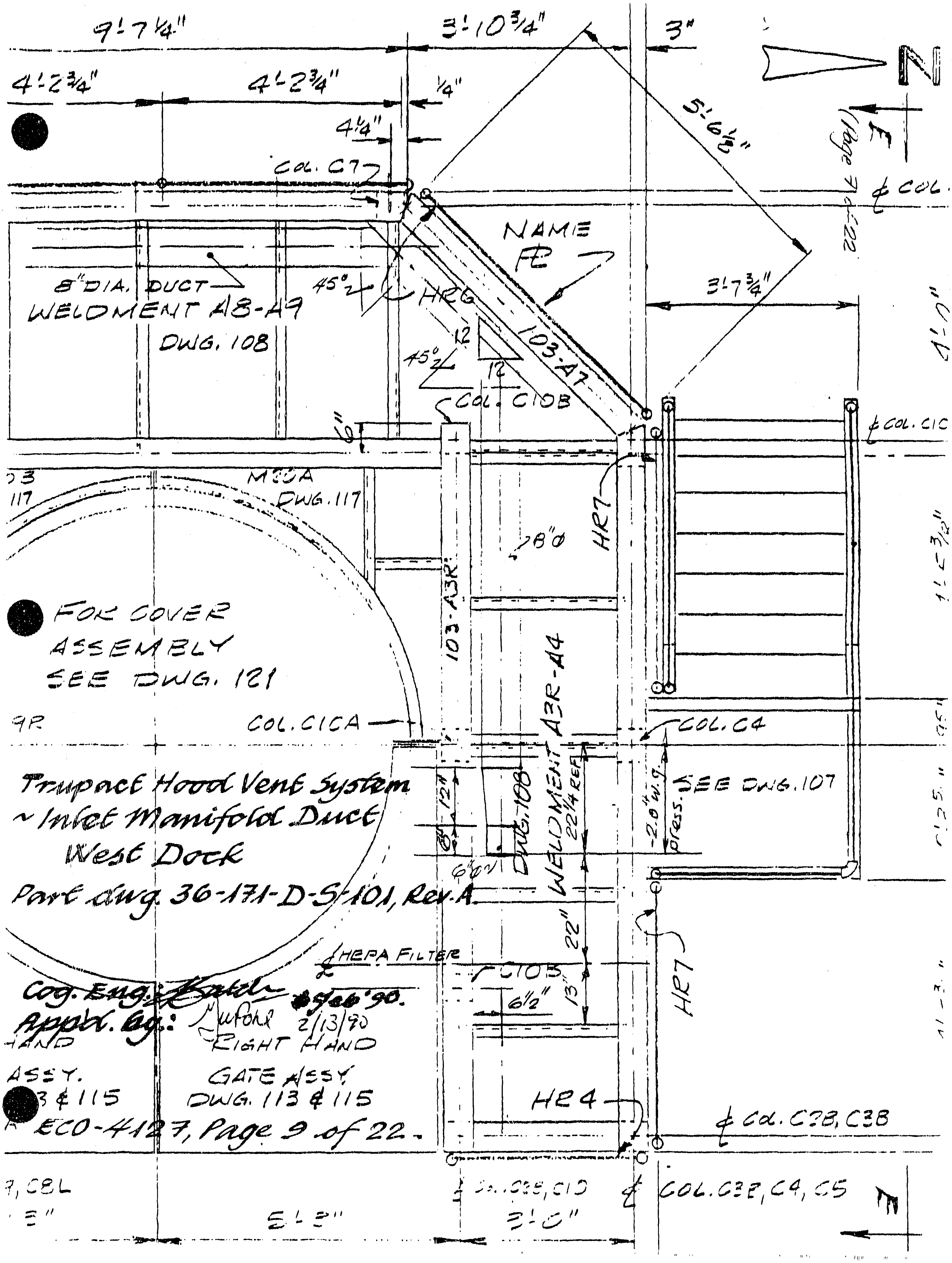
SECTION E E
(Page 9 of 22)

SECTION (B/101)

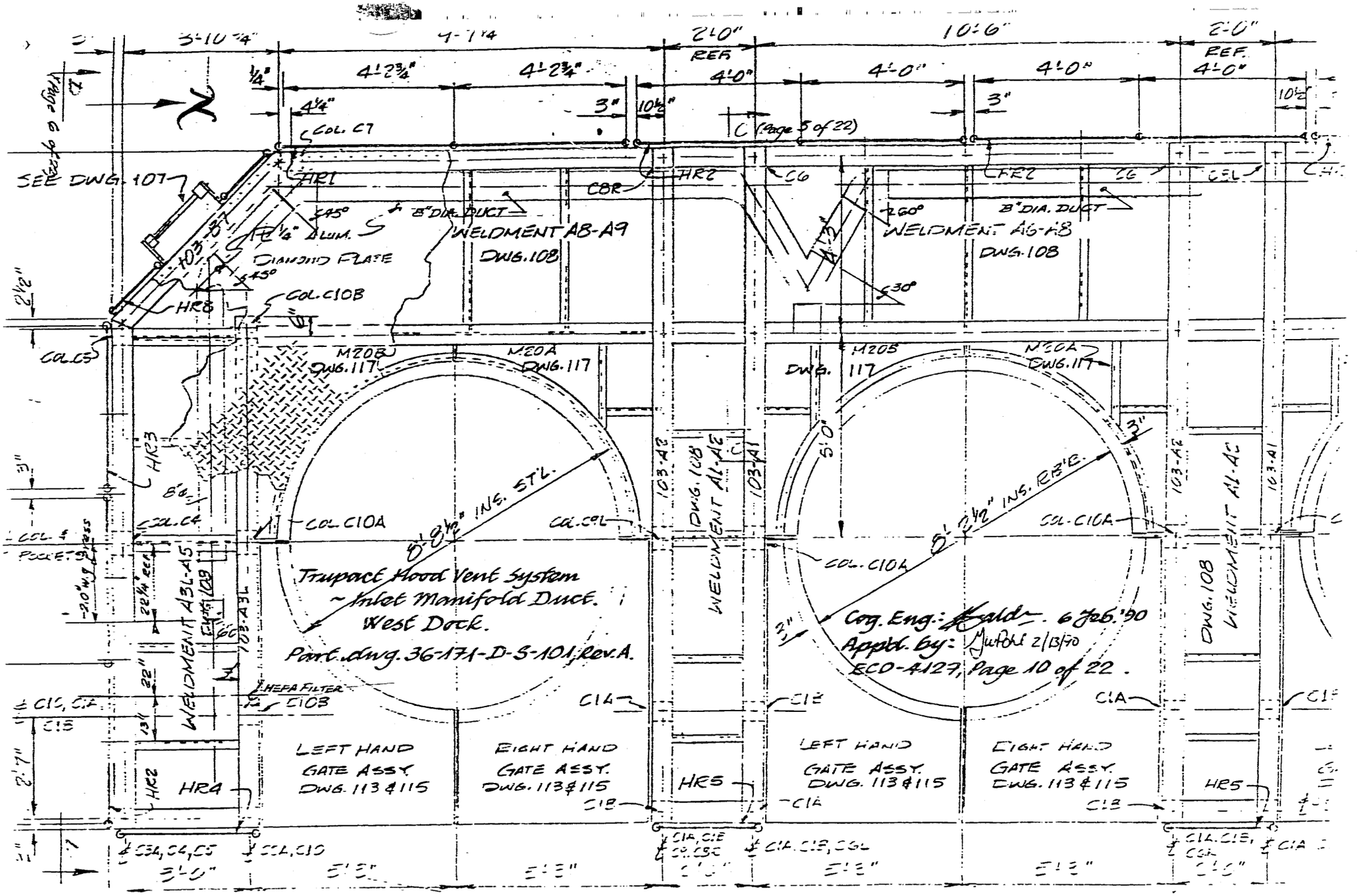
Trupact Hood Vent System
Inlet Manifold Duct.
West Dock
Part dwg. 36-171-D-S-102, Rev. A

Cog. Eng.: [signature] 6 Feb. '90.
Appr. by.: [signature] 2/13/90
ECO-4127, Page 7 of 22.

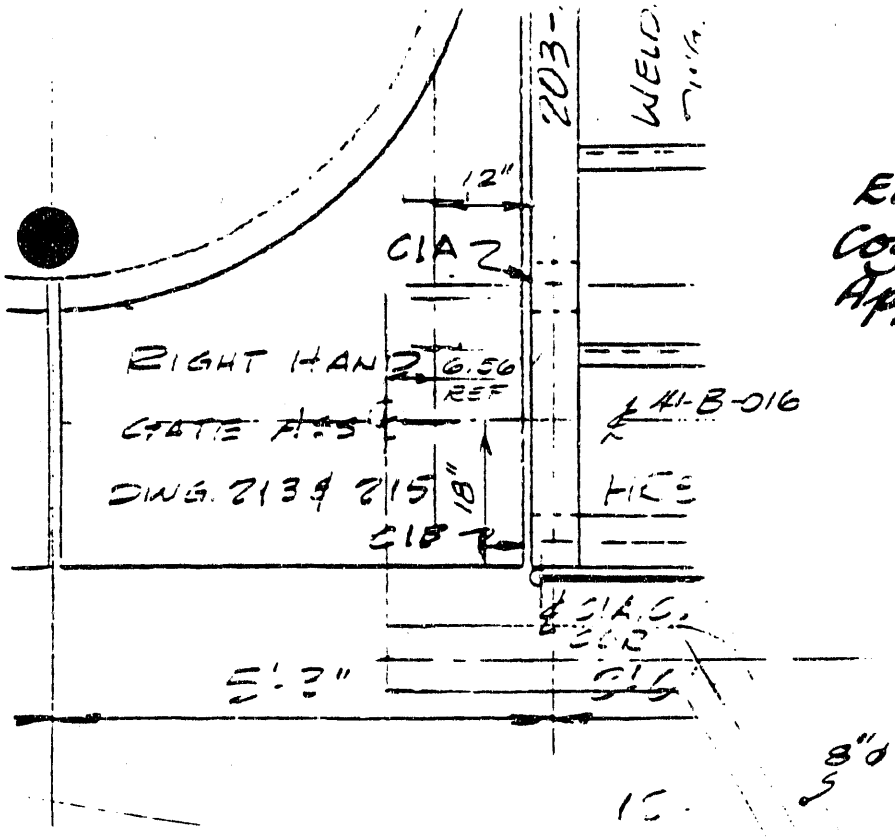

REF
4'-0"
4'-0"
4'-0"
REF.
4'-0"
3"
10½"
HR2
CG
HR2
CG
CBL
WELDMENT A6-A8
DWG. 108
4'-3"
12"
M20S
DWG. 117
M20A
DWG. 117
Fnipace Hood Vent System
Inlet Manifold Duct
West Dock. W/ToM 2/28/90
Part dwg. 36-171-75-102 Rev. A
(Page 4 of 22)
5'-0"
3"
103-A1
103-A2
DWG. 108
WELDMENT A1-A2
DWG. 108
WELDMENT A1-A2
12½" INS.
CCL. C1CA
CCL. C1CA
ECO-4127, Page 8 of 22.
Cog. Eng: Kalde 28 Feb '90
App'd by:
3"
8"Ø
C1B
12"
6"Ø
C1A
LEFT HAND
GATE ASSY.
DWG. 113 & 115
RIGHT HAND
GATE ASSY.
DWG. 113 & 115
3" REF
6.56 REF
C1A
18"
HR5
HR5
C1B
C1A, C1B
C9, CBR
C'O"
C1A, C1B, CGL
E'E"
E'E"
C1A, C1B, CGL
C'O"
C1A



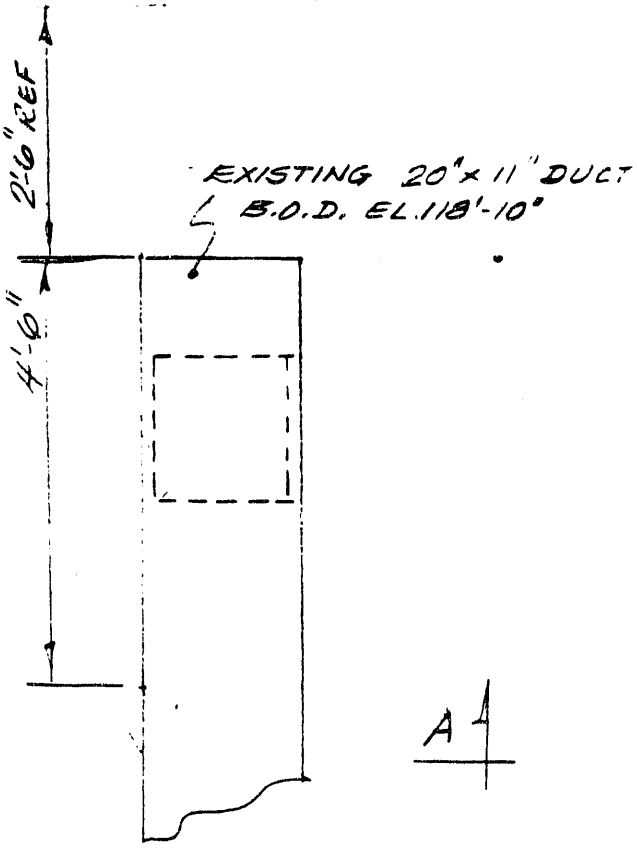
9'-7 1/4"
3'-10 3/4"
3"
4'-2 3/4"
4'-2 3/4"
1/4"
4 1/4"
5'-6 1/8"
N
E
(Page 7 of 22)
℄ COL.
COL. C7
NAME
HR6
8" DIA. DUCT
WELDMENT A8-A9
DWG. 108
45°
12
12
103-A7
3'-7 3/4"
4'-0"
COL. C10B
6"
℄ COL. C1C
M03A
DWG. 117
HR7
28"Ø
103-A3R
FOR COVER
ASSEMBLY
SEE DWG. 121
WELDMENT A3R-A4
1'-3 1/2"
COL. C1CA
COL. C4
Trupact Hood Vent System
~ Inlet Manifold Duct
West Dock
Part dwg. 36-171-D-S-101, Rev. A.
12"
22 1/4 REF
2.0" W.G. PRESS.
SEE DWG. 107
DWG. 108
6"Ø
22"
HEPA FILTER
C10B
13"
6 1/2"
HR7
Cog. Eng.
Appr. Eng.
2/13/90
RIGHT HAND
GATE ASSY
DWG. 113 & 115
HR4
ECO-4127, Page 9 of 22.
℄ Col. C3B, C3B
COL. C3B, C4, C5
3'-0"

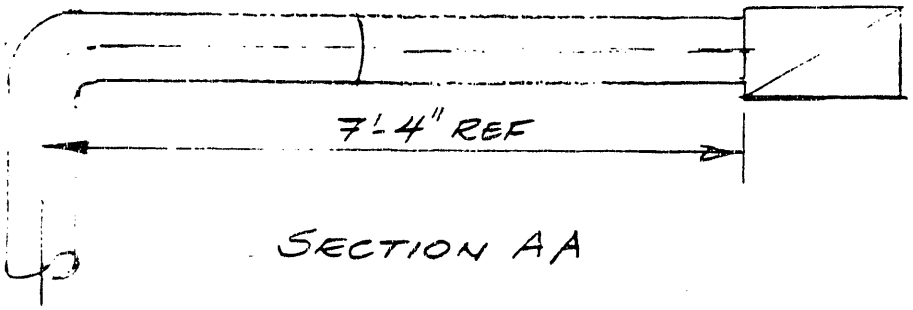

3'-10 1/4"
4'-7 1/4"
2'-0" REF
10'-6"
2'-0" REF.
4'-2 3/4"
4'-2 3/4"
4'-0"
4'-0"
4'-0"
4'-0"
3"
3"
10 1/2"
10 1/2"
C (Page 5 of 22)
SEE DWG. 107
HR1
HR2
HR3
HR4
HR5
HR6
C6
C8R
C8L
45°
60°
30°
8" DIA. DUCT
WELDMENT A8-A9
DWG. 108
WELDMENT A6-A8
DWG. 108
1/2" ALUM. DIAMOND PLATE
COL. C10B
COL. C5
COL. C4
M20B
DWG. 117
M20A
DWG. 117
M20B
DWG. 117
M20A
DWG. 117
51.0"
COL. C10A
COL. C9L
COL. C10A
COL. C10A
WELDMENT A1-A5
DWG. 108
WELDMENT A1-A5
DWG. 108
WELDMENT A1-A6
DWG. 108
103-A8
103-A1
103-A2
103-A1
HEPA FILTER
COL. C10B
C1A
C1B
C1E
C1A
C1F
LEFT HAND GATE ASSY. DWG. 113 & 115
RIGHT HAND GATE ASSY. DWG. 113 & 115
LEFT HAND GATE ASSY. DWG. 113 & 115
RIGHT HAND GATE ASSY. DWG. 113 & 115
C5A, C4, C5
C1L, C10
C1A, C1E
C9L, C9C
C1A, C1B, C9L
C1L, C1E, C9R, C1A
3'-0"
5'-3"
5'-3"
5'-3"
5'-3"
5'-3"
Truspace Hood Vent System
~ Inlet Manifold Duct.
West Dock.
Part dwg. 36-171-D-S-101, Rev. A.
Cog. Eng.: Gald 6 Feb. '90
Appld. by: Mulford 2/13/90
ECO-4127, Page 10 of 22.

ECO-4127; Page 11 of 22.
Cog. Eng.: ~~Baldr~~ 28 Feb. '90
Appd. by: JWFolk 2/28/90



Tripace Hood Vent System
CH area HVAC sys. interface.
East Dock.
Part dwg. 36-131-D-5-201, Rev A.





SECTION AA

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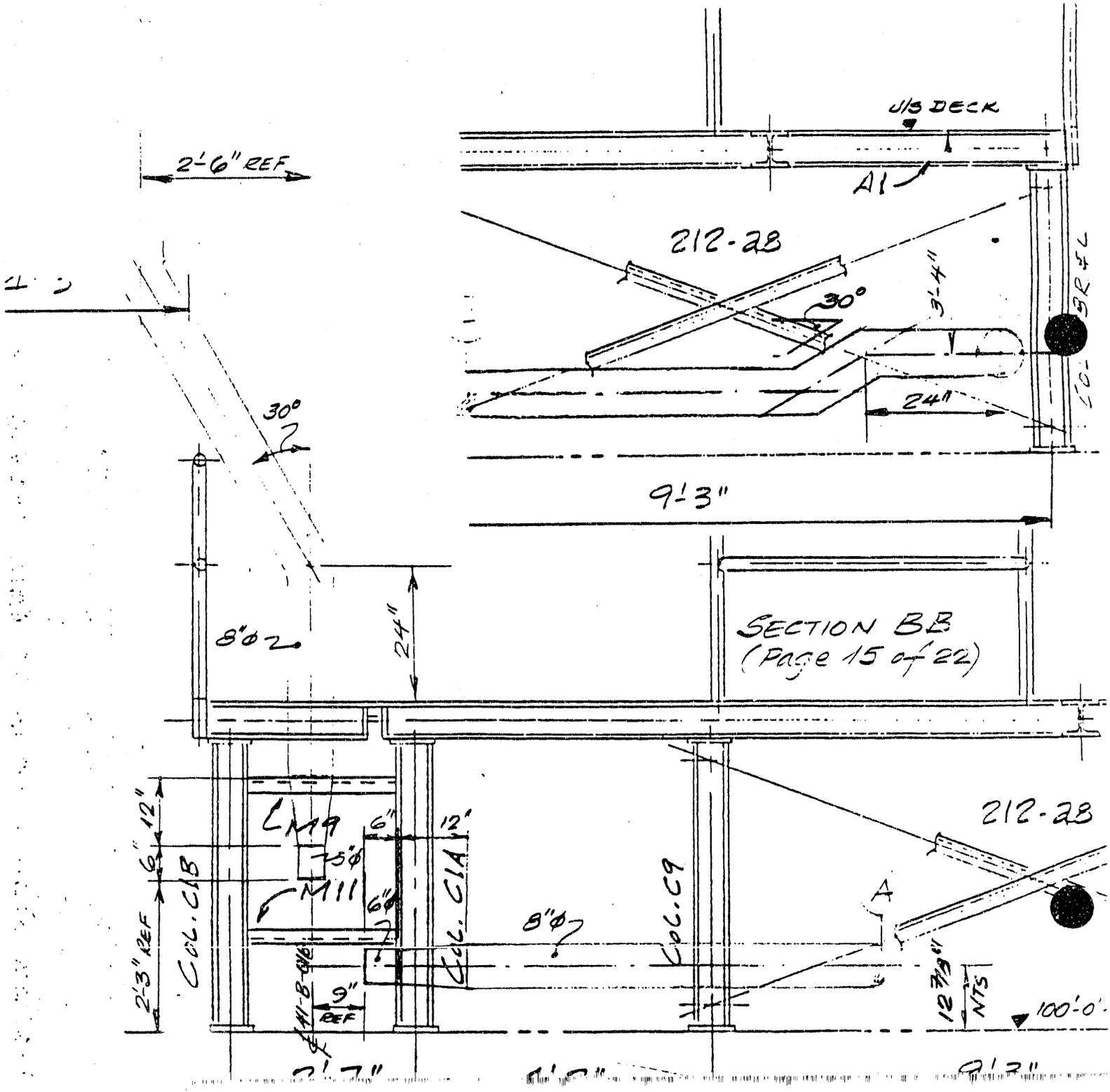
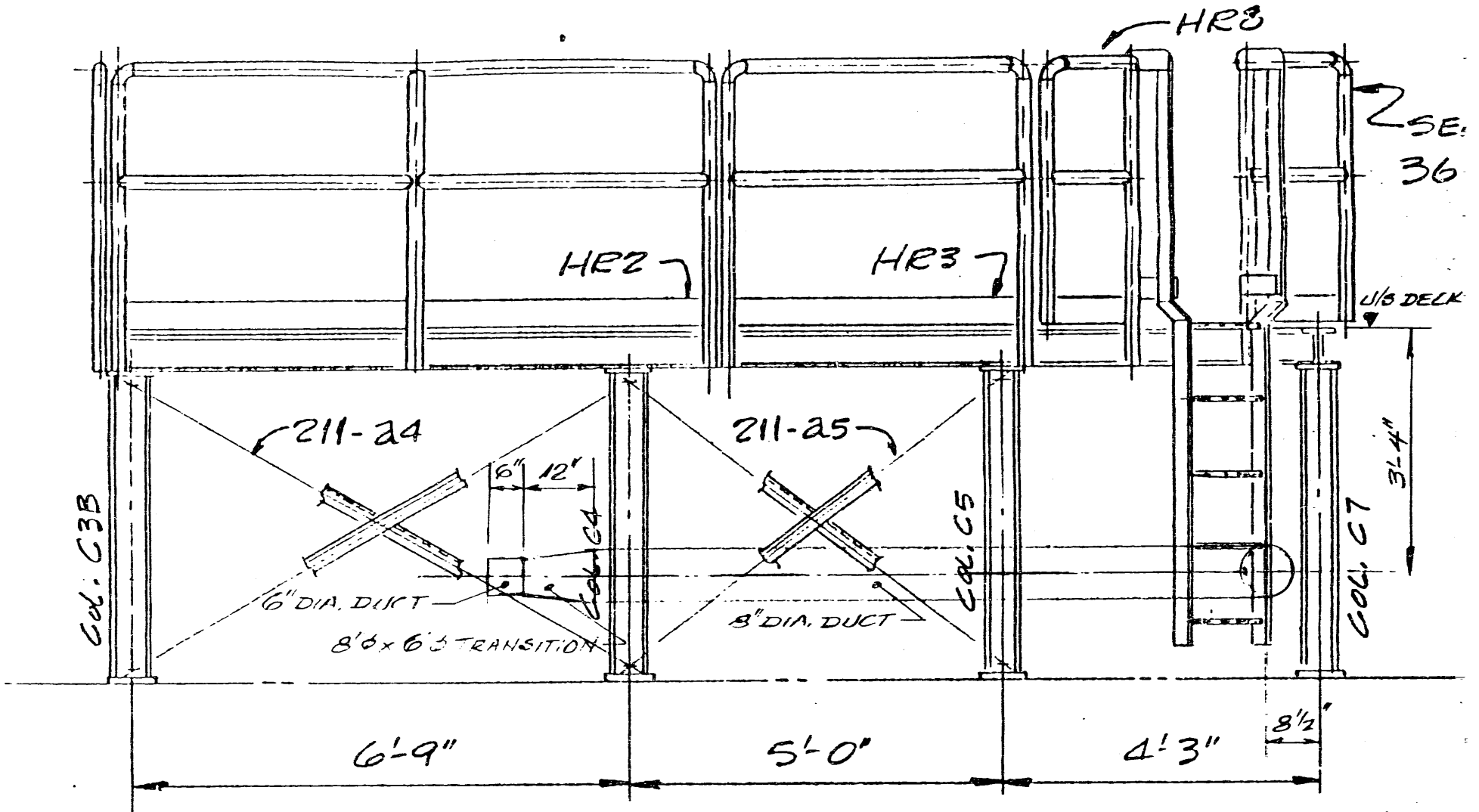
Cog. Eng.: ~~Balde~~ 28 Feb. '90.
App'd. by: JhiTone 2/28/90

Trupace Hood Vent System.
~Inlet Manifold Duct
East Dock
Pave. dwg. 36-171-D-5-202, Rev. A.



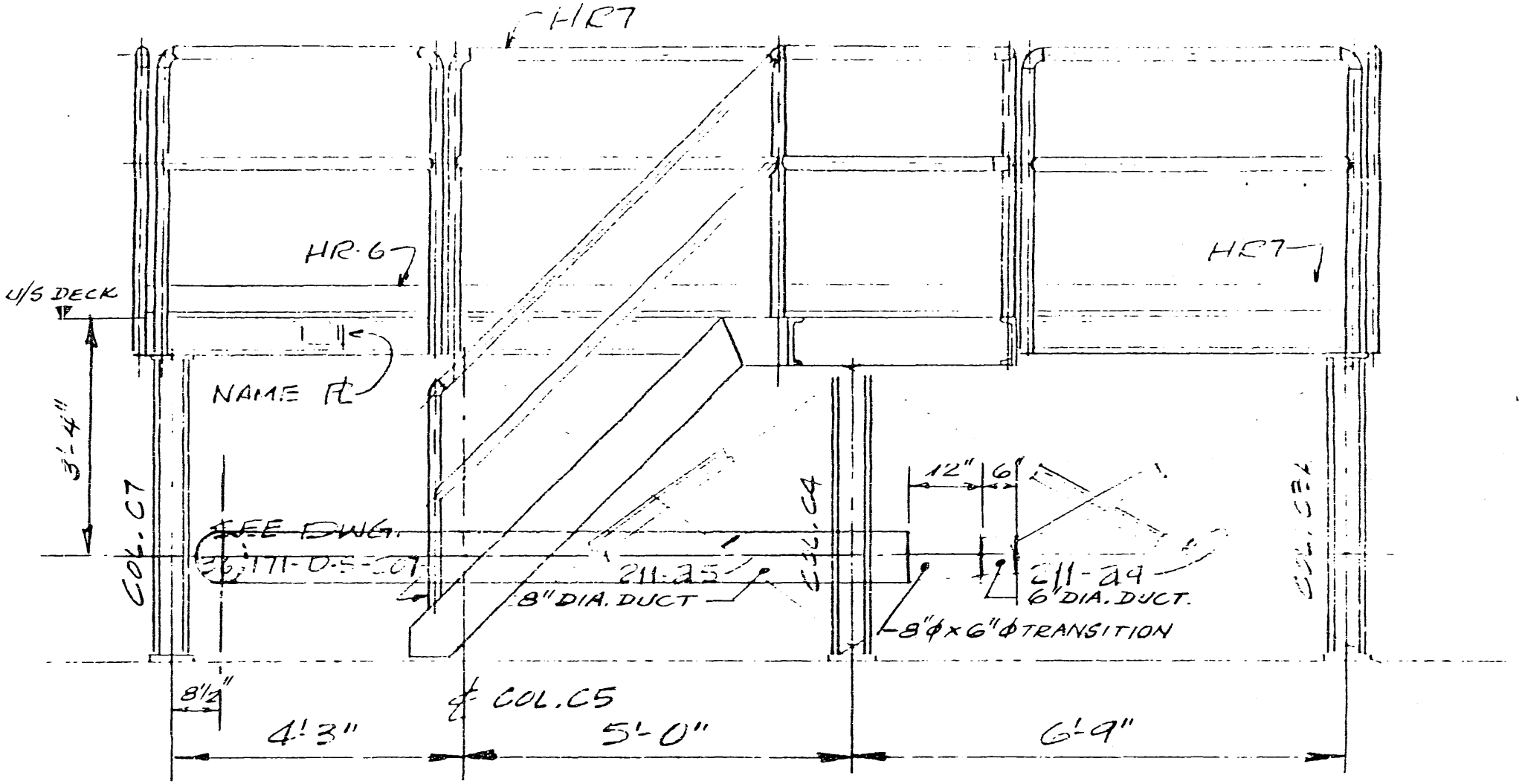


SECTION CC
(Page 16 of 22)

SECTION (C/201)

Trupace Hood Vent System.
~ Inlet Manifold Duct
East Dock
Part dwg. 36-171-D-S-202, Rev. A.

Cog. Eng.: Kalde - 6 Feb. '90
App'd. by: Durfee 2/13/90
ECO-4127, Page 13 of 22.



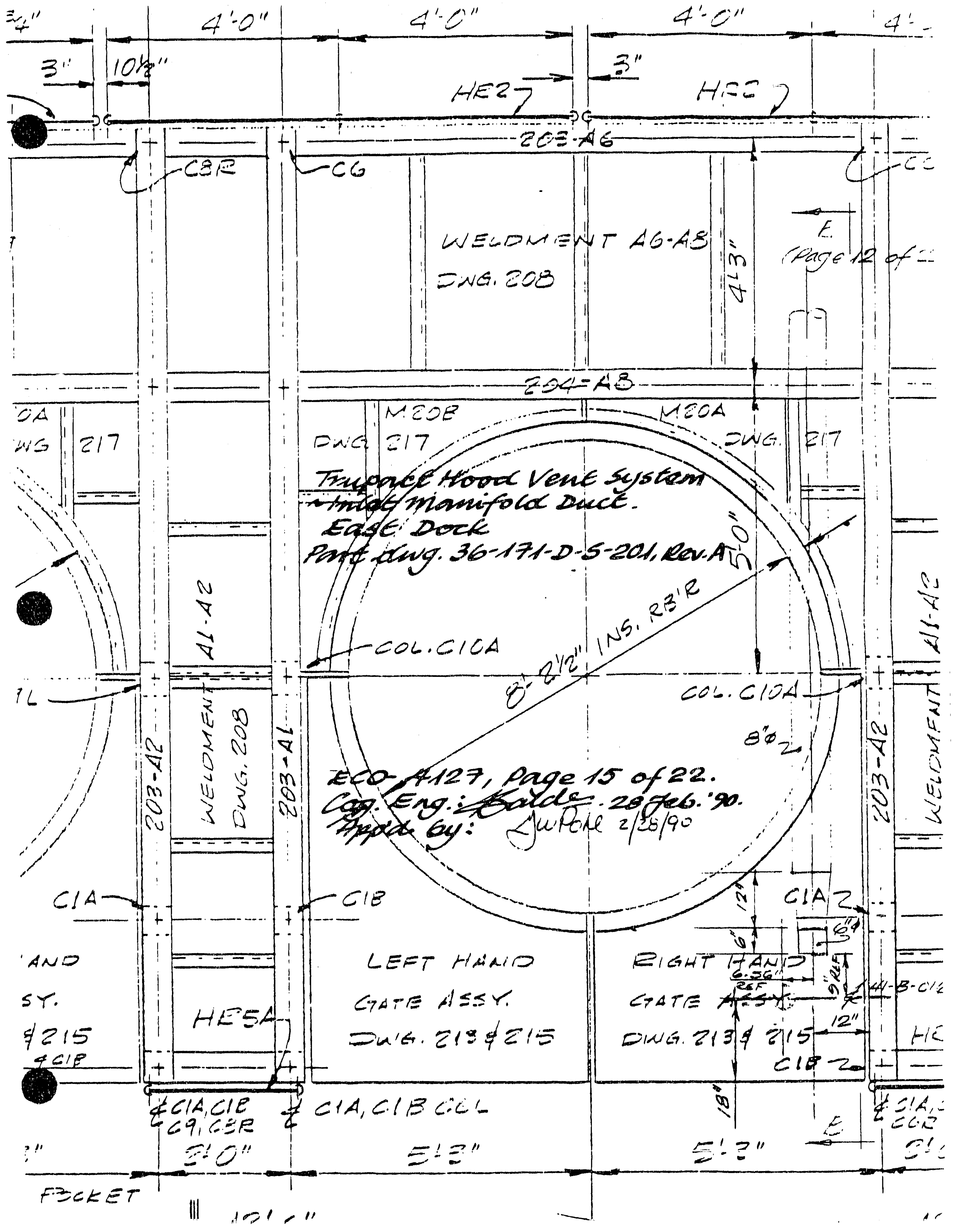
SECTION DD
(Page 17 of 22)

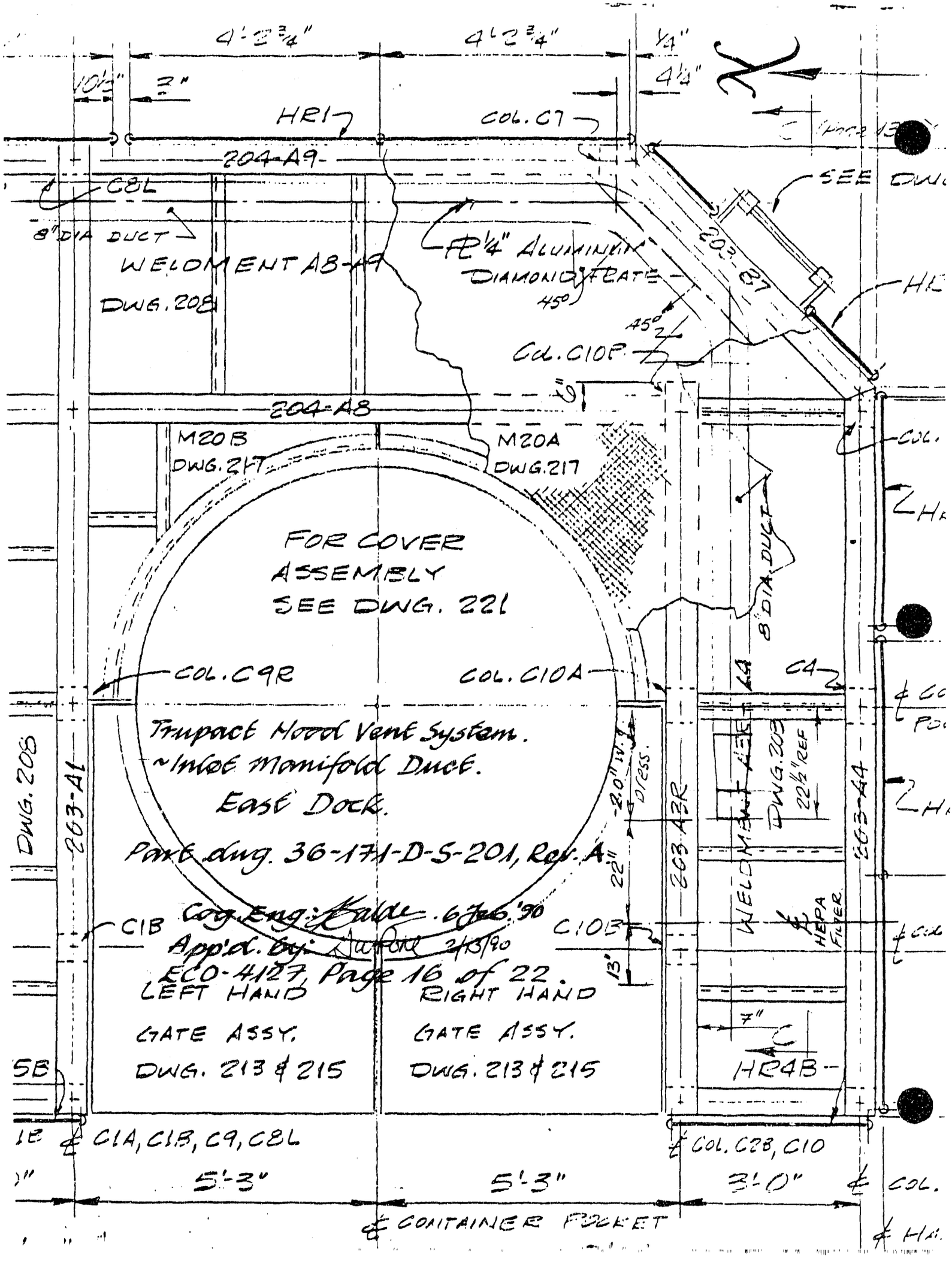
SECTION B/201

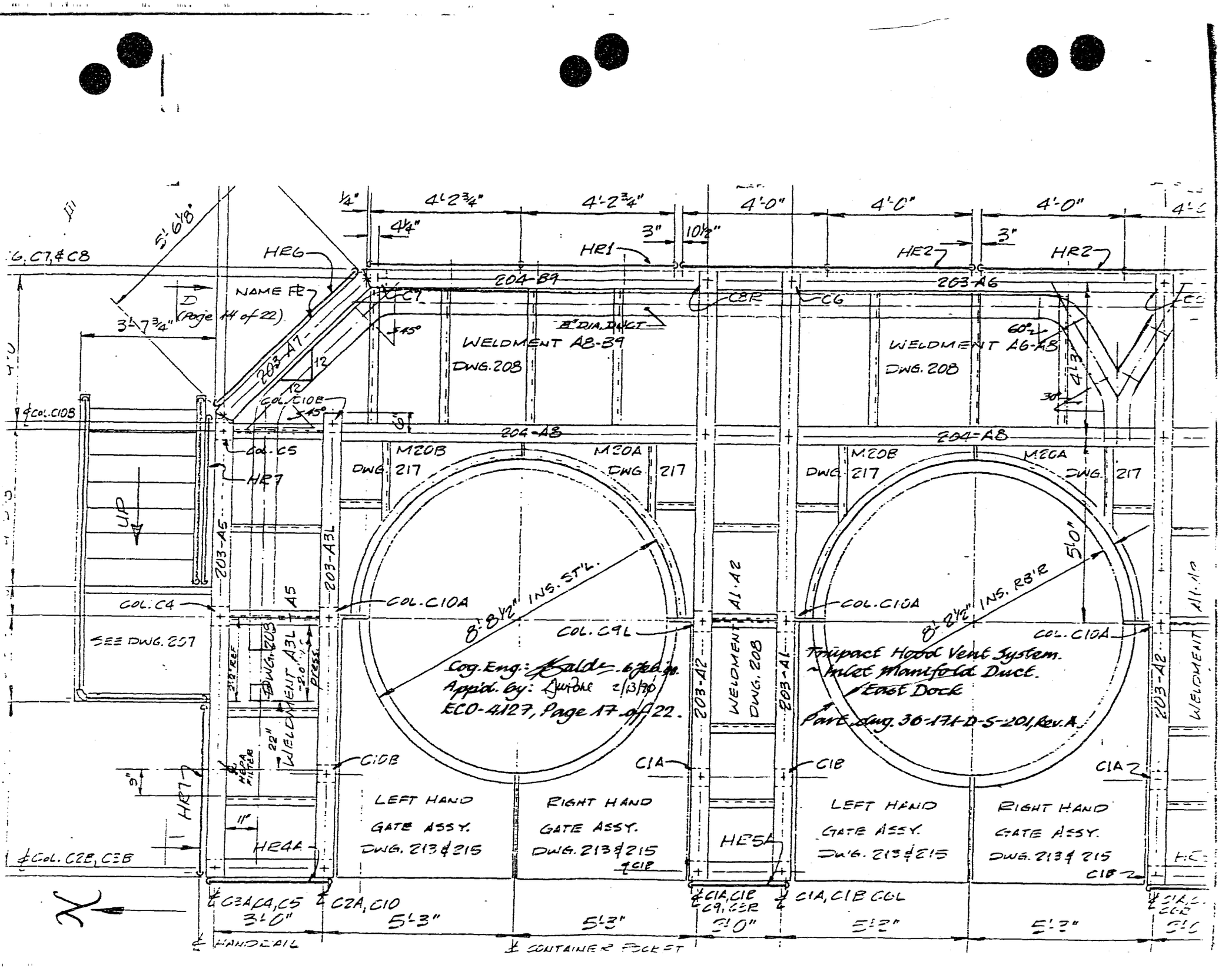
Trupace Hood Vent System.
~Inlet Manifold Duct
East Dock.

Part dwg. 36-171-D-5-202,
Rev. A.

Cog. Eng.: ~~K Balde~~ 6 Feb. '90
App'd. by: J Jurbine 2/13/90
ECO-4127 Page 14 of 22


4'-0"
4'-0"
4'-0"
3"
10½"
3"
HE2
203-A6
C8R
C6
WELDMENT A6-A8
DWG. 208
4'3"
E
(Page 12 of
204-A8
M20B
M20A
DWG. 217
DWG. 217
217
Trupact Hood Vent System
Manifold Duct.
Ease Dock
Part dwg. 36-171-D-S-201, Rev. A
5'0"
8'-8½" INS. R8'R
COL. C10A
COL. C10A
A1-A2
WELDMENT DWG. 208
203-A2
203-A1
8'0"
ECO-A127, Page 15 of 22.
Cog. Eng.: Balde 28 Feb. '90.
Appd by: JwPole 2/28/90
C1A
C1B
C1A
12"
6"
6"
LEFT HAND
GATE ASSY.
DWG. 213 & 215
RIGHT HAND
GATE ASSY.
DWG. 213 & 215
6.56"
REF
12"
C1B
HE5A
18"
℄ C1A, C1B
℄ C9, C8R
℄ C1A, C1B COL
3'-0"
5'-3"
5'-3"
E
POCKET


4'-2 3/4"
4'-2 3/4"
1/4"
4 1/2"
10 1/2"
3"
HR17
COL. C7
204-A9
C8L
8" DIA DUCT
WELDMENT A8-A9
DWG. 208
1/4" ALUMINUM DIAMOND PLATE
45°
45°
COL. C10P
204-A8
M20B
DWG. 217
M20A
DWG. 217
FOR COVER ASSEMBLY SEE DWG. 221
COL. C9R
COL. C10A
8" DIA DUCT
C4
Trupace Hood Vent System.
~Inlet Manifold Duct.
East Dock.
Part dwg. 36-171-D-S-201, Rev. A
Cog Eng: Kalle 6/26/90
App'd. by: Lawford 2/3/90
ECO-4127, Page 16 of 22
C1B
C10B
LEFT HAND GATE ASSY.
DWG. 213 & 215
RIGHT HAND GATE ASSY.
DWG. 213 & 215
DWG. 205
263-A1
263-A2R
263-A4
DWG. 203
22 1/2" REF
WELDMENT A4
HEPA FILTER
HR4B
5E
1E
7"
22"
20" W.
DIFFUSS.
13'
5'-3"
5'-3"
3'-0"
℄ C1A, C1B, C9, C8L
℄ COL. C2B, C10
℄ CONTAINER POCKET


4'-2¾"
4'-2¾"
4'-0"
4'-0"
4'-0"
4½"
3"
10½"
3"
HR6
HR1
HR2
HR2
204-B9
203-A6
C7
C8R
C6
NAME PL
(Page 14 of 22)
3'-7¾"
203-A7
12
12
45°
8" DIA. DUCT
WELDMENT A8-B9
DWG. 208
WELDMENT A6-A8
DWG. 208
60°
30°
41⅜"
C10B
C10B
15°
204-A8
204-A8
C5
HR7
M20B
DWG. 217
M20A
DWG. 217
M20B
DWG. 217
M20A
DWG. 217
UP
203-A5
203-A3L
C4
C10A
C10A
C9L
8'-8½" INS. ST'L.
8'-8½" INS. RS'L
5'-0"
SEE DWG. 257
A5
A1-A2
WELDMENT
DWG. 208
203-A2
203-A1
203-A2
WELDMENT
A1-A2
Cog. Eng.: [illegible] 6/26/90
Appld. by: [illegible] 2/13/90
ECO-4127, Page 17 of 22.
Fanjpact Hood Vent System.
~ Inlet Manifold Duct.
/ East Dock
Part dwg. 36-171-D-5-201, Rev. A
C10B
C1A
C1B
C1A
HR7
HEPA FILTER
22"
WELDMENT A3L
DWG. 208
9"
11"
HR4A
HR5A
LEFT HAND
GATE ASSY.
DWG. 213 & 215
RIGHT HAND
GATE ASSY.
DWG. 213 & 215
LEFT HAND
GATE ASSY.
DWG. 213 & 215
RIGHT HAND
GATE ASSY.
DWG. 213 & 215
C2B, C3B
C3A, C4, C5
C2A, C10
C1A, C1B
C9, C9R
C1A, C1B COL
C1A, C1B COL
3'-0"
5'-3"
5'-3"
3'-0"
5'-2"
5'-2"
HANDRAIL
CONTAINER POCKET

CORRIDOR

LINE NO.	EQUIV. ROUND DUCT DIA. IN	CFM	
1	44	19350	
2	44	19350	
3	60	~~38700~~	19350
4	40	~~15.950~~	7975
5	32	~~8980~~	4490
6	30	~~6970~~	3485
7	14	~~750~~	375
8	28	~~6220~~	3110
9	14	~~1820~~	910
10	14	~~750~~	375
11	18	~~1820~~	910
12	14	~~1080~~	540
13	13	~~750~~	375
14	48	~~22750~~	11375
15	36	~~12850~~	6425
16	25	~~4500~~	2250
17	14	~~1030~~	515
18	30	~~7320~~	3660
19	30	~~7100~~	3550
20	10	~~220~~	110
21	34	~~9900~~	4950
22	14	~~900~~	450
24	16	~~4380~~	690
25	26	~~4880~~	2335
26	6	~~50~~	30
27	10	~~340~~	170
28	6	~~50~~	25
29	12	~~400~~	200

LINE NO.	EQUIV. ROUND DUCT DIA. IN	CFM	
32	10	~~340~~	170
33	14	~~900~~	450
34	28	~~14290~~	7145/6500 *
35	14	~~15530~~	7765
36	16	~~1580~~	790
37	26	~~5000~~	2500
38	52	~~8885~~	4440
39	48	~~24415~~	12205
40	6	0/70 ■	
41	6	0/70 ■	
42	30	~~6925~~	3465
43	-	-	
44	30	~~6915~~	3465
45	11	~~570~~	285
46	52	~~31910~~	15955
47	8	~~140~~	70
48	52	~~42050~~	16025
50	42	~~32035~~	16025
51	18	1750	
52	44	~~22775~~	17775
53	18	1750	
54	44	~~22775~~	17775
55	44	0/0	
56	20	~~2550~~	1275
57	20	~~2305~~	1150
58	26	~~5000~~	2500
59	20	2500	
60	20	2500	
61	20	0/2500 ■	
62	26	~~5000~~	2500

■ NORMAL/OCCASIONAL FLOW

LINE NO.	EQUIV ROUND DUCT DIA. IN	CFM
63	-	~~50~~ 25
64	-	~~25~~ 15
65	-	~~25~~ 15
66	-	~~200~~ 100
67	-	50
68	-	30
69	-	50
70	-	700
71	-	700
72	-	700
73	-	1030
74	-	140

NOTE: THESE HAVE BEEN INCORPORATED BY ECO # 3551

Gibbs & Hill, Inc
ENGINEERS, DESIGNERS, CONSTRUCTORS
New York
REV. "B" ONLY

PS OF ENGINEERS — DACW47-84-B-0002

5 4 3

Cog. Eng.: Kalde 13 Feb. '90.
App'd. by: MWFoke 2/13/90
ECO-4127, Page 19 of 22.

PARTIAL DWG # 41-F-022-014

~~ATTACHMENT 1~~

ECO # 3551

4/E

41-B-939

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Part dwg. 41-F-022-014, Rev. D.
Cog. Eng.: Kalde. 13 Feb. '90.
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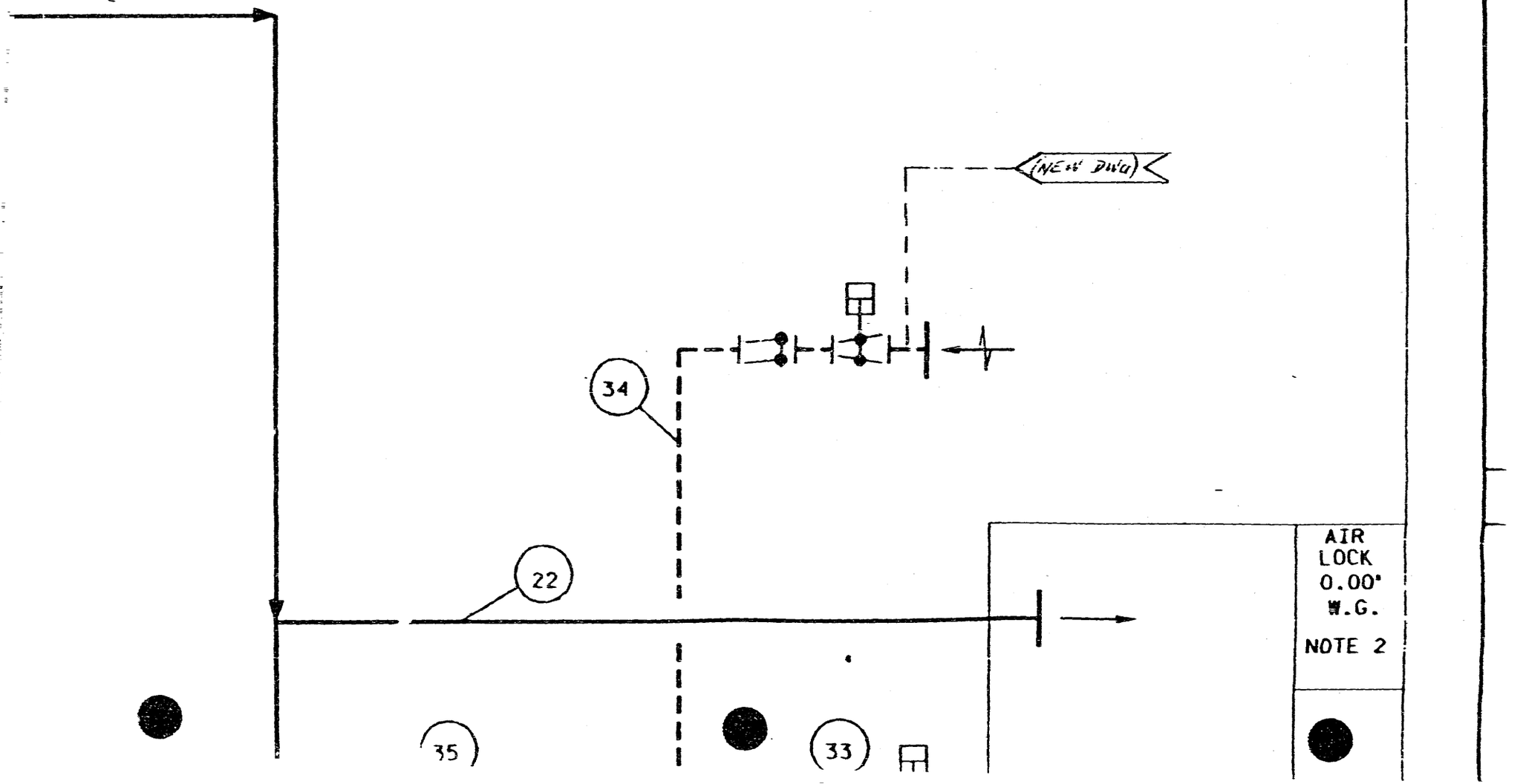
ECO-4127, Page 20 of 22.



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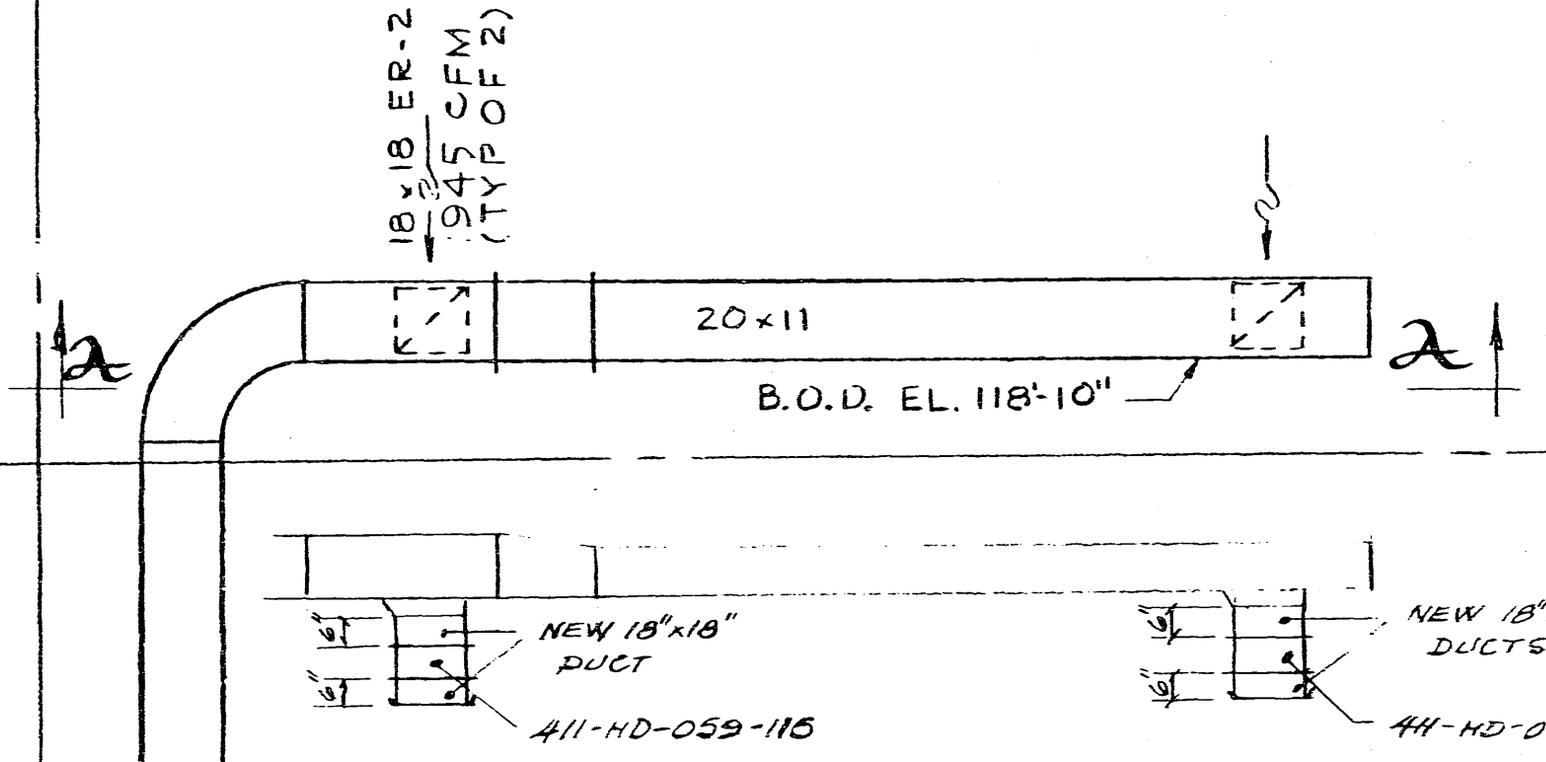


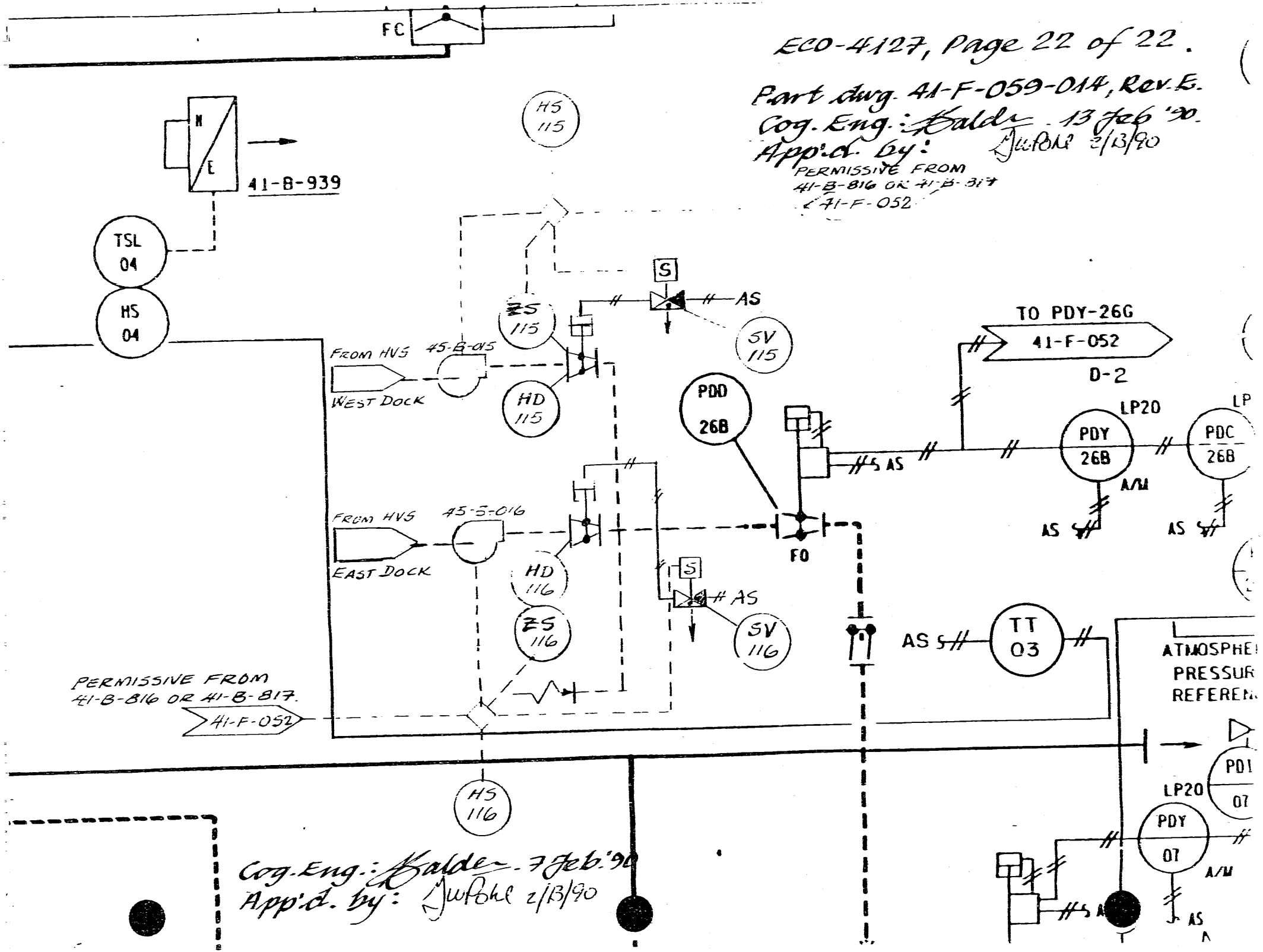
CONTACT HANDLING AREA 103

(INVENTORY & PREPARATION AREA)

Trupact Hood Vent System.
~CH Area HVAC system interface.
Part dwg.: 41-G-305-014, Rev D.

B.O.D. EL. 118'-10"

Part dwg. 41-F-059-014, Rev. E.
Cog. Eng.: Balde 13 Feb '90.
App'd. by: Jwfohl 2/13/90



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App'd. by: Jwfohl 2/13/90

ECO-4127; Attachment A.

Preliminary Design

Information and Calculations

TRUPACT-II DOOR HOOD VENT SYSTEMS (TDHVS) PROJECT

Contract No. 75WP52a6186

PREPARED FOR

Westinghouse Isolation Division

Waste Isolation Pilot Plant

Carlsbad, New Mexico

Report No. DR-2001
February 2, 1990

Prepared By

ENGINEERING, DESIGN & SYSTEMS

Federal Way, Washington

Dan L. Swannack

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2/2/90

Date

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1.0 INTRODUCTION

This design report provides the preliminary information and calculations for the air flow rates and component sizing of the TDHVS. Based on discussions during the proposal and the initial interface meeting at WIPP January 31, 1990, a nominal design flow rate for the system will be 300 cfm. This is expected to allow for operation of the system with three open access ports in the hood vent containment chamber and additional capacity for various in-leakage considerations. Examples of these additional in-leakages are the hood vent containment chamber at the vertical closure seam and the top and bottom diameter drawband contact surface with the TRUPACT-II package containments.

The system components provide a flexible capability to adjust the system for operation over a wide range of operating conditions. The actual system flow requirements are anticipated to vary from as little as 100 cfm to over 500 cfm. Among factors involved in this range are the hood vent containment chamber setup and installation techniques, number of access ports open or closed, and off gas collection requirements of the TRUPACT-II package payload drums. Margin has been provided for other variations anticipated from actual operation of the TRUPACT-II package unloading activities.

The extremely wide range of pressure and flow requirements to be experienced by the overall system do not lend themselves to the normal design and stationary balance of a normal system design operating point. To accommodate this wide range of conditions, an adjustable flow damper has been provided at each filter exit into the dock manifold and at the blower exit feeding into the facility HVAC system supply duct.

2.0 CONDITIONS and ASSUMPTIONS

The following items depict the facility conditions stated for the Carlsbad area and other assumptions about the design features. This data is presented so that the engineer may understand the nature of selection and the flexibility of some of the parameters used in arriving at the performance of the various system operating conditions.

Throughout this report reference will be made to various figures or table items which are used as reference data. Copies of the selected pages are included as attachments and are referred to by their own identification as used in the ASHRAE Handbooks, the Trane Air Conditioning Manual, vendor catalogs, etc.

Facility Conditions:

Elevation	=	3,409 ft.
Temperature	=	Max. 100 F dry bulb & 71 F wet bulb Min. 18 F dry bulb
Rel. Hum.	=	60-80%
WHB HVAC	=	0.1 ins. w.g. ~~pressure~~ negative

DLL 2/6/90

Adjustments for Temperature & Elevation:

From the Psychrometric Chart: (Attachment A)
sp.vol. = 14.32 cu ft/lb
density = 0.0698 lb/cu ft
(100 F db & 71 F db)

From Fig. C-5 Chart: (Attachment B)

Temperature Correction Factor	= 0.96
Elevation Correction Factor	= 0.89
Combined Factor (Temp x Elev)	= 0.85

Relative Humidity affect will not be included from advice of ASHRAE Handbook (Ref. 1981 Fundamentals Volume , Page 33.8) (Attachment C)

Other Source Suggested/Recommended Operating Features -

Capture Velocities for Evaporation from Tanks: 50 to 100 fpm
(Ref. 1984 ASHRAE SYSTEMS HANDBOOK, Page 20.2, Attachment D)

Containment Transport Velocities for Vapors, Gases & Smoke: Any
(Ref. 1984 ASHRAE SYSTEMS HANDBOOK, Page 20.6, Attachment E)

Recommended Duct Velocities: (Trane Air Conditioning Manual) (Attachment F)

Branch Ducts,	600-900	~~fpm~~ fpm
Riser Ducts,	500-700	~~fpm~~ fpm

DLL 2/6/90

3.0 ANALYSIS and DISCUSSIONS

The nominal design air flow rate will be 300 cfm. This allows for 3 open access ports based on a 150 fpm capture velocity used in the proposal calculation to obtain the exhaust requirement of 100 cfm per port. This is conservative, as noted in Section 2.C, for a suggested capture velocity of 50 to 100 fpm, but allows a 50% margin as well as accommodates the variation of more open access ports. Additional unobtained flow will also enter the chamber at the upper and lower draw strings/bands at the ICV and OCV periphery, which will distribute some inflow to aid in sweeping of the over-drum gases toward the exhaust port at the flexible hose.

Analysis

Assume/use a 4 inch I.D. flexible duct from the chamber to the filter entry port on the dock. Length of duct to be used will be 7 feet as measured at WIPP January 31, 1990, and includes one 90 degree bend used (equal to two hose diameters).

From Chart 1, Attachment G: Resistance = 5 ins. w.g. per 100 foot
(Straight Section) Resistance = 5 x 7/100 = 0.35 ins.w.g.

From Chart 2, Attachment G: Resistance = 7.5 diameters
(90 degree bend) Equiv. Lgth = 7.5 x 4 = 2.5 ft.
Resistance = 5 x 2.5/100
= 0.125 ins. w.g.
Total = 0.35 + 0.125 = 0.48 ins. w.g.

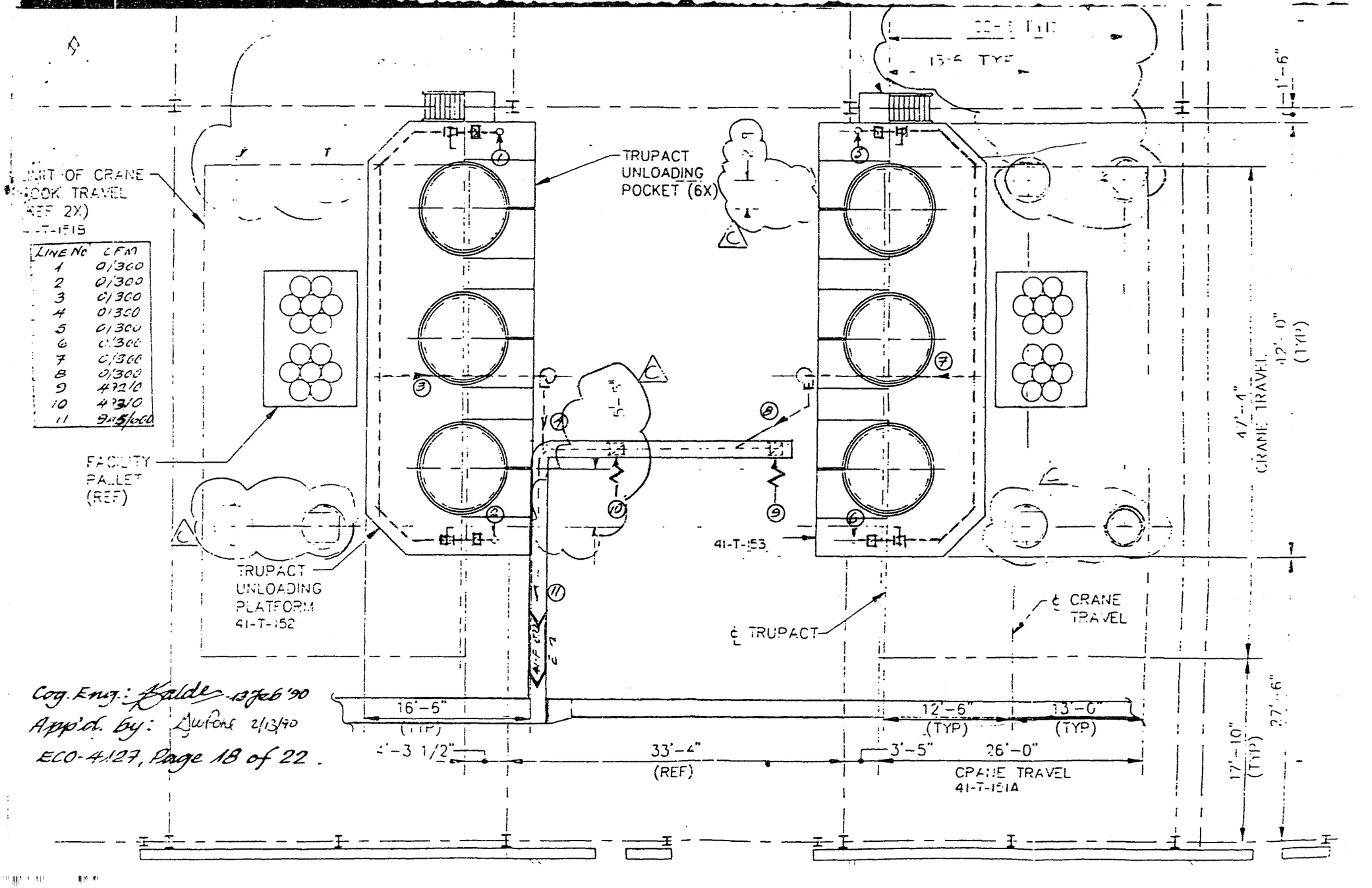
HEPA Filter pressure drop from curve plotted for #:1:TS-121220
(Vendor data, Attachment H)
At 300 cfm, press drop = 0.94 ins. w.g.

Filter exit elbow resistance estimated at 4 diameters. From Fig. C-1 (Attachment I) friction loss chart for ducting,
Loss = 0.68 inches/100 ft. & 6 inches x 4 = 2 ft.
Loss = 0.68 x 2/100 = 0.0136 ins. w.g.

Filter exit elbow damper and connections resistance estimated at 9 diameters. From Fig. C-1, Loss = 0.68/100 ft. & 9 x 4 = 3 ft.
Loss = 0.68 x 3/100 = 0.0204 ins. w.g.

Size the ducting going around/across the dock to the blower to bring air flow velocity near recommended low velocity range, (Fig. C-9, Attachment J). From the dock drawings/sketches provided of the WIPP Dock and proposed duct routing, the length of duct was determined as follows:

Straight sections = 52-1/2 ft.
Three 45 degree elbows = 4 diameters each x 3 = 12 dias.
One transition Y-entry = 4 diameters



Cog. Engr: Kalde 13 Feb '90
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ECO-4127, Page 18 of 22.

An 8 inch diameter duct was chosen for the 300 cfm flow to be near the low velocity range on the chart.
Equiv. Lgth. = 50-1/2 + (16 diam. x 8/12) = 50-1/2 + 10-2/3
= 63.17 ft., round up to 64 ft.

Loss = 0.165 ins. w.g./100 ft.
= 0.165 x 64/100 = 0.1056 ins. w.g.

The selected blower pressure rise at 300 cfm, is 4.2 ins. w.g. for the Model PB-10A with a 9 inch x 2-7/8 inch wheel operating at 3450 rpm (Ref. Attachment K). Blower inlet port is 6 inch O.D. and the exit is 5 inch O.D.. Maximum power required at free flow is less than 0.6 horsepower and maximum static pressure is 5.1 ins. w.g. at zero flow.

A check was made of the pressure loss from the blower to the building HVAC at 300 cfm using a 5 inch diameter duct to match blower outlet diameter. The resultant velocity is 2200 fpm and the pressure loss is 1.5 ins. w.g. per 100 feet. Note: This is in excess of the high velocity range and should <u>not</u> be used (will tend to add excessive noise to the work area, reduce flow margin in the system dock area and induce undesirable stress on the components for this application).

The outlet of the blower shall need a transition piece to increase the duct connection to an 8 inch diameter to reduce velocity, friction loss and expected noise. The ducting from the blower up to the building HVAC shall be 8 inch diameter.

From Fig. C-9, Friction Loss Chart:
@ 300 cfm and 8 inch diameter ducting
Loss = 0.165 ins. w.g. per 100 ft.

A duct length of 25 feet plus additional length (12 ft.) for elbows was assumed for the duct run from the blower to the intake of the HVAC duct at the ceiling.

Loss = 0.165 x (25 ft. + 12 ft.)/100 = 0.061 ins. w.g.

The friction losses involved with the component connections and transitions in either leg of the system have been estimated conservatively at a 0.1 inch w.g. loss each (0.2 for dampers) to account for additional dynamic losses that these configurations will add to the flow resistance. There items are listed to identify the quantity of features considered in the system estimate.

- o Entry at the flexible exhaust hose connection to the hood vent containment chamber exit.
- o Exit of the flexible exhaust hose connection into the HEPA filter inlet port.
- o Damper flow device at the filter elbow exit to the dock

- o Dock manifold transition connection (reducer) to the 6 inch diameter blower inlet
- o Damper flow device at the blower outlet port.
- o Blower 5 inch diameter outlet transition connection (enlarger) to the 8 inch facility duct running up to the building HVAC.

These six flow disturbance areas in either system leg have been estimated to add the equivalent of another 0.8 ins. w.g. loss added to the system. The actual loss of the three adjustable dampers will be a function of the positions/closure chosen during initial operation of the complete system. The blower size chosen has enough capability to provide a margin in the static pressure required for operation at "clean filter" system pressure losses. This margin can accommodate more than 1.0 inch increase in pressure resistance as the filter becomes loaded up with contaminants.

Summary

The total static pressure losses estimated in the system (with all dampers in the full open position) is calculated to be:

Loss, total: 0.48 + 0.94 + 0.0136 + 0.0204 + 0.1056 + 0.051 + 0.8

= 2.42 ins. w.g.

The blower static pressure capability at 300 cfm is 4.2 ins. w.g. (Ref. Attachment K) which allows for some additional margin over the requirements with a loaded filter (3.42 ins. w.g.). This provides margin for the effect the 100 degree temperature and 3,409 foot elevation factors have on the blower performance (0.83). Note: the velocity pressure component for a 300 cfm flow rate is only 0.01 ins. w.g. (Ref. Attachment L).

The blower output damper will allow the operator to adjust the system to the desired flow by increasing the system static pressure rise at the blower by the difference of the blower performance curve and the installed system resistance (4.2 - 2.42 = 1.78 ins. w.g. added by damper closing adjustment). The filter exit dampers can also provide additional adjustment flexibility in the operation of the system as activities observed at the hood vent containment chamber may require.

4.0 Systems Interface Data for HVAC and Electrical Systems

Blower Motor Size: 3/4 Horsepower, 460 VAC, 3 Phase

Blower Centerline Heights: Inlet = 11-1/2 inches
Outlet = 4-15/16 or 18-1/16 inches

Blower Inlet/Outlet Sizes: Inlet = 8 inch O.D.
Outlet = 8 inch O.D.

Dock IMDS duct diameter to be 8 inches O.D.

HEPA Filter Damper Connection Duct Diameter = 8 inch O.D.

HEPA Filter Damper Duct Horizontal Run Centerline Dimension from Dock Deck plate/down to underside centerline of 8" diameter duct = 40 inches. 2/8/90

HEPA Filter Duct Horizontal Run Position:

West Dock: Duct centerline to be 8 1/2 inches North of 103-A3R beam edge. Duct centerline to be 7 inches South of 103-A3L beam edge.

Filter location to be centered in the EAST-WEST direction at the 2nd panel position of each dock corner (near column C10B).

HEPA filter outlet elbow damper duct connection position to dock manifold to be 22 inches WEST of filter centerline.

East Dock: Duct centerline to be 11 inches South of 203-A5 beam edge. Duct centerline to be 7 inches South of 203-A3R beam edge.

Filter location to be centered in the EAST-WEST direction at the 2nd panel position of the South dock corner.

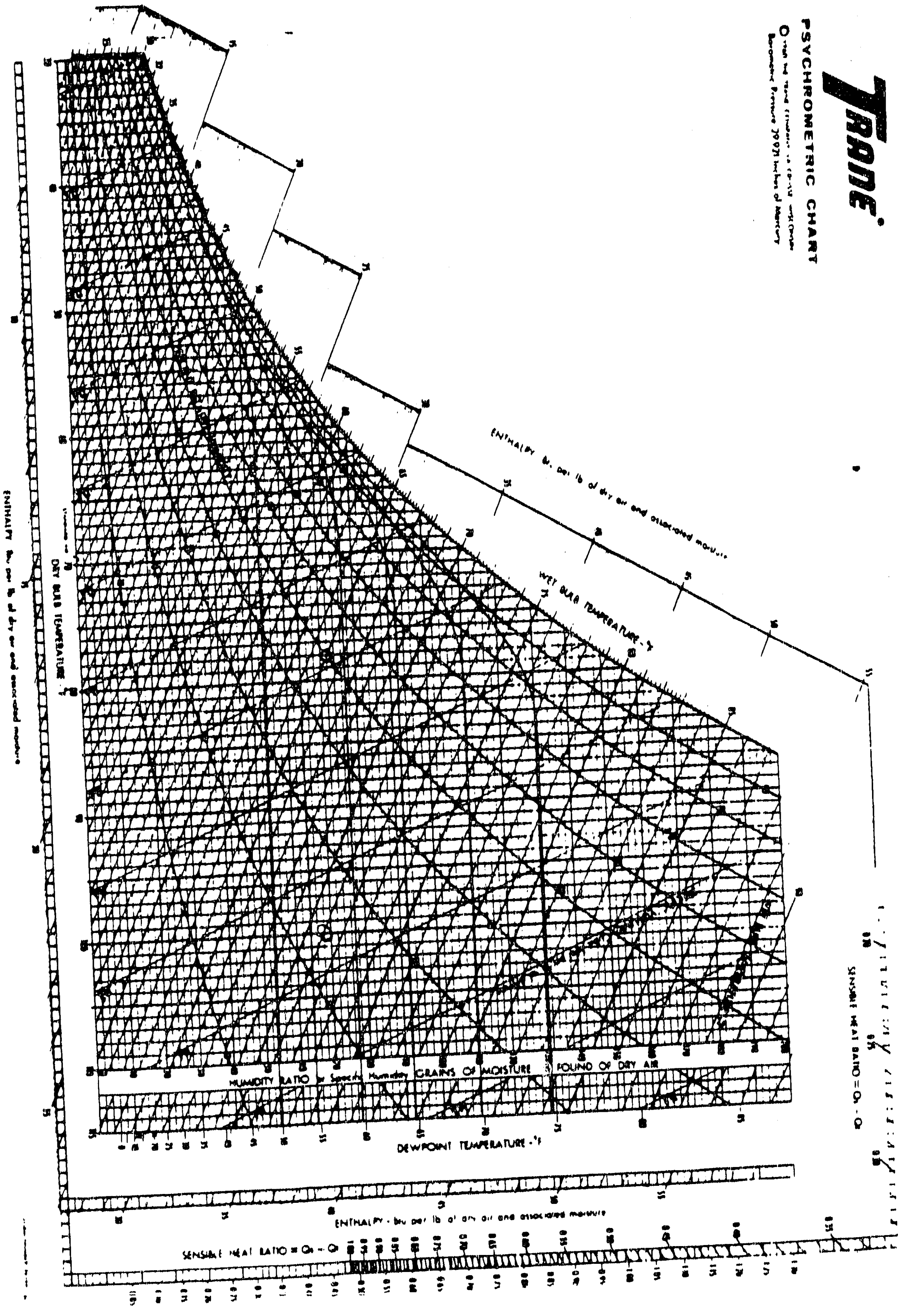
Filter location to be 8 inches East of cross member at the 2nd panel position of the North dock corner (near column C10B).

HEPA filter outlet elbow damper duct connection position to dock manifold to be 22 inches EAST of filter centerline.

ATTACHMENT A

Trane Air Conditioning Manual

PSYCHROMETRIC CHART


TRANE®
PSYCHROMETRIC CHART
ENTHALPY - btu per lb of dry air and associated moisture
WET BULB TEMPERATURE - °F
DRY BULB TEMPERATURE - °F
HUMIDITY RATIO or Specific Humidity GRAINS OF MOISTURE PER POUND OF DRY AIR
DEWPOINT TEMPERATURE - °F
SENSIBLE HEAT RATIO = Qs ÷ Qt

ATTACHMENT B

ASHRAE Handbook
1981 Fundamentals

FIG. C-5 Friction Chart
Correction Factors for
Elevation and Temperature
(Page 33.48)

33.48

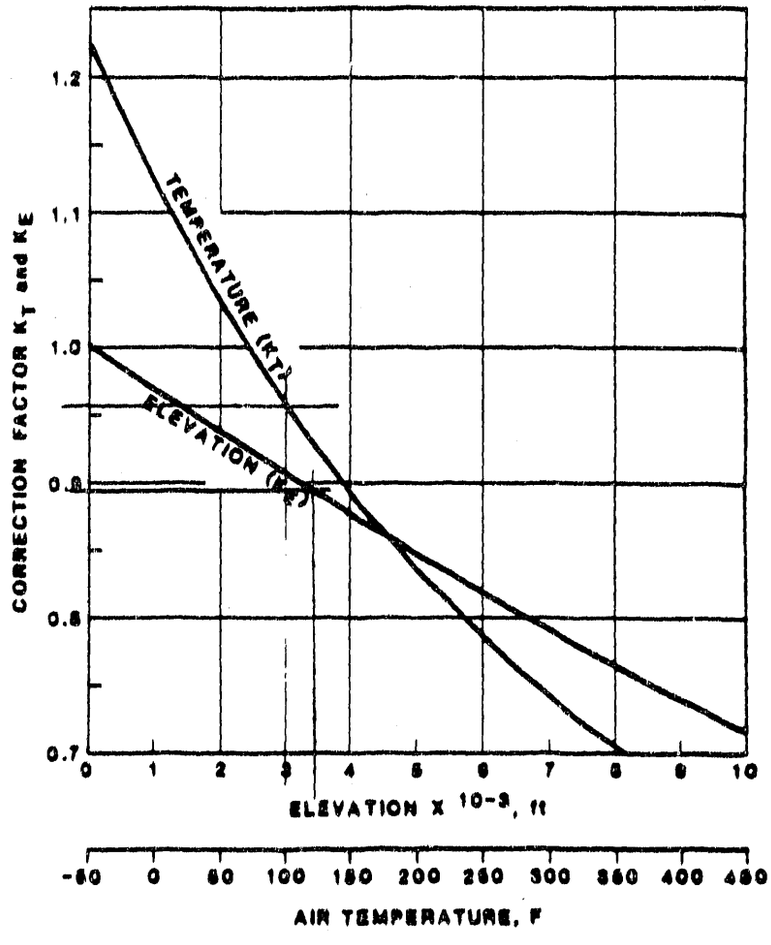


Fig. C-5 Friction Chart Correction Factors for Elevation and Temperature

ATTACHMENT C

ASHRAE Handbook
1981 Fundamentals

Correction Factors
(Page 33.6)

m (100 ft), which is equivalent to an absolute roughness factor of 0.15 m (0.0005 ft).

Changes in barometric pressure, temperature, and absolute/relative humidity change both the density and viscosity of air, and hence the Reynolds number. No corrections to the Friction Chart are needed for: (1) duct materials with an average roughness factor; (2) temperature variations in the order of ± 11°C (±20 F) from 20°C (70 F); and (3) the usual variations in barometric pressure or in pressures required to circulate air through low pressure duct systems.

CORRECTION FACTORS

For duct materials other than those indicated as having an *average* degree of roughness in Table 2, and for significant variations in temperature and barometric pressure/elevation, correction factors should be applied to the Friction Chart values as:

$$\Delta p_{fr,a} = K_M \, \Delta P_{fr,s} \qquad (24)$$

where

$\Delta p_{fr,a}$ = friction loss in terms of total pressure at actual conditions.
$\Delta p_{fr,s}$ = friction loss in terms of total pressure at standard conditions (from Friction Chart, Fig. A-1).
K = friction chart correction factor for density and/or viscosity, dimensionless.
K_M = friction chart correction factor for duct roughness, dimensionless.

For correction of material roughness, use Fig. 3. The generic classifications (smooth, medium smooth, average, medium rough, rough) in Fig. 3 are the same roughness categories as in Table 2. Fig. 4 provides an *additional* correction factor for straight flexible ducts not installed in the fully extended position.

For corrections of (ϱ) density, and viscosity (μ) use the following relationship.[16]

$$K = (\varrho_a/\varrho_s)^{0.90} \, (\mu_a/\mu_s)^{0.10} \qquad (25)$$

Where the subscript *a* refers to actual conditions and the subscript *s* refers to standard conditions. It is suggested that friction charts be developed using Eqs 21 and 23 for duct materials; and/or fluid densities and viscosities frequently used. Ref 4 presents the computer algorithms necessary to generate a friction chart.

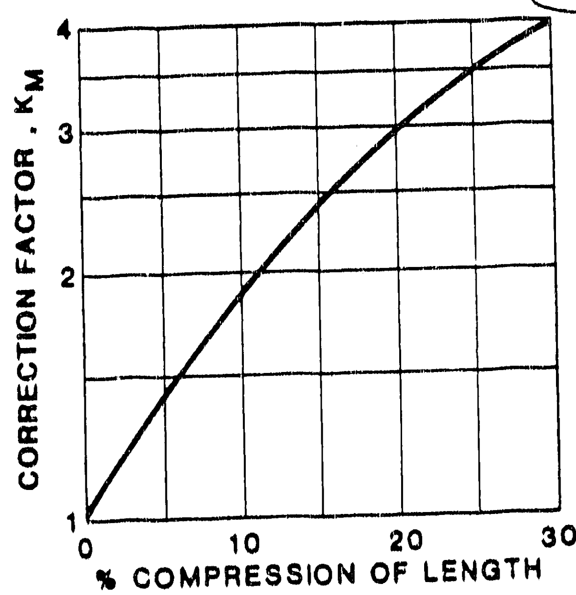


Fig. 4 Correction Factor for Unextended Flexible Duct

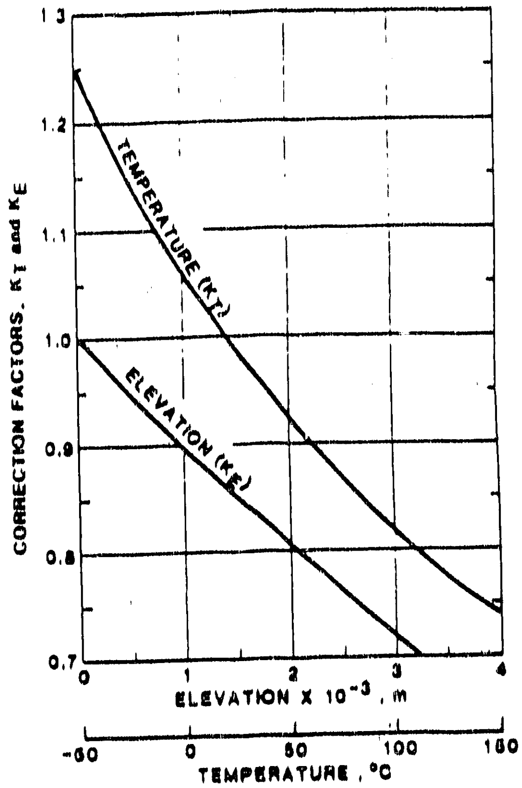


Fig. 5 Friction Chart Correction Factors for Elevation and Temperature

The viscosity of air is essentially a function of temperature, while density depends on both temperature and barometric pressure (elevation). *Humidity effect is sufficiently small and can be neglected.* For individual temperature and elevation correction factors, use Fig. 5 or Eqs 27 and 28, since:

$$K = K_T \, K_E \qquad (26)$$

where

K_T = friction chart correction factor for temperature, dimensionless.
K_E = friction chart correction factor for elevation, dimensionless.

Temperature correction factor:

$$K_T = \left[\frac{cf}{T_a + cf_1}\right]^{0.825} \qquad (27)$$

where

T_a = actual temperature of air, °C (F).
cf = conversion factor, 293 (530).
cf_1 = conversion factor, 273 (460).

Barometric pressure (elevation) correction factor:

$$K_E = (B/cf)^{0.9} \qquad (28)$$

where

B = actual barometric pressure, kPa (in. Hg).
cf = conversion factor, 101.3 (29.92).

If the barometric pressure for a specific elevation is not known, it may be estimated by Eq 29.[17]

ATTACHMENT D

ASHRAE Handbook
1984 Systems

Table 1
Range of Capture Velocities
(Page 20.2)

Table 1 Range of Capture Velocities*

Condition of Contaminant Dispersion	Examples	Capture (Control) Velocity	
		fpm	m/s
Released with essentially no velocity into still air	Evaporation from tanks, degreasing, plating	50 to 100	0.25 to 0.5
Released at low velocity into moderately still air	Container filling, low speed conveyor transfers, welding	100 to 200	0.5 to 1.0
Active generation into zone of rapid air motion	Barrel filling, chute loading of conveyors, crushing, cool shakeout	200 to 500	1.0 to 2.5
Released at high velocity into zone of very rapid air motion	Grinding, abrasive blasting, tumbling, hot shakeout	500 to 2000	2.5 to 10.0

In each category above, a range of capture velocities is shown. The proper choice of values depends on several factors:†

Lower End of Range	Upper End of Range
1. Room air currents or favorable to capture.	1. Distrubing room air currents.
2. Contaminants of low toxicity or of nuisance value only.	2. Contaminants of high toxicity.
3. Intermittent, low production.	3. High production, heavy use.
4. Large hood-large air mass in motion.	4. Small hood-local control only.

nant. Hood performance (i.e., how well it controls the contaminant) should be checked by an industrial hygienist.

Capture Velocities

Enough air per unit time must be exhausted through a hood to establish an air velocity (called *capture velocity*) at or beyond the point of contaminant release strong enough to carry the contaminant with it into the hood. Capture velocities for typical operations are listed in Table 1.[2] These velocities have a range of values for each situation, depending on the room air currents, the contaminant toxicity, the hood's use rate and the size of the air mass in motion. Therefore, there is no single value for the capture velocity. Each situation is determined separately.

ATTACHMENT E

ASHRAE Handbook
1984 Systems

Duct Considerations
(Page 20.5)

Table 2
Contaminant Transport Velocities
(Page 20.6)

TRUFACT DUCT HOOD VENT SYSTEM
Order No. "SWPS3e818EX

ER-0001
February-1990

overhang equal to 40% of the distance from the hot process to the hood face on all sides.[13] The hood flow rate can be increased by using:

$$Q_T = Q_o + V_f(A_f - A_p)cf \quad (13)$$

where

Q_T = total flow rate entering hood, cfm (L/s)
Q_o = the flow rate determined by Eq. (8) or (12)
V_f = the desired indraft velocity through the perimeter area, fpm (m/s)
A_f = hood face area, ft² (m²)
A_p = plan view area of Eq. (8) or (12) as discussed above
cf = 1 (1000)

A minimum indraft velocity of 100 fpm (0.5 m/s) should be used for most design conditions. However, when room air currents are appreciable or if the contaminant discharge rate is high and the design exposure limit is low, higher values of V_f might be required.

Sutton[14] reported that the volumetric flow rate for a high canopy hood (more than 10 ft (3 m) above the process) can be predicted empirically from round, square or nearly square sources by

$$Q_z = cf Z^{1.2} q^{1.3} \quad (14)$$

where

Q_z = volumetric flow rate at any elevation Z, cfm (L/s)
Z = vertical distance (see Fig. 7), ft (m)
cf = 7.4 (8.0)

Z can be obtained from:

$$Z = Y + 2B \quad (15)$$

where

Y = distance from the hot process to the hood face (see Fig. 7), ft (m)
B = maximum dimension of the hot process plan view (see Fig. 7), ft (m)

At Z, the rising air stream will be nearly round, with a diameter determined by

$$D_z = cf Z^{0.88} \quad (16)$$

where

D_z = flow diameter at any elevation Z above the apparent point source, ft (m)
cf = 0.5 (0.43)

High canopy hoods are extremely susceptible to room air currents. Therefore, they are typically much larger (often twice as large) than indicated by Eq. (16) and are used only if the low canopy hood cannot be used. The total flow rate exhausted from the hood should be evaluated using Eq. (13) *if* Q_o *is replaced by* Q_z.

Special Situations

Some operations may require exhaust volumes different from the quantities generated by the above equations. Typical reasons for different flow rates include:

1. Inducted air currents are created whenever anything is projected into an air space. For example, high speed rotating machines such as pulverizers, high speed belt material transfer systems, falling granular materials, and escaping compressed air from pneumatic tools all produce air currents. The size and direction of the air flow should be considered in hood design.

2. Exhaust volumes that are insufficient to dilute combustible vapor-air mixtures to less than about 25% of the lower explosive limit of the vapor.[15]

3. Room air currents caused by cross drafts, compensating air, spot cooling or motion of the machinery or operators. This is especially significant when designing high canopy hoods for hot process exhaust.

DUCT CONSIDERATIONS

The second component of a local exhaust ventilation system is the duct through which contaminated air is transported from the hood(s). Round ducts are preferred because they (1) offer a more uniform air velocity to resist settling of material and (2) can withstand the higher static pressures normally found in exhaust systems. When design limitations require rectangular ducts, the aspect ratio (height to width ratio) should be as close to unity as possible.

Minimum transport velocity is that velocity required to transport particulate without settling. Table 2 lists some generally accepted transport velocities as a function of the nature of the contaminant.[16] The values listed are typically higher than theoretical and experimental values to account for: (1) damage to ducts, which would increase system resistance and reduce volume and duct velocity, (2) duct leakage, which tends to decrease velocity in the duct system upstream of the leak, (3) fan wheel corrosion or erosion and/or belt slippage, which could reduce fan volume and (4) re-entrainment of settled particulate caused by improper operation of the exhaust system. Design velocities can be higher than the minimum transport velocities but should never be significantly lower.

Standard duct sizes and fittings should be used for economic and delivery time reasons. Information on available sizes and the cost impact of non-standard sizes should be obtained from the contractor(s).

Table 2 Contaminant Transport Velocities[16]

Nature of Contaminant	Examples	Minimum Transport Velocity	
		fpm	m/s
Vapors, gases, smoke	All vapors, gases and smokes	Any	Any
Fumes	Zinc and aluminum oxide fumes	1400 to 2000	7 to 10
Very fine light dust	Cotton lint, wood flour, litho powder	2000 to 2500	10 to 13
Dry dusts and powders	Fine rubber dust, Bakelite molding powder dust, jute lint, cotton dust, shavings (light), soap dust, leather shavings	2500 to 3500	13 to 18
Average industrial dust	Sawdust (heavy and wet), grinding dust, buffing lint (dry), wool jute dust (shaker waste), coffee beans, shoe dust, granite dust, silica flour, general material handling, brick cutting, clay dust, foundry (general), limestone dust, packaging and weighing asbestos dust in textile industries	3500 to 4000	18 to 20
Heavy dusts	Metal turnings, foundry tumbling barrels and shakeout, sand blast dust, wood blocks, hog waste, brass turnings, cast iron boring dust, lead dust	4000 to 4500	20 to 23
Heavy or moist dusts	Lead dust with small chips, moist cement dust, asbestos chunks from transite pipe cutting machines, buffing lint (sticky), quick-lime dust	4500 and up	23 and up

ATTACHMENT F

Trane Air Conditioning Manual

Table 9-3
Recommended & Maximum Duct
Velocities for Conventional Systems

Table 9-3

Recommended And Maximum Duct Velocities For Conventional Systems

DESIGNATION	RECOMMENDED VELOCITIES, FPM		
	RESIDENCES	SCHOOLS, THEATERS, PUBLIC BUILDINGS	INDUSTRIAL BUILDINGS
OUTDOOR AIR INTAKES[1]	500	500	500
FILTERS[1]	250	300	350
HEATING COILS[1,2]	450	500	600
COOLING COILS[1]	450	500	600
AIR WASHERS[1]	500	500	500
FAN OUTLETS	1000-1600	1300-2000	1600-2400
MAIN DUCTS[2]	700-900	1000-1300	1200-1800
BRANCH DUCTS[2]	600	600-900	800-1000
BRANCH RISERS[2]	500	600-700	800
	MAXIMUM VELOCITIES, FPM		
OUTDOOR AIR INTAKES[1]	800	900	1200
FILTERS[1]	300	350	350
HEATING COILS[1,2]	500	600	700
COOLING COILS[1]	450	500	600
AIR WASHERS[1]	500	500	500
FAN OUTLETS	1700	1500-2200	1700-2800
MAIN DUCTS[2]	800-1200	1100-1600	1300-2200
BRANCH DUCTS[2]	700-1000	800-1300	1000-1800
BRANCH RISERS[2]	650-800	800-1200	1000-1600

[1] THESE VELOCITIES ARE FOR TOTAL FACE AREA, NOT THE NET FREE AREA; OTHER VELOCITIES IN TABLE ARE FOR NET FREE AREA.

[2] FOR LOW VELOCITY SYSTEMS ONLY.

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ATTACHMENT G

The Flexaust Company
TC 860-2.5

Flexaust Hose Friction Loss Data

FLEXAUST HOSE FRICTION LOSS DATA

In the design of most dust collection, air conditioning, industrial ventilation and fume removal systems, air flow calculations are an integral part of the planning for high efficiency operation. This information is provided as a general guide to the friction loss values for all Flexaust hose types.

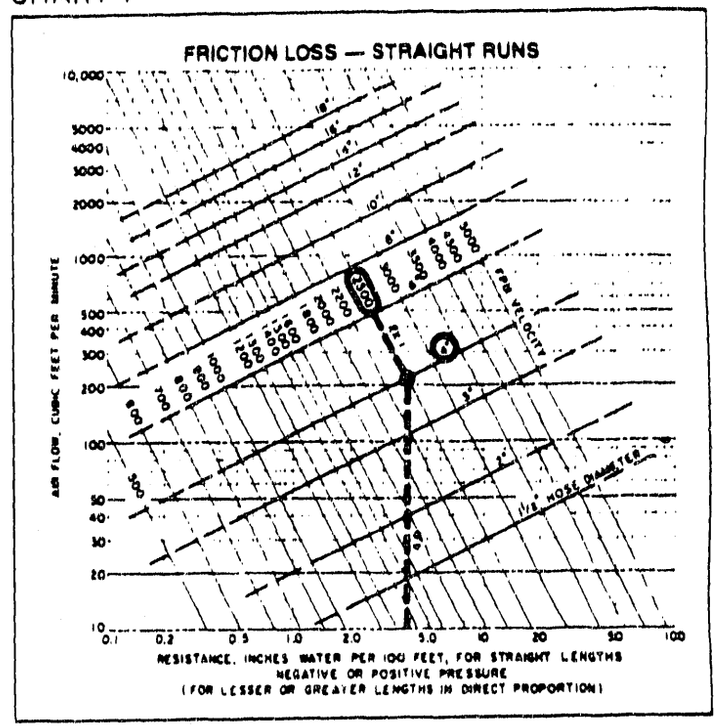
The air flow through flexible ducting is dependent upon its diameter, length, interior wall surface condition and configuration. When straight lengths of Flexaust hose are used, resistance values may be obtained from Chart 1.

EXAMPLE 1 — STRAIGHT RUNS

Q. What is the resistance in inches, w. g., of a 25 ft. straight length of 4 in. ID Flexaust hose with air velocity 2500 fpm?

A. Value obtained directly from Chart 1 is 4.00 ins. w. g. for 100 ft. For 25 ft., the resistance would be 1.0 ins. w. g.

CHART 1



When the hose length cited in Example 1 includes a bend, its resistance is increased. This increase is calculated as equivalent added length to the actual straight length of hose, and is shown on Chart 2 as a number of equivalent diameters. These are converted to length in feet, for which the appropriate resistance value is then obtained from Chart 1.

EXAMPLE 2 — BENDS

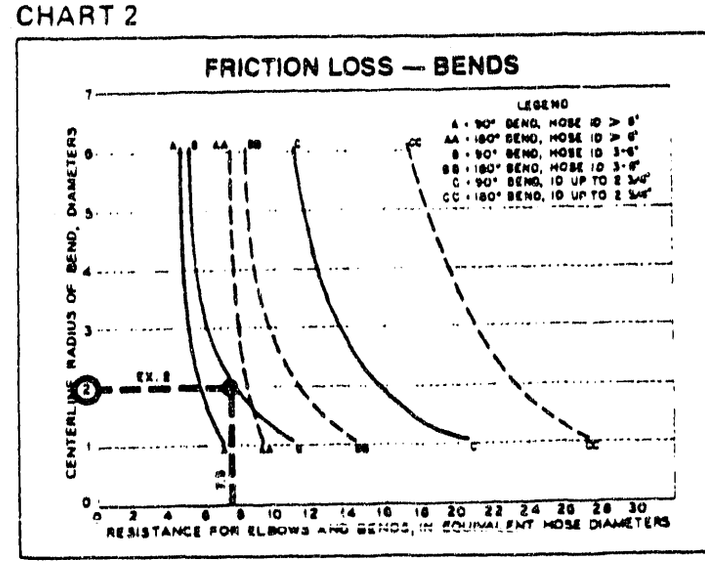
Q. What is the resistance in inches, w. g., for same hose as in Example 1, same velocity, but having in its length a 90° elbow with centerline bending radius of two hose diameters (8 ins.)?

A. (1) Value from Chart 2 = 7.5 diameters
(2) 7.5 x 4 ins. = 2.5 ft.
(3) Value for 2.5 ft. (Chart 1) = 0.10 ins. w. g.
(4) Resistance of straight hose plus resistance of elbow 1.0 plus 0.10 is total resistance factor = 1.10 ins. w. g.

An alternate procedure is as follows:

(5) Add 2.5 to 25 = 27.5 ft.
Using value from Chart 1 as above the resistance is
$\frac{27.5}{100}$ x 4 = 1.10 ins. w. g.

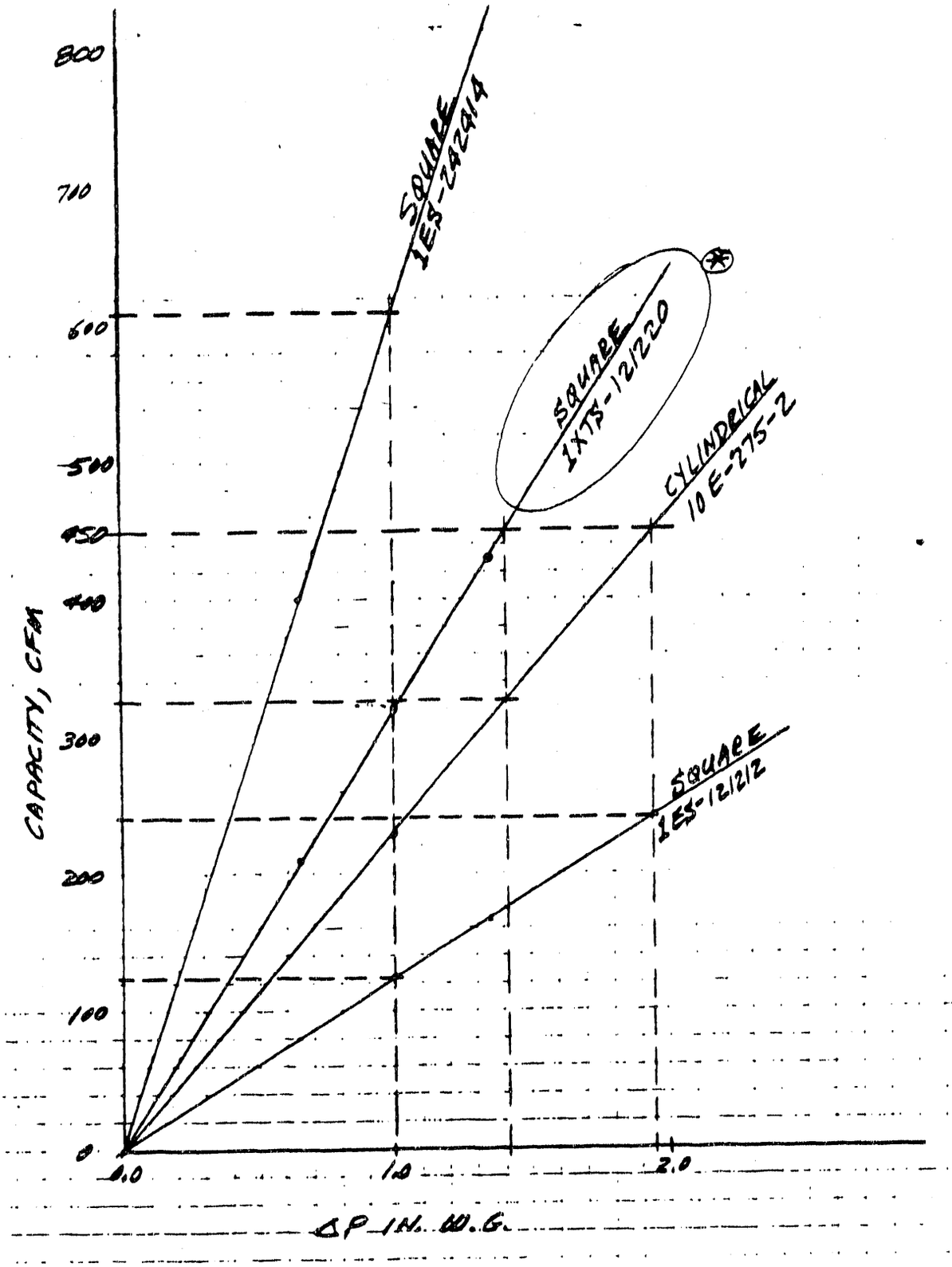
CHART 2



ATTACHMENT H

Cambridge Filter Corporation
Bulletin 12-104A

Cambridge Absolute Filter
Capacity vs Pressure Drop



CAMBRIDGE ABSOLUTE FILTERS

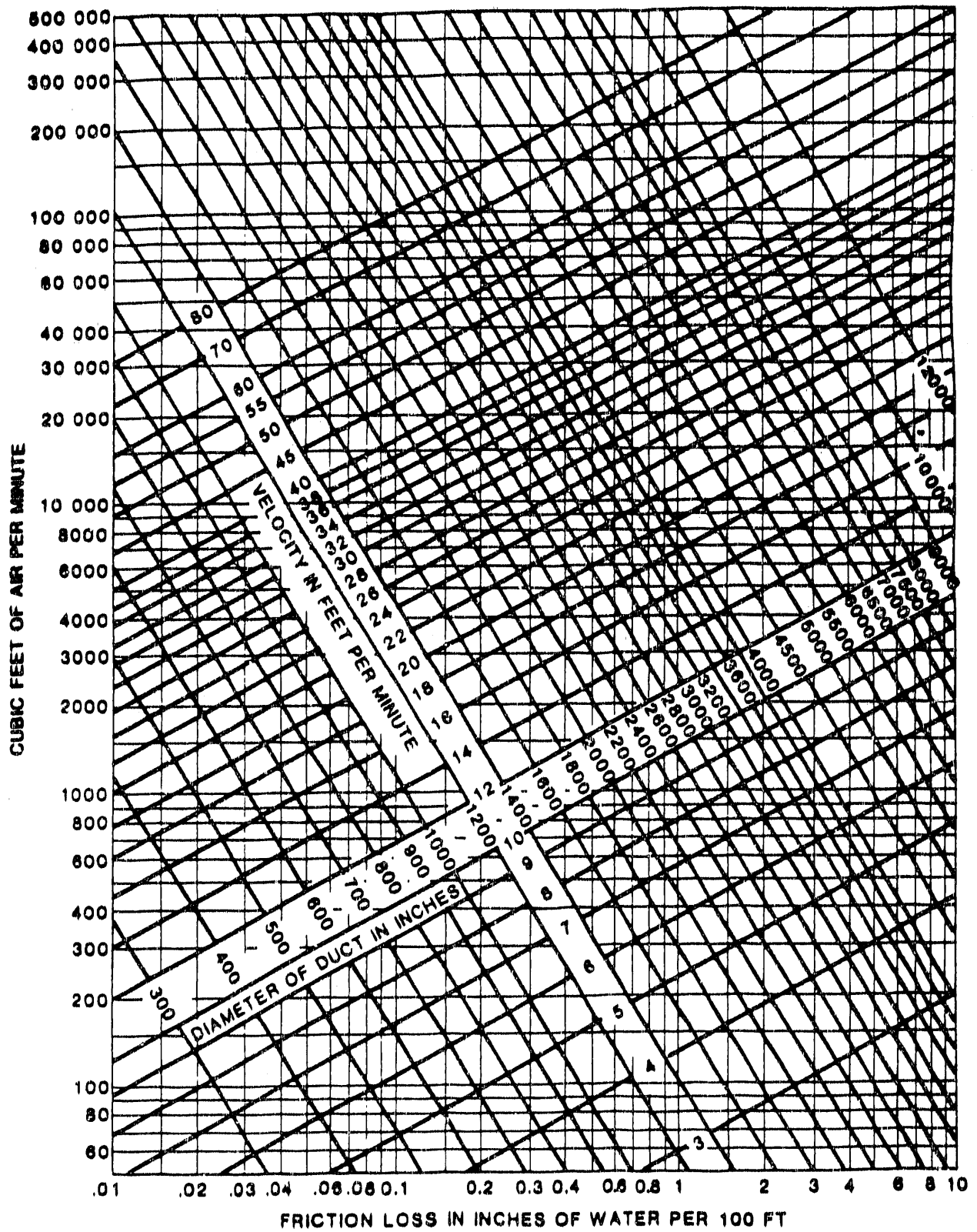
DWG. B12-1163-CB
DWG. B12-1361-C5

DLL
1-18-90

ATTACHMENT I

ASHRAE Handbook
1981 Fundamentals

FIG. C-1 Friction Chart
For Average Ducts
(Page 33.44)



Standard Air (29.921 in. Hg atmospheric pressure, ρ = 0.075 lb/ft^3), ϵ = 0.0005 ft

Fig. C-1 Friction Chart for Average Ducts (See Table 1)

ATTACHMENT J

ASHRAE Handbook
1981 Fundamentals

FIG. C-9 Suggested Velocity
and Friction Rate Design Limits

Duct Design

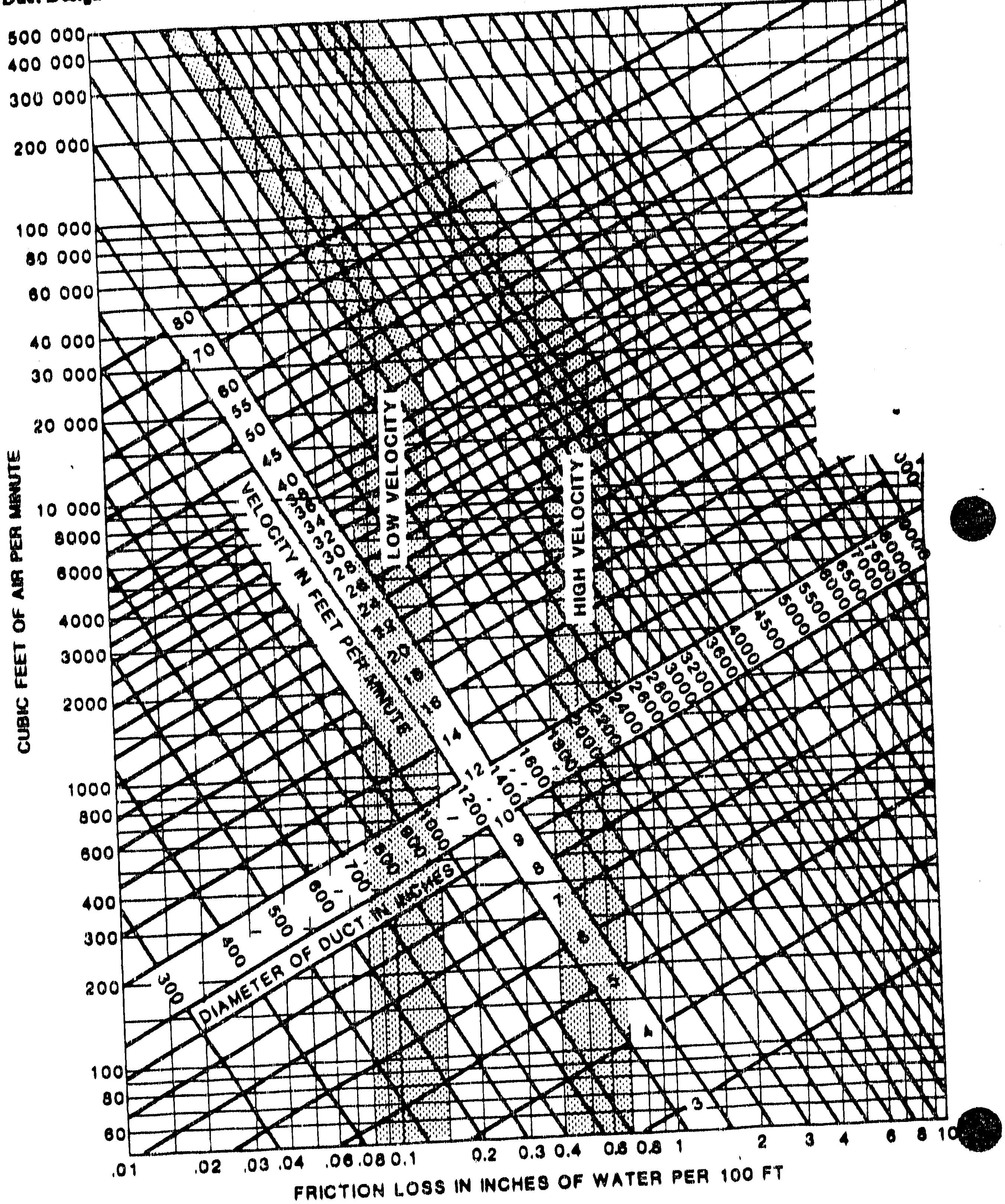
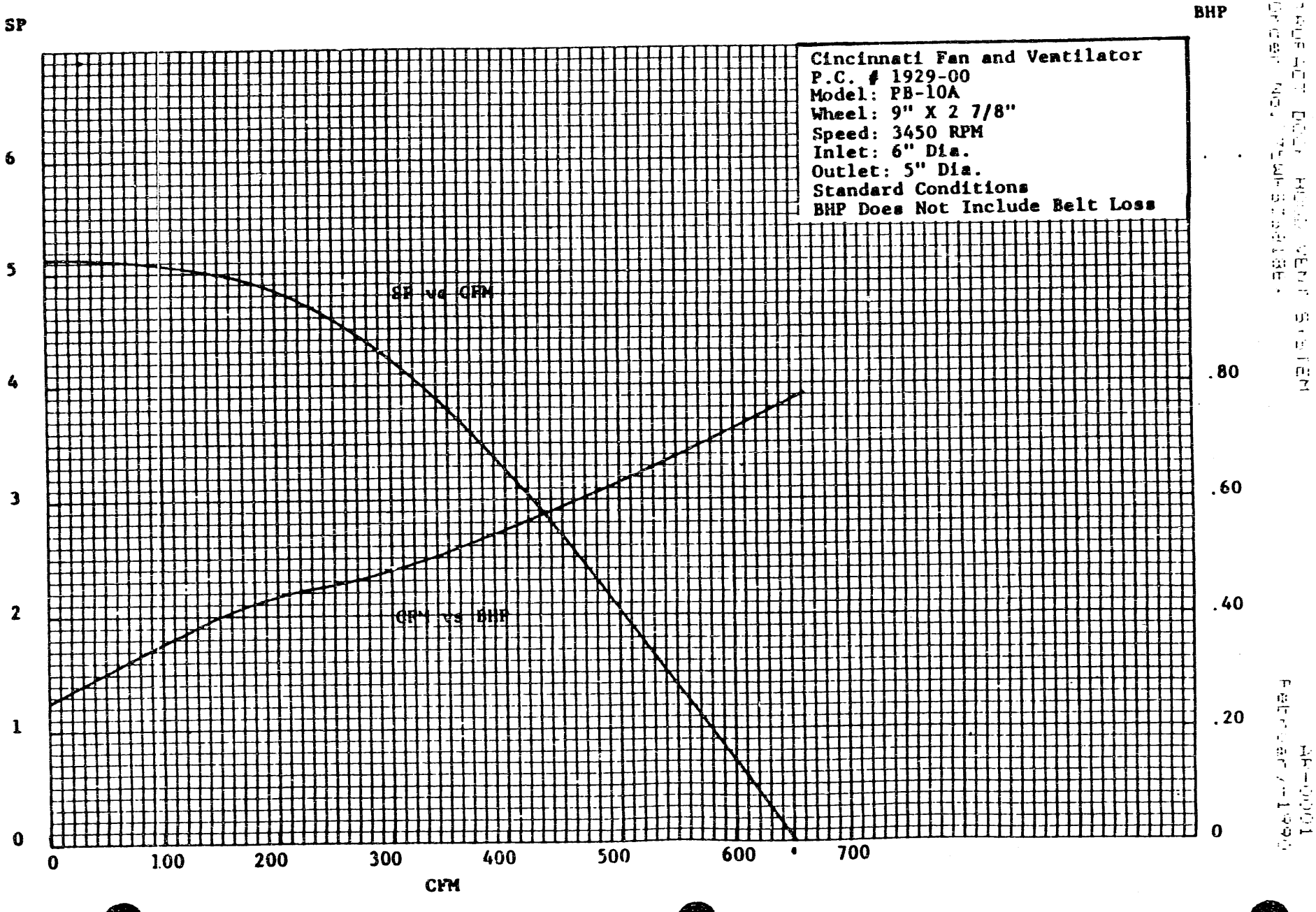


Fig. C-9 Suggested Velocity and Friction Rate Design Limits

ATTACHMENT K

Cincinnati Fan
Cat. No. A488

Cincinnati Fan Model FB-10A
CFM and BHP vs Static Pressure Data


SP
BHP
Cincinnati Fan and Ventilator
P.C. # 1929-00
Model: PB-10A
Wheel: 9" X 2 7/8"
Speed: 3450 RPM
Inlet: 6" Dia.
Outlet: 5" Dia.
Standard Conditions
BHP Does Not Include Belt Loss
SP vs CFM
CFM vs BHP
6
5
4
3
2
1
0
.80
.60
.40
.20
0
0
100
200
300
400
500
600
700
CFM

PB SERIES DIRECT DRIVE RATING TABLES at 3450 RPM

CFM and BHP at Static Pressure Shown — **Ratings at 70°F., .075 Density, Sea Level**

MODEL NO.	WHEEL DIA. & WIDTH	O.D. INLET SIZE	1" SP		2" SP		3" SP		4" SP		5" SP		6" SP		7" SP		8" SP	
			CFM	BHP	CFM	BHP	CFM	BHP	CFM	BHP	CFM	BHP	CFM	BHP	CFM	BHP	CFM	BHP
PB-8																		
PB-9	8x2 1/4		388	.39	341	.36	287	.32	160	.25								
	8 1/2x2 3/4		435	.46	385	.41	325	.37	240	.33								
	9x2 1/4		490	.52	450	.48	380	.42	310	.37	200	.31						
PB-10A	9x2 1/2		577	.70	500	.64	427	.58	319	.48	100	.35						
	10 1/2x3BC		609	.78	544	.71	480	.65	397	.59	295	.53	124	.42				
	9 1/2x2 1/2		719	1.04	649	.94	594	.89	519	.82	422	.72	321	.63				
	11 1/2x2 1/2		886	1.55	835	1.46	783	1.37	716	1.30	647	1.22	583	1.13	509	1.04	409	.93
PB-12A	11 1/2x2 1/2	7"	1259	2.44	1182	2.28	1105	2.12	1021	1.99	907	1.82	797	1.68	683	1.52	550	1.30
	12x2 1/2		1307	2.54	1223	2.42	1139	2.29	1053	2.15	964	2.01	874	1.85	783	1.71	679	1.58
	13x3 1/2BC		1309	2.58	1236	2.49	1163	2.39	1095	2.29	1030	2.18	945	2.08	858	1.96	793	1.84
PB-14A	13x3 1/2BC	6"	1182	2.27	1126	2.18	1081	2.14	1016	2.08	950	1.97	872	1.83	790	1.69	711	1.76
	12 1/2x2 1/2	6"	1258	2.76	1203	2.68	1142	2.52	1060	2.45	988	2.18	900	2.06	872	2.00	758	1.85
	14x3 1/2BC	6"	1341	2.93	1258	2.83	1190	2.78	1126	2.68	1075	2.58	1013	2.69	953	2.36	868	2.27
	12 1/2x2 1/2	7"	1440	3.40	1365	3.23	1282	3.05	1189	2.88	1103	2.65	1005	2.45	900	2.23	800	2.05
	12 1/2x2 1/2	8"	1586	3.44	1519	3.23	1433	3.02	1357	2.84	1260	2.62	1147	2.51	1022	2.09	879	1.99
	14x3 1/2	6"	1514	4.03	1427	3.76	1372	3.73	1315	3.71	1260	3.58	1204	3.44	1186	3.29	1075	3.13
	14x3 1/2	7"	1690	4.29	1641	4.22	1553	4.13	1492	4.01	1418	3.86	1357	3.78	1290	3.70	1215	3.52
	14x3 1/2BC	8"	1739	3.58	1659	3.35	1586	3.34	1513	3.23	1439	3.10	1360	3.01	1265	2.84	1161	2.68
	14x3 1/2	8"	1879	4.91	1807	4.80	1729	4.67	1652	4.52	1572	4.25	1492	3.98	1411	3.87	1330	3.76
PB-15	16 1/2x4 1/2BC	6"	1682	4.24	1654	4.23	1594	4.20	1535	4.15	1483	4.15	1432	4.00	1380	3.96	1288	3.83
	16 1/2x5BC	6"	1719	5.13	1678	5.08	1636	5.02	1594	4.98	1530	4.81	1466	4.63	1396	4.57	1327	4.50
	14x3 1/2BC	8"	1900	3.60	1820	3.53	1725	3.45	1640	3.37	1540	3.23	1442	3.12	1337	3.03	1210	2.85
	16 1/2x5	6"	2003	7.94	1977	7.88	1952	7.77	1927	7.66	1875	7.50	1823	7.33	1796	7.14	1769	6.95
	14x3 1/2	8"	2320	5.40	2220	5.20	2130	5.00	2020	4.80	1920	4.60	1810	4.50	1705	4.20	1600	4.00
	15 1/2x5BC	8"	2385	6.60	2305	6.30	2220	6.00	2125	5.85	2025	5.35	1927	5.05	1820	4.78	1720	4.45
	15 1/2x5	8"	2690	10.30	2640	10.00	2580	9.70	2510	9.30	2440	8.80	2360	8.40	2270	7.85	2180	7.40
	16 1/2x5BC	8"	2707	8.09	2689	8.02	2633	7.79	2578	7.56	2479	7.34	2381	7.12	2273	6.90	2166	6.67
	16 1/2x4 1/2BC	10"	2873	8.06	2796	7.82	2706	7.63	2616	7.44	2519	7.15	2422	6.86	2294	6.70	2166	6.54
	15 1/2x5	10"	3244	11.01	3184	10.92	3124	10.75	3060	10.58	2979	10.23	2899	9.87	2778	9.56	2653	9.45
	16 1/2x5	10"	3419	13.85	3338	13.60	3232	13.10	3127	12.60	3046	12.30	2966	12.00	2881	11.67	2796	11.34
	16 1/2x4 1/2	10"	3535	13.29	3510	13.18	3481	12.72	3453	12.26	3351	11.83	3249	11.39	3140	10.85	3031	10.31
PB-18	16 1/2x4 1/2BC	6"	1536	5.48	1492	5.46	1449	5.37	1407	5.28	1361	5.23	1316	5.17	1261	5.02	1206	4.86
	14x3 1/2BC	10"	1593	3.83	1513	3.68	1440	3.56	1351	3.38	1268	3.23	1193	3.03	1096	2.83	1010	2.82
	18x4 1/2BC	6"	1578	6.41	1513	6.39	1508	6.27	1503	6.15	1444	6.11	1385	6.07	1339	5.96	1293	5.84
	18x4 1/2	6"	1951	9.64	1927	9.57	1890	9.38	1853	9.19	1810	9.11	1767	9.03	1727	8.79	1687	8.55
	16 1/2x4 1/2BC	8"	2040	7.40	1995	7.25	1930	7.10	1865	6.90	1790	6.75	1715	6.50	1635	6.30	1560	6.10
	16 1/2x4 1/2BC	10"	2210	8.07	2161	7.88	2091	7.73	2021	7.58	1946	7.39	1871	7.19	1797	6.91	1723	6.63
	18x4 1/2	8"	2520	12.60	2480	12.40	2437	12.15	2395	11.90	2347	11.66	2300	11.30	2250	11.10	2200	10.90
	16 1/2x4 1/2	10"	2565	10.93	2530	10.86	2481	10.67	2393	10.47	2338	10.19	2280	9.90	2202	9.58	2125	9.25
	18x4 1/2	10"	2660	13.02	2636	12.44	2780	12.35	2725	12.26	2667	12.08	2609	11.89	2548	11.69	2488	11.49
PB-18WA	16 1/2x5BC	10"	2932	8.38	2823	8.19	2715	8.00	2606	7.82	2498	7.63	2379	7.43	2236	7.21	2097	6.96
	16 1/2x5	8"	2994	11.27	2907	10.93	2821	10.60	2734	10.28	2647	9.92	2557	9.68	2466	9.47	2381	9.20
	17x6	8"	3098	12.47	2995	12.16	2892	11.85	2790	11.54	2687	11.23	2584	10.92	2489	10.58	2397	10.21
	18 1/2x6	10"	4466	24.23	4330	23.37	4193	22.51	4057	21.65	3920	20.78	3783	19.92	3647	19.06	3510	18.20

ATTACHMENT L

ASHRAE Handbook
1981 Fundamentals

Table C-1
Velocities vs Velocity Pressures

Duct Design

33.45

Table C-1 Velocities vs. Velocity Pressures

Velocity, fpm	Velocity Pressure, in. H_2O	Velocity, fpm	Velocity Pressure, in. H_2O	Velocity, fpm	Velocity Pressure, in. H_2O	Velocity, fpm	Velocity Pressure, in. H_2O	Velocity, fpm
300	0.01	2050	0.26	3800	0.90	5550	1.92	7300
350	0.01	2100	0.27	3850	0.92	5600	1.95	7350
400	0.01	2150	0.29	3900	0.95	5650	1.99	7400
450	0.01	2200	0.30	3950	0.97	5700	2.02	7450
500	0.02	2250	0.32	4000	1.00	5750	2.06	7500
550	0.02	2300	0.33	4050	1.02	5800	2.10	7550
600	0.02	2350	0.34	4100	1.05	5850	2.13	7600
700	0.03	2400	0.36	4150	1.07	5900	2.17	7650
700	0.03	2450	0.37	4200	1.10	5950	2.21	7700
750	0.04	2500	0.39	4250	1.13	6000	2.24	7750
800	0.04	2550	0.41	4300	1.15	6050	2.28	7800
850	0.05	2600	0.42	4350	1.18	6100	2.32	7850
900	0.05	2650	0.44	4400	1.21	6150	2.36	7900
950	0.06	2700	0.45	4450	1.23	6200	2.40	7950
1000	0.06	2700	0.47	4450	1.23	6250	2.43	8000
1050	0.07	2800	0.49	4550	1.29	6300	2.47	8050
1100	0.08	2850	0.51	4600	1.32	6350	2.51	8100
1150	0.08	2900	0.52	4650	1.35	6400	2.55	8150
1200	0.09	2950	0.54	4700	1.38	6450	2.59	8200
1250	0.10	3000	0.56	4750	1.41	6500	2.63	8250
1300	0.11	3050	0.58	4800	1.44	6550	2.67	8300
1350	0.11	3100	0.60	4850	1.47	6600	2.71	8350
1400	0.12	3150	0.62	4900	1.50	6650	2.76	8400
1450	0.13	3200	0.64	4950	1.53	6700	2.80	8450
1500	0.14	3250	0.66	5000	1.56	6750	2.84	8500
1550	0.15	3300	0.58	5050	1.59	6800	2.88	8550
1600	0.16	3350	0.70	5100	1.62	6850	2.92	8600
1650	0.17	3400	0.72	5150	1.65	6900	2.97	8650
1700	0.18	3450	0.74	5200	1.69	6950	3.01	8700
1750	0.19	3500	0.76	5250	1.72	7000	3.05	8750
1800	0.20	3550	0.79	5300	1.75	7050	3.10	8800
1850	0.21	3600	0.81	5350	1.78	7100	3.14	8850
1900	0.22	3650	0.83	5400	1.82	7150	3.19	8900
1950	0.24	3700	0.85	5450	1.85	7200	3.23	8950
2000	0.25	3750	0.88	5500	1.89	7250	3.28	9000

3.74
3.79
3.84
3.89
3.94
3.99
4.04
4.09
4.14
4.19
4.24
4.29
4.35
4.40
4.45
4.50
4.56
4.61
4.66
4.72
4.77
4.83
4.88
4.94
4.99
5.05

ECO-4127, Attachment B.

ENGINEERING DATA TRANSMITTAL

TO: Radioactive Waste Handling Eng. EDT NO. E90-021

ATTN: J. Garcia / L. Jackson. PAGE 1 OF 2

PURCHASE ORDER/CONTRACT NO.	DESIGN DOCUMENT NO. ECO-4127	MAJOR ASSEMBLY DRAWING NO.
EQUIPMENT NO./FACILITY NO.	RESPONSIBLE ENGINEER [signature] 13 Feb '90	RESPONSIBLE DEPARTMENT
ORIGINATOR APPROVAL/DATE [signature] 2/13/90	RESPONSE REQUIRED DATE 16 Feb '90	REF. EDT'S

ORIGINATOR'S REMARKS Please perform independent review of ECO-4127 per Design Verification plan detailed in memo ref HA:90:04036 (copy attached)

ADDRESSEE'S REMARKS

DATA TRANSMITTED

ITEM NO.	DOCUMENT NO.	REV. NO.	SHT. NO.	TITLE OR DESCRIPTION	A APPROVAL LEVEL	B REASON FOR SUBMITTAL	C DISPOSITION	D	E
1	ECO-4127			Interface ductwork between Tripact HVS & CH Area HVAC system.		3			

REASON FOR SUBMITTAL (COL. B)
1. REQUEST APPROVAL
2. SUBMIT INFORMATION
3. PROGRESS REVIEW

DISPOSITION CODES (USE FOR COL. C, D & E)
4. APPROVED WITHOUT COMMENT
5. APPROVED FOR RELEASE SUBJECT TO ATTACHED COMMENTS
6. REVIEWED - NO COMMENTS
7. RECEIPT OF SUBMITTAL ACKNOWLEDGED
8. DISAPPROVED - COMMENTS ATTACHED
9. REVIEWED - COMMENTS ATTACHED

RESP. ENGR. REQUESTS RESPONSE BY

DOE DISPOSITION REQUESTED FROM (COL. D)
SIGNATURE _____
DATE _____

DOE DISPOSITION REQUESTED FROM (COL. E)
SIGNATURE _____
DATE _____

APPROVAL NAME	SIGNATURE/DATE	CON-CUR	C/WC	NC/WC	APPROVAL NAME	SIGNATURE/DATE	CON-CUR	C/WC	NC/WC
CONSTRUCTION MGR.									
L. Jackson	(SEE ATTACHED LETTER)	✓							
MAINTENANCE MGR.									
SAFETY									
QUALITY ASSURANCE									
RESPONSIBLE ENGR.									
RESPONSIBLE DEPT. MGR									

From: Engineering
MIN: 887-8194
Date: February 27, 1990
Subject: INDEPENDENT REVIEW OF HOOD VENT SYSTEM HVAC DUCTING

To: J. J. Garcia G. W. Pohl
T. W. Halverson K. A. Ealdon

cc: A. E. Gallegos M. J. Leroch

Engineering Design and Systems (EDS), 2012 S. 314th St., Federal Way, WA, 98003, is the basic supplier of the Hood Vent System (excluding ductwork). EDS designed the entire system which included sizing of the ductwork system. However, the EDS scope does not include detail design, routing under the TRUPACT docks or attachment to the HVAC system.

The major ductwork routing path, in general, was per Specification D-0070. Specifics of the routing path were jointly finalized during an interface meeting with EDS which included Radioactive Waste Handling and Facilities & Construction Engineering.

The principal scope of this review (of submitted package principally consisting of sketches from which ductwork drawings will be generated) was to determine if collective sizing information provided by the EDS preliminary design package has been correctly interpreted and applied.

An independent review was performed by the undersigned in accordance with WP 09-018 (DESIGN VERIFICATION). The design has been reviewed and found adequate for performing the intended function as specified per Design Specification D-0070. The HVAC ducting details as depicted per submitting sketches are consistent with the design basis.

L. Jackson
L. F. Jackson
Radio Active Waste Handling Engineering

jn

HA:90:7074

From Engineering
MS 887-8163
Date February 1, 1990
Subject TRUPACT HOOD VENT SYSTEM DUCTWORK INTERFACE WITH CH AREA HVAC SYSTEM

To T. W. Halverson

cc: K. Ealden

As required by procedure WP 09-018, Design Verification, Facility and Construction Engineering submits for your concurrence, the design verification plan for the inlet manifold duct and CH area HVAC system interface duct associated with the Trupact Hood Vent System.

Design Verification Plan:
Description of Equipment - The inlet manifold duct will be located beneath a Trupact II dock and will provide connections for component parts of the THVS.

The CH area HVAC system interface duct will provide the ducted connection from the THVS fan to existing CH area HVAC system exhaust duct.

Scope
The scope of the verification plan is to provide independent review of the design of the inlet manifold duct and the CH area HVAC system interface duct.

Reviewers
The independent review is to be carried out by the Radioactive Waste Handling Engineering Cognizant Engineer for the Trupact Hood Vent System.

G. W. Pohl, Manager
Facility & Construction Engineering

KAE:rs

HA:90:04036

I do ✓ do not ____ concur with the verification plan.

T. W. Halverson, Manager
Engineering

Westinghouse Electric Corporation

AR/VR DISPOSITION SHEET

For Internal Use Only

X APPROVAL/RECORD REQUEST ☐ VARIATION REQUEST ☐ DEVIATION ☐ WAIVER

AR/[redacted] Number: 55

Reference No.:

Purchase Order Or Subcontract Number: 75WRA31417FX / D.O.#31

Cognizant Buyer Or Subcontract Administrator: DENNIS CANTRELL

Project Name Or Number: CH DOCKS / HVAC

AR [redacted] Received: 7-12-90

Approval Required Date: 7-26-90

Equip No:

Drawing Or Specification Number: SC-20.3

Revision:

Supplier Or Subcontractor: CONSTRUCTORS, INC.

Type of Request: X Approval ☐ Record ☐ Other (Describe) AS BUILT

☐ Pre-Purchase Evaluation X Approval Data ☐ Information Record

Req'd	DISPOSITION		FOR APP ONLY	COMMENTS
	Design Engineer: N/A	Date	APPROVED / COND APP / DISAPPROVED	Use Form WP 1477-B For Continuation
	Cognizant Engineer: [signature]	Date: 19 July '90	✓ APPROVED / COND APP / DISAPPROVED	
	Other: N/A	Date	APPROVED / COND APP / DISAPPROVED	
	Other: [signature]	Date: 7/20/90	X APPROVED / COND APP / DISAPPROVED	
X	Quality Assurance: [signature]	Date: 7-20-90	X APPROVED / COND APP / DISAPPROVED	
X	Responsible Engineer: [signature]	Date: ~~12 July '90~~ 072090	X APPROVED / COND APP / DISAPPROVED	

JUL 24 1990 RECEIVED

FINAL DISPOSITION: X APPROVED ☐ CONDITIONALLY APPROVED ☐ DISAPPROVE ☐ RECEIPT ACKNOWLEDGED W/O COMMENTS ☐ RECEIPT ACKNOWLEDGED W/COMMENTS

COMMENTS, CONDITIONS, OR REASONS FOR DISAPPROVAL. All comments, conditions, or reasons for disapproval must be listed here and marked on each copy or attachments as applicable.

An amended AR/VR must be approved when all previously identified comments, conditions, or reasons for disapproval are satisfied.

Conditional approval grants the authorization to proce provided that all noted conditions are incorporat Requests which are conditionally approved or disappro require the processing of an amended AR/VR.

X Authorized To Proceed ☐ Do Not Proceed

X Amendment Not Required ☐ Amendment Required

[signature] 7/20/90

Approved — Responsible Engineering Manager

AR Form 1477-A (Rev. 10-6-89)

Westinghouse Electric Corporation

APPROVAL/VARIATION REQUEST

☒ APPROVAL/RECORD REQUEST ☐ VARIATION REQUEST ☐ DEVIATION ☐ WAIVER

AR/VR Number	Equip No	Reference No
AR #55		D.O. #31

Supplier Or Subcontractor And Address

Constructors, Inc.
P.O. Box 988
Carlsbad, NM 88220

Purchase Order Or Subcontract Number: 75-WRA-31417-FX

Project Name Or Number: Minor Construction Project Support

Drawing Or Specification Number: Special Conditions SC-20.3 Revision: 0

Requirements: Special Conditions SC-20.3 Rev.0

Type of Request: ☒ Approval ☐ Record ☐ Other (Describe)

Supplier Or Subcontractor Authorized Signature: Dale O. Lacy Title: Quality Assurance Chief Date: 7/11/90

DESCRIBE REQUEST IN DETAIL. Include Subcontract Title, AR/VR Number, Specification, or Drawing References on All Attachments.

Please find attached: Drawings of "Work As-Built for Delivery Order #31".

**PLEASE NOTE: Measurements highlighted in yellow are those that changed from original drawings.

JUL 12 1990 RECEIVED

DISPOSITION OF APPROVAL REQUEST: ☒ APPROVED ☐ CONDITIONALLY APROVED ☐ DISAPPROVED

DISPOSITION OF RECORD REQUEST ☐ RECEIPT ACKNOWLEDGED W/O COMMENTS ☐ RECEIPT ACKNOWLEDGED W/COMMENTS

Comments, Conditions, Or Reasons For Disapproval

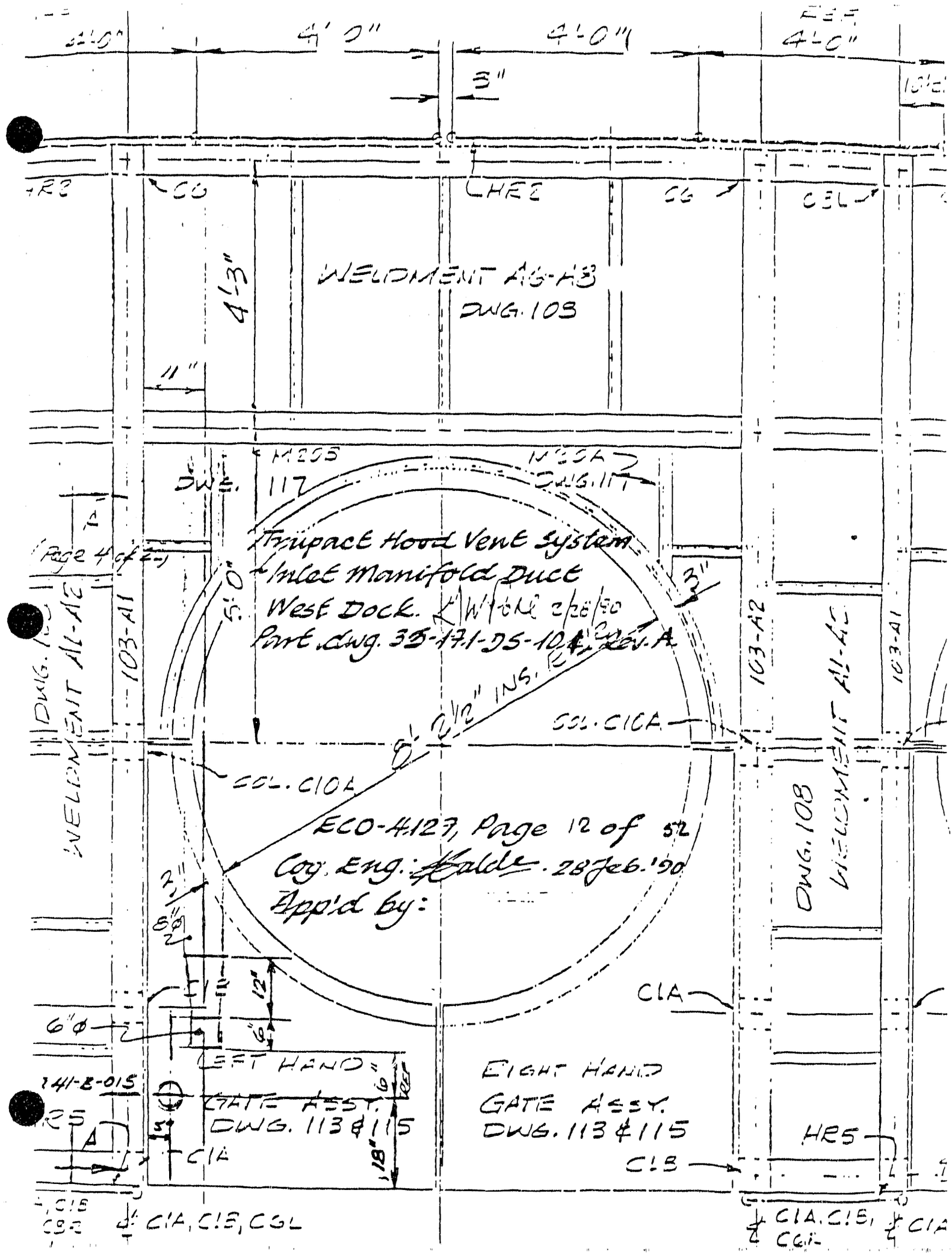
NOTE TO SUPPLIER OR SUBCONTRACTOR Requests that are conditionally approved grant an authorization to proceed provided that noted conditions are incorporated into the work

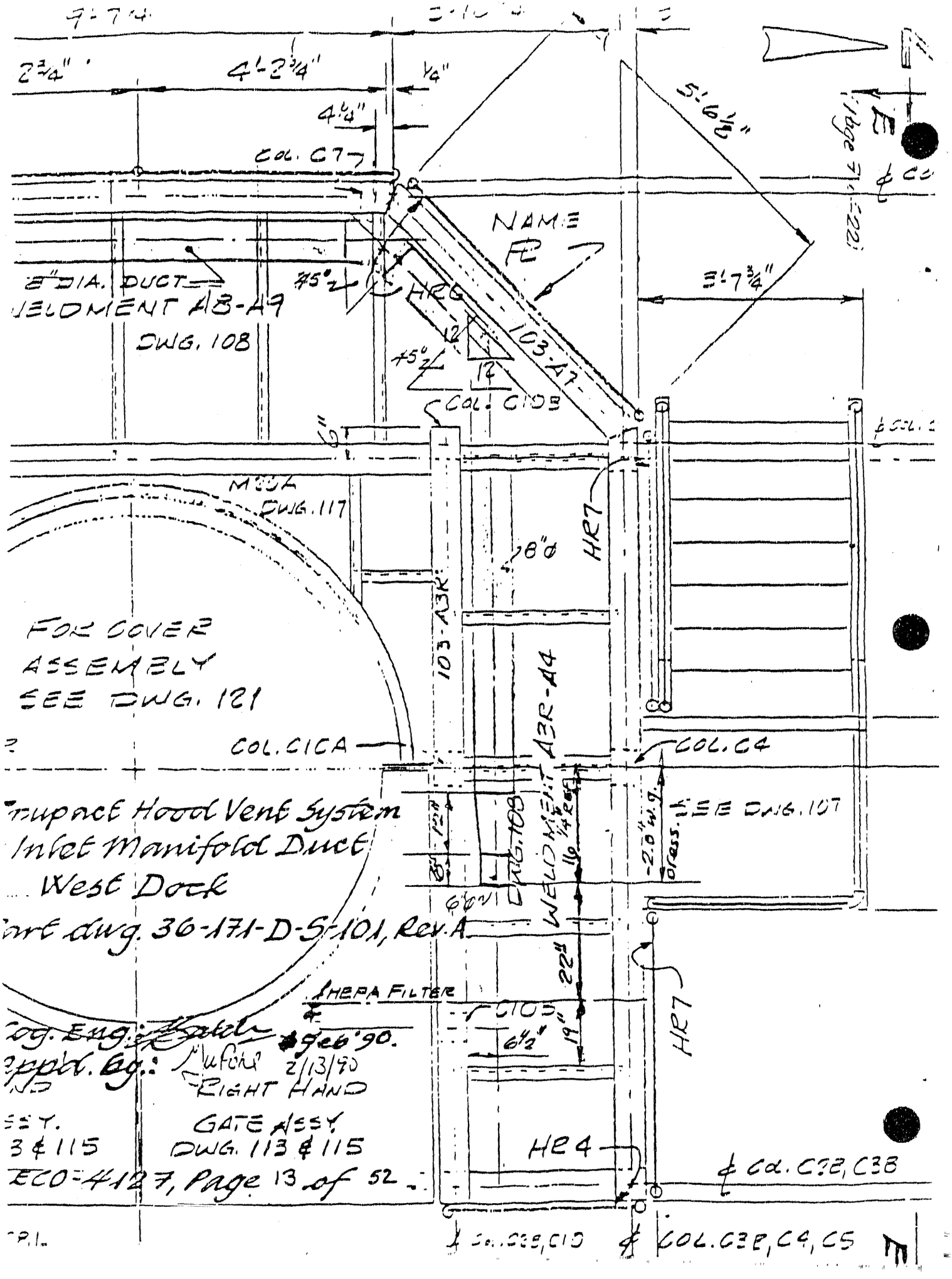
Requests that are conditionally approved or disapproved require an amended AR/VR to be processed

☒ Authorized To Proceed ☐ Do Not Proceed
☒ Amendment Not Required ☐ Amendment Required

AUTHORIZED BY D Cantrell 7/24/90
Purchasing Agent

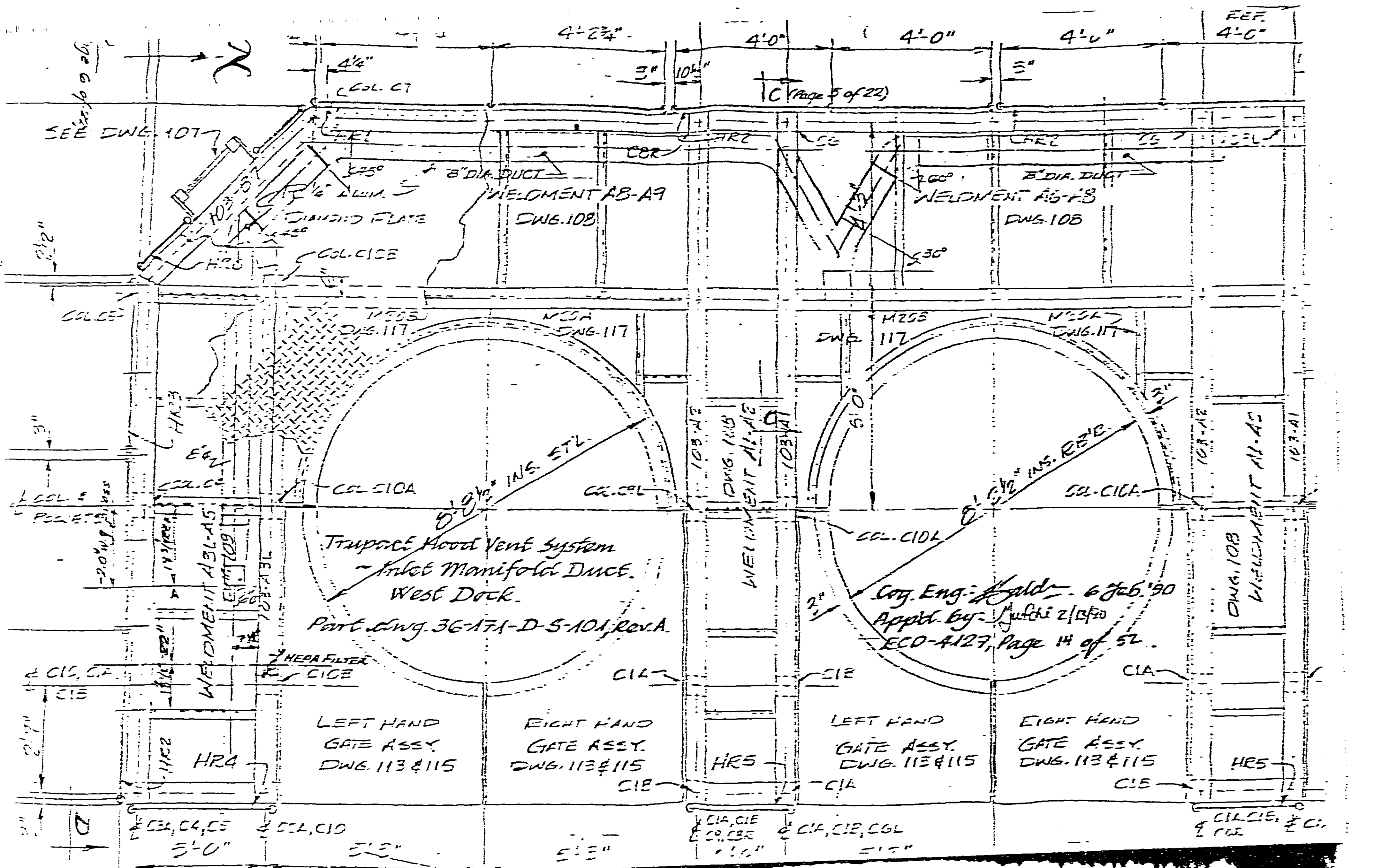
WP Form 1466-A revised 10 6/89
Page 1 of 1


4'-0"
4'-0"
4'-0"
3"
4'-3"
WELDMENT A6-A8
DWG. 108
11"
Furnace Hood Vent System
Inlet Manifold Duct
West Dock.
Part Dwg. 33-171-05-104, Rev. A
ECO-4127, Page 12 of 52
Cog. Eng.: Kalda - 28Feb.'90
Appd by:
WELDMENT A1-A2
DWG. 103-A1
DWG. 103-A2
DWG. 108
WELDMENT A1-A2
DWG. 103-A1
5'-0"
3"
12"
6"Ø
LEFT HAND
GATE ASSY.
DWG. 113 & 115
RIGHT HAND
GATE ASSY.
DWG. 113 & 115
141-E-015
18"
C1A
C1B
HRS
C1A, C1B, C6L
C1A, C1B, C6L
C1A



Surface Hood Vent System
Inlet Manifold Duct
West Dock
Part dwg. 36-171-D-S-101, Rev. A

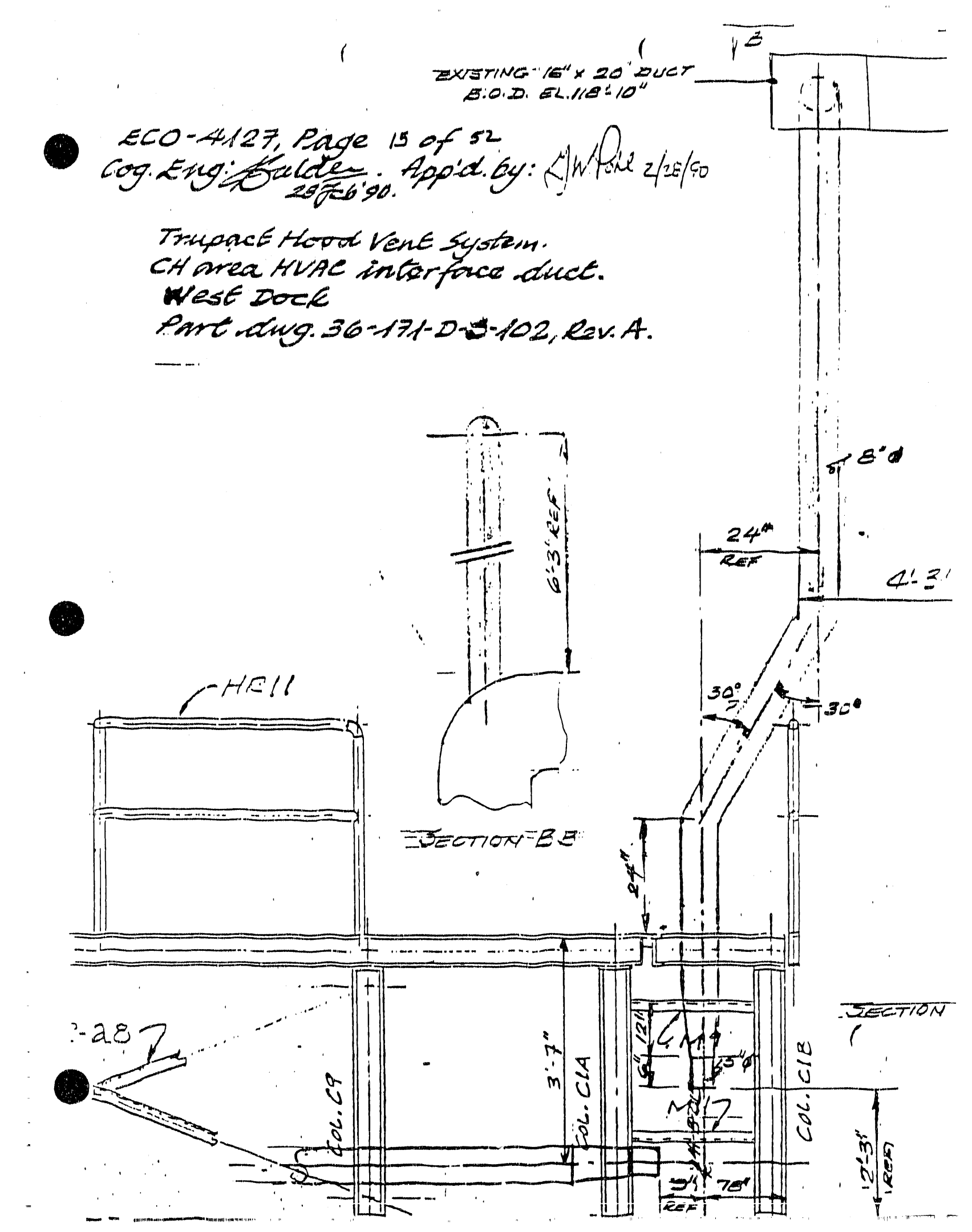
Dsg. Eng.: Feb '90.
Appl. Eng.: 2/13/90



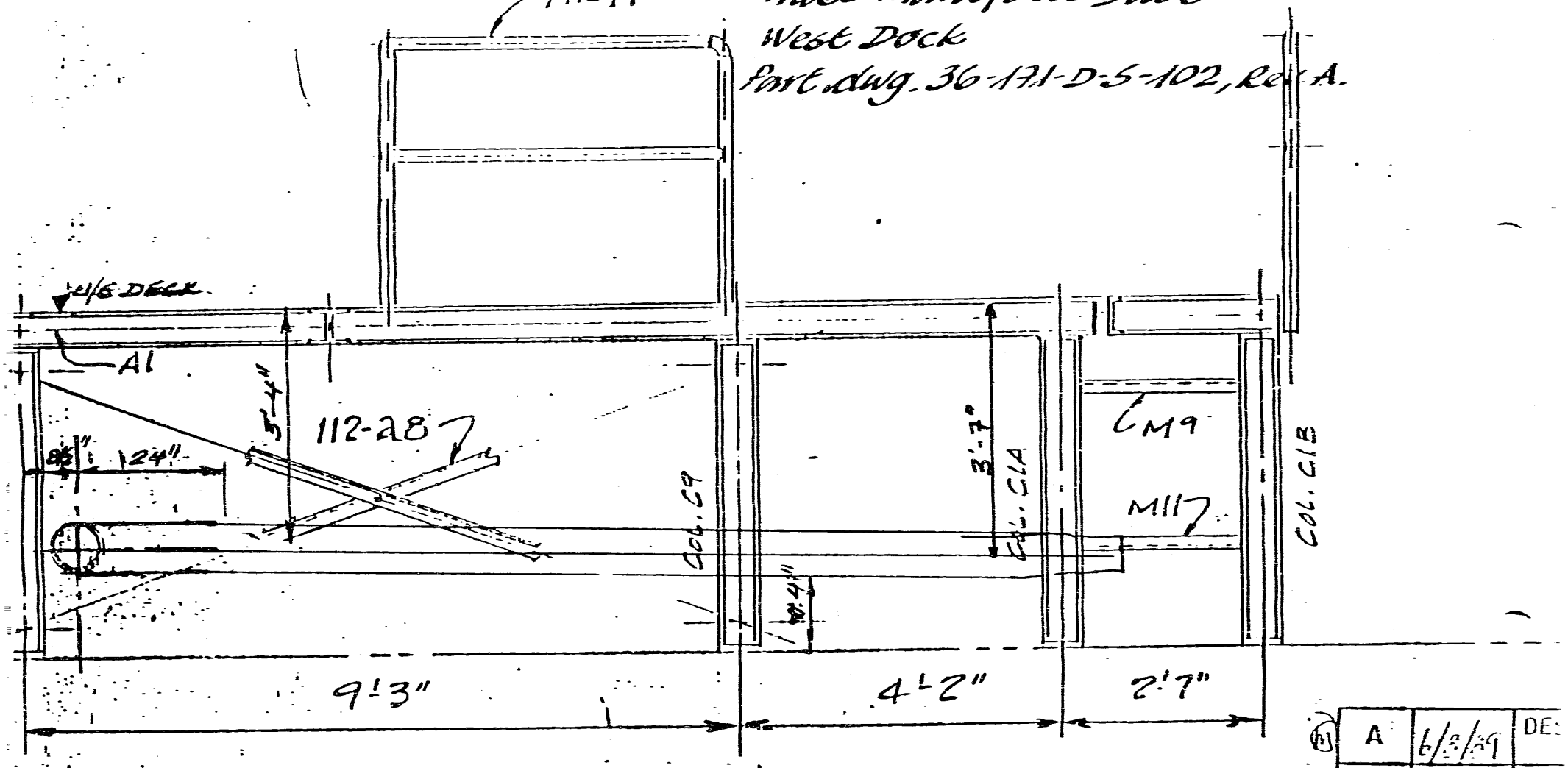
Trupact Hood Vent System
~ Inlet Manifold Duct
West Dock
Part Dwg. 36-171-D-S-101, Rev. A
Cog. Eng: 6 Feb. '90
Appd. By: 2/13/90
ECO-A127, Page 14 of 52
SEE DWG. 107
C (Page 5 of 22)
4'-2 3/4"
4'-0"
4'-0"
4'-0"
4'-0"
4 1/4"
3"
10 1/2"
3"
COL. C7
8" DIA. DUCT
WELDMENT A8-A9
DWG. 108
WELDMENT A6-A8
DWG. 108
DIAMOND PLATE
COL. C10E
30°
60°
45°
DWG. 117
DWG. 117
DWG. 117
DWG. 117
5'-0"
8'-0 1/2" INS. STL
8'-0 1/2" INS. RT'B
COL. C10A
COL. C10L
COL. C10A
WELDMENT A1-A2
DWG. 108
WELDMENT A3L-A5
HEPA FILTER
C10E
C1A
C1B
C1E
C1A
C1B
C1A
HR3
HR4
HR5
HR5
LEFT HAND
GATE ASSY.
DWG. 113 & 115
EIGHT HAND
GATE ASSY.
DWG. 113 & 115
LEFT HAND
GATE ASSY.
DWG. 113 & 115
EIGHT HAND
GATE ASSY.
DWG. 113 & 115
5'-0"

ECO-4127, Page 15 of 52
Cog. Eng: Gulde. App'd. by: EJW Pond 2/28/90
28 Feb 90.

Trupace Hood Vent System.
CH area HVAC interface duct.
West Dock
Part dwg. 36-171-D-3-102, Rev. A.



Trupace Hood Vent System
Inlet Manifold Duct
West Dock
Part dwg. 36-171-D-5-102, Rev. A.



SECTION D/101

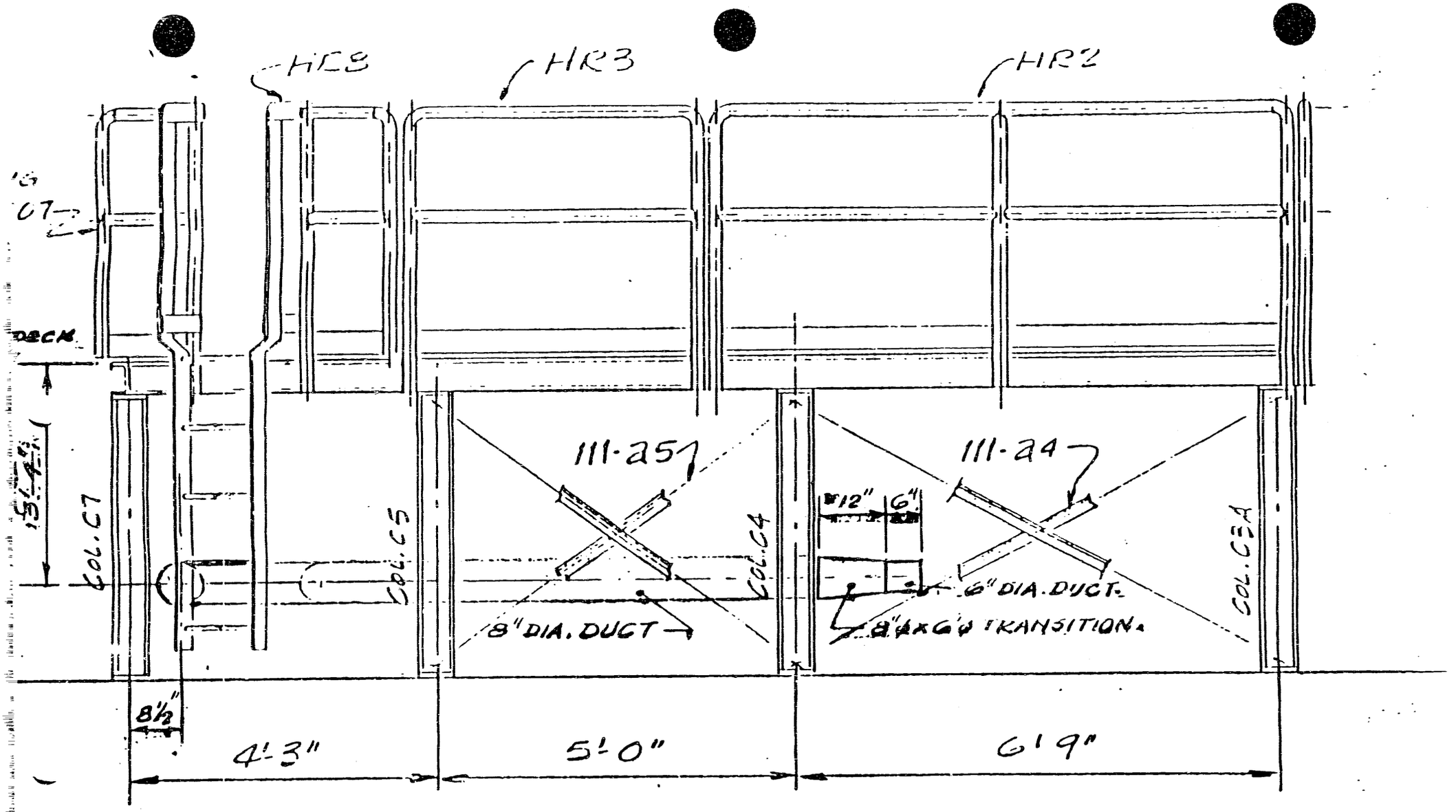
SECTION CC.
(Page 10 of 22)

ECO-4127, Page 16 of 52.
Cog. Eng.: [illegible] 28 Feb 90
Appd. by: [illegible]

REV	DATE	DES
A	6/8/89	

AS BU

NO



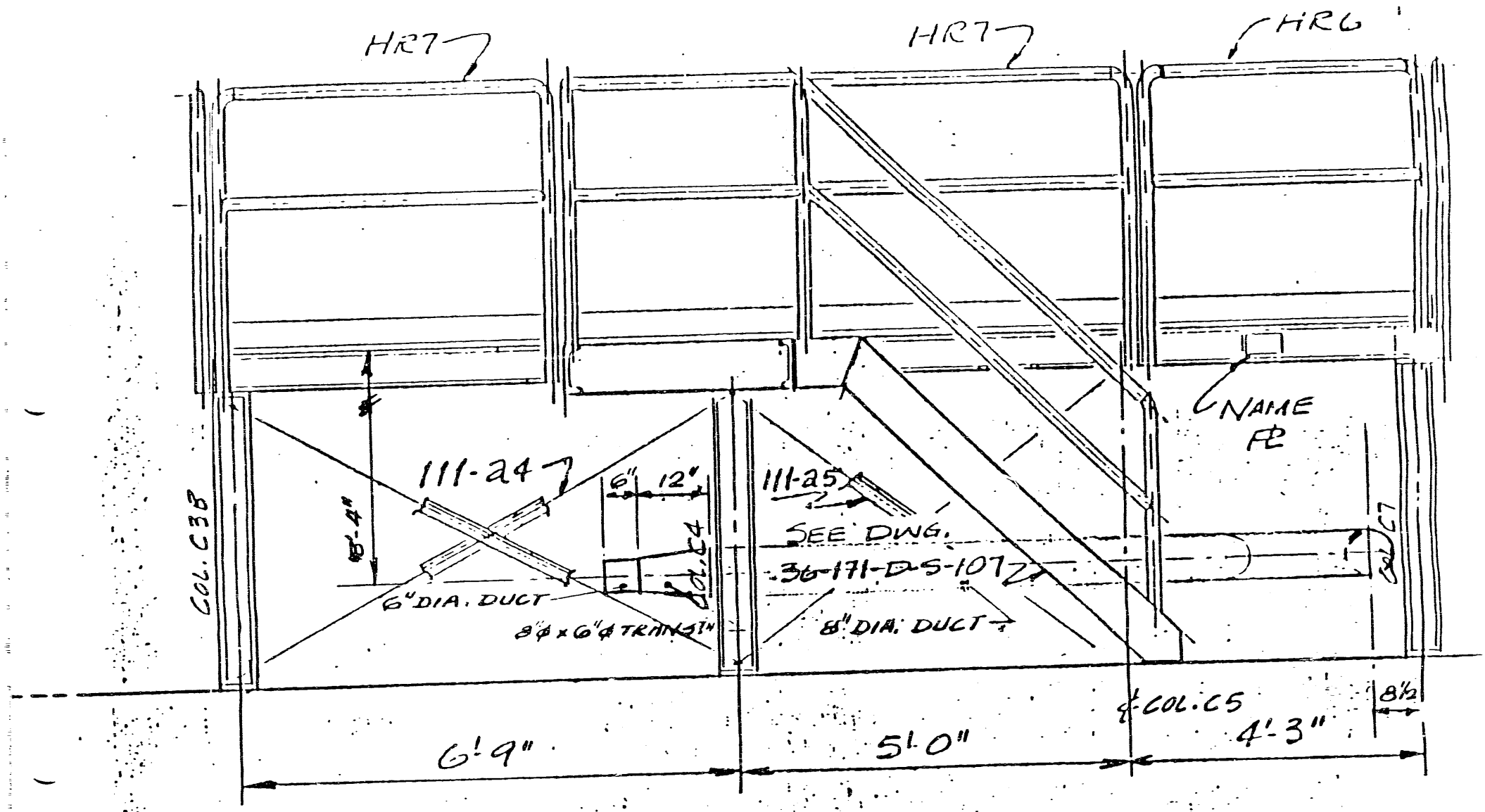
SECTION DD
(Page 10 of 22).

SECTION C/101

Tripace Hood Vent System
- Inlet Manifold Duct.
West Dock

Cog. Eng.: [signature] 6 Feb. '90.
App'd. by: [signature] 2/13/90
ECO-4127, Page 17 of 52.

Part dwg. 36-171-D-5-102, Rev. A



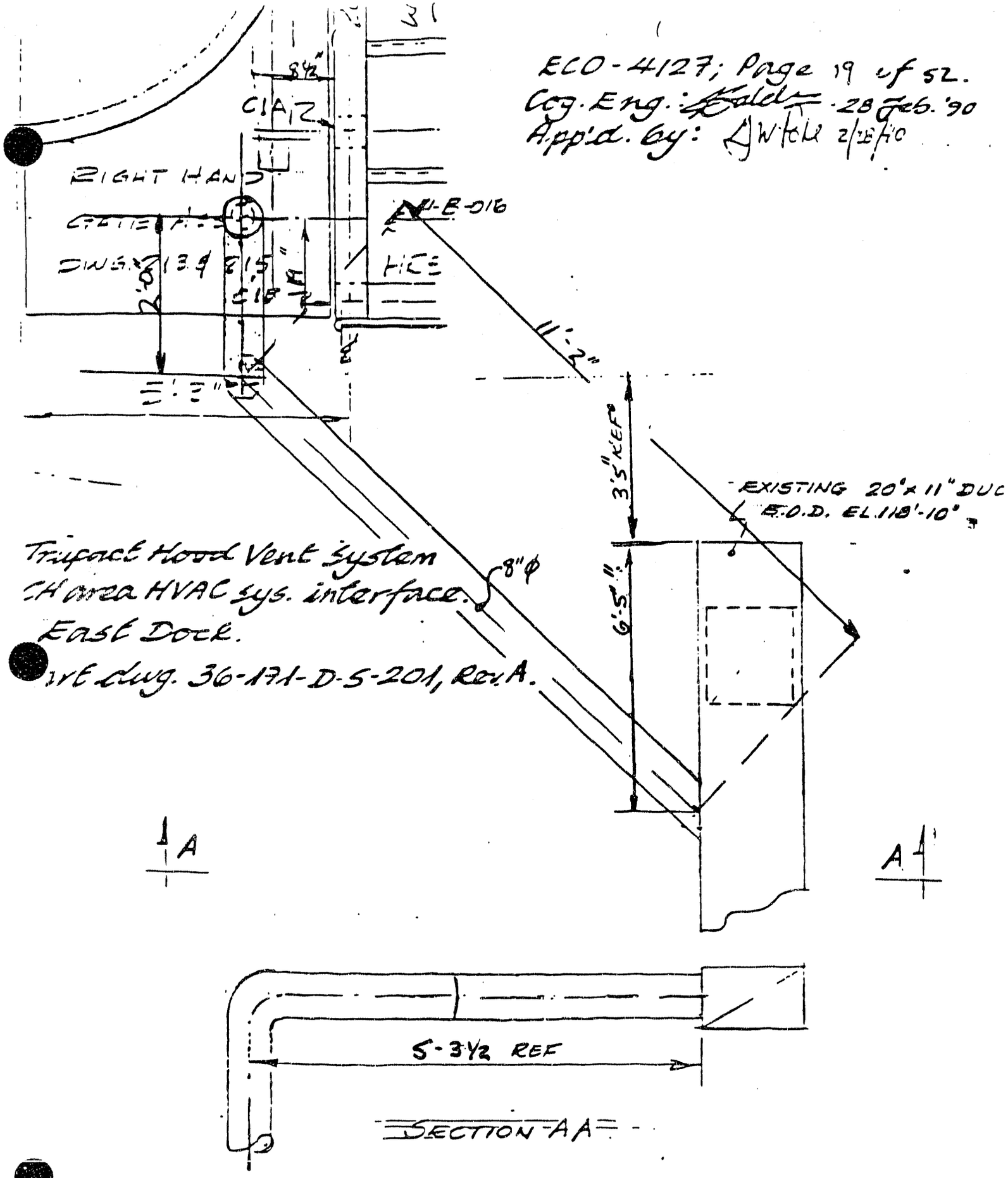
SECTION E.E.
(Page 9 of 24).

SECTION (B/101)

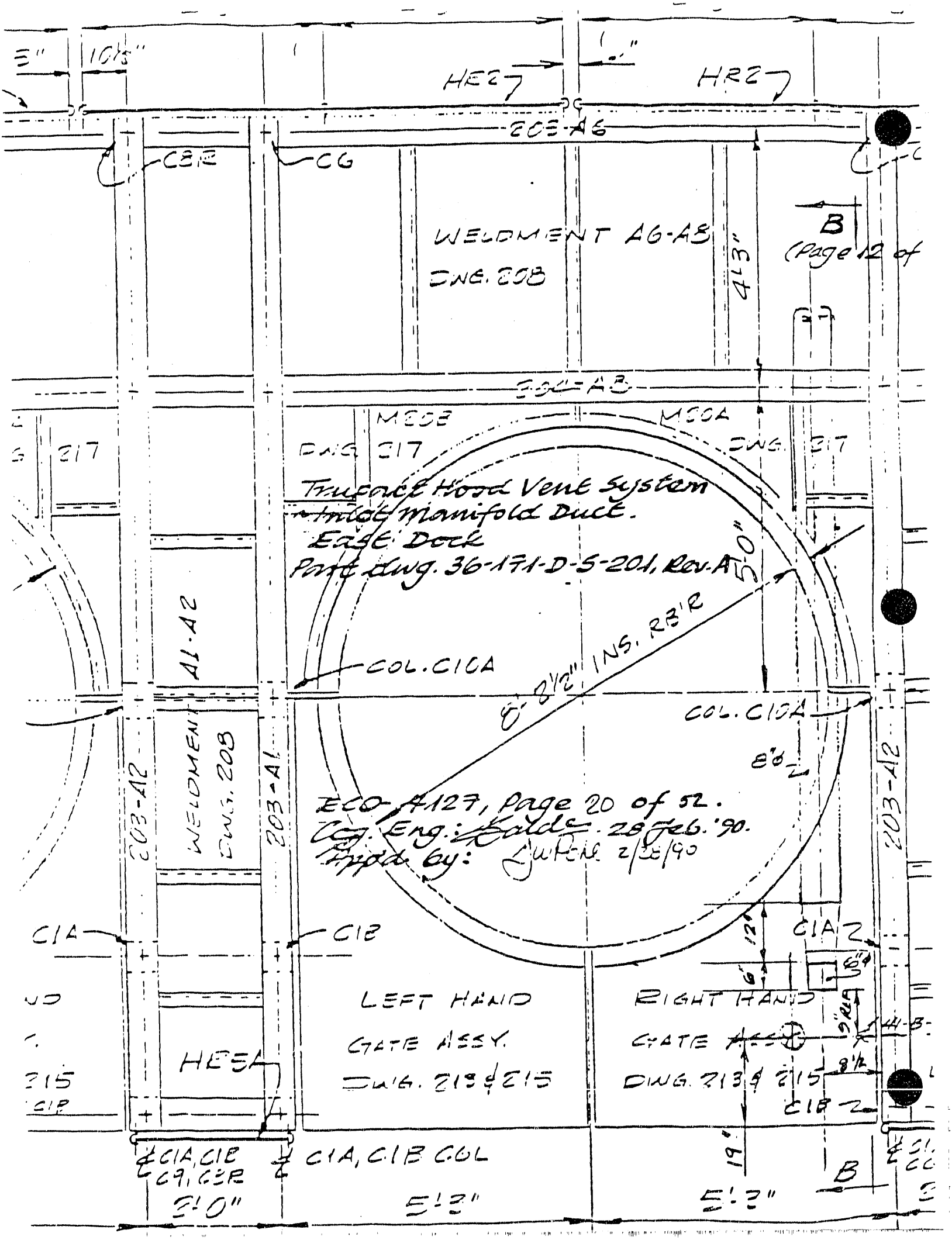
Trupact Hood Vent System
Inlet Manifold Duct.
West Dock
Part dwg. 36-171-D-S-102 Rev. A

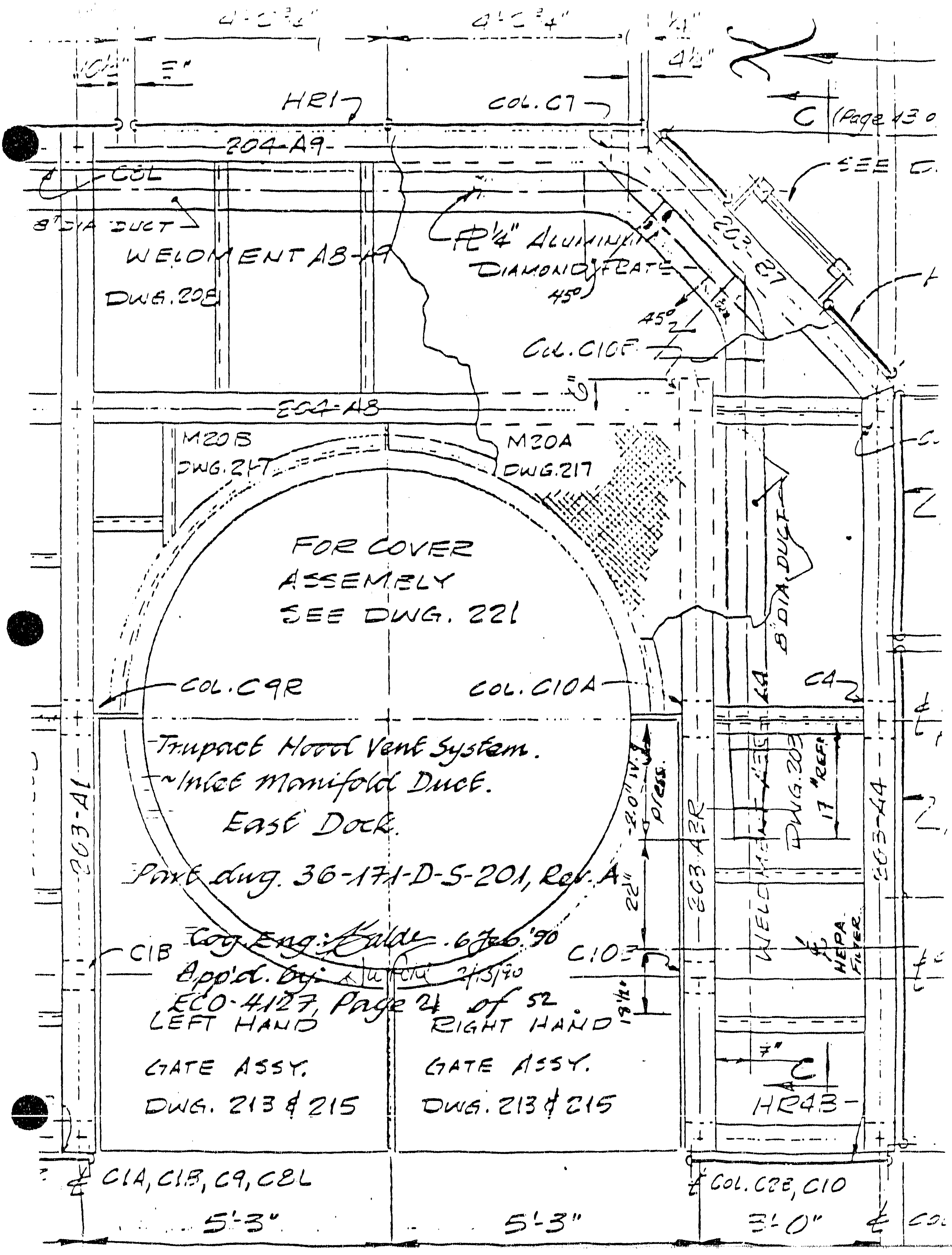
Cog. Eng.: [illegible] 6 Feb 90.
Appd. by: [illegible] 2/13/90
ECO #127; Page 18 of 52.

ECO-4127; Page 19 of 52.
Cog. Eng.: ~~Kalda~~ 28 Feb. '90
Appl. by: JWFeld 2/28/90

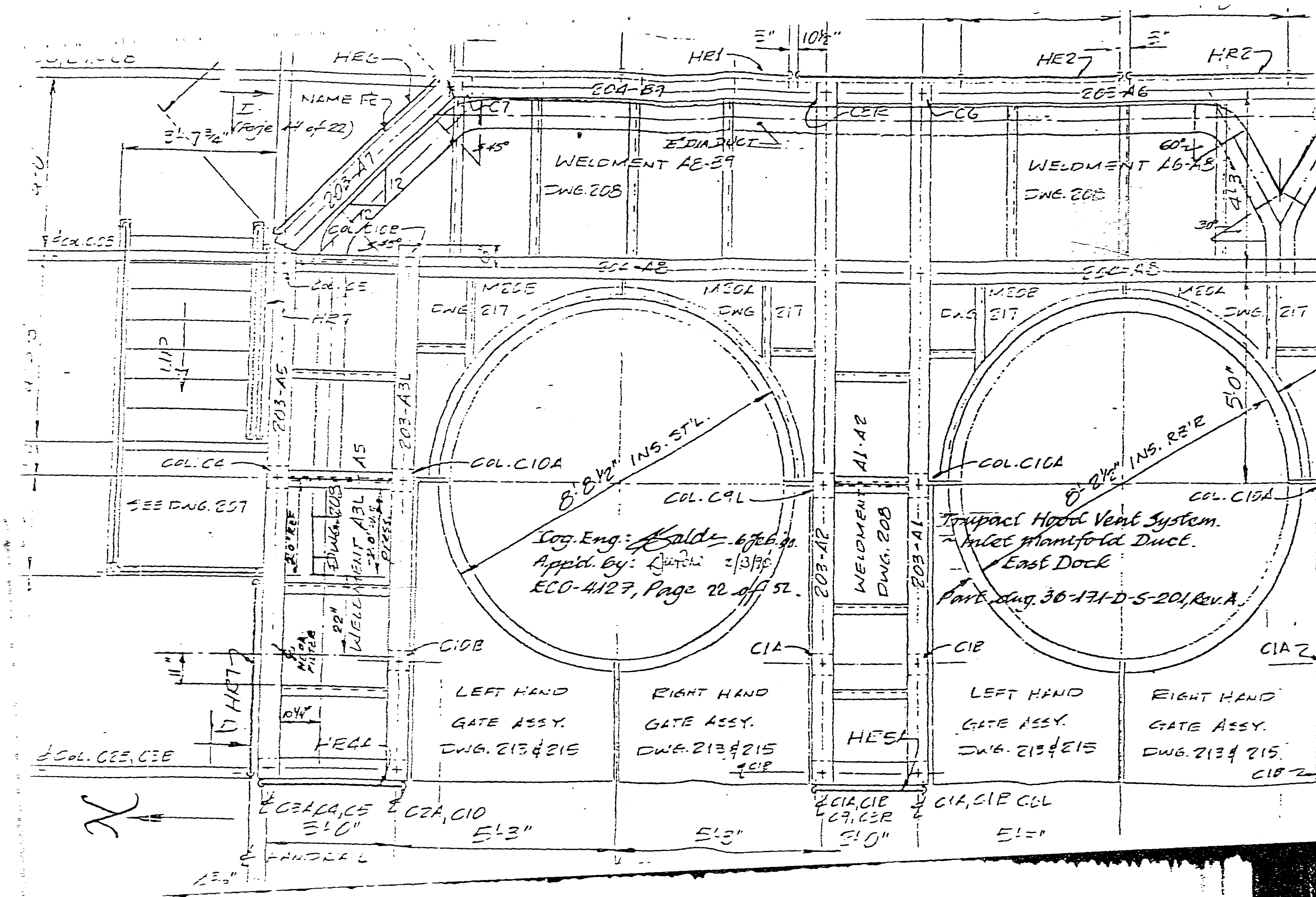


Trifoce Hood Vent System
CH area HVAC sys. interface.
East Dock.
Ref dwg. 36-171-D-5-201, Rev. A.


3"
10½"
HR27
HR27
208-A6
C8R
C6
WELDMENT A6-A8
DWG. 208
413"
B
(Page 12 of
208-A8
M208
DWG. 217
M204
DWG. 217
217
TruForce Hood Vent System
Inlet Manifold Duct.
Eagle Dock
Part dwg. 36-171-D-5-201, Rev. A
5'0"
A1-A2
COL. C10A
8½" INS. RB'R
6'
COL. C10A
8'6"
ECO 4127, Page 20 of 52.
Eng. Eng: Valdez 28 Feb. '90.
Appd. by: J. Wilson 2/28/90
203-A2
WELDMENT
DWG. 208
203-A1
203-A2
C1A
C1B
12"
C1A
6'
5'6"
LEFT HAND
GATE ASSY.
DWG. 213 & 215
RIGHT HAND
GATE
DWG. 213 & 215
HE5A
215
C1B
8½
C1B
19'
B
℄ C1A, C1B
C9, C8R
5'0"
℄ C1A, C1B COL
5'3"
5'3"
B



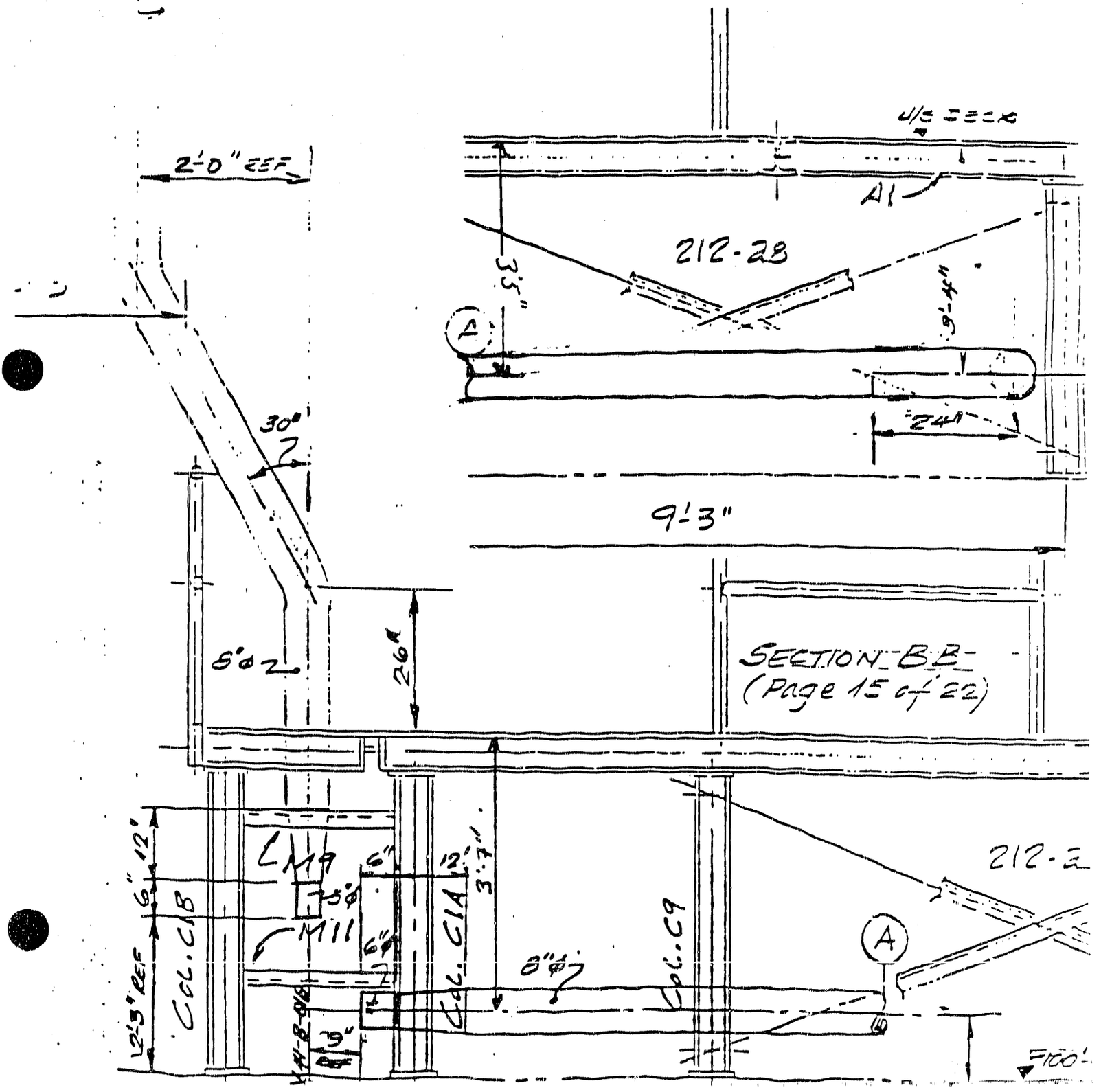
4'-0 3/4"
1/4"
4 1/2"
10 1/2"
3"
HR1
COL. C7
C (Page 13 o
SEE
204-A9
COL
8" DIA DUCT
WELDMENT A8-A9
DWG. 208
1/4" ALUMINUM DIAMOND PLATE
45°
203-B7
COL. C10F
204-A8
M20B
DWG. 217
M20A
DWG. 217
FOR COVER
ASSEMBLY
SEE DWG. 221
8" DIA. DUCT
COL. C9R
COL. C10A
C4
Trupact Hood Vent System.
~Inlet Manifold Duct.
East Dock.
Part dwg. 36-171-D-S-201, Rev. A
Cog. Eng: 6 Feb '90
App'd. by: 2/13/90
ECO-4127, Page 4 of 52
203-A1
203-A3R
203-A4
WELDMENT A3-A4
DWG. 209
17" REF
HEPA FILTER
22"
C1B
C10E
LEFT HAND
GATE ASSY.
DWG. 213 & 215
RIGHT HAND
GATE ASSY.
DWG. 213 & 215
7"
C
HR43
C1A, C1B, C9, C8L
COL. C8E, C10
5'-3"
5'-3"
3'-0"

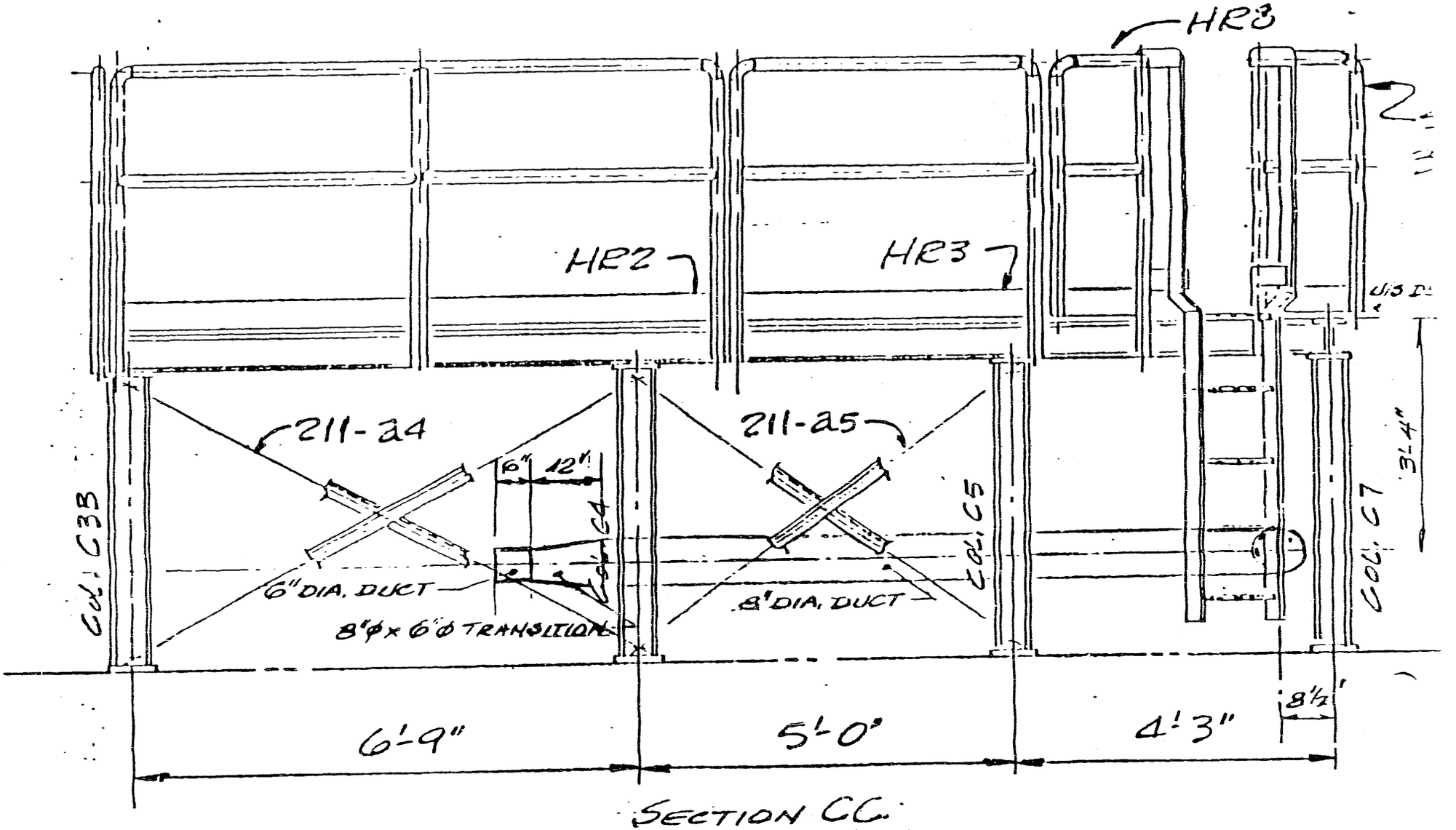


Impact Hood Vent System.
Inlet Manifold Duct.
East Dock
Part dwg. 36-171-D-S-201, Rev. A.
Cog. Eng: Kalde 6 Feb. 90.
Appd. By:
ECO-4127, Page 22 of 52.
WELDMENT AE-A9
DWG. 208
WELDMENT A6-A8
DWG. 208
WELDMENT A1-A2
DWG. 208
8'-8½" INS. ST'L.
8'-8½" INS. RE'R
LEFT HAND
GATE ASSY.
DWG. 213 & 215
RIGHT HAND
GATE ASSY.
DWG. 213 & 215
COL. C10A
COL. C9L
COL. C10B
COL. C1A
COL. C1B
203-A1
203-A2
203-A3L
203-A5
203-A7
204-B9
203-A6
SEE DWG. 207
5'-3"
3'-0"

Cog. Eng.: Gald. 29 Feb. '90
App'd. by: [illegible] 2/28/90

Tripace Hood Vent System.
~Inlet Manifold Duct
East Dock
Para. dwg. 36-171-D-5-202, Rev. A.



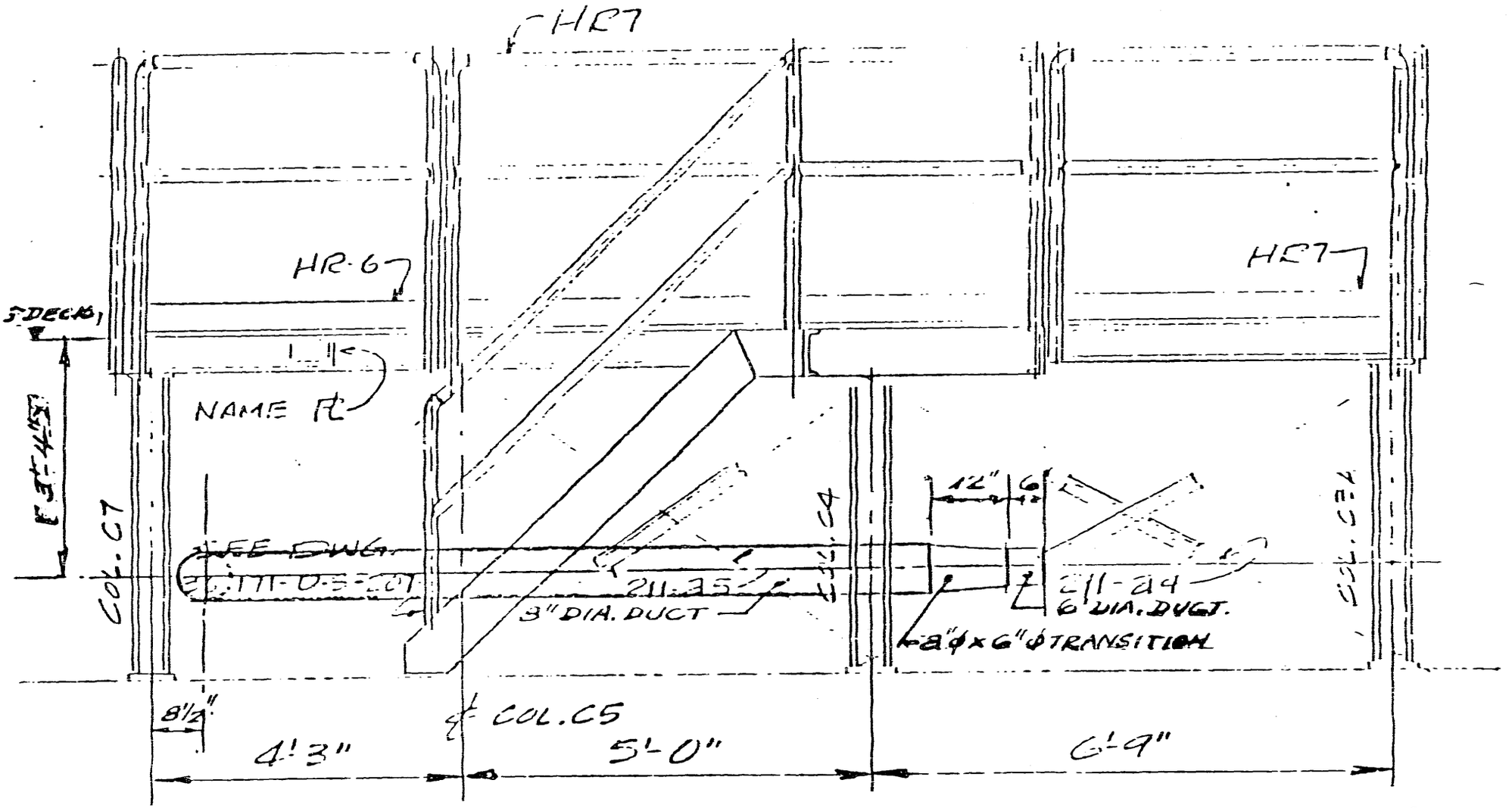


SECTION CC.
(Page 16 of 22).

SECTION C/201

Trupace Hood Vent System.
Inlet Manifold Duct
East Dock
Part dwg. 36-171-D-S-202, Rev. A.

Cog. Eng.: [signature] 6 Feb. '90
App'd. by: [signature] 2/13/90
ECO-4127. Page 21 of 22



SECTION DD:
(Page 17 of 22)

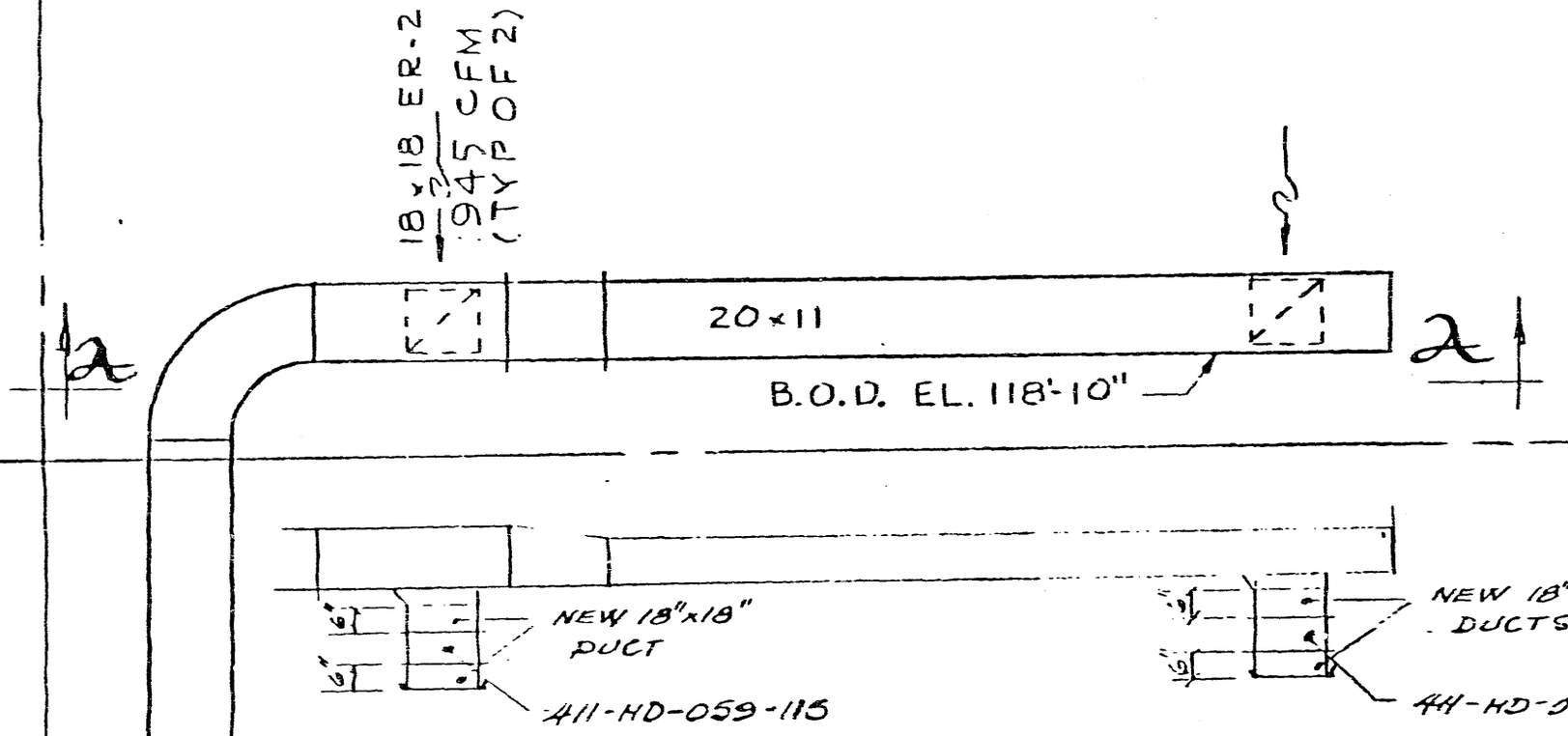
SECTION B/201

Trupace Hood Vent System
~Inlet Manifold Duct
East Dock.

Part dwg. 36-171-D-5-202,
Rev. A.

Cog. Eng.: [signature] 6 Feb. '90
App'd. by: [signature] 2/13/90
ECO-4127, Page 25 of 52.

Cog. Eng.: Bald. 13 Feb. 90
Appr'd by: JWFolk 2/13/90
ECO-4127, Page 29 of 52.

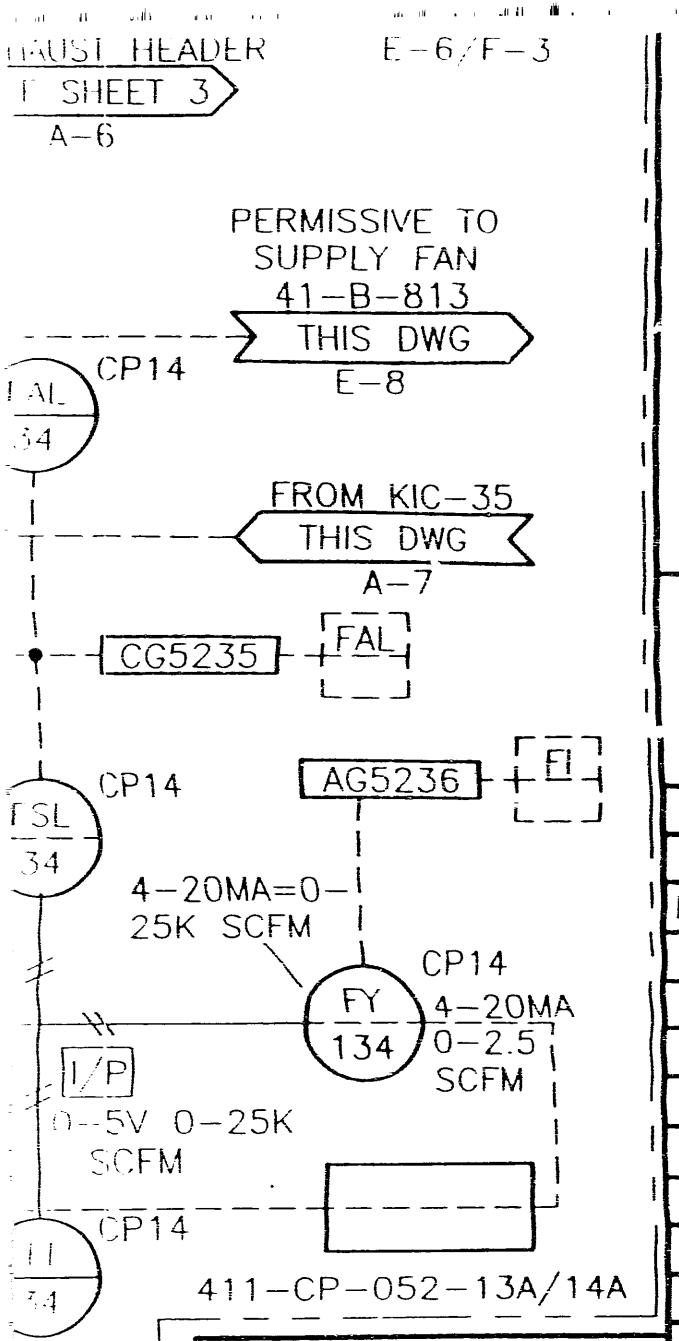


SECTION AA

CONTACT HANDLING AREA 103

(INVENTORY & PREPARATION AREA)

Trupact Hood Vent System.
~CH Area HVAC system interface.
Part dwg.: 41-G-305-014, Rev D.



16. ELECTRICAL INTERCONNECTIONS NOT VERIFIED BY MECHANICAL FVT

17. THIS DWG SUPERCEDES 41-F-052-014, 41-F-063-014, & 41-F-059-014

REV	DATE	ISSUE DESCRIPTION	BY	ENG	ECO	EWP
B	10/29/90	REVISED PER ECO F/D	MDSA		3992/4127 4536/4743 4755/4834 4911/4937	
A	05/16/90	APPROVED FOR USE	WJM	KAE	4222	
–	03/23/90	ISSUED FOR REVIEW	WJM	HMG	4222	

DFTG CHG/FBB
CHKR. B. Allen 10/29/90
COG. ENG [illegible] 29 Oct '90
COG. MGR G.W. POHL 5/16/90
Q.A. (RB) A.E. GALLEGOS 5/16/90
SAFETY N/A
APPD
APPD
DFTG. MGR H.W. Bell 10/29/90

DOE N/A
SCALE NTS

INTERPRET DWG PER ANSI Y14

REVISION	B	B	B
SHEET	3	2	1

REV STATUS OF SHEETS

U.S. DEPARTMENT OF ENERGY

Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

WASTE HANDLING BUILDING 411
CH AREA HVAC
PIPING & INSTRUMENT DIAGRAM

SYS. HV01 | DWG. NO. 41-B-001-W | REV. B | SH. 1 OF 3

7
G-B2A

REV	ISSUE DESCRIPTION	DFTR DATE	CHK DATE	DES DATE	DFTG MGR DATE	ECO	PWR
E	REVISED PER ECO	AES 5/22/91	OLH 5/28/91	[illegible] 5/23/91	BA 5/24/91	5383 5398	M10211 M10210
F	REVISED PER ECO	RS 10/23/91	AES 11/19/91	[illegible]	BA 11/21/91	3803 4127 5801	

CE	REV	DATE	ISSUE DESCRIPTION	BY	CK'D	S.O.V.	P.E.	PEM	DOE
NR	3	8/27/87	ISSUED AS BUILT	[illegible]	[illegible]				
NR	2	11/18/83	ISSUED FOR CONSTRUCTION	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
NR	1	10/21/83	ISSUED FOR APPROVAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
NR	0	7/2/83	ISSUED FOR PROGRESS REVIEW	RM		[illegible]	[illegible]	[illegible]	

U.S. DEPARTMENT OF ENERGY

WASTE ISOLATION PILOT PLANT

BECHTEL

SYSTEM
HV01/02

WASTE HANDLING BLDG 411
PIPING & HVAC ARRANGEMENT
PLAN @ EL. 100'-0" SH. 4 OF 8

JOB NO: 12484	DRAWING APPROVED BECHTEL — DATE 11/13
DOE CONTRACT NUMBER: DE-AC04-79AL10751	DRAWING APPROVED DEPARTMENT OF ENERGY — DATE 11/14/13

DRAWING NO	CCP	REV	PAGE NO
41-G-305-014		F	2

16

1

34 x 44 "E" SIZE

ENGINEERING CHANGE ORDER
(USE BLACK INK)

(1) CC&D REVIEW CC
ECO- WKH 4463 ~~M41691~~

(2) IMPACT LEVEL
☐ LEVEL-1 ☒ LEVEL-3
☐ LEVEL-2
(SEE SIDE 2 FOR APPROVALS)

(3) SYS/EQUIP NO./BLDG
GC00 / NO.41-Z-052/411

(4) ASSOCIATED DOCUMENTS
030 M41691
RELATED ECO
EDT
P.O.

(5) DOCUMENT NO.
DRAWING See #9 ☒
SPEC ☐
O&M MANUAL ☐
SDD ☐
41-G-503-014
41-E-006-014

(6) SHEET
#9

(7) REVISION ADVANCED
FROM B TO C
FROM C TO D

(8) DOCUMENT TITLE Modular Enclosure in H.V.B. Levise drawings

(9) DESCRIPTION OF CHANGE

41-G-503-014 RevB pg 2-17
41-E-006-014 RevC pg 2-29
See Attachments # 3, 4, & 5
to Ø3Ø M41691

Y/N
☒ ELECTRICAL LOAD LIST (25-X-001-W)
☒ PANEL SCHEDULE (INCLUDE MARK-UP)

☒ YES ☐ NO
**** MODIFICATION IN PROGRESS
(ECO NOT TO BE INCORPORATED)
☒ MODIFICATION COMPLETE 5/7/91
(ECO RELEASED FOR INCORPORATION)

(10) JUSTIFICATION To provide up to date information to reflect complete change made by Ø3Ø M41691 instructions that allow for environmental control to implement calibration of Plant HVAC system (KURZ Flow Control)

(11) ORIGINATOR (PRINT)	(12) PHONE	(13) ORGANIZATION	(14) DATE
William E. Horvath	8315-6	Maint I&C	3-20-90

(15) COG. ENGINEER (PRINT)	(12) PHONE	(16) DRAFTING REQUIRED DATE
J Kowalski	8167	5/5/90

(17) RELATED CHANGES. INDICATE THE DOCUMENTS, INSTRUCTIONS OR PROCEDURES (OTHER THAN THE DRAWINGS OR DOCUMENTS IDENTIFIED IN EITHER 5 OR 9) THAT WILL BE AFFECTED BY THE CHANGE DESCRIBED IN BLOCK 9. ENTER THE DOCUMENT NUMBER(S) IN BLOCK 18.

YES	NO	N/A		YES	NO	N/A	
☐	☐	☐	1. CONCEPTUAL DESIGN REPORT	☐	☐	☐	10. TRAINING MANUAL
☐	☐	☐	2. VENDOR DATA (WP 09-025)	☐	☐	☐	11. OPERATING PROCEDURES
☐	☐	☐	3. FSAR	☐	☐	☐	12. SPARES/MULTIPLE UNIT LISTINGS
☐	☐	☐	4. SEISMIC/STRESS ANALYSIS	☐	☐	☐	13. DO SPARES NEED MODIFIED
☐	☐	☐	5. DESIGN REPORT	☐	☐	☐	14. TEST PROCEDURES/SPECS.
☐	☐	☐	6. INTERFACE CONTROL DWGS.	☐	☐	☐	15. COMPONENT INDICES
☐	☐	☐	7. CALIBRATION PROCEDURES	☐	☐	☐	16. ASME CODED ITEMS
☐	☐	☐	8. INSTALLATION PROCEDURES	☐	☐	☐	17. HUMAN FACTOR CONSIDERATIONS
☐	☐	☐	9. MAINTAINANCE PROCEDURES	☐	☐	☐	18. COMPUTER SOFTWARE

(18) RELATED DOCUMENT NO.; INSTRUCTION NO.; IDENTIFIED IN BLOCK 17 (CHANGES TO DOCUMENTS LISTED IN BLOCK 18 WILL NOT BE INCOPRORATED BY THIS ECO).

DOCUMENT NO./REVISION	

(19) DISTRIBUTION

NAME	ORG.

(20) SIGNATURE REQUIREMENTS

KEY
A=APPR.
R=REVIEW

ECO # 4463

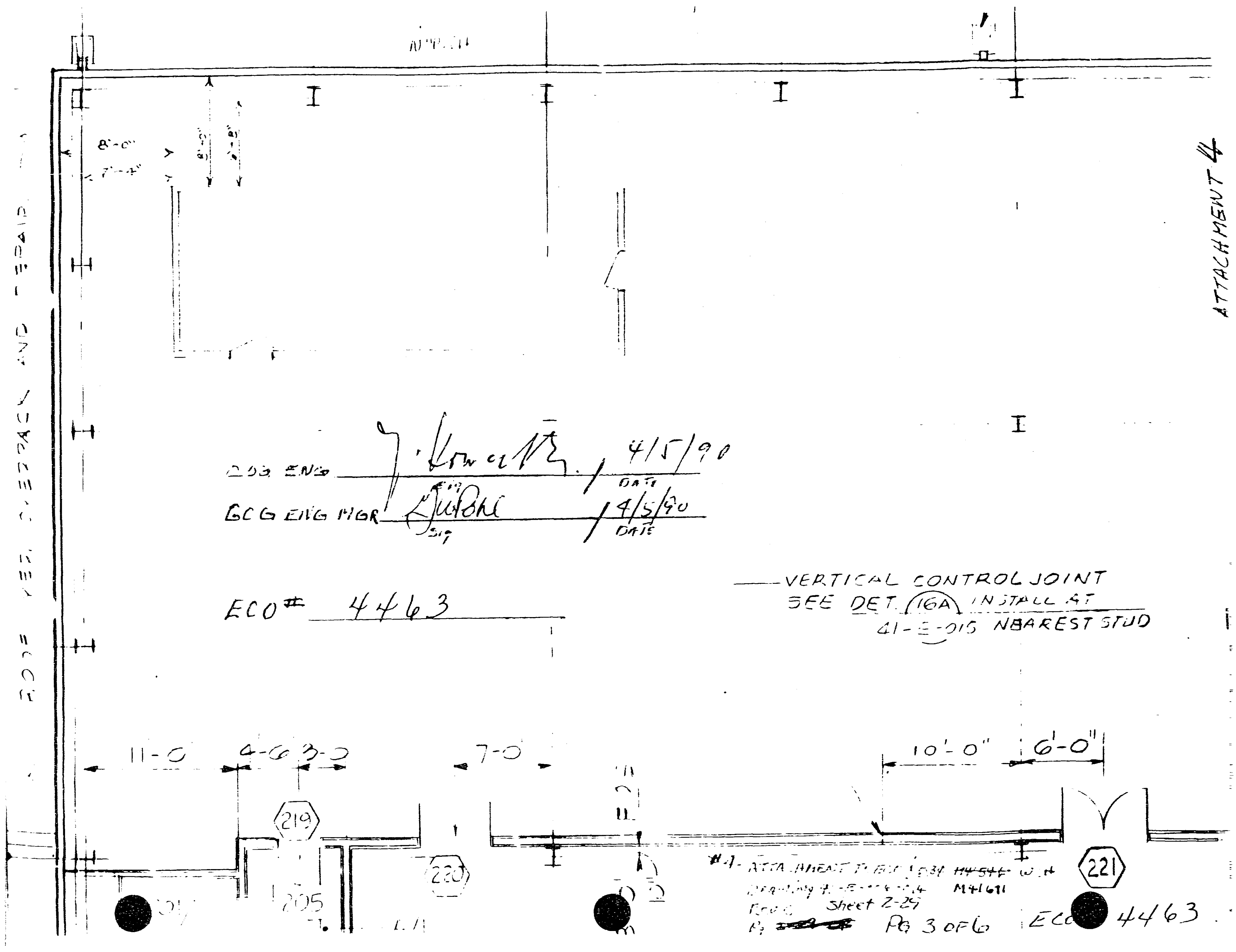
A	COG. ENGINEER	[signature]	
A	COG. ENGR. MGR.	[signature]	4/5/90
R	Q.A.	[signature]	4-5-90
	DOE		
A	SAFETY	Mel Rosenthal	4-12-90
	DEPT. MGR.		
A	OPERATIONS	W.W. Budge	4/12/90
	SECURITY		

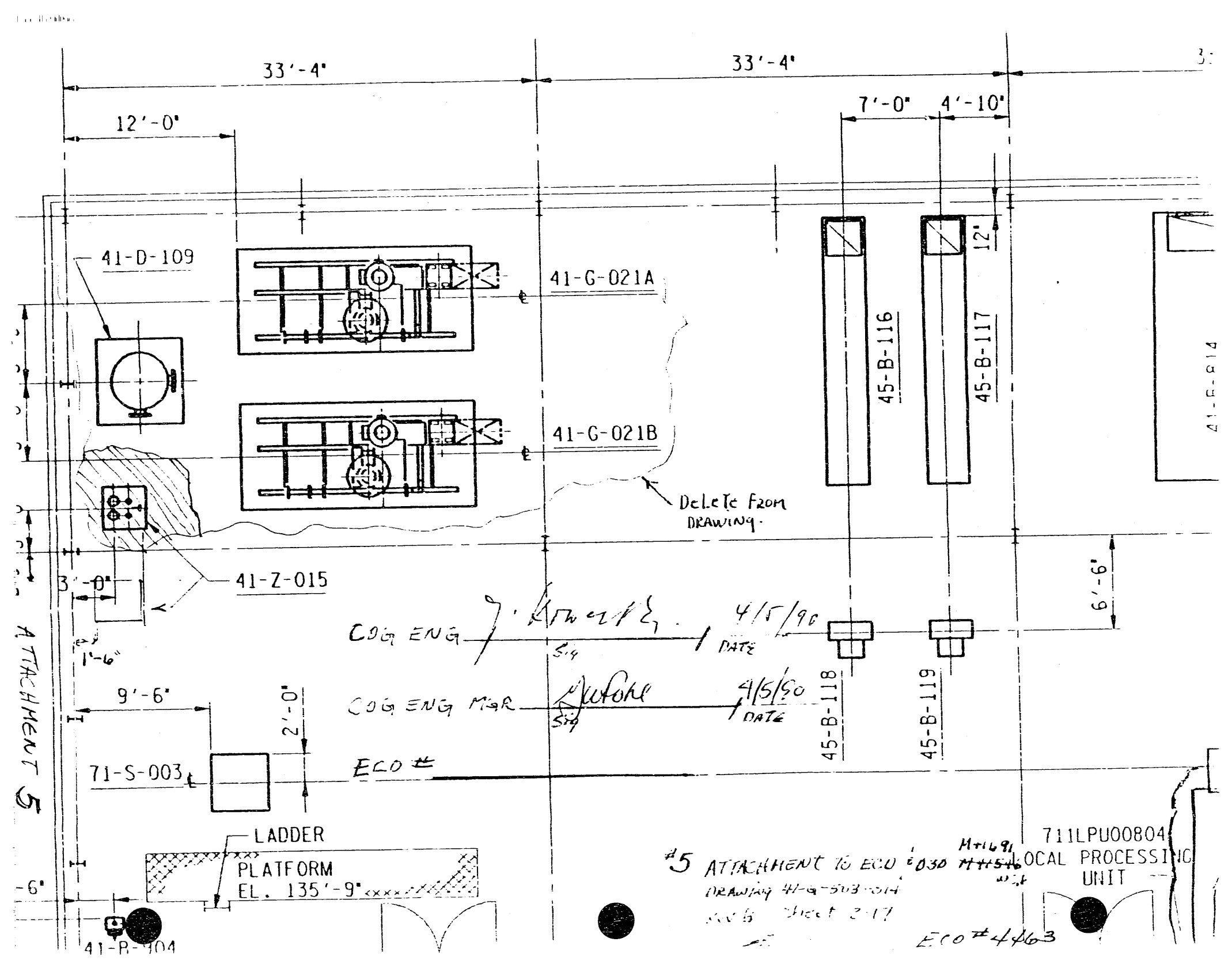
(21) DESIGN VERIFICATION REQUIREMENTS (PER WP 09-018)

Yes
1. REQUIREMENTS SATISFIED BY REVIEW/APPROVAL OF DESIGN DOCUMENT
2. INDEPENDENT REVIEW
3. ALTERNATE CALCULATIONS
4. DEVELOPMENT TESTING
5. DESIGN REVIEW
6. OTHER _____

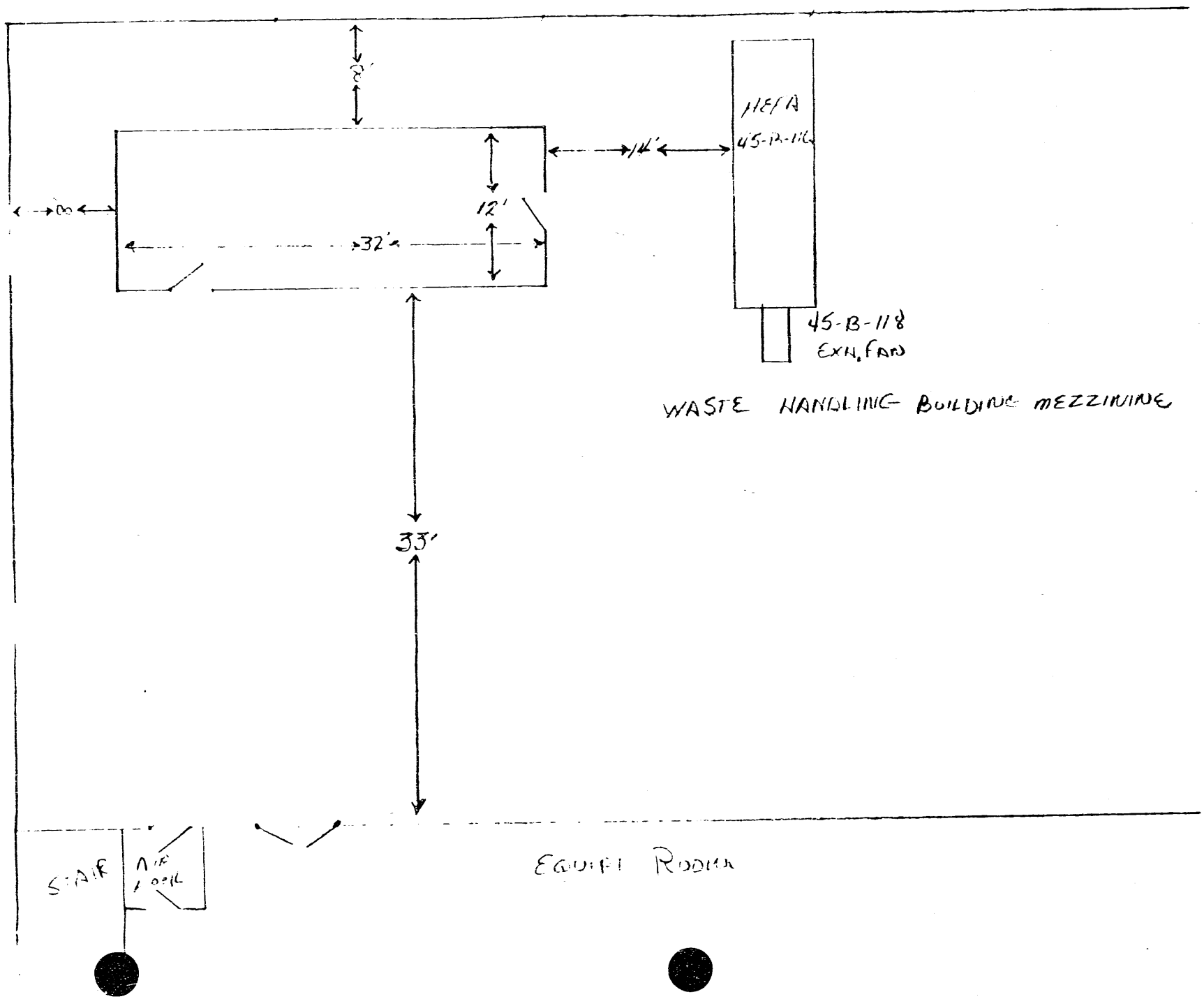
EDT# _____

(Side 2)


ATTACHMENT 4
8'-0"
QC ENG [signature] 4/5/90 DATE
GCG ENG MGR [signature] 4/5/90 DATE
ECO# 4463
VERTICAL CONTROL JOINT
SEE DET. 16A INSTALL AT
41-E-015 NEAREST STUD
11-0
4-6
3-2
7-0
10'-0"
6'-0"
219
220
221
205
Sheet 2-29
M4611
PG 3 OF 6
ECO 4463


33'-4"
33'-4"
12'-0"
7'-0"
4'-10"
41-D-109
41-G-021A
41-G-021B
45-B-116
45-B-117
12"
Delete From DRAWING.
41-Z-015
3'-0"
1'-6"
6'-6"
COG ENG
4/5/90
DATE
COG ENG MGR
4/5/90
DATE
45-B-118
45-B-119
9'-6"
2'-0"
71-S-003
ECO #
LADDER
PLATFORM
EL. 135'-9"
41-B-404
711LPU00804
LOCAL PROCESSING UNIT
ATTACHMENT 5
#5 ATTACHMENT TO ECO # 030 M#1691 M#1546
DRAWING 41-G-503-014
SHEET 2 OF 2
ECO #4463

ATTACHMENT 3
DIMENSIONAL LAY OUT (DETAILS)
Pg 5 of 6 ECO 4463



EQUIPMENT NUMBER REQUEST

|✓| ADDITION |_| DELETION

1. EQUIPMENT NUMBER NO. 41-Z-052

2. DESCRIPTION (1st 25 characters on Equipment Log)

MODULAIR BUILDING

NARRATIVE: SYSTEM: ~~G5000~~ WEM GC00

3. DRAWING NUMBER 41-E006-014
   P&ID
   LOCATION NORTH/WEST CORNER OF MEZZANINE

4. MANUFACTURER NATIONAL PARTITIONS & INTERIORS, INC.

5. MODEL NUMBER 324 SERIAL NUMBER N/A

6. RELATED CCP SPEC NUMBER

7. PURCHASE REQUISITION NUMBER PR 35668
   DATE PURCHASED
   PURCHASE COST 8,113.00
   CHARGE ACCT. NUMBER WAS 24201

8. COG MGR/ENGINEER

9. ORIGINAL SUPPLIER GLOBAL INDUSTRIAL EQUIP

10. DESIGN CLASS QUALITY CODE

11. CRITICAL EQUIPMENT/OSR ____ YES ✓ NO
    ASSOCIATED FSAR/FEIS (TECH) SPECS

12. SPARE PARTS IDENTIFIED ____ YES ✓ NO
    POSSIBLE SUPPLIER GLOBAL INDUSTRIAL EQUIP

13. LOCATION: BLDG 411 ROOM NUMBER 200

14. ELECTRICAL DISCONNECT OR BREAKER

15. O&M MANUAL IN FILE ROOM ____ YES ____ NO

16. EQUIPMENT LABELED ____ YES ____ NO

REQUESTOR William E. Howard DATE 3-21-90

ECO 4463
Page 6 of 6

41E-006 014

PAGE 1 OF 10

ENGINEERING CHANGE ORDER
(USE BLACK INK)

(1) CC&D REVIEW RB

ECO- 4983

(2) IMPACT LEVEL
☐ LEVEL-1 ☑ LEVEL-3
☐ LEVEL-2
(SEE SIDE 2 FOR APPROVALS)

(3) SYS/EQUIP NO./BLDG
ED04 / 141P-MPC0313/411

(4) ASSOCIATED DOCUMENTS
030 M41691
RELATED ECO 4463
EDT
P.O.

(5) DOCUMENT NO.
DRAWING see Block ☒
SPEC #9 ☐
O&M MANUAL ☐
SDD ☐

(6) SHEET

(7) REVISION ADVANCED
FROM See TO ____
FROM Block 9 TO ____

(8) DOCUMENT TITLE
Electrical Power Feed for Building 41-Z-052 (WIND TUNNEL FACILITY)

(9) DESCRIPTION OF CHANGE

Y/N
☑ ☐ ELECTRICAL LOAD LIST (25-X-001-W)
☑ ☐ PANEL SCHEDULE (INCLUDE MARK-UP)

Revise dwg. 41-J-543-014, Rev C per attached Mark-up.
Revise dwg. 41-E-006-014, Rev C per attached Mark-up.
Revise dwg. 41-J-512-W, Rev B per attached Mark-up.
Revise dwg. 41-G-503-014, Rev C per attached Mark-up.
Revise dwg. 41-J-657-W, Rev A per attached Mark-up.

☒ YES ☐ NO
**** MODIFICATION IN PROGRESS
(ECO NOT TO BE INCORPORATED)

☒ MODIFICATION COMPLETE 3/02/92
(ECO RELEASED FOR INCORPORATION)

(10) JUSTIFICATION
To provide up-to-date information that will reflect additional changes made by 030 M41691 instructions to furnish power to Bldg #41-Z-052 (Wind tunnel work Center).

(11) ORIGINATOR (PRINT)	(12) PHONE	(13) ORGANIZATION	(14) DATE
William E. Horvath	8674	Maint E&C	9-10-90

(15) COG ENGINEER (PRINT)	(12) PHONE	(16) DRAFTING REQUIRED DATE
R. L. ALVAREZ	5168	N/A

WP FORM 1200A. REVISED 3/8/90

(Side 1)

(17) RELATED CHANGES: INDICATE THE DOCUMENTS, INSTRUCTIONS OR PROCEDURES (OTHER THAN THE DRAWINGS OR DOCUMENTS IDENTIFIED IN EITHER 5 OR 9) THAT WILL BE AFFECTED BY THE CHANGE DESCRIBED IN BLOCK 9. ENTER THE DOCUMENT NUMBER(S) IN BLOCK 18.

YES	NO	N/A		YES	NO	N/A	
☐	☐	☑	1. CONCEPTUAL DESIGN REPORT	☐	☐	☑	10. TRAINING MANUAL
☐	☐	☑	2. VENDOR DATA (WP 09-025)	☐	☐	☑	11. OPERATING PROCEDURES
☐	☑	☐	3. FSAR	☐	☐	☑	12. SPARES/MULTIPLE UNIT LISTINGS
☐	☐	☑	4. SEISMIC/STRESS ANALYSIS	☐	☐	☑	13. DO SPARES NEED MODIFIED
☐	☐	☑	5. DESIGN REPORT	☒	☐	☑	14. TEST PROCEDURES/SPECS.
☑	☐	☐	6. INTERFACE CONTROL DWGS.	☑	☐	☐	15. COMPONENT INDICES
☐	☐	☑	7. CALIBRATION PROCEDURES	☐	☐	☑	16. ASME CODED ITEMS
☐	☐	☑	8. INSTALLATION PROCEDURES	☐	☐	☑	17. HUMAN FACTOR CONSIDERATIONS
☑	☐	☐	9. MAINTAINANCE PROCEDURES	☐	☐	☑	18. COMPUTER SOFTWARE

(18) RELATED DOCUMENT NO.; INSTRUCTION NO.; IDENTIFIED IN BLOCK 17. (CHANGES TO DOCUMENTS LISTED IN BLOCK 18 WILL NOT BE INCOPRORATED BY THIS ECO).

DOCUMENT NO./REVISION	

(19) DISTRIBUTION

NAME	ORG.
W. WHITE	F.O.
J. KOWALSKI	M&FE
J. WHITE	EE
C. BANNISTER	

(20) SIGNATURE REQUIREMENTS

ECO # 4983

KEY: A=APPR. R=REVIEW

KEY		
A	COG. ENGINEER	
A	COG. ENGR. MGR.	9/10/90
R	Q.A.	
	DOE	
A	SAFETY	10/10/90
	DEPT. MGR.	
A	OPERATIONS	10/2/90
	SECURITY	
R	START UP	9-10-90

(21) DESIGN VERIFICATION REQUIREMENTS (PER WP 09-018)

JAD

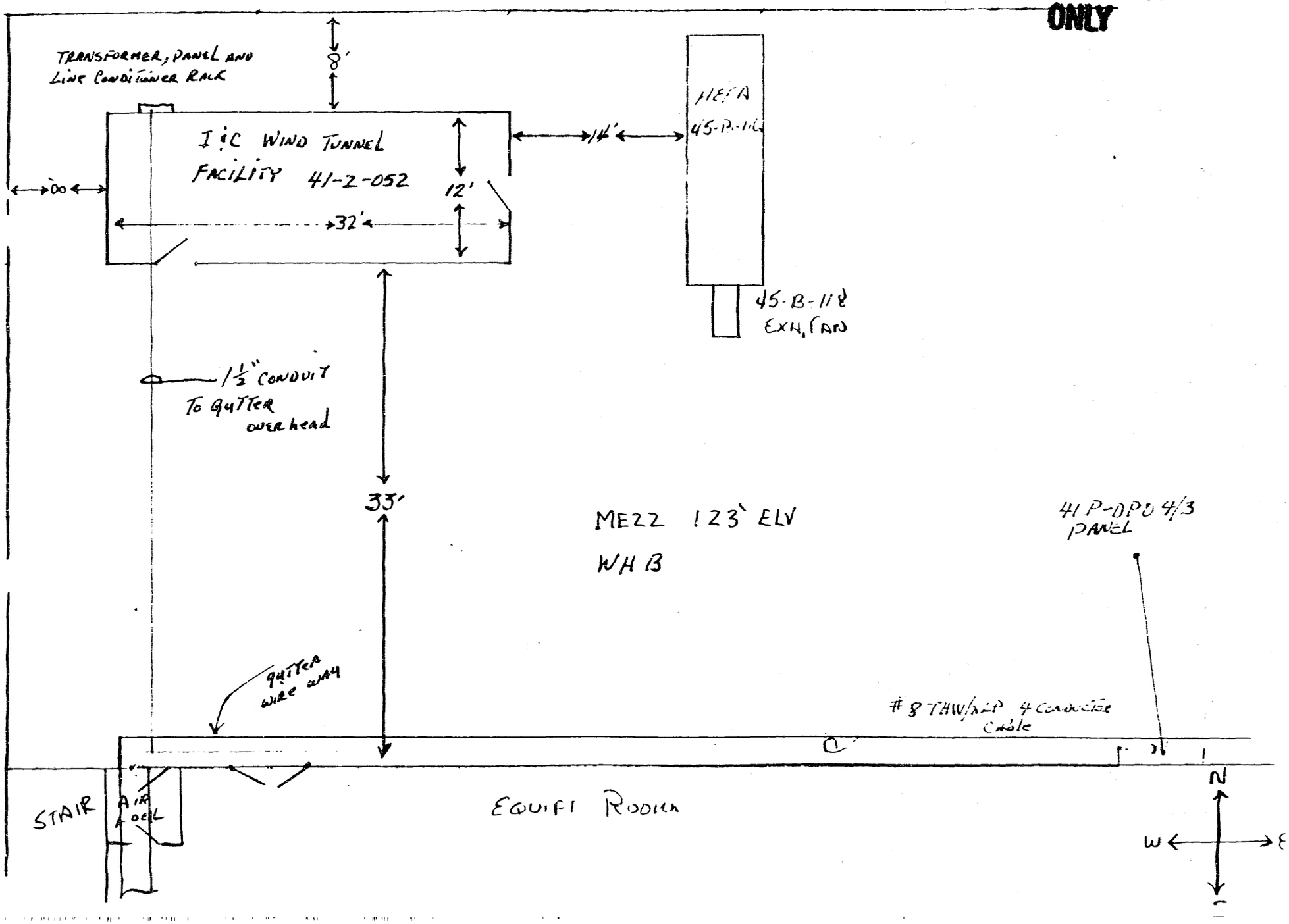
1. REQUIREMENTS SATISFIED BY REVIEW/APPROVAL OF DESIGN DOCUMENT
2. INDEPENDENT REVIEW
3. ALTERNATE CALCULATIONS
4. DEVELOPMENT TESTING
5. DESIGN REVIEW
6. OTHER _____

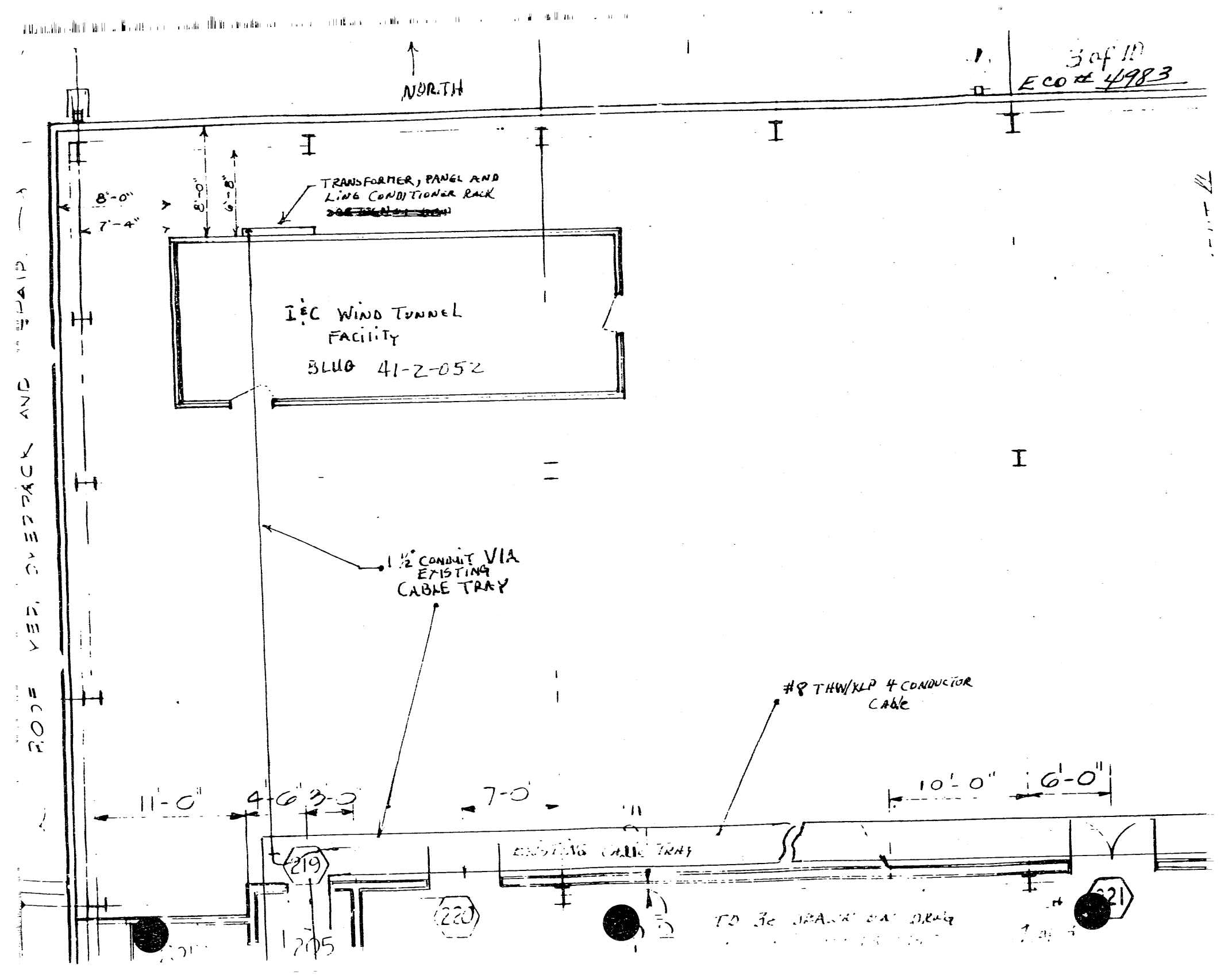
EDT# _____

(Side 2)

ECO # 4983 2 of 11

INFORMATION ONLY




3 of 11
ECO # 4983
NORTH
8'-0"
7'-4"
TRANSFORMER, PANEL AND LINE CONDITIONER RACK
I&C WIND TUNNEL FACILITY
BLDG 41-2-052
1½" CONDUIT VIA EXISTING CABLE TRAY
#8 THW/XLP 4 CONDUCTOR CABLE
11'-0"
4'-6"
3'-0"
7'-0"
10'-0"
6'-0"
EXISTING CABLE TRAY
219
220
221
1205

ECO # 4983

NORTH

41 P-DP04/3
PANEL

MECHANICAL EQ
FL. EL. 1

#8 THW/ALP 4 CONDUCTOR
CABLE

7'-0"

6'-0"

4'-6"

3'-0"

E.O.S.

8'-0"

10"

E.O.S.

220

221

223

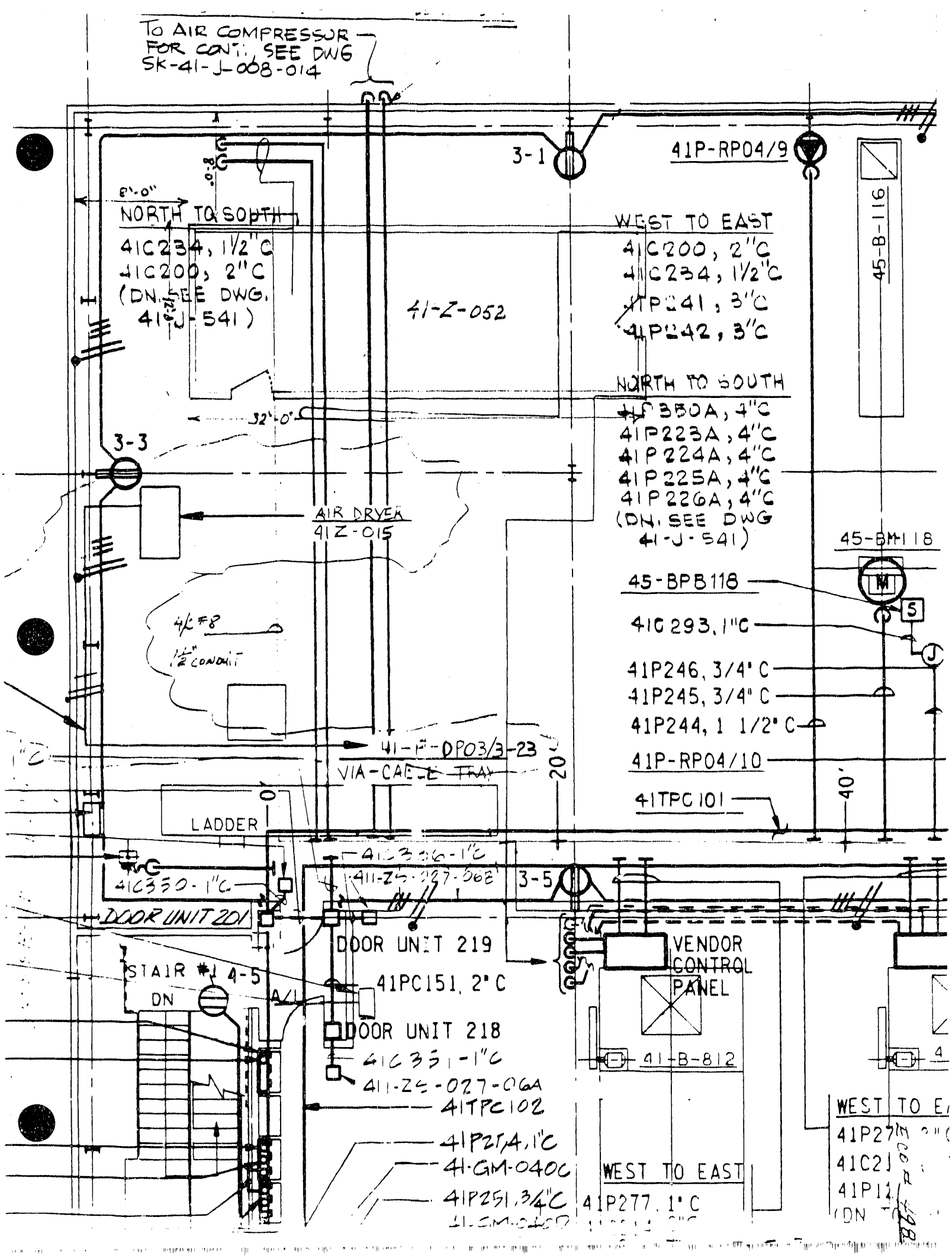
222

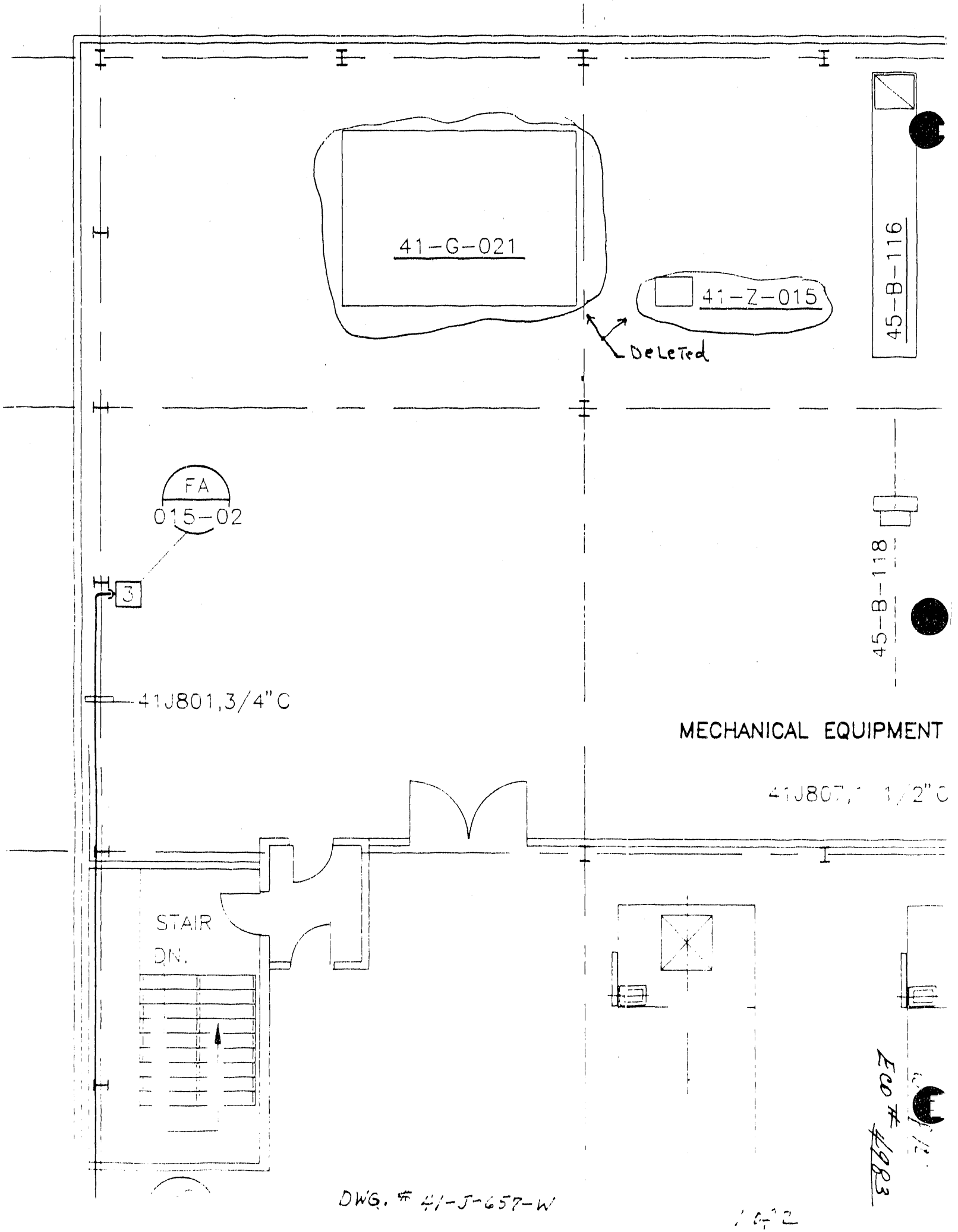
206

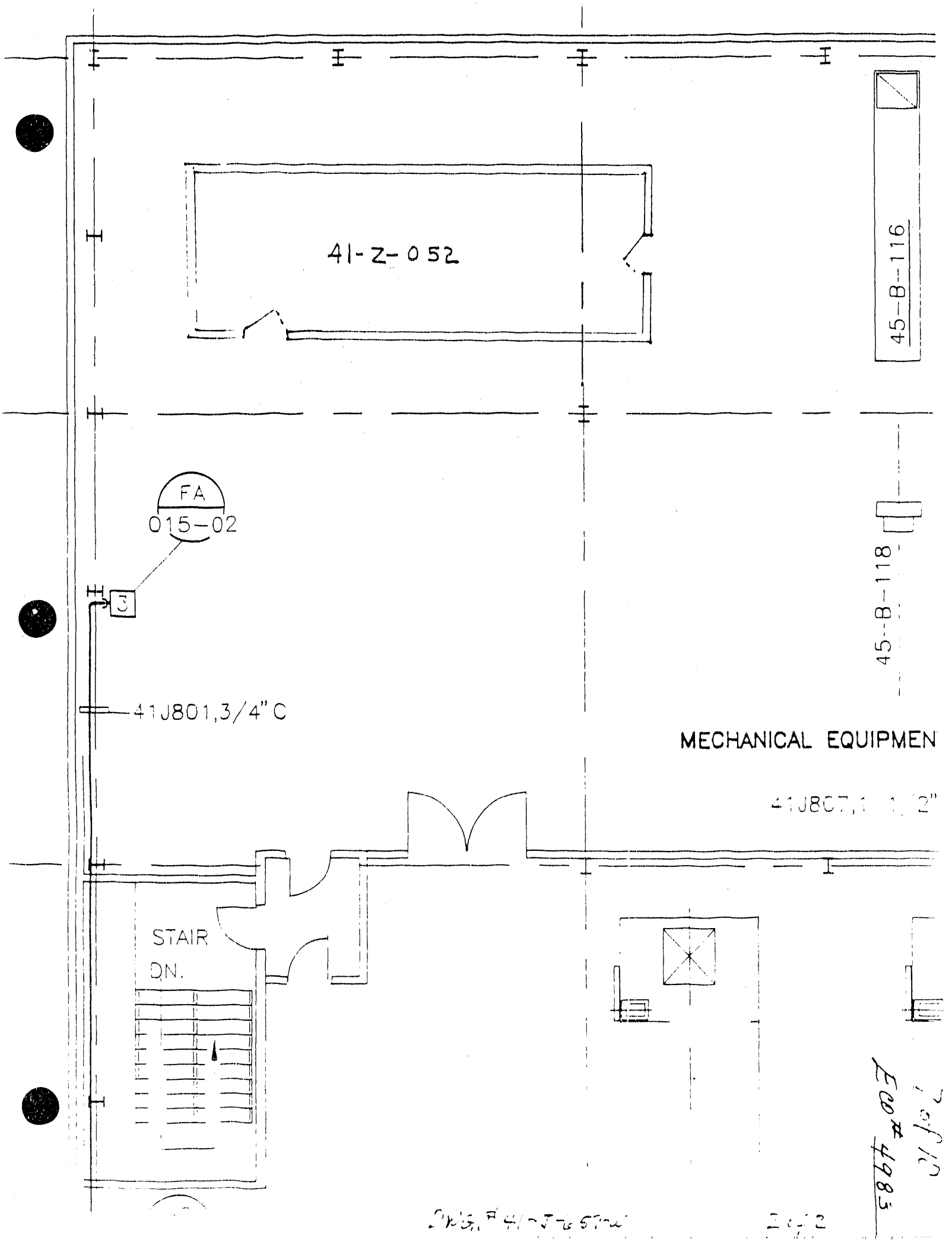
A/L

A/L

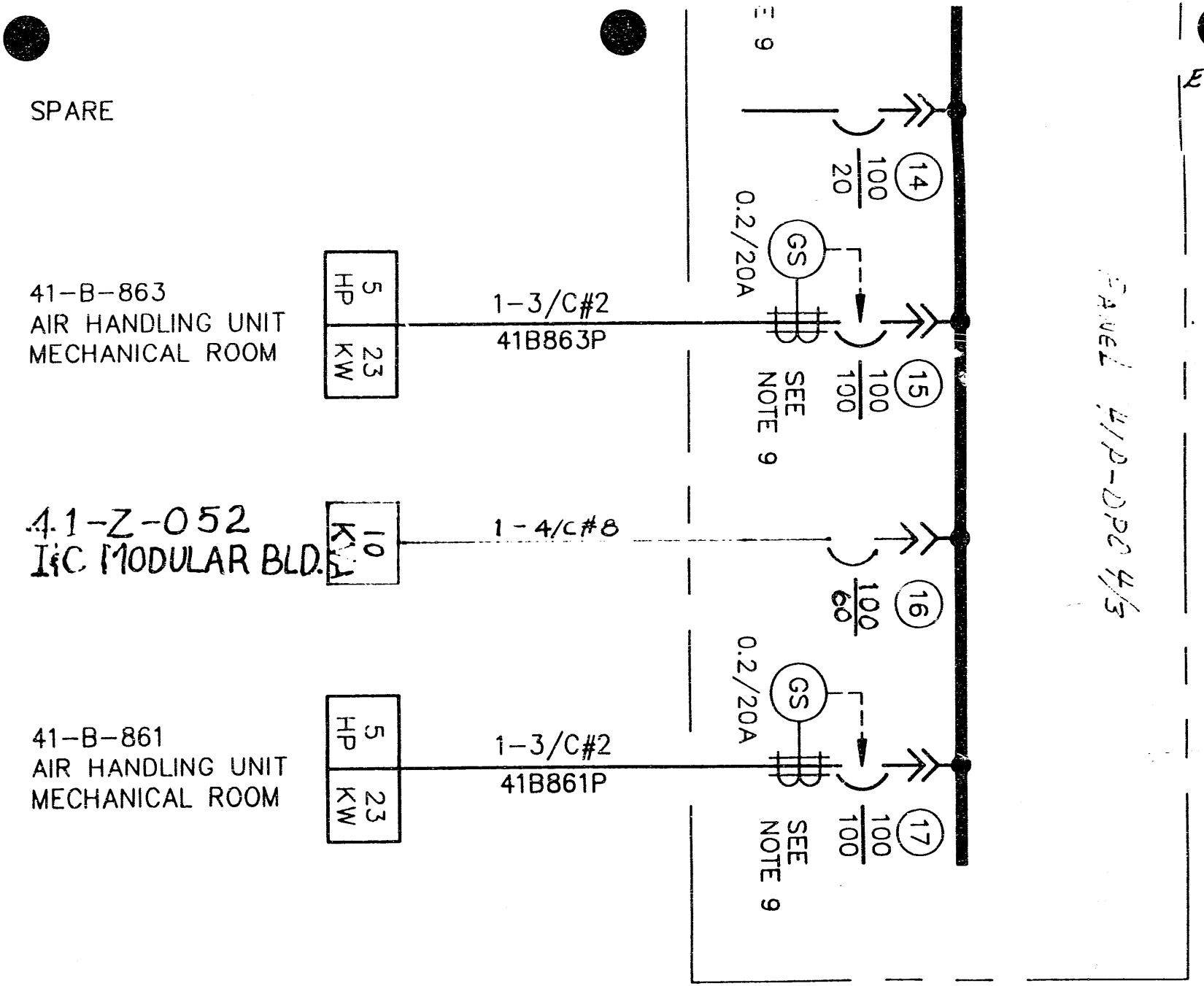
HOUR FIRE RATED
ALLS STAIR
NCLOSURE


TO AIR COMPRESSOR
FOR CONT. SEE DWG
SK-41-J-008-014
3-1
41P-RP04/9
45-B-116
8'-0"
NORTH TO SOUTH
41C234, 1 1/2" C
41C200, 2" C
(DN. SEE DWG.
41-J-541)
41-Z-052
WEST TO EAST
41C200, 2"C
41C234, 1 1/2"C
41P241, 3"C
41P242, 3"C
NORTH TO SOUTH
41P350A, 4"C
41P223A, 4"C
41P224A, 4"C
41P225A, 4"C
41P226A, 4"C
(DN. SEE DWG
41-J-541)
32'-0"
3-3
AIR DRYER
41Z-015
45-BMB118
45-BPB118
41C293, 1"C
4/C #8
1/2" CONDIT
41P246, 3/4" C
41P245, 3/4" C
41P244, 1 1/2" C
41-F-DP03/3-23
VIA CABLE TRAY
41P-RP04/10
41TPC101
20'
40'
LADDER
41C350-1"C
41C336-1"C
41-Z-027-068
3-5
DOOR UNIT 201
DOOR UNIT 219
VENDOR
CONTROL
PANEL
STAIR #1 4-5
DN
41PC151, 2" C
DOOR UNIT 218
41C351-1"C
41-Z-027-06A
41TPC102
41P271, 1"C
41-GM-040C
41P251, 3/4"C
WEST TO EAST
41P277, 1" C
41-B-812
WEST TO E
41P27
41C2
41P1
(DN


41-G-021
41-Z-015
DeLeTed
45-B-116
45-B-118
FA
015-02
3
41J801,3/4"C
MECHANICAL EQUIPMENT
41J807,1 1/2"C
STAIR
DN.
DWG. # 41-J-657-W
Eco # 4983


41-Z-052
45-B-116
FA
015-02
3
45-B-118
41J801,3/4" C
MECHANICAL EQUIPMEN
41J807,1
STAIR
DN.

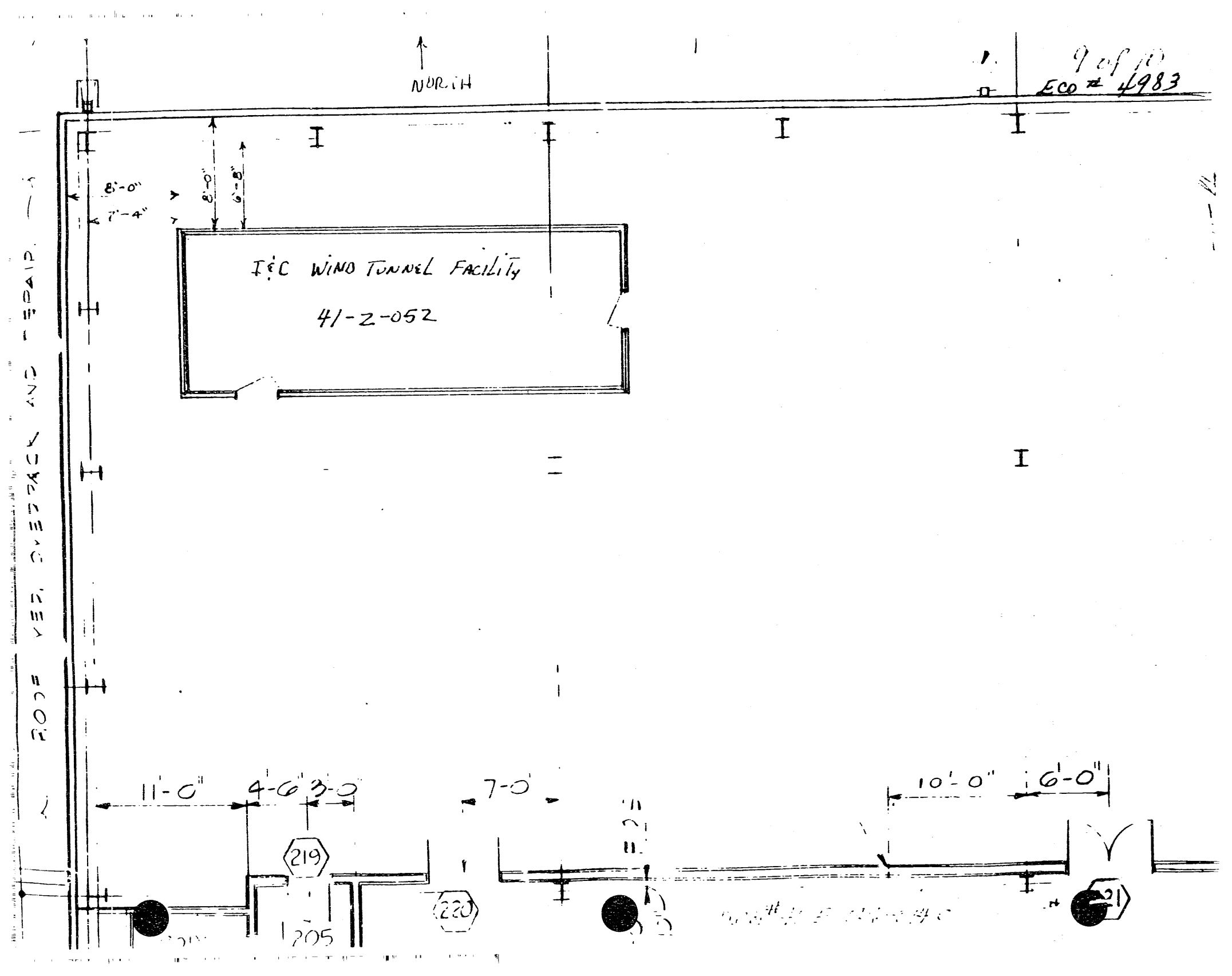
ECO # 4983

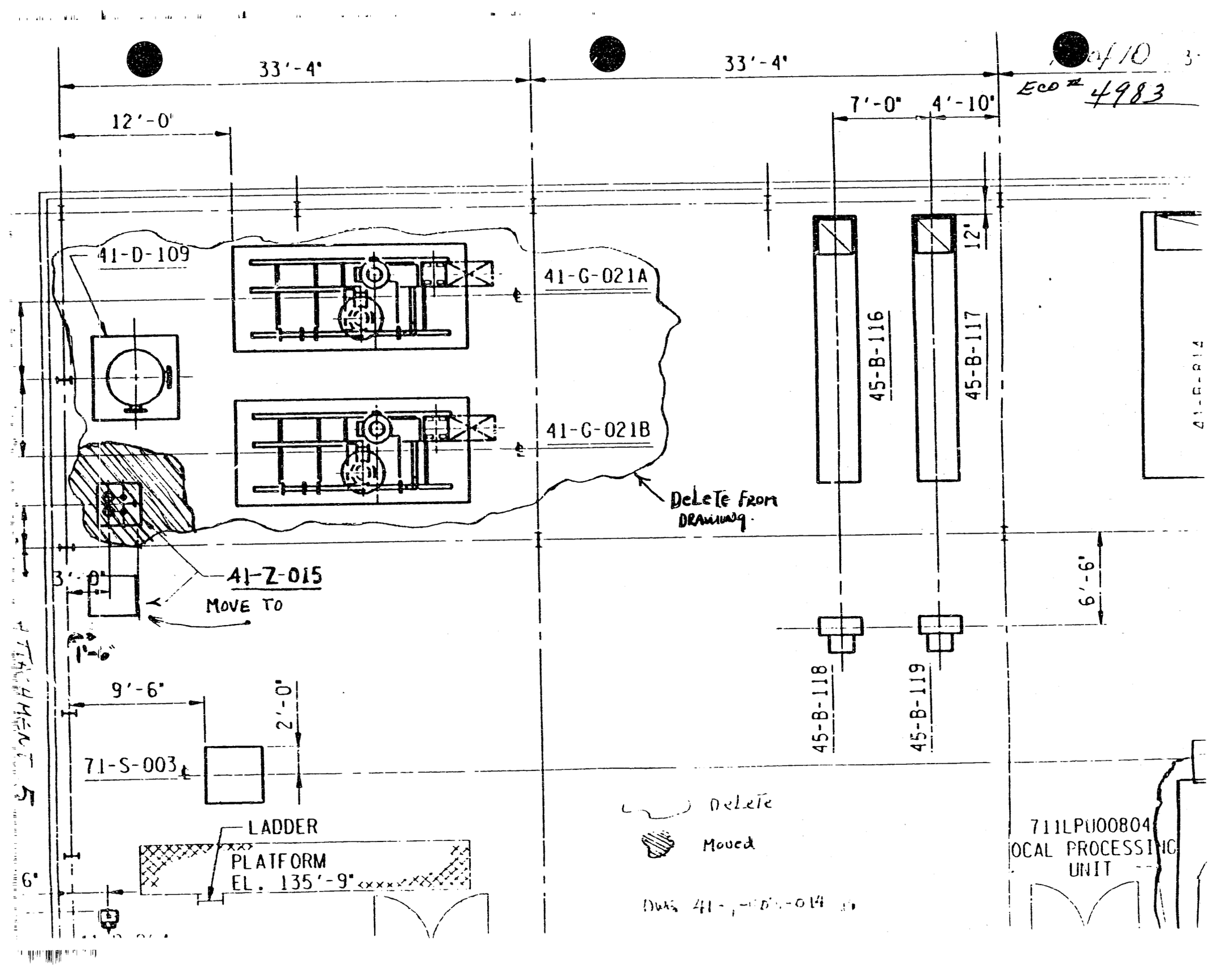


Dwg # 41-J-512-W

6" TYP

ECO # 4983


NORTH
8'-0"
7'-4"
8'-0"
6'-8"
I&C WIND TUNNEL FACILITY
41-2-052
ROOF VENT, OVERHANG AND FLEMISH
11'-0"
4'-6"
3'-0"
7'-0"
10'-0"
6'-0"
219
220
221
1205


33'-4"
33'-4"
12'-0"
7'-0"
4'-10"
ECO # 4983
41-D-109
41-G-021A
41-G-021B
45-B-116
45-B-117
12"
DeLeTe From DRAWING
41-Z-015
MOVE TO
3'-0"
6'-6"
45-B-118
45-B-119
9'-6"
2'-0"
71-S-003
LADDER
PLATFORM
EL. 135'-9"
6"
Delete
Moved
711LPU00804
OCAL PROCESSING
UNIT

ECO # 4963

EQUIPMENT NUMBER REQUEST

[✓] ADDITION [ ] DELETION

1. EQUIPMENT NUMBER 41P-MPC03/3

2. DESCRIPTION (1st 26 characters on Equipment Log)

MINI| IPIOIWIER| ICIEINITIERI | | | | | | | | |

NARRATIVE: SYSTEM: ED04

3. DRAWING NUMBER 41-J-543-014
   P&ID
   LOCATION W.H.B. ELEV. 123' MEZZANINE MECHANICAL AREA

4. MANUFACTURER SQUARE "D" COMPANY

5. MODEL NUMBER MPZ1DS4DF SERIAL NUMBER N/A

6. RELATED CCP N/A SPEC NUMBER

7. PURCHASE REQUISITION NUMBER N/A
   DATE PURCHASED
   PURCHASE COST
   CHARGE ACCT. NUMBER

8. COG MGR/ENGINEER JANE DAVIS/ALVAREZ

9. ORIGINAL SUPPLIER

10. DESIGN CLASS QUALITY CODE

11. CRITICAL EQUIPMENT/OSR ____ YES ✓ NO
    ASSOCIATED FSAR/FEIS (TECH) SPECS ____ ____ ____
    ____ ____ ____

12. SPARE PARTS IDENTIFIED ____ YES ✓ NO
    POSSIBLE SUPPLIER SQUARE "D" CO

13. LOCATION: BLDG 411 ROOM NUMBER

14. ELECTRICAL DISCONNECT OR BREAKER

15. O&M MANUAL IN FILE ROOM ____ YES ✓ NO

16. EQUIPMENT LABELED ____ YES ____ NO

REQUESTOR William E. Horvath DATE 9-10-90

ENGINEERING CHANGE ORDER

(USE BLACK INK)

(1) CC&D REVIEW [illegible]

ECO- 4998

(2) IMPACT LEVEL
☒ LEVEL-1 ☐ LEVEL-3
☐ LEVEL-2
(SEE SIDE 2 FOR APPROVALS)

(3) SYS/EQUIP NO./BLDG
UHOB/NA/311 DJ/

(4) ASSOCIATED DOCUMENTS
030 PWR 01015
RELATED ECO
EDT
P.O.

(5) DOCUMENT NO.
DRAWING ☒
SPEC ☐
O&M MANUAL ☐
SDD ☐
31-D-004-W Rev B
31-R-002-01D Rev A
31-D-003-W Rev. A

(6) SHEET

(7) REVISION ADVANCED
FROM ____ TO ____
FROM ____ TO ____

(8) DOCUMENT TITLE
WS Key Lower Tell-Tales
WS Lining and Key Section Details
WS and Key Construction Progress

(9) DESCRIPTION OF CHANGE

Y/N
☐ ☒ ELECTRICAL LOAD LIST (25-X-001-W)
☐ ☒ PANEL SCHEDULE (INCLUDE MARK-UP)

Two 4" Ø cores drilled through the liner penetrating the rock at ~~15" to 21"~~ 12.12 above and below the -834 level construction joint. Holes are to be inclined at ~~0° to~~ 10°. Holes are located at 265° (N=0°).

ok 0°-4 DJ 12.12.90

ADD DETAILS TO DWGS LISTED IN BLOCK 5.

Hole of 838.5' is id. as 834-1 DJ 12.12.91
" " -836.5' is " " 836-1
SEE ATTACHED ILLUSTRATIONS I & II

DJ ☒ YES ☒ NO

**** MODIFICATION IN PROGRESS
(ECO NOT TO BE INCORPORATED)

☑ MODIFICATION COMPLETE 12/12/90
(ECO RELEASED FOR INCORPORATION)

(10) JUSTIFICATION

Drilling cores through the liner into the formation is required to determine the nature and extent of concrete deterioration.
Drilling two 4" diameter cores at the -834' level are considered non-impactive not effecting the design integrity of the liner. See attached document from Bechtel.

(11) ORIGINATOR (PRINT)	(12) PHONE	(13) ORGANIZATION	(14) DATE
D. Galbraith	8185	ART/Mine Enginering	10/4/90

(15) COG. ENGINEER (PRINT)	(12) PHONE	(16) DRAFTING REQUIRED DATE
D. Galbraith	8185	

(17) RELATED CHANGES: INDICATE THE DOCUMENTS, INSTRUCTIONS OR PROCEDURES (OTHER THAN THE DRAWINGS OR DOCUMENTS IDENTIFIED IN EITHER 5 OR 9) THAT WILL BE AFFECTED BY THE CHANGE DESCRIBED IN BLOCK 9. ENTER THE DOCUMENT NUMBER(S) IN BLOCK 18.

YES	NO	N/A		YES	NO	N/A	
☐	☒	☒	1. CONCEPTUAL DESIGN REPORT	☐	☐	☒	10. TRAINING MANUAL
☐	☐	☒	2. VENDOR DATA (WP 09-025)	☐	☐	☒	11. OPERATING PROCEDURES
☐	☐	☒	3. FSAR	☐	☐	☒	12. SPARES/MULTIPLE UNIT LISTINGS
☐	☐	☒	4. SEISMIC/STRESS ANALYSIS	☐	☐	☒	13. DO SPARES NEED MODIFIED
☐	☐	☒	5. DESIGN REPORT	☐	☐	☒	14. TEST PROCEDURES/SPECS.
☐	☐	☒	6 INTERFACE CONTROL DWGS.	☐	☐	☒	15. COMPONENT INDICES
☐	☐	☒	7. CALIBRATION PROCEDURES	☐	☐	☒	16. ASME CODED ITEMS
☐	☐	☒	8. INSTALLATION PROCEDURES	☐	☐	☒	17. HUMAN FACTOR CONSIDERATIONS
☐	☐	☒	9. MAINTAINANCE PROCEDURES	☐	☐	☒	18. COMPUTER SOFTWARE

(18) RELATED DOCUMENT NO.; INSTRUCTION NO.; IDENTIFIED IN BLOCK 17. (CHANGES TO DOCUMENTS LISTED IN BLOCK 18 WILL NOT BE INCOPRORATED BY THIS ECO).

DOCUMENT NO./REVISION	

(19) DISTRIBUTION

NAME	ORG.

(20) SIGNATURE REQUIREMENTS

ECO # 4998

KEY
A=APPR.
R=REVIEW

A	COG. ENGINEER	L. Ballmaith 10/8/90
A	COG. ENGR. MGR.	[illegible] 10/4/90
A	Q.A.	[illegible] 10-15-90
A	DOE	[illegible] 10.15.90
A	SAFETY	C.P. Gordon 10/5/90
	DEPT. MGR.	
	OPERATIONS	
	SECURITY	
R	Start Up	[illegible] 10-13-90
A	SYS. ENGR	[illegible] 15 Oct 90

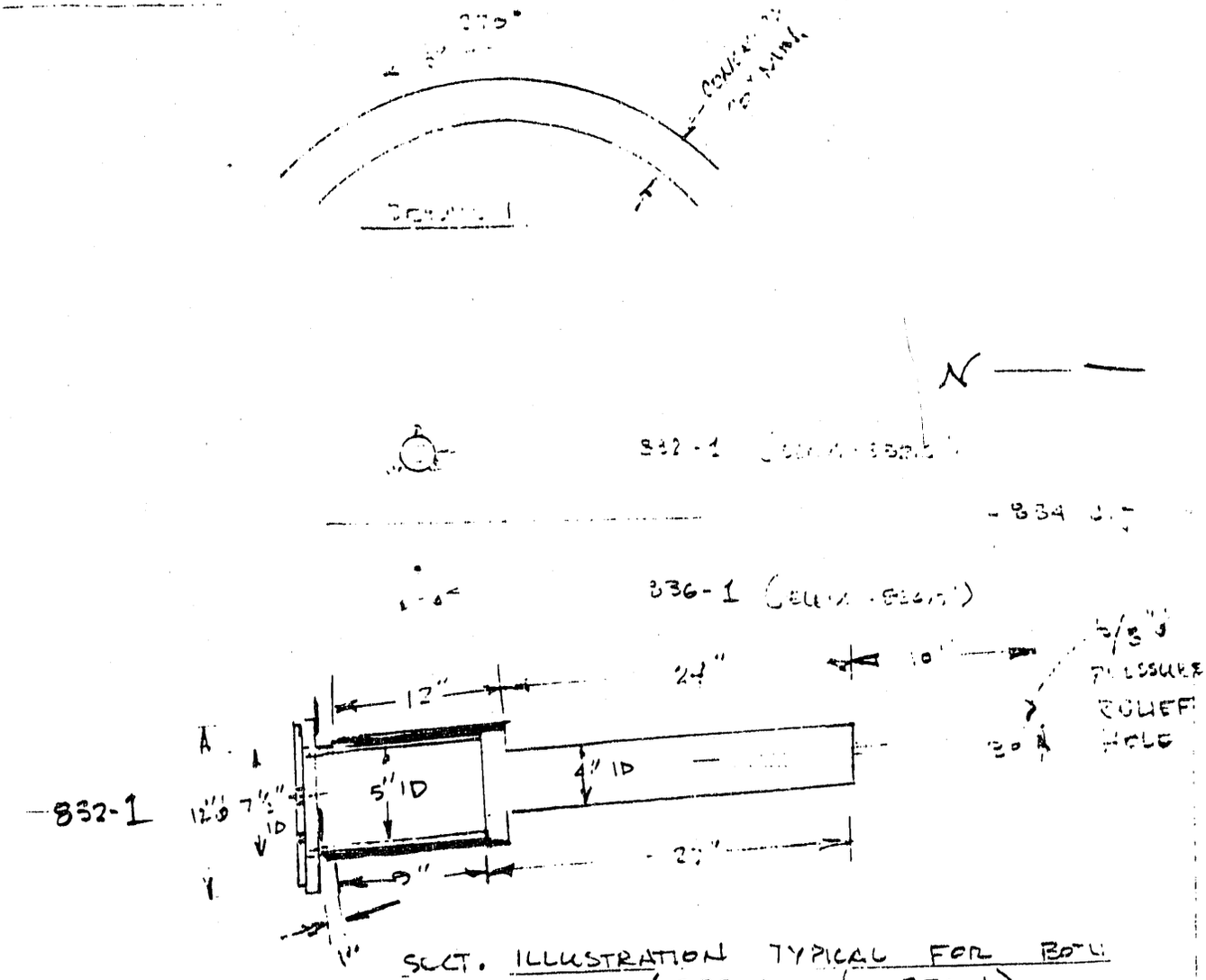
(21) DESIGN VERIFICATION REQUIREMENTS (PER WP 09-018)

1. REQUIREMENTS SATISFIED BY REVIEW/APPROVAL OF DESIGN DOCUMENT
2. INDEPENDENT REVIEW
3 ALTERNATE CALCULATIONS
4. DEVELOPMENT TESTING
5. DESIGN REVIEW
6. OTHER ~~Approved~~ Doc. from A&E

10/4

EDT# Not Required

(Side 2)

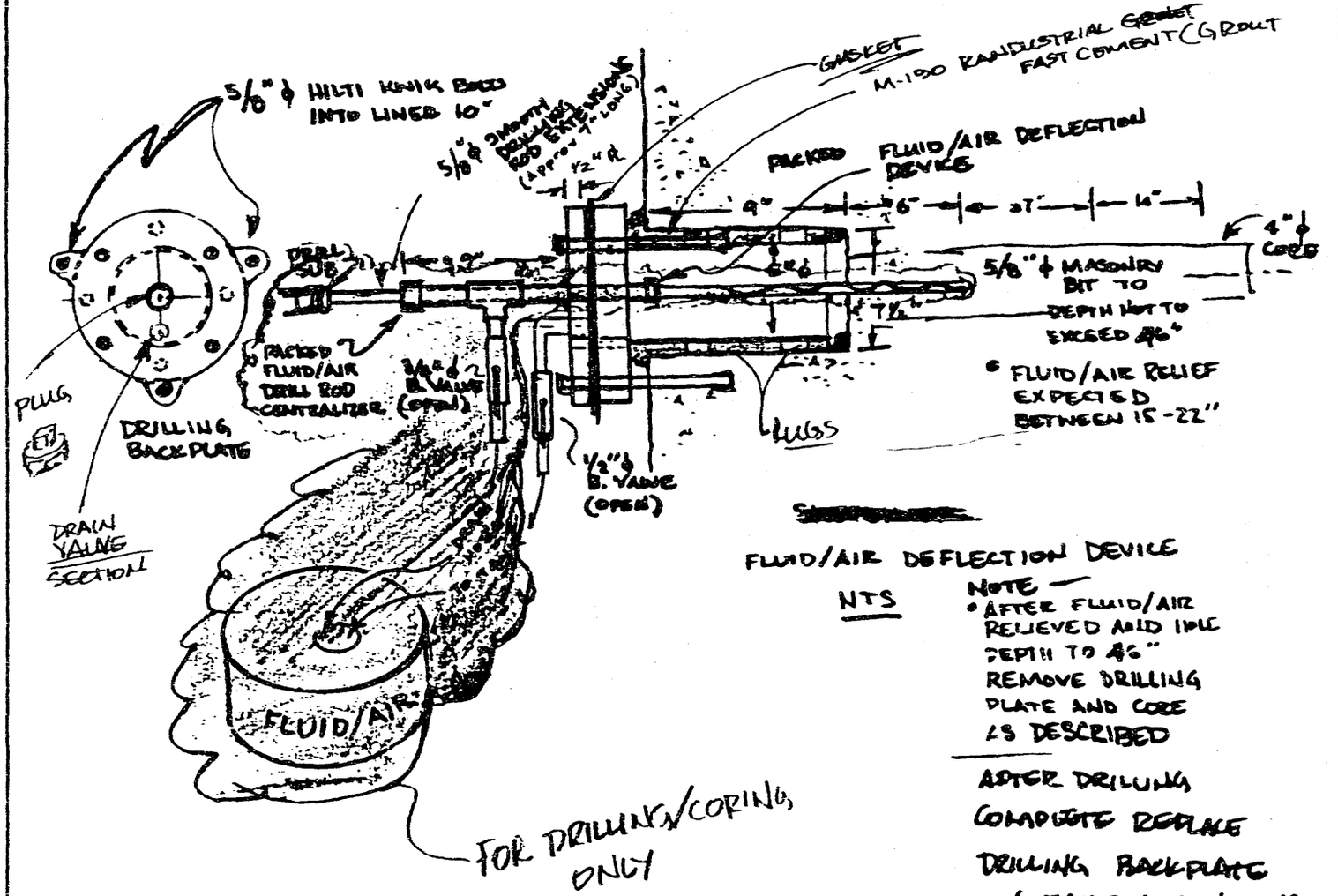


SECT. ILLUSTRATION TYPICAL FOR BOTH HOLES (832-1 and 836-1)

ILLUSTRATION 1

ILLUSTRATION II

S.O. | CALC. NO. | FILE NO. | SHEET



FLUID/AIR DEFLECTION DEVICE

NTS

NOTE —

- AFTER FLUID/AIR RELIEVED AND IDLE DEPTH TO 46" REMOVE DRILLING PLATE AND CORE AS DESCRIBED

AFTER DRILLING COMPLETE REPLACE DRILLING BACKPLATE W/ BACKPLATE HAVING VALVE TO DRAIN FLUIDS INSERT 1 1/2 - 3/4 ϕ PLUGS

* FLUID/AIR RELIEF EXPECTED BETWEEN 15 - 22"

Bechtel National, Inc.
Systems Engineers – Constructors
Fifty Beale Street
San Francisco, California
Mail Address: P.O. Box 3965, San Francisco, CA 94119

October 5, 1990

Westinghouse Electric Corp.
Waste Isolation Division
P. O. Box 2078
Carlsbad, N.M. 88221

Attention: Dick Scharinger
Sr. Procurement Specialist

Subject: Bechtel Job. No. 20585-002 WEC/WIPP Project
WEC P. O. Number 75WGM01520SG
Task 006, Waste Shaft Key Concrete

Dear Mr. Scharinger:

On Monday, October 1, 1990, I endeavored to contact Hardy Bellows to obtain a clarification and better understanding of the scope of Task 006 as outlined in your letter of intent to extend the Bechtel subcontract to December 31, 1990.

On October 1st, I didn't reach Hardy but did receive calls from Don Galbraith and Subash Sethie. Don explained that orders were issued to investigate any deterioration of the concrete in the Waste Shaft Key and determine the causes. Two cored holes were to be drilled immediately, one above and one below the construction joint at the 834 level.

I agreed that core drilling the two 3" or 4" diameter cores through the concrete and into the rock would not be detrimental to the integrity of the key or liner. The holes should have an edge distance to the construction joint of at least two hole diameters. If blowout preventors could not be readily obtained, the coring should be discontinued at least one hole diameter before reaching the concrete-rock contact and a small pilot hole drilled through the concrete and into the rock. Drillers are not to stand behind or in line with the drill and the drill should be anchored to the wall. The holes should also

be located to miss the rebar which is indicated on the design drawings to be immediately below level 834. (See Drawing 31-R-002-01D).

I also discussed the possible cause(s) of any deterioration of the concrete. From my last inspection of the concrete key earlier this year, it appeared that some of the inside surface of the concrete key had areas 1/8 to 1/4 inches deep where the cement constituent had been leached out, leaving a sand like finish. When this 1/8 to 1/4 inch surface was scrapped off, the concrete was very hard and sound. Based on several known conditions during construction, I have postulated the following events that could have caused this surface condition:

1. The waste shaft liner was cast/placed from the top down which is a conventional shaft construction procedure. This method, however, requires the next section below to be poured up against the already placed construction joint above which makes it very difficult to obtain a good tight joint.

2. The Waste Shaft Key area was excavated after the liner above was complete and was poured in lifts from the bottom up with the final lift poured up against the already poured joint at the 834 level. At this time, the poured concrete in the key was green, i.e., just poured, when the forms were stripped. The piezometric head was building up behind the liner and the brine solution was flowing through some of the joints and defects and running freely down the inside face of the concrete liner and freshly poured concrete key.

If the fresh concrete surfaces including patchwork and the joint at 834 level were not protected from the brine solution freely flowing over the surfaces, it is possible that the surface cement content could have been leached by this action.

Maybe this concept could be verified by casting a small slab of concrete and as soon as the concrete could stand by itself, say 12 to 24 hours, place it in a container having brine solution at the bottom. Then with a pump circulate the brine over the concrete specimen surface to determine if the same condition that is being observed on the key would develop on the specimen. The question here is, can enough indigenous brine be obtained to perform this experiment?

I have just received a sketch faxed from Don Galbraith, indicating the procedure planned for drilling the two 4" diameter core holes above and below the construction joint at the 834 level. I agree with the procedure indicated. It appears that the location of the rebar determined in the field is lower than that shown on the design drawing.

This investigation may extend for more than 30 days. I will cover Bechtel's estimate of the manhours for Task 006 under separate correspondence.

Very truly yours,

Howard G. Taylor
Project Manager

HGT:ld

cc: Don Galbraith

73 J 011 W

PAGE 1 OF 2

ENGINEERING CHANGE ORDER

(USE BLACK INK)

(1) CC&D REVIEW BA.

ECO- 5022.

(2) IMPACT LEVEL
☐ LEVEL-1 ☑ LEVEL-3
☐ LEVEL-2
(SEE SIDE 2 FOR APPROVALS)

(3) SYS/EQUIP NO./BLDG
PC02/NA/452
RESCUE ROOM

(4) ASSOCIATED DOCUMENTS
030 41444 M
RELATED ECO
EDT
P.O.

(5) DOCUMENT NO.
DRAWING ☑
SPEC ☐
O&M MANUAL ☐
SDD ☐
73-J-011-W
VENDOR E-2
SAFETY & EHG BLDG

(6) SHEET
1 of 73-J-011-W
27 of 28 E2

(7) REVISION ADVANCED
FROM A TO B
FROM G TO H

(8) DOCUMENT TITLE
U/G & SURFACE MINE PAGE PHONE

(9) DESCRIPTION OF CHANGE

Y/N
☐ ☐ ELECTRICAL LOAD LIST (25-X-001-W)
☐ ☐ PANEL SCHEDULE (INCLUDE MARK-UP)

73-J-011-W (U/G UHF MINE PAGING SYSTEM LAYOUT)
(ADD PHONE LOCATION - TEXT ONLY)

E-2 (CMA) 4A 10/22/90 SAFETY & EHG BLDG Sh. 27 of 28

CHANGE DRAWINGS TO CONFORM TO ATTACHED SHEETS

☑ YES ☐ NO
**** MODIFICATION IN PROGRESS
(ECO NOT TO BE INCORPORATED)

☐ MODIFICATION COMPLETE _____
(ECO RELEASED FOR INCORPORATION)

(10) JUSTIFICATION

ADD MINE TELEPHONE TO THE RESCUE MEETING ROOM FOR BETTER COMMUNICATIONS

(11) ORIGINATOR (PRINT)	(12) PHONE	(13) ORGANIZATION	(14) DATE
W.E. Briggs	8314	Elect. Eng	10/17/90

(15) COG. ENGINEER (PRINT)	(12) PHONE	(16) DRAFTING REQUIRED DATE
J.W. White	8170	when work completed

WP FORM 1200A. REVISED 3/8/90

(Side 1)

(17) RELATED CHANGES: INDICATE THE DOCUMENTS, INSTRUCTIONS OR PROCEDURES (OTHER THAN THE DRAWINGS OR DOCUMENTS IDENTIFIED IN EITHER 5 OR 9) THAT WILL BE AFFECTED BY THE CHANGE DESCRIBED IN BLOCK 9. ENTER THE DOCUMENT NUMBER(S) IN BLOCK 18.

YES	NO	N/A		YES	NO	N/A	
☐	☐	☑	1. CONCEPTUAL DESIGN REPORT	☐	☐	☑	10. TRAINING MANUAL
☐	☐	☑	2. VENDOR DATA (WP 09-025)	☐	☑	☐	11. OPERATING PROCEDURES
☐	☑	☐	3. FSAR	☑	☐	☐	12. SPARES/MULTIPLE UNIT LISTINGS
☐	☐	☑	4. SEISMIC/STRESS ANALYSIS	☑	☐	☐	13. DO SPARES NEED MODIFIED
☐	☐	☑	5. DESIGN REPORT	☐	☑	☐	14. TEST PROCEDURES/SPECS.
☐	☐	☑	6. INTERFACE CONTROL DWGS.	☑	☐	☐	15. COMPONENT INDICES
☐	☐	☑	7. CALIBRATION PROCEDURES	☐	☑	☐	16. ASME CODED ITEMS
☐	☐	☑	8. INSTALLATION PROCEDURES	☐	☑	☐	17. HUMAN FACTOR CONSIDERATIONS
☑	☐	☐	9. MAINTAINANCE PROCEDURES	☐	☐	☑	18. COMPUTER SOFTWARE

(18) RELATED DOCUMENT NO.; INSTRUCTION NO.; IDENTIFIED IN BLOCK 17. (CHANGES TO DOCUMENTS LISTED IN BLOCK 18 WILL NOT BE INCOPRORATED BY THIS ECO).

DOCUMENT NO./REVISION	
9- DOUG SCHEON	
12- WILLIE HOST	
13- WILLIE HOST	
15- RICHARD JOHNSON	

(19) DISTRIBUTION

NAME	ORG.
BILL BRIGGS	ELECT. ENG
JR STROBLE	ELECT. ENG
BILL BRIDGES	OPERATIONS

(20) SIGNATURE REQUIREMENTS

KEY
A=APPR.
R=REVIEW

ECO # 5022

A	COG. ENGINEER	10/24/90
A	COG. ENGR. MGR.	10/29/90
R	Q.A.	10/23/90
	DOE	
R	SAFETY	10/23/90
	DEPT. MGR.	
R	OPERATIONS	10/27/90
	SECURITY	
R	STARTUP	10-23-90

(21) DESIGN VERIFICATION REQUIREMENTS (PER WP 09-018)

X 1. REQUIREMENTS SATISFIED BY REVIEW/APPROVAL OF DESIGN DOCUMENT
2. INDEPENDENT REVIEW
3. ALTERNATE CALCULATIONS
4 DEVELOPMENT TESTING
5. DESIGN REVIEW
6. OTHER _____

EDT# _____

(Side 2)

SURFACE MINE PHONE LOCATIONS

SNL PHONES
- B-49- BLDG. 911F
- CAL LAB1 - BLDG. 911E
- SNL OFFICE - BLDG. 459A

AIS SHAFT
- BLDG. 362
- COLLAR - BLDG. 361

SH SHAFT > 73-J-021-W
- COLLAR - HEADFRAME 371
- 1ST LEVEL UP - HEADFRAME 371
- LAMPHOUSE BLDG. 384A
- HOISTMAN - BLDG. 384

WASTE HANDLING BUILDING - BLDG. 411 > 73-J-019-W1,W2
- CONVEYANCE LOADING ROOM - ROOM 116
- COLLAR AREA - ROOM 117
- WASTE HOIST CONTROL ROOM - ROOM 204
- 5TH FLOOR HOIST TOWER - ROOM 800
- 4TH FLOOR HOIST TOWER - ROOM 600
- 3RD FLOOR HOIST TOWER - ROOM 400

SUPPORT BUILDING - BLDG. 451 > 73-J-020-W
- SHAFTS SUPERINTENDENT - ROOM 118
- SHAFTS FOREMAN - ROOM 118
- BRASS ROOM - ROOM 119
- MINE SUPERINTENDENT - ROOM 137
- MINE FOREMAN - ROOM 137
- CMS CONTROL ROOM - ROOM 230 - 2 PHONES
- DOSIMETRY LAB - ROOM 130 (TEST LINE ONLY)
- ROOM 105 - U/G OPS
- CORRIDOR BETWEEN SUPPORT BLDG. & WASTE HANDLING BLDG.

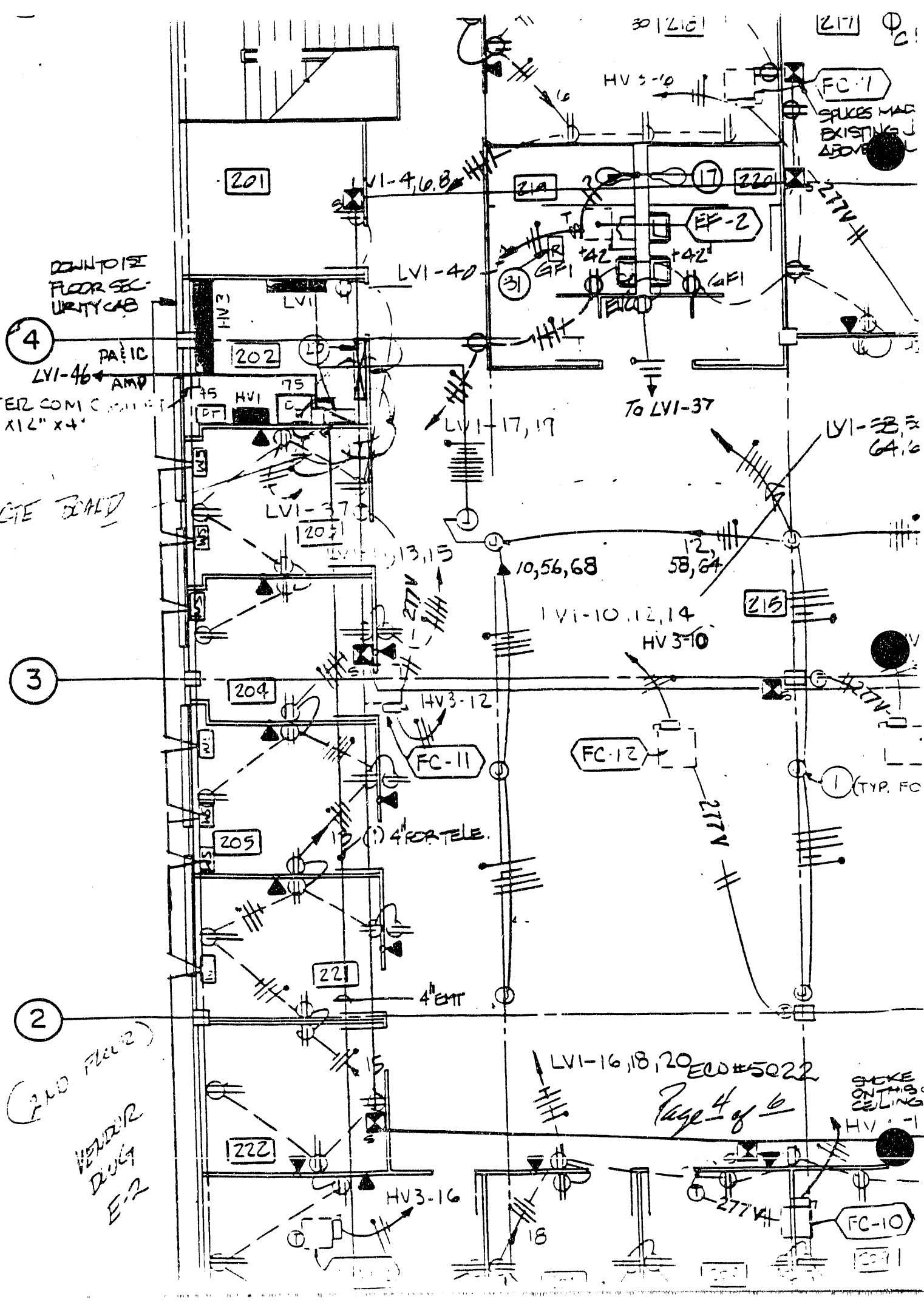
SAFETY AND EMERGENCY SERVICES - BLDG. 452
- COMMUNICATIONS ROOM - EOC
- MINE RESCUE MEETING ROOM

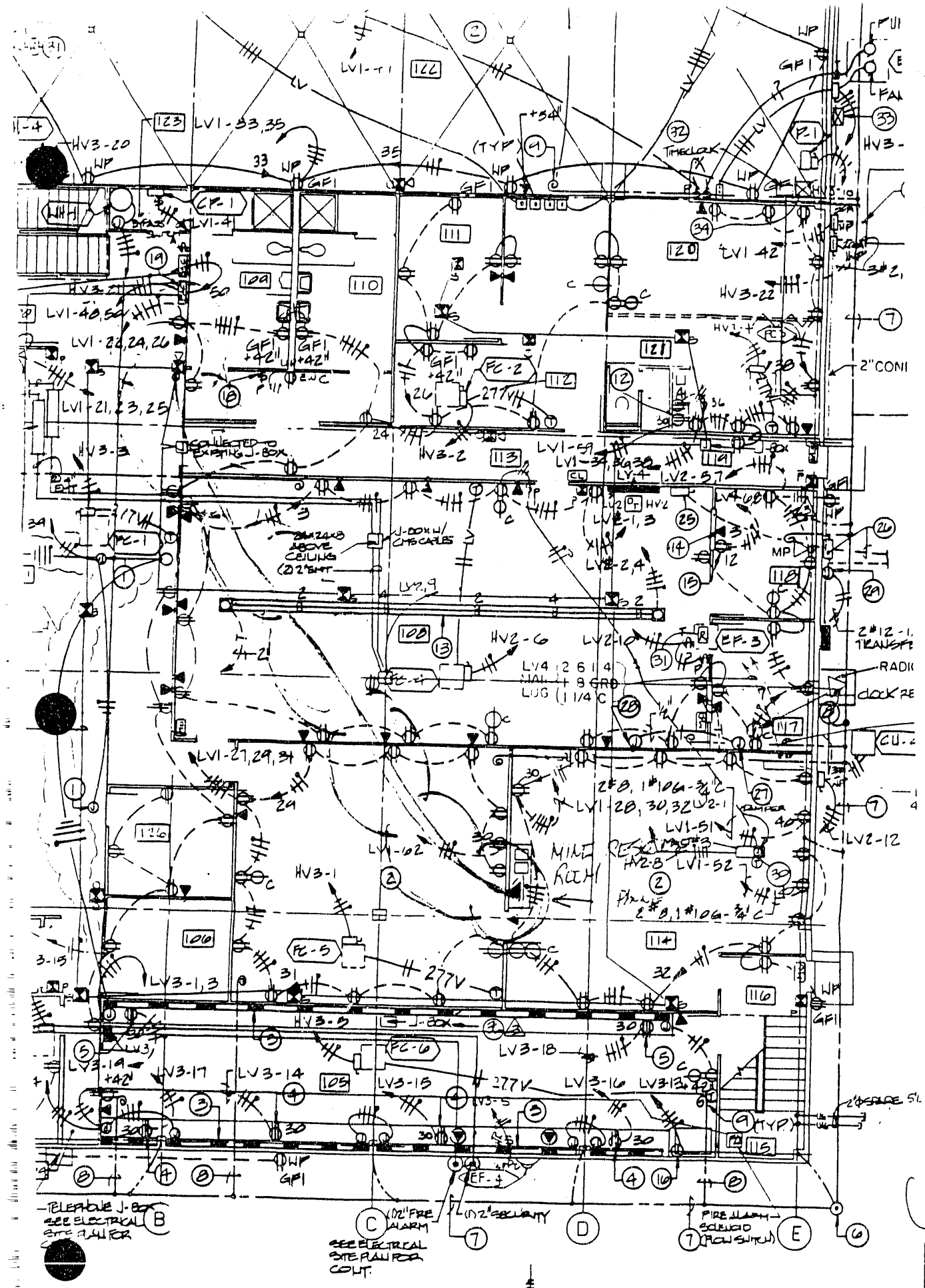
CORE STORAGE WAREHOUSE - BLDG. 459
- OFFICE

Dwg 73-J-011-W

ECO # 5022

CONSTRUCTION MGT. & MAINTENANCE COMPLEX - BLDG. 911
- EXPERIMENTAL OPS MANAGER'S OFFICE


201
202
204
205
221
222
216
217
220
215
FC-1
FC-10
FC-11
FC-12
EF-2
HV 3-10
HV3-12
HV3-16
LVI-4,6,8
LVI-40
LVI-17,19
LVI-37
LVI-10,12,14
LVI-16,18,20
ECO #5022
DOWN TO 1ST FLOOR SECURITY CAB
LVI-46
PA & IC AMP
INTERCOM
12" X 12" X 4"
4" FOR TELE.
4" EMT
277V
GFI
To LVI-37
Page 4 of 6



FLOOR POWER PLAN

1/8" = 1'-0"

ECO #5022

Page 1 of 6

ADDING

Main Substation | Circuit Breaker

Equipment # MINE PAGER PHONE
Description 1) GAI-TRONICS PAGER PHONE
Facility # 452 RESCUE ROOM
2)

Frame 1) | Trip 1) | Voltage 1) 24V
Size 2) | S.P. 2) | 2)

Feeder No & Size #18 (MP)
1)
2)
3)

Feed From Device
1) GTE PHONE DIST. PNL (2ND FLOOR)
2)
3)

Schematic/DWG.	Location Reference Drawing	Remarks
1)	1) VENDOR E-2	1)
2)	2) 73-V-011-W	2)
3)	3)	3)
	Room Number	4)

Organization Code
BLANK RECORD

Sort Number 0
Record Number 3

16:35:18 05/06/88

[F3](A)dd [F2](E)dit [F8]e(X)it [F9](Q)uit

ECO #5022
Rev 6 - 15

54 W004 W

ENGINEERING CHANGE ORDER
(USE BLACK INK)

(1) CC&D REVIEW SK BA.
ECO- 507/

(2) IMPACT LEVEL
☐ LEVEL-1 ☒ LEVEL-3
☐ LEVEL-2
(SEE SIDE 2 FOR APPROVALS)

(3) SYS/EQUIP NO./BLDG
74-B-344 ~~74W3~~ Eq.
74-B-343 VU03

(4) ASSOCIATED DOCUMENTS
030 02265 M
RELATED ECO
EDT
P.O.

(5) DOCUMENT NO.
DRAWING ☒
SPEC ☐
O&M MANUAL ☐
SDD ☐
74F-024W
54W-012-W

(6) SHEET
1

(7) REVISION ADVANCED
FROM B TO C
FROM ____ TO ____

(8) DOCUMENT TITLE
U/G Mine Plan Bulkhead Locations
U/G Equip Exp Shop Area Room #1 Area #1

(9) DESCRIPTION OF CHANGE

Y/N
☐ ☑ ELECTRICAL LOAD LIST (25-X-001-W)
☐ ☑ PANEL SCHEDULE (INCLUDE MARK-UP)

- Revise 54W-012W ~~-001-W~~ TO SHOW LOCATION OF BULKHEADS 74B-343, 74B-344 INSTALLATION. (Except 54W-0031)
- Revise 74-F-024W TO SHOW MODIFICATIONS MADE IN FIELD INSTALLATION OF BULKHEAD
- ALL MODS & LOCATION TO BE SHOWN ON AS BUILT OF 74-F-024W WHEN JOB IS COMPLETE. AND MOD IS SIGNED OFF.

☒ YES ☐ NO
**** MODIFICATION IN PROGRESS
(ECO NOT TO BE INCORPORATED)

☐ MODIFICATION COMPLETE ____
(ECO RELEASED FOR INCORPORATION)

(10) JUSTIFICATION
- Installation of preplanned bulkheads
- Asbuild to keep ventilation drawings current

(11) ORIGINATOR (PRINT)	(12) PHONE	(13) ORGANIZATION	(14) DATE
R.C. SUPKA	8189	MINE ENGINEERING	11/16/90
(15) COG. ENGINEER (PRINT)	(12) PHONE	(16) DRAFTING REQUIRED DATE	
R.C. SUPKA	8189	2/8/91	

(17) RELATED CHANGES: INDICATE THE DOCUMENTS, INSTRUCTIONS OR PROCEDURES (OTHER THAN THE DRAWINGS OR DOCUMENTS IDENTIFIED IN EITHER 5 OR 9) THAT WILL BE AFFECTED BY THE CHANGE DESCRIBED IN BLOCK 9. ENTER THE DOCUMENT NUMBER(S) IN BLOCK 18.

YES	NO	N/A		YES	NO	N/A	
☐	☐	☒	1. CONCEPTUAL DESIGN REPORT	☐	☐	☒	10. TRAINING MANUAL
☐	☐	☒	2. VENDOR DATA (WP 09-025)	☐	☐	☒	11. OPERATING PROCEDURES
☐	☐	☒	3. FSAR	☐	☐	☒	12. SPARES/MULTIPLE UNIT LISTINGS
☐	☐	☒	4. SEISMIC/STRESS ANALYSIS	☐	☐	☒	13. DO SPARES NEED MODIFIED
☐	☐	☒	5. DESIGN REPORT	☐	☐	☒	14. TEST PROCEDURES/SPECS.
☐	☐	☒	6. INTERFACE CONTROL DWGS.	☐	☐	☒	15. COMPONENT INDICES
☐	☐	☒	7. CALIBRATION PROCEDURES	☐	☐	☒	16. ASME CODED ITEMS
☐	☐	☒	8. INSTALLATION PROCEDURES	☐	☐	☒	17. HUMAN FACTOR CONSIDERATIONS
☐	☐	☒	9. MAINTAINANCE PROCEDURES	☐	☐	☒	18. COMPUTER SOFTWARE

(18) RELATED DOCUMENT NO.; INSTRUCTION NO.; DENTIFIED IN BLOCK 17. (CHANGES TO DOCUMENTS LISTED IN BLOCK 18 WILL NOT BE INCOPRORATED BY THIS ECO).

DOCUMENT NO./REVISION	

(19) DISTRIBUTION

NAME	ORG.
R.C. SUPKIS	MINE ENG
[redacted]	

(20) SIGNATURE REQUIREMENTS

KEY
A=APPR.
R=REVIEW

ECO # 5071

A	COG. ENGINEER	
A	COG. ENGR. MGR.	11/16/90
R	Q.A.	MC Ltr from, 11-16-90
	DOE	
	SAFETY	
	DEPT. MGR.	
	OPERATIONS	
	SECURITY	
R	START UP	11-16-90

(21) DESIGN VERIFICATION REQUIREMENTS (PER WP 09-018)

NA
1. REQUIREMENTS SATISFIED BY REVIEW/APPROVAL OF DESIGN DOCUMENT
2. INDEPENDENT REVIEW
3. ALTERNATE CALCULATIONS
4. DEVELOPMENT TESTING
5. DESIGN REVIEW
6. OTHER

EDT#

(Side 2)

73 J 025 W

ENGINEERING CHANGE ORDER

(USE BLACK INK)

(1) CC&D REVIEW SK

ECO- 5166

(2) IMPACT LEVEL
☐ LEVEL-1 ■ LEVEL-3
☐ LEVEL-2
(SEE SIDE 2 FOR APPROVALS)

(3) SYS/EQUIP NO./BLDG
SEE PAGE 3

(4) ASSOCIATED DOCUMENTS
030 00586M
RELATED ECO
EDT
P.O.

(5) DOCUMENT NO.
DRAWING ■
SPEC ☐
O&M MANUAL ☐
SDD ☐
SEE PAGE 4

(6) SHEET
ALL
SH. 1 OF 1

(7) REVISION ADVANCED
FROM (SEE PG 4) TO ____
FROM ____ TO ____

(8) DOCUMENT TITLE
SEE PAGE 4

(9) DESCRIPTION OF CHANGE

Y/N
☐ ■ ELECTRICAL LOAD LIST (25-X-001-W)
☐ ■ PANEL SCHEDULE (INCLUDE MARK-UP)

PLANT COMMUNICATIONS
SEE PAGE 5

☒ YES ☐ NO
**** MODIFICATION IN PROGRESS
(ECO NOT TO BE INCORPORATED)

☐ MODIFICATION COMPLETE ____
(ECO RELEASED FOR INCORPORATION)

(10) JUSTIFICATION

(1) THROUGH (7) TO ADD UNIQUE IDENTIFICATION TO VARIOUS PA & IC TERMINAL BOXES AT WIPP SITE.
(8) PROVIDED WIRING DIAGRAM FOR PRIMARY TERMINAL BOX FOR ZONE 3 PA & IC SYSTEM
(9) ENHANCED PUBLIC AND INTERCOM BLOCK DIAGRAM TO PROMOTE EASIER ACCESS TO REQUIRED REFERENCE DRAWINGS AND SPECIFIC COMPONENTS. (10) TO FACILITATE CONNECTION OF PA TO ENG. BLDG 48.

(11) ORIGINATOR (PRINT)	(12) PHONE	(13) ORGANIZATION	(14) DATE
J. RODNEY FUSTON	8660	ELECT. ENG.	01/07/91

(15) COG. ENGINEER (PRINT)	(12) PHONE	(16) DRAFTING REQUIRED DATE
J. R. STROBLE	8374	

(17) RELATED CHANGES: INDICATE THE DOCUMENTS, INSTRUCTIONS OR PROCEDURES (OTHER THAN THE DRAWINGS OR DOCUMENTS IDENTIFIED IN EITHER 5 OR 9) THAT WILL BE AFFECTED BY THE CHANGE DESCRIBED IN BLOCK 9. ENTER THE DOCUMENT NUMBER(S) IN BLOCK 18.

YES	NO	N/A		YES	NO	N/A	
☐	☑	☐	1. CONCEPTUAL DESIGN REPORT	☐	☑	☐	10. TRAINING MANUAL
☐	☑	☐	2. VENDOR DATA (WP 09-025)	☑	☐	☐	11. OPERATING PROCEDURES
☐	☑	☐	3. FSAR	☐	☑	☐	12. SPARES/MULTIPLE UNIT LISTINGS
☐	☑	☐	4. SEISMIC/STRESS ANALYSIS	☐	☑	☐	13. DO SPARES NEED MODIFIED
☐	☑	☐	5. DESIGN REPORT	☑	☐	☐	14. TEST PROCEDURES/SPECS.
☑	☐	☐	6. INTERFACE CONTROL DWGS.	☑	☐	☐	15. COMPONENT INDICES
☐	☑	☐	7. CALIBRATION PROCEDURES	☐	☑	☐	16. ASME CODED ITEMS
☐	☑	☐	8. INSTALLATION PROCEDURES	☐	☑	☐	17. HUMAN FACTOR CONSIDERATIONS
☑	☐	☐	9. MAINTAINANCE PROCEDURES	☐	☑	☐	18. COMPUTER SOFTWARE

(18) RELATED DOCUMENT NO.; INSTRUCTION NO.; IDENTIFIED IN BLOCK 17. (CHANGES TO DOCUMENTS LISTED IN BLOCK 18 WILL NOT BE INCOPRORATED BY THIS ECO).

		DOCUMENT NO./REVISION	
#6	JR STROBLE - BY THIS ECO		
#9	D SCHOEN	MAINT.	
#11	BILL WHITE	SURFACE CP	
#14	B CHIQUELIN	S/L	
#15	R. JOHNSON	CC&D	

(19) DISTRIBUTION

NAME	ORG.
JR STROBLE	ELECT ENG
D SCHOEN	MAINT
B WHITE	SURF CPS
B CHIQUELIN	S/L
R JOHNSON	CC&D

(20) SIGNATURE REQUIREMENTS

KEY
A=APPR.
R=REVIEW

ECO # 5166

A	COG. ENGINEER	J.R. Stroble	1-9-91
A	COG. ENGR. MGR	Jayne Addams	1-9-91
R	Q.A.		
	DOE		
R	SAFETY	Mel Rountree	1-17-91
	DEPT. MGR.		
R	OPERATIONS		1/17/91
	SECURITY		
R	Startup		01-15-91

(21) DESIGN VERIFICATION REQUIREMENTS (PER WP 09-018)

JD
1. REQUIREMENTS SATISFIED BY REVIEW/APPROVAL OF DESIGN DOCUMENT
2. INDEPENDENT REVIEW
3. ALTERNATE CALCULATIONS
4. DEVELOPMENT TESTING
5. DESIGN REVIEW
6. OTHER _____

EDT# _____

(Side 2)

ECO CONTINUATION SHEET	DOCUMENT NO.		ECO #
	DATE 01/07/91	PAGE 3 OF 21	5166

(3) CONTINUED

SYSTEM	EQUIPMENT NUMBER	FACILITY No.
PC03	25P-PBT/1	YARD
	38P-TBPA/1	384
	38TBPA1	384
	41P-TBPA/3	413
	41TBPA3	413
	45P-TBPA/1	451
	45P-TBPA/105	486
	45P-TBPA/107	452
	45P-TBPA/108	458
	45P-TBPA/109	453
	45P-TBPA/110	456
	45P-PBPA/111	451
	45TBPA1	451
	45TBPA105	486
	45TBPA107	452
	45TBPA108	458
	45TBPA109	453
	45TBPA110	456

ECO CONTINUATION SHEET	DOCUMENT NO.		ECO #
	DATE 01/07/91	PAGE 4 OF 21	5164

(5) DWG. NO.	(7) FROM/TO		(8) DOCUMENT TITLE
73-J-005-W SH. 1 OF 1	B		SAFETY AND EMERGENCY BLDG PA & IC SYSTEM GROUND AND 2ND FLOOR PLAN
73-J-014-W SH. 1 OF 1	B		SURFACE LAYOUT PLANT COMMUNICATIONS
73-J-015-W SH. 1 OF 1	B		GUARDHOUSE & SECURITY BLDG 458 PLANT COMMUNICATIONS
73-J-016-W SH. 1 OF 1	B		WATER PUMPHOUSE BLDG 456 PLANT COMMUNICATIONS
73-J-017-W SH. 1 OF 1	C		PLANT COMMUNICATIONS EXHAUST FILTER BUILDING 413
73-J-020-W SH. 1 OF 1	A		SUPPORT BLDG 451 PLANT COMMUNICATIONS
73-J-022-W SH. 1 OF 1	B		WAREHOUSE/SHOPS BLDG 453 PLANT COMMUNICATIONS
73-J-025-W SH. 1 OF 1	B		PUBLIC ADDRESS & INTERCOM BLOCK DIAGRAM & MASTER CONTROL CONSOLE WIRING DIAGRAM 73-P-006

ECO CONTINUATION SHEET	DOCUMENT NO.		ECO #
	DATE 01/07/91	PAGE 5 OF 21	5166

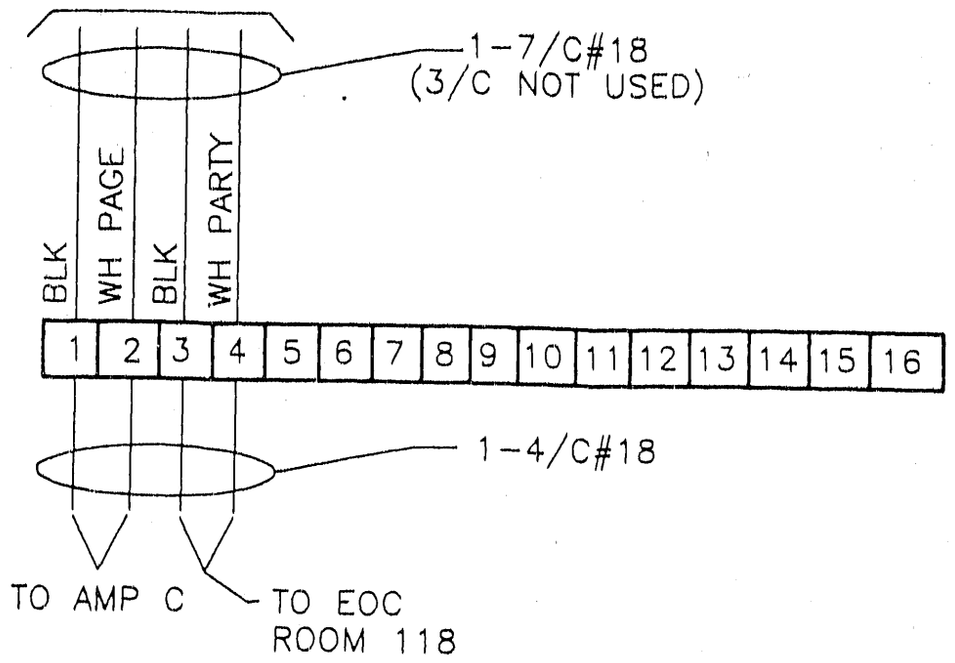
(9) CONTINUED FROM PAGE 1

1. Add unique identification to PA & IC terminal box(es) to drawing 73-J-005-W. See page(s) 6, 7.
2. Add unique identification to PA & IC terminal box(es) to drawing 73-J-014-W. See page(s) 8, 9.
3. Add unique identification to PA & IC terminal box(es) to drawing 73-J-015-W. See page(s) 10.
4. Add unique identification to PA & IC terminal box(es) to drawing 73-J-016-W. See page(s) 11.
5. Add unique identification to PA & IC terminal box(es) to drawing 73-J-017-W. See page(s) 12.
6. Add unique identification to PA & IC terminal box(es) to drawing 73-J-020-W. See page(s) 13, 14.
7. Add unique identification to PA & IC terminal box(es) to drawing 73-J-022-W. See page(s) 15, 16.
8. Provide wiring diagram for PA & IC terminal box 45P-TBPA/1 in Support Building 451 to drawing 73-J-020-W. See page 17.
9. Revise public address and intercom block diagram to indicate the addition of Engineering Building 486 and unique identification of various PA & IC terminal boxes to drawing 73-J-025-W. See page 18.
10. Revise public address conduit layout in Support Building 451 to drawing 73-J-020-W. See page(s) 19, 20, 21.

GROUND FLOOR

SCALE 1/8" = 1'-

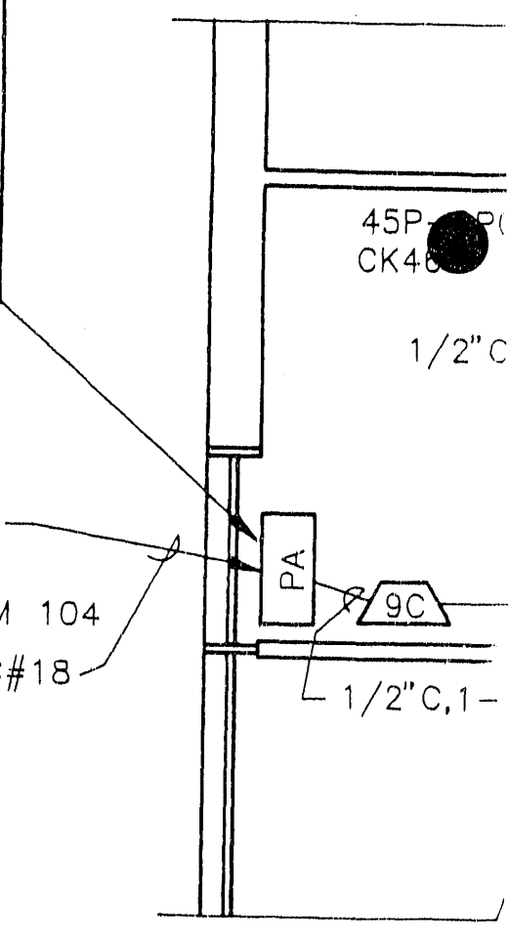
FROM SUPPORT BLDG. 451
ZONE 3 45P-TBPA/1



ADD

45P-TBPA/107

PA & IC TERMINAL BOX



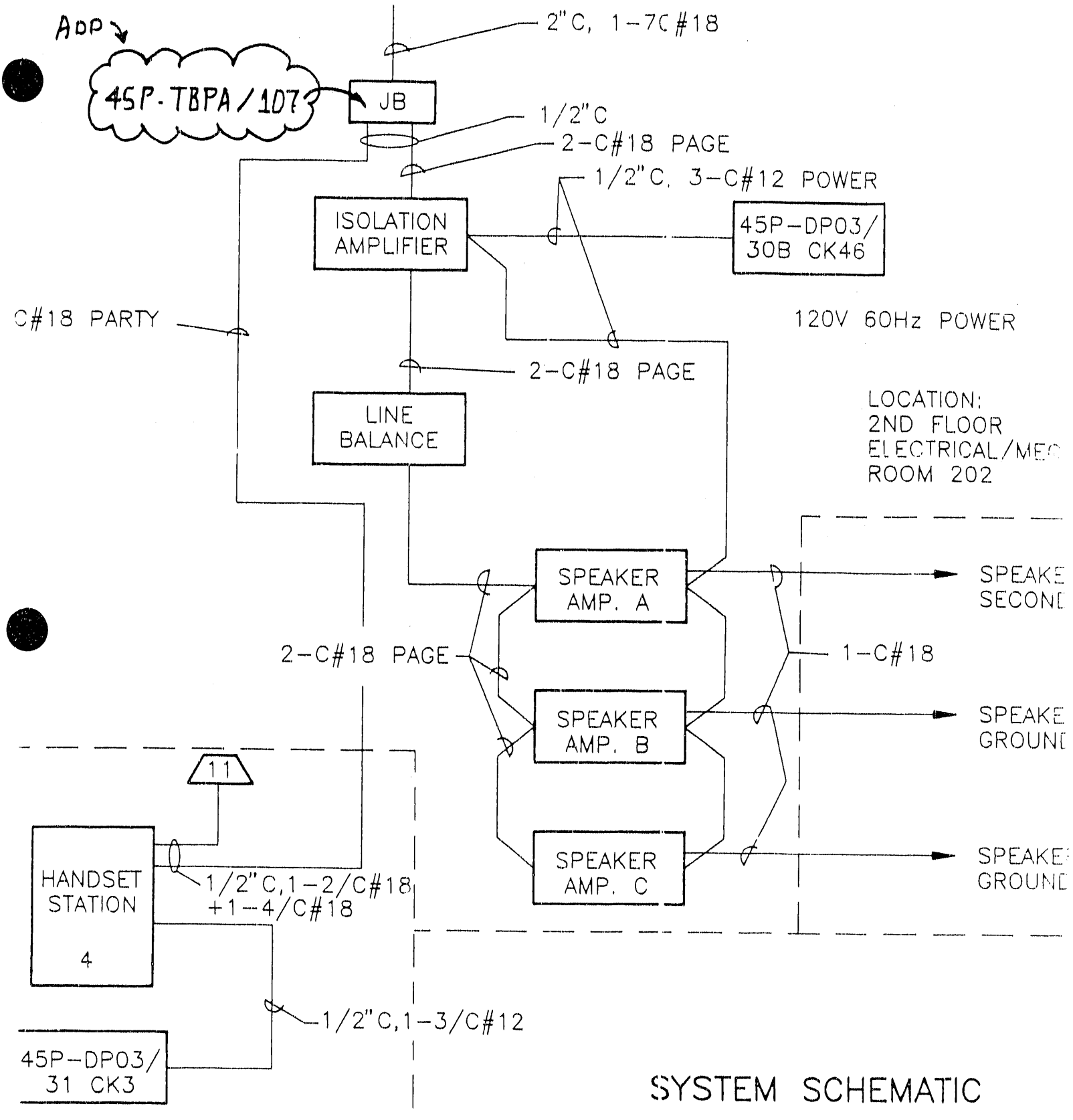
DET

ELECTRICAL/

ROOM

DRAWING NO. 73-J-005-W REV. B ECO# 5166 PAGE 6 OF 21

TO SUPPORT BUILDING PANEL 45P-TBPA/1

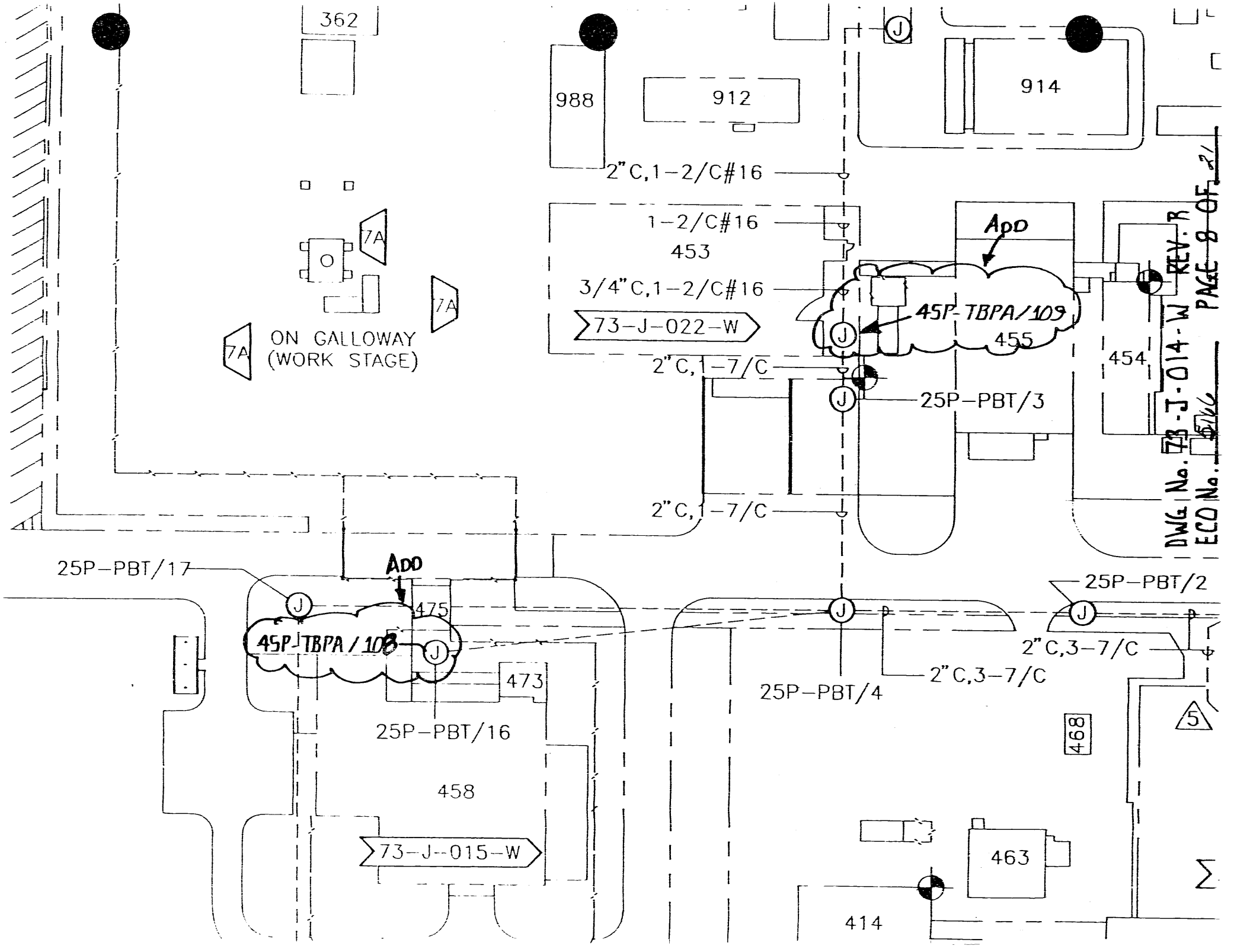


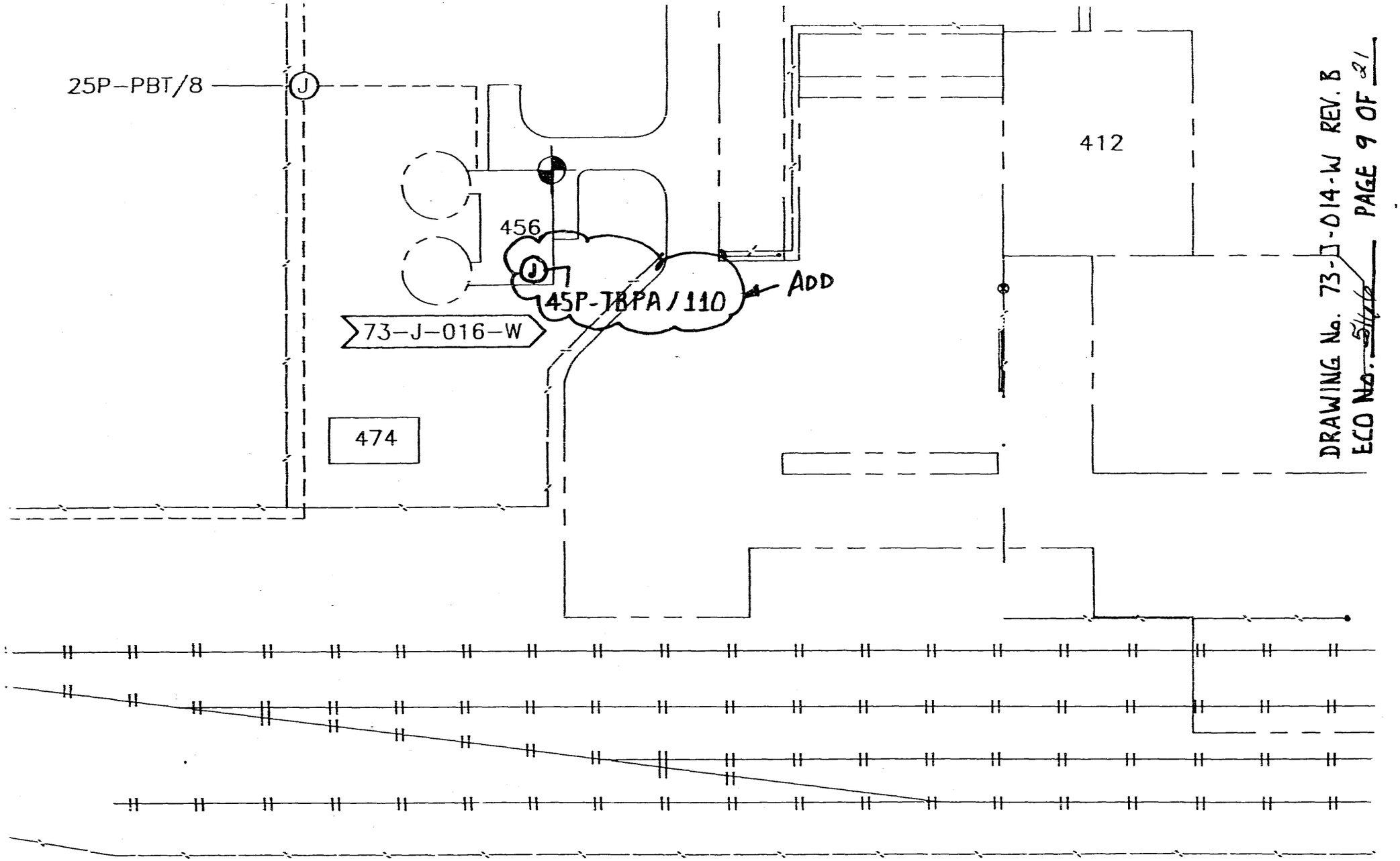
SYSTEM SCHEMATIC

NTS

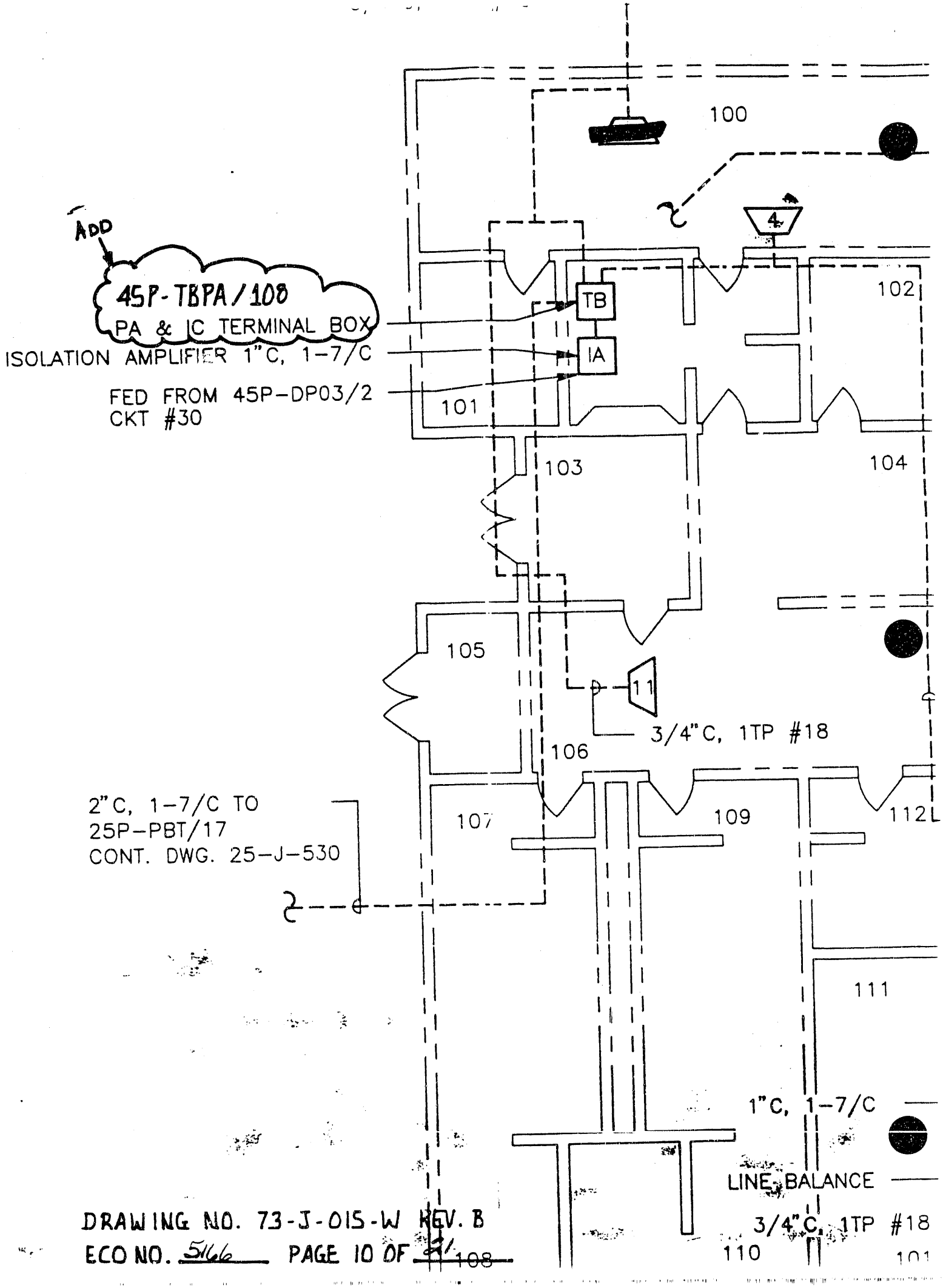
DWG. No. 73-J-005-W Rev. B

ECO # 5616 PAGE 7 OF 21

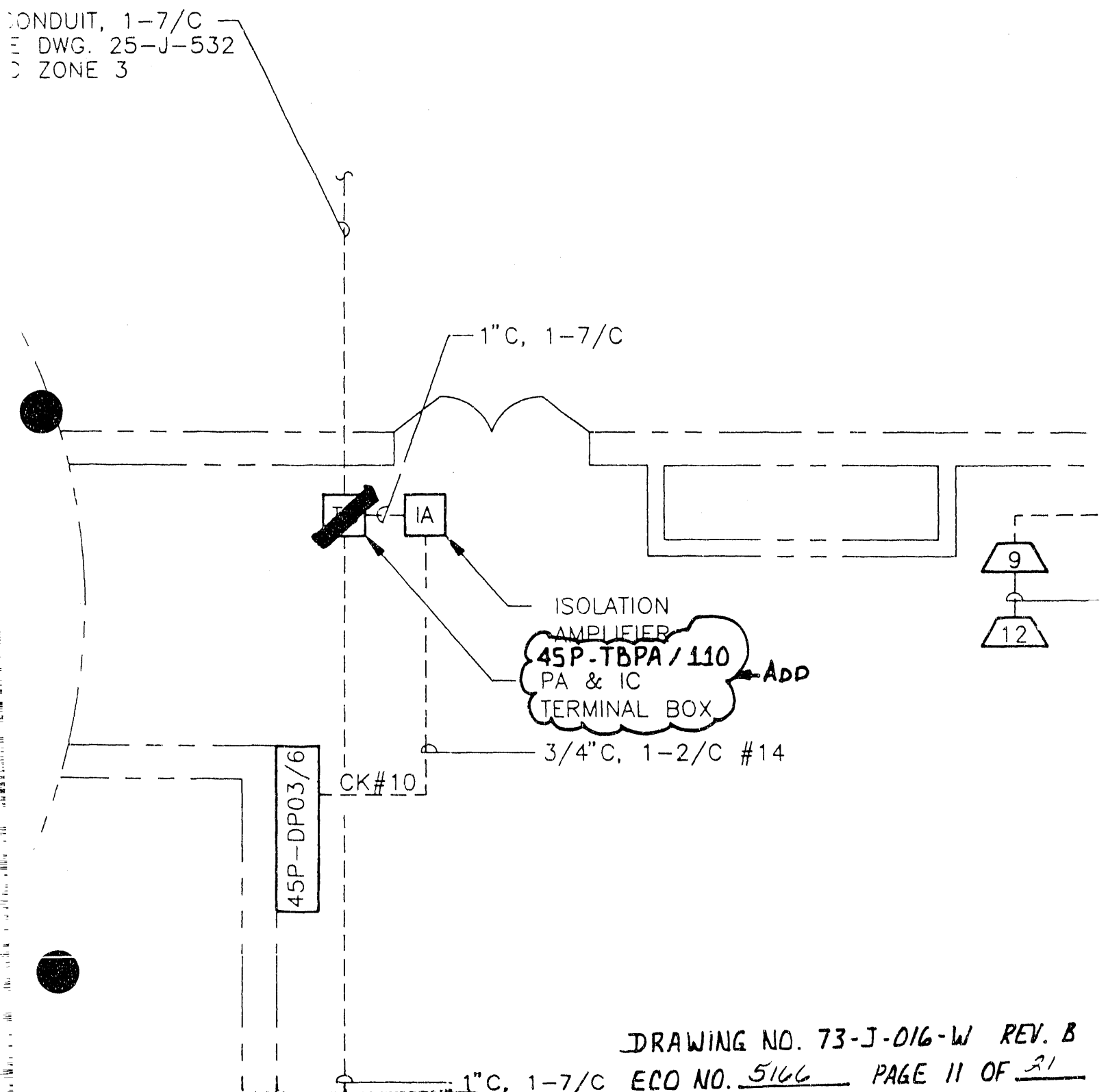

362
988
912
914
2"C,1-2/C#16
1-2/C#16
453
3/4"C,1-2/C#16
73-J-022-W
ADD
45P-TBPA/109
455
454
2"C,1-7/C
25P-PBT/3
7A
O
ON GALLOWAY
(WORK STAGE)
DWG No. 73-J-014-W REV. R
ECO No. 5746
PAGE 8 OF 21
25P-PBT/17
ADD
475
45P-TBPA/108
473
25P-PBT/16
458
73-J-015-W
25P-PBT/2
2"C,3-7/C
2"C,3-7/C
25P-PBT/4
468
5
463
414



DRAWING No. 73-J-014-W REV. B
ECO No. 5476 PAGE 9 OF 21

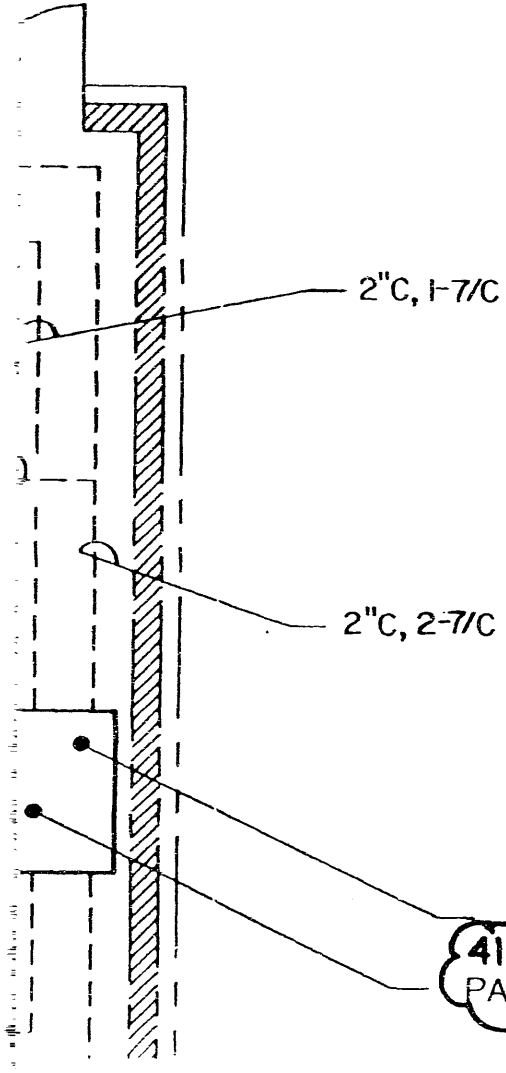


DRAWING NO. 73-J-015-W REV. B
ECO NO. 5166 PAGE 10 OF ~~21~~ 108



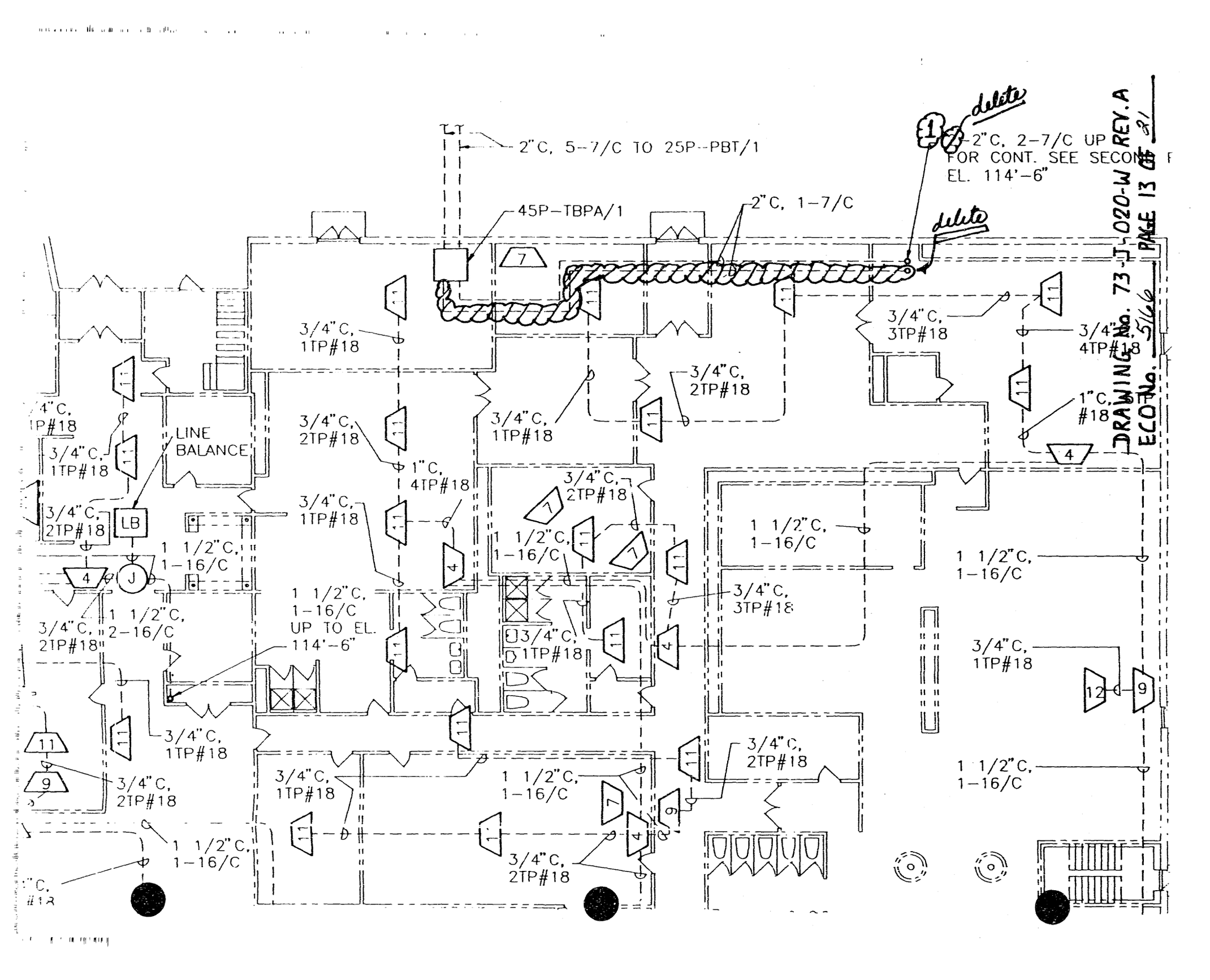
DRAWING NO. 73-J-016-W REV. B
ECO NO. 5166 PAGE 11 OF 21

DRAWING No. 73-J-017-W Rev. (
ECO No. Sheet PAGE ID OF



POWER SUPPLY FROM 41P-DP-03/29 CKT-9

41P-TBPA/3
PA & IC TERMINAL BOX ADD


2"C, 5-7/C TO 25P--PBT/1
45P-TBPA/1
2"C, 1-7/C
delete
2"C, 2-7/C UP
FOR CONT. SEE SECOND F
EL. 114'-6"
delete
DRAWING No. 73-J-020-W REV. A
ECO No. 5166 PAGE 13 OF 21
3/4"C, 1TP#18
3/4"C, 2TP#18
3/4"C, 1TP#18
3/4"C, 3TP#18
3/4"C, 4TP#18
3/4"C, 2TP#18
1"C, #18
LINE BALANCE
LB
3/4"C, 1TP#18
3/4"C, 2TP#18
1"C, 4TP#18
3/4"C, 1TP#18
3/4"C, 2TP#18
1 1/2"C, 1-16/C
1 1/2"C, 1-16/C
1 1/2"C, 1-16/C
1 1/2"C, 1-16/C
3/4"C, 3TP#18
3/4"C, 2TP#18
1 1/2"C, 2-16/C
1 1/2"C, 1-16/C UP TO EL. 114'-6"
3/4"C, 1TP#18
3/4"C, 1TP#18
3/4"C, 1TP#18
3/4"C, 2TP#18
3/4"C, 2TP#18
1 1/2"C, 1-16/C
1 1/2"C, 1-16/C
1 1/2"C, 1-16/C
3/4"C, 2TP#18
#18

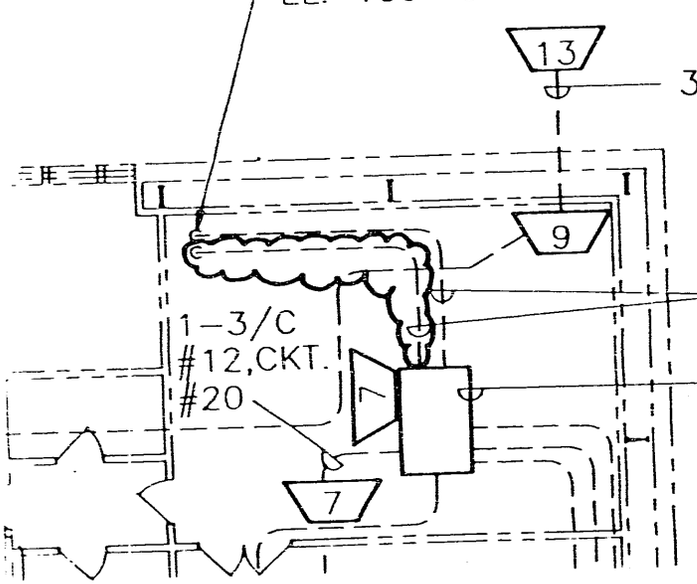
4

3

DRAWING NO. 73-J-040-W REV. A 21
ECO No. 5166 PAGE 14 OF 23 8/29/1074

delete

1 2"C, 2-7/C DOWN.
FOR CONT. SEE FIRST FLOOR THIS PRINT
EL. 100'-0"

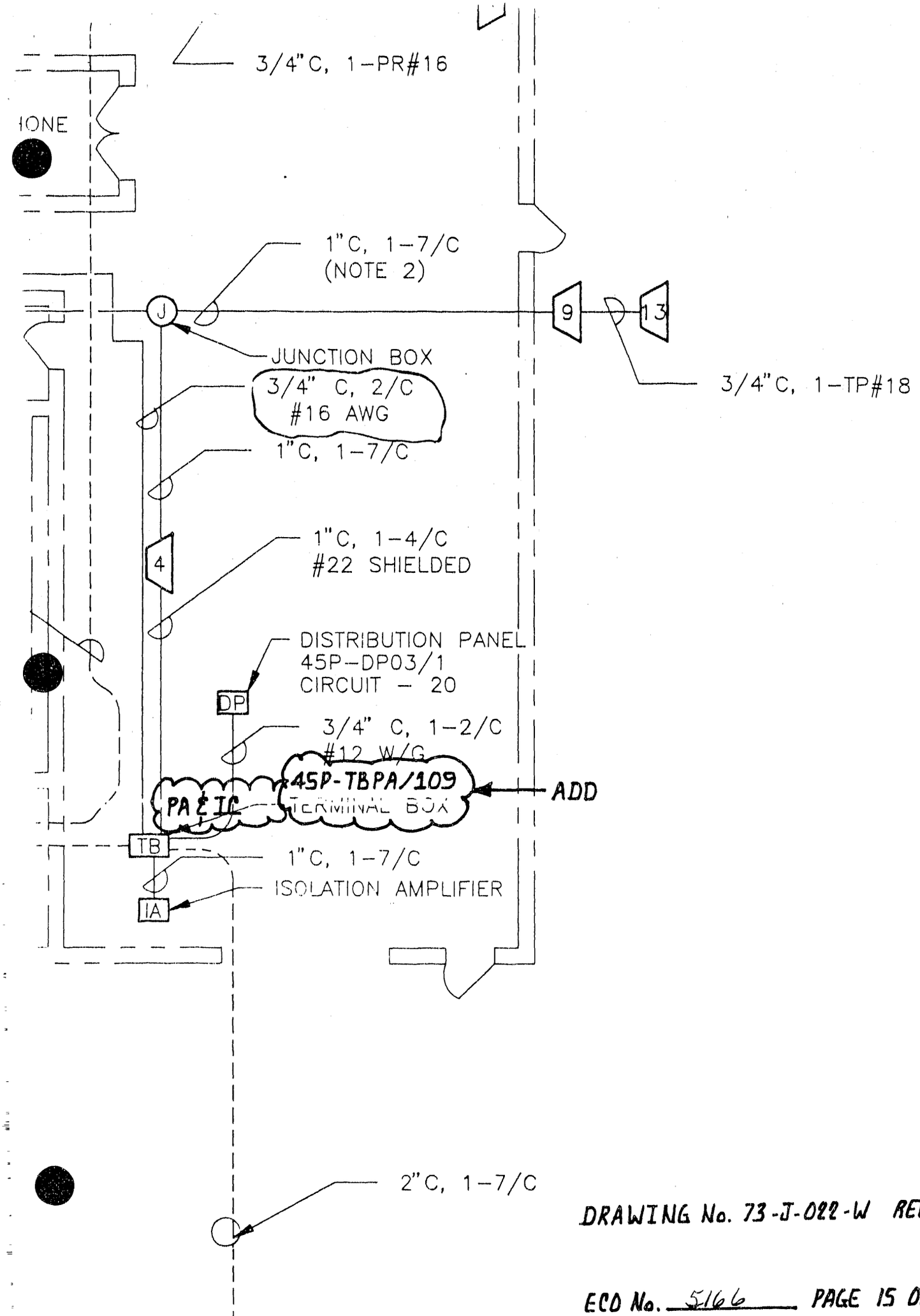


3/4"C, ITP#18 (TYP)

2"C, 1-7/C

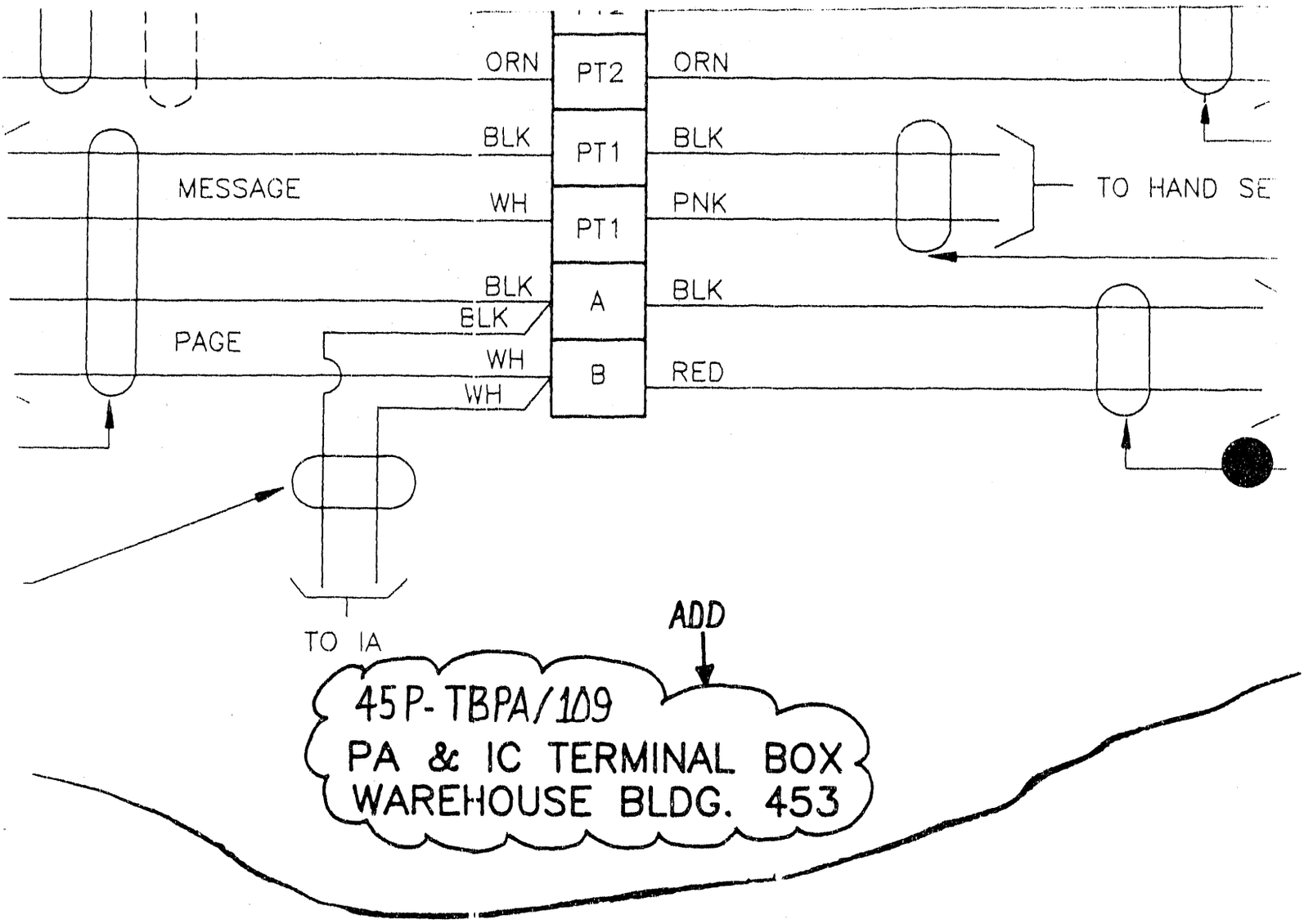
1-3/C
#12,CKT.
#20

MASTER PAGING STATION
PUBLIC ADDRESS CONSOLE 73-P-006
(NOTE 2)



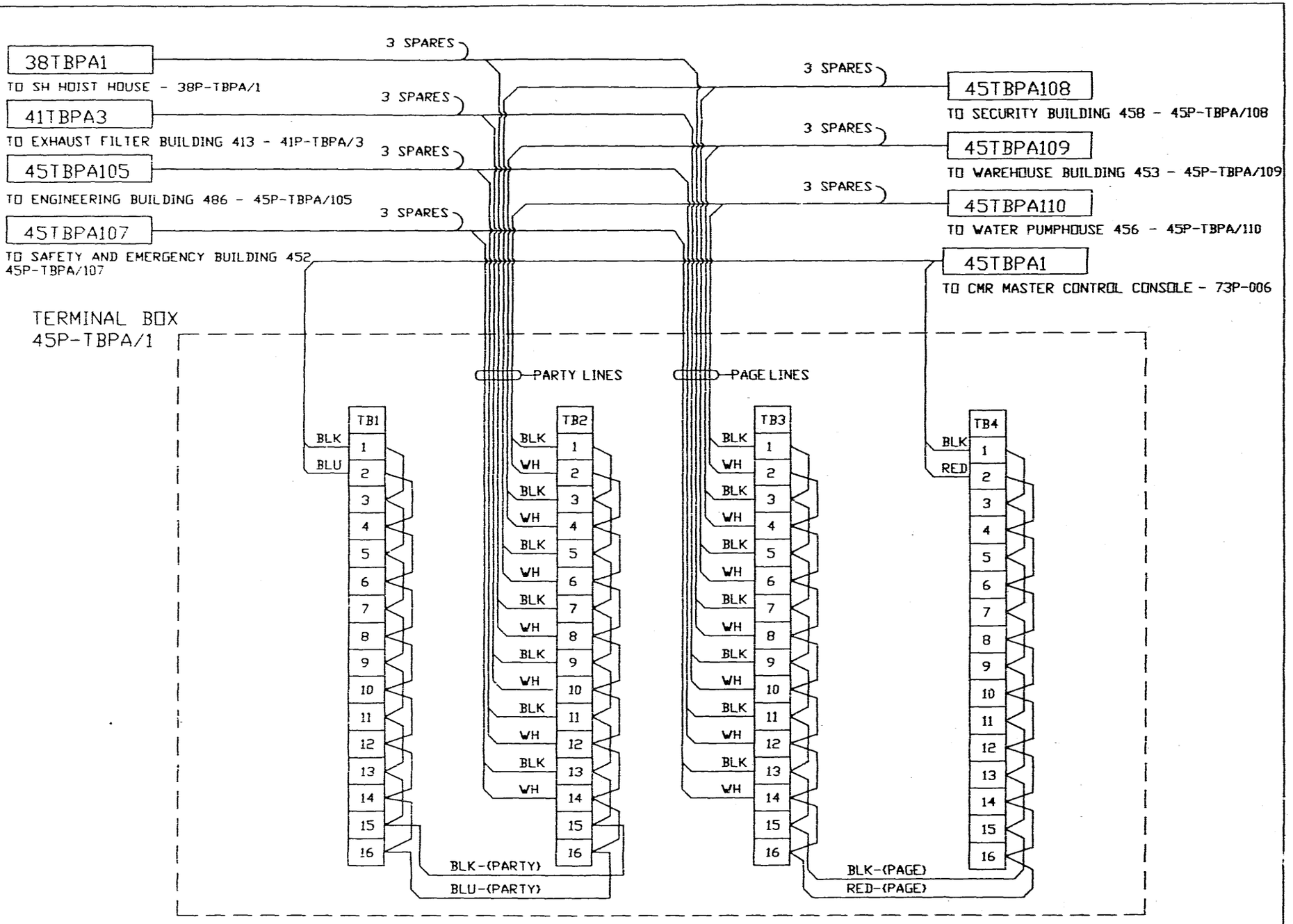
DRAWING No. 73-J-022-W REV. B

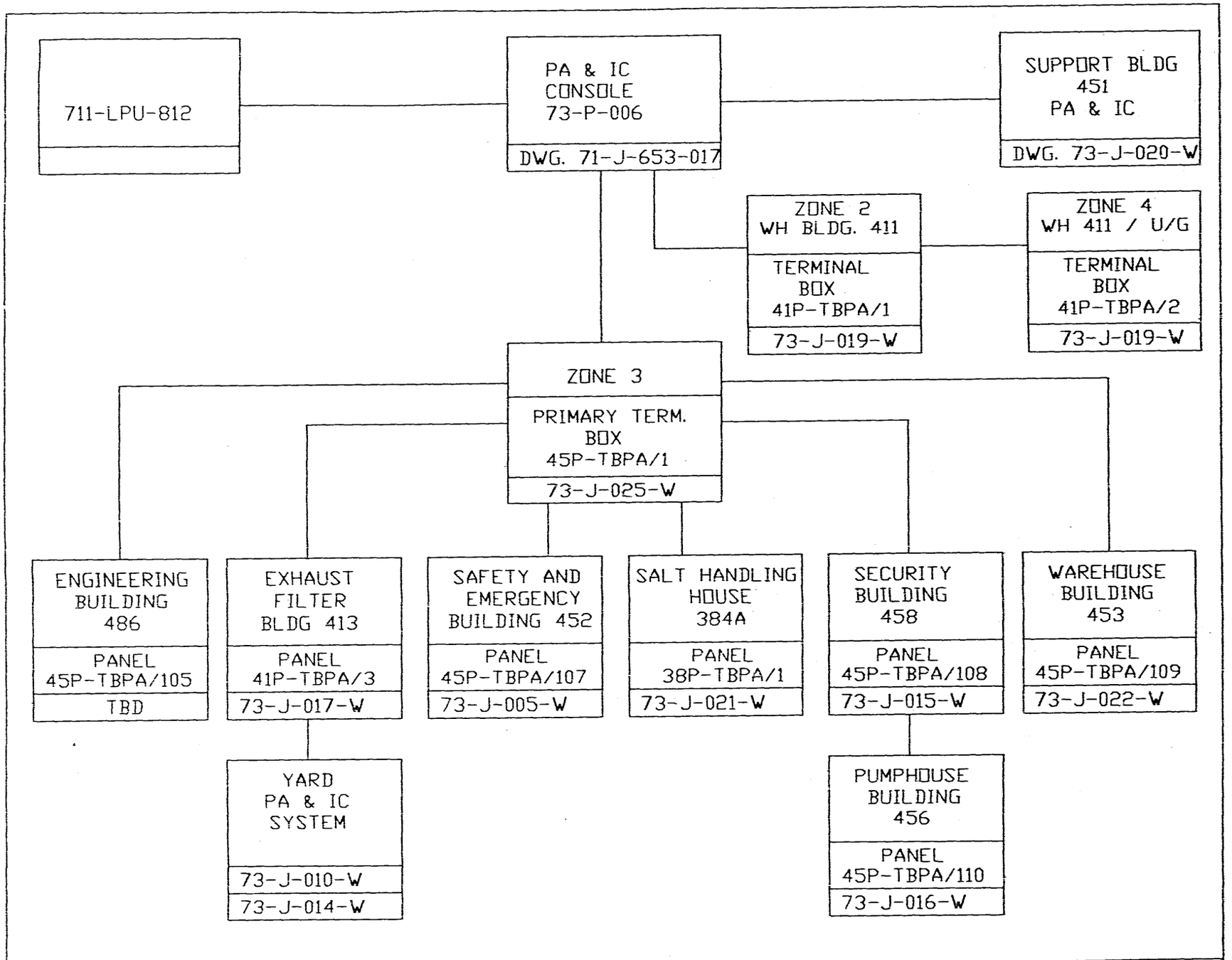
ECO No. 5166 PAGE 15 OF 21



DRAWING No. 73-J-022-W Rev. B

ECO No. 5166 PAGE 16 OF 21

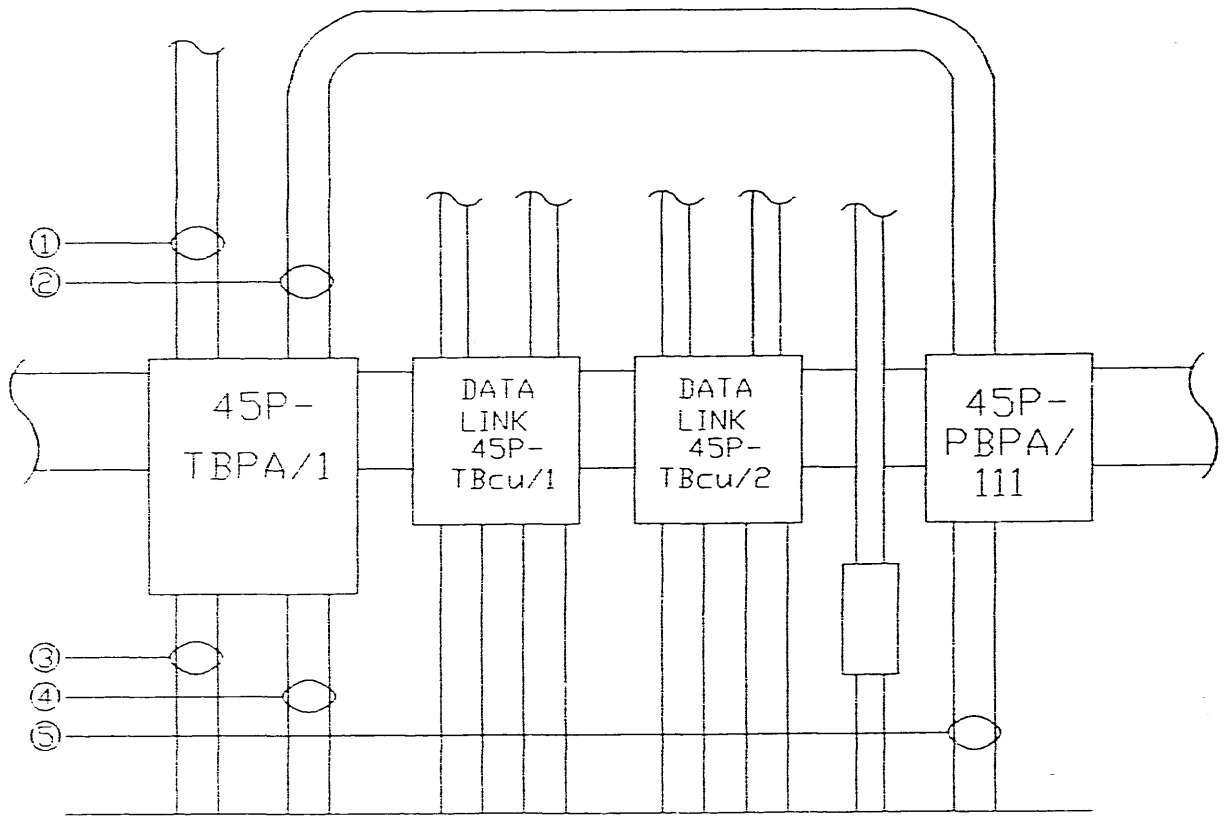

38TBPA1
TO SH HOIST HOUSE - 38P-TBPA/1
41TBPA3
TO EXHAUST FILTER BUILDING 413 - 41P-TBPA/3
45TBPA105
TO ENGINEERING BUILDING 486 - 45P-TBPA/105
45TBPA107
TO SAFETY AND EMERGENCY BUILDING 452
45P-TBPA/107
3 SPARES
3 SPARES
3 SPARES
3 SPARES
3 SPARES
3 SPARES
45TBPA108
TO SECURITY BUILDING 458 - 45P-TBPA/108
45TBPA109
TO WAREHOUSE BUILDING 453 - 45P-TBPA/109
45TBPA110
TO WATER PUMPHOUSE 456 - 45P-TBPA/110
45TBPA1
TO CMR MASTER CONTROL CONSOLE - 73P-006
TERMINAL BOX
45P-TBPA/1
PARTY LINES
PAGE LINES
TB1
TB2
TB3
TB4
BLK
BLU
WH
RED
BLK-(PARTY)
BLU-(PARTY)
BLK-(PAGE)
RED-(PAGE)



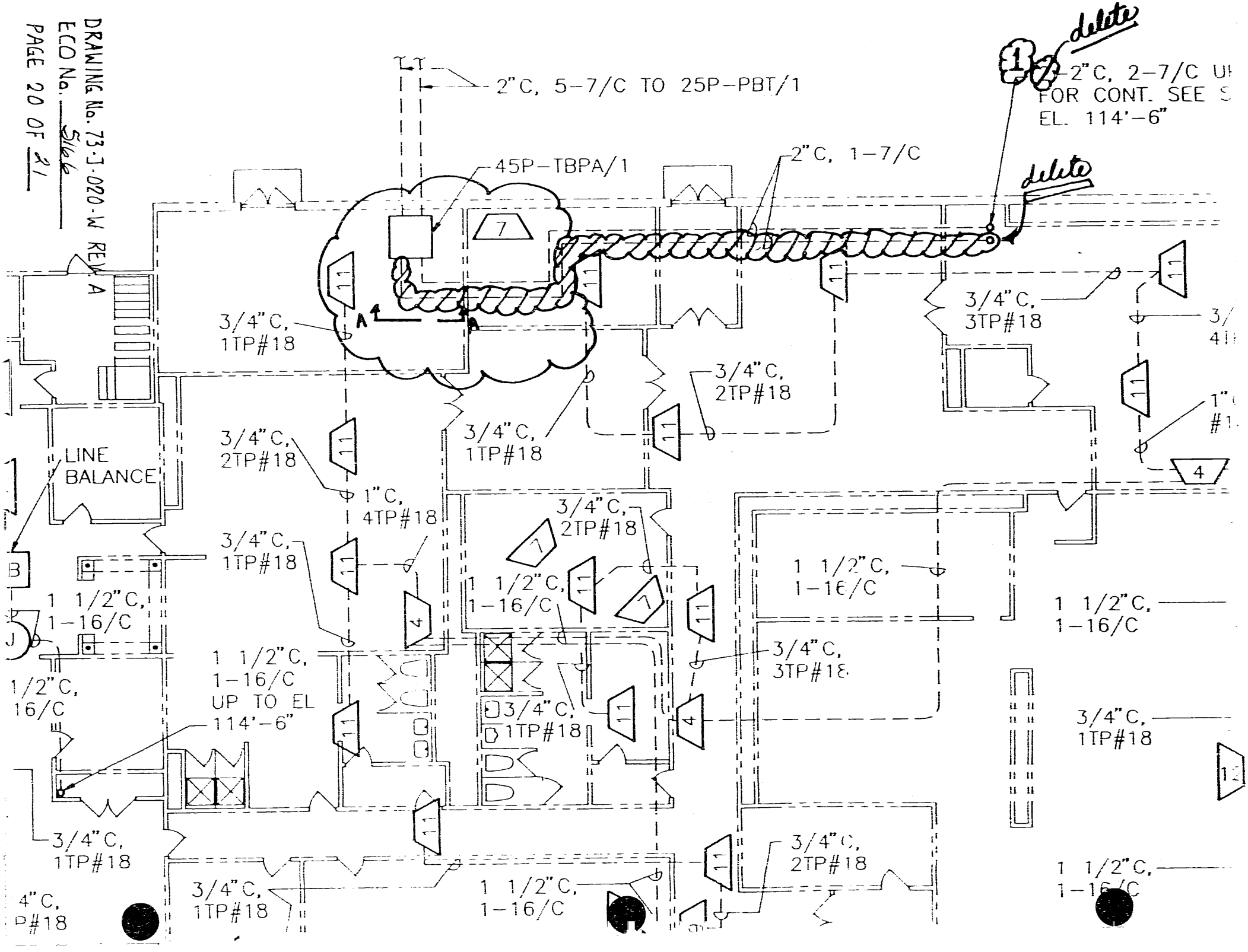
DRAWING NUMBER 73-J-025-W REV. B

ECO NUMBER 3166 PAGE 18 OF 21

CONDUIT SCHEDULE					
CONDUIT NO.		SIZE	TYPE	ORIGIN	DESTINATION
①	45-J-112	2.00	RGS	73-P-006	45P-TBPA/1
②	45-J-113	2.00	RGS	45P-TBPA/1	45P-PBPA/111
③	45-J-114	2.00	RGS	45P-TBPA/1	25P-PBT/1
④	45-J-115	2.00	RGS	45P-TBPA/1	25P-PBT/1
⑤	45-J-116	2.00	RGS	45P-PBPA/111	25P-PBT/1
⑥					



DRAWING No. 73-J-020-W REV. A
ECO No. Sheet
PAGE 20 OF 21



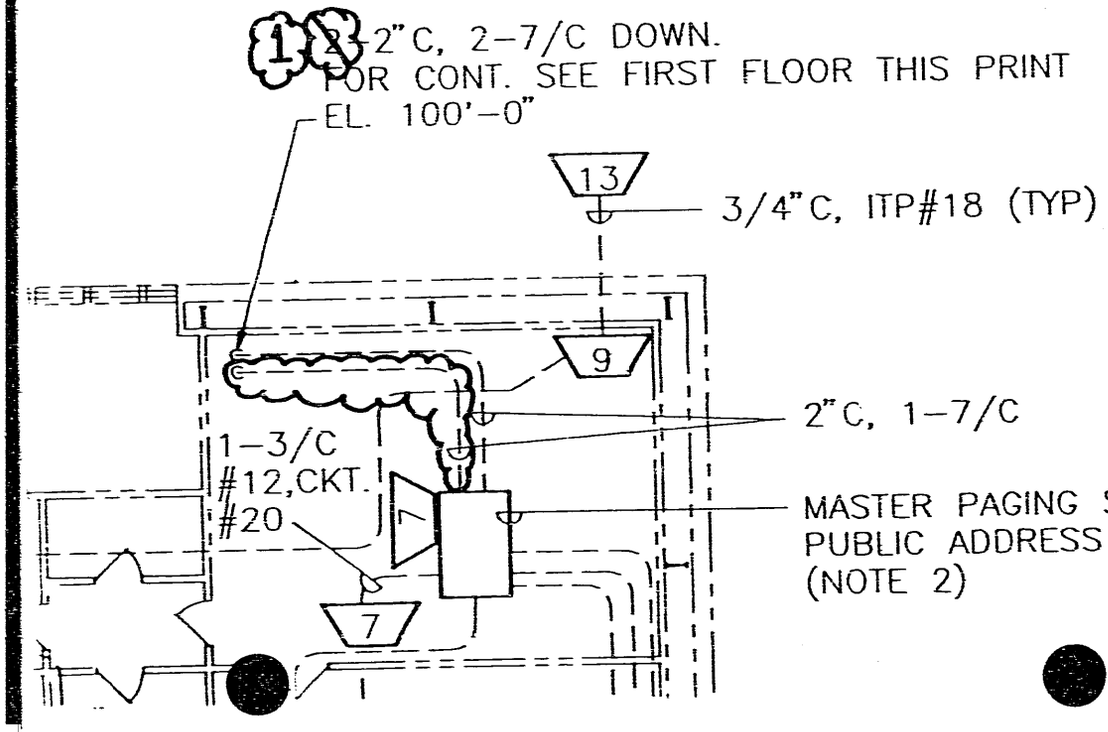
4 | 3

PAGE 21 OF 31

ECO No. 5166

DRAWING No. 73-J-020-W Rev. A

delete



412 F 017 W

ENGINEERING FILE ROOM COPY

ENGINEERING CHANGE ORDER
(USE BLACK INK)

(1) CC&D REVIEW RK JK
ECO- 5189

(2) IMPACT LEVEL
☐ LEVEL-1 ☐ LEVEL-3
☒ LEVEL-2
(SEE SIDE 2 FOR APPROVALS)

(3) SYS/EQUIP NO./BLDG
BIN SCALE TESTS
WHC

(4) ASSOCIATED DOCUMENTS
030 _____
RELATED ECO _____
EDT _____
P.O. _____

(5) DOCUMENT NO.
DRAWING ☐
SPEC ☐
O&M MANUAL ☐
SDD ☐
412-N-002-W
412-F-017-W

(6) SHEET
1 of 1
1 of 2

(7) REVISION ADVANCED
FROM E TO ____
FROM E TO ____

(8) DOCUMENT TITLE
BIN SCALE TESTS DRY TEST BIN ASSEMBLY
DRY TEST BIN DETAILS

(9) DESCRIPTION OF CHANGE

Y/N
☐ ☒ ELECTRICAL LOAD LIST (25-X-001-W)
☐ ☒ PANEL SCHEDULE (INCLUDE MARK-UP)

SEE ATTACHED SHEETS

APR 1992
COMPLETE

Addendum A & B Added 4-21-92

☒ YES ☐ NO
**** MODIFICATION IN PROGRESS
(ECO NOT TO BE INCORPORATED)

☑ MODIFICATION COMPLETE OM 2/27/91
(ECO RELEASED FOR INCORPORATION)

(10) JUSTIFICATION

SEE ATTACHED SHEETS

(11) ORIGINATOR (PRINT)	(12) PHONE	(13) ORGANIZATION	(14) DATE
OM MENDIRATTA	8377	RWHE	1/9/91
(15) COG. ENGINEER (PRINT)	(12) PHONE	(16) DRAFTING REQUIRED DATE	
OM MENDIRATTA	8377		

(17) RELATED CHANGES: INDICATE THE DOCUMENTS, INSTRUCTIONS OR PROCEDURES (OTHER THAN THE DRAWINGS OR DOCUMENTS IDENTIFIED IN EITHER 5 OR 9) THAT WILL BE AFFECTED BY THE CHANGE DESCRIBED IN BLOCK 9. ENTER THE DOCUMENT NUMBER(S) IN BLOCK 18.

YES	NO	N/A		YES	NO	N/A	
☐	☒	☐	1. CONCEPTUAL DESIGN REPORT	☐	☒	☐	10. TRAINING MANUAL
☐	☒	☐	2. VENDOR DATA (WP 09-025)	☐	☒	☐	11. OPERATING PROCEDURES
☐	☒	☐	3. FSAR	☐	☒	☐	12. SPARES/MULTIPLE UNIT LISTINGS
☐	☒	☐	4. SEISMIC/STRESS ANALYSIS	☐	☒	☐	13. DO SPARES NEED MODIFIED
☐	☒	☐	5. DESIGN REPORT	☐	☒	☐	14. TEST PROCEDURES/SPECS.
☐	☒	☐	6. INTERFACE CONTROL DWGS.	☐	☒	☐	15. COMPONENT INDICES
☐	☒	☐	7. CALIBRATION PROCEDURES	☐	☒	☐	16. ASME CODED ITEMS
☐	☒	☐	8. INSTALLATION PROCEDURES	☐	☒	☐	17. HUMAN FACTOR CONSIDERATIONS
☐	☒	☐	9. MAINTAINANCE PROCEDURES	☐	☒	☐	18. COMPUTER SOFTWARE

(18) RELATED DOCUMENT NO.; INSTRUCTION NO.; IDENTIFIED IN BLOCK 17. (CHANGES TO DOCUMENTS LISTED IN BLOCK 18 WILL NOT BE INCOPRORATED BY THIS ECO).

DOCUMENT NO /REVISION	

(19) DISTRIBUTION

NAME	ORG.
O. MENDIRATTA	RWHE

(20) SIGNATURE REQUIREMENTS

KEY
A=APPR.
R=REVIEW

ECO # 5189

A	COG. ENGINEER	Om Mendiratta 1/9/91
A	COG. ENGR. MGR.	John L Fraser 1/15/91
R	Q.A.	R Loop 1-16-91
R	DOE	By K. B. 1-16-91
A	SAFETY	C D. Gale 1/16/91
	DEPT. MGR.	
A	OPERATIONS	R Kelley 1-18-91
	SECURITY	
A	SNL	6343
A	Rad Safe	1/16/91
R	STARTUP	01-18-91

(21) DESIGN VERIFICATION REQUIREMENTS (PER WP 09-018)

JF ✓ 1. REQUIREMENTS SATISFIED BY REVIEW/APPROVAL OF DESIGN DOCUMENT
2. INDEPENDENT REVIEW
3. ALTERNATE CALCULATIONS
4. DEVELOPMENT TESTING
5. DESIGN REVIEW
JF ✓ 6. OTHER Final Drawing Review + Approval

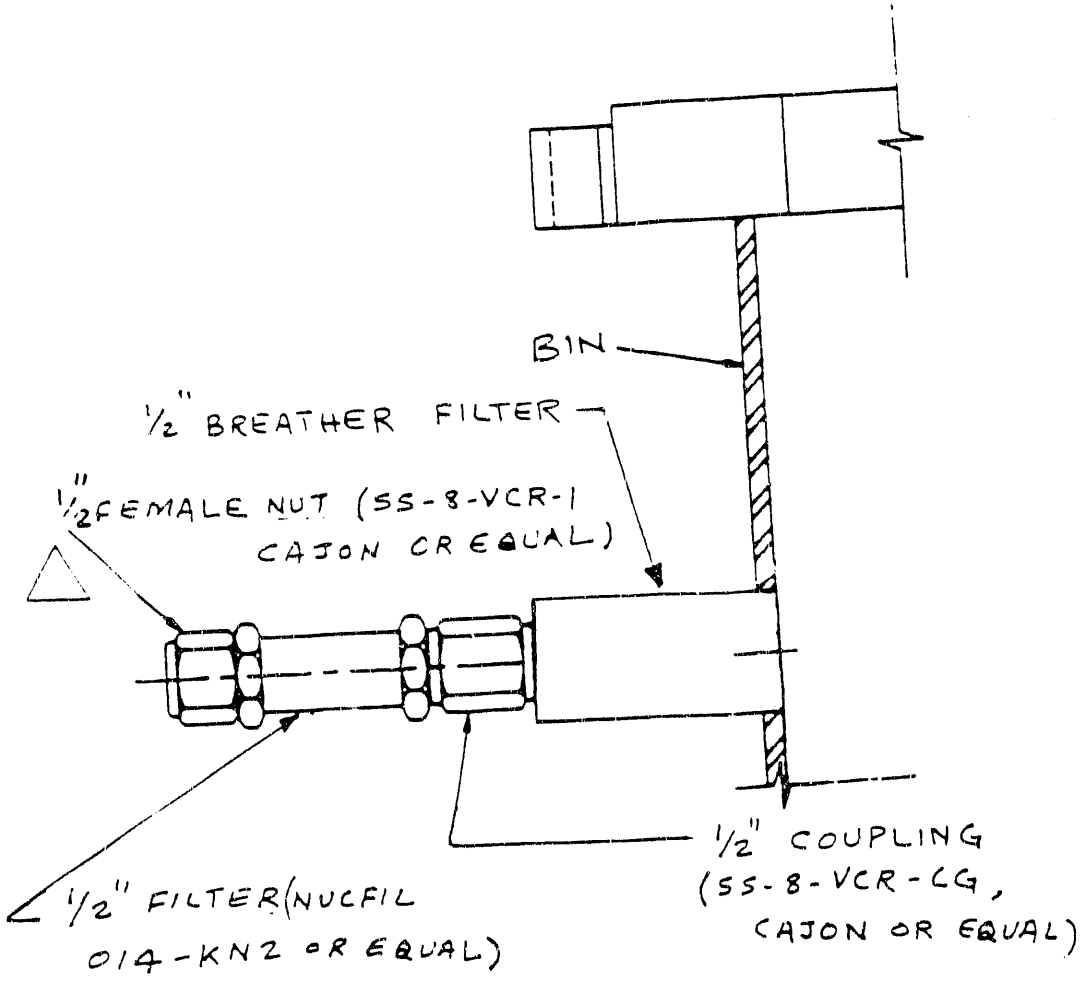
EDT# ____

(Side 2)

ENGINEERING CHANGE ORDER CONTINUATION SHEET	DOCUMENT NO. 412-N-002-W 412-F-017-W	ECO
	DATE 1/9/91	PAGE 3 OF 5
		5189

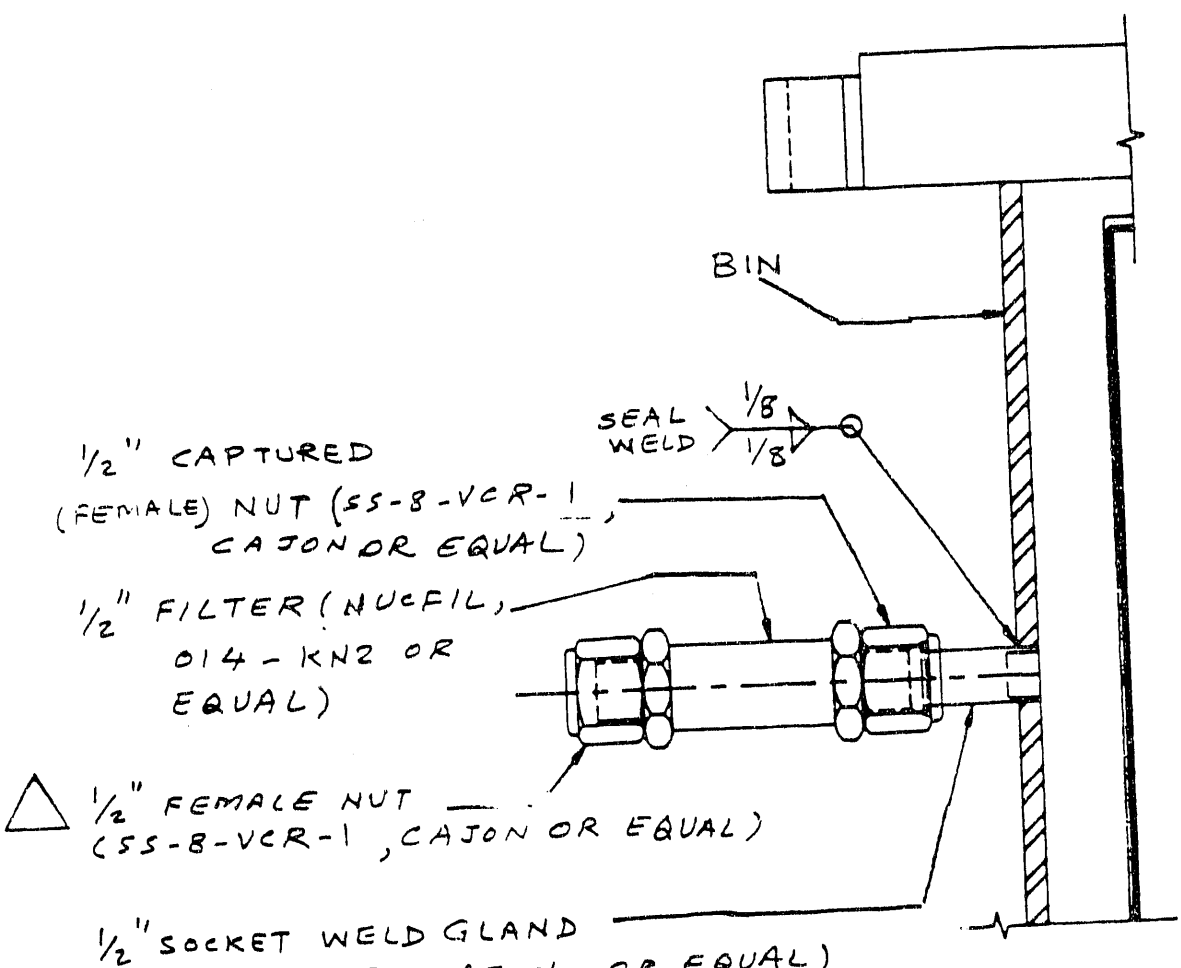
(9) DESCRIPTION OF CHANGE

1. REVISE DETAIL 1, DRAWING 412-N-002-W AS SHOWN AND LABEL THE DETAIL, " FOR TEST BINS PB-009 THROUGH PB-018 ONLY". S/N



ENGINEERING CHANGE ORDER CONTINUATION SHEET	DOCUMENT NO. 412-N-002-W 412-F-017-W	ECO
	DATE 1/9/91	PAGE 4 OF 5
		5189

2. ADD DETAIL ON DRAWING 412-N-002-W TO SHOW TRANSPORT FILTER (BREATHER FILTER) CONNECTION, LABEL DETAIL, "FOR TEST BINS PB-019 AND ONWARD".
S/N



ENGINEERING CHANGE ORDER CONTINUATION SHEET	DOCUMENT NO. 412-N-002-W 412-F-017-W		ECO
	DATE 1/9/91	PAGE 5 OF 5	5189

3. REVISE NOTE 15, DRAWING 412-N-002-W, "TRANSPORT FILTER TO BE FITTED WITH A FEMALE NUT AT THE FABRICATION SHOP, THIS FEMALE NUT TO BE REPLACED WITH A CAP NUT AT THE WIPP SITE PRIOR TO DOWNLOADING OF THE BIN." (NOTE: NOTE LOCATOR TRIANGLES ARE MARKED ON THE ATTACHED SKETCHES).

4. ADD A NOTE TO DRAWING 412-N-002-W, "ALL VCR CONNECTIONS SHALL BE MADE WITH PROPER SIZE GASKET, PREFERABLY HELD IN A GASKET RETAINER ASSEMBLY." CROSS REFERENCE THIS NOTE WITH THE BILL OF MATERIAL, ITEM DESCRIPTION FOR THE GASKET.

5. ADD TO THE DRAWING 412-N-002-W, BILL OF MATERIAL, THE GASKETS AS INDICATED BELOW:

   1/2" GASKET RETAINER ASSEMBLY (NI-8-VCR-2-GR-VS, CAJON OR EQUAL); QUANTITY = ONE PER CONNECTION; NOTE: FOLLOW VENDOR DIRECTIONS FOR REPEATED USE OF THE SAME ASSEMBLY.

   1" GASKET RETAINER ASSEMBLY (NI-16-VCR-2-GR-VS, CAJON OR EQUAL); QUANTITY = ONE PER CONNECTION; NOTE: FOLLOW VENDOR DIRECTIONS FOR REPEATED USE OF THE SAME ASSEMBLY.

6. REVISE ALL OTHER DETAILS ON THE DRAWINGS LISTED IN COLUMN 5, TO REFLECT CHANGES PER THIS ECO.

(10) **JUSTIFICATION**

WELDING OF THE FILTER HOUSING TO THE BIN WALL VOIDS DOP CERTIFICATION FOR THE FILTER MEDIA PERFORMED EARLIER (BEFORE WELDING).

ENGINEERING CHANGE ORDER
ADDENDUM SHEET

1. Addendum A to ECO Number: 5189 Drawing Number: 412-F-017

2. Description of change:

412-F-017-W1 :

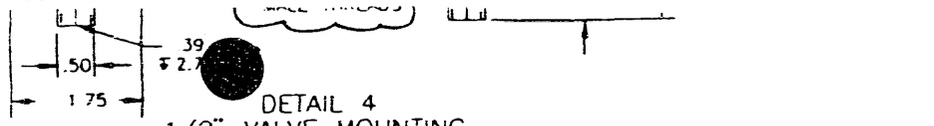
- ADD 1/8" X 45° CHAMFER TO ITEMS 18 AND 9 AT DETAILS 3 AND 4.
- CHANGE 1 15/16"-12 TO 1 5/16-12 AT DETAIL 3.
- CHANGE 9/16"-18 TO 3/4"-16 AT DETAIL 4.
- CHANGE .38 DIMENSION TO .41 AT DETAIL 4.
- CHANGE Ø.44 DIMENSION TO R.88 AT DETAIL 4.
- ADDITIONAL DIMENSIONS OF .88 AND .62 REQUIRED AT DETAILS 3 AND 4.
- CHANGE WELDING DESIGNATIONS AT ELEVATION VIEWS, DETAILS 2A AND 2B, 1" VALVE MOUNT ASSEMBLY-GR4, AND 1/2" VALVE MOUNT ASSEMBLY-GR-3.
- ADD NOTE 20.

412-F-017-W2 :

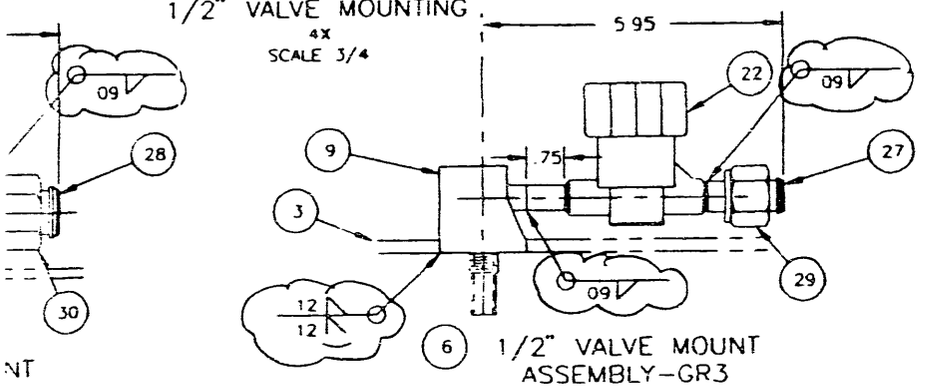
- CHANGE 9/16-18 TO 3/4-16 AT DETAIL OF ITEM 16.
- ADD REFERENCE TO NOTE 20 AT ITEM 20.
- REMOVE COUNTERBORE AND INCORPORATE COUNTERSINK AT DETAIL OF ITEMS 16 AND 24.

3. Approvals

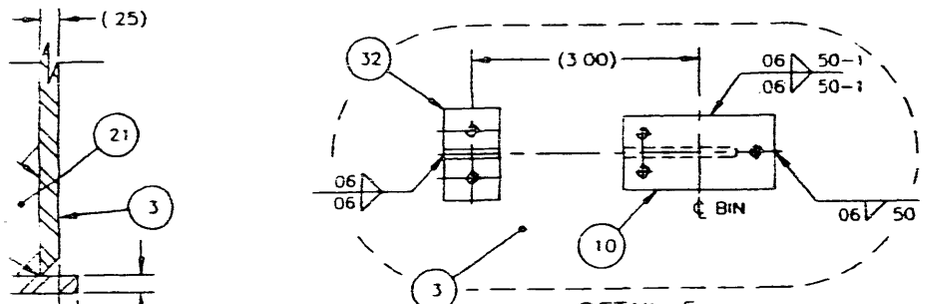
	Signature	Date
Cognizant Engineer:	[signature]	4/15/92
CC&D Mgr. /Desig. Rep.:	[signature]	4/16/92
Other Approval:	[signature]	4-21-92
Other Approval::		



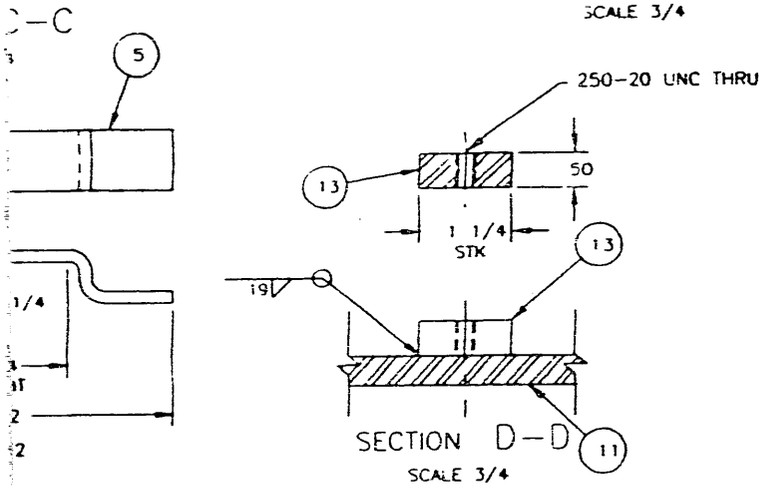
DETAIL 4
1/2" VALVE MOUNTING
4X
SCALE 3/4



6 1/2" VALVE MOUNT ASSEMBLY-GR3
SCALE 1/2



DETAIL 5
THERMOCOUPLE INSERT BLOCK
AND THERMOCOUPLE CLAMP
5X
SCALE 3/4



SECTION D-D
SCALE 3/4

E-Z-240, REV. 2. SYSTEM 1-16 FINISH COAT SHALL BE GRAY APPLY PAINT AFTER WELD TESTS AND APPROVALS SPEC[illegible] IN EQUIPMENT SPECIFICATION E-A-334. EXCEPT STAINLES[illegible]L SURFA[illegible]ES

8 PAINT INTERNAL SURFACE OF BIN AND UNDERSIDE OF COVER WITH PAINT 105C-5, WHITAKER COATINGS. 1500 LATHEM ST. BATAVIA, IL 60510 OR EQUAL APPLY FIRST COAT .0003" - .0004" DRY AND BAKE 10 - 12 MINUTES AT 300 - 315 F. APPLY SECOND COAT .0003" - .0004" DRY AND BAKE 10 - 12 MINUTES AT 400 - 425 F APPLY FIRST COAT AFTER WELD TESTS AND APPROVALS SPECIFIED IN EQUIPMENT SPECIFICATION E-A-334.

9 STENCIL BIN EQUIPMENT NO AND THREE DIGIT SERIAL NO. LETTERS SHALL BE 1/2"-1" HIGH INDELIBLE BLACK. LIDS AND BINS OF THE SAM SERIAL NO. SHALL BE SHIPPED TOGETHER. DRY TEST BIN EQUIP. NO.. 63-S-001, S/N -001, ETC.

10 REINFORCE HOLES IN LINER WITH TEFLON WASHER EMBEDDED IN TH[illegible] LINER.

11 SECOND WELD ON WALL OPTIONAL SINGLE WELD PERFERRED WITH SINGLE PIECE WALL.

12 TO BE INSTALLED TO BOTTOM OF BIN ONLY.

13. REMOVED

14 ALL 1/2" VALVES INSTALL ON ITEM 1 SHALL HAVE THE SAME PART NUMBER.

15 ALL 1" VALVES INSTALL ON ITEM 1 SHALL HAVE THE SAME PART NUMBER.

16. ARROWS ON ALL VALVES TO POINT AWAY FROM BIN WALL.

17 REMOVE THIS LENGTH AFTER FINAL INSTALLATION.

18. THIS DETAIL FOR TEST BINS S/N PB-009, PB-010, AND PB-011 ONLY

19 THIS DETAIL FOR TEST BINS S/N PB-012 AND ONWARD.

20 FOLD ITEM 20 AS REQUIRED TO FIT WITHIN THE BIN

ECO 5189
ADDENDUM A
PAGE 2 OF 3

REV	ISSUE DESCRIPTION						
		DFTR	CHK	COG	DFTG MGR	ECO	
		DATE	DATE	DATE	DATE		
F	REVISED PER ECO FD	RM				5189 5206 5848	
		4/13/92					
E	REVISED PER ECO	TRA	DLM	MB	HB	4869 5000	
		10/18/90	10/18/90	10/18/90	10/18/90		

THIS DRAWING CREATED BY ENGINEERING CHANGE ORDER (ECO) 5258

INTERPRET DWG PER ANSI Y14			
DIM IN INCHES BASED ON 58 F			
UNLESS OTHERWISE SPECIFIED TOLERANCES			
2 PL DEC	3 PL DEC	ANGLES	
.03	.005	1	
FRACTIONS 1/8			
ENGINEERING RELEASE			
BY WID-WIPP			
ECO	DATE		

DFTG A.E.SEWALD 10/31/[illegible]
CHKR. D. HUGHES 10/17/[illegible]
COG ENGR. BALI 10/17/9[illegible]
COG MGR J.J. GARCIA 1/12/9[illegible]
O.A. JAMES F. ALLEN 12/6/89
SAFETY C.D. JACKSON 12/6/89
APPD W.R. WHITE 12/6/89
APPD TERRY D. MERRILL (RS)
DFTG. MGR K.W. BELLOWS 10/18/90
SNL MARTY A. MOLECKE 12/6/89
DOE E.K. HUNTER 12/11/89
SCALE 1/8 U.N.O.

U.S. DEPARTMENT OF ENERG[illegible]
Westinghouse Waste Isolation Divi[illegible]on
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

BIN-SCALE TESTS
DRY TEST BIN DETAILS

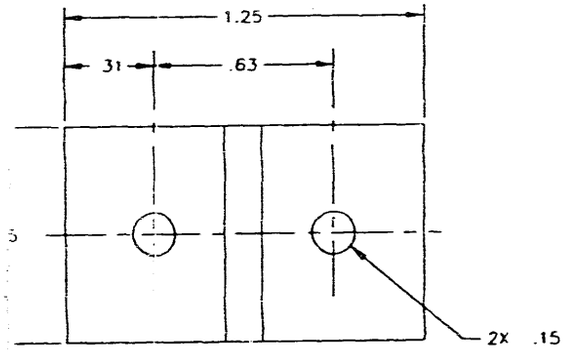
SYS WH06 | DWG NO 412-F-017-W | REV F | DWG [illegible]

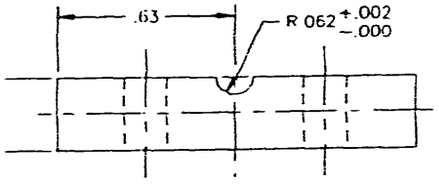
4 3 2 1

(188)

.875 $^{+.00}_{-.03}$

562





(34) SQUEEZE BLOCK
5 REQD.

E CLAMP
S=1

ECO 5189
ADDENDUM A
PAGE 3 OF 3

REV	ISSUE DESCRIPTION	DFTR	CHK	COG	DFTG MGR	ECO	PWC
		DATE	DATE	DATE	DATE		
F	REVISED PER ECO FD	RM 4/13/92				5189 5206 6081	
E	REVISED PER ECO	TRA 10/18/90	DLH 10/18/90	MF 10/18/90	HB 10/18/90	4869 5000	

THIS DRAWING CREATED BY ENGINEERING CHANGE ORDER (ECO) . 3258

INTERPRET DWG PER ANSI Y14
DIM IN INCHES BASED ON 68 F
UNLESS OTHERWISE SPECIFIED TOLERANCES

2 PL DEC	3 PL DEC	ANGLES
.03	.005	1

FRACTIONS 1/8

ENGINEERING RELEASE
BY (W) WID-WIPP
ECO DATE

DFTG A.E. SEWALD 10/31/89
CHKR D HUGHES 10/17/90
COG ENGR BALI 10/17/90
COG MGR J.J. GARCIA 1/12/90
Q.A. JAMES F. ALLEN 12/6/89
SAFETY C.D. JACKSON 12/6/89
APPD W.R. WHITE 12/6/89
APPD TERRY D. MERKLING (RS)
DFTG MGR B.W. BELLOWS 10/18/90
SNL MARTY A. MOLEOKE 12/6/89
DOE E.K. HUNTER 12/11/89
SCALE 1/8 UNO

U.S. DEPARTMENT OF ENERGY
Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

BIN-SCALE TESTS
DRY TEST BIN DETAILS

SYS WH06 | DWG NO 412-F-017-W2 | REV F | DWG 2 OF 2

4 3 2 1

ENGINEERING CHANGE ORDER
ADDENDUM SHEET

1. Addendum B to ECO Number: 5189 Drawing Number: 412-N-009-W

2. Description of change:

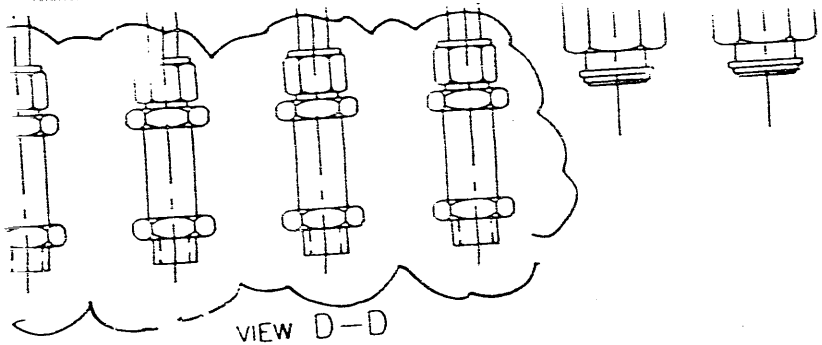
ADDITION OF MODIFIED NUCFIL FILTER, #014KN2, (HALL MACHINE DRWG. NO. HMW-014KN2) 4 PLACES TO 1/2" VALVE CONNECTION AT VIEW D-D AND AT SECTION A-A.

REFER TO ATTACHED MARKUP COPY OF 412-N-009-W FOR ADDITIONAL CLARIFICATION.

ITEMS 4, 5, 14, AND 17 SHOULD BE INCLUDED WITH GROUP 1 AT BILL OF MATERIAL.

3. Approvals

Cognizant Engineer:	Signature	4/15/92 Date
CC&D Mgr./Desig. Rep.:	Signature	4/16/92 Date
Other Approval:	Signature	4-21-92 Date
Other Approval::	Signature	Date



VIEW D–D

1/2

NOTE: FOR CONFIGURATION, ARROWS INDICATE STAMPED FLOW ON VALVES ONLY

06 SEAL

9

09 SEAL
09 SEAL

1.60
1.32

06 SEAL

2

7

17

4

15

•	TAG IDENTIFICATION TABLE 13	COLOR	• •
1	OG/AP–1 OXY GETT/ARGON	RED	448–422
2	PR–1 INSTR PORT	RED	448–422
3	TC – 1	BLACK	410–422
4	TC – 2	BLACK	410–422
5	TC – 3	BLACK	410–422
6	TC – 4	BLACK	410–422
7	TC – 5	BLACK	410–422
8	GR–1 RECIRC OUT	BLACK	410–422
9	GRB–1. OXY GETT/ RECIRC OUT BACKUP	BLACK	410–422
10	GR–2 RECIRC IN	GREEN	458–422
11	GRB–2. OXY GETT/ RECIRC IN BACKUP	GREEN	458–422
12	PR–2 INSTR PORT BACKUP	BLUE	426–422
13	OG/AP–2 OXY GETT/ARGON	BLUE	426–422

1. ITEM 1 UNLESS NOTED OTHERWISE IN THIS DRAWING

12 REMOVED

13 TAG COLOR SHALL BE PER IDENTIFICATION TABLE. TAGS SHALL BE [illegible] x 2". WITH 1/4"–1/2" CHARACTERS. TAGS TO BE MOUNTED WITH ITEM 16. TEXT TO BE PER TAG IDENTIFICATION TABLE

14 RECTANGULAR STRIPS OF THE SAME COLOR AS ASSIGNED TO EACH OF SHALL ALSO BE PROVIDED ON THE UNDERSIDE OF ITEM 6. ADJACEN TO THE RESPECTIVE VALVE. THE RECTANGULAR STRIPS SHALL BE 1/2" x 1" MATERIAL SHALL BE THE SAME AS ITEM 15 AND MOUNTED WITH ITEM 16.

15 THE STEM AT EITHER END OF ITEM 4 AND ITEM 14 SHALL BE PAIN D WITH THE SAME COLOR AS THE CORRESPONDING TAG ON THE PORT THE PAINT SHALL BE APPLIED AT THE BASE OF THE MALE HOSE ST 4 THE WIDTH OF THE PAINT SHALL NOT EXCEED 1/2". DO NOT PAIN MATING ENDS OR THREADS.

16 EACH VALVE AND HOSE SHALL BE TESTED BY THE MANUFACTURER TO A HELIUM LEAK RATE OF 4×10^{-9} STD CC/SEC OR LESS.

17 THE VALVES AND HOSES SHALL BE LEAK TESTED AS AN ASSEMBLY TO 1×10^{-8} SCC/SEC OF HELIUM. THE LEAK PROCEDURE SHALL BE SUBMITTED FOR APPROVAL PRIOR TO ANY TESTING. THE HOSES SH L REMOVED FROM THE LID FOR SHIPPING. THE MEASURED LEAK RATE SHALL BE RECORDED AND REPORTED. TEST RESULTS SHALL BE INFOR REPORTED AS THE OCCUR. FAILURE OF A JOINT OF DIFFICULTY A OBTAINING A SEAL SHALL BE RECORDED SO THAT A DATA BASE MAY BE DEVELOPED ON THE PERFORMANCE OF THE VCR FITTINGS. THE INSTRUMENTS USED TO MEASURE THE LEAK RATE SHALL BE CAPABLE OF MEASURING 5×10^{-9} SCC/SEC OF HELIUM OR BETTER

ECO 5189
ADDENDUM B
PAGE 2 OF 2

REV	ISSUE DESCRIPTION	DFTR DATE	CHK DATE	COG DATE	DFTG MGR DATE	ECO	
G	REVISED PER ECO	PM 3/31/92				5189	
F	REVISED PER ECO FD	TRA 06/25/91	[illegible] 06/25/91	OM 06/25/91	BA 06/26/91	5354 5429	

THIS DRAWING CREATED BY ENGINEERING CHANGE ORDER (ECO) 4168

INTERPRET DWG PER ANSI Y14
DIM IN INCHES BASED ON 68 F
UNLESS OTHERWISE SPECIFIED TOLERANCES

2 PL DEC	3 PL DEC	ANGLES
06	—	1

FRACTIONS 1/8

ENGINEERING RELEASE
BY WHD–WPP
ECO DATE

DFTG T ALSTON 3/21/90
CHKR D HUGHES 10/18/90
COG ENG M BAU 10/18/90
COG MGR JOHN J GIBOR 5/18/90
Q.A. JIM AICHENSON 5/16/91
SAFETY CD JACKSON 5/21/90
RAD SAF [illegible] 5/18/90
APHO CLINT KELLEY 5/9/90
DFTG. MGR [illegible] 5/18/90
SML MARTY MOLECKE 5/31/90
DOE W.A WALKER 5/18/90
SCALE NOTED

U.S. DEPARTMENT OF ENERGY
Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

BIN SCALE TESTS
SWB LID MODIFICATION
FOR RCB LID
ASSEMBLY AND DETAILS

SYS WH06 | DWG NO 412–N–009–W | REV

A

4 3 2 1

5. LINER MATERIAL SHALL BE POLYETHYLENE, NOMINAL THICKNESS: .030". LINER SHALL NOT RELEASE ANY GASES BETWEEN 70° F AND 90° F.

6. REMOVED

7. PREPARE AND PAINT EXTERNAL SURFACES OF BIN PER SPECIFICATION E-Z-240, REV. 2, SYSTEM 1-16. FINISH COAT SHALL BE GRAY. APPLY PAINT AFTER WELD TESTS AND APPROVALS SPECIFIED IN EQUIPMENT SPECIFICATION E-A-334, EXCEPT STAINLESS STEEL SURFACES.

8. PAINT INTERNAL SURFACE OF BIN AND UNDERSIDE OF COVER WITH PAINT 105C-5, WHITAKER COATINGS, 1500 LATHEM ST., BATAVIA, IL. 60510 OR EQUAL. APPLY FIRST COAT .0003" - .0004" DRY AND BAKE 10 - 12 MINUTES AT 300° - 315° F. APPLY SECOND COAT .0003" - .0004" DRY AND BAKE 10 - 12 MINUTES AT 400° - 425°F. APPLY FIRST COAT AFTER WELD TESTS AND APPROVALS SPECIFIED IN EQUIPMENT SPECIFICATION E-A-334.

9. STENCIL BIN EQUIPMENT NO. AND THREE DIGIT SERIAL NO. LETTERS SHALL BE 1/2"-1" HIGH INDELIBLE BLACK. LIDS AND BINS OF THE SAME SERIAL NO. SHALL BE SHIPPED TOGETHER. DRY TEST BIN EQUIP. NO.: 63-S-001, S/N -001, ETC.

10. REINFORCE HOLES IN LINER WITH TEFLON WASHER EMBEDDED IN THE LINER.

11. SECOND WELD ON WALL OPTIONAL. SINGLE WELD PERFERRED WITH SINGLE PIECE WALL.

12. TO BE INSTALLED TO BOTTOM OF BIN ONLY.

13. REMOVED

14. ALL 1/2" VALVES INSTALL ON ITEM 1 SHALL HAVE THE SAME PART NUMBER.

15. ALL 1" VALVES INSTALL ON ITEM 1 SHALL HAVE THE SAME PART NUMBER.

16. ARROWS ON ALL VALVES TO POINT AWAY FROM BIN WALL.

17. REMOVE THIS LENGTH AFTER FINAL INSTALLATION.

18. THIS DETAIL FOR TEST BINS S/N PB-009, PB-010, AND PB-011 ONLY.

19. THIS DETAIL FOR TEST BINS S/N PB-012 AND ONWARD.

20. FOLD ITEM 20 AS REQUIRED TO FIT WITHIN THE BIN.

REV	ISSUE DESCRIPTION	DFTR / DATE	CHK / DATE	COG / DATE	DFTG MGR / DATE	ECO	PWR
F	REVISED PER ECO FD	RM 4/15/92	[illegible] 4/15/92	[illegible] 4/15/92	[illegible] 4/16/92	5189 5206 5848	
E	REVISED PER ECO	TRA 10/18/90	DLH 10/18/90	MB 10/18/90	HB 10/18/90	4869 5000	

THIS DRAWING CREATED BY ENGINEERING CHANGE ORDER (ECO) : 3258

INTERPRET DWG PER ANSI Y14
DIM. IN INCHES BASED ON 68° F
UNLESS OTHERWISE SPECIFIED TOLERANCES

2 PL DEC	3 PL DEC	ANGLES	
± .03	± .005	± 1°	√AA

FRACTIONS ± 1/8

ENGINEERING RELEASE
BY WID-WIPP
ECO _____ DATE _____

DFTG A.E.SEWALD 10/31/89
CHKR. D. HUGHES 10/17/90
COG. ENGM. BALI 10/17/90
COG. MGR J.J. GARCIA 1/12/90
Q.A. JAMES F. ALLEN 12/6/89
SAFETY C.D. JACKSON 12/6/89
APPD W.R. WHITE 12/6/89
APPD TERRY D. MERKLING (RS)
DFTG. MGR H.W. BELLOWS 10/18/90
SNL MARTY A. MOLECKE 12/6/89
DOE E.K. HUNTER 12/11/89
SCALE 1/8 U.N.O.

U.S. DEPARTMENT OF ENERGY

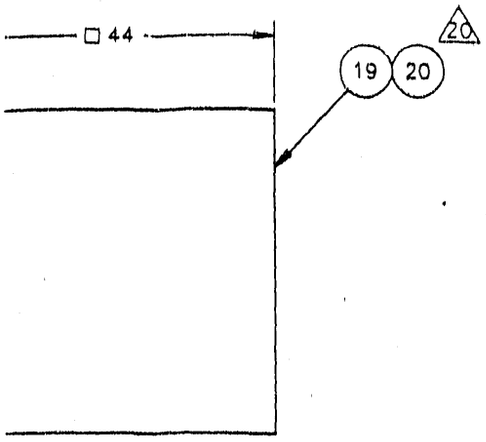
Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

BIN-SCALE TESTS
DRY TEST BIN DETAILS

SYS.	DWG. NO.	REV.
WH06	412-F-017-W1	F

DWG 1 OF 2

2 1



REV	ISSUE DESCRIPTION	DFTR DATE	CHK DATE	COG DATE	DFTG MGR DATE	ECO	PWR
F	REVISED PER ECO FD	RM 4/15/92	AES 4/15/92	GH 4/15/92	KR 4/16/92	5189 5206 6081	
E	REVISED PER ECO	TRA 10/18/90	DLH 10/18/90	MB 10/18/90	HB 10/18/90	4869 5000	

THIS DRAWING CREATED BY ENGINEERING CHANGE ORDER (ECO) : 3258

INTERPRET DWG PER ANSI Y14
DIM. IN INCHES BASED ON 68° F
UNLESS OTHERWISE SPECIFIED TOLERANCES

2 PL DEC	3 PL DEC	ANGLES
± .03	± .005	± 1°

AA

FRACTIONS ± 1/8

ENGINEERING RELEASE
BY WID-WIPP
ECO _____ DATE _____

DFTG A.E.SEWALD 10/31/89
CHKR. D. HUGHES 10/17/90
COG. ENG'M. BALI 10/17/90
COG. MGR J.J. GARCIA 1/12/90
Q.A. JAMES F. ALLEN 12/6/89
SAFETY C.D. JACKSON 12/6/89
APPD W.R. WHITE 12/6/89
APPD TERRY D. MERKLING (RS)
DFTG. MGR H.W. BELLOWS 10/18/90
SNL MARTY A. MOLECKE 12/6/89
DOE E.K HUNTER 12/11/89
SCALE 1/8 U.N.O.

U.S. DEPARTMENT OF ENERGY

Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

BIN-SCALE TESTS
DRY TEST BIN DETAILS

SYS.	DWG. NO.	REV.
WH06	412-F-017-W2	F

DWG 2 OF 2

D C B A

2 1

2. FILTER HOUSING SHALL BE NUPRO SS-3[illegible] WITH A SS 316 SILVER-PLATED SS 316 GASKET. HOUSING SHALL HAVE NO MICRON SIZE OR OTHER SPECIFICATION STAMPED ON IT. DISCARD THE NUPRO FILTER ELEMENT IN THE HOUSING.

3. FIBERBOARD LINERS TAPED TOGETHER AT TAB END WITH ITEM 18.

4. SHIP ITEM 4 PLACED INSIDE ITEM 2. NO SHARP BENDS ON GASKET.

5. TAGS TO BE RED WITH WHITE LETTERING ON A 3" X 2" TAG, WITH 1/4"-1/2" CHARACTERS. TAGS TO BE MOUNTED WITH ITEM 20. TEXT OF EACH TAG SHOWN IN TAG IDENTIFICATION TABLE.

6. REMOVED

7. REMOVED

8. REMOVED

9. STANDARD HEX-HEAD BOLTS WITH INTEGRAL WASHERS. BOLTS SHALL BE 1/2-13 UNC X 1-1/4 LG. WITH AN INTEGRAL FLAT WASHER 1" DIAMETER.

10. LEAVE TOP OF ITEM 12 LOOSE AFTER INSTALLING ITEMS 13, 14, 29, & 30.

11. STENCIL BIN EQUIPMENT NO. AND THREE DIGIT SERIAL NO. LETTERS SHALL BE 1/2"-1" HIGH INDELIBLE BLACK. LIDS AND BINS OF THE SAME SERIAL NUMBER SHALL BE SHIPPED TOGETHER. SOLID WASTE BIN EQUIP. NO.: 63-S-001, S/N -001, ETC. PS/SC BIN EQUIP. NO.: 63-S-004, S/N -001, ETC.

12. SANDIA NATIONAL LABS. TO SUPPLY AND INSTALL ITEMS 23, 24, 25, 26, AND 27 PER PROCEDURES APPROVED BY W-WID.

13. TIGHTEN TO 30 FT-LB TORQUE.

14. STENCIL WORDS "MAX GROSS WEIGHT 3,200 LBS." LETTERS SHALL BE 1-2" HIGH, INDELIBLE BLACK, ON NEAR AND FAR SIDE OF BIN, STENCILED AFTER PAINTING BIN.

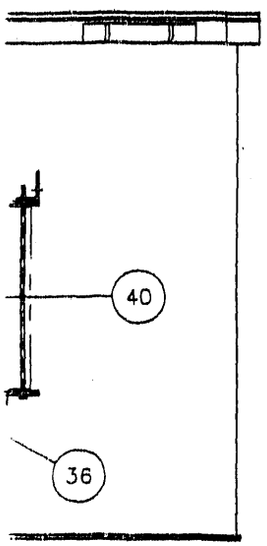
15. TRANSPORT FILTERS (ITEM 38) TO BE FITTED WITH A FEMALE NUT AT THE FABRICATION SHOP. THIS NUT WILL BE REPLACED WITH A CAP NUT AT THE WIPP SITE PRIOR TO DOWN-LOADING OF THE BIN.

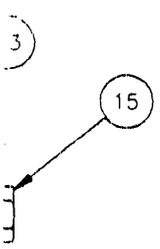
16. ALL VCR CONNECTIONS SHALL BE MATED WITH PROPER SIZE GASKET, PREFERABLY HELD IN A GASKET RETAINER ASSEMBLY (ITEM 32, ITEM 33).

17. FOLLOW VENDOR DIRECTIONS FOR REPEATED USE OF THE SAME ASSEMBLY.

18. FILTER MEDIA SHALL BE REMOVED FROM THE NUPRO FILTER HOUSING (ITEM 21) FOR THE PRODUCTION BINS S/N PB-009 THROUGH PB-018.

19. CUT WIRE CLOTH INTO 20 FT. LONG PIECES. FOLD INTO SIX APPROXIMATELY 40" LONG ACCORDIAN STYLE BENDS. LOAD 3 PIECES (60 L.F.) OF THE FOLDED WIRE CLOTH DIRECTLY ONTO THE GAS MANIFOLD ASSEMBLY (DWG. NOS. 412-M-005-W AND 412-M-007-W). INSTALL PRIOR TO SHIPMENT OF BIN TO GENERATOR SITE.





REV	ISSUE DESCRIPTION	DFTR / DATE	CHK / DATE	COG / DATE	DFTG MGR / DATE	ECO	PWR
F	REVISED PER ECO FD	RM 4/15/92	[illegible] 4/15/92	[illegible] 4/15/92	[illegible] 4/15/92	5183 5206 5848	
E	REVISED PER ECO FD	DLH 10/18/90	TRA 10/17/90	MB 10/17/90	HB 10/18/90	4869 5000	

THIS DRAWING CREATED BY ENGINEERING CHANGE ORDER (ECO) :

INTERPRET DWG PER ANSI Y14	DFTG A.E.SEWALD 10/30/89
DIM. IN INCHES BASED ON 68° F	CHKR. TONY ALSTON 10/17/90
UNLESS OTHERWISE SPECIFIED TOLERANCES	COG. ENG M. BALI 10/17/90
2 PL DEC: ±.06 / 3 PL DEC: - / ANGLES: - / AA	COG. MGR J.J. GARCIA 1/12/90
FRACTIONS: ±1/8 TORQUE ±2 FT-LB or +2 -0 IN-LB	Q.A. JAMES F. ALLEN 12/6/89
ENGINEERING RELEASE BY (W) WID--WIPP ECO _____ DATE _____	SAFETY C.D. JACKSON 12/6/89
	APPD W.R. WHITE 12/6/89
	APPD TERRY C. MERKLING (RS)
	DFTG. MGR. BELLOWS 10/18/90
	SNL MARTY A. MOLECKE 12/6/89
	DOE E.K. HUNTER 12/11/89
	SCALE 1/8 UNO

U.S. DEPARTMENT OF ENERGY

Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

BIN-SCALE TESTS
DRY TEST BIN ASSEMBLY

SYS	DWG. NO.	REV.
WH06	412-N-002-W	F

DWG. 1 OF 1

2 1

8. TO BE INSTALLED AT WIPP AT TIME OF LID INSTALLATION ON RCB.

9. ITEM 4 AND ITEM 14 TO BE SHIPPED WITH ITEM 1 BUT NOT ATTACHED.

10. AFTER INSTALLING ITEM 10 IN ITEM 2, MATCH MACHINE THE GROOVES OF ITEM 10 INTO ITEM 2.

11. THE REQUIREMENTS SPECIFIED IN SPEC. E-I-343 SHALL APPLY TO ITEM 1 UNLESS NOTED OTHERWISE IN THIS DRAWING.

12. REMOVED

13. TAG COLOR SHALL BE PER IDENTIFICATION TABLE. TAGS SHALL BE 3" X 2", WITH 1/4"-1/2" CHARACTERS. TAGS TO BE MOUNTED WITH ITEM 16. TEXT TO BE PER TAG IDENTIFICATION TABLE.

14. RECTANGULAR STRIPS OF THE SAME COLOR AS ASSIGNED TO EACH PORT SHALL ALSO BE PROVIDED ON THE UNDERSIDE OF ITEM 6, ADJACENT TO THE RESPECTIVE VALVE. THE RECTANGULAR STRIPS SHALL BE 1/2" X 1". MATERIAL SHALL BE THE SAME AS ITEM 15 AND MOUNTED WITH ITEM 16.

15. THE STEM AT EITHER END OF ITEM 4 AND ITEM 14 SHALL BE PAINTED WITH THE SAME COLOR AS THE CORRESPONDING TAG ON THE PORT. THE PAINT SHALL BE APPLIED AT THE BASE OF THE MALE HOSE STEM. THE WIDTH OF THE PAINT SHALL NOT EXCEED 1/2". DO NOT PAINT MATING ENDS OR THREADS.

16. EACH VALVE AND HOSE SHALL BE TESTED BY THE MANUFACTURER TO A HELIUM LEAK RATE OF 4 X 10^{-9} STD. C.C./SEC OR LESS.

17. THE VALVES AND HOSES SHALL BE LEAK TESTED AS AN ASSEMBLY TO 1 X 10^{-8} SCC/SEC OF HELIUM. THE LEAK PROCEDURE SHALL BE SUBMITTED FOR APPROVAL PRIOR TO ANY TESTING. THE HOSES SHALL BE REMOVED FROM THE LID FOR SHIPPING. THE MEASURED LEAK RATE SHALL BE RECORDED AND REPORTED. TEST RESULTS SHALL BE INFORMALLY REPORTED AS THE OCCUR. FAILURE OF A JOINT OF DIFFICULTY IN OBTAINING A SEAL SHALL BE RECORDED SO THAT A DATA BASE MAY BE DEVELOPED ON THE PERFORMANCE OF THE VCR FITTINGS. THE INSTRUMENTS USED TO MEASURE THE LEAK RATE SHALL BE CAPABLE OF MEASURING 5 X 10^{-9} SCC/SEC OF HELIUM OR BETTER.

REV	ISSUE DESCRIPTION	DFTR	CHK	COG	DFTG MGR	ECO	PWR
		DATE	DATE	DATE	DATE		
G	REVISED PER ECO	RM 4/15/92	ABS 4/15/92	[illegible] 4/15/92	[illegible] 4/15/92	5189	
F	REVISED PER ECO FD	TRA 06/25/91	TOM KOCWALSKI 06/25/91	OM 06/25/91	BA 06/26/91	5354 5429	

THIS DRAWING CREATED BY ENGINEERING CHANGE ORDER (ECO) : 4388

INTERPRET DWG PER ANSI Y14
DIM. IN INCHES BASED ON 68° F
UNLESS OTHERWISE SPECIFIED TOLERANCES

2 PL DEC	3 PL DEC	ANGLES	
±.06	—	±1°	√AA

FRACTIONS ±1/8

ENGINEERING RELEASE
BY (W) WID-WIPP
ECO _____ DATE _____

DFTG T. ALSTON 3/21/90
CHKR. D. HUGHES 10/18/90
COG. ENG M. BALI 10/18/90
COG. MGR JOHN J. GARCIA 5/18/90
Q.A. JIM ATCHENSON 5/18/90
SAFETY C.D. JACKSON 5/21/90
RAD.SAF. ORMAND CORDES 5/18/90
WHO. CLINT KELLEY 5/9/90
DFTG. MGR H.W BELLOWS 10/18/90
SNL MARTY MOLECKE 5/31/90
DOE W.A. WALKER 5/18/90
SCALE NOTED

U.S. DEPARTMENT OF ENERGY
Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

BIN SCALE TESTS SWB LID MODIFICATION FOR RCB LID ASSEMBLY AND DETAILS

SYS. WH06 | DWG. NO. 412-N-009-W | REV. G | SH. 1 OF 1

D C B A

2 1

ORIGINAL

USE BLACK INK

ENGINEERING CHANGE ORDER

1. ECO No.: 5204
CC&D Review: RL

Initials

Posted

2. Impact Level 1 ☐ 2 ☐ 3 ☒ 4 ☐

3. System: GC01 Equipment No.: N/A Building: Roads

4. Associated Documents:
PWR M-04424
ECP 2-GC91-B14
P.O. ____
Others ____

5. Document Type:
Drawing 24-C-140-022 ☒
Specification 24-C-143-022, 24-C-145-022 ☐
Vendor Data 24-C-147-022, 24-C-149-022 ☐
SDD 24-C-010-W ☐
Others ____

6. Title of Change: Traffic Guardrails, CCP-22 dwgs

7. Originator: (print) J. Kowalski | Ext. No.: #167 | Department: MACE | Date: 01/15/91

8. Cognizant Engineer: (print) J. Kowalski

9. Description of Change:

Yes ☐ No ☒ Component indices change required (if yes, attach sheets)

~~1. Assign numbers to the attached sketches~~

2. Incorporate the information from the attached (Sk-1 & Sk-2) on the drawings listed below:
24-C-140
24-C-143
24-C-145
24-C-149 – Post detail (sk-2 only)
24-C-010 – Sheet 1 & 2
24-C-147

☒ 9a Drawing Change Sheet attached
☐ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

10. Yes ☐ No ☒ MODIFICATION IN PROGRESS
Modification complete: _____ (Signature) / 1/14/91 (Date)
ECO will be incorporated after M.I.P. signed complete

☐ Change drawing per as-built markup dated: ____
☒ Change drawing per ECO-provided data
☐ Temporary modification

11. Design Verification Requirements: (per WP 09-018) EDT No.: ____

JWP 1. Requirements satisfied by review/approval of design document
____ 2. Independent review
____ 3. Alternate calculations
____ 4. Development testing
____ 5. Design review
____ 6. Other: ____

12. Addendum Sheet added: ____ (Signature) / ____ (Date)

13.. Justification

Compliance with Safety Traffic Code
30 CFR-57

14a. Administrative Tracking

YES	N/A		YES	N/A	
☐	☒	1. FSAR	☐	☒	6. Startup/Acceptance Test
☐	☒	2. Calibration Procedures	☐	☒	7. Test Requirement & Spec.
☐	☒	3. Maintenance Procedures	☐	☐	8. _____
☐	☒	4. Computer Software	☐	☐	9. _____
☐	☒	5. Operations Procedures	☐	☐	10. _____

15. Signature Requirements

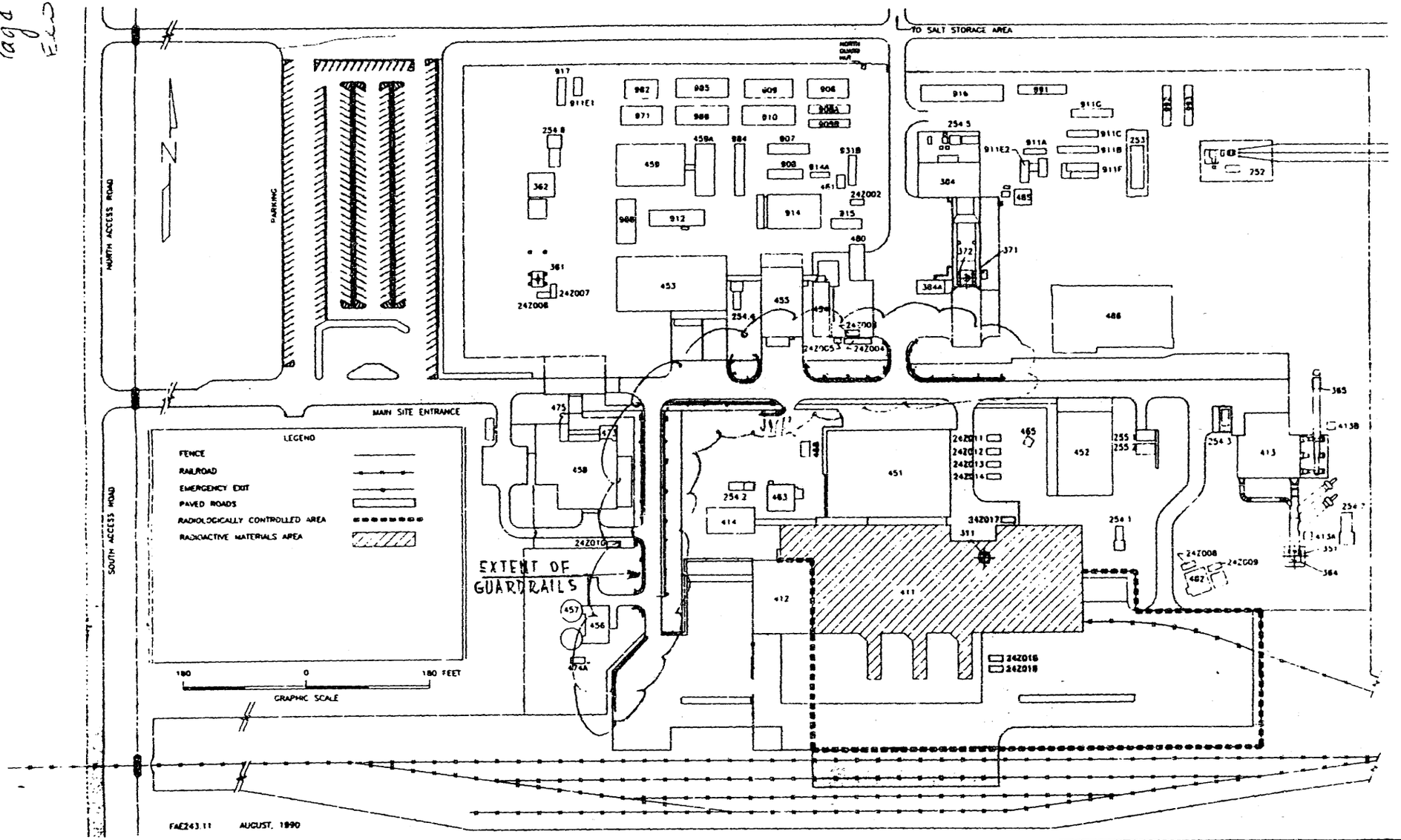
KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

A	Cog. Engineer	J. Knight 1/15/91
A	Cog. Eng. Mgr.	Sanford 1/15/91
R	Startup	01-28-91
R	QA	1/31/91
☐	DOE	
A	Safety	1-29-91
☐	Dept. Manager	
R	Operations	1/30/91
☐	Security	
☐	SNL	
☐		
☐		
☐		

16. Distribute as Marked

☐	Maintenance (MANDATORY) _____
☐	Ops. Support (MANDATORY) _____
☐	Startup _____
☐	Facility Operations _____
☐	U/G Operations _____
☐	Orig./Design Engr. _____
☐	Cog. Engineer _____
☐	Others _____
☐	_____
☐	_____
☐	_____
☐	_____
☐	_____

Page 3 of 18
Enclosed



SITE GUARDRAIL

SKETCH SK-1

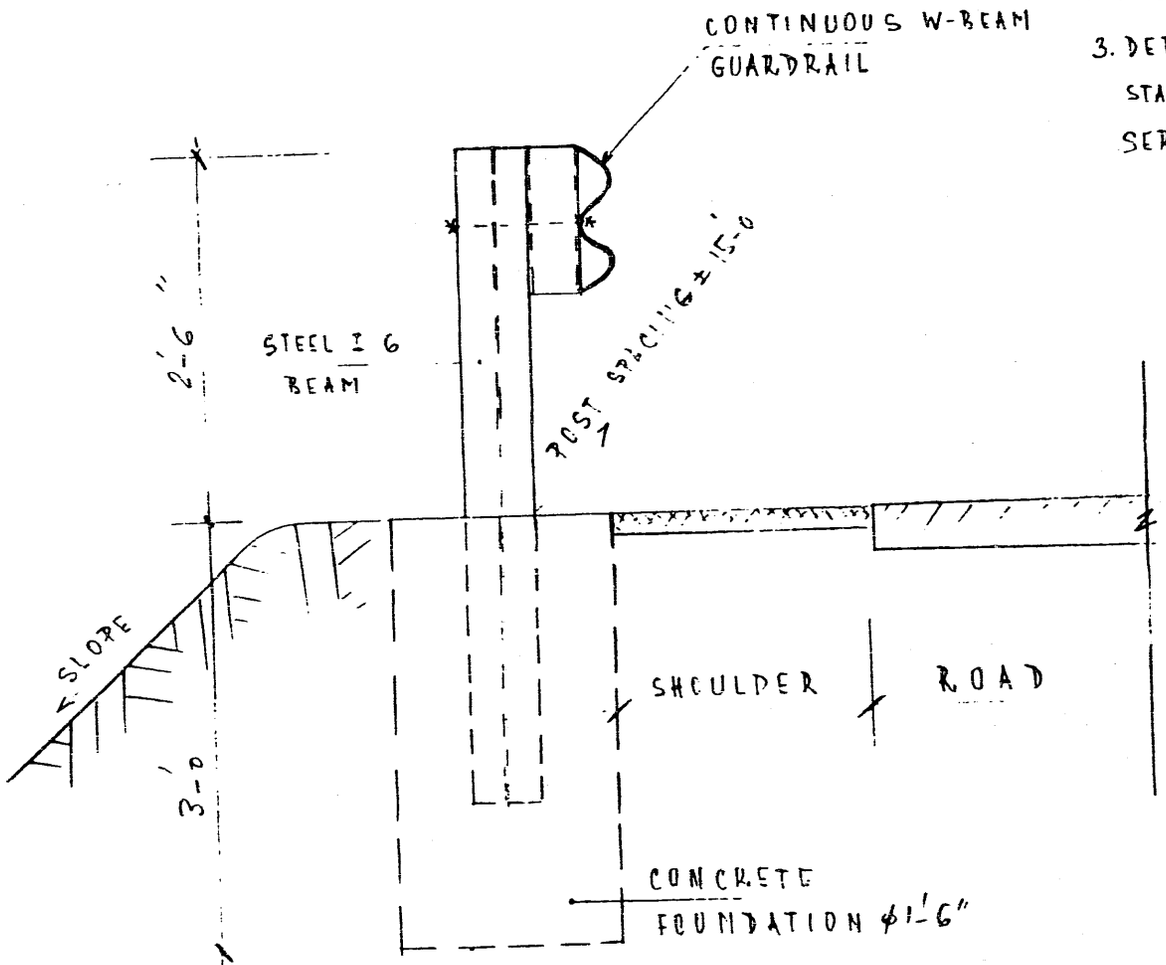
COG ENG: [illegible] 1/25/91

COG NGD: [illegible] 1/25/91

Page 4 of 10
LC0501014

NOTES:

1. MATERIAL & INSTALLATION SHALL COMPLY W/ N.M. HGHWY DEP. SPECIFICATION
2. ALL STEEL TO BE GALVANIZED
3. DETAILS AS PER NEW MEXICO STATE HIGHWAY DEP DRAWING SERIAL M-21-[illegible] & M-21-[illegible]



GUARDRAIL DETAIL

SITE GUARDRAIL

SKETCH - SK-2

COG ENG: [illegible]

COG MGR: [illegible] 1/25/21

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 24-C-140-022 ECO Number: 5204

2. ECO Search List: _____ _____ _____ _____

3. Description of Change:

Show location of the guardrails as per attached sketch SK-1.

4. Drawing Cog. Engineer Approval: J. Krwa Mg Date: 1/24/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

1290:B0006

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 24-C-143-022 ECO Number: 5204

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Show location of the guardrails as per attached sketch SK-1.

4. Drawing Cog. Engineer Approval: J. Kmart Date: 1/24/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 24-C-145-022 ECO Number: 5204

2. ECO Search List: _____ _____ _____ _____

3. Description of Change:

Show location of the guardrails as per the attached sketch SK-1.

4. Drawing Cog. Engineer Approval: J. Kovach Date: 1/24/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 24-C-147-022 ECO Number: 5204

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Show location of the guardrails as per the attached sketch SK-1.

4. Drawing Cog. Engineer Approval: J. Howard Date: 11/24/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 24-C-149-022 ECO Number: 5201

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Show the guardrail detail as per attached sketch SK-2.

4. Drawing Cog. Engineer Approval: J. Kowalik Date: 1/24/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 24-C-0101N, Sheet 1 & 2 ECO Number: 5204

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Show location of the guardrails as per the sketch SK-1. (attached)

4. Drawing Cog. Engineer Approval: J. Howard Date: 1/24/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

USE BLACK INK

ENGINEERING CHANGE ORDER ENGINEERING FILE ROOM COP

1. ECO No.: 5206
CC&D Review: BF

Initials

Posted

APR 1992
COMPLETE

2. Impact Level 1 ☐ 2 ☒ 3 ☐ 4 ☐

3. System: WH06 Equipment No.: N/A Building: U/G

4. Associated Documents:
PWR
ECP
P.O.
Others

5. Document Type:
Drawing 4-12-W-002-W ☒
Specification 4-12-F-07-W ☒
Vendor Data E-17-33 ☐
SDD ☐
Others

6. Title of Change: BIN MODIFICATION

7. Originator: (print)	Ext. No.:	Department:	Date:	8. Cognizant Engineer: (print)
OM MENDIRATTA	8377	RWHE	1/25/91	OM MENDIRATTA

9. Description of Change:

Yes ☐ No ☒ Component indices change required (if yes, attach sheets)

BIN SCALE TESTS - DRY
TEST BIN ASSEMBLY :

1. MODIFY THERMOCOUPLE MOUNTING ARRANGEMENT PER ATTACHED SHEETS
2. PROVIDE CRADLE STABILITY SUPPORTS PER ATTACHED SHEETS

☒ 9a Drawing Change Sheet attached
☐ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

10. Yes ☒ No ☐ MODIFICATION IN PROGRESS
☑ Modification complete: Om Mendiratta / 2/27/91 (Signature / Date)
ECO will be incorporated after M.I.P. signed complete

☐ Change drawing per as-built markup dated:
☑ Change drawing per ECO-provided data
☐ Temporary modification

11. Design Verification Requirements: (per WP 09-018) EDT No.:

JF ✓1. Requirements satisfied by review/approval of design document
2. Independent review
3. Alternate calculations
4. Development testing
5. Design review
JF ✓6. Other: Final drawing review & approval

12. Addendum Sheet added: A. Kramer / 8-2-91 (Signature / Date) Addendum #1 added 8-21-91 SW

13. Justification

1. SNL request to install thermocouples on the external bin wall. Solved issue of potential leak paths with bin internal installation configuration.
2. Cradle stability supports are being provided to reduce rocking and accidental damage to the valves by the filter assy.

14. Administrative Tracking

YES	N/A		YES	N/A	
☐	☒	1. FSAR	☐	☒	6. Startup/Acceptance Test
☐	☒	2. Calibration Procedures	☐	☒	7. Test Requirement & Spec.
☐	☒	3. Maintenance Procedures	☐	☐	8. _____
☐	☒	4. Computer Software	☐	☐	9. _____
☐	☒	5. Operations Procedures	☐	☐	10. _____

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

[A]	Cog. Engineer	Gu Mendiratta 1/25/91
[A]	Cog. Eng. Mgr.	Tim Patricia 1/25/91
[R]	Startup	01-28-91
[R]	QA	James P. Allen 1/24/91
[R]	DOE	1-28-91
[R]	Safety	1-28-91
[ ]	Dept. Manager	
[R]	Operations	CR Tilley 1-28-91
[ ]	Security	
[A]	SNL	H. Dwell 1/25/91
[A]	Rad Safety	Ted Hall 1/28/91
[ ]		
[ ]		

16. Distribute as Marked

[X]	Maintenance (MANDATORY)	
[X]	Ops. Support (MANDATORY)	
[ ]	Startup	
[ ]	Facility Operations	
[ ]	U/G Operations	
[ ]	Orig./Design Engr.	
[X]	Cog. Engineer	
[ ]	Others	
[ ]		
[ ]		
[ ]		
[ ]		
[ ]		

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 412-N-002-W ECO Number: 5206

2. ECO Search List: 5189

3. Description of Change:

Revise drawing 412-N-002-W, Rev. E, per attached sheets for (i) thermo couple mounting arrangement, (ii) Cradle support.

4. Drawing Cog. Engineer Approval: Date: 1/25/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 412 - F - 017 - W ECO Number: 5206

2. ECO Search List: 5189

3. Description of Change:

Revise drawing 412-F-017-W, Rev. E, per attached sheets for (i) Thermocouple mounting details (ii) Cradle support details.

4. Drawing Cog. Engineer Approval: Ron Mendiratta Date: 1/25/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

1290:B00C

ENGINEERING CHANGE ORDER Continuation Sheet	Document Number: 412-N-002-W		ECO 5206
	Date: 1/25/91	Page 5 of 18	

1. Delete item 7 from the B.O.M.

2. Delete thermocouple mounting arrangement shown on Detail-1.

3. Delete note 8

4. Delete thermocouple ports on the view "TC LOCATIONS VIEW C-C" (F-7)

5. Delete thermocouple ports and coils under the view "TC LOCATIONS VIEW C-C" (D-7)

6. Delete thermocouple location and configuration enveloped by bubble for Detail-1 (E-7)

ENGINEERING CHANGE ORDER Continuation Sheet	Document Number: 412-F-017-W		ECO 5206
	Date: 1/25/91	Page 6 of 18	

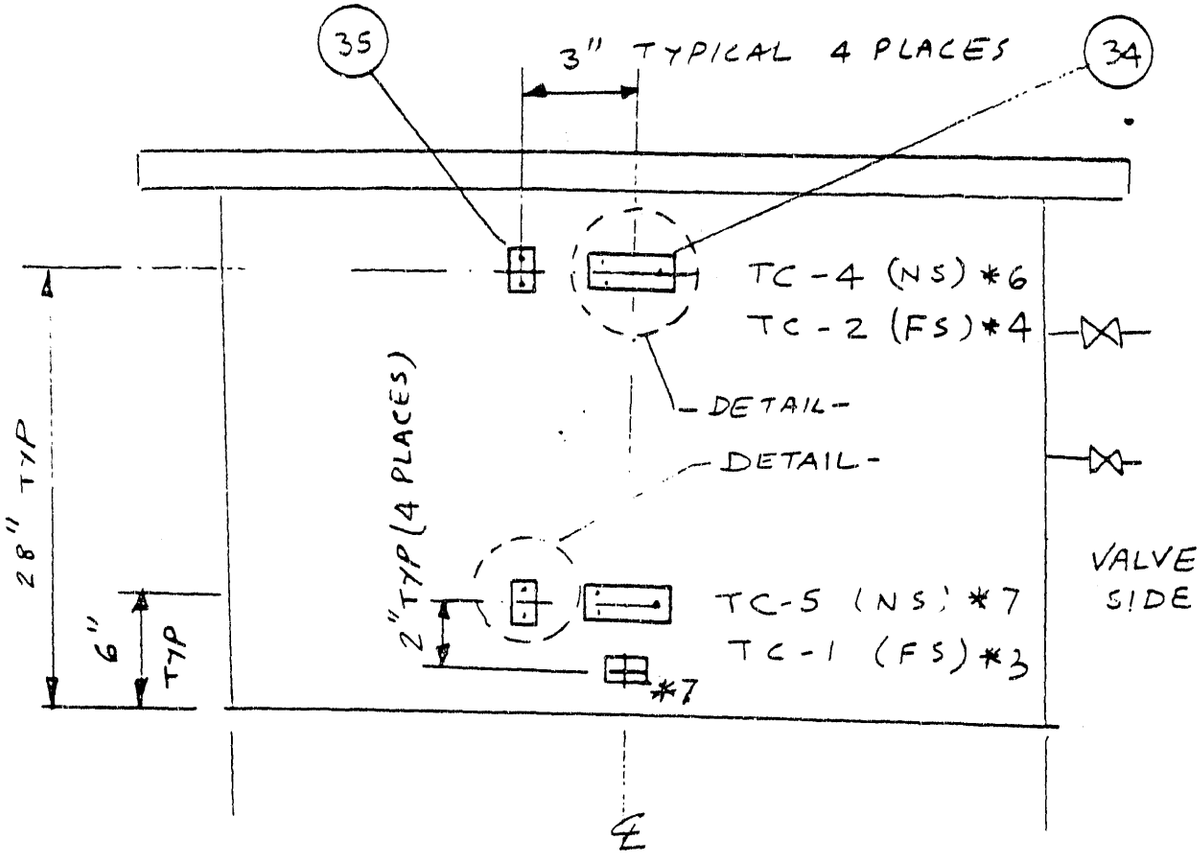
7. Delete item 10 from B.O.M.

8. Delete Detail 5 "Thermocouple mounting" (C-3)

9. Delete thermocouple ports in the bin side-view (F-7)

ENGINEERING CHANGE ORDER Continuation Sheet	Document Number: 412-N-002-W		ECO 5206
	Date: 1/25/91	Page 7 of 18	

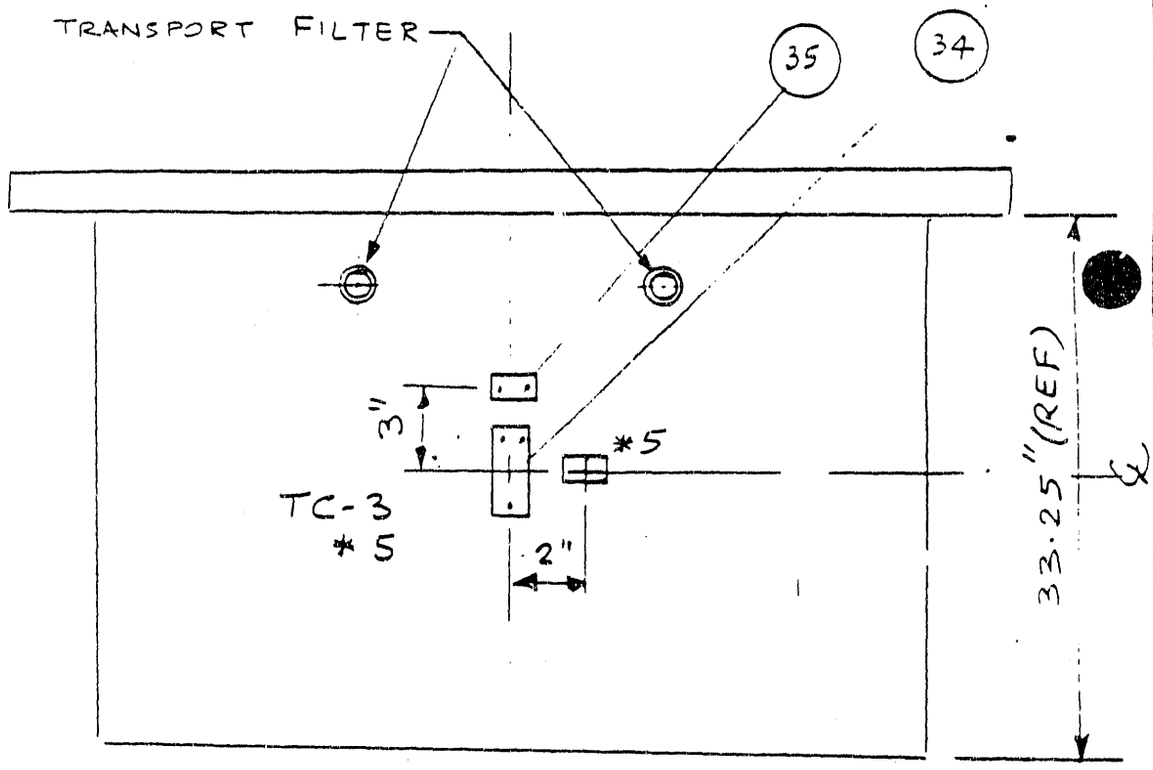
10. Show revised thermo couple mounting location on the "bin side view" (D-6) as under (TAG NUMBERS ARE PROVIDED FOR CROSS REFERENCE)



THERMOCOUPLE MOUNTING ARRANGEMENT

ENGINEERING CHANGE ORDER Continuation Sheet	Document Number: 412-N-002-W		ECO 5206
	Date: 1/25/91	Page 8 of 18	

11. Show revised thermocouple mounting location on the "bin transport filter side" view (D-8) as under.



THERMOCOUPLE MOUNTING ARRANGEMENT

TRANSPORT FILTER SIDE

ENGINEERING CHANGE ORDER Continuation Sheet	Document Number: 412-N-002-W		ECO 5206
	Date: 1/25/91	Page 9 of 18	

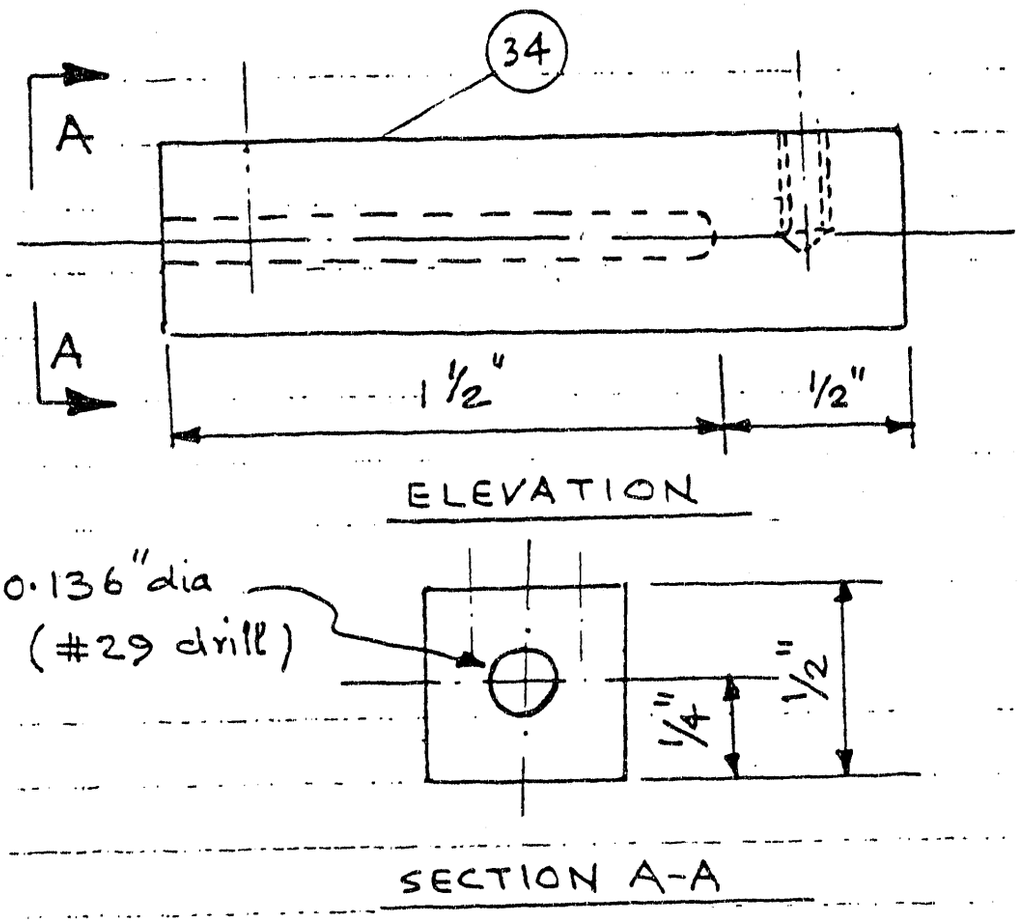
12. Add item 34 and 35 (number as appropriate) to the B.O.M. :

(i) #34 ; Qty = 5 ; THERMOCOUPLE Insert block ; 412-F-017-H xx ; SS 304 L

(ii) #35 ; Qty = 5 ; THERMOCOUPLE CLAMP; 412-F-017-H xx ; SS 304L

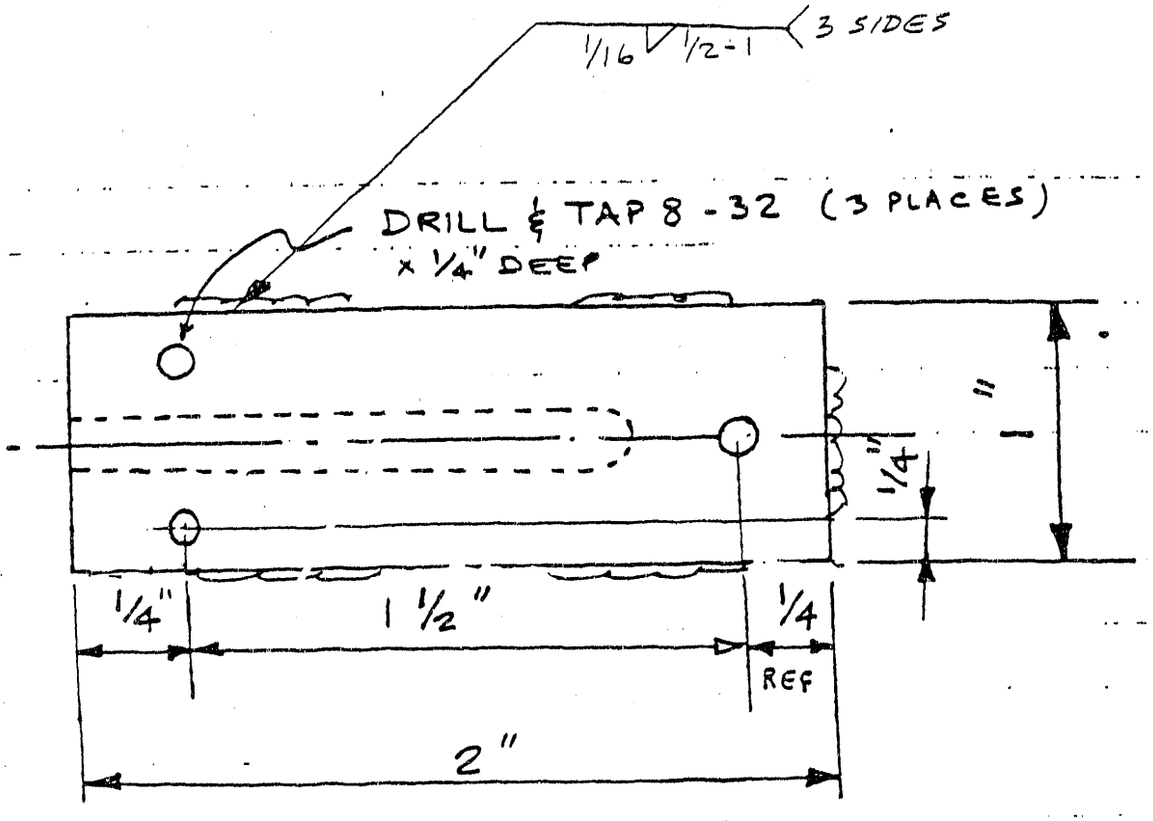
ENGINEERING CHANGE ORDER Continuation Sheet	Document Number: 412-F-017-W		ECO 5206
	Date: 1/25/91	Page 10 of 18	

13. Add Thermocouple Insert block detail as shown under (NOTE: PLAN VIEW on next page)



ENGINEERING CHANGE ORDER Continuation Sheet	Document Number: 412 - F - 017 - W		ECO 5206
	Date: 1/25/91	Page 11 of 18	

13. (Continued) Plan view for item 34



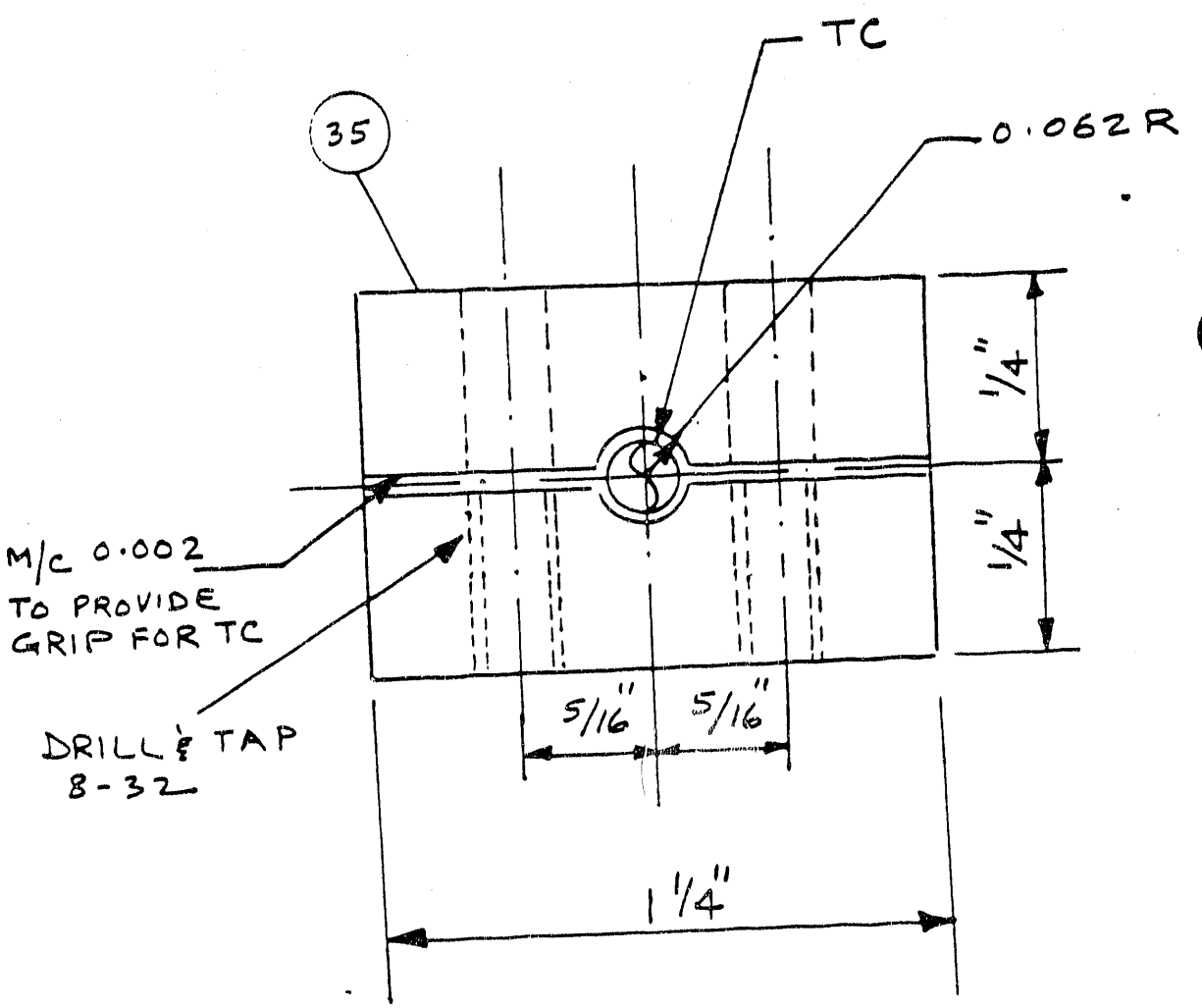
PLAN VIEW

14. Indicate "item 34 to bin wall" weld :

$\frac{1}{16}$ F ; $\frac{1}{2}$" L , 5 Places (see location in plan view)

ENGINEERING CHANGE ORDER Continuation Sheet	Document Number: 412 - F - 017 - W		ECO 5206
	Date: 1/25/91	Page 12 of 18	

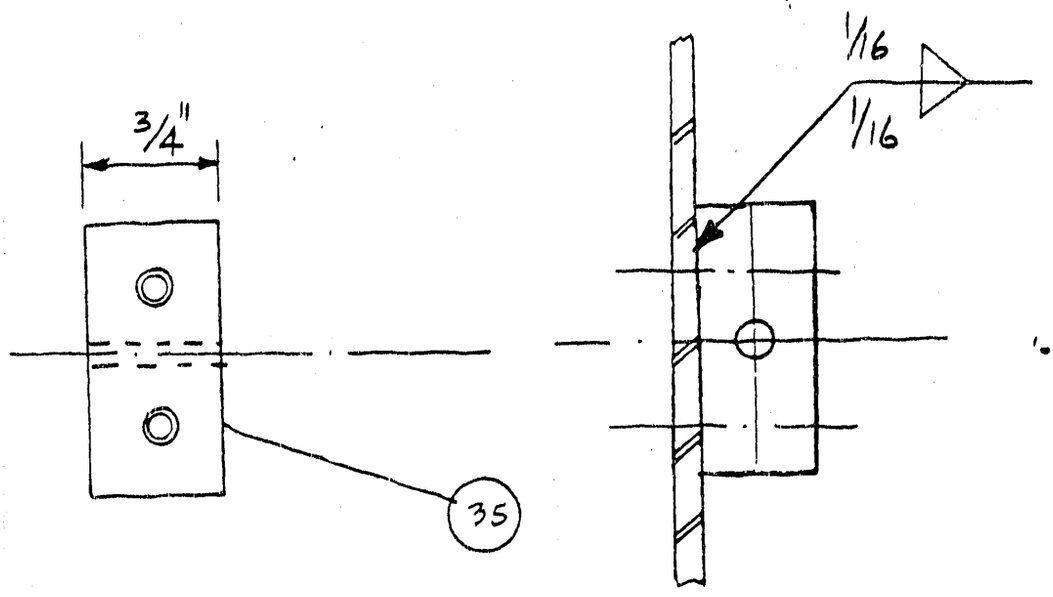
15. Add thermocouple clamp (item 35) detail as shown under.



STOCK SIZE: 1/4" x 3/4" x 1 1/4"

ENGINEERING CHANGE ORDER Continuation Sheet	Document Number: 412-F-017-W		ECO 5206
	Date: 1/25/91	Page 13 of 18	

15. (Continued)



16. Add item 36, Hex Socket Head stainless Steel Cap screw x 1/2" lg ; Qty = 10 (for use with item 35)

ENGINEERING CHANGE ORDER Continuation Sheet	Document Number: 412-N-002-W		ECO 5206
	Date: 1/25/91	Page 14. of 18	

17. Revise dimension 3 1/2" for stenciling words "Max Gross Weight 3,200 lbs", to 20" in the bin side view (E-5)

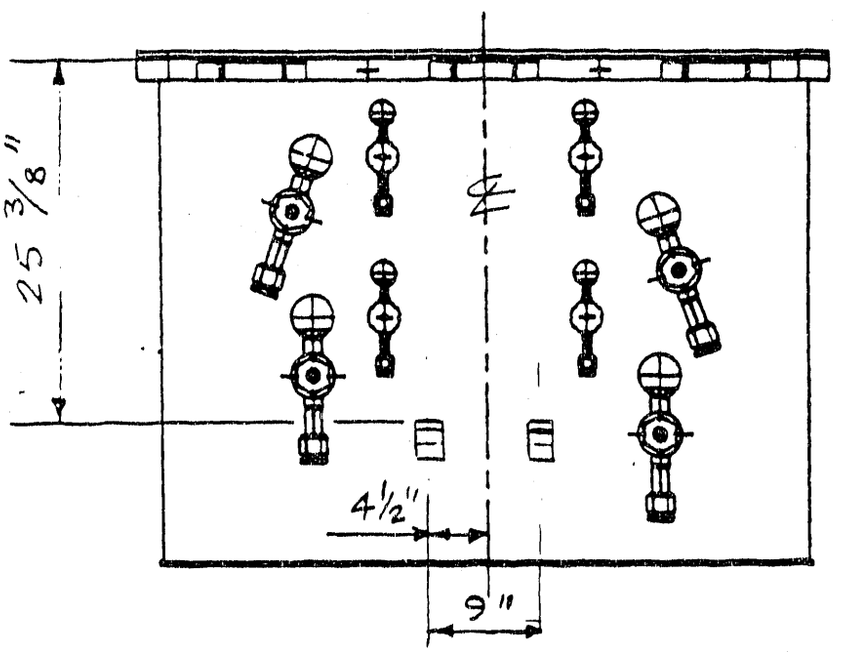
18. Add ∠ 2" x 1 1/2" x 1/4" x 1" lg to the BOM as item 3.

37 ; Qty = 2 ; Cradle Support;

412-F-017-H XX ; ASTM A-36

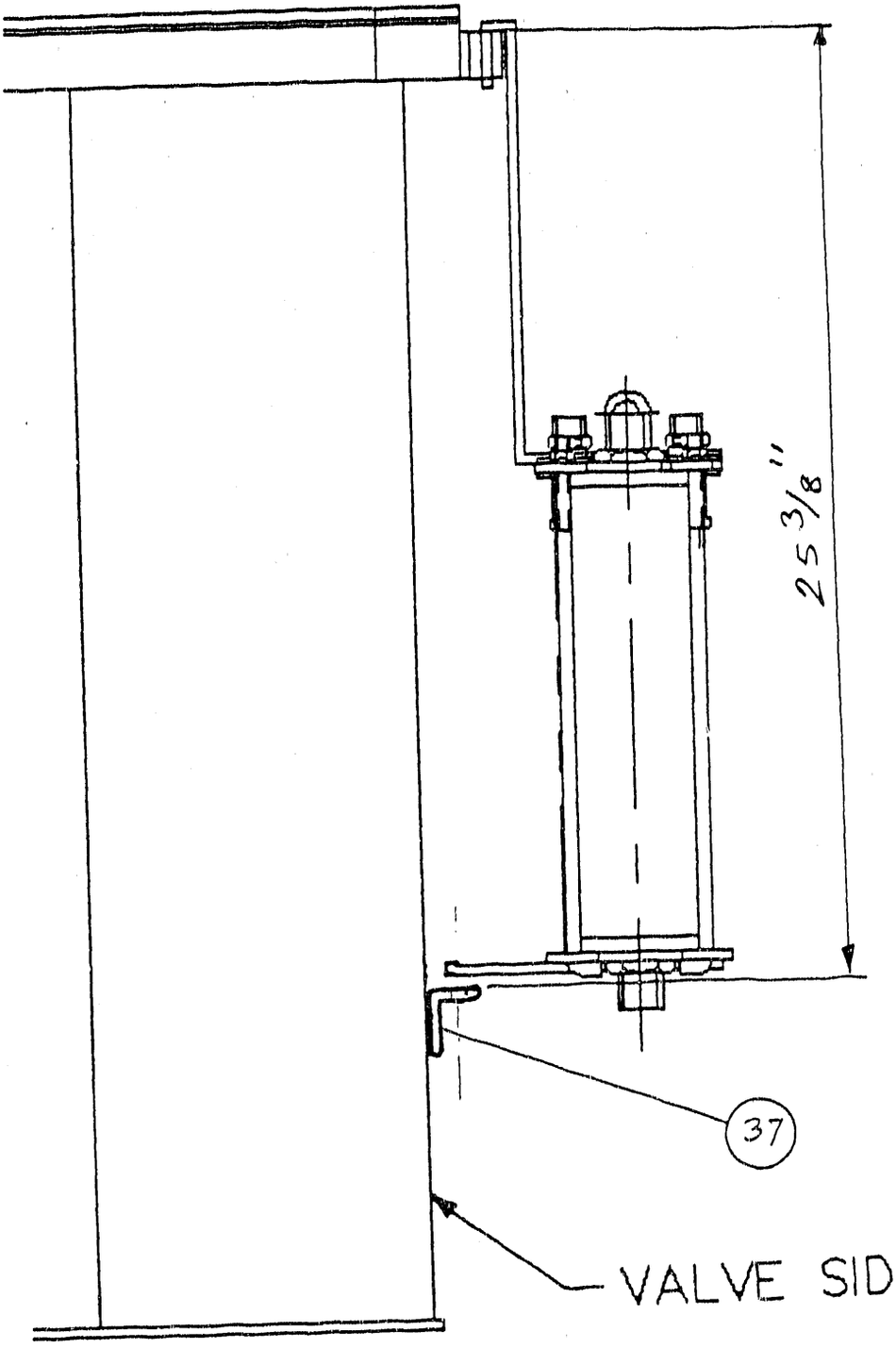
ENGINEERING CHANGE ORDER Continuation Sheet	Document Number: 412-N-002-W		ECO 5206
	Date: 1/25/91	Page 15 of 18	

19. Locate Cradle Support Angles on bin front view (D-4) as shown under.

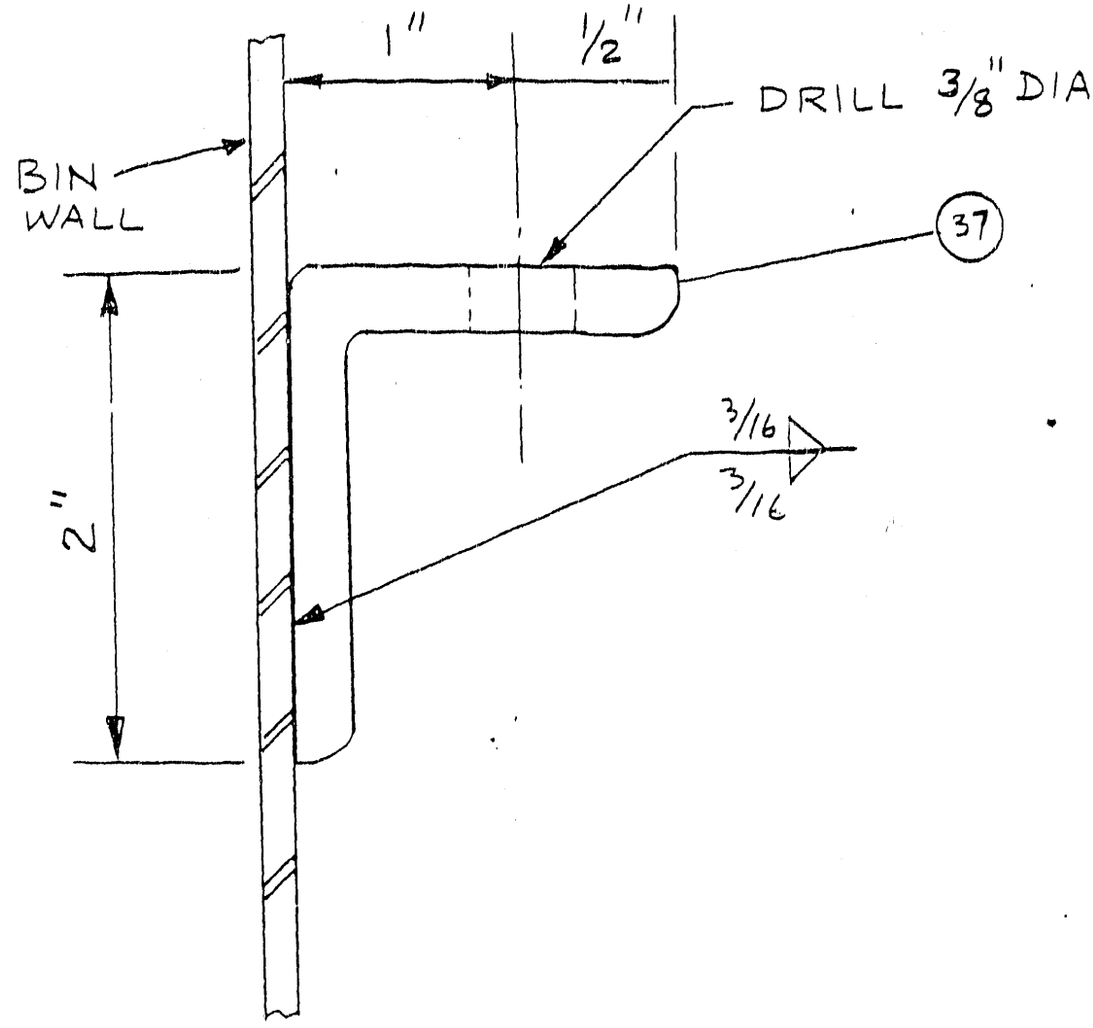


20. Add Enlarged view as shown on next page to locate Cradle support angle on dwg 412-F-017-W

ENGINEERING CHANGE ORDER Continuation Sheet	Document Number: 412 -F-017- W		ECO 5206
	Date: 1/25/91	Page 16 of 18	



ENGINEERING CHANGE ORDER Continuation Sheet	Document Number: 412-F-017-W		ECO 5206
	Date: 1/25/91	Page 17 of 18	



21. Add detail for item 37, as shown above.

ENGINEERING CHANGE ORDER Continuation Sheet	Document Number: 412-N-002-W		ECO 5206
	Date: 1/25/91	Page 18 of 18	

22. Editorial changes:

(i) Delete last two lines of note 2, "Filter element ---------- Technology, INC."

(ii) Add a note," Filter media shall be removed from the NUPRO filter housing (item 21) for the production bins S/N PB-009 through PB-018.

(iii) Revise Part name/Description for item 21 in B.O.M. to read "Breather Filter Housing."

ENGINEERING CHANGE ORDER
ADDENDUM SHEET #1

SPECIFICATION: E-A-334

1. Addendum Sheet to ECO Number: 5206 Drawing Number: _____

2. Description of change:

(1) List specification E-A-334 in Section 5 of ECO #5206.

(2) Delete reference to the internally mounted thermocouples. Call it- mounted as Externally mounted where necessary. (e.g. Delete para 3.3.16 last item, Thermocouple ports and the following note; revise 3.3.17 (page 6) to state: "externally mounted thermocouples)

Note: The approved scope of ECO #5206 is not changed. This addendum references an affected document omitted from the original ECO.

(3) Replace pages 6 and 7 of spec. E-A-334, Rev. 1 with attached pages.

3. Approvals

Cognizant Engineer:	Signature	8/2/91 Date
CC&D Mgr. /Desig. Rep.:	Signature	8/02/91 Date
Other Approval:	Signature	8/2/91 Date
Other Approval:: QA	Signature	8-2-91 Date

1290:B0009

Equipment	Function	Number
Pressure Relief Valves	To prevent the bin's internal pressure from exceeding 0.6 psig.	2
Brine Injection Ports	For the equipment that will inject brine into the bin.	2 minimum
Pressure Gauges	To monitor the bin's internal pressure.	2
Brine Sampling Ports	For the equipment that will take brine samples out of the bin.	2 minimum
Gas Injection	For the equipment that will inject gases into the bin.	2
Oxygen Sensing/Gas Sample Port	For sensing the oxygen in the bin. An inlet and an outlet are required. The same ports will be used to connect the sampling apparatus to. The sampling apparatus is not within the scope of this specification.	1 Inlet, 1 Outlet
Oxygen Gettering Port	To remove the oxygen in the bin. An inlet and an outlet are required.	1 Inlet, 1 Outlet
~~Thermocouple Ports~~	~~For thermocouples to monitor the bin's internal temperature.~~	~~5~~

Dm 8/2/91

~~Note: SNL shall specify and supply the instrumentation to be attached to the bin for gathering test data. SNL shall also provide thermocouple installation procedures to the Supplier and instruct the Supplier on the installation.~~

3.3.17 The bin shall be designed to allow the monitoring of its ~~internal~~ temperature through externally mounted 8/2/91 thermocouples reading at five points on the bin floor and walls. The location of the points shall be as below.

a. One at the diagonal center of the floor

b. Two at the horizontal center of one wall, 6" and 30" above the floor

c. Two at the horizontal center of the opposite wall, 6" and 30" above the floor

8/2/91

~~3.3.18 The thermocouples shall be protected from the corrosive elements that will reside in the bin. If a liner is used to protect the bin walls and floor from corrosion, then the thermocouples shall be inserted between the liner and the walls or floor.~~

3.3.19 If plastic materials are used in the bin, such as for gaskets and liners, if any, these materials shall be fire-resistant.

3.3.20 The bin shall be designed such that it can be made from standard metals; for example: steel conforming to ASTM A36.

3.3.21 The bin shall be constructed of materials that do not release VOCs or other gases that will contaminate the gas samples to be drawn from the bin.

Particulate Filters

3.3.22 Gases from the bin shall be filtered for radioactive contamination. This shall be achieved by means of one or more particulate filter(s). The paragraphs that follow in this section pertain to the requirements imposed on each particulate filter.

The bin has two sizes of particulate filters: small and large. Some requirements below are common to both. Where the requirements of one are different form the other, they are so stated.

3.3.23 NQA-1

The extent to which NQA-1 applies to the bin supplier shall also apply to the filter manufacturer(s). The extent to which NQA-1 applies is specified elsewhere in this specification.

3.3.24 Dimensions

Small Filter: The filter shall be cylindrical with outside dimensions not exceeding 2" in diameter and 4" long. Large Filter: The filter shall be cylindrical with dimensions not exceeding 4" diameter and 16" long. If a larger diameter becomes necessary, one of the two filter ports shall be offset from the filter's centerline such that the port's axis is 4", +0, -1/8" from the nearest edge of the filter. For both small and large filters, inlet and outlet shall be interchangeable, and the outside dimensions shall include the ports specified below.

3.3.25 Ports

There shall be only two ports on the filters: an inlet and an outlet. Small Filter: Both ports shall be 1/2" Swagelok tube fittings or equal. Large Filter: Both ports shall be 1" Swagelok tube fittings or equal.

3.3.26 Air Flow Capacity

Small Filter: The minimum capacity of the filter shall be 200 cc/min at 1" of water gage pressure drop across the filter using air. Large Filter: The minimum capacity of the filter shall be 500 liters/min at 1" of water gage pressure drop across the filter using air. For both filters, the filter

SPEC. NO. E-A-334
REVISION NO. 2
REVISION DATE 01-28-92
SYSTEM WH06

BIN FOR BIN-SCALE TESTS

WASTE ISOLATION PILOT PLANT

Westinghouse Electric Corporation
Carlsbad, New Mexico 88220

ENGINEERING CHANGE ORDER
ADDENDUM SHEET

1. Addendum H to ECO Number: 5206 Drawing Number: 412-F-017-W
412-N-002-W

2. Description of change:

ECO 5206, MODIFICATION #10 AT PAGE 7 OF 18 SHOULD APPLY TO 412-F-017-W IN ADDITION TO 412-N-002-W.

ECO 5206, MODIFICATION #11 AT PAGE 8 OF 18 SHOULD APPLY TO 412-F-017-W IN ADDITION TO 412-N-002-W.

ECO 5206, MODIFICATION #12 AT PAGE 9 OF 18 SHOULD APPLY TO 412-F-017-W IN ADDITION TO 412-N-002-W AND SHOULD READ:

12. ADD: ITEM #10, QTY. 5; THERMOCOUPLE INSERT BLOCK AND ITEM #31, QTY. 5; THERMOCOUPLE CLAMP ASSEMBLY TO DWG. 412-F-017-W.

ADD: ITEM #34, QTY. 10; SOCKET HEAD CAP SCREW #91251A192 McMASTER CARR OR EQUAL AND ITEM #35, QTY. 5; SQUEEZE BLOCK # 412-F-017-W1-H34 TO DWG. 412-N-002-W.

ECO 5206, MODIFICATION #18 AT PAGE 14 OF 18 SHOULD APPLY TO 412-F-017-W IN ADDITION TO 412-N-002-W.

ECO 5206, MODIFICATION #19 AT PAGE 15 OF 18 SHOULD APPLY TO 412-F-017-W IN ADDITION TO 412-N-002-W.

ECO 5206, MODIFICATION #20 AT PAGES 15 AND 16 OF 18 SHOULD BE SHOWN AT 412-N-002-W RATHER THAN 412-F-017-W

CONTINUED AT SHEET 2 OF 2.

3. Approvals

	Signature	Date
Cognizant Engineer:	[signature]	4/15/92
CC&D Mgr. /Desig. Rep.:	[signature]	4/16/92
Other Approval:	[signature]	4-21-92
Other Approval::		

ENGINEERING CHANGE ORDER
ADDENDUM SHEET

1. Addendum ____ to ECO Number: 5206 Drawing Number: 412-F-017-W
412-N-002-W

2. Description of change:

CONTINUED FROM PAGE 1 OF 2

ITEM NUMBERS SPECIFIED IN ECO 5206, MODIFICATIONS 10, 11, 12, 13, 14, 15, 16, 18, 20, 21, 22, MAY NOT BE THE SAME AS THE ITEM NUMBERS IMPLEMENTED INTO THE DRAWINGS 412-F-017-W AND 412-N-002-W.

MODIFICATION 16 AT PAGE 13 OF 18 TO ECO 5206 SHOULD APPLY TO 412-N-002-W RATHER THAN 412-F-017-W.

3. Approvals

Cognizant Engineer: N/A JB 4/16/92 - SEE PAGE 1
Signature Date

CC&D Mgr. /Desig. Rep.: _____
Signature Date

Other Approval: _____
Signature Date

Other Approval:: _____
Signature Date

392B:0C

2. FILTER HOUSING SHALL BE NUPRO SS-3. SYSTEM IS FACTORY SUPPLIED WITH SILVER-PLATED SS 316 GASKET. HOUSING SHALL HAVE NO MICRON SIZE OR OTHER SPECIFICATION STAMPED ON IT. DISCARD THE NUPRO FILTER ELEMENT IN THE HOUSING.

3. FIBERBOARD LINERS TAPED TOGETHER AT TAB END WITH ITEM 18.

4. SHIP ITEM 4 PLACED INSIDE ITEM 2. NO SHARP BENDS ON GASKET.

5. TAGS TO BE RED WITH WHITE LETTERING ON A 3" X 2" TAG, WITH 1/4"-1/2" CHARACTERS. TAGS TO BE MOUNTED WITH ITEM 20. TEXT OF EACH TAG SHOWN IN TAG IDENTIFICATION TABLE.

6. REMOVED

7. REMOVED

8. REMOVED

9. STANDARD HEX-HEAD BOLTS WITH INTEGRAL WASHERS. BOLTS SHALL BE 1/2-13 UNC X 1-1/4 LG. WITH AN INTEGRAL FLAT WASHER 1" DIAMETER.

10. LEAVE TOP OF ITEM 12 LOOSE AFTER INSTALLING ITEMS 13, 14, 29, & 30.

11. STENCIL BIN EQUIPMENT NO. AND THREE DIGIT SERIAL NO. LETTERS SHALL BE 1/2"-1" HIGH INDELIBLE BLACK. LIDS AND BINS OF THE SAME SERIAL NUMBER SHALL BE SHIPPED TOGETHER. SOLID WASTE BIN EQUIP. NO.: 63-S-001, S/N -001, ETC. PS/SC BIN EQUIP. NO.: 63-S-004, S/N -001, ETC.

12. SANDIA NATIONAL LABS. TO SUPPLY AND INSTALL ITEMS 23, 24, 25, 26, AND 27 PER PROCEDURES APPROVED BY W-WID.

13. TIGHTEN TO 30 FT-LB TORQUE.

14. STENCIL WORDS "MAX GROSS WEIGHT 3,200 LBS." LETTERS SHALL BE 1-2" HIGH, INDELIBLE BLACK, ON NEAR AND FAR SIDE OF BIN, STENCILED AFTER PAINTING BIN.

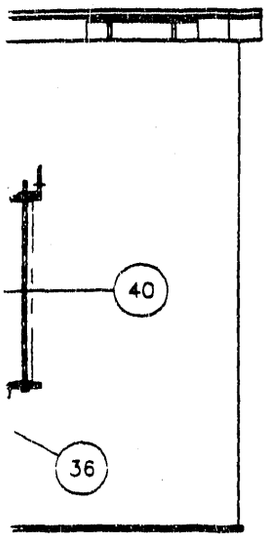
15. TRANSPORT FILTERS (ITEM 38) TO BE FITTED WITH A FEMALE NUT AT THE FABRICATION SHOP. THIS NUT WILL BE REPLACED WITH A CAP NUT AT THE WIPP SITE PRIOR TO DOWN-LOADING OF THE BIN.

16. ALL VCR CONNECTIONS SHALL BE MATED WITH PROPER SIZE GASKET, PREFERABLY HELD IN A GASKET RETAINER ASSEMBLY (ITEM 32, ITEM 33).

17. FOLLOW VENDOR DIRECTIONS FOR REPEATED USE OF THE SAME ASSEMBLY.

18. FILTER MEDIA SHALL BE REMOVED FROM THE NUPRO FILTER HOUSING (ITEM 21) FOR THE PRODUCTION BINS S/N PB-009 THROUGH PB-018.

19. CUT WIRE CLOTH INTO 20 FT. LONG PIECES. FOLD INTO SIX APPROXIMATELY 40" LONG ACCORDIAN STYLE BENDS. LOAD 3 PIECES (60 L.F.) OF THE FOLDED WIRE CLOTH DIRECTLY ONTO THE GAS MANIFOLD ASSEMBLY (DWG. NOS. 412-M-005-W AND 412-M-007-W). INSTALL PRIOR TO SHIPMENT OF BIN TO GENERATOR SITE.



TION
ASSY)

3

15

SEMBLY

REV	ISSUE DESCRIPTION	DFTR / DATE	CHK / DATE	COG / DATE	DFTG MGR / DATE	ECO	PWR
F	REVISED PER ECO FD	RM 4/15/92	AES 4/15/92	Ann 4/15/92	JB 4/15/92	5189 5206 5848	
E	REVISED PER ECO FD	DLH 10/18/90	TRA 10/17/90	MB 10/17/90	HB 10/18/90	4869 5000	

THIS DRAWING CREATED BY ENGINEERING CHANGE ORDER (ECO) :

INTERPRET DWG PER ANSI Y14
DIM. IN INCHES BASED ON 68° F
UNLESS OTHERWISE SPECIFIED TOLERANCES

2 PL DEC	3 PL DEC	ANGLES	
±.06	-	-	√ AA

FRACTIONS: ±1/8
TORQUE ±2 FT-LB
or +2 -0 IN-LB

ENGINEERING RELEASE
BY (W) WID-WIPP
ECO _____ DATE _____

DFTG A.E. SEWALD 10/30/89
CHKR. TONY ALSTON 10/17/90
COG. ENG M. BALI 10/17/90
COG. MGR J.J. GARCIA 1/12/90
Q.A. JAMES F. ALLEN 12/6/89
SAFETY C.D. JACKSON 12/6/89
APPD W.R. WHITE 12/6/89
APPD TERRY D. MERKLING (RS)
DFTG. MGR. BELLOWS 10/18/90
SNL MARTY A. MOLECKE 12/6/89
DOE E.K. HUNTER 12/11/89
SCALE 1/8 UNO

U.S. DEPARTMENT OF ENERGY
Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

BIN-SCALE TESTS
DRY TEST BIN ASSEMBLY

SYS.	DWG. NO.	REV.
WH06	412-N-002-W	F

DWG. 1 OF 1

2 1

5. LINER MATERIAL SHALL BE POLYETHYLENE, NOMINAL THICKNESS .005". LINER SHALL NOT RELEASE ANY GASES BETWEEN 70° F AND 90° F.

6. REMOVED

7. PREPARE AND PAINT EXTERNAL SURFACES OF BIN PER SPECIFICATION E-Z-240, REV. 2, SYSTEM I-16. FINISH COAT SHALL BE GRAY. APPLY PAINT AFTER WELD TESTS AND APPROVALS SPECIFIED IN EQUIPMENT SPECIFICATION E-A-334, EXCEPT STAINLESS STEEL SURFACES.

8. PAINT INTERNAL SURFACE OF BIN AND UNDERSIDE OF COVER WITH PAINT 105C-5, WHITAKER COATINGS, 1500 LATHEM ST., BATAVIA, IL. 60510 OR EQUAL. APPLY FIRST COAT .0003" - .0004" DRY AND BAKE 10 - 12 MINUTES AT 300° - 315° F. APPLY SECOND COAT .0003" - .0004" DRY AND BAKE 10 - 12 MINUTES AT 400° - 425°F. APPLY FIRST COAT AFTER WELD TESTS AND APPROVALS SPECIFIED IN EQUIPMENT SPECIFICATION E-A-334.

9. STENCIL BIN EQUIPMENT NO. AND THREE DIGIT SERIAL NO. LETTERS SHALL BE 1/2"-1" HIGH INDELIBLE BLACK. LIDS AND BINS OF THE SAME SERIAL NO. SHALL BE SHIPPED TOGETHER. DRY TEST BIN EQUIP. NO.: 63-S-001, S/N -001, ETC.

10. REINFORCE HOLES IN LINER WITH TEFLON WASHER EMBEDDED IN THE LINER.

11. SECOND WELD ON WALL OPTIONAL. SINGLE WELD PERFERRED WITH SINGLE PIECE WALL.

12. TO BE INSTALLED TO BOTTOM OF BIN ONLY.

13. REMOVED

14. ALL 1/2" VALVES INSTALL ON ITEM 1 SHALL HAVE THE SAME PART NUMBER.

15. ALL 1" VALVES INSTALL ON ITEM 1 SHALL HAVE THE SAME PART NUMBER.

16. ARROWS ON ALL VALVES TO POINT AWAY FROM BIN WALL.

17. REMOVE THIS LENGTH AFTER FINAL INSTALLATION.

18. THIS DETAIL FOR TEST BINS S/N PB-009, PB-010, AND PB-011 ONLY.

19. THIS DETAIL FOR TEST BINS S/N PB-012 AND ONWARD.

20. FOLD ITEM 20 AS REQUIRED TO FIT WITHIN THE BIN.

REV	ISSUE DESCRIPTION	DFTR	CHK	COG	DFTG MGR	ECO	PWR
		DATE	DATE	DATE	DATE		
F	REVISED PER ECO FD	RM 4/15/92	[illegible] 4/15/92	[illegible] 4/15/92	[illegible] 4/16/92	5189 5206 5848	
E	REVISED PER ECO	TRA 10/18/90	DLH 10/18/90	MB 10/18/90	HB 10/18/90	4869 5000	

THIS DRAWING CREATED BY ENGINEERING CHANGE ORDER (ECO) : 3258

INTERPRET DWG PER ANSI Y14
DIM. IN INCHES BASED ON 68° F
UNLESS OTHERWISE SPECIFIED TOLERANCES

2 PL DEC	3 PL DEC	ANGLES
± .03	± .005	± 1°

FRACTIONS ± 1/8

ENGINEERING RELEASE
BY (W) WID--WIPP
ECO _____ DATE _____

DFTG A.E.SEWALD 10/31/89
CHKR. D. HUGHES 10/17/90
COG. ENGM. BALI 10/17/90
COG. MGR J.J. GARCIA 1/12/90
Q.A. JAMES F. ALLEN 12/6/89
SAFETY C.D. JACKSON 12/6/89
APPD W.R. WHITE 12/6/89
APPD TERRY D. MERKLING (RS)
DFTG. MGR H.W. BELLOWS 10/18/90
SNL MARTY A. MOLECKE 12/6/89
DOE E.K. HUNTER 12/11/89
SCALE 1/8 U.N.O.

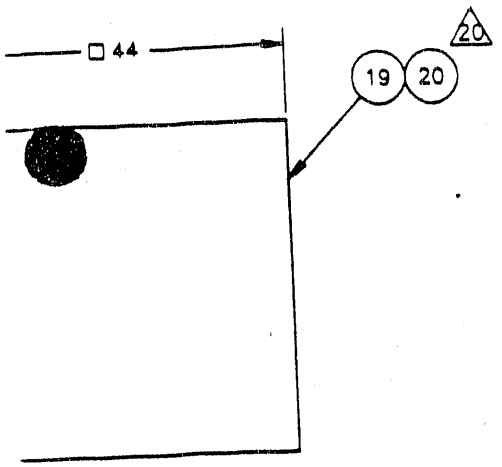
U.S. DEPARTMENT OF ENERGY

Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

BIN-SCALE TESTS
DRY TEST BIN DETAILS

SYS.	DWG. NO.	REV.
WH06	412-F-017-W1	F
		DWG 1 OF 2

2 1



REV	ISSUE DESCRIPTION	RM / DFTR / DATE		CHK / DATE	COG / DATE	DFTG MGR / DATE	ECO	PWR
F	REVISED PER ECO FD	RM	A.E.S	CH	H.B	5189 5206 6081		
		4/15/92	4/15/92	4/15/92	4/16/92			
E	REVISED PER ECO	TRA	DLH	MB	HB	4869 5000		
		10/18/90	10/18/90	10/18/90	10/18/90			

THIS DRAWING CREATED BY ENGINEERING CHANGE ORDER (ECO) : 3258

INTERPRET DWG PER ANSI Y14
DIM. IN INCHES BASED ON 68° F
UNLESS OTHERWISE SPECIFIED TOLERANCES

2 PL DEC	3 PL DEC	ANGLES	
± .03	± .005	± 1°	√ AA

FRACTIONS ± 1/8

ENGINEERING RELEASE
BY WID-WIPP
ECO _____ DATE _____

DFTG A.E.SEWALD 10/31/89
CHKR. D. HUGHES 10/17/90
COG. ENG M. BALI 10/17/90
COG. MGR J.J. GARCIA 1/12/90
Q.A. JAMES F. ALLEN 12/6/89
SAFETY C.D. JACKSON 12/6/89
APPD W.R. WHITE 12/6/89
APPD TERRY D. MERKLING (RS)
DFTG. MGR H.W. BELLOWS 10/18/90
SNL MARTY A. MOLECKE 12/6/89
DOE E.K. HUNTER 12/11/89
SCALE 1/8 U.N.O.

U.S. DEPARTMENT OF ENERGY

Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

BIN-SCALE TESTS
DRY TEST BIN DETAILS

SYS. WH06 | DWG. NO. 412-F-017-W2 | REV. F | DWG 2 OF 2

D C B A

2 1

41 A 001 W

ENGINEERING CHANGE ORDER

USE BLACK INK

1. ECO No.: 5292
SK EC&D Review: JKB

Initials

Posted

2. Impact Level 1 ☐ 2 ☐ 3 ☒ 4 ☐

3. System: HVAC Equipment No.: 41-B-100A & B Building: N/A

4. Associated Documents:
PWR 01534-M
ECP
P.O.
Others

5. Document Type:
Drawing ☒
Specification ☐
Vendor Data ☐
SDD ☐
Others DCC 71-X-001-W

6. Title of Change: INSTALL VIBRATION X-MTRS

7. Originator: (print)	Ext. No.:	Department:	Date:	8. Cognizant Engineer: (print)	
JOE HART	8285	M&CE	2/28/91	K. EALDEN	X 3174

9. Description of Change:

Component indices change required (if yes, attach sheets) — Yes ☒ No ☐

1. MAKE A NEW DWG ENTITLED MECHANICAL EQUIP ARRGMT USING DWG 54-W-008-W AS A TEMPLATE. NEW DWG NO. WILL BE 54-F-003-W
2. MODIFY NEW DWG PER ATTACHED SKETCH 1646-S ENTITLED VIBRATION XMTR INSTALLATION & MARK UP OF DWG 54-W-008-W. AFTER APPROVAL OF NEW DWG, SKETCH 1646-S WILL BE SUPERSEDED BY THE NEW DWG. WHEN APPROVED.
3. ASSIGN A SKETCH NO 1646-S FOR SKETCH ENTITLED, VIBRATION XMTR INSTALLATION.
4. REVISE DCC 71-X-001-W, SHEET 32 (LAD 008/35 PER ATTACHED MARK UP. (PAGE 6 OF 21)
5. REVISE DWG NO 41-A-001-W PER ATTACHED MARK UP, UG EXH P&ID
6. INSTRUMENT REQUEST FORM ATTACHED AS REF ONLY

☒ 9a Drawing Change Sheet attached
☐ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

10. Yes ☒ No ☐ MODIFICATION IN PROGRESS (ITEM 2 #5 ONLY)
☒ Modification complete: [signature] Signature / 26 Nov. '91 Date
ECO will be incorporated after M.I.P. signed complete

☐ Change drawing per as-built markup dated:
☐ Change drawing per ECO-provided data
☐ Temporary modification

11. Design Verification Requirements: (per WP 09-018) EDT No.:

JWP	1.	Requirements satisfied by review/approval of design document
	2.	Independent review
	3.	Alternate calculations
	4.	Development testing
	5.	Design review
JWP	6.	Other: Review/approval of drawing

12. Addendum Sheet added: Signature / Date

1190B:0005

13. Justification

1. NO DWG CURRENTLY AVAILABLE ON WESTINGHOUSE/BECHTEL FORMAT THAT SHOWS SUFFICIENT DETAIL REQD TO DOCUMENT PROPOSED CHANGE
2. MOD TO NEW DWG REQD TO DOCUMENT PROPOSED CHANGE
3. SKETCH REQD TO ACCOMPLISH FIELD MOD IN PROGRESS
4. LPU'S REQD TO MONITOR AND TREND FAN VIBRATION ALSO TO ALERT CMR TO SHUT DOWN FAN ON HIGH ALARM.
5. TO INCORPORATE MOD IN PROGRESS XMTR INSTALLATION TO THE APPROPIATE P&ID DWG

14. Administrative Tracking

YES	N/A		YES	N/A	
☐	☒	1. FSAR	☒	☐	6. Startup/Acceptance Test
☒	☐	2. Calibration Procedures	☒	☐	7. Test Requirement & Spec.
☒	☐	3. Maintenance Procedures	☐	☐	8. _____
☒	☐	4. Computer Software	☐	☐	9. _____
☒	☐	5. Operations Procedures	☐	☐	10. _____

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

A	Cog. Engineer	2/26/91
A	Cog. Eng. Mgr.	3/4/91
R	Startup	03-05-91
R	QA	3/6/91
☐	DOE	
☐	Safety	
☐	Dept. Manager	
R	Operations	3/6/91
☐	Security	
☐	SNL	
R		Pete Bindel 3-5-91
☐		
☐		

16. Distribute as Marked

X	Maintenance (MANDATORY)	
X	Ops. Support (MANDATORY)	
☒	Startup	
☒	Facility Operations	
☐	U/G Operations	
☐	Orig./Design Engr.	
☒	Cog. Engineer	
☐	Others	
X		PETE BINDEL
☐		
☐		
☐		
☐		

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 71-X-001-W, SHEET 32 ECO Number: 5292
PAGE 3 OF 20

2. ECO Search List: NONE

3. Description of Change:

REVISE SHEET 32 PER ATTACHED MARK UP OF SHEET 32

Pete Brandl 3-5-91

4. Drawing Cog. Engineer Approval: [signature] Date: 28 Feb. '91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

1290:B0006

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 54-F-003-W ECO Number: 5292

PAGE 4 OF 10

2. ECO Search List: NONE

3. Description of Change:

AB 3/05/91 ~~REVISE~~ CREATE NEW DWG 54-F-003-W THAT WILL BE A TEMPLATE OF 54-W-008-W, REVISED PER MARK UP OF 54-W-008-W AND PER ATTACHED SKETCH 1646-S ENTITLED VIBRATION XMTR INSTALLATION.

ADDITIONAL INFORMATION FOR NEW DRAWING TO BE PROVIDED BY COG. ENGINEER AFTER COMPLETION OF FIELD WORK.

4. Drawing Cog. Engineer Approval: _____ Date: 28 Feb. '91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

1290:B0006

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 41-A-001-W ECO Number: 5292
PAGE 5 OF 20

2. ECO Search List: ~~41-A-001-W~~ SK 3/4/91
4954 (M)

3. Description of Change:

REVISE P&ID DWG 41-A-001-W PER ATTACHED DWG MARK UP TO REFLECT ADDITION OF VIBRATION XMTRS TO 41-B-700 A&B FANS

4. Drawing Cog. Engineer Approval: [signature] Date: 28 Feb. '91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

Local Processing Unit 711-LPU-008/35

Q-Crate 1

*** Zone A ***

A1 02:QTB1 (90H == 120H) | A2 06:GAV1 (8FH == 11EH) | A3 10:QC12 (97H == 12EH) | A4 14:QRD1 (A0H == 140H) | A5 18:GAV1 | A6 22:

T	PT ID	D	T	PT ID	D	T	PT ID	D	T	PT ID	D	T	PT ID	D	T	PT ID	D
1	QTB		1	AP2403	N	1			1			1	AH1000	N			
2	"		2	(500)	S	2	CP2456	x	2	DH5707	P	2	"SD"	S			
3	"		3	"	P	3	------	x	3	"	C	3	"				
4	"		4	AP2408	N	4	CM9911	o	4	DH5708	P	4	AH1001	N			
5	"		5	(500)	S	5	CM9912	o	5	"	C	5	"SD"	S			
6	"		6	"	P	6	CM9913	o	6	DH5717	P	6	"				
7	"		7	------	N	7	CM9914	o	7	"	C	7	AH1002	N			
8	"		8	"	S	8	CM9915	o	8	------	P	8	"SD"	S			
9	"		9	"	P	9	CR1208	x	9	"	C	9	"				
10	"		10	------	N	10	CR1209	x	10	------	P	10	AH1003	N			
11	"		11	"	S	11	CR1210	x	11	"	C	11	"SD"	S			
12	"		12	"	P	12	CR1213	o	12	------	P	12	"				
13	"		13	AH5705	N	13	------	o	13	"	C	13	AH1004	N			
14	"		14	(500)	S	14	------	o	14	------	P	14	"SD"	S			
15	"		15	"	P	15	------	o	15	"	C	15	"				
16	"		16	AH5712	N	16	------	o	16	------	P	16	AH1005	N			
17	"		17	(500)	S	17	------	o	17	"	C	17	"SD"	S			
18	"		18	"	P	18			18			18	"				

*** Zone B ***

B1 04:GAV1 (8BH == 11DH) | B2 08:QC12 (8EH == 11CH) | B3 12:QC12 (96H == 12CH) | B4 16:GAV1 (98H == 13AH) | B5 20:GAV1 (A8H == 150H) | B6 24:QR12 (FBH == 1FDH)

T	PT ID	D	T	PT ID	D	T	PT ID	D	T	PT ID	D	T	PT ID	D	T	PT ID	D
1	AP2404	N	1			1			1	AH6726	N	1	AH1006	N	1	AH9909	N
2	(500)	S	2	CM5725	o	2	CM5701	o	2	(500)	S	2	"SD"	S	2	"	S
3	"	P	3	CM5726	x	3	CM5702	x	3	"	P	3	"		3	"	P
4	AP2405	N	4	CM5727	o	4	CM5703	o	4	AH6727	N	4	AH1007	N	4	"	R
5	(500)	S	5	CM5728	x	5	CM5704	o	5	(500)	S	5	"SD"	S	5		
6	"	P	6	------	x	6	CM5706	o	6	"	P	6	"		6	------	R
7	AP2406	N	7	CP2444	x	7	CM5709	o	7	AH6728	N	7	AH1008	N	7	"	N
8	(500)	S	8	CP2443	x	8	------	o	8	(500)	S	8	"SD"	S	8	"	S
9	"	P	9	------	x	9	CM5713	o	9	"	P	9	"		9	"	P
10	AP2409	N	10	CP2446	x	10	CM5714	o	10	AH6729	N	10	AH1009	N	10	------	N
11	(500)	S	11	------	x	11	CM5715	x	11	(500)	S	11	"SD"	S	11	"	S
12	"	P	12	ch5655	o	12	CM5718	o	12	"	P	12	"		12	"	P
13	AP2415	N	13	ch5656	o	13	CM5721	o	13	AH6730	N	13	------	N	13	"	R
14	(500)	S	14	------	x	14	CM5722	x	14	(500)	S	14	"	S	14		
15	"	P	15	CP2453	x	15	CM5723	o	15	"	P	15	"	P	15	------	R
16	------	N	16	CP2454	x	16	CM5724	x	16	AP2426	N	16	------	N	16	"	N
17	"	S	17	------	x	17	------	o	17	(500)	S	17	"	S	17	"	S
18	"	P	18			18			18	"	P	18	"	P	18	"	P

Q-Crate 2

*** Zone C ***

C1 02: | C2 06: | C3 10: | C4 14: | C5 18: | C6 22:

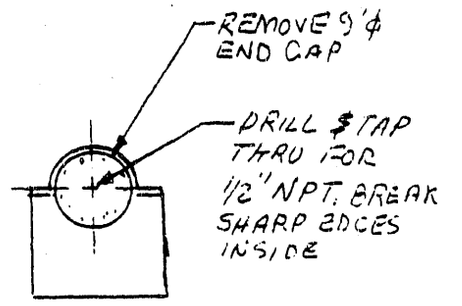
*** Zone D ***

D1 04: | D2 08: | D3 12: | D4 16: | D5 20: | D6 24:

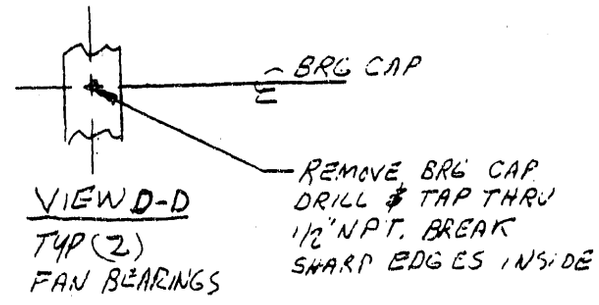
PWR WORK REQUEST FORM
CONTINUATION OF RESOLUTION

Page _____ of _____ Pages

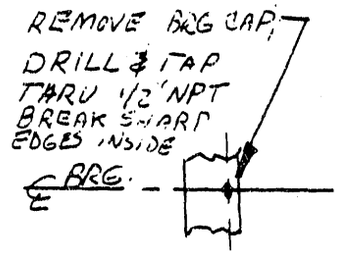
Work Request No. _____



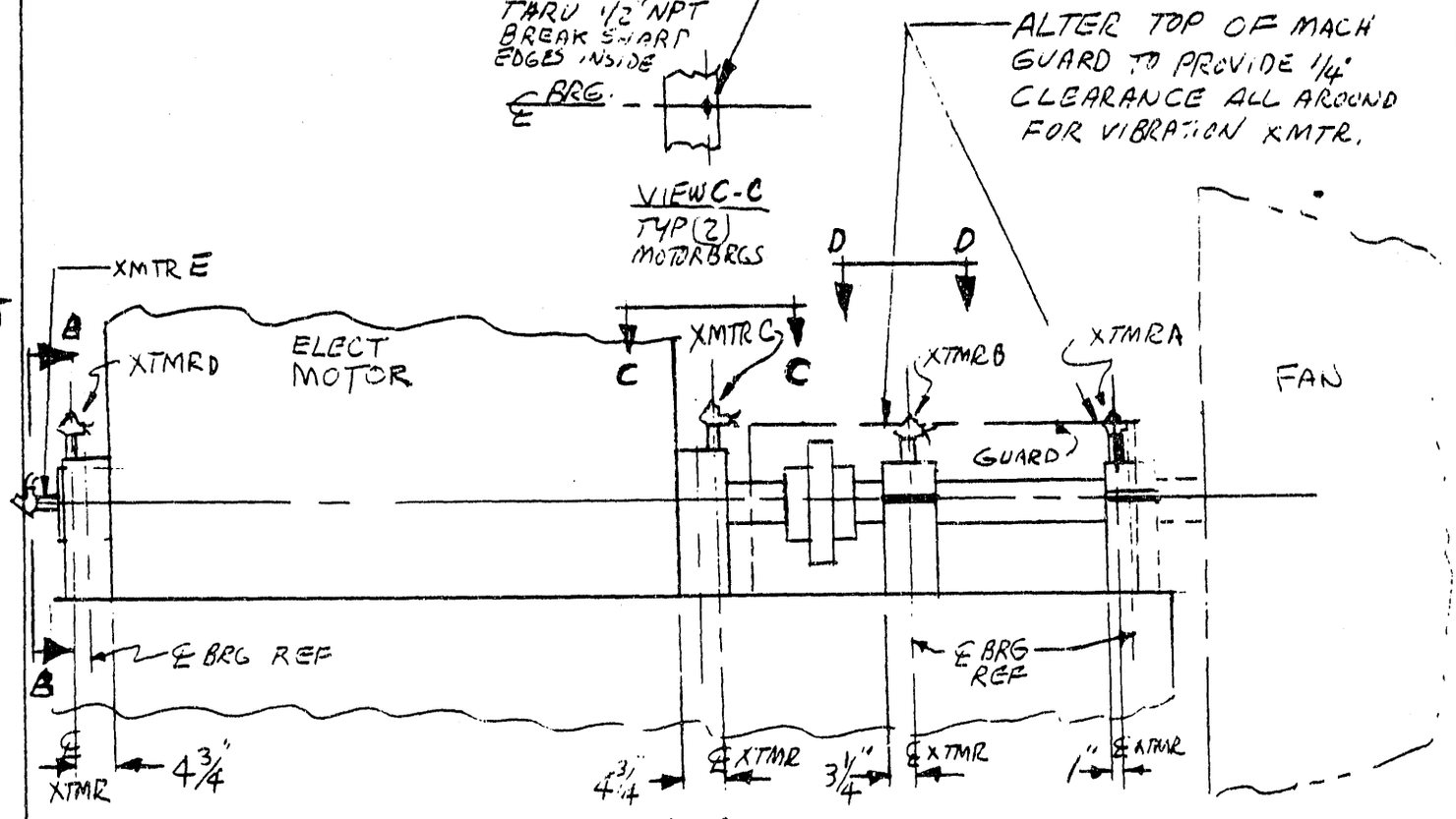
VIEW B-B



VIEW D-D
TYP (2)
FAN BEARINGS



VIEW C-C
TYP (2)
MOTOR BRGS



VIEW A-A
PARTIAL ELEV VIEW
41-B-700 A & B FANS

NOTE: REMOVE BRG CAPS & END PLATE PER VIEW B-B C-C & D-D. PERFORM WORK IN SHOP. CLEAN INSIDE BRG CAP & END PLATE CAREFULLY BEFORE REPLACING.

VIBRATION XMTR. INSTALLATION
SKETCH NO 1646-S
DES ENGR Joe Hart 2/28/91
COG ENGR [illegible] 28 Feb. '91
COG ENGR MGR [illegible] 3/4/91

ECO 5292 PAGE 7 OF 20

DOE ORDER 6430.1A DESIGN CRITERIA CHECKLIST

ENGINEERING CHANGE ORDER (ECO) NO. 5292 DATE 3/1/91 COG. ENGINEER [illegible]

PAGE 8 OF 20

The design requirements in DOE Order 6430.1A checked below have been applied to this ECO.

	DIVISION	SUBDIVISION
|_| 1	General Requirements	|_| 0101 |_| 0106 |_| 0109 |_| 0110 |_| 0111 |_| 0140 |_| 0150 |_| 0170
|_| 2	Site and Civil Engineering	|_| 0200 |_| 0201 |_| 0202 |_| 0203 |_| 0205 |_| 0210 |_| 0214 |_| 0215 |_| 0220 |_| 0235 |_| 0245 |_| 0250 |_| 0256 |_| 0260 |_| 0262 |_| 0266 |_| 0267 |_| 0270 |_| 0272 |_| 0275 |_| 0276 |_| 0278 |_| 0279 |_| 0280 |_| 0281 |_| 0283 |_| 0285 |_| 0290 |_| 0291
|_| 3	Concrete	|_| 0300 |_| 0301 |_| 0310 |_| 0320 |_| 0330 |_| 0340 |_| 0350 |_| 0370 |_| 0380
|_| 4	Masonry	|_| 0400 |_| 0401 |_| 0410 |_| 0420 |_| 0455
|_| 5	Metals	|_| 0500 |_| 0512 |_| 0514 |_| 0521 |_| 0531 |_| 0532
|_| 6	Wood and Plastics	|_| 0600 |_| 0610 |_| 0630
|_| 7	Thermal and Moisture Protection	|_| 0710 |_| 0711 |_| 0714 |_| 0715 |_| 0719 |_| 0720 |_| 0721 |_| 0722 |_| 0724 |_| 0727 |_| 0730 |_| 0750 |_| 0751 |_| 0753 |_| 0760 |_| 0790
|_| 8	Doors and Windows	|_| 0800 |_| 0810 |_| 0820 |_| 0830 |_| 0833 |_| 0836 |_| 0839 |_| 0850 |_| 0860 |_| 0880
|_| 9	Finishes	|_| 0900 |_| 0910 |_| 0920 |_| 0925 |_| 0930 |_| 0950 |_| 0965 |_| 0968 |_| 0970 |_| 0980 |_| 0990 |_| 0995
|_| 10	Specialties	|_| 1015 |_| 1020 |_| 1024 |_| 1027 |_| 1030 |_| 1040 |_| 1050 |_| 1052 |_| 1053 |_| 1055 |_| 1060 |_| 1065 |_| 1070 |_| 1075 |_| 1080
|_| 11	Equipment	|_| 1100 |_| 1161
|_| 12	Furnishings	|_| 1201 |_| 1230 |_| 1250 |_| 1260 |_| 1270
|_| 13	Special Facilities	|_| 1300 |_| 1304 |_| 1305 |_| 1306 |_| 1307 |_| 1310 |_| 1319 |_| 1320 |_| 1321 |_| 1322 |_| 1323 |_| 1324 |_| 1325 |_| 1326 |_| 1328
|_| 14	Conveying Systems	|_| 1401 |_| 1420 |_| 1440 |_| 1460
|_| 15	Mechanical	|_| 1525 |_| 1530 |_| 1540 |_| 1550 |_| 1555 |_| 1565 |_| 1574 |_| 1589 |_| 1595
|_| 16	Electrical	|_| 1600 |_| 1605 |_| 1620 |_| 1630 |_| 1639 |_| 1640 |_| 1650 |_| 1660 |_| 1670 |_| 1671 |_| 1685 |_| 1694

Note: A checked placed in the Division column signifies that the entire Division shall be applicable to the ECO, unless modified by checks indicated for specific Subdivisions.

☐ CHANGE

INSTRUMENT NUMBER ~~DEST FORM~~

1. INSTRUMENT NUMBER: 413-YT-307-10A 2. SYS/SUBSYSTEM VU01
3. DESCRIPTION: VIBRATION TRANSMITTER
4. LOOP NUMBER ~~FBD~~ 10 5. ECP NUMBER 2-VU90-60
6. INPUT RANGE 0 - 1.0 IPS 7. OUTPUT RANGE 4-20MA

9. CMS SETPOINTS		10. LOCAL SETPOINTS (NOT APPLICABLE)	
EXAMPLE	⊕ 1 1 . 0 1 0 E ⊕ 0 1 2	EXAMPLE	⊖ 1 1 . 0 1 0 E ⊕ 0 1 2
HI ALARM LIMIT	± . E ± 1.31	HI ALARM LIMIT	± . E ±
DBND	± . E ± 1.310	DBND	± . E ±
LO	± . E ± 1.212	LO	± . E ±
DBND	± . E ± 1.211	DBND	± . E ±
ENGR UNITS	± . E ± IPS	ENGR UNITS	± . E ±

11. MANUFACTURER METRIX INSTRUMENT CO
12. SERIAL NUMBER N/A 13. MODEL NUMBER 5484C
14. LOCATION DRAWING 54-W-608-W 15. P&ID DRAWING 41-A-001-W
16. DESIGN CLASS IIC B
17. BLDG NUMBER N/A 18. ROOM NUMBER N/A
19. ASSOCIATED PANEL OR SUBEQUIPMENT NO. ~~413-CP-304-01B~~ (now) TBD
20. OSR/LCO EQUIPMENT YES ___ NO X FOR

☐ SAFETY CLASS	☒ OPERATIONAL COMPLIANCE CLASS	☐ ENVIRONMENTAL COMPLIANCE CLASS	☐ OTHER ___

21. ELECTRICAL POWER FROM ~~413-DP03; 6a~~ (now) TBD
22. CAL./PM PROCEDURE NUMBER N/A
23. IF CHANGING INST. NUMBER, WHAT IS RELATED ECO NUMBER N/A
24. REMARKS: N/A

NOTE: DO NOT LEAVE ANY BLANKS. USE N/A IF IT NON APPLICABLE.

REQUESTOR JOE HART DATE 2/27/91

ECO 5292

☐ CHANGE

INSTRUMENT NUMBER REQUEST FORM

1. INSTRUMENT NUMBER: 413-YT-307-1013 2. SYS/SUBSYSTEM VU01

3. DESCRIPTION: VIBRATION TRANSMITTER

4. LOOP NUMBER FB2 10 5. ECP NUMBER 2-VU90-600

6. INPUT RANGE 0 - 1.0 IPS 7. OUTPUT RANGE 4-20 MA

9. CMS SETPOINTS	10. LOCAL SETPOINTS
EXAMPLE ⊕ L.L . L0 1 0 E ⊕ L0 1 2	EXAMPLE NOT APPLICABLE ⊖ L.L . L0 1 0 E ⊕ L0 ##
HI ALARM	HI ALARM
LIMIT ± L.L . L.L E ± L 3 1	LIMIT ± L.L . L.L E ± L.L
DBND ± L.L . L.L E ± L 3 0	DBND ± L.L . L.L E ± L.L
LO ± L.L . L.L E ± L 2 2	LO ± L.L . L.L E ± L.L
DBND ± L.L . L.L E ± L 2 1	DBND ± L.L . L.L E ± L.L
ENGR UNITS ± L.L . L.L E ± IPS	ENGR UNITS ± L.L . L.L E ± L.L

11. MANUFACTURER METRIX INSTRUMENT CO

12. SERIAL NUMBER N/A 13. MODEL NUMBER 54EA[illegible]

14. LOCATION DRAWING 5Y-W-608-W 15. P&ID DRAWING 41-A-[illegible]1-W

16. DESIGN CLASS IIB

17. BLDG NUMBER N/A 18. ROOM NUMBER N/A

19. ASSOCIATED PANEL OR SUBEQUIPMENT NO. ~~413 CP-309-01B~~ TBD

20. OSR/LCO EQUIPMENT YES ___ NO X FOR

☐ SAFETY CLASS	☒ OPERATIONAL COMPLIANCE CLASS	☐ ENVIRONMENTAL COMPLIANCE CLASS	☐ OTHER ___

21. ELECTRICAL POWER FROM ~~413-DP03/29~~ TBD

22. CAL./PM PROCEDURE NUMBER N/A

23. IF CHANGING INST. NUMBER, WHAT IS RELATED ECO NUMBER N/A

24. REMARKS: N/A

NOTE: DO NOT LEAVE ANY BLANKS. USE N/A IF IT NON APPLICABLE

REQUESTOR JOE HART DATE 2/27/9

ECO 5292

☐ CHANGE

INSTRUMENT NUMBER REQUEST FORM

1. INSTRUMENT NUMBER: 413-YT-307-10C 2. SYS/SUBSYSTEM VU01

3. DESCRIPTION: VIBRATION TRANSMITTER

4. LOOP NUMBER ~~TBD~~ 10 5. ECP NUMBER 2-VU90-60

6. INPUT RANGE 0 - 1.0 IPS 7. OUTPUT RANGE 4-20MA

9. CMS SETPOINTS		10. LOCAL SETPOINTS (NOT APPLICABLE)	
EXAMPLE	⊕ 1.1 . 1010 E ⊕ 1012	EXAMPLE	⊖ 1.1 . 1010 E ⊕ 1012
HI ALARM LIMIT	± 1.1 . 1.1 E ± 1.31	HI ALARM LIMIT	± . E ±
DBND	± 1.1 . 1.1 E ± 1.30	DBND	± . E ±
LO	± 1.1 . 1.1 E ± 1.22	LO	± . E ±
DBND	± 1.1 . 1.1 E ± 1.21	DBND	± . E ±
ENGR UNITS	± 1.1 . 1.1 E ± IPS	ENGR UNITS	± . E ±

11. MANUFACTURER METRIX INSTRUMENT CO

12. SERIAL NUMBER N/A 13. MODEL NUMBER 5484C

14. LOCATION DRAWING 54-W-008-W 15. P&ID DRAWING 41-A-001-W

16. DESIGN CLASS IIB

17. BLDG NUMBER N/A 18. ROOM NUMBER N/A

19. ASSOCIATED PANEL OR SUBEQUIPMENT NO. ~~413-CP-309-01B~~ TBD

20. OSR/LCO EQUIPMENT YES ___ NO X FOR

☐ SAFETY CLASS	☒ OPERATIONAL COMPLIANCE CLASS	☐ ENVIRONMENTAL COMPLIANCE CLASS	☐ OTHER ___

21. ELECTRICAL POWER FROM ~~413-DP03/29~~ TBD

22. CAL./PM PROCEDURE NUMBER N/A

23. IF CHANGING INST. NUMBER, WHAT IS RELATED ECO NUMBER N/A

24. REMARKS: N/A

NOTE: DO NOT LEAVE ANY BLANKS. USE N/A IF IT NON APPLICABLE.

REQUESTOR JOE HART DATE 2/27/91

ECO 5292

☐ CHANGE

INSTRUMENT NUMBER REQUEST FORM

☐ DELETION

1. INSTRUMENT NUMBER: 413-YT-307-100 2. SYS/SUBSYSTEM VU01

3. DESCRIPTION: VIBRATION TRANSMITTER

4. LOOP NUMBER ~~TBD~~ 10 5. ECP NUMBER 2-VU90-60

6. INPUT RANGE 0 - 1.0 IPS 7. OUTPUT RANGE 4-20MA

9. CMS SETPOINTS		10. LOCAL SETPOINTS (NOT APPLICABLE)	
EXAMPLE	⊕ 1 . 0 1 0 E ⊕ 0 1 2	EXAMPLE	⊖ 1 . 0 1 0 E ⊕ 0 1 2
HI ALARM LIMIT	± . E ± 1.3 1	HI ALARM LIMIT	± . E ±
DBND	± . E ± 1.3 0	DBND	± . E ±
LO	± . E ± 1.2 2	LO	± . E ±
DBND	± . E ± 1.2 1	DBND	± . E ±
ENGR UNITS	± . E ± IPS	ENGR UNITS	± . E ±

11. MANUFACTURER METRIX INSTRUMENT CO

12. SERIAL NUMBER N/A 13. MODEL NUMBER 5484C

14. LOCATION DRAWING 54-W-008-W 15. P&ID DRAWING 41-A-001-W

16. DESIGN CLASS IICB

17. BLDG NUMBER N/A 18. ROOM NUMBER N/A

19. ASSOCIATED PANEL OR SUBEQUIPMENT NO. ~~413-CP-309-01B~~ (now) TBD

20. OSR/LCO EQUIPMENT YES ___ NO X FOR

☐ SAFETY CLASS	☒ OPERATIONAL COMPLIANCE CLASS	☐ ENVIRONMENTAL COMPLIANCE CLASS	☐ OTHER ___

21. ELECTRICAL POWER FROM ~~413-DP03/bg~~ (now) TBD

22. CAL./PM PROCEDURE NUMBER N/A

23. IF CHANGING INST. NUMBER, WHAT IS RELATED ECO NUMBER N/A

24. REMARKS: N/A

NOTE: DO NOT LEAVE ANY BLANKS. USE N/A IF IT NON APPLICABLE

REQUESTOR JOE HART DATE 2/27/91

ECO 5292

☐ CHANGE

INSTRUMENT NUMBER REQUEST FORM

☐ DELETION

1. INSTRUMENT NUMBER: 413-YT-301-105 2. SYS/SUBSYSTEM VU01

3. DESCRIPTION: VIBRATION TRANSMITTER

4. LOOP NUMBER ~~FBD 10~~ 5. ECP NUMBER 2-VU90-60

6. INPUT RANGE 0 - 1.0 IPS 7. OUTPUT RANGE 4-20MA

9. CMS SETPOINTS	10. LOCAL SETPOINTS
EXAMPLE ⊕ L L . L 0 1 0 E ⊕ L 0 1 2	NOT APPLICABLE EXAMPLE ⊖ L L . L 0 1 0 E ⊕ L 0 1 2
HI ALARM LIMIT ± L . L E ~~±~~ L 3 1	HI ALARM LIMIT ± L . L E ± L
DBND ± L . L E ~~±~~ L 3 C	DBND ± L . L E ± L
LO ± L . L E ~~±~~ L 2 2	LO ± L . L E ± L
DBND ± L . L E ~~±~~ L 2 1	DBND ± L . L E ± L
ENGR UNITS ± L . L E ~~±~~ IPS	ENGR UNITS ± L . L E ± L

11. MANUFACTURER METRIX INSTRUMENT CO

12. SERIAL NUMBER N/A 13. MODEL NUMBER 5484C

14. LOCATION DRAWING ~~54-W-CCS-W~~ 15. P&ID DRAWING 41-A-001-W

16. DESIGN CLASS IIB

17. BLDG NUMBER N/A 18. ROOM NUMBER N/A

19. ASSOCIATED PANEL OR SUBEQUIPMENT NO. ~~413-CP-309-01B~~ TBD

20. OSR/LCO EQUIPMENT YES ___ NO X FOR

☐ SAFETY CLASS	☒ OPERATIONAL COMPLIANCE CLASS	☐ ENVIRONMENTAL COMPLIANCE CLASS	☐ OTHER ___

21. ELECTRICAL POWER FROM ~~413-DP03/bc~~ TBD

22. CAL./PM PROCEDURE NUMBER N/A

23. IF CHANGING INST. NUMBER, WHAT IS RELATED ECO NUMBER N/A

24. REMARKS: N/A

NOTE: DO NOT LEAVE ANY BLANKS. USE N/A IF IT NON APPLICABLE.

REQUESTOR JOE LAU DATE 2/27/91

ECO 5292

☐ CHANGE

INSTRUMENT NUMBER REQUEST FORM

1. INSTRUMENT NUMBER: 413-YT-309-11A 2. SYS/SUBSYSTEM VU01

3. DESCRIPTION: VIBRATION TRANSMITTER

4. LOOP NUMBER ~~TBD~~ 11 5. ECP NUMBER 2-VU90-60

6. INPUT RANGE 0 - 1.0 IPS 7. OUTPUT RANGE 4-20MA

9. CMS SETPOINTS		10. LOCAL SETPOINTS	
EXAMPLE	⊕ 1.1 . 0101 E ⊕ 0012	EXAMPLE	NOT APPLICABLE ⊖ 1.1 . 0101 E ⊕ 0012
HI ALARM LIMIT	± 1.1 . 11 E ± 0311	HI ALARM LIMIT	± 1.1 . 11 E ± 11
DBND	± 1.1 . 11 E ± 0310	DBND	± 1.1 . 11 E ± 11
LO	± 1.1 . 11 E ± 0212	LO	± 1.1 . 11 E ± 11
DBND	± 1.1 . 11 E ± 0211	DBND	± 1.1 . 11 E ± 11
ENGR UNITS	± 1.1 . 11 E ± IPS	ENGR UNITS	± 1.1 . 11 E ± 11

11. MANUFACTURER METRIX INSTRUMENT CO

12. SERIAL NUMBER N/A 13. MODEL NUMBER 5484C

14. LOCATION DRAWING ~~54-W-008-W~~ 15. P&ID DRAWING ~~41-A-001-W~~

16. DESIGN CLASS TCB

17. BLDG NUMBER N/A 18. ROOM NUMBER N/A

19. ASSOCIATED PANEL OR SUBEQUIPMENT NO. ~~413 CP-309-01B~~ TBD (Jmw)

20. OSR/LCO EQUIPMENT YES ___ NO X FOR

☐ SAFETY CLASS	☒ OPERATIONAL COMPLIANCE CLASS	☐ ENVIRONMENTAL COMPLIANCE CLASS	☐ OTHER ___

21. ELECTRICAL POWER FROM ~~41P-DP03/22~~ TBD (Jmw)

22. CAL./PM PROCEDURE NUMBER N/A

23. IF CHANGING INST. NUMBER, WHAT IS RELATED ECO NUMBER N/A

24. REMARKS: N/A

NOTE: DO NOT LEAVE ANY BLANKS. USE N/A IF IT NON APPLICABLE.

REQUESTOR JOE HART DATE 2/27/91

ECO 5292

☐ CHANGE

INSTRUMENT NUMBER REQUEST FORM

1. INSTRUMENT NUMBER: 413-YT-307-11B 2. SYS/SUBSYSTEM VU01

3. DESCRIPTION: VIBRATION TRANSMITTER

4. LOOP NUMBER ~~TBD~~ 11 5. ECP NUMBER 2-VU90-60

6. INPUT RANGE 0 - 1.0 IPS 7. OUTPUT RANGE 4-20MA

9. CMS SETPOINTS		10. LOCAL SETPOINTS	
EXAMPLE	⊕ L.L . L0L0 E ⊕L0L2	EXAMPLE	NOT APPLICABLE ⊖ L.L . L0L0 E ⊕L0L2
HI ALARM LIMIT	± L.L E ± L3L1	HI ALARM LIMIT	± L.L E ± L.L
DBND	± L.L E ± L3L0	DBND	± L.L E ± L.L
LO	± L.L E ± L2L2	LO	± L.L E ± L.L
DBND	± L.L E ± L2L1	DBND	± L.L E ± L.L
ENGR UNITS	± L.L E ± IPS L.L	ENGR UNITS	± L.L E ± L.L

11. MANUFACTURER METRIX INSTRUMENT CO

12. SERIAL NUMBER N/A 13. MODEL NUMBER 5484C

14. LOCATION DRAWING 54-W-008-W 15. P&ID DRAWING 41-A-001-W

16. DESIGN CLASS TCB

17. BLDG NUMBER N/A 18. ROOM NUMBER N/A

19. ASSOCIATED PANEL OR SUBEQUIPMENT NO. ~~413-CP-309-01B~~ TBD

20. OSR/LCO EQUIPMENT YES ___ NO X FOR

☐ SAFETY CLASS	☒ OPERATIONAL COMPLIANCE CLASS	☐ ENVIRONMENTAL COMPLIANCE CLASS	☐ OTHER ___

21. ELECTRICAL POWER FROM ~~41P-DP03/22~~ TBD

22. CAL./PM PROCEDURE NUMBER N/A

23. IF CHANGING INST. NUMBER, WHAT IS RELATED ECO NUMBER N/A

24. REMARKS: N/A

NOTE: DO NOT LEAVE ANY BLANKS. USE N/A IF IT NON APPLICABLE.

REQUESTOR JOE HART DATE 2/27/91

ECO 5292

☐ CHANGE

INSTRUMENT NUMBER REQUEST FORM

1. INSTRUMENT NUMBER: 413-YT-309-11C 2. SYS/SUBSYSTEM VU01

3. DESCRIPTION: VIBRATION TRANSMITTER

4. LOOP NUMBER ~~TBD~~ 11 5. ECP NUMBER 2-VU90-60

6. INPUT RANGE 0 - 1.0 IPS 7. OUTPUT RANGE 4-20MA

9. EMMS SETPOINTS		10. LOCAL SETPOINTS	
EXAMPLE	=1.1, 1010 E⊕1012	EXAMPLE (NOT APPLICABLE)	⊖1.1, 1010 E⊕1012
HI ALARM LIMIT	=__, ___ E ±1311	HI ALARM LIMIT	±__, ___ E ±___
DBND	=__, ___ E ±1310	DBND	±__, ___ E ±___
LO	=__, ___ E ±1212	LO	±__, ___ E ±___
DBND	=__, ___ E ±1211	DBND	±__, ___ E ±___
ENGR UNITS	=__, ___ E ± IPS	ENGR UNITS	±__, ___ E ±___

11. MANUFACTURER METRIX INSTRUMENT CO

12. SERIAL NUMBER N/A 13. MODEL NUMBER 5484C

14. LOCATION DRAWING 54-W-008-W 15. P&ID DRAWING 41-A-001-W

16. DESIGN CLASS IIB

17. BLDG NUMBER N/A 18. ROOM NUMBER N/A

19. ASSOCIATED PANEL OR SUBEQUIPMENT NO. ~~413-CP-309-01B~~ TBD

20. OSR/LCO EQUIPMENT YES ☐ NO ☒ FOR

☐ SAFETY CLASS	☒ OPERATIONAL COMPLIANCE CLASS	☐ ENVIRONMENTAL COMPLIANCE CLASS	☐ OTHER _____

21. ELECTRICAL POWER FROM ~~413-DP03/bg~~ TBD

22. CALIBRATION PROCEDURE NUMBER N/A

23. IF CHANGING INST. NUMBER, WHAT IS RELATED ECO NUMBER N/A

24. REMARKS: N/A

NOTE: DO NOT LEAVE ANY BLANKS. USE N/A IF IT NON APPLICABLE.

REQUESTOR JOE HART DATE 2/27/91

ECO 5292

☐ CHANGE **INSTRUMENT NUMBER REQUEST FORM** ☐ DELETION

1. INSTRUMENT NUMBER: 413-YT-307-11D 2. SYS/SUBSYSTEM VU01

3. DESCRIPTION: VIBRATION TRANSMITTER

4. LOOP NUMBER ~~FB7 11~~ 5. ECP NUMBER 2-VU90-60

6. INPUT RANGE 0 - 1.0 IPS 7. OUTPUT RANGE 4-20MA

9. CMS SETPOINTS		10. LOCAL SETPOINTS	
EXAMPLE	⊕ ⊔. 0101 E ⊕ 0102	EXAMPLE	NOT APPLICABLE ⊖ ⊔. 0101 E ⊕ 0102
HI ALARM LIMIT	± ⊔. ⊔⊔ E ± 0.31	HI ALARM LIMIT	± ⊔. ⊔⊔ E ± ⊔⊔
DBND	± ⊔. ⊔⊔ E ± 0.30	DBND	± ⊔. ⊔⊔ E ± ⊔⊔
LO	± ⊔. ⊔⊔ E ± 0.22	LO	± ⊔. ⊔⊔ E ± ⊔⊔
DBND	± ⊔. ⊔⊔ E ± 0.21	DBND	± ⊔. ⊔⊔ E ± ⊔⊔
ENGR UNITS	± ⊔. ⊔⊔ E ± ⊔⊔ IPS	ENGR UNITS	± ⊔. ⊔⊔ E ± ⊔⊔

11. MANUFACTURER METRIX INSTRUMENT CO

12. SERIAL NUMBER N/A 13. MODEL NUMBER 5484C

14. LOCATION DRAWING 54-W-008-W 15. P&ID DRAWING 41-A-001-W

16. DESIGN CLASS IIB

17. BLDG NUMBER N/A 18. ROOM NUMBER N/A

19. ASSOCIATED PANEL OR SUBEQUIPMENT NO. ~~413-CP-307-01B~~ TBD (JMM)

20. OSR/LCO EQUIPMENT YES ___ NO X FOR

☐ SAFETY CLASS	☒ OPERATIONAL COMPLIANCE CLASS	☐ ENVIRONMENTAL COMPLIANCE CLASS	☐ OTHER ___

21. ELECTRICAL POWER FROM ~~413-DP03/22~~ (JMM) TBD

22. CAL./PM PROCEDURE NUMBER N/A

23. IF CHANGING INST. NUMBER, WHAT IS RELATED ECO NUMBER N/A

24. REMARKS: N/A

NOTE: DO NOT LEAVE ANY BLANKS. USE N/A IF IT NON APPLICABLE.

REQUESTOR JOE HART DATE 2/27/91

ECO 5292

☐ CHANGE INSTRUM. NUMBER REQUEST FORM ☐ DELETION

1. INSTRUMENT NUMBER: 413-YT-309-11/E 2. SYS/SUBSYSTEM VU01

3. DESCRIPTION: VIBRATION TRANSMITTER

4. LOOP NUMBER ~~TBD~~ 11 5. ECP NUMBER 2-VU90-60

6. INPUT RANGE 0 - 1.0 IPS 7. OUTPUT RANGE 4-20MA

9. CMS SETPOINTS		10. LOCAL SETPOINTS (NOT APPLICABLE)	
EXAMPLE	⊕ 1 . 0 1 0 E ⊕ 0 1 2	EXAMPLE	⊖ 1 . 0 1 0 E ⊕ 0 1 2
HI ALARM LIMIT	± . E ± 1.31	HI ALARM LIMIT	± . E ±
DBND	± . E ± 1.310	DBND	± . E ±
LO	± . E ± 1.212	LO	± . E ±
DBND	± . E ± 1.211	DBND	± . E ±
ENGR UNITS	± . E ± IPS	ENGR UNITS	± . E ±

11. MANUFACTURER METRIX INSTRUMENT CO

12. SERIAL NUMBER N/A 13. MODEL NUMBER 5484C

14. LOCATION DRAWING 54-W-608-W 15. P&ID DRAWING 41-A-001-W

16. DESIGN CLASS TLB

17. BLDG NUMBER N/A 18. ROOM NUMBER N/A

19. ASSOCIATED PANEL OR SUBEQUIPMENT NO. ~~413-CP-309-01B~~ TBD

20. OSR/LCO EQUIPMENT YES ___ NO X FOR

☐ SAFETY CLASS	☒ OPERATIONAL COMPLIANCE CLASS	☐ ENVIRONMENTAL COMPLIANCE CLASS	☐ OTHER ___

21. ELECTRICAL POWER FROM ~~413-DP03/3B~~ TBD

22. CAL./PM PROCEDURE NUMBER N/A

23. IF CHANGING INST. NUMBER, WHAT IS RELATED ECO NUMBER N/A

24. REMARKS: N/A

NOTE: DO NOT LEAVE ANY BLANKS. USE N/A IF IT NON APPLICABLE.

REQUESTOR JOE HART DATE 2/27/91

ECO 5292

WHEN FILTRATION MODE IS INITIATED BY CAM SIGNAL, THE FOLLOWING EVENTS OCCUR:

A) ISOLATION DAMPERS HD-001A, HD-001B, HD-002A, AND HD-002B CLOSE. THE TWO ISOLATION DAMPERS HD-003A AND HD-003B ARE NORMALLY CLOSED.

B) FANS 41-B-700A AND/OR 41-B-700B STOP.

C) ONE OF THE FANS 860-A, 860-B, OR 860-C WILL START AUTOMATICALLY.

D) ISOLATION DAMPERS AT THE INLET AND OUTLET OF HEPA FILTER UNITS OPENS DIVERTING EXHAUST AIR THROUGH THE FILTERS.

ON LOSS OF OFFSITE POWER, ALL FANS STOP. ONLY ONE OF THE THREE FANS 860-A, 860-B, OR 860-C CAN BE STARTED MANUALLY AFTER THE EMERGENCY DIESEL GENERATOR IS IN OPERATION. THE SYSTEM WILL OPERATE IN THE FILTRATION MODE DURING LOSS OF OFFSITE POWER.

ALL FANS CAN BE STARTED OR STOPPED, EITHER FROM THE LOCAL PANEL IN THE EXHAUST FILTER BUILDING. BOTH FANS 41-B-700A & B CAN BE STOPPED ONLY FROM THE CMR BUT NOT STARTED.

STATUS OF BUTTERFLY VALVES HD-001A, HD-001B, HD-002A, AND HD-002B ARE MONITORED FROM THE LOCAL PANEL AND THE CMR.

INTERFACE IS SHOWN ON ELECTRICAL SCHEME 41-J-404-34B.

FSL-10, FSL-11, AND FSL-12 SHALL BE LOCATED IN 413LP30701K. FSL-10, FSL-11, AND FSL-12 AND EXISTING FAL-10, FAL-11, AND FAL-12 IN 413LP05601.

DAMPERS HD-003A, HD-003B ARE NORMALLY CLOSED, OPEN ONLY WHEN FANS 41-B-700A AND 41-B-700B ARE OUT OF SERVICE, AND FILTRATION MODE IS TO BE BYPASSED. THEREFORE USE OF FANS 41-B-860A, 41-B-860B, OR 41-B-860C ARE ACCESSED DIRECTLY THROUGH OUTLET PLENUM, FILTER BYPASSED AND USED FOR U/G VENTILATION.

PRESSURE CONTROL-WASTE HOIST TOWER

PIT 201-101 IS USED TO MONITOR AND CONTROL W.H.T. PRESSURE (NEGATIVE) BY CONTROLLING EXHAUST FOR 41-B-700-A OR B

-.25 IN WG YOU HAVE AN ALARM IN CMR

-.50 IN WG ONE(1) 700 U/G FAN WILL SHUT DOWN

-.75 IN WG BOTH 700 U/G FANS WILL SHUT DOWN

DRAWINGS SUPERCEDED PER ECO 4229:
41-F-056-019
41-F-307-348

REVISED PER ECO	TB	AES		AA	5244	
	02/14/91	2/13/91	2/14/91	2/4/91		
REVISED PER ECO	PA	AES	KAE	BA	4989	
	10/24/90	10/24/90	10/24/90	10/24/90		
ISSUE DESCRIPTION	DFTR	CHK	COG	DFTG MGR	ECO	PWR
	DATE	DATE	DATE	DATE		

DRAWING CREATED BY ENGINEERING CHANGE ORDER (ECO) :

CHG/TMW
A.E.SEWALD 10/24/90
ENG K.A.EALDEN 10/24/90
MGR G.W. POHL 04/17/90
B) A.E. GALLEGOS 04/18/90
N/A
MGR B.ALLEN 10/24/90
N/A

U.S. DEPARTMENT OF ENERGY

Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

EXHAUST FILTER BUILDING 413 UNDERGROUND EXHAUST AND VENTILATION SYSTEM PIPING & INSTRUMENT DIAGRAM

SYS.	DWG. NO.	REV.
VU01	41-A-001-W	D
		SH. 1 OF 1

ECO 5292

THIS DRAWING IS IN ACCORDANCE WITH THE FOLLOWING ENGINEERING CHANGE ORDERS:

D04954 D05071

THIS DRAWING OBSOLETE AFTER 3 (6-91)

SIGNED GW 2-27-91 CC&D

DWG NO

SH

REV	DATE	ISSUE DESCRIPTION	BY	ENG	ECO	EWP
A	5/25/88	APPROVED FOR USE	RM		2426	N/A
–	4/22/88	ISSUE FOR REVIEW	DEG		2426	N/A

INTERPRET DWG PER ANSI Y14.5M. IN INCHES BASED ON 68° F

UNLESS OTHERWISE SPECIFIED TOLERANCES

2 PL DEC	3 PL DEC	ANGLES	
			AA

NEXT ASSY

ENGINEERING RELEASE

BY (W) WID-WIPP

ECO _____ DATE _____

DFTG D. GREEN 4/22/88

CHKR. A. E Sawdy 5/13/88

COG. ENG [signature] 5/17/88

COG. MGR [signature] 5/17/88

Q.A. [signature] 5/18/88

SAFETY [signature]

APPD [signature] 5/18/88

APPD [signature] 5/16/88

DFTG. MGR [signature]

DOE [signature] 5/24/88

SCALE 1/8"= 1'-0"

U.S. DEPARTMENT OF ENERGY

Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

SURFACE EXHAUST FILTER BUILDING & EXHAUST SHAFT ARRANGEMENT FOR UNDERGROUND VENTILATION NORMAL MODE (OCTOBER, 1988)

SYS. VU01

DWG. NO. 54-W-003-W

REV. A

SH. 1 OF 1

2

ECO 5292

PAGE 20 OF 20

ECO #2-4490-60 . Page 5 of 6. Sht. 3 of 4.

MINIATURE 2 WIRE VIBRATION TRANSMITTER MODELS 5484C AND 5491B

METRIX INSTRUMENT CO.

713-461-2131

1711 TOWNHURST
HOUSTON, TX 77043
DEAN WICHERT

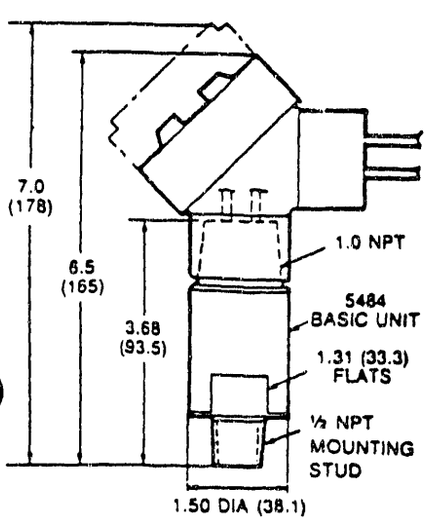
REDUCE THE COST AND COMPLEXITY OF VIBRATION MONITORING WITH THESE TWO WIRE, LOOP POWERED VIBRATION TRANSMITTERS.

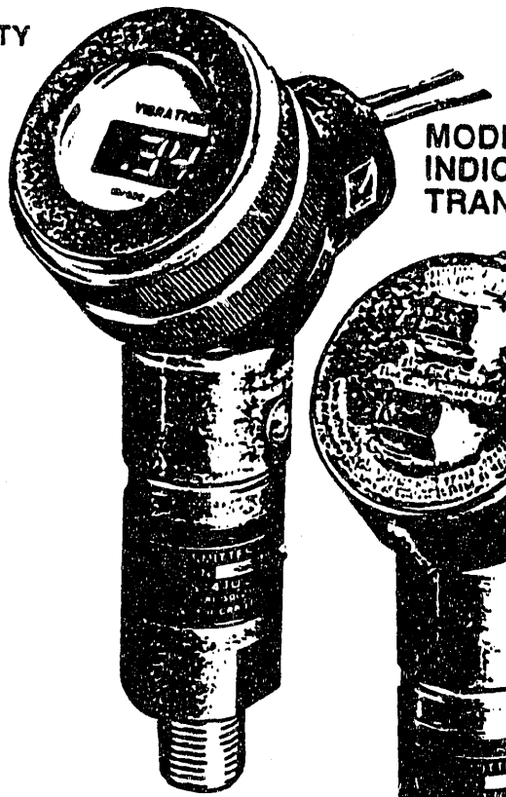
Two models are available. The Model 5484C is the non-indicating version and can be supplied with a screw cover elbow fitting for connecting field wiring. The Model 5491B is the indicating version and comes with an integral 2½ digit LCD indicator for local vibration readout.

Simply mount the transmitter into a single tapped hole in the machine case, connect its two wires into a 4-20 ma current loop, and it will transmit the machine's vibration level to your milliamp monitor, data logger or computer.

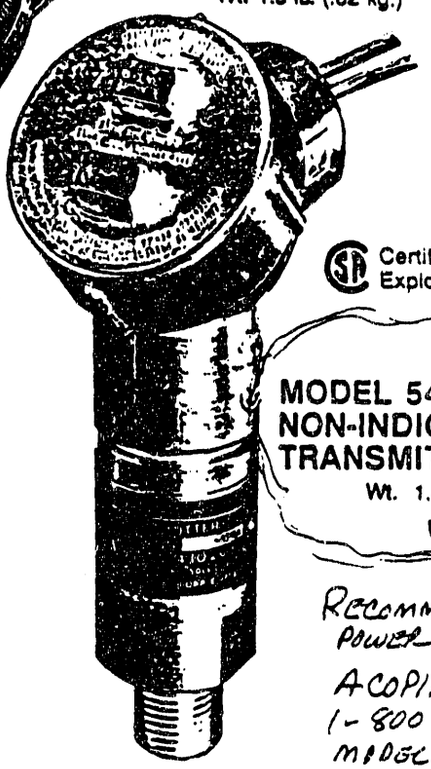
Employing no moving parts, the basic transmitter is all solid state and epoxy encapsulated in a zinc plated steel housing. The LCD indicator is packaged in a sealed module that can be positioned in 90° increments within the elbow fitting to allow proper viewing when the transmitter is installed.

Both units are weatherproof and suitable for use in hazardous locations. Each transmitter is factory calibrated to the nameplate sensitivity. However, when necessary, the span control can be field adjusted.





MODEL 5491B INDICATING TRANSMITTER
Wt. 1.8 lb. (.82 kg.)



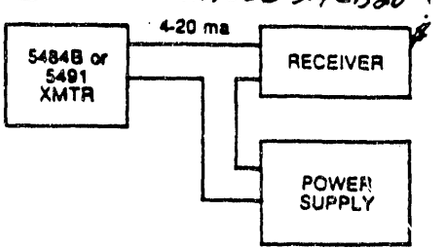
Certified Explosion-proof

MODEL 5484C NON-INDICATING TRANSMITTER
Wt. 1.4 lb. (.64 kg.)

160°F

ECO 5292
PAGE 21 OF 21

RECOMMENDED POWER SUPPLY
ACOPIA Co.
1-800-523-9478
MODEL 24EB20 ? @ $75.00



SPECIFICATIONS

Vibration Range: See table
Output Current: 4 to 20 ma.
Frequency Range: 10 Hz to 1500 Hz, ±5%
Axis Orientation: Any
Supply Voltage (Vs):
Model 5484C: 10 to 60 vdc
Model 5491B: 12 to 62 vdc
Maximum Load Resistance (RL):
Model 5484C: 50(Vs-10) ohms
Model 5491B: 50(Vs-12) ohms
Isolation: 500v, circuit to case.
Electrical Connection: 2 wires, AWG #18, 24 inches (610 mm) long
Temperature Range at Mtg. Stud: −10°C to +70°C
Hazard Rating:
Model 5484C: Class I (B, C & D); Class II (E, F & G)
Model 5491B; Class I (C & D); Class II (E, F & G)
Compliances: NEC, ISA Class 2U.

HOW TO ORDER

MODEL	DESCRIPTION
5484C-021	Vibration Transmitter 0 to 1.0 ips (25 mm/s), pk
5484C-023	Vibration Transmitter 0 to 2.0 ips (50 mm/s), pk
91174-019	Conduit Elbow Fitting (Aluminum) Class I (C & D); Class II (E, F & G)
5491B-021	Indicating Transmitter 0 to 1.00 ips
5491B-022	Indicating Transmitter 0 to 19.9 mm/s

Note: Units with extended temperature range or with other vibration ranges are available. Consult factory.

ENGINEERING CHANGE ORDER

USE BLACK INK

1. **ECO No.:** 5294
5 ☒ CC&D Review: RL

Initials

Posted

2. **Impact Level** 1 ☐ 2 ☐ 3 ☒ 4 ☐

3. **System:** CF02 Equipment No.: N/A Building: #411

4. **Associated Documents:**
PWR R-01533
ECP
P.O.
Others

5. **Document Type:**
Drawing 1647-S ☒
Specification ☐
Vendor Data ☐
SDD ☐
Others

6. **Title of Change:** Waste Handlers Office - relocation

7. **Originator:** (print)	Ext. No.:	Department:	Date:	8. **Cognizant Engineer:** (print)
J. Kowalski	9167	M&C.E.	07/6/91	J. Kowalski

9. **Description of Change:**

Yes ☐ No ☒ Component indices change required (if yes, attach sheets)

1. Assign sketch number to the attachment.
2. Remove the W. Handlers Office from dwgs: 41-E-001-014 & 41-E-003-014
3. Show relocated offices on dwgs. 41-E-600-021 and 41-E-602-021 as per attachment - see item 1, above.

☒ 9a Drawing Change Sheet attached
☐ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

10. Yes ☒ No ☐ **MODIFICATION IN PROGRESS**
☒ Modification complete: J. Kowalski (Signature) 7/30/91 (Date)
ECO will be incorporated after M.I.P. signed complete

☐ Change drawing per as-built markup dated:
☐ Change drawing per ECO-provided data
☐ Temporary modification

11. **Design Verification Requirements: (per WP 09-018)** EDT No.:

WBamhart for D. Cobb 1. Requirements satisfied by review/approval of design document
2. Independent review
3. Alternate calculations
4. Development testing
5. Design review
6. Other:

12. **Addendum Sheet added:** (Signature) (Date)

13. Justification

Waste Handlers Offices have to be moved away from the present location due to the proximity of the waste.

14. Administrative Tracking

YES	N/A			YES	N/A	
☐	☒	1.	FSAR	☐	☒	6. Startup/Acceptance Test
☐	☒	2.	Calibration Procedures	☐	☒	7. Test Requirement & Spec.
☐	☒	3.	Maintenance Procedures	☐	☒	8. _____
☐	☒	4.	Computer Software	☐	☐	9. _____
☐	☒	5.	Operations Procedures	☐	☐	10. _____

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

A	Cog. Engineer	J. Kwa 05/6/91
A	Cog. Eng. Mgr.	D Bernhardt for D Pahl
R	Startup	03-07-91
R	QA	3/7/91
☐	DOE	
A	Safety	3/7/91
☐	Dept. Manager	
☐	Operations	
☐	Security	
☐	SNL	
☐		
☐		
☐		

16. Distribute as Marked

☒	Maintenance (MANDATORY)	
☒	Ops. Support (MANDATORY)	
☒	Startup	
☒	Facility Operations	
☐	U/G Operations	
☐	Orig./Design Engr.	
☒	Cog. Engineer	
☐	Others	
☐		
☐		
☐		
☐		
☐		

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

pg 3 of 7

1. Drawing: 41-E-001-01X ECO Number: 5294

2. ECO Search List: 4623(M)

3. Description of Change:

Remove the Waste Handlers Office.

4. Drawing Cog. Engineer Approval: J. Howard Date: 03/5/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

1290:B0006

9a

DRAWING CHANGE SHEET

pg 4 of 7

(1 SHEET PER DRAWING)

1. Drawing: 41-E-003-014 ECO Number: 5294

2. ECO Search List: 4622(n)

3. Description of Change:

Remove the Waste Handlers Office

4. Drawing Cog. Engineer Approval: J. Kwasny Date: 03/6/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

1290:B0006

pg 5 of 7

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 41-E-600-021 ECO Number: 5294

2. ECO Search List: NONE

3. Description of Change:

Show Waste Handlers Office in location as per sketch no

4. Drawing Cog. Engineer Approval: [signature] Date: 03/6/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

9a

pg 6 of 7

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 41-E-603-021 ECO Number: 5294

2. ECO Search List: None

3. Description of Change:

Show Waste Handlers Office as per Refs no. 1647-S.

4. Drawing Cog. Engineer Approval: John Howard Date: 03/6/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

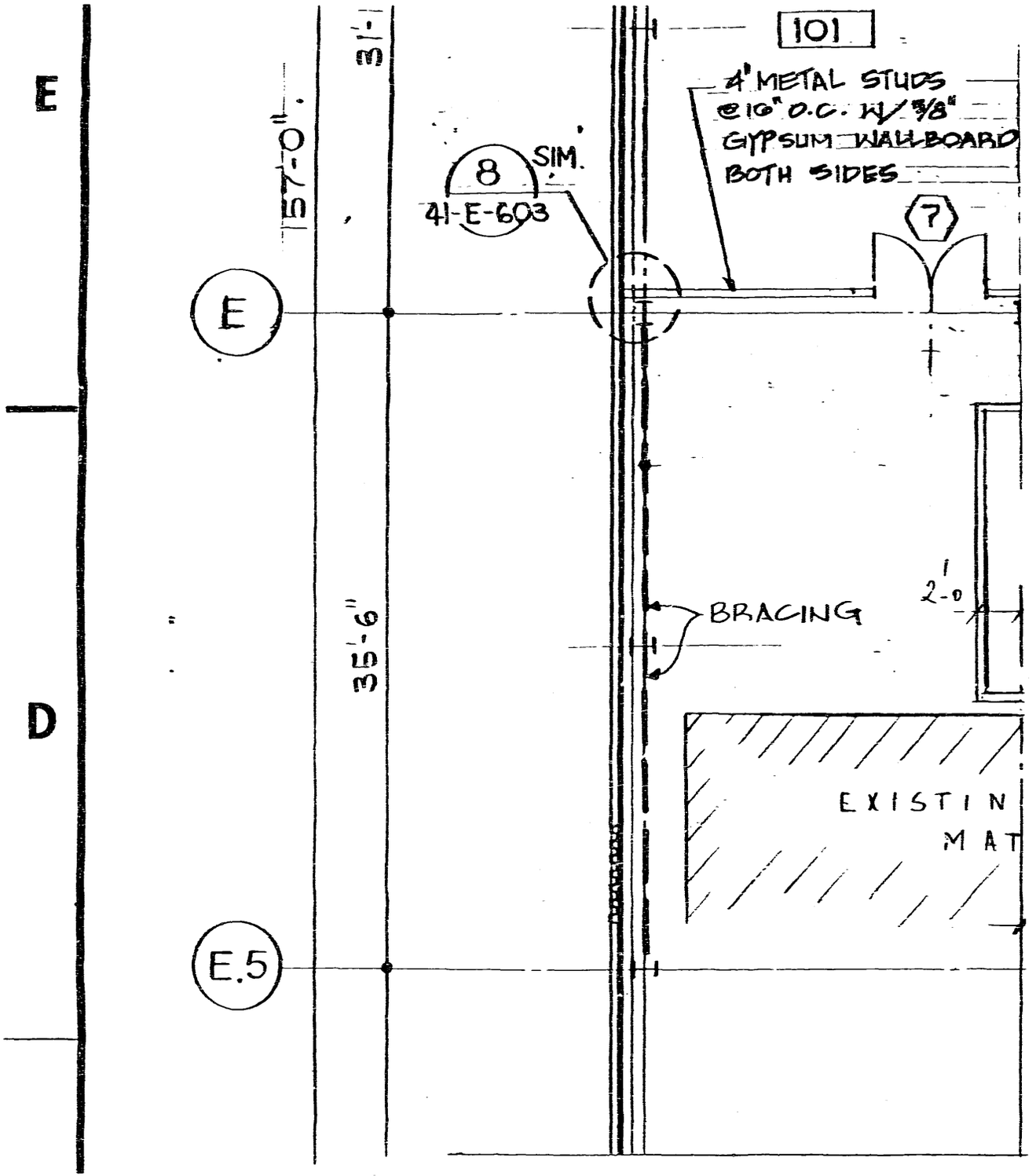
Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

1290:B0006


E
D
E.5
157'-0"
31'-
35'-6"
101
4" METAL STUDS
@16" O.C. W/ 5/8"
GYPSUM WALLBOARD
BOTH SIDES
8 SIM.
41-E-603
7
BRACING
2'-0"
EXISTIN
MAT

WHB HST TWR-FL SLBS PLNS AT EL, 185'-6 & 41-D-087

SYS. CF02	REV	ISSUE DESCRIPTION	DFTR / DATE	CHK / DATE	COG / DATE	DFTG MGR / DATE	ECO	PWR
	F	REVISED PER ECO	T B / 11/1/	[illegible] 01/04/92	[illegible] 01/13/92	BA 1/14/92	5294	
	E	REVISED PER ECO	[illegible]	[illegible]	[illegible]	[illegible]		

CE	REV	DATE	ISSUE DESCRIPTION	BY	CKD	SUPV	PE	PEM	DOE
NR	6	8/27/84	ISSUED AS BUILT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
NR	5	6/[illegible]/83	INCORP. AMENDMENTS NO. 0001, NO. 0003	VM	[illegible]	[illegible]	[illegible]	[illegible]	
✓	4	11/16/82	ISSUED FOR CONSTRUCTION	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
✓	3	10/21/82	ISSUED FOR APPROVAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
NR	2	7/8/82	ISSUED FOR PROGRESS REVIEW	MET	[illegible]	DCJ	[illegible]	[illegible]	
NR	1	2/18/82	ISSUED FOR PROGRESS REVIEW	MET	/	CL	RLB	HGT	
NR	0	12/16/81	ISSUED FOR PROGRESS REVIEW	MET	/	EB DJW	LB	[illegible]	

U.S. DEPARTMENT OF ENERGY
WASTE ISOLATION PILOT PLANT

BECHTEL

SYSTEM
CF02 GC02

SAN FRANCISCO

WASTE HANDLING BUILDING NO.411
ARCHITECTURAL
GENERAL KEY PLANS

JOB NO.	DRAWING APPROVED / DATE
12484	[signature] BECHTEL 11/18/82
DOE CONTRACT NUMBER: DE-AC04-79AL10751	DRAWING APPROVED / DEPARTMENT OF ENERGY [signature] DATE 11/18/82

DRAWING NO.	CCP	REV	PAGE NO.
41-E-001-014		F	2-26

STUDS & GYP BD

	F	REVISED PER ECO	TIB 11/21/11	Tony 01/09/12	VMK 01/13/12	BA 1/14/96	5294	K-1-1
	E	REVISED PER ECO	TMP 8/20/11	DLL 9/1/11	[illegible]	[illegible]	[illegible]	
YS. 3C02	REV	ISSUE DESCRIPTION	DFTR DATE	CHK DATE	COG DATE	DFTG MGR DATE	ECO	PWR

CE	REV	DATE	ISSUE DESCRIPTION	BY	CK'D	SUPV	P E	PEM	DC E
NR	6	8/27/87	ISSUED AS BUILT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
NR	5	[illegible]	INCORP AMENDMENTS NO 0001 NO 0002 AND NO 0003	YM	[illegible]	[illegible]	[illegible]	[illegible]	
✓	4	11/18/83	ISSUED FOR CONSTRUCTION	JLM	[illegible]	[illegible]	[illegible]	[illegible]	
✓	3	10/21/83	ISSUED FOR APPROVAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
NR	2	7/8/83	ISSUED FOR PROGRESS REVIEW	MET	[illegible]	[illegible]	[illegible]	[illegible]	
NR	1	2/18/83	ISSUED FOR PROGRESS REVIEW	MET	[illegible]	[illegible]	RB	[illegible]	
NR	0	10/12/81	REVISED AS INDICATED AND ISSUED FOR PROGRESS REVIEW	EB	[illegible]	[illegible]	JT	B	

B

U.S. DEPARTMENT OF ENERGY
WASTE ISOLATION PILOT PLANT

SYSTEM

CF02

BECHTEL

SAN FRANCISCO

WASTE HANDLING BUILDING NO. 411
ARCHITECTURAL
C H. AREA-PLAN AT EL 100'-0"

JOB NO 12484	DRAWING APPROVED BECHTEL — DAT 11/15/87
DOE CONTRACT NUMBER DE-AC04-79AL10751	DRAWING APPROVED DEPARTMENT OF ENERGY — DATE 11/1/87

A

DRAWING NO	CCP	REV	PAGE NO
41-E-003-014		F	2

51 W 102 W

ENGINEERING CHANGE ORDER

USE BLACK INK

1. **ECO No.:** 5299
CC&D Review: RL

Initials

Posted

2. **Impact Level** 1 ☐ 2 ☐ 3 ☒ 4 ☐

3. **System:** AU01 Equipment No.: N/A Building: U/6

4. Associated Documents:
PWR #10605
ECP
P.O.
Others

5. **Document Type:**
Drawing S1-W-102-W ☒
Specification ☐
Vendor Data ☐
SDD ☐
Others

6. **Title of Change:** CRIB INSTALLATION AT EXP. ROOMS

7. **Originator:** (print)	Ext. No.:	Department:	Date:	8. **Cognizant Engineer:** (print)
J. GONZALEZ	8192	MIN. ENG.	3/7/91	J. GONZALEZ

9. **Description of Change:**

Yes ☐ No ☒ Component indices change required (if yes, attach sheets)

TIMBER CRIBS INSTALLATION AT NORTH + SOUTH ENDS OF EXPERIMENTAL ROOMS A2, A3 + B3

☒ 9a Drawing Change Sheet attached
☐ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

10. Yes ☒ No ☐ **MODIFICATION IN PROGRESS**
☐ Modification complete: _____ / _____ (Signature / Date)
ECO will be incorporated after M.I.P. signed complete

☐ Change drawing per as-built markup dated: _____
☐ Change drawing per ECO-provided data
☐ Temporary modification

11. **Design Verification Requirements: (per WP 09-018)** EDT No.: _____

N/A 1. Requirements satisfied by review/approval of design document
_____ 2. Independent review
_____ 3. Alternate calculations
_____ 4. Development testing
_____ 5. Design review
_____ 6. Other: _____

12. **Addendum Sheet added:** _____ / _____ (Signature / Date)

13. Justification

TIMBER CRIBS ARE INSTALLED AT THE INTERSECTION OF ROOMS A2, A3 + B3 WITH MAIN ENTRIES TO PROVIDE ROOF PROTECTION AT N1100 + N1400 DRIFTS

14. Administrative Tracking

YES	N/A		YES	N/A	
☐	☒	1. FSAR	☐	☒	6. Startup/Acceptance Test
☐	☒	2. Calibration Procedures	☐	☒	7. Test Requirement & Spec.
☐	☒	3. Maintenance Procedures	☐	☐	8. _____
☐	☒	4. Computer Software	☐	☐	9. _____
☐	☒	5. Operations Procedures	☐	☐	10. _____

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

A	Cog. Engineer	3/7/91
A	Cog. Eng. Mgr.	3/7/91
R	Startup	03-08-91
R	QA	
☐	DOE	
☐	Safety	
☐	Dept. Manager	
☐	Operations	
☐	Security	
☐	SNL	
☐		
☐		
☐		

16. Distribute as Marked

☐	Maintenance (MANDATORY)	
☐	Ops. Support (MANDATORY)	
☐	Startup	
☐	Facility Operations	
☐	U/G Operations	
☐	Orig./Design Engr.	
☒	Cog. Engineer	
☐	Others	
☐		
☐		
☐		
☐		
☐		

3 OF 3

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: S1-W-102-W REV A ECO Number: 5299

2. ECO Search List: NONE

3. Description of Change:

SHOW LOCATION OF TIMBER CRIBS IN THIS DWG USING AS BUILT DATA PROVIDED AFTER FIELD WORK IS COMPLETED

4. Drawing Cog. Engineer Approval: _____ Date: 3/7/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

ENGINEERING CHANGE ORDER

USE BLACK INK

ENGINEERING FILE ROOM COPY

1. ECO No.: 5315
CC&D Review: CK

Initials

Posted

JAN 1992
COMPLETE

2. Impact Level 1 ☐ 2 ☒ 3 ☐ 4 ☐

3. System: WH06 Equipment No.: N/A Building: 616

4. Associated Documents:
PWR 00412M
ECP 1-WH91-9
P.O. N/A
Others

5. Document Type:
Drawing 52-L-002-W ☒
Specification ☐
Vendor Data ☐
SDD ☐
Others

6. Title of Change: ANCHOR FOR 2" DRCPS

7. Originator: (print) Merle King Ext. No.: 8286 Department: RLWHE Date: 3/14/91

8. Cognizant Engineer: (print) Om Mendiratta

9. Description of Change:

Yes ☐ No ☒ Component indices change required (if yes, attach sheets)

Make a drawing of a brace for each of the 21 drops for the VOC manifold in Room 1. Use the attached sketch. The drawing will be an additional sheet or detail on drawing 52-L-002-W.

☒ 9a Drawing Change Sheet attached
☐ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

10. Yes ☒ No ☐ MODIFICATION IN PROGRESS
Yes ☒ Modification complete: M. King / 10/7/91 (Signature / Date)

ECO will be incorporated after M.I.P. signed complete

☐ Change drawing per as-built markup dated:
☐ Change drawing per ECO-provided data
☐ Temporary modification

11. Design Verification Requirements: (per WP 09-018) EDT No.:

1. Requirements satisfied by review/approval of design document
2. Independent review Design Review #90-04 4/12/90 completed 3/14/91
3. Alternate calculations
4. Development testing
5. Design review
6. Other:

12. Addendum Sheet added: / (Signature / Date)

1190B:0005

13. Justification

The 9-foot 2"-tubing drops from the VOC manifold need to be braced. The attached sketch will provide the required support and ~~adjust for the~~ room closure.
MWR 3/12/91

14. Administrative Tracking

YES	N/A		YES	N/A	
☐	☒	1. FSAR	☐	☒	6. Startup/Acceptance Test
☐	☒	2. Calibration Procedures	☐	☒	7. Test Requirement & Spec.
☐	☒	3. Maintenance Procedures	☐	☐	8. _____
☐	☒	4. Computer Software	☐	☐	9. _____
☐	☒	5. Operations Procedures	☐	☐	10. _____

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

A	Cog. Engineer	Jim Tendrich 3/12/91
A	Cog. Eng. Mgr.	John F. Ward 3/12/91
R	Startup	03-14-91
A	QA	3-12-91
A	DOE	3-13-91
A	Safety	3-12-91
☐	Dept. Manager	_____
☐	Operations	_____
☐	Security	_____
☐	SNL	_____
☐		_____
☐		_____
☐		_____

16. Distribute as Marked

- ☐ Maintenance (MANDATORY) _____
- ☐ Ops. Support (MANDATORY) _____
- ☐ Startup _____
- ☐ Facility Operations _____
- ☐ U/G Operations _____
- ☐ Orig./Design Engr. _____
- ☐ Cog. Engineer _____
- ☐ Others _____
- ☐ _____
- ☐ _____
- ☐ _____
- ☐ _____
- ☐ _____

1190B:0005a

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-W ECO Number: 5315

2. ECO Search List: _____ _____ _____ _____

3. Description of Change:

Add the bracket shown in the attached sketch, SK-010391, to the subject drawing. Dimensions are to be field determined.

4. Drawing Cog. Engineer Approval: [signature] Date: 3/14/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

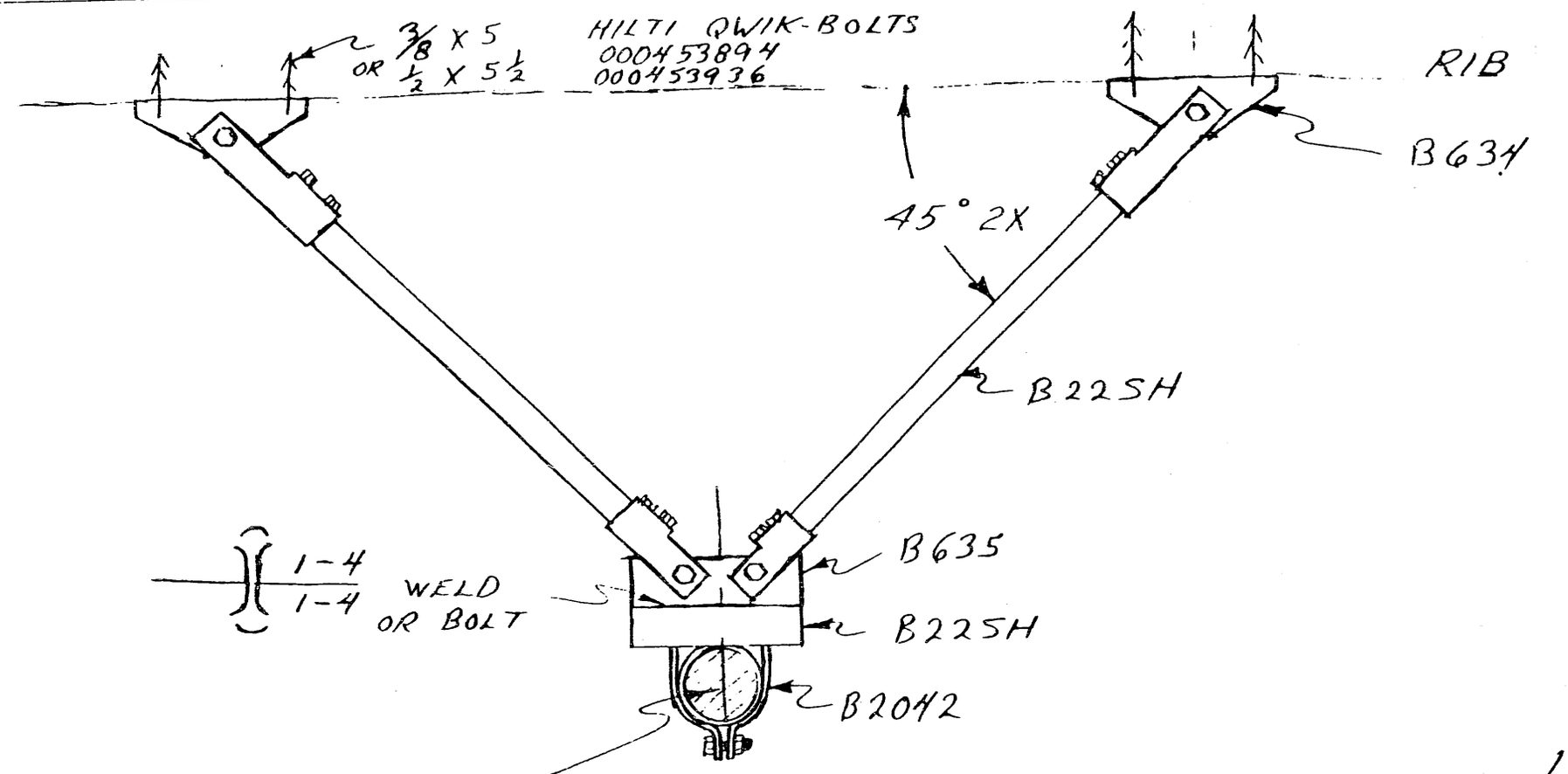
Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date



N.T.S.

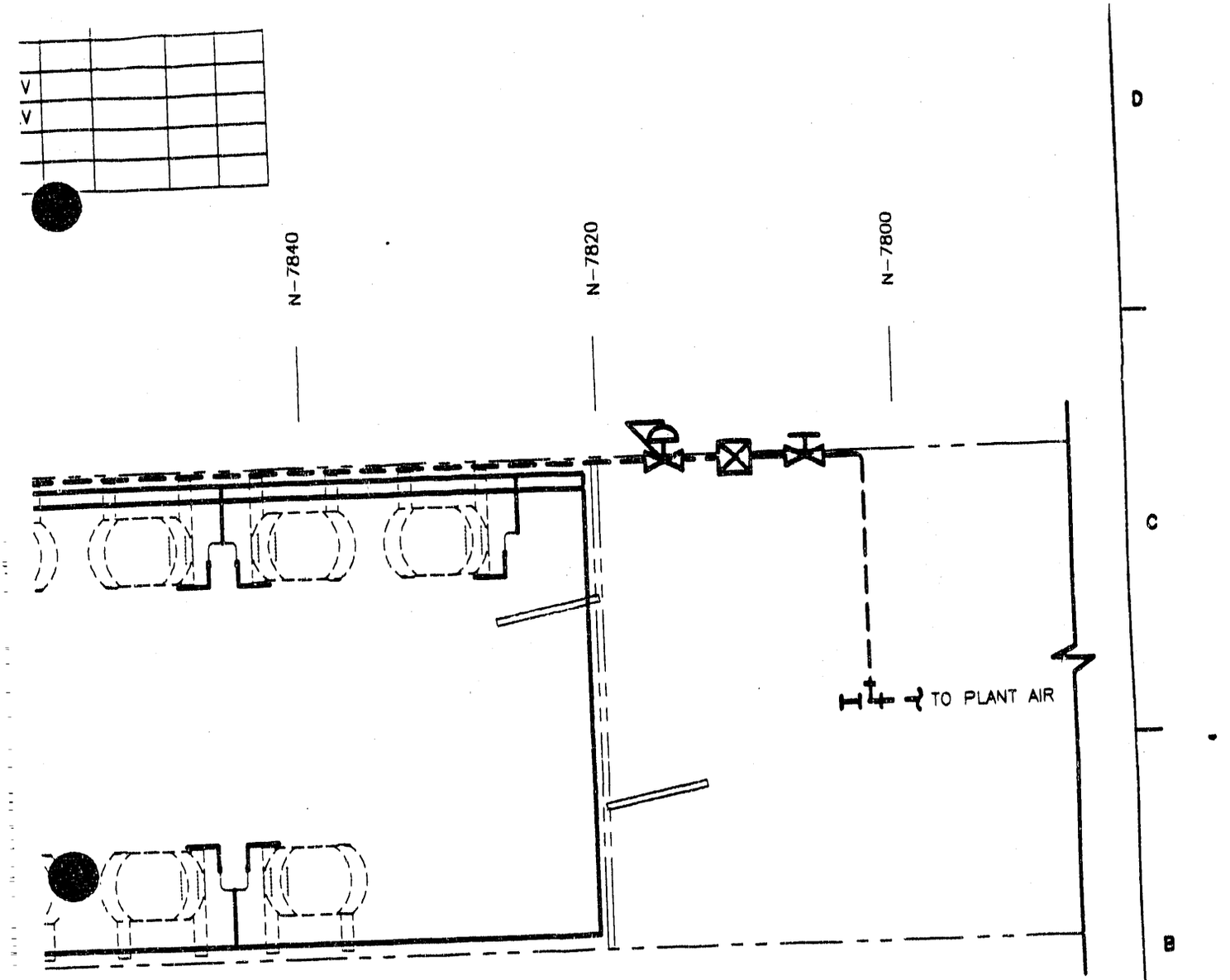
21 REQ'D.

ATTACH ANCHOR ~~JUST~~ 1" to 2" ABOVE THE 2" UNION.

VOC MONITORING SYSTEM
ANCHOR FOR 2" DROPS
SK 010391 REV NEW

3/1/91

ECC # 5215 P. 3 of 4



REV	ISSUE DESCRIPTION	DFTR / DATE	CHK / DATE	COG / DATE	DFTG MGR / DATE	ECO	PWR
C	REVISED PER ECO	DLH 1/21/92	[illegible]	[illegible]	[illegible] 1/22/92	5315	00412M
B	REVISED PER ECO	DLH 5/30/91	TRA 5/30/91	OM 6/7/91	BA 6/7/91	5428	

THIS DRAWING CREATED BY ENGINEERING CHANGE ORDER (ECO) : 4924 / PWR 00412M

INTERPRET DWG PER ANSI Y14
DIM. IN INCHES U.N.O.
UNLESS OTHERWISE SPECIFIED TOLERANCES
2 PL DEC | 3 PL DEC | ANGLES
NEXT ASSY
ENGINEERING RELEASE
BY WID-WIPP
ECO _____ DATE _____

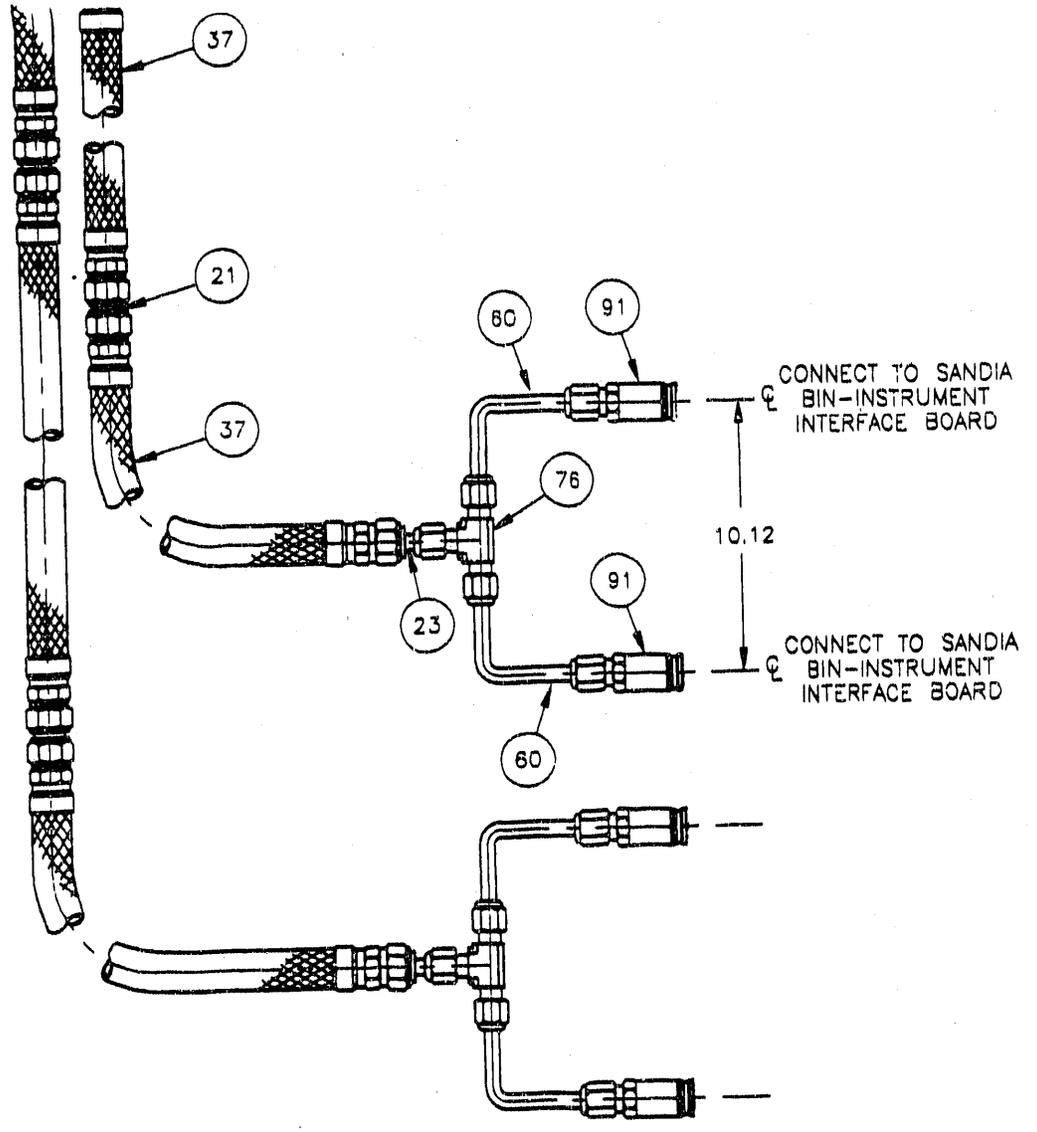
DFTG M.D.S. ABE
CHKR. D. HUGHES 02/05/91
COG. ENG O.P. MENDORETTA 02/05/91
COG. MGR J.J. GARCIA 02/05/91
Q.A. J.F. ALLEN 02/06/91
SAFETY L. RENCEHAUSEN 02/06/91
APPD M.W. KING 02/05/91
APPD
DFTG. MGR B. ALLEN 02/06/91
DOE
SCALE NTS

U.S. DEPARTMENT OF ENERGY

Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

BIN-SCALE TESTS, VOC MONITORING AND HELIUM STATIONS, DETAILS

SYS. EM05 | DWG. NO. 52-L-002-W1 | REV. C | DWG. 1 OF 10



REV	ISSUE DESCRIPTION	DFTR	CHK	COG	DFTG MGR	ECO	PWR
		DATE	DATE	DATE	DATE		
A	REVISED PER ECO/FD	DLH 5/30/91	TRA 5/30/91	ON 6/7/91	BA 6/7/91	5428	
B	REVISED PER ECO/FD	DLH 1/14/92	[illegible]	[illegible]	[illegible] 1/22/92	5315	00412M

THIS DRAWING CREATED BY ENGINEERING CHANGE ORDER (ECO) : 4924 / PWR 00412M

INTERPRET DWG PER ANSI Y14
DIM. IN INCHES U.N.O.
UNLESS OTHERWISE SPECIFIED TOLERANCES
2 PL DEC | 3 PL DEC | ANGLES | AA

NEXT ASSY

ENGINEERING RELEASE
BY WID-WIPP
ECO _____ DATE _____

DFTG M.D.S. ABE
CHKR. D. HUGHES 02/05/91
COG. ENG G.P. MENDORETTA 02/05/91
COG. MGR J.J. GARCIA 02/05/91
Q.A. J.F. ALLEN 02/06/91
SAFETY L RENCENHAUSEN 02 06/91
APPD M.W. KING 02/05/91
APPD
DFTG. MGR B. ALLEN 02/06/91

DOE
SCALE NTS

U.S. DEPARTMENT OF ENERGY

Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

BIN-SCALE TESTS, VOC MONITORING AND HELIUM STATIONS, DETAILS

SYS. EM05 | DWG. NO. 52-L-002-W9 | REV. B | DWG. 9 OF 10

2 1

41 S 003 WL

ENGINEERING CHANGE ORDER

USE BLACK INK

1. ECO No.: 5353
CC&D Review: RL

Initials

Posted

2. Impact Level 1 ☐ 2 ☐ 3 ☒ 4 ☐

3. System: FP02 Equipment No.: _____ Building: 411

4. Associated Documents:
PWR M40850, WCN #2
ECP 2-FP91-46
P.O. _____
Others _____

5. Document Type:
Drawing 41-S-003-W Sht 2 ☒
Specification 12.53.15 ☐
Vendor Data ☐
SDD ☐
Others _____

6. Title of Change: Exit Portal Sprinkler Piping

7. Originator: (print) Wm BARNHART Ext. No.: 8169 Department: M+CE Date:

8. Cognizant Engineer: (print) Wm BARNHART

9. Description of Change:

Yes ☒ No ☐ Component indices change required (if yes, attach sheets)

The WHB "zone 2" sprinkler system will be extended to provide sprinkler coverage within the Exit Portal, which is to be built as an attachment to the existing Overpack Enclosure. One sprinkler head will be installed in each chamber of the portal and a supply piping (to the portal) isolation valve will be provided. The sprinkler system modification will be performed in accordance with NFPA-13, (W) spec D-0065, Rev 1, and the attached sketch.

☒ 9a Drawing Change Sheet attached
☐ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

10. Yes ☒ No ☐ MODIFICATION IN PROGRESS
Yes ☒ Modification complete: W E Barnhart (Signature) / 2/20/92 (Date)
ECO will be incorporated after M.I.P. signed complete

☐ Change drawing per as-built markup dated: _____
☒ Change drawing per ECO-provided data
☐ Temporary modification

11. Design Verification Requirements: (per WP 09-018) EDT No.: _____

JWP 1. Requirements satisfied by review/approval of design document
_____ 2. Independent review
_____ 3. Alternate calculations
_____ 4. Development testing
_____ 5. Design review
_____ 6. Other: _____

12. Addendum Sheet added: _____ (Signature) / _____ (Date)

9 WEB 4/3/91

13. Justification

DOE/AL Order 5480.7 requires automatic fire protection in areas where the dollar value exceeds one million dollars. To ~~maintain~~ NEB 3/27/91 the WHB into WEB 3/27/91 compliance with this order, automatic fire protection is needed in the "exit portal".

14. Administrative Tracking

YES	N/A			YES	N/A	
☐	☒	1.	FSAR	☐	☒	6. Startup/Acceptance Test
☐	☒	2.	Calibration Procedures	☐	☒	7. Test Requirement & Spec.
☐	☒	3.	Maintenance Procedures	☐	☐	8. _____
☐	☒	4.	Computer Software	☐	☐	9. _____
	☒	5.	Operations Procedures	☐	☐	10. _____

15. Signature Requirements

KEY: A=APPR. R=REVIEW S=SIGN NEW DRAWING

A	Cog. Engineer	WE Bamford 3/28/91
A	Cog. Eng. Mgr.	W Bahl 3/28/91
R	Startup	04-03-91
R	QA	4/4/91
☐	DOE	
A	Safety	Mickey Lovell 4-4-91
☐	Dept. Manager	
☐	Operations	
☐	Security	
☐	SNL	
☐		
☐		
☐		

16. Distribute as Marked

☒	Maintenance (MANDATORY) _____
☒	Ops. Support (MANDATORY) _____
☐	Startup _____
☐	Facility Operations _____
☐	U/G Operations _____
☐	Orig./Design Engr. _____
☐	Cog. Engineer _____
☐	Others _____
☒	Safety — Mickey Lovell
☐	
☐	
☐	
☐	

ENGINEERING CHANGE ORDER Continuation Sheet	Document Number:		ECO
	Date: 3/28/91	Page 3 of 8 (9 WKB 4/3/91)	5353

1. Provide a sketch number for the attached sketch:
   1653-5

2. Following mod. completion, revise dwg 41-5-003-W, sht. 2 to reflect this change.

3. Following mod. completion, remove the attached sketch from the active dwg. register.

1190B:0005b

DOE ORDER 6430.1A DESIGN CRITERIA
CHECKLIST

ENGINEERING CHANGE ORDER (ECO) NO. _____ DATE 3/28/91 COG. ENGINEER Wm BARNHART

The design requirements in DOE Order 6430.1A checked below have been applied to this ECO.

	DIVISION	SUBDIVISION
☐	1 General Requirements	☐ 0101 ☐ 0106 ☐ 0109 ☐ 0110 ☐ 0111 ☐ 0140 ☐ 0150 ☐ 0170
☐	2 Site and Civil Engineering	☐ 0200 ☐ 0201 ☐ 0202 ☐ 0203 ☐ 0205 ☐ 0210 ☐ 0214 ☐ 0215 ☐ 0220 ☐ 0235 ☐ 0245 ☐ 0250 ☐ 0256 ☐ 0260 ☐ 0262 ☐ 0266 ☐ 0267 ☐ 0270 ☐ 0273 ☐ 0275 ☐ 0276 ☐ 0278 ☐ 0279 ☐ 0280 ☐ 0281 ☐ 0283 ☐ 0285 ☐ 0290 ☐ 0291
☐	3 Concrete	☐ 0300 ☐ 0301 ☐ 0310 ☐ 0320 ☐ 0330 ☐ 0340 ☐ 0350 ☐ 0370 ☐ 0380
☐	4 Masonry	☐ 0400 ☐ 0401 ☐ 0410 ☐ 0420 ☐ 0435
☐	5 Metals	☐ 0500 ☐ 0512 ☐ 0514 ☐ 0521 ☐ 0531 ☐ 0532
☐	6 Wood and Plastics	☐ 0600 ☐ 0610 ☐ 0650
☐	7 Thermal and Moisture Protection	☐ 0710 ☐ 0711 ☐ 0714 ☐ 0715 ☐ 0719 ☐ 0720 ☐ 0721 ☐ 0722 ☐ 0724 ☐ [illegible] ☐ 0730 ☐ 0750 ☐ 0751 ☐ 0753 ☐ 0760 ☐ 0790
☐	8 Doors and Windows	☐ 0800 ☐ 0810 ☐ 0820 ☐ 0830 ☐ 0833 ☐ 0836 ☐ 0839 ☐ 0850 ☐ 0860 ☐ 0870 ☐ 0880
☐	9 Finishes	☐ 0900 ☐ 0910 ☐ 0920 ☐ 0925 ☐ 0930 ☐ 0950 ☐ 0965 ☐ 0968 ☐ 0970 ☐ 0980 ☐ 0990 ☐ 0995
☐	10 Specialties	☐ 1015 ☐ 1020 ☐ 1024 ☐ 1027 ☐ 1030 ☐ 1040 ☐ 1050 ☐ 1052 ☐ 1053 ☐ 1055 ☐ 1060 ☐ 1065 ☐ 1070 ☐ 1075 ☐ 1080
☐	11 Equipment	☐ 1100 ☐ 1161
☐	12 Furnishings	☐ 1201 ☐ 1230 ☐ 1250 ☐ 1260 ☐ 1270
☐	13 Special Facilities	☐ 1300 ☐ 1304 ☐ 1305 ☐ 1306 ☐ 1307 ☐ 1318 ☐ 1319 ☐ 1320 ☐ 1321 ☐ 1322 ☐ 1323 ☐ 1324 ☐ 1325 ☐ 1326 ☐ 1328
☐	14 Conveying Systems	☐ 1401 ☐ 1420 ☐ 1440 ☐ 1460
■	15 Mechanical	☐ 1525 ■ 1530 ☐ 1540 ☐ 1550 ☐ 1555 ☐ 1565 ☐ 1574 ☐ 1589 ☐ 1595
☐	16 Electrical	☐ 1600 ☐ 1605 ☐ 1620 ☐ 1630 ☐ 1639 ☐ 1640 ☐ 1650 ☐ 1660 ☐ 1670 ☐ 1671 ☐ 1685 ☐ 1694

Note: A checked placed in the Division column signifies that the entire Division shall be applicable to the ECO, unless modified by checks indicated for specific Subdivisions.

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 1653-5 ECO Number: 5353

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Provide a sketch number for the sketch "Exit Portal Sprinkler Piping". See attached page 6.

4. Drawing Cog. Engineer Approval: W E Barnhart Date: 4/3/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

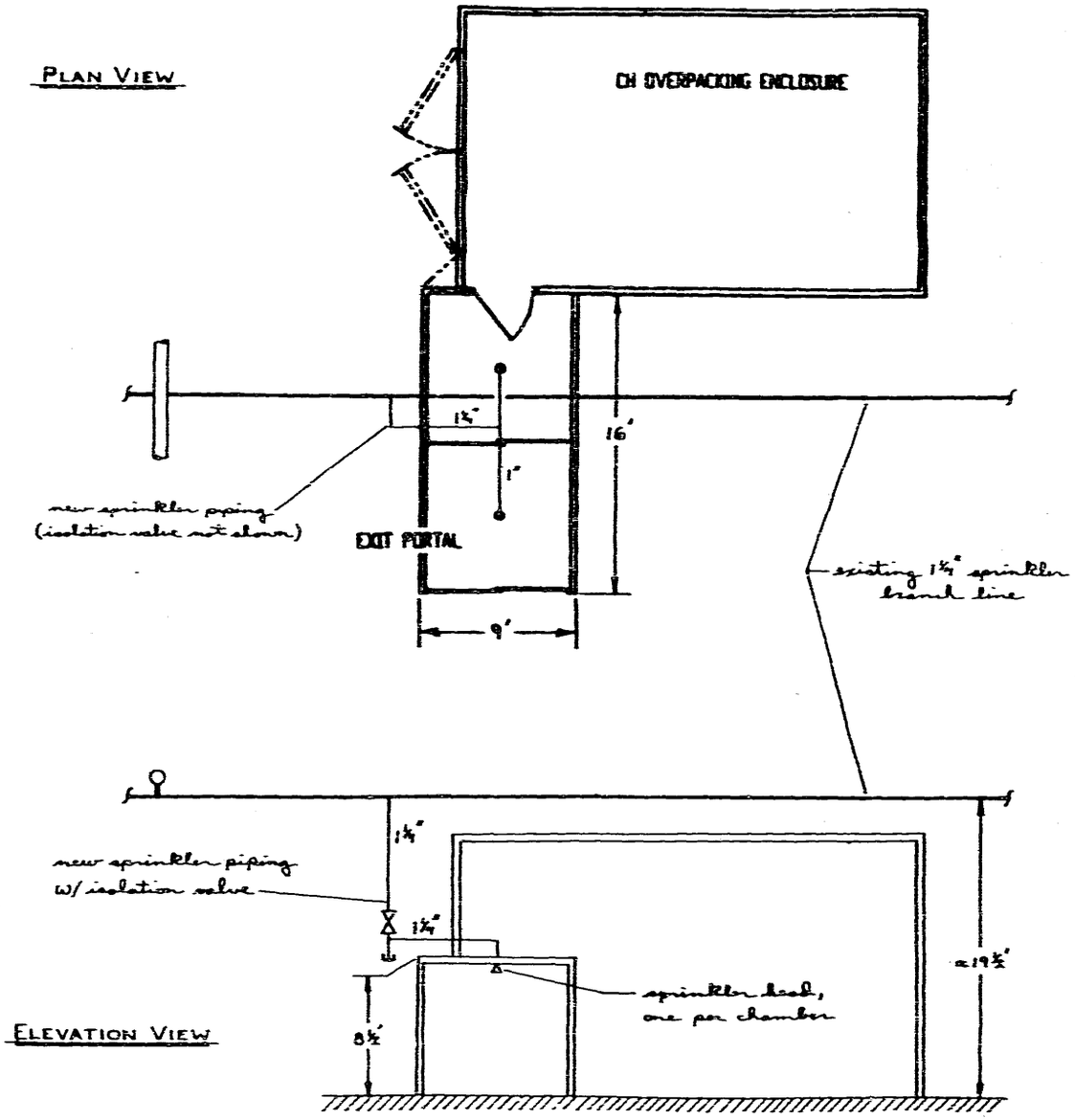
Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date



Notes:

1. The new Exit Portal sprinkler piping arrangement shown here is conceptual only. The contractor shall perform sprinkler system hydraulic calculations in accordance with NFPA 13 to verify that this arrangement is acceptable. If it is not, the contractor shall design an alternative piping arrangement. Original hydraulic calculations and the associated working drawing will be provided to the contractor. All calculations shall be submitted for approval as required by Spec D-[illegible]65, Rev. 1.
2. The structural members of the Exit Portal may be used to support the new sprinkler piping.
3. The sprinkler heads shall be recessed pendant or flush mounted, regardless of the Exit Portal ceiling height. Ref: Spec D-[illegible]65, Rev. 1, para. 3.3.2.c.
4. The isolation valve shall be an "OS & Y" bronze gate valve with screwed end connections and approved for fire protection service.
5. The sprinkler head penetrations thru the Exit Portal's roof shall be appropriately sealed.
6. All the new sprinkler piping shall be hydrostatically tested up to the point of attachment to the existing sprinkler piping. Appropriate pipe fittings shall be installed as required to allow this requirement to be met.
7. All work shall be in accordance with NFPA 13, Spec D-[illegible]65, Rev. 1, this drawing, and approved contractor working drawings.

REV	DATE	ISSUE DESCRIPTION	ENG	ECO

U.S. DEPARTMENT OF ENERGY

Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

COG. ENG [illegible]
COG. MGR [illegible]

EXIT PORTAL SPRINKLER PIPING

SYS.	DWG. NO.	REV.	FWR NO.
FP02	1653-S	A	M40880
		SH 1 OF 1	

pg 8 of 8
7 9

WEB
4/3/91

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 41-5-003-W, Rev C, Sht 2 ECO Number: 5353

2. ECO Search List: _____ _____ _____ _____

3. Description of Change:

Revise dwg. to show the footprint of the exit portal (9'x16') and the new sprinkler system piping associated with it. See attached markup, page 8.

4. Drawing Cog. Engineer Approval: WE Barnhart Date: 3/28/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

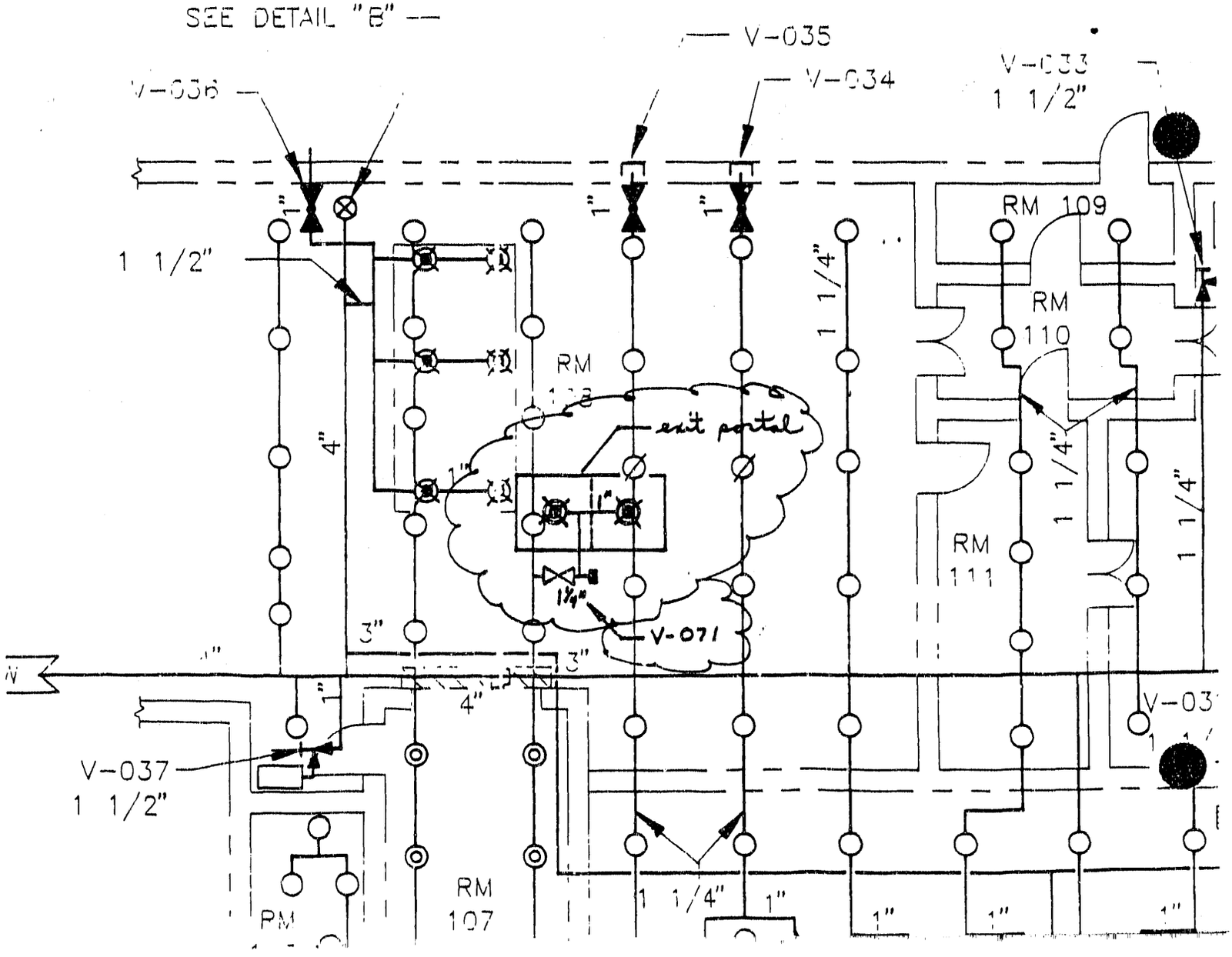
Return to EFR: _____ Initials / Date

ECO #: 5353
pg 8 of 8
9
NEB
4/3/91

7 | 6

1. Add "footprint" of exit portal to floorplan.

2. Show new sprinkler piping arrangement when as-built information is provided by Cog Sys Eng. ~~Piping shown is conceptual only!~~



ECO #: 5353

pg 8 of 8 WEB 4/3/91

VALVE IDENTIFICATION SHEET

NEW VALVE ☒ REVISED DATA ☐ VALVE REMOVED ☐

1. Tag Number: FW-411-V-071 2. Size: _____ 3. Pressure: _____
4. Building: 411 5. Location: ~~OP+RR/ sprinkler piping~~ "Exit Portal"
6. Valve Type: GATE 7. Valve Operator: HAND
8. Valve Bonnet: _____
9. Manufacturer: _____ 10. Catalog No.: _____
11. Body: _____ 12. Trim: _____ 13. Ends: _____
14. Piping Code: NFPA 13 15. Seis. Class: NA
16. Working Pressure: 150 PSIG 17. Working Temperature: 80°F
18. Normal Valve Position/Full Open: X Full Closed: _____ % Throttled: _____
19. Spec. Number: NA 20. P.O. Number: NA
21. Design Class: III B
22. P&ID 41-5-003-W Sht.: 2 Zone: _____
23. Plan Drawing Number: NA Sht.: _____ Zone: _____
24. Isometric Drawing Number: NA
25. Piping Line Number: NA
26. **Document Providing Information**

030 _____ ECO 5353 EWP _____

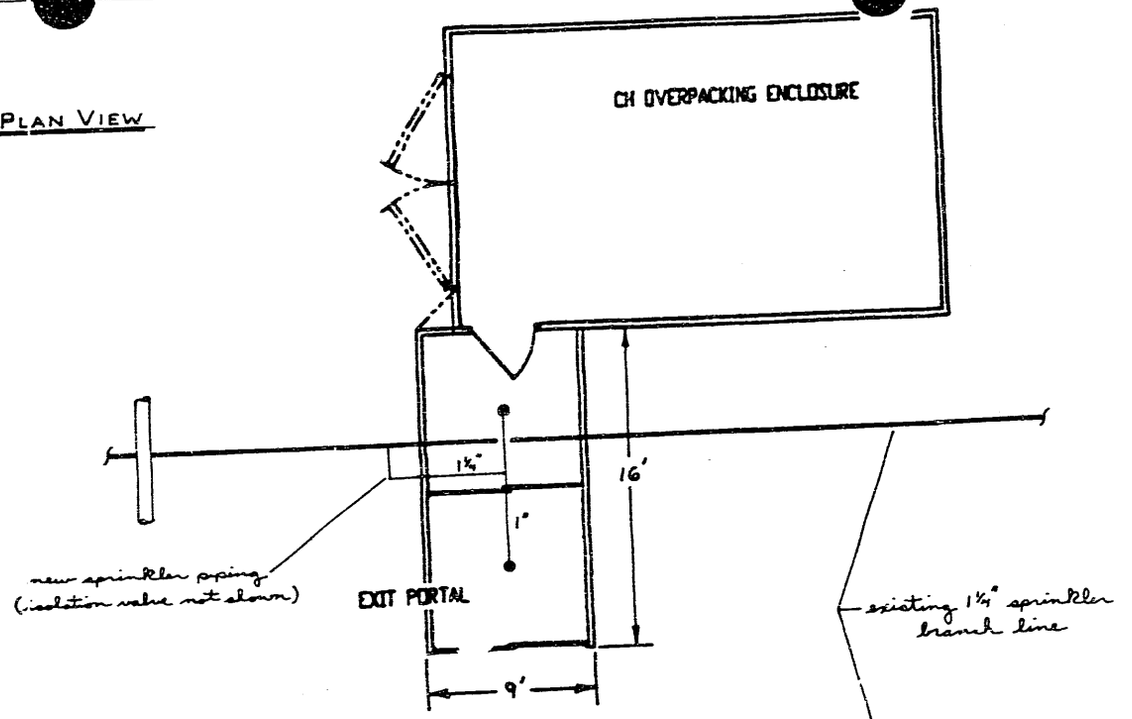
27. Service Remarks: To provide the ability to isolate the "Exit Portal" sprinkler piping from the WHB "gone 2" sprinkler piping

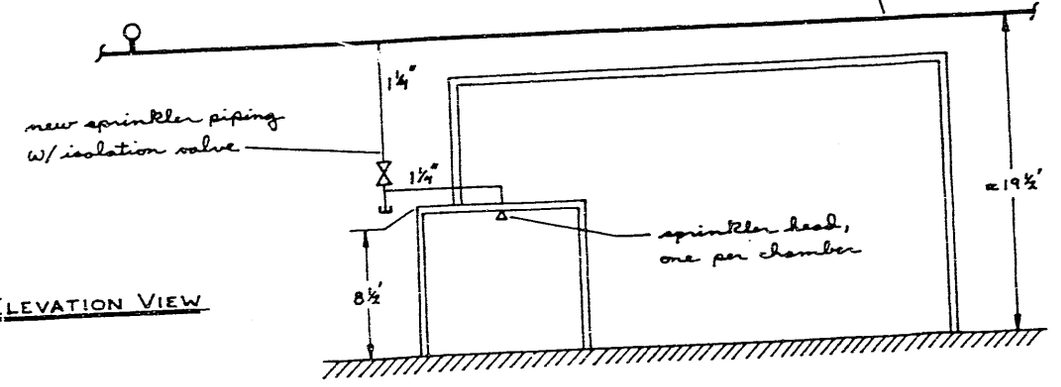
WE Barnhart 3/26/91
Information by Date

TAG NUMBER EXAMPLE	SYSTEM RW	BUILDING 457	INDICATES VALVE V	NUMBER 001

11898:3308

PLAN VIEW





ELEVATION VIEW

Notes:

1. The new Exit Portal sprinkler piping arrangement sho here is conceptual only. The contractor shall perfo sprinkler system hydraulic calculations in accordanc with NFPA 13 to verify that this arrangement is acce able. If it is not, the contractor shall design an ternative piping arrangement. Original hydraulic ca culations and the associated working drawing will be provided to the contractor. All calculations shall submitted for approval as required by Spec D-0065, R 1.

2. The structural members of the Exit Portal may be us to support the new sprinkler piping.

3. The sprinkler heads shall be recessed pendant or fl mounted, regardless of the Exit Portal ceiling heig Ref: Spec D-0065, Rev. 1, para. 3.3.2.c.

4. The isolation valve shall be an "OS & Y" bronze ga valve with screwed end connections and approved for fire protection service.

5. The sprinkler head penetrations thru the Exit Porta roof shall be appropriately sealed.

6. All the new sprinkler piping shall be hydrostatica tested up to the point of attachment to the existin sprinkler piping. Appropriate pipe fittings shall installed as required to allow this requirement to met.

7. All work shall be in accordance with NFPA 13, Spec 0065, Rev. 1, this drawing, and approved contracto working drawings.

REV	DATE	ISSUE DESCRIPTION		
A	4-4-91	Approval For Use	WIB	5
			ENG	

U.S. DEPARTMENT OF ENERGY

Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

COG. ENG	W Gamble 4/3/91
COG. MGR	[illegible] 4/3/91
	Jr Black 4/3/91

EXIT PORTAL SPRINKLER PIPI

SYS.	DWG. NO.	REV.	F WI
FP02	1653-S	A	M40
		SH. 1 OF 1	

ENGINEERING CHANGE ORDER

USE BLACK INK

1. **ECO No.:** 5313
CC&D Review: [X]

Initials / Posted

2. **Impact Level** 1 ☐ 2 ☐ 3 ☒ 4 ☐

3. **System:** CF02 Equipment No.: N/A Building: 412 & 411

4. Associated Documents:
PWR 05749 M
ECP
P.O.
Others

5. **Document Type:**
~~Drawing~~ SKETCH 1678-5 ☒
Specification 41-E-C03-C14 ☐
41-E-W00-0021
Vendor Data ☐
SDD ☐
Others

6. **Title of Change:** PERMANENT CROSS BRACINGS GUARDS

7. Originator: (print)	Ext. No.:	Department:	Date:	8. Cognizant Engineer: (print)
HADI SAYAHI	8780	M+C.E	5/31/91	JOHN KOWALSKI

9. **Description of Change:**

Yes ☐ No ☒ Component indices change required (if yes, attach sheets)

- ASSIGN A NUMBER FOR THE ATTACHED PERMANENT CROSS BRACINGS GUARDS SKETCH. 1678-5
- AFTER COMPLETION OF THE JOB, INCORPORATE (AS BUILT) NEW ADDITIONS ON AFFECTED DRAWINGS. SEE ATTACHED 9a SHEETS.
- SUPERCEDE SKETCH #1678-5 .

☒ 9a Drawing Change Sheet attached
☐ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

10. Yes ☒ No ☐ **MODIFICATION IN PROGRESS**
☐ Modification complete: J. Kowalski (Signature) MK 02/20/92 (Date) — ECO will be incorporated after M.I.P. signed complete
☐ Change drawing per as-built markup dated:
☐ Change drawing per ECO-provided data
☐ Temporary modification

11. **Design Verification Requirements: (per WP 09-018)** EDT No.:

JWP 1. Requirements satisfied by review/approval of design document
2. Independent review
3. Alternate calculations
4. Development testing
5. Design review
6. Other:

12. **Addendum Sheet added:** / (Signature) (Date)

13. Justification

TO PREVENT PERSONNEL INJURY AND TO SATISFY OSHA REQUIREMENTS.

14. Administrative Tracking

YES	N/A		YES	N/A	
☐	☒	1. FSAR	☐	☒	6. Startup/Acceptance Test
☐	☒	2. Calibration Procedures	☐	☒	7. Test Requirement & Spec.
☐	☒	3. Maintenance Procedures	☐	☒	8. _____
☐	☒	4. Computer Software	☐	☐	9. _____
☐	☒	5. Operations Procedures	☐	☐	10. _____

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

A	Cog. Engineer	J. Howard 6/4/91
A	Cog. Eng. Mgr.	6/4/91
R	Startup	6/5/91
R	QA	6/6/91
☐	DOE	
R	Safety	6-7-91
☐	Dept. Manager	
☐	Operations	
☐	Security	
☐	SNL	
☐		
☐		
☐		

16. Distribute as Marked

☒	Maintenance (MANDATORY)
☐	Ops. Support (MANDATORY)
☐	Startup
☐	Facility Operations
☐	U/G Operations
☒	Orig./Design Engr.
☒	Cog. Engineer
☐	Others
☐	
☐	
☐	
☐	
☐	

ENGINEERING CHANGE ORDER

DOE ORDER 6430.1A DESIGN CRITERIA CHECKLIST

1. ECO # 5521
2. DATE 5/31/91

The design requirements in DOE Order 6430.1A checked below have been applied to this Design.

3. DIVISION	SUBDIVISION
☐ 1 General Requirements	☐ 0101 ☐ 0106 ☐ 0109 ☐ 0110 ☐ 0111 ☐ 0140 ☐ 0150 ☐ 0170
☐ 2 Site and Civil Engineering	☐ 0200 ☐ 0201 ☐ 0202 ☐ 0203 ☐ 0205 ☐ 0210 ☐ 0214 ☐ 0215 ☐ 0220 ☐ 0235 ☐ 0245 ☐ 0250 ☐ 0256 ☐ 0260 ☐ 0262 ☐ 0265 ☐ 0267 ☐ 0270 ☐ 0273 ☐ 0275 ☐ 0276 ☐ 0278 ☐ 0279 ☐ 0280 ☐ 0281 ☐ 0283 ☐ 0285 ☐ 0290 ☐ 0291
☐ 3 Concrete	☐ 0300 ☐ 0301 ☐ 0310 ☐ 0320 ☐ 0330 ☐ 0340 ☐ 0350 ☐ 0370 ☐ 0380
☐ 4 Masonry	☐ 0400 ☐ 0401 ☐ 0410 ☐ 0420 ☐ 0455
☒ 5 Metals	☐ 0500 ☒ 0512 ☐ 0514 ☐ 0521 ☐ 0531 ☐ 0532
☐ 6 Wood and Plastics	☐ 0600 ☐ 0610 ☐ 0650
☐ 7 Thermal and Moisture Protection	☐ 0710 ☐ 0711 ☐ 0714 ☐ 0715 ☐ 0719 ☐ 0720 ☐ 0721 ☐ 0722 ☐ 0724 ☐ 0725 ☐ 0730 ☐ 0750 ☐ 0751 ☐ 0753 ☐ 0760 ☐ 0790
☐ 8 Doors and Windows	☐ 0800 ☐ 0810 ☐ 0820 ☐ 0830 ☐ 0833 ☐ 0836 ☐ 0839 ☐ 0850 ☐ 0860 ☐ 0870 ☐ 0880
☐ 9 Finishes	☐ 0900 ☐ 0910 ☐ 0920 ☐ 0925 ☐ 0930 ☐ 0950 ☐ 0965 ☐ 0968 ☐ 0970 ☐ 0981 ☐ 0990 ☐ 0995
☐ 10 Specialties	☐ 1015 ☐ 1020 ☐ 1024 ☐ 1027 ☐ 1030 ☐ 1040 ☐ 1050 ☐ 1052 ☐ 1053 ☐ 1056 ☐ 1060 ☐ 1065 ☐ 1070 ☐ 1075 ☐ 1080
☐ 11 Equipment	☐ 1100 ☐ 1161
☐ 12 Furnishings	☐ 1201 ☐ 1230 ☐ 1250 ☐ 1260 ☐ 1270
☐ 13 Special Facilities	☐ 1300 ☐ 1304 ☐ 1305 ☐ 1306 ☐ 1307 ☐ 1318 ☐ 1319 ☐ 1320 ☐ 1321 ☐ 1322 ☐ 1323 ☐ 1324 ☐ 1325 ☐ 1326 ☐ 1328
☐ 14 Conveying Systems	☐ 1401 ☐ 1420 ☐ 1440 ☐ 1460
☐ 15 Mechanical	☐ 1525 ☐ 1530 ☐ 1540 ☐ 1550 ☐ 1555 ☐ 1565 ☐ 1574 ☐ 1589 ☐ 1595
☐ 16 Electrical	☐ 1600 ☐ 1605 ☐ 1620 ☐ 1630 ☐ 1639 ☐ 1640 ☐ 1650 ☐ 1655 ☐ 1660 ☐ 1671 ☐ 1671 ☐ 1685 ☐ 1694
4. ☐ NOT APPLICABLE	No portion of DOE Order 6430.1A is applicable to this Design.
5. ☐ AS-BUILT	ECO is for as-built field verified changes only.

NOTE: A check placed in the Division column signifies that the entire Division shall be applicable to the Design, unless modified by checks indicated for specific Subdivisions.

COMMENTS: _____

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: NO 41-E-003-014 ECO Number: 5513

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

SHOW (AS BUILT) LOCATION OF NEW BRACINGS GUARDS ON PLAN AND ALSO REDRAW THE TYPICAL DETAIL, PER SKETCH NO. .

4. Drawing Cog. Engineer Approval: J. Kovacs Date: 6/4/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

PAGE 5 OF 6

1. Drawing: No. 41-E-600-021 ECO Number: 5513

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

SHOW (AS BUILT) LOCATION OF NEW BRACINGS GUARDS ON PLAN AND ALSO REDRAW THE TYPICAL DETAIL, PER SKETCH NO .

4. Drawing Cog. Engineer Approval: J. Kwan Date: 6/4/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

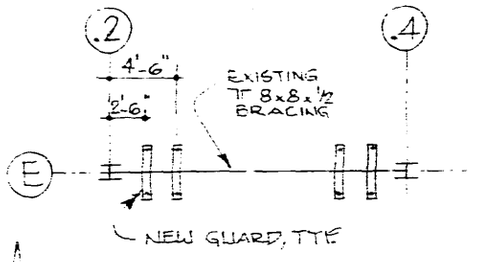
Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

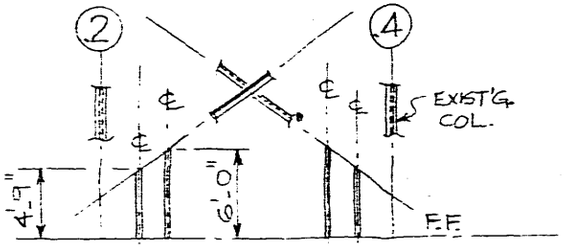
Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

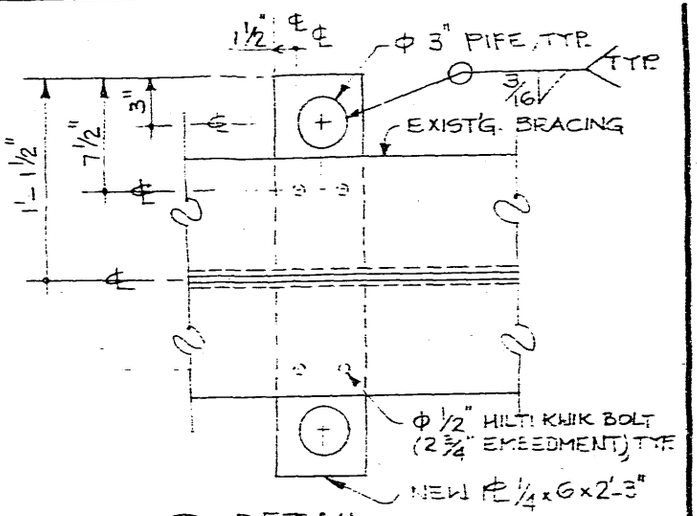
Return to EFR: _____ Initials / Date



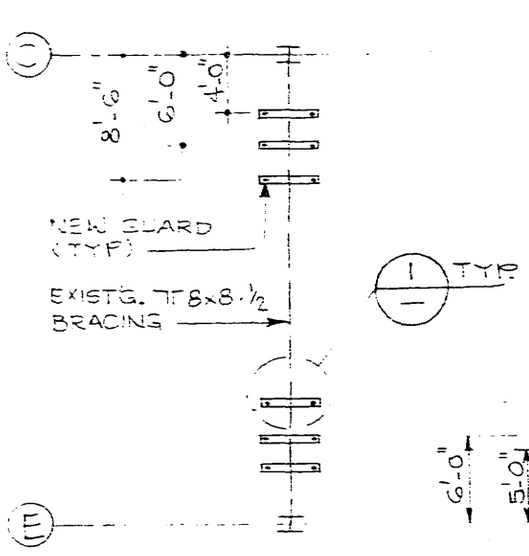
PLAN / TRUPACT BLDG.
N.T.S.



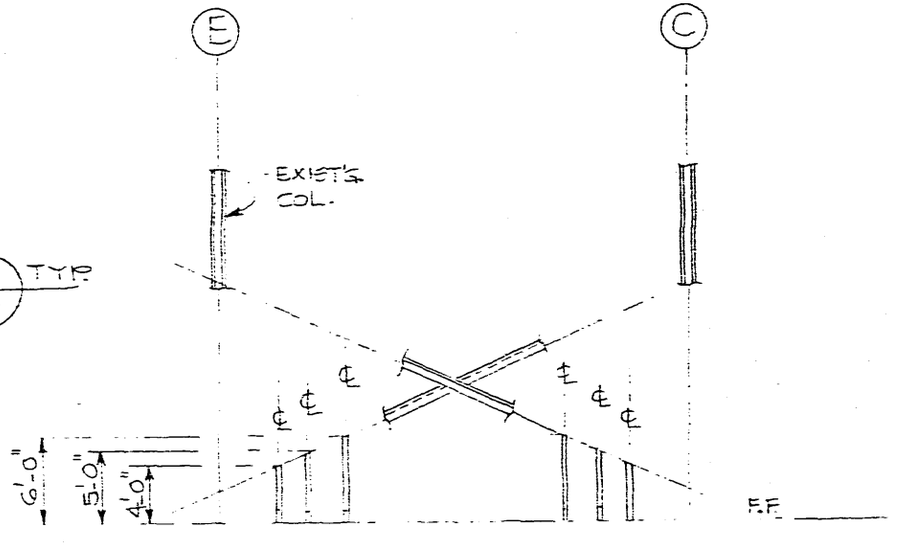
ELEVATION / TRUPACT BLDG.
N.T.S.



1 / — DETAIL
N.T.S.



PLAN, WASTE HANDLING BLDG.
N.T.S



ELEVATION / WASTE HANDLING BLDG.
(LOOKING WEST)
N.T.S.

NOTES:

1. STEEL A 36
2. FYES A 120
3. COLOR OF PAINT SHALL BE SAFETY YELLOW.

TRUPACT AND WASTE HANDLING BUILDINGS PERMANENT CROSS BRACINGS GUARDS

TITLE

SKETCH

COG ENG.

COG ENG. MGR.

USE BLACK INK

ENGINEERING CHANGE ORDER

ENGINEERING FILE ROOM COPY

1. **ECO No.:** 5532
CC&D Review: RL

Initials

Posted

SUPERSEDED

DR [redacted]

ECO 5565

2. **Impact Level** 1 ☐ 2 ☐ 3 ☒ 4 ☐

3. **System:** EM05 Equipment No.: VC-534-RV-009 Building: LIG

4. Associated Documents:
PWR _____
ECP _____
P.O. _____
Others PWRM41816

5. **Document Type:** gc 6/3/91
Drawing ~~52-L-002-W4~~ ☒
Specification 52-L-002-W5 ☐
Vendor Data 52-L-002-W6 ☐
SDD 52-L-002-W2 ☐
Others 52-L-002-W3 ☐
52-L-001-W
52-L-002-W1

6. **Title of Change:** VOC 10 MODIFICATIONS

7. Originator: (print)	Ext. No.:	Department:	Date:	8. Cognizant Engineer: (print)
JERRY CAMP	8750	EE	6-7-91	J.R. STROBLE

9. **Description of Change:**

Yes ☐ No ☒ Component indices change required (if yes, attach sheets)

(1) CHANGE TUBING CONFIGURATION TO PRESSURE RELIEF VALVE ~~534~~ gc 6/7/91 VC-534-RV-009 AS SHOWN ON ATTACHED SHEETS.

(2) ADD FLAG NOTE AS SHOWN ON ATTACHED SHEETS.
ADD NOTE TO SHEET 1 (52-L-002-W1). DRAFTING TO ~~DET~~ DETERMINE NOTE NO. gc. 6/3/91
△ : ~~AD~~ ALL TUBING FROM THE MAIN CARBON BED OUTLET TO THE SAMPLER INLET IS WRAPPED WITH HEAT TAPE. (3.25 WATTS PER SQUARE INCH)

☒ 9a Drawing Change Sheet attached
☐ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

10. Yes ☒ No ☒ ~~JRS~~ gc 6/3/91 **MODIFICATION IN PROGRESS**
☐ Modification complete: J.R. Stroble (Signature) 6-24-91 (Date)
ECO will be incorporated after M.I.P. signed complete

☒ Change drawing per as-built markup dated: NEW ECO
☐ Change drawing per ECO-provided data
☐ Temporary modification

11. **Design Verification Requirements: (per WP 09-018)** EDT No.: _____

_____ 1. Requirements satisfied by review/approval of design document
_____ 2. Independent review
_____ 3. Alternate calculations
_____ 4. Development testing
_____ 5. Design review
_____ 6. Other: _____

12. **Addendum Sheet added:** _____ / _____ (Signature / Date)

13. Justification

(1) THIS TUBING CHANGE WILL PROVIDE GREATER PROTECTION AGAINST MANIFOLD OVER PRESSURIZATION.

(2) COVERING TUBING WITH HEAT TAPE WILL MAKE SYSTEM CLEANING AND CERTIFICATION EASIER.

14. Administrative Tracking

YES	N/A		YES	N/A	
☐	☒	1. FSAR	☐	☒	6. Startup/Acceptance Test
☐	☒	2. Calibration Procedures	☐	☒	7. Test Requirement & Spec.
☐	☒	3. Maintenance Procedures	☐	☐	8. _____
☐	☒	4. Computer Software	☐	☐	9. _____
☐	☒	5. Operations Procedures	☐	☐	10. _____

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

[A]	Cog. Engineer	J.R. Stuffle 6-10-91
[A]	Cog. Eng. Mgr	6/10/91
[R]	Startup	6/11/91
☐	QA	6-14-91
☐	DOE	
☐	Safety	
☐	Dept. Manager	
☐	Operations	
☐	Security	
☐	SNL	
☐		
☐		
☐		

16. Distribute as Marked

☒	Maintenance (MANDATORY)	
☐	Ops. Support (MANDATORY)	
☐	Startup	
☐	Facility Operations	
☐	U/G Operations	
☐	Orig./Design Engr.	
☒	Cog. Engineer	
☐	Others	
☒	H.R. Ceas	
☒	-JERRY CAMP	
☐		
☐		
☐		

DOE ORDER 6430.1A DESIGN CRITERIA
CHECKLIST

ENGINEERING CHANGE ORDER (ECO) NO. 5532 DATE 6-7-91 COG. ENGINEER J.R. STEBBLE

The design requirements in DOE Order 6430.1A checked below have been applied to this ECO.

	DIVISION	SUBDIVISION
[ ]	1 General Requirements	[ ] 0101 [ ] 0106 [ ] 0109 [ ] 0110 [ ] 0111 [ ] 0140 [ ] 0150 [ ] 0170
[X]	2 Site and Civil Engineering	[ ] 0200 [ ] 0201 [ ] 0202 [ ] 0203 [ ] 0205 [ ] 0210 [ ] 0214 [ ] 0215 [ ] 0220 [ ] 0235 [ ] 0245 [ ] 0250 [ ] 0256 [ ] 0260 [ ] 0262 [ ] 0264 [ ] 0267 [ ] 0270 [ ] 0273 [ ] 0275 [ ] 0276 [ ] 0278 [ ] 0279 [ ] 0280 [ ] 0281 [X] 0283 [ ] 0285 [ ] 0290 [ ] 0291
[ ]	3 Concrete	[ ] 0300 [ ] 0301 [ ] 0310 [ ] 0320 [ ] 0330 [ ] 0340 [ ] 0350 [ ] 0370 [ ] 0380
[ ]	4 Masonry	[ ] 0400 [ ] 0401 [ ] 0410 [ ] 0420 [ ] 0455
[X]	5 Metals	[ ] 0500 [ ] 0512 [ ] 0514 [ ] 0521 [ ] 0531 [X] 0532
[ ]	6 Wood and Plastics	[ ] 0600 [ ] 0610 [ ] 0630
[X]	7 Thermal and Moisture Protection	[ ] 0710 [ ] 0711 [ ] 0714 [ ] 0715 [ ] 0719 [ ] 0720 [X] 0721 [ ] 0722 [ ] 0724 [ ] 0727 [ ] 0730 [ ] 0750 [ ] 0751 [ ] 0753 [ ] 0760 [ ] 0790
[X]	8 Doors and Windows	[ ] 0800 [X] 0810 [ ] 0820 [ ] 0830 [ ] 0833 [ ] 0836 [ ] 0837 [ ] 0850 [ ] 0860 [ ] 0870 [ ] 0880
[ ]	9 Finishes	[ ] 0900 [ ] 0910 [ ] 0920 [ ] 0925 [ ] 0930 [ ] 0950 [ ] 0965 [ ] 0968 [ ] 0970 [ ] 0980 [ ] 0990 [ ] 0995
[ ]	10 Specialties	[ ] 1015 [ ] 1020 [ ] 1024 [ ] 1027 [ ] 1030 [ ] 1040 [ ] 1050 [ ] 1052 [ ] 1053 [ ] 1055 [ ] 1060 [ ] 1065 [ ] 1070 [ ] 1075 [ ] 1080
[ ]	11 Equipment	[ ] 1100 [ ] 1161
[ ]	12 Furnishings	[ ] 1201 [ ] 1230 [ ] 1250 [ ] 1260 [ ] 1270
[ ]	13 Special Facilities	[ ] 1300 [ ] 1304 [ ] 1305 [ ] 1306 [ ] 1307 [ ] 1310 [ ] 1319 [ ] 1320 [ ] 1321 [ ] 1322 [ ] 1323 [ ] 1324 [ ] 1325 [ ] 1326 [ ] 1328
[ ]	14 Conveying Systems	[ ] 1401 [ ] 1420 [ ] 1440 [ ] 1460
[ ]	15 Mechanical	[ ] 1525 [ ] 1530 [ ] 1540 [ ] 1550 [ ] 1555 [ ] 1565 [ ] 1574 [ ] 1580 [ ] 1595
[X]	16 Electrical	[ ] 1600 [X] 1605 [ ] 1620 [ ] 1630 [ ] 1639 [ ] 1640 [ ] 1650 [ ] 1660 [ ] 1670 [ ] 1671 [ ] 1685 [ ] 1694

Note: A checked placed in the Division column signifies that the entire Division shall be applicable to the ECO, unless modified by checks indicated for specific Subdivisions.

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 52-L-001-W1 ECO Number: 5532

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

① ADD THE FOLLOWING FLAG NOTE TO SHEET 1 OF 10 :
(DRAFTING TO DETERMINE NOTE NUMBER)

⚠2 : ALL TUBING FROM THE MAIN CARBON BED OUTLET TO THE SAMPLER UNIT INLET IS WRAPPED WITH HEAT TAPE (3.25 WATTS PER SQUARE INCH).

4. Drawing Cog. Engineer Approval: J.R. Stuble Date: 6-10-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-W2 ECO Number: 5532

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

① REVISE TUBING TO VC-534-RV-009 (ZONE B-7) AS SHOWN ON SHEET 6 OF 14 . ALL OTHER DETAILS REMAIN SAME.

② ADD FLAG NOTE ⚠2 AT ZONE B-7 AS SHOWN ON SHEET 6 OF 14 .

4. Drawing Cog. Engineer Approval: J.R. Stobbe Date: 6-10-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-W3 ECO Number: 5532

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

① REVISE TUBING TO VC-534-RV-009 (ZONE B-7) AS SHOWN ON SHEET 8 OF 14.

② ADD FLAG NOTE ⚠ AT ZONE B-7 AS SHOWN ON SHEET 8 OF 14.

4. Drawing Cog. Engineer Approval: J.R. Stroble Date: 6-10-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-WS ECO Number: 5532

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

① CHANGE FIELD OF DWG AS SHOWN ON SHEET 10 OF 14. ALL OTHER DETAILS REMAIN SAME.

4. Drawing Cog. Engineer Approval: J.R. Stubble Date: 6-10-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

1290:B0006

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-W6 ECO Number: 5532

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

(1) CHANGE FIELD OF DWG AS SHOWN ON SHEET 12 OF 14. ALL OTHER DETAILS REMAIN SAME.

4. Drawing Cog. Engineer Approval: J.R. Stroble Date: 6-10-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 52-L-001-W ECO Number: 5522

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

① REVISE FIELD OF DWG AS SHOWN ON SHEET 14 OF 14. ALL OTHER DETAILS REMAIN SAME.

4. Drawing Cog. Engineer Approval: J.R. Struble Date: 6-10-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

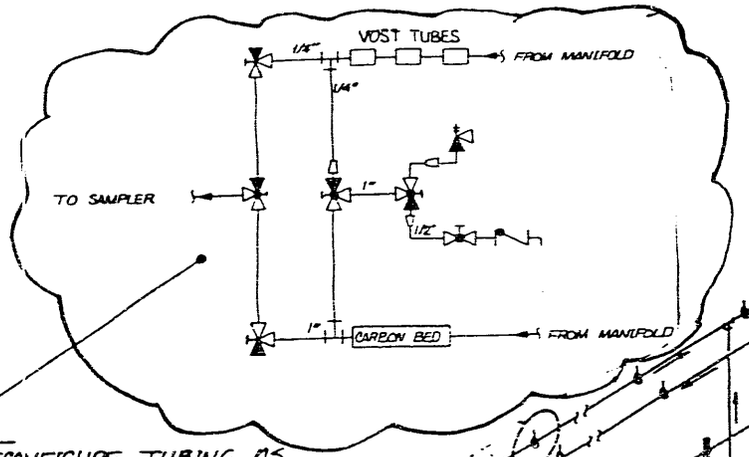
Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

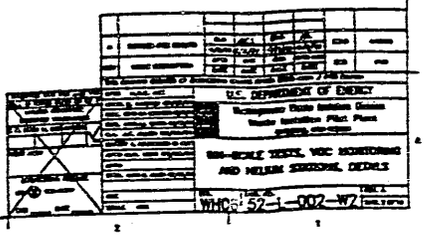
ECO 5532
SHEET 6 OF 14



RECONFIGURE TUBING AS SHOWN.

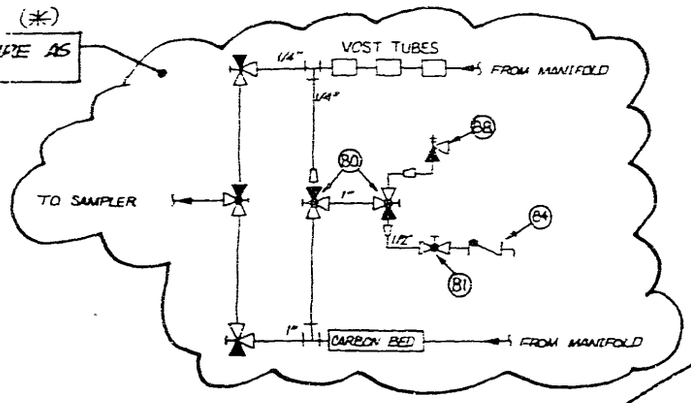
SEE ABOVE

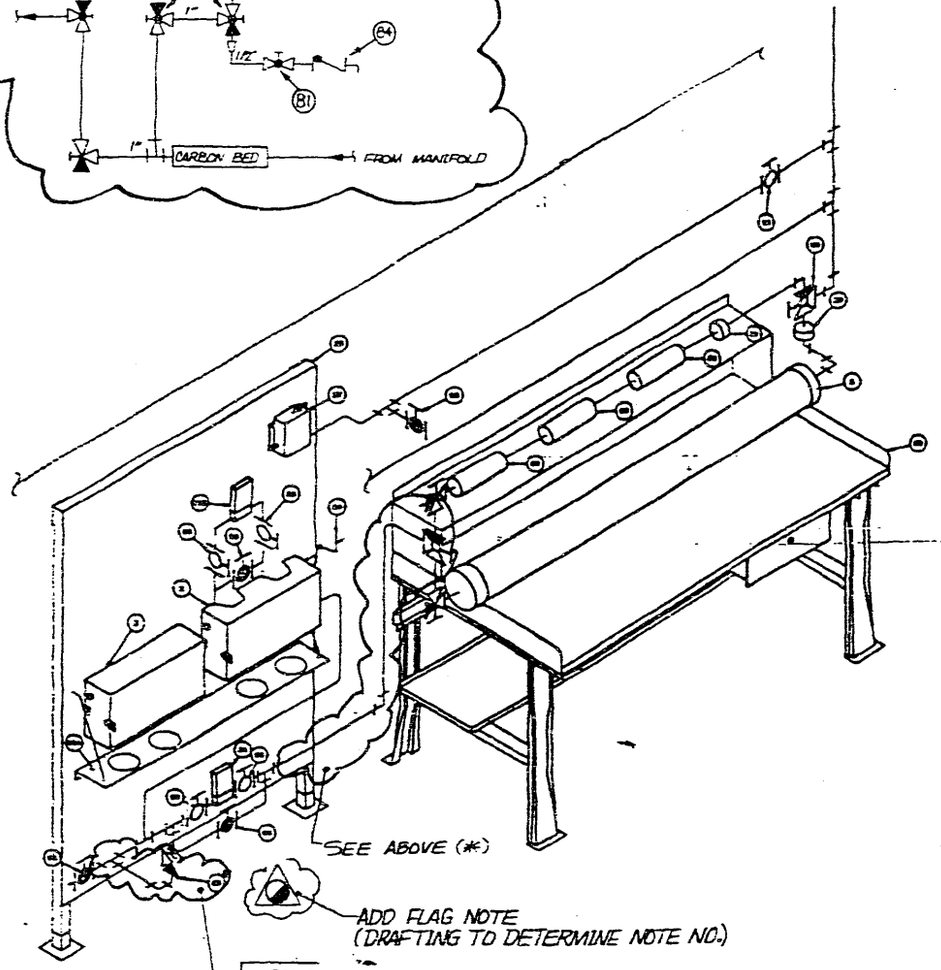
ADD FLAG NOTE (DRAFTING TO DETERMINE NOTE NO.)

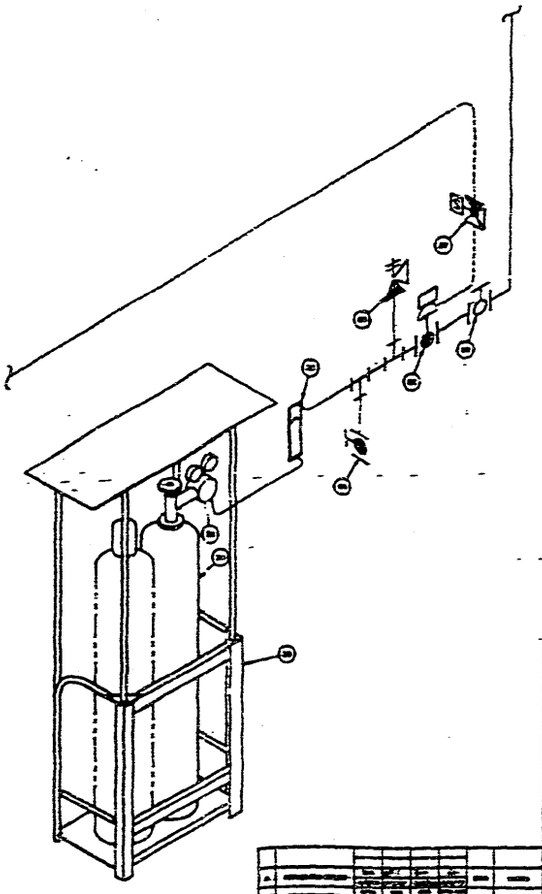


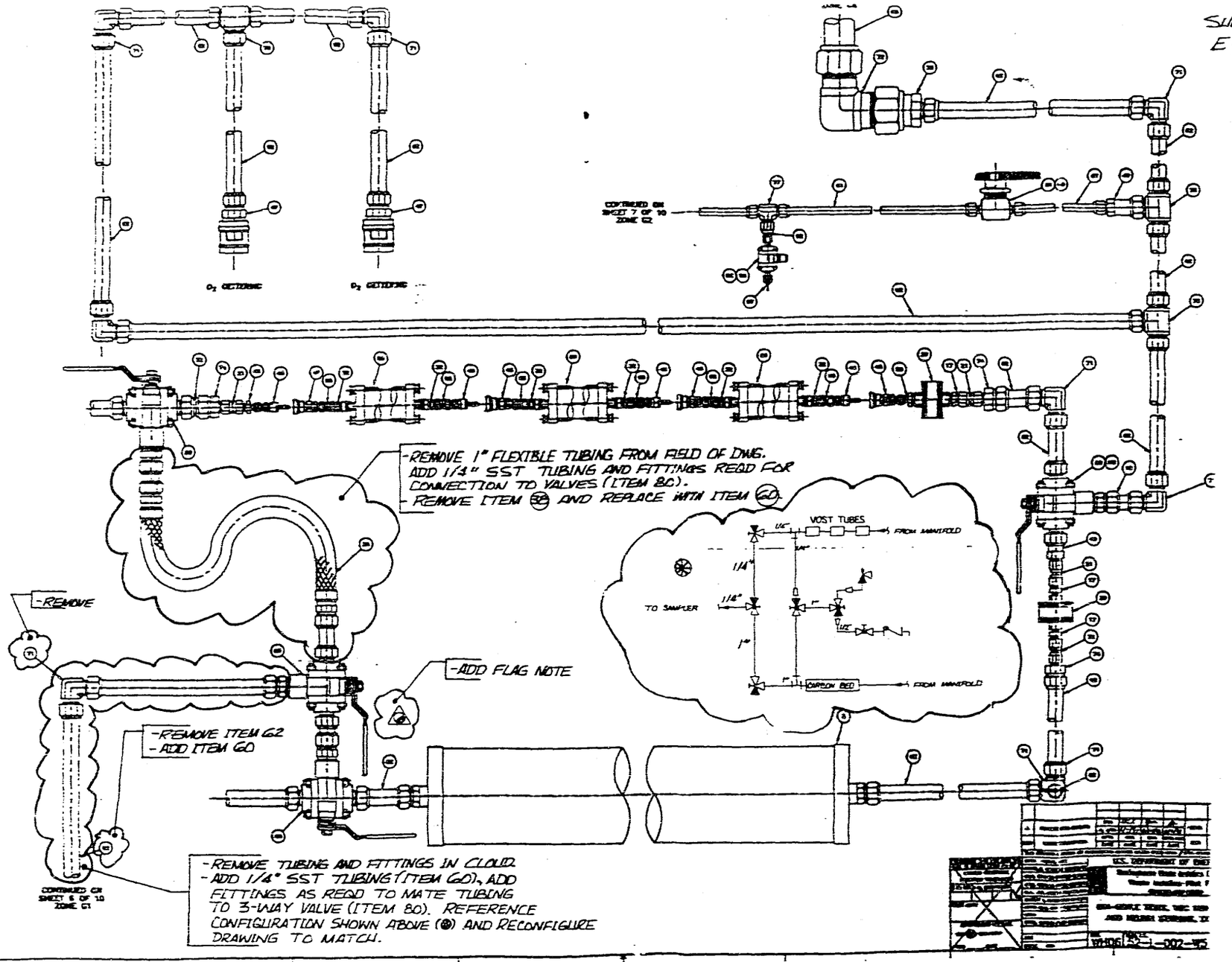
ECD 5532
SHEET 8 OF 14

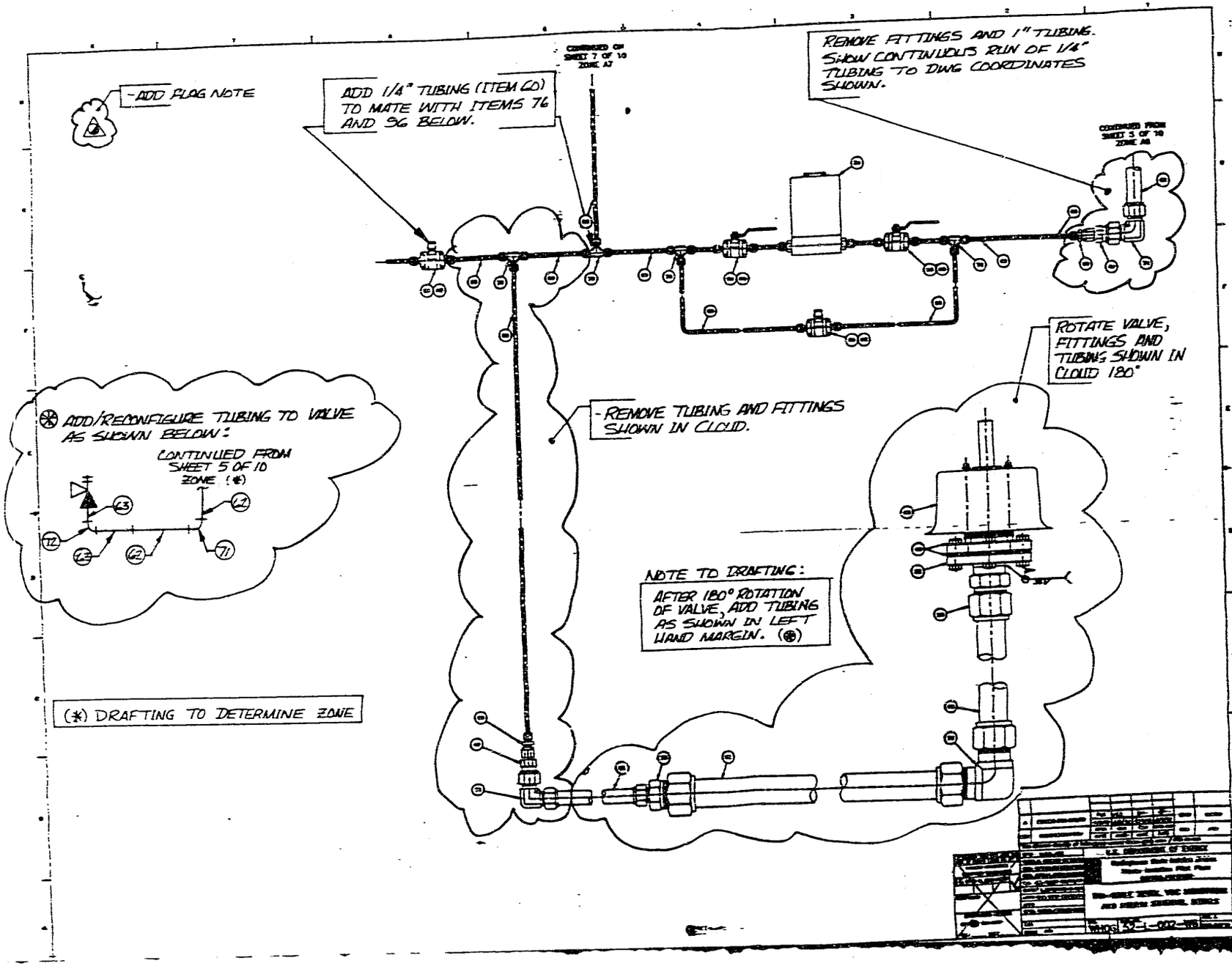
(*)
RECONFIGURE AS SHOWN



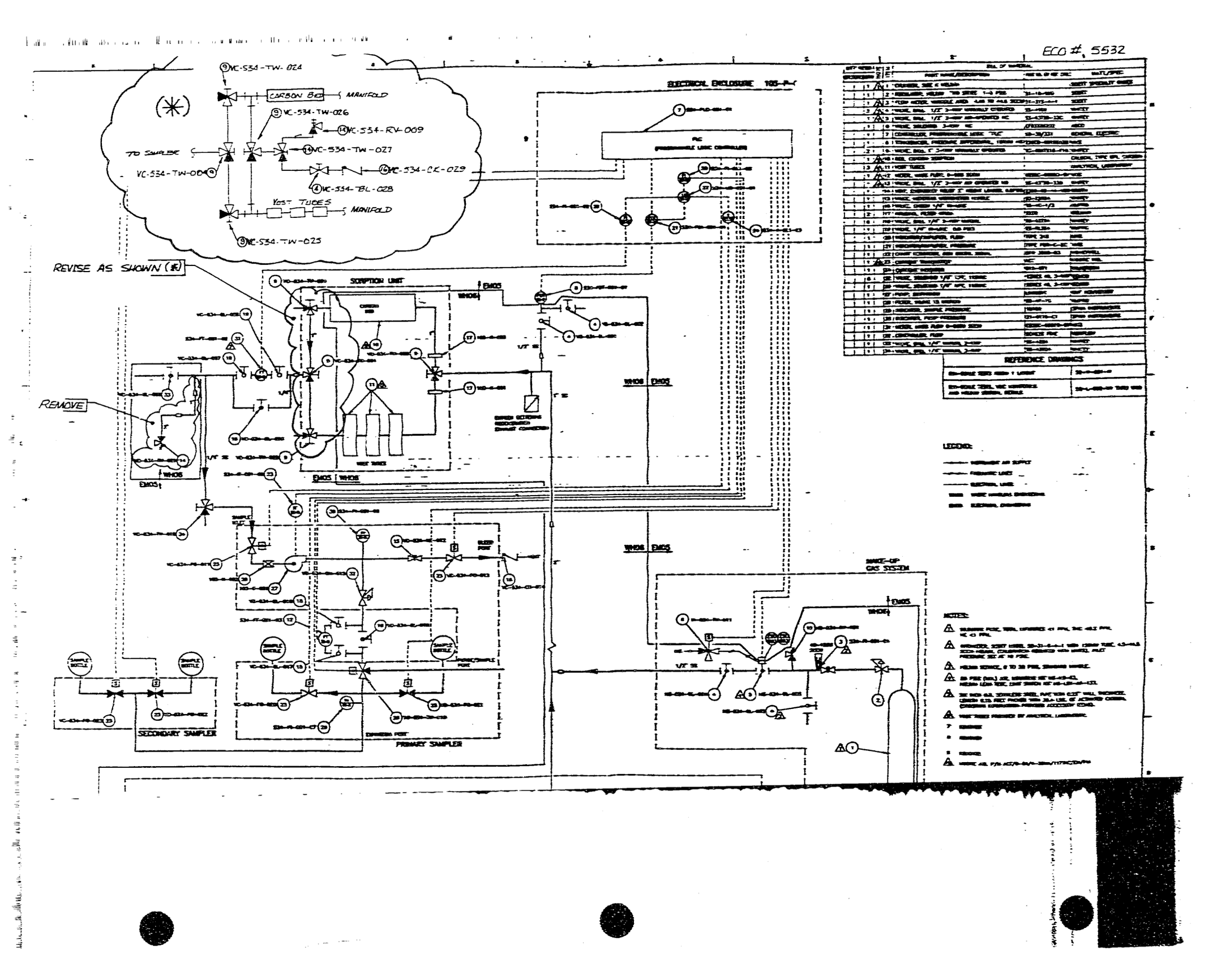





-REMOVE 1" FLEXIBLE TUBING FROM FIELD OF DWG. ADD 1/4" SST TUBING AND FITTINGS READ FOR CONNECTION TO VALVES (ITEM 80).
- REMOVE ITEM 52 AND REPLACE WITH ITEM 60.
VOST TUBES
FROM MANIFOLD
TO SAMPLER
FROM MANIFOLD
-REMOVE
-ADD FLAG NOTE
-REMOVE ITEM 62
-ADD ITEM 60
-REMOVE TUBING AND FITTINGS IN CLOUD.
-ADD 1/4" SST TUBING (ITEM 60), ADD FITTINGS AS READ TO MATE TUBING TO 3-WAY VALVE (ITEM 80). REFERENCE CONFIGURATION SHOWN ABOVE (8) AND RECONFIGURE DRAWING TO MATCH.


-ADD PLUG NOTE
ADD 1/4" TUBING (ITEM CO) TO MATE WITH ITEMS 76 AND 56 BELOW.
REMOVE FITTINGS AND 1" TUBING. SHOW CONTINUOUS RUN OF 1/4" TUBING TO DWG COORDINATES SHOWN.
ROTATE VALVE, FITTINGS AND TUBING SHOWN IN CLOUD 180°
-REMOVE TUBING AND FITTINGS SHOWN IN CLOUD.
ADD/RECONFIGURE TUBING TO VALVE AS SHOWN BELOW:
CONTINUED FROM SHEET 5 OF 10 ZONE (*)
NOTE TO DRAFTING:
AFTER 180° ROTATION OF VALVE, ADD TUBING AS SHOWN IN LEFT HAND MARGIN. (*)
(*) DRAFTING TO DETERMINE ZONE

ECO #, 5532


(*)
VC-534-TW-024
CARBON BED
MANIFOLD
VC-534-TW-026
VC-534-RV-009
TO SAMPLER
VC-534-TW-027
VC-534-TW-004
VC-534-CK-029
VC-534-BL-028
YOST TUBES
MANIFOLD
VC-534-TW-025
ELECTRICAL ENCLOSURE
REVISE AS SHOWN (*)
REMOVE
SORPTION UNIT
SECONDARY SAMPLER
PRIMARY SAMPLER
MAKE-UP GAS SYSTEM
REFERENCE DRAWINGS
NOTES:

ENGINEERING CHANGE ORDER

USE BLACK INK

1. **ECO No.:** 3541
CC&D Review: RL

Initials

Posted

2. **Impact Level** 1 ☐ 2 ☐ 3 ☒ 4 ☐

3. **System:** HVO1/CFO2 (WHO2) Equipment No.: EXIT PORTAL Building: 411

4. Associated Documents:
PWR M40880
ECP
P.O.
Others

5. **Document Type:**
Drawing ☒
Specification ☐
Vendor Data ☐
SDD ☐
Others

6. **Title of Change:** As-Building of Drawings

7. **Originator:** (print)	Ext. No.:	Department:	Date:	8. **Cognizant Engineer:** (print)
Wm BARNHART	8169	M+CE		Wm BARNHART

9. **Description of Change:**

Yes ☒ No ☐ Component Indices change required (if yes, attach sheets)

The following dwgs need to be revised to show the addition of one or more of these items: Overpack Enclosure, Exit Portal, 41-R-080.

41-B-001-W, Sht 2 41-E-013-014 41-G-172-014 41-G-509-014
41-E-001-014 41-F-022-014 41-G-302-014
41-E-003-014 41-G-170-014 41-G-501-014

The following dwgs need to be revised to show that a referenced dwg has been superseded: 41-B-001-W, Sht 1
41-B-001-W, Sht 3

☒ 9a Drawing Change Sheet attached
☐ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

10.

Yes	No	
☐	☒	**MODIFICATION IN PROGRESS**
☐		Modification complete: _____ / _____ (Signature / Date)

ECO will be incorporated after M.I.P. signed complete

☐ Change drawing per as-built markup dated: _____
☐ Change drawing per ECO-provided data
☐ Temporary modification

11. **Design Verification Requirements: (per WP 09-018)** EDT No.: _____

_____ 1. Requirements satisfied by review/approval of design document
_____ 2. Independent review
_____ 3. Alternate calculations
_____ 4. Development testing
_____ 5. Design review
_____ 6. Other: _____

12. **Addendum Sheet added:** _____ / _____ (Signature / Date)

13. Justification

The dwgs need to be revised to reflect existing site conditions..

14. Administrative Tracking

YES	N/A		YES	N/A	
☐	☒	1. FSAR	☐	☒	6. Startup/Acceptance Test
☐	☒	2. Calibration Procedures	☐	☒	7. Test Requirement & Spec.
☐	☒	3. Maintenance Procedures	☐	☐	8. _____
☐	☒	4. Computer Software	☐	☐	9. _____
☐	☒	5. Operations Procedures	☐	☐	10. _____

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

A	Cog. Engineer	6/14/91
A	Cog. Eng. Mgr.	6/19/91
R	Startup	6/17/91
R	QA	6/17/91
☐	DOE	
☐	Safety	
☐	Dept. Manager	
☐	Operations	
☐	Security	
☐	SNL	
☐		
☐		
☐		

16. Distribute as Marked

☒	Maintenance (MANDATORY)	
☒	Ops. Support (MANDATORY)	
☐	Startup	
☐	Facility Operations	
☐	U/G Operations	
☐	Orig./Design Engr.	
☐	Cog. Engineer	
☐	Others	
☐		
☐		
☐		
☐		
☐		

DOE ORDER 6430.1A DESIGN CRITERIA CHECKLIST

ENGINEERING CHANGE ORDER (ECO) NO. 5541 pg 3 of 32 DATE 6/14/91

COGNIZANT ENGINEER Wm BARNHART

The design requirements in DOE Order 6430.1A checked below have been applied to this Design.

DIVISION	SUBDIVISION
☐1 General Requirements	☐ 0101 ☐ 0106 ☐ 0109 ☐ 0110 ☐ 0111 ☐ 0140 ☐ 0150 ☐ 0170
☐2 Site and Civil Engineering	☐ 0200 ☐ 0201 ☐ 0202 ☐ 0203 ☐ 0205 ☐ 0210 ☐ 0214 ☐ 0215 ☐ 0220 ☐ 0235 ☐ 0245 ☐ 0250 ☐ 0256 ☐ 0260 ☐ 0262 ☐ 0266 ☐ 0267 ☐ 0270 ☐ 0273 ☐ 0275 ☐ 0276 ☐ 0278 ☐ 0279 ☐ 0280 ☐ 0281 ☐ 0283 ☐ 0285 ☐ 0290 ☐ 0291
☐3 Concrete	☐ 0300 ☐ 0301 ☐ 0310 ☐ 0320 ☐ 0330 ☐ 0340 ☐ 0350 ☐ 0370 ☐ 0380
☐4 Masonry	☐ 0400 ☐ 0401 ☐ 0410 ☐ 0420 ☐ 0455
☐5 Metals	☐ 0500 ☐ 0512 ☐ 0514 ☐ 0521 ☐ 0531 ☐ 0532
☐6 Wood and Plastics	☐ 0600 ☐ 0610 ☐ 0650
☐7 Thermal and Moisture Protection	☐ 0710 ☐ 0711 ☐ 0714 ☐ 0715 ☐ 0719 ☐ 0720 ☐ 0721 ☐ 0722 ☐ 0724 ☐ 0727 ☐ 0730 ☐ 0750 ☐ 0751 ☐ 0753 ☐ 0760 ☐ 0790
☐8 Doors and Windows	☐ 0800 ☐ 0810 ☐ 0820 ☐ 0830 ☐ 0833 ☐ 0836 ☐ 0839 ☐ 0850 ☐ 0860 ☐ 0870 ☐ 0880
☐9 Finishes	☐ 0900 ☐ 0910 ☐ 0920 ☐ 0925 ☐ 0930 ☐ 0950 ☐ 0965 ☐ 0968 ☐ 0970 ☐ 0980 ☐ 0990 ☐ 0995
☐10 Specialties	☐ 1015 ☐ 1020 ☐ 1024 ☐ 1027 ☐ 1030 ☐ 1040 ☐ 1050 ☐ 1052 ☐ 1053 ☐ 1055 ☐ 1060 ☐ 1065 ☐ 1070 ☐ 1075 ☐ 1080
☐11 Equipment	☐ 1100 ☐ 1161
☐12 Furnishings	☐ 1201 ☐ 1230 ☐ 1250 ☐ 1280 ☐ 1270
☐13 Special Facilities	☐ 1300 ☐ 1304 ☐ 1305 ☐ 1306 ☐ 1307 ☐ 1318 ☐ 1319 ☐ 1320 ☐ 1321 ☐ 1322 ☐ 1323 ☐ 1324 ☐ 1325 ☐ 1326 ☐ 1328
☐14 Conveying Systems	☐ 1401 ☐ 1420 ☐ 1440 ☐ 1460
☐15 Mechanical	☐ 1525 ☐ 1530 ☐ 1540 ☐ 1550 ☐ 1555 ☐ 1565 ☐ 1574 ☐ 1589 ☐ 1595
☐16 Electrical	☐ 1600 ☐ 1605 ☐ 1620 ☐ 1630 ☐ 1639 ☐ 1640 ☐ 1650 ☐ 1660 ☐ 1670 ☐ 167 ☐ 1685 ☐ 1694
■ No portion of DOE Order 6430.1A is applicable to this Design.	

NOTE: A check placed in the Division column signifies that the entire Division shall be applicable to the Design, unless modified by checks indicated for specific Subdivisions.

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 41-B-001-W, Sht 1, Rev C ECO Number: 5541
pg 4 of 32

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Revise dwg to show referenced dwg 71-H-006 has been superseded by dwg 105-J-004-W. See attached markup.

4. Drawing Cog. Engineer Approval: _____ Date: 14 June '91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

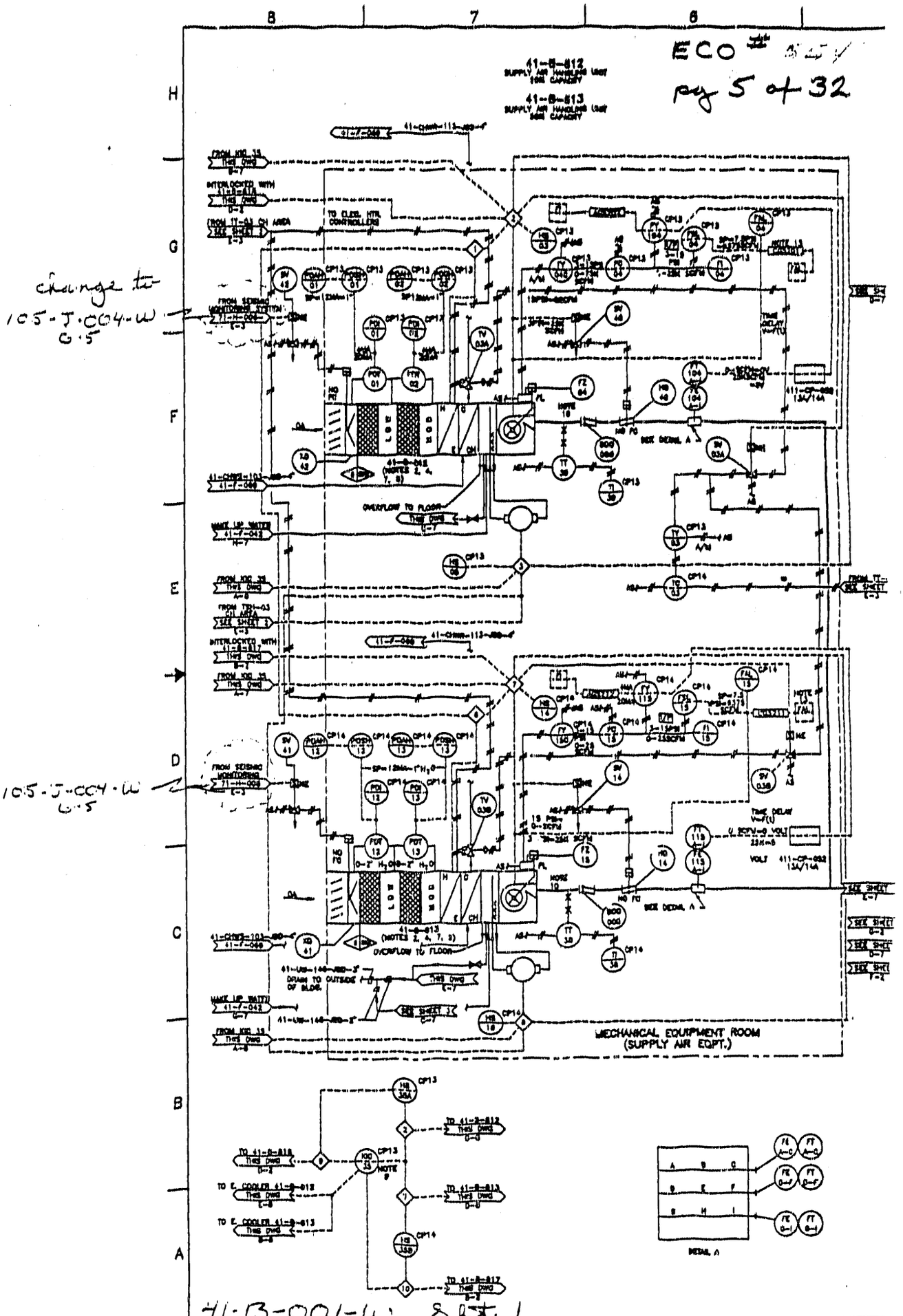
Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date


ECO # [illegible]
pg 5 of 32
41-B-012
SUPPLY AIR HANDLING UNIT
41-B-013
SUPPLY AIR HANDLING UNIT
change to
105-J-004-W
0-5
105-J-004-W
0-5
MECHANICAL EQUIPMENT ROOM
(SUPPLY AIR EQPT.)
41-B-001-W, Sht. 1

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 41-B-001-W, Sht 2, Rev C ECO Number: 5541
pg 6 of 32

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Revise dwg to show referenced dwg 71-H-006 has been superseded by dwg 105-J-004-W.

Revise dwg to show addition of Exit Portal w/HEPA filters and PDI's 32-35.

See attached markup.

4. Drawing Cog. Engineer Approval: _____ Date: 14 Jul 91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

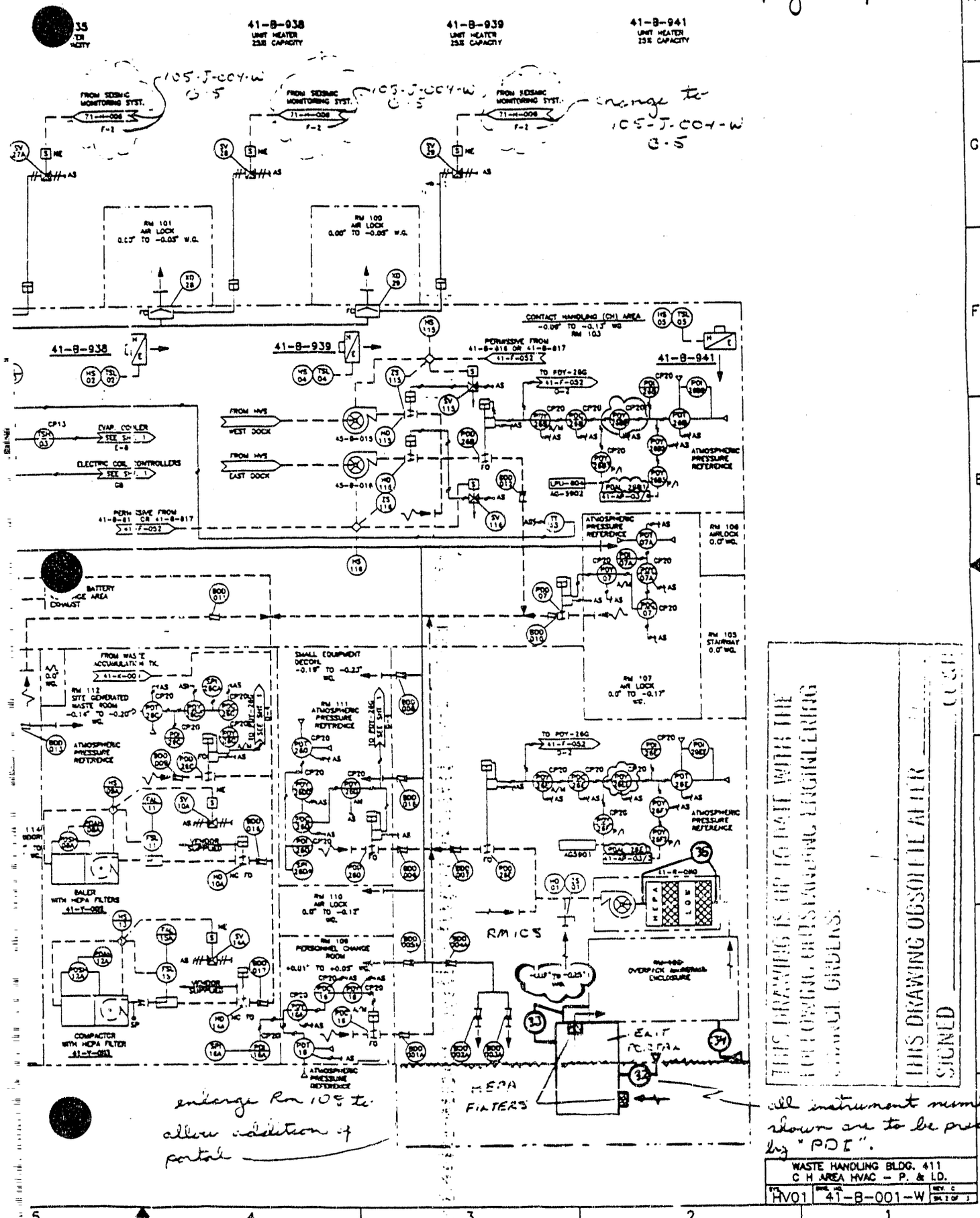
Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

ECO #175 #1

pg 7 of 32



THIS DRAWING IS UP TO DATE WITH THE FOLLOWING CHANGES AS ISSUED BY ENGINEERING CHANGE ORDERS:

THIS DRAWING OBSOLETE AFTER _____

SIGNED _____ DATE _____

WASTE HANDLING BLDG. 411 C H AREA HVAC – P. & I.D.		
HV01	41-B-001-W	REV. C SH. 2 OF 3

41-B-001-W, Sh 2

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 41-B-001-W, Sht 3, Rev B ECO Number: 5541

pg 8 of 32

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Revise dwg to show referenced dwg 71-H-006 has been superseded by dwg 105-J-004-W. See attached markups.

4. Drawing Cog. Engineer Approval: _____ Date: 14 JUIN 91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

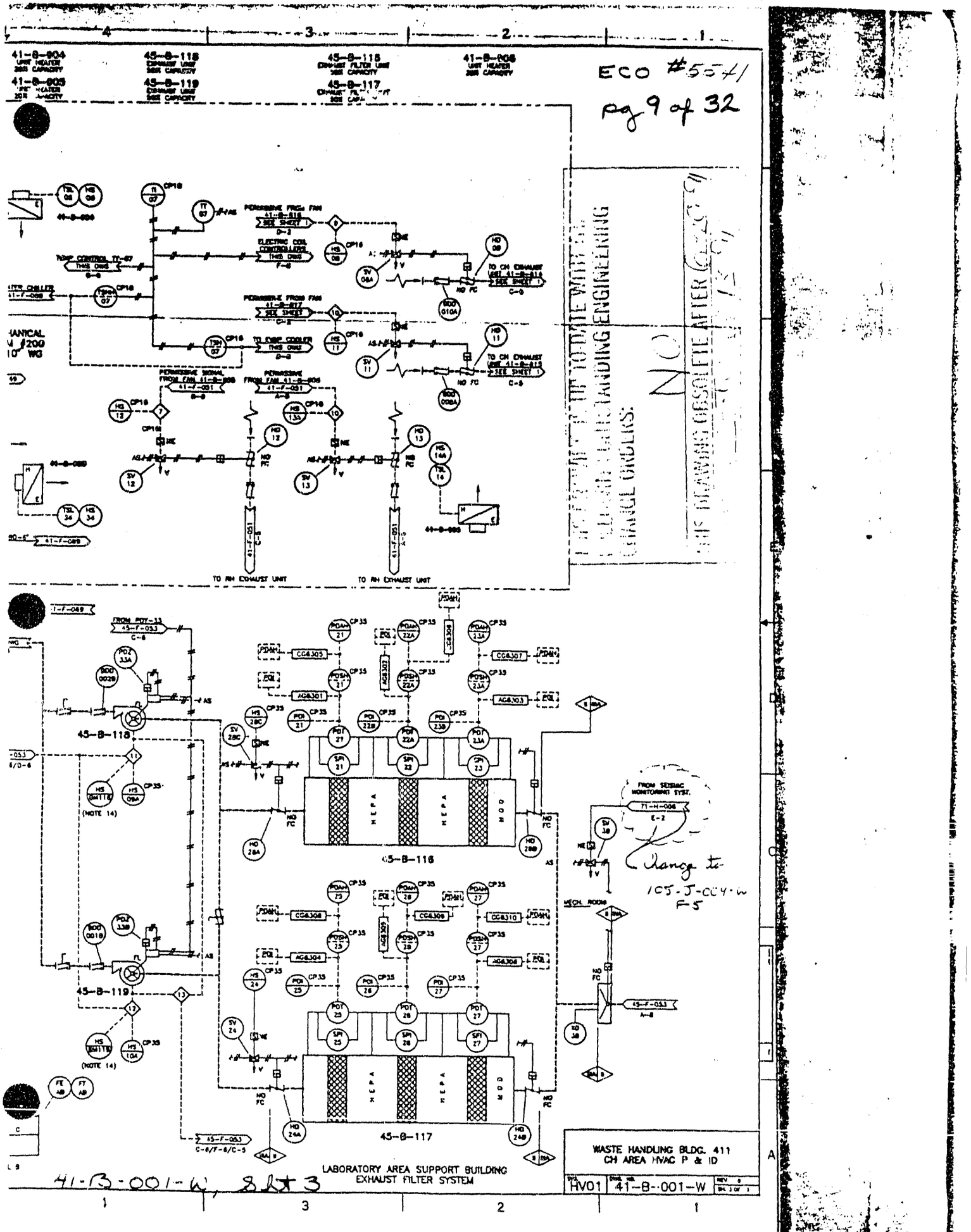
Date Assigned: _____ Initials / Date

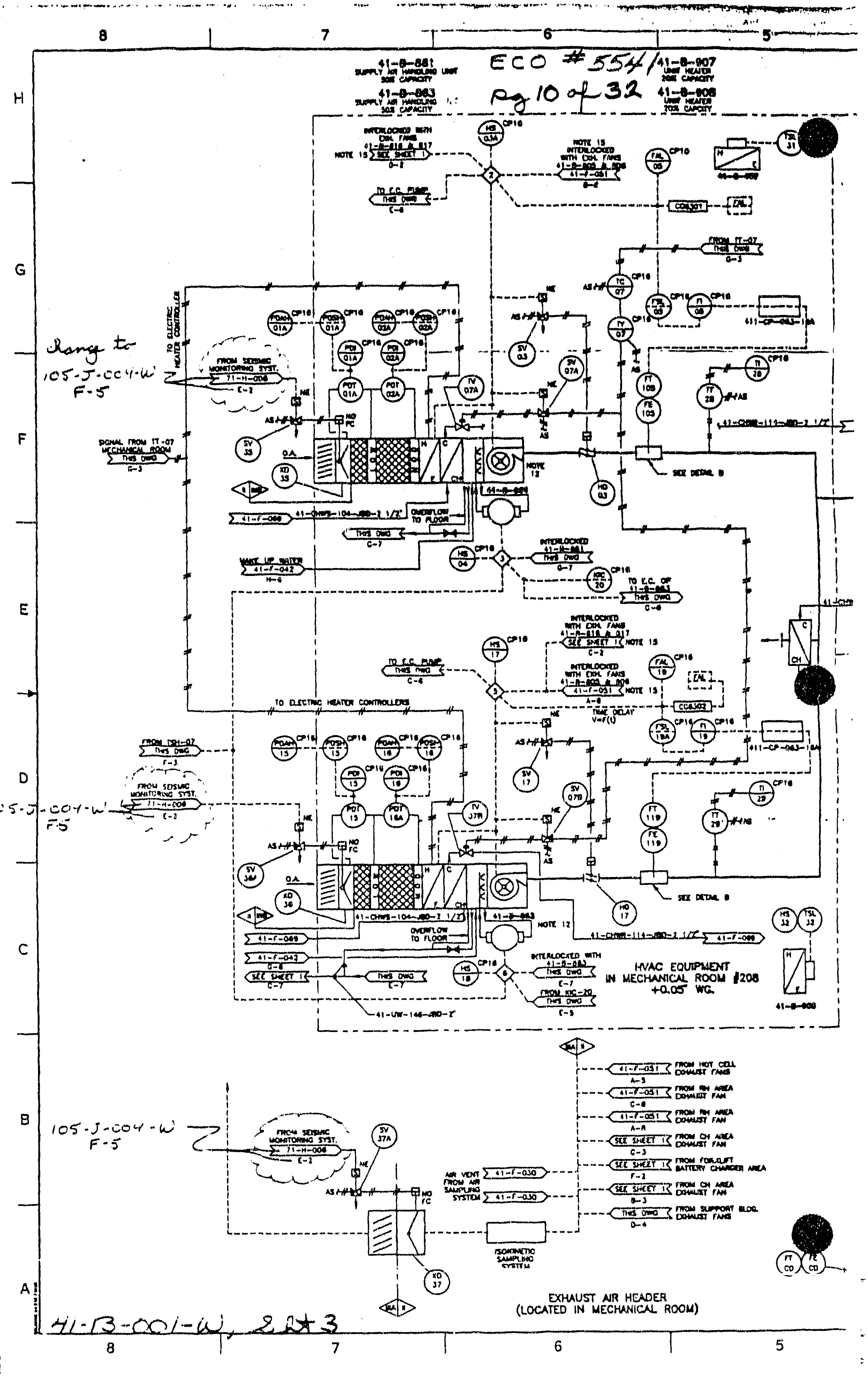
Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

1290:B0006


ECO #5541
pg 9 of 32
41-B-004
45-B-118
45-B-116
41-B-005
45-B-119
45-B-117
41-B-006
TO RH EXHAUST UNIT
TO RH EXHAUST UNIT
45-B-118
45-B-116
45-B-119
45-B-117
FROM SEISMIC MONITORING SYST.
Change to 105-J-004-W F-5
LABORATORY AREA SUPPORT BUILDING
EXHAUST FILTER SYSTEM
WASTE HANDLING BLDG. 411
CH AREA HVAC P & ID
HV01
41-B-001-W
41-B-001-W, Sht 3



ECO #554/
Pg 10 of 32
41-B-861 SUPPLY AIR HANDLING UNIT 50% CAPACITY
41-B-863 SUPPLY AIR HANDLING UNIT 50% CAPACITY
41-B-907 UNIT HEATER 20% CAPACITY
41-B-906 UNIT HEATER 70% CAPACITY
change to 105-J-C04-W F-5
FROM SEISMIC MONITORING SYST. 71-H-006 E-2
105-J-C04-W F-5
105-J-C04-W F-5
SIGNAL FROM TT-07 MECHANICAL ROOM THIS DWG G-3
TO ELECTRIC HEATER CONTROLLER
TO ELECTRIC HEATER CONTROLLERS
MAKE UP WATER 41-F-042 H-6
OVERFLOW TO FLOOR
SEE DETAIL B
NOTE 12
NOTE 15
INTERLOCKED WITH EXH. FANS
TO F.C. PUMP THIS DWG C-6
TIME DELAY V=F(t)
HVAC EQUIPMENT IN MECHANICAL ROOM #208 +0.05" WG.
41-UW-146-JBD-2"
AIR VENT FROM AIR SAMPLING SYSTEM 41-F-030
FROM HOT CELL EXHAUST FANS
FROM RH AREA EXHAUST FAN
FROM CH AREA EXHAUST FAN
FROM FORKLIFT BATTERY CHARGER AREA
FROM SUPPORT BLDG. EXHAUST FANS
ISOKINETIC SAMPLING SYSTEM
EXHAUST AIR HEADER (LOCATED IN MECHANICAL ROOM)
41-B-001-W, 2 of 3

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 41-E-001-014, Rev D ECO Number: 5541
pg 11 of 32

2. ECO Search List: 4622
5294

3. Description of Change:

Revise dwg to show footprint for "Overpack Enclosure" and "Exit Portal". Delete "Waste Handling Office". See attached markup.

4. Drawing Cog. Engineer Approval: T. Krawczyk Date: 6/14/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

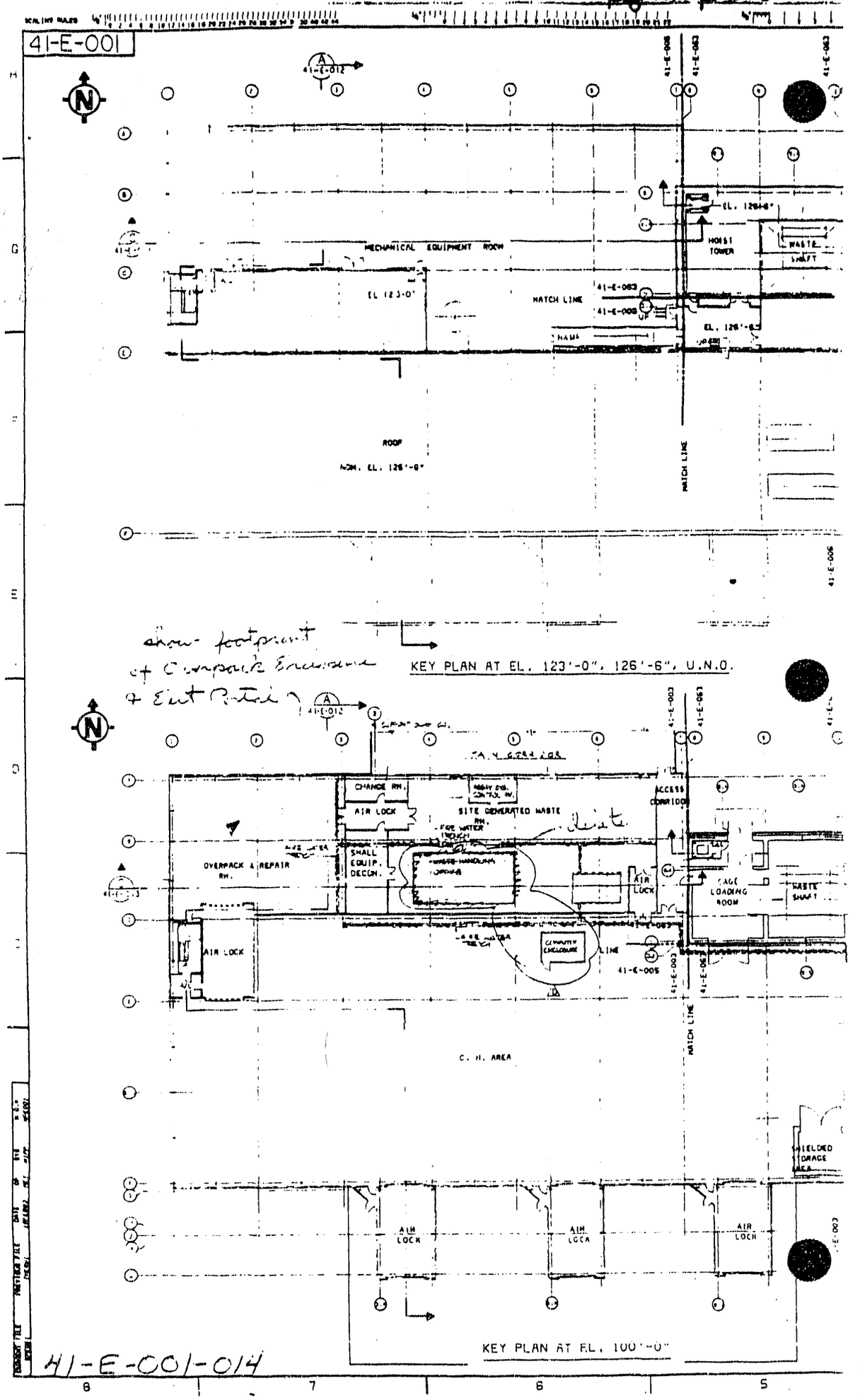
Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

ECO # 5541
pg 12 of 32



41-E-001-014

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 41-E-003-014, Rev D ECO Number: 5541

pg 13 of 32

2. ECO Search List: 4622
5294

3. Description of Change:

Revise dwg to show footprint for "Overpack Enclosure" and "Exit Portal". Delete "Waste Handling Office". See attached markup.

4. Drawing Cog. Engineer Approval: J. Kmetz Date: 6/14/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

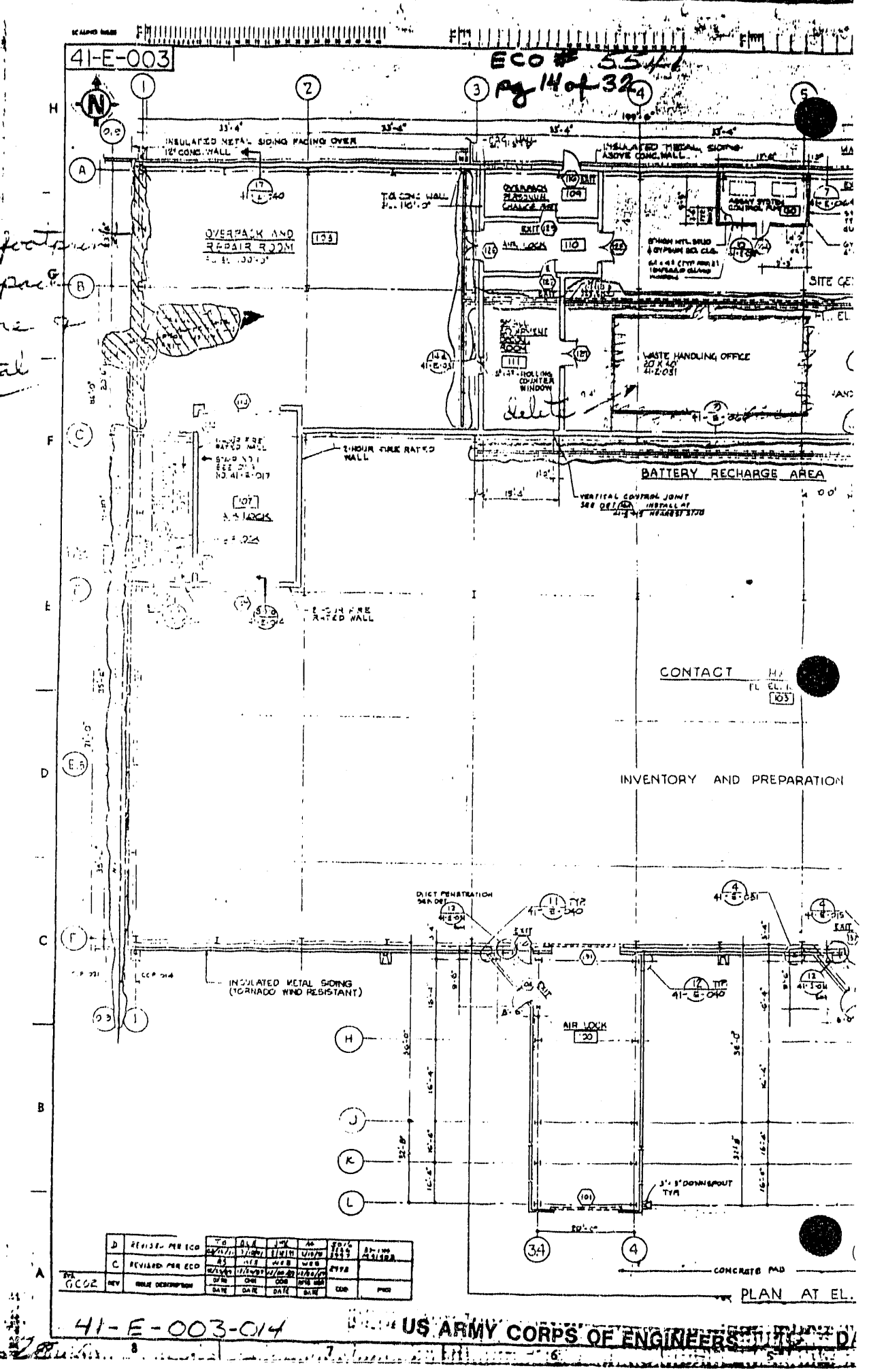
Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date


41-E-003
ECO # 5544
Pg 14 of 32
show footprint of Overpack Enclosure at Exit Portal
OVERPACK AND REPAIR ROOM
133
INSULATED METAL SIDING FACING OVER 12" CONC. WALL
INSULATED METAL SIDING ABOVE CONC. WALL
TO CONC. WALL EL. 110'-0"
OVERPACK PLATFORM CHANGE AREA
104
EXIT
AIR LOCK
110
WASTE HANDLING OFFICE
20 X 40
41-E-031
ROLLING COUNTER WINDOW
Delete
SITE GE
BATTERY RECHARGE AREA
3-HOUR FIRE RATED WALL
VERTICAL CONTROL JOINT
107
AIR LOCK
CONTACT
INVENTORY AND PREPARATION
INSULATED METAL SIDING (TORNADO WIND RESISTANT)
AIR LOCK
20
3'-3" DOWNSPOUT TYP
CONCRETE PAD
PLAN AT EL.
41-E-003-014
US ARMY CORPS OF ENGINEERS

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 41-E-013-014, Rev A ECO Number: 5541

pg 15 of 32

2. ECO Search List: 5016

3. Description of Change:

Revise dwg to show "Overpark Enclosure" and "Exit Portal". See attached markup.

4. Drawing Cog. Engineer Approval: J. Krwarth Date: 6/14/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

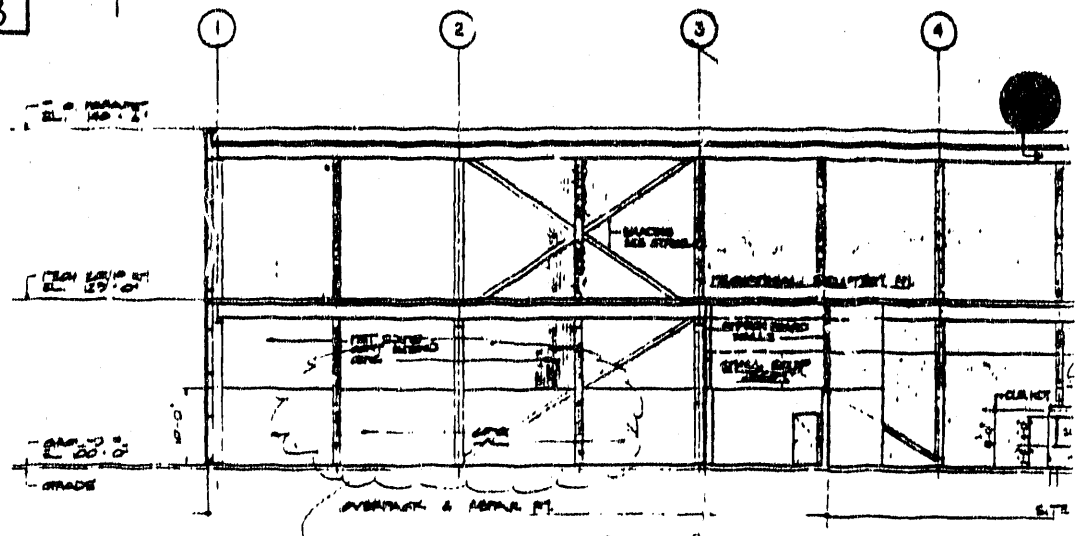
Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

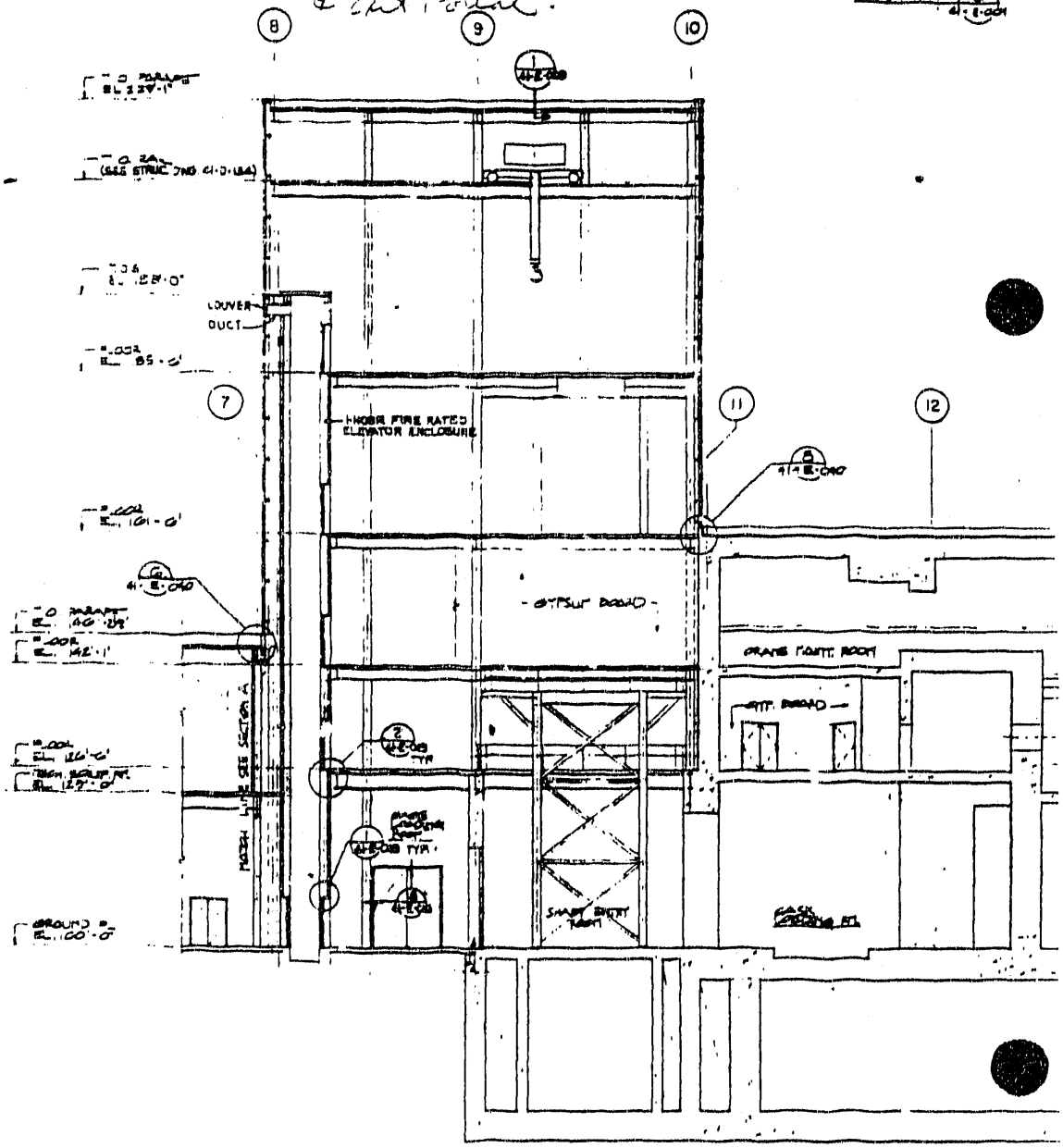
ECO #5541
pg 16 of 32

41-E-013



Show Overpass Enclosure & Exit Portal.

SECTION C
41-E-001



SECTION D
41-E-001

41-E-013-014

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 41-F-022-014, Rev F ECO Number: 5571
pg 17 of 32

2. ECO Search List: _____ _____ _____ _____

3. Description of Change:

Revise dwg to show the addition of the "Exit Portal" to the "Overpack Enclosure". Add "41-R-080" to top of dwg. See attached markup.

4. Drawing Cog. Engineer Approval: _____ Date: 12/11/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

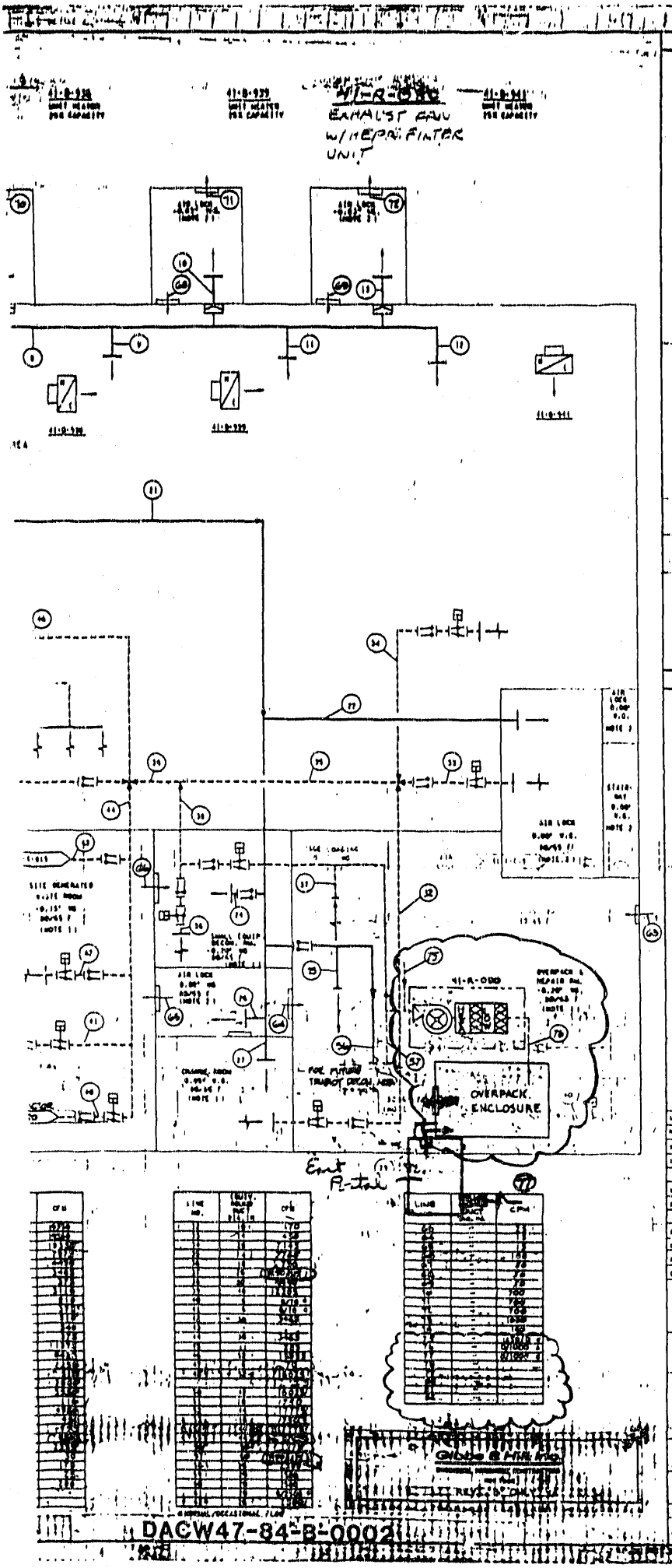
Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

1290:B0006

ECO # 5
pg 18 of 32



NOTES

1. [illegible]
2. [illegible]
3. PRESSURES INDICATED IN THE ROOMS ARE WITH RESPECT TO 0.0 INCH WG. OUTSIDE AMBIENT PRESSURE.
4. [illegible]
5. [illegible]
6. [illegible]

REFERENCE DRAWINGS

76-F-011	MECHANICAL STANDARDS-HVAC SYMBOLS FLOW DIAGRAMS AND P & ID'S
76-F-013	MECHANICAL STANDARDS EQUIPMENT AND PIPING SYMBOLS P&ID'S AND HF & I&C'S
41-F-033	[illegible] HVAC FLOW DIAGRAM
41-F-035	CHILLED WATER SYSTEM SHEET 2 OF 2 FLOW DIAGRAM
41-F-042	[illegible] SYSTEM P & ID
41-F-052	[illegible] SHEET 1 OF 2 PAID
41-F-053	[illegible] SHEET 2 OF 2 PAID
41-F-055	WASTE HANDLING BUILDING SUSPECT LIQUID WASTE COLLECTION FLOW DIAGRAM
41-F-072	WASTE HANDLING BUILDING SOLID RADWASTE HANDLING SYSTEM FLOW DIAGRAM

add Ent Portal w/HEPA filter.
Delete flow arrow at "enclosure" and show at portal.

NO.	REV	DATE	ISSUE DESCRIPTION	BY	CHD	APP
NS	1	[illegible]	ISSUED FOR CONSTRUCTION	[illegible]		
NS	1	[illegible]	ISSUED FOR APPROVAL	[illegible]		
NS	1	[illegible]	[illegible]	[illegible]		
[illegible]			[illegible]	[illegible]		
NS	2	[illegible]	ISSUED FOR PROJECT USE	[illegible]		
NS	1	[illegible]	[illegible]	[illegible]		
	C	[illegible]	ISSUED FOR PROGRESS REVIEW	[illegible]		
NS	C	[illegible]	ISSUED FOR TITLE I (80%-[illegible])	[illegible]		
NS	B	[illegible]	ISSUED FOR CLIENT APPROVAL	[illegible]		
NS	A	[illegible]	ISSUED FOR CLIENT REVIEW	[illegible]		

U.S. DEPARTMENT OF ENERGY
WASTE ISOLATION PILOT PLANT

BECHTEL
SAN FRANCISCO

WASTE HANDLING BUILDING 411
CH AREA HVAC
FLOW DIAGRAM

JOB NO.	DRAWING APPROVED	DATE
12484	[illegible]	4/11/85
DOE CONTRACT NUMBER	BECHTEL	DATE
DE-AC04-77WL10175	[illegible]	4/11/85
DRAWING NO.	CAD	REV
41-F-022401 4		2

41-F-022-014

DACW47-84-B-0002

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 41-G-120-014, Rev C ECO Number: 5541
Pg 19 of 32

2. ECO Search List: 4622

3. Description of Change:

Revise dwg to show "Overpack Enclosure", "Exit Portal", and "41-R-080". Delete outdated information. See attached markups.

4. Drawing Cog. Engineer Approval: [signature] Date: 6/14/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

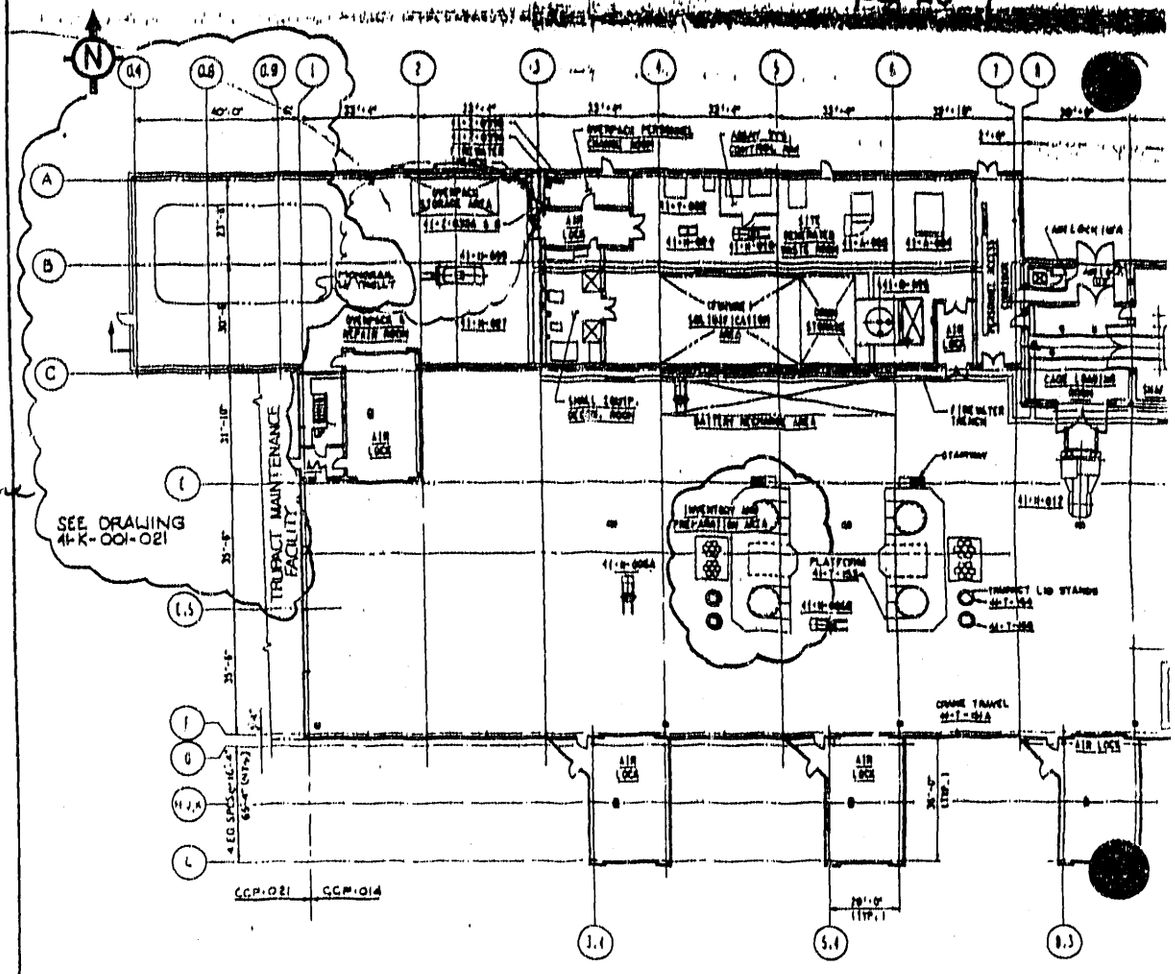
41-G-170

ECO # 5541
pg 20 of 32

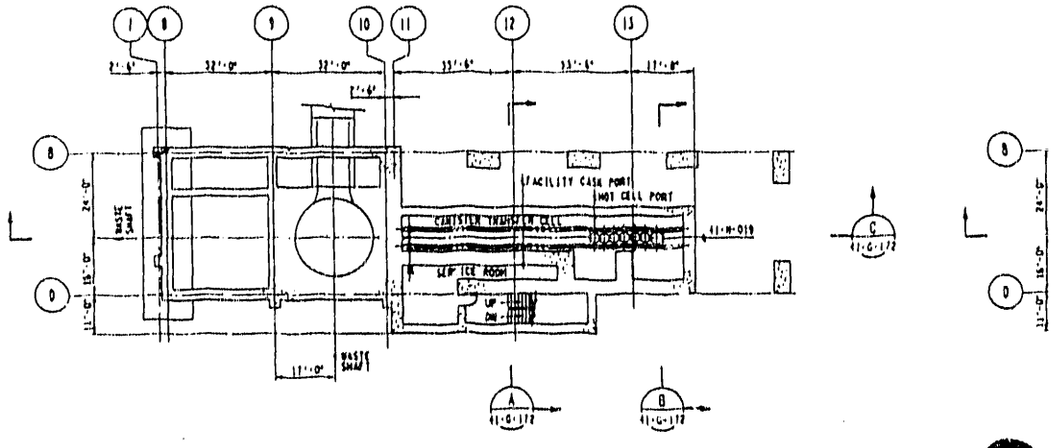
delete
- overpack storage area
- 41-Z-035A+B
- 41-H-009

add:
- overpack welding Exit Portal
- 41-R-090

as shown on 41-G-501-014, pg 4 of this ECO



PLAN AT EL. 100'-0"



PLAN AT EL. 86'-0"

41-G-170-014

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 41-G-172-014, Rev B ECO Number: 5541

Pg 21 of 32

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Revise dwg to show "Overpack Enclosure", Exit Portal", and "41-R-080". Delete outdated information. See attached markup.

4. Drawing Cog. Engineer Approval: Matt J. Lucek Date: 6/14/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

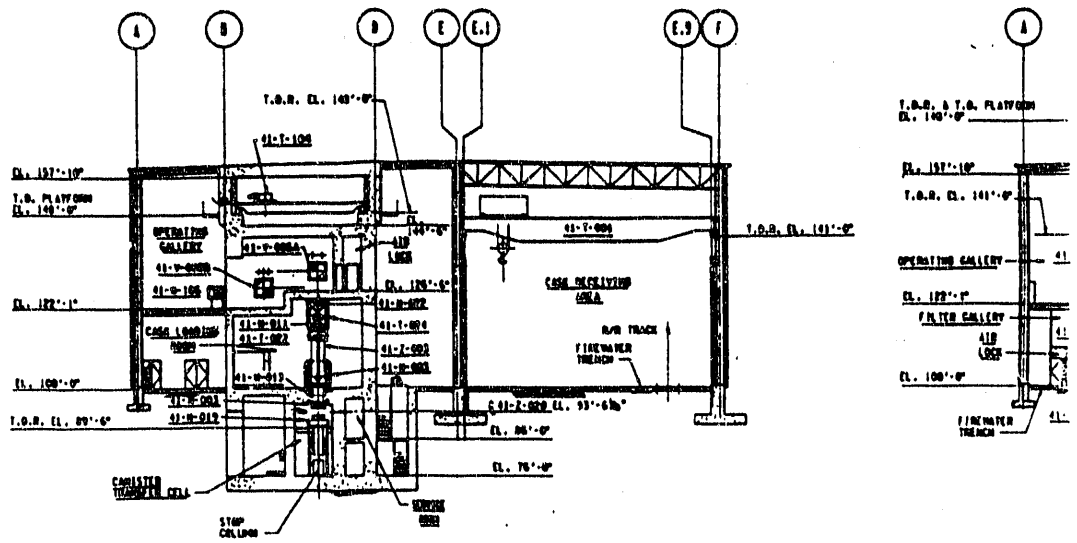
Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

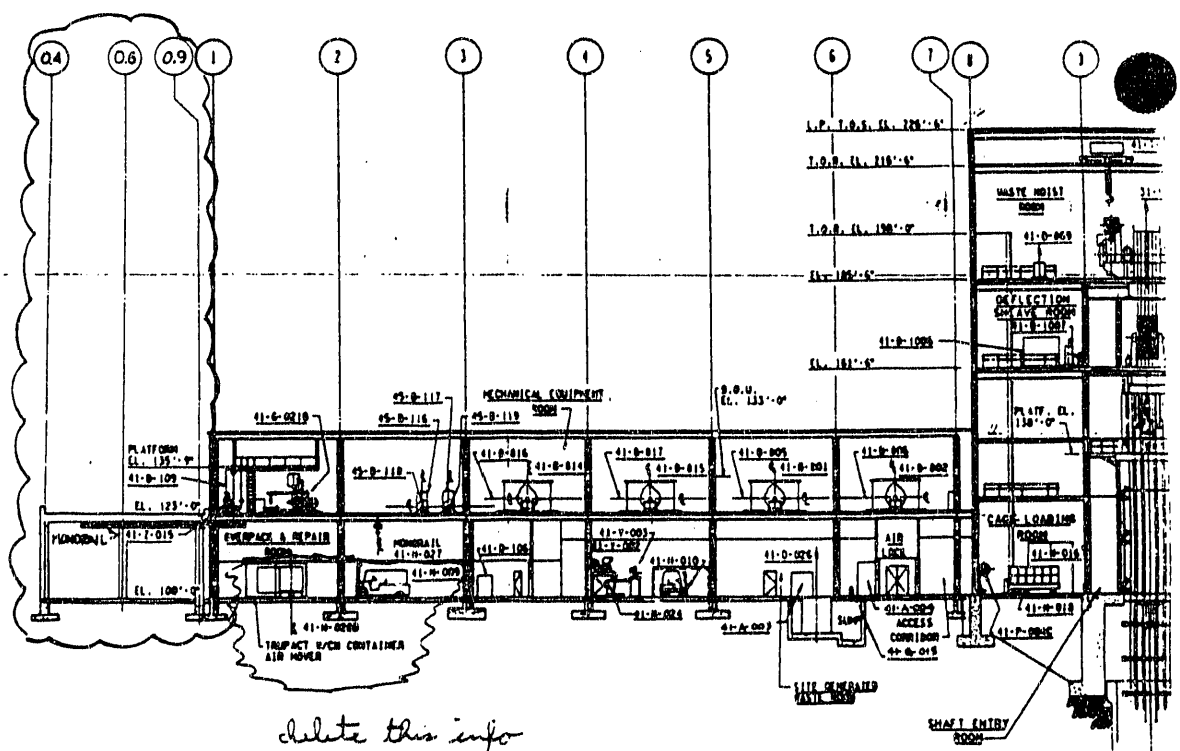
Return to EFR: _____ Initials / Date

41-G-172

ECO # 554
pg 22 of 32



SECTION A
41-G-170



delete this info and show Overpack Enclosure, East Portal, & 41-R-050 to the extent that's practical.

SECTION C
41-G-1

41-G-172-014

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 41-G-302-014, Rev G ECO Number: 5541

pg 23 of 32

2. ECO Search List: 3992

3. Description of Change:

Revise the dwg to show the addition of the "Exit Portal" to the "Overpack Enclosure". See attached markup.

4. Drawing Cog. Engineer Approval: [signature] Date: 14 June '91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

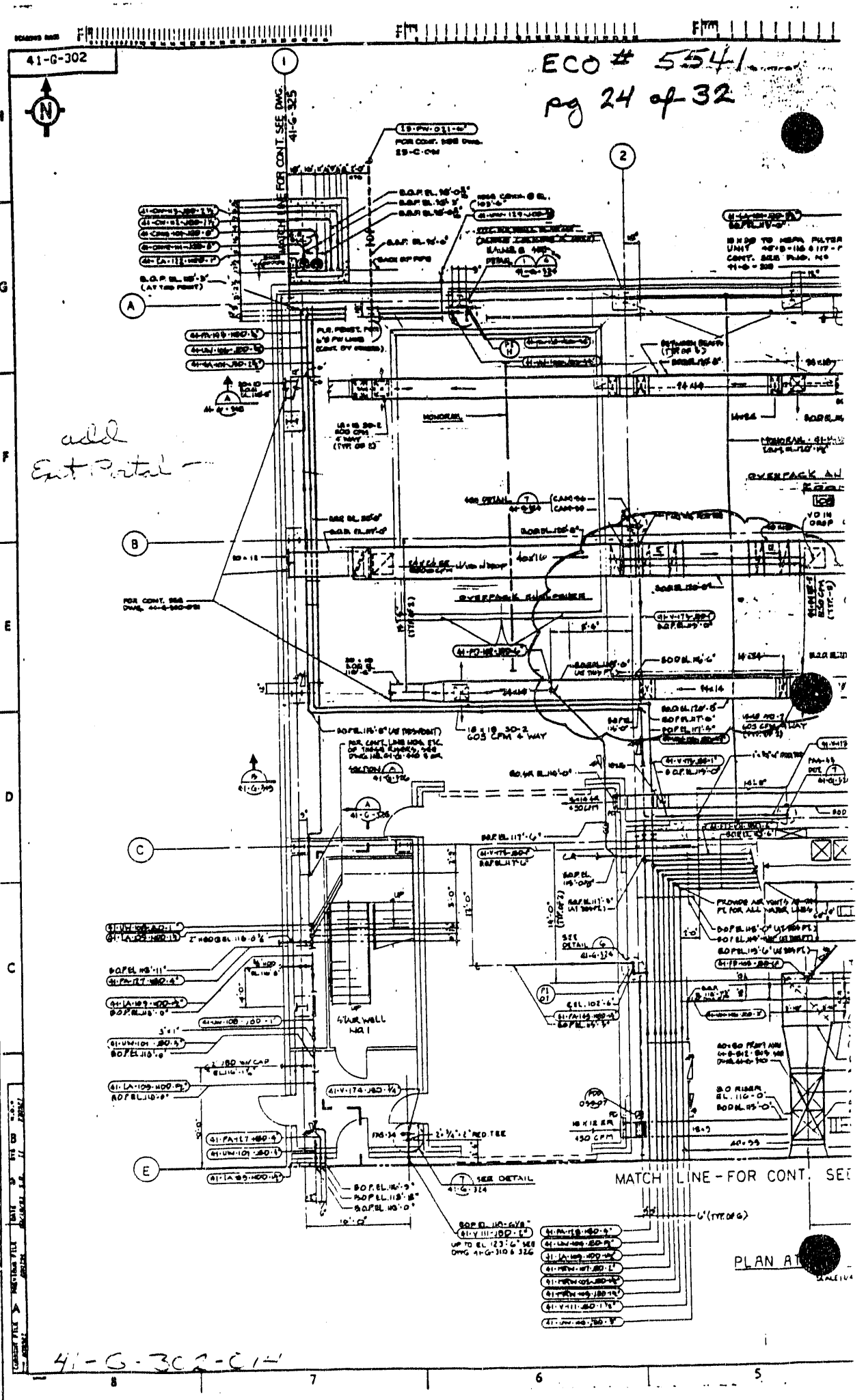
Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date


41-G-302
ECO # 5541
pg 24 of 32
add
Ent Portal
MATCH LINE - FOR CONT. SEE DWG. 41-G-325
MATCH LINE - FOR CONT. SEE
PLAN AT
41-G-302-C14

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 41-G-501-014, Rev C ECO Number: 5541

pg 25 of 32

2. ECO Search List: 4622

3. Description of Change:

Revise dwg to show updated information concerning "Exit Portal" and "41-R-080". See attached markup.

4. Drawing Cog. Engineer Approval: J. Kovacs Date: 6/14/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

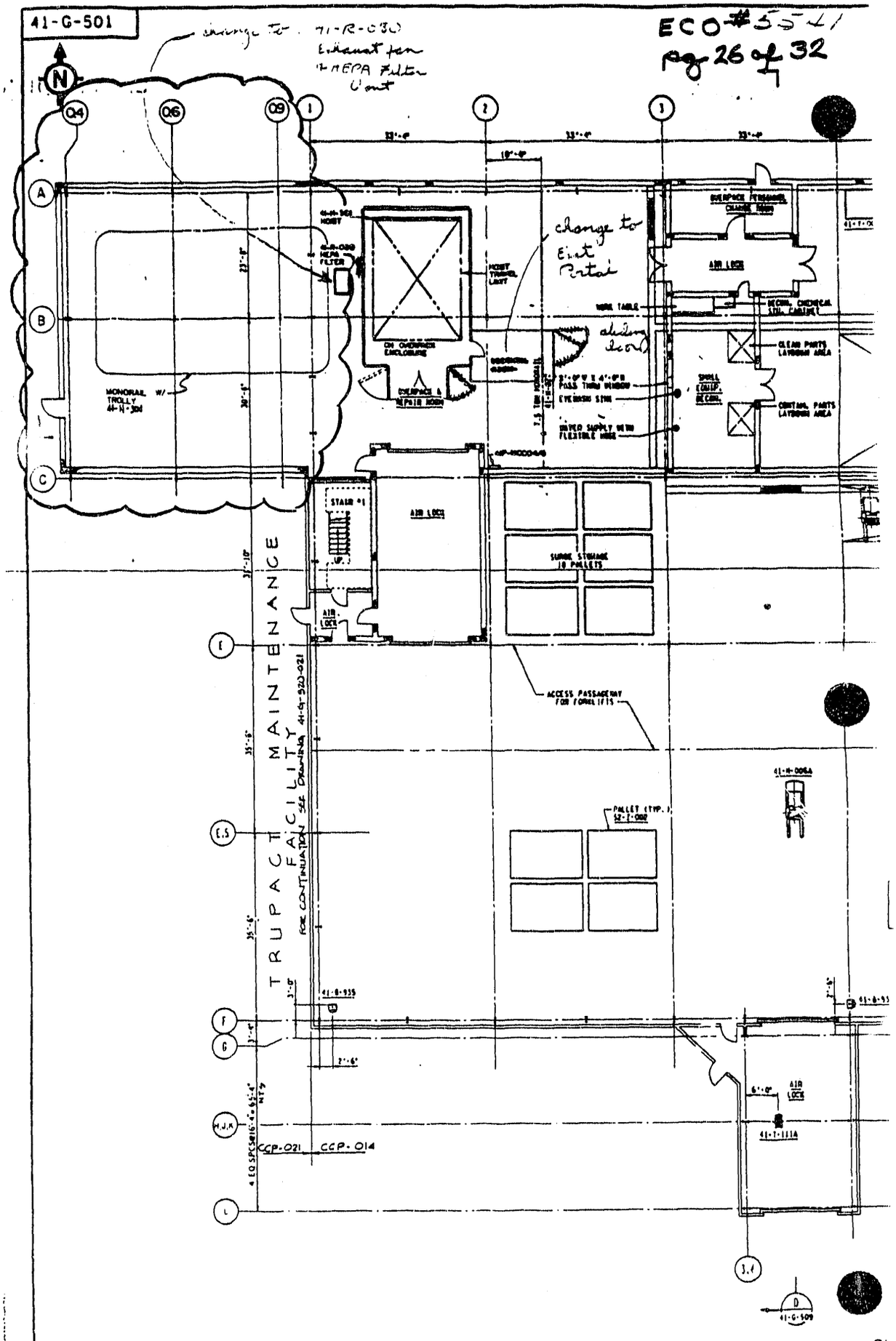
Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date


41-G-501
ECO #5541
pg 26 of 32
change to 71-R-030 Exhaust fan HEPA Filter Unit
change to Exit Portal
sliding door
TRUPACT MAINTENANCE FACILITY
FOR CONTINUATION SEE DRAWING 41-G-523-021
ACCESS PASSAGEWAY FOR FORKLIFTS
MONORAIL W/ TROLLY 44-H-304
HOIST TRAVEL LIMIT
OH OVERHEAD ENCLOSURE
EXCLOSURE & REPAIR HOOD
AIR LOCK
STAIR #1
SHORT STORAGE 10 PALLETS
PALLET (TYP.)
CCP-021
CCP-014
41-G-501-014
US ARMY CORPS OF ENGINEERS

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 41-G-509-014, Rev B ECO Number: 5541

pg 27 of 32

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Revise dwg to show "Overpack Enclosure", "Exit Portal", and "41-R-080". See attached markup.

4. Drawing Cog. Engineer Approval: J. Krmpotic Date: 6/14/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

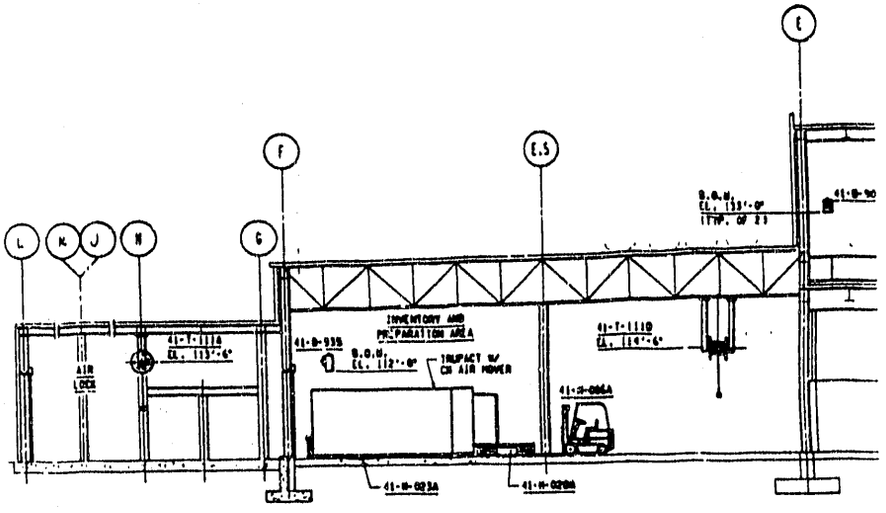
Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

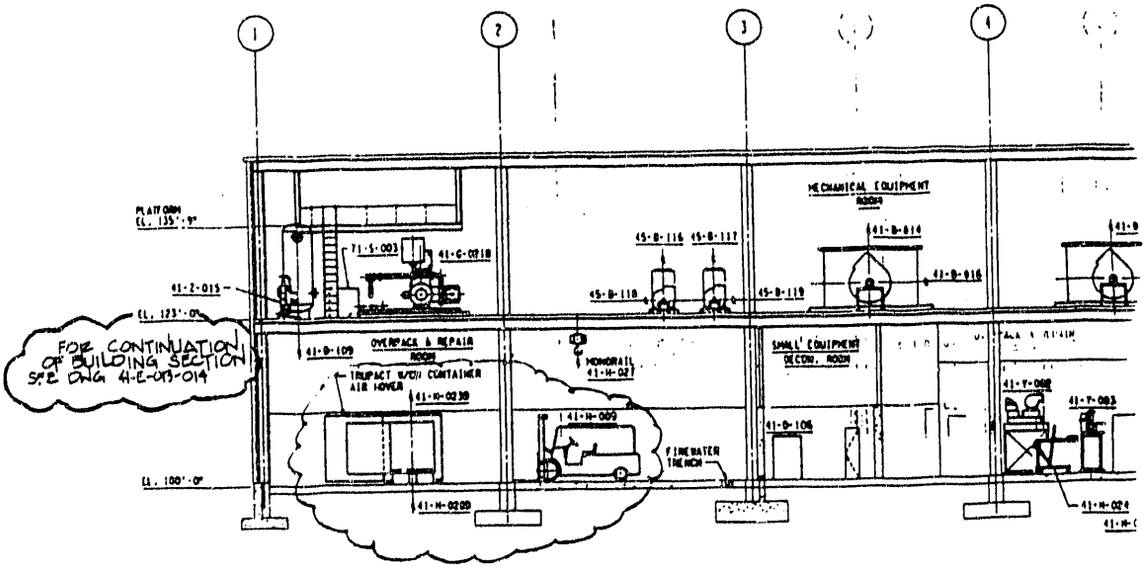
Return to EFR: _____ Initials / Date

41-G-509

ECO # 5541
pg 28 of 32



SECTION D
41-G-501, 41-G-503



Delete this info and show Overpack Enclosure, East Portal, and 41-2-080 to the extent that's practical.

SECTION E
41-G-501, 41-G-503

41-G-509-014

US ARMY CORPS OF ENGINEERS

ECO # [illegible]
pg 29 of 32

ATTACHMENT 3
WP 09-021, Rev. 1
Page 1 of 2

INSTRUMENT NUMBER REQUEST

1. Instrument Number 411-PDI-001-32
2. Description PRESSURE DIFFERENTIAL INDICATOR
   Narrative: local diff. pressure indication for inlet HEPA filter installation for the Exit Portal of the CH Ovapack Enclosure.
3. Subequipment EXIT PORTAL INLET HEPA FILTERS
4. Loop Number
5. Drawing Number
   P&ID Drawing Number 41-B-001-(W)-W2
6. System HVO1
7. CMS Point NONE
8. ~~Input Type/~~Range 0-4" W.G.
9. Output Type/Range NONE
10. Set Points NONE
11. Cal./PM Procedure Number
12. Manufacturer DWYER
13. Model Number 2004 Serial Number
14. Design Class III B
15. Critical Equipment ____ Yes X No
16. Location: Building 411 Room Number 108
17. Electrical Power From NA
18. O&M Manual in File Room ____ Yes X No
19. Cognizant Manager/Engineer POHL/EALDEN
20. Equipment Labeled ____ Yes X No

Remarks:

Requestor Wm BARNHART Date 6/10/91

WP Form 1870; 10/17/89
Page 1 of 2

INSTRUMENT NUMBER REQUEST

1. Instrument Number 411-PDI-001-33
2. Description PRESSURE DIFFERENTIAL INDICATOR
   Narrative: Local diff. pressure indication for inlet HEPA filter installation for the CH Overpack Enclosure.
3. Subequipment CH OVERPACK ENCLOSURE INLET HEPA FILTERS
4. Loop Number
5. Drawing Number
   P&ID Drawing Number 41-B-001-W
6. System HVO1
7. CMS Point NONE
8. ~~Input Type~~/Range 0-4" W.G.
9. Output Type/Range NONE
10. Set Points NONE
11. Cal./PM Procedure Number
12. Manufacturer DWYER
13. Model Number 2004 Serial Number
14. Design Class III B
15. Critical Equipment ____ Yes X No
16. Location: Building 411 Room Number 108
17. Electrical Power From NA
18. O&M Manual in File Room ____ Yes X No
19. Cognizant Manager/Engineer POHL / EALDEN
20. Equipment Labeled ____ Yes X No

Remarks:

Requestor Wm BARNHART Date 6/10/91

ECO #5541
pg 31 of 32

INSTRUMENT NUMBER REQUEST

1. Instrument Number 411-PDI-001-34
2. Description PRESSURE DIFFERENTIAL INDICATOR
   Narrative: Local diff. pressure indication for the CH Overpack Enclosure in relation to the Overpack & Repair Room.
3. Subequipment CH OVERPACK ENCLOSURE
4. Loop Number
5. Drawing Number
   P&ID Drawing Number 41-B-001-W
6. System HVO1
7. CMS Point NONE
8. ~~Input Type~~/Range 0-4" W.G.
9. Output Type/Range NONE
10. Set Points
11. Cal./PM Procedure Number
12. Manufacturer DWYER
13. Model Number 2004 Serial Number
14. Design Class III B
15. Critical Equipment ____ Yes X No
16. Location: Building 411 Room Number 108
17. Electrical Power From NA
18. C&M Manual in File Room ____ Yes X No
19. Cognizant Manager/Engineer POHL/FALDEN
20. Equipment Labeled ____ Yes X No

Remarks:

Requestor Wm BARNHART Date 6/10/91

ECO #5241
Pg 32 of 32

ATTACHMENT 3
WP 09-021, Rev. 1
Page 1 of 2

INSTRUMENT NUMBER REQUEST

1. Instrument Number 411-PDI-001-35
2. Description PRESSURE DIFFERENTIAL INDICATOR
   Narrative: Local differential pressure indication across HEPA filter housings, for both roughing and HEPA filters.
3. Subequipment 41-R-080
4. Loop Number
5. Drawing Number
   P&ID Drawing Number 41-B-001-W
6. System HVO1
7. CMS Point NONE
8. ~~Input Type~~/Range 0-4" W.G.
9. Output Type/Range NONE
10. Set Points NONE
11. Cal./PM Procedure Number
12. Manufacturer DWYER
13. Model Number 2004 Serial Number
14. Design Class III B
15. Critical Equipment ____ Yes X No
16. Location: Building 411 Room Number 108
17. Electrical Power From NA
18. O&M Manual in File Room ____ Yes X No
19. Cognizant Manager/Engineer POHL/EALDEN
20. Equipment Labeled ____ Yes X No

    Remarks:

    Requestor Wm BARNHART Date 6/10/91

WP Form 1870; 10/17/89
Page 1 of 2

ENGINEERING CHANGE ORDER

USE BLACK INK

Page 1 of 29

1. **ECO No.:** 5515
CC&D Review: [ ] Initials
Posted

2. **Impact Level** 1 ☐ 2 ☐ 3 ☒ 4 ☐

3. **System:** EM05/WH06 Equipment No.: 105-P-013 Building: U/G ROOM 1

4. Associated Documents:
PWR M41816
ECP 1-WH-91-9
P.O. ____
Others DR91-01, D-0077 REV B.

5. **Document Type:**
Drawing 52-L-001-W, 52-L-002-W, 105-H-005-W ☒
Specification 105-J-022-W, 105-L-002-W ☐
Vendor Data 105-F-013-W, 105-J-030-W ☐
SDD ☐
Others ____

6. **Title of Change:** VOC 10 AS-BUILTS

7. Originator: (print)	Ext. No.:	Department:	Date:	8. Cognizant Engineer: (print)
J.R. STROBLE	8374	ELEC. ENG.	6-22-91	J.R. STROBLE

9. **Description of Change:**

Yes ☐ No ☒ Component indices change required (if yes, attach sheets)

1. CHANGE VOC 10 DRAWINGS TO SHOW AS-BUILT CONFIGURATION AFTER INSTALLATION AND TESTING.
2. SUPERCEED ECO 5532.

☒ 9a Drawing Change Sheet attached
☐ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

10.
Yes ☐ No ☒ **MODIFICATION IN PROGRESS**
☐ Modification complete: ____ (Signature) ____ (Date) — ECO will be incorporated after M.I.P. signed complete
☐ Change drawing per as-built markup dated: ____
☐ Change drawing per ECO-provided data
☐ Temporary modification

11. **Design Verification Requirements: (per WP 09-018)** EDT No.: ____
____ 1. Requirements satisfied by review/approval of design document
____ 2. Independent review
____ 3. Alternate calculations
____ 4. Development testing
____ 5. Design review
____ 6. Other: ____ ADDENDUM VOIDED

12. **Addendum Sheet added:** ____ (Signature) ____ (Date) (3 ADDENDUMS ADDED)

13. Justification

1. TO SHOW AS-BUILT CONFIGURATION
2. ALL OF THE CHANGES IN ECO 5532 ARE AS-BUILT & INCLUDED IN THIS ECO.

14. Administrative Tracking

YES	N/A		YES	N/A	
☒	☐	1. FSAR	☐	☒	6. Startup/Acceptance Test
☒	☐	2. Calibration Procedures	☐	☒	7. Test Requirement & Spec.
☒	☐	3. Maintenance Procedures	☐	☐	8 _____
☐	☒	4. Computer Software	☐	☐	9. _____
☒	☐	5. Operations Procedures	☐	☐	10. _____

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

A	Cog. Engineer	J.R. Stroble 6-22-91
A	Cog. Eng. Mgr.	[illegible] 6/24/91
R	Startup	[illegible] 6/26/91
R	QA	[illegible] 6-26-91
☐	DOE	
☐	Safety	
☐	Dept. Manager	
☐	Operations	
☐	Security	
☐	SNL	
A		[illegible]
☐		
☐		

16. Distribute as Marked

☒	Maintenance (MANDATORY)	
☒	Ops. Support (MANDATORY)	
☐	Startup	
☐	Facility Operations	
☐	U/G Operations	
☐	Orig./Design Engr.	
☒	Cog. Engineer	J.R. STROBLE
☐	Others	
☒		JERRY CAMP
☐		
☐		
☐		
☐		

1190B:0005a

ECO 5565

Files C.L.6430.1A

3 of 29
JRS 6-24-91

~~3 of 2~~ July 27, 6/24/91

DOE ORDER 6430.1A DESIGN CRITERIA
CHECKLIST

ENGINEERING CHANGE ORDER (ECO) NO. 5565 DATE _____ COG. ENGINEER J.R. Stuble

The design requirements in DOE Order 6430.1A checked below have been applied to this ECO.

	DIVISION	SUBDIVISION
|_| 1	General Requirements	|_| 0101 |_| 0106 |_| 0109 |_| 0110 |_| 0111 |_| 0140 |_| 0150 |_| 0170
|_| 2	Site and Civil Engineering	|_| 0200 |_| 0201 |_| 0202 |_| 0203 |_| 0205 |_| 0210 |_| 0214 |_| 0215 |_| 0220 |_| 0235 |_| 0245 |_| 0250 |_| 0256 |_| 0260 |_| 0262 |_| 0266 |_| 0267 |_| 0270 |_| 0273 |_| 0275 |_| 0276 |_| 0278 |_| 0279 |_| 0280 |_| 0281 |_| 0283 |_| 0285 |_| 0290 |_| 0291
|_| 3	Concrete	|_| 0300 |_| 0301 |_| 0310 |_| 0320 |_| 0330 |_| 0340 |_| 0350 |_| 0370 |_| 0380
|_| 4	Masonry	|_| 0400 |_| 0401 |_| 0410 |_| 0420 |_| 0455
|_| 5	Metals	|_| 0500 |_| 0512 |_| 0514 |_| 0521 |_| 0531 |_| 0532
|_| 6	Wood and Plastics	|_| 0600 |_| 0610 |_| 0650
|_| 7	Thermal and Moisture Protection	|_| 0710 |_| 0711 |_| 0714 |_| 0715 |_| 0719 |_| 0720 |_| 0721 |_| 0722 |_| 0724 |_| 0727 |_| 0730 |_| 0750 |_| 0751 |_| 0753 |_| 0760 |_| 0790
|_| 8	Doors and Windows	|_| 0800 |_| 0810 |_| 0820 |_| 0830 |_| 0833 |_| 0836 |_| 0839 |_| 0850 |_| 0860 |_| 0870 |_| 0880
|_| 9	Finishes	|_| 0900 |_| 0910 |_| 0920 |_| 0925 |_| 0930 |_| 0950 |_| 0965 |_| 0968 |_| 0970 |_| 0980 |_| 0990 |_| 0995
|_| 10	Specialties	|_| 1015 |_| 1020 |_| 1024 |_| 1027 |_| 1030 |_| 1040 |_| 1050 |_| 1052 |_| 1053 |_| 1055 |_| 1060 |_| 1065 |_| 1070 |_| 1075 |_| 1080
|_| 11	Equipment	|_| 1100 |_| 1161
|_| 12	Furnishings	|_| 1201 |_| 1230 |_| 1250 |_| 1260 |_| 1270
|_| 13	Special Facilities	|_| 1300 |_| 1304 |_| 1305 |_| 1306 |_| 1307 |_| 1310 |_| 1319 |_| 1320 |_| 1321 |_| 1322 |_| 1323 |_| 1324 |_| 1325 |_| 1326 |_| 1328
|_| 14	Conveying Systems	|_| 1401 |_| 1420 |_| 1440 |_| 1460
|_| 15	Mechanical	|_| 1525 |_| 1530 |_| 1540 |_| 1550 |_| 1555 |_| 1565 |_| 1574 |_| 1589 |_| 1595
|_| 16	Electrical	|_| 1600 |_| 1605 |_| 1620 |_| 1630 |_| 1639 |_| 1640 |_| 1650 |_| 1660 |_| 1670 |_| 167 |_| 1685 |_| 1694

Note: A checked placed in the Division column signifies that the entire Division shall be applicable to the ECO, unless modified by checks indicated for specific Subdivisions.

☒ N/A

4 OF ~~29~~ 43

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 52-L-001-W ECO Number: 5565

2. ECO Search List: 5532

3. Description of Change:

1. PRESSURE RELIEF VALVE (VC-534-RV-009):
   - A. MOVE TO UPSTREAM OF VALVES VC-534-TW-024 & 25
   - B. RUN OFF 3-WAY VALVE VC-534-TW-027 ON ONE PORT
   - C. PUT A 2-WAY VALVE & A CHECK VALVE ON OTHER PORT
   - D. TO ALLOW FOR MANIFOLD RELIEF DURING CLEANING & CERTIFICATION.
2. CHANGE QTY. FOR ITEMS:
   4
   9
   14
   16
3. CHANGE 15 MICRON FILTER IN ITEM 28 TO JUST HOUSING (NO FILTER).
4. CHANGE PART NUMBER FROM "0258C-~~00500~~ 00050-SV" TO "0258C-00500-SV". JRB 6-21-91

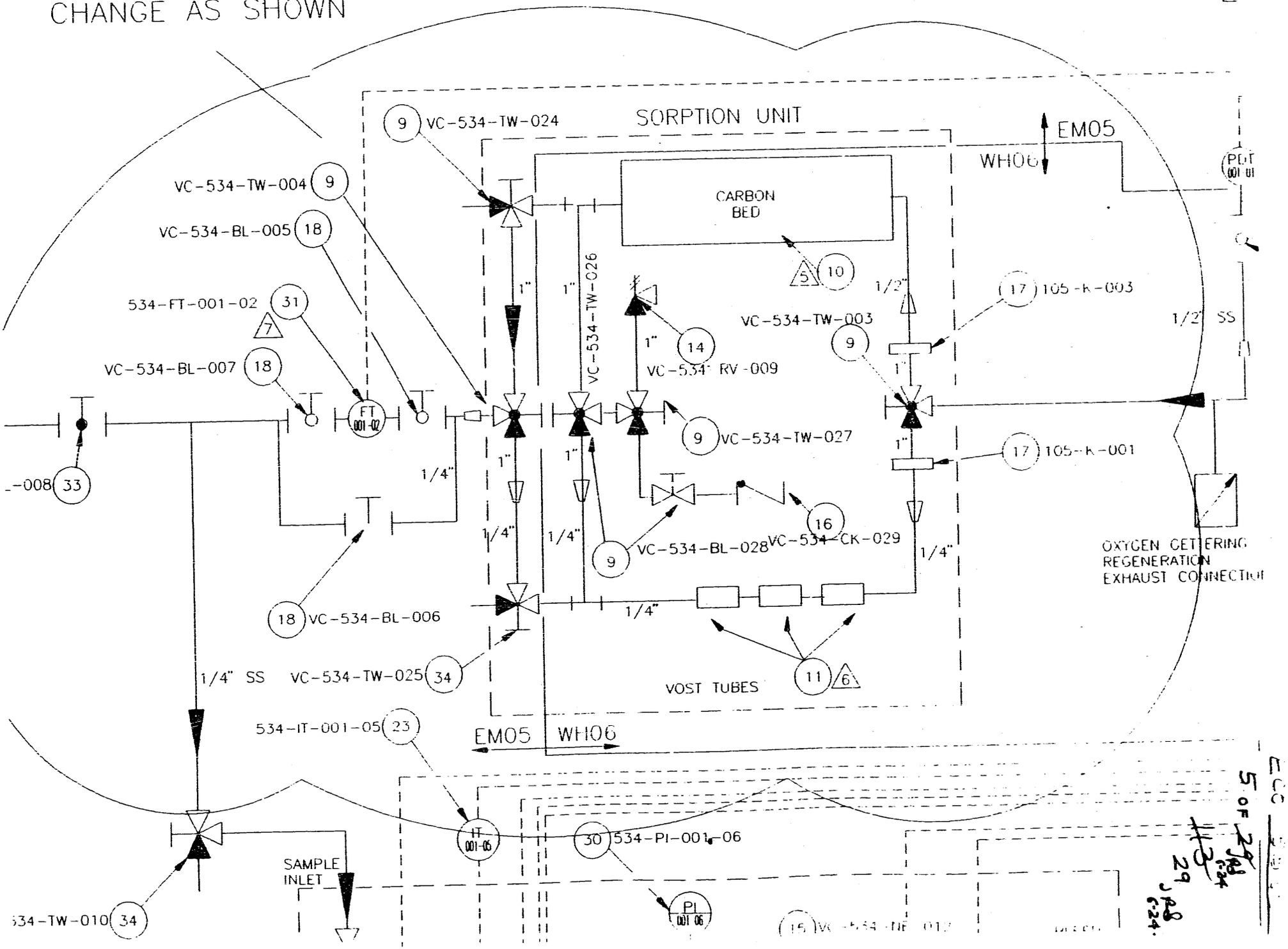
SEE ATTACHED PAGES

4. Drawing Cog. Engineer Approval: [signature] Date: 6/24/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date		Drafting Started: _____ Initials / Date	
Date Assigned: _____ Initials / Date		Drafting Completed: _____ Initials / Date	
Assigned to: _____ (Same as data base entry)		Return to EFR: _____ Initials / Date	

CHANGE AS SHOWN



5 OF 29

QTY REQD GR3	GR2	GR1	NOTE	ITEM	PART NAME/DESCRIPTION	PART NO OR REF DWG	MAT'L/SPEC
		1	1	1	CYLINDER, SIZE K HELIUM		SCOTT SPECIALTY GASES
		1		2	REGULATOR, HELIUM TWO STAGE 1-5 PSIG	51-18-580	SCOTT
		1	2	3	FLOW METER, VARIABLE AREA 4.46 TO 44.6 SCCM	51-31S-4-1	SCOTT
		4	3	4	VALVE, BALL 1/2" 2-WAY MANUALLY OPERATED	SS-45S8	WHITEY
		1	4	5	VALVE, BALL 1/2" 2-WAY AIR-OPERATED NC	SS-63TS8-33C	WHITEY
		1		6	VALVE, SOLENOID 3-WAY NC	EF8320G202	ASCO
		1		7	CONTROLLER, PROGRAMMABLE LOGIC "PLC"	90-30/331	GENERAL ELECTRIC
		1		8	TRANSDUCER, PRESSURE DIFFERENTIAL, 100MM HG	220CD-00100A2B	MKS
		4		9	VALVE, BALL 1" 3-WAY MANUALLY OPERATED	SS-65XTS16-F16	WHITEY
		1	5	10	BED, CARBON SORPTION		CALGON, TYPE BPL CARBON
		3	6	11	VOST TUBES		ANALYTICAL LABORATORY
		1		12	METER, MASS FLOW, 0-500 SCCM	0258C-00500-SV	MKS
		1	4	13	VALVE, BALL 1/2" 2-WAY AIR OPERATED NO	SS-63TS8-330	WHITEY
		2		14	VENT, EMERGENCY RELIEF 2" WEIGHT LOADED, 0.8PSIG	2300-02-44-V00	GROTH
		1		15	VALVE, METERING MICROMETER HANDLE	SS-22RS4	WHITEY
		2		16	VALVE, CHECK 1/4" IN-LINE	SS-4C-1/3	NUPRO
		2		17	HOUSING, FILTER 47MM	2220	GELMAN
		6		18	VALVE, BALL 1/4" 2-WAY MANUAL	SS-62TS4	WHITEY
		1		19	VALVE, 1/4" IN-LINE 0.8 PSIG	SS-RL3S4	NUPRO
		1		20	INDICATOR/AMPLIFIER, FLOW	TYPE 246	MKS
		1		21	INDICATOR/AMPLIFIER, PRESSURE	TYPE PDR-C-2C	MKS
		1		22	CHART RECORDER, 8CH DIGITAL SIGNAL	DPR 3000-D3	HONEYWELL
		1	10	23	CURRENT TRANSMITTER	ACT	MOORE IND.
		1		24	CURRENT INDICATOR	D15-871	WILKERSON
		6		25	VALVE, SOLENOID 1/8" NPT, 115VAC	SERIES 40, 2-WAY	EEMCO
		1		26	VALVE, SOLENOID 1/8" NPT, 115VAC	SERIES 40, 3-WAY	EEMCO
		1		27	PUMP, DIAPHRAGM	LIN05SV1	KNF NEUBERGER
		1		28	HOUSING, FILTER (NO FILTER)	SS-4F-15	NUPRO
		1		29	INDICATOR, SAMPLE PRESSURE	1D109	SPAN INSTRUMENTS
		1		30	INDICATOR, PUMP PRESSURE	21-0119-C1	SPAN INSTRUMENTS
		1		31	METER, MASS FLOW 0-5000 SCCM	0258C-05000-SV	MKS
		1		32	CONTROLLER, FLOW	SC423S,FINF	VERIFLOW
		1		33	VALVE, BALL 1/4" MANUAL 2-WAY	SS-42S4	WHITEY
		1		34	VALVE, BALL 1/4" MANUAL 3-WAY	SS-43XS4	WHITEY

BILL OF MATERIAL

REFERENCE DRAWINGS

52-L-001-W

ECO 55
6 OF 29

7 OF ~~29~~ 29 JK 6-24 ~~H3~~ mr 6/24/91

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-W2 ECO Number: 5565

2. ECO Search List: 5532

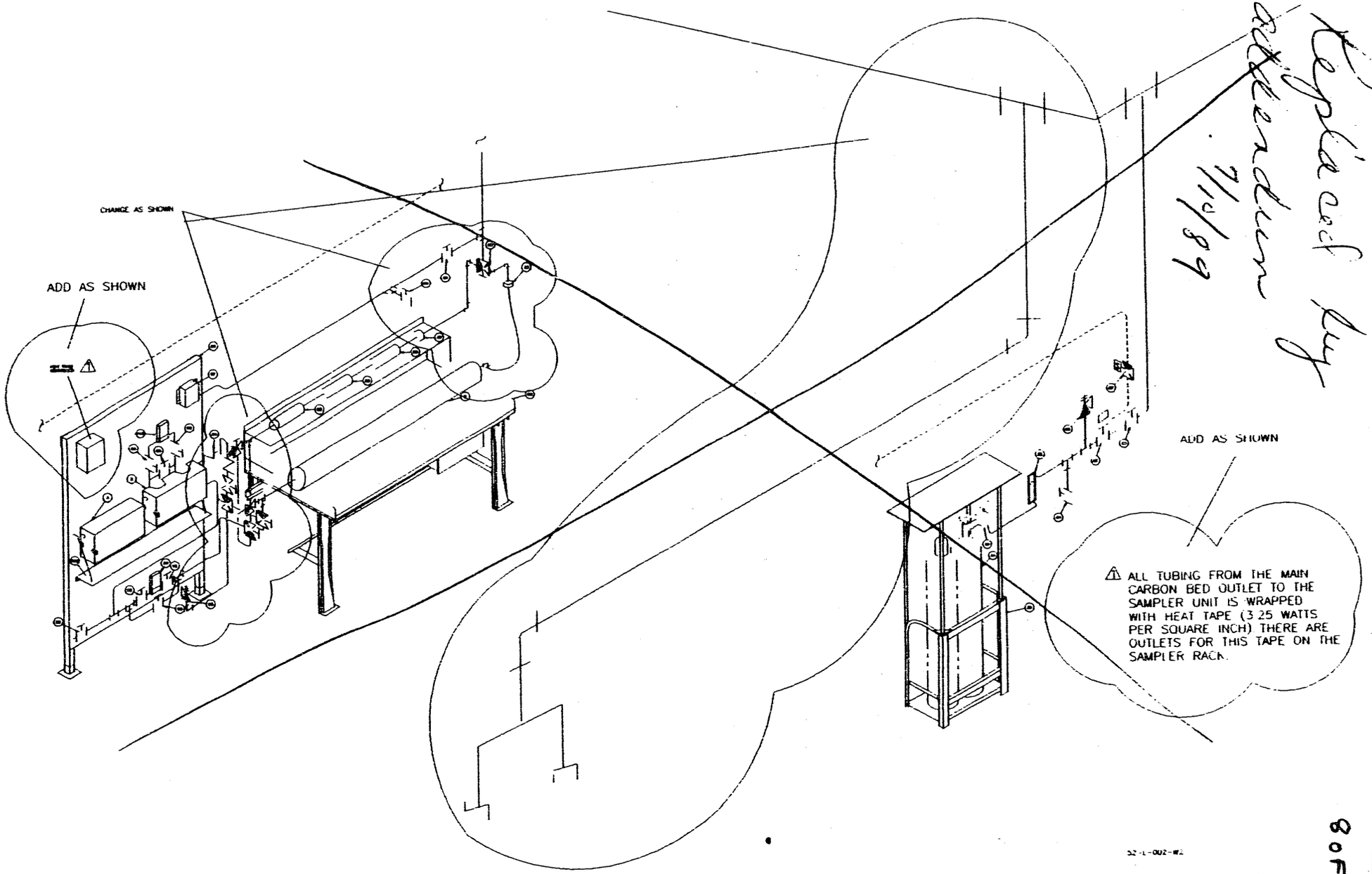
3. Description of Change: SEE ATTACHED PAGES

1. CHANGE THE CONFIGURATION BETWEEN THE CARBON BED AND THE SAMPLER:
   - A. MOVE THE PRESSURE RELIEF VALVE TO JUST DOWNSTREAM OF BOTH THE CARBON BED & THE VOST TUBES.
   - B. HAVE A 3-WAY VALVE BEFORE THE PRV, TO ROUTE FLOW TO EITHER THE PRV OR THRU A CHECK VALVE & ISOLATION VALVE ADDED.
   - C. HAVE FLOW COME FROM EITHER THE CARBON BED OR THE VOST TUBES AS BEFORE.
2. ADD A NOTE TO READ:
   ALL TUBING FROM THE MAIN CARBON BED OUTLET TO THE SAMPLER UNIT IS WRAPPED WITH HEAT TAPE (3.25 WATTS PER SQUARE INCH). THERE ARE OUTLETS FOR THIS TAPE ON THE SAMPLER RACK
3. ADD THE HEAT TAPE CONTROL BOX TO THE RACK.
4. MOVE THE "TEE" FOR THE OXYGEN GETTERING SYSTEM TO THE MANIFOLD FROM THE CARBON BED SIDE OF THE ROOM TO HELIUM SIDE OF THE ROOM.

4. Drawing Cog. Engineer Approval: [signature] Date: 6/24/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date		Drafting Started: _____ Initials / Date	
Date Assigned: _____ Initials / Date		Drafting Completed: _____ Initials / Date	
Assigned to: _____ (Same as data base entry)		Return to EFR: _____ Initials / Date	



Replaced by Addendum 7/6/89

ECO 5[illegible]
8 of 29

9 OF ~~29~~ 29 d. 6. ~~113~~ MK 6/24/91

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-W3 ECO Number: 5565

2. ECO Search List: 5532

3. Description of Change:

SAME AS 1. AND 3. ON SHEET 9a OF DRAWING 52-L-002-W2 OF THIS ECO.

SEE ATTACHED PAGES

4. Drawing Cog. Engineer Approval: M. W. 6/24/91 Date: 6/24/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

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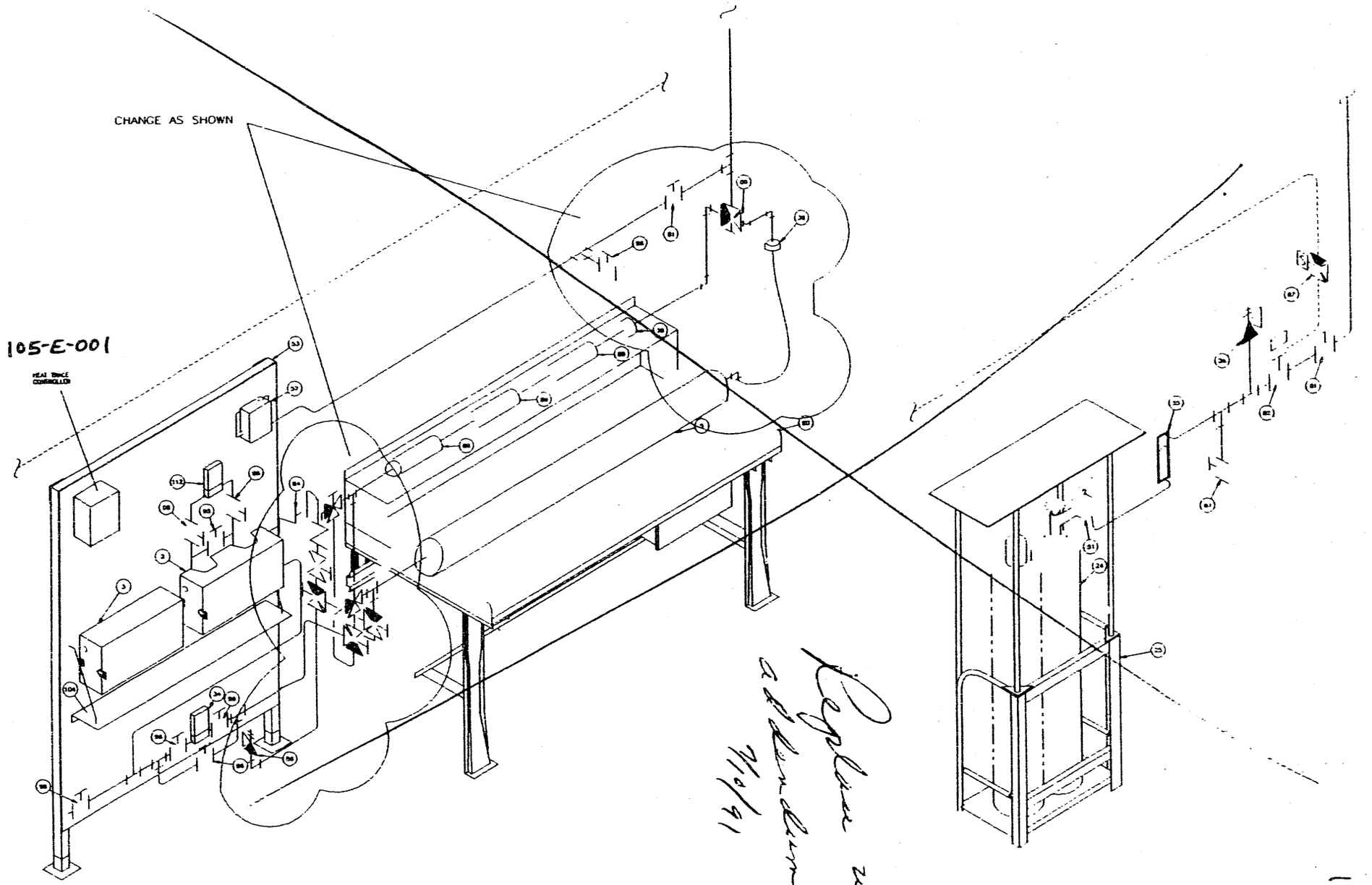
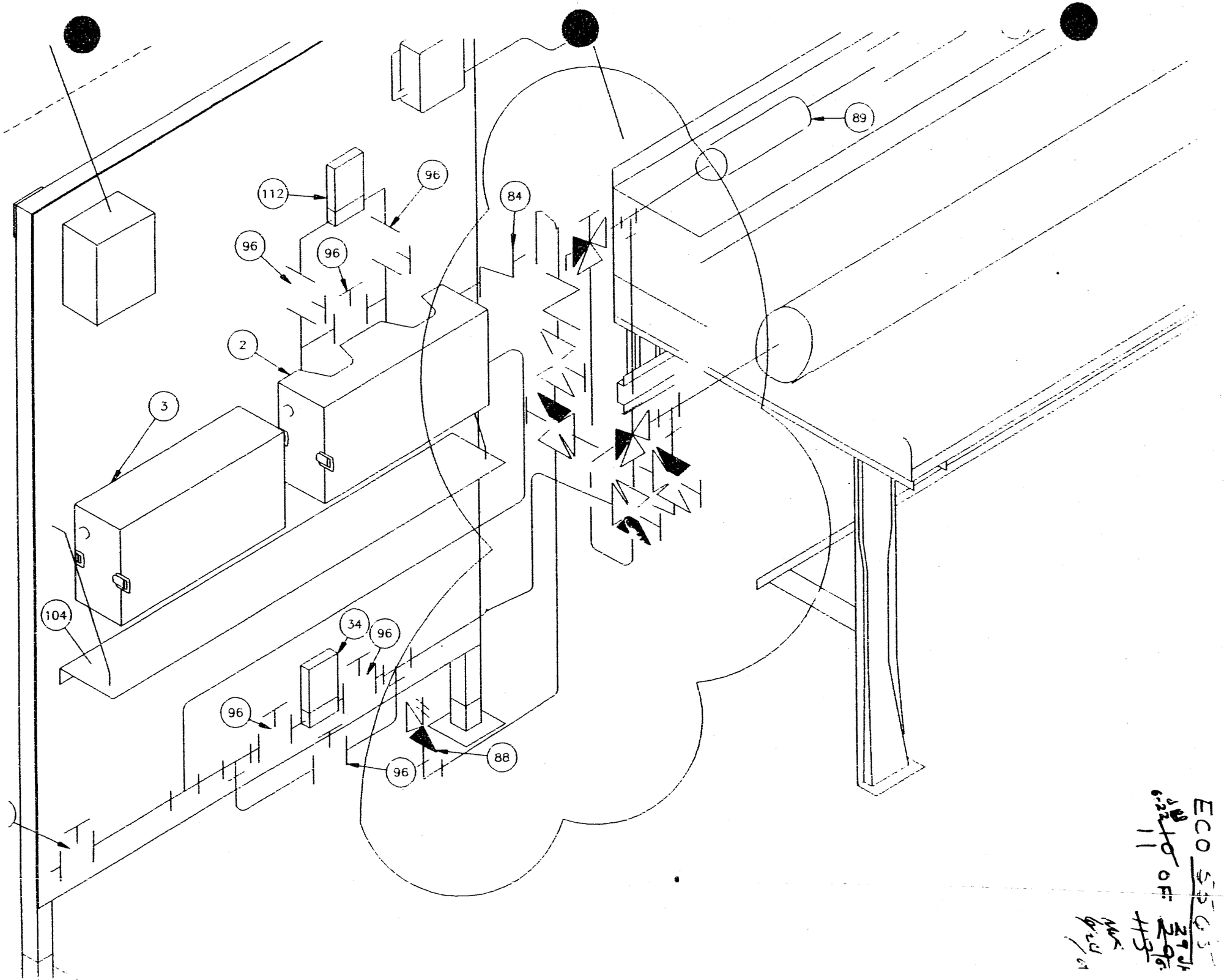


Replaces w/
Addendum #1
7/19/91

52-E-002-W3

ECO 5565
29 JAN 92
10 OF 29


89
112
96
96
96
84
2
3
104
34
96
96
96
88

29,
12 OF ~~29~~ ~~+13~~

MM 6/24/91

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-W5 ECO Number: 5565

2. ECO Search List: 5532

3. Description of Change:

SAME AS 1. ON SHEET 9a OF DRAWING 52-L-002-W2 OF THIS ECO.

SEE ATTACHED PAGE

4. Drawing Cog. Engineer Approval: M. M. Yendiratta Date: 6/24/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

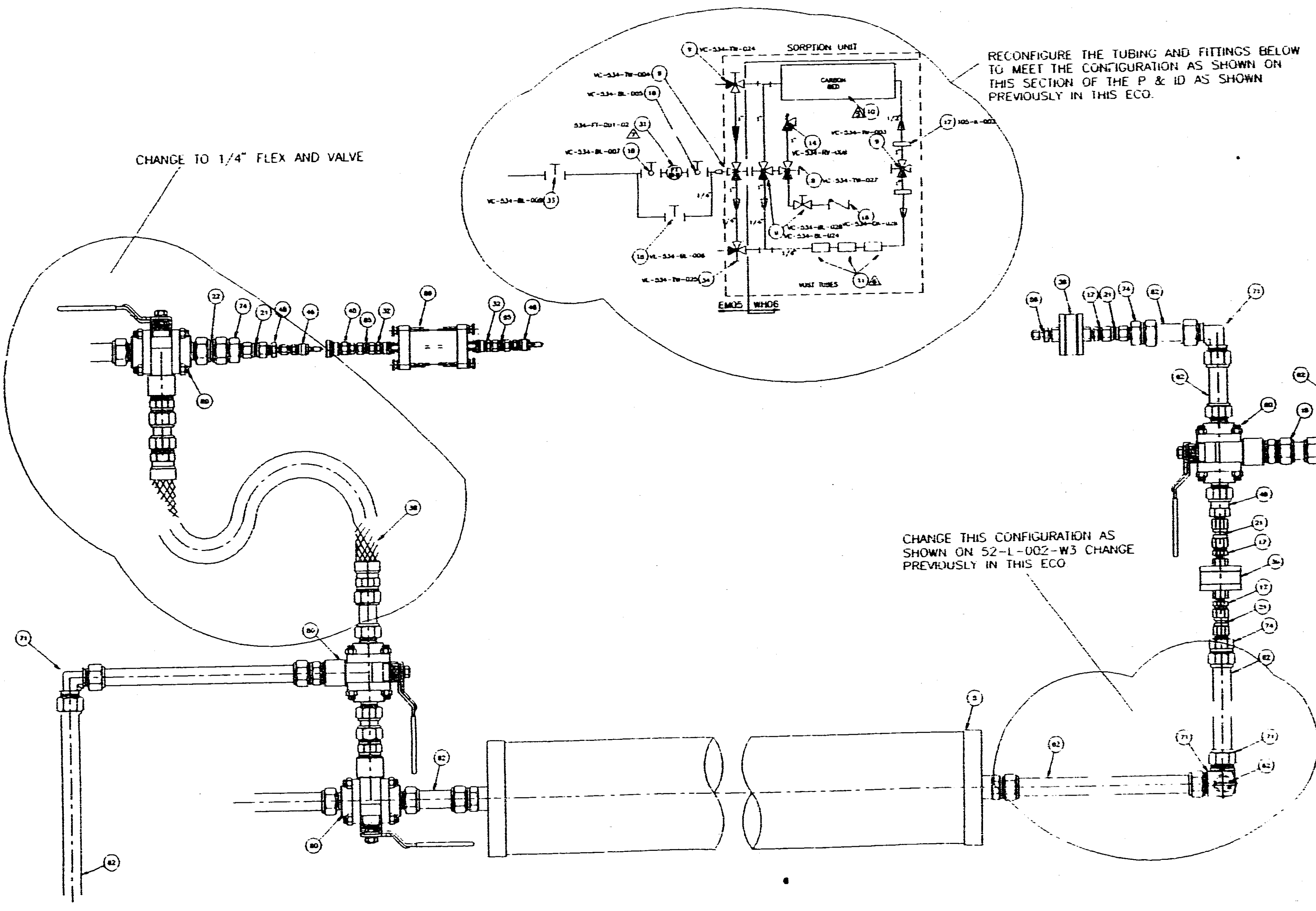
Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date


RECONFIGURE THE TUBING AND FITTINGS BELOW TO MEET THE CONFIGURATION AS SHOWN ON THIS SECTION OF THE P & ID AS SHOWN PREVIOUSLY IN THIS ECO.
CHANGE TO 1/4" FLEX AND VALVE
CHANGE THIS CONFIGURATION AS SHOWN ON 52-L-002-W3 CHANGE PREVIOUSLY IN THIS ECO
SORPTION UNIT
CARBON BED
EM05
WH06

14 OF ~~29~~ 29.6
~~H3~~
MK 6/24/91

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-W6 ECO Number: 5565

2. ECO Search List: 5532

3. Description of Change:

MOVE THE PRV AND TUBING TO 52-L-002-W5.

~~REPLACE TEE WITH A MALE CONNECTOR~~ JRB 6-24-91

4. Drawing Cog. Engineer Approval: [signature] Date: 6/24/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

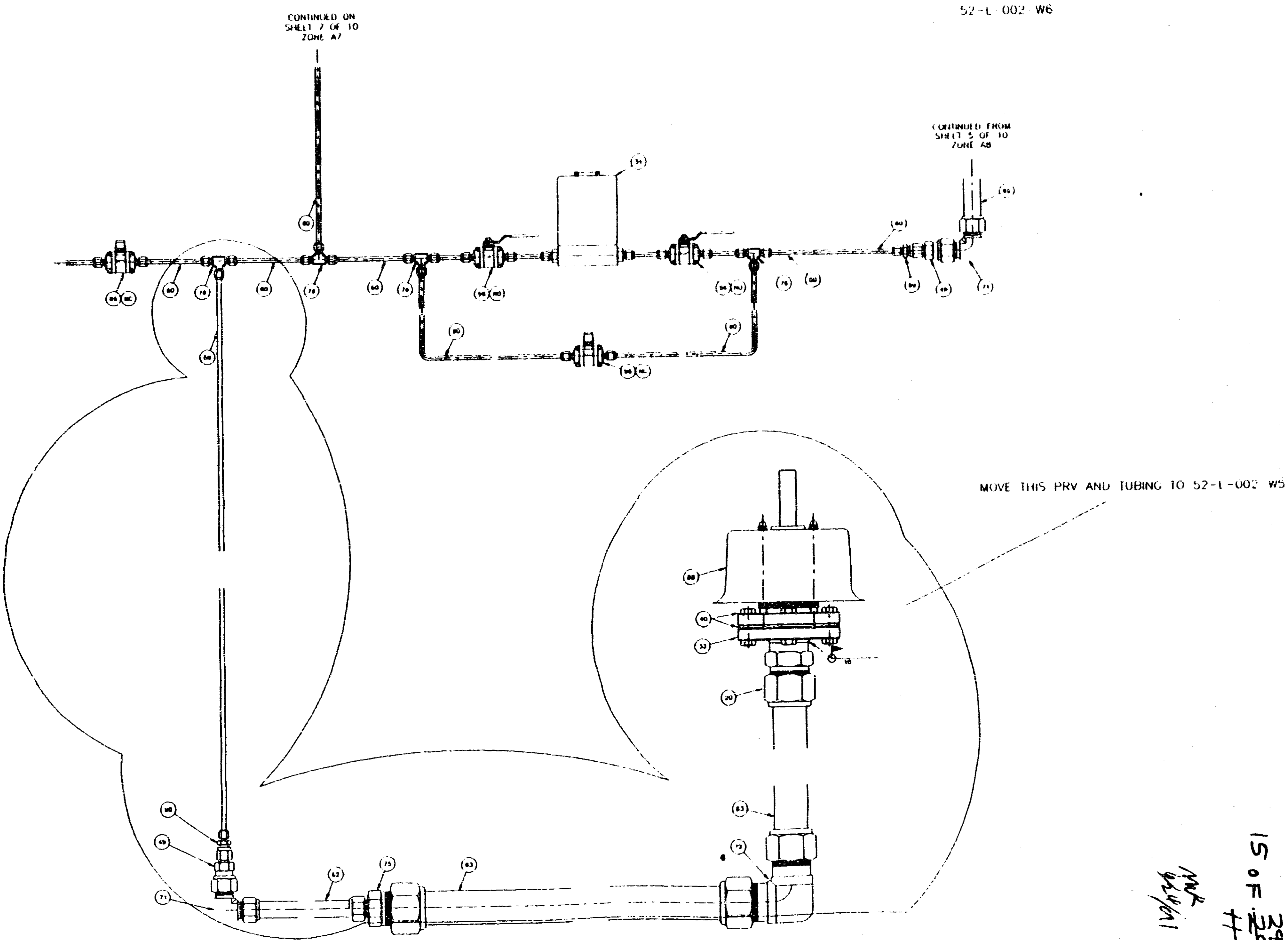
Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

ECO [illegible]
15 OF 29
H3
[illegible] 6/24/01



ECO 5565
16 OF 29 JRS 6-24
43
MWR 6/24/91

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 105-F-013-W ECO Number: 5565

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

ADD THE INSTRUMENT AND VALVE NUMBER TAGS TO THIS DRAWING AS SHOWN ONTHE ATTACHED PAGE

4. Drawing Cog. Engineer Approval: J. R. Stubble Date: 6-22-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

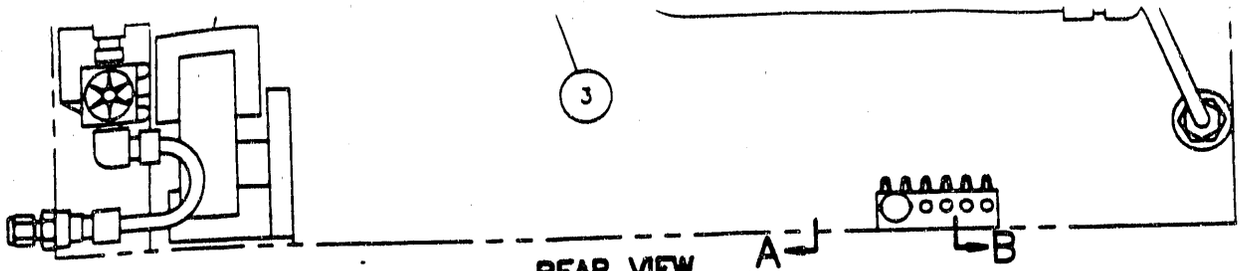
Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

ECO 5[illegible]

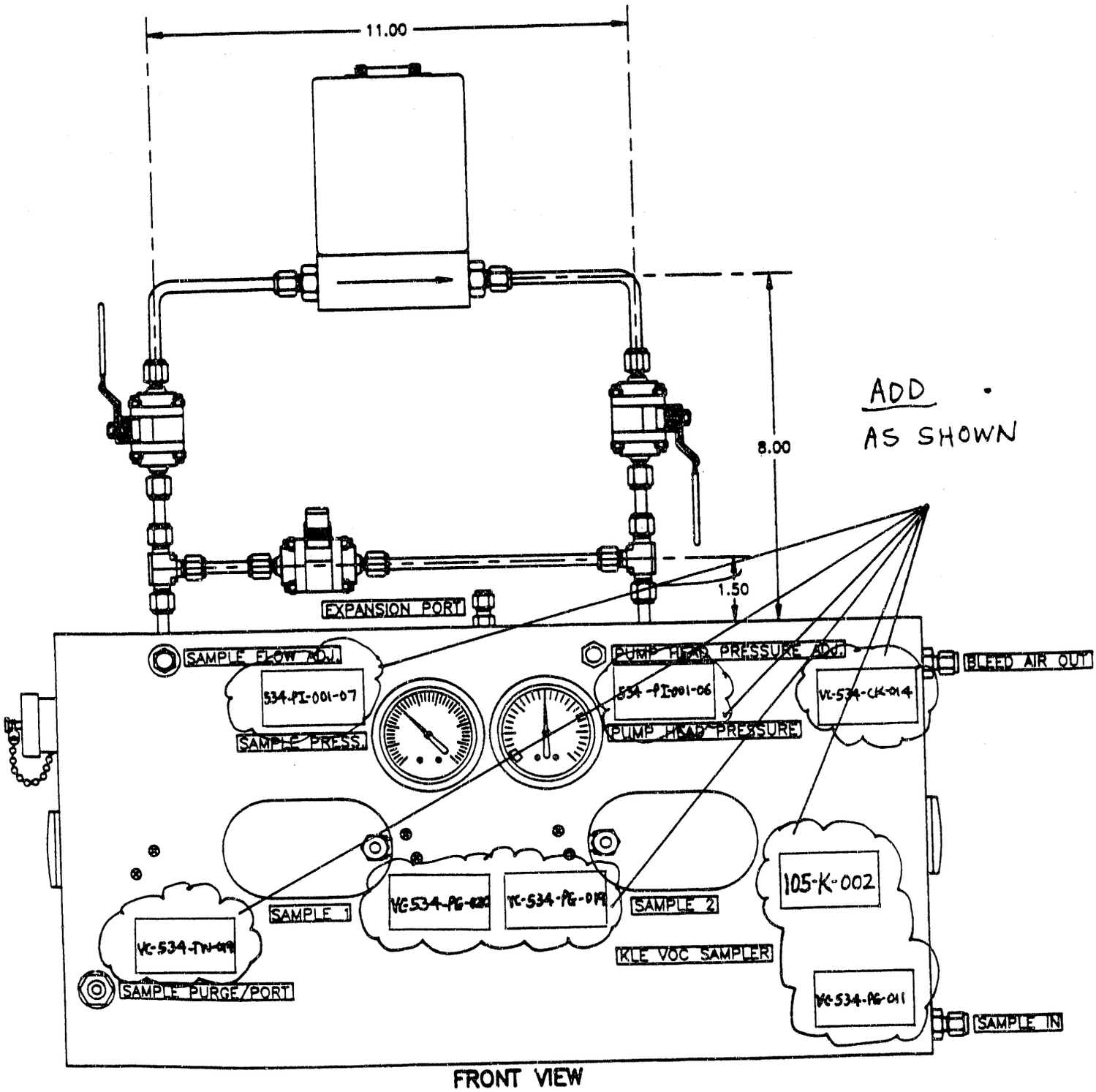
17 OF 29

~~43~~



REAR VIEW

ENCLOSURE SHOWN IN PHANTOM
FOR CLARITY ONLY.



ADD
AS SHOWN

FRONT VIEW

6 5

105-F-013-W

ECO 5565

18 OF 29 JRS 6-24

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 105-H-005-W ECO Number: 5565

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

1. EXCHANGE "CR1" & "CR2" DESIGNATIONS
2. CORRECT THE PRIORITY ALARM DESIGNATIONS
3. ADD HALFSHELL NUMBER IN LPU
4. ADD SYSTEM DESIGNATIONS
5. ADD RESISTOR TO 105-H-001-05 LOOP, PLC TERMINALS 11 & 13
6. ADD SCT-02 TO 105-H-001-01 LOOP (±10V OUT)
7. CHANGE TERMINAL BLOCK DESIGNATIONS IN 105-H-001-02 LOOP
8. "PRIORITY 1" TO "HIGH PRIORITY" & "PRIORITY 2" TO "LOW PRIORITY".

SEE ATTACHED PAGES

4. Drawing Cog. Engineer Approval: J. R. Struble Date: 6-22-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

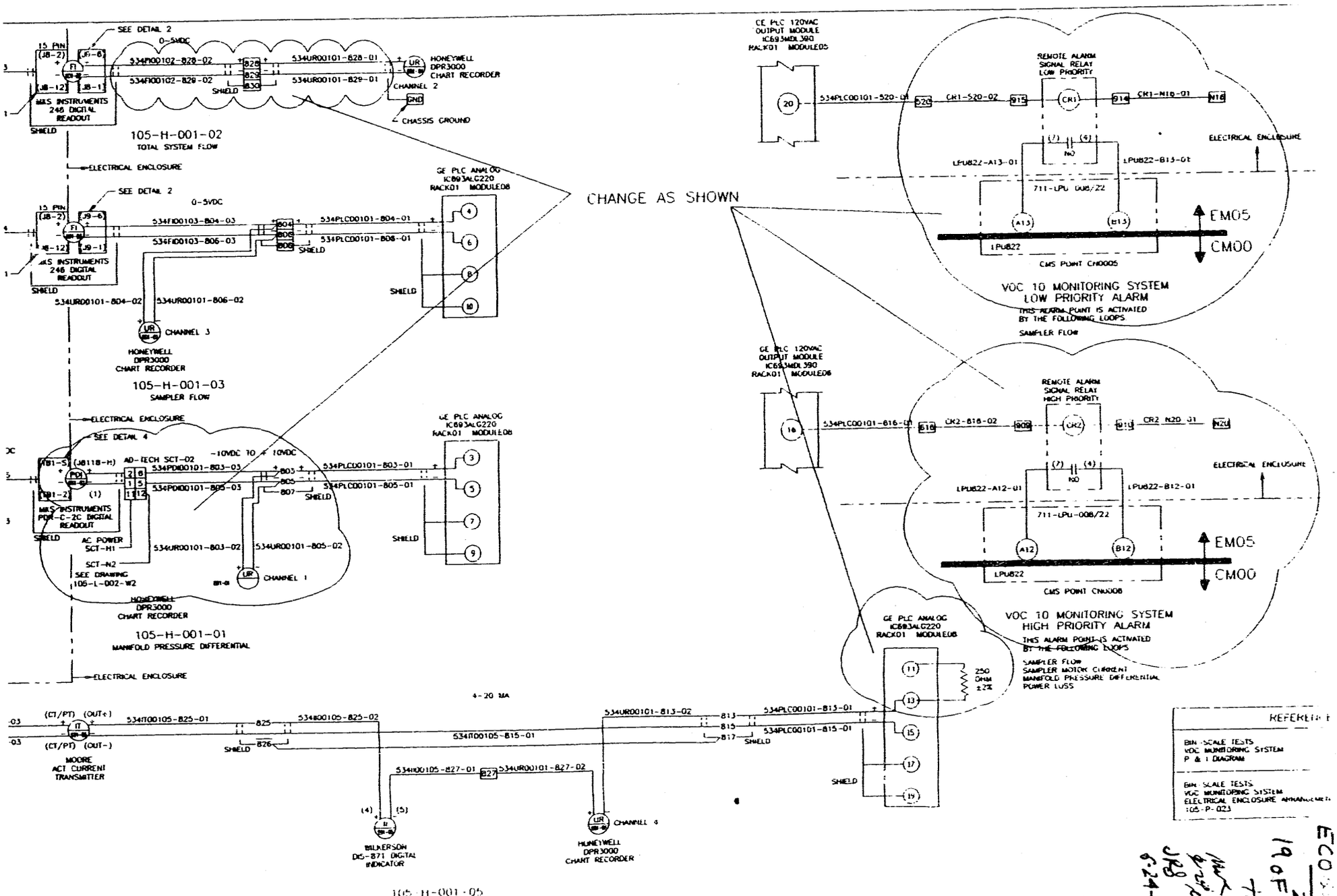
Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

105-H-005-W



ECO
19 of 2
JRB 6-24-

20 OF ~~29~~ 43

29 v1 6-24

mk 6/24

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 105-L-002-W2 ECO Number: 5505

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

1. ADD WIRING FOR THE SIGNAL CONDITIONING TRANSMITTER (SCT) AS SHOWN ON THE ATTACHED PAGES.
2. EXCHANGE "CR1" & "CR2" DESIGNATIONS
3. ADD A 15A CIRCUIT BREAKER IN-LINE BEFORE THE LINE PROTECTOR
4. ADD SYSTEM DESIGNATOR ON BLOCK DIAGRAM

SEE ATTACHED PAGES

4. Drawing Cog. Engineer Approval: J.R. Stroble Date: 6-22-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

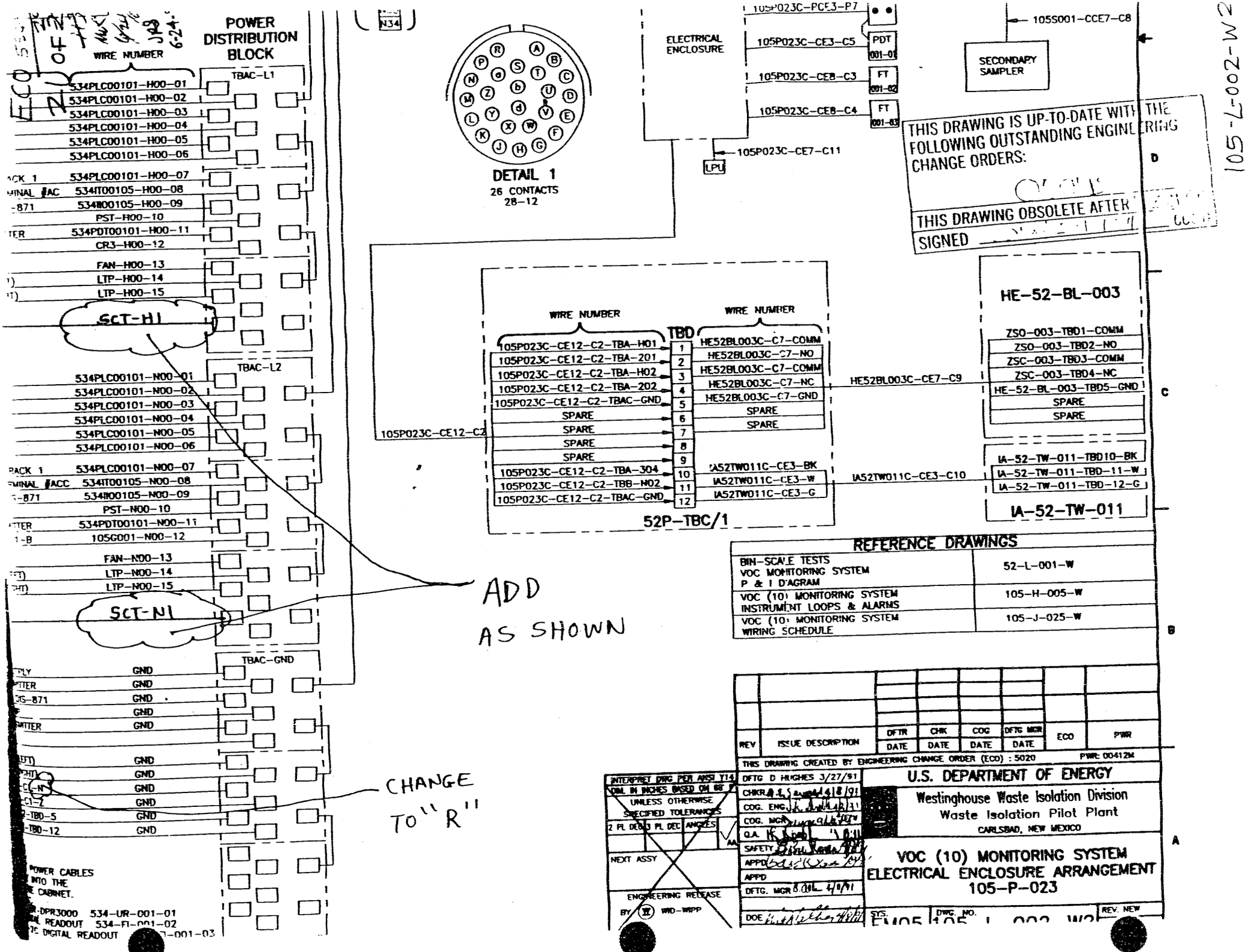
Drafting Started: _____ Initials / Date

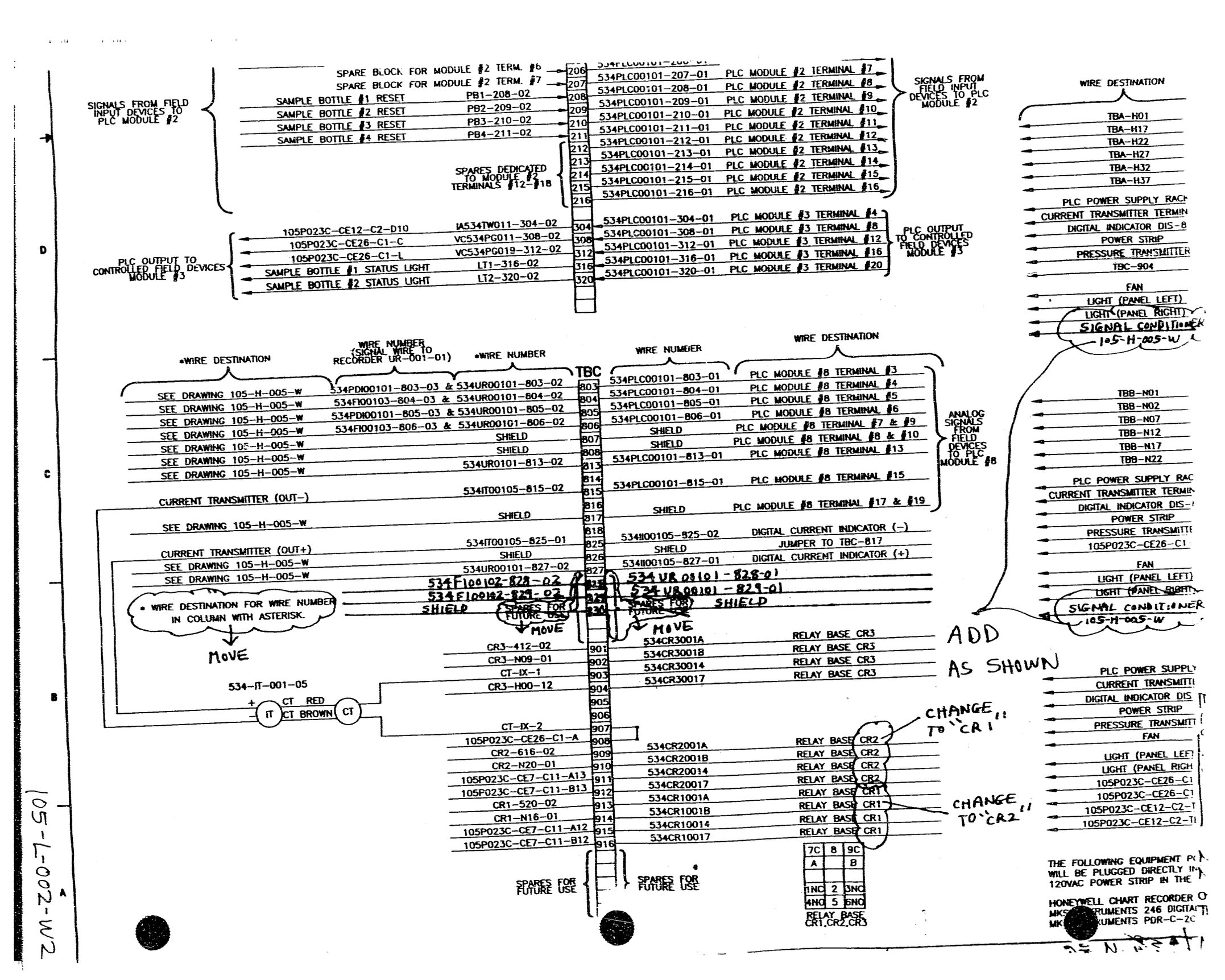
Date Assigned: _____ Initials / Date

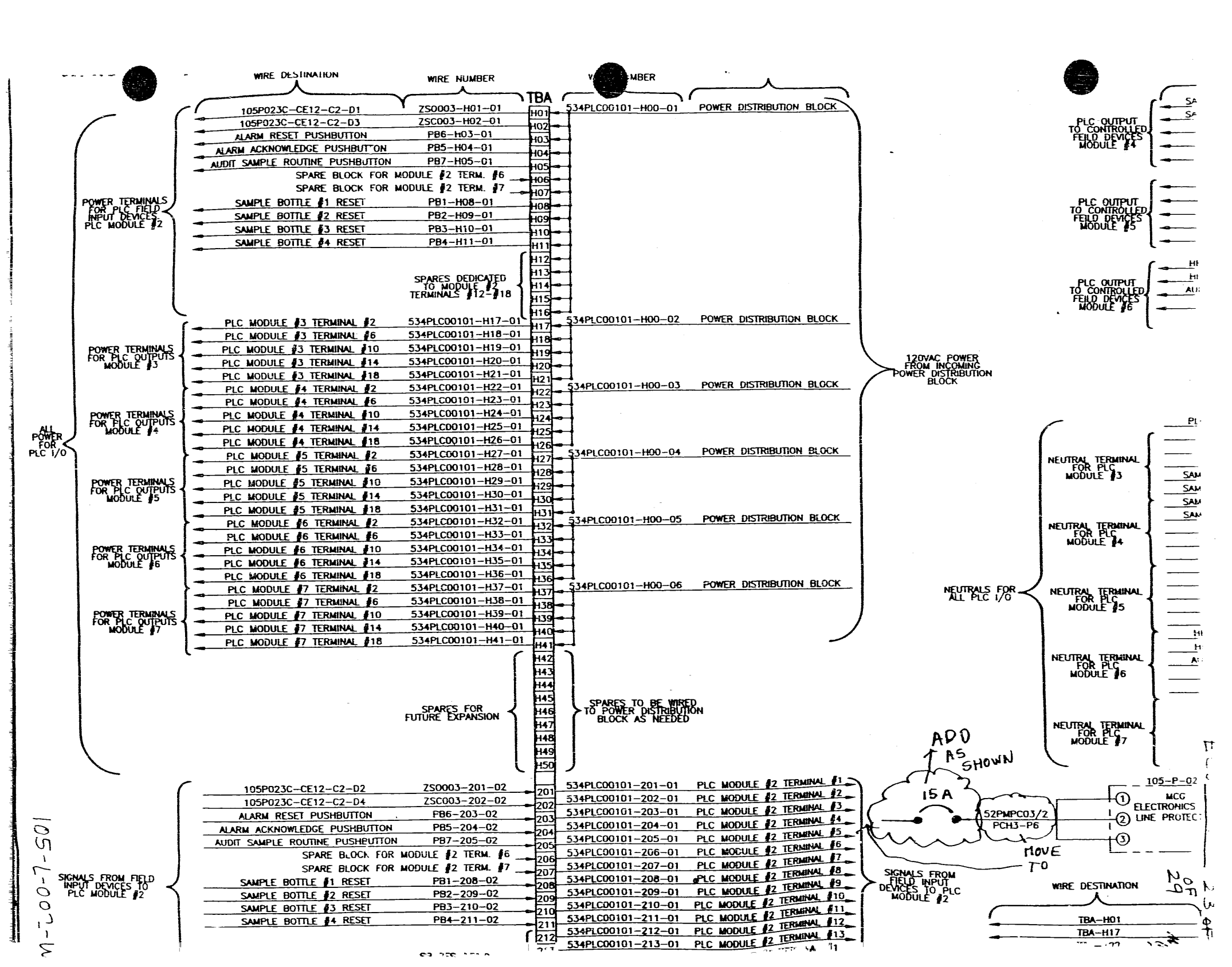
Drafting Completed: _____ Initials / Date

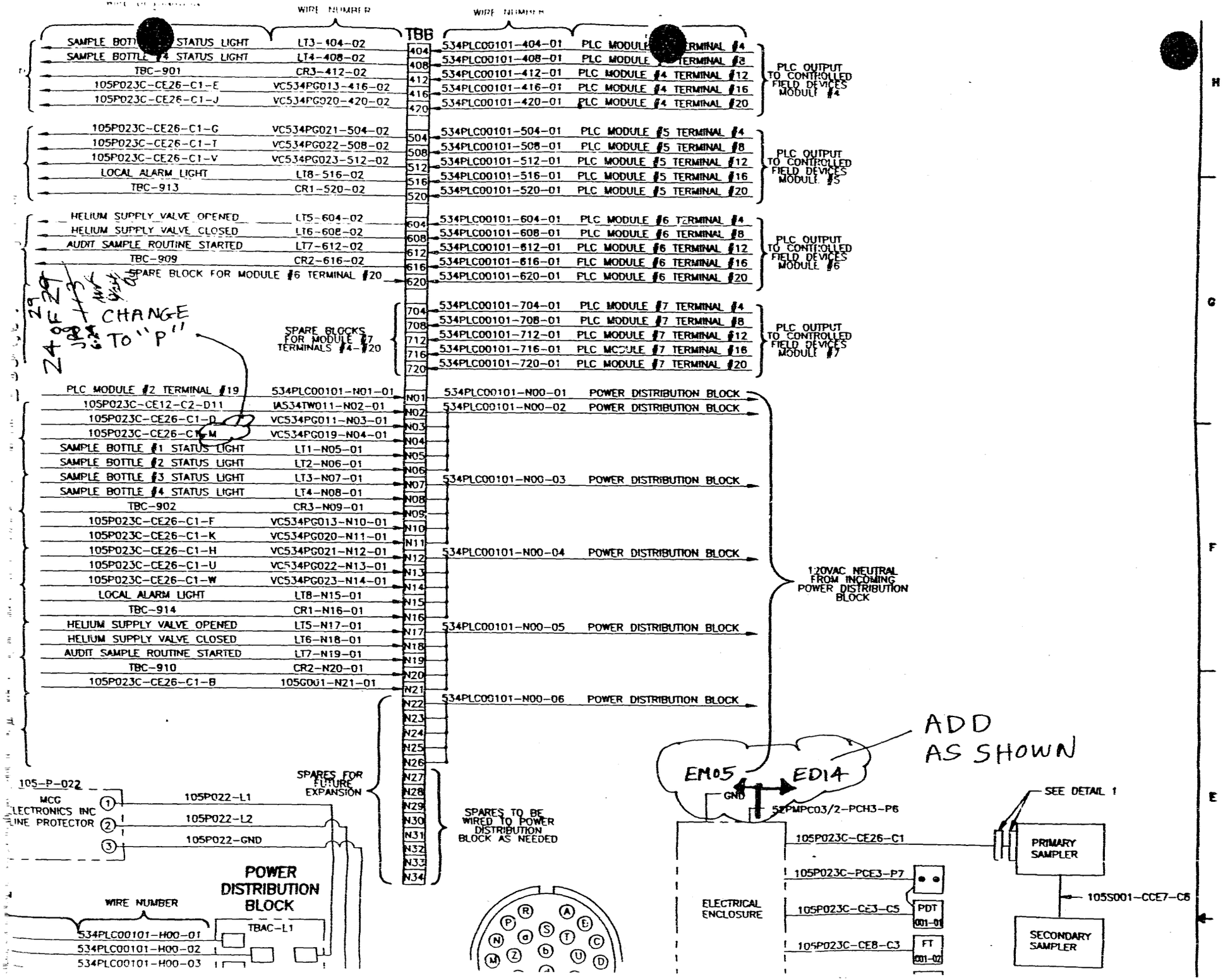
Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date


POWER DISTRIBUTION BLOCK
WIRE NUMBER
TBAC-L1
534PLC00101-H00-01
534PLC00101-H00-02
534PLC00101-H00-03
534PLC00101-H00-04
534PLC00101-H00-05
534PLC00101-H00-06
534PLC00101-H00-07
534IT00105-H00-08
534IR00105-H00-09
PST-H00-10
534PDT00101-H00-11
CR3-H00-12
FAN-H00-13
LTP-H00-14
LTP-H00-15
SCT-H1
TBAC-L2
534PLC00101-N00-01
534PLC00101-N00-02
534PLC00101-N00-03
534PLC00101-N00-04
534PLC00101-N00-05
534PLC00101-N00-06
534PLC00101-N00-07
534IT00105-N00-08
534IR00105-N00-09
PST-N00-10
534PDT00101-N00-11
105G001-N00-12
FAN-N00-13
LTP-N00-14
LTP-N00-15
SCT-N1
TBAC-GND
GND
N34
DETAIL 1
26 CONTACTS
28-12
ELECTRICAL ENCLOSURE
105P023C-PCE3-P7
105P023C-CE3-C5
105P023C-CE8-C3
105P023C-CE8-C4
PDT
FT
105P023C-CE7-C11
LPU
105S001-CCE7-C8
SECONDARY SAMPLER
THIS DRAWING IS UP-TO-DATE WITH THE FOLLOWING OUTSTANDING ENGINEERING CHANGE ORDERS:
THIS DRAWING OBSOLETE AFTER
SIGNED
105-L-002-W2
WIRE NUMBER
TBD
105P023C-CE12-C2-TBA-H01
105P023C-CE12-C2-TBA-201
105P023C-CE12-C2-TBA-H02
105P023C-CE12-C2-TBA-202
105P023C-CE12-C2-TBAC-GND
SPARE
105P023C-CE12-C2-TBA-304
105P023C-CE12-C2-TBB-N02
105P023C-CE12-C2-TBAC-GND
HE52BL003C-C7-COMM
HE52BL003C-C7-NO
HE52BL003C-C7-COMM
HE52BL003C-C7-NC
HE52BL003C-C7-GND
IA52TW011C-CE3-BK
IA52TW011C-CE3-W
IA52TW011C-CE3-G
52P-TBC/1
HE52BL003C-CE7-C9
IA52TW011C-CE3-C10
HE-52-BL-003
ZSO-003-TBD1-COMM
ZSO-003-TBD2-NO
ZSC-003-TBD3-COMM
ZSC-003-TBD4-NC
HE-52-BL-003-TBD5-GND
IA-52-TW-011-TBD10-BK
IA-52-TW-011-TBD-11-W
IA-52-TW-011-TBD-12-G
IA-52-TW-011
REFERENCE DRAWINGS
BIN-SCALE TESTS VOC MONITORING SYSTEM P & I D'AGRAM 52-L-001-W
VOC (10) MONITORING SYSTEM INSTRUMENT LOOPS & ALARMS 105-H-005-W
VOC (10) MONITORING SYSTEM WIRING SCHEDULE 105-J-025-W
ADD AS SHOWN
CHANGE TO "R"
POWER CABLES INTO THE CABINET.
DPR3000 534-UR-001-01
READOUT 534-FI-001-02
DIGITAL READOUT
REV
ISSUE DESCRIPTION
DFTR DATE
CHK DATE
COG DATE
DFTG MGR DATE
ECO
PWR
THIS DRAWING CREATED BY ENGINEERING CHANGE ORDER (ECO) : 5020
PWR: 004124
DFTG D HUGHES 3/27/91
CHKR
COG. ENG
COG. MGR
Q.A.
SAFETY
APPD
APPD
DFTG. MGR
DOE
INTERPRET DWG PER ANSI Y14.5M IN INCHES BASED ON 68°F
UNLESS OTHERWISE SPECIFIED TOLERANCES
2 PL DECIMAL 3 PL DEC ANGLES
NEXT ASSY
ENGINEERING RELEASE BY WID-WPP
U.S. DEPARTMENT OF ENERGY
Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO
VOC (10) MONITORING SYSTEM
ELECTRICAL ENCLOSURE ARRANGEMENT
105-P-023
SYS.
DWG. NO.
REV. NEW


SIGNALS FROM FIELD INPUT DEVICES TO PLC MODULE #2
SPARE BLOCK FOR MODULE #2 TERM. #6
SPARE BLOCK FOR MODULE #2 TERM. #7
SAMPLE BOTTLE #1 RESET
PB1-208-02
SAMPLE BOTTLE #2 RESET
PB2-209-02
SAMPLE BOTTLE #3 RESET
PB3-210-02
SAMPLE BOTTLE #4 RESET
PB4-211-02
SPARES DEDICATED TO MODULE #2 TERMINALS #12-#18
534PLC00101-207-01 PLC MODULE #2 TERMINAL #7
534PLC00101-208-01 PLC MODULE #2 TERMINAL #8
534PLC00101-209-01 PLC MODULE #2 TERMINAL #9
534PLC00101-210-01 PLC MODULE #2 TERMINAL #10
534PLC00101-211-01 PLC MODULE #2 TERMINAL #11
534PLC00101-212-01 PLC MODULE #2 TERMINAL #12
534PLC00101-213-01 PLC MODULE #2 TERMINAL #13
534PLC00101-214-01 PLC MODULE #2 TERMINAL #14
534PLC00101-215-01 PLC MODULE #2 TERMINAL #15
534PLC00101-216-01 PLC MODULE #2 TERMINAL #16
SIGNALS FROM FIELD INPUT DEVICES TO PLC MODULE #2
WIRE DESTINATION
TBA-H01
TBA-H17
TBA-H22
TBA-H27
TBA-H32
TBA-H37
PLC POWER SUPPLY RACK
CURRENT TRANSMITTER TERMIN
DIGITAL INDICATOR DIS-8
POWER STRIP
PRESSURE TRANSMITTER
TBC-904
FAN
LIGHT (PANEL LEFT)
LIGHT (PANEL RIGHT)
SIGNAL CONDITIONER
105-H-005-W
PLC OUTPUT TO CONTROLLED FIELD DEVICES MODULE #3
105P023C-CE12-C2-D10 IA534TW011-304-02
105P023C-CE26-C1-C VC534PG011-308-02
105P023C-CE26-C1-L VC534PG019-312-02
SAMPLE BOTTLE #1 STATUS LIGHT LT1-316-02
SAMPLE BOTTLE #2 STATUS LIGHT LT2-320-02
534PLC00101-304-01 PLC MODULE #3 TERMINAL #4
534PLC00101-308-01 PLC MODULE #3 TERMINAL #8
534PLC00101-312-01 PLC MODULE #3 TERMINAL #12
534PLC00101-316-01 PLC MODULE #3 TERMINAL #16
534PLC00101-320-01 PLC MODULE #3 TERMINAL #20
PLC OUTPUT TO CONTROLLED FIELD DEVICES MODULE #3
*WIRE DESTINATION
WIRE NUMBER (SIGNAL WIRE TO RECORDER UR-001-01)
*WIRE NUMBER
TBC
WIRE NUMBER
WIRE DESTINATION
SEE DRAWING 105-H-005-W 534PDI00101-803-03 & 534UR00101-803-02
SEE DRAWING 105-H-005-W 534FI00103-804-03 & 534UR00101-804-02
SEE DRAWING 105-H-005-W 534PDI00101-805-03 & 534UR00101-805-02
SEE DRAWING 105-H-005-W 534FI00103-806-03 & 534UR00101-806-02
SEE DRAWING 105-H-005-W SHIELD
SEE DRAWING 105-H-005-W SHIELD
SEE DRAWING 105-H-005-W 534UR0101-813-02
CURRENT TRANSMITTER (OUT-) 534IT00105-815-02
SEE DRAWING 105-H-005-W SHIELD
CURRENT TRANSMITTER (OUT+) 534IT00105-825-01
SEE DRAWING 105-H-005-W SHIELD
SEE DRAWING 105-H-005-W 534UR00101-827-02
534FI00102-828-02
534FI00102-829-02
SHIELD
SPARES FOR FUTURE USE
MOVE
534PLC00101-803-01 PLC MODULE #8 TERMINAL #3
534PLC00101-804-01 PLC MODULE #8 TERMINAL #4
534PLC00101-805-01 PLC MODULE #8 TERMINAL #5
534PLC00101-806-01 PLC MODULE #8 TERMINAL #6
SHIELD PLC MODULE #8 TERMINAL #7 & #9
SHIELD PLC MODULE #8 TERMINAL #8 & #10
534PLC00101-813-01 PLC MODULE #8 TERMINAL #13
534PLC00101-815-01 PLC MODULE #8 TERMINAL #15
SHIELD PLC MODULE #8 TERMINAL #17 & #19
534II00105-825-02 DIGITAL CURRENT INDICATOR (-)
SHIELD JUMPER TO TBC-817
534II00105-827-01 DIGITAL CURRENT INDICATOR (+)
534UR00101-828-01
534UR00101-829-01
SHIELD
SPARES FOR FUTURE USE
MOVE
ANALOG SIGNALS FROM FIELD DEVICES TO PLC MODULE #8
WIRE DESTINATION
TBB-N01
TBB-N02
TBB-N07
TBB-N12
TBB-N17
TBB-N22
PLC POWER SUPPLY RAC
CURRENT TRANSMITTER TERMIN
DIGITAL INDICATOR DIS-
POWER STRIP
PRESSURE TRANSMITTE
105P023C-CE26-C1
FAN
LIGHT (PANEL LEFT)
LIGHT (PANEL RIGHT)
SIGNAL CONDITIONER
105-H-005-W
* WIRE DESTINATION FOR WIRE NUMBER IN COLUMN WITH ASTERISK.
MOVE
ADD AS SHOWN
534-IT-001-05
+ CT RED
- IT CT BROWN CT
CR3-412-02
CR3-N09-01
CT-IX-1
CR3-H00-12
CT-IX-2
105P023C-CE26-C1-A
CR2-616-02
CR2-N20-01
105P023C-CE7-C11-A13
105P023C-CE7-C11-B13
CR1-520-02
CR1-N16-01
105P023C-CE7-C11-A12
105P023C-CE7-C11-B12
534CR3001A RELAY BASE CR3
534CR3001B RELAY BASE CR3
534CR30014 RELAY BASE CR3
534CR30017 RELAY BASE CR3
534CR2001A RELAY BASE CR2
534CR2001B RELAY BASE CR2
534CR20014 RELAY BASE CR2
534CR20017 RELAY BASE CR2
534CR1001A RELAY BASE CR1
534CR1001B RELAY BASE CR1
534CR10014 RELAY BASE CR1
534CR10017 RELAY BASE CR1
CHANGE TO "CR1"
CHANGE TO "CR2"
7C 8 9C
A B
1NC 2 3NO
4NO 5 6NO
RELAY BASE CR1,CR2,CR3
SPARES FOR FUTURE USE
SPARES FOR FUTURE USE
PLC POWER SUPPLY
CURRENT TRANSMITTI
DIGITAL INDICATOR DIS
POWER STRIP
PRESSURE TRANSMITT
FAN
LIGHT (PANEL LEFT
LIGHT (PANEL RIGH
105P023C-CE26-C1
105P023C-CE26-C1
105P023C-CE12-C2-T
105P023C-CE12-C2-TI
THE FOLLOWING EQUIPMENT P
WILL BE PLUGGED DIRECTLY IN
120VAC POWER STRIP IN THE
HONEYWELL CHART RECORDER O
MK
MK
105-L-002-W2


WIRE DESTINATION
WIRE NUMBER
TBA
105P023C-CE12-C2-D1
ZS0003-H01-01
H01
534PLC00101-H00-01
POWER DISTRIBUTION BLOCK
105P023C-CE12-C2-D3
ZSC003-H02-01
H02
ALARM RESET PUSHBUTTON
PB6-H03-01
H03
ALARM ACKNOWLEDGE PUSHBUTTON
PB5-H04-01
H04
AUDIT SAMPLE ROUTINE PUSHBUTTON
PB7-H05-01
H05
SPARE BLOCK FOR MODULE #2 TERM. #6
H06
SPARE BLOCK FOR MODULE #2 TERM. #7
H07
SAMPLE BOTTLE #1 RESET
PB1-H08-01
H08
SAMPLE BOTTLE #2 RESET
PB2-H09-01
H09
SAMPLE BOTTLE #3 RESET
PB3-H10-01
H10
SAMPLE BOTTLE #4 RESET
PB4-H11-01
H11
POWER TERMINALS FOR PLC FIELD INPUT DEVICES PLC MODULE #2
SPARES DEDICATED TO MODULE #2 TERMINALS #12-#18
H12
H13
H14
H15
H16
PLC MODULE #3 TERMINAL #2
534PLC00101-H17-01
H17
534PLC00101-H00-02
POWER DISTRIBUTION BLOCK
PLC MODULE #3 TERMINAL #6
534PLC00101-H18-01
H18
PLC MODULE #3 TERMINAL #10
534PLC00101-H19-01
H19
PLC MODULE #3 TERMINAL #14
534PLC00101-H20-01
H20
PLC MODULE #3 TERMINAL #18
534PLC00101-H21-01
H21
POWER TERMINALS FOR PLC OUTPUTS MODULE #3
PLC MODULE #4 TERMINAL #2
534PLC00101-H22-01
H22
534PLC00101-H00-03
POWER DISTRIBUTION BLOCK
PLC MODULE #4 TERMINAL #6
534PLC00101-H23-01
H23
PLC MODULE #4 TERMINAL #10
534PLC00101-H24-01
H24
PLC MODULE #4 TERMINAL #14
534PLC00101-H25-01
H25
PLC MODULE #4 TERMINAL #18
534PLC00101-H26-01
H26
POWER TERMINALS FOR PLC OUTPUTS MODULE #4
PLC MODULE #5 TERMINAL #2
534PLC00101-H27-01
H27
534PLC00101-H00-04
POWER DISTRIBUTION BLOCK
PLC MODULE #5 TERMINAL #6
534PLC00101-H28-01
H28
PLC MODULE #5 TERMINAL #10
534PLC00101-H29-01
H29
PLC MODULE #5 TERMINAL #14
534PLC00101-H30-01
H30
PLC MODULE #5 TERMINAL #18
534PLC00101-H31-01
H31
POWER TERMINALS FOR PLC OUTPUTS MODULE #5
PLC MODULE #6 TERMINAL #2
534PLC00101-H32-01
H32
534PLC00101-H00-05
POWER DISTRIBUTION BLOCK
PLC MODULE #6 TERMINAL #6
534PLC00101-H33-01
H33
PLC MODULE #6 TERMINAL #10
534PLC00101-H34-01
H34
PLC MODULE #6 TERMINAL #14
534PLC00101-H35-01
H35
PLC MODULE #6 TERMINAL #18
534PLC00101-H36-01
H36
POWER TERMINALS FOR PLC OUTPUTS MODULE #6
PLC MODULE #7 TERMINAL #2
534PLC00101-H37-01
H37
534PLC00101-H00-06
POWER DISTRIBUTION BLOCK
PLC MODULE #7 TERMINAL #6
534PLC00101-H38-01
H38
PLC MODULE #7 TERMINAL #10
534PLC00101-H39-01
H39
PLC MODULE #7 TERMINAL #14
534PLC00101-H40-01
H40
PLC MODULE #7 TERMINAL #18
534PLC00101-H41-01
H41
POWER TERMINALS FOR PLC OUTPUTS MODULE #7
ALL POWER FOR PLC I/O
SPARES FOR FUTURE EXPANSION
H42
H43
H44
H45
H46
H47
H48
H49
H50
SPARES TO BE WIRED TO POWER DISTRIBUTION BLOCK AS NEEDED
120VAC POWER FROM INCOMING POWER DISTRIBUTION BLOCK
PLC OUTPUT TO CONTROLLED FEILD DEVICES MODULE #4
PLC OUTPUT TO CONTROLLED FEILD DEVICES MODULE #5
PLC OUTPUT TO CONTROLLED FEILD DEVICES MODULE #6
NEUTRAL TERMINAL FOR PLC MODULE #3
NEUTRAL TERMINAL FOR PLC MODULE #4
NEUTRAL TERMINAL FOR PLC MODULE #5
NEUTRAL TERMINAL FOR PLC MODULE #6
NEUTRAL TERMINAL FOR PLC MODULE #7
NEUTRALS FOR ALL PLC I/O
105P023C-CE12-C2-D2
ZS0003-201-02
201
534PLC00101-201-01
PLC MODULE #2 TERMINAL #1
105P023C-CE12-C2-D4
ZSC003-202-02
202
534PLC00101-202-01
PLC MODULE #2 TERMINAL #2
ALARM RESET PUSHBUTTON
PB6-203-02
203
534PLC00101-203-01
PLC MODULE #2 TERMINAL #3
ALARM ACKNOWLEDGE PUSHBUTTON
PB5-204-02
204
534PLC00101-204-01
PLC MODULE #2 TERMINAL #4
AUDIT SAMPLE ROUTINE PUSHBUTTON
PB7-205-02
205
534PLC00101-205-01
PLC MODULE #2 TERMINAL #5
SPARE BLOCK FOR MODULE #2 TERM. #6
206
534PLC00101-206-01
PLC MODULE #2 TERMINAL #6
SPARE BLOCK FOR MODULE #2 TERM. #7
207
534PLC00101-207-01
PLC MODULE #2 TERMINAL #7
SAMPLE BOTTLE #1 RESET
PB1-208-02
208
534PLC00101-208-01
PLC MODULE #2 TERMINAL #8
SAMPLE BOTTLE #2 RESET
PB2-209-02
209
534PLC00101-209-01
PLC MODULE #2 TERMINAL #9
SAMPLE BOTTLE #3 RESET
PB3-210-02
210
534PLC00101-210-01
PLC MODULE #2 TERMINAL #10
SAMPLE BOTTLE #4 RESET
PB4-211-02
211
534PLC00101-211-01
PLC MODULE #2 TERMINAL #11
212
534PLC00101-212-01
PLC MODULE #2 TERMINAL #12
534PLC00101-213-01
PLC MODULE #2 TERMINAL #13
SIGNALS FROM FIELD INPUT DEVICES TO PLC MODULE #2
ADD AS SHOWN
15A
52PMPC03/2
PCH3-P6
MOVE TO
105-P-02
MCG ELECTRONICS
LINE PROTEC
WIRE DESTINATION
TBA-H01
TBA-H17
M-105-7-001


WIRE NUMBER
TBB
SAMPLE BOTTLE #3 STATUS LIGHT
LT3-404-02
SAMPLE BOTTLE #4 STATUS LIGHT
LT4-408-02
TBC-901
CR3-412-02
105P023C-CE26-C1-E
VC534PG013-416-02
105P023C-CE26-C1-J
VC534PG020-420-02
534PLC00101-404-01 PLC MODULE #4 TERMINAL #4
534PLC00101-408-01 PLC MODULE #4 TERMINAL #8
534PLC00101-412-01 PLC MODULE #4 TERMINAL #12
534PLC00101-416-01 PLC MODULE #4 TERMINAL #16
534PLC00101-420-01 PLC MODULE #4 TERMINAL #20
PLC OUTPUT TO CONTROLLED FIELD DEVICES MODULE #4
105P023C-CE26-C1-G
VC534PG021-504-02
105P023C-CE26-C1-T
VC534PG022-508-02
105P023C-CE26-C1-V
VC534PG023-512-02
LOCAL ALARM LIGHT
LT8-516-02
TBC-913
CR1-520-02
534PLC00101-504-01 PLC MODULE #5 TERMINAL #4
534PLC00101-508-01 PLC MODULE #5 TERMINAL #8
534PLC00101-512-01 PLC MODULE #5 TERMINAL #12
534PLC00101-516-01 PLC MODULE #5 TERMINAL #16
534PLC00101-520-01 PLC MODULE #5 TERMINAL #20
PLC OUTPUT TO CONTROLLED FIELD DEVICES MODULE #5
HELIUM SUPPLY VALVE OPENED
LT5-604-02
HELIUM SUPPLY VALVE CLOSED
LT6-608-02
AUDIT SAMPLE ROUTINE STARTED
LT7-612-02
TBC-909
CR2-616-02
SPARE BLOCK FOR MODULE #6 TERMINAL #20
534PLC00101-604-01 PLC MODULE #6 TERMINAL #4
534PLC00101-608-01 PLC MODULE #6 TERMINAL #8
534PLC00101-612-01 PLC MODULE #6 TERMINAL #12
534PLC00101-616-01 PLC MODULE #6 TERMINAL #16
534PLC00101-620-01 PLC MODULE #6 TERMINAL #20
PLC OUTPUT TO CONTROLLED FIELD DEVICES MODULE #6
CHANGE TO "P"
SPARE BLOCKS FOR MODULE #7 TERMINALS #4-#20
534PLC00101-704-01 PLC MODULE #7 TERMINAL #4
534PLC00101-708-01 PLC MODULE #7 TERMINAL #8
534PLC00101-712-01 PLC MODULE #7 TERMINAL #12
534PLC00101-716-01 PLC MODULE #7 TERMINAL #16
534PLC00101-720-01 PLC MODULE #7 TERMINAL #20
PLC OUTPUT TO CONTROLLED FIELD DEVICES MODULE #7
PLC MODULE #2 TERMINAL #19
534PLC00101-N01-01
105P023C-CE12-C2-D11
WA534TW011-N02-01
105P023C-CE26-C1-D
VC534PG011-N03-01
105P023C-CE26-C1-M
VC534PG019-N04-01
SAMPLE BOTTLE #1 STATUS LIGHT
LT1-N05-01
SAMPLE BOTTLE #2 STATUS LIGHT
LT2-N06-01
SAMPLE BOTTLE #3 STATUS LIGHT
LT3-N07-01
SAMPLE BOTTLE #4 STATUS LIGHT
LT4-N08-01
TBC-902
CR3-N09-01
105P023C-CE26-C1-F
VC534PG013-N10-01
105P023C-CE26-C1-K
VC534PG020-N11-01
105P023C-CE26-C1-H
VC534PG021-N12-01
105P023C-CE26-C1-U
VC534PG022-N13-01
105P023C-CE26-C1-W
VC534PG023-N14-01
LOCAL ALARM LIGHT
LT8-N15-01
TBC-914
CR1-N16-01
HELIUM SUPPLY VALVE OPENED
LT5-N17-01
HELIUM SUPPLY VALVE CLOSED
LT6-N18-01
AUDIT SAMPLE ROUTINE STARTED
LT7-N19-01
TBC-910
CR2-N20-01
105P023C-CE26-C1-B
105G001-N21-01
534PLC00101-N00-01 POWER DISTRIBUTION BLOCK
534PLC00101-N00-02 POWER DISTRIBUTION BLOCK
534PLC00101-N00-03 POWER DISTRIBUTION BLOCK
534PLC00101-N00-04 POWER DISTRIBUTION BLOCK
534PLC00101-N00-05 POWER DISTRIBUTION BLOCK
534PLC00101-N00-06 POWER DISTRIBUTION BLOCK
120VAC NEUTRAL FROM INCOMING POWER DISTRIBUTION BLOCK
SPARES FOR FUTURE EXPANSION
SPARES TO BE WIRED TO POWER DISTRIBUTION BLOCK AS NEEDED
ADD AS SHOWN
EM05
ED14
GND
52PMPC03/2-PCH3-P6
105-P-022
MCG ELECTRONICS INC LINE PROTECTOR
105P022-L1
105P022-L2
105P022-GND
POWER DISTRIBUTION BLOCK
WIRE NUMBER
TBAC-L1
534PLC00101-H00-01
534PLC00101-H00-02
534PLC00101-H00-03
ELECTRICAL ENCLOSURE
105P023C-CE26-C1
105P023C-PCE3-P7
105P023C-CE3-C5
105P023C-CE8-C3
PDT 001-01
FT 001-02
SEE DETAIL 1
PRIMARY SAMPLER
105S001-CCE7-C6
SECONDARY SAMPLER
105-L-002-W2

25 OF ~~29~~ 29½ ~~43~~

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 105-J-022-W ECO Number: 5545

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

1. EXCHANGE "CR1" & "CR2" DESIGNATIONS
2. CHANGE "1" & "2" PRIORITY TO "HIGH" & "LOW".

SEE ATTACHED PAGES

4. Drawing Cog. Engineer Approval: J.R. Stroble Date: 6-22-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

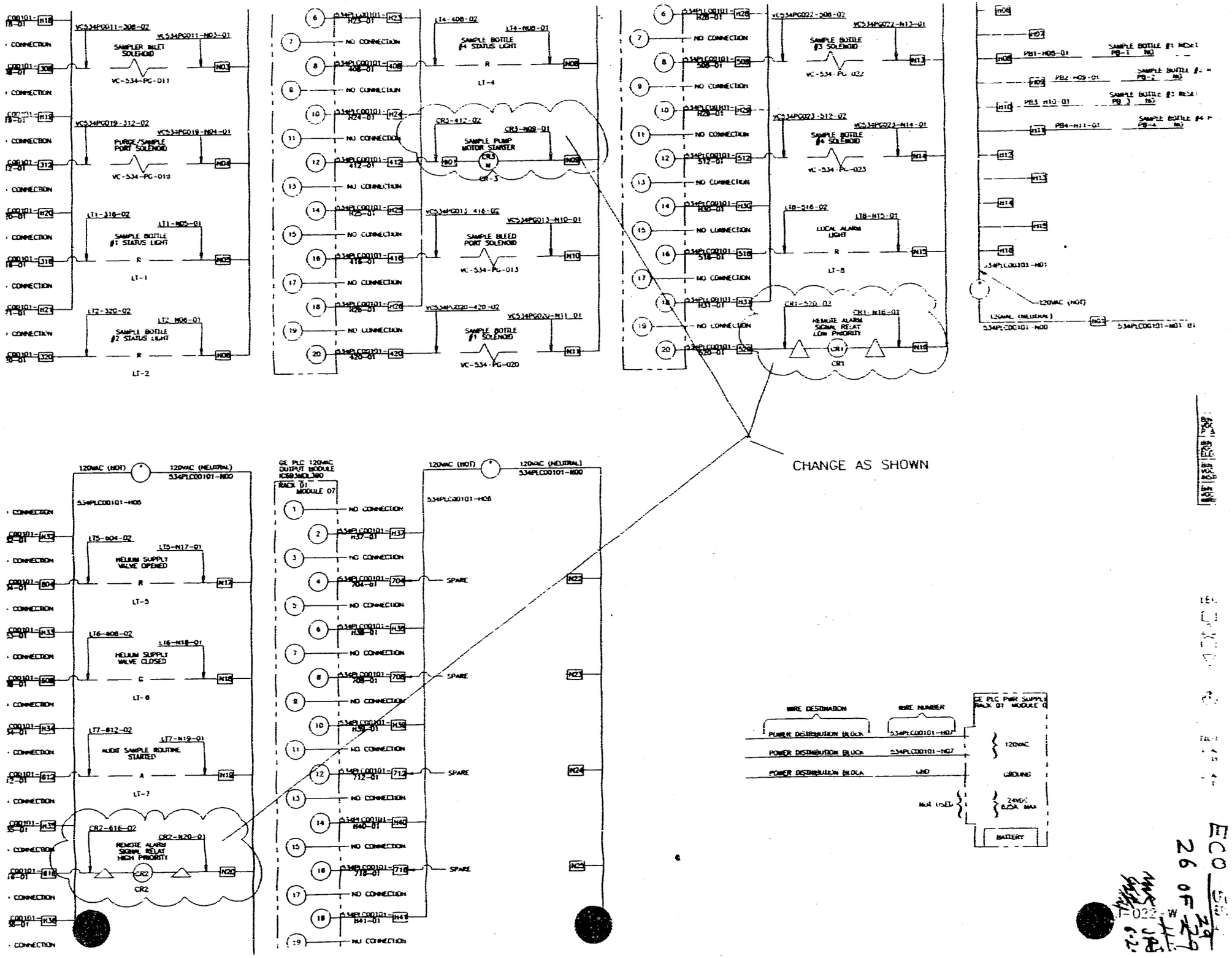
Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

1290:B0006



ECO
26 OF 29
T-022-W

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 105-)-030-W ECO Number: 5565

2. ECO Search List: ____

3. Description of Change:

1. MOVE THE WIRES FROM "M" & "N" TO "P" & "R" ON THE INPUT CONNECTOR.

2. ADD THE DIODE & CAPACITOR CIRCUIT FOR S4.

SEE ATTACHED PAGES

4. Drawing Cog. Engineer Approval: J. R. Stroble Date: 6-22-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: ____ Initials / Date

Drafting Started: ____ Initials / Date

Date Assigned: ____ Initials / Date

Drafting Completed: ____ Initials / Date

Assigned to: ____ (Same as data base entry)

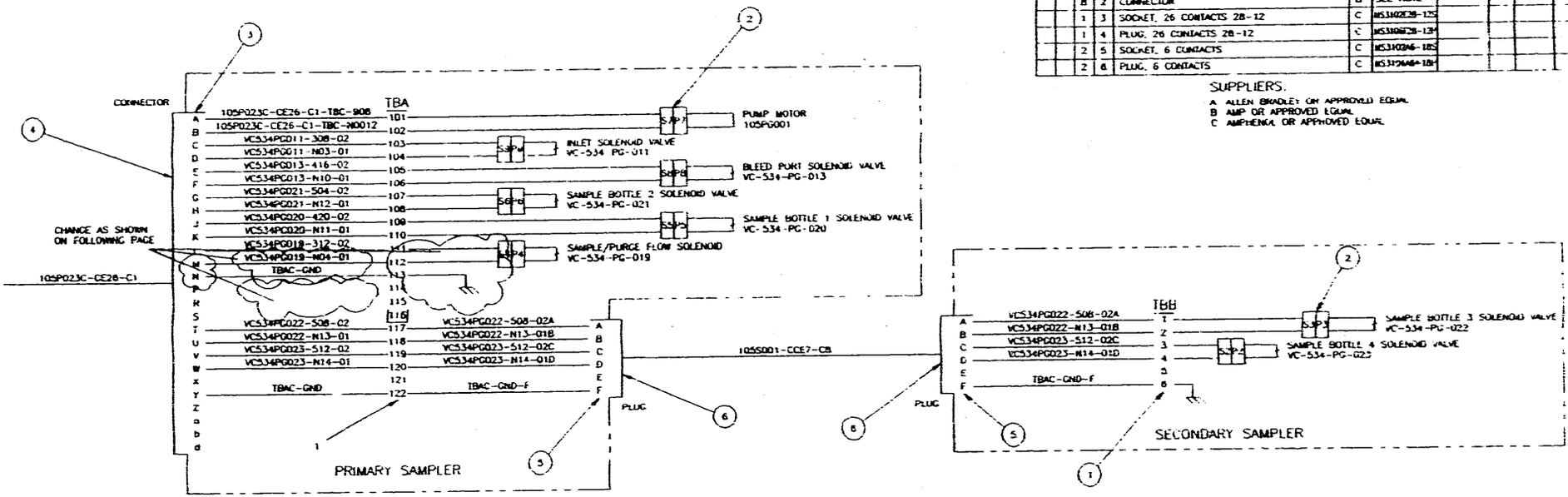
Return to EFR: ____ Initials / Date

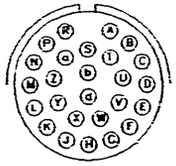
LIST OF MATERIAL

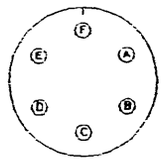
QTY REQ GR3	QTY REQ GR2	QTY REQ GR1	ITEM NO.	ORDERING INFORMATION	USAGE	DRAWING NO OR PART NO	MATERIAL SPECIFICATION MATL	STS	NUMBER	COMP	ELEM
		2	1	BOARD TERMINAL	A	FUSC12					
		8	2	CONNECTOR	B	SEE NOTE 1					
		1	3	SOCKET, 26 CONTACTS 28-12	C	MS3102E28-12S					
		1	4	PLUG, 26 CONTACTS 28-12	C	MS3106E28-12P					
		2	5	SOCKET, 6 CONTACTS	C	MS3102A8-1S					
		2	6	PLUG, 6 CONTACTS	C	MS3106A8-1P					

SUPPLIERS.

A ALLEN BRADLEY OR APPROVED EQUAL
B AMP OR APPROVED EQUAL
C AMPHENOL OR APPROVED EQUAL

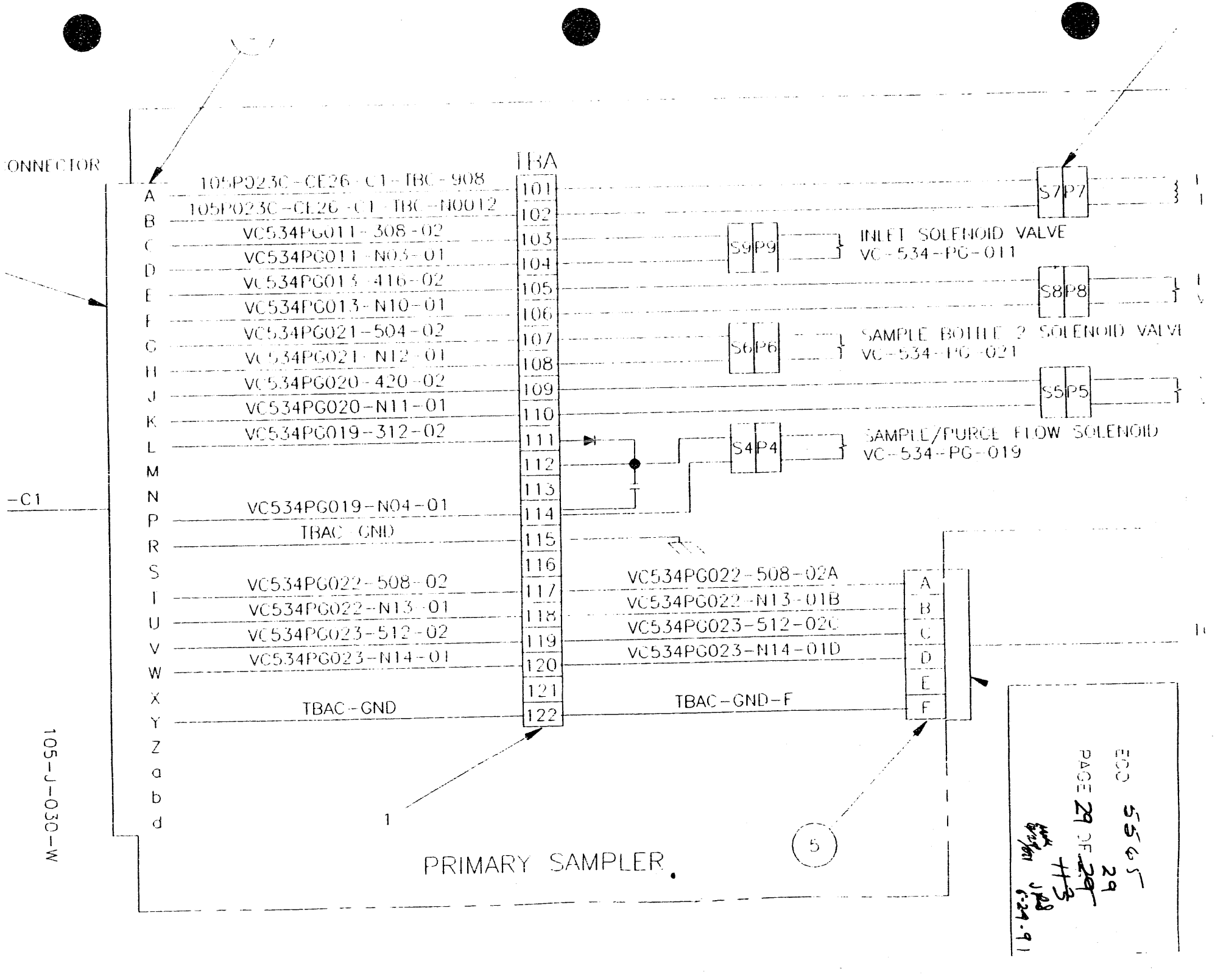






NOTES:
1 770145-1, 77014-1, 770968-1, 770968-1

105-J-030-W


ONNECTOR
TBA
105P023C-CE26-C1-TBC-908
105P023C-CE26-C1-TBC-N0012
VC534PG011-308-02
VC534PG011-N05-01
VC534PG013-416-02
VC534PG013-N10-01
VC534PG021-504-02
VC534PG021-N12-01
VC534PG020-420-02
VC534PG020-N11-01
VC534PG019-312-02
VC534PG019-N04-01
TBAC-GND
VC534PG022-508-02
VC534PG022-N13-01
VC534PG023-512-02
VC534PG023-N14-01
TBAC-GND
S7P7
S9P9
INLET SOLENOID VALVE
VC-534-PG-011
S8P8
S6P6
SAMPLE BOTTLE 2 SOLENOID VALVE
VC-534-PG-021
S5P5
S4P4
SAMPLE/PURGE FLOW SOLENOID
VC-534-PG-019
-C1
VC534PG022-508-02A
VC534PG022-N13-01B
VC534PG023-512-02C
VC534PG023-N14-01D
TBAC-GND-F
105-J-030-W
PRIMARY SAMPLER
ECO 5565
PAGE 29 OF 29
6-24-91

ENGINEERING CHANGE ORDER

USE BLACK INK

1. ECO No.: 5532
SK CC&D Review: RL Initials
Posted

SUPERSEDED
5565

2. Impact Level 1 ☐ 2 ☐ 3 ☒ 4 ☐

3. System: EMOS Equipment No.: VC-534-RV-009 Building: UG

4. Associated Documents:
PWR
ECP
P.O.
Others PWRM41816

5. Document Type: 9C 6/4/91
Drawing ~~52-L-002-W4~~ ☒
Specification 52-L-002-W5 52-L-002-W6 ☐
Vendor Data 52-L-002-W2 52-L-002-W3 ☐
SDD 52-L-001-W ☐
Others 52-L-002-W1

6. Title of Change: VOC 10 MODIFICATIONS

7. Originator: (print)	Ext. No.:	Department:	Date:	8. Cognizant Engineer: (print)
JERRY CAMP	8750	EE	6-7-91	J.R. STROBLE

9. Description of Change:

Yes ☐ No ☒ Component indices change required (if yes, attach sheets)

(1) CHANGE TUBING CONFIGURATION TO PRESSURE RELIEF VALVE ~~534~~ 9C 6/7/91 VC-534-RV-009 AS SHOWN ON ATTACHED SHEETS.

(2) ADD FLAG NOTE AS SHOWN ON ATTACHED SHEETS.
ADD NOTE TO SHEET 1 (52-L-002-W1). DRAFTING TO ~~PER~~ DETERMINE NOTE NO. 9C 6/3/91
△: ~~AD~~ ALL TUBING FROM THE MAIN CARBON BED OUTLET TO THE SAMPLER INLET IS WRAPPED WITH HEAT TAPE. (3.25 WATTS PER SQUARE INCH)

☒ 9a Drawing Change Sheet attached
☐ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

10. Yes ☒ No ☒ ~~JRS-13-91~~ MODIFICATION IN PROGRESS
☐ Modification complete: J.R. Stroble (Signature) 6-24-91 (Date)
ECO will be incorporated after M.I.P. signed complete

☒ Change drawing per as-built markup dated: NEW ECO
☐ Change drawing per ECO-provided data
☐ Temporary modification

11. Design Verification Requirements: (per WP 09-018) EDT No.:
1. Requirements satisfied by review/approval of design document
2. Independent review
3. Alternate calculations
4. Development testing
5. Design review
6. Other:

12. Addendum Sheet added: (Signature) / (Date)

ENGINEERING CHANGE ORDER
ADDENDUM SHEET

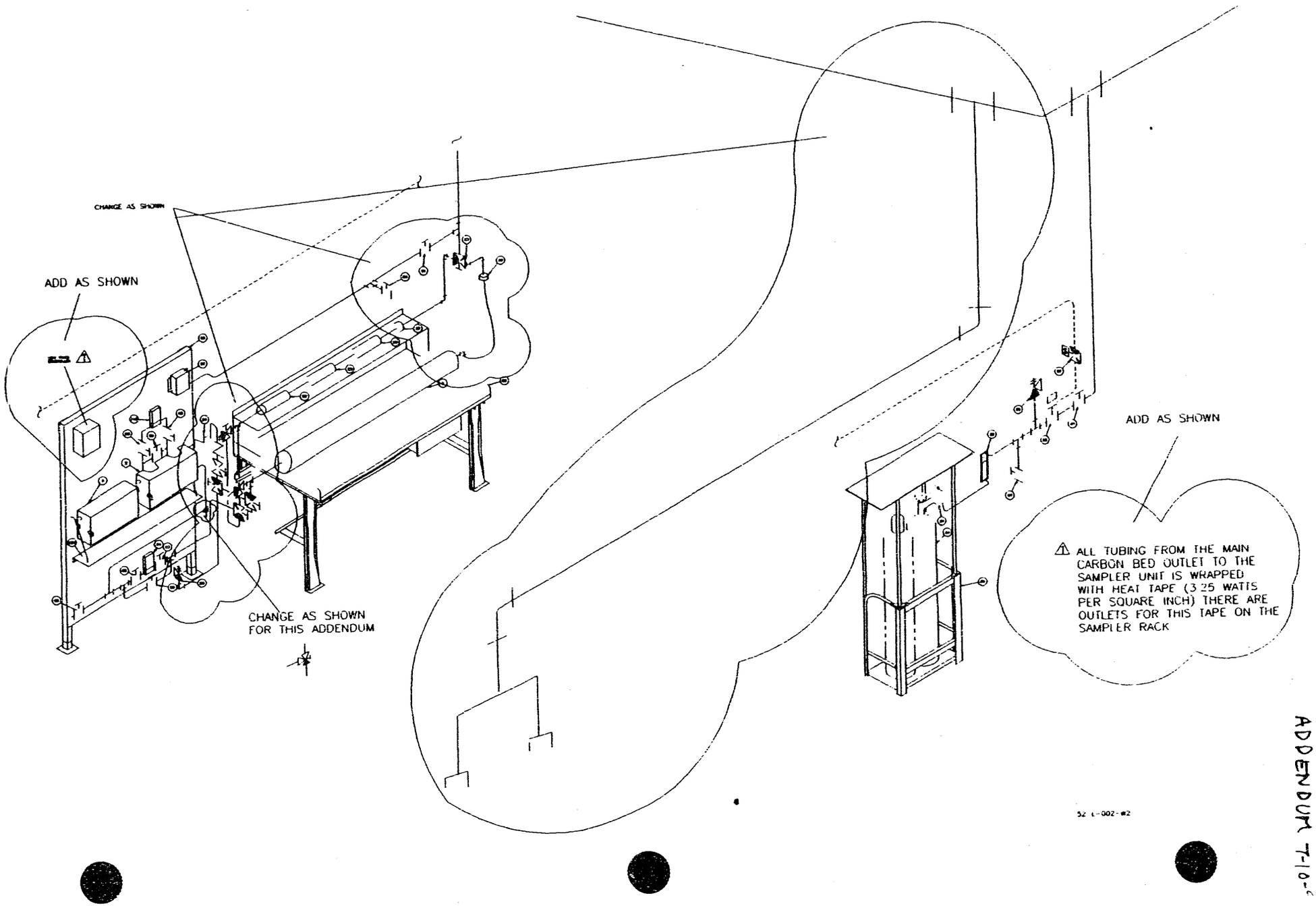
1. Addendum Sheet to ECO Number: 5565   Drawing Number: 52-L-002-W2

2. Description of change:

REPLACE PAGE 8 OF THE ECO WITH THE ONE ATTACHED. A 3-WAY VALVE WAS LEFT OFF OF THIS PAGE BY MISTAKE. ITS SHOWN ON PAGE 5 OF THE ECO IN P+ID DRAWING 52-L-001-W. THE VALVE IS 534-TW-010.

3. Approvals

	Signature	Date
Cognizant Engineer:	J. R. Strobble Ory Meredith	7-10-91
CC&D Mgr. /Desig. Rep.:	B. Alle	7/10/91
Other Approval:	S. Krause	7/10/91
Other Approval::		



ECO 5565
ADDENDUM 7-10-

ENGINEERING CHANGE ORDER
ADDENDUM SHEET

1. Addendum Sheet to ECO Number: 5565 Drawing Number: 52-L-002-W 3

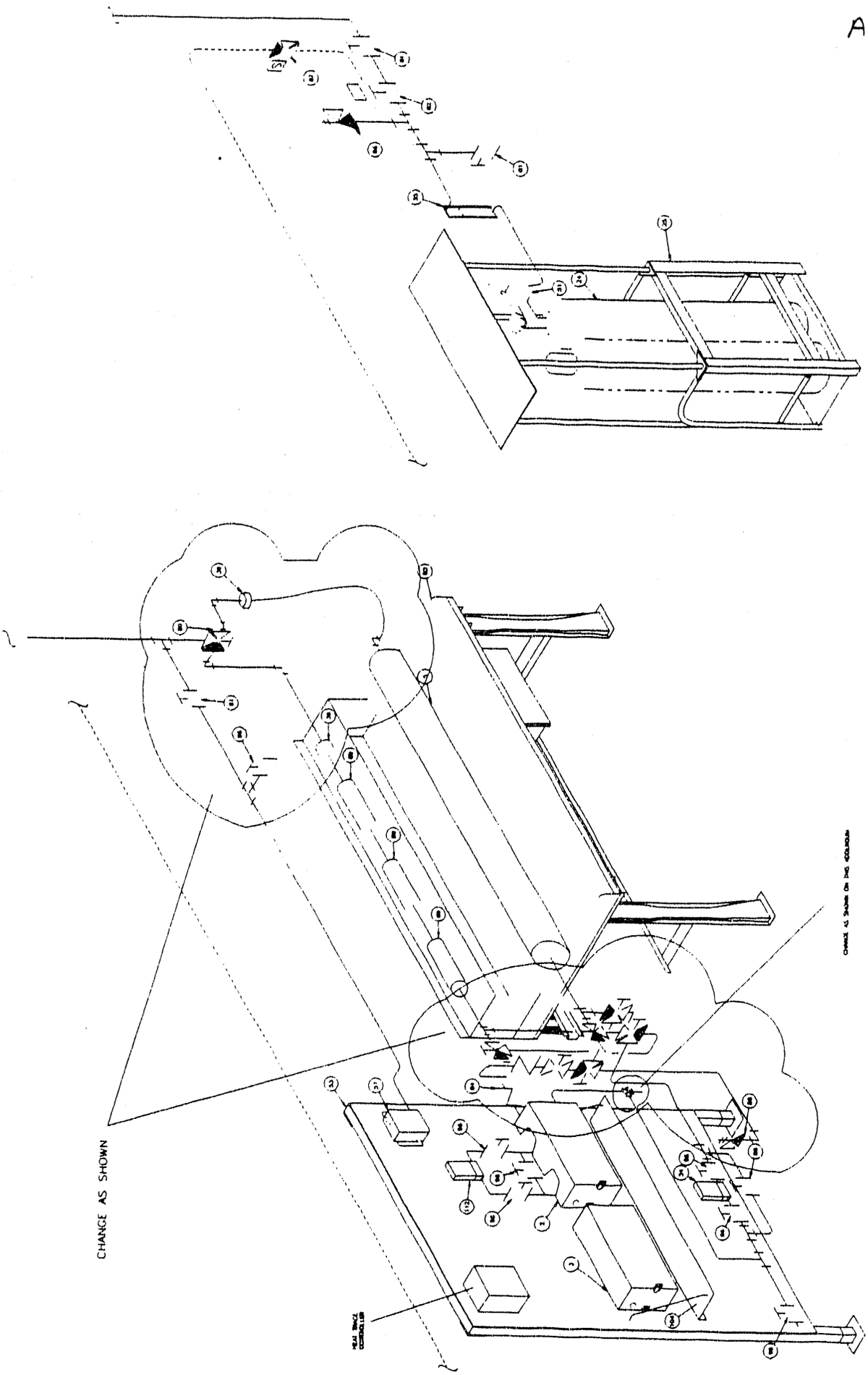
2. Description of change:

REPLACE PAGE 10 OF THE ECO WITH THE ONE ATTACHED. A 3-WAY VALVE WAS LEFT OFF OF THIS PAGE BY MISTAKE. ITS SHOWN ON PAGE 5 OF THE ECO IN P&ID DRAWING 52-L-001-W. THE VALVE IS 534-TW-010.

3. Approvals

Cognizant Engineer:	J.R. Stubb for Steve Hendricks Signature	7-10-91 Date
CC&D Mgr. /Desig. Rep.:	B. Allen Signature	7/10/91 Date
Other Approval:	Signature	Date
Other Approval::	Signature	Date

ECO 5565
ADDENDUM
7-10-91



52-L-002-W3

ENGINEERING CHANGE ORDER
ADDENDUM SHEET

1. Addendum Sheet to ECO Number: 5565 Drawing Number: 52-L-001-W

2. Description of change: SEE ATTACHED PAGES

1. DELETE THE "A" NOTE MARKER. THE NOTE HAS BEEN DELETED, BUT THE MARKER STILL APPEARS ON THE DRAWING.

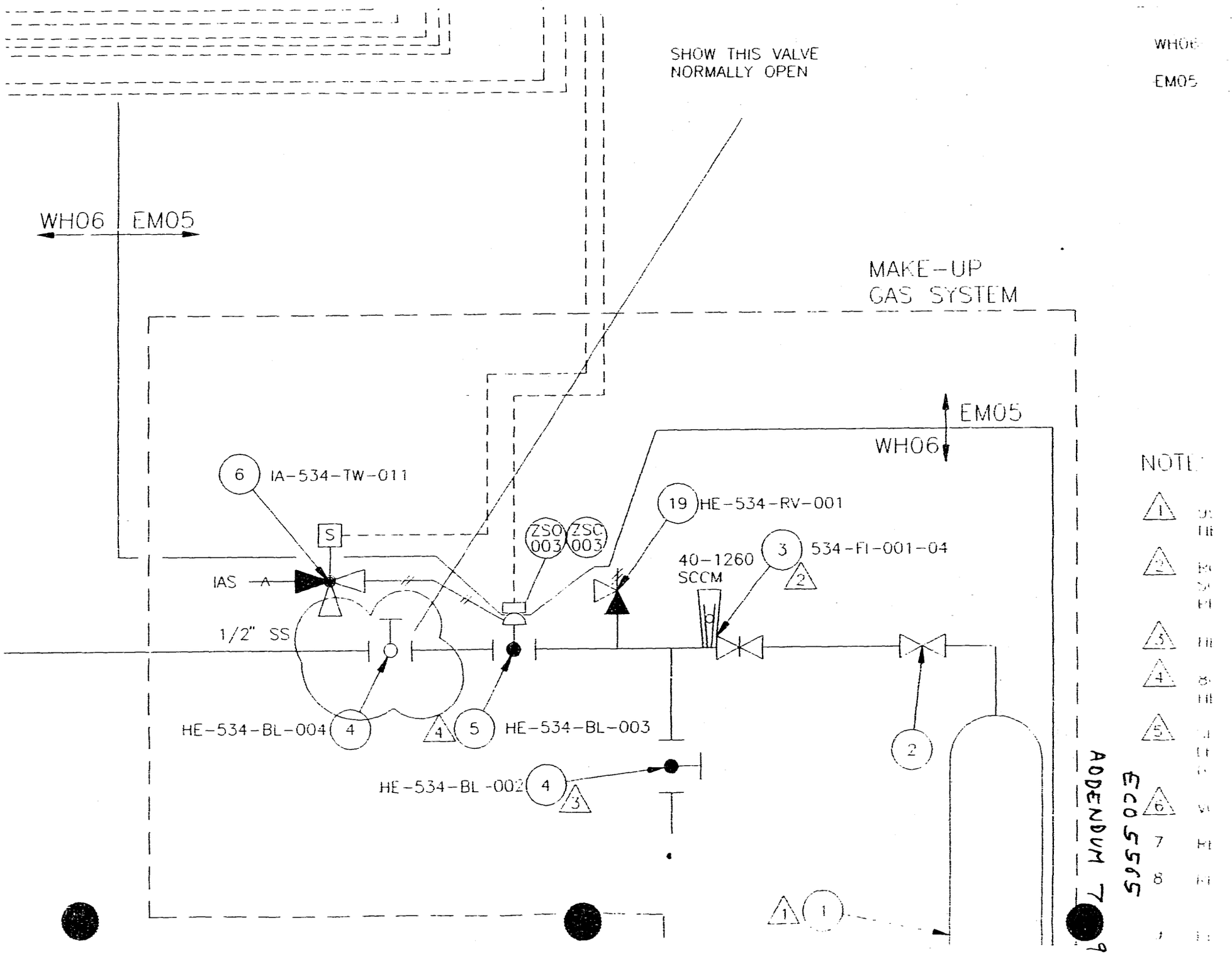
2. ADD A BOUNDARY BETWEEN THE WH0.6 MANIFOLD AND SANDIA NATIONAL LAB'S OXYGEN GETTERING SYSTEM.

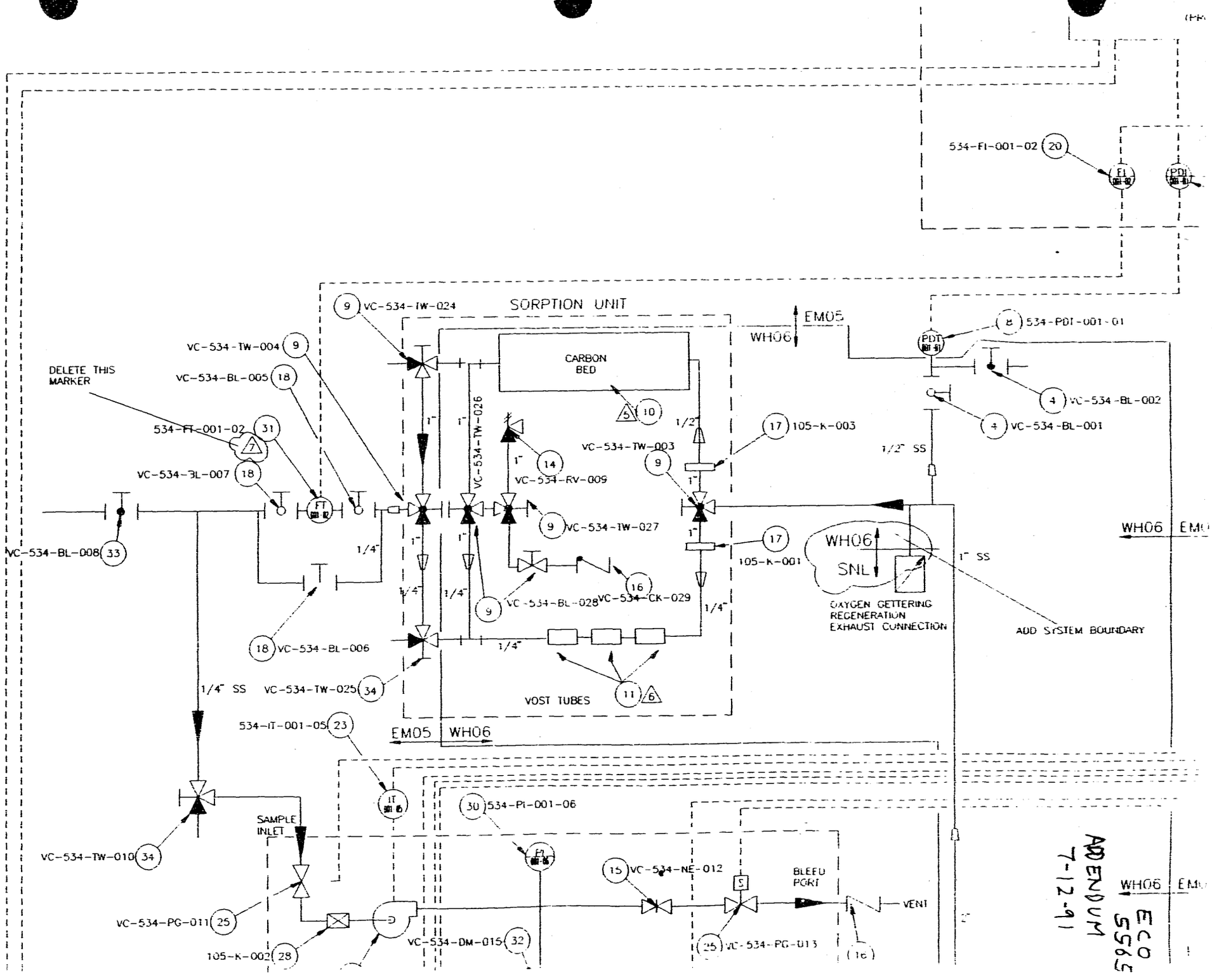
3. VALVE HE-534-BL-004 SHOULD BE SHOWN AS NORMALLY OPEN.

3. Approvals

Cognizant Engineer:	Signature	7/12/91 Date
CC&D Mgr. /Desig. Rep.:	B. Allen Signature	7/12/91 Date
Other Approval:	Signature	Date
Other Approval::	Signature	Date

1290:B0009


SHOW THIS VALVE
NORMALLY OPEN
WH06
EM05
WH06 EM05
MAKE-UP
GAS SYSTEM
EM05
WH06
6 IA-534-TW-011
S
IAS A
1/2" SS
ZSO 003
ZSC 003
19 HE-534-RV-001
40-1260
SCCM
3 534-FI-001-04
2
HE-534-BL-004 4
4
5 HE-534-BL-003
HE-534-BL-002 4
3
2
1 1
NOTE
1
2
3
4
5
6
7
8
ADDENDUM 7
ECO 5565



ECO 5565
ADDENDUM
7-12-91

9-12-91

ENGINEERING CHANGE ORDER
ADDENDUM SHEET

1. Addendum Sheet to ECO Number: 5565 Drawing Number: 52-L-002-W1

2. Description of change:

CHANGE THE DESCRIPTION AND PART NO. FOR ITEM 70 FROM "UNION, ELBOW 1/2" SS-810-9" TO "UNION, TEE 1/2" SS-810-3." THE ITEM 70 IS SHOWN ON 52-L-002-W4 & IS CORRECT, BUT THE DESCRIPTION AND PART NO. ARE INCORRECT ON THIS DRAWING. 9-11-91

3. Approvals

Cognizant Engineer:	Jon Mendiratta / J.R. Stubble (Signature)	9-12-91 / 9-11-91 (Date)
CC&D Mgr. /Desig. Rep.:	B. Allen (Signature)	9/12/91 (Date)
Other Approval:	S. Spencer (Signature)	9-12-91 (Date)
Other Approval::	(Signature)	(Date)

1290:B0009

ECC [illegible]
PAGE 2 OF 2
ADDENDUM 9-12-9.

52-L-002-W1

6 5

LIST OF MATERIAL

QTY REQ GR3	QTY REQ GR2	QTY REQ GR1	ITEM NO.	ORDERING INFORMATION	NOTE	DRAWING NO. OR PART NO.	MATERIAL SPECIFICATION MATL	STD	NUMBER	COMP	FORM
		AR	56	STRAP, VELCRO BACK-TO-BACK 2" WIDE	L	3955T16					
		1	57	TRANSDUCER, PRESSURE DIFFERENRIAL 100mm HG		52-L-001-H08					
		AR	58	TUBE ADAPTER, MALE 1/4" X 3/8"	K	SS-4-TA-1-6	SST		316		
		AR	59	TUBING, 1/4" X 0.049" WALL	L	8955K11	SOFT COPPER				
		AR	60	TUBING, 1/4" X 0.028" WALL			SST	ASTM	A269		
		AR	61	TUBING, 1/2" X 0.049" WALL			SST	ASTM	A269		
		AR	62	TUBING, 1" X 0.083" WALL			SST	ASTM	A269		
		AR	63	TUBING, 2" X 0.188" WALL			SST	ASTM	A269		
		AR	64	UNION, 1/4"	C	SS-400-6	SST		316		
		AR	65	UNION, 1/2"	C	SS-810-6	SST		316		
		AR	66	UNION, 1"	C	SS-1610-6	SST		316		
		AR	67	UNION, 2"	D	SS-3200-6	SST		316		
		1	68	UNION, ULTRA-TORR 1/2" X 1/2"	J	SS-8-UT-6-810	SST		316		
		AR	[illegible]	[illegible]	C	SS-400-9	SST		316		
		AR	70	UNION, ELBOW 1/2"	C	SS-810-9	SST		316		
		AR	[illegible]	[illegible]	C	[illegible]	SST		316		
		AR	72	UNION, ELBOW 2"	D	SS-3200-9	SST		316		
		AR	73	UNION, REDUCING 1/2" X 1/4"	C	SS-810-6-4	SST		316		
		AR	74	UNION, REDUCING 1" X 1/2"	C	SS-1610-6-8	SST		316		
		AR	75	UNION, REDUCING 2" X 1"		SS-1610-R-32	SST		316		
		AR	76	UNION, TEE 1/4"	C	SS-400-3	SST		316		
		AR	77	UNION, TEE 1/2"	C	SS-810-9	SST		316		
		AR	78	UNION, TEE 1"	C	SS-1610-3	SST		316		
		AR	79	UNION, TEE 2"	D	SS-3200-3	SST		316		
		4	80	VALVE, BALL 3-WAY MANUALLY OPERATED 1"		52-L-001-H09					
		3	81	VALVE, BALL 2-WAY MANUALLY OPERATED 1/2"		52-L-001-H04					
		1	82	VALVE, BALL 2-WAY AIR-OPERATED 1/2" NC		52-L-001-H05					
			83								
		1	84	VALVE, CHECK IN-LINE 1/4"		52-L-001-H16					
			85								
		1	86	VALVE, RELIEF IN-LINE, 0.8 PSIG 1/4"		52-L-001-H19					
		3	87	VALVE, SOLENOID 3-WAY NC 1/4"		52-L-001-H06					
		1	88	VENT, EMERGENCY RELIEF, WEIGHT LOADED 0.8 PSIG, 2"		52-L-001-H14					
		3	89	VOST TUBE		52-L-001-H11					
		1	90	WORK STATION, W/DRAWER AND INSTRUMENT SHELF	L	SB-3872					
		AR	91	QUICK-CONNECT, STEM 1/4"	F	SS-QT2-D-400					
			92								
		AR	93	UNION CROSS 1/2"	C	SS-810-4	SST		316		
		AR	94	HOSE, FLEXIBLE TUBING 1/4" OD 36" L	M	321-8-X-36B2	SST		316		
		AR	95	CONNECTOR, PORT 1/4"	C	SS-401-PC	SST		316		
		4	96	VALVE, BALL 2-WAY MANUALLY OPERATED 1/4"	N	SS-62TS4					
		AR	97	PLUG [illegible]"	C	SS-400-P	SST		316		
		AR	98	UNION CROSS 1/4"	C	SS-400-4	SST		316		

CHANGE TO
UNION, TEE 1/2"
SS-810-3

ENGINEERING CHANGE ORDER

USE BLACK INK

1. **ECO No.:** 5625
   CC&D Review: SA. Initials
   Posted

2. **Impact Level** 1 ☐ 2 ☐ 3 ☒ 4 ☐

3. **System:** EMOS Equipment No.: VC-534-TW-024 Building: UG

4. **Associated Documents:**
   PWR 12072
   ECP
   P.O.
   Others

5. **Document Type:**
   Drawing S2-L-002-W1 ☒
   Specification ☐
   Vendor Data ☐
   SDD ☐
   Others

6. **Title of Change:** ADDITION OF TUBING DWNSTRM OF CARBON BED

7. Originator: (print)	Ext. No.:	Department:	Date:	8. Cognizant Engineer: (print)
TERRY CAMP	6756	EE	7-18-91	J.R. STROBLE

9. **Description of Change:**

Yes ☐ No ☒ Component indices change required (if yes, attach sheets)

(S2-L-002-W5)
(A) ADDITION OF FLEXIBLE STEEL TUBING DOWNSTREAM OF CARBON BED.

(S2-L-002-W1)
(B) ADDITION OF FLEXIBLE STEEL TUBING TO BILL OF MATL.

☒ 9a Drawing Change Sheet attached
☐ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

10. Yes ☒ No ☐ **MODIFICATION IN PROGRESS**
☒ Modification complete: J.R. Stroble (Signature) / 8-1-91 (Date)
ECO will be incorporated after M.I.P. signed complete

☐ Change drawing per as-built markup dated:
☒ Change drawing per ECO-provided data
☐ Temporary modification

11. **Design Verification Requirements: (per WP 09-018)** EDT No.:

JD 1. Requirements satisfied by review/approval of design document
2. Independent review
3. Alternate calculations
4. Development testing
5. Design review
6. Other:

12. **Addendum Sheet added:** Signature / Date

1190B:0005

13. Justification

THIS CHANGE IS REQUIRED TO ALLOW OPERATIONS EASIER REPLACEMENT OF THE CARBON BED.

14. Administrative Tracking

7/22/91

YES	N/A		YES	N/A	
☐	☒	1. FSAR	☒	☒	6. ~~Startup~~/Acceptance Test
☐	☒	2. Calibration Procedures	☐	☒	7. Test Requirement & Spec.
☐	☒	3. Maintenance Procedures	☐	☐	8. _____
☐	☒	4. Computer Software	☐	☐	9. _____
☐	☒	5. Operations Procedures	☐	☐	10. _____

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

A	Cog. Engineer	J.R. Stubble 7-19-91
A	Cog. Eng. Mgr	Jaymes Harris 7/19/91
R	Startup	Michael R. [illegible] 7/19/91
R	QA	[illegible] 7/22/91
☐	DOE	
☐	Safety	
☐	Dept. Manager	
☐	Operations	
☐	Security	
☐	SNL	
A	RWHE WH06 COG.	[illegible] 7/19/91
A	RWHE CogEng Mgr	J. Patterson 7/19/91
☐		

Gen Member

16. Distribute as Marked

☐	Maintenance (MANDATORY) _____
☐	Ops. Support (MANDATORY) _____
☐	Startup _____
☐	Facility Operations _____
☐	U/G Operations _____
☐	Orig./Design Engr. _____
☐	Cog. Engineer _____
☒	Others JERRY CAMP
☐	_____
☐	_____
☐	_____
☐	_____
☐	_____

ENGINEERING CHANGE ORDER

DOE ORDER 6430.1A DESIGN CRITERIA

CHECKLIST

1. ECO # 5625
2. DATE 7-18-97

The design requirements in DOE Order 6430.1A checked below have been applied to this Design.

3. DIVISION	SUBDIVISION
☐ 1 General Requirements	☐ 0101 ☐ 0106 ☐ 0109 ☐ 0110 ☐ 0111 ☐ 0140 ☐ 0150 ☐ 0170
☒ 2 Site and Civil Engineering	☐ 0200 ☐ 0201 ☐ 0202 ☐ 0203 ☐ 0205 ☐ 0210 ☐ 0214 ☐ 0215 ☐ 0220 ☐ 0235 ☐ 0245 ☐ 0250 ☐ 0256 ☐ 0260 ☐ 0262 ☐ 0265 ☐ 0267 ☐ 0270 ☐ 0273 ☐ 0275 ☐ 0276 ☐ 0278 ☐ 0279 ☐ 0280 ☐ 0281 ☒ 0283 ☐ 0285 ☐ 0290 ☐ 0291
☐ 3. Concrete	☐ 0300 ☐ 0301 ☐ 0310 ☐ 0320 ☐ 0330 ☐ 0340 ☐ 0350 ☐ 0370 ☐ 0380
☐ 4 Masonry	☐ 0400 ☐ 0401 ☐ 0410 ☐ 0420 ☐ 0455
☒ 5 Metals	☐ 0500 ☐ 0512 ☐ 0514 ☐ 0521 ☐ 0531 ☒ 0532
☐ 6 Wood and Plastics	☐ 0600 ☐ 0610 ☐ 0650
☒ 7 Thermal and Moisture Protection	☐ 0710 ☐ 0711 ☐ 0714 ☐ 0715 ☐ 0719 ☐ 0720 ☒ 0721 ☐ 0722 ☐ 0724 ☐ 0727 ☐ 0730 ☐ 0750 ☐ 0751 ☐ 0753 ☐ 0760 ☐ 0790
☒ 8 Doors and Windows	☐ 0800 ☒ 0810 ☐ 0820 ☐ 0830 ☐ 0833 ☐ 0836 ☐ 0839 ☐ 0850 ☐ 0860 ☐ 0870 ☐ 0880
☐ 9 Finishes	☐ 0900 ☐ 0910 ☐ 0920 ☐ 0925 ☐ 0930 ☐ 0950 ☐ 0965 ☐ 0968 ☐ 0970 ☐ 0980 ☐ 0990 ☐ 0995
☐ 10 Specialties	☐ 1015 ☐ 1020 ☐ 1024 ☐ 1027 ☐ 1030 ☐ 1040 ☐ 1050 ☐ 1052 ☐ 1053 ☐ 1055 ☐ 1060 ☐ 1065 ☐ 1070 ☐ 1075 ☐ 1080
☐ 11 Equipment	☐ 1100 ☐ 1161
☐ 12 Furnishings	☐ 1201 ☐ 1230 ☐ 1250 ☐ 1260 ☐ 1270
☐ 13 Special Facilities	☐ 1300 ☐ 1304 ☐ 1306 ☐ 1308 ☐ 1307 ☐ 1318 ☐ 1319 ☐ 1320 ☐ 1321 ☐ 1322 ☐ 1323 ☐ 1324 ☐ 1325 ☐ 1326 ☐ 1328
☐ 14 Conveying Systems	☐ 1401 ☐ 1420 ☐ 1440 ☐ 1460
☐ 15 Mechanical	☐ 1525 ☐ 1530 ☐ 1540 ☐ 1550 ☐ 1555 ☐ 1565 ☐ 1574 ☐ 1589 ☐ 1595
☒ 15 Electrical	☐ 1600 ☒ 1605 ☐ 1620 ☐ 1630 ☐ 1639 ☐ 1640 ☐ 1650 ☐ 1655 ☐ 1660 ☐ 1670 ☐ 1671 ☐ 1685 ☐ 1694
4. ☐ NOT APPLICABLE	No portion of DOE Order 6430.1A is applicable to this Design.
5. ☐ AS-BUILT	ECO is for as-built field verified changes only.

NOTE: A check placed in the Division column signifies that the entire Division shall be applicable to the Design, unless modified by checks indicated for specific Subdivisions.

7/19/97

COMMENTS: _____

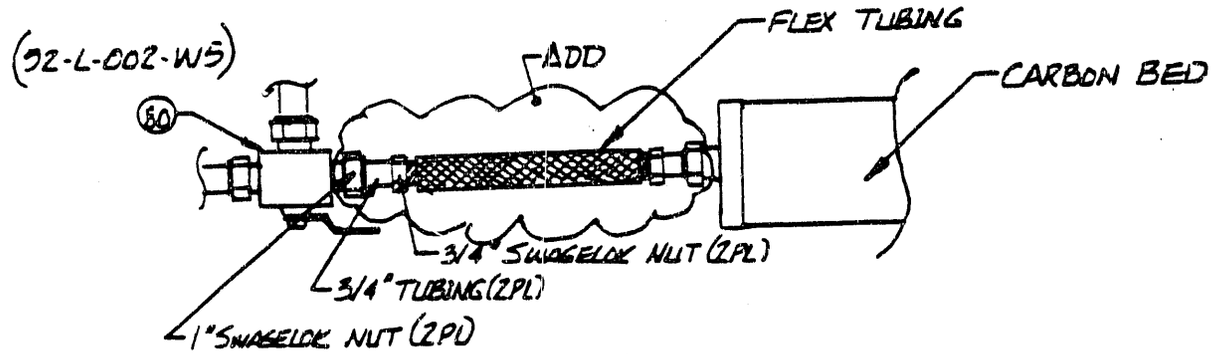
9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-WS ECO Number: 5625

2. ECO Search List: _____ _____ _____ _____

3. Description of Change:

WITH ECO 5565 SH 13 OF 29 ADD FLEXIBLE STAINLESS STEEL TUBING (SWAGELOK P.N. SS-12H0-G-S12) AND (2) 3/4"X 1" CONNECTIONS AT EACH END. ADD AS SHOWN BELOW.



4. Drawing Cog. Engineer Approval: [signature] Date: 7/22/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

1290:B0006

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-W1 ECO Number: 5625

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

ADD FLEXIBLE STAINLESS STEEL TUBING, SWAGELOK P.N. SS-12HO-6-S12 TO BILL OF MATL.

4. Drawing Cog. Engineer Approval: [signature] Date: 7/22/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

1290:B0006

ENGINEERING CHANGE ORDER

USE BLACK INK

1. **ECO No.:** 567
   CC&D Review: RJ

Initials

Posted

2. **Impact Level** 1 ☐ 2 ☐ 3 ☒ 4 ☐

3. **System:** GC00 Equipment No.: N/A Building: N/A

4. Associated Documents:
   - PWR _____
   - ECP _____
   - P.O. _____
   - Others _____

5. **Document Type:**
   - Drawing ☒
   - Specification ☐
   - Vendor Data ☐
   - SDD ☐
   - Others _____

6. **Title of Change:** CONSOLIDATION OF SITE DRAWINGS

7. Originator: (print)	Ext. No.:	Department:	Date:	8. Cognizant Engineer: (print)
RICK MAYNARD	8905	CC&D	7/26/91	JOHN KOWALSKI

9. **Description of Change:**

GENERATE NEW DRAWINGS:

Component indices change required (if yes, attach sheets): Yes ☐ No ☒

24-C-020-W	WIPP SITE AND VICINITY
24-C-022-W	WIPP SITE PLAN
24-C-024-W	WIPP SITE FENCE PLAN AND DETAILS
24-C-026-W	WIPP SITE UTILITIES
24-C-028-W	WIPP SITE FINISH GRADING AND PAVING

☒ 9a Drawing Change Sheet attached
☐ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

10. Yes ☐ No ☒ **MODIFICATION IN PROGRESS**
    Modification complete: _____ (Signature) _____ (Date)
    ECO will be incorporated after M.I.P. signed complete
    ☐ Change drawing per as-built markup dated: _____
    ☐ Change drawing per ECO-provided data
    ☐ Temporary modification

11. **Design Verification Requirements: (per WP 09-018)** EDT No.: _____

JWP	1. Requirements satisfied by review/approval of design document
	2. Independent review
	3. Alternate calculations
	4. Development testing
	5. Design review
	6. Other: _____

12. **Addendum Sheet added:** _____ (Signature) _____ (Date)

13. Justification

CONSOLIDATION OF EXISTING SITE-RELATED DRAWINGS INTO A MINIMUM QUANTITY OF WORKING DRAWINGS WILL FACILITATE IMPROVED PROFICIENCY IN FUTURE UPDATES.

14. Administrative Tracking

YES	N/A		YES	N/A	
☐	☒	1. FSAR	☐	☒	6. Startup/Acceptance Test
☐	☒	2. Calibration Procedures	☐	☒	7. Test Requirement & Spec.
☐	☒	3. Maintenance Procedures	☐	☒	8. _____
☐	☒	4. Computer Software	☐	☒	9. _____
☐	☒	5. Operations Procedures	☐	☒	10. _____

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

A	Cog. Engineer	7/29/91
A	Cog. Eng. Mgr.	7/29/91
R	Startup	
R	QA	
☐	DOE	
☐	Safety	
☐	Dept. Manager	
☐	Operations	
☐	Security	
☐	SNL	
☐		
☐		
☐		

16. Distribute as Marked

☒	Maintenance (MANDATORY)
☐	Ops. Support (MANDATORY)
☐	Startup
☐	Facility Operations
☐	U/G Operations
☐	Orig./Design Engr.
☐	Cog. Engineer
☐	Others
☐	
☐	
☐	
☐	
☐	

1. ECO # 5674
2. DATE _____

ENGINEERING CHANGE ORDER

DOE ORDER 6430.1A DESIGN CRITERIA

CHECKLIST

The design requirements in DOE Order 6430.1A checked below have been applied to this Design.

3. DIVISION	SUBDIVISION
☐ 1 General Requirements	☐ 0101 ☐ 0106 ☐ 0109 ☐ 0110 ☐ 0111 ☐ 0140 ☐ 0150 ☐ 0170
☐ 2 Site and Civil Engineering	☐ 0200 ☐ 0201 ☐ 0202 ☐ 0203 ☐ 0205 ☐ 0210 ☐ 0214 ☐ 0215 ☐ 0220 ☐ 0245 ☐ 0250 ☐ 0256 ☐ 0260 ☐ 0262 ☐ 0265 ☐ 0267 ☐ 0270 ☐ 0273 ☐ 0276 ☐ 0278 ☐ 0279 ☐ 0280 ☐ 0281 ☐ 0283 ☐ 0285 ☐ 0290 ☐ 0291
☐ 3 Concrete	☐ 0300 ☐ 0301 ☐ 0310 ☐ 0320 ☐ 0330 ☐ 0340 ☐ 0350 ☐ 0370 ☐ 0380
☐ 4 Masonry	☐ 0400 ☐ 0401 ☐ 0410 ☐ 0420 ☐ 0455
☐ 5 Metals	☐ 0500 ☐ 0512 ☐ 0514 ☐ 0521 ☐ 0531 ☐ 0532
☐ 6 Wood and Plastics	☐ 0600 ☐ 0610 ☐ 0650
☐ 7 Thermal and Moisture Protection	☐ 0710 ☐ 0711 ☐ 0714 ☐ 0715 ☐ 0719 ☐ 0720 ☐ 0721 ☐ 0722 ☐ 0724 ☐ 0730 ☐ 0750 ☐ 0751 ☐ 0753 ☐ 0760 ☐ 0790
☐ 8 Doors and Windows	☐ 0800 ☐ 0810 ☐ 0820 ☐ 0830 ☐ 0833 ☐ 0836 ☐ 0839 ☐ 0850 ☐ 0860 ☐ 0880
☐ 9 Finishes	☐ 0900 ☐ 0910 ☐ 0920 ☐ 0925 ☐ 0930 ☐ 0950 ☐ 0965 ☐ 0968 ☐ 0970 ☐ 0990 ☐ 0995
☐ 10 Specialties	☐ 1015 ☐ 1020 ☐ 1024 ☐ 1027 ☐ 1030 ☐ 1040 ☐ 1050 ☐ 1052 ☐ 1053 ☐ 1060 ☐ 1065 ☐ 1070 ☐ 1075 ☐ 1080
☐ 11 Equipment	☐ 1100 ☐ 1161
☐ 12 Furnishings	☐ 1201 ☐ 1230 ☐ 1250 ☐ 1260 ☐ 1270
☐ 13 Special Facilities	☐ 1300 ☐ 1304 ☐ 1305 ☐ 1306 ☐ 1307 ☐ 1318 ☐ 1319 ☐ 1320 ☐ 1321 ☐ 1323 ☐ 1324 ☐ 1325 ☐ 1326 ☐ 1328
☐ 14 Conveying Systems	☐ 1401 ☐ 1420 ☐ 1440 ☐ 1460
☐ 15 Mechanical	☐ 1525 ☐ 1530 ☐ 1540 ☐ 1550 ☐ 1555 ☐ 1565 ☐ 1574 ☐ 1589 ☐ 1595
☐ 16 Electrical	☐ 1600 ☐ 1605 ☐ 1620 ☐ 1630 ☐ 1639 ☐ 1640 ☐ 1650 ☐ 1655 ☐ 1660 ☐ 1671 ☐ 1685 ☐ 1694
4. ☒ NOT APPLICABLE	No portion of DOE Order 6430.1A is applicable to this Design.
5. ☐ AS-BUILT	ECO is for as-built field verified changes only.

NOTE: A check placed in the Division column signifies that the entire Division shall be applicable to the Design, unless modified by checks indicated for specific Subdivisions.

COMMENTS: _____

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 24-C-020-W ECO Number: 5674

2. ECO Search List: _____ _____ _____ _____

3. Description of Change:

NEW DRAWING, "WIPP SITE AND VICINITY," INCORPORATING APPROXIMATELY 500 SQ. MILES OF AREA BORDERING THE WIPP SITE; INCLUDING TOPOGRAPHIC INFORMATION, COUNTY AND STATE ROADS, ACCESS ROADS, AND SECTION MARKERS.

SHEET 2 IS TO INCORPORATE AN ENLARGED DETAIL OF THE D.O.E. EXCLUSIVE USE AREA FROM INFORMATION ON SHEET 1.

UPON APPROVAL OF 24-C-020-W, SUPERCEDE DRAWINGS:

24-C-041-022
24-C-041-34C

4. Drawing Cog. Engineer Approval: J. Kowalik Date: 7/29/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 24-C-022-W ECO Number: 5674

2. ECO Search List: _____ _____ _____ _____

3. Description of Change:

NEW DRAWING INCORPORATING DRAWINGS 24-C-009-W, 24-C-140-022, AND ANY AVAILABLE AS-BUILT INFORMATION.

UPON APPROVAL OF 24-C-022-W, SUPERCEDE DRAWINGS:

24-C-009-W
24-C-001-022
24-C-001-34C
24-C-140-022

4. Drawing Cog. Engineer Approval: J. Howell Date: 7/29/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date
Drafting Started: _____ Initials / Date
Date Assigned: _____ Initials / Date
Drafting Completed: _____ Initials / Date
Assigned to: _____ (Same as data base entry)
Return to EFR: _____ Initials / Date

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 24-C-024-W ECO Number: 567L

2. ECO Search List: _____ _____ _____ _____

3. Description of Change:

NEW DRAWING INCORPORATING DRAWING 24-C-147-022 AND ANY AVAILABLE AS-BUILT INFORMATION. SUBSEQUENT SHEETS WILL BE ADDED AS REQUIRED TO INCORPORATE ADDITIONAL FENCING PLANS AND DETAILS.

UPON APPROVAL OF 24-C-024-W, SUPERCEDE DRAWINGS:

24-C-147-022
24-C-102-34C
24-C-102-022
24-C-102-1FC-5
24-C-102-005
24-C-102-05A
24-C-102-009
23-C-177-005
24-C-107-009

4. Drawing Cog. Engineer Approval: J. Kwalz Date: 7/29/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date
Drafting Started: _____ Initials / Date
Date Assigned: _____ Initials / Date
Drafting Completed: _____ Initials / Date
Assigned to: _____ (Same as data base entry)
Return to EFR: _____ Initials / Date

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 24-C-026-W ECO Number: 5674

2. ECO Search List: _____ _____ _____ _____

3. Description of Change:

NEW DRAWING INCORPORATING EXISTING WIPP SITE UTILITY SEXTANT DRAWINGS; 24-C-011-W, 24-C-012-W, 24-C-013-W, 24-C-014-W, 24-C-015-W, AND 24-C-016-W AS 24-C-026-W, SHEETS 1-6.

UPON APPROVAL OF 24-C-026-W, SHEETS 1-6, SUPERCEDE DRAWINGS:

24-C-011-W
24-C-012-W
24-C-013-W
24-C-014-W
24-C-015-W
24-C-016-W

4. Drawing Cog. Engineer Approval: J. Kwaka Date: 7/29/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 24-C-028-W ECO Number: 5674

2. ECO Search List: _____ _____ _____ _____

3. Description of Change:

NEW DRAWING INCORPORATING EXISTING WIPP SITE FINISH GRADING AND PAVING PLANS; 24-C-008-W, 24-C-010-W, 24-C-143-022, 24-C-145-022, AND 24-C-146-W AS DRAWING 24-C-028-W, SHEETS 1-6.

UPON APPROVAL OF 24-C-028-W, SHEETS 1-6, SUPERCEDE DRAWINGS:

24-C-008-W
24-C-010-W
24-C-143-022
24-C-145-022
24-C-146-022
23-C-175-005
23-C-175-05A
23-C-176-005
23-C-176-05A

4. Drawing Cog. Engineer Approval: J. Howard Date: 7/29/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date
Drafting Started: _____ Initials / Date
Date Assigned: _____ Initials / Date
Drafting Completed: _____ Initials / Date
Assigned to: _____ (Same as data base entry)
Return to EFR: _____ Initials / Date

ENGINEERING CHANGE ORDER

USE BLACK INK

1. **ECO No.:** 5723
SKCC&D Review: RL — Initials — Posted

2. **Impact Level** 1 ☐ 2 ☒ 3 ☐ 4 ☐

3. **System:** WH06.14 Equipment No.: NA Building: 6-5

4. **Associated Documents:**
PWR 13062M
ECP NA
P.O. 50652
Others NA

5. **Document Type:**
Drawing 52-L-002-W1, 52-L-002-W10 ☒
Specification ☐
Vendor Data ☐
SDD ☐
Others ____

6. **Title of Change:** Revise VOC-10 Manifold Hangers

7. **Originator:** (print) M. W. KING — Ext. No.: 3586 — Department: RCWHE — Date: 9-21-91

8. **Cognizant Engineer:** (print) C. P. LIENNEMANN

9. **Description of Change:**

Yes ☐ No ☒ Component Indices change required (if yes, attach sheets)

Change hanger details and Bill of Material on drawings 52-L-002-W10 and 52-L-002-W1.

☒ 9a Drawing Change Sheet attached
☐ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

10. Yes ☒ No ☐ **MODIFICATION IN PROGRESS**
☒ Modification complete: M. W. King (Signature) 10/7/91 (Date)
ECO will be incorporated after M.I.P. signed complete

☐ Change drawing per as-built markup dated: ____
☐ Change drawing per ECO-provided data
☐ Temporary modification

11. **Design Verification Requirements: (per WP 09-018)** EDT No.: ____

✓ 1. Requirements satisfied by review/approval of design document
2. Independent review
3. Alternate calculations
4. Development testing
5. Design review
✓ 6. Other: Final Drawing Review & Approval

12. **Addendum Sheet added:** ____ (Signature) ____ (Date)

13. Justification

These changes are required to lower the VOC-10 manifold to allow installation of back support in Room 1, system

JF 8/30/91

14. Administrative Tracking

YES	N/A			YES	N/A	
☐	☒	1.	FSAR	☐	☒	6. Startup/Acceptance Test
☐	☒	2.	Calibration Procedures	☐	☒	7. Test Requirement & Spec.
☐	☒	3.	Maintenance Procedures	☐	☐	8.
☐	☒	4.	Computer Software	☐	☐	9.
☐	☒	5.	Operations Procedures	☐	☐	10.

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

A	Cog. Engineer	M. W. King 8/29/91 (Supervisor Alt. 8/29/91)
A	Cog. Eng. Mgr.	[illegible] 8/29/91
R	Startup	[illegible] 8/21/91
R	QA	[illegible] 8/22/91
☐	DOE	
R	Safety	[illegible] 8/27/91
☐	Dept. Manager	
R	Operations	[illegible] 8-23-91
☐	Security	
☐	SNL	
R		J.K. Stroble 8-20-91
☐		
☐		

16. Distribute as Marked

☑	Maintenance (MANDATORY)	
☑	Ops. Support (MANDATORY)	
☑	Startup	
☐	Facility Operations	
☑	U/G Operations	
☑	Orig./Design Engr.	M. King
☐	Cog. Engineer	
☐	Others	
☑		Bob Roland
☑		J.R. Stroble
☑		Jaime Gonzalez
☐		
☐		

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-W1 ECO Number: 5723

2. ECO Search List: _____ _____ _____ _____

3. Description of Change:

Revise the Bill of Material as follows

Change item 36 to 1/4" MANKEY CLIP w/ 5/8" DIA HOLE 52 EA.

Add 9/32" GALVANIZED ALLOY CHAIN GRADE 80 OR EQUAL 250 FT

4. Drawing Cog. Engineer Approval: M. Hamblin 9/21/91 Date: 8-20-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-W10 ECO Number: 5723

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Revise Detail 1 per the attached marked print.

8/21/91

4. Drawing Cog. Engineer Approval: _____ Date: 8-20-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

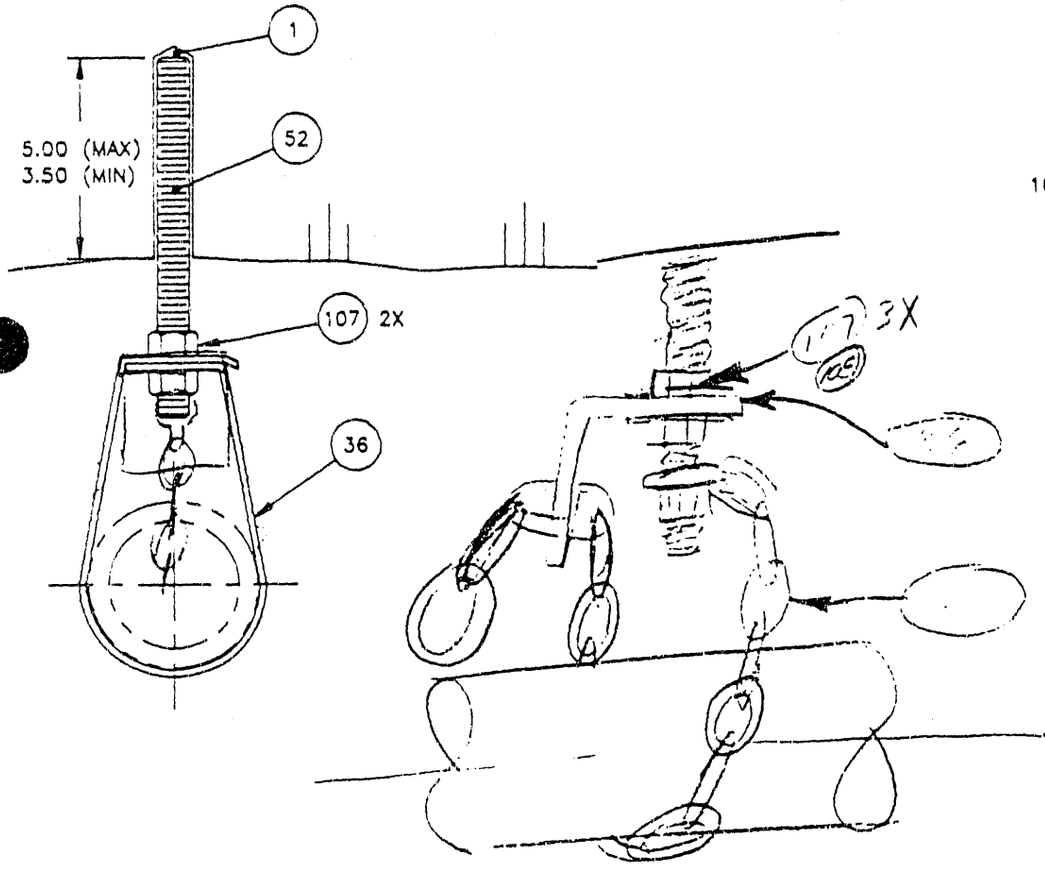
Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

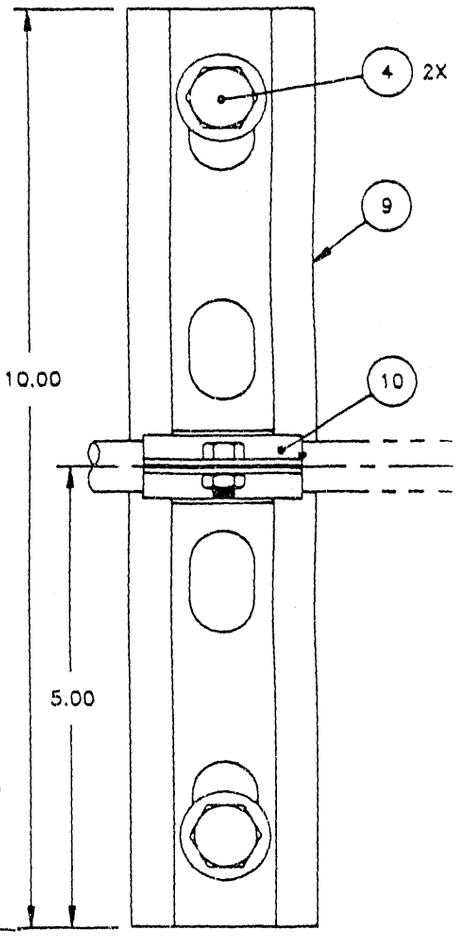
Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date



DETAIL 1

PIPE HANGER
(SEE NOTE 1)



DETAIL 2

RIB MOUNTED TUBING SUPPORT
(SEE NOTE 2)

52-L-002-W10

ENGINEERING CHANGE ORDER

PAGE 93 OF 6

1. ECO # 5723

2. DATE

DOE ORDER 6430.1A DESIGN CRITERIA

CHECKLIST

The design requirements in DOE Order 6430.1A checked below have been applied to this Design.

3.	DIVISION	SUBDIVISION
☐	1 General Requirements	☐ 0101 ☐ 0106 ☐ 0109 ☐ 0110 ☐ 0111 ☐ 0140 ☐ 0150 ☐ 0170
☐	2 Site and Civil Engineering	☐ 0200 ☐ 0201 ☐ 0202 ☐ 0203 ☐ 0205 ☐ 0210 ☐ 0214 ☐ 0215 ☐ 0220 ☐ 02.. ☐ 0245 ☐ 0250 ☐ 0256 ☐ 0260 ☐ 0262 ☐ 0265 ☐ 0267 ☐ 0270 ☐ 0273 ☐ 02.. ☐ 0276 ☐ 0278 ☐ 0279 ☐ 0280 ☐ 0281 ☐ 0283 ☐ 0285 ☐ 0290 ☐ 0291
☐	3 Concrete	☐ 0300 ☐ 0301 ☐ 0310 ☐ 0320 ☐ 0330 ☐ 0340 ☐ 0350 ☐ 0370 ☐ 0380
☐	4 Masonry	☐ 0400 ☐ 0401 ☐ 0410 ☐ 0420 ☐ 0455
☐	5 Metals	☐ 0500 ☐ 0512 ☐ 0514 ☐ 0521 ☐ 0531 ☐ 0532
☐	6 Wood and Plastics	☐ 0600 ☐ 0610 ☐ 0650
☐	7 Thermal and Moisture Protection	☐ 0710 ☐ 0711 ☐ 0714 ☐ 0715 ☐ 0719 ☐ 0720 ☐ 0721 ☐ 0722 ☐ 0724 ☐ 07.. ☐ 0730 ☐ 0750 ☐ 0751 ☐ 0753 ☐ 0760 ☐ 0790
☐	8 Doors and Windows	☐ 0800 ☐ 0810 ☐ 0820 ☐ 0830 ☐ 0833 ☐ 0836 ☐ 0839 ☐ 0850 ☐ 0860 ☐ 08.. ☐ 0880
☐	9 Finishes	☐ 0900 ☐ 0910 ☐ 0920 ☐ 0925 ☐ 0930 ☐ 0950 ☐ 0965 ☐ 0968 ☐ 0970 ☐ 09.. ☐ 0990 ☐ 0995
☐	10 Specialties	☐ 1015 ☐ 1020 ☐ 1024 ☐ 1027 ☐ 1030 ☐ 1040 ☐ 1050 ☐ 1052 ☐ 1053 ☐ 10.. ☐ 1060 ☐ 1065 ☐ 1070 ☐ 1075 ☐ 1080
☐	11 Equipment	☐ 1100 ☐ 1161
☐	12 Furnishings	☐ 1201 ☐ 1230 ☐ 1250 ☐ 1260 ☐ 1270
☐	13 Special Facilities	☐ 1300 ☐ 1304 ☐ 1305 ☐ 1306 ☐ 1307 ☐ 1318 ☐ 1319 ☐ 1320 ☐ 1321 ☐ 13.. ☐ 1323 ☐ 1324 ☐ 1325 ☐ 1326 ☐ 1328
☐	14 Conveying Systems	☐ 1401 ☐ 1420 ☐ 1440 ☐ 1460
☐	15 Mechanical	☐ 1525 ☐ 1530 ☐ 1540 ☐ 1550 ☐ 1555 ☐ 1565 ☐ 1574 ☐ 1589 ☐ 1595
☐	16 Electrical	☐ 1600 ☐ 1605 ☐ 1620 ☐ 1630 ☐ 1639 ☐ 1640 ☐ 1650 ☐ 1655 ☐ 1660 ☐ 16.. ☐ 1671 ☐ 1685 ☐ 1694
4. ☒	NOT APPLICABLE	No portion of DOE Order 6430.1A is applicable to this Design.
5. ☐	AS-BUILT	ECO is for as-built field verified changes only.

NOTE: A check placed in the Division column signifies that the entire Division shall be applicable to the Design, unless modified by checks indicated for specific Subdivisions.

COMMENTS: _____

52L002WIC

ENGINEERING CHANGE ORDER

USE BLACK INK

1. **ECO No.:** 5741
CC&D Review: RS

Initials

Posted

2. **Impact Level** 1 ☐ 2 ☐ 3 ☒ 4 ☐

3. **System:** WH06.1 Equipment No.: NA Building: 4G

4. **Associated Documents:** AB 8/27/91

PWR NA
ECP NA
P.O. NA
Others —

5. **Document Type:**

Drawing 52-L-002-W11 ☒
Specification ☐
Vendor Data ☐
SDD ☐
Others

6. **Title of Change:** Manifold Block VOC Monitoring System

7. **Originator:** (print) Merle King | Ext. No.: 8286 | Department: RWHE | Date: 8/9/91

8. **Cognizant Engineer:** (print) Om Mendiratta

9. **Description of Change:**

Yes ☐ No ☒ Component indices change required (if yes, attach sheets)

Make an engineering fabrication drawing for the file.
USING AS BUILT ~~SKETCH~~ FIGURE ATTACHED.
THE DRAWING WILL BE SHEET 11 OF 52-L-002-W4

☒ 9a Drawing Change Sheet attached
☐ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

10. Yes ☐ No ☒ **MODIFICATION IN PROGRESS**
☐ Modification complete: _____ / _____ (Signature / Date)
ECO will be incorporated after M.I.P. signed complete

☐ Change drawing per as-built markup dated: _____
☐ Change drawing per ECO-provided data
☐ Temporary modification

11. **Design Verification Requirements: (per WP 09-018)** EDT No.: _____

_____ 1. Requirements satisfied by review/approval of design document
_____ 2. Independent review
_____ 3. Alternate calculations
_____ 4. Development testing
_____ 5. Design review
_____ 6. Other: _____

12. **Addendum Sheet added:** _____ / _____ (Signature / Date)

1190B:0005

13. Justification

Create a drawing from the sketch used to procure manifold blocks for the VOC-10 system. ~~As-built~~ 8/29. Manufacturing details currently not shown on a drawing.

14. Administrative Tracking

YES	N/A			YES	N/A	
☐	☒	1.	FSAR	☐	☒	6. Startup/Acceptance Test
☐	☒	2.	Calibration Procedures	☐	☒	7. Test Requirement & Spec.
☐	☒	3.	Maintenance Procedures	☐	☐	8. _____
☐	☒	4.	Computer Software	☐	☐	9. _____
☐	☒	5.	Operations Procedures	☐	☐	10. _____

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

A	Cog. Engineer	8/28/91 8/29/91
A	Cog. Eng. Mgr.	John J. Petrucci 8/27/91
R	Startup	8/27/91
R	QA	James T. Allen 8/28/91
☐	DOE	
☐	Safety	
☐	Dept. Manager	
☐	Operations	
☐	Security	
☐	SNL	
A	JR Strobble	J.R. Strobble 8-23-91
☐		
☐		

16. Distribute as Marked

☑	Maintenance (MANDATORY)	
☑	Ops. Support (MANDATORY)	
☑	Startup	
☐	Facility Operations	
☐	U/G Operations	
☑	Orig./Design Engr.	M. King
☑	Cog. Engineer	O. Mandiratta
☑	Others	J.R. Strobble
☐		
☐		
☐		
☐		
☐		

DOE ORDER 6430.1A DESIGN CRITERIA CHECKLIST

ENGINEERING CHANGE ORDER (ECO) NO. 5741 DATE 8-9-91

COGNIZANT ENGINEER Jon Mendiratta / Lou Pennimilli

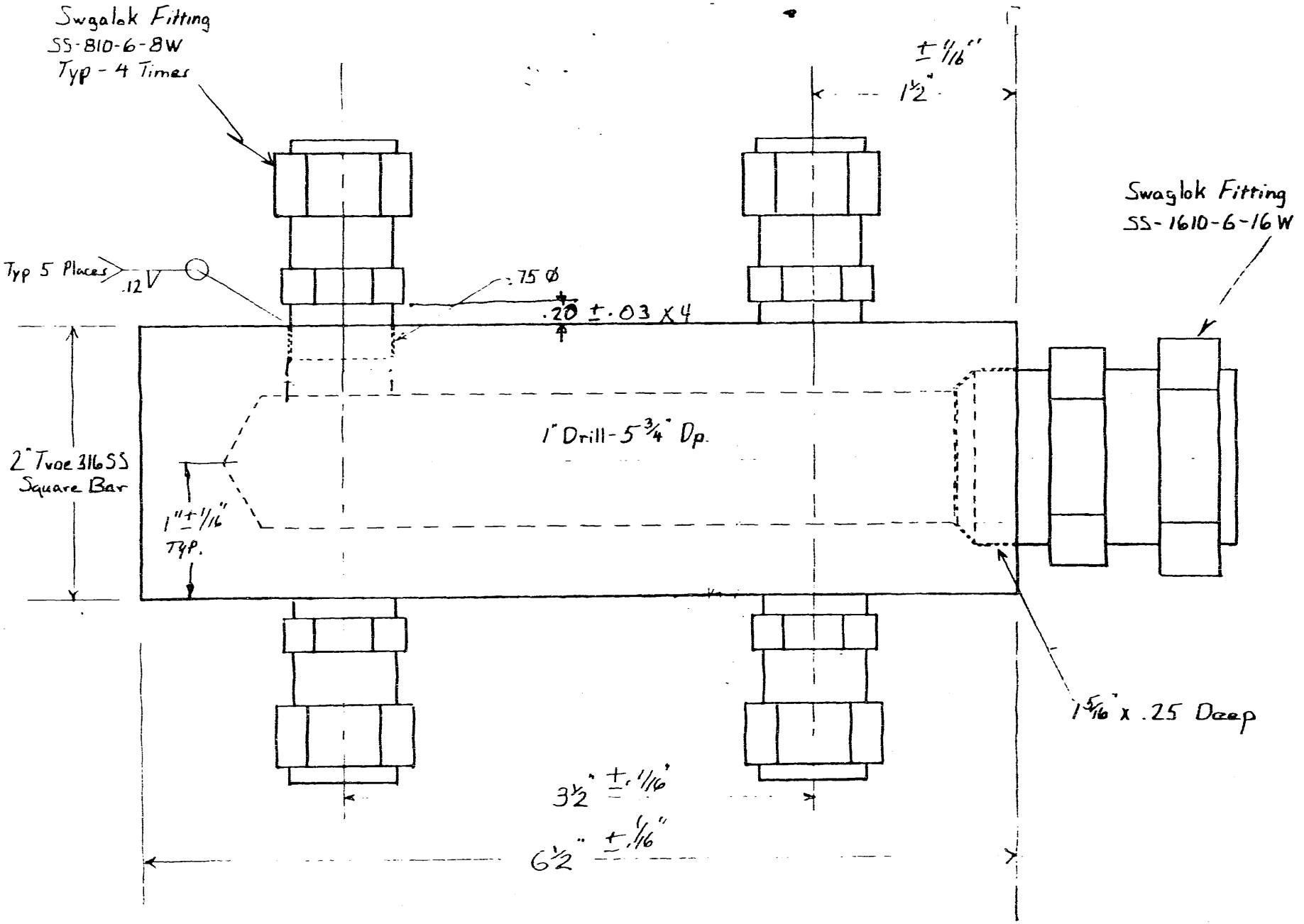
The design requirements in DOE Order 6430.1A checked below have been applied to this Design.

DIVISION	SUBDIVISION
☐ 1 General Requirements	☐ 0101 ☐ 0106 ☐ 0109 ☐ 0110 ☐ 0111 ☐ 0140 ☐ 0150 ☐ 0170
☐ 2 Site and Civil Engineering	☐ 0200 ☐ 0201 ☐ 0202 ☐ 0203 ☐ 0205 ☐ 0210 ☐ 0214 ☐ 0215 ☐ 0220 ☐ (☐ 0245 ☐ 0250 ☐ 0256 ☐ 0260 ☐ 0262 ☐ 0266 ☐ 0267 ☐ 0270 ☐ 0273 ☐ (☐ 0276 ☐ 0278 ☐ 0279 ☐ 0280 ☐ 0281 ☐ 0283 ☐ 0285 ☐ 0290 ☐ 0291
☐ 3 Concrete	☐ 0300 ☐ 0301 ☐ 0310 ☐ 0320 ☐ 0330 ☐ 0340 ☐ 0350 ☐ 0370 ☐ 0380
☐ 4 Masonry	☐ 0400 ☐ 0401 ☐ 0410 ☐ 0420 ☐ 0455
☐ 5 Metals	☐ 0500 ☐ 0512 ☐ 0514 ☐ 0521 ☐ 0531 ☐ 0532
☐ 6 Wood and Plastics	☐ 0600 ☐ 0610 ☐ 0650
☐ 7 Thermal and Moisture Protection	☐ 0710 ☐ 0711 ☐ 0714 ☐ 0715 ☐ 0719 ☐ 0720 ☐ 0721 ☐ 0722 ☐ 0724 ☐ 0 ☐ 0730 ☐ 0750 ☐ 0751 ☐ 0753 ☐ 0760 ☐ 0790
☐ 8 Doors and Windows	☐ 0800 ☐ 0810 ☐ 0820 ☐ 0830 ☐ 0833 ☐ 0836 ☐ 0839 ☐ 0850 ☐ 0860 ☐ 0 ☐ 0880
☐ 9 Finishes	☐ 0900 ☐ 0910 ☐ 0920 ☐ 0925 ☐ 0930 ☐ 0950 ☐ 0965 ☐ 0968 ☐ 0970 ☐ 0 ☐ 0990 ☐ 0995
☐ 10 Specialties	☐ 1015 ☐ 1020 ☐ 1024 ☐ 1027 ☐ 1030 ☐ 1040 ☐ 1050 ☐ 1052 ☐ 1053 ☐ 1 ☐ 1060 ☐ 1065 ☐ 1070 ☐ 1075 ☐ 1080
☐ 11 Equipment	☐ 1100 ☐ 1161
☐ 12 Furnishings	☐ 1201 ☐ 1230 ☐ 1250 ☐ 1260 ☐ 1270
☐ 13 Special Facilities	☐ 1300 ☐ 1304 ☐ 1305 ☐ 1306 ☐ 1307 ☐ 1318 ☐ 1319 ☐ 1320 ☐ 1321 ☐ 1 ☐ 1323 ☐ 1324 ☐ 1325 ☐ 1326 ☐ 1328
☐ 14 Conveying Systems	☐ 1401 ☐ 1420 ☐ 1440 ☐ 1460
☐ 15 Mechanical	☐ 1525 ☐ 1530 ☐ 1540 ☐ 1550 ☐ 1555 ☐ 1585 ☐ 1574 ☐ 1589 ☐ 1595
☐ 16 Electrical	☐ 1600 ☐ 1605 ☐ 1620 ☐ 1630 ☐ 1639 ☐ 1640 ☐ 1650 ☐ 1660 ☐ 1670 ☐ 1 ☐ 1685 ☐ 1694

☒ No portion of DOE Order 6430.1A is applicable to this Design.

NOTE: A check placed in the Division column signifies that the entire Division shall be applicable to the Design, unless modified by checks indicated for specific Subdivisions.

"Manifolds"



ECO 5741

4 of 7

NOTES:

1. GTAW PER ASME B&PV CODE SECTION VIII USING WELD FILLER METAL PER AWS A5.9.

2. LIQUID PENETRANT TEST WELDS PER ARTICLE 6 OF SECTION V OF ASME B&PV CODE.

3. WELDER SHALL BE QUALIFIED PER SECTION IX OF ASME B&PV CODE.

4. THE ASSEMBLY SHALL BE VISUALLY CLEAN. NO VOLATILE ORGANIC COMPOUNDS MAY BE USED FOR CLEANING. DETERGENT WITH A HOT WATER RINSE OR A SIMILAR PROCESS IS SUGGESTED.

6 of 6

MWC 8/23

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-WA MWC 8/23/91 ECO Number: 5741

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Create a fabrication drawing from the attached sketch, DWG NO TO BE SHEET 11 OF 11, DWG 52-L-002-WA MWC 8/23/91

Dan Meredith 8/26/91

4. Drawing Cog. Engineer Approval: M. W. Zinn Date: 8-23-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

1 of 6
MK 8/23/91

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-WK MK 8/23/91 ECO Number: 5741

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

MK 8/23/91

3. Description of Change: 52-C-002-WK, SHT 11

Add the drawing number created by this ECO to item #1 of the List of Material.

Burpendeville 8/26/91

4. Drawing Cog. Engineer Approval: MK Date: 8-23-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

41 E W5614

ENGINEERING CHANGE ORDER

ENGINEERING FILE ROOM COPY

USE BLACK INK

Page 1 of 8

1. ECO No.: 5716
CC&D Review: RT

Initials

Posted

CANCELLED
4-4-92 / 12/27/91
H.F.S SCOPE OF WORK HAS BEEN CANCELLED
HR 4/27/91

2. Impact Level 1 ☐ 2 ☐ 3 ☒ 4 ☐

3. System: SC02 Equipment No.: N/A Building: 411

4. Associated Documents:
PWR 11733 M
ECP
P.O.
Others

5. Document Type:
~~Drawing~~ SKETCH 1703-S ☒
Specification ☐
Vendor Data ☐
SDD ☐
Others

6. Title of Change: Ladder Relocation @ R.H Cask Loading R..

7. Originator: (print)	Ext. No.:	Department:	Date:	8. Cognizant Engineer: (print)
HADI SAFARI	8780	M&C.E	8/27/91	JOHN KOWALSKI

9. Description of Change:

Yes ☐ No ☒ Component Indices change required (If yes, attach sheets)

1- Assign a Sketch number for "Ladder Relocation @ R.H. Cask Loading Rm. SKID 411-S-147 Bldg #411" Sketch: 1703-S

2- ~~After~~ Completion of relocation, show new changes on affected drawings (See attached 9a Sheets).

3- After completion of item 2, remove sketch from active drawing file and send to MRC.

☒ 9a Drawing Change Sheet attached
☐ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

10. Yes ☒ No ☐ MODIFICATION IN PROGRESS
☐ Modification complete: _____ / _____ (Signature / Date)
ECO will be incorporated after M.I.P. signed complete

☐ Change drawing per as-built markup dated: _____
☐ Change drawing per ECO-provided data
☐ Temporary modification

11. Design Verification Requirements: (per WP 09-018) EDT No.: _____

JHK 1. Requirements satisfied by review/approval of design document
2. Independent review
3. Alternate calculations
4. Development testing
5. Design review
6. Other: _____

12. Addendum Sheet added: _____ / _____ (Signature / Date)

13. Justification

To satisfy OSHA requirements.

14. Administrative Tracking

YES	N/A		YES	N/A	
☐	☒	1. FSAR	☐	☒	6. Startup/Acceptance Test
☐	☒	2. Calibration Procedures	☐	☒	7. Test Requirement & Spec.
☐	☒	3. Maintenance Procedures	☐	☒	8. _____
☐	☒	4. Computer Software	☐	☐	9. _____
☐	☒	5. Operations Procedures	☐	☐	10. _____

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

A	Cog. Engineer	8/28/91
A	Cog. Eng. Mgr.	8/28/91
R	Startup	8/29/91
R	QA	8/29/91
☐	DOE	
R	Safety	8-29-91
☐	Dept. Manager	
☐	Operations	
☐	Security	
☐	SNL	
☐		
☐		
☐		

16. Distribute as Marked

☒	Maintenance (MANDATORY)	
☒	Ops. Support (MANDATORY)	
☐	Startup	
☐	Facility Operations	
☐	U/G Operations	
☒	Orig./Design Engr.	
☒	Cog. Engineer	
☐	Others	
☐		
☐		
☐		
☐		
☐		

1. ECO # 5726
2. DATE

ENGINEERING CHANGE ORDER

DOE ORDER 6430.1A DESIGN CRITERIA

CHECKLIST

The design requirements in DOE Order 6430.1A checked below have been applied to this Design.

	DIVISION	SUBDIVISION
☐	1 General Requirements	☐ 0101 ☐ 0106 ☐ 0109 ☐ 0110 ☐ 0111 ☐ 0140 ☐ 0150 ☐ 0170
☐	2 Site and Civil Engineering	☐ 0200 ☐ 0201 ☐ 0202 ☐ 0203 ☐ 0205 ☐ 0210 ☐ 0214 ☐ 0215 ☐ 0220 ☐ 0235 ☐ 0245 ☐ 0250 ☐ 0256 ☐ 0260 ☐ 0262 ☐ 0265 ☐ 0267 ☐ 0270 ☐ 0273 ☐ 0275 ☐ 0276 ☐ 0278 ☐ 0279 ☐ 0280 ☐ 0281 ☐ 0283 ☐ 0285 ☐ 0290 ☐ 0291
☐	3 Concrete	☐ 0300 ☐ 0301 ☐ 0310 ☐ 0320 ☐ 0330 ☐ 0340 ☐ 0350 ☐ 0370 ☐ 0380
☐	4 Masonry	☐ 0400 ☐ 0401 ☐ 0410 ☐ 0420 ☐ 0455
☒	5 Metals	☐ 0500 ☒ 0512 ☐ 0514 ☐ 0521 ☐ 0531 ☐ 0532
☐	6 Wood and Plastics	☐ 0600 ☐ 0610 ☐ 0650
☐	7 Thermal and Moisture Protection	☐ 0710 ☐ 0711 ☐ 0714 ☐ 0715 ☐ 0719 ☐ 0720 ☐ 0721 ☐ 0722 ☐ 0724 ☐ 0725 ☐ 0730 ☐ 0750 ☐ 0751 ☐ 0753 ☐ 0760 ☐ 0790
☐	8 Doors and Windows	☐ 0800 ☐ 0810 ☐ 0820 ☐ 0830 ☐ 0833 ☐ 0836 ☐ 0839 ☐ 0850 ☐ 0860 ☐ 0870 ☐ 0880
☐	9 Finishes	☐ 0900 ☐ 0910 ☐ 0920 ☐ 0925 ☐ 0930 ☐ 0950 ☐ 0965 ☐ 0968 ☐ 0970 ☐ 0981 ☐ 0990 ☐ 0995
☐	10 Specialties	☐ 1015 ☐ 1020 ☐ 1024 ☐ 1027 ☐ 1030 ☐ 1040 ☐ 1050 ☐ 1052 ☐ 1053 ☐ 1054 ☐ 1060 ☐ 1065 ☐ 1070 ☐ 1075 ☐ 1080
☐	11 Equipment	☐ 1100 ☐ 1161
☐	12 Furnishings	☐ 1201 ☐ 1230 ☐ 1250 ☐ 1260 ☐ 1270
☐	13 Special Facilities	☐ 1300 ☐ 1304 ☐ 1305 ☐ 1306 ☐ 1307 ☐ 1318 ☐ 1319 ☐ 1320 ☐ 1321 ☐ 1322 ☐ 1323 ☐ 1324 ☐ 1325 ☐ 1326 ☐ 1328
☐	14 Conveying Systems	☐ 1401 ☐ 1420 ☐ 1440 ☐ 1460
☐	15 Mechanical	☐ 1525 ☐ 1530 ☐ 1540 ☐ 1550 ☐ 1555 ☐ 1565 ☐ 1574 ☐ 1589 ☐ 1595
☐	16 Electrical	☐ 1600 ☐ 1605 ☐ 1620 ☐ 1630 ☐ 1639 ☐ 1640 ☐ 1650 ☐ 1655 ☐ 1660 ☐ 1671 ☐ 1671 ☐ 1685 ☐ 1694
4. ☐	NOT APPLICABLE	No portion of DOE Order 6430.1A is applicable to this Design.
5. ☐	AS-BUILT	ECO is for as-built field verified changes only.

NOTE: A check placed in the Division column signifies that the entire Division shall be applicable to the Design, unless modified by checks indicated for specific Subdivisions.

COMMENTS: _____

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 41-D-021-014 ECO Number: 5744

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Show (AS BUILT) new ladder location and delete existing location at R.H. cask Loading Rm. as per Sk. no. 1703 -S.

4. Drawing Cog. Engineer Approval: J. Krawczyk Date: 8/28/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

1290:B0006

14

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 41-D-144-014 ECO Number: 5746

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Show (AS BUILT) new ladder location and delete existing location at R.H. cask Loading Rm. as per Sk. no. 1703-5.

4. Drawing Cog. Engineer Approval: J. Kwan Date: 8/29/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

1290:B0006

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 41-G-170-014 ECO Number: 5746

2. ECO Search List: _____ _____ _____ _____

3. Description of Change:

Show (as-built) new ladder location at R.H. Cask Loading Room. as per Sk. No. 1703-5

4. Drawing Cog. Engineer Approval: [signature] Date: 09/30/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

1290:B0006

~~13~~ 14

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 41-G-508-014 ECO Number: 5716

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Show (AS BUILT) new ladder location and delete existing location at R.H. Cask Loading Rm. as per SK. NO. 1703-S.

4. Drawing Cog. Engineer Approval: [signature] Date: 8/28/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

1290:B0006

P. 8/13 14 H·S

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 41-G-455-014 ECO Number: 5746

2. ECO Search List: _____ _____ _____ _____

3. Description of Change:

Show (as built) new ladder location at R.H. cask Loading Room as per Sk. No. 1703-S.

4. Drawing Cog. Engineer Approval: J. Brown Date: 8/29/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

1290:B0006

P. 9/13 14 H.S

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 41-G-502-014 ECO Number: 5716

2. ECO Search List: _____ _____ _____ _____

3. Description of Change:

Show (as built) new ladder location at R.H. cask loading Rm. as per Sk. no. 1703-5.

4. Drawing Cog. Engineer Approval: T. Kmart Date: 8/28/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

F. 10/13 14 H.S

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 41-G-510-014 ECO Number: 5744

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Show (as built) new ladder location at R.H. cask loading Rm. as per Sk no. 1703-S.

4. Drawing Cog. Engineer Approval: T. Kovach Date: 8/29/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

1290:B0006

F. 11/13/14 H.5

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 41-E-005-014 ECO Number: 5716

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Show (as built) new ladder location at R.H cask loading Rm. as per Sk. No. 1703 - S.

4. Drawing Cog. Engineer Approval: J. Kowalke Date: 8/28/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

1290:B0006

F. 12/13/14 H-5

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 41-G-453-014 ECO Number: 5726

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Show (as built) new ladder location at R.H. Cask Loading Room as per Sk. No. 1703-S.

4. Drawing Cog. Engineer Approval: J. Knowles Date: 8/28/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

1290:B0006

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 41-G-172-014 ECO Number: _____

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Show (as-built) new ladder location at R.H. cask Loading Room as per Sk. No. 1703-5

4. Drawing Cog. Engineer Approval: J. Gwee PE Date: 8/28/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

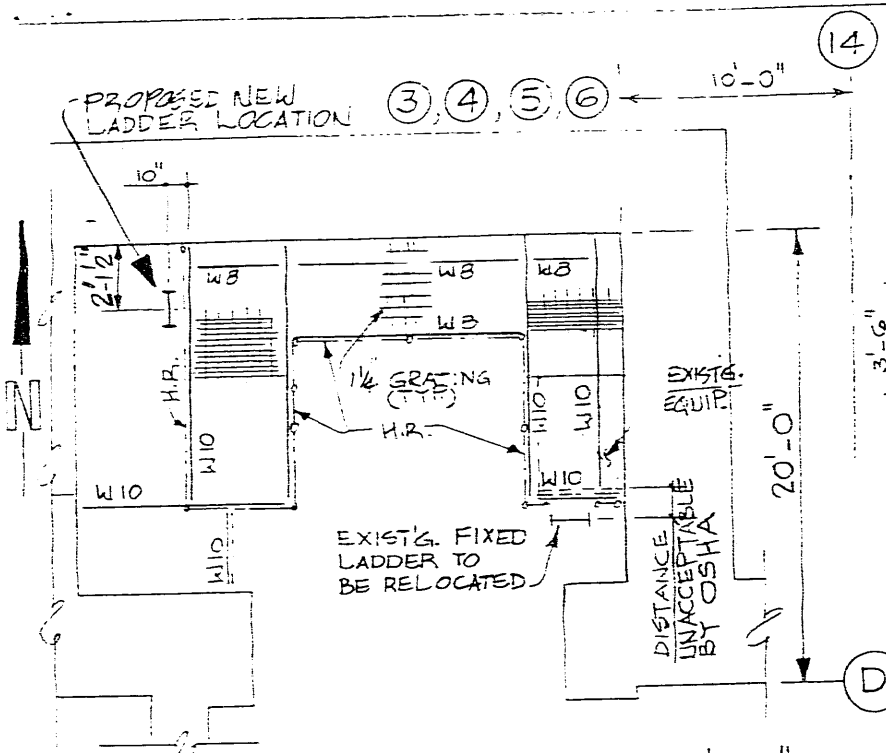
Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

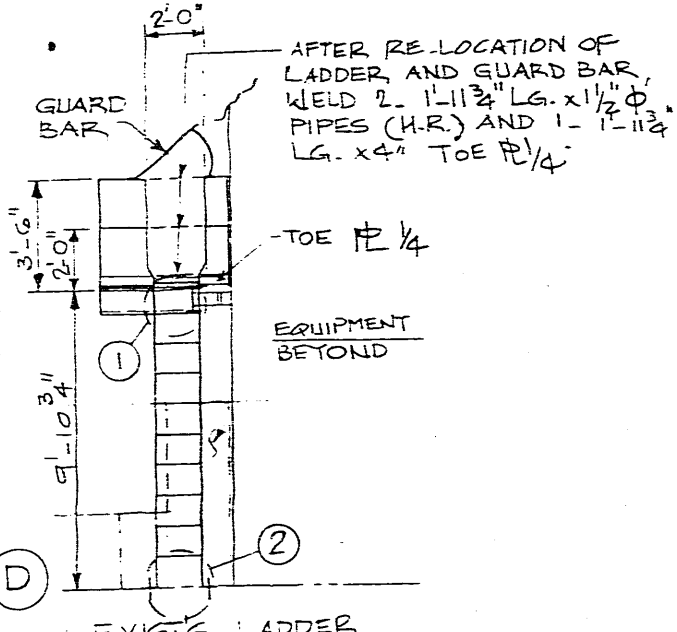
Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

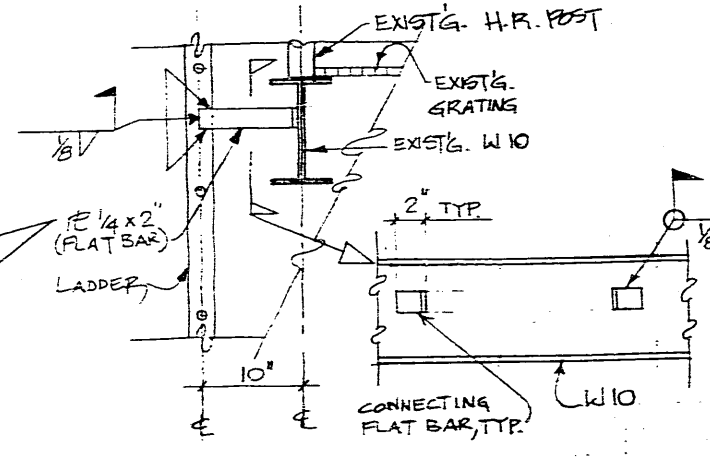
Return to EFR: _____ Initials / Date



EXIST'G. PLATFORM ②, EL. 110'-0"
T.O.S. EL. 109'-10¾"



EXIST'G. LADDER ELEVATION



1. FLAME CUT CONNECTING FLAT BARS FROM PLATFORM FRAMING BEAM (W10) AT EXIST'G. LOCATION.
2. UNBOLT LADDER FROM FLOOR TO FREE LADDER FOR RE-LOCATION.
3. ANCHOR LADDER WITH 2- ½" Φ HILTI KWIK W/3" EMBDT. TO FLOOR AT NEW LOCATION.
4. PROVIDE AND WELD NEW CONNECTING FLAT BARS TO PLATFORM BEAM (W10) AT NEW LOCATION.
5. CUT 2'-0" OPENING THROUGH EXISTING HANDRAILS AND TOE PL TO FACILITATE LADDER TO PLATFORM ACCESS AT NEW LOCATION.
6. RE-LOCATE GUARD BAR FROM EXIST'G. TO NEW LOCATION.

LADDER RELOCATION @ RH CASK LOADING RM
SKID 411 S 147 BLDG. #411

TITLE
SKETCH # 7703-S
COG. ENG. 8/28/91
COG. ENG. MGR. 8/28/91
ECO-5746

PWR # M11733

73 J 014 W

ENGINEERING CHANGE ORDER

USE BLACK INK

1. **ECO No.:** 5776
CC&D Review: RS

Initials

Posted

2. **Impact Level** 1 ☐ 2 ☐ 3 ☑ 4 ☐

3. **System:** PC03 Equipment No.: 25P-TRPA/144 Building: 453

4. Associated Documents:
PWR M17272
ECP
P.O.
Others

5. **Document Type:**
Drawing 73-J-022-W1 ☑
Specification 73-J-022-W2, 73-J-014-W1 ☐
Vendor Data ☐
SDD ☐
Others

6. **Title of Change:** PA FOR WHSE 453 & NW QUAD D/3

7. **Originator:** (print)	Ext. No.:	Department:	Date:	8. **Cognizant Engineer:** (print)
J RODNEY FUSTON	2660	FE/EE	9/12/91	J RODNEY FUSTON

9. **Description of Change:**

Yes ☑ No ☐ Component indices change required (if yes, attach sheets)

A DRAWING NO 73-J-022-W REV B (A SHEET 4A & 4B INCLUDED)
(1) ADD CONDUIT AND JUNCTION BOXES TO DWG.
(2) ADD IN-GROUND PULL-BOX TO DWG.
(3) ADD CONDUIT SCHEDULE
(4) ADD EQUIPMENT SCHEDULE
(5) ADD JUNCTION BOX SCHEDULE.

B DRAWING NO. 73-J-014-W REV 13
(1) PLAN VIEW OF DUCT BANK SYSTEM
(2) SECTION VIEWS OF DUCT BANK PULL BOXES

☑ 9a Drawing Change Sheet attached
☐ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

10. Yes ☑ No ☐ **MODIFICATION IN PROGRESS**
☐ Modification complete: _____ / _____ (Signature / Date)
ECO will be Incorporated after M.I.P. signed complete

☐ Change drawing per as-built markup dated: _____
☐ Change drawing per ECO-provided data
☐ Temporary modification

11. **Design Verification Requirements: (per WP 09-018)** EDT No.: _____

Joe
1. Requirements satisfied by review/approval of design document
2. Independent review
3. Alternate calculations
4. Development testing
5. Design review
6. Other: _____

12. **Addendum Sheet added:** _____ / _____ (Signature / Date)

13. Justification

TO PROVIDE ENGINEERING AND INSTALLATION DETAILS FOR NEW PUBLIC ADDRESS COMPONENTS TO BE ADDED TO FACILITY 453

14. Administrative Tracking

YES	N/A			YES	N/A	
☐	☑	1.	FSAR	☒	☑ GLS 9-19-91	6. Startup/Acceptance Test
☐	☑	2.	Calibration Procedures	☐	☑	7. Test Requirement & Spec.
☑	☐	3.	Maintenance Procedures	☐	☐	8.
☐	☑	4.	Computer Software	☐	☐	9.
☑	☐	5.	Operations Procedures	☐	☐	10.

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

A	Cog. Engineer	J. Rodney Linton 9/11/91
A	Cog. Eng. Mgr.	[illegible] 9/13/91
R	Startup	[illegible] 9/18/91
R	QA	[illegible] 10-2-91
☐	DOE	
☐	Safety	[illegible] 10/2/91
☐	Dept. Manager	
☐	Operations	
☐	Security	
☐	SNL	
☐		
☐		
☐		

16. Distribute as Marked

☐	Maintenance (MANDATORY)	
☐	Ops. Support (MANDATORY)	
☐	Startup	
☐	Facility Operations	
☐	U/G Operations	
☐	Orig./Design Engr.	J. Rodney Linton
☑	Cog. Engineer	
☑	Others cc: D	R J Johnson
☐		
☐		
☐		
☐		
☐		

ENGINEERING CHANGE ORDER

1. ECO # S726
2. DATE _____

DOE ORDER 6430.1A DESIGN CRITERIA CHECKLIST

The design requirements in DOE Order 6430.1A checked below have been applied to this Design.

3. DIVISION	SUBDIVISION
☒ 1 General Requirements	☑ 0101 ☐ 0106 ☑ 0109 ☑ 0110 ☐ 0111 ☐ 0140 ☐ 0150 ☐ 0170
☐ 2 Site and Civil Engineering	☐ 0200 ☐ 0201 ☐ 0202 ☐ 0203 ☐ 0205 ☐ 0210 ☐ 0214 ☐ 0215 ☐ 0220 ☐ 02 ☐ 0245 ☐ 0250 ☐ 0256 ☐ 0260 ☐ 0262 ☐ 0268 ☐ 0267 ☐ 0270 ☐ 0273 ☐ 02 ☐ 0276 ☐ 0278 ☐ 0279 ☐ 0280 ☐ 0281 ☐ 0283 ☐ 0285 ☐ 0290 ☐ 0291
☐ 3. Concrete	☐ 0300 ☐ 0301 ☐ 0310 ☐ 0320 ☐ 0330 ☐ 0340 ☐ 0350 ☐ 0370 ☐ 0380
☐ 4 Masonry	☐ 0400 ☐ 0401 ☐ 0410 ☐ 0420 ☐ 0455
☐ 5 Metals	☐ 0500 ☐ 0512 ☐ 0514 ☐ 0521 ☐ 0531 ☐ 0532
☐ 6 Wood and Plastics	☐ 0600 ☐ 0610 ☐ 0650
☐ 7 Thermal and Moisture Protection	☐ 0710 ☐ 0711 ☐ 0714 ☐ 0715 ☐ 0719 ☐ 0720 ☐ 0721 ☐ 0722 ☐ 0724 ☐ 07 ☐ 0730 ☐ 0750 ☐ 0751 ☐ 0753 ☐ 0760 ☐ 0790
☐ 8 Doors and Windows	☐ 0800 ☐ 0810 ☐ 0820 ☐ 0830 ☐ 0833 ☐ 0836 ☐ 0839 ☐ 0850 ☐ 0860 ☐ 08 ☐ 0880
☐ 9 Finishes	☐ 0900 ☐ 0910 ☐ 0920 ☐ 0925 ☐ 0930 ☐ 0950 ☐ 0965 ☐ 0968 ☐ 0970 ☐ 09 ☐ 0990 ☐ 0995
☐ 10 Specialties	☐ 1015 ☐ 1020 ☐ 1024 ☐ 1027 ☐ 1030 ☐ 1040 ☐ 1050 ☐ 1052 ☐ 1053 ☐ 10 ☐ 1060 ☐ 1065 ☐ 1070 ☐ 1075 ☐ 1080
☑ 11 Equipment	☑ 1100 ☐ 1161
☐ 12 Furnishings	☐ 1201 ☐ 1230 ☐ 1250 ☐ 1260 ☐ 1270
☐ 13 Special Facilities	☐ 1300 ☐ 1304 ☐ 1305 ☐ 1306 ☐ 1307 ☐ 1318 ☐ 1319 ☐ 1320 ☐ 1321 ☐ 13 ☐ 1323 ☐ 1324 ☐ 1325 ☐ 1326 ☐ 1328
☐ 14 Conveying Systems	☐ 1401 ☐ 1420 ☐ 1440 ☐ 1460
☐ 15 Mechanical	☐ 1525 ☐ 1530 ☐ 1540 ☐ 1550 ☐ 1555 ☐ 1565 ☐ 1574 ☐ 1589 ☐ 1595
☑ 16 Electrical	☑ 1600 ☑ 1605 ☐ 1620 ☐ 1630 ☑ 1639 ☐ 1640 ☐ 1650 ☐ 1655 ☐ 1660 ☑ 16 ☑ 1671 ☐ 1685 ☐ 1694
4. ☐ NOT APPLICABLE	No portion of DOE Order 6430.1A is applicable to this Design.
5 ☐ AS-BUILT	ECO is for as-built field verified changes only.

NOTE: A check placed in the Division column signifies that the entire Division shall be applicable to the Design, unless modified by checks indicated for specific Subdivisions.

COMMENTS: _____

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 73-J-022-W ECO Number: 5776

2. ECO Search List: 4668
5116 M

3. Description of Change:

A. ADD CONDUIT 25-J-560 TO DWG. SEE PAGE 5.
25-J-576
B. ADD JUNCTION BOX 25P-TBPA/144 TO DWG. SEE PAGE 5.6.
C. ADD IN-GROUND PULL-BOX TO DWG - 25P-PBJC/133 SEE PAGE 6.
D ADD CONDUIT SCHEDULE TO DWG. SEE PAGE 7
E. ~~ADD EQUIPMENT SCHEDULE TO DWG. SEE PAGE 10~~ 9123 9/13/91
F. ADD JUNCTION BOX SCHEDULE TO DWG. SEE PAGE 8.9
G. ~~ADD CABLE SCHEDULE TO DWG. SEE PAGE 12~~ 9123 9/13/91
H. ADD YARD CONDUIT LAYOUT. SEE PAGE 6
I. ADD CONDUIT 25-J-561 TO DWG. SEE PAGE 6
~~J. CREATE NEW SHEET FOR ITEMS D E F ABOVE.~~
~~TITLE BLOCK: WAREHOUSE/SHOPS BUILDING 453~~
~~PLANT COMMUNICATIONS~~
~~COMPONENT SCHEDULES~~ 9123 9/16/91

4. Drawing Cog. Engineer Approval: J. Rodney Fuston Date: 9/12/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date
Drafting Started: _____ Initials / Date
Date Assigned: _____ Initials / Date
Drafting Completed: _____ Initials / Date
Assigned to: _____ (Same as data base entry)
Return to EFR: _____ Initials / Date

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 73-J-012-0002 ECO Number: 5776

2. ECO Search List: 4608
5166

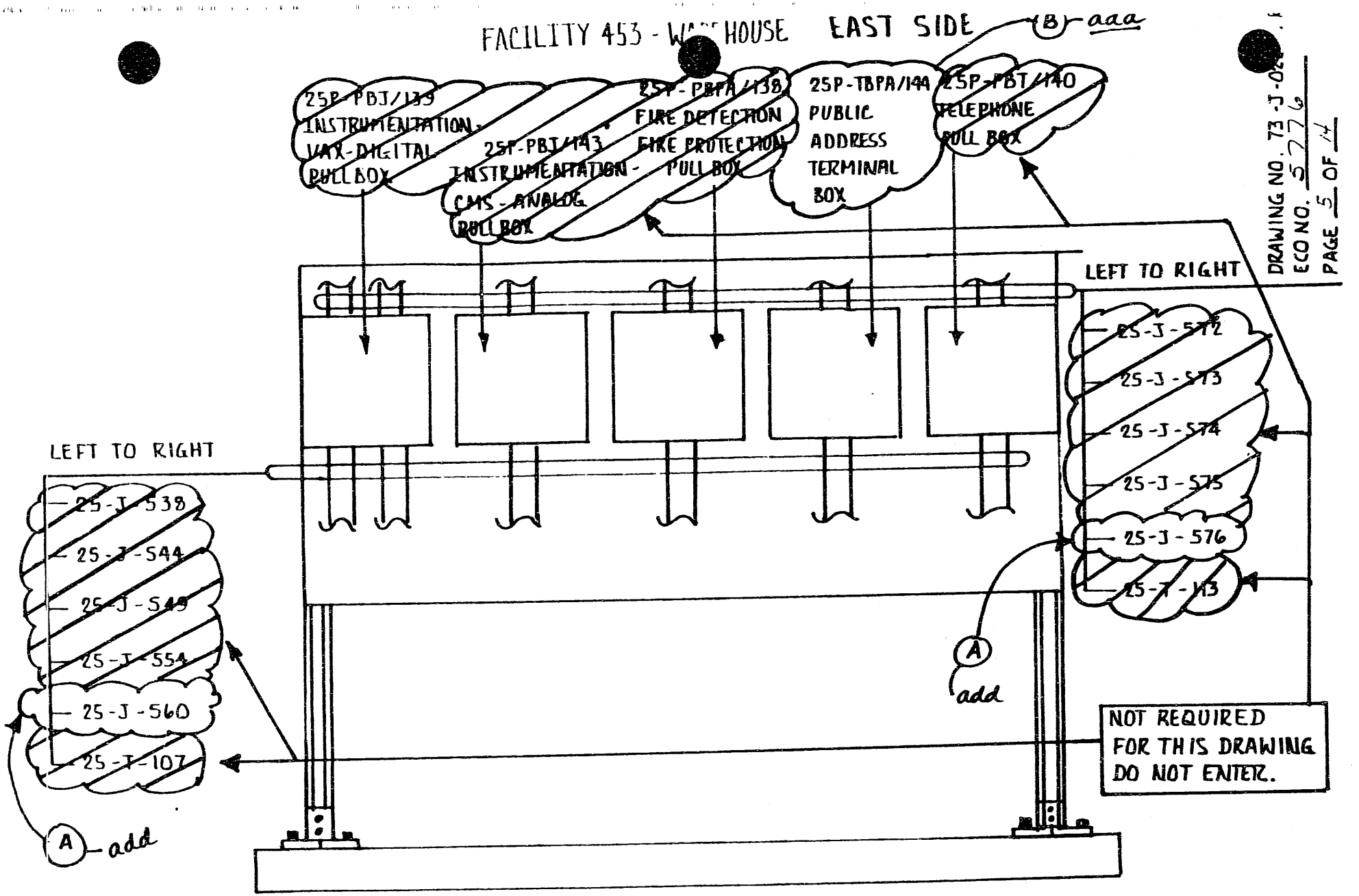
3. Description of Change:

A. CREATE A NEW SHEET FOR THIS DRAWING FROM ITEMS D E F OF SHEET 4A OF 43 OF THIS ECO 9/16/91 DRD

TITLE BLOCK: WAREHOUSE / SHOPS ~~45~~ BUILDING 453
PLANT COMMUNICATIONS
COMPONENT SCHEDULES.

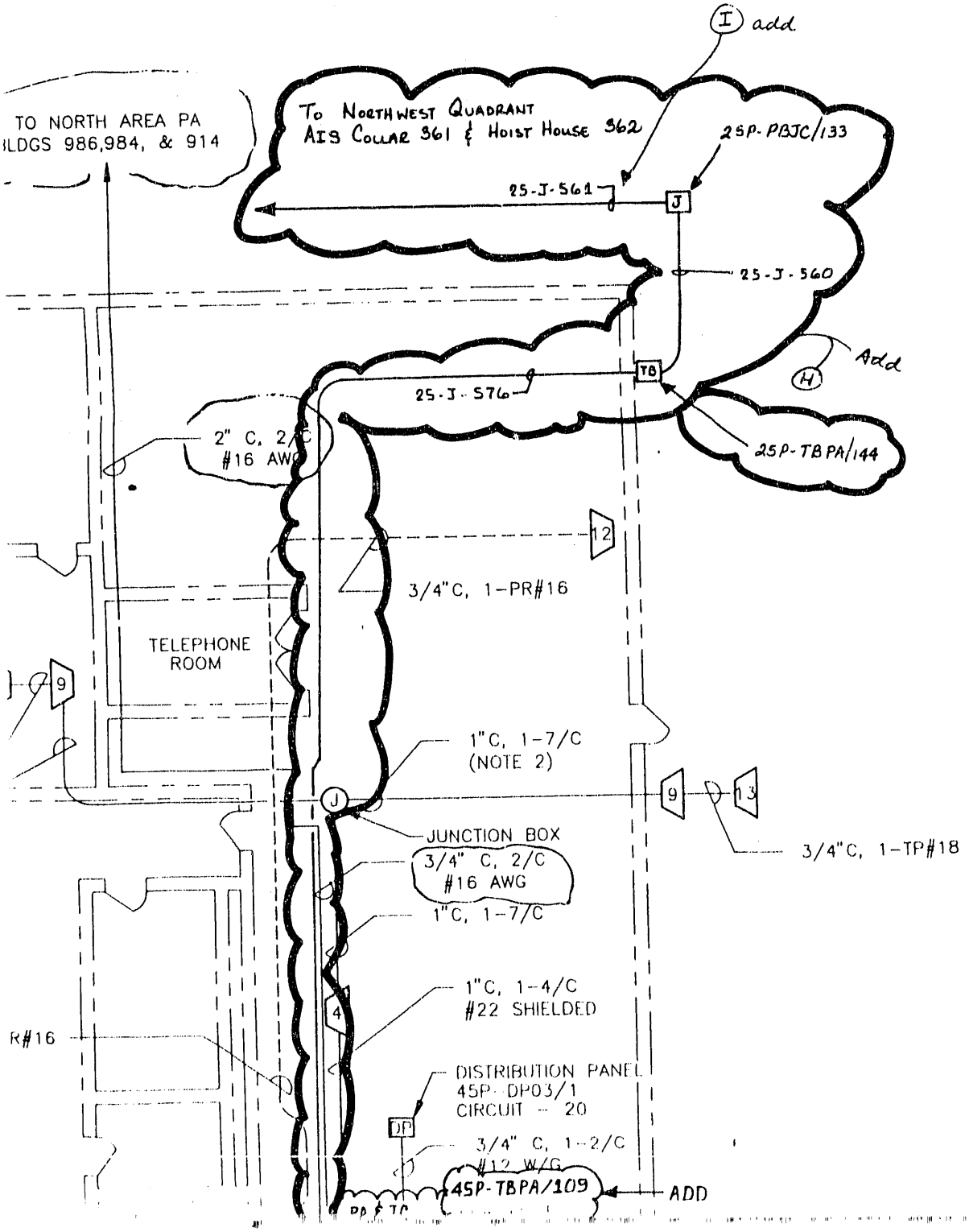
4. Drawing Cog. Engineer Approval: J. Rodney Fuston Date: 9/16/91

1290:B0006



SECTION I-I
ELEVATION VIEW
(LOOKING ~~EAST~~) WEST

JR2
9/12/91


(I) add
TO NORTH AREA PA
BLDGS 986,984, & 914
To NORTHWEST QUADRANT
AIS COLLAR 561 & HOIST HOUSE 562
25P-PBJC/133
25-J-561
J
25-J-560
Add
(H)
TB
25-J-576
25P-TBPA/144
2" C, 2/C
#16 AWG
12
3/4"C, 1-PR#16
TELEPHONE
ROOM
9
1"C, 1-7/C
(NOTE 2)
J
9
13
3/4"C, 1-TP#18
JUNCTION BOX
3/4" C, 2/C
#16 AWG
1"C, 1-7/C
4
1"C, 1-4/C
#22 SHIELDED
R#16
DISTRIBUTION PANEL
45P-DP03/1
CIRCUIT - 20
DP
3/4" C, 1-2/C
#12 W/G
45P-TBPA/109
ADD

Drawing No. 73-J-022-W Rev. B
ECO No 5226
Page 7 of 14

NOT REQUIRED THIS DRAWING DO NOT ADD

ADD

CONDUIT LEGEND

DESIGN/INSTALLATION INFORMATION					OPERATIONS INFORMATION			
CONDUIT NUMBER	SIZE	TYPE	ORIGIN	DESTINATION	VOLTAGE	DISCONNECT DEVICE	P & ID DRAWING	LOCATION DRAWING
25-J-558	4.00	PVC	25P-PBJC/136	25P-PBJC/137	120	N/A	N/A	24-C-012-W
559	2.00	RGS/PVC	25P-PBJC/137	25P-TBFA/141				
560	4.00		25P-TBPA/144	25P-PBJC/133		45P-DP03/1 SPARE	73-J-014-W	
561		PVC	25P-PBJC/133	134				
562			134	135				
563			135	136				
564			136	137				
565	2.00	RGS/PVC	137	25P-TBPA/145				
566	1.00	RGS	25P-TBPA/145	73-P-015 HANDSET STA.				
567			73-P-015 HANDSET STA.	918A-PA-001 SPEAKER				
568			25P-TBPA/145	73-P-018 SPEAKER AMP				
569	2.00	RGS/PVC	73-P-018 SPEAKER AMP	918-PA-001 SPEAKER				
570	1.00	RGS	918-PA-001 SPEAKER	-002 SPEAKER				
571			-002	-003				
572	4.00	RGS	TELEPHONE ROOM WHSE453	25P-PBJ/138	FIBER OPTIC			
573	4.00	RGS		25P-PBJ/139				
575	2.00	RGS	WHSE 453 LPU	25P-PBFA/138	120	N/A	N/A	
576	2.00	RGS	45P-TBPA/109	25P-TBPA/144	120		73-J-022-W	
578			WHSE 453 LPU	28P-PBJ/143 (RESERVED)			RESERVED	
577	2.00	RGS/PVC	25P-PBJC/137	25P-PBFA/147	N/A			

LIST OF MATERIALS

EQUIPMENT NUMBER	ORDERING INFORMATION					MATERIAL SPECIFICATION		NOTE
	QTY REQ.	VENDOR	PART NO.	DESCRIPTION	NOTE	NUMBER	PARAGRAPH	
25P-TBPA/144	1	HOFFMAN	A-20H20BLP	SINGLE DOOR NEMA TYPE 4	1	E-P-246	3.2.1.b.1, 3.2.2.c,d	1. See Table 1 for Nameplate Engraving Schedule
	1		A-20P20	17" x 17" INTERIOR PANEL			3.2.3.b.c	
/145	1		A-L2BR	KEY LOCKING HANDLE				
	1		A-20T	TERMINAL STRAP				

Add

DRAWING NO. 73-J-022-W REV. B ECO. NO. 5

NAMEPLATE SCHEDULE (1/2 INCH LETTERS)

ENCLOSURE JRJ 8/23/91 TABLE 1

ITEM NO.	~~INSTRUMENT~~ TAG NO	COLOR	SIZE	LINE 1	LINE 2	LINE 3
1	25P-TBPA/144	BLACK	AS REQ	25P-TBPA/144	PUBLIC ADDRESS	TERMINAL BOX
2	↓ 145	↓	↓	↓ /145	↓	↓
3	[illegible]	↓	↓	[illegible]	↓	↓
4	↓ /6	↓	↓	↓ /6	↓	↓
5						
6						
7						
8						
9						
10						
11						
12						
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14						
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17						
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21						
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26						
27						
28						
29						
30						
31						
32						
33						
34						

Do Not Add
Not Required
This Dwg

Add

ATTACHMENT C: NAMEPLATE STANDARDS
REFERENCE. E-P-309 PARA. 3.2.12

Drawing No 73-J-022-W Rev 1
ECO No 5776
Page 4 of 14

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

Page 10 of 14 JR3 9/13/91

1. Drawing: 73-J-014-W ECO Number: 5776

2. ECO Search List: 4608, 5141, 5166

3. Description of Change:

A. ADD THE FOLLOWING IN-GROUND PULL BOXES. SEE PAGE 11. JR3 9/13/91

25P-PBJC/133
134
135
136
137

B. ADD THE FOLLOWING SURFACE TERMINAL BOXES: SEE PAGE 12 JR3 9/13/91

25P-TBPA/144 ↓ 145 33P-TBPA/5 ↓ 6

C. ADD THE FOLLOWING CONDUIT. SEE PAGE 12 JR3 9/11/91 JR3 9/13/91

25-J-560 to 25-J-565 33-J-005 ↓ 006

D. ADD CONDUIT SCHEDULE TO DWG. SEE PAGE 13 JR3 9/13/91

E. ADD JUNCTION BOX SCHEDULE TO DWG. SEE PAGE 14. JR3 9/13/91

4. Drawing Cog. Engineer Approval: J. Rodney Juston Date: 9/11/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

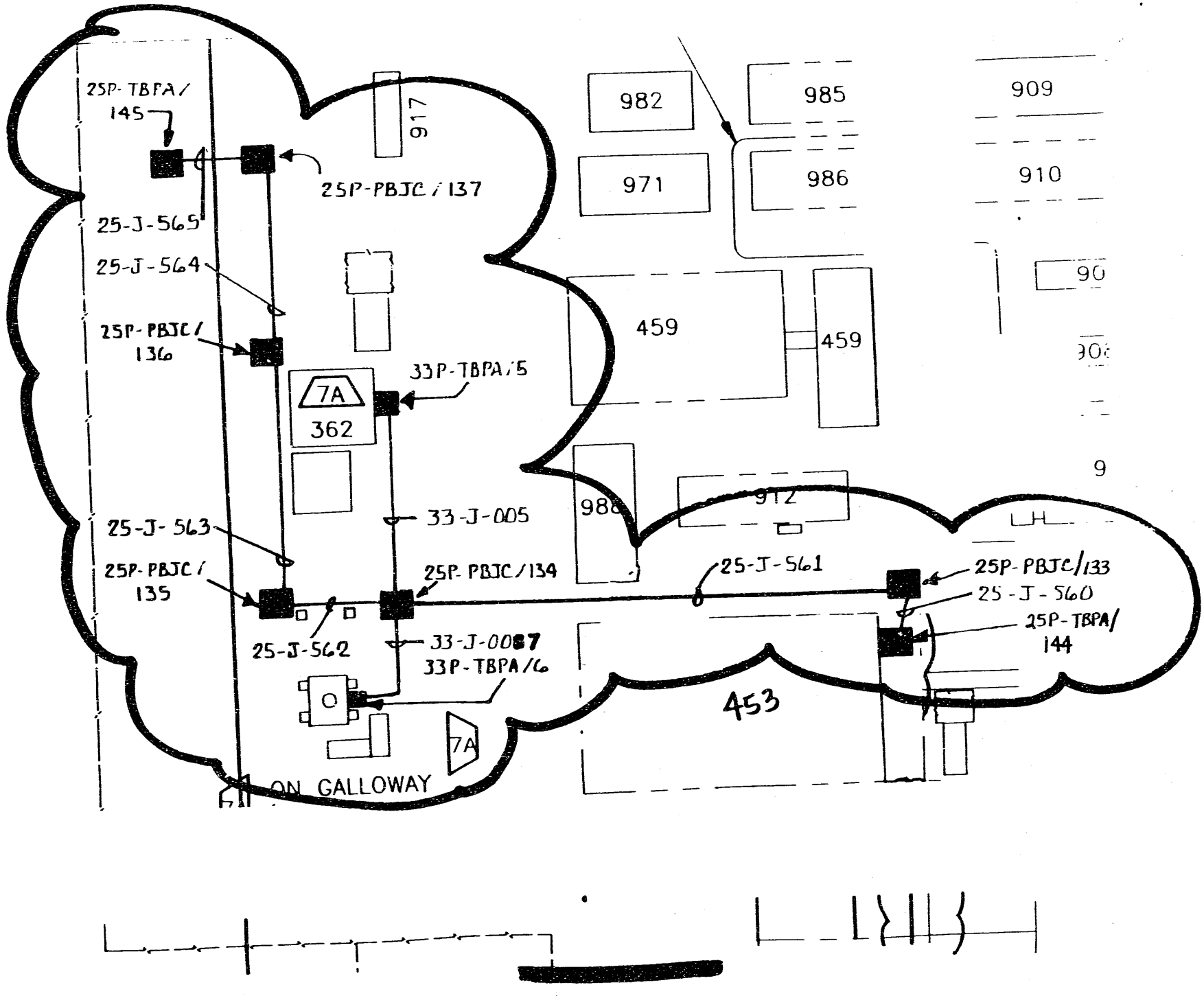
Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date



DRAWING NO. 73-J-014-W REV. B
ECO NO. 5776
PAGE 11 OF 14
9/13/11

DO NOT ADD.
NOT REQUIRED
THIS DWG.

ADP

CONDUIT LEGEND

DESIGN/INSTALLATION INFORMATION					OPERATIONS INFORMATION			
CONDUIT NUMBER	SIZE	TYPE	ORIGIN	DESTINATION	VOLTAGE	DISCONNECT DEVICE	P & ID DRAWING	LOCATION DRAWING
25-J 558	4.00	PVC	25P-PBJC/136	25P-PBJC/137	120	N/A	N/A	24-C-012-W
559	2.00	RGS/PVC	25P-PBJC/137	25P-TBFA/141				
560	4.00	↓	25P-TBPA/144	25P-PBJC/133		45P-DP03/1 CKTS 1&2	73-J-014-W	
561		PVC	25P-PBJC/133	134				
562			134	135				
563			135	136				
564			136	137				
565	2.00	RGS/PVC	137	25P-TBPA/145				
566	1.00	RGS	25P-TBPA/145	73-P-015 HANDSET STA.				
567			73-P-015 HANDSET STA.	918A-PA-001 SPEAKER				
568			25P-TBPA/145	73-P-018 SPEAKER AMP				
569	2.00	RGS/PVC	73-P-018 SPEAKER AMP	918-PA-001 SPEAKER				
570	1.00	RGS	918-PA-001 SPEAKER	-002 SPEAKER				
571			-002	-003				
572	4.00	RGS	TELEPHONE ROOM WHSE 453	25P-PBJ/139	FIBER OPTIC			
573	4.00	RGS	↓	25P-PBJ/139	↓	N/A	N/A	
578	2.00	RGS	WHSE 453 LPU	25P-PBFA/138	120		73-J-022-W	
576	2.00	RGS	45P-TBPA/109	25P-TBPA/144	120		RESERVED	
574			WHSE 453 LPU	25P-PBJ/143 (RESERVED)				
577	2.00	RGS/PVC	25P-PBJC/137	28P-[illegible]A/147	N/A			

Dwg 73-J-014-W Rev 13
ECC No. 5776
Page 14 of 14
9/13/01

Do Not ADD. Not REQUIRED THIS Dwg.

CONDUIT LEGEND

DESIGN/INSTALLATION INFORMATION					OPERATIONS INFORMATION			
CONDUIT NUMBER	SIZE	TYPE	ORIGIN	DESTINATION	VOLTAGE	DISCONNECT DEVICE	P & ID DRAWING	LOCAT. DRAWI.
33-J-005	2.00	RGS/PVC	25P-PBJC/134	33P-TBPA/5	120 V		73-J-014-W	24-C-012-W
A	1.00	RGS	33P-TBPA/5	73-P-016 HANDSET STA.				
B			73-P-016 HANDSET STA.	362-PA-001 Speaker				
C			33P-TBPA/5	73-P-019 SPEAKER AMP.				
D			73-P-019 SPEAKER AMP.	362-PA-002 SPEAKER				
E			362-PA-002 SPEAKER	362-PA-003 SPEAKER				
F			362-PA-003 SPEAKER	-004 SPEAKER				
33-J-006	2.00	RGS/PVC	33P-PBFA/10	25P-PBJC/134 FD/FP			N/A	
33-J-007			25P-PBJC/134	33P-TBPA/6			73-J-014-W	
A	1.00	RGS	33P-TBPA/6	73-P-020 HANDSET STA.				
B			73-P-020 HANDSET STA.	361-PA-001 SPEAKER				
C			33P-TBPA/6	73-P-020 SPEAKER AMP.				
D			73-P-020 SPEAKER AMP.	361-PA-002 SPEAKER				
E			361-PA-002 SPEAKER	361-PA-003				
F			003	004				
33-J-008	2.00	RGS/P	33P-PBEA/8	25P-PBC/134 FD/FP			N/A	
33-J-009	2.00		25P-PBJ/134	33P-PBJ/11				

ADD

Dwg No 73-J-014-W R
ECN No 5776 Page 13 of 1

LIST OF MATERIALS

	ORDERING INFORMATION				NOTE	MATERIAL SPECIFICATION		NOTE
	QTY REQ.	VENDOR	PART NO	DESCRIPTION		NUMBER	PARAGRAPH	
2SP-PBJC/1133	1	QUAZITE	PV3636BA30	3'x 3' PANEL VAULT	1	E-P-846	3.2.2.a	2. IN-GROUND PULL BOXES DO NOT RECEIVE ENGRAVED NAMEPLATES.
			PV3636CA00	3'x 3' LOCKING PANEL COVER				
			PV3636DA00	STANDARD BASE				
/1134								
/1135								
/1136								
/1137								

9/13/11 Dwg No. 73-J-0114-W Rev 13
ECO No. 5276
Page 14 of 14

ENGINEERING CHANGE ORDER 412 M 003 W

USE BLACK INK

1. ECO No.: 5821

CC&D Review: _____ Initials

Posted

2. **Impact Level** 1 ☐ 2 ☐ 3 ☒ 4 ☐

3. **System:** EM05 Equipment No.: 105-P-023 Building: U/G Rm-1

4. Associated Documents:

PWR 12080M, 12085M

ECP 2-EM91-185

P.O. 48460, 48470, 51057

Others _____

5. **Document Type:** 412-M-003-W

Drawing 52-L-002-W1 to W10, 105-M-005-W ☒

Specification 105-J-022-W ☐

Vendor Data 105-L-002-W1,W2, 105-L-003-W, 105-J-030-W ☐

SDD 105-F-013-W, 53-J-063-W2 ☐

Others _____

6. **Title of Change:** VOC-10 Modification to Carbon Bed Ass'y

7. Originator: (print)	Ext. No.:	Department:	Date:	8. Cognizant Engineer: (print)
J. R. Stroble	8374	Elec. Eng.	10/4/91	J. R. Stroble

9. **Description of Change:**

Yes ☒ No ☐ Component indices change required (if yes, attach sheets)

Change VOC-10 as follows:

1. Place the carbon bed upright on a rack
2. Place valves, tubing, and instruments associated with the carbon bed on the same rack
3. Add a flow meter/indicator just upstream of the pressure relief valve (PRV)
4. Move the PRV closer to the exit (top) of the carbon bed
5. Remove valves VC-534-TW-010, 025, 026, 027, and 008
6. change all valves and tubing from manifold to PRV to 1"
7. change all valves and tubing from PRV to sampler to 1/4"
8. Delete drawings 52-L-002-W6, W8, and W10
9. Change system designator on above drawings all to EM05

☒ 9a Drawing Change Sheet attached

☐ 9b Design Documentation Sheet attached

☐ 9c Vendor Data Change Sheet attached

10. Yes ☒ No ☐ **MODIFICATION IN PROGRESS**

☐ Modification complete: _____ / _____ (Signature / Date) — ECO will be incorporated after M.I.P. signed complete

☐ Change drawing per as-built markup dated: _____

☐ Change drawing per ECO-provided data

☐ Temporary modification

11. **Design Verification Requirements: (per WP 09-018)** EDT No.: E91-319, E91-283

_____ 1. Requirements satisfied by review/approval of design document

EDT's E-91-319, E91-283 2. Independent review

_____ 3. Alternate calculations

_____ 4. Development testing

_____ 5. Design review

_____ 6. Other: _____

12. **Addendum Sheet added:** _____ / _____ (Signature / Date)

13. Justification

1. Inverting the carbon bed will prevent the possibility of gases bypassing the carbon due to settling.
2. Associated components will need to be close to the carbon bed.
3. If the PRV opens, the amount of gas released will be unknown.
4. A 1" flow path was chosen to remain consistent with the existing system upstream of the carbon bed. This also reduces the number of pressure gradients in the system.
5. These valves are no longer necessary (See EDT E91-319).
6. Same as number 4 above.
7. 1/4" valves and line will increase the efficiency of the cleaning process.
8. This information was needed for construction, but is not needed for configuration control.

14. Administrative Tracking

YES	N/A		YES	N/A	
[X]	[ ]	1. FSAR	[X]	[ ]	6. Startup/Acceptance Test
[X]	[ ]	2. Calibration Procedures	[X]	[ ]	7. Test Requirement & Spec.
[ ]	[X]	3. Maintenance Procedures	[ ]	[ ]	8. _____
[ ]	[X]	4. Computer Software	[ ]	[ ]	9. _____
[X]	[ ]	5. Operations Procedures (D&AT)	[ ]	[ ]	10. _____

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

[A]	Cog. Engineer	[illegible]	10/24/91
[A]	Cog. Eng. Mgr.	[illegible]	10/24/91
[R]	Startup	[illegible]	10/24/91
[A]	QA	[illegible]	10/24/91
[ ]	DOE		
[A]	Safety	[illegible]	10/24/91
[ ]	Dept. Manager		
[ ]	Operations		
[ ]	Security		
[ ]	SNL		
[A]	D & AT	[illegible]	10/24/91
[A]	RWHE MGR	[illegible]	10/24/91
[ ]			

16. Distribute as Marked

[X]	Maintenance (MANDATORY)	
[ ]	Ops. Support (MANDATORY)	
[ ]	Startup	
[ ]	Facility Operations	
[ ]	U/G Operations	
[ ]	Orig./Design Engr.	
[ ]	Cog. Engineer	
[ ]	Others	
[ ]		
[ ]		
[ ]		
[ ]		
[ ]		

1. ECO # 5521
2. DATE 9-30-91

ENGINEERING CHANGE ORDER

DOE ORDER 6430.1A DESIGN CRITERIA

CHECKLIST

The design requirements in DOE Order 6430.1A checked below have been applied to this Design.

3. DIVISION	SUBDIVISION
☐ 1 General Requirements	☐ 0101 ☐ 0106 ☐ 0109 ☐ 0110 ☐ 0111 ☐ 0140 ☐ 0150 ☐ 0170
☐ 2 Site and Civil Engineering	☐ 0200 ☐ 0201 ☐ 0202 ☐ 0203 ☐ 0205 ☐ 0210 ☐ 0214 ☐ 0215 ☐ 0220 ☐ 02 ☐ 0245 ☐ 0250 ☐ 0256 ☐ 0260 ☐ 0262 ☐ 0265 ☐ 0267 ☐ 0270 ☐ 0273 ☐ 02 ☐ 0276 ☐ 0278 ☐ 0279 ☐ 0280 ☐ 0281 ☐ 0283 ☐ 0285 ☐ 0290 ☐ 0291
☐ 3 Concrete	☐ 0300 ☐ 0301 ☐ 0310 ☐ 0320 ☐ 0330 ☐ 0340 ☐ 0350 ☐ 0370 ☐ 0380
☐ 4 Masonry	☐ 0400 ☐ 0401 ☐ 0410 ☐ 0420 ☐ 0455
☐ 5 Metals	☐ 0500 ☐ 0512 ☐ 0514 ☐ 0521 ☐ 0531 ☐ 0532
☐ 6 Wood and Plastics	☐ 0600 ☐ 0610 ☐ 0650
☐ 7 Thermal and Moisture Protection	☐ 0710 ☐ 0711 ☐ 0714 ☐ 0715 ☐ 0719 ☐ 0720 ☐ 0721 ☐ 0722 ☐ 0724 ☐ 07 ☐ 0730 ☐ 0750 ☐ 0751 ☐ 0753 ☐ 0760 ☐ 0790
☐ 8 Doors and Windows	☐ 0800 ☐ 0810 ☐ 0820 ☐ 0830 ☐ 0833 ☐ 0836 ☐ 0839 ☐ 0850 ☐ 0860 ☐ 08 ☐ 0880
☐ 9 Finishes	☐ 0900 ☐ 0910 ☐ 0920 ☐ 0925 ☐ 0930 ☐ 0950 ☐ 0965 ☐ 0968 ☐ 0970 ☐ 09 ☐ 0990 ☐ 0995
☐ 10 Specialties	☐ 1015 ☐ 1020 ☐ 1024 ☐ 1027 ☐ 1030 ☐ 1040 ☐ 1050 ☐ 1052 ☐ 1053 ☐ 10 ☐ 1060 ☐ 1065 ☐ 1070 ☐ 1075 ☐ 1080
☐ 11 Equipment	☐ 1100 ☐ 1161
☐ 12 Furnishings	☐ 1201 ☐ 1230 ☐ 1250 ☐ 1260 ☐ 1270
☐ 13 Special Facilities	☐ 1300 ☐ 1304 ☐ 1305 ☐ 1306 ☐ 1307 ☐ 1318 ☐ 1319 ☒ 1320 ☐ 1321 ☐ 13 ☐ 1323 ☐ 1324 ☐ 1325 ☒ 1326 ☐ 1328
☐ 14 Conveying Systems	☐ 1401 ☐ 1420 ☐ 1440 ☐ 1460
☐ 15 Mechanical	☐ 1525 ☐ 1530 ☒ 1540 ☒ 1550 ☒ 1555 ☐ 1565 ☒ 1574 ☐ 1589 ☐ 1595
☐ 16 Electrical	☐ 1600 ☐ 1605 ☐ 1620 ☐ 1630 ☐ 1639 ☐ 1640 ☐ 1650 ☐ 1655 ☐ 1660 ☐ 16 ☐ 1671 ☐ 1685 ☐ 1694
4. ☐ NOT APPLICABLE	No portion of DOE Order 6430.1A is applicable to this Design.
5. ☐ AS-BUILT	ECO is for as-built field verified changes only.

NOTE: A check placed in the Division column signifies that the entire Division shall be applicable to the Design, unless modified by checks indicated for specific Subdivisions.

COMMENTS: _____

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 52-L-001-W ECO Number: 5821

2. ECO Search List: _____ _____ _____ _____

3. Description of Change:

1. CHANGE THE PIPING SIZE AND ARRANGEMENT FROM THE CARBON BED + VOST TUBES TO THE SAMPLER.
2. DELETE VALVES VC-534-TW-010, 025, 026 + 027, + 008
3. ADD A FLOW METER AND THREE 2-WAY VALVES.
4. DELETE SYSTEM BOUNDARIES BETWEEN EM05 + WH06. (THE WHOLE SYSTEM + DRAWINGS ARE NOW EM05)
5. CHANGE BILL OF MATERIALS.
6. ADD DRAWING REFERENCES.
7. CHANGE SYSTEM DESIGNATOR TO JUST EM05

SEE ATTACHED PAGES.

4. Drawing Cog. Engineer Approval: J.R. Stubbe Date: 10-7-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

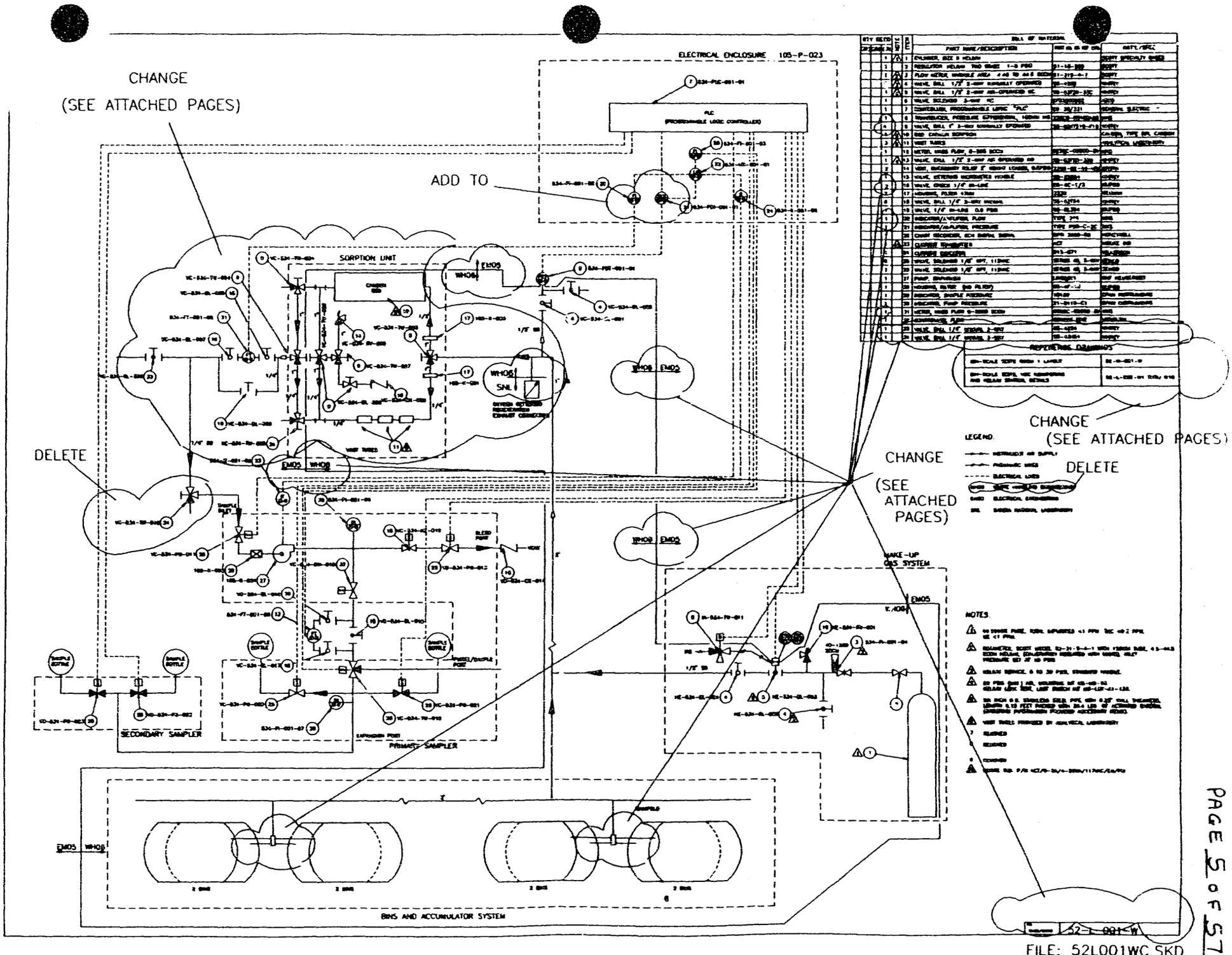
Assigned to: _____ (Same as data base entry)

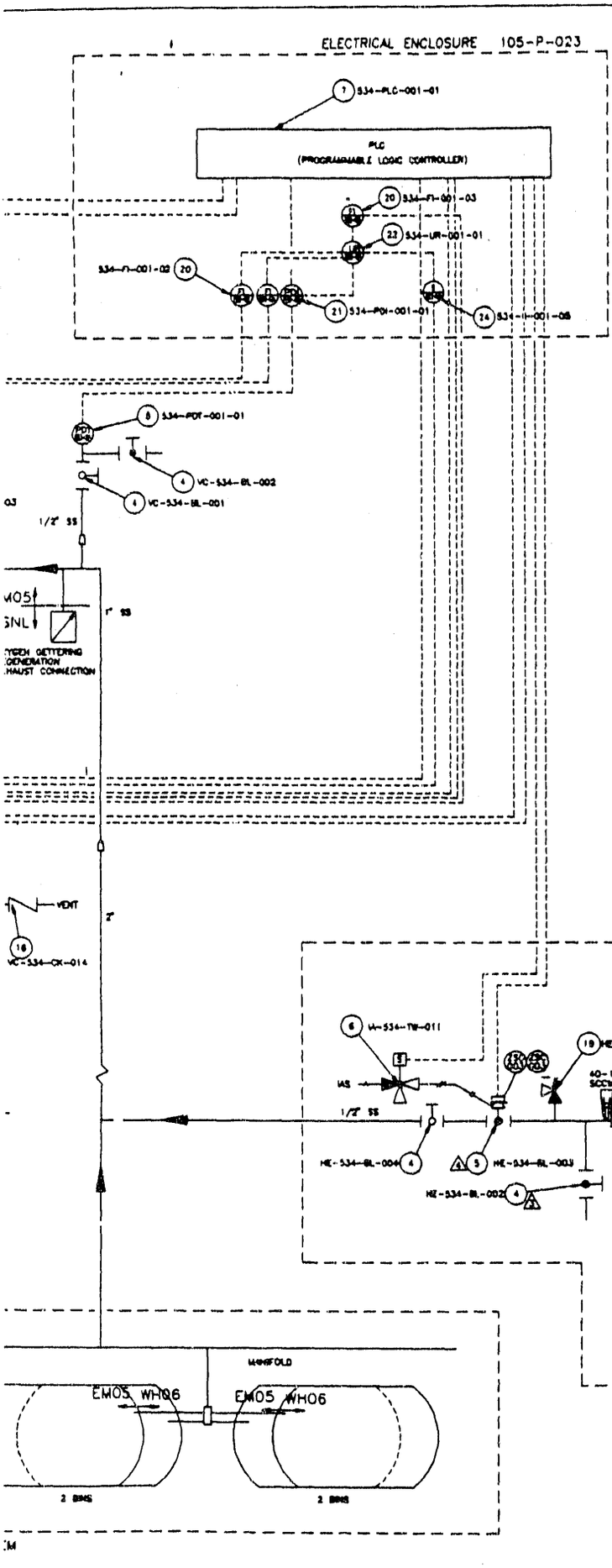
Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

1290:B0006


CHANGE
(SEE ATTACHED PAGES)
ADD TO
ELECTRICAL ENCLOSURE 105-P-023
SORPTION UNIT
DELETE
CHANGE
(SEE ATTACHED PAGES)
DELETE
CHANGE
(SEE ATTACHED PAGES)
SECONDARY SAMPLER
PRIMARY SAMPLER
MAKE-UP GAS SYSTEM
BINS AND ACCUMULATOR SYSTEM
LEGEND
NOTES
FILE: 52L001WC.SKD



QTY REQD	NOTE	ITEM	PART NAME/DESCRIPTION	PART NO. OR REF. NO.	MFR./SPEC
1	1	1	CYLINDER, SIZE K HELIUM		SCOTT SPECIALTY GASES
1		2	REGULATOR, HELIUM TWO STAGE 1-5 PSIG	81-10-580	SCOTT
1	2	3	FLOW METER, VARIABLE AREA 4.46 TO 44.6 SCCM	31-315-4-1	SCOTT
4	3	4	VALVE, BALL 1/2" 3-WAY MANUALLY OPERATED	SS-4P6W	WHITEY
1	4	5	VALVE, BALL 1/2" 2-WAY AIR-OPERATED NC	SS-43TS4-13C	WHITEY
1		6	VALVE, SOLENOID 3-WAY NC	0711J00203	ASCO
1		7	CONTROLLER, PROGRAMMABLE LOGIC "PLC"	98-30/331	GENERAL ELECTRIC
1		8	TRANSDUCER, PRESSURE DIFFERENTIAL, 100mm HG	229CD-00100A2B	MKS
2		9	VALVE, BALL 1" 3-WAY MANUALLY OPERATED	SS-65T316-F16	WHITEY
1	5	10	BED, CARBON SORPTION		CALGON, TYPE BPL CARBON
3	6	11	VOST TUBES		ANALYTICAL LABORATORY
1		12	METER, MASS FLOW, 0-500 SCCM	825MC-00500-SV	MKS
1	4	13	VALVE, BALL 1/2" 3-WAY AIR OPERATED NO	SS-43TS2-13D	WHITEY
2		14	VENT, EMERGENCY RELIEF 2" WIDDHT LOADED, 0.5PSIG	2300-02-44-V00	GROTH
1		15	VALVE, METERING MICROMETER HANDLE	SS-22094	WHITEY
1		16	VALVE, CHECK 1/4" IN-LINE	SS-4C-1/3	NUPRO
2		17	HOUSING, FILTER 47MM	2220	GELMAN
8		18	VALVE, BALL 1/4" 2-WAY MANUAL	SS-42T54	WHITEY
1		19	VALVE, 1/4" IN-LINE 0.8 PSIG	SS-4L154	NUPRO
2		20	INDICATOR/AMPLIFIER, FLOW	TYPE 240	MKS
1		21	INDICATOR/AMPLIFIER, PRESSURE	TYPE PDR-C-1C	MKS
1		22	CHART RECORDER, 8CH DIGITAL SIGNAL	DPR 3000-03	HONEYWELL
1	7	23	CURRENT TRANSMITTER	ADT	MOORE IND
1		24	CURRENT INDICATOR	015-671	WILKERSON
8		25	VALVE, SOLENOID 1/8" NPT, 115VAC	SERIES 40, 2-WAY	EDMCO
1		26	VALVE, SOLENOID 1/8" NPT, 115VAC	SERIES 40, 3-WAY	EDMCO
1		27	PUMP, DIAPHRAGM	UNOOSSN1	KNF NEUBERGER
1		28	HOUSING, FILTER (NO FILTER)	SS-4F-15	NUPRO
1		29	INDICATOR, SAMPLE PRESSURE	1D100	SPAN INSTRUMENTS
1		30	INDICATOR, PUMP PRESSURE	21-0118-01	SPAN INSTRUMENTS
2		31	METER, MASS FLOW 0-5000 SCCM	825BC-05000-SV	MKS
1		32	CONTROLLER, FLOW	SC4235 FME	VERIFLOW
4		33	VALVE, BALL 1"	SS-65T316-4	WHITEY
1		34	VALVE, CHECK 1"	SS-1RC-1/3	WHITEY
1		35	METER, MASS FLOW, 0-10000 SCCM, 1"	0.388C-10000SV	MKS

REFERENCE DRAWINGS

BIN SCALE TESTS ROOM 1 LAYOUT	52-M-001-W
BIN SCALE TESTS, VOC(10) MONITORING SYSTEM PIPING AND INSTRUMENT DIAGRAM (P&ID)	52-L-001-W
BIN SCALE TESTS, VOC(10) MONITORING SYSTEM LAYOUT, FLOW SCHEME, AND DETAILS	52-L-002-W
BIN SCALE TESTS, VOC(10) MONITORING SYSTEM SAMPLER ASSEMBLY 105-S-008	105-F-013-W
BIN SCALE TESTS, VOC(10) MONITORING SYSTEM INSTRUMENT LOOPS AND ALARMS WIRING	105-H-005-W
BIN SCALE TESTS, VOC(10) MONITORING SYSTEM PLC WIRING 534-PLC-001-01	105-J-022-W
BIN SCALE TESTS, VOC(10) MONITORING SYSTEM SAMPLER WIRING 105-S-008	105-J-030-W
BIN SCALE TESTS, VOC(10) MONITORING SYSTEM ELECTRICAL ENCLOSURE 105-P-023	105-L-002-W
BIN SCALE TESTS, VOC(10) MONITORING SYSTEM PLAN ARRANGEMENT	105-L-003-W
BIN SCALE TESTS, VOC(10) MONITORING SYSTEM CARBON SORPTION BED	412-M-003-W

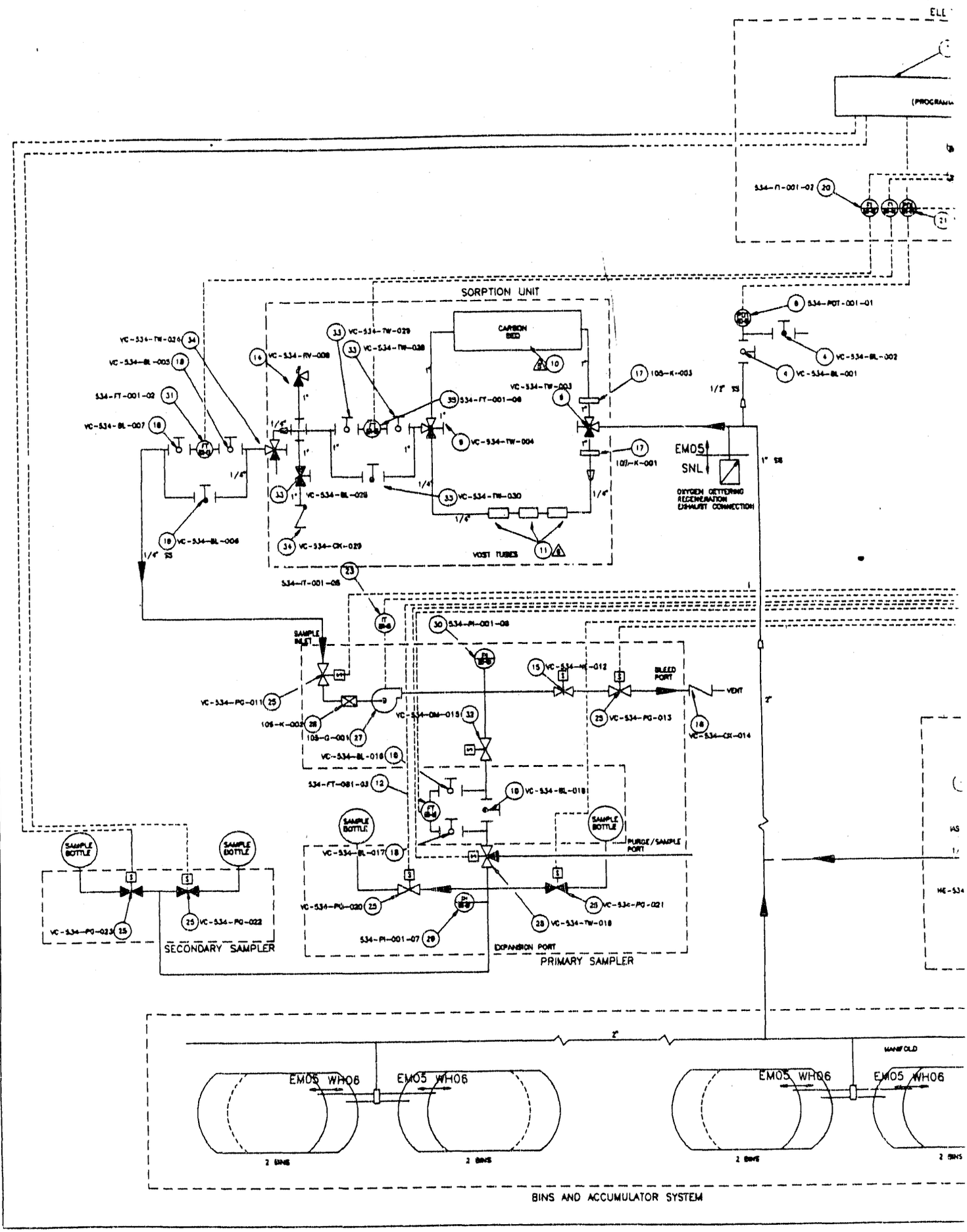
NOTES:

1. 99.999% PURE, TOTAL IMPURITIES <1 PPM, THC <0.2 PPM. NE <1 PPM.
2. ROTAMETER, SCOTT MODEL 32-31-S-4-1 WITH 150MM TUBE, 4.5-44.6 SCCM HELIUM, (CALIBRATION REQUIRED WITH UNITS), INLET PRESSURE SET AT 10 PSIG.
3. HELIUM SERVICE, 0 TO 30 PSIG, STANDARD HANDLE.
4. 80 PSIG (MIN.) AIR, MOUNTING KIT MS-MB-63, HELIUM LEAK TEST, LIMIT SWITCH KIT MS-LSK-A1-133.
5. SIX INCH O.D. STAINLESS STEEL PIPE WITH 0.25" WALL THICKNESS, LENGTH 6.15 FEET PACKED WITH 24.4 LBS. OF ACTIVATED CARBON, (ORDERING INFORMATION PROVIDED ACCESSORY ITEMS).
6. VOST TUBES PROVIDED BY ANALYTICAL LABORATORY
7. REMOVED
8. REMOVED
9. REMOVED
10. MOORE IND P/N ACT/0-5A/4-20MA/115VAC/EM/PM

BIN SCALE TESTS, VOC(10) MONITORING SYSTEM
PIPING AND INSTRUMENT DIAGRAM (P&ID)

EM05 | 52-L-001-W

FILE: 52L001WB.SKD


SORPTION UNIT
CARBON BED
VOST TUBES
EMOS
SNL
OXYGEN GETTERING REGENERATION EXHAUST CONNECTION
SAMPLE BOTTLE
SECONDARY SAMPLER
PRIMARY SAMPLER
EXPANSION PORT
PURGE/SAMPLE PORT
BLEED PORT
VENT
MANIFOLD
EMOS WH06
2 BINS
BINS AND ACCUMULATOR SYSTEM

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-W1 ECO Number: 5521

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

1. CHANGE THE SYSTEM DESIGNATOR TO EM05
2. CHANGE THE TITLE TO:

   BINSCALE TESTS, VOC (10) MONITORING SYTEM
   PANEL-1, ROOM-1 LAYOUT
3. CHANGE THE MATERIALS LIST ~~ON~~ AS SHOWN ON ATTACHED* PAGES
4. CHANGE THE "TABLE" TO A "RACK

4. Drawing Cog. Engineer Approval: J.R. Stubbe Date: 10-7-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

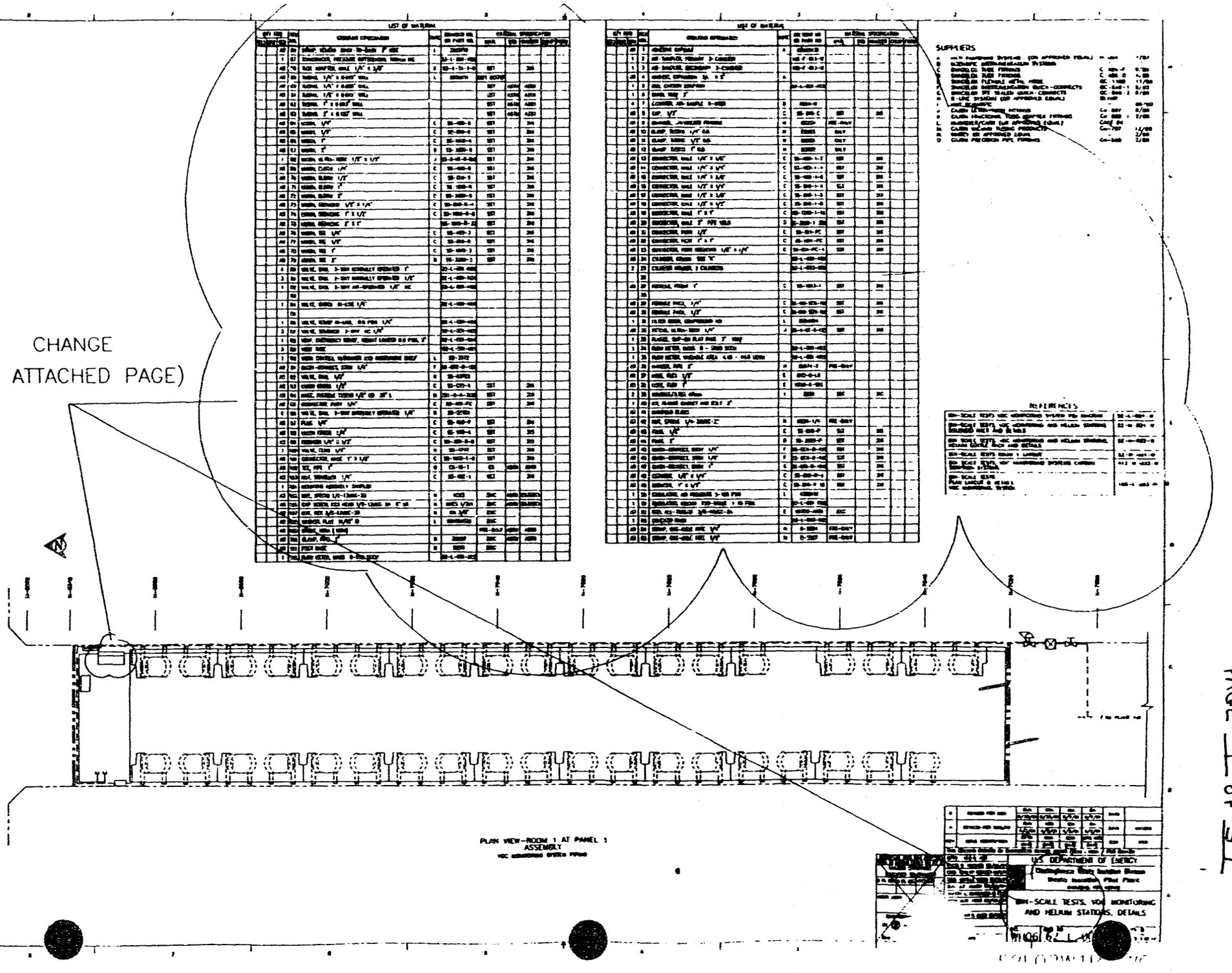
Date Assigned: _____ Initials / Date

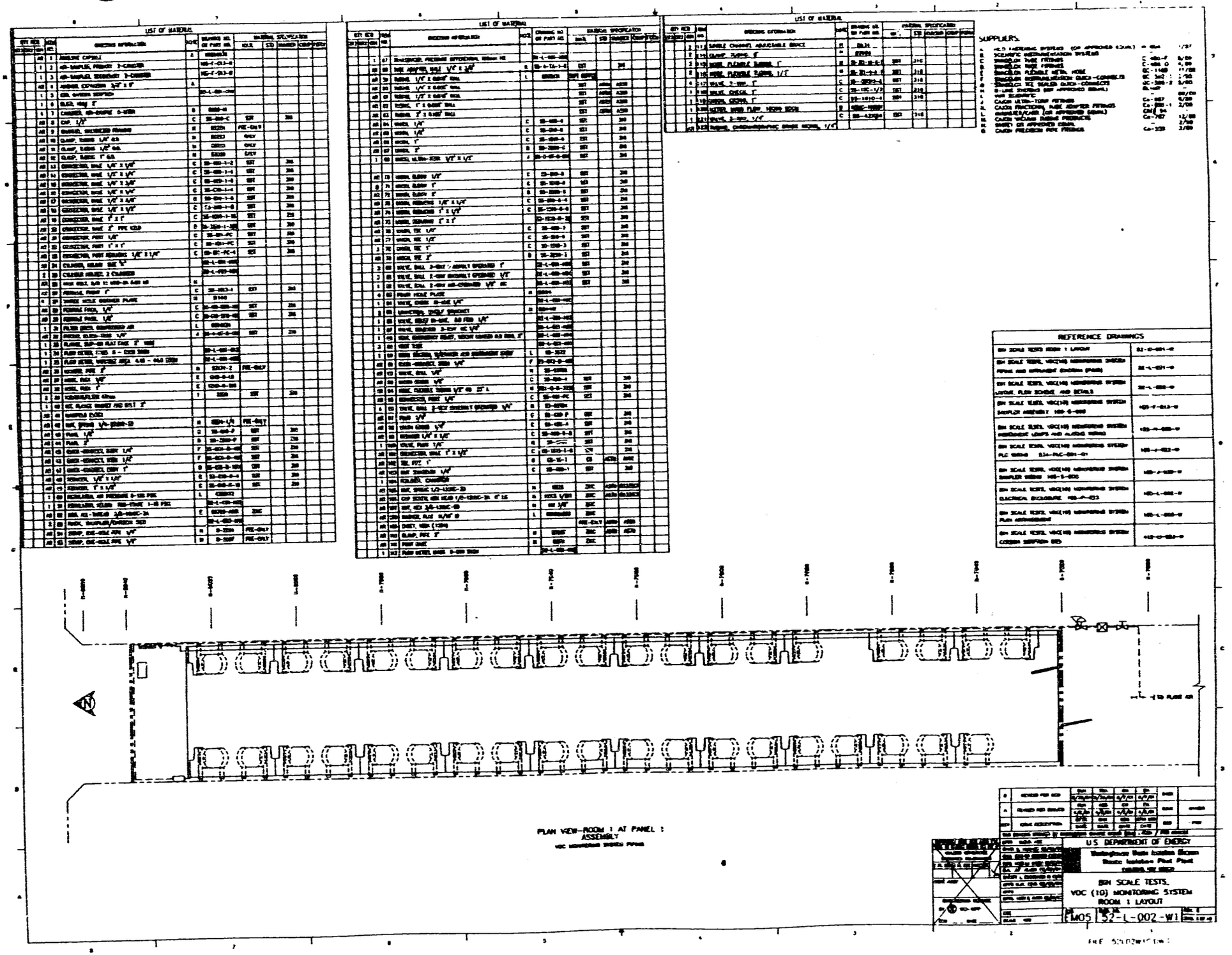
Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

CHANGE
(SEE ATTACHED PAGE)




LIST OF MATERIAL
LIST OF MATERIAL
LIST OF MATERIAL
SUPPLIERS
REFERENCE DRAWINGS
PLAN VIEW—ROOM 1 AT PANEL 1
ASSEMBLY
U.S. DEPARTMENT OF ENERGY
Washington State Isolation Division
Waste Isolation Pilot Plant
BIN SCALE TESTS
VOC (10) MONITORING SYSTEM
ROOM 1 LAYOUT
WIPP
WMO
52-L-002-W1

LIST OF MATERIAL

QTY REQ GR3	QTY REQ GR2	QTY REQ GR1	ITEM NO	ORDERING INFORMATION	NOTE	DRAWING NO OR PART NO	MATERIAL SPECIFICATION MATL	STD	NUMBER	COMP	FORM
		AR	1	ADHESIVE CAPSULE	A	00068038					
		1	2	AIR-SAMPLER, PRIMARY 2-CANISTER		105-F-013-W					
		1	3	AIR-SAMPLER, SECONDARY 2-CANISTER		105-F-013-W					
		AR	4	ANCHOR, EXPANSION 3/8" X 5"	A						
		1	5	BED, CARBON SORPTION		52-L-001-H10					
		1	6	BLIND, 150# 2"							
		4	7	CANISTER, AIR-SAMPLE 6-LITER	B	0650-M					
		AR	8	CAP, 1/2"	C	SS-810-C	SST		316		
		AR	9	CHANNEL, GALVINEZED FRAMING	H	B22SH	PRE-GALV				
		AR	10	CLAMP, TUBING 1/4" O.D.	H	B2023	GALV				
		AR	11	CLAMP, TUBING 1/2" O.D	H	B2026	GALV				
		AR	12	CLAMP, TUBING 1" O.D.	H	B2029	GALV				
		AR	13	CONNECTOR, MALE 1/4" X 1/8"	C	SS-400-1-2	SST		316		
		AR	14	CONNECTOR, MALE 1/4" X 1/4"	C	SS-400-1-4	SST		316		
		AR	15	CONNECTOR, MALE 1/4" X 3/8"	C	SS-400-1-6	SST		316		
		AR	16	CONNECTOR, MALE 1/2" X 1/4"	C	SS-810-1-4	SST		316		
		AR	17	CONNECTOR, MALE 1/2" X 3/8"	C	SS-810-1-6	SST		316		
		AR	18	CONNECTOR, MALE 1/2" X 1/2"	C	SS-810-1-8	SST		316		
		AR	19	CONNECTOR, MALE 1" X 1"	C	SS-1610-1-16	SST		316		
		AR	20	CONNECTOR, MALE 2" PIPE WELD	D	SS-3200-1-32W	SST		316		
		AR	21	CONNECTOR, PORT 1/2"	C	SS-811-PC	SST		316		
		AR	22	CONNECTOR, PORT 1" X 1"	C	SS-1611-PC	SST		316		
		AR	23	CONNECTOR, PORT REDUCING 1/2" X 1/4"	C	SS-811-PC-4	SST		316		
		AR	24	CYLINDER, HELIUM SIZE "K"		52-L-001-H01					
		2	25	CYLINDER HOLDER, 2 CYLINDERS		52-L-003-H01					
		AR	26	KWIK COLT 5/8 11 UNC-2A 6.00 LG	H						
		AR	27	FERRULE, FRONT 1"	C	SS-1613-1	SST		316		
		4	28	THREE HOLE CORNER PLATE	H	B140					
		AR	29	FERRULE PACK, 1/4"	C	SS-400-SETS-100	SST		316		
		AR	30	FERRULE PACK, 1/2"	C	SS-810-SETS-100	SST		316		
		1	31	FILTER DRIER, COMPRESSED AIR	L	9994K24					
		AR	32	FITTING, ULTRA-TORR 1/4"	J	SS-4-UT-6-400	SST		316		
		1	33	FLANGE, SLIP-ON FLAT FACE 2" 150#							
		1	34	FLOW METER, MASS 0 - 5000 SCCM		52-L-001-H12					
		1	35	FLOW METER, VARIABLE AREA 4.46 - 44.6 SCCM		52-L-001-H03					
		AR	36	HANGER, PIPE 2"	H	B3174-2	PRE-GALV				
		AR	37	HOSE, FLEX 1/2"	E	8H0-6-L8					
		AR	38	HOSE, FLEX 1"	E	16H0-6-S16					
		2	39	HOUSING,FILTER 47mm	I	2220	SST		316		
		1	40	KIT, FLANGE GASKET AND BOLT 2"							
		AR	41	MANIFOLD BLOCK							
		AR	42	NUT, SPRING 1/4-20UNC-2B	H	N224-1/4	PRE-GALV				
		AR	43	PLUG, 1/2"	C	SS-810-P	SST		316		
		AR	44	PLUG, 2"	D	SS-3200-P	SST		316		
		AR	45	QUICK-CONNECT, BODY 1/4"	F	SS-QC4-B-400	SST		316		
		AR	46	QUICK-CONNECT, STEM 1/4"	F	SS-QC4-D-400	SST		316		
		AR	47	QUICK-CONNECT, BODY 1"	G	SS-QC8-B-1610	SST		316		
		AR	48	REDUCER, 1/2" X 1/4"	C	SS-810-R-4	SST		316		
		AR	49	REDUCER, 1" X 1/2"	C	SS-810-R-16	SST		316		
		1	50	REGULATOR, AIR PRESSURE 5-125 PSIG	L	4328K12					
		1	51	REGULATOR, HELIUM TWO-STAGE 1-15 PSIG		52-L-001-H02					
		AR	52	ROD, ALL-THREAD 3/8-16UNC-2A	E	96790-A031	ZINC				
		2	53	RACK, SAMPLER/CARBON BED		52-L-003-H01					
		AR	54	STRAP, ONE-HOLE PIPE 1/4"	H	B-2084	PRE-GALV				
		AR	55	STRAP, ONE-HOLE PIPE 1/2"	H	B-2087	PRE-GALV				

LIST OF MATERIAL

QTY REQ GR3	QTY REQ GR2	QTY REQ GR1	ITEM NO.	ORDERING INFORMATION	NOTE	DRAWING NO. OR PART NO.	MATERIAL SPECIFICATION MATL	STD	NUMBER	COMP	FORM
		1	57	TRANSDUCER, PRESSURE DIFFERENRIAL 100mm HC		52-L-001-H08					
		AR	58	TUBE ADAPTER, MALE 1/4" X 3/8"	K	SS-4-TA-1-6	SST		316		
		AR	59	TUBING, 1/4" X 0.049" WALL	L	8955K11	SOFT COPPER				
		AR	60	TUBING, 1/4" X 0.028" WALL			SST	ASTM	A269		
		AR	61	TUBING, 1/2" X 0.049" WALL			SST	ASTM	A269		
		AR	62	TUBING, 1" X 0.083" WALL			SST	ASTM	A269		
		AR	63	TUBING, 2" X 0.188" WALL			SST	ASTM	A269		
		AR	64	UNION, 1/4"	C	SS-400-6	SST		316		
		AR	65	UNION, 1/2"	C	SS-810-6	SST		316		
		AR	66	UNION, 1"	C	SS-1610-6	SST		316		
		AR	67	UNION, 2"	D	SS-3200-6	SST		316		
		1	68	UNION, ULTRA-TORR 1/2" X 1/2"	J	SS-8-UT-6-810	SST		316		
		AR	70	UNION, ELBOW 1/2"	C	SS-810-9	SST		316		
		8	71	UNION, ELBOW 1"	C	SS-1610-9	SST		316		
		AR	72	UNION, ELBOW 2"	D	SS-3200-9	SST		316		
		AR	73	UNION, REDUCING 1/2" X 1/4"	C	SS-810-6-4	SST		316		
		AR	74	UNION, REDUCING 1" X 1/2"	C	SS-1610-6-8	SST		316		
		AR	75	UNION, REDUCING 2" X 1"		SS-1610-R-32	SST		316		
		AR	76	UNION, TEE 1/4"	C	SS-400-3	SST		316		
		AR	77	UNION, TEE 1/2"	C	SS-810-9	SST		316		
		3	78	UNION, TEE 1"	C	SS-1610-3	SST		316		
		AR	79	UNION, TEE 2"	D	SS-3200-3	SST		316		
		2	80	VALVE, BALL 3-WAY MANUALLY OPERATED 1"		52-L-001-H09	SST		316		
		3	81	VALVE, BALL 2-WAY MANUALLY OPERATED 1/2"		52-L-001-H04	SST		316		
		1	82	VALVE, BALL 2-WAY AIR-OPERATED 1/2" NC		52-L-001-H05	SST		316		
		4	83	FOUR HOLE PLATE	H	B504					
		1	84	VALVE, CHECK IN-LINE 1/4"		52-L-001-H16					
		2	85	UNIVERSAL SHELF BRACKET	H	B844W					
		1	86	VALVE, RELIEF IN-LINE, 0.8 PSIG 1/4"		52-L-001-H19					
		1	87	VALVE, SOLENOID 3-WAY NC 1/4"		52-L-001-H06					
		1	88	VENT, EMERGENCY RELIEF, WEIGHT LOADED 0.8 PSIG, 2"		52-L-001-H14					
		3	89	VOST TUBE		52-L-001-H11					
		1	90	WORK STATION, W/DRAWER AND INSTRUNENT SHELF	L	SB-3672					
		AR	91	QUICK-CONNECT, STEM 1/4"	F	SS-QT2-D-400					
		AR	92	VALVE, BALL 1/2"	N	SS-63TS8					
		AR	93	UNION CROSS 1/2"	C	SS-810-4	SST		316		
		AR	94	HOSE, FLEXIBLE TUBING 1/2" OD 36" L	M	321-8-X-3682	SST		316		
		AR	95	CONNECTOR, PORT 1/4"	C	SS-401-PC	SST		316		
		4	96	VALVE, BALL 2-WAY MANUALLY OPERATED 1/4"	N	SS-62TS4					
		AR	97	PLUG 1/4"	C	SS-400-P	SST		316		
		AR	98	UNION CROSS 1/4"	C	SS-400-4	SST		316		
		AR	99	REDUCER 1/4" X 1/2"	C	SS-400-R-8	SST		316		
		1	100	VALVE, PLUG 1/4"	N	SS-4P4T	SST		316		
		AR	101	CONNECTOR, MALE 1" X 1/2"	C	SS-1610-1-8	SST		316		
		AR	102	TEE, PIPE 1"	O	CS-16-T	CS	ASTM	A108		
		AR	103	NUT, SWAGELOK 1/4"	C	SS-402-1	SST		316		
		1	104	HOLDER, CANISTER							
		AR	105	NUT, SPRING 1/2-13UNC-2B	H	N225	ZINC	ASTM	B633SC1		
		AR	106	CAP SCREW, HEX HEAD 1/2-13UNC-2A 6" LG	H	HHCS 1/2X1	ZINC	ASTM	B633SC1		
		AR	107	NUT, HEX 3/8-13UNC-2B	H	HN 3/8"	ZINC				
		AR	108	WASHER, FLAT 11/16" ID	L	90108A035	ZINC				
		AR	109	SHEET, 10GA (.1354)			PRE-GALV	ASTM	A525		
		AR	110	CLAMP, PIPE 2"	H	B2037	ZINC	ASTM	A570		
		AR	111	POST BASE	H	B279	ZINC				
		1	112	FLOW METER, MASS 0-500 SCCM		52-L-001-H12					

LIST OF MATERIAL

QTY REQ GR3	QTY REQ GR2	QTY REQ GR1	ITEM NO.	ORDERING INFORMATION	NOTE	DRAWING NO. OR PART NO.	MATERIAL SPECIFICATION MATL	STD	NUMBER	COMP	FORM
		2	113	SINGLE CHANNEL ADJUSTABLE BRACE	H	B634					
		2	114	CLAMP, TUBING, 6"	H	B2069					
		3	115	HOSE, FLEXIBLE TUBING, 1"	M	SS-321-16-X-?	SST	316			
		2	116	HOSE, FLEXIBLE TUBING, 1/4"	M	SS-321-4-X-?	SST	316			
		4	117	VALVE, 2-WAY, 1"	C	SS--65TS16-JL	SST	316			
		1	118	VALVE, CHECK, 1"	C	SS-16C-1/3	SST	316			
		1	119	UNION, CROSS, 1"	C	SS-1610-4	SST	316			
		1	120	METER, MASS FLOW, 10000 SCCM	B	0358C-1000SV					
		1	121	VALVE, 3-WAY, 1/4"	C	SS-42XS4	SST	316			
		AR	122	TUBING, CHROMATIGRAPHIC GRADE NICKEL, 1/4"							

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-W2 ECO Number: 5821

2. ECO Search List: 5565

3. Description of Change:

1. CHANGE THE SYSTEM DESIGNATOR TO EM05
2. CHANGE THE TITLE TO:

   BIN SCALE TESTS, B JR 10-4-91 VOC (10) MONITORING SYSTEM LAYOUT AND FLOW ~~ARRANGEMENT~~ SCHEME

3. USING THE SAME CONFIGURATIONASON THIS DRAWING (SYMBOLS FOR VALVES, FLOW, & STRUCTURES), REPLACE THE CARBON BED ARRANGEMENT ON THE TABLE TO AN ARRANGEMENT WITH THE ATTACHED PAGE.

4. Drawing Cog. Engineer Approv: J.R. Stubbe Date: 10-7-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

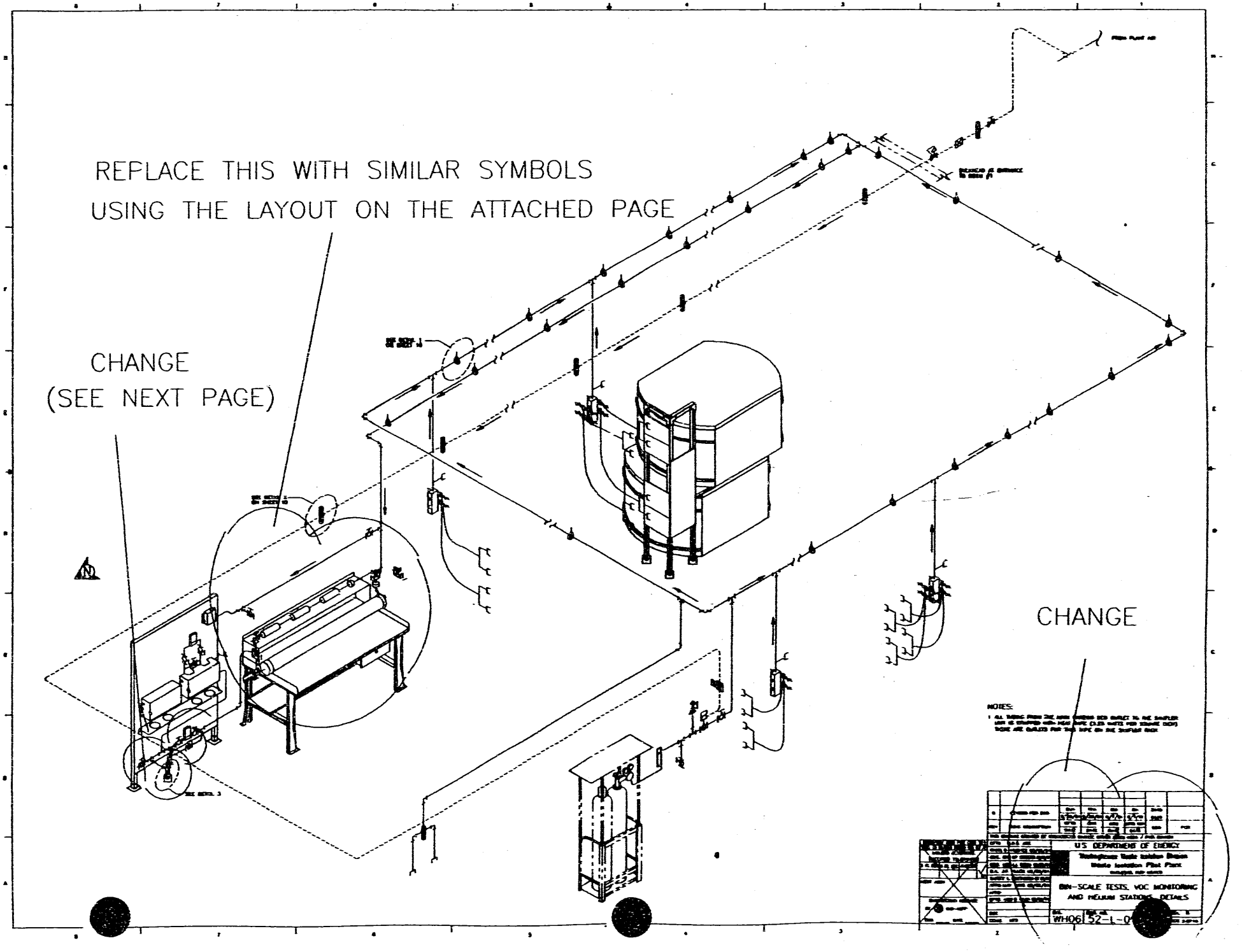
Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

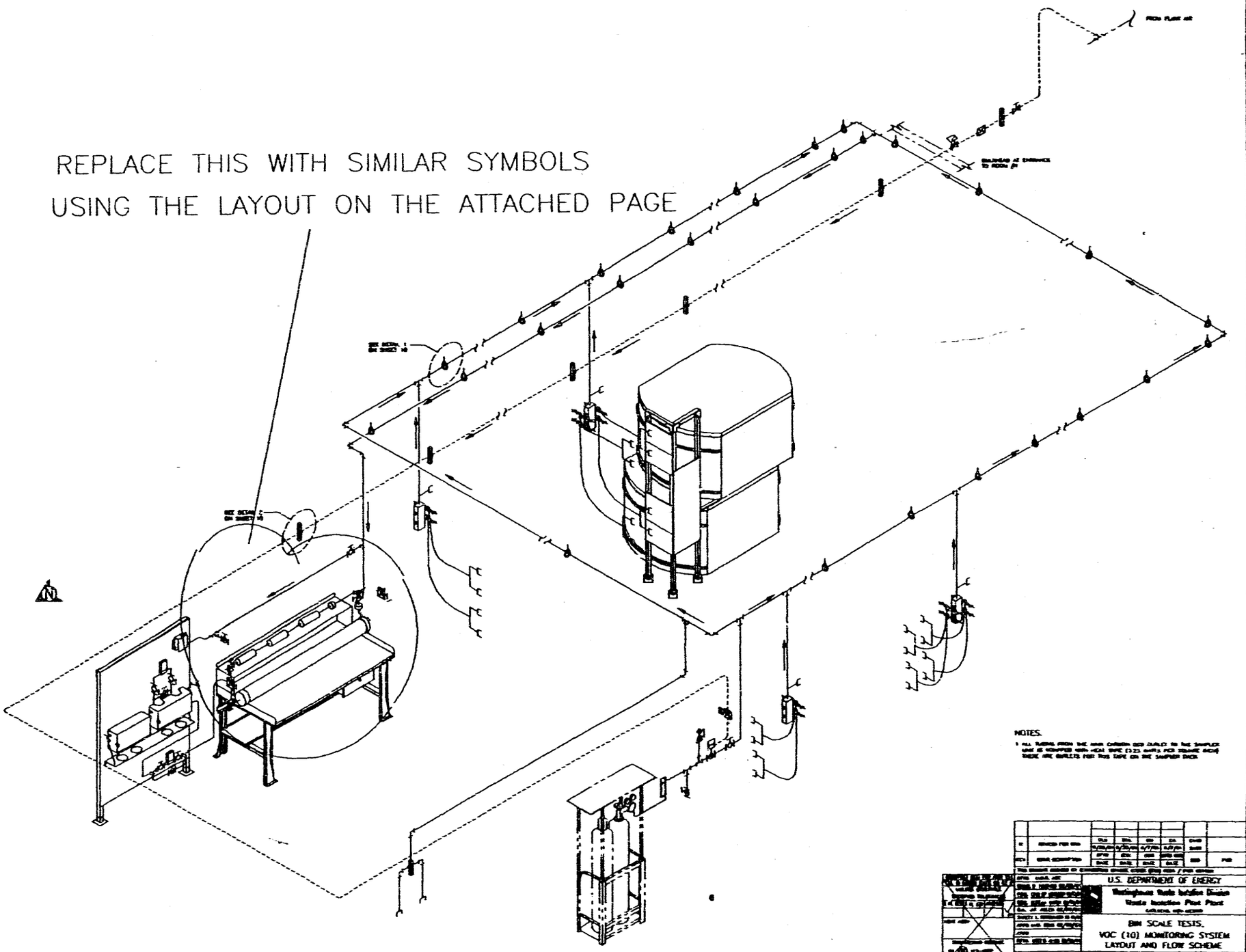
Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

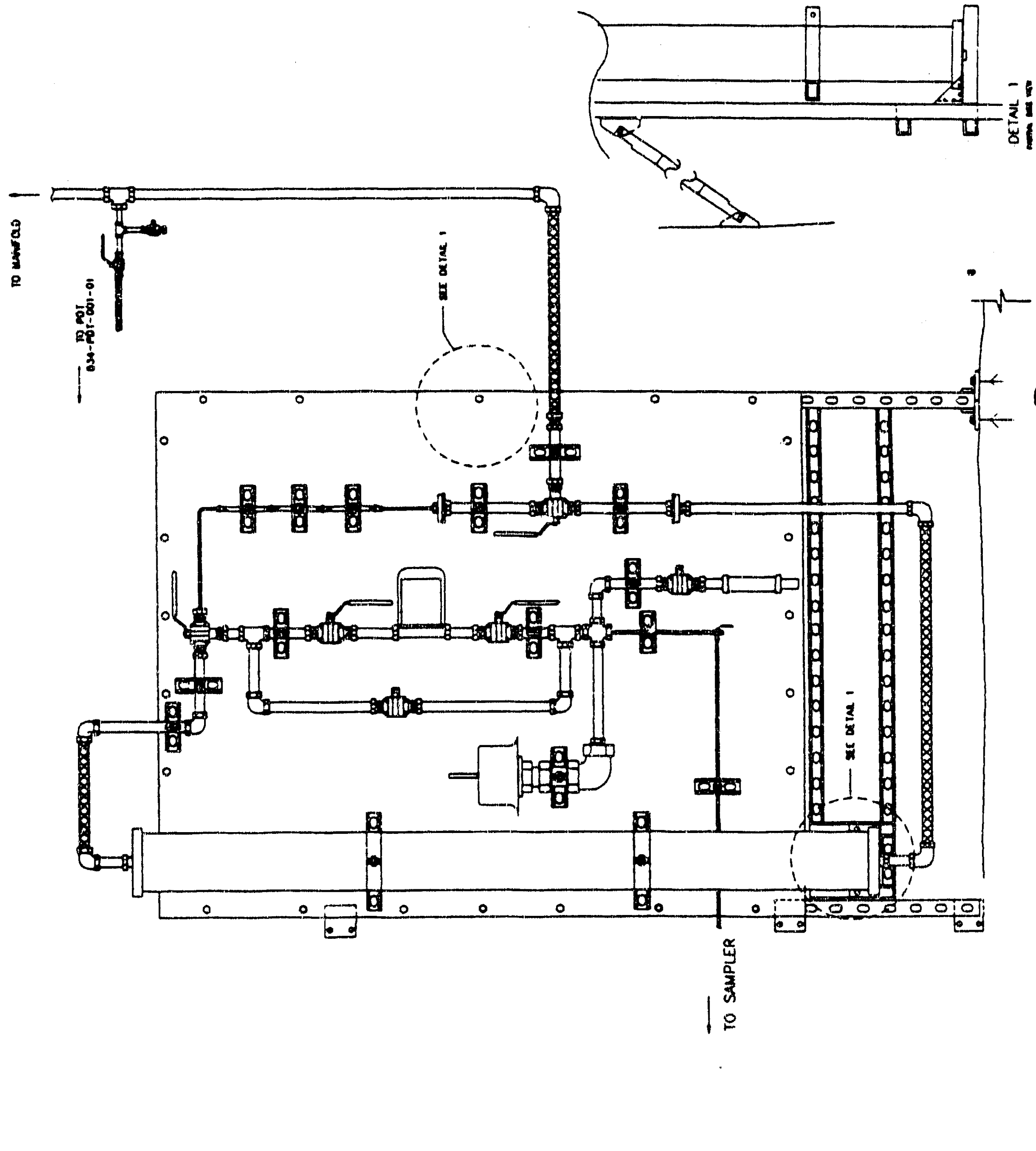

REPLACE THIS WITH SIMILAR SYMBOLS
USING THE LAYOUT ON THE ATTACHED PAGE
CHANGE
(SEE NEXT PAGE)
CHANGE
NOTES:
U.S. DEPARTMENT OF ENERGY
BIN-SCALE TESTS, VOC MONITORING AND HELIUM STATIONS DETAILS
WHO6 52-L-0

REPLACE THIS WITH SIMILAR SYMBOLS
USING THE LAYOUT ON THE ATTACHED PAGE



NOTES.

U.S. DEPARTMENT OF ENERGY
Waste Isolation Pilot Plant
BIN SCALE TESTS.
VOC (10) MONITORING SYSTEM
LAYOUT AND FLOW SCHEME
EMG 132: L-0012 - W2


TO MANIFOLD
TO PDT
034-PDT-001-01
SEE DETAIL 1
DETAIL 1
SEE DETAIL 1
TO SAMPLER

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-W3 ECO Number: 5821

2. ECO Search List: 5565

3. Description of Change:

1. CHANGE THE SYSTEM DESIGNATOR TO EMOS
2. CHANGE THE TITLE TO:

   BIN SCALE TESTS, VOC (10) MONITORING SYSTEM LAYOUT AND FLOW SCHEME

3. USING THE SAME CONFIGURATION AS ON THIS DRAWING (SYMBOLS FOR VALVES, FLOW, & STRUCTURES), REPLACE THE CARBON BED ARRANGEMENT ON THE TABLE TO AN ARRANGEMENT WITH THE ATTACHED PAGE. NOTE: PUT THE APPROPRIATE ITEM NUMBER ON THE PARTS.

4. Drawing Cog. Engineer Approval: J. R. Stubbe Date: 10-7-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date		Drafting Started: _____ Initials / Date	
Date Assigned: _____ Initials / Date		Drafting Completed: _____ Initials / Date	
Assigned to: _____ (Same as data base entry)		Return to EFR: _____ Initials / Date	

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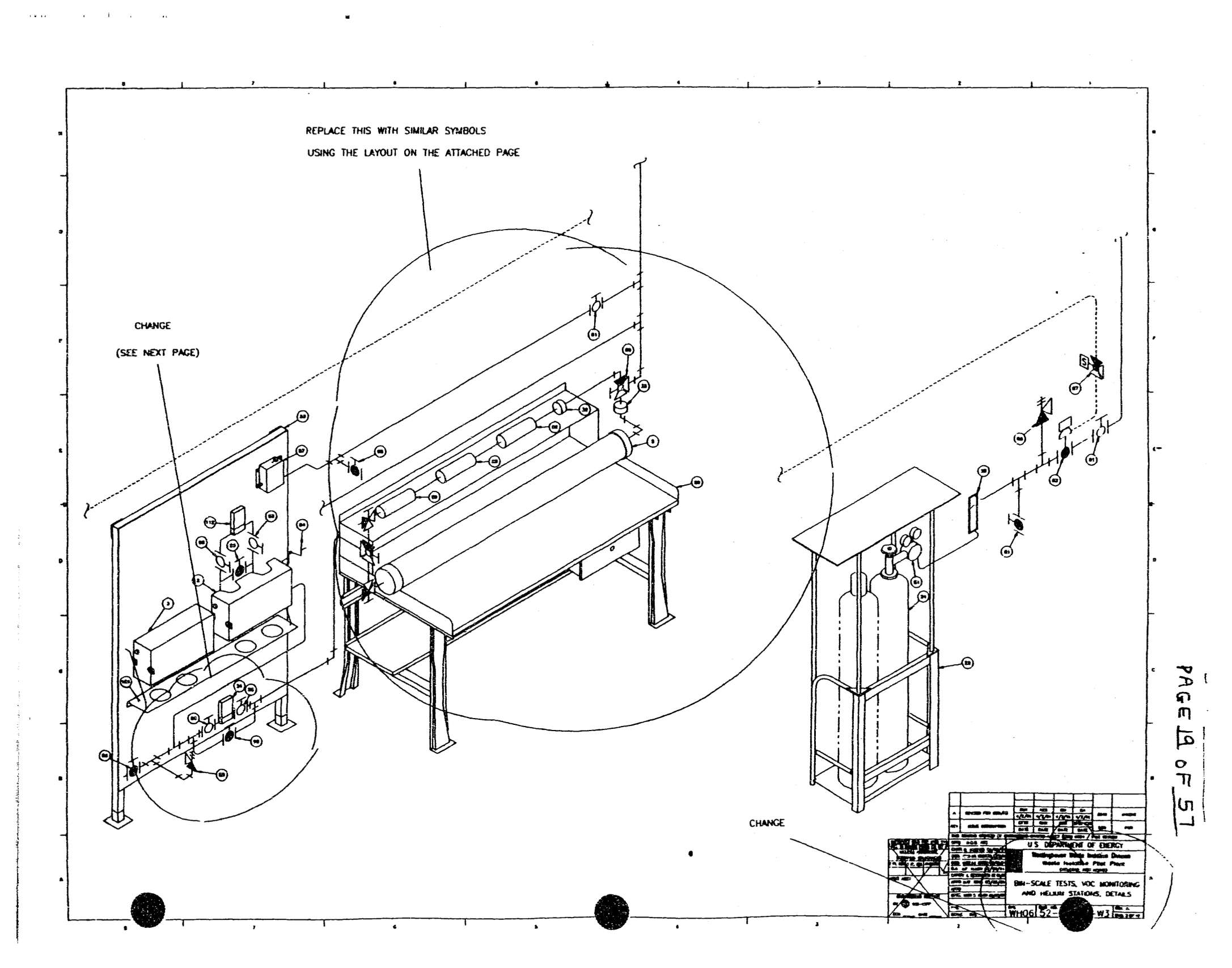
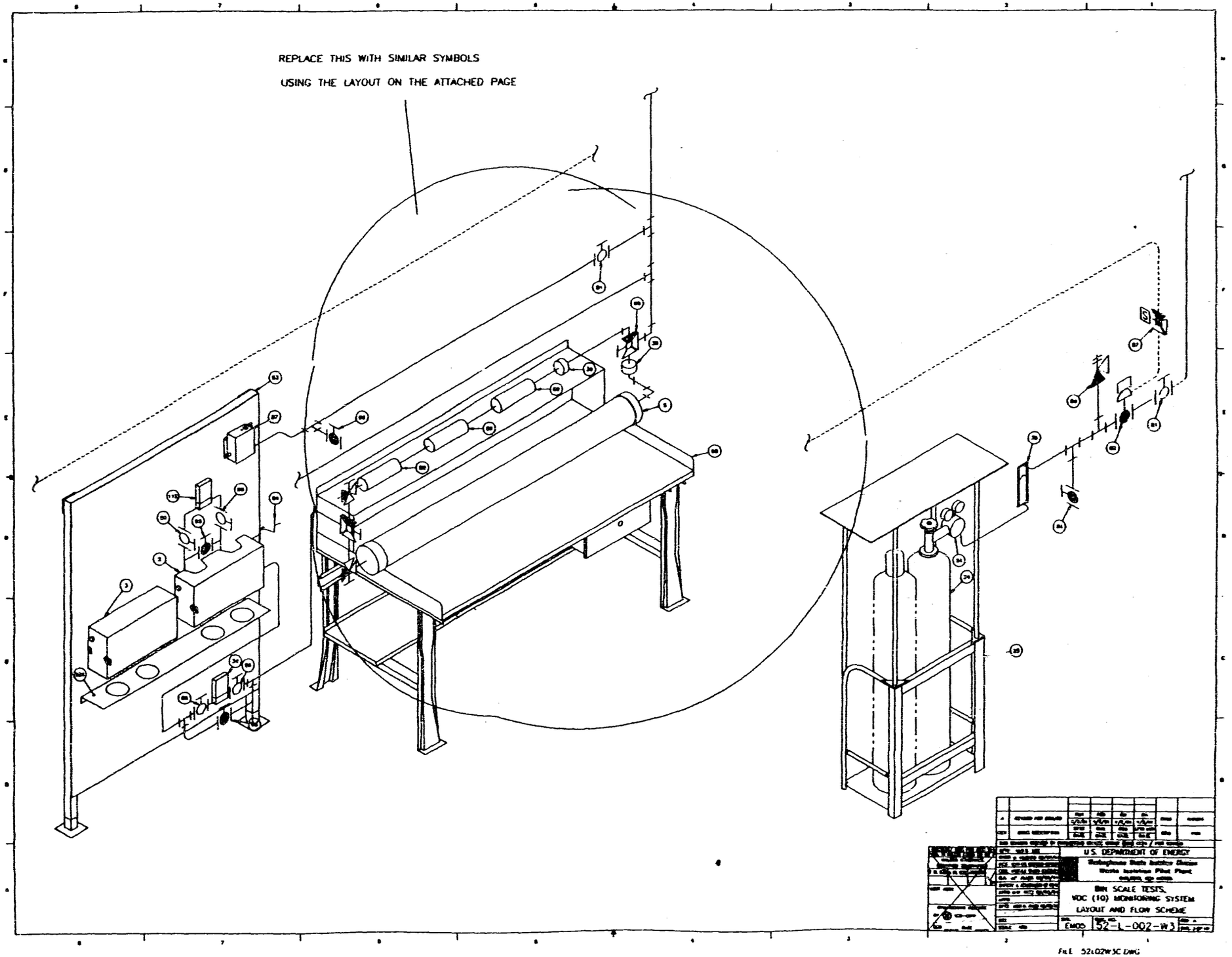
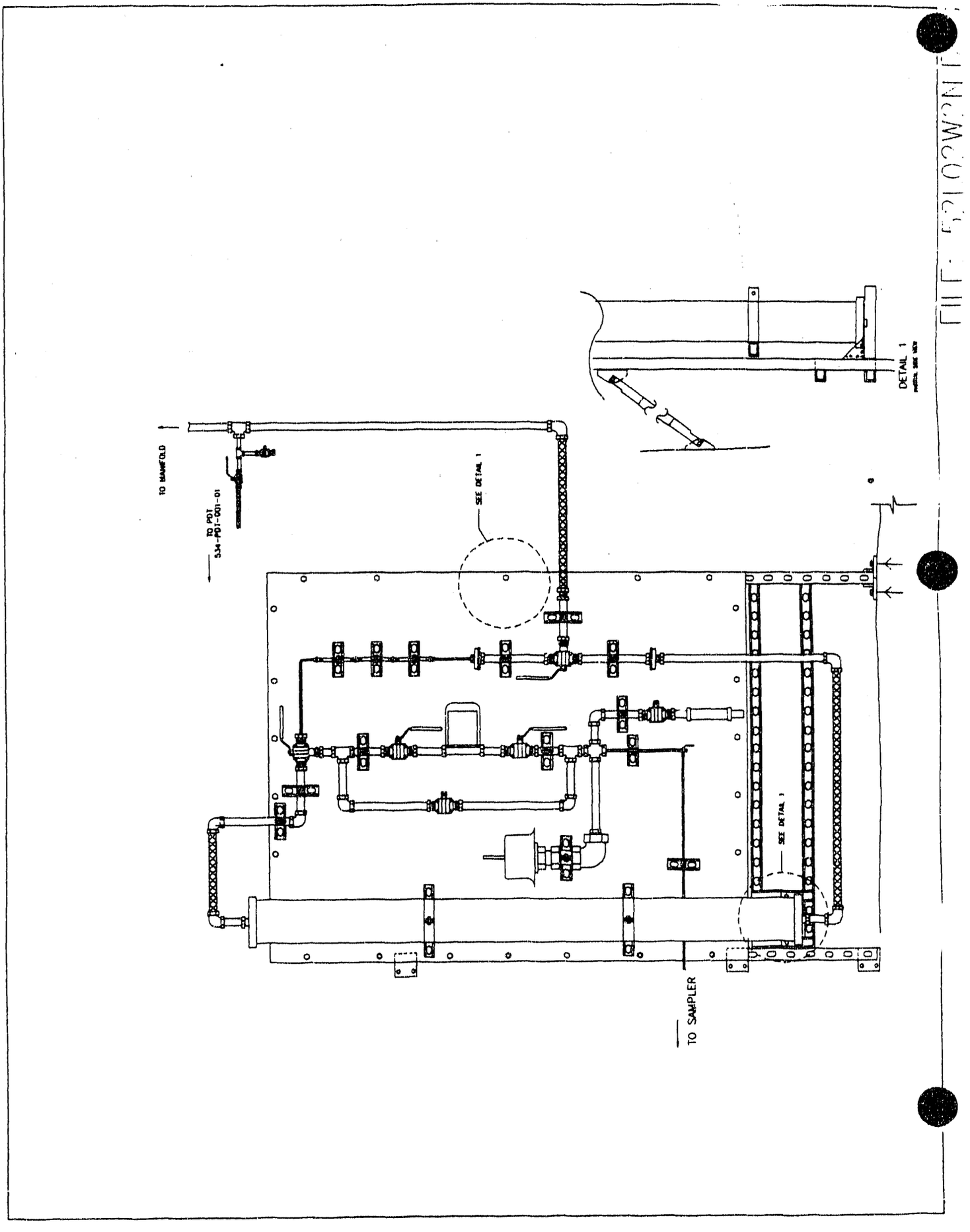

REPLACE THIS WITH SIMILAR SYMBOLS
USING THE LAYOUT ON THE ATTACHED PAGE
CHANGE
(SEE NEXT PAGE)
CHANGE
U.S. DEPARTMENT OF ENERGY
BIN-SCALE TESTS, VOC MONITORING AND HELIUM STATIONS, DETAILS
WH06 52-
W3


REPLACE THIS WITH SIMILAR SYMBOLS
USING THE LAYOUT ON THE ATTACHED PAGE
U.S. DEPARTMENT OF ENERGY
BIN SCALE TESTS
VOC (10) MONITORING SYSTEM
LAYOUT AND FLOW SCHEME
52-L-002-W3


TO MANIFOLD
TO PDT
534-PDT-001-01
SEE DETAIL 1
SEE DETAIL 1
TO SAMPLER
DETAIL 1

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-W4 ECO Number: 5821

2. ECO Search List: _____ _____ _____ _____

3. Description of Change:

1. DELETE DETAILS ON 2" TUBING.

2. ADD INFORMATION ON 52-L-002-W8 TO THIS DRAWING.

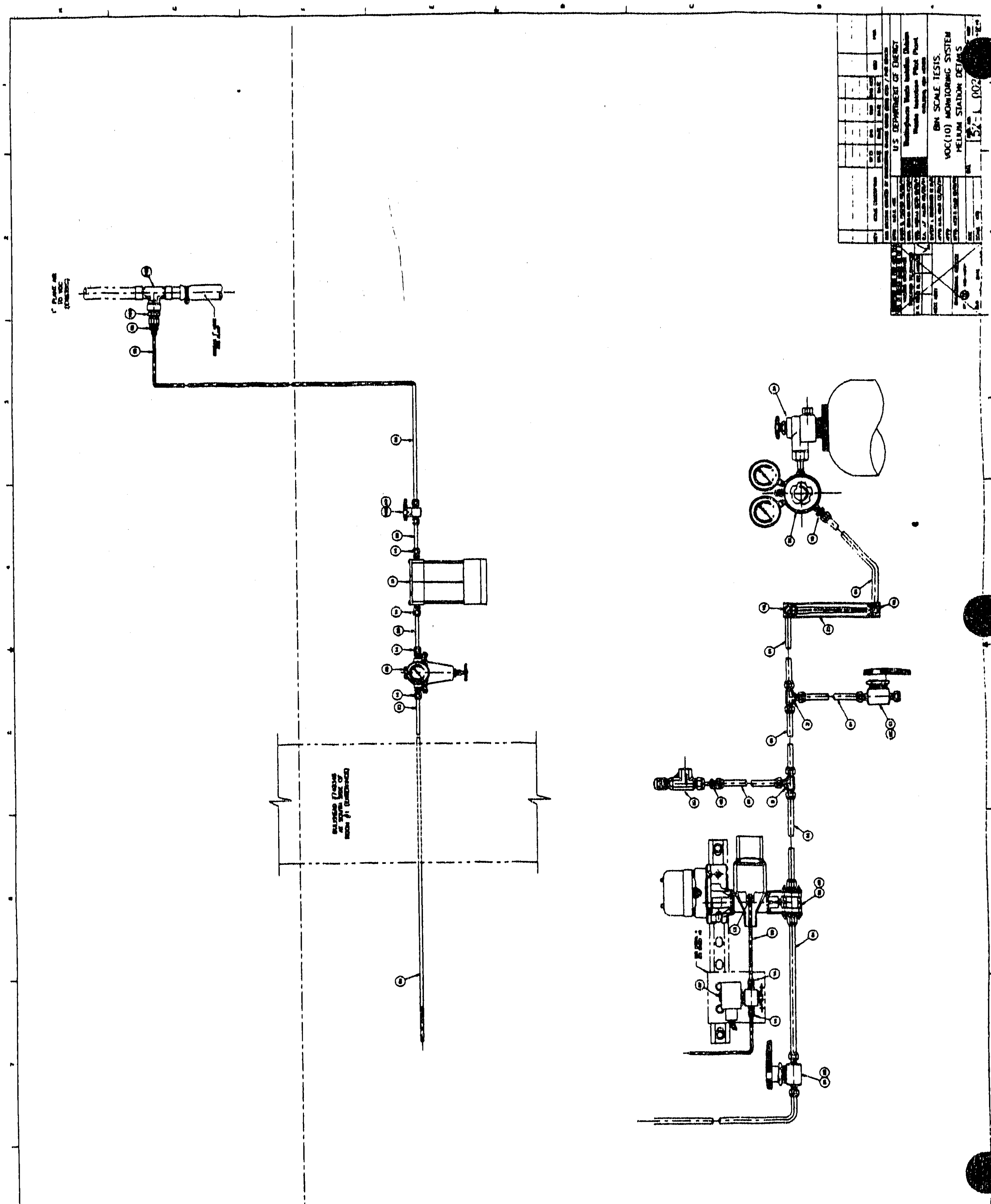
3. CHANGE SYSTEM TO EMOS & TITLE TO: BIN SCALE TESTS, VOC(10) MONITORING SYSTEM HELIUM SYSTEM DETAILS
SEE ATTACHED PAGE(S)

4. CHANGE "TEE'S" FROM ITEM "70" TO "77"

4. Drawing Cog. Engineer Approval: J.R. Strobl Date: 10-7-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date
Drafting Started: _____ Initials / Date
Date Assigned: _____ Initials / Date
Drafting Completed: _____ Initials / Date
Assigned to: _____ (Same as data base entry)
Return to EFR: _____ Initials / Date


U.S. DEPARTMENT OF ENERGY
Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
BIN SCALE TESTS
VOC(10) MONITORING SYSTEM
MEDIUM STATION DETAILS

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-W5 ECO Number: 5821

2. ECO Search List: 5565

3. Description of Change:

1. EXCHANGE THE DETAILED PIPING INFORMATION ON THIS DRAWING WITH THE ATTACHED PAGE.
2. CHANGE THE SYSTEM DESIGNATOR TO EM05
3. CHANGE THE TITLE TO:

   BIN SCALE TESTS, VOC(10) MONITORING SYSTEM CARBON BED RACK ARRANGEMENT

4. Drawing Cog. Engineer Approval: J.R. Strobl Date: 10-7-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

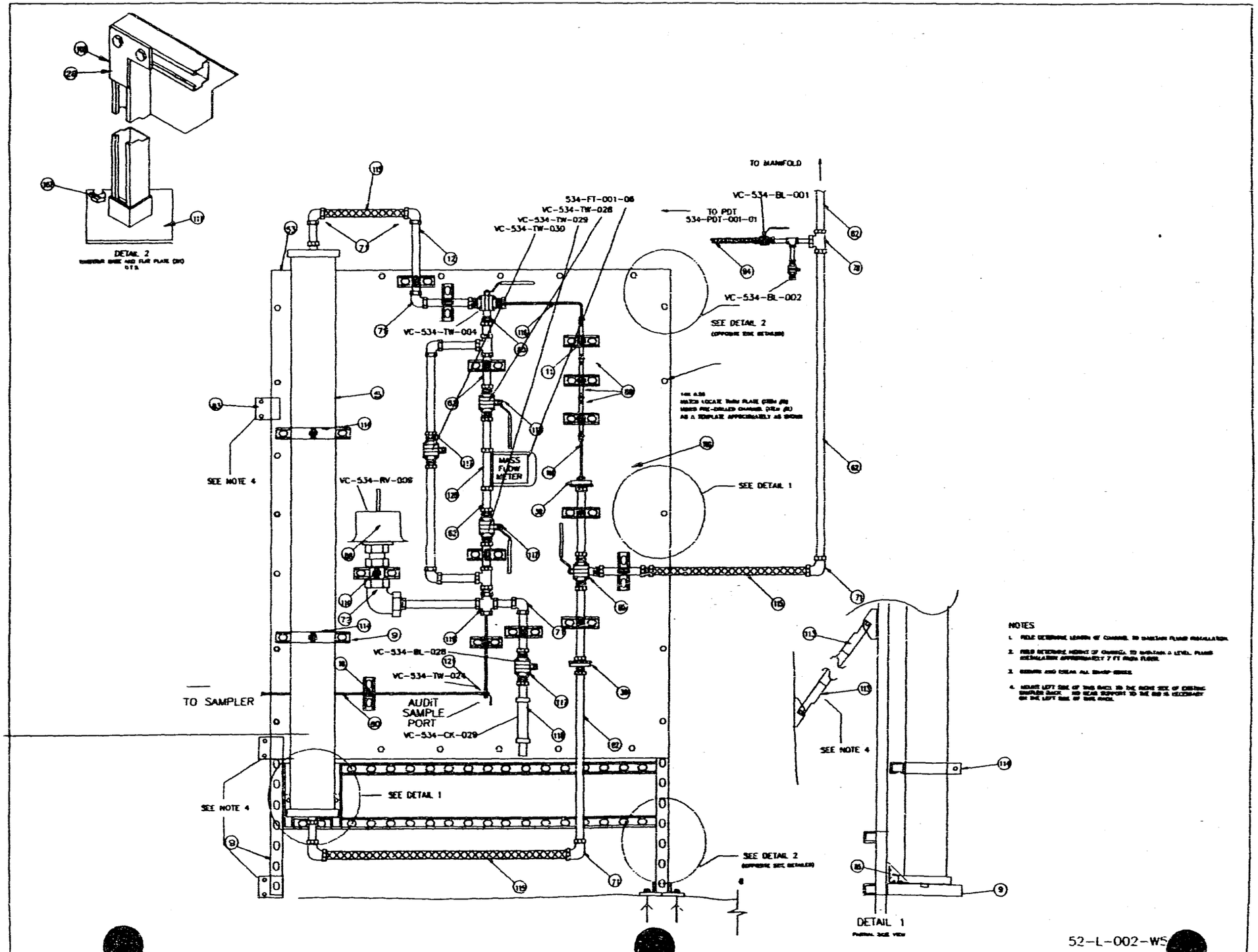
Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date


DETAIL 2
TO MANIFOLD
VC-534-BL-001
534-FT-001-08
VC-534-TW-028
VC-534-TW-029
VC-534-TW-030
TO PDT
534-PDT-001-01
VC-534-BL-002
SEE DETAIL 2
VC-534-TW-004
MASS FLOW METER
SEE NOTE 4
VC-534-RV-008
SEE DETAIL 1
VC-534-BL-028
VC-534-TW-026
TO SAMPLER
AUDIT SAMPLE PORT
VC-534-CK-029
SEE NOTE 4
SEE DETAIL 1
SEE DETAIL 2
SEE NOTE 4
DETAIL 1
NOTES
1.
2.
3.
4.

52-L-002-WS

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-W6 ECO Number: 5821

2. ECO Search List: 5565

3. Description of Change:

DELETE THIS DRAWING. PUT THIS INFORMATION ON 52-L-002-W7.

4. Drawing Cog. Engineer Approval: J. R. Stobb Date: 10-7-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-W7 ECO Number: 5821

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

1. ADD THE INFORMATION ON 52-L-002-W6 TO THIS DRAWING. SEE ATTACHED PAGE(S).
2. CHANGE THE SYSTEM DESIGNATOR TO EM05.
3. CHANGE THE TITLE TO:

   BIN SCALE TESTS, VOC (10) MONITORING SYSTEM SAMPLER RACK DETAILS
4. CHANGE 1/4" FLEXIBLE TUBING TO 1/4" CHROMATOGRAPHIC GRADE NICKEL TUBING

4. Drawing Cog. Engineer Approval: J.R. Stubble Date: 10-7-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

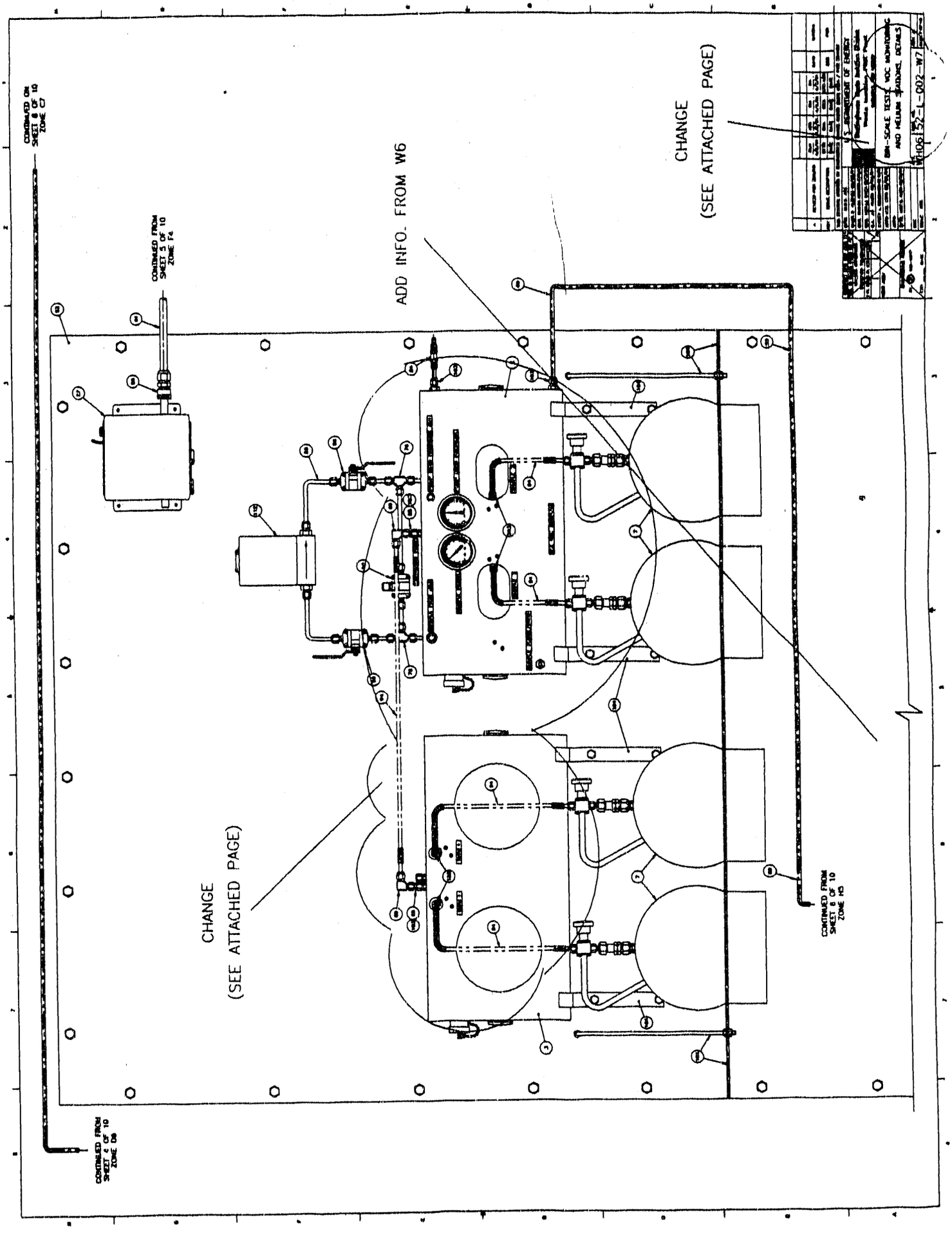
Date Assigned: _____ Initials / Date

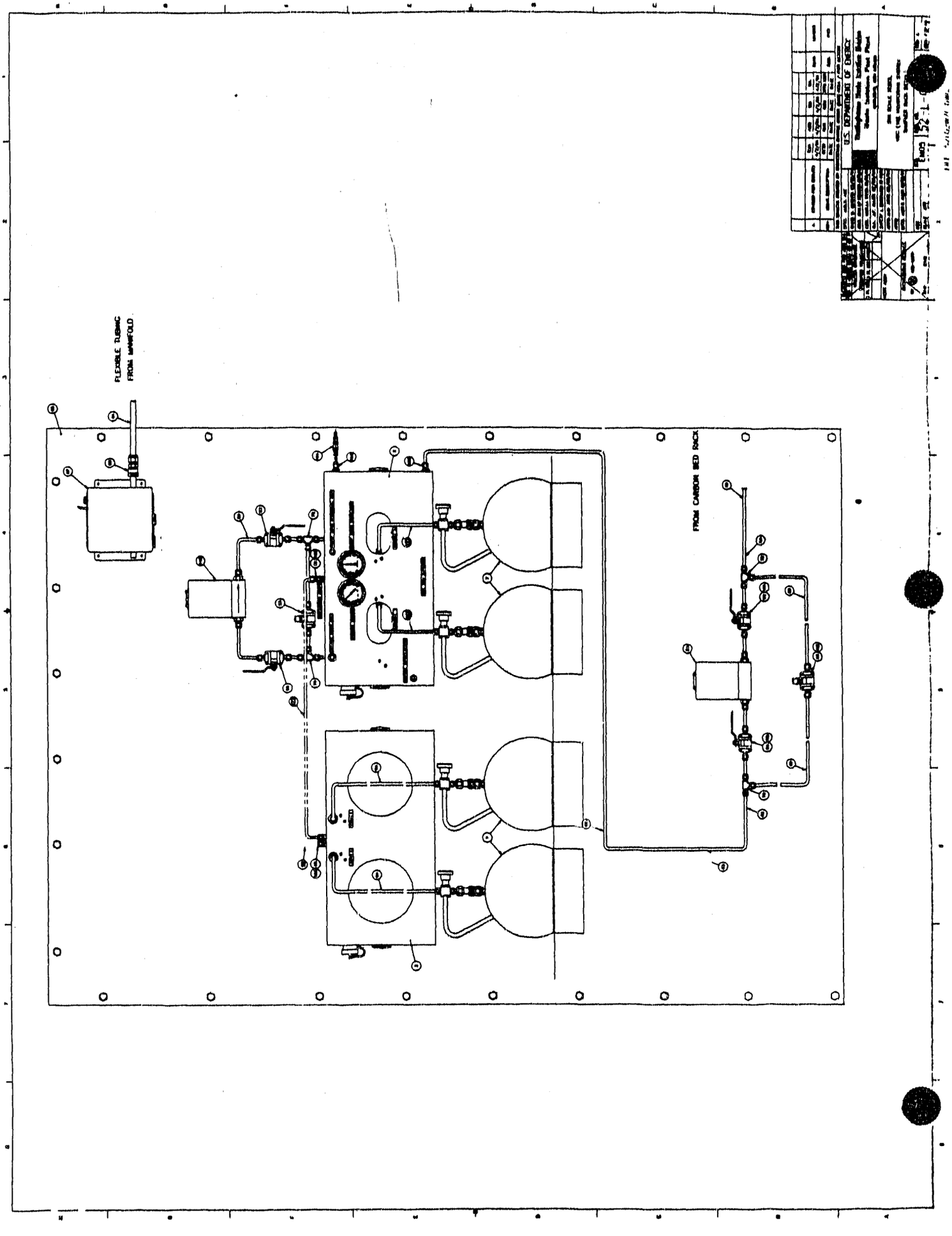
Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date


CHANGE
(SEE ATTACHED PAGE)
ADD INFO. FROM W6
CHANGE
(SEE ATTACHED PAGE)
CONTINUED FROM SHEET 5 OF 10 ZONE F4
CONTINUED ON SHEET 8 OF 10 ZONE C7
CONTINUED FROM SHEET 8 OF 10 ZONE H5
CONTINUED FROM SHEET 4 OF 10 ZONE D8
BIN-SCALE TESTS / VOC MONITORING AND HELIUM STANDARDS DETAILS
W106 152-1-002-W7


FLEXIBLE TUBING FROM MANIFOLD
FROM CARBON BED RACK

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-W8 ECO Number: 5821

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

DELETE THIS DRAWING. PUT THIS INFORMATION ON 52-L-002-W4.

4. Drawing Cog. Engineer Approval: J.R. Stroble Date: 10-7-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 52-L-002-W9 ECO Number: 5821

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

1. CHANGE THE SYSTEM DESIGNATOR TO EMOS

2. CHANGE THE TITLE TO :

BINSCALE TESTS, VOC (10) MONITORING SYSTEM
BIN CONNECTION & RISER DETAILS

JR 10-4-91

~~SEE ATTACHED PAGE~~

4. Drawing Cog. Engineer Approval: J. R. Stubbe Date: 10-7-91

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 52-6-002-W10 ECO Number: 5821

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

DELETE THIS DRAWING

4. Drawing Cog. Engineer Approval: J. R. Stroble Date: 10-7-91

1290:B0006

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 53-J-053-W2 ECO Number: 5821

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

1. CHANGE THE TABLE FOR VOC (10) TO A RACK.

4. Drawing Cog. Engineer Approval: Gary Perry Date: 10/6/91

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 105-F-013-W ECO Number: 5821

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

1. CHANGE THE DRAWING TITLE TO:

BIN SCALE TESTS, VOC (10) MONITORING SYSTEM SAMPLER ASSEMBLY 105-S-008

4. Drawing Cog. Engineer Approval: J.R. Stobb Date: 10-7-91

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 105-H-005-W ECO Number: 5821

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

1. ADD FLOW LOOP 105-H-001-06 AS SHOWN.

2. ADD TO REFERENCE DRAWING.

SEE ATTACHED PAGES

4. Drawing Cog. Engineer Approval: J.R. Strobl Date: 10-7-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

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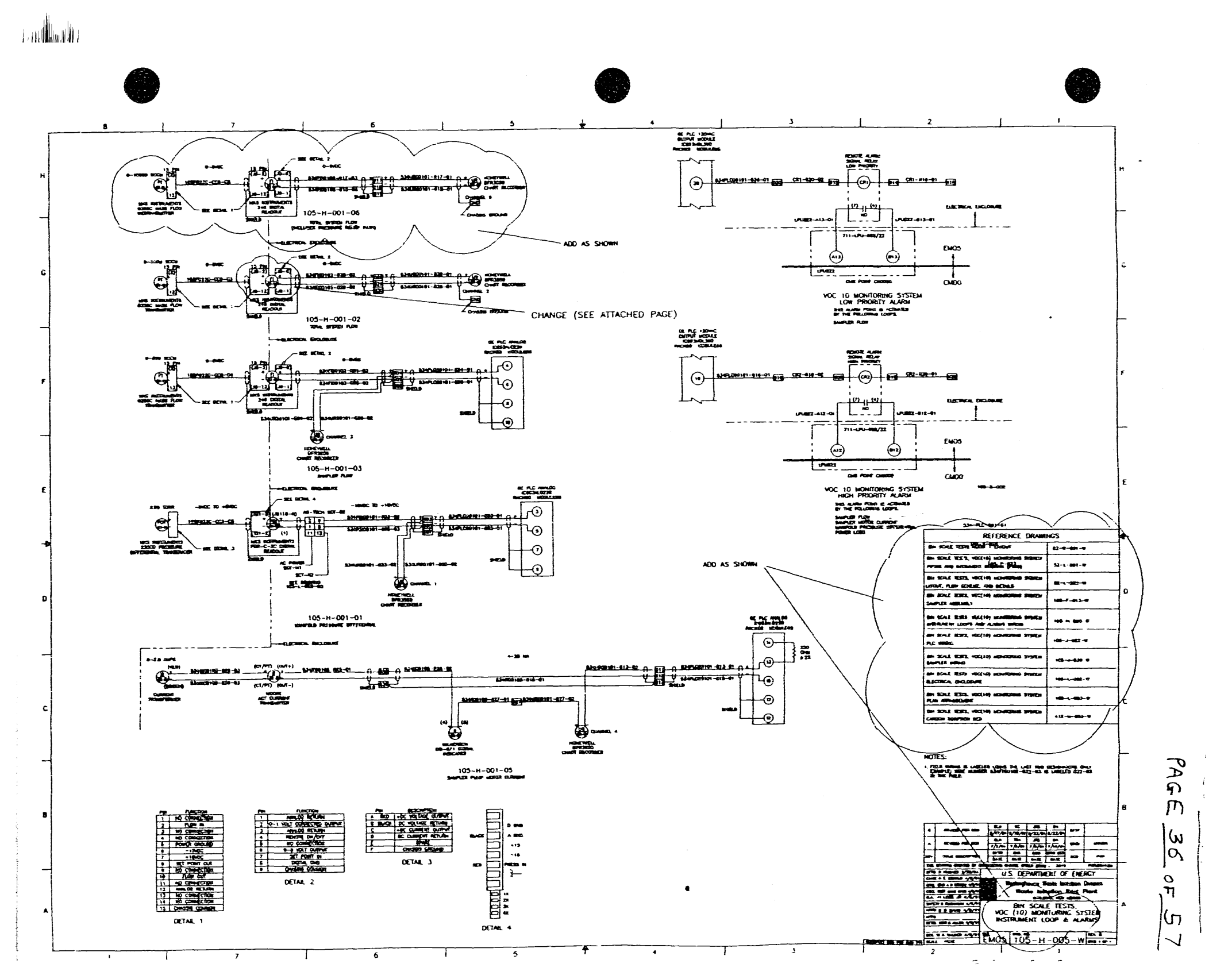
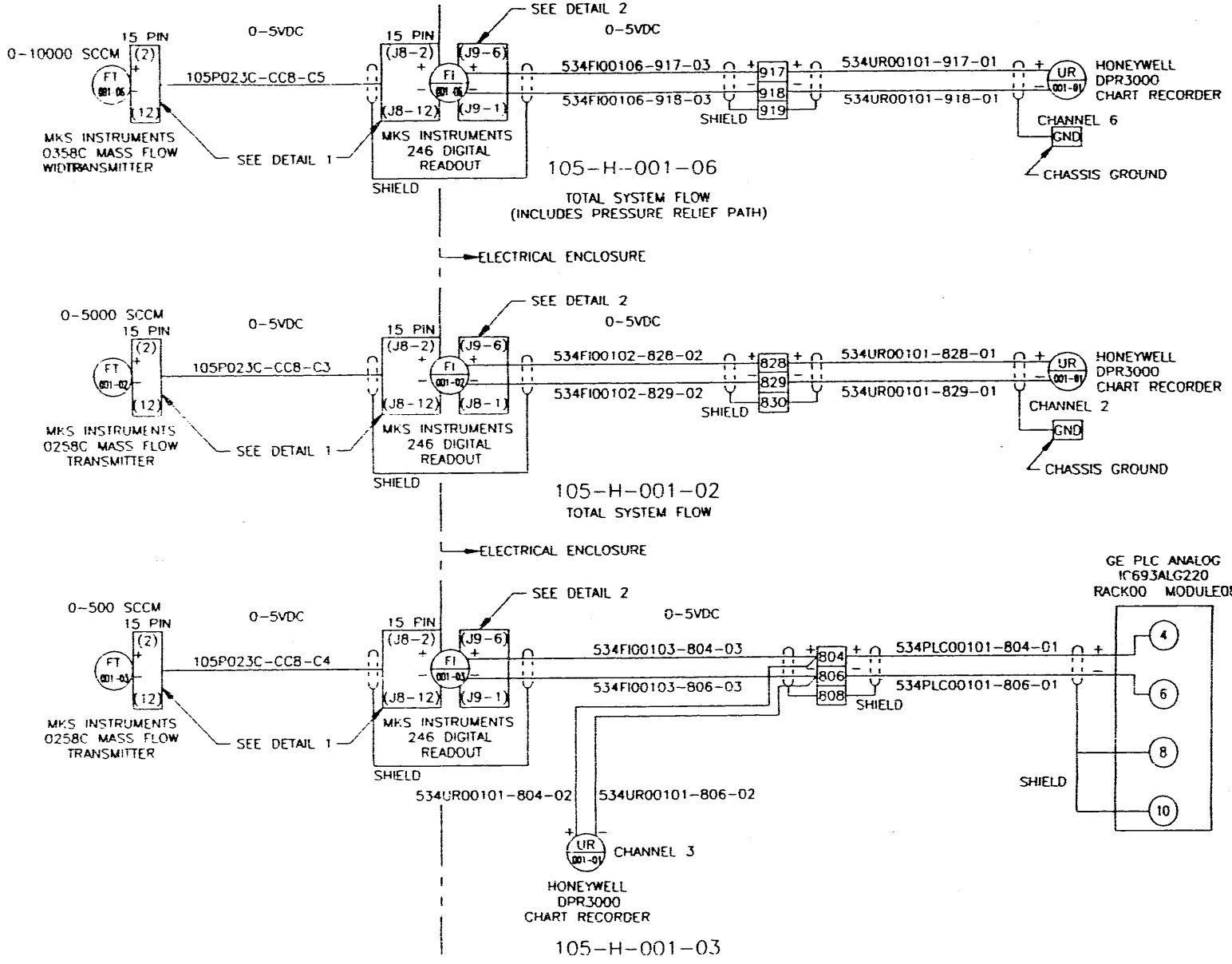

105-H-001-05
ADD AS SHOWN
105-H-001-02
CHANGE (SEE ATTACHED PAGE)
VOC 10 MONITORING SYSTEM
LOW PRIORITY ALARM
105-H-001-03
VOC 10 MONITORING SYSTEM
HIGH PRIORITY ALARM
105-H-001-01
ADD AS SHOWN
REFERENCE DRAWINGS
NOTES:
105-H-001-05
DETAIL 1
DETAIL 2
DETAIL 3
DETAIL 4
U.S. DEPARTMENT OF ENERGY
8IN SCALE TESTS
VOC (10) MONITORING SYSTEM
INSTRUMENT LOOP & ALARMS
EMOS
105-H-005-W

PAGE 36 OF 57


8
7
6
5
H
G
F
0-10000 SCCM
15 PIN
(2)
FT
001-06
(12)
0-5VDC
105P023C-CC8-C5
MKS INSTRUMENTS
0358C MASS FLOW
WIDTRANSMITTER
SEE DETAIL 1
15 PIN
(J8-2)
FI
001-06
(J8-12)
SEE DETAIL 2
(J9-6)
(J9-1)
0-5VDC
MKS INSTRUMENTS
246 DIGITAL
READOUT
SHIELD
534FI00106-917-03
534FI00106-918-03
917
918
919
SHIELD
534UR00101-917-01
534UR00101-918-01
UR
001-01
HONEYWELL
DPR3000
CHART RECORDER
CHANNEL 6
GND
CHASSIS GROUND
105-H--001-06
TOTAL SYSTEM FLOW
(INCLUDES PRESSURE RELIEF PATH)
ELECTRICAL ENCLOSURE
0-5000 SCCM
15 PIN
(2)
FT
001-02
(12)
0-5VDC
105P023C-CC8-C3
MKS INSTRUMENTS
0258C MASS FLOW
TRANSMITTER
SEE DETAIL 1
15 PIN
(J8-2)
FI
001-02
(J8-12)
SEE DETAIL 2
(J9-6)
(J8-1)
0-5VDC
MKS INSTRUMENTS
246 DIGITAL
READOUT
SHIELD
534FI00102-828-02
534FI00102-829-02
828
829
830
SHIELD
534UR00101-828-01
534UR00101-829-01
UR
001-01
HONEYWELL
DPR3000
CHART RECORDER
CHANNEL 2
GND
CHASSIS GROUND
105-H-001-02
TOTAL SYSTEM FLOW
ELECTRICAL ENCLOSURE
0-500 SCCM
15 PIN
(2)
FT
001-01
(12)
0-5VDC
105P023C-CC8-C4
MKS INSTRUMENTS
0258C MASS FLOW
TRANSMITTER
SEE DETAIL 1
15 PIN
(J8-2)
FI
001-01
(J8-12)
SEE DETAIL 2
(J9-6)
(J9-1)
0-5VDC
MKS INSTRUMENTS
246 DIGITAL
READOUT
SHIELD
534FI00103-804-03
534FI00103-806-03
804
806
808
SHIELD
534PLC00101-804-01
534PLC00101-806-01
GE PLC ANALOG
IC693ALG220
RACK00 MODULE08
4
6
8
10
SHIELD
534UR00101-804-02
534UR00101-806-02
UR
001-01
CHANNEL 3
HONEYWELL
DPR3000
CHART RECORDER
105-H-001-03

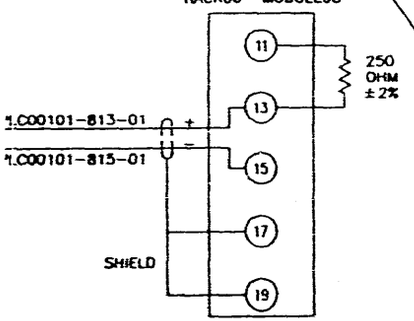
BY THE FOLLOWING LOOPS.

SAMPLER FLOW
SAMPLER MOTOR CURRENT
MANIFOLD PRESSURE DIFFERENTIAL
POWER LOSS

534-PLC-001-01

ADD AS SHOWN

GE PLC ANALOG
IC693ALG220
RACK00 MODULE08



REFERENCE DRAWINGS	
BIN SCALE TESTS ROOM 1 LAYOUT	52-W-001-W
BIN SCALE TESTS, VOC(10) MONITORING SYSTEM PIPING AND INTRUMENT DIAGRAM (P&ID)	52-L-001-W
BIN SCALE TESTS, VOC(10) MONITORING SYSTEM LAYOUT, FLOW SCHEME, AND DETAILS	52-L-002-W
BIN SCALE TESTS, VOC(10) MONITORING SYSTEM SAMPLER ASSEMBLY	105-F-013-W
BIN SCALE TESTS, VOC(10) MONITORING SYSTEM INSTRUMENT LOOPS AND ALARMS WIRING	105-H-005-W
BIN SCALE TESTS, VOC(10) MONITORING SYSTEM PLC WIRING	105-J-022-W
BIN SCALE TESTS, VOC(10) MONITORING SYSTEM SAMPLER WIRING	105-J-030-W
BIN SCALE TESTS, VOC(10) MONITORING SYSTEM ELECTRICAL ENCLOSURE	105-L-002-W
BIN SCALE TESTS, VOC(10) MONITORING SYSTEM PLAN ARRANGEMENT	105-L-003-W
BIN SCALE TESTS, VOC(10) MONITORING SYSTEM CARBON SORPTION BED	412-M-003-W

105-S-008
105-P-023

NOTES:

1. FIELD WIRING IS LABELED USING THE LAST TWO DESIGNATORS ONLY. EXAMPLE: WIRE NUMBER 534FT00102-822-03 IS LABELED 822-03 IN THE FIELD.

REV	ISSUE DESCRIPTION	DFTR	CHK	COG	DFTG MGR	ECO	PWR
		DATE	DATE	DATE	DATE		
B	REVISED PER ECO	DLH 9/17/91	GC 9/20/91	JRS 9/23/91	BA 9/23/91	5737	
A	REVISED PER ECO	DLH 7/2/91	TRA 7/9/91	JRS 7/9/91	BA 7/10/91	5565	M41816

THIS DRAWING CREATED BY ENGINEERING CHANGE ORDER (ECO) : 5019 PWR-00-4124

DFTG D HUGHES 3/20/91
CHKR A E SEWALD 4/8/91
COG. ENG J R STROBLE 4/8/91
COG. MGR JAIME DAVIS 4/8/91
Q.A. H LEOS JR 4/8/91
SAFETY G BUCHANAN 4/8/91
APPD D D DAVIS 4/8/91
APPD
DFTG. MGR B ALLEN 4/8/91
DOE W A WALKER 4/8/91

U.S. DEPARTMENT OF ENERGY
Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

BIN SCALE TESTS,
VOC (10) MONITORING SYSTEM
INSTRUMENT LOOP & ALARMS

SYS EMOS | DWG. NO. 105-H-005-W | REV B | DWG 1 OF 1

INTERPRET DWG PER ANSI Y14 | SCALE NONE

FILE: 105H005WC.DWG

ECO 5019
PAGE 38 OF 57
JRS
10-7-91

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 105-J-022-W ECO Number: 5821

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

1. CHANGE REFERENCE DRAWINGS.

2. CHANGE TITLE TO:

BIN SCALE TESTS, VOC (10) MONITORING SYSTEM
PLC WIRING 534-PLC-001-01

4. Drawing Cog. Engineer Approval: J.R. Stroble Date: 10-7-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

CHANGE REFERENC
DRAWINGS TO
STANDARD REFERENC
AS SHOWN IN THIS
ECO.

THIS DRAWING IS UP-TO-DATE WITH THE FOLLOWING OUTSTANDING ENGINEERING CHANGE ORDERS:

No

THIS DRAWING OBSOLETE AFTER 10-4-91

ISSUED SW 9-27-91 GG&D

AC BOARD CONNECTION WITHIN CONTROL CABINET.

SIGN AT FIELD DEVICE OR REMOTE LOCATION.

AC CONNECTION ON PLC MODULE FACE.

SION TO COMPONENTS WITHIN CONTROL CABINET.

SION WITHIN SAMPLER UNIT OR SAMPLER EXPANSION UNIT.

AC SOURCE, SURGE & SPIKE PROTECTED.

C

BLOCKS REFERENCED AS SYMBOL [ ] ON THIS ON TRA & TB1 ON DWG 105-J-002-W?

POSITION, AND RELAY NUMBERS ON THIS DRAWING ARE SEDED BY 105-P-023.

B

	DLH	[illegible]	[illegible]	BA	5737	
	9/17/91	9/20/91	9/23/91	9/23/91	5687	M12071
	DLH	TRA	JRS	BA	5565	M41816
	7/2/91	7/3/91	7/5/91	7/8/91		
	DFTR	CHK	CDG	DFTG MGR	ECO	PWR
	DATE	DATE	DATE	DATE		

RELATED RF ENGINEERING CHANGE ORDER (ECO) : 5005 PWR: 00412

S 3/18/91
ALD 4/3/91
STROBLE 4/3/91
DAVIS 4/3/91
SR 4/8/91
ANAN 4/8/91
VIS 4/8/91
LEEN 4/8/91
SER 4/8/91

U.S. DEPARTMENT OF ENERGY

Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

BIN SCALE TESTS,
VOC (10) MONITORING SYSTEM
PLC FIELD WIRING S34-PLC-001-01

ADD

A

DELETE

EM05	DWG NO 105-J-022-W	REV. U	
		DWG 1 OF 1	

1

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 105-J-022-W ECO Number: _____

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

1. CHANGE THE TITLE TO:

BIN SCALE TESTS, VOC (10) MONITORING SYSTEM

PLC WIRING 534-PLC-001-01

4. Drawing Cog. Engineer Approval: J. R. Stubb Date: 10-7-91

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 105-J-030-W ECO Number: 5521

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

1. CHANGE THE TITLE TO:

BIN SCALE TESTS, VOC(10) MONITORING SYSTEM SAMPLER WIRING.

4. Drawing Cog. Engineer Approval: J. R. Stuble Date: _____

1290:B0006

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 105-L-002-W1 ECO Number: 5821

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

1. MOVE LIGHTS AND BUTTONS SHOWN INSIDE CABINET ON LEFT TO THE RIGHT SIDE, AND ADD ANOTHER DISPLAY (7) IN THEIR PLACE.
2. ADD REFERENCE DRAWINGS.
3. ADD ONE BUTTON & LIGHT, AND REMOVE THE 4 BOTTOM LIGHTS ON THE FRONT DOORS
4. CHANGE PART NO. AND DESCRIPTION OF PILOT LIGHTS TO PUSH-TO-TEST LIGHTS - PART NO. ALLEN-BRADLEY 800T-PT16

SEE ATTACHED PAGES

4. Drawing Cog. Engineer Approval: J.R. Stubb Date: 10-7-91

5. Cover Sheet Block (CC&D Use Only)

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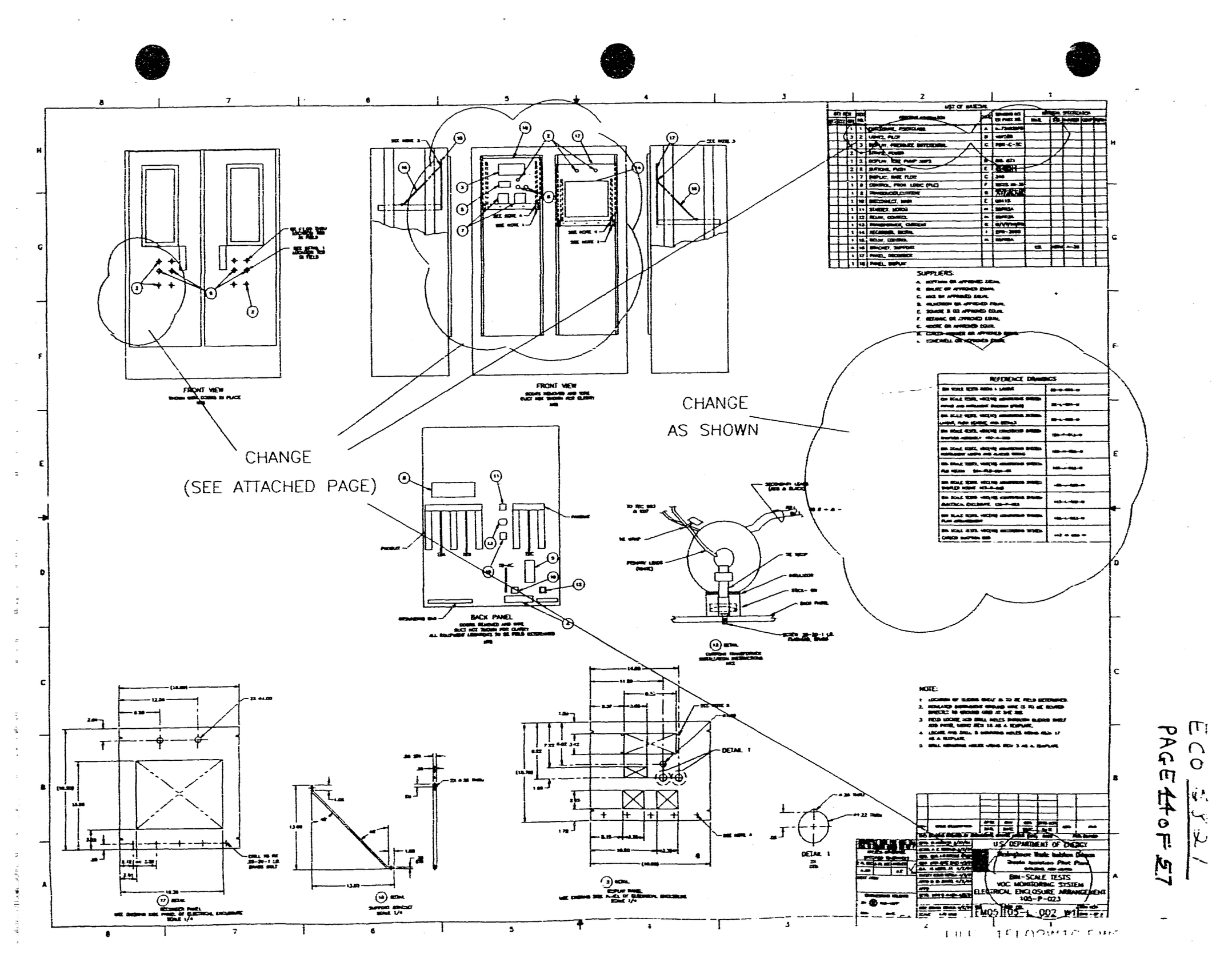
Date Assigned: _____ Initials / Date

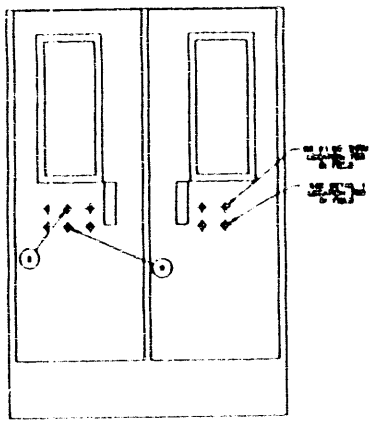
Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

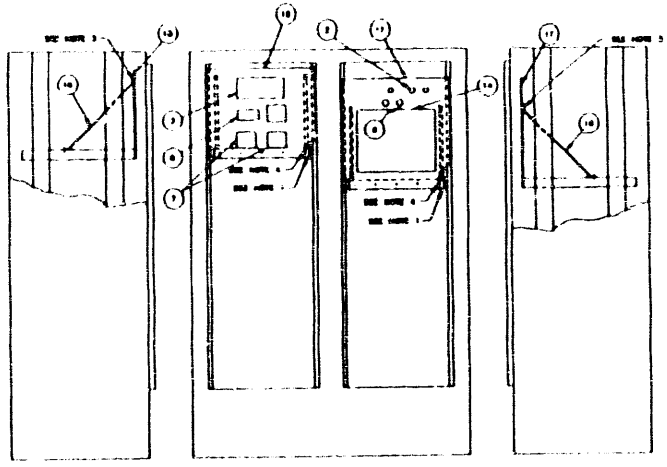
Return to EFR: _____ Initials / Date



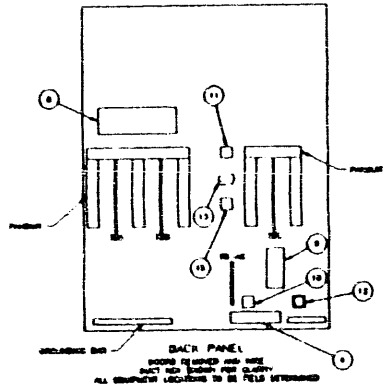
ECO [illegible]
PAGE 14 OF 27



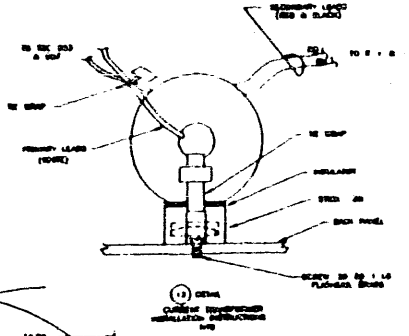
FRONT VIEW



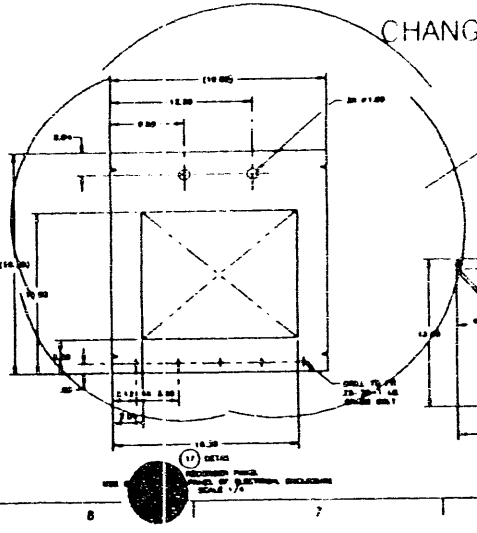
FRONT VIEW

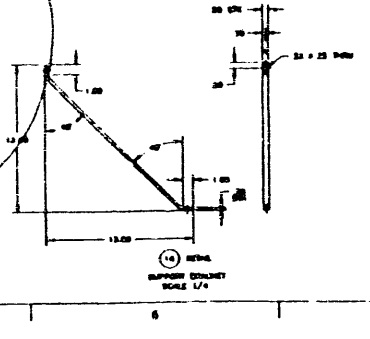


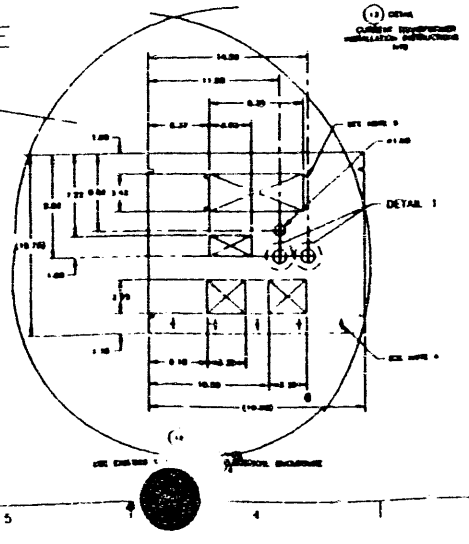
BACK PANEL



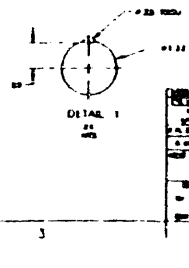
CHANGE TO REFLECT ABOVE







DETAIL 1



DETAIL 1

LIST OF MATERIAL									
QTY REQ	ITEM NO	DESCRIPTION	MFR	MANUFACTURER OR PART NO	SPECIFICATION				
					MIL	TS	AMERICAN	OTHER	NOTES
	1	ENCLOSURE, FIBERGLASS	A						
	2	LIGHT, PILOT	B						
	3	DISPLAY, PRESSURE DIFFERENTIAL	C						
	4	SWITCH, POWER							
	5	DISPLAY, SEVEN SEGMENT	B						
	6	SWITCH, PUSH	C						
	7	DISPLAY, BAR FLOW	C						
	8	CONTROL, PROG LOGIC (PLC)	F						
	9	PROCESSOR/CONTROL	G						
	10	DISCONNECT, DRAW	I						
	11	SWITCH, HOOKER	A						
	12	RELAY, CONTROL	A						
	13	TRANSFORMER, CURRENT	H						
	14	TERMINAL BLOCK	A						
	15	RELAY, CONTROL	A						
	16	SOCKET, SUPPORT							
	17	PANEL, ACCESS							
	18	PANEL, DISPLAY							

SUPPLIERS:

REFERENCE DRAWINGS	

NOTE

U.S. DEPARTMENT OF ENERGY	
Rocky Flats Plant	
BIN-SCALE TESTS	
VOC (10) MONITORING SYSTEM	
ELECTRICAL ENCLOSURE ARRANGEMENT	
105-P-01A	
EM05 105-L	

FILE 1510

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 105-L-002-W2 ECO Number: 5821

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

1. DELETE REFERENCE DRAWINGS

2. CHANETHE TITLE TO:

BIN SCALE TESTS, VOC (10) MONITORING SYSTEM ELECTRICAL ENCLOSURE WIRING 105-P-023

3. ADD WIRES TO TBC AS SHOWN.

SEE ATTACHED PAGES

4. Drawing Cog. Engineer Approval: J.R. Stubb Date: 10-7-91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

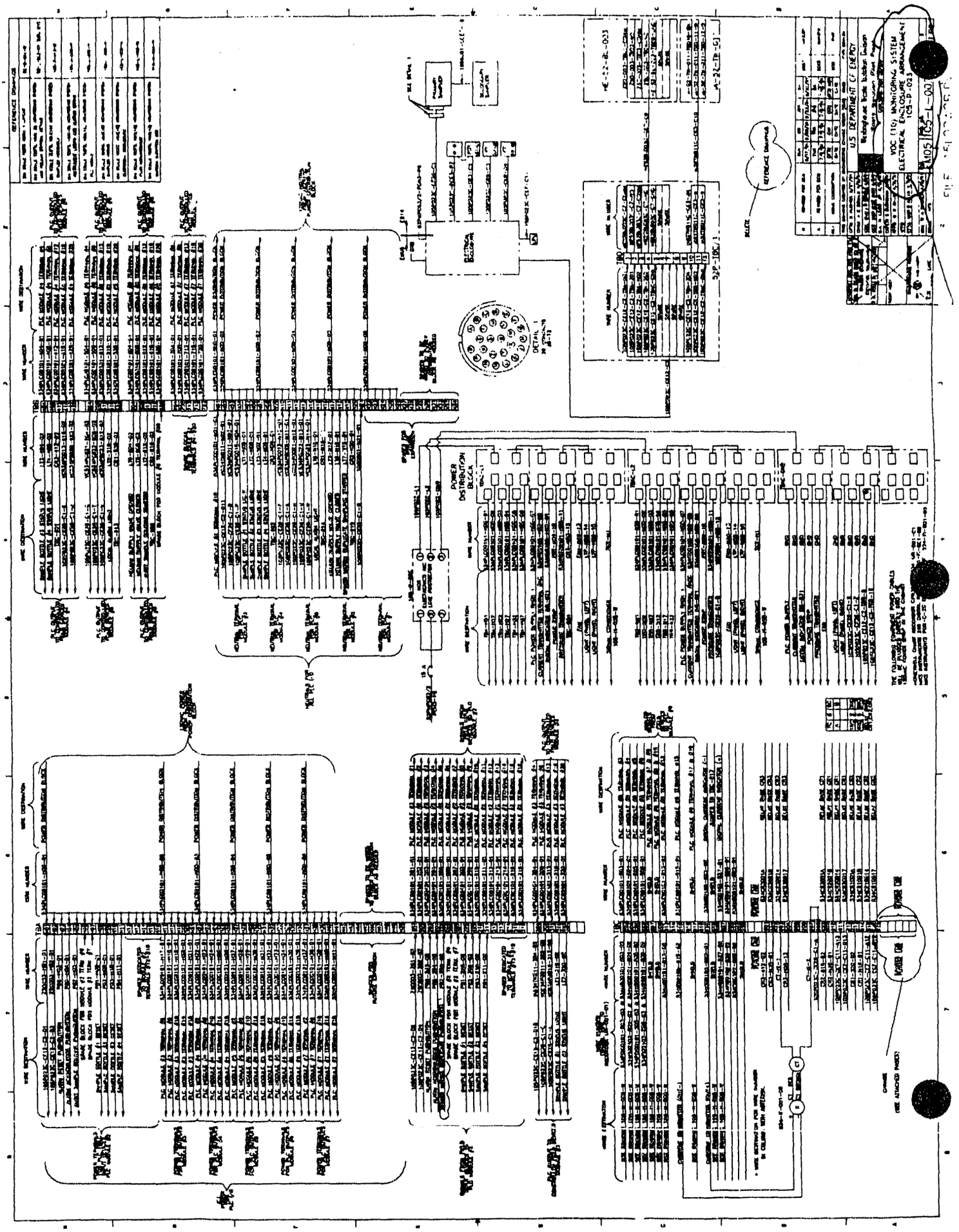
Drafting Started: _____ Initials / Date

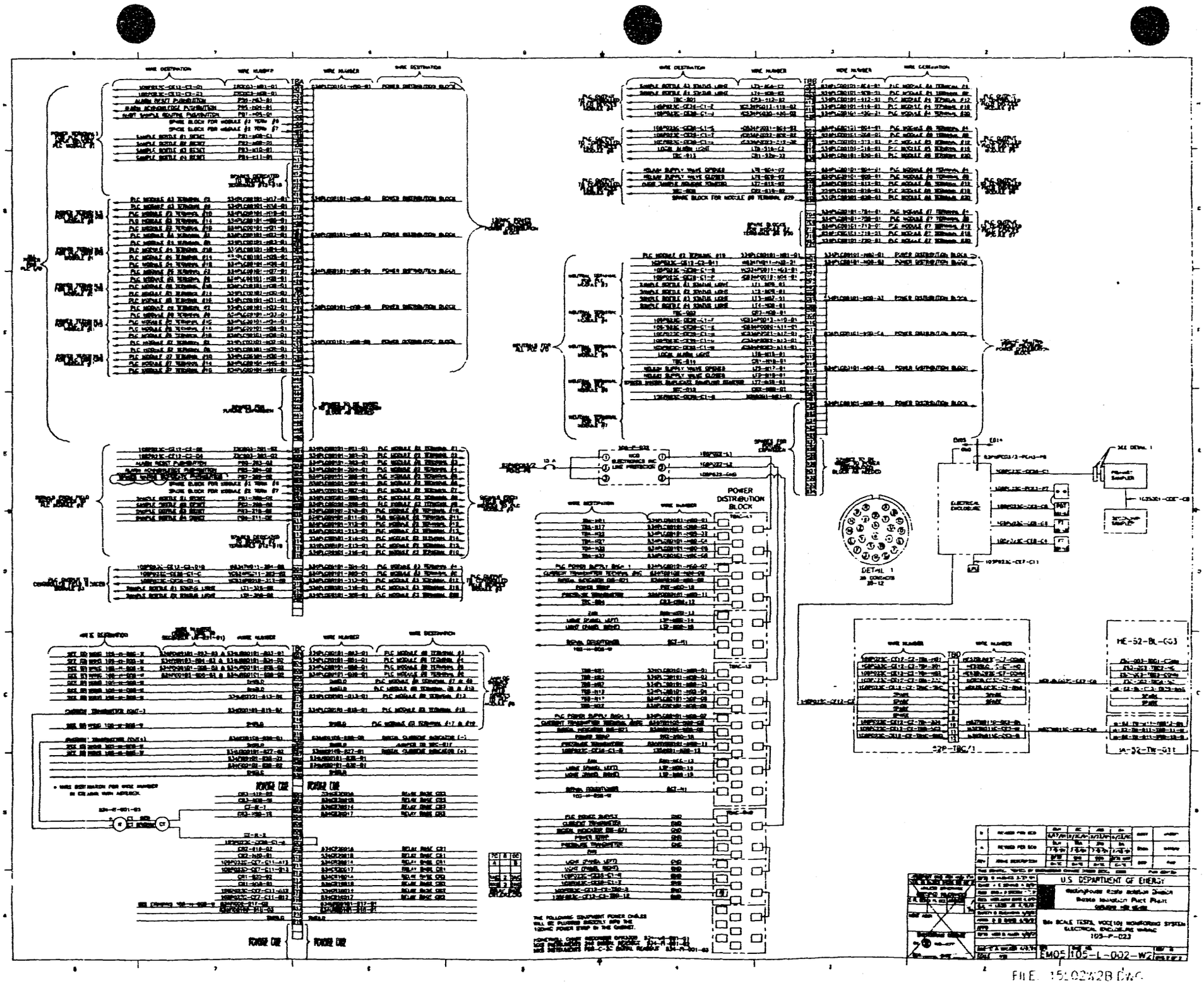
Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

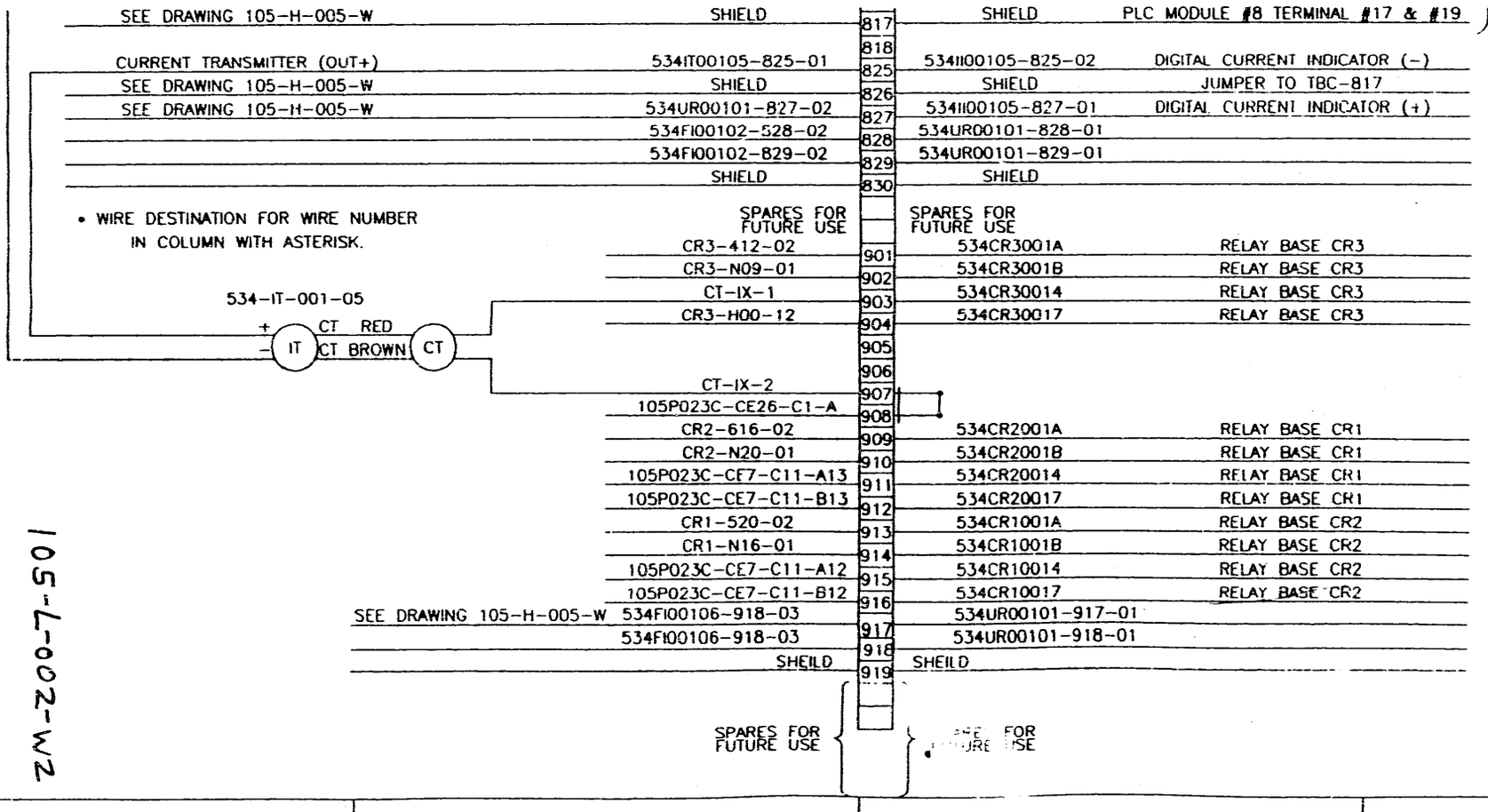
Return to EFR: _____ Initials / Date





ECO 15342
PAGE 48 OF 57

FILE: 15023428.DWG



ECO
PAGE 44 OF 57

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 105-L-003-W ECO Number: 5821

2. ECO Search List: _____ _____ _____ _____

3. Description of Change:

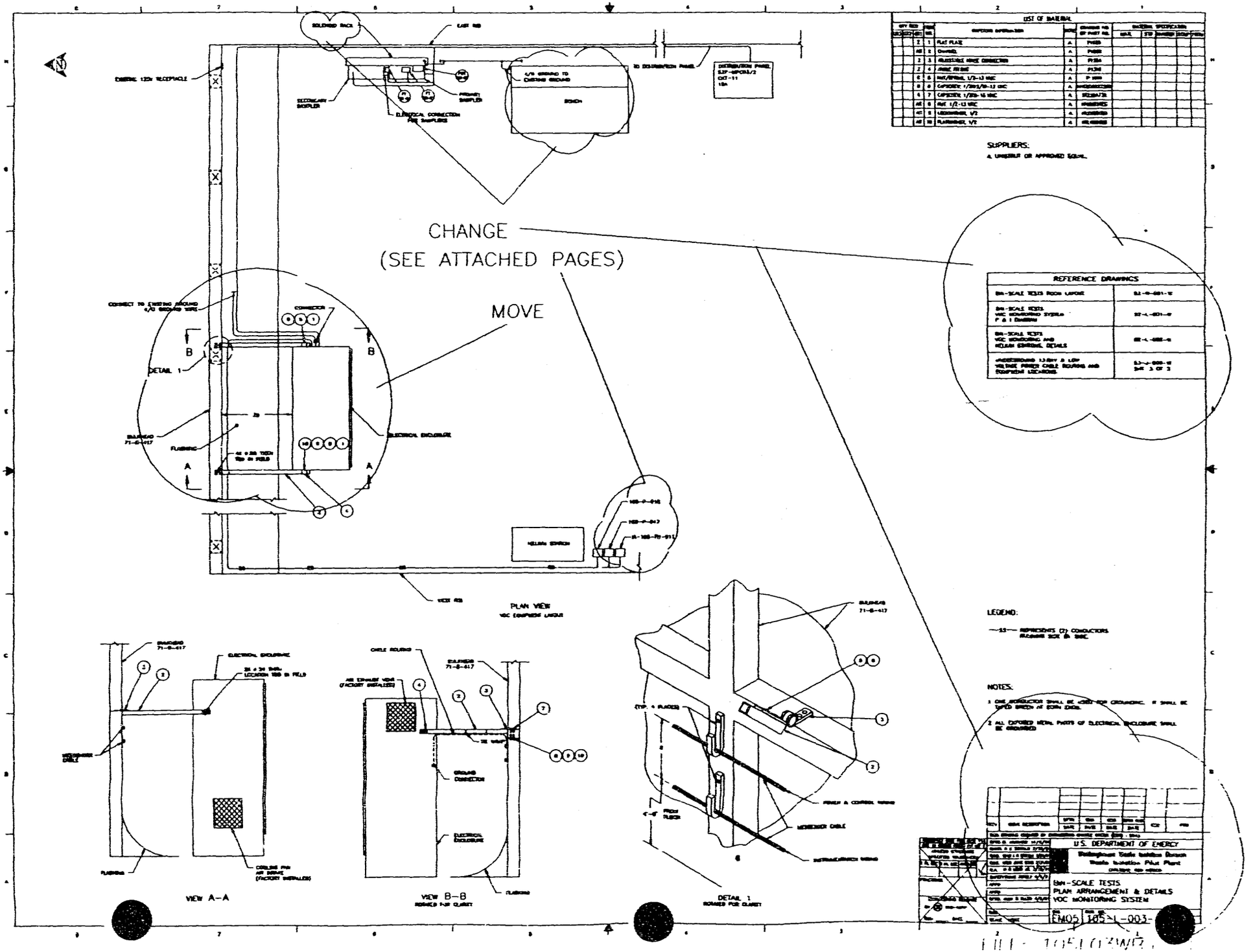
1. CHANGE THE "BENCH" TO A RACK SIMILAR TO THE "SOLENOID RACK".
2. CHANGE THE DESCRIPTION "SOLENOID RACK" TO "SAMPLER RACK".
3. MOVE THE "ELECTRICAL ENCLOSURE TO THE EAST.

SEE ATTACHED PAGES

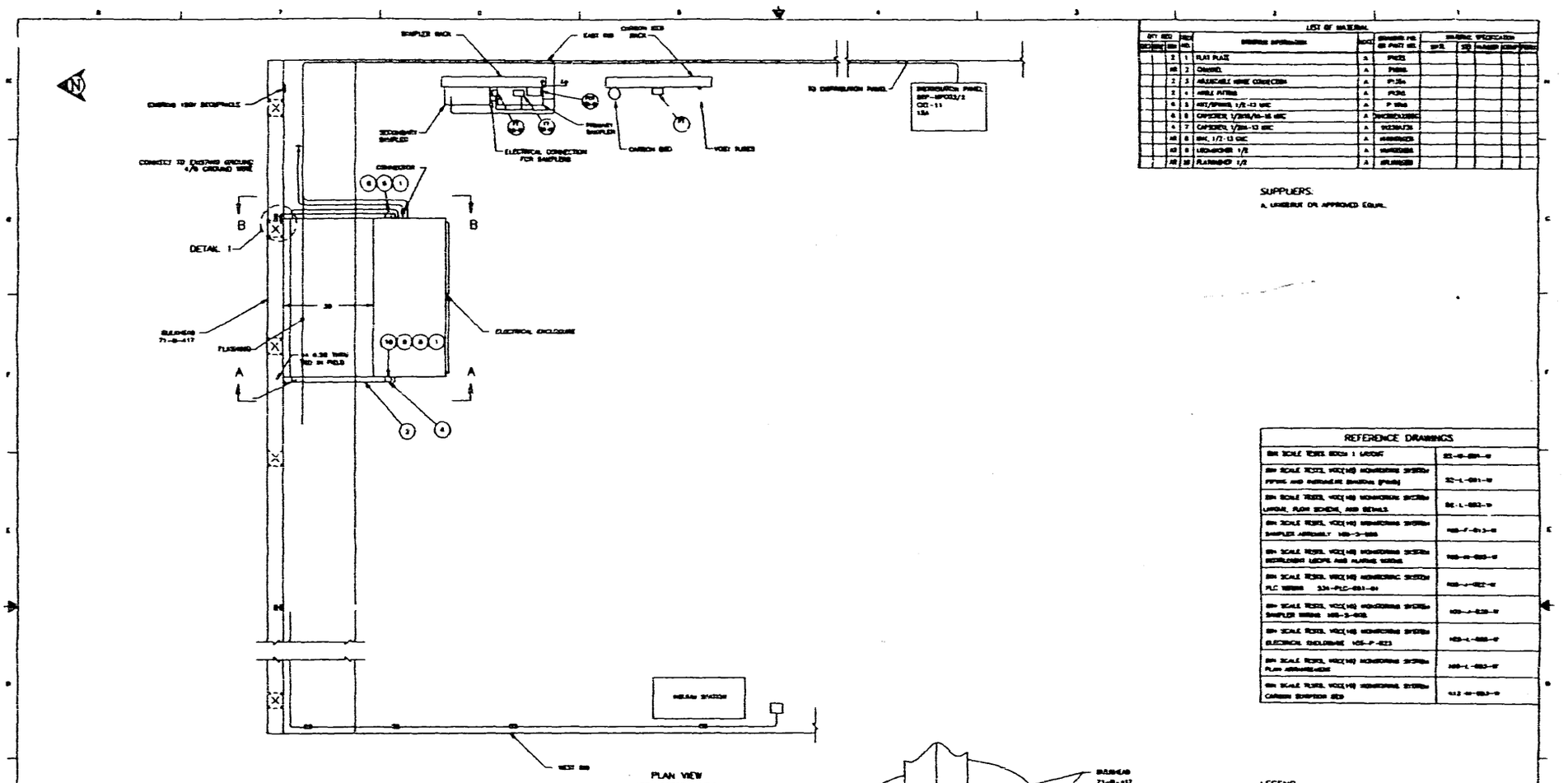
4. Drawing Cog. Engineer Approval: J.R. Stubbe Date: 10-7-91

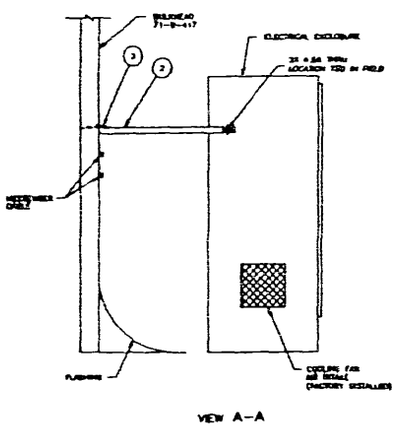
5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date
Drafting Started: _____ Initials / Date
Date Assigned: _____ Initials / Date
Drafting Completed: _____ Initials / Date
Assigned to: _____ (Same as data base entry)
Return to EFR: _____ Initials / Date

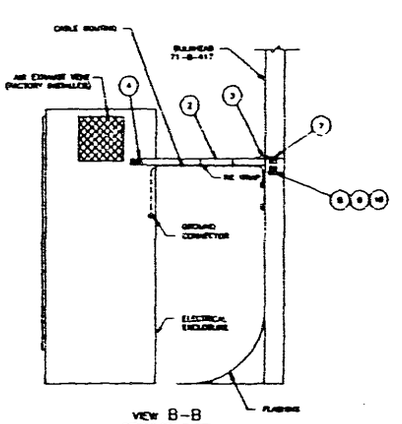


ECO 3521
PAGE 51 OF 57

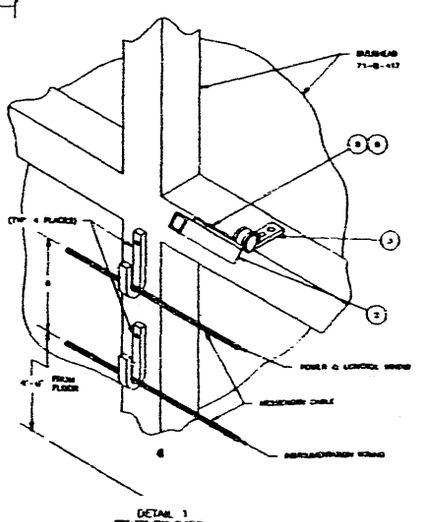




VIEW A–A



VIEW B–B
ROTATED FOR CLARITY



DETAIL 1
ROTATED FOR CLARITY

LIST OF MATERIAL

QTY REQ	ITEM NO.	DRAWING INFORMATION	SOURCE	DRAWING NO. OR PART NO.	MATERIAL SPECIFICATION
	1	FLAT PLATE	A		
	2	CHANNEL	A		
	3	ADJUSTABLE HOSE CONNECTION	A		
	4	ANGLE FITTING	A		
	5	HEX BOLT, 1/2-13 UNC	A		
	6	CAPSCREW, 1/2-13 UNC	A		
	7	CAPSCREW, 1/2-13 UNC	A		
	8	NUT, 1/2-13 UNC	A		
	9	LOCKWASHER 1/2	A		
	10	FLATWASHER 1/2	A		

SUPPLIERS:
A. GRAINGER OR APPROVED EQUAL

REFERENCE DRAWINGS	
8th SCALE TESTS, BOOth 1 LAYOUT	
8th SCALE TESTS, VOC(HS) MONITORING SYSTEM PIPING AND INSTRUMENT DIAGRAM (P&ID)	
8th SCALE TESTS, VOC(HS) MONITORING SYSTEM LAYOUT, FLOW SCHEME, AND DETAILS	
8th SCALE TESTS, VOC(HS) MONITORING SYSTEM SAMPLER ASSEMBLY	
8th SCALE TESTS, VOC(HS) MONITORING SYSTEM DISTRIBUTION UNITS AND PIPING SYSTEM	
8th SCALE TESTS, VOC(HS) MONITORING SYSTEM PLC	
8th SCALE TESTS, VOC(HS) MONITORING SYSTEM SAMPLER	
8th SCALE TESTS, VOC(HS) MONITORING SYSTEM ELECTRICAL ENCLOSURE	
8th SCALE TESTS, VOC(HS) MONITORING SYSTEM PLAN ARRANGEMENT	
8th SCALE TESTS, VOC(HS) MONITORING SYSTEM CARBON ADSORPTION BED	

LEGEND:

—36— REPRESENTS (2) CONDUCTORS #12 AWG, BLACK

NOTES:

1. ONE CONDUCTOR SHALL BE USED FOR GROUNDING. IT SHALL BE TAPED GREEN AT BOTH ENDS.
2. ALL EXPOSED METAL PARTS OF ELECTRICAL ENCLOSURE SHALL BE GROUNDED.

U.S. DEPARTMENT OF ENERGY
Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant

8th SCALE TEST, VOC(HS) MONITORING SYSTEM
PLAN ARRANGEMENT AND DETAILS

EM05 105-L-003-W

ECO 9[illegible]
PAGE 52 OF 57

[illegible] TOP OF SWC DWG

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 412-M-003-W ECO Number: 5821

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

1. CHANGE TITLE TO :

BIN SCALE TESTS, VOC (10) MONITORING SYSTEM

CARBON SORPTION BED

2. CHANGE SYSTEM DESIGNATOR TO EM05

4. Drawing Cog. Engineer Approval: J.R. Stubb Date: 10-7-91

VALVE IDENTIFICATION SHEET

NEW VALVE ☐ REVISED DATA ☐ VALVE REMOVED ☒

1. Valve Number: VC-534-TW-010
2. System: EMOS
3. Building/Location: V/G, PANEL-1, RM-1
4. Size: 1/4"
5. Pressure: 100 PSI
6. Valve Type: BALL 3-WAY
7. Valve Operator: MANUAL
8. Valve Bonnet: N/A
9. Manufacturer: SWAGE LOK (WHITEY
10. Catalog No.: SS-43XS4
11. Body: SS-316
12. Trim: SS-316
13. Ends: SS-316
14. Piping Code: N/A
15. Seis. Class: N/A
16. Working Pressure: ATM (0 PSIG)
17. Working Temperature: 85°F
18. Normal Valve Position/Full Open: X (CARBON BED TO SAMPLER) Full Closed: _____ % Throttled: _____
19. Spec. Number: D-0077
20. P.O. Number: N/A
21. Design Class: III A
22. P&ID: 52-L-001-W Sht.: _____ Zone: _____
23. Plan Drawing Number: 52-L-002-W Sht.: _____ Zone: _____
24. Isometric Drawing Number: 52-L-002-W
25. Piping Line Number: N/A
26. Document Providing Information

    030 M41816 ECO 5346/5565 EWP _____
27. Service Remarks: _____

J.R. Struble
Information by

10-1-91
Date

TAG NUMBER	SYSTEM	BUILDING	INDICATES VALVE	NUMBER
EXAMPLE	RW	457	V	001

VALVE IDENTIFICATION SHEET

NEW VALVE ☐ REVISED DATA ☐ VALVE REMOVED ☒

1. Valve Number: VC-534-TW-025 2. System: EMOS
3. Building/Location: U/G, PANEL-1, RM-1 4. Size: 1"
5. Pressure: 100 PSI 6. Valve Type: BALL 3-WAY
7. Valve Operator: MANUAL 8. Valve Bonnet: N/A
9. Manufacturer: SWAGELOK (WHITEY) 10. Catalog No.: SS-65XT616-F16
11. Body: SS-316 12. Trim: SS-316 13. Ends: SS-316
14. Piping Code: N/A 15. Seis. Class: N/A
16. Working Pressure: ATM (0 PSIG) 17. Working Temperature: 85°F (VOST TUBES TO SAMPLER)
18. Normal Valve Position/Full Open: X Full Closed: _____ % Throttled: _____
19. Spec. Number: D-0077 20. P.O. Number: N/A
21. Design Class: III A
22. P&ID: 52-L-001-W Sht.: _____ Zone: _____
23. Plan Drawing Number: 52-L-001-W Sht.: _____ Zone: _____
24. Isometric Drawing Number: 52-L-002-W
25. Piping Line Number: N/A
26. Document Providing Information

030 M41816 ECO 5346/5565 EWP _____

27. Service Remarks: _____

J.R. Stroble — Information by

10-1-91 — Date

TAG NUMBER	SYSTEM	BUILDING	INDICATES VALVE	NUMBER
EXAMPLE	RW	457	V	001

VALVE IDENTIFICATION SHEET

NEW VALVE ☐ REVISED DATA ☐ VALVE REMOVED ☒

1. Valve Number: VC-534-TW-026 2. System: EMOS
3. Building/Location: U/G, PANEL-1, RM-1 4. Size: 1"
5. Pressure: 100 PSI 6. Valve Type: BALL 3-WAY
7. Valve Operator: MANUAL 8. Valve Bonnet: N/A
9. Manufacturer: SWAGELOK (WHITEY) 10. Catalog No.: SS-65XT616-F16
11. Body: SS-316 12. Trim: SS-316 13. Ends: SS-316
14. Piping Code: N/A 15. Seis. Class: N/A
16. Working Pressure: ATM (0 PSIG) 17. Working Temperature: 85°F (CARBON BED OR VAST TUBES TO PAV)
18. Normal Valve Position/Full Open: X Full Closed: _____ % Throttled: _____
19. Spec. Number: D-0077 20. P.O. Number: N/A
21. Design Class: III A
22. P&ID: 52-L-001-W Sht.: _____ Zone: _____
23. Plan Drawing Number: 52-L-002-W Sht.: _____ Zone: _____
24. Isometric Drawing Number: 52-L-002-W
25. Piping Line Number: N/A
26. Document Providing Information

030 M41816 ECO 5346/5565 EWP _____

27. Service Remarks: _____

J.R. Stroble
Information by

10-1-91
Date

TAG NUMBER EXAMPLE	SYSTEM RW	BUILDING 457	INDICATES VALVE V	NUMBER 001

VALVE IDENTIFICATION SHEET

NEW VALVE ☐ REVISED DATA ☐ VALVE REMOVED ☒

1. Valve Number: VC-534-TW-027 2. System: EM05
3. Building/Location: U/G, PANEL-1, RM-1 4. Size: 1"
5. Pressure: PSI 6. Valve Type: BALL 3-WAY
7. Valve Operator: MANUAL 8. Valve Bonnet: N/A
9. Manufacturer: SWAGELOK (WHITEY) 10. Catalog No.: SS-65XT616-F16
11. Body: SS-316 12. Trim: SS-316 13. Ends: SS-316
14. Piping Code: N/A 15. Seis. Class: N/A
16. Working Pressure: ATM (0 PSIG) 17. Working Temperature: 85°F (PRV OR BYPASS)
18. Normal Valve Position/Full Open: X Full Closed: ____ % Throttled: ____
19. Spec. Number: D-0077 20. P.O. Number: N/A
21. Design Class: III A
22. P&ID: 52-L-001-W Sht.: ____ Zone: ____
23. Plan Drawing Number: 52-L-001-W Sht.: ____ Zone: ____
24. Isometric Drawing Number: 52-L-002-W
25. Piping Line Number: N/A
26. Document Providing Information

030 M41816 ECO 5346/5565 EWP ____

27. Service Remarks: ____

J.R. Stroble — Information by

10-1-91 — Date

TAG NUMBER EXAMPLE	SYSTEM RW	BUILDING 457	INDICATES VALVE V	NUMBER 001

25 F 003 W

ENGINEERING CHANGE ORDER

USE BLACK INK

Page 1 of 13

1. **ECO No.:** 5835
SC&D Review: RV

Initials

Posted

2. **Impact Level** 1 ☐ 2 ☐ 3 ☒ 4 ☐

3. **System:** FP01/FP02 Equipment No.: _____ Building: 474B

4. Associated Documents:
PWR 12008M
ECP NA
P.O. _____
Others _____

5. **Document Type:**
Drawing 1714-S ☒
Specification 25-F-003-W ☐
Vendor Data 24-C-015-W ☐
SDD ☐
Others _____

6. **Title of Change:** BLDG. 474B RELOCATION

7. **Originator:** (print)	Ext. No.:	Department:	Date:	8. **Cognizant Engineer:** (print)
Wm BARNHART	8169	M&CE		Wm BARNHART

9. **Description of Change:**

Yes ☒ No ☐ Component Indices change required (If yes, attach sheets)

Bldg 474B is to be relocated from its temporary location west of Bldg 456 to its permanent foundation within the Haz. Mat. Facility.

Following the bldg's relocation, its sprinkler system will be connected to an existing FW piping stubup with new permanent sprinkler system supply piping (a riser). This new piping will have an isolation valve, pressure gage, drain, and provisions for tie-in of Bldg 474A (future). The bldg's temporary FW provisions will be removed.

☒ 9a Drawing Change Sheet attached ☐ 9c Vendor Data Change Sheet attached
☐ 9b Design Documentation Sheet attached

10. Yes ☒ No ☐ **MODIFICATION IN PROGRESS**
☐ Modification complete: _____ / _____ (Signature / Date)
ECO will be incorporated after M.I.P. signed complete

☐ Change drawing per as-built markup dated: _____
☐ Change drawing per ECO-provided data
☐ Temporary modification

11. **Design Verification Requirements: (per WP 09-018)** EDT No.: _____

JWP 1. Requirements satisfied by review/approval of design document
_____ 2. Independent review
_____ 3. Alternate calculations
_____ 4. Development testing
_____ 5. Design review
_____ 6. Other: _____

12. **Addendum Sheet added:** _____ / _____ (Signature / Date)

13. Justification

The Haz. Mat. Facility was designed with provisions for Bldg 4743 to be permanently located there. This "change" will make Bldg 4743 a permanent part of the Haz. Mat. Facility as intended.

Changes to the bldg's sprinkler system are being made to comply with "code" requirements.

14. Administrative Tracking

YES	N/A			YES	N/A	
☐	☒	1.	FSAR	☐	☒	6. Startup/Acceptance Test
☐	☒	2.	Calibration Procedures	☐	☒	7. Test Requirement & Spec.
☐	☒	3.	Maintenance Procedures	☒	☐	8. WP 12-116
☐	☒	4.	Computer Software	☐	☐	9.
☐	☒	5.	Operations Procedures	☐	☐	10.

15. Signature Requirements

KEY: A=APPR. R=REVIEW S=SIGN NEW DRAWING

A	Cog. Engineer	[illegible] 10/25/91
A	Cog. Eng. Mgr.	10/28/91
R	Startup	10/24/91
R	QA	10/25/91
☐	DOE	
A	Safety	Mickey L. Lovell 10-25-91
☐	Dept. Manager	
☐	Operations	
☐	Security	
☐	SNL	
☐		
☐		
☐		

16. Distribute as Marked

☒	Maintenance (MANDATORY)	
☒	Ops. Support (MANDATORY)	
☐	Startup	
☒	Facility Operations	CONT. DOC. FILE
☐	U/G Operations	
☐	Orig./Design Engr.	
☐	Cog. Engineer	
☐	Others	
☒	Safety	Mickey Lovell
☐		
☐		
☐		
☐		

ENGINEERING CHANGE ORDER

1. ECO # 5331
2. DATE 10/23/91

DOE ORDER 6430.1A DESIGN CRITERIA CHECKLIST

The design requirements in DOE Order 6430.1A checked below have been applied to this Design.

3. DIVISION	SUBDIVISION
☐ 1 General Requirements	☐ 0101 ☐ 0106 ☐ 0109 ☐ 0110 ☐ 0111 ☐ 0140 ☐ 0150 ☐ 0170
☐ 2 Site and Civil Engineering	☐ 0200 ☐ 0201 ☐ 0202 ☐ 0203 ☐ 0205 ☐ 0210 ☐ 0214 ☐ 0215 ☐ 0220 ☐ 02 ☐ 0245 ☐ 0250 ☐ 0256 ☐ 0260 ☐ 0262 ☐ 0265 ☐ 0267 ☐ 0270 ☐ 0273 ☐ 02 ☐ 0276 ☐ 0278 ☐ 0279 ☐ 0280 ☐ 0281 ☐ 0283 ☐ 0285 ☐ 0290 ☐ 0291
☐ 3 Concrete	☐ 0300 ☐ 0301 ☐ 0310 ☐ 0320 ☐ 0330 ☐ 0340 ☐ 0350 ☐ 0370 ☐ 0380
☐ 4 Masonry	☐ 0400 ☐ 0401 ☐ 0410 ☐ 0420 ☐ 0455
☐ 5 Metals	☐ 0500 ☐ 0512 ☐ 0514 ☐ 0521 ☐ 0531 ☐ 0532
☐ 6 Wood and Plastics	☐ 0600 ☐ 0610 ☐ 0650
☐ 7 Thermal and Moisture Protection	☐ 0710 ☐ 0711 ☐ 0714 ☐ 0715 ☐ 0719 ☐ 0720 ☐ 0721 ☐ 0722 ☐ 0724 ☐ 07 ☐ 0730 ☐ 0750 ☐ 0751 ☐ 0753 ☐ 0760 ☐ 0790
☐ 8 Doors and Windows	☐ 0800 ☐ 0810 ☐ 0820 ☐ 0830 ☐ 0833 ☐ 0836 ☐ 0839 ☐ 0850 ☐ 0860 ☐ 08 ☐ 0880
☐ 9 Finishes	☐ 0900 ☐ 0910 ☐ 0920 ☐ 0925 ☐ 0930 ☐ 0950 ☐ 0965 ☐ 0968 ☐ 0970 ☐ 09 ☐ 0990 ☐ 0995
☐ 10 Specialties	☐ 1015 ☐ 1020 ☐ 1024 ☐ 1027 ☐ 1030 ☐ 1040 ☐ 1050 ☐ 1052 ☐ 1053 ☐ 10 ☐ 1060 ☐ 1065 ☐ 1070 ☐ 1075 ☐ 1080
☐ 11 Equipment	☐ 1100 ☐ 1161
☐ 12 Furnishings	☐ 1201 ☐ 1230 ☐ 1250 ☐ 1260 ☐ 1270
☐ 13 Special Facilities	☐ 1300 ☐ 1304 ☐ 1305 ☐ 1306 ☐ 1307 ☐ 1318 ☐ 1319 ☐ 1320 ☐ 1321 ☐ 13 ☐ 1323 ☐ 1324 ☐ 1325 ☐ 1326 ☐ 1328
☐ 14 Conveying Systems	☐ 1401 ☐ 1420 ☐ 1440 ☐ 1460
■ 15 Mechanical	☐ 1525 ■ 1530 ☐ 1540 ☐ 1550 ☐ 1555 ☐ 1565 ☐ 1574 ☐ 1589 ☐ 1595
☐ 16 Electrical	☐ 1600 ☐ 1605 ☐ 1620 ☐ 1630 ☐ 1639 ☐ 1640 ☐ 1650 ☐ 1655 ☐ 1660 ☐ 16 ☐ 1671 ☐ 1685 ☐ 1694
4. ☐ NOT APPLICABLE	No portion of DOE Order 6430.1A is applicable to this Design.
5. ☐ AS-BUILT	ECO is for as-built field verified changes only.

NOTE: A check placed in the Division column signifies that the entire Division shall be applicable to the Design, unless modified by checks indicated for specific Subdivisions.

COMMENTS: _____

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 1714-S ECO Number: 5830

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Provide a sketch number for the sketch "Bldg. 474B Relocation". See attached page 6.

4. Drawing Cog. Engineer Approval: W E Barnhart Date: 10/23/91

ENGINEERING CHANGE ORDER Continuation Sheet	Document Number: -S/25-F-003-W/24-C-015-W		ECO 5 of 30
	Date:	Page 3 of 13	

As part of this change, two deficiencies with the bldg's sprinkler system will be corrected:

1) the sprinkler head configuration will be changed from upright to pendant to clear obstructions in the bldg's roof.

2) an Inspectors Test Connection will be added to allow testing of the sprinkler system flow switch and alarm system.

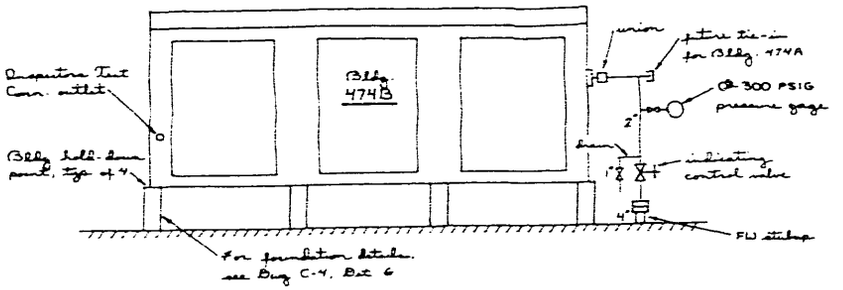
All fire protection work will be performed in accordance with the attached sketch and Spec. D-0065, Rev. 1.

1. Provide a sketch number for the attached sketch:
   1714 -S

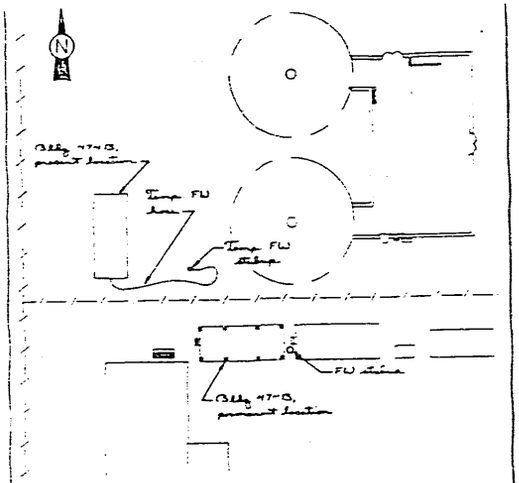
2. Following mod. completion, revise dwgs 25-F-003-W & 24-C-015-W to reflect this change.

3. Following mod. completion, remove the attached sketch from the active dwg. register.

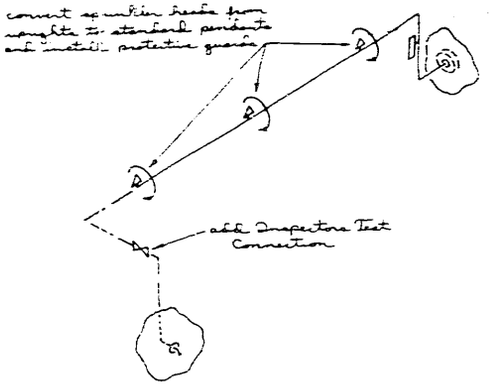
** Electrical changes to support relocation of Bldg 4743 are being addressed by a different ECO.



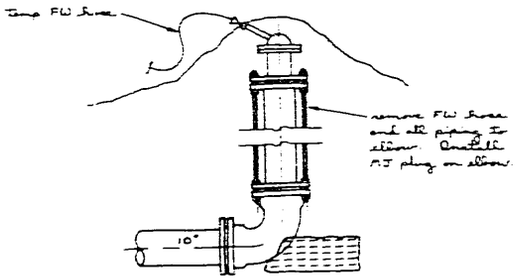
BLDG. RELOCATION & SPRINKLER SYSTEM SUPPLY PIPING INSTALLATION



KEY PLAN



SPRINKLER SYSTEM MODIFICATIONS



TEMP F.W. STUBUP REMOVAL

NOTES

1. The temporary firewater hose and electrical cables to Bldg. 474B must be removed, and the bldg. empty, prior to its relocation.
2. Westinghouse shall provide a forklift and driver to assist in the relocation of Bldg. 474B.
3. Bldg. 474B shall be shimmed as required to provide a level installation and to insure proper support from all foundation piers.
4. The sprinkler system supply piping shall have a union (or equivalent) to facilitate possible future disassembly.
5. Bldg. 474B's Fire Dept Conn. may be modified or eliminated as part of the sprinkler system supply piping installation.
6. The indicating control valve shall be an OS & Y gate valve. All required valves shall be bronze with screwed end connections and approved for fire protection service. A catalog cut of each valve shall be submitted "for record" prior to its installation.
7. The sprinkler system supply piping pressure gauge shall be furnished by Westinghouse.
8. All sprinkler system work shall be performed by a licensed fire protection system design and installation contractor.
9. The 10" mechanical joint plug shall be ductile iron, with bituminous coating, and shall conform to AWWA C110. After its installation, all associated bolts, etc. shall be coated with asphalt (or equivalent).
10. The new sprinkler system piping shall be flushed, via the Inspectors Test Connection of Bldg. 474B, to clean the piping and to verify that the piping is free of obstructions.
11. The new sprinkler system piping shall be hydrostatically tested, using the control valve as the upstream boundary. The test pressure gage shall be in calibration and the associated calibration data submitted for record prior to test performance. The test is satisfactory if test pressure remains above 210 PSIG for two hours (minimum), and the all pressure drop is less than 5 PSI, and there are no visible water leaks. All piping and joints not hydrostatically tested shall be leak checked at normal system operating pressure.
12. Work shall be in accordance with Specification [illegible], Dwg. 1, this sketch, and approved contractor working drawings. Required electrical work is addressed elsewhere.

BLDG. 474B RELOCATION - MECH. WORK ONLY

1. DISCONNECT TEMPORARY FIREWATER HOSE SUPPLY TO THE BLDG.
2. MOVE AND INSTALL THE BLDG. ON ITS FOUNDATION PIERS.
3. MODIFY THE BLDG. 5 SPRINKLER SYSTEM BY CHANGING POSITION AND STYLE OF SPRINKLER HEADS AND ADDING AN INSPECTORS TEST CONNECTION.
4. DESIGN, FABRICATE, AND INSTALL PERMANENT SPRINKLER SYSTEM SUPPLY PIPING TO THE BLDG.
5. FLUSH AND HYDROTEST THE NEW AND EXISTING SPRINKLER PIPING.
6. REMOVE TEMP. FW STUBUP, PLUG SAME BELOW GRADE, AND PERFORM LEAK CHECK.
7. REESTABLISH GRADE AT BLDG. 5 FORMER LOCATION.

REV	DATE	ISSUE DESCRIPTION	ENG	ECO
A				

U.S. DEPARTMENT OF ENERGY

Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

COC ENG
COC MGR

BLDG. 474B RELOCATION

SYS. FP01/FP02 | DWG NO. 7-4-3 | REV A | SH 1 OF 1 | 12008M

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 25-F-003-W, Rev A ECO Number: 5830

2. ECO Search List: 5514 5170 4603

3. Description of Change:

Revise dwg. to show the following:

- relocation of Bldg 474B to its permanent foundation within the Haz. Mat. Facility.
- removal of temp. fire hose and FW piping stubup.
- tie-in of Bldg 474B to FW piping stubup within Haz. Mat. Facility.

* Markups not provided because dwg. does not yet show Haz. Mat. Facility.

4. Drawing Cog. Engineer Approval: WE Bosshart Date: 10/23/91

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 24-C-015-(2), Rev B ECO Number: 5830

2. ECO Search List:

5795	5788	5772	5674
5683	3891		

3. Description of Change:

Revise dwg. to show the following:

- relocation of Bldg 474B to its permanent foundation within the Haz. Mat. Facility.
- removal of temp.. fire hose and FW piping stubup.
- tie-in of Bldg 474B to FW piping stubup within Haz. Mat. Facility.

* Markups not provided because dwg. does not yet show Haz. Mat. Facility.

4. Drawing Cog. Engineer Approval: L E Barnhart Date: 10/23/91

1290:B0006

ECO #. 5330
Pg 9 of 13

VALVE IDENTIFICATION SHEET

NEW VALVE ☒ REVISED DATA ☐ VALVE REMOVED ☐

1. Valve Number: FW-25-V-007 2. System: FP02
3. Building/Location: YARD NEAR BLDG 424B 4. Size: 2"
5. Pressure: _____ 6. Valve Type: GATE
7. Valve Operator: HANDWHEEL 8. Valve Bonnet: _____
9. Manufacturer: _____ 10. Catalog No.: _____
11. Body: _____ 12. Trim: _____ 13. Ends: SCREWED
14. Piping Code: NFPA 13 15. Seis. Class: NA
16. Working Pressure: 175 PSIG 17. Working Temperature: AMBIENT
18. Normal Valve Position/Full Open: X Full Closed: _____ % Throttled: _____
19. Spec. Number: NA 20. P.O. Number: NA
21. Design Class: III B
22. P&ID: NA Sht.: _____ Zone: _____
23. Plan Drawing Number: NA Sht.: _____ Zone: _____
24. Isometric Drawing Number: NA
25. Piping Line Number: NA
26. Document Providing Information

030 12008M ECO _____ EWP _____

27. Service Remarks: Provides the ability to isolate Bldgs. 424A (future) and 424B sprinkler systems from the firewater system.

W E Barnhart — Information by
10/23/91 — Date

TAG NUMBER EXAMPLE	SYSTEM RW	BUILDING 457	INDICATES VALVE V	NUMBER 001

ECC # 5850
pg 10 of 13

VALVE IDENTIFICATION SHEET

NEW VALVE ☒ REVISED DATA ☐ VALVE REMOVED ☐

1. Valve Number: FW-25-V-008
2. System: FP02
3. Building/Location: YARD/BLDG NEAR 474B
4. Size: 1"
5. Pressure: _____
6. Valve Type: GLOBE
7. Valve Operator: HANDWHEEL
8. Valve Bonnet: _____
9. Manufacturer: _____
10. Catalog No.: _____
11. Body: _____
12. Trim: _____
13. Ends: SCREWED
14. Piping Code: NFPA 13
15. Seis. Class: NA
16. Working Pressure: 175 PSIG
17. Working Temperature: AMBIENT
18. Normal Valve Position/Full Open: _____ Full Closed: X % Throttled: _____
19. Spec. Number: NA
20. P.O. Number: NA
21. Design Class: III B
22. P&ID: NA Sht.: _____ Zone: _____
23. Plan Drawing Number: NA Sht.: _____ Zone: _____
24. Isometric Drawing Number: NA
25. Piping Line Number: NA
26. Document Providing Information

030 12008M ECO _____ EWP _____

27. Service Remarks: Drain valve for draining Bldgs 474A (future) and 474B sprinkler systems.

W E Barnhart — Information by

10/23/91 — Date

TAG NUMBER	SYSTEM	BUILDING	INDICATES VALVE	NUMBER
EXAMPLE	RW	457	V	001

ECO #: 583
pg 11 of 13

VALVE IDENTIFICATION SHEET

NEW VALVE ☒ REVISED DATA ☐ VALVE REMOVED ☐

1. Valve Number: FW-25-V-009 2. System: FP02
3. Building/Location: YARD/NEAR BLDG 474B 4. Size: 1/4"
5. Pressure: _____ 6. Valve Type: GLOBE
7. Valve Operator: HANDWHEEL 8. Valve Bonnet: _____
9. Manufacturer: _____ 10. Catalog No.: _____
11. Body: _____ 12. Trim: _____ 13. Ends: SCREWED
14. Piping Code: NFPA 13 15. Seis. Class: NA
16. Working Pressure: 175 PSIG 17. Working Temperature: AMBIENT
18. Normal Valve Position/Full Open: X Full Closed: _____ % Throttled: _____
19. Spec. Number: NA 20. P.O. Number: NA
21. Design Class: III B
22. P&ID: NA Sht.: _____ Zone: _____
23. Plan Drawing Number: NA Sht.: _____ Zone: _____
24. Isometric Drawing Number: NA
25. Piping Line Number: NA
26. Document Providing Information

030 12008M ECO _____ EWP _____

27. Service Remarks: Gauge test valve which allows gauge to be tested or removed without system shutdown.

W E Barnhart — Information by
10/23/91 — Date

TAG NUMBER	SYSTEM	BUILDING	INDICATES VALVE	NUMBER
EXAMPLE	RW	457	V	001

ECC #. 333..
pg 12 of 13

VALVE IDENTIFICATION SHEET

NEW VALVE ☒ REVISED DATA ☐ VALVE REMOVED ☐

1. Valve Number: FW-424B-V-001 2. System: FP02
3. Building/Location: 424B 4. Size: 1"
5. Pressure: ____ 6. Valve Type: GLOBE
7. Valve Operator: HANDWHEEL 8. Valve Bonnet: ____
9. Manufacturer: ____ 10. Catalog No.: ____
11. Body: ____ 12. Trim: ____ 13. Ends: SCREWED
14. Piping Code: NFPA 13 15. Seis. Class: NA
16. Working Pressure: 175 PSIG 17. Working Temperature: AMBIENT
18. Normal Valve Position/Full Open: ____ Full Closed: X % Throttled: ____
19. Spec. Number: NA 20. P.O. Number: NA
21. Design Class: III B
22. P&ID: NA Sht.: ____ Zone: ____
23. Plan Drawing Number: NA Sht.: ____ Zone: ____
24. Isometric Drawing Number: NA
25. Piping Line Number: NA
26. Document Providing Information

030 12008M ECO ____ EWP ____

27. Service Remarks: Sprinkler system's Inspectors Test Connection valve.

W E Baanhart — Information by
10/23/91 — Date

TAG NUMBER	SYSTEM	BUILDING	INDICATES VALVE	NUMBER
EXAMPLE	RW	457	V	001

11898:3308

ECO [illegible]

pg 13 of 13

ATTACHMENT 3
WP 09-021, Rev. 1
Page 1 of 2

INSTRUMENT NUMBER REQUEST

1. Instrument Number 25-PI-001-01
2. Description Sprinkler System Pressure Indication
   Narrative: Pressure indication for sprinkler systems in Bldgs 474A (future) and 474B.
3. Subequipment NA
4. Loop Number NA
5. Drawing Number NA
   P&ID Drawing Number NA
6. System FP02
7. CMS Point NA
8. Input Type/Range 0-300 PSIG
9. Output Type/Range NA
10. Set Points NA
11. Cal./PM Procedure Number
12. Manufacturer
13. Model Number ____ Serial Number ____
14. Design Class IIIB
15. Critical Equipment ____ Yes __X__ No
16. Location: Building ____ Room Number ____
17. Electrical Power From
18. O&M Manual in File Room ____ Yes __X__ No
19. Cognizant Manager/Engineer POHL / BARNHART
20. Equipment Labeled ____ Yes __X__ No

    Remarks: Gage to be installed by PWR # 120088M
    SKETCH 1714-S

Requestor WE Barnhart Date 10/23/91

WP Form 1870; 10/17/89
Page 1 of 2

41B C01 W1

ENGINEERING CHANGE ORDER

USE BLACK INK

1. **ECO No.:** 5845

CC&D Review: ✓ Initials

Posted

2. **Impact Level** 1 ☐ 2 ☒ 3 ☐ 4 ☐

3. **System:** HV01 Equipment No.: 41B816/817 Building: 411

4. Associated Documents:

PWR _____

ECP ~~1-HV01-231~~

P.O. _____

Others ~~ORR P/L It.2.1.2.2~~

5. **Document Type:**

Drawing ☐

Specification ☐

Vendor Data ☐

SDD HV00 ☒

Others _____

6. **Title of Change:** 41B816/817 Interlocks.

7. **Originator:** (print)	Ext. No.:	Department:	Date:	8. **Cognizant Engineer:** (print)
Keith Ealden	8174	M. & C.E	102491	Keith Ealden

9. **Description of Change:**

Yes ☐ No ☑ Component indices change required (if yes, attach sheets)

Provide interlocks between 41-B-816 and 41-B-817 fans to prevent simultaneous operation of both HV01 system ventilation trains.

This provision was requested by the above referenced HV01 System ORR punchlist item.

The interlocks are to be provided by using a spare, normally closed, contact on the respective exhaust fan motor starter auxiliary relay.

Provision of the interlock will require revisions to the HV00 System SDD; HV01 System P. & I. D., Control Logic Diagram and Electrical Schematic and Wiring Diagram, details of which are given on the following pages.

Page 31 of 31 is included for info. only for MCC changes.

☒ 9a Drawing Change Sheet attached

☒ 9b Design Documentation Sheet attached

☐ 9c Vendor Data Change Sheet attached

10.

Yes	No	
☒	☐	**MODIFICATION IN PROGRESS**
☐		Modification complete: _____ / _____ (Signature / Date)

ECO will be incorporated after M.I.P. signed complete

☐ Change drawing per as-built markup dated: _____

☐ Change drawing per ECO-provided data

☐ Temporary modification

11. **Design Verification Requirements: (per WP 09-018)** EDT No.: E91-348

_____	1. Requirements satisfied by review/approval of design document
JWP	2. Independent review
_____	3. Alternate calculations
_____	4. Development testing
_____	5. Design review
_____	6. Other: _____

12. **Addendum Sheet added:** #1, 2 & 3 D. Keaton Signature 11-8-92 Date

13. Justification

In the past, dual train operation of the main HV01 System has resulted in deformation of the system exhaust duct downstream of the room pressure control dampers, due to the original design under estimating the negative pressure that would be developed in the ducts.

The prevention of simultaneous operation of the trains is currently achieved administratively. The internal ORR review considered that this was inadequate in the long term and that the associated fans should be interlocked to prevent simultaneous operation under all control conditions.

14. Administrative Tracking

YES	N/A			YES	N/A	
☐	☒	1.	FSAR	☒	☐	6. Startup/Acceptance Test
☐	☒	2.	Calibration Procedures	☒	☐	7. Test Requirement & Spec.
☐	☒	3.	Maintenance Procedures	☒	☐	8. SOD
☐	☒	4.	Computer Software	☐	☐	9.
☐	☐	5.	Operations Procedures	☐	☐	10.

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

A	Cog. Engineer	[signature]	24 Oct. '91
A	Cog. Eng. Mgr.	[signature]	10/31/91
R	Startup	[signature]	11/1/91
A	QA	[signature]	11/6/91
A	DOE	[signature]	11/14/91
R	Safety	[signature]	11/19/91
☐	Dept. Manager		
A	Operations	[signature]	11/12/91
☐	Security		
☐	SNL		
R	ELECT. ENG'G.	[signature]	
☐			
☐			

16. Distribute as Marked

X	Maintenance (MANDATORY)	
X	Ops. Support (MANDATORY)	
X	Startup	
X	Facility Operations	Controlled Dwg. File
☐	U/G Operations	
☐	Orig./Design Engr.	
X	Cog. Engineer	
☐	Others	
☐		
☐		
☐		
☐		
☐		

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 41-J-032-W1 ECO Number: 5845

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

On HS-052-25 change labelling of wire no.21 as shown marked up on page 4 of 31.

4. Drawing Cog. Engineer Approval: [signature] Date: 24 Oct. '91.

ENGINEERING CHANGE ORDER

1. ECO # 5045
2. DATE

DOE ORDER 6430.1A DESIGN CRITERIA CHECKLIST

The design requirements in DOE Order 6430.1A checked below have been applied to this Design.

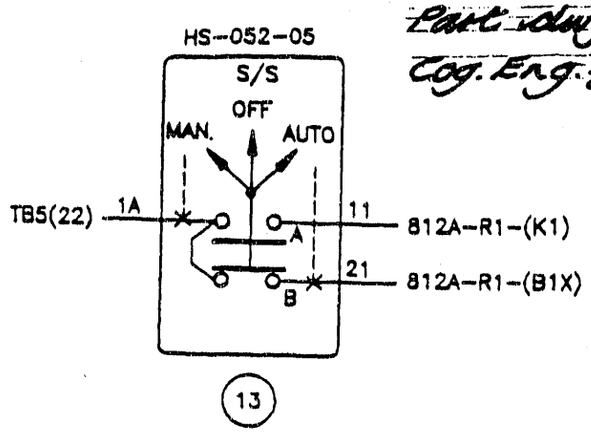
3.	DIVISION	SUBDIVISION
☐	1 General Requirements	☐ 0101 ☐ 0106 ☐ 0109 ☐ 0110 ☐ 0111 ☐ 0140 ☐ 0150 ☐ 0170
☐	2 Site and Civil Engineering	☐ 0200 ☐ 0201 ☐ 0202 ☐ 0203 ☐ 0205 ☐ 0210 ☐ 0214 ☐ 0215 ☐ 0220 ☐ 0221 ☐ 0245 ☐ 0250 ☐ 0256 ☐ 0260 ☐ 0262 ☐ 0265 ☐ 0267 ☐ 0270 ☐ 0273 ☐ 0275 ☐ 0276 ☐ 0278 ☐ 0279 ☐ 0280 ☐ 0281 ☐ 0283 ☐ 0285 ☐ 0290 ☐ 0291
☐	3 Concrete	☐ 0300 ☐ 0301 ☐ 0310 ☐ 0320 ☐ 0330 ☐ 0340 ☐ 0350 ☐ 0370 ☐ 0380
☐	4 Masonry	☐ 0400 ☐ 0401 ☐ 0410 ☐ 0420 ☐ 0455
☐	5 Metals	☐ 0500 ☐ 0512 ☐ 0514 ☐ 0521 ☐ 0531 ☐ 0532
☐	6 Wood and Plastics	☐ 0600 ☐ 0610 ☐ 0650
☐	7 Thermal and Moisture Protection	☐ 0710 ☐ 0711 ☐ 0714 ☐ 0715 ☐ 0719 ☐ 0720 ☐ 0721 ☐ 0722 ☐ 0724 ☐ 0725 ☐ 0730 ☐ 0750 ☐ 0751 ☐ 0753 ☐ 0760 ☐ 0790
☐	8 Doors and Windows	☐ 0800 ☐ 0810 ☐ 0820 ☐ 0830 ☐ 0833 ☐ 0836 ☐ 0839 ☐ 0850 ☐ 0860 ☐ 0870 ☐ 0880
☐	9 Finishes	☐ 0900 ☐ 0910 ☐ 0920 ☐ 0925 ☐ 0930 ☐ 0950 ☐ 0965 ☐ 0968 ☐ 0970 ☐ 0980 ☐ 0990 ☐ 0995
☐	10 Specialties	☐ 1015 ☐ 1020 ☐ 1024 ☐ 1027 ☐ 1030 ☐ 1040 ☐ 1050 ☐ 1052 ☐ 1053 ☐ 1054 ☐ 1060 ☐ 1065 ☐ 1070 ☐ 1075 ☐ 1080
☐	11 Equipment	☐ 1100 ☐ 1161
☐	12 Furnishings	☐ 1201 ☐ 1230 ☐ 1250 ☐ 1260 ☐ 1270
☐	13 Special Facilities	☐ 1300 ☐ 1304 ☐ 1305 ☐ 1306 ☐ 1307 ☐ 1318 ☐ 1319 ☐ 1320 ☐ 1321 ☐ 1322 ☐ 1323 ☐ 1324 ☐ 1325 ☐ 1326 ☐ 1328
☐	14 Conveying Systems	☐ 1401 ☐ 1420 ☐ 1440 ☐ 1460
☑	15 Mechanical	☐ 1525 ☐ 1530 ☐ 1540 ☒ 1550 ☐ 1555 ☐ 1565 ☐ 1574 ☐ 1589 ☐ 1595
☑	16 Electrical	☒ 1600 ☒ 1605 ☐ 1620 ☐ 1630 ☐ 1639 ☒ 1640 ☐ 1650 ☐ 1655 ☐ 1660 ☐ 1670 ☐ 1671 ☐ 1685 ☐ 1694
4. ☐	NOT APPLICABLE	No portion of DOE Order 6430.1A is applicable to this Design.
5. ☐	AS-BUILT	ECO is for as-built field verified changes only.

NOTE: A check placed in the Division column signifies that the entire Division shall be applicable to the Design, unless modified by checks indicated for specific Subdivisions.

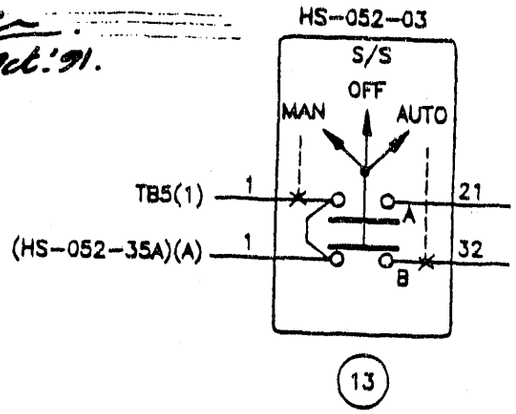
COMMENTS: _____

—(T)— MAIN BUS ANNUNCIATOR

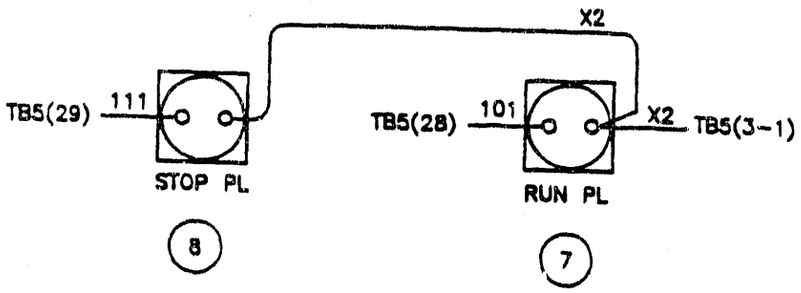
ECO-5645, Page 4 of 32
Part dwg: 41-J-032-W1.
Cog. Eng.: Balder
17 Oct. '91.



SCHEME 418812A

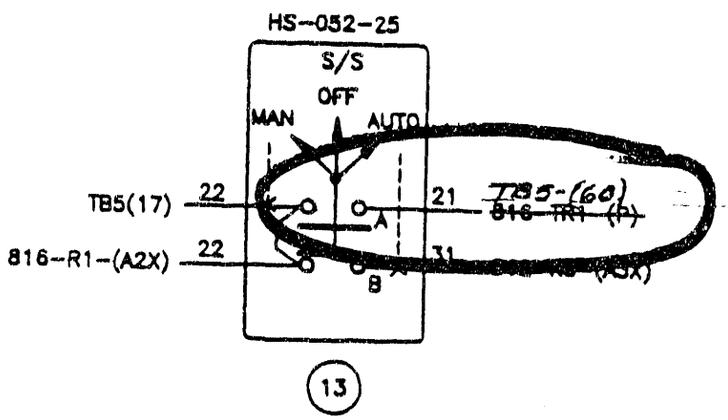


SCHEME 418812



12

(HS-052-03)(B)AUTO 1
812-R1-(A2X) 1



SCHEME 418816

WIRING DIAGRAM—FRONT PANEL REAR VIEW

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

Page 2 of 32

1. Drawing: 41-J-032-W2 ECO Number: 5845

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

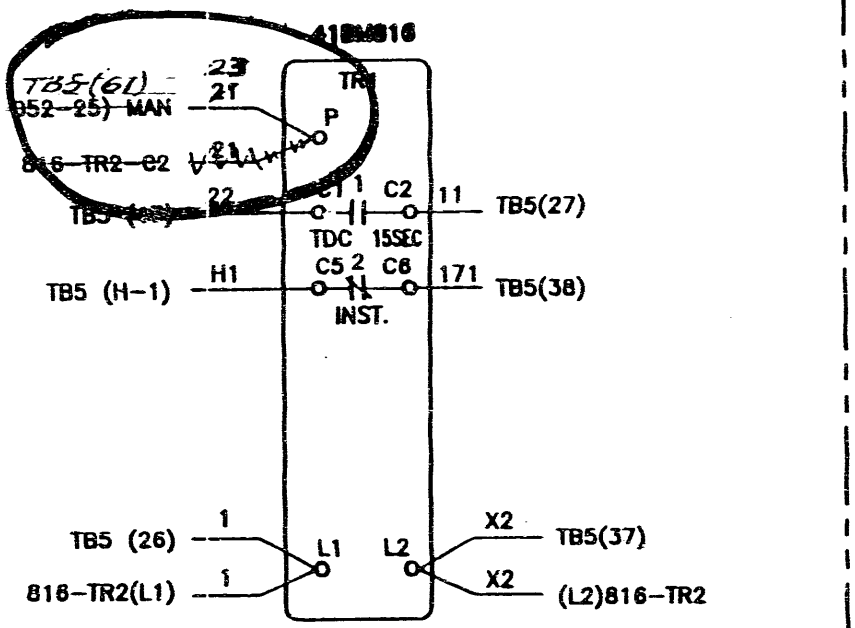
On Scheme 41B816 make revisions as follows:

a)Timing Relay TR1, change labelling on wire no. 21 and wire number;

b)Timing Relay TR2, change labelling on wire no. 21;

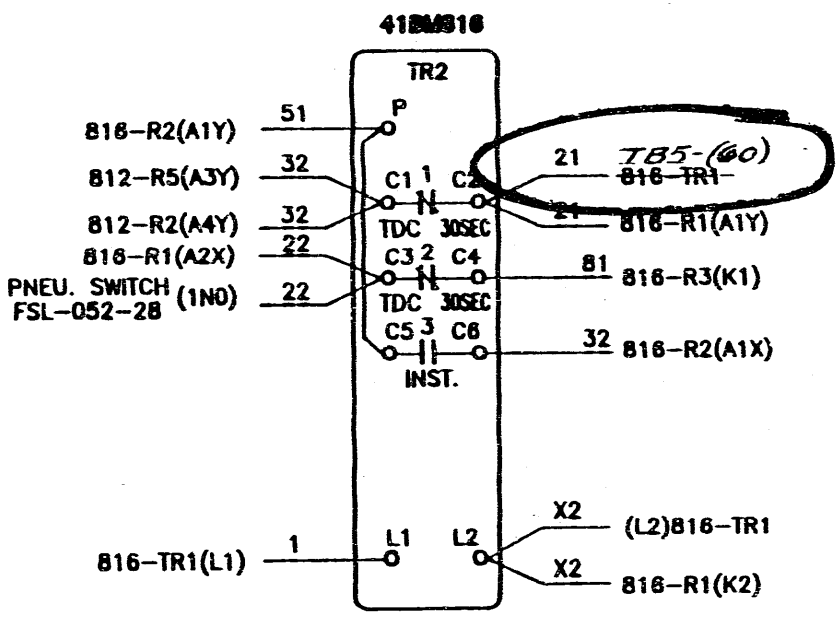
both as shown marked up on page 6 of 31.

4. Drawing Cog. Engineer Approval: _____ Date: 24 Oct. '91



TIMING RELAY TR1-ON DELAY(120 SEC)

34



TIMING RELAY TR2-ON DELAY(120 SEC)

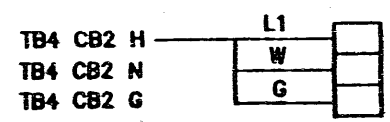
32

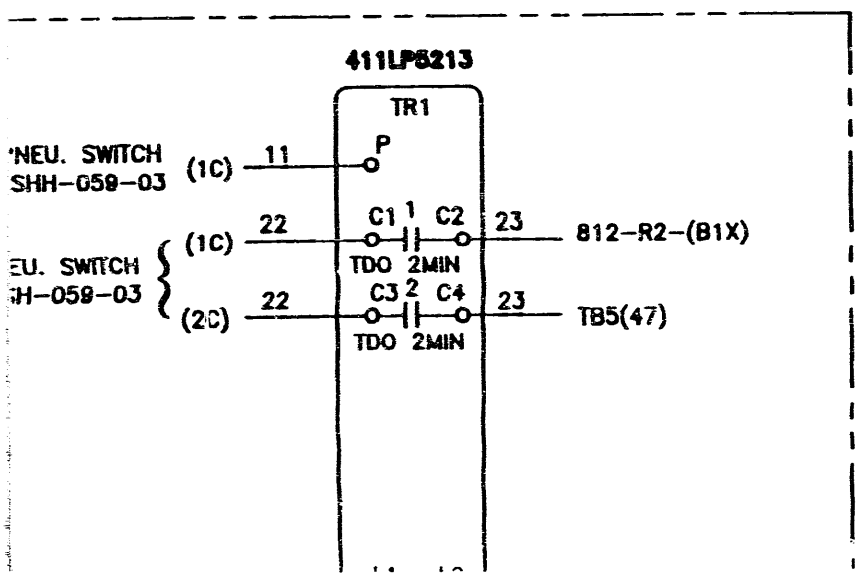
PNEU. SWIT
FSL-052-2
812-R2
(HS-052-25
816-TR

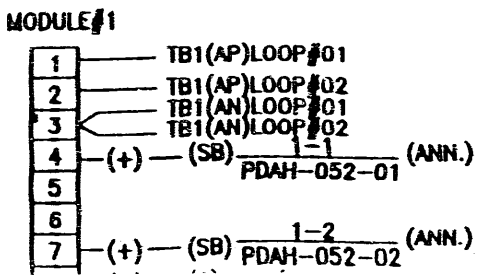
SCHEME 41B816.

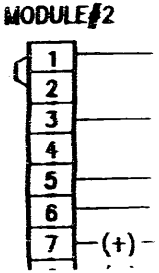
WIRING

ECO-5845, Page 6 of 32
Part dwg.: 41-J-032-W2.
Cog. Eng.: Balde
17 Oct. '91.









9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

24 Oct

1. Drawing: 41-J-032-W3 ECO Number: 5845

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

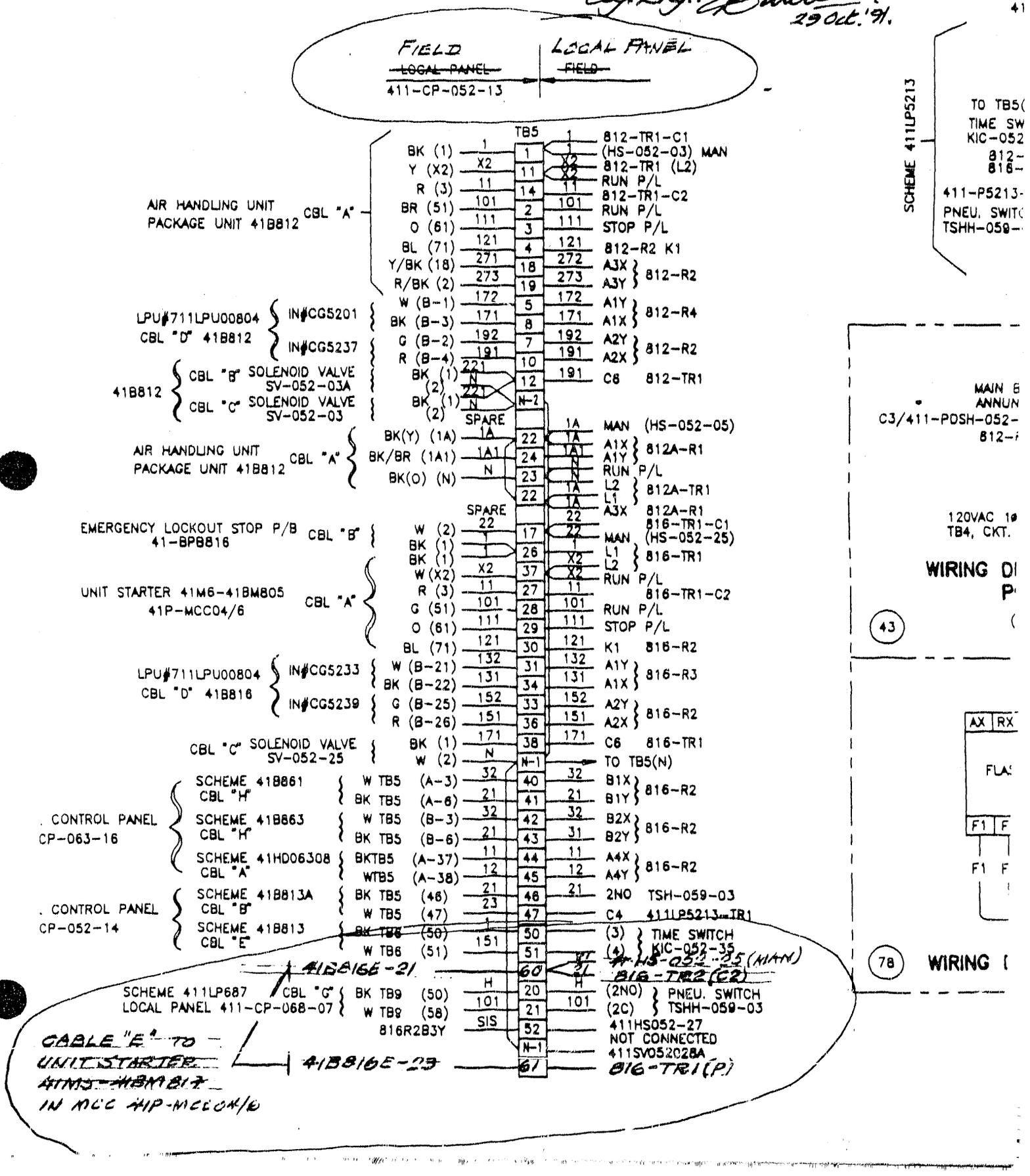
_____ _____ _____ _____

3. Description of Change:

On TB5 make changes as shown marked up on page 8 of 31.

4. Drawing Cog. Engineer Approval: _____ Date: 24 Oct. '91

ECO-5845, Page 8 of 32.
Part dwg.: 44J-032-W3
Cog. Eng.: Balde
29 Oct. '91.



41B816E-21

CABLE "E" TO UNIT STARTER 41M5-41BM817 IN MCC 41P-MCC04/6

41B816E-23

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

24 Oct

1. Drawing: 41-J-032-W5 ECO Number: 5845

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

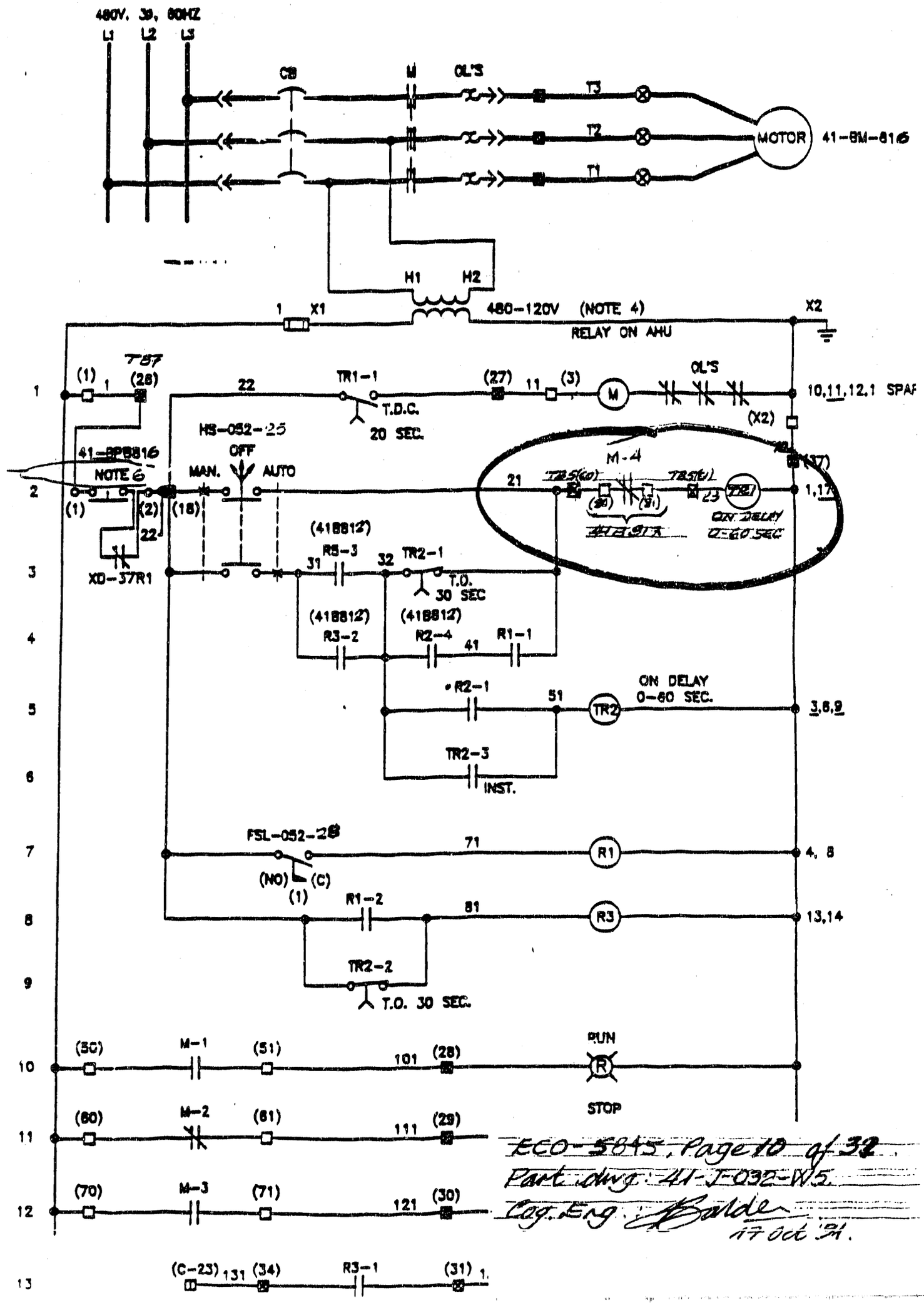
3. Description of Change:

For scheme 41BM816 make the following changes:

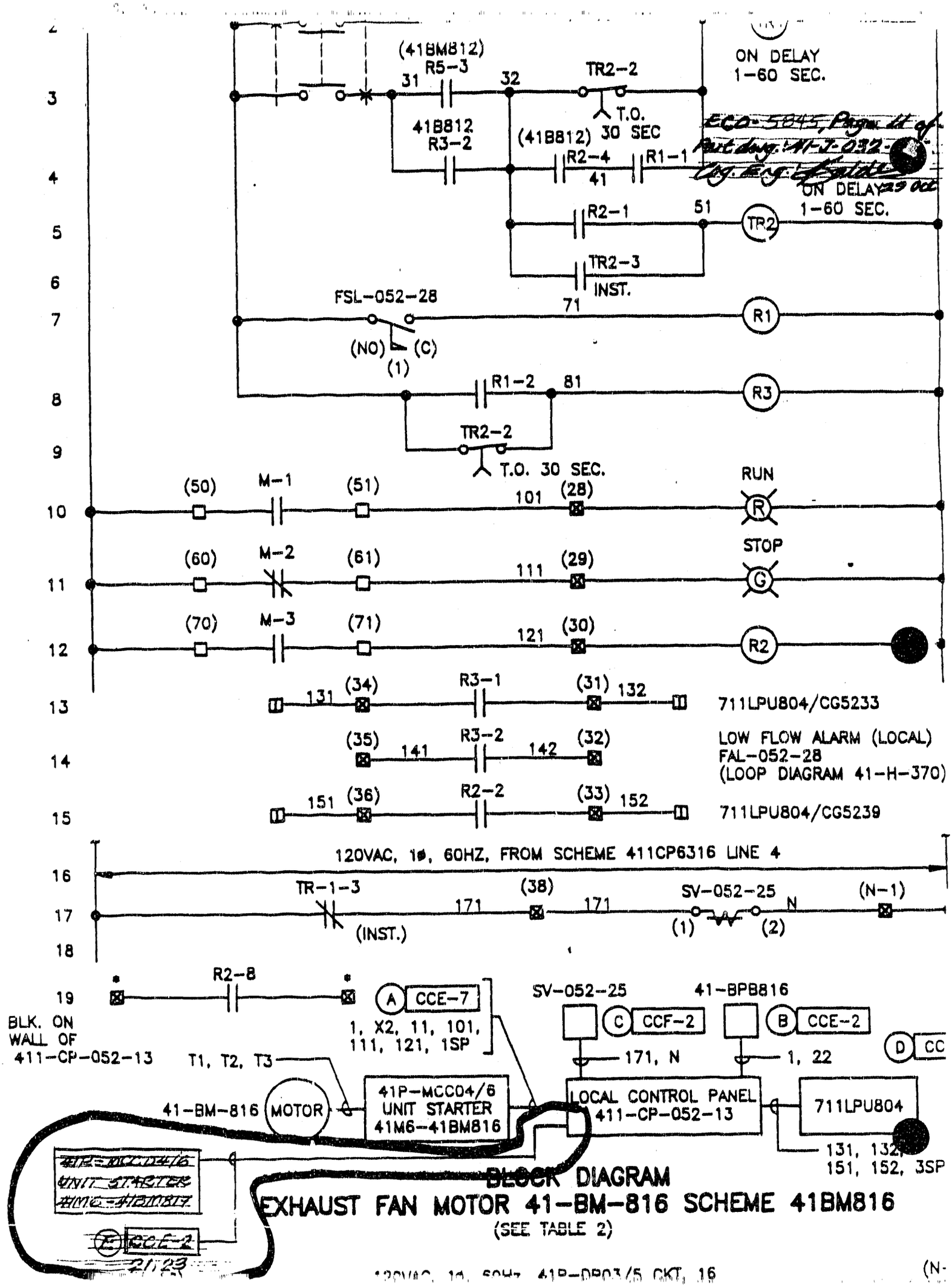
a)Revise Schematic Diagram as shown marked up on page 10 of 31.

b)Revise Block Diagram as shown marked up on page 11 of 31.

4. Drawing Cog. Engineer Approval: _____ Date: 24 Oct. '91



ECO-5845. Page 10 of 32.
Part dwg: 41-J-032-W5.
Cog. Eng: Balder
17 Oct '91.



BLOCK DIAGRAM

EXHAUST FAN MOTOR 41-BM-816 SCHEME 41BM816

(SEE TABLE 2)

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

24 Oct.

1. Drawing: 41-J-032-W6 ECO Number: 5845

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

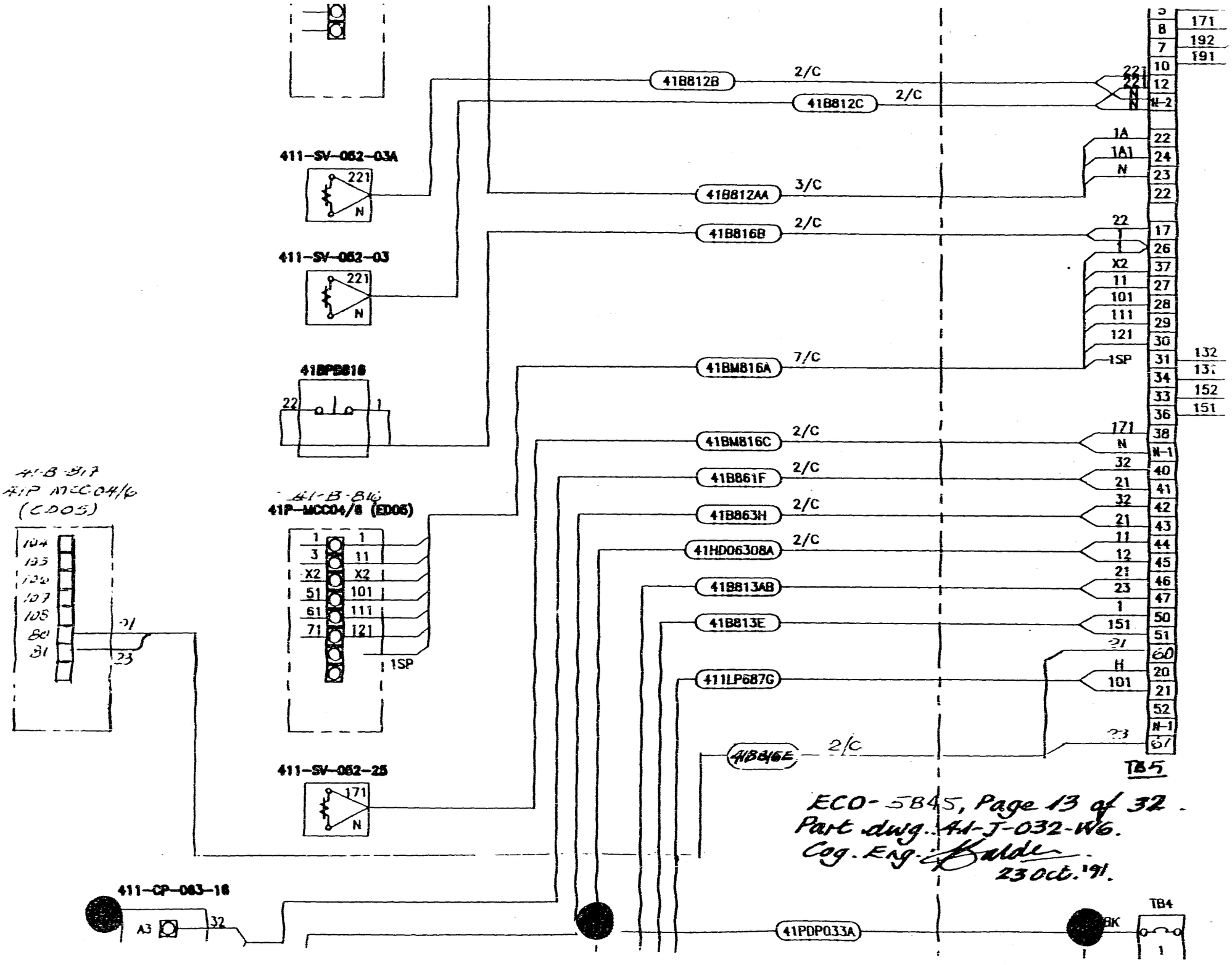
_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Revise the Interconnect diagram as shown marked up on page 13 of 31.

4. Drawing Cog. Engineer Approval: _____ Date: 24 Oct. '91.



ECO-5845, Page 13 of 32.
Part dwg. 41-J-032-W6.
Cog. Eng. Kalde
23 Oct. '91.

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

24 Oct. '91

1. Drawing: 41-B-001-W1 ECO Number: 5R45

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

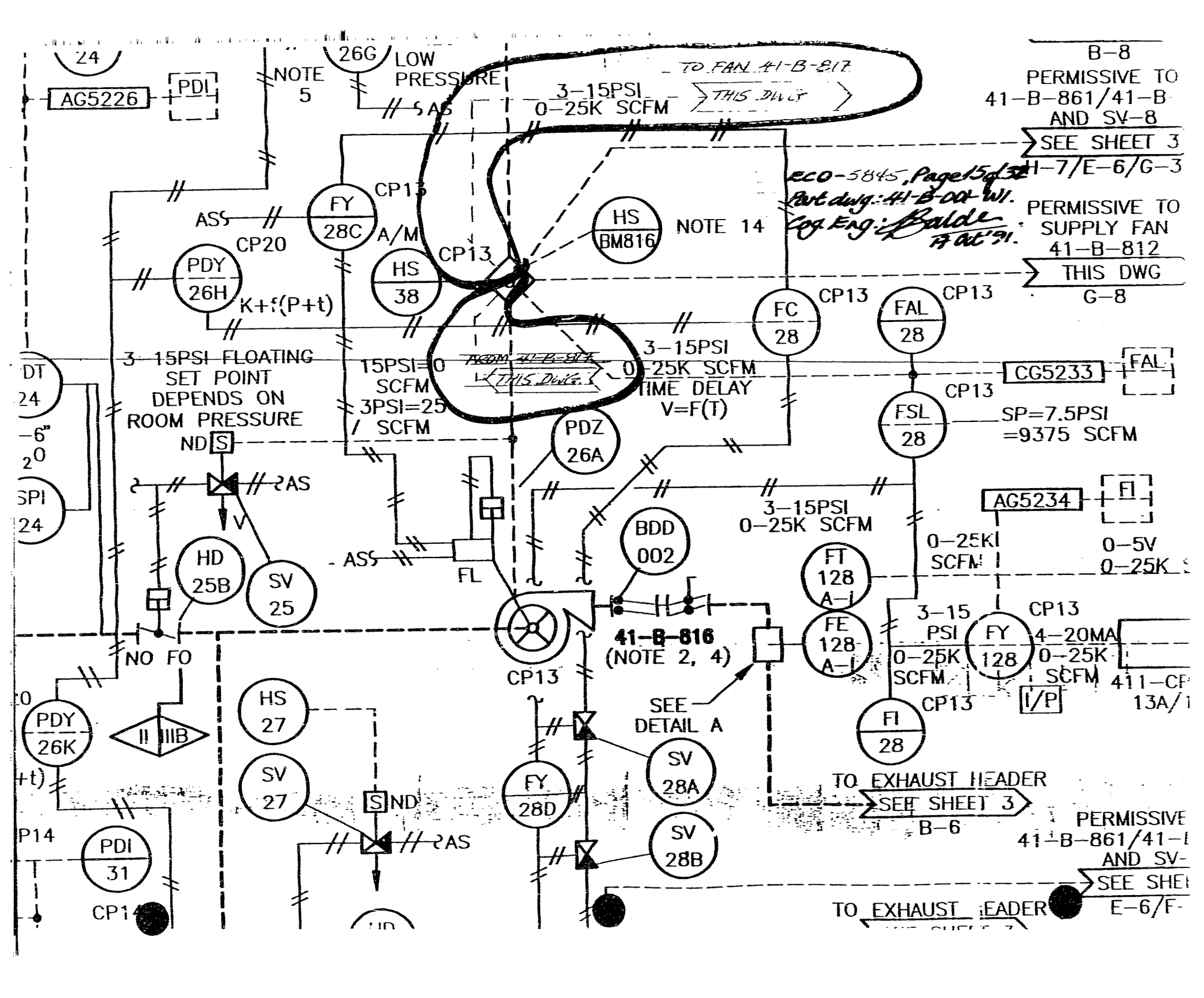
3. Description of Change:

Revise P. & I. D. as follows:

a) For fan 41-B-816 as shown marked up on page 15 of 31.

b) For fan 41-B-817 as shown marked up on page 29 of 31.

4. Drawing Cog. Engineer Approval: _____ Date: 24 Oct. '91.


24
AG5226
PDI
NOTE 5
26G
LOW PRESSURE
3AS
3-15PSI
0-25K SCFM
TO FAN 41-B-817
THIS DWG
B-8
PERMISSIVE TO 41-B-861/41-B AND SV-8
SEE SHEET 3
H-7/E-6/G-3
ECO-5845, Page 15 of 32
Part dwg: 41-B-001 WI.
Eng: Balde
8 Oct 91.
FY 28C
CP13
ASS
CP20
A/M
HS BM816
NOTE 14
PERMISSIVE TO SUPPLY FAN 41-B-812
THIS DWG
G-8
PDY 26H
K+f(P+t)
HS 38
CP13
FC 28
CP13
FAL 28
CP13
3-15PSI FLOATING SET POINT DEPENDS ON ROOM PRESSURE
15PSI=0 SCFM
3PSI=25 SCFM
FROM 41-B-816 THIS DWG.
3-15PSI
0-25K SCFM
TIME DELAY
V=F(T)
CG5233
FAL
CP13
FSL 28
SP=7.5PSI
=9375 SCFM
PDZ 26A
ND S
2AS
V
HD 25B
SV 25
ASS
FL
3-15PSI
0-25K SCFM
AG5234
FI
0-25K SCFM
0-5V
0-25K
BDD 002
FT 128 A-1
NO FO
41-B-816
(NOTE 2, 4)
CP13
SEE DETAIL A
FE 128 A-1
3-15 PSI
0-25K SCFM
FY 128
CP13
4-20MA
0-25K SCFM
I/P
411-CP
13A/1
FI 28
CP13
PDY 26K
II III IIB
HS 27
SV 27
ND S
2AS
FY 28D
SV 28A
SV 28B
TO EXHAUST HEADER
SEE SHEET 3
B-6
PERMISSIVE
41-B-861/41-B
AND SV-
SEE SHEE
E-6/F-
PDI 31
CP14
TO EXHAUST HEADER

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

24 Oct

1. Drawing: 41-H-152-014 ECO Number: 5845

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

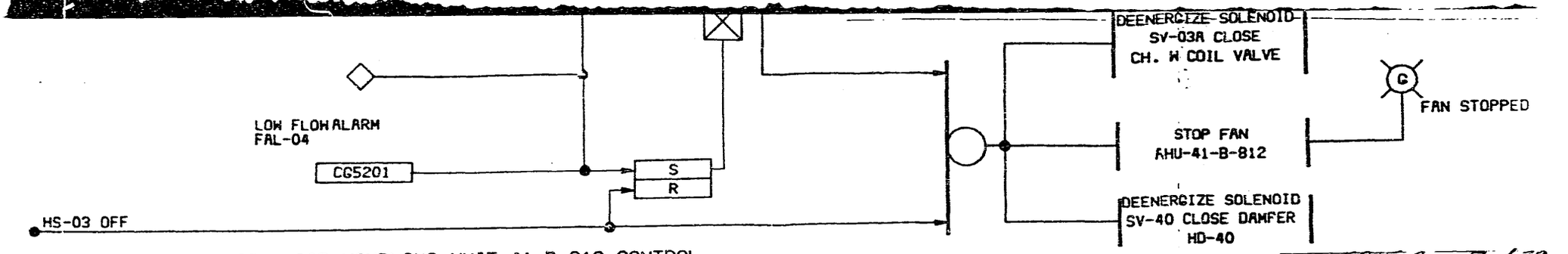
Revise Control Logic diagram as follows:

a) For fan 41-B-816 as shown marked up on page 17 of 31.

b) For fan 41-B-817 as shown marked up on page 30 of 31.

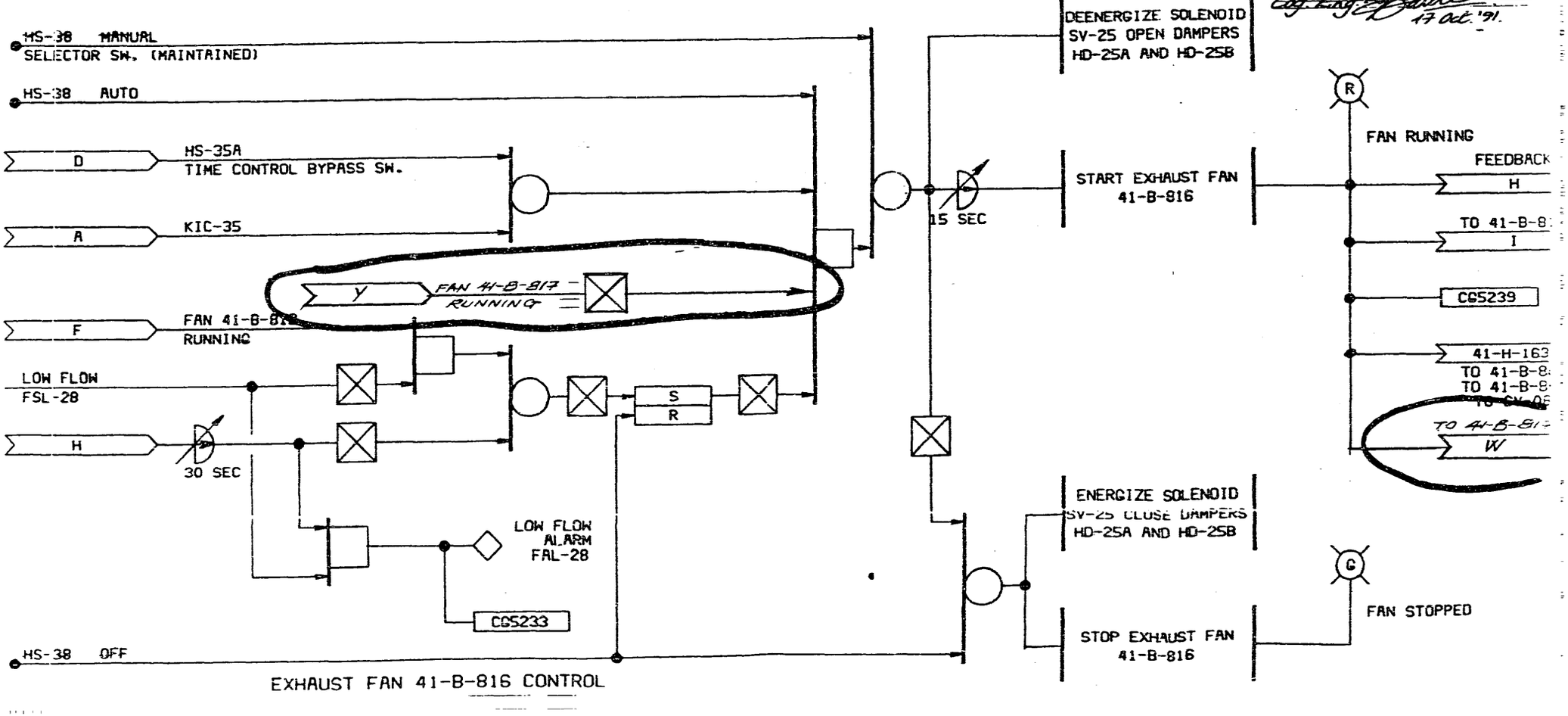
4. Drawing Cog. Engineer Approval: _____ Date: 24 Oct '91.

1290:E0006



SUPPLY AIR HANDLING UNIT 41-B-812 CONTROL

ECO-5045, page 11 of 32
Part dwg: 41-H-352-014.
Eng. Engr: Baldt
17 Oct. '91.



EXHAUST FAN 41-B-816 CONTROL

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

24 Oct '91

1. Drawing: 41-J-047-W2 ECO Number: 5845

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

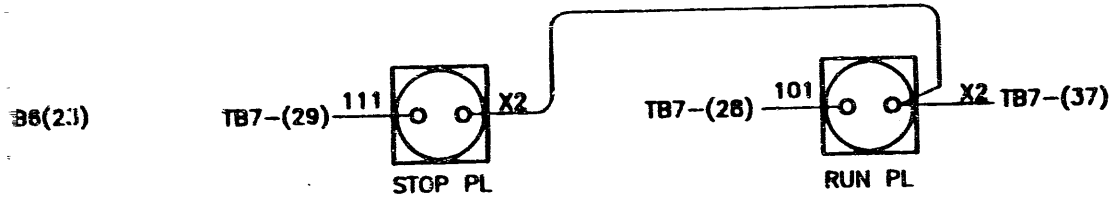
_____ _____ _____ _____

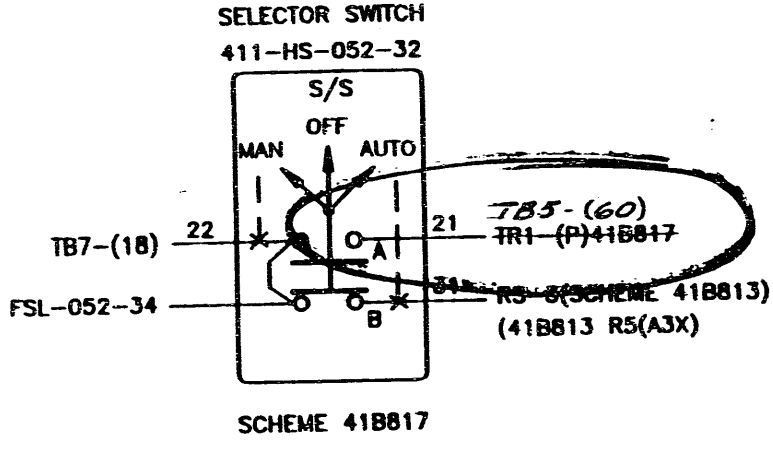
_____ _____ _____ _____

3. Description of Change:

On HS-052-32 change labelling of wire no. 21 as shown marked up on page 19 of 31.

4. Drawing Cog. Engineer Approval: [signature] Date: 24 Oct. '91.





SCHEME 41B817

ECO-5845, Page 19 of 32.
Part dwg.: 41-J-047-W2
Eng. Eng.: Balder 16 Oct '91.

THIS DRAWING IS UP-TO DATE WITH THE FOLLOWING OUTSTANDING ENGINEERING CHANGE ORDERS: NONE

THIS DRAWING OBSOLETE AFTER 10-21

SIGNED

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

24 Oct '91.

1. Drawing: 41-J-047-W3 ECO Number: 5845

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

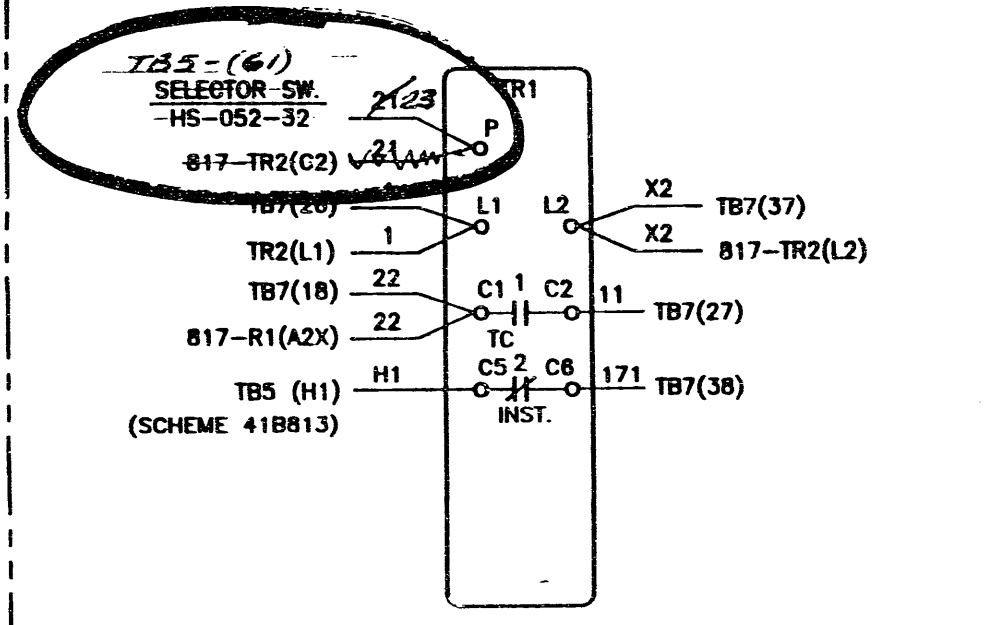
On Scheme 41B817 make revisions as follows:

a) Timing Relay TR1, change labelling on wire no. 21 and wire number;

b) Timing Relay TR2, change labelling on wire no. 21;

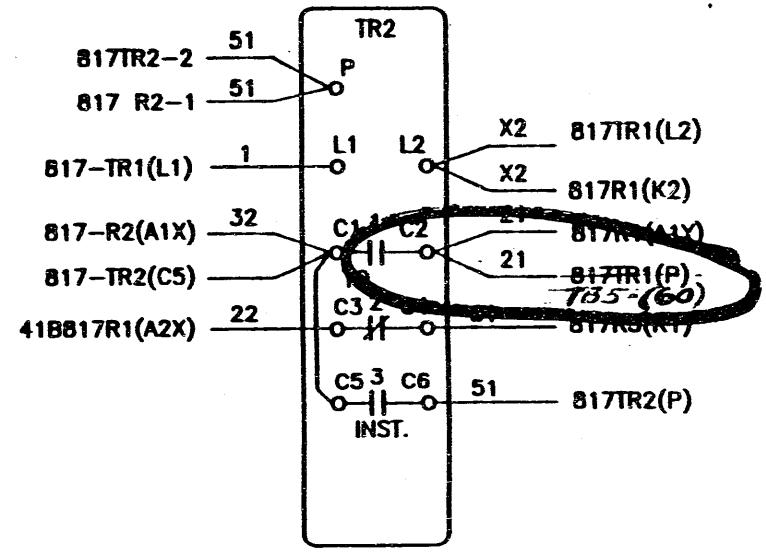
both as shown marked up on page 21 of 31.

4. Drawing Cog. Engineer Approval: _____ Date: 24 Oct. '91



ON DELAY
TIMING RANGE: 1 MIN.

TIME DELAY RELAY TR1
(20 SEC.)

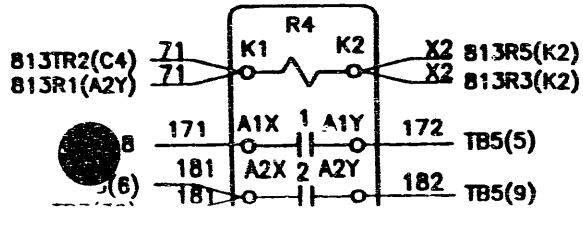


ON DELAY
TIMING RANGE: 1 MIN.

TIME DELAY RELAY TR2
(30 SEC.)

SCHEME 41B817.

ECO-5845, Page 21 of 32.
Part dwg.: 41-J-047-W3.
Cog. Eng: Balde
16 Oct '91.



9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

24 Oct 91

1. Drawing: 41-J-047-W5 ECO Number: 5845

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

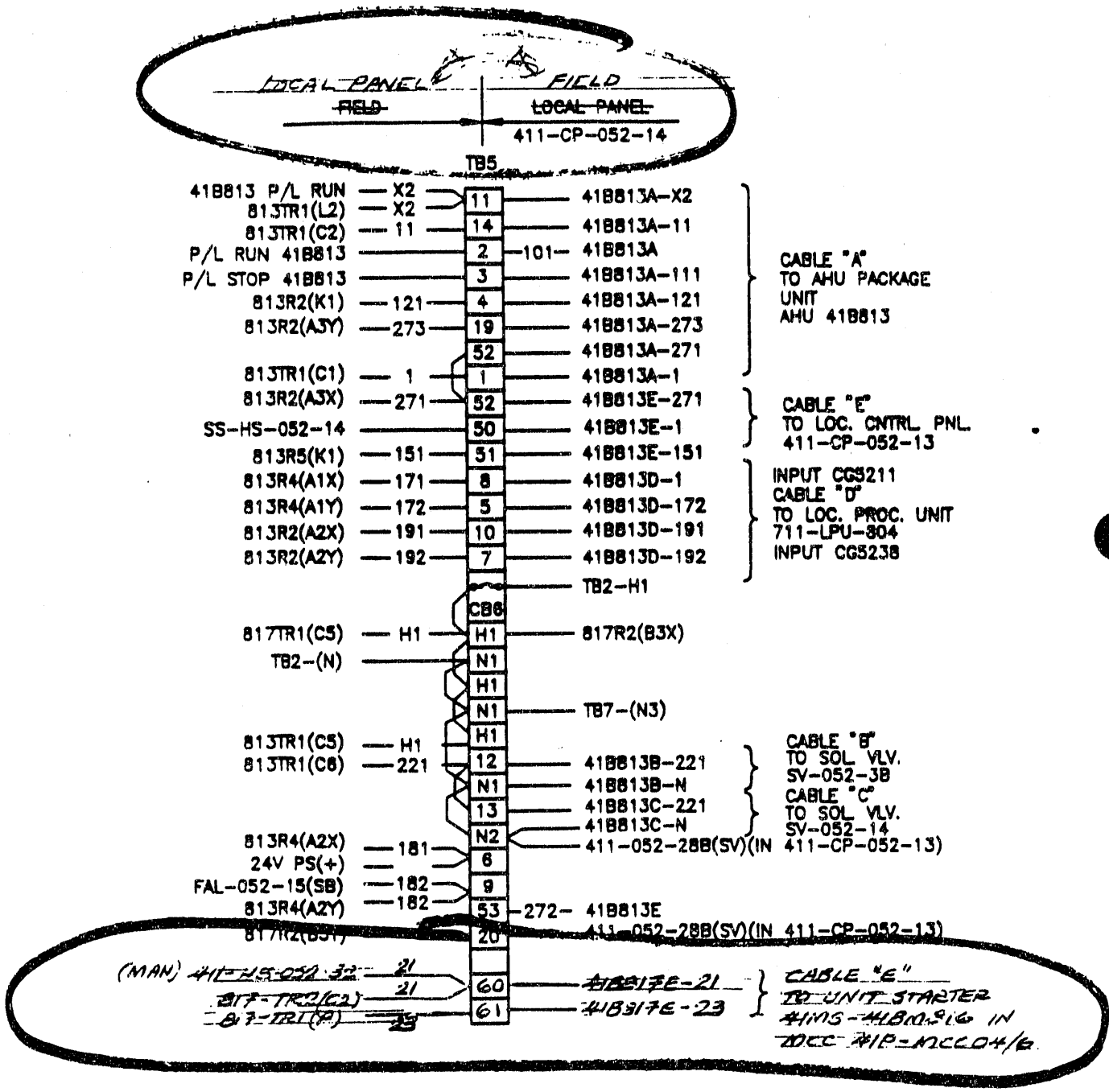
_____ _____ _____ _____

3. Description of Change:

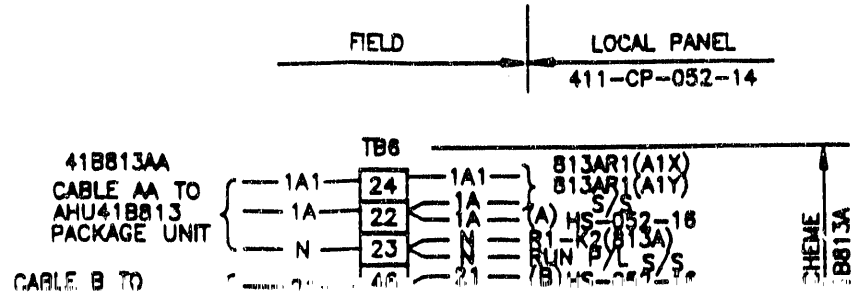
On TB5 make changes as shown marked up on page 23 of 31.

4. Drawing Cog. Engineer Approval: _____ Date: 24 Oct '91.

1290:B0006



ECO-5845, Page 23 of 32
Part dwg: 411-I-047-W5
Cog. Eng. E. Balde 16 Oct.



9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

24 Oct '91

1. Drawing: 41-J-047-W7 ECO Number: 5845

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

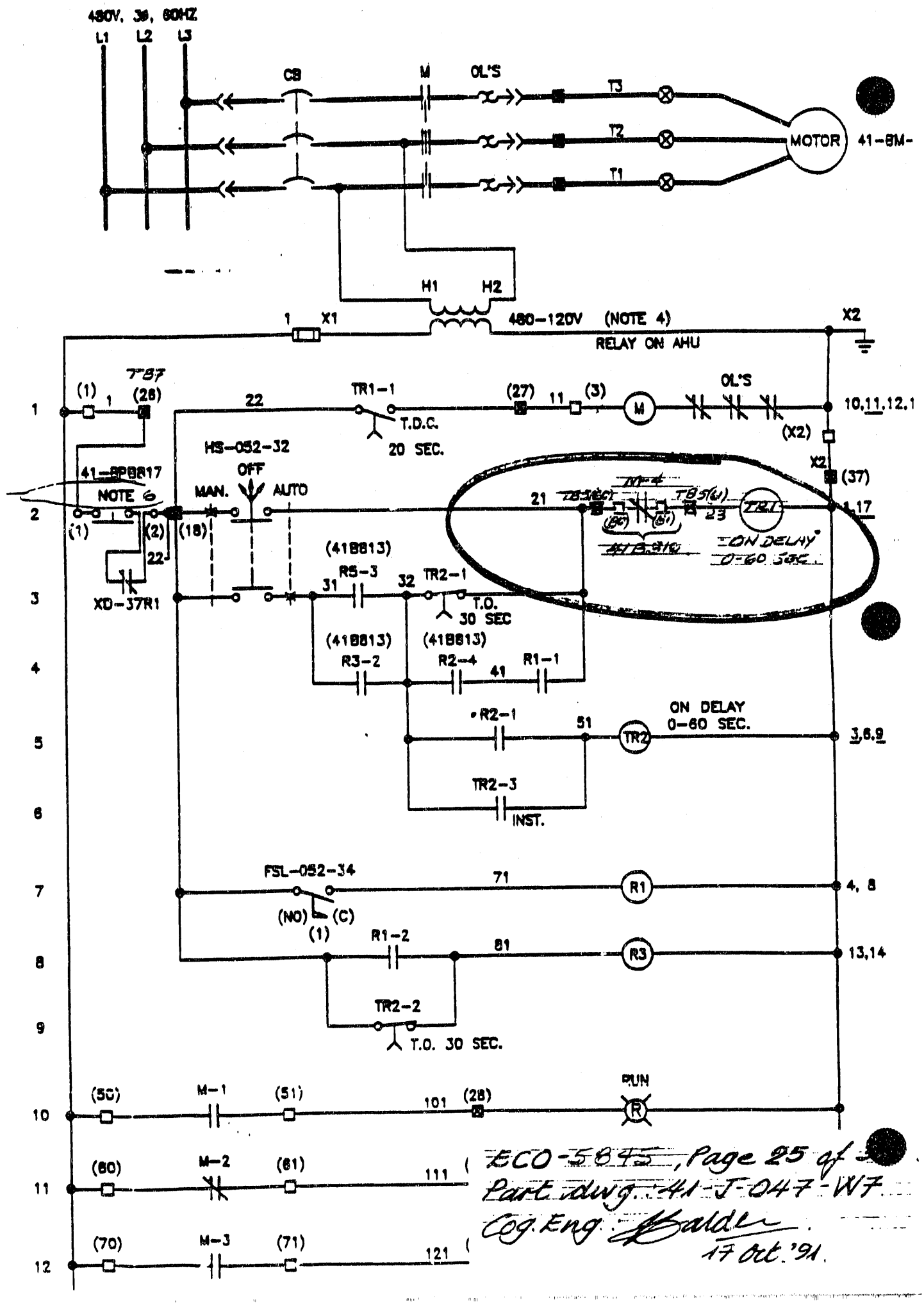
3. Description of Change:

For Scheme 41BM817 make the following revisions:

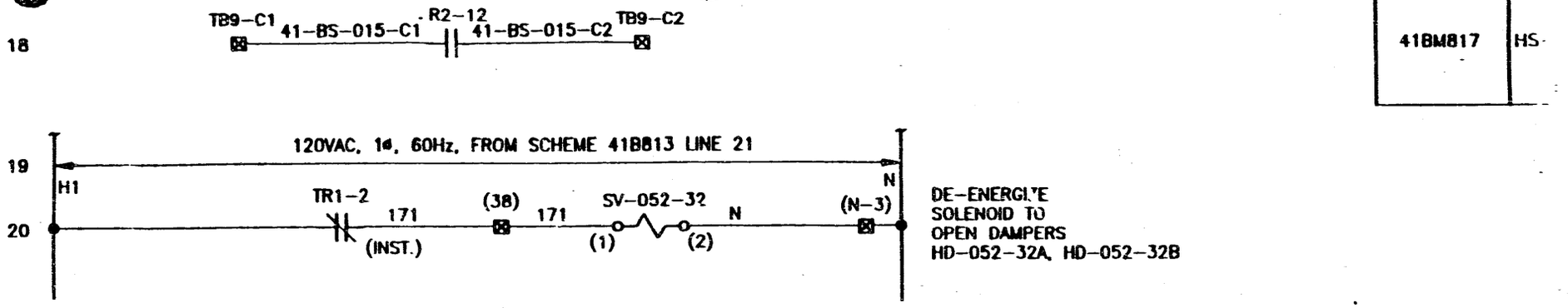
a) Revise Schematic Diagram as shown marked up on page 25 of 31.

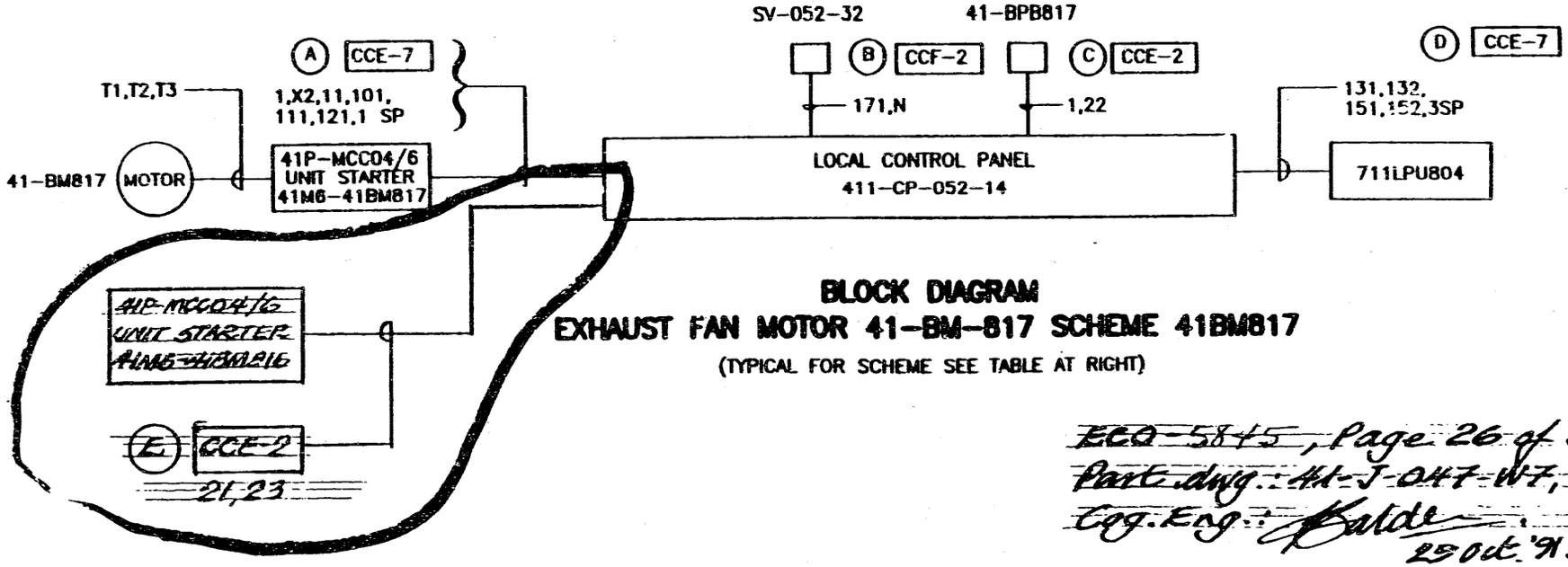
b) Revise Block Diagram as shown marked up on page 26 of 31.

4. Drawing Cog. Engineer Approval: _____ Date: 24 Oct. '91.



ECO-5845, Page 25 of
Part dwg. 41-J-047-WF
Cog. Eng. Balder
17 Oct. '91.





BLOCK DIAGRAM
EXHAUST FAN MOTOR 41-BM-817 SCHEME 41BM817
(TYPICAL FOR SCHEME SEE TABLE AT RIGHT)

~~ECO-5845~~, Page 26 of 32.
Part dwg.: 41-J-047-W7,
Cog. Eng.: Balde
25 Oct '91.

8 7 6

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

24 Oct '91

1. Drawing: 41-J-047-W8 ECO Number: 5845

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

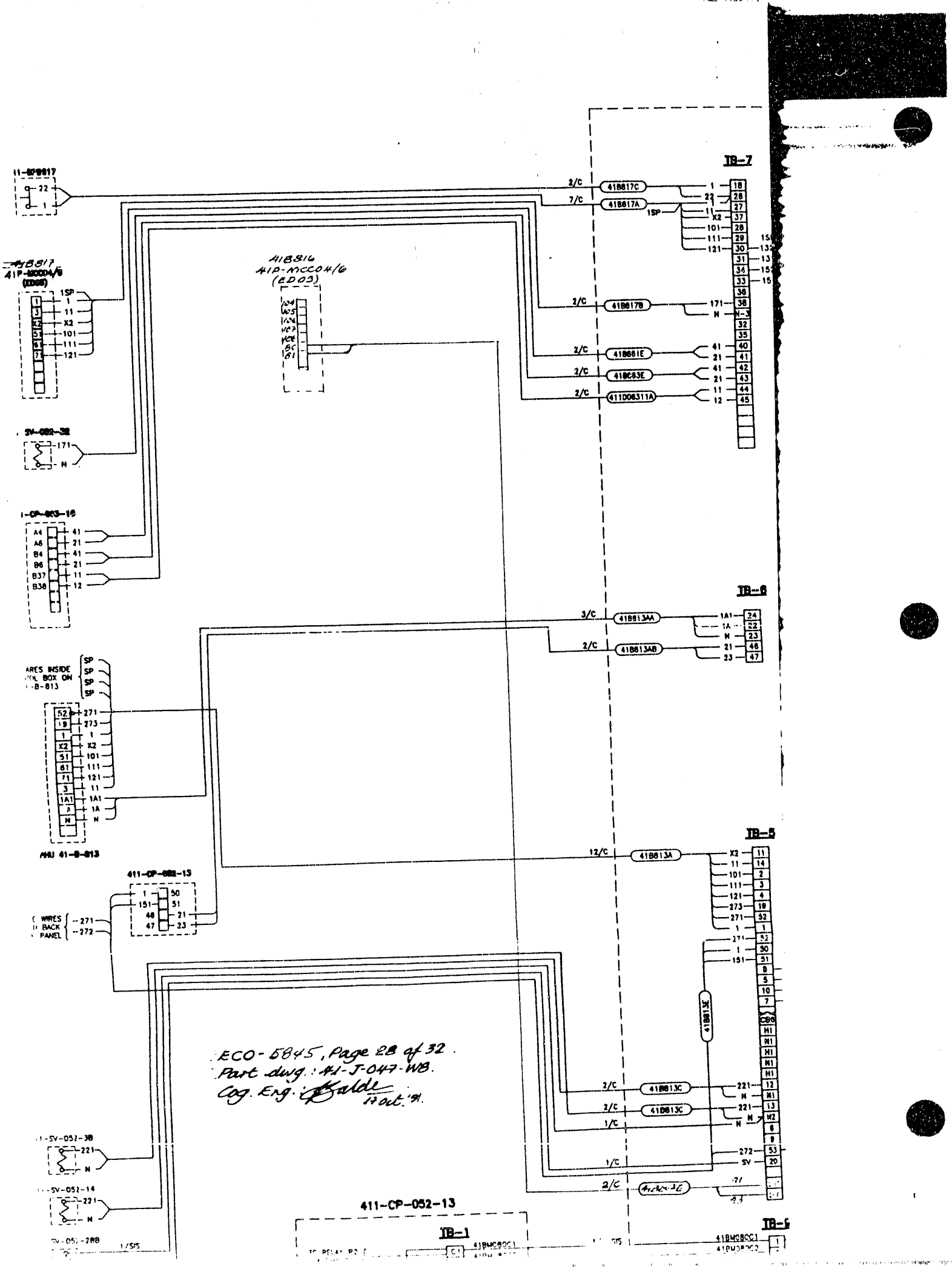
_____ _____ _____ _____

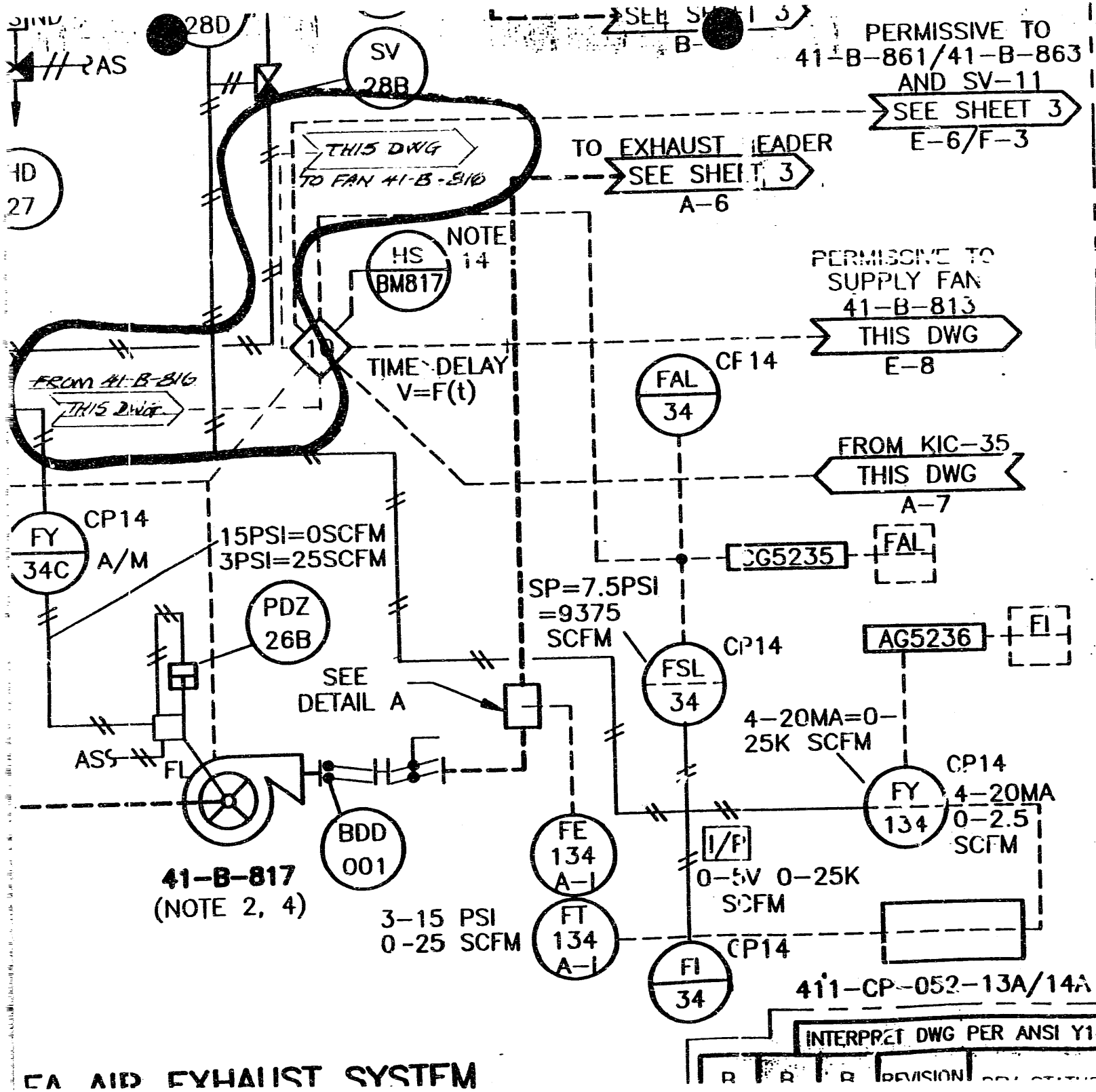
_____ _____ _____ _____

3. Description of Change:

Revise the Interconnect Diagram as shown marked up on page 28 of 31.

4. Drawing Cog. Engineer Approval: _____ Date: 24 Oct '91


JB-7
JB-6
JB-5
JB-1
41B816
41P-MCC04/6
(ED03)
411-CP-052-13
ECO-5845, Page 28 of 32.
Part dwg.: 41-J-047-WB.
Cog. Eng.: Galde
Oct. '91.



WHEN ONE TWO CH

B-50% CAPACITY OPE
ONE MECHANICAL S
ONE CH AND ONE

16. ELECTRICAL INTERCONN

17. THIS DWG SUPERCEDI

ECO-5845 Page 2 of 34
Part dwg: 41-B-001-WI.
Cog. Eng. Gold
17 Oct '91.

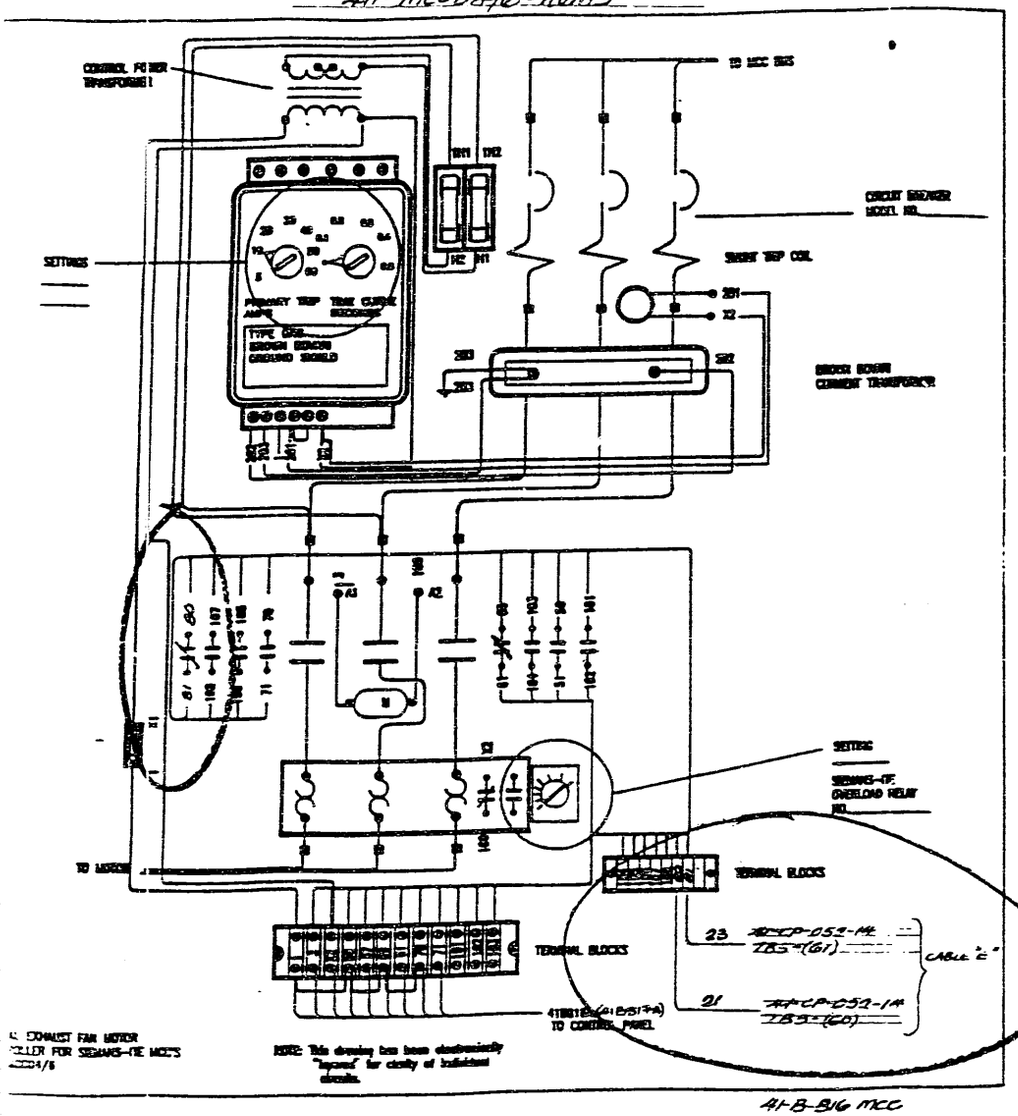
REV	DATE	REVISE
B	10/24/90	
A	05/16/90	APPR
–	03/23/90	ISSU
REV	DATE	ISSU

DFTG CHG/FBB
CHKR. B. Allen 10/29/90
COG. ENG Gold 29 Oct '90
COG. MGR G.W. POHL 5/16/90
Q.A. (RB) A.E. GALLEGOS 5/16/90
SAFETY N/A
APPD
APPD
DFTG. MGR J.W. Bell 10/29/90

REVISION

Cog. Eng. Dale 17 Oct. '98.

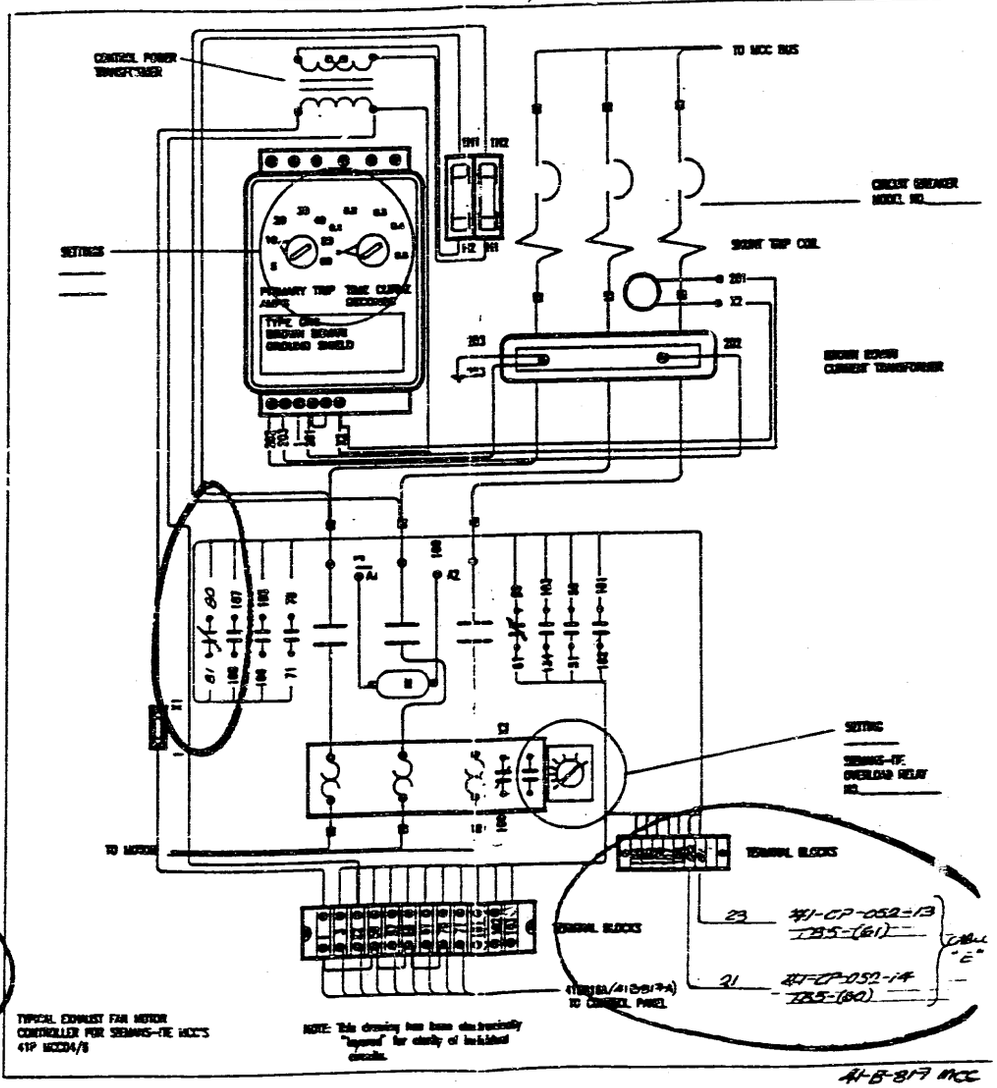
41P-MCC04/6 Item 3



TYPICAL EXHAUST FAN MOTOR CONTROLLER FOR SIEMENS-TE MCC'S 41P MCC04/6

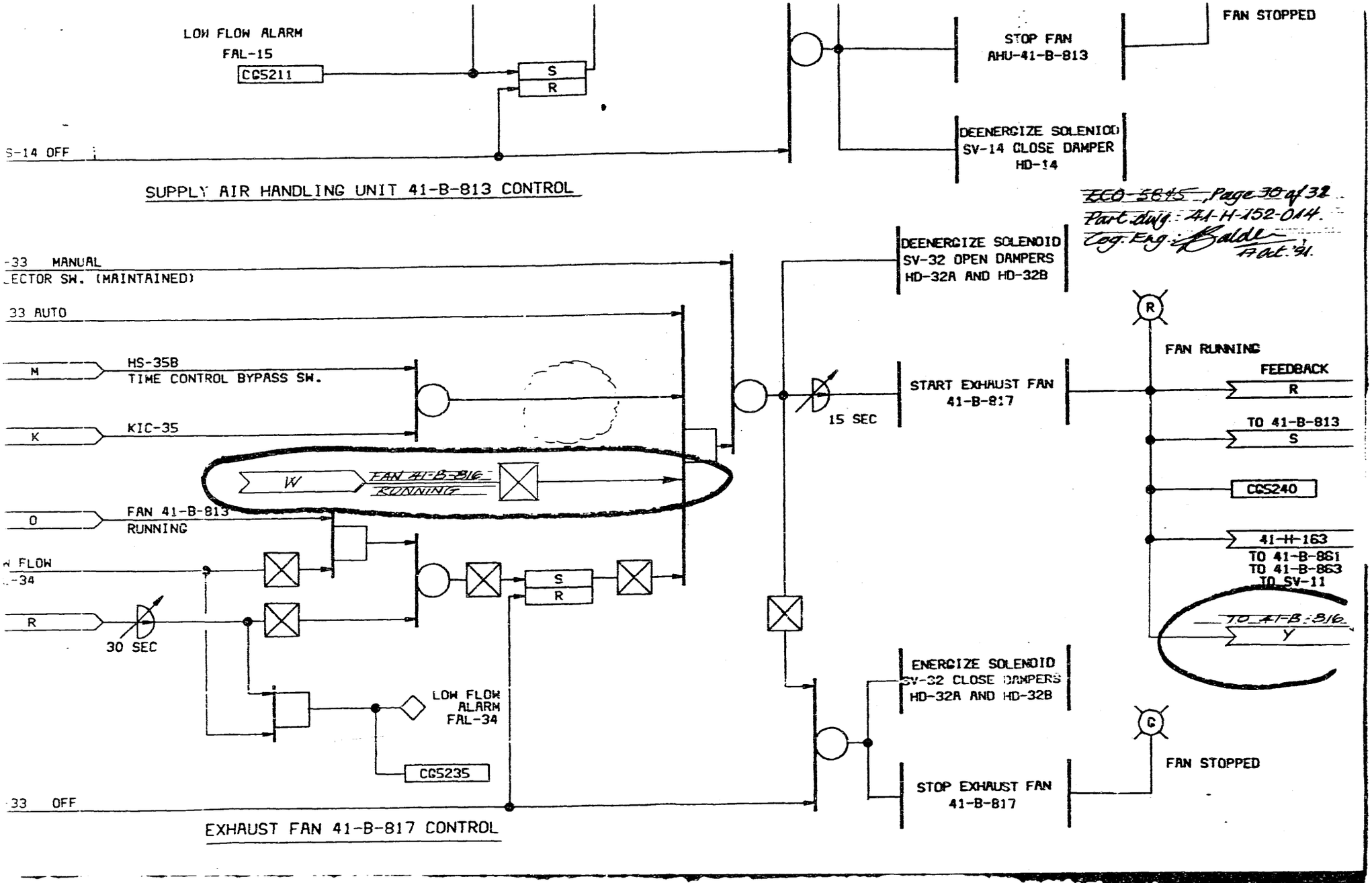
41-B-B16 MCC

41P-MCC04/6 Item 6



TYPICAL EXHAUST FAN MOTOR CONTROLLER FOR SIEMENS-TE MCC'S 41P MCC04/6

41-B-B17 MCC


LOW FLOW ALARM
FAL-15
CG5211
S
R
S-14 OFF
STOP FAN
AHU-41-B-813
FAN STOPPED
DEENERGIZE SOLENOID
SV-14 CLOSE DAMPER
HD-14
SUPPLY AIR HANDLING UNIT 41-B-813 CONTROL
ECO-5645 Page 30 of 32
Part dwg: 41-H-152-014.
Cog. Eng: Balde Dat. '91.
-33 MANUAL
LECTOR SW. (MANTAINED)
33 AUTO
M
HS-35B
TIME CONTROL BYPASS SW.
K
KIC-35
W
FAN 41-B-816 RUNNING
O
FAN 41-B-813
RUNNING
W FLOW
-34
R
30 SEC
S
R
LOW FLOW
ALARM
FAL-34
CG5235
-33 OFF
EXHAUST FAN 41-B-817 CONTROL
DEENERGIZE SOLENOID
SV-32 OPEN DAMPERS
HD-32A AND HD-32B
15 SEC
START EXHAUST FAN
41-B-817
R
FAN RUNNING
FEEDBACK
R
TO 41-B-813
S
CG5240
41-H-163
TO 41-B-861
TO 41-B-863
TO SV-11
TO 41-B-816
Y
ENERGIZE SOLENOID
SV-32 CLOSE DAMPERS
HD-32A AND HD-32B
C
FAN STOPPED
STOP EXHAUST FAN
41-B-817

9b

DESIGN DOCUMENT CHANGE SHEET

(1 SHEET PER SYSTEM DESIGN DESCRIPTION REQUIRED)

1. Title and Document Number: HVAC System Design description, SDD-HV00

2. Changes: Add HV01 system interlock to prevent simultaneous operation of ventilation trains.

3. Markups attached (Note: Pages must be revised to reflect actual change as implemented)

4. Description of change:

Add paragraph in the appropiate control section to describe the requirement for interlocking the HV01 system trains to prevent simultaneous operation.

To be written by SDD dept. when the appropriate section is prepared.

1 Nov. 91.

5. Posted by: _____ 24 Oct. '91
Signature Date

ATTACHMENT to
ECO 5845
2 of 2

Please indicate your concurrence with this plan by your signature below.

G. W. Pohl, Manager
Mechanical & Construction Engineering

ljw

I do ☒ do not ☐ concur with this Design Verification Plan.

G W Pohl for 1/4/91
T. F. Kocialski Date

HA:91:2467

ATTACHMENT TO ECO SP&E 192

From Engineering
MN 887-8163
Date October 31, 1991
Subject DESIGN VERIFICATION OF CONTROL INTERLOCKS FOR EXHAUST FANS 41-B-816 AND 41-B-817

To T. F. Kocialski

cc: J. P. Clayton
K. A. Ealden

The following Design Verification Plan is submitted for your concurrence in accordance with WIPP Procedure WP 09-018, Design Verification.

I. Background

Dual train operation of the main Contact Handled (CH) area Heating, Ventilation, and Air Conditioning (HVAC) system has resulted in deformation of the system exhaust duct downstream of the room pressure control dampers, due to the original design under estimating the negative pressure that would develop in the ducts. The prevention of simultaneous operation of the trains is currently achieved administratively. The internal Operational Readiness Review (ORR) considered that this was inadequate in the long term and that the associated fans should be interlocked to prevent simultaneous operation under all conditions.

II. Design Verification

The proposed design is to provide interlocks between 41-B-816 and 41-B-817 fans to prevent simultaneous operation of both CH HVAC system ventilation trains. The interlocks are to be provided by using a spare, normally closed, contact on the respective exhaust fan motor starter auxiliary relay. The control logic was designed by Keith Ealden, system cognizant engineer. The design verification will be an Independent Review performed by Jim Clayton of the Electrical Engineering section. Jim is the designated electrical support engineer and is knowledgeable in the HVAC area. Jim was not directly involved in the design effort. Jim's verification of the design will be noted by his signature on the Engineering Change Order.

ENGINEERING CHANGE ORDER
ADDENDUM SHEET # 1

1. Addendum Sheet to ECO Number: 5845 Drawing Number: 41-J-032-W

2. Description of change:

On pages 3 & 4 of 32 change drawing reference number to 41-J-032-W2.

3. Approvals

Cognizant Engineer:	Signature	7 Jan '92. Date
CC&D Mgr. /Desig. Rep.:	Signature	1/8/92 Date
Other Approval:	Signature	1-8-92 Date
Other Approval::	Signature	Date

ENGINEERING CHANGE ORDER
ADDENDUM SHEET #2

1. Addendum Sheet to ECO Number: 5845 Drawing Number: 41-J-032-W2

2. Description of change:

On pages 5 & 6 of 32 change drawing reference to read 41-J-032-W3

3. Approvals

Cognizant Engineer:	Signature	7 Jan. '92. Date
CC&D Mgr. /Desig. Rep.:	Signature	1/8/92 Date
Other Approval:	Signature	1-8-92 Date
Other Approval::	Signature	Date

ENGINEERING CHANGE ORDER
ADDENDUM SHEET # 3

1. Addendum Sheet to ECO Number: 5845 Drawing Number: 41-J-032-[redacted]

2. Description of change:

On pages 7 & 8 of 32 change drawing reference to read 41-J-032-W4.

3. Approvals

Cognizant Engineer:	[signature] Signature	7 Jan 92 Date
CC&D Mgr. /Desig. Rep.:	[signature] Signature	1/8/92 Date
Other Approval:	[signature] Signature	1-8-92 Date
Other Approval::	Signature	Date

ENGINEERING FILE ROOM

ENGINEERING CHANGE ORDER

USE BLACK INK

1. ECO No.: 5878
S/C CC&D Review: [illegible] Initials

Posted APR 1992 COMPLETE

2. Impact Level 1 ☐ 2 ☐ 3 ☒ 4 ☐

3. System: W106 Equipment No.: N/A Building: U/G

4. Associated Documents:
PWR N/A
ECP
P.O.
Others

5. Document Type:
Drawing 412-F-017-W ☒
Specification [illegible] ☐
Vendor Data ☐
SDD ☐
Others

6. Title of Change: Incorporate VRs

7. Originator: (print)	Ext. No.:	Department:	Date:	8. Cognizant Engineer: (print)
OM MENDIRATTA	8377	RWHE	10/25/91	OM MENDIRATTA

9. Description of Change:

Yes ☐ No ☒ Component indices change required (if yes, attach sheets)

1. Incorporate VR # 38777-008 for change in bin color final coat to Gray, and for revision to the Identification table.

2. Incorporate VR # 38777-010 that deletes Gasket Retainer Plate, #23.

☒ 9a Drawing Change Sheet attached
☐ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

10. Yes ☒ No ☐ MODIFICATION IN PROGRESS
☒ Modification complete: Om Mendiratta 3/27/92 (Signature / Date) — ECO will be incorporated after M.I.P. signed complete
☐ Change drawing per as-built markup dated:
☐ Change drawing per ECO-provided data
☐ Temporary modification

11. Design Verification Requirements: (per WP 09-018) EDT No.:

JY ✓ 1. Requirements satisfied by review/approval of design document
2. Independent review
3. Alternate calculations
4. Development testing
5. Design review
JY ✓ 6. Other: Final Drawing Review & Approval

12. Addendum Sheet added: Dayle White, 4-21-92 (Signature / Date)

13. Justification

Incorporated previously approved VRs. 10/28/91

Incorporation of these VR's is required to ensure drawing number 412-F-017-00 depicts the as built configuration.

14. Administrative Tracking

YES	N/A	Item	YES	N/A	Item
☐	☒	1. FSAR	☐	☒	6. Startup/Acceptance Test
☐	☒	2. Calibration Procedures	☐	☒	7. Test Requirement & Spec.
☐	☒	3. Maintenance Procedures	☐	☐	8.
☐	☒	4. Computer Software	☐	☐	9.
☐	☒	5. Operations Procedures	☐	☐	10.

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

Key	Function	Signature / Date
A	Cog. Engineer	[signature] 10/25/91
A	Cog. Eng. Mgr.	[signature] 10/28/91
R	Startup	[signature] 11-4-91
A	QA	[signature] 11-4-91
	DOE	
✓	Safety	[signature] 10/30/91
	Dept. Manager	
	Operations	
	Security	
R	SNL	[signature] 10/30/91

16. Distribute as Marked

Mark	Distribution
✓	Maintenance (MANDATORY)
✓	Ops. Support (MANDATORY)
✓	Startup
	Facility Operations
	U/G Operations
	Orig./Design Engr.
✓	Cog. Engineer
	Others
✓	SNL (A. Orrell)
✓	QA (H. Leos)

1. ECO # 5442
2. DATE _____

ENGINEERING CHANGE ORDER

DOE ORDER 6430.1A DESIGN CRITERIA

CHECKLIST

The design requirements in DOE Order 6430.1A checked below have been applied to this Design.

	DIVISION	SUBDIVISION
☐	1 General Requirements	☐ 0101 ☐ 0106 ☐ 0109 ☐ 0110 ☐ 0111 ☐ 0140 ☐ 0150 ☐ 0170
☐	2 Site and Civil Engineering	☐ 0200 ☐ 0201 ☐ 0202 ☐ 0203 ☐ 0205 ☐ 0210 ☐ 0214 ☐ 0215 ☐ 0220 ☐ 0231 ☐ 0245 ☐ 0250 ☐ 0256 ☐ 0260 ☐ 0262 ☐ 0265 ☐ 0267 ☐ 0270 ☐ 0273 ☐ 0275 ☐ 0276 ☐ 0278 ☐ 0279 ☐ 0280 ☐ 0281 ☐ 0283 ☐ 0285 ☐ 0290 ☐ 0291
☐	3 Concrete	☐ 0300 ☐ 0301 ☐ 0310 ☐ 0320 ☐ 0330 ☐ 0340 ☐ 0350 ☐ 0370 ☐ 0380
☐	4 Masonry	☐ 0400 ☐ 0401 ☐ 0410 ☐ 0420 ☐ 0455
☐	5 Metals	☐ 0500 ☐ 0512 ☐ 0514 ☐ 0521 ☐ 0531 ☐ 0532
☐	6 Wood and Plastics	☐ 0600 ☐ 0610 ☐ 0650
☐	7 Thermal and Moisture Protection	☐ 0710 ☐ 0711 ☐ 0714 ☐ 0715 ☐ 0719 ☐ 0720 ☐ 0721 ☐ 0722 ☐ 0724 ☐ 072 ☐ 0730 ☐ 0750 ☐ 0751 ☐ 0753 ☐ 0760 ☐ 0790
☐	8 Doors and Windows	☐ 0800 ☐ 0810 ☐ 0820 ☐ 0830 ☐ 0833 ☐ 0836 ☐ 0839 ☐ 0850 ☐ 0860 ☐ 087 ☐ 0880
☐	9 Finishes	☐ 0900 ☐ 0910 ☐ 0920 ☐ 0925 ☐ 0930 ☐ 0950 ☐ 0965 ☐ 0968 ☐ 0970 ☐ 093 ☐ 0990 ☐ 0995
☐	10 Specialties	☐ 1015 ☐ 1020 ☐ 1024 ☐ 1027 ☐ 1030 ☐ 1040 ☐ 1050 ☐ 1052 ☐ 1053 ☐ 105 ☐ 1060 ☐ 1065 ☐ 1070 ☐ 1075 ☐ 1080
☐	11 Equipment	☐ 1100 ☐ 1161
☐	12 Furnishings	☐ 1201 ☐ 1230 ☐ 1250 ☐ 1260 ☐ 1270
☐	13 Special Facilities	☐ 1300 ☐ 1304 ☐ 1305 ☐ 1306 ☐ 1307 ☐ 1318 ☐ 1319 ☐ 1320 ☐ 1321 ☐ 132 ☐ 1323 ☐ 1324 ☐ 1325 ☐ 1326 ☐ 1328
☐	14 Conveying Systems	☐ 1401 ☐ 1420 ☐ 1440 ☐ 1460
☐	15 Mechanical	☐ 1525 ☐ 1530 ☐ 1540 ☐ 1550 ☐ 1555 ☐ 1565 ☐ 1574 ☐ 1589 ☐ 1595
☐	16 Electrical	☐ 1600 ☐ 1605 ☐ 1620 ☐ 1630 ☐ 1639 ☐ 1640 ☐ 1650 ☐ 1655 ☐ 1660 ☐ 167 ☐ 1671 ☐ 1685 ☐ 1694
A	☒ NOT APPLICABLE	No portion of DOE Order 6430.1A is applicable to this Design.
B	☐ AS-BUILT	ECO is for as-built field verified changes only.

NOTE: A check placed in the Division column signifies that the entire Division shall be applicable to the Design, unless modified by checks indicated for specific Subdivisions.

COMMENTS: Dan Mendinatto 10/25/91

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 412-F-017-W ECO Number: 5848

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Incorporated bin VRs # 38777-008 and 38777-010 for change in paint color and removal of gasket retainer plate.

4. Drawing Cog. Engineer Approval: [signature] Date: 10/25/91

E005843 p5 78

Westinghouse Electric Corporation

AR/VR DISPOSITION SHEET

For Internal Use Only

Page of

☐ APPROVAL RECORD REQUEST   X VARIATION REQUEST   ☐ DEVIATION ☐ WAIVER

AR/VR Number: 38777-008
Reference No:

Purchase Order Or Subcontract Number: 75WSA38777 EK

Customer/Buyer Or Subcontract Administrator: Sam Azzinaro

Project Name Or Number: Dry Bins

AR/VR Received: 11-16-90   Approval Required Date: 11-16-90   Equip No:

Drawing Or Specification Number: 412-N-817-W

Supplier Or Subcontractor: Hall Machine & Welding Co., Inc. 122 W. Mermod Carlsbad, N.M. 88220 Attn: Tell Ellyson

Type of Request: X Approval ☐ Record ☐ Other (Describe)

☐ Pre-Purchase Evaluation   Approval Date   ☐ Information Record

Req	Disposition	Date	For App Only
	Design Engineer		☐ APPROVED ☐ COND APP ☐ DISAPPROVED
	Cognizant Engineer		☐ APPROVED ☐ COND APP ☐ DISAPPROVED
	Other		☐ APPROVED ☐ COND APP ☐ DISAPPROVED
	Other		☐ APPROVED ☐ COND APP ☐ DISAPPROVED
X	Quality Assurance: R Lzof	11-19-90	X APPROVED ☐ COND APP ☐ DISAPPROVED
X	Responsible Engineer: Gus Mandinattz	11/19/90	X APPROVED ☐ COND APP ☐ DISAPPROVED

Comments — Use Form WP 1677-B For Continuation

FINAL DISPOSITION: X APPROVED ☐ CONDITIONALLY APPROVED ☐ DISAP... ☐ RECEIPT ACKNOWLEDGED W/O COMMENTS ☐ RECEIPT ACKNOWLEDGED W/COMME...

COMMENTS CONDITIONS OR REASONS FOR DISAPPROVAL All comments, conditions, or reasons for disapproval must be listed here and marked on each copy or attachments as applicable.

An amended AR/VR must be approved when all previously identified comments, conditions, or reasons for disapproval are satisfied.

Conditional approval grants the authorizatio... provided that all noted conditions are in... Requests which are conditionally approved o... require the processing of an amended AR/VR.

☐ Authorized To Proceed   ☐ Amendment Not Required   ☐ Do Not Proceed   ☐ Amendment Required

John J Garcia   11-19-

Westinghouse Electric Corporation

APPROVAL / VARIATION REQUEST

ECO 5848 628

APPROVAL REQUEST ☒ VARIATION REQUEST

AR/VR Number: VR38777-008

Supplier Or Subcontractor And Address:
Hall Machine & Welding Co., Inc.
102 W. Mermod
Carlsbad , NM 88220

Purchase Order Or Subcontract Number: 75-WSA-38777-EX

Item Name: Dry Bin

Drawing Or Specification Number: 412-F-017-W Revs.: E

Requirements
1. Note on Drawing

Type of Request
☐ Material ☐ Procedure
☒ For Record Only ☐ Other (Describe)
☐ Certification

Supplier Or Subcontractor Authorized Signature: Todd Sellmer | Title: Q.A. Dept. | Date: 11/16/90

DESCRIBE REQUEST IN DETAIL: Include Title, Number and Revision To All Attachments, Specification or Drawing References

1. Note #7 on drawing #412-F-017-W Revision E , calls for the color of the external coating of the Bin Assembly to be white. The final coat of the Bin was decided to be Grey . This decision was made by Westinghouse Engineering group .

2. Dwg. WHO6 412-N-002-W, tag identification table, label #9 & 11 are modified to read as follows:

#9	GRB-1 Recirc Out Backup	#11	GRB-2 Recirc In Backup

3. Dwg. WHO6 412-N-002-W, stencil Bin serial number, revise dimension 6 ± ½ to read 27.5 ± ½

DISPOSITION: ☒ APPROVED ☐ CONDITIONALLY APPROVED ☐ DISAPPROVED

Conditions, Exceptions, or Reasons For Disapproval

TO SUPPLIER OR SUBCONTRACTOR. Requests that are conditionally approved grant an authorization to proceed provided that noted conditions are incorporated into the work.

Requests that are conditionally approved or disapproved require an amended AR/VR to be processed.

☐ Authorized To Proceed ☐ Do Not Proceed
☐ Amendment Not Required ☐ Amendment Required

AUTHORIZED BY _____ 11/2
Purchasing Agent

WP Form 14[illegible]

EC 5843 78

Westinghouse Electric Corporation

RECEIVED
APR - 4 1991
SERVICES PROCUREMENT BUYER

AR/VR DISPOSITION SHEET

For Internal Use Only

☐ APPROVAL RECORD REQUEST ☒ VARIATION REQUEST ☐ DEVIATION

AR/VR Number	Reference No
38777-010	

Cognizant Contract Or Subcontract Administrator: SAM HAZZINARO

Purchase Order Or Subcontract Number: 75WLSA38777EX

AR/VR Received	Approval Required Date	Equip No
3-1-91	3-4-91	

Project Name Or Number: BIN SCALE-DRY BIN AS

Drawing Or Specification Number: 412-F-017-W

Supplier Or Subcontractor:
HALL MACHINE & WELDING CO., INC.
102 W. MERMOD
CARLSBAD, N.M. 88220

Type of Request
☐ Approval ☒ Record
☐ Other (Describe)

☐ Pre-Purchase Evaluation ☐ Approval Data ☒ Information Record

Req	DISPOSITION	Date	FOR APP. ONLY	COMMENTS
	Design Engineer		APPROVED / COND APP / DISAPPROVED	Use Form WP 1477-8 For Continuation Gasket Plate deleted (It interfered with Gasket assem
	Cognizant Engineer		APPROVED / COND APP / DISAPPROVED	
	Other		APPROVED / COND APP / DISAPPROVED	
	Other		APPROVED / COND APP / DISAPPROVED	
X	Quality Assurance	3-3-91	X APPROVED / COND APP / DISAPPROVED	
X	Responsible Engineer	3/1/91	X APPROVED / COND APP / DISAPPROVED	

FINAL DISPOSITION ☒ APPROVED ☐ CONDITIONALLY APPROVED ☐ DISA
☐ RECEIPT ACKNOWLEDGED W/O COMMENTS ☐ RECEIPT ACKNOWLEDGED W/COMM

COMMENTS, CONDITIONS, OR REASONS FOR DISAPPROVAL. All comments, conditions, or reasons for disapproval must be listed here and marked on each copy or attachments as applicable.

An amended AR/VR must be approved when all previously identified comments, conditions, or reasons for disapproval are satisfied.

Conditional approval grants the authorizatio provided that all noted conditions are Requests which are conditionally approved requires the processing of an amended AR/VR

RECEIVED
1991

☐ Authorized To Proceed ☐ Do Not Proceed
☐ Amendment Not Required ☐ Amendment Required

For Disposition Approved: John J. Garcia 3/7/91

WP Form 1477-A (10-6-89)

MAR- 1-91 FRI

EC 55[illegible]

APPROVAL / VARIATION REQUEST

Westinghouse Electric Corporation

Page 1 of

☐ APPROVAL REQUEST ☒ VARIATION REQUEST

AR/VR Number: VR 638777-010

Reference No.

Purchase Order Or Subcontract Number: 75NSA38777EX

Supplier Or Subcontractor And Address:
Hall Machine & Welding Co., Inc.
102 West Mermod
Carlsbad, NM 88220

Item Name: Bin Scale - Dry Test Bin Assembly

Drawing Or Specification Number: 412-[illegible]-017-W, Rev. E

Revision

Requirements:
1) Omit Item 23

Type of Request:
☐ Material ☐ Procedure
☒ For Record Only ☐ Other (Describe)
☐ Certification

Supplier Or Subcontractor Authorized Signature | Title: QA Dept Mgr | Date: 3/1/91

DESCRIBE REQUEST IN DETAIL: Include Title, Number and Revision To All Attachments, Specification or Drawing References

1) Omit Item 23 per the instructions of Mr. O.P. Mendiratta, Westinghouse Engineering.

DISPOSITION: ☒ APPROVED ☐ CONDITIONALLY APPROVED ☐ DISAPPROVED

Conditions, Exceptions, or Reasons For Disapproval

NOTE TO SUPPLIER OR SUBCONTRACTOR: Requests that are conditionally approved grant an authorization to proceed provided that noted conditions are incorporated into the work.

Requests that are conditionally approved or disapproved require an amended AR/VR to be processed.

☐ Authorized To Proceed ☐ Do Not Proceed
☐ Amendment Not Required ☐ Amendment Required

AUTHORIZED BY: [signature] Purchasing Agent

WP Form 1466-A

ENGINEERING CHANGE ORDER
ADDENDUM SHEET

1. Addendum #A to ECO Number: 5845 Drawing Number: 412-N-002-W

2. Description of change:

INCORPORATE VR# 38777-008 ITEM # 2 INTO DRAWING 412-N-002-W; MODIFYING TAG IDENTIFICATION TABLE AT LABELS 9 AND 11 AND RELOCATING STENCIL BIN SERIAL NUMBER AS SPECIFIED AND OMIT ITEM 17.

REMOVE ITEM 28 AND RELATED NOTE 6

ADD ANGULAR DIMENSION OF 20° TO TWO 1" VALVES AT VALVE SIDE ELEVATION OF BIN ASSEMBLY.

ADD ITEM 41, 60 L.F. OF WIRE CLOTH, Mc Master-Carr # 9219T312 OR EQUAL AND RELATED NOTE 19.

3. Approvals

	Signature	Date
Cognizant Engineer:	Jim Fondriest	4/15/92
CC&D Mgr. /Desig. Rep.:	H W Bell	4/16/92
Other Approval:	Doyle White	4-21-92
Other Approval::		

392B:000

5. LINER MATERIAL SHALL BE POLYETHYLENE, NOMINAL THICKNESS, .030". LINER SHALL NOT RELEASE ANY GASES BETWEEN 70° F AND 90° F.

6. REMOVED

7. PREPARE AND PAINT EXTERNAL SURFACES OF BIN PER SPECIFICATION E-Z-240, REV. 2, SYSTEM I-16. FINISH COAT SHALL BE GRAY. APPLY PAINT AFTER WELD TESTS AND APPROVALS SPECIFIED IN EQUIPMENT SPECIFICATION E-A-334, EXCEPT STAINLESS STEEL SURFACES.

8. PAINT INTERNAL SURFACE OF BIN AND UNDERSIDE OF COVER WITH PAINT 105C-5, WHITAKER COATINGS, 1500 LATHEM ST., BATAVIA, IL. 60510 OR EQUAL. APPLY FIRST COAT .0003" - .0004" DRY AND BAKE 10 - 12 MINUTES AT 300° - 315° F. APPLY SECOND COAT .0003" - .0004" DRY AND BAKE 10 - 12 MINUTES AT 400° - 425°F. APPLY FIRST COAT AFTER WELD TESTS AND APPROVALS SPECIFIED IN EQUIPMENT SPECIFICATION E-A-334.

9. STENCIL BIN EQUIPMENT NO. AND THREE DIGIT SERIAL NO. LETTERS SHALL BE 1/2"-1" HIGH INDELIBLE BLACK. LIDS AND BINS OF THE SAME SERIAL NO. SHALL BE SHIPPED TOGETHER. DRY TEST BIN EQUIP. NO.: 63-S-001, S/N -001, ETC.

10. REINFORCE HOLES IN LINER WITH TEFLON WASHER EMBEDDED IN THE LINER.

11. SECOND WELD ON WALL OPTIONAL. SINGLE WELD PERFERRED WITH SINGLE PIECE WALL.

12. TO BE INSTALLED TO BOTTOM OF BIN ONLY.

13. REMOVED

14. ALL 1/2" VALVES INSTALL ON ITEM 1 SHALL HAVE THE SAME PART NUMBER.

15. ALL 1" VALVES INSTALL ON ITEM 1 SHALL HAVE THE SAME PART NUMBER.

16. ARROWS ON ALL VALVES TO POINT AWAY FROM BIN WALL.

17. REMOVE THIS LENGTH AFTER FINAL INSTALLATION.

18. THIS DETAIL FOR TEST BINS S/N PB-009, PB-010, AND PB-011 ONLY.

19. THIS DETAIL FOR TEST BINS S/N PB-012 AND ONWARD.

20. FOLD ITEM 20 AS REQUIRED TO FIT WITHIN THE BIN.

REV	ISSUE DESCRIPTION	DFTR / DATE	CHK / DATE	COG / DATE	DFTG MGR / DATE	ECO	PWR
F	REVISED PER ECO FD	RM 4/15/92	KES 4/15/92	QM 4/15/92	DLH 4/16/92	5189 5206 5848	
E	REVISED PER ECO	TRA 10/18/90	DLH 10/18/90	MB 10/18/90	HB 10/18/90	4869 5000	

THIS DRAWING CREATED BY ENGINEERING CHANGE ORDER (ECO) : 3258

INTERPRET DWG PER ANSI Y14
DIM IN INCHES BASED ON 68° F
UNLESS OTHERWISE SPECIFIED TOLERANCES

2 PL DEC	3 PL DEC	ANGLES
± .03	± .005	± 1°

FRACTIONS ± 1/8

ENGINEERING RELEASE
BY (W) WID-WIPP
ECO _____ DATE _____

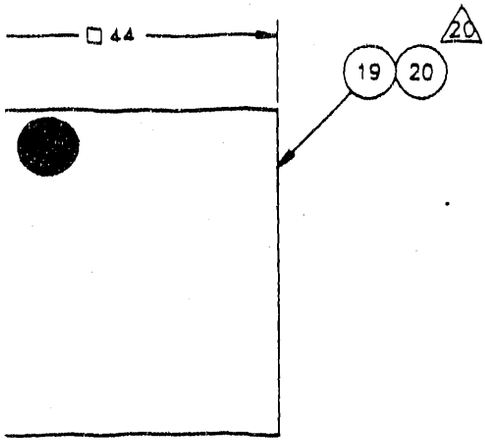
DFTG A.E.SEWALD 10/31/89
CHKR. D. HUGHES 10/17/90
COG. ENGM. BALI 10/17/90
COG. MGR J.J. GARCIA 1/12/90
Q.A. JAMES F. ALLEN 12/6/89
SAFETY C.D. JACKSON 12/6/89
APPD W.R. WHITE 12/6/89
APPD TERRY D. MERKLING (RS)
DFTG. MGR H.W. BELLOWS 10/16/90
SNL MARTY A. MOLECKE 12/6/89
DOE E.K. HUNTER 12/11/89
SCALE 1/8 U.N.O.

U.S. DEPARTMENT OF ENERGY
Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

BIN-SCALE TESTS
DRY TEST BIN DETAILS

SYS. WH06 | DWG. NO. 412-F-017-W1 | REV. F | DWG 1 OF 2

2 1



REV	ISSUE DESCRIPTION						
		DFTR	CHK	COG	DFTG MGR	ECO	PWR
		DATE	DATE	DATE	DATE		
F	REVISED PER ECO FD	RM	AES	CLH	RHR	5189 5206 6081	
		4/15/92	4/15/92	4/15/92	4/16/92		
E	REVISED PER ECO	TRA	DLH	MB	HB	4869 5000	
		10/18/90	10/18/90	10/18/90	10/18/90		

THIS DRAWING CREATED BY ENGINEERING CHANGE ORDER (ECO) : 3258

INTERPRET DWG PER ANSI Y14
DIM. IN INCHES BASED ON 68° F
UNLESS OTHERWISE SPECIFIED TOLERANCES

2 PL DEC	3 PL DEC	ANGLES
± .03	± .005	± 1°

125 AA

FRACTIONS ± 1/8

ENGINEERING RELEASE
BY (W) WID-WIPP
ECO _____ DATE _____

DFTG A.E. SEWALD 10/31/89
CHKR. D. HUGHES 10/17/90
COG. ENG M. BALI 10/17/90
COG. MGR J.J. GARCIA 1/12/90
Q.A. JAMES F. ALLEN 12/6/89
SAFETY C.D. JACKSON 12/6/89
APPD W.R. WHITE 12/6/89
APPD TERRY D. MERKLING (RS)
DFTG. MGR H.W. BELLOWS 10/18/90
SNL MARTY A. MOLECKE 12/6/89
DOE E.K. HUNTER 12/11/89
SCALE 1/8 U.N.O.

U.S. DEPARTMENT OF ENERGY

Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

BIN-SCALE TESTS
DRY TEST BIN DETAILS

SYS.	DWG. NO.	REV.
WH06	412-F-017-W2	F
		DWG 2 OF 2

D
C
B
A

2 1

2. FILTER HOUSING SHALL BE NUPRO SS-6T-VCR-2 WITH AN SS SPRING, SILVER-PLATED SS 316 GASKET. HOUSING SHALL HAVE NO MICRON SIZE OR OTHER SPECIFICATION STAMPED ON IT. DISCARD THE NUPRO FILTER ELEMENT IN THE HOUSING.

3. FIBERBOARD LINERS TAPED TOGETHER AT TAB END WITH ITEM 18.

4. SHIP ITEM 4 PLACED INSIDE ITEM 2. NO SHARP BENDS ON GASKET.

5. TAGS TO BE RED WITH WHITE LETTERING ON A 3" X 2" TAG, WITH 1/4"-1/2" CHARACTERS. TAGS TO BE MOUNTED WITH ITEM 20. TEXT OF EACH TAG SHOWN IN TAG IDENTIFICATION TABLE.

6. REMOVED

7. REMOVED

8. REMOVED

9. STANDARD HEX-HEAD BOLTS WITH INTEGRAL WASHERS. BOLTS SHALL BE 1/2-13 UNC X 1-1/4 LG. WITH AN INTEGRAL FLAT WASHER 1" DIAMETER.

10. LEAVE TOP OF ITEM 12 LOOSE AFTER INSTALLING ITEMS 13, 14, 29, & 30.

11. STENCIL BIN EQUIPMENT NO. AND THREE DIGIT SERIAL NO. LETTERS SHALL BE 1/2"-1" HIGH INDELIBLE BLACK. LIDS AND BINS OF THE SAME SERIAL NUMBER SHALL BE SHIPPED TOGETHER. SOLID WASTE BIN EQUIP. NO.: 63-S-001, S/N -001, ETC. PS/SC BIN EQUIP. NO.: 63-S-004, S/N -001, ETC.

12. SANDIA NATIONAL LABS. TO SUPPLY AND INSTALL ITEMS 23, 24, 25, 26, AND 27 PER PROCEDURES APPROVED BY W-WID.

13. TIGHTEN TO 30 FT-LB TORQUE.

14. STENCIL WORDS "MAX GROSS WEIGHT 3,200 LBS." LETTERS SHALL BE 1-2" HIGH, INDELIBLE BLACK, ON NEAR AND FAR SIDE OF BIN, STENCILED AFTER PAINTING BIN.

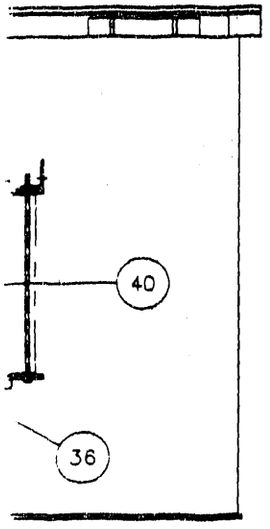
15. TRANSPORT FILTERS (ITEM 38) TO BE FITTED WITH A FEMALE NUT AT THE FABRICATION SHOP. THIS NUT WILL BE REPLACED WITH A CAP NUT AT THE WIPP SITE PRIOR TO DOWN-LOADING OF THE BIN.

16. ALL VCR CONNECTIONS SHALL BE MATED WITH PROPER SIZE GASKET, PREFERABLY HELD IN A GASKET RETAINER ASSEMBLY (ITEM 32, ITEM 33).

17. FOLLOW VENDOR DIRECTIONS FOR REPEATED USE OF THE SAME ASSEMBLY.

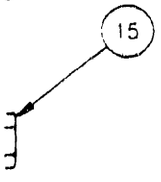
18. FILTER MEDIA SHALL BE REMOVED FROM THE NUPRO FILTER HOUSING (ITEM 21) FOR THE PRODUCTION BINS S/N PB-009 THROUGH PB-018.

19. CUT WIRE CLOTH INTO 20 FT. LONG PIECES. FOLD INTO SIX APPROXIMATELY 40" LONG ACCORDIAN STYLE BENDS. LOAD 3 PIECES (60 L.F.) OF THE FOLDED WIRE CLOTH DIRECTLY ONTO THE GAS MANIFOLD ASSEMBLY (DWG. NOS. 412-M-005-W AND 412-M-007-W). INSTALL PRIOR TO SHIPMENT OF BIN TO GENERATOR SITE.



LLATION
ARITY)

3



EMBLY

OLES

REV	ISSUE DESCRIPTION					ECO	PWR
		DFTR	CHK	COG	DFTG MGR		
		DATE	DATE	DATE	DATE		
F	REVISED PER ECO FD	RM	AES	Dlm	JB	5189 5206 5848	
		4/15/92	4/15/92	4/15/92	4/15/92		
E	REVISED PER ECO FD	DLH	TRA	MB	HB	4869 5000	
		10/18/90	10/17/90	10/17/90	10/18/90		

THIS DRAWING CREATED BY ENGINEERING CHANGE ORDER (ECO) :

INTERPRET DWG PER ANSI Y14	DFTG A.E.SEWALD 10/30/89
DIM. IN INCHES BASED ON 68° F	CHKR. TONY ALSTON 10/17/90
UNLESS OTHERWISE SPECIFIED TOLERANCES	COG. ENG M. BALI 10/17/90
2 PL DEC: ±.06 / 3 PL DEC: - / ANGLES: - / √ AA	COG. MGR J.J. GARCIA 1/12/90
	Q.A. JAMES F. ALLEN 12/6/89
	SAFETY C.D. JACKSON 12/6/89
FRACTIONS: ±1/8 TORQUE ±2 FT-LB or +2 -0 IN-LB	APPD W.R. WHITE 12/6/89
	APPD TERRY D. MERKUNG (RS)
ENGINEERING RELEASE BY (W) WID-WIPP	DFTG. MGR. BELLOWS 10/18/90
	SNL MARTY A. MOLECKE 12/6/89
ECO ____ DATE ____	DOE E.K. HUNTER 12/11/89
	SCALE 1/8 UNC

U.S. DEPARTMENT OF ENERGY

Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

BIN-SCALE TESTS
DRY TEST BIN ASSEMBLY

SYS	DWG. NO	REV.
WH06	412-N-002-W	F
		DWG. OF

2 1

ENGINEERING CHANGE ORDER

USE BLACK INK

1. **ECO No.:** 5849
CC&D Review: [signature]

Initials

Posted

2. **Impact Level** 1 ☐ 2 ☐ 3 ☒ 4 ☐

3. **System:** FP03 Equipment No.: 534-FP-00601 Building: U/G-W.S.

4. Associated Documents:
PWR 00436M
ECP 2-FP91-220
P.O. _____
Others _____

5. **Document Type:**
Drawing 53-J-042-W ☒
Specification ☐
Vendor Data ☐
SDD ☐
Others _____

6. **Title of Change:** REMOVE THERMAL DETECTORS IN S700 & S1000

7. **Originator:** (print) J.R. STROBLE
Ext. No.: 8374
Department: ELEC. ENG.
Date: 11-1-91

8. **Cognizant Engineer:** (print) J.R. STROBLE

9. **Description of Change:**

Yes ☐ No ☒ Component indices change required (if yes, attach sheets)

REMOVE THE THERMAL DETECTORS IN U/G DRIFTS S700 & S1000 BETWEEN E140 & E300.

☒ 9a Drawing Change Sheet attached
☐ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

10.
Yes ☒ No ☐ **MODIFICATION IN PROGRESS**
☒ Modification complete: J.R. Stroble / 4-6-92 (Signature / Date)
ECO will be incorporated after M.I.P. signed complete

☐ Change drawing per as-built markup dated: _____
☒ Change drawing per ECO-provided data
☐ Temporary modification

11. **Design Verification Requirements: (per WP 09-018)** EDT No.: _____

[signature] I.A.D. 11-1-91 1. Requirements satisfied by review/approval of design document
_____ 2. Independent review
_____ 3. Alternate calculations
_____ 4. Development testing
_____ 5. Design review
_____ 6. Other: _____

12. **Addendum Sheet added:** _____ / _____ (Signature / Date)

13. Justification

THESE DETECTORS ARE NOT REQUIRED. THEY CAUSE INADVERTANT ALARMS AND CONFUSION ON THE APPLICABILITY OF FSAR CHAPTER 10 LCO STATEMENT ON "THERMAL DETECTORS" IN THE "RMA".

SEE APPROVAL OF ECP 2-FP91-220.

14. Administrative Tracking

YES	N/A		YES	N/A	
☒	☐	1. FSAR	☒	☐	6. Startup/Acceptance Test
☐	☒	2. Calibration Procedures	☐	☒	7. Test Requirement & Spec.
☐	☒	3. Maintenance Procedures	☐	☐	8. _____
☐	☒	4. Computer Software	☐	☐	9. _____
☒	☐	5. Operations Procedures	☐	☐	10. _____

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

[A]	Cog. Engineer	J.R. Stubbe	11-1-91
[A]	Cog. Eng. Mgr.	[illegible] for J.A. Davis	11/4/91
[R]	Startup	[illegible]	11/4/91
[A]	QA	[illegible]	11/8/91
[ ]	DOE		
[A]	Safety (FPE)	[illegible]	11-18-91
[ ]	Dept. Manager		
[A]	Operations (U/G)	[illegible]	11-19-91
[ ]	Security		
[ ]	SNL		
[ ]			
[ ]			
[ ]			

16. Distribute as Marked

☒	Maintenance (MANDATORY)	
☒	Ops. Support (MANDATORY)	
☒	Startup	
☐	Facility Operations	
☒	U/G Operations	Controlled Dwg. File
☐	Orig./Design Engr.	
☐	Cog. Engineer	
☐	Others	
☐		
☐		
☐		
☐		
☐		

ENGINEERING CHANGE ORDER

1. ECO # 5527
2. DATE 11-1-91

DOE ORDER 6430.1A DESIGN CRITERIA CHECKLIST

The design requirements in DOE Order 6430.1A checked below have been applied to this Design.

3. DIVISION	SUBDIVISION
☐ 1 General Requirements	☐ 0101 ☐ 0106 ☐ 0109 ☐ 0110 ☐ 0111 ☐ 0140 ☐ 0150 ☐ 0170
☐ 2 Site and Civil Engineering	☐ 0200 ☐ 0201 ☐ 0202 ☐ 0203 ☐ 0205 ☐ 0210 ☐ 0214 ☐ 0215 ☐ 0220 ☐ 02 ☐ 0245 ☐ 0250 ☐ 0256 ☐ 0260 ☐ 0262 ☐ 0266 ☐ 0267 ☐ 0270 ☐ 0273 ☐ 0 ☐ 0276 ☐ 0278 ☐ 0279 ☐ 0280 ☐ 0281 ☐ 0283 ☐ 0285 ☐ 0290 ☐ 0291
☐ 3. Concrete	☐ 0300 ☐ 0301 ☐ 0310 ☐ 0320 ☐ 0330 ☐ 0340 ☐ 0350 ☐ 0370 ☐ 0380
☐ 4 Masonry	☐ 0400 ☐ 0401 ☐ 0410 ☐ 0420 ☐ 0455
☐ 5 Metals	☐ 0500 ☐ 0512 ☐ 0514 ☐ 0521 ☐ 0531 ☐ 0532
☐ 6 Wood and Plastics	☐ 0600 ☐ 0610 ☐ 0650
☐ 7 Thermal and Moisture Protection	☐ 0710 ☐ 0711 ☐ 0714 ☐ 0715 ☐ 0719 ☐ 0720 ☐ 0721 ☐ 0722 ☐ 0724 ☐ 0 ☐ 0730 ☐ 0750 ☐ 0751 ☐ 0753 ☐ 0760 ☐ 0790
☐ 8 Doors and Windows	☐ 0800 ☐ 0810 ☐ 0820 ☐ 0830 ☐ 0833 ☐ 0836 ☐ 0839 ☐ 0850 ☐ 0860 ☐ 0 ☐ 0880
☐ 9 Finishes	☐ 0900 ☐ 0910 ☐ 0920 ☐ 0925 ☐ 0930 ☐ 0950 ☐ 0965 ☐ 0968 ☐ 0970 ☐ 0 ☐ 0990 ☐ 0995
☐ 10 Specialties	☐ 1015 ☐ 1020 ☐ 1024 ☐ 1027 ☐ 1030 ☐ 1040 ☐ 1050 ☐ 1052 ☐ 1053 ☐ 10 ☐ 1060 ☐ 1065 ☐ 1070 ☐ 1075 ☐ 1080
☐ 11 Equipment	☐ 1100 ☐ 1161
☐ 12 Furnishings	☐ 1201 ☐ 1230 ☐ 1250 ☐ 1260 ☐ 1270
☐ 13 Special Facilities	☐ 1300 ☐ 1304 ☐ 1305 ☐ 1306 ☐ 1307 ☐ 1318 ☐ 1319 ☐ 1320 ☐ 1321 ☐ 13 ☐ 1323 ☐ 1324 ☐ 1325 ☐ 1326 ☐ 1328
☐ 14 Conveying Systems	☐ 1401 ☐ 1420 ☐ 1440 ☐ 1460
☐ 15 Mechanical	☐ 1525 ☐ 1530 ☐ 1540 ☐ 1550 ☐ 1555 ☐ 1565 ☐ 1574 ☐ 1589 ☐ 1595
☐ 16 Electrical	☐ 1600 ☐ 1605 ☐ 1620 ☐ 1630 ☐ 1639 ☐ 1640 ☐ 1650 ☐ 1655 ☐ 1660 ☐ 16 ☐ 1671 ☐ 1685 ☐ 1694
4. ☒ NOT APPLICABLE	No portion of DOE Order 6430.1A is applicable to this Design.
5. ☐ AS-BUILT	ECO is for as-built field verified changes only.

NOTE: A check placed in the Division column signifies that the entire Division shall be applicable to the Design, unless modified by checks indicated for specific Subdivisions.

COMMENTS: _____

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 53-J-042-W ECO Number: 5849

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

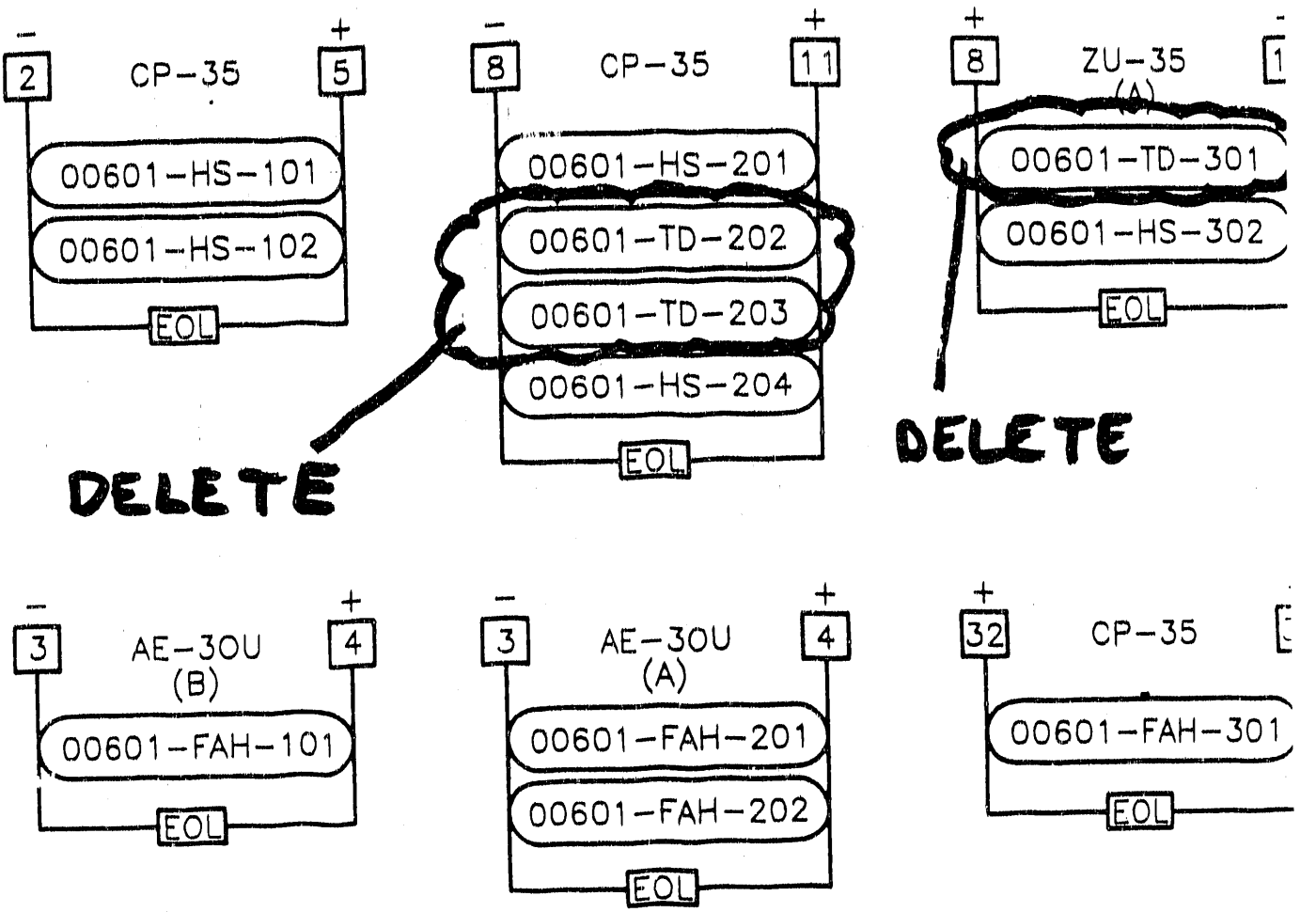
3. Description of Change:

DELETE 00601-TD-202 & 00601-TD-203 & 00601-TD-301 FROM THE LADDER DIAGRAM.

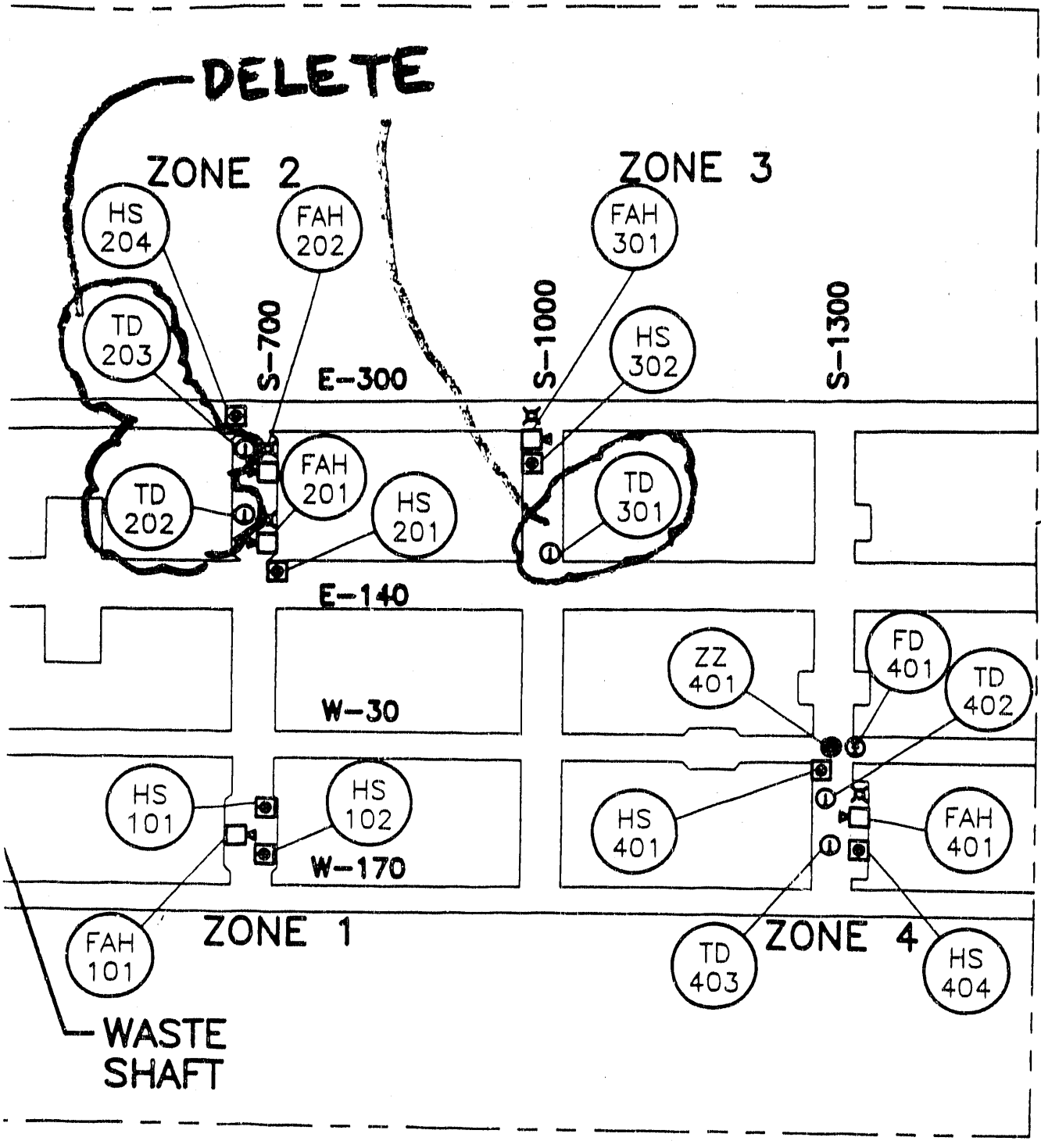
DELETE TD 202, TD 203, & TD 301 AND THEIR SYMBOLS FROM THE FLOOR PLAN.

SEE ATTACHED PAGES

4. Drawing Cog. Engineer Approval: J.R. Stubbs Date: 11-1-91



53-J-042-W
REV. E.



53-J-042-W
REV. E

53J 042 W

ENGINEERING CHANGE ORDER

ENGINEERING FILE ROOM COPY

USE BLACK INK

1. ECO No.: 5866

JK CC&D Review: [signature]

Initials

Posted

APR 1992 COMPLETE

2. Impact Level 1 ☐ 2 ☐ 3 ☒ 4 ☐

3. System: FP03 Equipment No.: 534-FP-00601 Building: V/G-WS

4. Associated Documents:

PWR

ECP N/A

P.O.

Others

5. Document Type:

Drawing 53-J-042-W ☒

Specification ☐

Vendor Data ☐

SDD ☐

Others

6. Title of Change: MOVE CMS POINT CM0612 WIRES

7. Originator: (print)	Ext. No.:	Department:	Date:	8. Cognizant Engineer: (print)
J.R. STROBLE	8374	ELEC. ENG.	11-11-91	J.R. STROBLE

9. Description of Change:

Yes ☐ No ☒ Component indices change required (if yes, attach sheets)

MOVE THE WIRES TO ACTUATE CMS POINT CM0612 IN FIRE PANEL 534-FP-00601 TO ANOTHER RELAY.

☒ 9a Drawing Change Sheet attached

☐ 9b Design Documentation Sheet attached

☐ 9c Vendor Data Change Sheet attached

10.

Yes ☒ No ☐ MODIFICATION IN PROGRESS

☐ Modification complete: J.R. Stroble (Signature) 3-16-92 (Date)

ECO will be incorporated after M.I.P. signed complete

☒ Change drawing per as-built markup dated: 3-16-92

☐ Change drawing per ECO-provided data

☐ Temporary modification

11. Design Verification Requirements: (per WP 09-018) EDT No.:

[signature] 1. Requirements satisfied by review/approval of design document

[signature] 2. Independent review

3. Alternate calculations

4. Development testing

5. Design review

6. Other:

12. Addendum Sheet added: [signature] (Signature) 3-16-92 (Date)

11908:0005

13. Justification

THE POINT DOESN'T COME IN UPON A FIRE ALARM. MAINTENANCE FOUND RELAY WAS BAD, AND A REPLACEMENT BOARD WILL HAVE TO BE ORDERED.

14. Administrative Tracking

YES	N/A		YES	N/A	
☐	☒	1. FSAR	☐	☒	6. Startup/Acceptance Test
☐	☒	2. Calibration Procedures	☐	☒	7. Test Requirement & Spec.
☐	☒	3. Maintenance Procedures	☐	☐	8. _____
☐	☒	4. Computer Software	☐	☐	9. _____
☐	☒	5. Operations Procedures	☐	☐	10. _____

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

A	Cog. Engineer	J.R. Strobe 11-11-91
A	Cog. Eng. Mgr	Lynn A Travis 11/12/91
R	Startup Received 11-16-91	J.A. Strait 11-16-91
A	QA	12/3/91
☐	DOE	
A	Safety (FPE)	Mickey V. Ewell 11-27-91
☐	Dept. Manager	
☐	Operations	
☐	Security	
☐	SNL	
☐		
☐		
☐		

16. Distribute as Marked

☒	Maintenance (MANDATORY)
☒	Ops. Support (MANDATORY)
☐	Startup
☐	Facility Operations
☒	U/G Operations Controlled Dwg. File
☐	Orig./Design Engr.
☐	Cog. Engineer
☐	Others
☒	U/G ELEC. R. GUERRA
☐	
☐	
☐	
☐	

1. ECO # 5866
2. DATE 11-11-91

ENGINEERING CHANGE ORDER

DOE ORDER 6430.1A DESIGN CRITERIA

CHECKLIST

The design requirements in DOE Order 6430.1A checked below have been applied to this Design.

3. DIVISION	SUBDIVISION
☐ 1 General Requirements	☐ 0101 ☐ 0106 ☐ 0109 ☐ 0110 ☐ 0111 ☐ 0140 ☐ 0150 ☐ 0170
☐ 2 Site and Civil Engineering	☐ 0200 ☐ 0201 ☐ 0202 ☐ 0203 ☐ 0205 ☐ 0210 ☐ 0214 ☐ 0215 ☐ 0220 ☐ 0 ☐ 0245 ☐ 0250 ☐ 0256 ☐ 0260 ☐ 0262 ☐ 0268 ☐ 0267 ☐ 0270 ☐ 0273 ☐ 0 ☐ 0276 ☐ 0278 ☐ 0279 ☐ 0280 ☐ 0281 ☐ 0283 ☐ 0285 ☐ 0290 ☐ 0291
☐ 3. Concrete	☐ 0300 ☐ 0301 ☐ 0310 ☐ 0320 ☐ 0330 ☐ 0340 ☐ 0350 ☐ 0370 ☐ 0380
☐ 4 Masonry	☐ 0400 ☐ 0401 ☐ 0410 ☐ 0420 ☐ 0455
☐ 5 Metals	☐ 0500 ☐ 0512 ☐ 0514 ☐ 0521 ☐ 0531 ☐ 0532
☐ 6 Wood and Plastics	☐ 0600 ☐ 0610 ☐ 0650
☐ 7 Thermal and Moisture Protection	☐ 0710 ☐ 0711 ☐ 0714 ☐ 0715 ☐ 0719 ☐ 0720 ☐ 0721 ☐ 0722 ☐ 0724 ☐ 0 ☐ 0730 ☐ 0750 ☐ 0751 ☐ 0753 ☐ 0760 ☐ 0790
☐ 8 Doors and Windows	☐ 0800 ☐ 0810 ☐ 0820 ☐ 0830 ☐ 0833 ☐ 0836 ☐ 0839 ☐ 0850 ☐ 0860 ☐ 0 ☐ 0880
☐ 9 Finishes	☐ 0900 ☐ 0910 ☐ 0920 ☐ 0925 ☐ 0930 ☐ 0950 ☐ 0965 ☐ 0968 ☐ 0970 ☐ 0 ☐ 0990 ☐ 0995
☐ 10 Specialties	☐ 1015 ☐ 1020 ☐ 1024 ☐ 1027 ☐ 1030 ☐ 1040 ☐ 1050 ☐ 1052 ☐ 1053 ☐ 1 ☐ 1060 ☐ 1065 ☐ 1070 ☐ 1075 ☐ 1080
☐ 11 Equipment	☐ 1100 ☐ 1161
☐ 12 Furnishings	☐ 1201 ☐ 1230 ☐ 1250 ☐ 1260 ☐ 1270
☐ 13 Special Facilities	☐ 1300 ☐ 1304 ☐ 1305 ☐ 1306 ☐ 1307 ☐ 1318 ☐ 1319 ☐ 1320 ☐ 1321 ☐ 1. ☐ 1323 ☐ 1324 ☐ 1325 ☐ 1326 ☐ 1328
☐ 14 Conveying Systems	☐ 1401 ☐ 1420 ☐ 1440 ☐ 1460
☐ 15 Mechanical	☐ 1525 ☐ 1530 ☐ 1540 ☐ 1550 ☐ 1555 ☐ 1565 ☐ 1574 ☐ 1589 ☐ 1595
☐ 16 Electrical	☐ 1600 ☐ 1605 ☐ 1620 ☐ 1630 ☐ 1639 ☐ 1640 ☐ 1650 ☐ 1655 ☐ 1660 ☐ 1 ☐ 1671 ☐ 1685 ☐ 1694
4. ☒ NOT APPLICABLE	No portion of DOE Order 6430.1A is applicable to this Design.
5. ☐ AS-BUILT	ECO is for as-built field verified changes only.

NOTE: A check placed in the Division column signifies that the entire Division shall be applicable to the Design, unless modified by checks indicated for specific Subdivisions.

COMMENTS: _____

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 53-J-042-W ECO Number: 5866

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

MOVE WIRES CONNECTED TO SR-33/17 & SR-33/18 (534FP0060IJ-21 & 534FP0060IJ-22) TO SR-33/23 & SR-33/24 RESPECTIVELY.

4. Drawing Cog. Engineer Approval: J.R. Stroble Date: 11-11-91

PAGE 5 OF 5

F

E

534FP00601F
ALARM DEVICE
ZONE 3

TO
LPU
807

534FP00601J-11
534FP00601J-12
534FP00601J-13
534FP00601J-14
534FP00601J-15
534FP00601J-16
534FP00601J-17
534FP00601J-18
534FP00601J-19
534FP00601J-20
534FP00601J-21
534FP00601J-22

MOVE

SR-33

ZU-35
(A)

P1 P2

ZONE 3

ZONE 4

7 8 9 10 11 12

1 2 3 4 5 6

534FP00601D
INITIATING DEVICE
ZONE 4

534FP00601C
INITIATING DEVICE
ZONE 3

534FP00601J-3

ZU-35
(B)

P1 P2

SPARE

ZONE 5

7 8 9 10 11 12

1 2 3 4 5 6

534FP00601E
INITIATING DEVICE
ZONE-5

AE-
(A

P1

AL
CI
TF

7 8

1 2 3

534FP
ALARM
ZON

ENGINEERING CHANGE ORDER
ADDENDUM SHEET

1. Addendum Sheet to ECO Number: 5866 Drawing Number: 53-J-047-[illegible]

2. Description of change: REPLACE PAGE 5 OF THIS ECO WITH ATTACHED PAGE

REPLACE THE SR-33 RELAY BOARD WITH AN SR-35 RELAY BOARD, AND CHANGE THE WIRING AS SHOWN ON THE ATTACHED PAGES.

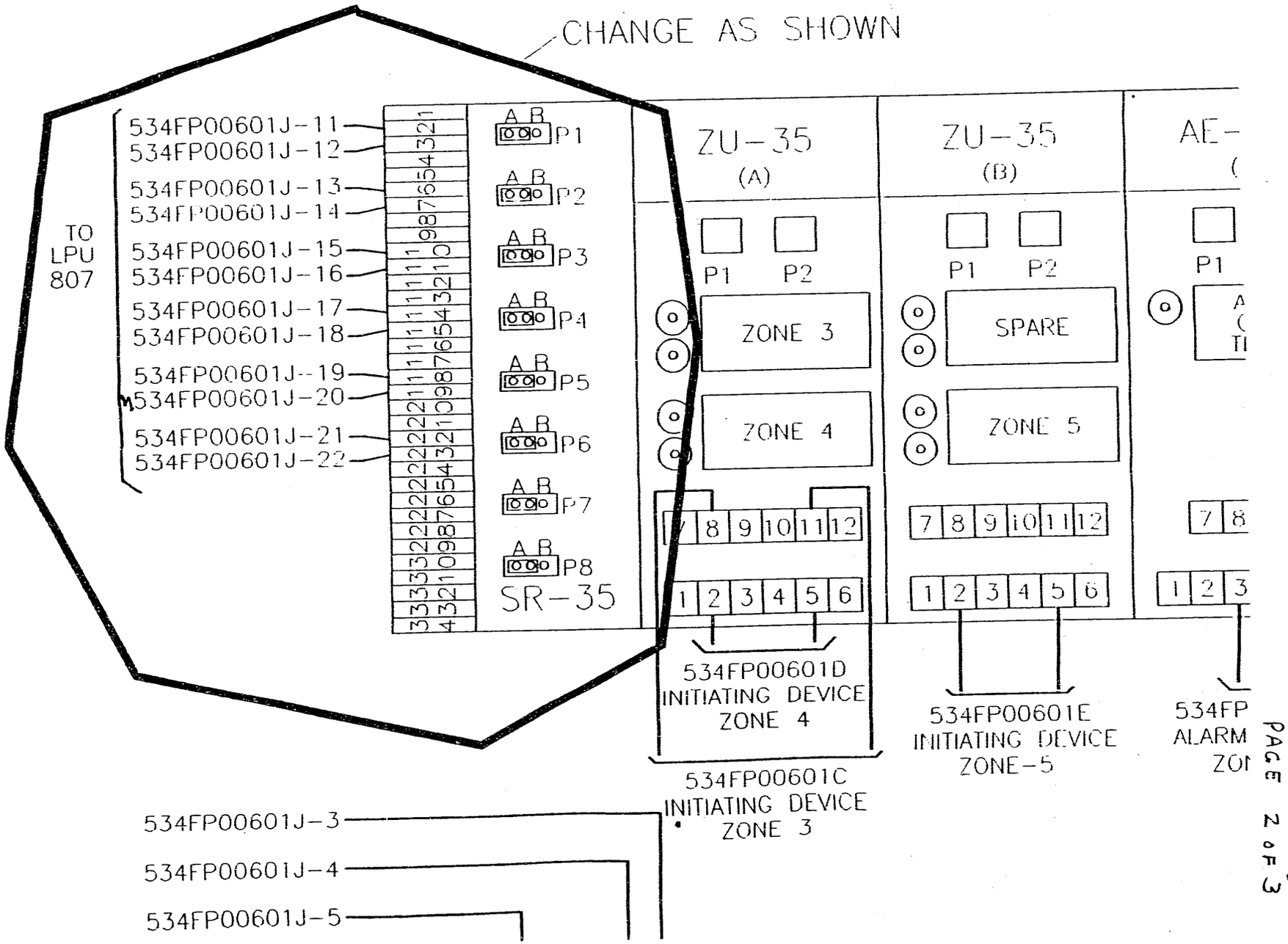
JUSTIFICATION: MAINTENANCE HAD TO REPLACE THE SR-33 BOARD DUE TO A MALFUNCTIONING RELAY. PYROTRONICS NO LONGER MAKES THIS BOARD, SO THE SR-35 WAS AN APPROVED SUBSTITUTE. SEE PWR 15828S.

3. Approvals

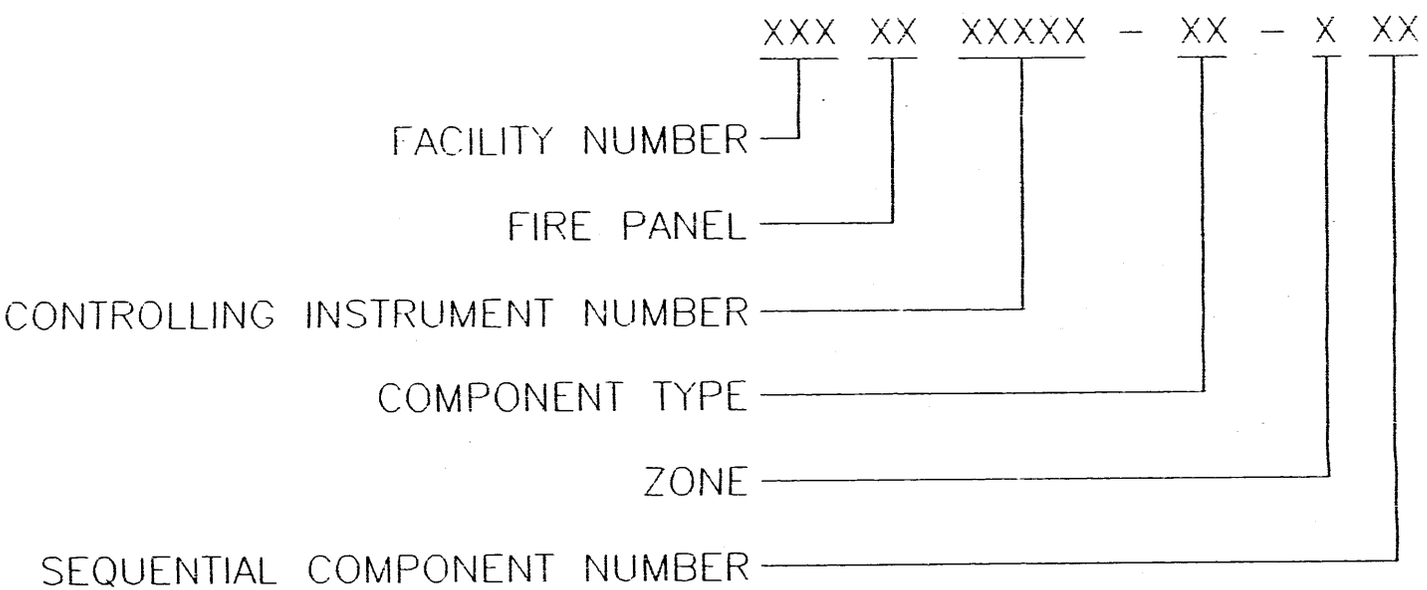
Cognizant Engineer:	J. R. Stroh Signature	3-16-92 Date
CC&D Mgr. /Desig. Rep.:	Bill Ott Signature	3/16/92 Date
Other Approval:	Dayton Akito Signature	3-16-92 Date
Other Approval::	Signature	Date

ZONE 5

CHANGE AS SHOWN



ECO 5866
ADDENDUM 3-16-
PAGE 2 OF 3



2. THE FIRE ARLARM PORTION OF THE FOLLOWING DRAWINGS HAVE BEEN SUPERCEDED PER ECO 4606.
   53-J-572-01E
   53-J-533-01E
   53-J-532-01E

3. THIS DRAWING SUPERCEDES DRAWING GZC 6653-FA-1, PER ECO NO 3210

ADD

4. P1-P8 ON SR-35 IS FOR "HIGH GOING INPUT SIGNAL" (ALARM OUTPUT FROM ZU-35)

E	10/01/90	REVISED PER ECO	TB	JWW	4838	
D	08/06/90	REVISED PER ECO	TP	JWW	4761	
C	7/17/90	REVISED PER ECO	AES	JWW	4576/4606	R-03242
B	4/25/90	REVISED PER CHG ADP FP03-00	RCN	JWW	4191	

M10680

ECO 5966
ADDENDUM 3.16.
PAGE 3 OF 3

TD = THERMAL DETECTOR
PS = PRESSURE SWITCH (WATER PRESSURE)
ZZ = FIRE DOOR SOLENOID
FD = FIRE DAMPER
= TERM AND POLARITY IN FIRE PANEL
EOL = END OF LINE DEVICE
TR = TANK RELEASE
H/L = HORN WITH STROBE OR LIGHT

NOTES

1. FIRE PROTECTION SYSTEM EQUIPMENT IS LABELED AS FOLLOWS:

EG: 413-FP-01003 - HS - 3 01

XXX XX XXXXX - XX - X XX

- XXX — FACILITY NUMBER
- XX — FIRE PANEL
- XXXXX — CONTROLLING INSTRUMENT NUMBER
- XX — COMPONENT TYPE
- X — ZONE
- XX — SEQUENTIAL COMPONENT NUMBER

2. THE FIRE ARLARM PORTION OF THE FOLLOWING DRAWINGS HAVE BEEN SUPERCEDED PER ECO 4606.
   53-J-572-01E
   53-J-533-01E
   53-J-532-01E
3. THIS DRAWING SUPERCEDES DRAWING GZC 6653-FA-1, PER ECO NO 3210.
4. P1-P8 ON SR-35 IS FOR "HIGH GOING INPUT SIGNAL" (ALARM OUTPUT FROM ZU-35)

-LPU-807
U TERM
B3A17
B3B17
A4A6
A4B6
A4A5
A4B5
D2A11
D2B11
D2A13
D2B13
A4A02
A4B02
A4A7
A4B7
D2A12
D2B12
D2A14
D2B14
C2A15
C2B15

REV	ISSUE DESCRIPTION	DFTR	CHK	COG	DFTG MGR	ECO	PWR
		DATE	DATE	DATE	DATE		
G	REVISED PER ECO	TB	AES	[illegible]	3/30/92	5868	
		03/28/92	[illegible]	[illegible]			
F	REVISED PER ECO	RS	BC	JRS	BA	5837	
		12/17/91	12/17/91	12/17/91	12/17/91		

THIS DRAWING CREATED BY ENGINEERING CHANGE ORDER (ECO) : 3210 M040877 M40880

DFTG R.SEXTON
CHKR. B.ALLEN 10/01/90
COG. ENG J.WHITE 10/1/90
COG. MGR J. DAVIS 8/3/90
Q.A. A. GALLEGOS 8/3/90
SAFETY N/A
APPD
APPD
DFTG. MGR H.HUBBELLOWS 10/1/90
ASB ENG C. ALDRIDGE 8/2/90
DOE N/A
SCALE NONE

U.S. DEPARTMENT OF ENERGY
Westinghouse Waste Isolation Division
Waste Isolation Pilot Plant
CARLSBAD, NEW MEXICO

UNDERGROUND UTILITIES FIRE PANEL 534-FP-00601

SYS.	DWG. NO.	REV.
FP03	53-J-042-W	G

DWG PER ANSI Y14 — DWG, 1 OF 1

41 E 003 014

ENGINEERING CHANGE ORDER

USE BLACK INK

1. **ECO No.:** 5873
C&D Review: RJ

Initials

Posted

2. **Impact Level** 1 ☐ 2 ☐ 3 ☒ 4 ☐

3. **System:** 66 Equipment No.: 41-T-152 & 41-T-153 Building: 411

4. **Associated Documents:**
PWR M-17295
ECP
P.O.
Others

5. **Document Type:**
~~Drawing~~ SKETCH 1715-3 ☒
Specification ☐
Vendor Data ☐
SDD ☐
Others

6. **Title of Change:** ANCHOR TRIPACT DOCKS @ CH-BAY

7. Originator: (print)	Ext. No.:	Department:	Date:	8. Cognizant Engineer: (print)
HADI SAYAHI	5780	M&CE	11/11/91	J. KOWALSKI

9. **Description of Change:**

Yes ☐ No ☒ Component Indices change required (if yes, attach sheets)

1- To anchor the docks, the floor shall be drilled through existing column base pre-drilled holes, then 5/8" ϕ bolts be placed with a max. embedment of 2 3/4" at perimeter columns (there are two holes per PL) because of the location of existing column cross bracings, some columns may be anchored with one bolt only. Shimming shall be provided for all columns (including the interior ones). All column base PLS. shall be sealed with SILICONE (a polymeric organic Silicon compound) to prevent waste penetration in the event of spill/release and to provide a smooth surface that will allow adequate clean-up activity.
2- Assign a sketch number for the TRIPACT Docks LOCATION SKETCH.
☒ 9a Drawing Change Sheet attached ☐ 9c Vendor Data Change Sheet attached
☐ 9b Design Documentation Sheet attached
3- Incorporate changes in dwgs 41-G-176-014 41-G-501-014 & 41-E-003-014 and issue ISK # 1715-3 after completion.

10. Yes ☐ No ☒ **MODIFICATION IN PROGRESS**
☐ Modification complete: _____ / _____ (Signature / Date)
ECO will be incorporated after M.I.P. signed complete

☐ Change drawing per as-built markup dated: _____
☐ Change drawing per ECO-provided data
☐ Temporary modification

11. **Design Verification Requirements: (per WP 09-018)** EDT No.: _____

WRG for DNFSB 1. Requirements satisfied by review/approval of design document
_____ 2. Independent review
_____ 3. Alternate calculations
_____ 4. Development testing
_____ 5. Design review
_____ 6. Other: _____

12. **Addendum Sheet added:** _____ / _____ (Signature / Date)

13. Justification

At existing state (not anchored to the floor) both docks are vulnerable to accident, and any relatively strong impact will cause the docks to shift/move laterally.

14. Administrative Tracking

YES	N/A		YES	N/A	
☐	☒	1. FSAR	☐	☒	6. Startup/Acceptance Test
☐	☒	2. Calibration Procedures	☐	☒	7. Test Requirement & Spec.
☐	☒	3. Maintenance Procedures	☐	☒	8. _____
☐	☒	4. Computer Software	☐	☒	9. _____
☐	☒	5. Operations Procedures	☐	☒	10. _____

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

A	Cog. Engineer	11/13/91
A	Cog. Eng. Mgr.	for D Cobb 11/14/91
R	Startup	11-18-91
R	QA	11/13/91
☐	DOE	
K	Safety	11/19/91
☐	Dept. Manager	
A	Operations (WASTE HANDLING)	11-18-91
☐	Security	
☐	SNL	
A	RAD. ENG. (RWHE)	11/20/91
☐		
☐		

16. Distribute as Marked

☒	Maintenance (MANDATORY) _____
☒	Ops. Support (MANDATORY) Control Dwg E1R
☐	Startup _____
☐	Facility Operations _____
☐	U/G Operations _____
☐	Orig./Design Engr. _____
☐	Cog. Engineer _____
☐	Others _____
☐	_____
☐	_____
☐	_____
☐	_____
☐	_____

ENGINEERING CHANGE ORDER

1. ECO # 5973
2. DATE 4/14/94

DOE ORDER 6430.1A DESIGN CRITERIA CHECKLIST

The design requirements in DOE Order 6430.1A checked below have been applied to this Design.

3. DIVISION	SUBDIVISION
☐ 1 General Requirements	☐ 0101 ☐ 0108 ☐ 0109 ☐ 0110 ☐ 0111 ☐ 0140 ☐ 0150 ☐ 0170
☐ 2 Site and Civil Engineering	☐ 0200 ☐ 0201 ☐ 0202 ☐ 0203 ☐ 0205 ☐ 0210 ☐ 0214 ☐ 0215 ☐ 0220 ☐ 023 ☐ 0246 ☐ 0250 ☐ 0256 ☐ 0260 ☐ 0262 ☐ 0265 ☐ 0267 ☐ 0270 ☐ 0273 ☐ 027 ☐ 0276 ☐ 0278 ☐ 0279 ☐ 0280 ☐ 0281 ☐ 0283 ☐ 0285 ☐ 0290 ☐ 0291
☐ 3 Concrete	☐ 0300 ☐ 0301 ☐ 0310 ☐ 0320 ☐ 0330 ☐ 0340 ☐ 0350 ☐ 0370 ☐ 0380
☐ 4 Masonry	☐ 0400 ☐ 0401 ☐ 0410 ☐ 0420 ☐ 0455
☒ 5 Metals	☐ 0500 ☒ 0512 ☐ 0514 ☐ 0521 ☐ 0531 ☐ 0532
☐ 6 Wood and Plastics	☐ 0600 ☐ 0610 ☐ 0650
☐ 7 Thermal and Moisture Protection	☐ 0710 ☐ 0711 ☐ 0714 ☐ 0715 ☐ 0719 ☐ 0720 ☐ 0721 ☐ 0722 ☐ 0724 ☐ 073 ☐ 0730 ☐ 0750 ☐ 0751 ☐ 0753 ☐ 0760 ☐ 0790
☐ 8 Doors and Windows	☐ 0800 ☐ 0810 ☐ 0820 ☐ 0830 ☐ 0833 ☐ 0836 ☐ 0839 ☐ 0850 ☐ 0860 ☐ 087 ☐ 0880
☐ 9 Finishes	☐ 0900 ☐ 0910 ☐ 0920 ☐ 0925 ☐ 0930 ☐ 0950 ☐ 0965 ☐ 0968 ☐ 0970 ☐ 099 ☐ 0990 ☐ 0995
☐ 10 Specialties	☐ 1015 ☐ 1020 ☐ 1024 ☐ 1027 ☐ 1030 ☐ 1040 ☐ 1050 ☐ 1052 ☐ 1053 ☐ 106 ☐ 1060 ☐ 1065 ☐ 1070 ☐ 1075 ☐ 1080
☐ 11 Equipment	☐ 1100 ☐ 1161
☐ 12 Furnishings	☐ 1201 ☐ 1230 ☐ 1250 ☐ 1260 ☐ 1270
☐ 13 Special Facilities	☐ 1300 ☐ 1304 ☐ 1305 ☐ 1306 ☐ 1307 ☐ 1318 ☐ 1319 ☐ 1320 ☐ 1321 ☐ 132 ☐ 1323 ☐ 1324 ☐ 1325 ☐ 1326 ☐ 1328
☐ 14 Conveying Systems	☐ 1401 ☐ 1420 ☐ 1440 ☐ 1460
☐ 15 Mechanical	☐ 1525 ☐ 1530 ☐ 1540 ☐ 1550 ☐ 1555 ☐ 1565 ☐ 1574 ☐ 1589 ☐ 1595
☐ 16 Electrical	☐ 1600 ☐ 1605 ☐ 1620 ☐ 1630 ☐ 1639 ☐ 1640 ☐ 1650 ☐ 1655 ☐ 1660 ☐ 16 ☐ 1671 ☐ 1685 ☐ 1694
4. ☐ NOT APPLICABLE	No portion of DOE Order 6430.1A is applicable to this Design.
5. ☐ AS-BUILT	ECO is for as-built field verified changes only.

NOTE: A check placed in the Division column signifies that the entire Division shall be applicable to the Design, unless modified by checks indicated for specific Subdivisions.

COMMENTS: _____

F 4 87

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 41-G-170-014 ECO Number: 5373

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Show location of TRUPACT Docks 41-T-152 & 41-T-153 As per sketch # 1715-S

4. Drawing Cog. Engineer Approval: J. Kruse Date: 11/14/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

1 > 7

9a

DRAWING CHANGE SHEET

(1 SHEET PER DRAWING)

1. Drawing: 41-G-501-014 ECO Number: 5873

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Show location of TRUPACT Docks 41-T-152 & 41-T-153 As per Sketch # 1715-S

4. Drawing Cog. Engineer Approval: J. Gomez Date: 11/14/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Date Assigned: _____ Initials / Date

Assigned to: _____ (Same as data base entry)

Drafting Started: _____ Initials / Date

Drafting Completed: _____ Initials / Date

Return to EFR: _____ Initials / Date

1290:B0006

T 6 9 7

9a
DRAWING CHANGE SHEET
(1 SHEET PER DRAWING)

1. Drawing: 41-E-003-014 ECO Number: 5873

2. ECO Search List: _____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

_____ _____ _____ _____

3. Description of Change:

Show location of TRUPACT Dock 41-T-152 & 41-T-153 (in dotted lines). per Sketch number 1715-5

4. Drawing Cog. Engineer Approval: _____ Date: 11/14/91

5. Cover Sheet Block (CC&D Use Only)

Received from EFR: _____ Initials / Date

Drafting Started: _____ Initials / Date

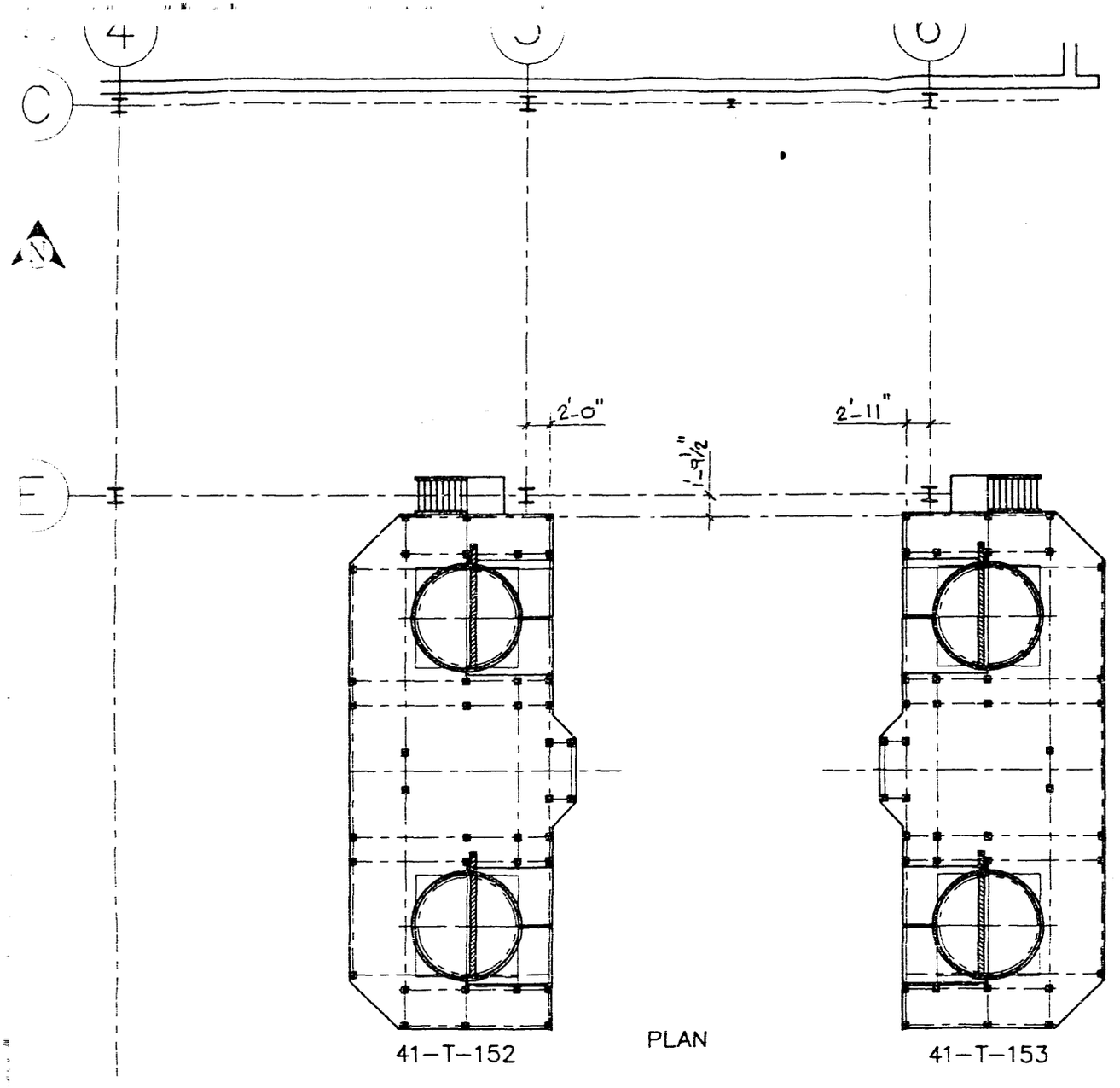
Date Assigned: _____ Initials / Date

Drafting Completed: _____ Initials / Date

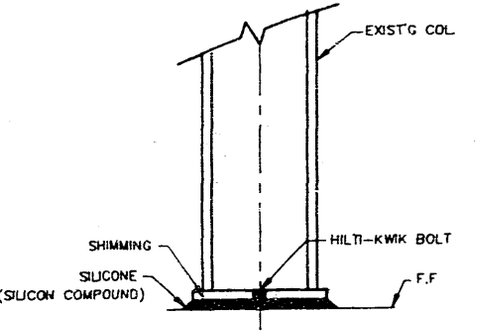
Assigned to: _____ (Same as data base entry)

Return to EFR: _____ Initials / Date

1290:B0006



PLAN



COL. DETAIL
N.T.S

NOTES:

1. ALL COLUMN BASES SHALL BE SHIMMED AS NEEDED.
2. ALL PERIMETER COLUMNS SHALL BE ANCHORED TO FLOOR WITH ø5/8 HILTI-KWIK BOLT OR APPROVED EQUAL (2 3/4 EMBEDMENT)
3. ALL COLUMN BASES SHALL BE SEALED WITH SILICONE (A POLYMERIC ORGANIC SILICON COMPOUND)

TRUPACT DOCKS/ANCHOR PLAN AND DETAILS

TITLE CH-BAY / BLDG. # 411

SKETCH # 1715-S

COG. ENG. [illegible] 11/3/91

COG. ENG. MGR. W Beamhart for DCell 11/4/91

73J010W

ENGINEERING CHANGE ORDER

USE BLACK INK

1. ECO No.: 5193
SI CC&D Review: [initials]

Initials

Posted

2. **Impact Level** 1 ☐ 2 ☐ 3 ☑ 4 ☐

3. **System:** PC03 Equipment No.: 5SP-TB1/42 Building: U/G

4. Associated Documents:
PWR 14860 M
ECP
P.O.
Others

5. **Document Type:**
Drawing 73-J-010-W ☒
Specification ☐
Vendor Data ☐
SDD ☐
Others

6. **Title of Change:** REMOVE FEEDER CABLES

7. Originator: (print)	Ext. No.:	Department:	Date:	8. Cognizant Engineer: (print)
BILL BRIGGS	8314	FE/EE	11/26/91	RODNEY FUSTON

9. **Description of Change:**

Yes ☑ No ☐ Component indices change required (if yes, attach sheets)

CHANGE DRAWING 73-J-010-W TO SHOW ADDITION OF 2 JUNCTION BOXES AND "ABANDONED IN PLACE" OF 2 CABLES & PHONES IN ROOMS 2~~8~~3 OF N-1400
SEE ATTACHED SHEETS

☑ 9a Drawing Change Sheet attached
☐ 9b Design Documentation Sheet attached
☐ 9c Vendor Data Change Sheet attached

10.
Yes ☑ No ☐ **MODIFICATION IN PROGRESS**
☐ Modification complete: _____ / _____ (Signature / Date)
ECO will be incorporated after M.I.P. signed complete

☐ Change drawing per as-built markup dated: _____
☐ Change drawing per ECO-provided data
☐ Temporary modification

11. **Design Verification Requirements: (per WP 09-018)** EDT No.: _____

JAD 1. Requirements satisfied by review/approval of design document
2. Independent review
3. Alternate calculations
4. Development testing
5. Design review
6. Other: _____

12. **Addendum Sheet added:** _____ / _____ (Signature / Date)

13. Justification

THE BACK IS COMING IN IN ROOMS 2 & 3 OFF N1400 DRIFT IT IS NECESSARY TO RE-ROUTE THE FEEDERS TO THESE AREA PHONES - IF THE ROOF FALLS NOW THE GAI-TRONICS SYSTEM COULD BE KNOCKED OUT

14. Administrative Tracking

YES	N/A		YES	N/A	
☐	☒	1. FSAR	☐	☒	6. Startup/Acceptance Test
☐	☒	2. Calibration Procedures	☐	☒	7. Test Requirement & Spec.
☒	☐	3. Maintenance Procedures	☐	☐	8. _____
☐	☒	4. Computer Software	☐	☐	9. _____
☒	☐	5. Operations Procedures	☐	☐	10. _____

15. Signature Requirements

KEY
A=APPR.
R=REVIEW
S=SIGN NEW DRAWING

A	Cog. Engineer	J. Rodney Lyster 11/27/91
A	Cog. Eng. Mgr.	11/27/91
R	Startup	Michael [illegible] 12/2/91
R	QA	12/2/91
☐	DOE	
R	Safety	12/4/91
☐	Dept. Manager	
N/A R	Operations	
☐	Security	
☐	SNL	
☐		
☐		
☐		

16. Distribute as Marked

☑	Maintenance (MANDATORY)
☑	Ops. Support (MANDATORY)
☐	Startup
☑	Facility Operations
☑	U/G Operations
☑	Orig./Design Engr.
☑	Cog. Engineer
☐	Others
☐	
☐	
☐	
☐	
☐	

DOE ORDER 6430.1A DESIGN CRITERIA CHECKLIST

ENGINEERING CHANGE ORDER (ECO) NO. 5893 DATE 11/26/91 COG. ENGINEER S. Fuston

The design requirements in DOE Order 6430.1A checked below have been applied to this ECO.

	DIVISION	SUBDIVISION
|_| 1	General Requirements	|_| 0101 |_| 0106 |_| 0109 |_| 0110 |_| 0111 |_| 0140 |_| 0150 |_| 0170
|_| 2	Site and Civil Engineering	|_| 0200 |_| 0201 |_| 0202 |_| 0203 |_| 0205 |_| 0210 |_| 0214 |_| 0215 |_| 0220 |_| 0235 |_| 0245 |_| 0250 |_| 0256 |_| 0260 |_| 0262 |_| 0264 |_| 0267 |_| 0270 |_| 0270 |_| 0275 |_| 0276 |_| 0278 |_| 0279 |_| 0280 |_| 0281 |_| 0283 |_| 0285 |_| 0290 |_| 0291
|_| 3	Concrete	|_| 0300 |_| 0301 |_| 0310 |_| 0320 |_| 0330 |_| 0340 |_| 0350 |_| 0370 |_| 0380
|_| 4	Masonry	|_| 0400 |_| 0401 |_| 0410 |_| 0420 |_| 0435
|_| 5	Metals	|_| 0500 |_| 0512 |_| 0514 |_| 0521 |_| 0531 |_| 0532
|_| 6	Wood and Plastics	|_| 0600 |_| 0610 |_| 0650
|_| 7	Thermal and Moisture Protection	|_| 0710 |_| 0711 |_| 0714 |_| 0715 |_| 0719 |_| 0720 |_| 0721 |_| 0722 |_| 0724 |_| 0727 |_| 0730 |_| 0750 |_| 0751 |_| 0753 |_| 0760 |_| 0790
|_| 8	Doors and Windows	|_| 0800 |_| 0810 |_| 0820 |_| 0830 |_| 0833 |_| 0836 |_| 0837 |_| 0850 |_| 0860 |_| 0870 |_| 0880
|_| 9	Finishes	|_| 0900 |_| 0910 |_| 0920 |_| 0925 |_| 0930 |_| 0950 |_| 0965 |_| 0968 |_| 0970 |_| 0980 |_| 0990 |_| 0995
|_| 10	Specialties	|_| 1015 |_| 1020 |_| 1024 |_| 1027 |_| 1030 |_| 1040 |_| 1050 |_| 1052 |_| 1050 |_| 1055 |_| 1060 |_| 1065 |_| 1070 |_| 1075 |_| 1090
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|_| 16	Electrical	|_| 1600 |_| 1605 |_| 1620 |X| 1630 |X| 1639 |X| 1640 |_| 1650 |_| 1660 |X| 1670 |X| 1671 |_| 1685 |_| 1694

Note: A checked placed in the Division column signifies that the entire Division shall be applicable to the ECO, unless modified by checks indicated for specific Subdivisions.

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3. Description of Change:

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4. Drawing Cog. Engineer Approval: J. Rodney Luston Date: 11/27/91

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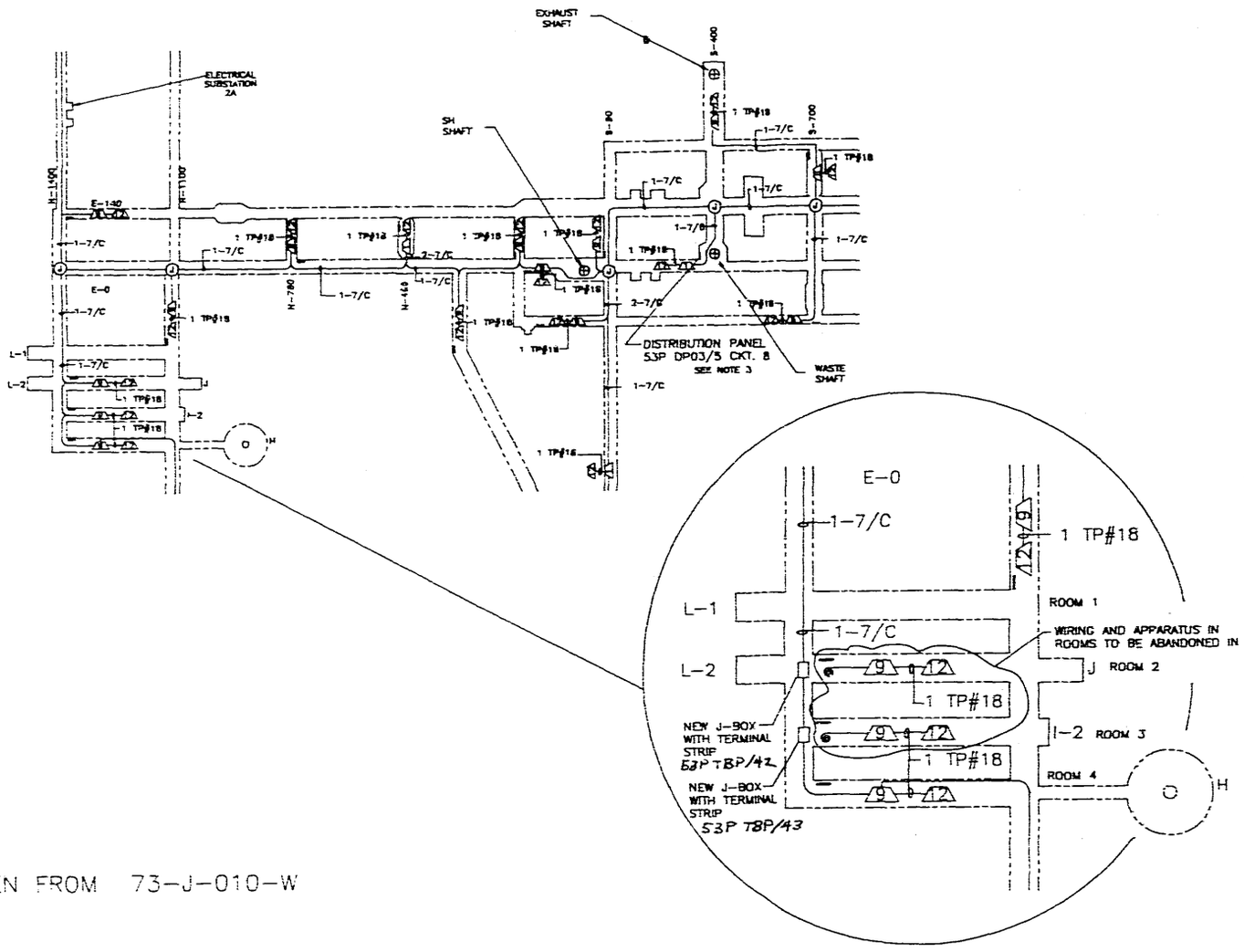

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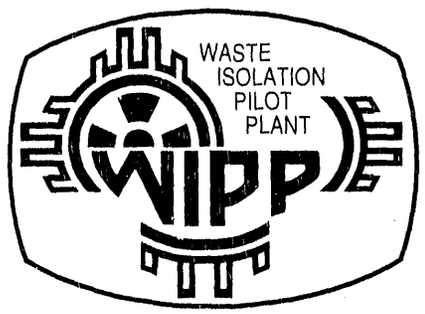

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Carlsbad, New Mexico

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APPENDIX D4

WASTE ISOLATION PILOT PLANT SITE ENVIRONMENTAL REPORT FOR CALENDAR YEAR 1990

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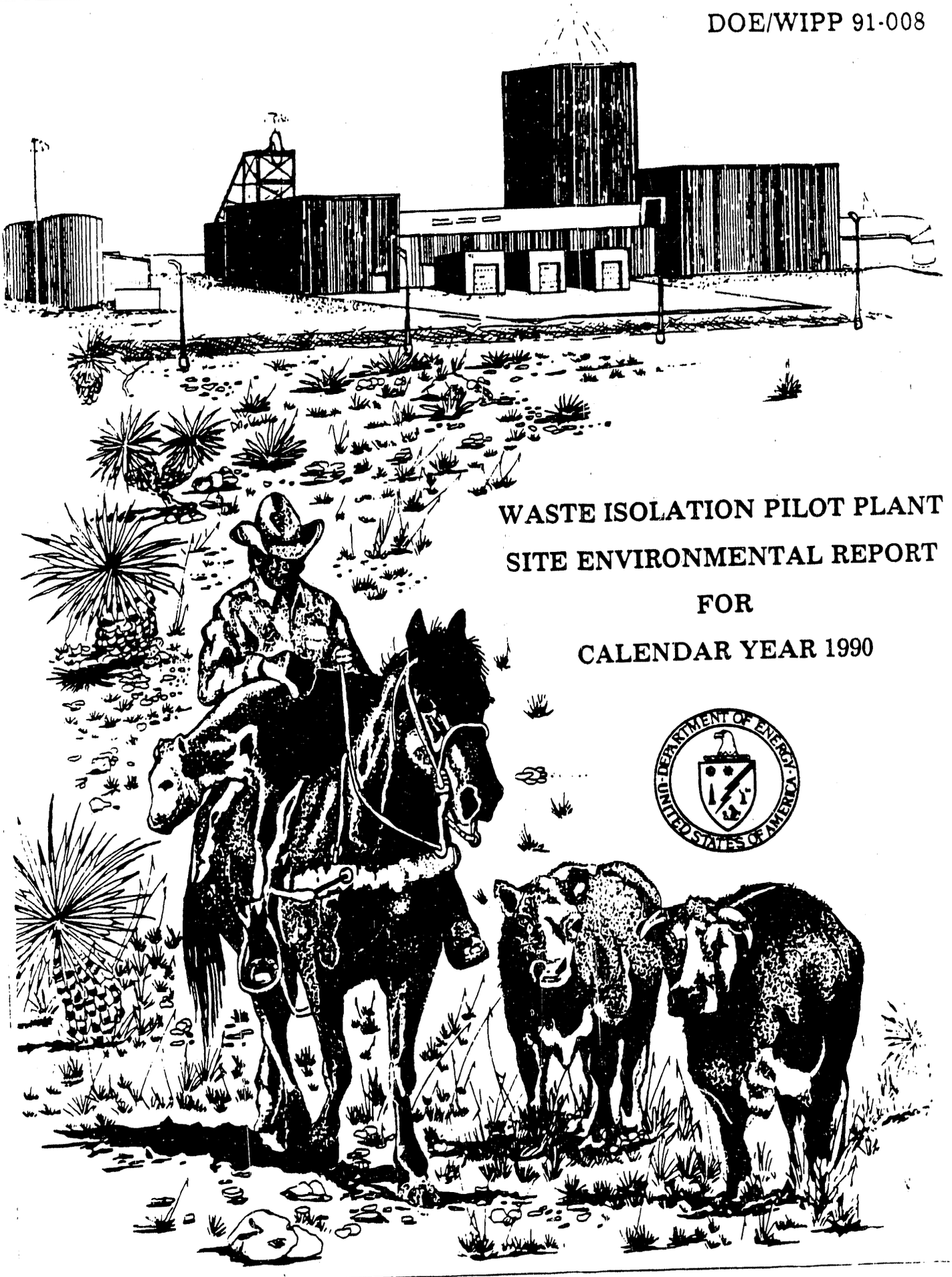
U.S. Department of Energy (DOE), 1991, DOE/WIPP 91-008
Carlsbad, New Mexico

DOE/WIPP 91-008



WASTE ISOLATION PILOT PLANT
SITE ENVIRONMENTAL REPORT
FOR
CALENDAR YEAR 1990

This document is issued by Westinghouse Electric Corporation, Waste Isolation Division, as the Managing and Operating Contractor for the Department of Energy, Waste Isolation Pilot Plant, Carlsbad, New Mexico, 88221 .

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WASTE ISOLATION PILOT PLANT

SITE ENVIRONMENTAL REPORT

FOR CALENDAR YEAR 1990

Any comments or questions regarding this report should
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This report was prepared for the U.S. Department of Energy
by the Environmental Monitoring and the Environmental Analysis and
Compliance Sections of the Environment, Safety and Health Department
the Management and Operating Contractor
Westinghouse Electric Corporation, under Contract No. DE-AC04-86AL31950

PREFACE

This is the seventh Annual Site Environmental Report for the U.S. Department of Energy, Waste Isolation Pilot Plant (WIPP). The most significant addition to the 1990 report is the inclusion of the Annual Water Quality Data Report which addresses groundwater surveillance at the WIPP. The Water Quality Report was previously issued as a separate document. The combination of these two reports allow readers to have all environmental monitoring information consolidated together for an easy reference.

As you read this document you will notice the groundwater data in Chapter 7 is either presented in metric or English units. The equivalent units have not been shown. To assist the reader in reviewing Chapter 7, a conversion table from metric units to English units can be found as the last page in this report.

Additionally, it is anticipated that this will be the last Annual Site Environmental Report for the WIPP issued with the facility in a preoperational state. When the WIPP is operational, certain sections of this report will change to address the operational status. The significant changes will be in Chapter 5, Environmental Radiological Program Information.

The Secretary of Energy has made strong commitments for sound environmental management. The Management and Operating Contractor for the WIPP, Westinghouse Electric Corporation, completely supports the Secretary's commitments with a Total Quality attitude in the true spirit of environmental awareness.

To recognize the Department of Energy's concern for environmental awareness, this document has been printed on recycled paper. It is our intention that this be the beginning of a significant step for the WIPP in to use recycled products whenever possible, and when this is not possible, to use the least environmental degradable product available.

COVER ILLUSTRATION

This illustration depicts the coexistence of historic land used in southeastern New Mexico with modern day technology for the approaching 21st century. The U. S. Department of Energy is committed to preserving multiple land use for this area with sound environmental practices. (The illustration is by Bill Briggs, who is an electrical engineer at the WIPP.)

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ACRONYMS AND ABBREVIATIONS

AMS	Atmospheric Monitoring Station
AMSL	Above Mean Sea Level
ANOVA	Analysis of Variance
ASER	Annual Site Environmental Report
BLM	U. S. Bureau of Land Management
Bq	Becquerel
CAA	Clean Air Act
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act (also known as Superfund)
CFM	Cubic Feet per Minute
CH-TRU	Contact Handled Transuranic Waste
CT-1	Control 1
CT-2	Control 2
CWA	Clean Water Act
CY	Calendar Year
DOE	U.S. Department of Energy
DOE-EML	U.S. Department of Energy Environmental Measurements Laboratory
DOT	U. S. Department of Transportation
EC	Electrical Conductivity
EEG	Environmental Evaluation Group
EID	New Mexico Environmental Improvement Division
EMP	Ecological Monitoring Program
EPA	U. S. Environmental Protection Agency
FEIS	Final Environmental Impact Statement
FDA	Fluorescardiacetate Hydrolysis Assay
FSAR	Final Safety Analysis Report
FT	Feet
FWPCA	Federal Water Pollution Control Act

ACRONYMS AND ABBREVIATIONS

GOCO	Government-Owened, Contractor Operated
HEPA	High Efficiency Particulate Air (filter)
HPIC	High Pressure Ionization Chamber
ITAS	International Technologies Analytical Services Laboratory
MOU	Memorandum of Understanding
MPS	Meters Per Second
NA	Not Applicable
NCRP	National Council on Radiation Protection and Measurement
NEPA	National Environmental Policy Act
NES	Nonradiological Environmental Surveillance
NESHAPs	National Emmissions Standards for Hazardous Air Pollutants
NMGF	New Mexico Department of Game of Fish
NMSA	New Mexico Statutes Act
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution discharge Elimination System
NRC	Nuclear Regulatory Commission
NT	Not Tested
NW 2	Northwest 2
OEMP	Operational Environmental Monitoring Program
OP	Optical Density
PCB	Polychlorinated Biphenyls
PSD	Prevention of Significant Deterioration
QA	Quality Assurance
QC	Quality Control
RBP	Radiological Baseline Program
RCRA	Resource Conservation and Recovery Act
RES	Radiological Environmental Surveillance
RH-TRU	Remote Handled Transuranic Waste

ACRONYMS AND ABBREVIATIONS

SARA	Superfund Amendments and Reauthorization Act
SE-2	Southeast 2
SEIS	Supplement Environmental Impact Statement
SNL	Sandia National Laboratories
SNK	Student-Newman-Keuls
TDS	Total Dissolved Solids
TLD	Thermoluminescent Dosimeters
TOC	Top of Casing
TRU	Transuranic Waste
TSP	Total Suspended Particles
UST	Underground Storage Tank
VOCs	Volatile Organic Compounds
WAESD	Westinghouse Advanced Energy Systems Division
WIPP	Waste Isolation Pilot Plant
WPO	WIPP Project Office
WQA	Water Quality Act
WQSP	Water Quality Sampling Program

CHAPTER 1

EXECUTIVE SUMMARY

The U. S. Department of Energy (DOE) Waste Isolation Pilot Plant (WIPP) Operational Environmental Monitoring Plan (OEMP) monitors a comprehensive set of parameters in order to detect any potential environmental impacts and establish baselines for future quantitative environmental impact evaluations. Surface water and groundwater, soil, and biotics are measured for background radiation. Nonradiological environmental monitoring activities include meteorological, air quality, soil properties, and the status of the local biological community. Ecological studies focus on the immediate area surrounding the site with emphasis on the salt storage pile, whereas baseline radiological surveillance covers a broader geographic area including nearby ranches, villages, and cities.

Since the WIPP is still in a preoperational state, no waste has been received; therefore, certain elements required by Order DOE 5400.1 are not presented in this report. For example, no discussion of radionuclide emissions with subsequent doses to the public is included. With the WIPP in a preoperational state, discussions of radioactivity for specific radionuclides released as effluents are not included.

Additionally it is important to state to the reader of this document that a summarization of the radiological and nonradiological data baselines for the preoperational phase of the WIPP are being compiled and will be presented in a summarized form once completed. It is anticipated these data summarizes will be completed in 1991.

1.1 COMPLIANCE SUMMARY

In 1990, the WIPP complied with applicable federal and state environmental regulations. The WIPP project maintains active permits from the Bureau of Land Management (BLM) and an Environmental Improvement Division (EID) permit for open burning.

Additionally, the DOE has notified the EID of hazardous waste activities associated with the management of site-generated hazardous waste. The WIPP has a hazardous waste management program in place which is in compliance with Resource Conservation and Recovery Act (RCRA) requirements. The WIPP submitted RCRA Part A in January and Part B in February, 1991. Also during the year, WIPP submitted the required Emergency and Hazardous Chemical Inventory Report. This report was submitted to satisfy the requirements of Section 312 of Title III for the Superfund Amendments and Reauthorization Act (SARA).

On November 14, 1990, the U. S. Environmental Protection Agency (EPA), through publication in the Federal Register granted a Conditional No-Migration Determination for the DOE WIPP (EPA, 1990). This determination granted DOE's request for a variance from land disposal restrictions under the RCRA during a ten year period covering the five year WIPP Test Phase. This variance had been requested by the DOE through submittal of the No-Migration Variance Petition and its subsequent revision in March 1990 (DOE, 1990a).

To satisfy National Environmental Policy Act (NEPA) requirements, the DOE developed a Final Supplement Environmental Impact Statement (SEIS) which was issued in January 1990 (DOE, 1990b). This document covered both new information obtained since the original Final Environmental Impact Statement (FEIS) was issued in October 1980, and newly proposed activities, such as the Test Phase activities. On June 22, 1990, the Record of Decision for the SEIS was published in the Federal Register (DOE, 1990c).

A technical data package was prepared in 1990 to demonstrate compliance with 40 CFR 61, Subpart H, National Emissions Standard for Hazardous Air Pollutants (NESHAPs). The data package estimated doses to the public to be well below the 0.1 mrem limit at which a formal application must be submitted. The data package further documented the design of the airborne effluent monitoring system used at WIPP.

The WIPP Waste Minimization and Pollution Prevention Awareness Plan has been drafted and is currently being revised to incorporate comments. The final plan will be submitted to DOE WIPP Project Office (WPO) in June of 1991.

In September 1990, during a pressure test of petroleum product storage tanks, a leak was indicated in the associated piping above the unleaded fuel tank. The EID and the EPA Region IV offices were promptly notified of a potential leak and the unleaded fuel tank drained. A remedial investigation was performed.

1.2 ENVIRONMENTAL PROGRAM INFORMATION

The effort to establish environmental baseline conditions at the WIPP site before arrival of waste has been ongoing since 1975. These studies are continuing to characterize the local environment both radiologically and nonradiologically until the WIPP is operational. Once the WIPP is operational, these programs will transition into the operational phase and pertinent data collection will continue through the life of the project.

1.2.1 Operational Environmental Monitoring Program

The WIPP OEMP lists schedules and guidelines for monitoring a comprehensive set of parameters in order to detect and quantify any present or potential environmental impacts. Nonradiological portions of the program focus on the immediate area surrounding the site, whereas radiological surveillance generally covers a broader geographic area including nearby ranches, villages and cities. Environmental monitoring will continue at the site during project operations and through decommissioning activities. The sampling activities will continue to be performed at the established monitoring locations which are unchanged from earlier Annual Site Environmental Reports (ASERs).

1.2.2 Significant Environmental Activities

This section addresses significant environmental activities which occurred during 1990.

- **Raptor Research Program**

In calendar year (CY) 1990, 80 raptor nests and 31 Chihuahuan raven nests were monitored. Reproductive success was poor, especially for Chihuahuan ravens. The trend remains consistent with proceeding years of low nest success rates. The poor success continues to correlate with low numbers of prey species which are beginning to recover from three previous years of below normal precipitation in the area.

- **Reclamation of Disturbed Lands**

No reclamation activities, other than monitoring, are reportable for CY 1990. Reclamation techniques and experimental parameters from the 1988 and 1989 reclamation activities are currently being addressed in a thesis entitled "Examination of Native Plants and Tillage for Reclamation of Caliche, Dune Soil, and Salt-Impacted Soil in the Los Medanos of New Mexico." The study is being conducted by a graduate student of New Mexico State University and funded by the DOE.

Monitoring of reclamation plots consisted of photographing all caliche roads, drill pads, borrow pits, batch plants, and the Brinderson landfill. Total land area photographed was approximately 19.6ha. (49 acres). Photographs were taken during September and October.

1.3 ENVIRONMENTAL RADIOLOGICAL PROGRAM INFORMATION

The following subsections present monitoring topics for the subprograms of the OEMP. These programs are consistent with Draft Order DOE 5400.6, Requirements for Radiological Effluent Monitoring and Environmental Surveillance for U.S. DOE Operations.

With the WIPP status being preoperational it is not required by Order DOE 5400.1, that annual radiological analysis of samples be performed once the required radiological baseline has been established. However, to further substantiate the data baseline, certain radiological sampling programs have continued with the samples being archived for future analysis, if conditions warrant further data.

As specifically outlined in the OEMP, five subprograms are being conducted to document the background levels of possible radionuclide pathways leading from the WIPP to man.

1.3.1 Airborne Particulate and Effluent Monitoring

Sampling airborne aerosol particulates was initiated in 1985 and is an important subprogram of the OEMP. The Final Safety Analysis Report (FSAR) (DOE, 1990) identifies the atmosphere pathway as the only credible release pathway resulting in a potential dose to the public. Continuous particulate aerosol samplers operate at eight locations, three within the Zone II boundary, four at local ranches and communities, and one as a sample control site.

The continuous aerosol samplers presently being utilized maintain a regulated flow rate of approximately 950 milliliters per second (two cubic feet per minute) of air through a 47-millimeter 1.9 inch) fiber filter for particulate collection. Particulate filters were collected weekly at all locations in 1990. The collected filters were counted at the Environmental Counting Laboratory at the WIPP, where gross alpha and gross beta counts of each filter were calculated yielding weekly counts and a quarterly average for each location. Table 5-1 of Chapter 5 of this document lists the quarterly alpha and beta concentrations for each sampling location.

1.3.2 Soil Sampling

Soil samples were collected in December 1990 at seven locations. A template insert allows the collection of samples at three depths at each location: (1) surface samples, 0-2 cm (0-0.8 in), (2) intermediate sample 2-5 cm (0.8-2.0 in) and (3) deep sample, 5-10 centimeters (2.0-3.9 in). Every sample was a composite of 10 randomly located subsamples, each collected within a 10 by 10 centimeter (3.9 by 3.9 inches) stainless steel template. Soil samples collected during 1990 were archived as the required number of samples had already been collected to establish the soil radiological baseline.

1.3.3 Groundwater

Groundwater surveillance continued routinely throughout CY 1990 with 18 wells sampled. All samples collected were archived for future analysis. Should curcumstances warrent analysis, the radiological groundwater collected in 1990 can then be analyzed.

1.3.4 Surface Water and Sediment Sampling

Surface water and sediment samples were not collected in CY 1990. As with soil sampling, once background measurements have been established, annual collections of surface water and sediments is not required. However, periodic samples of surface water and sediments will be collected prior to the operational phase of the WIPP to further substantiate the background radiological data for the surface.

1.3.5 Beef, Game Animals, and Aquatic Fish Samples

In CY 1990, game animals (quail, rabbits) and fish were collected as directed in the OEMP. beef samples were not collected in 1990. The biotics collected were processed and archived for future radiological analysis.

1.4 NONRADIOLOGICAL MONITORING INFORMATION

Nonradiological Environmental Surveillance (NES) was conducted by the Regulatory and Environmental Program department. As of February, 1991 this department was reorganized and future environmental monitoring will be under the direction of the Environment, Safety, and Health department.

This program was preceded by the WIPP Biology Program (1975-1982), which combined scientific and technical expertise from six universities. These universities developed an extensive baseline of information describing the major components of the Los Medanos ecosystem prior to the initiation of WIPP construction activities.

1.4.1 Meteorology

The WIPP NES includes a meteorological station that provides support for various programs at the WIPP. The primary function of this station is to generate data to aid in modeling atmospheric conditions for Radiological Environmental Surveillance (RES). The meteorological station records standard meteorological measurements of wind speed, wind direction, and temperature at 3, 10, and 40 meters (10, 32, and 130 ft), respectively, with dew point and precipitation monitored at ground level. These parameters are continuously measured and the data are stored as real time data.

The annual precipitation at the WIPP for 1990 was 41 cm (15.97 in), which is above the average for this area by 10 cm (3.97 in). The precipitation for 1990 was 62 percent greater than that recorded for 1989. This precipitation increase has helped to alleviate the drought effects on the ecosystem of the area.

In CY 1990 the winds in the WIPP area were consistent with previous wind direction data with winds from the southeast being predominate.

1.4.2 Environmental Photography

Aerial photographs of the WIPP site have been taken semiannually from 1982 until 1989, during the winter and summer seasons. In 1990, the decision was made to take aerial photographs annually during the peak growing season, late August through September. Any vegetative changes due to WIPP activities will be best identified during this time of year. These photographs document surface disturbance, development, and reclamation activities at the WIPP and surrounding BLM Lands.

Surface photography has been conducted semiannually at seven ecological study plots since 1984. These photographs are used to document surface impacts at the study plots examined, and found to show very little surface impact.

1.4.3 Air Quality Monitoring

Seven classes of pollutant gases are monitored at the WIPP site on a continuous basis: sulfur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), hydrogen sulfide (H_2S), and oxides of nitrogen (NO_x). In addition, weekly measurements of Total Suspended Particulates (TSP) are made from the particulates collected by the low-volume continuous air sampler at the far-field air sampling location.

The ambient gas monitors are extremely sensitive instruments that require semiannual recertification by a factory engineer. Other than typical replacement of worn parts, the ambient gas analyzers required no significant maintenance actions.

The data generated by the analyzers was at the lower limit of detection which was below the New Mexico State standard.

1.4.4 Surface Water and Sediment Quality Monitoring

During CY 1990, no surface water or sediment quality monitoring was conducted since a baseline has been established. Preoperational monitoring to establish a baseline began in 1985 and continued through 1988 with samples collected annually. It is currently proposed that surface water and sediment quality monitoring will be conducted biennially until the WIPP is operational.

1.4.5 Groundwater

Groundwater surveillance continued routinely throughout CY 1990 with 18 wells sampled for water quality. Twelve wells were sampled for the fifth time, three wells were sampled for the fourth time, two wells were sampled for the third time and one well was sampled for the secondtime. Groundwater Level Surveillance took place utilizing 57 separate well bores, six of which were equipped with production inflated packers to allow surveillance of more than one production zone through the same well bore. Groundwater level measurements of the Culebra dolomite were taken at 46 locations and measurements of the Magenta dolomite were taken at 11 locations. The remaining measurements were taken in a formation of lesser interest.

1.4.6 Wildlife Population Monitoring

Population density measurements of birds and small nocturnal mammals are preformed annually to assess the effects of WIPP activities on wildlife populations.

- **Bird Densities**

In 1990 species numbers varied from previous years' data. This disparity can be attributed to below normal precipitation from the winter of 1989 into early spring of 1990.

Overall, species distribution patterns between WIPP transits and Control transits remain relatively constant with the most significant species diversity occurring near the facility. More abundant food, most notably insects and greater habitat diversity, probably account for the increase in numbers of the WIPP transits compared to those of the controls. Insect dependant species such as Flycatchers and King birds were the prominent species on the increase near the facility.

- **Small Nocturnal Mammal Population Densities**

In 1990, Ord's kangaroo rats remained the most common species encountered. Several Ords Kangaroo rats were recaptured 70 to 90 meters from their original capture location, while the average recapture ventured 30 to 50 meters from their original capture location. Grasshopper mice were the next most common species encountered. Other species encountered in this area were plains wood rats, white-footed mice, deer mice, and silky pocket mice. Only one hispid cotton rat was encountered

1.4.7 Surface and Subsurface Soil

During CY 1990, the quarterly sampling of the surface soil as well as the annual deep series was conducted during the second quarter. The subsurface soil is collected at two depths, 30 to 45 centimeters (11.8 to 17.7 inches) and 75 centimeters (23.6 to 29.5 inches), in the soil profile. However, with the WIPP being in a preoperational state during 1990, and with an adequate baseline established concerning soil properties at the WIPP. No analysis was performed on the soil samples collected. The soil samples collected will be archived pending future analysis data if conditions indicate additional soil analysis is warranted.

With the established baseline data, continuing the quarterly soil analysis was not required by the OEMP. However with the anticipation of the WIPP becoming operational in 1991 the quarterly analysis of soil samples will once again commence as directed by the OEMP.

1.4.8 Vegetation Monitoring

The CY 1989 vegetation monitoring data showed a decline in several parameters with increasing proximity to the salt piles, indicating a detrimental effect of these storage piles on the surrounding ecosystem. However, the 1990 data do not show such an effect. The total coverages in all plots were relatively uniform over all distances from the piles. The densities of annuals and species richness were also relatively uniform across all plots. A pattern observed in the 1989 data that was also seen in the 1990 data is an increase in shrub cover with increasing proximity to the piles and an approximately equal decrease in perennial grass cover. The responses of these plots to higher rainfall in later years will reveal whether this pattern is reflecting the start of a significant change in the structure of the plant community or whether it is only a short-term effect caused by short-term weather conditions.

Of greatest significance in the 1990 vegetation monitoring data, was the observation that the drought conditions of this year have had a uniform effect on vegetation in all plots. A differential effect resulting from salt-induced physiological stress near the salt piles was not observed.

1.5 QUALITY ASSURANCE

This document adheres to policies set forth by federal QA regulations including: ASME NQA-1, Quality Assurance Program Requirements for Nuclear Facilities, (ASME, 1989) and EPA, QAMS-005/80, Interim Guidelines and Specifications for Preparing Quality Assurnce Project Plans, (EPA, 1980), fulfills the requirements of the QA plan specified in DOE Orders 5400.1 (DOE, 1988d), 5400.3 (DOE, 1988e), 5700.6B (DOE, 1986c) and draft DOE 5400.6 (DOE, 1988f).

CHAPTER 2

INTRODUCTION

This is the WIPP Site Environmental Report for CY 1990. The WIPP site is located in southeastern New Mexico. The WIPP is a government owned and contractor operated facility. The WIPP project is operated by Westinghouse Electric Corporation for the DOE. The purpose of the WIPP is to provide a research and development facility to demonstrate the safe disposal of transuranic (TRU) wastes generated by the defense activities of the U.S. Government. This document is prepared in accordance with the guidance contained in Order DOE 5400.1, General Environmental Protection Program Requirements (DOE, 1988a); Order DOE 5400.5, Radiation Protection of the Public and the Environment; and DOE/WIPP 90-050, Environmental Protection Implementation Plan for the Waste Isolation Pilot Plant, which requires DOE facilities to submit an ASER to the Office of Operational Safety. This report provides a comprehensive description of environmental activities at the WIPP during calendar year 1990.

The WIPP facility will not receive waste until all concerns affecting opening the WIPP are addressed to the satisfaction of the Secretary of Energy. Therefore, this report describes the status of the preoperational activities of the RES program, which are outlined in the Radiological Baseline Program (RBP) for the WIPP (WTSD-TME-057). Since the WIPP is in a preoperational state, meaning no defense facility waste contaminated with radionuclides has been shipped to the WIPP, certain elements of Order DOE 5400.1 are not presented in this report.

In March 1989, the monitoring activities of the RBP and the Ecological Monitoring Program (EMP) were combined into the OEMP. This program is described in the Operational Environmental Monitoring Plan for the Waste Isolation Pilot Plant (DOE/WIPP 88-025). This plan defines the scope and extent of the WIPP effluent and environmental monitoring programs during the operational life of the facility. It also discusses the quality assurance and quality control programs which ensure that samples collected and the resulting analytical data are representative of actual conditions at the WIPP site. The OEMP is the guidance document under which all of the environmental monitoring programs follow. Its purpose is to ensure that all appropriate sampling efforts are inplace to establish the amount and type of naturally occurring radiation in the WIPP area before the WIPP is operational. Then to provide a database for comparisons between preoperational and operational environmental conditions once the WIPP is operating as a waste repository for low level radioactive waste.

The OEMP was prepared in accordance with the guidance contained in Order DOE 5400.1 and draft Order 5400.5, Radiation Protection of the Public and the Environment (DOE, 1988b), which was subsequently issued as Order DOE 5400.5 in February, 1990. This plan also responds to the requirements and guidelines presented in draft Order DOE 5400.6, Radiological Effluent Monitoring and Environmental Surveillance for U.S. DOE Operations (DOE, 1988c). Since waste has not been received and WIPP is still in a preoperational state, certain elements of Order DOE 5400.1 are not presented in this report. For example, no discussion of radionuclide emissions with subsequent of doses to the public is included.

2.1 DESCRIPTION OF THE WIPP PROJECT

Once designated as an operational facility by the DOE, TRU wastes will be transported from 10 generator sites around the United States to the WIPP. Initially, the waste will be transported from the Idaho National Engineering Laboratory and the Rocky Flats facility, in Colorado for the test phase. These waste materials are contaminated with alpha emitting radionuclides having atomic numbers greater than 92 and half lives longer than 20 years. Also to be classified as a transuranic (TRU) waste, the specific activity of these radionuclides in TRU waste must be higher than 100 nCi/g. General criteria defining the various categories of radioactive waste, including TRU waste, appear in Order DOE 5820.2A (DOE, 1988d). Isotopes of plutonium, americium, and curium will be the predominant radionuclides contaminating TRU waste shipped to the WIPP.

The TRU waste to be received from the 10 generator sites will be transported to the WIPP via tractor-trailor trucks. Each truck can haul up to three tranuranic package transporter (TRUPACT IIs) containing 14, 55 gallon drums or two standard waste boxes. The TRUPACT II is a durable, reuseable container which has been approved by the Nuclear Regulatory Commission (NRC) to transport the contact-handled transuranic waste to the WIPP. (The NRC is the nationally recognized governing agency that regulates safe handling and proper safety concerns pertaining to radiation exposure to the public and the environment).

Once these TRUPACT IIs have arrived at the WIPP and they are brought into the Waste Handling Building, waste containers will be removed from the TRUPACT II, placed on the waste handling hoist, and lowered to the repository level of 655 m (2150 feet). Waste containers will then be removed from the hoist and emplaced in excavated storage rooms in the Salado formation, a thick sequence of salt beds deposited approximately 250 million years ago (Permian Age). After filling a storage area, specially designed seals and plugs will be placed in the excavated storage rooms and in the shafts. The plastic self-healing nature of the salt formation will result in gradual creep closure, causing encapsulation and isolation of the waste within the Salado formation. It is presently designated that the first five years of WIPP operations will be a test phase period, during which time tests will be performed to support the WIPP design and long-term isolation performance.

During site operations, the underground area will be ventilated by ambient air which enters the Air Intake Shaft, and the Salt Handling Shaft, the Waste Handling Shaft, and exits through the exhaust shaft. In the event of an underground accident involving radioactivity, exhaust air will be circulated at a reduced flow rate through the Exhaust Filter Building, which contains banks of high efficiency particulate air (HEPA) filters that remove potentially contaminated particulates. Exhaust ventilation from the Waste Handling Building is continuously HEPA filtered to the atmosphere, and air emissions are not expected to represent a significant effluent release point.

2.2 DESCRIPTION OF THE ENVIRONMENT

The WIPP site is located in Eddy county in southeastern New Mexico (Figure 2-1). The site is approximately 40 kilometers (26 miles) east-southeast of Carlsbad in an area known as Los Medanos (the dunes), which is a sparsely inhabited plateau with little water and limited land uses. The land is owned by the United States Department of Interior, BLM and is leased to permittees for grazing livestock. Other land uses in the general area include mining for potash; exploring for and/or extracting oil and natural gas; recreational use such as hunting, trapping, birdwatching; and other uses as permitted by the BLM.

The WIPP site consists of 16 sections (6.48 ha) of Federal land in Township 22 South, Range 31 East. Except for the 2.75 square kilometers (1 square mile) encompassing the facility (known as the DOE Exclusive Use Area), surface land uses remain largely unchanged. Mining and drilling for purposes other than support of the WIPP project are restricted within this 16 section (6.48 ha) area.

The WIPP site is divided into zones as represented in Figure 2-1. Zone I, surrounded by a chain-link fence, includes all major surface facilities. The secured area boundary, bounded by a barbed wire fence, includes other facilities associated with construction. Zone II indicates the maximum extent of underground development. The WIPP site boundary extends at least 1.6 kilometers (1 mile) beyond any underground development and is defined on the surface by the 16 section (6.48 ha) land withdrawal area. This boundary provides a functional barrier of intact salt between the underground region defined by Zone II and the accessible environment.

The approximate distribution of the local population in 1985 within 80 kilometers (50 miles) of the WIPP site is illustrated in Figure 2-2. The nearest residents to the site include eight individuals living at the Mills Ranch, 5.8 kilometers (3.5 miles) south-southwest of the site, and 13 individuals living at the Smith Ranch, 11.7 kilometers (7 miles) west-northwest of the site. Both neighboring ranches have been, and

will continue to be, monitored as part of the environmental monitoring program. Also, the International Minerals and Chemical Corporation potash mine plant site is located 15 kilometers (9 miles) west-northwest of the site. Detailed demographic summaries and projections are in the WIPP FEIS (DOE, 1980), SEIS (DOE, 1990), and the FSAR (DOE, 1990).

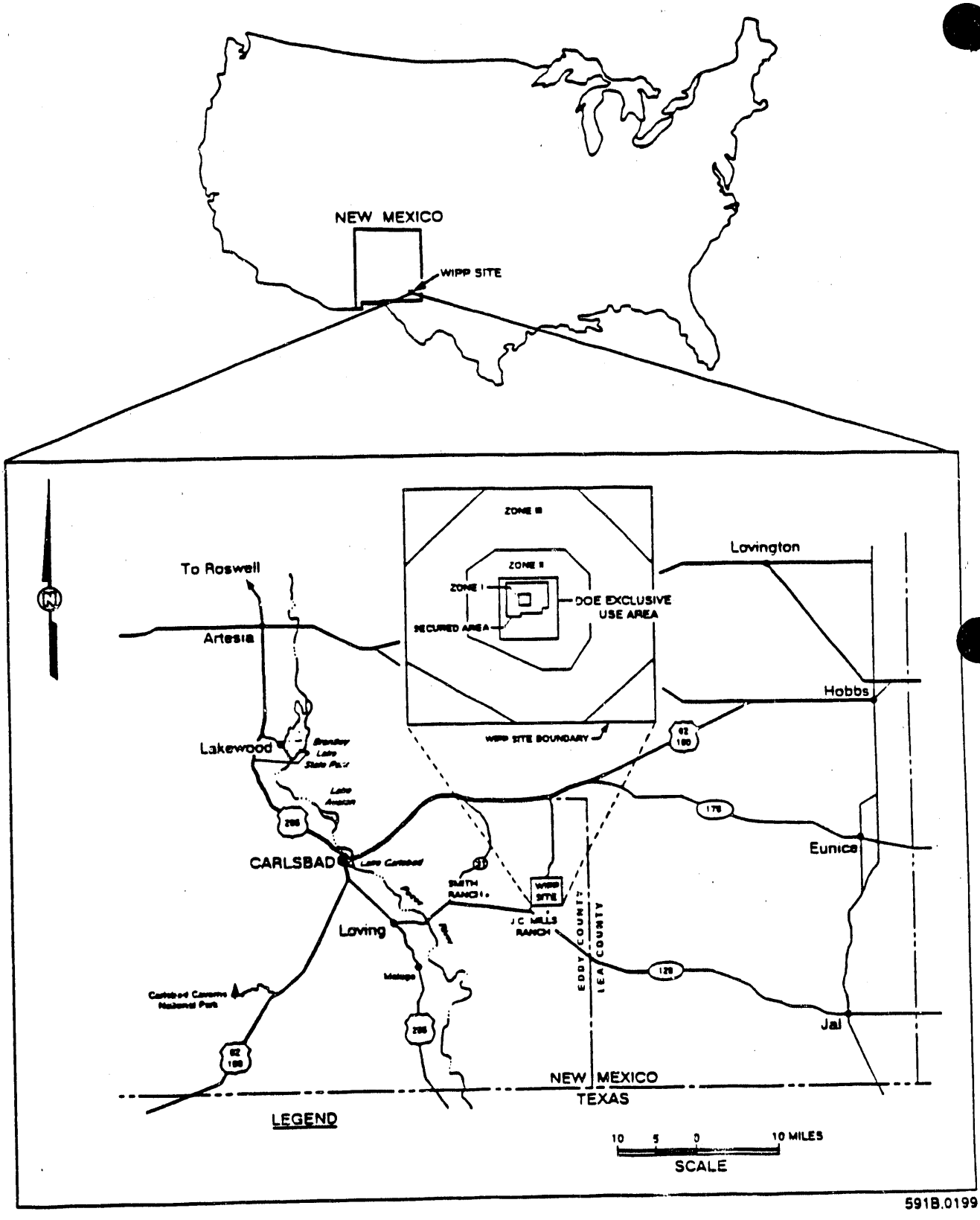

Figure 2-1
Location Of The WIPP Site

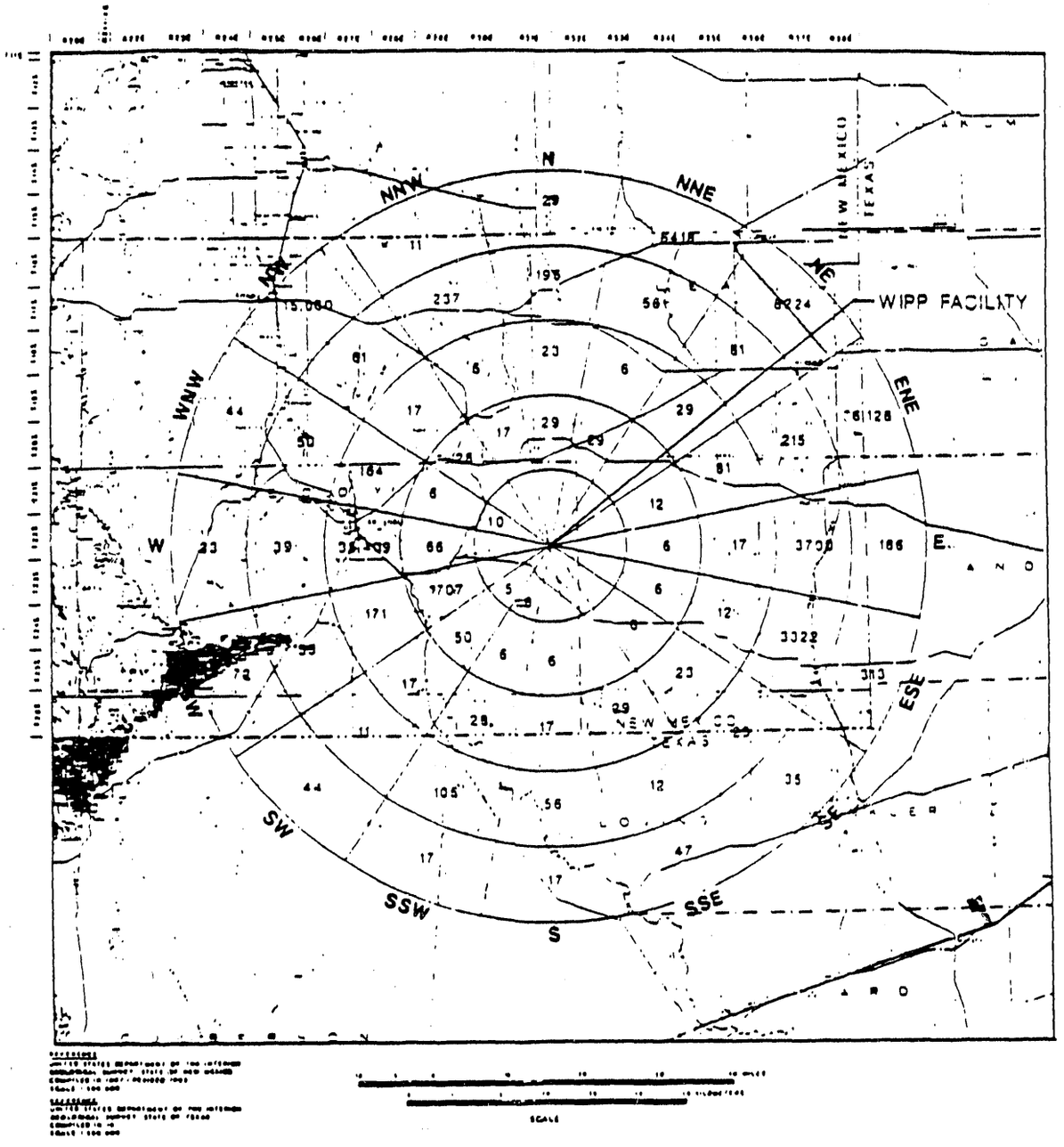

Figure 2-2
1985 Population Within 50 Miles
Of The WIPP Site

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CHAPTER 3

COMPLIANCE SUMMARY

The WIPP is required to comply with all applicable federal and state laws and regulations such as those specified in Order DOE 5400.1, General Environmental Protection Program (DOE, 1988a). Documentation of required federal and state permits, notifications, and approvals is maintained by the Environment, Safety and Health Department of the Management and Operating contractor. Regulatory requirements are implemented by incorporating them into facility plans and procedures.

Table 3-1 presents Compliance Status of Federal and New Mexico Statutes Applicable to the WIPP Project. Table 3-2 presents DOE Orders and Agreements Affecting the WIPP environmental program. Table 3-3 is a Summary Of Agreements Between the DOE and the State of New Mexico that affect the environmental program. Table 3-4 presents details concerning active environmental permits for the WIPP in 1990.

3.1 COMPLIANCE ASSESSMENT FOR CALENDAR YEAR 1990

In 1990, the WIPP complied with applicable federal and state environmental regulations. The WIPP project maintains 25 active permits from the BLM, the EID, the EPA, the New Mexico Department of Game and Fish, and the New Mexico Commissioner of Public Lands. It is also appropriate to note that the WIPP is in compliance with all applicable requirements of the Nuclear Waste Policy, Act of 1982 as implemented by the EPA through 40 CFR 191.

Additionally, the DOE has notified the EID of hazardous waste activities associated with the management of site-generated hazardous waste. The WIPP has a hazardous waste management program inplace which is in compliance with RCRA requirements. In accordance with RCRA requirements, storage areas are operated by written procedure and routine inspections of satellite accumulation areas are performed. WIPP will submit RCRA Parts A and B during the first two months of 1991. Also during the year, WIPP submitted the required Emergency and Hazardous Chemical Inventory Report. This report was submitted to satisfy the requirements of section 312 of Title III for the SARA.

On November 14, 1990, the Environmental Protection Agency, through publication in the Federal Register, granted a Conditional No-Migration Determination for the Department of Energy Waste Isolation Pilot Plant. This determination granted DOE's request for a variance from land disposal restrictions under the RCRA during a ten year period covering the five year WIPP Test Phase. This variance had been requested by the DOE through submittal of the No-Migration Variance Petition and its subsequent revision in March 1990 (DOE, 1990a). Conditions of the determination include:

- No waste other than that needed for testing
- A limitation on the volume of waste allowed during the Test Phase to one percent of the total WIPP capacity or approximately 8500 drum equivalents of waste
- All waste must be removed if long term acceptability of the site cannot be demonstrated
- All waste must be readily retrievable
- Annual written reports on performance assessment must be prepared
- A carbon adsorption unit for the control of volatile organic compounds (VOCs) must be in the discharge system of the bin scale test rooms and achieve a control efficiency for VOCs of at least 95 percent

- An Air Monitoring Plan must be implemented
- A characterization program for the test waste must be performed
- During 1990 the WIPP was in a preoperational phase, there was not a release at the WIPP which requires notification to Federal and State authorities. However, once, operational if a release of regulated materials occurs all appropriate agencies will be notified as protocol mandates.

To satisfy National Environmental Policy Act requirements, the DOE developed a Final Supplement Environmental Impact Statement (FEIS) which was issued in January 1990. (DOE, 1990b) This document covered both new information obtained since the original FEIS was issued in October 1980 and newly proposed activities, such as the Test Phase activities. Other changes included waste inventories, the transportation of waste to WIPP, and the management of transuranic waste containing hazardous chemical constituents (i.e., "mixed" waste). On June 22, 1990, the Record of Decision for the SEIS was published in the Federal Register. (DOE, 1990c)

A technical data package was prepared in 1990 to demonstrate compliance with 40 CFR 61, Subpart H, NESHAPs. The data package estimated doses to the public to be well below the 0.1 mrem limit at which a formal application must be submitted. The data package further documented the design of the airborne effluent monitoring system used at WIPP.

A tightness test was conducted on the WIPP Underground Storage Tank (UST) systems utilized for the storage of petroleum products on September 28, 1990. The unleaded gasoline storage tank system failed the test for tightness at the 25 inches above the tank's top, and passed the test at 6 inches above the tank's top. This verified the presence of a leak in the associated piping. The EID and EPA Region VI UST division offices were notified. A report outlining corrective actions was issued per regulatory requirements on October 5, 1990 (to both agencies). An extension to the required 45 day subsurface investigation was conducted on November 27, 1990. Samples collected during the investigation were submitted to a subcontracted laboratory for analyses. The analytical data generated were included in the subsurface investigation report submitted to both EID and EPA Region VI on December 19, 1990. EID responded that no further remediation actions were necessary. The planned upgrade of both UST systems is to begin in August of 1991.

The unleaded fuel storage tank system will remain empty and out of service until completion of the aforementioned upgrade. Alternative unleaded fuel storage at the WIPP is to be provided through the use of a 1000-gallon above-ground storage tank. This will occur once the diked containment system is constructed. Currently, unleaded fuel is acquired from off-site sources.

During CY 1990 the Waste Acceptance Certification Criteria Committee (WACCC) issued the draft entitled WACCC management program (WP 90-004) in December 1990. The WACCC is to ensure that all waste coming to the WIPP follows all guidance and requirements as required by the NEPA, the FSAR and the No-Migration Determination.

In June 1990 the WIPP Final Safety Analysis Report was approved by the DOE.

On July 25, 1990, the state of New Mexico received authority under the federal RCRA program to regulate mixed wastes. In a letter dated August 27, 1990, the state of New Mexico notified the WIPP that the Part A RCRA permit application was due by January 22, 1991, and the Part B permit application by February 28, 1991.

3.2 CURRENT ISSUES AND ACTIONS

The state of New Mexico was granted authorization to regulate mixed waste during 1990. Plans are being made to file RCRA Parts A & B permit applications during calendar year 1991.

The State of New Mexico and DOE have entered into an agreement which will allow the EID to monitor clean-up and on-going environmental activities at the WIPP.

This agreement comes from an initiative called for in April 1989 by a group of ten state governors with DOE nuclear facilities within or adjacent to their states.

Memorandum of Understanding (MOU) between DOE/WPO and BLM effective October 24, 1990 allows for an administrative land withdrawl between the DOE and the BLM for the 8746 acres which is outside the existing 1454 acres of the DOE exclusive use area. These remaining 8746 acres completes the 16 section land withdrawal.

In order to comply with the Clean Air Act (CAA), a NESHAPs a technical data package was prepared in 1990 and submitted to the DOE, EPA headquarters, and EPA Region VI offices in February 1991. Since non-reference methods are in use at WIPP to collect samples, an explanation of the design documentation, testing, and operation of the system has been prepared for the EPA.

Reclamation of abandoned caliche pits, roads, and well pads, which are required by Public Land Order 6403 and the associated MOU between the DOE and the BLM, is in progress. Land-Use Permit NM 067-LUP-237 for the construction landfill expired on February 9, 1990. Since the BLM no longer permits landfills, the landfill was closed and will be reclaimed in accordance with the permit conditions.

3.3 PERMITS

The status of required permits is tracked on a monthly basis, and permits are renewed as necessary to comply with the BLM, the EID, the NMGF, the New Mexico Commissioner of Public Lands, and the New Mexico Department of Finance and Administration Planning Division (Historic Preservation Bureau).

The WIPP held 13 active permits from the BLM in 1990. These permits are primarily land-use, free-use, and right-of-way permits. There were no noncompliance for BLM-administered permits in 1990.

The WIPP holds two New Mexico EID permits, one for open burning, and the other for the food or drink purveyor permit for the WIPP cafeteria. These permits are renewed annually.

3.4 COMPLIANCE SUMMARY UPDATE FOR JANUARY - MARCH 1991

This section addresses the first quarter of 1991 Compliance issues at the WIPP and their status.

3.4.1 COMPLIANCE STATUS FOR JANUARY-MARCH 1991

During the period January-March 1991, compliance was maintained for applicable EPA regulations (i.e., RCRA, SARA, the Clean Water Act (CWA), and the CAA.

Compliance with all BLM and state of New Mexico permits and regulations was also maintained during this period.

Significant environmental compliance actions in the period January-March 1991 are listed below:

- The RCRA Part A application was hand-delivered to the EID on January 22, 1991. A second copy was delivered to the EPA Region VI office in Dallas, Texas, on the same day. The RCRA Part B application was delivered to the same agencies at the end of February 1991.

- RCRA Implementation: In February 1989, the Governor of New Mexico signed legislation which authorized the EID to regulate mixed waste at the WIPP. In August, 1990, the Environmental Protection Agency delegated RCRA mixed waste authority to the State of New Mexico. Accordingly, both hazardous waste generated at the WIPP and mixed waste generated at other sites and transported to the WIPP are now subject to RCRA requirements.

- DOE is currently working with EID and the Environmental Protection Agency to develop a waste characterization plan which satisfies both the requirements of the No-Migration Variance and the RCRA waste management facility characterization requirements.

- The WID prepared and shipped hazardous wastes from the WIPP site on two occasions during the first quarter of 1991. A 30 day extension to the 90 day period allotted by regulation for shipping hazardous wastes off-site was applied for and received from the regulator. The WIPP has maintained compliance with the RCRA requirements as it applies to hazardous waste generator activities. All reporting requirements applicable to facilites regulated under RCRA were submitted as required.

- WID submitted Section 312 TIER II reports to DOE/WPO on February 15, 1991, and to other Federal, State and Local Agencies as required by the SARA Title III.

- During the first quarter of 1991, the WIPP was in a preoperational phase, there was not a release at the WIPP which requires notification to Federal and State authorities. However, once operational if a release of regulated materials occurs all appropriate agencies will be notifeid as protocol mandates.

3.4.2 CURRENT ISSUES AND ACTIONS

In order to comply with the CAA, a NESHAPs a technical data package was prepared in 1990 and submitted to the DOE, EPA headquarters, and EPA Region VI offices in February 1991. Since non-reference methods are in use at WIPP to collect samples, an explanation of the design documentation, testing, and operation of the system has been prepared for the EPA.

3.4.3 PERMITS

The applicable environmental requirements, permits, and the respective permit status for the first quarter of 1991 are listed in Table 3-5, Environmental Permit Matrix for January - March 1991. The status of required permits is tracked on a monthly basis, and they are renewed as necessary to comply with the BLM, the EID, the New Mexico Department of Game and Fish, the New Mexico Commissioner of Public Lands, and the New Mexico Department of Finance and Administration Planning Division (Historic Preservation Bureau).

The WIPP currently holds 10 active permits from the BLM for the first quarter of 1991. These permits are primarily land-use, free-use, and right-of-way permits. This number has been reduced down from 13 in 1990. There were no noncompliance for BLM-administered permits in 1990. The WIPP was granted an additional permit in January 1991, by the New Mexico Department of Game and Fish for banding protected raptor species.

Table 3-1

COMPLIANCE STATUS OF FEDERAL AND NEW MEXICO STATUTES APPLICABLE TO THE WIPP PROJECT

NAME OF STATUTE	CITATION	ANNOTATION
Clean Air Act	42 U.S.C. §§ 7401 et seq.	Establishes a national regulatory strategy to protect and enhance the nation's air resources. Regulates "criteria" pollutants such as particulates, SO_2, CO, NO_2, ozone, photochemical oxidants, and lead.
New Mexico Environmental Improvement Act	§§ 74-1-1 through 74-1-10 NMSA (1978)	Creates the Environmental Improvement Division with authority to regulate water supply, water pollution, liquid and solid waste, air quality, noise, low-level radioactive waste disposal, and sanitation.
New Mexico Air Quality Control Act	§§ 74-2-1 through 74-2-155 NMSA (1978)	Establishes a State regulatory strategy patterned after the Federal Clean Air Act. (Gives New Mexico primary jurisdiction for air quality regulations.)
Clean Water Act	33 U.S.C. §§ 1251 et seq.	Establishes a national regulatory strategy to restore and maintain the chemical, physical, and biological integrity of the nation's waters.
New Mexico Water Quality Act	§§ 74-6-1 through 74-6-13 NMSA (1978)	Establishes a State regulatory strategy patterned after the Federal Clean Water Act. (Gives the State "primacy" for water quality control regulation.)
National Historic Preservation Act of 1966	16 U.S. C. §§ 470 et seq.	Establishes the National Register of Historic Places and requires Federal agencies to consider the effect of any Federal undertaking on sites, structures, or objects included in the National Register.
New Mexico Cultural Properties Act	§§ 18-6-1 through 18-6-17 NMSA (1978)	Establishes a committee to review proposals for preservation of cultural properties. Requires permits for excavation of archeological sites. Establishes the State Historic Division and the State Historic Preservation Officer (SHPO).
Endangered Species of 1973	16 U.S.C. §§ 1531 et seq.	Authorizes determination of threatened and endangered plant and animal species and provides for Federal, State, and local conservation programs.
National Environmental Policy Act	42 U.S.C. 4321 et seq. (1970)	Establishes a broad national policy to encourage productive and enjoyable harmony between persons and their environment and to ensure that consideration is given to environmental values and factors in Federal decision making.
New Mexico Wildlife Conservation Act	§§ 17-2-37 through 178-2-46 NMSA (1978)	Empowers the State Game and Fish Commission to list endangered species, promulgate regulations, and enter into cooperative agreements with the U.S. Fish and Wildlife Service to protect such species.
Federal Land Policy and Management Act	16 U.S.C. §§ 1701 et seq.	Authorizes "administrative" public land withdrawals by the Secretary of Interior for a period not to exceed 20 years. Also authorizes exchanges of Federal for State or private lands where the "public interest will be well served." Applies to BLM lands.

Table 3-1
(continued)

COMPLIANCE STATUS OF FEDERAL AND NEW MEXICO STATUTES APPLICABLE TO THE WIPP PROJECT

NAME OF STATUTE	CITATION	ANNOTATION
Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980	Public Law (PL) 96-540 and PL 96-164; 42 U.S.C. §§ 7272 and 7273	Authorizes construction of the WIPP as a DOE defense R&D facility exempted from NRC regulation. Mandates DOE consultation and cooperation with the State of New Mexico.
New Mexico Emergency Management Act	§§ 74-3-1 through 74-3-16 NMSA (1978)	Provides for development of a comprehensive statewide hazardous materials emergency management plan covering hazardous and radioactive materials. Establishes a Hazardous Materials Safety Board.
New Mexico Radioactive Materials Act	§§ 74-4A-2 through 74-4A-14 NMSA (1978)	Establishes the Radioactive Waste Consultation Task Force, empowered to negotiate for the state with the federal government regarding federal facilities for disposal of high-level radioactive waste, transuranic waste, and low-level radioactive waste.
Hazardous Materials Transportation Act of 1976	49 U.S.C. §§ 1801 et seq.	Establishes authority of the Department of Transportation to uniformly regulate the transportation of hazardous materials which pose risks to life and property.
Resource Conservation and Recovery Act (RCRA)	PL 94-580 and amended by PL 95-609, PL 96-463, PL 96-482, PL 96-510, PL 97-272, PL 97-375, PL 98-48, PL 98-371, PL 98-616, PL 99-339, and PL 99-499	Provides cradle-to-grave regulation over hazardous waste. The DOE and the EPA have determined that radioactive mixed waste are regulated under both the Resource Conservation and Recovery Act and the Atomic Energy Act.
New Mexico Hazardous Waste Management Regulations	§§ 74-4-1 through 74-4-13 (1977, 1981, 1983, 1987, 1989)	Implements Hazardous Waste Management Program for the State of New Mexico.
Atomic Energy Act	42 U.S.C. 2201/AEA 161	Requires the USEPA to promulgate generally applicable standards for the protection of the public and the environment with regards to radiation.
Safe Drinking Water Act	42 U.S.C. 300/SDWA 1412	Regulates the protection of primary drinking waters with regard to radionuclides.
Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)	40 CFR 162 Parts 150-189	Regulate the registration, use, application, experimental use, restrictions, penalities, certified applicators, inport-export, research, and monitoring of all chemicals under the FIFRA.

Table 3-2

DOE ORDERS AND AGREEMENTS AFFECTING THE WIPP ENVIRONMENTAL PROGRAM

ORDER NO.	DATE	TITLE	ANNOTATION
DOE 5400.1	11/09/88	General Environmental Protection Program	Establishes environmental protection program requirements, authorities, and responsibilities for DOE operations for ensuring compliance with Federal and State environmental protection laws and regulations, Federal executive orders, and internal department policies.
DOE 5400.2A	01/31/89	Environmental Compliance Issue Coordination	Establishes DOE requirements for coordination of significant environmental compliance issues.
DOE 5400.3	02/22/89	Hazardous and Radioactive Mixed Waste Program	Establishes DOE hazardous and radioactive mixed waste policies and requirements for RCRA compliance.
DOE 5400.4	10/06/89	Comprehensive Environmental Response, Compensation, and Liability Act Requirements	Establishes basic requirements for implementation of the superfund at DOE facilities
DOE 5400.5	02/08/90	Radiation Protection of the Public and the Environment	Establishes standards and requirements for operations of the DOE and DOE contractors with respect to protection of the public and the environment against undue risk from radiation.
DOE 5440.1D	04/09/85	National Environmental Policy Act	Establishes DOE policy for implementation of the National Environmental Policy Act of 1969 (PL 91-190).
DOE 5480.1B	09/23/86	Environmental Protection, Safety, and Health Protection Program for DOE Operations	Establishes an overall framework of program requirements for safety, environmental, and health protection, including criteria for radiation exposure and radioactive releases for operating facilities and sites.
DOE 5480.3	09/23/86	Safety Requirements for the Packaging of Fissile and Other Radioactive Materials	Establishes requirements for packaging and transportation of radioactive materials for DOE facilities.
DOE 5484.1	10\17\90	Environmental Protection, Safety, and Health Protection Information Reporting Requirements	Establishes requirements and procedures for reporting information having environmental protection, safety, or health significance for DOE operations.
AL 5484.1	08/23/82	Environmental Protection, Safety and Health Protection Information Reporting Requirements	Albuquerque Operations Office implementation of 5484.1.

Table 3-2
(Continued)

DOE ORDERS AND AGREEMENTS AFFECTING THE WIPP ENVIRONMENTAL PROGRAM

ORDERS

ORDER NO.	DATE	TITLE	ANNOTATION
DOE 5481.1B AL 5481.1B	09/23/86 01/27/88	Safety Analysis and Review System	To establish uniform requirements for the preparation and review of safety analyses of DOE operations which include: identification of hazards, their elimination or control, assessment of the risk, and documented management authorization of the operation.
DOE 5482.1A	08/13/81	Environmental, Safety and Health Appraisal Program	To establish the Environmental Protection, Safety, and Health (ES&H) appraisal program for the DOE.
DOE 5500.3	08/13/81	Emergency Planning, Preparedness, and Response for Operations	To establish requirements for the development of DOE site-specific emergency plans and procedures for radiological emergencies occurring in existing or planned DOE reactors and nonreactor nuclear facilities. Furthermore, it requires that comprehensive emergency actions are planned, coordinated, and implemented to respond effectively to the on-site and off-site consequences of a radiological emergency at these facilities and it provides for appropriate coordination between DOE and off-site officials to ensure the protection of on-site personnel, public health and safety, and the environment.
DOE 5700.6B	09/23/86	Quality Assurance	To provide DOE policy, set forth principles, and assign responsibilities for establishing, implementing, and maintaining programs of plans and actions to ensure quality achievement in DOE programs.
DOE 5820.2A	09/26/88	Radioactive Waste Management	Establishes policies and guidelines by which DOE manages radioactive waste, waste byproducts, and radioactively contaminated surplus facilities.
DOE 5480.4	05/15/84	Environmental Protection, Safety, and Health Protection	To specify and provide requirements for the application of the mandatory Environmental Protection, Safety, and Health (ES&H) standards applicable to all DOE and DOE contractor operations; to provide a listing of reference ES&H standards; and to and references ES&H standards.
DOE 6430.1A	04/06/89	General Design Criteria	To provide general design criteria for use in the acquisition of DOE facilities and to establish responsibilities and authorities for the development and maintenance of these criteria.

Table 3-3

SUMMARY OF AGREEMENTS BETWEEN DOE AND THE STATE OF NEW MEXICO THAT AFFECT THE ENVIRONMENTAL PROGRAM

Stipulated Agreement. This agreement, approved by the U.S. District Court when it stayed (held in abeyance) proceedings in the lawsuit against the DOE by the State, was executed on July 1, 1981. The eight-page agreement ensures that a binding, enforceable "consultation and cooperation" agreement will be entered into by the DOE and the State and that the DOE will make a "good faith effort" to resolve certain State off-site concerns (which are covered in the Supplemental Stipulated Agreement). The Stipulated Agreement also addresses a number of additional studies and experiments to be conducted by the DOE for the Site Preliminary Design Validation (SPDV) phase of the WIPP.

Agreement for Consultation and Cooperation. Usually referred to as the "C&C Agreement," this agreement is contained in Appendix A to the Stipulated Agreement. It affirms the intent of the Secretary of Energy to consult and cooperate with New Mexico with respect to State public health and safety concerns.

Working Agreement for Consultation and Cooperation. This agreement, Appendix B to the Stipulated Agreement, identifies in Article IV over 60 "key events" and "milestones" in the construction and operation of the WIPP that must be reviewed by the State before they are commenced. Many environmental items are included. (Article IV of the Working Agreement was revised on April 8, 1983.)

Supplemental Stipulated Agreement Resolving Certain State Off-Site Concerns Over WIPP. This agreement, dated December 27, 1982, addresses five State concerns including the need for State "verification" of the WIPP operational environmental monitoring program. The concerns addressed are: State liability (for a nuclear incident), emergency response preparedness, transportation monitoring of the WIPP waste, WIPP environmental monitoring by the State, and upgrading of State highways.

First Modification to the Agreement for Consultation and Cooperation. Signed November 30, 1984, wherein the DOE and the State agreed to address certain concerns of the State regarding: (1) the specific mission of the WIPP, (2) a demonstration of retrievably prior to waste emplacement, (3) post-closure control and responsibility, (4) completion of certain additional scientific testing and reports, (5) compliance with applicable Federal regulatory standards for waste repositories, and (6) a program for encouraging and reporting upon the hiring of New Mexico residents at the WIPP.

Second Modification to the Agreement for Consultation and Cooperation. Signed August 4, 1987, wherein the DOE and the state agree to address certain concerns of the state regarding: (1) surface and subsurface mining and drilling after closure of the WIPP site, (2) the disposal of salt tailings at the WIPP site, and (3) compliance with Environmental Protection Agency (EPA), Department of Transportation (DOT), and Nuclear Regulatory Commission (NRC) regulations.

1988 Modification to the Working Agreement of the Consultation and Cooperation Agreement Between the Department of Energy and the State of New Mexico on the Waste Isolation Pilot Plant. Signed March 1988, this modification deleted the sorbing tracer test from the list of required reports and substituted additional tests. In addition, the State is allowed to operate a fixed air sampler in the mine ventilation effluent air stream.

Memorandum of Understanding between United States Department of Energy WIPP Project Office and United States Department of the Interior Rosell District, Bureau of Land Management. This memorandum effective October 26, 1990 allows for an administration land withdrawl between the U.S. DOE the BLM for the BLM for the 8746 acres outside 1454 acres of the DOE exclusive use acarage. This remaining 8746 acres completes the 16 section land withdrawl.

Table 3-4
1990 Active Environmental Permits

GRANTING AGENCY	TYPE OF PERMIT/ APPROVAL	PERMIT NUMBER	DATE GRANTED	DATE EXPIRATION	PERMIT STATUS	PERMIT CONDITIONS	ACTION REQUIRED	COMMENTS
DEPARTMENT OF THE I[illegible]OR, BUREAU [illegible] AND MANAGEMENT	APPROVAL TO DRILL 2 NEW TEST WELLS ON EXISTING PADS AT P-1 AND P-2.	NA	9/18/86	NA	ACTIVE			
NEW MEXICO ENVIRONMENTAL IMROVEMENT DIVISION	OPEN BURNING PERMIT TO TRAIN FIRE CONTROL CREWS.	NA	01/23/90	01/23/91	ACTIVE			
NEW MEXICO ENVIRONMENTAL IMPROVEMENT DIVISION	FOOD OR DRINK PURVEYOR PERMIT FOR CAFETERIA.	4CA08CARRS184A	10/10/86	NA	ACTIVE			RENEWED ANNUALLY
NEW MEXICO DEPARTMENT OF GAME AND FISH	PERMIT TO COLLECT BIO-LOGICAL SAMPLES.	1894	01/08/90	12/31/90	ACTIVE	LIMIT OF 25 QUAIL AND 50 CATFISH		
NEW MEXICO DEPARTMENT OF GAME AND FISH	CONCURRENCE THAT CONSTRUCTION OF WIPP WILL HAVE NO SIGNIFICANT ADVERSE IMPACT UPON THREATENED OR ENDANGERED SPECIES.	NA	4/7/80	NA	ACTIVE			LETTER TRANSMITTED TO UPDATE CONSULTATION WITH REGARD TO RECENT AMENDMENTS TO STATE ENDANGERED SPECIES LIST(COPY NEEDED FOR PERMIT FILE).
NEW MEXICO COMMISSIONER OF PUBLIC LANDS	RIGHT-OF-WAY FOR HIGH VOLUME AIR SAMPLER. (16,35,29)	RW-22789	10/03/85	10/3/2020	ACTIVE	$500 ANNUAL FEE.		
NEW MEXICO DEPARTMENT OF FINANCE AND ADMINISTRATION PLANNING DIVISION, HISTORIC PRESERVATION BUREAU	CONCURRENCE THAT THE ARCHAEO-LOGICAL [illegible]CES PROTECT[illegible] PREPARED B[illegible] THE DOE IS ADEQUATE TO MITIGATE ANY ADVERSE IMPACTS UPON CULTURAL RESOURCES RESULT-ING FROM CON-STRUCTION OF THE FULL WIPP FACILITY.	NA	7/25/83	NA	ACTIVE	NA	NA	

Table 3-4
1990 Active Environmental Permits
(continued)

GRANTING AGENCY	TYPE OF PERMIT/ APPROVAL	PERMIT NUMBER	DATE GRANTED	DATE EXPIRATION	PERMIT STATUS	PERMIT CONDITIONS	ACTION REQUIRED	COMMENTS
U.S. ENVIRONMENTAL PROTECTION AGENCY	ACKNOWLEDGEMENT OF NOTIFICATION OF HAZARDOUS WASTE ACTIVITY (WIPP).	NM4890139088	1/88	NA	ACTIVE			BIENNIAL REPORT SUBMITTED 3/90
U.S. ENVIRONMENTAL PROTECTION AGENCY	NOTIFICATION OF PRESENCE OF 2 UNDERGROUND FUEL STORAGE TANKS AT WIPP.	NA	04/15/86	NA	ACTIVE		INVENTORY CONTROL	$200 ANNUAL FEE SUBMITTED 7/11/90. ANNUAL FEE DUE 7/91.
NEW MEXICO ENVIRONMENTAL IMPROVEMENT DIVISION	SUBMITTAL OF PART A RCRA PERMIT APPLICATION.		7/88	NA	ACTIVE		RESUBMIT BY 1/22/91	PART A RETURNED BY NM EID 12/89, TO BE RESUBMITTED WITHIN 6 MO. OF STATE AUTHORIZATION FOR MIXED WASTE. (7/25/90)
NEW MEXICO ENVIRONMENTAL IMPROVEMENT DIVISION	SUBMITTAL OF PART B RCRA PERMIT APPLICATION.	N/A					SUBMIT PERMIT APPLICATION BY 2/28/91	EID CALLED FOR PART B APPLICATION WITHIN 6 MO. OF REQUEST
U.S. ENVIRONMENTAL PROTECTION AGENCY	NESHAPS (RADIONUCLIDES).							DATA PACKAGE SUBMITTED TO THE DOE ON 11/07/90
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	RIGHT-OF-WAY FOR WATER PIPELINE.	NM53809	8/17/83	NA	ACTIVE			RIGHT-OF-WAY EXTENDED IN PERPETUITY, MODIFIED FOR CONSTRUCTION OF FENCE ALONG E AND W SIDES OF NORTH ACCESS ROAD.

Table 3-4
1990 Active Environmental Permits
(continued)

GRANTING AGENCY	TYPE OF PERMIT/ APPROVAL	PERMIT NUMBER	DATE GRANTED	DATE EXPIRATION	PERMIT STATUS	PERMIT CONDITIONS	ACTION REQUIRED	COMMENTS
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	RIGHT-OF-WAY FOR NORTH ACCESS ROAD. (20,32,33,06)	NM55676	8/24/83	NA	ACTIVE			RIGHT-OF-WAY EXTENDED IN PERPETUITY, MODIFIED FOR CONSTRUCTION OF FENCE ALONG E AND W SIDES OF NORTH ACCESS ROAD AND TO INSTALL OVERHEAD ELECTRIC LINE.
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	RIGHT-OF-WAY FOR RAILROAD.	NM55699	9/27/83	NA	ACTIVE			RIGHT-OF-WAY EXTENDED IN PERPETUITY.
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	RIGHT-OF-WAY FOR DOSIMETRY AND AEROSOL SAMPLING SITES. (22,31,20,07)	NM63136	7/3/86	NA	ACTIVE			
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	RIGHT-OF-WAY FOR SEVEN SUBSIDENCE MONUMENTS. (22,31,20,07) (22,31,21,05)	NM65801	11/7/86	NA	ACTIVE			
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	RIGHT-OF-WAY FOR AEROSOL SAMPLING SITE. (24,32,06,13)	NM77921	8/18/89	8/18/2019	ACTIVE			
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	RIGHT-OF-WAY FOR TEN RAPTOR NESTING PLATFORMS	NM82212	09/12/89	09/12/92	ACTIVE			REPLACES NM-060-LUP-235
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	RIGHT-OF-WAY FOR SURVEY MONUMENT INSTALLATION (22,31,16,04) (22,31,17,01).	NM82245	12/13/89	12/13/2019	ACTIVE			

Table 3-4
1990 Active Environmental Permits
(continued)

GRANTING AGENCY	TYPE OF PERMIT/ APPROVAL	PERMIT NUMBER	DATE GRANTED	DATE EXPIRATION	PERMIT STATUS	PERMIT CONDITIONS	ACTION REQUIRED	COMMENTS
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	FREE USE PERMIT (21,32,33,05).	NM-060-FU9-7020	1/31/89	1/23/90	ACTIVE THROUGH 1/23/90	MAXIMUM EXCAVATION 28,000 CU YDS.		CALICHE USE REPORTS SUBMITTED 1/90
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	FREE USE PERMIT (23,30,01,07).	NM-060-FU9-7030	6/8/89	6/8/90	ACTIVE THROUGH 6/8/90	MAXIMUM EXCAVATION 4000 CU YDS.		CALICHE USE REPORTS SUBMITTED 1/90
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	LAND USE PERMIT TO DISPOSE OF CONSTRUCTION DEBRIS.	NM-067-LUP-237	2/9/87	2/9/90	ACTIVE THROUGH 2/9/90			LANDFILL CLOSED IN ACCORDANCE WITH PERMIT REQUIREMENTS. RECLAMATION REQUIRED.
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	RIGHT-OF-WAY FOR SECURITY FENCE INSTALATION.	NA	NA	NA	PENDING			PENDING BLM APPROVAL.
U.S. ENVIRONMENTAL PROTECTION AGENCY	ACKNOWLEDGEMENT OF NOTIFICATION OF HAZARDOUS WASTE ACTIVITY (TRUPACT).	NMD982283566	10/87	NA	INACTIVE	NA		ACTIVE GENERATOR STATUS: TERMINATE 3/90

Table 3-5
1991 Active Environmental Permits

GRANTING AGENCY	TYPE OF PERMIT/ APPROVAL	PERMIT NUMBER	DATE GRANTED	DATE EXPIRATION	PERMIT STATUS	PERMIT CONDITIONS	ACTION REQUIRED	COMMENTS
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	APPROVAL TO DRILL 2 NEW TEST WELLS ON EXISTING PADS AT P-1 AND P-2.	NA	9/18/86	NA	ACTIVE			
NEW MEXICO ENVIRONMENTAL IMROVEMENT DIVISION	OPEN BURNING PERMIT TO TRAIN FIRE CONTROL CREWS.	NA	03/08/91	03/08/92	ACTIVE			
NEW MEXICO ENVIRONMENTAL IMPROVEMENT DIVISION	FOOD OR DRINK PURVEYOR PERMIT FOR CAFETERIA.	4CA08CARRS184A	10/10/86	NA	ACTIVE			RENEWED ANNUALLY
NEW MEXICO DEPARTMENT OF GAME AND FISH	PERMIT TO COLLECT BIOLOGICAL SAMPLES.	1894	01/25/91	12/31/91	ACTIVE	LIMIT OF 25 QUAIL AND 50 CATFISH		
NEW MEXICO DEPARTMENT OF GAME AND FISH	CONCURRENCE THAT CONSTRUCTION OF WIPP WILL HAVE NO SIGNIFICANT ADVERSE IMPACT UPON THREATENED OR ENDANGERED SPECIES.	NA	4/7/80	NA	ACTIVE			LETTER TRANSMITTED TO UPDATE CONSULTATION WITH REGARD TO RECENT AMENDMENTS TO STATE ENDANGERED SPECIES LIST(COPY NEEDED FOR PERMIT FILE).
NEW MEXICO DEPARTMENT OF GAME AND FISH	PROTECTED SPECIES PERMIT RAPTOR BANDING	1608	02/27/91	12/31/91	ACTIVE	NO FEDERALLY PROTECTED/ENDANGERED SPECIES MAY BE CAPTURED OR BANDED		
NEW MEXICO COMMISSIONER OF PUBLIC LANDS	RIGHT-OF-WAY FOR HIGH VOLUME AIR SAMPLER. (16,35,29)	RW-22789	10/03/85	10/3/2020	ACTIVE	$500 ANNUAL FEE.		

Table 3-5
1991 Active Environmental Permits
(continued)

GRANTING AGENCY	TYPE OF PERMIT/ APPROVAL	PERMIT NUMBER	DATE GRANTED	DATE EXPIRATION	PERMIT STATUS	PERMIT CONDITIONS	ACTION REQUIRED	COMMENTS
NEW MEXICO DEPARTMENT OF FINANCE AND ADMINISTRATION PLANNING DIVISION, HISTORIC PRESERVATION BUREAU	CONCURRENCE THAT THE ARCHAEOLOGICAL RESOURCES PROTECTION PLAN PREPARED BY THE DOE IS ADEQUATE TO MITIGATE ANY ADVERSE IMPACTS UPON CULTURAL RESOURCES RESULTING FROM CONSTRUCTION OF THE FULL WIPP FACILITY.	NA	7/25/83	NA	ACTIVE	NA	NA	
U.S. ENVIRONMENTAL PROTECTION AGENCY	ACKNOWLEDGEMENT OF NOTIFICATION OF HAZARDOUS WASTE ACTIVITY (WIPP).	NM4890139088	1/88	NA	ACTIVE			BIENNIAL REPORT SUBMITTED 3/90
U.S. ENVIRONMENTAL PROTECTION AGENCY	NOTIFICATION OF PRESENCE OF 2 UNDERGROUND FUEL STORAGE TANKS AT WIPP.	NA	04/15/86	NA	ACTIVE		INVENTORY CONTROL	$200 ANNUAL FEE SUBMITTED 7/25/91. ANNUAL FEE DUE 7/92.
NEW MEXICO ENVIRONMENTAL IMPROVEMENT DIVISION	SUBMITTAL OF PART A RCRA PERMIT APPLICATION.		7/88	NA	ACTIVE		AWAITING APPROVAL	PART A WAS SUBMITTED TO BOTH EID AND EPA REGION VI ON 1/22/91
NEW MEXICO ENVIRONMENTAL IMPROVEMENT DIVISION	SUBMITTAL OF PART B RCRA PERMIT APPLICATION.	N/A					UNTIL PERMIT IS ISSUED THE WIPP WILL OPERATE UNDER INTERIM STATUS	PART B WAS SUBMITTED TO EID ON 2/26/91 AND TO EPA REGION VI ON 2/27/91

Table 3-5
1991 Active Environmental Permits
(continued)

GRANTING AGENCY	TYPE OF PERMIT/ APPROVAL	PERMIT NUMBER	DATE GRANTED	DATE EXPIRATION	PERMIT STATUS	PERMIT CONDITIONS	ACTION REQUIRED	COMMENTS
U.S. ENVIRONMENTAL PROTECTION AGENCY	NESHAPS (RADIONUCLIDES).							DATA PACKAGE SUBMITTED TO THE DOE ON 11/07/90 DATA PACKAGE SUBMITTED TO THE EPA ON 02/19/91
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	RIGHT-OF-WAY FOR WATER PIPELINE.	NM53809	8/17/83	NA	ACTIVE			RIGHT-OF-WAY EXTENDED IN PERPETUITY, MODIFIED FOR CONSTRUCTION OF FENCE ALONG E AND W SIDES OF NORTH ACCESS ROAD.
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	RIGHT-OF-WAY FOR NORTH ACCESS ROAD. (20,32,33,06)	NM55676	8/24/83	NA	ACTIVE			RIGHT-OF-WAY EXTENDED IN PERPETUITY, MODIFIED FOR CONSTRUCTION OF FENCE ALONG E AND W SIDES OF NORTH ACCESS ROAD AND TO INSTALL OVERHEAD ELECTRIC LINE.
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	RIGHT-OF-WAY FOR RAILROAD.	NM55699	9/27/83	NA	ACTIVE			RIGHT-OF-WAY EXTENDED IN PERPETUITY.
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	RIGHT-OF-WAY FOR DOSIMETRY AND AEROSOL SAMPLING SITES. (22,31,20,07)	NM63136	7/3/86	NA	ACTIVE			
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	RIGHT-OF-WAY FOR SEVEN SUBSIDENCE MONUMENTS. (22,31,20,07) (22,31,21,05)	NM65801	11/7/86	NA	ACTIVE			

Table 3-5
1991 Active Environmental Permits
(continued)

GRANTING AGENCY	TYPE OF PERMIT/ APPROVAL	PERMIT NUMBER	DATE GRANTED	DATE EXPIRATION	PERMIT STATUS	PERMIT CONDITIONS	ACTION REQUIRED	COMMENTS
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	RIGHT-OF-WAY FOR AEROSOL SAMPLING SITE. (24,32,06,13)	NM77921	8/18/89	8/18/2019	ACTIVE			
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	RIGHT-OF-WAY FOR TEN RAPTOR NESTING PLATFORMS	NM82212	09/12/89	09/12/92	ACTIVE			REPLACES NM-060-LUP-235
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	RIGHT-OF-WAY FOR SURVEY MONUMENT INSTALLATION (22,31,16,04) (22,31,17,01).	NM82245	12/13/89	12/13/2019	ACTIVE			
DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT	RIGHT-OF-WAY FOR SECURITY FENCE INSTALATION.	NA	NA	NA	PENDING			PENDING BLM APPROVAL.

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CHAPTER 4

ENVIRONMENTAL PROGRAM INFORMATION

It is the policy of the WIPP to conduct its operations so as to comply with all applicable environmental laws and regulations.

4.1 OPERATIONAL ENVIRONMENTAL MONITORING PROGRAM

The OEMP monitors a comprehensive set of parameters in order to detect and quantify any present or potential future environmental impacts. Nonradiological portions of the program focus on the immediate area surrounding the site, whereas radiological surveillance generally covers a broader geographic area including nearby ranches, villages, and cities. Environmental monitoring will continue at the site during project operations and through decommissioning activities.

The goal of the OEMP is to determine whether there are impacts during the operational phase of WIPP on the local ecosystem and, if so, to evaluate their severity, geographic extent, and environmental significance, and identify correctable actions and make every effort to minimize the environmental impacts of the WIPP. Table 4-1 summarizes the OEMP sampling schedule and sampling type, whereas Table 4-2 denotes the analytical array for the various sample types. The tables list the sample types, the number of sampling stations, the approximate sampling schedule, and the environmental/ecological parameters to be monitored or analyzed. Additional or different types of samples will be collected and analyzed as necessary to investigate and explain trends or anomalies that may have a bearing on environmental impacts.

As recommended in DOE/EP-0023 (Corley et al., 1981), the OEMP monitors levels of naturally occurring radionuclides and those associated with world-wide fallout, in addition to those expected in the WIPP waste. The geographic scope of radiological sampling is based on projections of potential release pathways (see Figure 4-1, Primary Pathway Exposure) and the types of radionuclides in WIPP waste. Also, the surrounding population centers are monitored even though release scenarios involving radiation dose to residents of those population centers are improbable due to the extended distances from the WIPP. Ecological sampling activities will continue to be performed at the permanent ecological monitoring plots, whose locations are unchanged from the earlier EMP.

4.2 CLEAN AIR ACT

The CAA is a broad federal statute which, among other things, specifies national ambient air quality standards and sets emission limits for specific air pollutants from certain sources. These standards are to be achieved by the states through development and adoption of implementation plans. The CAA also authorizes the EPA to set new source performance standards and NESHAPs. The EPA has also developed special programs for prevention of significant deterioration of air quality. The WIPP complies with CAA criteria.

4.3 CLEAN WATER ACT

The Federal Water Pollution Control Act (FWPCA) of 1972, as amended by the CWA and the Water Quality Act (WQA) of 1987, forms a legal framework intended to support the maintenance and restoration of water quality in surface water, with the ultimate goal of "fishable and swimmable" water quality. The FWPCA established the National Pollutant Discharge Elimination System (NPDES) as the regulatory mechanism to achieve this goal by regulating discharge to navigable streams, rivers, and lakes.

The WQA has significantly changed the thrust of enforcement activities. In the future, much greater emphasis will be placed on monitoring and control of toxic constituents in wastewater, permitting of outfall compose entirely of stormwater, and imposition of regulations governing sewage sludge disposal. Best management practices will influence waste handling from point of discharge back to the source. As applicable the WIPP does comply with the CWA.

4.4 RESOURCE CONSERVATION AND RECOVERY ACT

The RCRA was enacted in 1976, and implementing regulations were promulgated in May of 1980. This body of regulations is intended to ensure that hazardous wastes are disposed of in an environmentally safe manner, and that facilities that store, treat, or dispose of hazardous waste do so in a way that protects human health and the environment. The Hazardous and Solid Waste Amendments of 1984 created a set of restrictions on land disposal of hazardous wastes unless certain treatment standards can be satisfied. This act also places increased emphasis on waste minimization activities and serves as a mechanism to enforce cleanup.

Non-hazardous solid waste generated on site consists primarily of paper and cardboard, construction wastes, and cafeteria waste. Whereas, hazardous wastes are principally petroleum based products. In February 1989, the governor of New Mexico signed legislation which authorizes the EID to regulate radioactive mixed waste at the WIPP. The WIPP complies with RCRA requirements as applicable to the facility.

4.5 SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT

The SARA Title III provisions added significant public notification requirements to the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). There are no declared CERCLA sites at the WIPP site. At this time, all of the inactive solid waste units and release sites at the WIPP site are being investigated/remediated under regulations of RCRA and not CERCLA. The summary toxic chemical inventory data required under SARA Title III will be prepared in June 1990.

4.6 FEDERAL INSECTICIDE, FUNGICIDE AND RODENTICIDE ACT

The Federal Insecticide, Fungicide and Rodenticide Act, as amended, contains federal regulations governing the manufacture and use of biocides. Procedures promulgated under this act (40 CFR 150-180) govern the use, storage, and disposal of all pesticides, pesticide containers, and pesticide residues. At the WIPP site, pesticides are used in accordance with these regulations.

4.7 ACCIDENTAL RELEASES

The WIPP site had no accidental releases into the environment during 1990. In the future during operations if a release occurs all state and federal regulatory agencies will be promptly notified of the release.

4.8 SIGNIFICANT ENVIRONMENTAL ACTIVITIES

This section addresses significant environmental activities that occurred during 1989.

4.8.1 Waste Minimization and Pollution Prevention Awareness Plan

The WIPP Waste Minimization and Pollution Prevention Awareness Plan has been drafted and is currently being revised to incorporate comments. A second managerial review and an interactive comment session occurred in April of 1991. The final plan will be submitted to DOE/WPO by May 1991.

4.8.2 Environmental Training

During 1990 there were six environmental training courses offer to WIPP personal they were:

- 40 hour hazardous waste operations
- RCRA training
- Environmental regulations
- Basic environmental training
- Fundamentals of groundwater and wells
- Westinghouse School for Environmental Excellence

4.8.3 Cooperative Raptor Research and Management Program

In 1985, the Los Medanos Cooperative Raptor Research and Management Program was initiated under the sponsorship of the DOE with support from the BLM and the New Mexico Living Desert State Park. Part of the goal of this program, which is being conducted by researchers from the University of New Mexico, is to evaluate the impacts of WIPP activities on the breeding success of raptors (i.e., hawks and owls) that are found in great abundance in the area.

During 1990, 80 raptor nests and 31 Chihuahuan raven nests were located and monitored in the study area. Reproductive success of raptor species was poor, especially for Chihuahuan Ravens. The poor success rate was probably due to low prey availability, particularly rabbits. The average clutch size for Harris Hawks, averaged 2.47 with 1.00 offspring fledged, for a total recruitment of 14 individuals into the study population. Similarly, Swainson's hawks and great horned owls experienced low numbers of young fledged.

The calendar year 1990 precipitation was 10cm (3.97in) above normal with a total precipitation amount of 41cm (15.97in). Typically the majority of precipitation occurs in July and August, however only 36 percent of the annual precipitation was received in these months.

With three proceeding years of below normal precipitation prey species have been slow to respond to an above normal year. The previous years reduction in prey lead to a decrease in the nesting success of indigenous raptors. As plant communities and dependant prey species recover, raptor populations should respond accordingly.

4.3.4 Reclamation of Disturbed Lands

There was no reclamation activities performed for WIPP disturbed areas in CY 1990 reclamation studies conducted in 1988 and 1989 were evaluated through 1990.

The WIPP's current studies aim to answer the following questions relative to seed bed preparation and seed mix selection:

- Does single ripping the seed bed on caliche roads produce different results than double ripping?
- Does use of caliche as a top dressing produce different results on a reserve pit than not using it?
- Do different directions of tillage produce different results on a dune site?
- Do native forbs and grasses from commercial sources produce different results than a prescribed BLM mix? Current studies examine a total of 30 native plant species including 10 grasses, 5 shrubs, and 15 forbs.

Plots on roads, an 18 acre reserve pit, and a brine pit have been marked with permanent identification labels which should allow for long-term identification of plot treatments in the field and facilitate a long-term monitoring schedule.

To fulfill DOE commitments for reclamation of disturbed lands, a draft reclamation plan was written to guide future reclamation projects. The reclamation plan takes effect in 1991 with the filling of reserve pits on WIPP well pads and ultimately ends with site decommissioning.

TABLE 4-1

OEMP SAMPLING SCHEDULE

TYPE OF SAMPLE	SAMPLING LOCATIONS	SAMPLING FREQUENCY
Liquid Influent	1	Semiannual
Liquid Effluent	1	Semiannual
Airborne Effluent	3	Continuous
Meteorology	2	Continuous
Exposure Rate Meter	1	Continuous
Atmospheric Particulate	7	Weekly
Air Quality	1	Continuous
Vegetation-Radioanalysis	4	Annual
Beef	2	Annual*
Game Birds	2	Annual
Rabbits	2	Annual
Soil-Radioanalysis	7	Biennial
Surface Water	8	Annual
Groundwater	14	Annual
Fish	2	Annual
Sediment	6	Biennial
Aerial Photography	Site Wide	Annual
Salt Impact Studies		
Surface Photography	7	Biannual
Soil Chemistry	7	Quarterly
Soil Microbiota	7	Semiannual
Vegetation Survey	7	Biannual
Wildlife Survey	4	Annual

TABLE 4-2

OEMP ANALYTICAL ARRAY

TYPE OF SAMPLE	ANALYSIS
Liquid Influent	Gross α, Gross β, pH, TSS, Specific Radionuclides
Liquid Effluent	Gross α, Gross β, pH, TSS, Specific Radionuclides, Chemical Constituents
Airborne Effluent	Gross α, Gross β, Specific Radionuclides
Meteorology	Temperature, Wind Speed, Wind Direction, Precipitation, Dew Point, Barometric Pressure
Exposure Rate Meter	Penetrating Radiation
Atmospheric Particulate	Gross α, Gross β, TSP, Specific Radionuclide
Air Quality	O_3, CO, H_2S, SO_2, NO_x
Vegetation Radioanalysis	Specific Radionuclides
Beef	Specific Radionuclides
Game Birds	Specific Radionuclides
Rabbits	Specific Radionuclides
Soil Radioanalysis	Gross α, Gross β, Specific Radionuclides
Surface Water	Gross α, Gross β, Specific Radionuclides TSS, pH
Groundwater	Specific Radionuclides, pH
Fish	Specific Radionuclides
Sediment	Gross α, Gross β, Specific Radionuclides
Aerial Photography	Area of Land Disturbed

TABLE 4-2
(Continued)

OEMP ANALYTICAL ARRRAY

TYPE OF SAMPLE	ANALYSIS
Salt Impact Study	
Surface Photography	Visual Impacts
Soil Chemistry	pH, EC, Na, Cl, Mg, Ca, K
Soil Micorbiota	Microbial Activity, Litter Decomposition
Vegetation Survey	Foliar Coverage, Species Richness, Annual Plant Density
Wildlife Survey	Bird and Small Mammal Population Densities

TSS = Total Suspended Solids
TSP = Total Suspended Particulates
EC = Electrical Conductivity

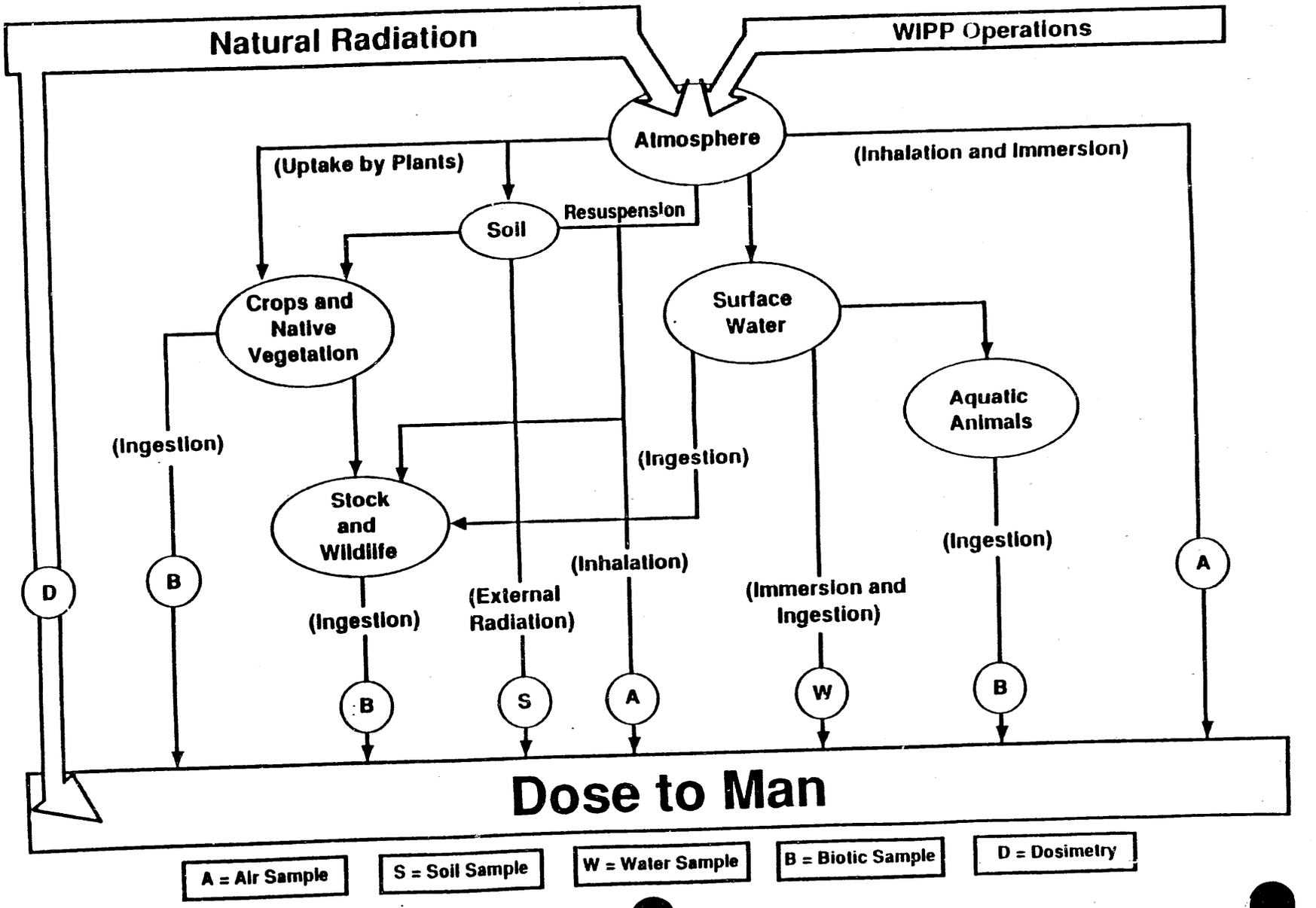
Specific Radionulides = ^{238}Pu, $^{239/240}Pu$, ^{241}Pu, ^{233}U, ^{235}U, ^{241}Am, ^{232}Th, ^{226}Ra, ^{137}Cs, ^{90}Sr, ^{40}K, ^{7}Be, ^{60}Co, U_{nat}, Th_{nat}

Chemical Constituents = Chloride, iron, manganese, phenols, sodium, sulfate, pH, specific conductance, total organic cabon, total organic halogen, arsenic, barium, cadmium, chromium, fluoride, lead, mercury, nitrate, selenium, silver, endrin, methoxychlor, toxaphene, 2, 4-D, 2, 4, 5-T, silvex.

*In addition, surface water samples from Hill Tank and Red Tank will be analyzed for the above chemical constituents biannually.

FIGURE 4-1

PRIMARY PATHWAYS TO MAN FOR RADIOACTIVE RELEASES FROM THE WIPP FACILITY



CHAPTER 5

ENVIRONMENTAL RADIOLOGICAL PROGRAM INFORMATION

The following sections provide a description of the various subprograms constituting the OEMP at the WIPP.

5.1 RADIOACTIVE EFFLUENT MONITORING

During March 1989, the monitoring activities of the Radiological Baseline Program (RBP) were combined into the OEMP. This program is described in the Operational Environmental Monitoring Plan for the Waste Isolation Pilot Plant, (DOE/WIPP 88-025). This plan defines the scope and extent of the WIPP effluent and environmental monitoring programs during the operational life of the facility. The OEMP is the database for all environmental comparisons once the WIPP is operational.

Draft Order DOE 5400.6, Requirements for Radiological Effluent Monitoring and Environmental Surveillance for U.S. DOE Operations (DOE,1988c), requires that monitoring of liquid waste effluent streams be adequate to demonstrate compliance with dose limits in Order DOE 5400.5, Radiation Protection of the Public and the Environment (DOE, 1990). This order also requires the monitoring of potential sources of contaminated airborne emissions. Since no radioactive waste was received at the WIPP site in 1990, no effluent sampling or release data are reported in this document.

It should be noted that a complete environmental radiological baseline summarization is forthcoming from a WIPP subcontractor. It is anticipated this report will be available in CY 1991.

5.2 ENVIRONMENTAL RADIOACTIVITY MONITORING

The following subsections present the monitoring results of the various subprograms of the OEMP for 1990. These include aerosol monitoring, ambient radiation, terrestrial radioactivity, hydrologic radioactivity, and biotic radioactivity baseline subprograms. Figures 5-1 through 5-6 summarize sample type and location for the WIPP and vicinity for the various subprograms.

5.2.1 The Atmospheric Radiation Baseline

Sampling airborne aerosol particulates is an important component of the OEMP. The Final Safety Analysis Report (FSAR) (DOE, 1990) identifies the atmospheric pathway as essentially the only release pathway resulting in a potential dose to the public. Nine continuous particulate aerosol samplers operate at eight locations (two at WIPP East), three within the Zone II boundary and four at local ranches and communities (Figure 5-1). The continuous aerosol samplers presently in use maintain a regulated flow rate of approximately 950 milliliters per second (two cubic feet per minute) of air through a 47-millimeter (1.9-inch) glass fiber filter for particulate collection. Table 5-1 lists the quarterly average concentrations of the alpha and beta activity on the low-volume aerosol filters from each location for the first and second quarters of 1990.

Airborne particulate sampling was initiated in July 1985 at a few locations. Routine weekly filter collections and subsequent radiochemical analysis began in early 1986 for all locations except the Far Field location, where data collection began in October 1986. Particulate filters were collected weekly at all locations in 1990. These filters were analyzed at the Environmental Counting Lab at the WIPP, where a gross alpha and gross beta count of each weekly filter was completed.

Figure 5-2 represents the mean gross alpha concentrations for all eight sampling locations. The individual gross alpha concentrations reported for each location is documented in Appendix I. The mean gross alpha concentrations in Figure 5-2 shows limited fluctuation throughout the year and are consistently less than 1 E-9 Bq/ml. These fluctuations appeared to be consistent among all sampling locations.

The mean gross beta concentrations Figure 5-3, fluctuate throughout the year, typically within the range of 1.0-3.0 E-9 Bq/ml. Appendix II shows the 1990 gross beta concentration for each individual sampling location which was used to establish the mean.

Gross beta and alpha measurements provide an indication of total radionuclide concentration or may indicate changes in a specific radionuclide concentration. These measurements are also used for screening to ensure that important radionuclides are not overlooked when performing a specific measurement. However, gamma spectroscopy is performed in the WIPP Environmental low-level counting lab which identifies individual radionuclides and defines specific baseline environmental parameters. These analysis techniques have previously been performed under a contract issued to a contract laboratory.

5.2.2 Ambient Radiation Baseline

A Reuter-Stokes High Pressure Ionization Chamber (HPIC), designed to monitor low levels of gamma radiation in the environment, was put into operation in May 1986. This unit is located at the WIPP far field location which is 1000 meters northwest of the site. The detector used to measure low levels of gamma radiation is a pressurized ion chamber and measures levels of radiation from 1 to 100 microroentgen per hour (μR/hr). Using the average rate of 7.4 μR/hr, the estimated annual dose is approximately 65 millirem. The fluctuations noted are primarily due to calibration of the system and meteorological events such as the high intensity thunderstorms which frequent this area in late summer.

The Reuter-Stokes shows a rise in the average radiation level for the fourth quarter. A seasonal rise in ambient radiation has been observed in the first and fourth quarters each year. As stated in previous reports, it is speculated that this fluctuation may be due to variations in the emission and dispersion of Radon-222 from the soil around the WIPP site. These variations can be caused by meteorological conditions, such as inversions, which would prevent the radon progeny from dispersing.

This sensor was down for 2.5 months in CY 1990 as the main battery which supplies the high voltage input to the pressure chamber ceased to accept the recharge capability from the charging unit. Thus, a new battery had to be procured, installed and the entire system had to be recalibrated thus requiring downtime.

These estimated annual dose of 65 millirem are calculated from the operational time in CY 90 and from historical known values typical for this area as indicated from the HPIC.

5.2.3 Radiological Soil Monitoring

The annual collection of radiological soil samples was conducted December in 1990 at 7 locations (Figure 5-4). A template insert allows the collection of samples at three depths at each location: (1) surface sample, 0 - 2 centimeters (0.8 inch deep); (2) intermediate (middle) sample, 2 - 5 centimeters (0.8 - 2.0 inches); and (3) deep sample, 5 - 10 centimeters (2.0 - 3.9 inches deep). Every sample was a composite of 10 randomly located subsamples, each delineated by a 10 by 10 centimeter (3.9 by 3.9 inches) stainless steel template. Soil samples collected during 1990 were archived since the required number of baseline soil samples had already been collected and analyzed for the OEMP.

This program is also valuable in documenting any possible radiological contamination of the soil from any of the local potash mines located primarily in Nash Draw or from the Gnome site which is approximately 12.8 Km (8 miles) southwest of the WIPP site.

5.2.4 Hydrologic Radioactivity

This subprogram is designed to establish baseline radiation levels in surface water bodies, bottom sediments, and groundwater. The following discussion of the hydrologic program includes sampling locations, times and data collected during 1990, and refinements made to the program since the publication of the RBP Sampling Plan (Reith and Daer, 1985). There were no annual surface water or sediment samples collected during CY 1990.

- **Radiological Surface Water and Sediment Monitoring**

  Surface Water and sediment samples were collected in 1985-1988 as directed by the OEMP (Figure 5-5). This baseline data is being compiled by a subcontractor and should be available by the end of 1991. Two years of preoperational data are required by Order DOE 5400.1 to establish a preoperational baseline for nuclear facilities. This program is also valuable in documenting any possible radiological contamination of the soil from any of the local potash mines located primarily in Nash Draw or from the Gnome site.

- **Radiological Groundwater Monitoring**

  Groundwater samples were collected in accordance with the Water Quality Sampling Program (WQSP). The primary objective of the WQSP is to obtain representative and repeatable ground water quality data from selected wells under rigorous field and laboratory procedures and protocols. At each well site, the well is pumped and the ground water serially analyzed for specific field parameters. Once the field parameters have stabilized, denoting a chemical steady state with respect to those parameters analyzed, a final groundwater sample is collected to be analyzed for radionuclides. The controlling document for the WQSP is the WIPP Water Quality Sampling Plan and Procedures Manual, WP 02-1, Rev 2.

The primary water bearing units being evaluated by the WQSP are the Culebra and Magenta Dolomite members of the Rustler Formation. Samples have also been collected from the Dewey Lake Redbeds Formation at local ranches. An indepth discussion of groundwater hydrology appears in Chapter 7.0, Groundwater Protection.

Figure 5-6 provides a map of the groundwater sampling locations. Approximately 23 wells are being monitored by the WQSP in support of the OEMP. In 1990, 16 Culebra and three Magenta wells were sampled and analyzed . Four recently drilled wells were added to the WQSP and sampled for the first time in 1987. Wells H-14 and H-15 were drilled in 1986. Wells H-17 and H-18 were drilled in 1987. WIPP-19 was also sampled for the first time in 1987. All five wells are completed in the Culebra and are located to give the RBP and WQSP a more complete coverage of the area surrounding the WIPP site.

For the WQSP, groundwater was sampled at ten privately owned water wells that supply drinking water for livestock and human consumption. Of these ten wells, nine supply groundwater for livestock consumption and one (Barn Well) supplies groundwater for human consumption.

There is extensive oil and gas production in the WIPP vicinity as well and the Gnome site which is located approximately 12.8 Km (8 miles) southwest of the site. However, there is no known source for radiological contamination of the groundwater near the site.

The radiological groundwater samples collected in 1990 CY were archived. The required amount of baseline groundwater samples have been collected and analyzed as specified in the OEMP for the preoperational baseline.

5.2.5 Biotic Radioactivity

This subprogram characterizes background radioactivity levels in key organisms along possible food chain pathways to man. Vegetation, rabbits, quail, beef, and fish are sampled, and palatable tissues are analyzed for concentrations of transuranics and common naturally occurring radionuclides. During 1990, samples of fish, quail, and rabbits were collected and archived since the required number of baseline biotic samples had already been collected and analyzed for the OEMP. Representative sample locations are shown in Figure 5-7.

5.3 ASSESSMENT OF POTENTIAL DOSE TO THE PUBLIC

There was no waste received at the WIPP in 1990, therefore, there was no exposure of the public to radiation due to WIPP operations. Documentation of naturally occurring background radiation is discussed in Section 5.2.2, Ambient Radiation Baseline.

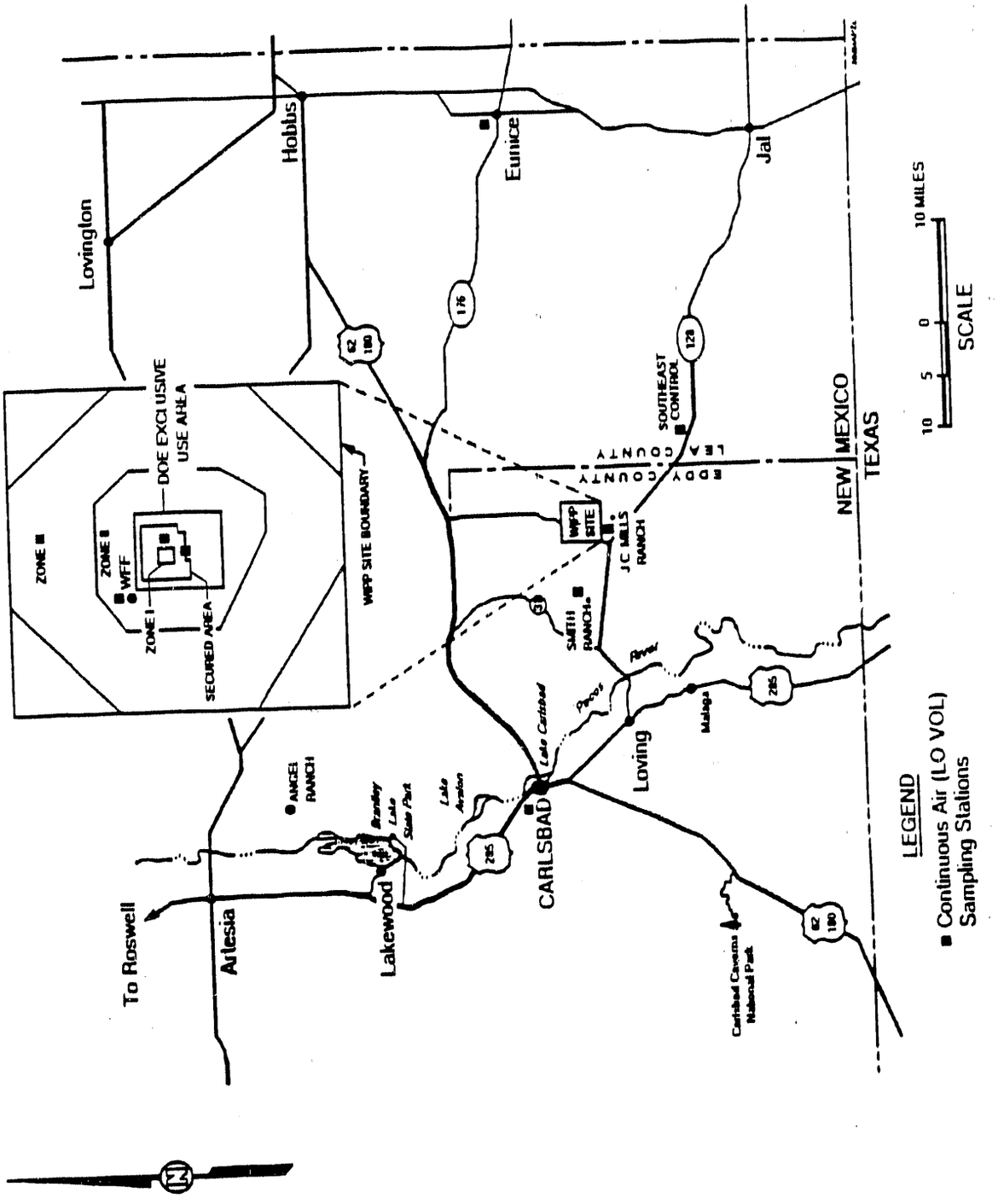


Figure 5-1
Continous Air Sampling Stations

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TABLE 5-1

ACTIVITY CONCENTRATIONS IN QUARTERLY AVERAGES OF THE LOW VOLUME AEROSOL FILTERS (Bq/ml)

FIRST QUARTER 1990

LOCATION	ALPHA	BETA
Carlsbad	5.8 E-10	1.5 E-9
Smith Ranch	4.8 E-10	1.3 E-9
Mills Ranch	5.8 E-10	1.3 E-9
WIPP Far Field	4.6 E-10	1.0 E-9
WIPP South	5.1 E-10	1.3 E-9
WIPP East (1)	5.0 E-10	1.3 E-9
WIPP East (2)	5.5 E-10	1.2 E-9
Eunice	5.5 E-10	1.3 E-9
South East Control	5.0 E-10	1.3 E-9

SECOND QUARTER 1990

LOCATION	ALPHA	BETA
Carlsbad	4.1 E-10	1.2 E-9
Smith Ranch	3.0 E-10	1.2 E-9
Mills Ranch	3.7 E-10	1.0 E-9
WIPP Far Field	3.6 E-10	1.1 E-9
WIPP South	3.4 E-10	1.1 E-9
WIPP East (1)	4.0 E-10	1.1 E-9
WIPP East (2)	3.8 E-10	1.1 E-9
Eunice	3.9 E-10	1.1 E-9
South East Control	4.2 E-10	1.3 E-9

THIRD QUARTER 1990

LOCATION	ALPHA	BETA
Carlsbad	3.9 E-10	1.3 E-9
Smith Ranch	7.3 E-10	2.4 E-9
Mills Ranch	6.1 E-10	1.5 E-9
WIPP Far Field	3.8 E-10	2.0 E-9
WIPP South	4.1 E-10	1.0 E-9
WIPP East (1)	3.6 E-10	9.7 E-9
WIPP East (2)	3.8 E-10	1.1 E-9
Eunice	4.0 E-10	1.1 E-9
South East Control	5.1 E-10	1.6 E-9

FOURTH QUARTER

LOCATION	ALPHA	BETA
Carlsbad	6.7 E-10	2.2 E-9
Smith Ranch	6.2 E-10	2.0 E-9
Mills Ranch	6.9 E-10	1.9 E-9
WIPP Far Field	7.0 E-10	2.0 E-9
WIPP South	7.0 E-10	1.8 E-9
WIPP East (1)	7.3 E-10	2.0 E-9
WIPP East (2)	6.7 E-10	1.8 E-9
Euince	6.9 E-10	1.9 E-9
South East Control	4.0 E-10	1.3 E-9

Figure 5-2

ALPHA CONCENTRATION

ALL LOCATIONS

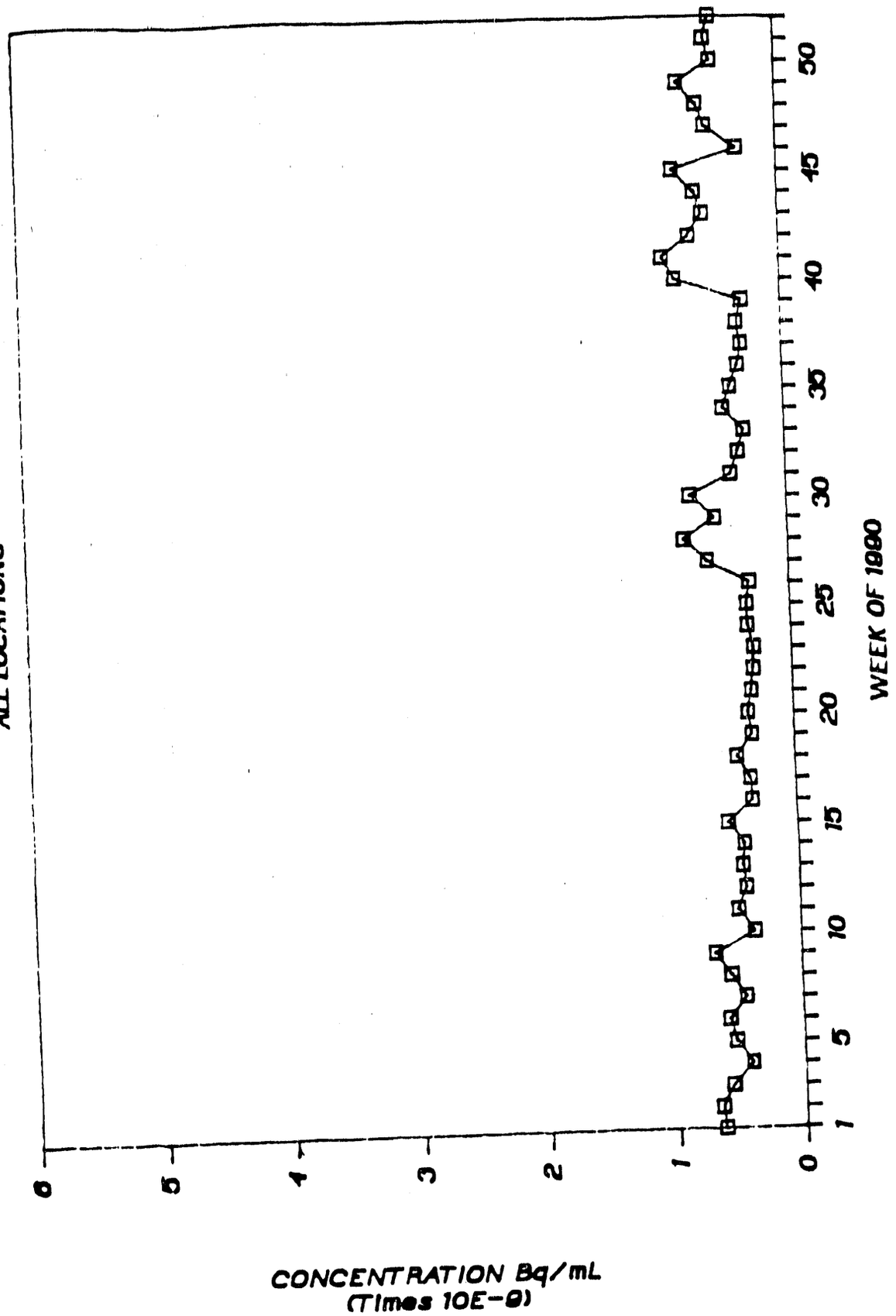
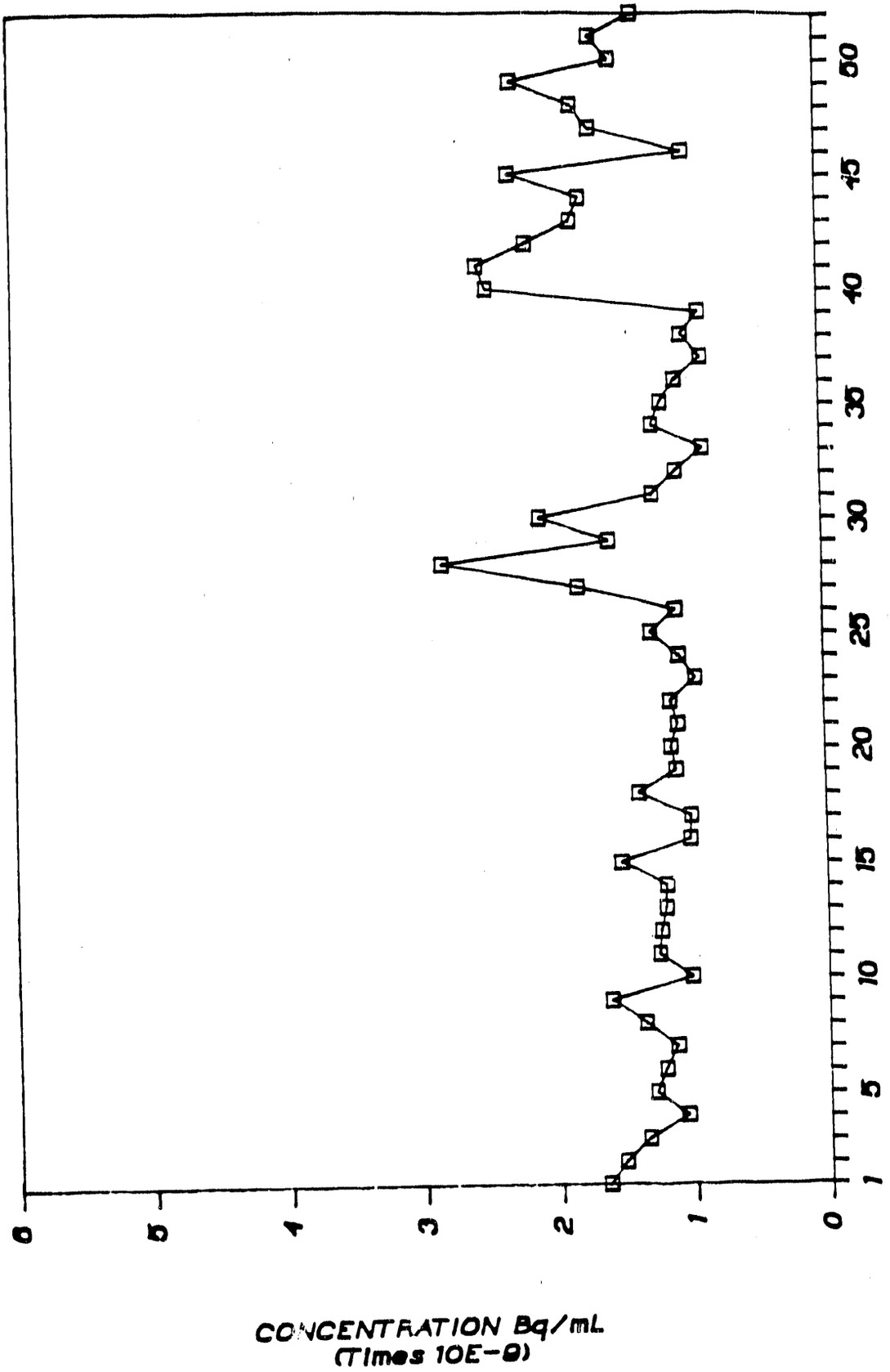


Figure 5-3

BETA CONCENTRATION

ALL LOCATIONS



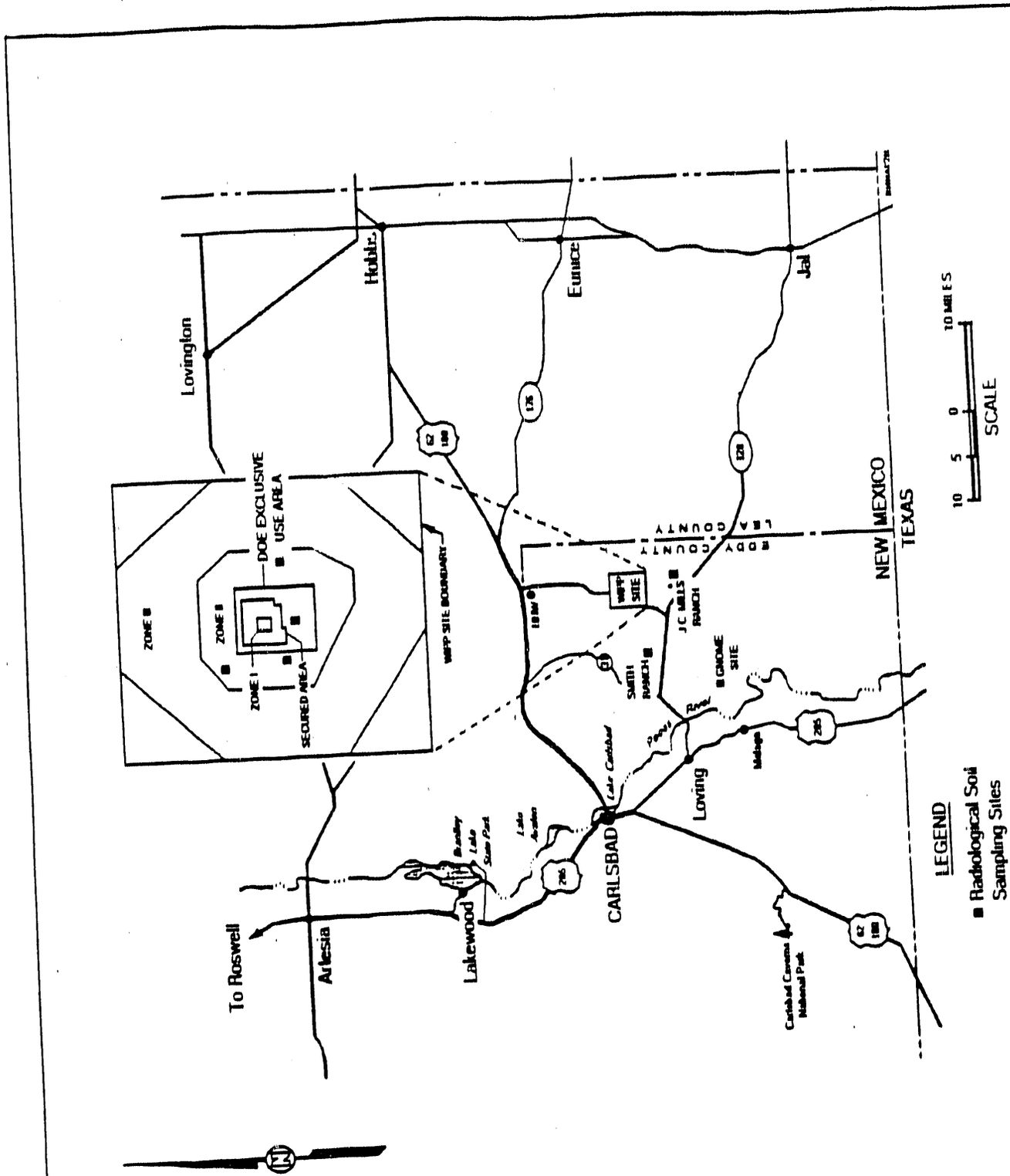


Figure 5-4
Radiological Soil Sampling Sites

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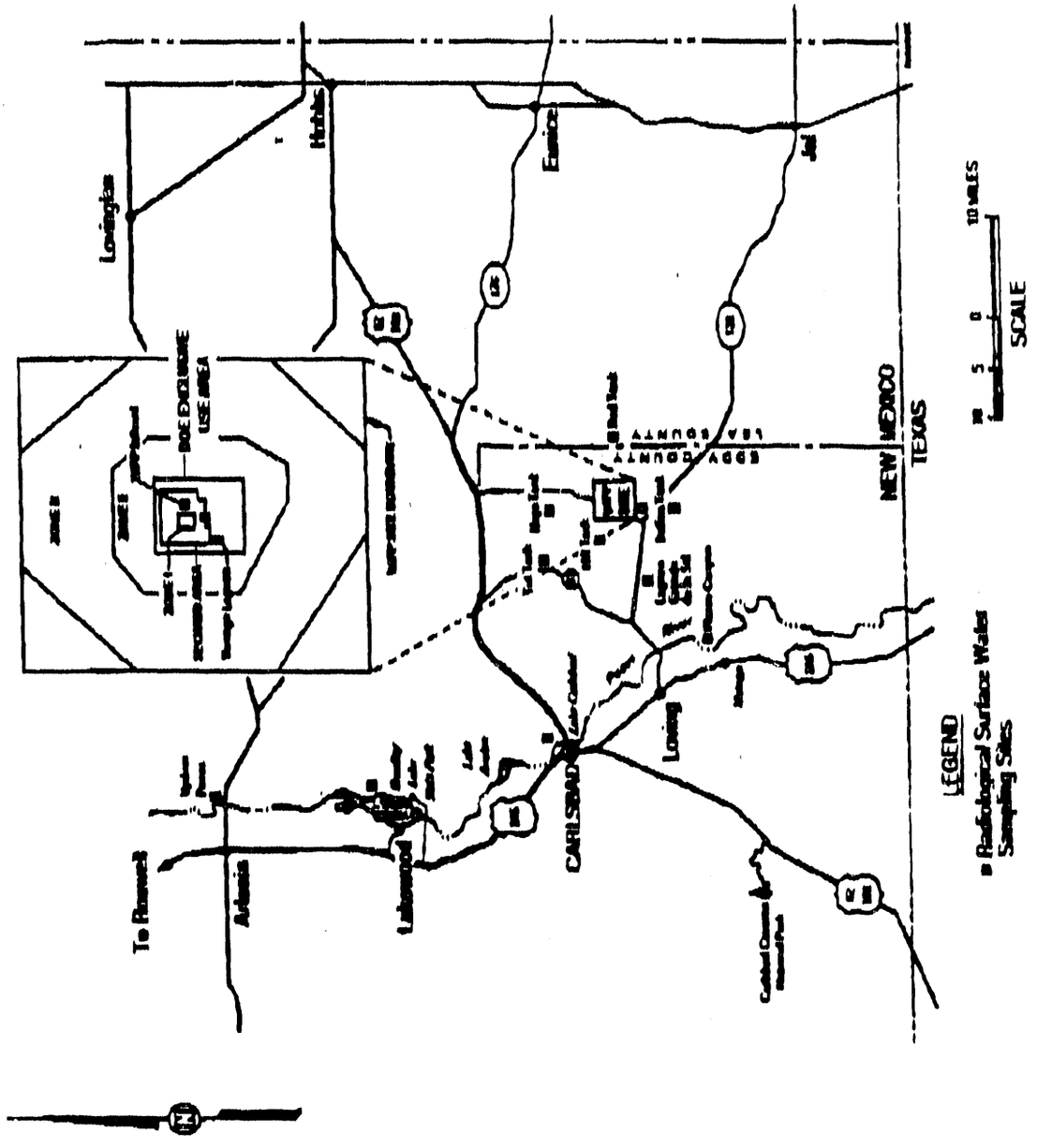

Figure 5-5
Radiological Surface Water Sampling Sites

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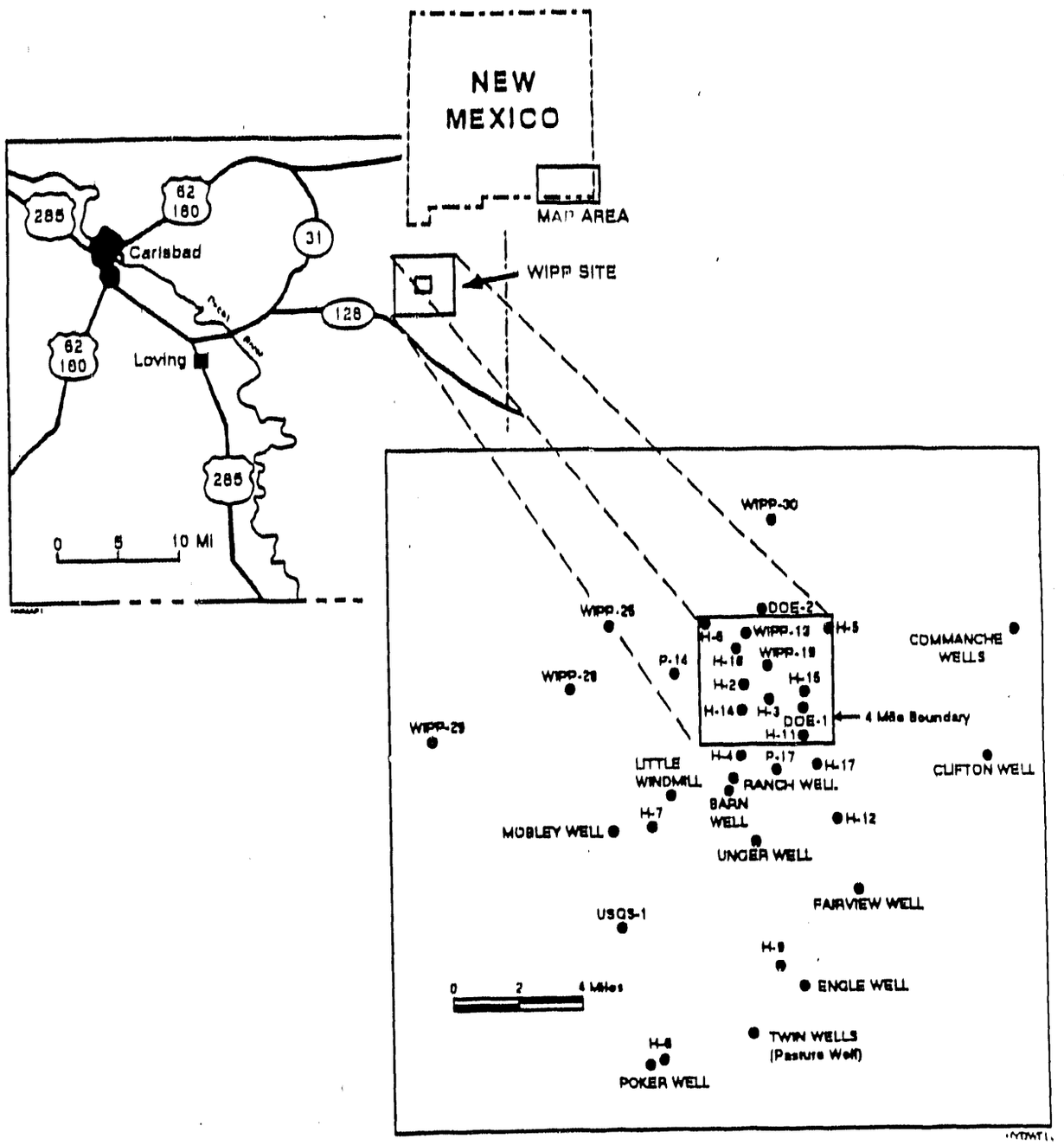

Figure 5-6
Groundwater Sampling Locations

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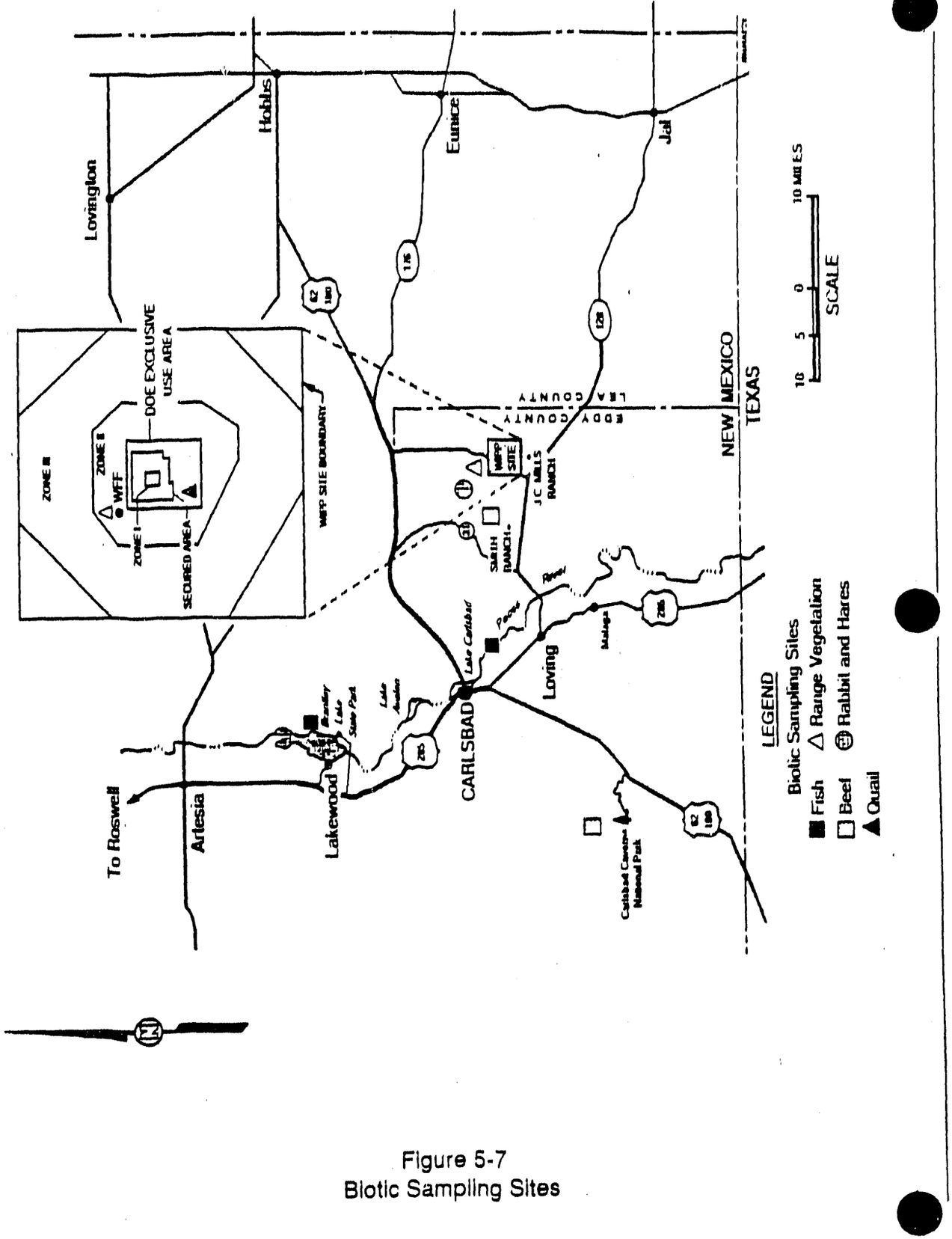

Figure 5-7
Biotic Sampling Sites

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CHAPTER 6

ENVIRONMENTAL NONRADIOLOGICAL PROGRAM INFORMATION

During March 1989, the monitoring activities of the EMP were combined into the OEMP. This program is described in DOE/WIPP 88-025 Operational Environmental Monitoring Plan for the Waste Isolation Pilot Plant. This plan defined the scope and extent of the WIPP effluent and environmental monitoring programs during the operational life of the facility. The OEMP is the data base for all environmental comparisons once the WIPP is operational. It also discusses the quality assurance and quality control programs. The Non Radiological Environmental Surveillance (NES) is conducted by the Environmental Monitoring Section of the Environment, Safety, Health Department. This program was preceded by the WIPP Biology Program (1975-1982), which combined scientific and technical expertise from six universities to develop an extensive baseline of information describing the major components of the Los Medanos ecosystem prior to the initiation of WIPP construction activities. The principal functions of the NES are:

- To detect and quantify the impacts of construction and operational activities at the WIPP on the surrounding ecosystem
- To continue the development of the ecological data base for the Los Medanos Area which was initiated by the WIPP biology program
- To investigate unusual and unexpected elements in the ecological and radiological data bases
- To provide environmental data which are important to the mission of the WIPP project, but which have not or will not be acquired by other programs

This section of the ASER presents and discusses data collected between January 1, 1990, and December 31, 1990, as part of the NES of the OEMP. Ecological monitoring at the WIPP includes five subprograms (1) meteorological monitoring, (2) air quality monitoring, (3) water quality monitoring, (4) wildlife population monitoring, and (5) surface disturbance monitoring through the analysis of aerial photographs. The salt impact studies include three subprograms: soil chemistry, soil microbial activity, and vegetation. The results of the environmental monitoring activities and discussions of significant findings are presented in this report.

Unless otherwise noted, all methods used in data collection are those described in the first Ecological Monitoring Program semiannual report (DOE/WIPP 86-002) and incorporating the modifications described in subsequent reports (Fisher et al., 1985; Fisher, 1987; Fisher, 1988; Jones, 1989).

6.1 METEOROLOGY

The WIPP NES includes a primary meteorological station which provides support for various programs at the WIPP. Its primary function is to generate data to aid in modeling atmospheric conditions for RES. The meteorological station documents standard meteorological measurements of wind speed, wind direction, and temperatures at 3, 10, and 40 meters, respectively, with dew point, and precipitation monitored at ground level. These parameters are continuously measured and the data are stored as real time data in the central monitoring system.

In addition to the primary meteorological station, the WIPP is equipped with an atmospheric monitoring station (AMS) which monitors pollutant gases. At the AMS a secondary meteorological station measures and records temperature and barometric pressure, with wind speed and wind direction at 30 feet (10 meters).

6.1.1 Climatic Data Summary

The average annual temperature for the WIPP area in 1990 was 18 °C (64°F). The range for monthly mean temperatures for the WIPP area was 7° to 32 ° C (45° to 89 ° F). (Daily maximum, minimum, and average temperature are presented in Appendix III.) Maximum temperatures occur May through August and minimums occur in December through February.

The last freezing day of the 1989-90 winter season was May 2, with a temperature of 0° C (32°F). The first freezing day of the 1990-91 winter season occurred November 5, with 0° C (32° F). The maximum temperature recorded was 46 °C (115 ° F) on June 24. The minimum temperature was -14 °C (7 ° F) on December 23, 1990.

The annual precipitation at the WIPP for 1990 was 41 cm (15.97 in), which is above the average for this area by 10 cm (3.97 in). The precipitation for 1990 was 62% more than that recorded for 1989. This has helped to alleviate the drought effects on the ecosystem of this area. Figure 6-1 displays the monthly precipitation at the WIPP for CY 1990.

6.1.2 Wind Direction and Wind Speed

In 1990 the predominate winds in the WIPP area were from the southeast sector. Other notable winds occur in late spring and are primarily from the west. Various storm systems move through this area which briefly alter the predominate southeasterly winds. Wind speed noted as calm (less than 0.5 meters per second (MPS) occurred less than one percent of the time. Winds of 1.4 through 10.7 MPS were the most prevalent over 1990.

6.2 ENVIRONMENTAL PHOTOGRAPHY

Aerial photographs of the WIPP site were taken semiannually from 1982 till 1989. The 1990, aerial photographs were taken once, during late summer, to document surface disturbance, development, and reclamation activities at the WIPP site and surrounding BLM/DOE lands. Spot photographs and aerial flight lines are archived for future reference use.

Surface photography has been conducted at seven ecological study plots since 1984. These photographs are used to document surface impacts at the study plots. Other than the development of trails beginning in some plots due to foot traffic, 1990 comparative examinations of these photographs show very little surface impact.

6.3 AIR QUALITY MONITORING

Seven classes of pollutant gases are monitored 1000 meters (0.6 mile) northeast of the exhaust shaft at the WIPP site on a continuous basis. These are: sulfur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), hydrogen sulfide (H_2S), and oxides of nitrogen (NO, NO_2, NO_x). In addition, weekly measurements of Total Suspended Particulates are made from the particulates collected by the low-volume continuous air sampler at the far-field air sampling location.

The ambient gas monitors are extremely sensitive instruments which require semiannual recertification by a factory engineer. Other than typical adjustments, replacement of filters, and replacement of worn parts the ambient gas analyzers required no significant maintenance action.

The data generated by the analyzers was at the lower limit of detection, which is below the permissible concentrations for the State of New Mexico. The permissible New Mexico state standard for the gases monitored at the WIPP are listed below:

- SO_2 10 ppm annually
- CO 8.70 ppm per eight hour average
- O_3 0.06 ppm per one hour average
- NO_x 0.10 ppm per one-hour average
- H_2S 0.10 ppm per one-half hour average

6.4 SURFACE WATER AND SEDIMENT QUALITY MONITORING

During CY 1990, no annual surface water or sediment quality monitoring was conducted. The OEMP requires annual collection and monitoring of these parameters when the WIPP is operational. However, with the WIPP being in a preoperational state during 1990, there is no requirement to sample annually, since a preoperational baseline has been established. Preoperational monitoring began in 1985 and continued through 1988 with samples collected annually (Figure 6-2). With three years of background data, continuing with annual monitoring is not required.

6.5 WILDLIFE POPULATION MONITORING

Population density measurements of breeding birds and small nocturnal mammals are performed annually to assess the effects of the WIPP activities on wildlife populations. Two permanent study sites adjacent to the WIPP facility are used for each of these two classes of wildlife. The data are compared to two control sites for each class in order to assess the effects of WIPP on wildlife populations. Trap grids are used to measure small mammal populations, and 2500 ft Emlen-type transacts are used to measure bird population densities.

6.5.1 Breeding Bird Densities

Breeding bird densities maintained similar pattern variations as previous years as is represented in Table 6-1, Breeding Bird Densities. Population densities were low in control plots compared to previous years data. Additionally, control plots displayed densities lower than those found in WIPP transects. Variations worthy of note occurred in Northern Mockingbirds, Bobwhites, and Mourning dove. Insect dependant species, most notable ladderbacked woodpeckers, were more abundant near the site than in previous years. Overall, the patterns of species distribution between the WIPP transacts and the Control transacts follow that of previous years. More species and a higher total density were found in the WIPP transects, probably due to greater habitat diversity near the facility and perhaps more abundant food. Greater numbers of flycatchers account for the largest increase of birds near the facility.

6.5.2 Small Nocturnal Mammal Population Densities

Tables 6-2 and 6-3 summarize the results of the 1990 small mammal surveys in the Control 1 and 2 (CT1 and CT2, respectively) and WIPP Northwest 2 and Southeast 2 (NW2 and SE2, respectively) trap grids. Grids are composed of 100 traps set in a 150m x 150m grid with traps spaced 15m apart; the Y axis is noted as 1 through 10 and the X axis is noted as A through J. Trapping sessions began May 15, 1990 for the NW2 and CT2 grids and ended on May 25, 1990, and May 30, respectively. For the SE2 and CT1 grids, they were initiate May 30 and completed June 21, 1991. Mammals were trapped using Sherman live traps baited with cracked grains.

Mammals were trapped and released for two weeks, three successive nights per week. For kangaroo rats, wood and hispid cotton rats, deer mice, and grasshopper mice, numbered ear tags were used to identify individuals while clipping of the rear left outer digit was used for the smaller pocket mice. Grid location of trapped individuals as well as genus, species, new or recapture, tag number or digit removal, sex and weight were logged on Small Mammal Data Sheets. From this data population densities, actual numbers of captures for each genus, travel distances for recaptured individuals, and male/female ratios were calculated.

Population densities were calculated using the "Schnabel method" (Tanner 1978) for mark and recapture mammal trapping. Kangaroo rats were the most common species encountered and are the only genus calculable (Table 6-2) for determining the maximum likelihood estimation of population and variance estimation. All other genera were generally too small in number to calculate population densities using the "Schnabel method" and are listed in Table 6-3 which lists the actual number of captures (including kangaroo rats) rather than statistical populations for each plot.

Within each grid, all the rodents occupy a certain amount of space. By using the data sheets and plotting all recaptured animals, their unique numbers and their grid locations, total distances each animal moved within the grids during the two trapping sessions was determinable. Of the 115 kangaroo rats surveyed, 25 moved 0m (that is they were recaptured consecutively each night in the same trap location). This may be due to home ranges or lactating females, as 17 of the 25 were females. The longest distance traveled was a male in NW2 which traveled 246m. (807 ft.) The average distance males traveled in all plots was 55.1m (180.8ft.), females traveled an average of 48.9m (160.4ft.).

In all grids, except NW2, females were dominant. The CT1 population was 69.23% female and 30.77% male, CT2 was 72.22 % female and 27.78% male, SE2 was 85.71% female and 14.29% male, and NW2 was 42.86% female and 57.14% male.

Densities were generally higher in all species in 1990 than the six year average except for the Plains Pocket Mouse. Plains Pocket Mice were most dense in the control plots. Populations of White-footed and Deer Mice were most prevalent around the site. Of interest to note, one Hispid Cotton Rat (Sigmodon hispidus) was trapped in Control 1. This genus was last trapped in the same plot in 1985 and has not been trapped in any other plot since the previous 1985 trapping

6.6 SURFACE AND SUBSURFACE SOIL MONITORING

During CY 1990 the quarterly sampling of the surface soil as well as the annual deep series was conducted during the second quarter. The subsurface soil is collected at two depths, 30 to 45 centimeters (11.8 to 17.7 in) and 60 to 75 centimeters (23.6 to 29.5 in), in the soil profile (Figure 6-3). However, with the WIPP being in a preoperational, state during 1990, and with on adequate baseline established concerning soil properties at the WIPP. No analysis was performed on the soil samples collected. The sample collected are archived for future analysis if conditions indicate additional soil analytical data is warranted.

With the baseline data established, continuing the quarterly soil analysis was not required by the OEMP. However with the anticipation of the WIPP becoming operational in 1991. The quarterly analysis of soil samples will once again commence as directed by the OEMP with the awarding of a new laboratory contract for soil analysis.

6.7 SOIL MICROBIOTA

The soil microbial sampling subprogram is designed to monitor an important portion of the biological community which can be affected by changes in chemical properties at the soil surface. The normal cycle of microbial activity is generally influenced by climatic factors as well as the physical and chemical nature of the substrate, which in this study is plant litter. Microbial activity levels and the rate at which the surface litter is decomposed by the microbial community in the control plots are compared to those in the near-field and far-field plots to detect any effect of salt deposition on these biological processes.

6.7.1 Methods

A litter sample is composed of two nylon mesh bags fastened together with a nylon tie, each containing ten grams of oven-dried shinnery oak leaves (Quercus havardii) which are collected at the time of leaf fall. In February, six samples of litter are placed at random locations in each of the ecological monitoring plots. Each sample is attached to the base of a shinnery oak stem. Three samples are collected from each plot every six months.

Two parameters are measured for each litter sample collected: the level of microbial activity and the rate at which organic matter is lost from the sample via decomposition. Microbial activity levels are measured indirectly using the fluorescein diacetate hydrolysis assay (FDA), described by Schnurer and Rosswall (1982). The assayed enzymes are produced in small quantities in dormant organisms and spores relative to the quantity produced by active colonies. Therefore, the optical density of the sample, which is a measure of the amount of breakdown product produced from a known quantity of fluorescein diacetate substrate, is proportional to the total microbial respiration in the sample. Activity levels measured at a given time are affected by the immediate chemical and physical conditions in the environment, (i.e., moisture, temperature, and nutrient availability).

The rate at which plant litter is broken down by microbial action is another indirect measure of a biotic soil process. The amount of organic matter lost from the litter over time is determined using the ashing technique described by Santos, et al. (1984). Decomposition rates reflect to a greater degree than microbial activity levels, the long-term impacts of the physical and chemical environment.

Results of the FDA assay are analyzed using an analysis of variance (ANOVA) method. To determine decomposition rates, an arcsine transformation is applied to the percentage values prior to the ANOVA use. When the ANOVA indicates that significant differences exist between plot means, a Student-Newan-Keuls test is performed to identify homogeneous means.

In February 1990, six litter samples were placed in each of the ecological monitoring plots. Three samples were collected from each plot in August. The second set was collected in February 1990. No significant differences were found in either the rate of decomposition or the microbial activity between plots in 1990.

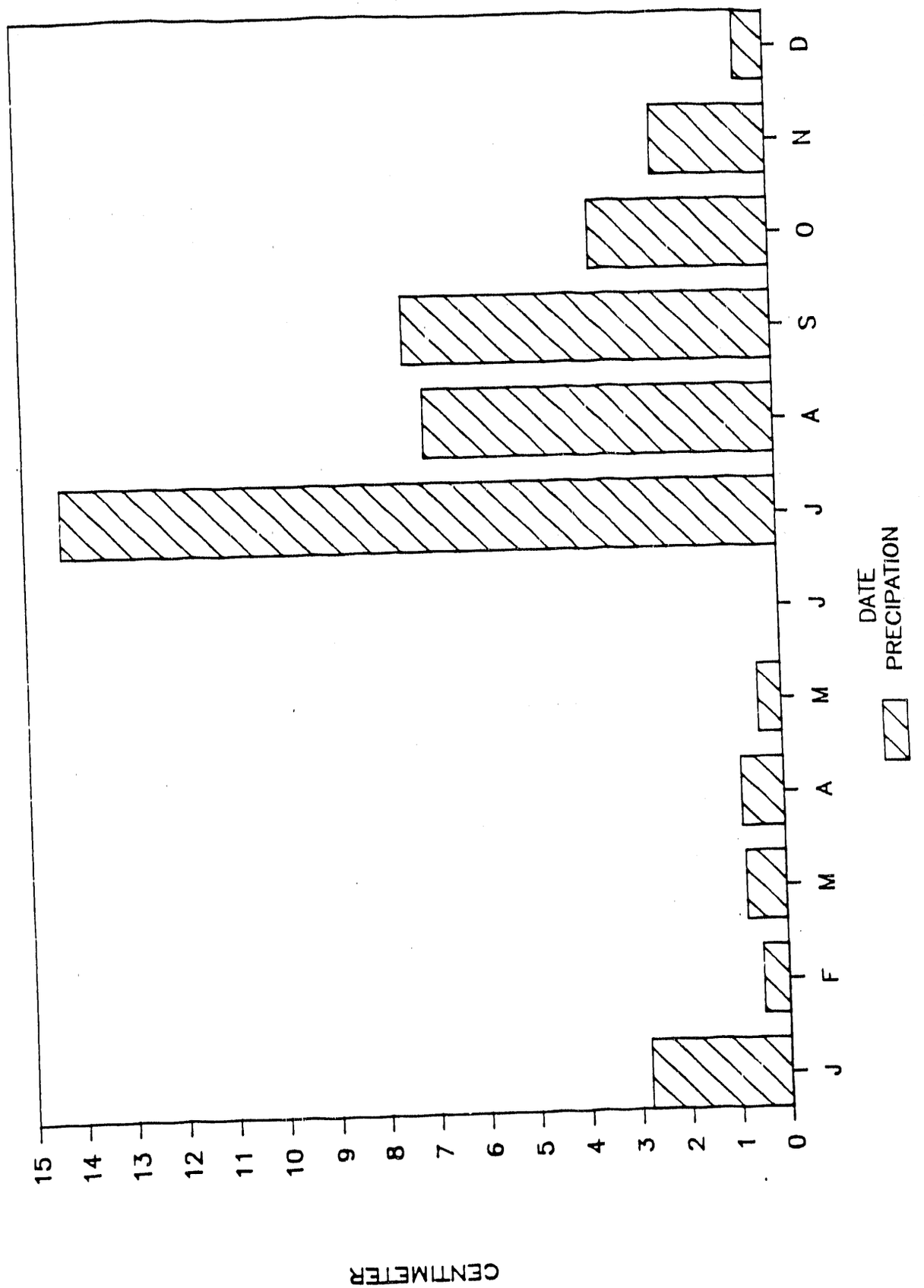
6.8 VEGETATION MONITORING

The vegetation in each of the seven ecological monitoring plots was measured in the early summer (June and July) and again in the early fall (September and October) to assess the effect the salt piles may be having on proximal plant community structures. In each plot, foliage of each species, and species diversity are measured using the methods described in Reith, et al, 1985; and of 20 quadrat frames ($1m^2$) was also calculated. The frequency of a species is defined as the proportion (percent) of the quadrats containing that species.

Summaries of the data for the spring and fall sampling periods are presented in Tables 6-4 and 6-5, respectively. The CY 1990 precipitation of 41 cm (15.97 in) was a substantial increase over the 1989 drought condition of 25 cm (9.84 in). Drought conditions persisted form February through June, as is reflected in the spring vegetation data Table 6-4, but dramatically changed as precipitation began in July and continued through November which is reflected in the increases in all parameters for the fall vegetation data, Table 6-5.

The 1990 vegetation monitoring data showed a continual increase in shrub cover and a continual decrease in the grasses in proximity to the salt piles. These values are consistent with the 1988 and 1989 data. The responses of these plots to higher rainfall in later years will reveal whether this pattern is reflecting the start of a significant change in the structure of the plant community or whether it is only a short-term effect caused by short-term weather conditions. A differential effect resulting from salt-induced physiological stress near the salt pile was not observed. Of greatest significance in the 1990 vegetation monitoring data was the observation that the drought conditions of this year have had a uniform effect on vegetation in all plots. A differential effect resulting from salt-induced physiological stress near the salt piles was not observed.

FIGURE 6-1


1990 PRECIPATION
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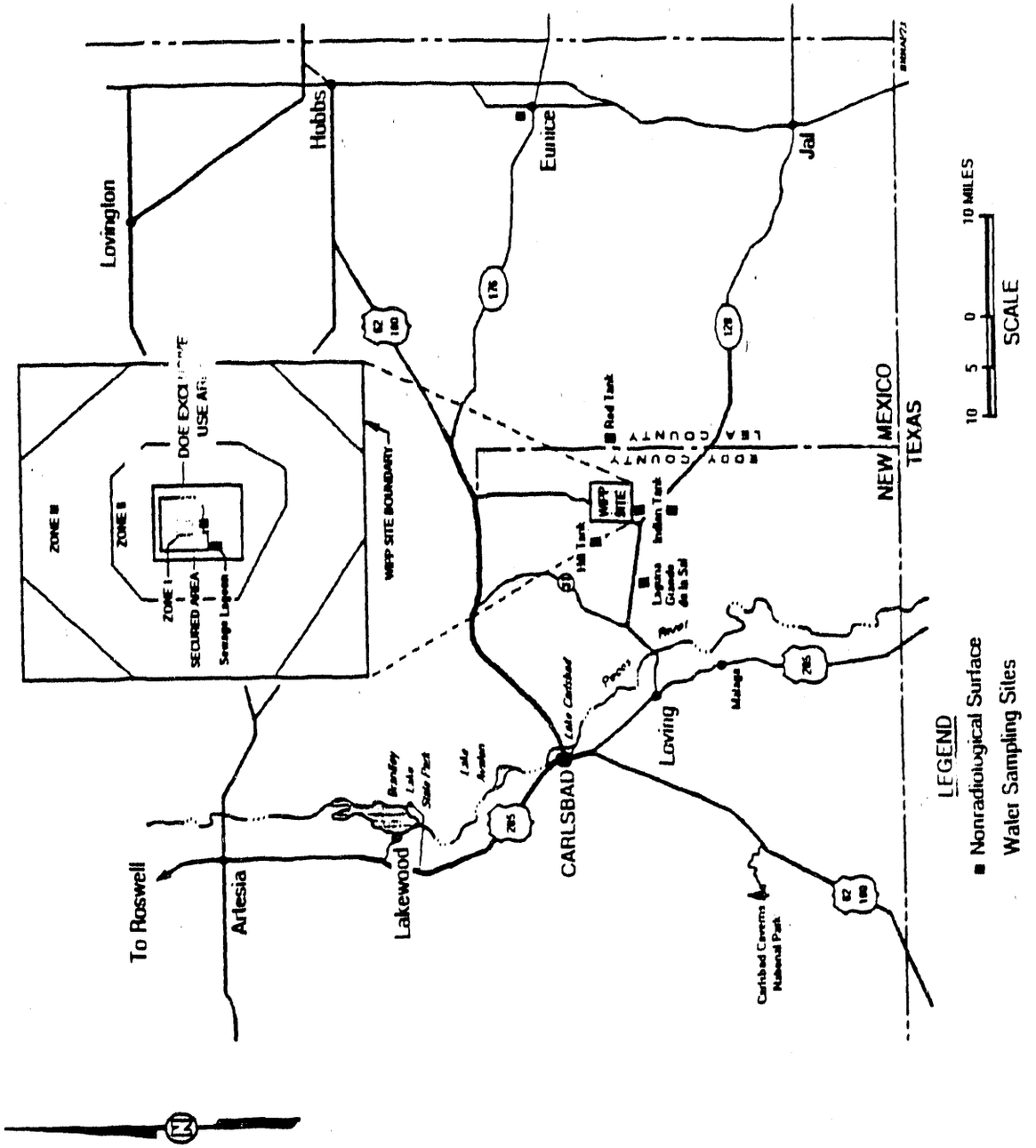

Figure 6-2
Nonradiological Surface Water Sampling Sites

591B.0199J

Table 6-1

SUMMARY OF THE 1990 BREEDING BIRD DENSITY MEASUREMENTS (in birds per 40ha)

	CONTROL TRANSECTS				WIPP TRANSECTS			
	CT1	CT2	AVERAGE 1990	AVERAGE 1984-1990	NW	SE	AVERAGE 1990	AVERAGE 1984-1990
-DOMINANT CONTROL SPECIES-								
BLACK-THROATED SPARROW	16.1	30.1	23.1	25.8	17.2	17.2	17.2	22.0
PYRRHULOXIA	23.7	22.6	23.2	18.8	23.7	19.4	21.6	16.5
NORTHERN MOCKINGBIRD	4.3	2.2	3.3	10.7	8.6	8.6	8.6	13.6
NORTHERN BOBWHITE	1.1	0.0	0.6	9.8	2.2	1.1	1.7	4.9
MOURNING DOVE	0.0	0.0	0.0	7.1	6.5	2.2	4.4	4.3
BROWN-HEADED COWBIRD	4.3	4.3	4.3	5.0	4.3	8.6	6.5	3.0
LOGGERHEAD SHRIKE	0.5	4.3	2.4	4.5	0.5	4.3	2.4	3.1
EASTERN MEADOWLARK	0.0	1.1	0.6	3.0	0.0	0.0	0.0	1.1
CACTUS WREN	3.2	8.6	5.9	2.6	0.0	8.6	4.3	6.4
COMMON NIGHTHAWK	0.0	4.3	2.2	2.5	1.1	2.2	1.7	2.1
SCALED QUAIL	1.1	0.0	0.6	2.3	0.0	0.0	0.0	0.5
CHIHUAHUAN RAVEN	2.2	0.0	1.1	1.2	0.0	4.3	2.2	1.3
WESTERN KINGBIRD	8.6	0.0	4.3	1.1	4.3	12.9	8.6	6.6
-MINOR CONTROL SPECIES-								
CASSIN'S SPARROW	1.1	0.0	0.6	0.9	2.2	0.0	1.1	0.4
CRISSAL THRASHER	1.1	2.2	1.7	0.8	0.0	0.0	0.0	0.0
ASH-THROATED FLYCATCHER	0.0	0.0	0.0	0.8	2.2	12.9	7.6	3.8
POORWILL	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.3
SCISSOR-TAILED FLYCATCHER	0.0	1.1	0.6	0.7	0.0	0.5	0.3	0.6
BREWER'S SPARROW	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
HOUSE FINCH	0.0	0.0	0.0	0.4	0.0	0.0	0.0	1.7
LARK BUNTING	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.3
YELLOW-HEADED BLACKBIRD	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.3
GREAT HORNED OWL	0.0	0.0	0.0	0.1	2.2	0.0	1.1	0.5
SWAINSON'S HAWK	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
HARRIS' HAWK	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-WIPP SPECIES-								
NORTHERN ORIOLE	0.0	0.0	0.0	0.0	2.2	4.3	3.3	2.1
LADDER-BACKED WOODPECKER	0.0	0.0	0.0	0.0	4.3	8.6	6.5	1.7
BARN SWALLOW	0.0	0.0	0.0	0.0	0.0	4.3	2.2	1.4
GREATER ROADRUNNER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
LARK SPARROW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
LESSER GOLDFINCH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
BELL'S VIREO	0.0	0.0	0.0	0.0	0.0	4.3	2.2	0.3
YELLOW WARBLER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
KILLDEER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
HOUSE SPARROW	0.0	0.0	0.0	0.0	0.0	2.2	1.1	0.2
TOTAL DENSITY	67.3	80.8	74.1	99.6	81.5	126.5	104.0	101.1
NUMBER OF SPECIES	12	10	15	23	14	18	20	32

Table 6-1
(continued)

SUMMARY OF THE 1990 BREEDING BIRD DENSITY MEASUREMENTS (IN BIRDS PER 40ha) CONTINUED

	AVERAGE 1984-1989		AVERAGE 1990	AVERAGE 1984-1990	AVERAGE 1984-1989		AVERAGE 1990	AVE 1984
-DOMINANT CONTROL SPECIES-	----------CONTROL TRANSECTS----------				----------WIPP TRANSECTS----------			
BLACK-THROATED SPARROW	26.3	157.8	23.1	25.8	22.8	136.8	17.2	2
PYRRHULOXIA	18.1	108.6	23.2	18.8	15.6	93.6	21.6	16
NORTHERN MOCKINGBIRD	11.9	71.4	3.3	10.7	14.4	86.4	8.6	13
NORTHERN BOBWHITE	11.3	67.8	0.6	9.8	5.4	32.4	1.7	4
MOURNING DOVE	8.3	49.8	0.0	7.1	4.3	25.8	4.4	4
BROWN-HEADED COWBIRD	5.1	30.6	4.3	5.0	2.4	14.4	6.5	3
LOGGERHEAD SHRIKE	4.8	28.8	2.4	4.5	3.2	19.2	2.4	3
EASTERN MEADOWLARK	3.4	20.4	0.6	3.0	1.3	7.8	0.0	1
CACTUS WREN	2.0	12.0	5.9	2.6	6.7	40.2	4.3	6
COMMON NIGHTHAWK	2.5	15.0	2.2	2.5	2.2	13.2	1.7	2
SCALED QUAIL	2.6	15.6	0.6	2.3	0.6	3.6	0.0	0
CHIHUAHUAN RAVEN	1.2	7.2	1.1	1.2	1.2	7.2	2.2	
WESTERN KINGBIRD	0.6	3.6	4.3	1.1	6.3	37.8	8.6	6
-MINOR CONTROL SPECIES-								
CASSIN'S SPARROW	0.9	5.4	0.6	0.9	0.3	1.8	1.1	0
CRISSAL THRASHER	0.7	4.2	1.7	0.8	0.0	0.0	0.0	0
ASH-THROATED FLYCATCHER	0.9	5.4	0.0	0.8	3.2	19.2	7.6	3
POORWILL	0.9	5.4	0.0	0.8	0.3	1.8	0.0	0
SCISSOR-TAILED FLYCATCHER	0.7	4.2	0.6	0.7	0.6	3.6	0.3	0
BREWER'S SPARROW	0.6	3.6	0.0	0.5	0.0	0.0	0.0	0
HOUSE FINCH	0.5	3.0	0.0	0.4	2.0	12.0	0.0	1
LARK BUNTING	0.2	1.2	0.0	0.2	0.4	2.4	0.0	0
YELLOW-HEADED BLACKBIRD	0.2	1.2	0.0	0.2	0.3	1.8	0.0	0
GREAT HORNED OWL	0.1	0.6	0.0	0.1	0.4	2.4	1.1	0
SWAINSON'S HAWK	0.0	0.0	0.0	0.0	0.2	1.2	0.0	0
HARRIS' HAWK	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
-WIPP SPECIES-								
NORTHERN ORIOLE	0.0	0.0	0.0	0.0	1.9	11.4	3.3	
LADDER-BACKED WOODPECKER	0.0	0.0	0.0	0.0	0.9	5.4	6.5	
BARN SWALLOW	0.0	0.0	0.0	0.0	1.3	7.8	2.2	
GREATER ROADRUNNER	0.0	0.0	0.0	0.0	0.8	4.8	0.0	
LARK SPARROW	0.0	0.0	0.0	0.0	0.6	3.6	0.0	
LESSER GOLDFINCH	0.0	0.0	0.0	0.0	0.4	2.4	0.0	
BELL'S VIREO	0.0	0.0	0.0	0.0	0.0	0.0	2.2	
YELLOW WARBLER	0.0	0.0	0.0	0.0	0.3	1.8	0.0	
KILLDEER	0.0	0.0	0.0	0.0	0.3	1.8	0.0	
HOUSE SPARROW	0.0	0.0	0.0	0.0	0.0	2.2	1.1	
TOTAL DENSITY	103.8	622.8	74.1	99.6	100.6	605.8	104.0	1
NUMBER OF SPECIES	23	23	15	23	30	31	20	

TABLE 6-2

Maximum estimation and variance for population density of Dipodomys ordii (Ords Kangaroo Rat).

ORD'S KANGAROO RAT		CT1	CT2	NW2	SE2
ESTIMATED POPULATION	39.8	18.8	34.6	24.6	
ESTIMATED MINIMUM	33.3	14.7	28.8	19.6	
ESTIMATED MAXIMUM	49.5	26.2	43.3	33.2	
ACTUAL CAPTURES	42	21	36	25	

TABLE 6-3

Actual captures of nocturnal mammals in 1990.

	CT1	CT2	NW2	SE2
ORD'S KANGAROO RAT	42	21	36	25
WHITE FOOTED/DEER MOUSE	0	0	1	8
PLAINS POCKET MOUSE	4	3	1	0
GRASSHOPPER MOUSE	7	0	0	3
HISPID COTTON RAT	1	0	0	0
PLAINS WOOD RAT	3	0	5	2

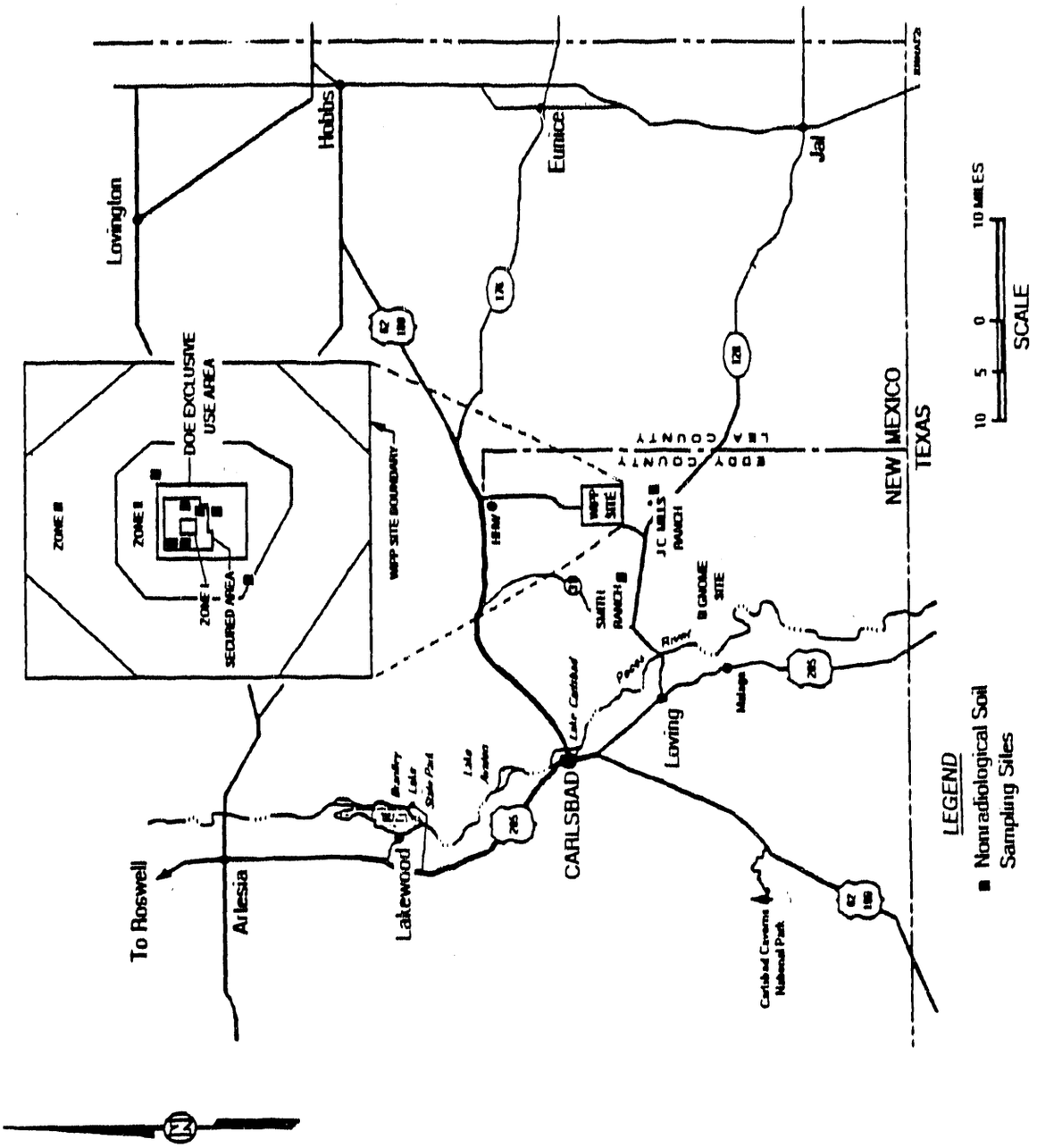

Figure 6-3
Nonradiological Soil Sampling Sites

591B:01991

Table 6-4

WIPP 1990 SPRING VEGETATION REPORT

	CONTROL PLOTS (1)			EXCLOSURE PLOTS (2)		
	COVER (5)	FREQ. (6)	DENS. (7)	COVER	FREQ.	DENS.
.....SHRUBS.....						
SAND SAGE	0.52	33%	0.00	0.42	35%	0.00
FOUR-WING SALTBUSH	0.00	0%	0.00	0.00	0%	0.00
HARTWEG PRIMROSE	0.00	0%	0.00	0.00	0%	0.00
SOUTHWEST RABBITBUSH	0.15	8%	0.00	0.09	10%	0.00
CROTON	0.34	10%	0.00	0.25	8%	0.00
SNAKEWEED	0.08	3%	0.00	0.00	0%	0.00
ENGELMANN PRICKLY-PEAR	0.81	10%	0.00	1.88	8%	0.00
HONEY MESQUITE	3.41	78%	0.00	2.72	80%	0.00
SHINNERY OAK						
WILD CHINABERRY						
YUCCA	1.62	30%	0.00	0.18	5%	0.00
---PERENNIAL FORBES---						
SNAPDRAGON						
MILKWEED						
COMMELINA SP.						
CYPERUS SP.						
WOOLLEY DALA						
SPINY YELLOW ASTER	0.18	10%	0.00	0.00	0%	0.00
HOG POTATO	0.01	3%	0.00	0.00	0%	0.00
SMOOTH OXYBAPHUS						
LEAF-FLOWER						
CLIMBING MILKWEED						
ELEGANT NIGHTSHADE						
COTTA						
GOLDEN CROWNBEARD						
----ANNUAL FORBES-----						
RAGWEED	0.01	3%	0.00	0.00	0%	0.00
ARIZONA DOZE DAISY						
BUGSEED						
ANNUAL BUCKWHEAT	0.00	0%	0.00	0.01	3%	0.05
FLEABANE						
LACE SPURGE						
EUPHORBIA SP.						
FORB SEEDLING						
BINDWEED HELIOTROPE						
PRAIRIE SUNFLOWER	0.00	0%	0.00	0.00	0%	0.00
WHITE RAGWEED						
KOCHIA						
INDIAN CHICKWEED						
PALAFOXIA						
FETID MARIGOLD						
PORTULACE SP.						
DUNE DEVILS-CLAW						
RUSSIAN THISTLE						
PRICKLY SOWTHISTLE						
--PERENNIAL GRASSES---						
LITTLE BLUESTEM	1.09	63%	0.00	0.23	45%	0.00
PURPLE THREE-AWN	0.00	0%	0.00	0.00	0%	0.00
BLACK GRAMA	0.00	0%	0.00	0.00	0%	0.00
SANDHILL GRASS	0.00	0%	0.00	0.00	0%	0.00
SANDBUR	0.03	8%	0.00	0.01	3%	0.00
INTERMEDIATE LOVEGRASS						
MEXICAN LOVEGRASS	0.00	0%	0.00	0.02	5%	0.00
FALL WITCHGRASS	0.00	0%	0.00	0.00	0%	0.00
EAR MUHLY						
KNOTGRASS						
PLAINS BRISTLEGRASS	0.02	8%	0.00	0.02	5%	0.00
SPIKE DROPSEED	0.08	13%	0.00	0.16	38%	0.00
SAND DROPSEED						
MESA DROPSEED	0.00	0%	0.00	0.07	18%	0.00
GIANT DROPSEED						
----ANNUAL GRASSES----						
GRASS SEEDLING						
FALSE BUFALOGRASS						
PURPLE SANDGRASS						

TOTALS BY GROUP

	CONTROL			EXCLOSURE		
----SPECIES GROUP-----	COVER	DENS.	NO. OF SP.	COVER	DENS.	NO. OF SP.
SHRUBS (8)	6.12	0.00	7	3.66	0.00	6
PERENNIAL FORBES	0.19	0.00	2	0.00	0.00	0
ANNUAL FORBES	0.01	0.00	1	0.01	0.05	1
PERENNIAL GRASSES	1.22	0.00	4	0.51	0.00	6
ANNUAL GRASSES (9)	0.00	0.00	0	0.00	0.00	0
TOTAL	7.54	0.00	14	4.18	0.05	13

(1) Control Plots include plots CT1 and CT2, more than 2km from the salt piles
(2) Exclosure Plots include plots DOE-1 and E2-RR, which are fenced areas
(3) Far Field Plots include plots NW2 and SE2, approximately 200km from the salt piles
(4) Near Field Plots include plots NW1, SE1 and E1, which are adjacent to the salt piles
(5) Foliar cover, in percent
(6) Frequeny in the sample, in percent
(7) Density of annual species only, in plants per square meter
(8) Coverage does not include honey mesquite
(9) Number of species does not include grass seedlings

WIPP 1990 SPRING VEGETATION REPORT

	FAR FIELD PLOTS (3)			NEAR FIELD PLOTS (4)		
	COVER	FREQ.	DENS.	COVER	FREQ.	DENS.
---------SHRUBS---------						
SAND SAGE	1.13	53%	0.00	3.94	60%	0.00
FOUR-WING SALTBUSH	0.00	0%	0.00	0.02	2%	0.00
HARTWEG PRIMROSE	0.01	3%	0.00	0.01	2%	0.00
SOUTHWEST RABBITBUSH						
CROTON	0.00	0%	0.00	0.06	3%	0.00
SNAKEWEED	0.00	0%	0.00	0.11	7%	0.00
ENGELMANN PRICKLY-PEAR	0.00	0%	0.00	0.01	2%	0.00
HONEY MESQUITE	1.02	8%	0.00	2.55	12%	0.00
SHINNERY OAK	4.39	88%	0.00	6.04	83%	0.00
WILD CHINABERRY						
YUCCA	1.05	20%	0.00	1.11	12%	0.00
---PERENNIAL FORBES---						
SNAPDRAGON						
MILKWEED						
COMMELINA SP.						
CYPERUS SP.						
WOOLLEY DALA						
SPINY YELLOW ASTER	0.00	0%	0.00	0.00	0%	0.00
HOG POTATO	0.01	3%	0.00	0.03	5%	0.00
SMOOTH OXYBAPHUS						
LEAF-FLOWER						
CLIMBING MILKWEED						
ELEGANT NIGHTSHADE						
COTTA						
GOLDEN CROWNBEARD						
----ANNUAL FORBES-----						
RAGWEED	0.00	0%	0.00	0.00	0%	0.00
ARIZONA DOZE DAISY						
BUGSEED						
ANNUAL BUCKWHEAT	0.00	0%	0.00	0.04	3%	0.00
FLEABANE						
LACE SPURGE						
EUPHORBIA SP.						
FORB SEEDLING						
BINDWEED HELIOTROPE						
PRAIRIE SUNFLOWER	0.00	0%	0.00	0.01	2%	0.02
WHITE RAGWEED						
KOCHIA						
INDIAN CHICKWEED						
PALAFOXIA						
FETID MARIGOLD						
PORTULACE SP.						
DUNE DEVILS-CLAW						
RUSSIAN THISTLE						
PRICKLY SOWTHISTLE						
--PERENNIAL GRASSES---						
LITTLE BLUESTEM						
PURPLE THREE-AWN	0.42	45%	0.00	0.29	28%	0.00
BLACK GRAMA	0.01	3%	0.00	0.00	0%	0.00
SANDHILL GRASS	0.00	0%	0.00	0.02	2%	0.00
SANDBUR	0.04	8%	0.00	0.00	0%	0.00
INTERMEDIATE LOVEGRASS	0.03	3%	0.00	0.02	3%	0.00
MEXICAN LOVEGRASS						
FALL WITCHGRASS	0.01	3%	0.00	0.00	0%	0.00
EAR MUHLY	0.01	3%	0.00	0.00	0%	0.00
KNOTGRASS						
PLAINS BRISTLEGRASS						
SPIKE DROPSEED	0.01	3%	0.00	0.03	8%	0.00
SAND DROPSEED	0.08	18%	0.00	0.02	5%	0.00
MESA DROPSEED						
GIANT DROPSEED	0.07	18%	0.00	0.02	2%	0.00
----ANNUAL GRASSES----						
GRASS SEEDLING						
FALSE BUFALOGRASS						
PURPLE SANDGRASS						

----------TOTALS BY GROUP----------

	FAR FIELD			NEAR FIELD		
----SPECIES GROUP-----	COVER	DENS.	NO. OF SP.	COVER	DENS.	NO. OF
SHRUBS (8)	6.58	0.00	5	11.30	0.00	9
PERENNIAL FORBES	0.01	0.00	1	0.03	0.00	1
ANNUAL FORBES	0.00	0.00	0	0.05	0.02	2
PERENNIAL GRASSES	0.68	0.00	9	0.40	0.00	6
ANNUAL GRASSES (9)	0.00	0.00	0	0.00	0.00	0
TOTAL	7.27	0.00	15	11.78	0.02	18

(1) Control Plots include plots CT1 and CT2, more than 2km from the salt piles
(2) Exclosure Plots include plots DOE-1 and EZ-RR, which are fenced areas
(3) Far Field Plots include plots NW2 and SE2, approximately 200km from the salt piles
(4) Near Field Plots include plots NW1, SE1 and E1, which are adjacent to the salt pile
(5) Foliar cover, in percent
(6) Frequency in the sample, in percent
(7) Density of annual species only, in plants per square meter
(8) Coverage does not include honey mesquite
(9) Number of species does not include grass seedlings

Table 6-5

WIPP 1990 FALL VEGETATION REPORT

	CONTROL PLOTS (1)			EXCLOSURE PLOTS (2)		
	COVER (5)	FREQ. (6)	DENS. (7)	COVER	FREQ.	DENS.
---------SHRUBS---------						
SAND SAGE	1.89	25%	0.00	2.86	53%	0.00
FOUR-WING SALTBUSH						
HARTWEG PRIMROSE	0.00	0%	0.00	0.03	3%	0.00
SOUTHWEST RABBITBRUSH	0.00	0%	0.00	0.16	3%	0.00
CROTON	0.37	18%	0.00	0.45	15%	0.00
SNAKEWEED	0.11	3%	0.00	0.40	5%	0.00
ENGELMANN PRICKLY-PEAR	0.00	0%	0.00	0.00	0%	0.00
HONEY MESQUITE	3.53	28%	0.00	1.00	8%	0.00
SHINNERY OAK	10.17	78%	0.00	10.20	85%	0.00
WILD CHINABERRY	0.11	3%	0.00	0.00	0%	0.00
YUCCA	0.29	10%	0.00	0.31	8%	0.00
---PERENNIAL FORBES---						
MILKWEED	0.00	0%	0.00	0.03	3%	0.00
COMMELINA SP.	0.01	3%	0.00	0.00	0%	0.00
CYPERUS SP.	0.23	25%	0.00	0.07	10%	0.00
WOOLLY DALA	0.39	25%	0.00	0.09	15%	0.00
SPINY YELLOW ASTER	0.05	8%	0.00	0.00	0%	0.00
HOG POTATO	0.00	0%	0.00	0.00	0%	0.00
SNAPDARGON	0.00	0%	0.00	0.06	3%	0.00
SMOOTH OXYBAPHUS	0.17	13%	0.00	0.07	8%	0.00
LEAF-FLOWER	0.34	48%	0.00	0.65	53%	0.00
CLIMBING MILKWEED	0.00	0%	0.00	0.03	3%	0.00
ELEGANT NIGHTSHADE	0.16	10%	0.00	0.02	3%	0.00
COTTA	0.01	3%	0.00	0.00	0%	0.00
GOLDEN CROWNBEARD	0.12	5%	0.00	0.00	0%	0.00
----ANNUAL FORBES-----						
RAGWEED	0.13	5%	0.20	0.00	0%	0.00
ARIZONA DOZE DAISY	0.00	0%	0.00	0.00	0%	0.00
BUGSEED	0.00	0%	0.00	0.00	0%	0.00
ANNUAL BUCKWHEAT	0.06	8%	0.10	0.00	0%	0.00
FLEABANE	0.02	3%	0.03	0.02	8%	0.08
LACE SPURGE	0.63	63%	0.88	0.61	48%	0.80
EUPHORBIA SP.	0.73	23%	1.28	0.36	15%	0.70
FORB SEEDLING	0.00	0%	0.00	0.01	3%	0.03
BINDWEED HELIOTROPE	0.15	18%	0.13	0.02	3%	0.03
PRAIRIE SUNFLOWER	0.01	3%	0.00	0.00	0%	0.00
WHITE RAGWEED	0.14	23%	0.38	0.07	5%	0.20
KOCHIA	0.02	3%	0.03	0.03	3%	0.03
INDIAN CHICKWEED	0.69	50%	1.50	0.28	28%	0.58
PALAFOXIA	0.36	30%	0.48	0.26	18%	0.35
FETID MARIGOLD	1.40	55%	3.18	1.00	28%	2.73
PORTULACE SP.	0.02	3%	0.03	0.00	0%	0.00
DUNE DEVILS-CLAW	0.07	8%	0.05	0.00	0%	0.00
RUSSIAN THISTLE	0.00	0%	0.00	0.00	0%	0.00
PRICKLY SOWTHISTLE	0.00	0%	0.00	0.02	3%	0.03
--PERENNIAL GRASSES---						
LITTLE BLUESTEM	0.00	0%	0.00	0.00	0%	0.00
PURPLE THREE-AWN	1.96	75%	0.00	1.43	60%	0.00
BLACK GRAMA	0.01	3%	0.00	0.13	5%	0.00
SANDHILL GRASS						
SANDBUR	1.55	78%	0.00	0.87	45%	0.00
INTERMEDIATE LOVEGRASS						
MEXICAN LOVEGRASS	0.04	3%	0.00	0.01	3%	0.00
FALL WITCHGRASS	0.48	23%	0.00	1.71	58%	0.00
EAR MUHLY	0.00	0%	0.00	0.00	0%	0.00
KNOTGRASS	0.17	15%	0.00	0.36	18%	0.00
PLAINS BRISTLEGRASS	0.15	8%	0.00	0.00	0%	0.00
SPIKE DROPSEED	0.04	5%	0.00	0.02	5%	0.00
SAND DROPSEED	0.38	35%	0.00	1.04	35%	0.00
MESA DROPSEED	0.25	25%	0.00	0.45	18%	0.00
GIANT DROPSEED	0.16	18%	0.00	0.77	28%	0.00
----ANNUAL GRASSES----						
GRASS SEEDLING	0.34	78%	6.45	0.32	53%	8.53
FALSE BUFFALOGRASS	0.60	50%	1.35	0.57	48%	1.25
PURPLE SANDGRASS	0.21	18%	0.40	0.07	10%	0.15

----------TOTALS BY GROUP----------

	CONTROL PLOTS			EXCLOSURE		
----SPECIES GROUP-----	COVER	DENS.	NO. OF SP.	COVER	DENS.	NO. OF SP.
SHRUBS (8)	12.94	0.00	7	14.41	0.00	8
PERENNIAL FORBES	1.47	0.00	9	1.02	0.00	8
ANNUAL FORBES	4.43	8.27	14	2.66	5.56	11
PERENNIAL GRASSES	5.18	0.00	11	6.78	0.00	10
ANNUAL GRASSES (9)	1.15	8.20	2	0.96	9.93	2
TOTAL	25.16	16.47	43	25.82	15.49	39

(1) Control Plots include plots CT1 and CT2, more than 2km from the salt piles
(2) Exclosure Plots include plots DOE-1 and EZ-RR, which are fenced areas
(3) Far Field Plots include plots NW2 and SE2, approximately 200km from the salt piles
(4) Near Field Plots include plots NW1, SE1 and E1, which are adjacent to the salt piles
(5) Foliar cover, in percent
(6) Frequency in the sample, in percent
(7) Density of annual species only, in plants per square meter
(8) Coverage does not include honey mesquite
(9) Number of species does not include grass seedlings

Table 6-5
(continued)

WIPP 1990 FALL VEGETATION REPORT

	FAR FIELD PLOTS (3)			NEAR FIELD PLOTS (4)		
	COVER	FREQ.	DENS.	COVER	FREQ.	DENS.
--------SHRUBS--------						
SAND SAGE	3.00	50%	0.00	2.85	52%	0.00
FOUR-WING SALTBUSH						
HARTWEG PRIMROSE	0.02	5%	0.00	0.00	0%	0.00
SOUTHWEST RABBITBRUSH	0.01	3%	0.00	0.00	0%	0.00
CROTON	0.02	3%	0.00	0.13	7%	0.00
SNAKEWEED	0.00	0%	0.00	0.05	2%	0.00
ENGELMANN PRICKLY-PEAR	0.00	0%	0.00	0.03	2%	0.00
HONEY MESQUITE	0.39	5%	0.00	1.11	10%	0.00
SHINNERY OAK	10.25	95%	0.00	12.37	87%	0.00
WILD CHINABERRY	0.00	0%	0.00	0.00	0%	0.00
YUCCA	0.55	10%	0.00	0.74	10%	0.00
---PERENNIAL FORBES---						
MILKWEED	0.05	3%	0.00	0.01	2%	0.00
COMMELINA SP.	0.00	0%	0.00	0.34	3%	0.00
CYPERUS SP.	0.09	15%	0.00	0.11	22%	0.00
WOOLLY DALA	0.11	13%	0.00	0.14	12%	0.00
SPINY YELLOW ASTER	0.00	0%	0.00	0.07	2%	0.00
HOG POTATO	0.05	5%	0.00	0.23	17%	0.00
SNAPDARGON	0.00	0%	0.00	0.00	0%	0.00
SMOOTH OXYBAPHUS	0.07	10%	0.00	0.17	10%	0.00
LEAF-FLOWER	2.03	95%	0.00	0.90	55%	0.00
CLIMBING MILKWEED	0.00	0%	0.00	0.02	2%	0.00
ELEGANT NIGHTSHADE	0.00	0%	0.00	0.00	0%	0.00
COTTA	0.00	0%	0.00	0.00	0%	0.00
GOLDEN CROWNBEARD	0.00	0%	0.00	0.01	2%	0.00
----ANNUAL FORBES-----						
RAGWEED	0.00	0%	0.00	0.00	0%	0.00
ARIZONA DOZE DAISY	0.05	3%	0.00	0.00	0%	0.00
BUGSEED	0.00	0%	0.00	0.01	2%	0.00
ANNUAL BUCKWHEAT	0.01	0%	0.03	0.00	0%	0.00
FLEABANE	0.00	0%	0.00	0.00	0%	0.00
LACE SPURGE	0.47	45%	0.68	0.59	65%	0.93
EUPHORBIA SP.	0.03	5%	0.03	0.42	7%	0.62
FORB SEEDLING	0.00	0%	0.00	0.03	10%	0.12
BINDWEED HELIOTROPE	0.03	5%	0.05	0.03	7%	0.06
PRAIRIE SUNFLOWER	0.00	0%	0.00	0.00	0%	0.00
WHITE RAGWEED	0.00	0%	0.00	0.01	3%	0.03
KOCHIA	0.00	0%	0.00	0.00	0%	0.00
INDIAN CHICKWEED	0.16	18%	0.40	0.06	12%	0.13
PALAFOXIA	0.11	18%	0.20	0.11	17%	0.10
FETID MARIGOLD	0.52	30%	1.53	2.36	55%	11.50
PORTULACE SP.	0.00	0%	0.00	0.00	0%	0.00
DUNE DEVILS-CLAW	0.00	0%	0.00	0.01	2%	0.02
RUSSIAN THISTLE	0.00	0%	0.00	0.09	2%	0.05
PRICKLY SOWTHISTLE	0.00	0%	0.00	0.00	0%	0.00
--PERENNIAL GRASSES---						
LITTLE BLUESTEM	0.27	5%	0.00	0.00	0%	0.00
PURPLE THREE-AWN	1.56	70%	0.00	1.37	48%	0.00
BLACK GRAMA	0.05	3%	0.00	0.00	0%	0.00
SANDHILL GRASS						
SANDBUR	1.01	58%	0.00	1.32	67%	0.00
INTERMEDIATE LOVEGRASS						
MEXICAN LOVEGRASS	0.00	0%	0.00	0.03	2%	0.00
FALL WITCHGRASS	1.05	55%	0.00	0.86	35%	0.00
EAR MUHLY	0.00	0%	0.00	0.02	2%	0.00
KNOTGRASS	0.29	28%	0.00	0.26	20%	0.00
PLAINS BRISTLEGRASS	0.00	0%	0.00	0.00	0%	0.00
SPIKE DROPSEED	0.07	10%	0.00	0.07	3%	0.00
SAND DROPSEED	0.45	43%	0.00	0.38	25%	0.00
MESA DROPSEED	0.07	8%	0.00	0.41	18%	0.00
GIANT DROPSEED	0.29	33%	0.00	0.39	23%	0.00
----ANNUAL GRASSES----						
GRASS SEEDLING	0.17	45%	2.23	0.76	60%	8.92
FALSE BUFFALOGRASS	0.59	53%	1.63	0.67	63%	2.23
PURPLE SANDGRASS	0.08	15%	0.15	0.10	13%	0.22

TOTALS BY GROUP

	FAR FIELD PLOTS			NEAR FIELD PLOTS		
----SPECIES GROUP-----	COVER	DENS.	NO. OF SP.	COVER	DENS.	NO. OF SP.
SHRUBS (8)	13.85	0.00	7	16.17	0.00	7
PERENNIAL FORBES	2.37	0.00	6	2.00	0.00	10
ANNUAL FORBES	1.37	2.92	7	3.73	13.56	11
PERENNIAL GRASSES	5.10	0.00	10	5.09	0.00	11
ANNUAL GRASSES (9)	0.83	4.01	2	1.08	11.37	2
TOTAL	23.52	6.93	32	28.06	24.93	41

(1) Control Plots include plots CT1 and CT2, more than 2km from the salt piles
(2) Exclosure Plots include plots EXC-1 and EZ-RR, which are fenced areas
(3) Far Field Plots include plots NW2 and SE2, approximately 200km from the salt piles
(4) Near Field Plots include plots NW1, SE1 and E1, which are adjacent to the salt piles
(5) Foliar cover, in percent
(6) Frequency in the sample, in percent
(7) Density of annual species only, in plants per square meter
(8) Coverage does not include honey mesquite
(9) Number of species does not include grass seedlings

CHAPTER 7

GROUNDWATER PROTECTION

Current groundwater protection activities at the WIPP are outlined in the WIPP Groundwater Monitoring Program Plan and Procedure Manual. WP 02-1, Rev. 2 is a Quality Assurance document that contains program plans for each of the activities performed by groundwater surveillance personnel. Detailed procedures for performing specific activities such as pumping system installations, field parameter analysis and document and quality assurance records management are also contained in WP 02-1 Rev 2. Groundwater protection activities are also defined in the OEMP .

The objective of this program is to determine the physical and chemical characteristics of the groundwater surrounding the WIPP facility, both before and throughout the operational lifetime of the facility. Baseline water quality data has been collected since January 1985. A report is currently being prepared by IT Corporation evaluating the baseline data from 1985 through the 1990 sampling period and should be available for publication in early 1992. This preoperational data will be compared to water quality data collected after TRU waste is placed in the WIPP facility. Data generated by groundwater surveillance programs are also useful in determining future regulatory needs, land use decisions, and updating information for site documents such as the Final Environmental Impact Statement Addendum.

The water quality data obtained by the WQSP in 1990 supported three major programs at the WIPP: (1) Site Characterization; (2) Performance Assessment (in compliance with 40 CFR 191); and (3) The OEMP. Each of these programs requires a unique set of analyses and data, but overlap of analytical needs does occur. Particular sample needs are defined by each program. Radionuclide samples were collected for the Environmental Analysis and Compliance section of the Westinghouse , Waste Isolation Division (WID.) Results of radionuclide sampling are discussed in Chapter 5 of this report. In addition, water samples from each 1990 sampling location were offered to the New Mexico Environmental Evaluation Group (EEG) for their independent analysis, however due to budgetary constraints the EEG was forced to decline a number of offered samples.

The WIPP is located within the Pecos Valley section of the Southern Great Plains physiographic province (Powers et al., 1978). The primary Industries in the area which could contribute to pollution of the ground water are local potash mining, gas and oil drilling activities and cattle ranching. Geologically, the WIPP is located in the northern portion of the Delaware Basin, the western most subsection of the Permian Basin. The northern Delaware Basin is bounded by the Capitan Limestone, a Permian Age reef which is the only major source of potable groundwater in the basin. Interior to the basin, eight rock units make up the stratigraphic column in the vicinity of the WIPP. In ascending order, these units are the Delaware Mountain group (consists of the Brushy Canyon, Cherry Canyon, and the Bell Canyon formations), The Castile Formation, the Salado Formation, The Rustler Formation, the Dewey Lake Redbeds, and the Triassic Dockum group also referred to as the Dockum formation.

The rock units which were sampled in 1990 are in descending order ; the Dewey Lake Redbeds, the Magenta Dolomite, and the Culebra Dolomite, (Figure 7-1). Fluids form these rock units have been collected either from wells at the WIPP or from privately owned wells (windmills). Groundwater sampling at WIPP focuses on the Magenta and Culebra Dolomite Members of the Rustler Formation. The Magenta and Culebra Dolomites are the most significant water bearing units within the vicinity of the WIPP. No known hydrologic connection exists between the repository horizon and these rock units. Surveillance of the characteristics of the water contained in both the Culebra and the Magenta Dolomite is beneficial to the WIPP because it provides data which can be used to determine if the characteristics of the water in either the Culebra or Magenta is changing. It also provides additional data for use in hydrologic modules designed to predict long term performance of the repository environment (i.e., performance assessment). A brief description of these geological formations and their hydrology follows.

The Dewey lake Redbeds are comprised of a deltaic sequence of alternating thin, even beds of orange-red siltstone and mudstone with lenticular interbeds of fine grained sandstone. Geologic data for the area around the WIPP facility indicate that the sands are lenticular and pinch out laterally. Hydrologic

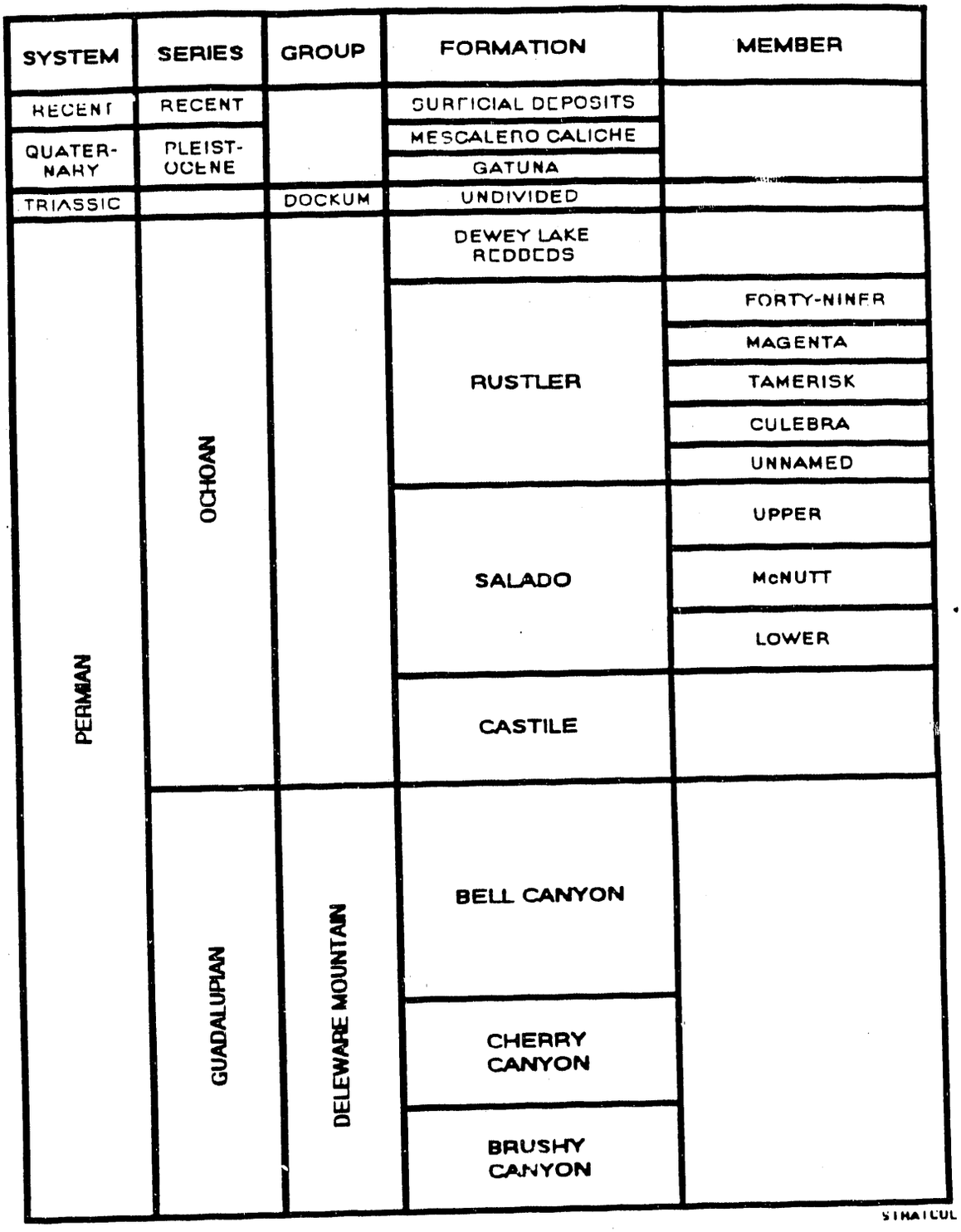

Figure 7-1
Stratigraphic Column

591B 0199k

TABLE 7-1.0

MONTHLY GROUND-WATER LEVEL MEASUREMENTS

CULEBRA

AEC-07	H-09b	WIPP-12
CABIN BABY (CB-1)	H-10b	WIPP-13
D-268	H-11b2	WIPP-18
DOE-01	H-12	WIPP-19
DOE-02	H-14	WIPP-21
ERDA-09	H-15	WIPP-22
H-01	H-17	WIPP-25
H-02b2	H-18	WIPP-26
H-03b2	P-14	WIPP-27
H-04b	P-15	WIPP-29
H-05b	P-17	WIPP-30
H-06b	P-18	
H-07b1		

MAGENTA

H-01	H-05c	WIPP-25
H-02b1	H-06c	WIPP-27
H-03b1	H-08a	WIPP-30
H-04c	H-10a	

OTHER FORMATIONS

AEC-08	BELL CANYON
H-03d/49	FORTY-NINER
H-03d/DL	DEWEY LAKE
H-08c	RUSTLER/SALADO
WIPP-28	RUSTLER/SALADO

TABLE 7-1.1

QUARTERLY GROUND WATER-LEVEL MEASUREMENTS

CULEBRA

H-02a	H-07b2	H-11b3
H-02c	H-07c	H-11b4
H-03b3	H-09a	WIPP-28
H-05a	H-09c	
H-06a	H-11b1	

TABLE 7-2

WATER QUALITY SAMPLING PROGRAM MONITORING LOCATIONS

LOCATIONS MONITORED EACH YEAR

1. H-02c	CULEBRA
2. H-03b1	MAGENTA
3. H-03b3	CULEBRA
4. H-04b	CULEBRA
5. H-04c	MAGENTA
6. H-05b	CULEBRA
7. H-05c	MAGENTA
8. H-06b	CULEBRA
9. H-06c	MAGENTA
10. H-14	CULEBRA
11. WIPP-19	CULEBRA
12. RANCH WELL	DEWEY LAKE
13. BARN WELL	DEWEY LAKE
14. TWIN WELL (PASTURE)	DEWEY LAKE

WELLS MONITORED EVERY THREE YEARS

1. H-09b	CULEBRA
2. H-11b3	CULEBRA
3. H-12	CULEBRA
4. H-07b	CULEBRA
5. H-15	CULEBRA
6. H-18	CULEBRA
7. P-14	CULEBRA
8 P-17	CULEBRA
9. WIPP-25	CULEBRA

investigations at and near the WIPP facility have not identified a continuous zone of saturation within the Dewey Lake Redbeds. Several private wells (located approximately 5 miles south of the WIPP site) are completed in the Dewey Lake Redbeds. These wells appear to be producing from thin lenticular sands that are locally recharged (Mercer, 1983). Four private wells in this area have been sampled by WIPP (Barn well, Fairview Well, Unger Well, and Ranch Well), and the data are reported in Randall et al., 1988, and Lyon 1989. Each of these wells supply water for livestock.

The Rustler formation underlies the Dewey Lake Redbeds and consists of interbedded anhydrite, gypsum, halite, polyhalite, dolomite, and limestone. The Rustler formation is divided into five lithologic units. These units are in descending order; the Forty-niner member, the Magenta Dolomite, the Tamarisk member, the Culebra Dolomite, and the Unnamed lower member consisting of reddish-brown siltstone interbedded with gypsum or anhydrite and halite. The Forty-niner and Tamarisk members are primarily anhydrite and include some halite and potash minerals. Where dissolution has occurred, the anhydrite has altered to gypsum, and halite salts are absent. The Magenta and Culebra Dolomites are aerially extensive and are the most significant water-bearing units in the WIPP vicinity. Water from the Magenta and Culebra has undergone five years of sampling (Broberg et. al, 1990; Lyon 1989; Randall et al., 1988; Uhland et al, 1987, and Uhland et al., 1986).

The Magenta dolomite is the uppermost significant water-bearing stratum in the Rustler formation and consists of a clastic carbonate bed with thin laminae of anhydrite. The unit ranges in thickness from 20 to 30 feet and is a vuggy , finely crystalline dolomite. The formation contains water (under confined conditions) of variable density ranging from brackish to brine. Hydrologic testing has shown the Culebra Dolomite to be a heterogenous, fractured unit with transmissibility varying locally from 0.07 to greater than 200 square feet per day (Mercer, 1983). The high transmissibility values in the Culebra have been reported from well locations south and west of the WIPP facility. In this area near the WIPP, the Culebra fluids exhibit relatively low concentrations of Total Disolved Solids (TDS). South of the WIPP site (Engle, Poker Trap) a few wells that are completed in the Culebra are used by local ranchers for watering livestock. In areas lying east of the WIPP, transmissibility in the Culebra are quite low, and fluid samples show high TDS concentrations. Based on actual formation measurements, Crawley, 1988 estimated that regional groundwater flow directions near the WIPP site are towards the south and southwest. It has been suggested, since the water flow in the Culebra Dolomite is affected by fractures, variable fluid densities, and heterogeneity of the rock, that regional flow direction may have little, if any, relationship to localized flow paths.

Groundwater surveillance activities during 1990 consisted of two separate programs, groundwater quality sampling and groundwater level measurements. Groundwater surveillance programs utilize 57 well bores to gather data. Six of these bores are equipped with production inflated packers in order to allow groundwater level surveillance of more than one producing zone through the same well bore. Groundwater level measurements are taken at each well location either monthly or quarterly see Tables 7-1.0 and 7-1.1 for the sampling frequency of each particular location.

Groundwater Quality data are gathered from 23 well locations. Data are collected at 16 locations completed in the Culebra dolomite and 4 locations completed in the Magenta dolomite. Water quality data are also collected from three privately owned wells in the vicinity of the WIPP that are completed in the Dewey Lake Redbeds. Sampling is performed at each location either yearly or every three years see Table 7-2 for the sampling frequency of water quality locations.

The water quality sampling process has been developed around the logistics of using groundwater wells that were originally constructed for characterization and not groundwater monitoring activities. The WIPP site has been given a conditional No-Migration Determination and is not required to have a monitoring program in compliance with the RCRA. The original wells are therefore being used for surveillance. These wells, not being designed for a long term surveillance program, did not consider the geochemistry of the area, anticipated lifetime of the surveillance program nor the chemical parameters to be analyzed. A majority of the wells were drilled using saturated brine water as a drilling fluid which was left standing in the open well bore for various time periods. Many of the wells were cored through the culebra dolomite into the upper part of the Unnamed member of the Rustler formation leaving halite deposits exposed to the waters of the Culebra. Most of the wells are constructed with J-55 or K-55 iron casing. In order to decrease the sampling bias created by well construction deficiencies and combined

with the low transmissibilities of the formations involved a labor intensive sampling process has been initiated. Because of the time involved to collect a representative sample and the number of wells to be sampled each year, wells are sampled only once per year. Sampling episodes are referred to as a "sampling round". Each yearly sampling round consists of the collection of two types of samples: (1) serial samples and (2) final samples. Serial samples are taken once a day, while the well is being purged. Key physical and chemical parameters (known as field parameters) are analyzed daily until a chemical steady state has been reached. A chemical steady state is usually defined as + \- 5% of the average of the three preceding parameter measurements. Stabilization of these field parameters is a function of purging and is used as an indicator to determine if the groundwater is representative of the zone being sampled. A final sample is collected, once it has been determined the pumped groundwater has achieved a representative state, and is sent off site to a contract laboratory for analysis.

Groundwater level measurements are conducted by lowering an electronic Water-Level conductance probe to the water level. When the probe contacts water it trips a buzzer alarm at the surface. The graduated tape on the conductance probe is read, adjusted to the top of the casing and documented in the field. The probe is then brought to the surface, rinsed with fresh water and wiped clean with a cloth. Top of casing elevation is later referenced to sea level and a groundwater elevation above mean sea level is calculated.

Groundwater surveillance activities during 1990 consisted of water quality sampling of 18 well sites and groundwater level measurements at 57 well locations. The results of the data gathered in each of these subprograms is discussed below. The results of the data gathered in 1990 are presented in appendices at the end of this report.

7.1 GROUNDWATER QUALITY

Sampling for groundwater quality was performed at 18 well locations including 4 privately owned well sites during 1990 (Figure 7-2). With the exception of the four privately owned wells each well was purged a minimum of 24 hours prior to the commencement of the serial sampling phase of the purging process. Field analysis for Eh, pH, alkalinity, chloride, divalent cations, and Iron (total and ferrous) were performed on a daily basis during serial sampling. Specific gravity and specific conductance were performed on the first and last day of serial sampling. These field parameters were used as an indicator, during the purging process, to better determine when the formation water being pumped had reached a representative state. Normally this process required seven to ten days to complete. Following the field analysis of the final serial sample, samples were collected and shipped to International Technologies Analytical Services Laboratory (ITAS), an independent contracted laboratory, for analysis. Parameters of analysis by the contracted laboratory are listed in table 7.1.1. Splits of samples were also offered to the EEG, Sandia National Laboratories (SNL) and selected samples were collected by the University of New Mexico Geology Department. Samples were also archived at the WIPP site for future analytical needs.

During the 1990 calendar year 11 Culebra, 4 Magenta and 3 Dewey Lake well bore completions were sampled. The 3 wells sampled in the Dewey Lake formation (Barn, Ranch, and Twin Pasture) and 1 of the wells sampled in the Culebra dolomite (Engle) were privately owned wells utilized for the supply of water to area ranch live stock. Because these wells are pumped on a routine basis year around the purging and serial sampling process was not necessary.

The total gallons of water removed from the Culebra dolomite member of the Rustler formation as a result of water quality sampling activity was approximately 52,400 gallons through out the year. The total gallons removed from the Magenta Dolomite member of the Rustler formation during the same period was approximately 5,986 gallons of water. The final day average results of final serial analysis show relative consistency when compared to averages of earlier sampling rounds. Appendices IV through VIII contain detailed results of data for each individual well sampled. Data in these appendices are presented in summary discussion, tabulated and graphical form.

Water quality of the Magenta and Culebra are naturally poor and the waters are not usable for human consumption or for agricultural purposes. The waters contain naturally high concentrations of total dissolved solids and mineral constituents primarily of chloride, calcium, magnesium, sodium and potassium (Mercer, 1983). The generally high TDS of the waters poses a problem in the analysis of the

waters because it tends to clog or interfere with standard laboratory equipment such as Atomic Absorption Inductively Coupled Plasma or ICP, causing detection limits to be inconsistent. No other inconsistencies of general chemistry parameters were noted in either the Magenta or Culebra during the 1990 sampling period.The only usable water in the area of the WIPP are from wells Completed in the Dewey Lake Redbeds which produce water from discontinuous saturated zones of thin lenticular sands that are believed to be locally recharged. Three Wells were sampled in the Dewey Lake Redbeds these were; Ranch Well located approximately 3 and 2 tenths miles south to the WIPP site, Barn well located approximately 3 and 4 tenths miles south of the WIPP site and Twin well Pasture well located approximately 10 miles south of the WIPP site. Each of these wells showed elevated levels of nitrate in the groundwater analysis. Ranch well showed the highest concentration with 71 mg/l followed by Twin well and Barn with concentrations of 9.2 mg/l and 8.9 mg/l respectively. The most probable source of these nitrate concentrations are the large numbers of livestock that utilize these wells for drinking water.

7.1.1 SUSPECT DATA

The chloride concentration reported for H-04B round five of 615 mg/l, as reported by the contracted laboratory, appears abnormally low when compared to previous rounds rounds 1, 3 and 4) where the chloride content normally averaged approximately 7500 mg/l. Round 2 chloride content was 12,000 mg/l which may have been considered suspect also.

The sodium concentration reported by ITAS for H-04c round five of 3600 mg/l appears low when compared to the average value of 8875 mg/l for rounds one through four.

The lower detection limit of 50 mg/l set by ITAS for the Potassium value for H-07b1 round five appears inconsistent with previous rounds where values reported for rounds one through four were 7.0 mg/l, 7.7 mg/l, 8.3 mg/l and 7.3 mg/l respectively.

The reported concentration for H-09b, round four, by ITAS of 20 mg/l 1-3-dichlorobenzene is suspect for the following reasons: (1) rounds one, two and three all show less than detectable limits for 1-3-dichlorobenzene, (2) the analysis also show 13 mg/l concentration of 1-3-dichlorobenzene for a method blank composed of deionized water and (3) 1-3-dichlorobenzene is a constituent of various cleaning compounds used by laboratories on a routine basis, to clean laboratory instruments and glass ware.

7.1.2 ANALYSIS FOR ORGANIC COMPOUNDS

Analysis for organic compounds were completed on 6 of the 18 wells sampled as part of the Groundwater quality sampling program. These wells were H-09B Culebra, Engle well Culebra, H-06B Culebra, H-06c Magenta, H-18 Culebra and H-05b Culebra. Only one analysis revealed concentrations of organic compounds above detectable limits. The value for 1-3-dichlorobenzene as reported for H-09b of 20 mg/l has been discussed in the previous section. Organic analysis was not performed on the remaining 12 wells sampled in 1990 due to budgetary concerns.

Observations have been made that pose concerns as to the validity of volatile organic analysis for the wells sampled in 1990 as well as previous years. Solutions as to the problems posed in validating these data are currently being considered.

7.2 GROUND WATER LEVEL SURVEILLANCE

In October 1988 the Westinghouse, WID was tasked with conducting a groundwater level surveillance program in the area of the WIPP Site. The 57 well bores are utilized to perform surveillance of six water bearing zones in the WIPP area. The two zones of primary interest are the Culebra dolomite and Magenta dolomite members of the Rustler formation, 46 measurements are taken in the Culebra dolomite and 11 measurements are taken in the Magenta dolomite. Two measurements are taken in the Rustler/Salado

TABLE 7-2.1

Variation Table For Water Levels Culebra Dolomite

WELL #	FEET GAIN/LOSS JAN-DEC	FEET AMSL HIGH	MONTH	FEET AMSL LOW	MONTH	FEET TOTAL VARIATION
AEC-07	+0.13	3034.50	5/90	3034.05	3/90	0.45
CABIN BABY	-6.77	2990.52	4/90	2981.85	12/90	8.67
DOE-01	+1.70	2975.99	12/90	2974.29	1/90	1.70
DOE-02	+1.11	3054.77	12/90	3053.56	3/90	1.21
D-268	+1.44	3005.61	8/90	3002.51	3/90	3.10
ERDA-09	+3.66	2947.57	12/90	2943.91	1/90	3.66
H-01	+3.54	2975.18	2/90	2971.34	1/90	3.84
H-02a (Q)*	+3.69	3002.50	12/90	2998.81	3/90	3.69
H-02b2	+4.56	3006.89	12/90	2984.31	7/90	22.58
H-02c (Q)	+3.44	3003.88	12/90	3000.44	3/90	3.44
H-03b2	+2.50	2984.36	12/90	2978.31	8/90	6.05
H-03b3 (Q)	+2.22	2984.59	12/90	2982.37	3/90	2.22
H-04b	+1.20	2999.02	12/90	2997.82	1/90	1.20
H-05a (Q)	+0.04	3024.87	12/90	3021.10	6/90	3.77
H-05b	+0.50	3020.29	4/90	3011.35	5/90	8.94
H-06a (Q)	+0.80	3045.99	12/90	3045.19	3/90	0.80
H-06b	+0.91	3045.67	12/90	3044.62	2/90	1.05
H-07b1	+0.40	2995.60	12/90	2995.08	4/90	0.52
H-07b2 (Q)	+0.46	2995.40	12/90	2994.94	3/90	0.46
H-09a (Q)	+1.54	2990.50	12/90	2988.79	6/90	1.71
H-09b	+1.51	2990.78	12/90	2989.23	2/90	1.55
H-09c (Q)	+1.51	2990.70	12/90	2989.19	3/90	1.51
H-10b	+0.06	2989.30	9/90	2989.01	3/90	0.29
H-11B1 (Q)	+0.96	2976.95	12/90	2975.99	3/90	0.96
H-11B2	+1.28	2976.56	12/90	2975.28	1/90	1.28
H-11B3 (Q)	+1.13	2976.30	12/90	2975.17	3/90	1.13
H-12	+1.18	2967.44	12/90	2966.26	1/90	1.18
H-14	+1.37	3001.59	12/90	3000.22	1/90	1.37
H-15	+1.68	2954.28	12/90	2952.60	1/90	1.68
H-17	+1.95	2951.80	12/90	2949.85	1/90	1.95
H-18	+3.29	3048.58	12/90	3043.63	4/90	4.95
P-14	+1.15	3039.07	12/90	3037.87	2/90	1.20
P-15	+1.10	3010.15	12/90	3009.05	1/90	1.10
P-17	+1.11	2984.16	12/90	2983.05	1/90	1.11
P-18	+32.51	3039.43	12/90	3006.92	1/90	32.51
WIPP-12	+0.67	3024.46	12/90	3023.34	6/90	1.12
WIPP-13	+1.08	3053.79	12/90	3052.58	3/90	1.21
WIPP-18	+1.92	3012.41	12/90	3006.88	6/90	5.53
WIPP-19	+3.51	3003.00	12/90	2988.86	6/90	14.14
WIPP-21	+3.73	2945.00	12/90	2941.27	1/90	3.73
WIPP-22	+3.56	2978.45	12/90	2965.85	6/90	12.60
WIPP-25	+1.78	3051.84	12/90	3050.06	1/90	1.78
WIPP-26	+0.91	3017.48	12/90	3016.42	5/90	1.06
WIPP-27	+0.80	3075.32	10/90	3074.49	1/90	0.83
WIPP-29	-0.36	2967.93	2/90	2966.67	6/90	1.26
WIPP-30	+0.85	3061.87	12/90	3060.98	2/90	0.89

TABLE 7-2.2

Variation Table For Water Levels Magenta Dolomite

WELL #	FEET GAIN/LOSS JAN-DEC	FEET AMSL HIGH	MONTH	FEET AMSL LOW	MONTH	FEET TOTAL VARIATION
H-01	-0.39	3121.77	1/90	3120.92	3/90	0.85
H-02b1	+21.82	3124.95	12/90	3103.13	1/90	21.82
H-03b1	-1.08	3138.72	8/90	3133.34	9/90	5.38
H-04c	-0.96	3141.86	8/90	3137.22	10/90	4.64
H-05c	-0.07	3153.86	4/90	3107.63	5/90	46.23
H-06c	+1.01	3058.60	12/90	3050.93	3/90	7.67
H-08a	+0.30	3027.20	11/90	3026.88	1/90	0.32
H-10a	+0.12	3158.56	10/90	3158.41	1/90	0.15
WIPP-25	+1.51	3052.96	12/90	3051.45	1/90	1.51
WIPP-27	+0.34	3070.89	8/90	3070.20	1/90	0.69
WIPP-30	+0.79	3124.91	12/90	3124.12	1/90	0.79

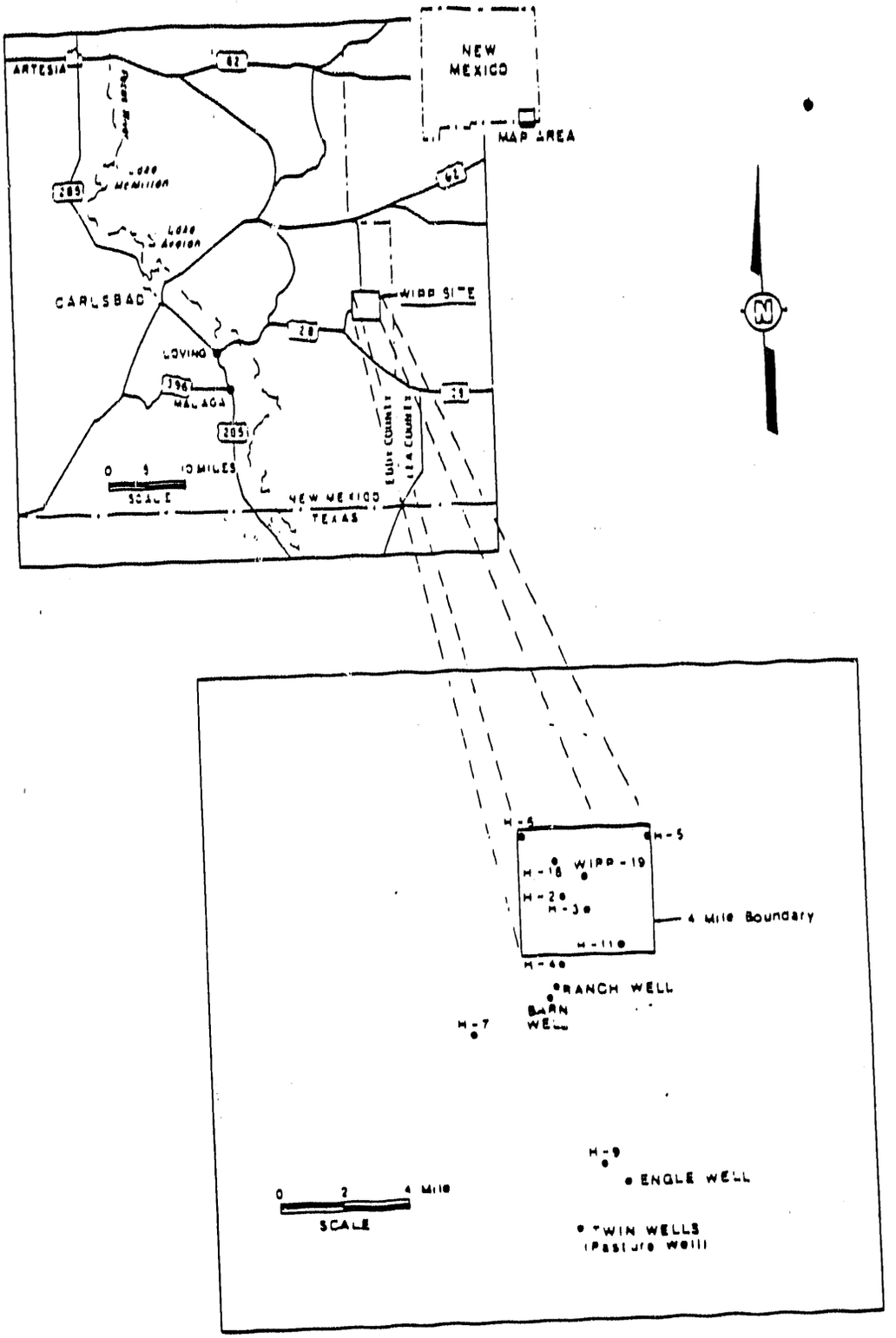

FIGURE 7-2 GROUNDWATER SAMPLING LOCATIONS SAMPLED IN 1990

TABLE 7.1.1

GROUND WATER MONITORING CHEMICAL PARAMETERS

GENERAL CHEMISTRY	METALS (CATIONS)	TOTAL METALS
pH	Calcium	Aluminum
Specific Conductance	Magnesium	Antimony
Bicarbonate	Potassium	Arsenic
Bromide	Sodium	Barium
Carbonate		Beryllium
Chloride		Boron
Cyanide, Total		Cadmium
Fluoride		Cesium
Iodide		Chromium
Nitrate		Cobalt
Total Phenolics		Copper
Total Phosphorus		Iron
Residue filterable at 180 C (TDS)		Lead
Residue nonfilterable at 105 C (TSP)		Lithium
Silica		Manganese
Sulfate		Mercury
Total organic Carbon		Molybdenum
Total organic Halides		Nickel
		Selenium
		Silver
		Strontium
		Thallium
		Vanadium
		Zinc

In addition to the above list;

Volatile Organic Hazardous Substance analyses were performed for H-05b, H-06b, H-06c, H-09b, H-18 and Engle wells.

Semi-volatile Organic Hazardous Substance analyses were performed for H-09b and Engle wells.

Pesticide analyses were performed for Engle well.

contact and one measurement each are taken in Bell Canyon, the Forty-niner member of the Rustler formation and the Dewey Lake formation. H-16 was added to the program in November 1990 which provides a surveillance location for the Unnamed lower member of the Rustler formation and an additional location for the Dewey Lake formation. Groundwater elevations for November and December 1990 for the Unnamed Lower Member were 3062.97 feet above mean sea level (AMSL) and 3062.76 feet amsl respectively. For the Dewey Lake formation at H-16 the measurements were 3381.10 feet AMSL in November and 3380.16 feet AMSL for the month of December 1990. These measurements reflect a loss of elevation in water levels for the Unnamed Lower Member of 0.21 feet and a loss of 0.94 feet of elevation in water levels for the Dewey Lake formation. Tabulated and graphical data for H-16 are not presented in this report due to a lack of data points. Measurements for November and December 1990 will be presented with data presented in the 1992 Environmental Report.

The groundwater level data presented in this report indicates that there is a gradual trend of rising water level elevations within the Culebra dolomite (Table 7.2.1). Forty-four of forty-six surveillance locations showed some increase in water level elevations within the Culebra dolomite. Two anomalous occurrences were noted in the data presented in this report. The first, was a net loss of 8.67 feet of groundwater level elevation at Cabin Baby well site located approximately 2.5 miles south of the WIPP site from April through December 1990, and the second was a gain of 32.51 feet of groundwater level elevation at P-18 located approximately 3 miles southeast of the WIPP site. The two wells are located within five miles of each other. Groundwater elevation measurements in the Culebra dolomite indicate that the generalized directional flow of ground water is north to south. However, caution should be used when making assumptions based on groundwater level data alone, recent studies in the Culebra dolomite have shown that fluid density variations in the Culebra dolomite can affect flow direction (Crawley, 1988); (Davies, 1989). One should also be aware that the fractured media of the Culebra dolomite coupled with variable fluid densities can cause localized flow patterns to have little or no relationship to general flow patterns. (Crawley, 1988)

Measurements at 11 surveillance locations in the Magenta dolomite also indicated an upward trend in water level elevations (Table 7.2.2). No anomalous losses or gains were noted within the Magenta dolomite. Seven of eleven Magenta surveillance locations show a gain in the elevation of groundwater levels from January to December 1990. Four wells showed a lower elevation of groundwater level elevation in December than in January of 1990. Three of the four surveillance locations that indicate a loss of head elevation from January to December were wells that are pumped routinely as part of the water quality sampling program. These locations are H-03B1, H-04C and H-05C.

Recovery from these pumping events may have influenced the water level data collected at these locations. A 21.82 foot rise in water level elevation at H-02b1 well location from January and continuing through December may appear anomalous, however it may be attributed to a water quality sampling attempt which occurred in November 1989.

Groundwater flow directions in the Magenta dolomite appear to be generally from a easterly to a western direction across the WIPP site. No studies have been performed in the Magenta dolomite to the magnitude that the Culebra dolomite has been studied to determine spacial variations in the fluid densities of the Magenta. It is very possible if not likely that density variations do occur in the Magenta dolomite. Therefore the potential may exist that to some extent flow patterns in the Magenta dolomite may be affected by variations in fluid density. Also flow through the fractured media of the Magenta dolomite may well dictate the behavior of localized flow patterns.

Groundwater elevations in the Dewey Lake Redbeds did not yield sufficient data to draw any conclusions as to trends in groundwater elevation or the direction of groundwater flow in that formation. However groundwater flow in the Dewey Lake Redbeds is considered to be restricted due to the perched characteristics of the formation (Mercer 1983).

When groundwater elevations taken in 1990 are compared to potentiometric elevation maps produced by Mercer, 1983, groundwater elevations appear to be below 1983 levels. The 1983 Mercer study was performed prior to the onset of the large scale hydrologic activities which took place in the vicinity of the WIPP to support site characterization and other hydrological orientated activities during the mid to late 1980's. Since the end of the 1980's only modest amounts of groundwater have been removed from these

formations. The possibility exists that the trends toward increasing groundwater elevations observed in 1990 is a natural trend for the formations to recover to groundwater elevations near those of 1983 potentiometric elevations.

Detailed tabular and graphical data of data collected in 1990 are listed in appendix X. Historical data from October 1988 through December 1989 is presented in graphical form in appendix XI.

CHAPTER 8

QUALITY ASSURANCE

This chapter outlines the Quality Assurance/Quality Control (QA/QC) program goals and procedures for the radiological and nonradiological monitoring programs at the WID and offsite subcontractor laboratories. The purpose of the program is to monitor the reliability, accuracy, and precision of all data, and to detect problems in the sample collection, preparation, analysis, or data evaluation phases of the monitoring program.

QA comprises all planned and programmed events undertaken to ensure the validity of the results of a monitoring program. QA includes QC, which is task specific and provides a context for assessing the performance of equipment, instruments, and procedures. The QA/QC program for the WIPP environmental programs is established within the framework of the overall Quality Assurance Program Manual of the Westinghouse Electric Corporation, Waste Isolation Division.

A comprehensive QA program has been implemented to ensure that the data collected reflects actual concentrations in the environment and has been obtained prior to commencement of operations in order to provide sound baseline data for comparison with potential impacts of the WIPP. The focus of this program includes:

- Sample collection at all locations, according to procedures based on accepted practices and widely recognized methodologies and criteria
- Procedure review and revision as appropriate to minimize uncertainty due to sampling error while maintaining comparability and continuity between past and future data
- Data verification through a continuing program of analytical laboratory quality control, including participation in inter-laboratory cross-checks; duplicate sample analysis, and, for radiological samples, splits provided to the EEG for analysis

Adherence to policies set forth by federal QA regulations including: ASME NQA-1, Quality Assurance Program Requirements for Nuclear Facilities, (ASME, 1989) and EPA, QAMS-005/80, Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans, (EPA, 1980), fulfills the requirements of the QA plan specified in DOE Orders 5400.1 (DOE, 1988d), 5400.3 (DOE, 1988e), 5700.6B (DOE, 1986c) and draft DOE 5400.6 (DOE, 1988f).

8.1 BASELINE DATA

There are four environmental programs currently in place at the WIPP: the NES , the Radiological Environmental Surveillance (RES), the Cooperative Raptor Research Program, and the WIPP Groundwater Surveillance Program. Their purpose is to collect the data needed to detect and quantify any impacts that construction and operational activities at the WIPP site may have on the surrounding ecosystem. A baseline data base spanning several years prior to operations at the WIPP can provide objective evidence of location-specific anomalies in the test results.

Preliminary studies are important when considering WIPP environmental monitoring efforts since they contribute to the baseline data useful during the construction phase, and because they are the predecessors to the long-term monitoring programs. These studies include:

- WIPP Site Characterization Program - instituted in 1976 by SNL to monitor air quality, background radiation levels, and groundwater quality (Pocalujka et al., 1979; 1980a, b, c; 1981a, b; Powers et al., 1978; Lappin, 1989)

- WIPP Biology Program - begun in 1975 with baseline studies of climate, soils, vegetation, arthropods, and vertebrates (Best, 1980)
- Investigations of the site geohydrology - conducted by the U.S. Geological Survey (USGS) at the request of the DOE. In addition, the NRC issued a contract to Columbia University to perform a study of radionuclide mobility in the highly saline groundwaters of the Delaware Basin (U.S. Geological Survey, 1983)
- Radiological monitoring of air, water, and biological media - conducted by the Atomic Energy Commission before and after the Project Gnome nuclear detonation (USAEC, 1962a,b,c,d)

8.2 SAMPLE COLLECTION METHODOLOGIES

Written procedures provide guidance to field personnel for every sample taken and form the basis of an auditable program. The QA Department periodically conducts surveillance reports, inspection reports, and internal audits to ensure compliance with established procedures. An inspection report surveys personnel performance in one activity. A surveillance report assesses a procedure from data collection through data management. Surveillances are conducted according to WP 13-011. An internal audit, a more comprehensive investigation, evaluates the adequacy and effectiveness of the QA program implementation and related procedures and practices. An audit may include procedure review, file management, and test equipment. Audits are conducted according to WP 13-005. Results of each audit, surveillance, and overview are kept on file at the WIPP. In 1990, Westinghouse QA conducted a total of 13 evaluations of the Environmental Department. There were two surveillance reports performed on the Environmental Monitoring Section. One was closed out and the other is awaiting an engineering upgrade to alleviate the use of strip charts, whose performance was noted as inadequate. (Note: the strip charts are a secondary data collection method to the Central Monitoring System.)

There were a total of 11 inspection reports performed on the Environmental Department in 1990. There were five performed on the Environmental Monitoring Section. For the Environmental Monitoring Section, three addressed the WQSP (groundwater surveillance) and three on overall environmental monitoring surveillance (other than groundwater surveillance). Two inspection reports required further action, Inspection Report 90-28, 828A identified and required that all data loggers and pressure transducers receive periodic recertification by the WIPP Calibration laboratory. Inspection Report 90-038, noted appropriate procedures and updated procedures were lacking as well as, ventilation, labeling, wall brackets for spill canisters, and training records. A draft procedure, Management of Hazardous Materials WP 02-507 is being reviewed to correct these deficiencies.

One QA audit was performed which involved the Environmental Department's equipment from a maintenance and calibration standpoint. After review of the calibration and maintenance records it was noted that an exemplary system was being utilized to track, update and recertify monitoring equipment in the Environmental Department. Corrective actions are implemented as directed in WP 13-002, Waste Isolation Pilot Plant, Waste Isolation, Division Quality Assurance Program Manual.

Sampling procedures are contained in the following documents:

- WIPP Groundwater Monitoring Program Plan and Procedure Manual (WP 02-1)
- WIPP Environmental Procedures Manual (WP 02-3)
- Geotechnical Engineering QA Program Plan (WP 07-1)
- Water Quality Sampling Program (WP 07-2)
- Ecological Monitoring Program Semiannual Report (Reith et al., 1985)
- Radiation Safety Manual (WP 12-5)
- WIPP Quality Assurance Program Manual (WP 13-1)

The sampling procedures describe the methods for sample location determination; timing of collection; equipment calibration; specific steps for sample collection, analysis, and shipment preparation; and the shipment method. The sampling procedures also provide program requirements for data entry, sample tracking, and record-keeping; this ensures data collected and entered becomes a quality record. Standard sample location codes are used for reporting results. The OEMP, the current guiding document for all environmental programs, provides details on the sampling procedures and cites the document containing those procedures. Chapter 11 of the OEMP defines the policies and practices that are applied to provide confidence in the quality of the data.

The data collected in the NES monitoring programs are analyzed as stated in guidance documents, DOE/EH-0023 (Corley et al., 1981) and DOE/EH-XXX (DOE, 1987). Section 8.0 of the OEMP discusses at length the procedures used to analyze the data statistically.

8.3 REVISION OF PROCEDURES

One of the responsibilities of data collection personnel is to assess the performance of collection and analysis methodologies. Sample collection field procedures, analysis preparation, and the laboratory analysis methodology are periodically reviewed and updated and continually scrutinized for adequacy. The method for modifying procedures is set forth in WP 15-101. Additionally, cooperative sampling efforts and radiological samples split with the EEG act as a check that procedures are adequate and that data results are comparable between WIPP and EEG samples. All procedure manuals are reviewed regularly and updated and expanded as necessary.

8.4 INTERLABORATORY COMPARISONS

In October 1990, the WIPP was notified that it was accepted by the DOE-Environmental Measurements Laboratory (EML) to be included in the DOE-EML cross check intercomparison program. The first set of samples for the interlaboratory comparison were shipped to the WIPP in March 1991.

The DOE-EML will periodically send to the WIPP samples of soil, water, vegetation, animal tissues, and air filters. Analytical results are reported to DOE-EML within 90 days and compared with the test results of other participating laboratories. The DOE-EML evaluates and distributes the results to the participating laboratories.

This 1990 Site Environmental Report makes no reference to data comparison's from the comparison program as the WIPP did not participate in 1990.

8.5 LABORATORY QUALITY CONTROL

The WIPP has had contract analytical support for the environmental programs from Westinghouse Advanced Energy Systems Division, Waltz Mill, Pennsylvania; Eberline Analytical Corporation, Santa Fe, New Mexico; the University of New Mexico, Albuquerque, New Mexico; International Technology Corporation Laboratories (Export, Pennsylvania, and Cerritos, California); and United Nuclear Corporation Grand Junction, Colorado.

The contracts with the above mentioned laboratories are currently being rebid/renegotiated. Upon the acceptance of any laboratory to perform analytical analysis for the WIPP. They must adhere to and provide evidence of the following compliance with the ASME NQA-1.

- Routine calibration of instruments
- Frequent source and background counts (as appropriate)
- Routine yield determinations of radiochemical procedures

- Replicate/duplicate analyses to check precision
- Analyses of reagents to ensure chemical purity that could affect the results of the analytical process

Each laboratory will have a written and implemented QA program that utilizes standard analysis methods for each parameter studied. These methods are listed in detail in the OEMP.

Participation in interlaboratory cross-checks can reveal outdated, previously acceptable lab procedures that are currently unsuitable or inadequate. Steps are then taken to find updated methodologies. The four laboratories providing chemical analytical services for the WIPP are required to participate in interlaboratory cross-checks conducted by the EPA.

8.6 RECORD KEEPING

Records generated in support of the OEMP are controlled and maintained in accordance with Order DOE 1324.2 (DOE, 1982a), W Records Management Procedures (WP 15-030). All original records are maintained in a fire resista. cabinet at the WIPP until they are transmitted to the WIPP Master Records Center for permanen (WP 15-030). All records, including raw data, calculations, computer programs or other anipulation, are subject to review and verification under the WIPP Quality Assurance Program. Environmental Monitoring Section is responsible for validation of these records prior to transmittal to the Master Records Center in accordance with the Records Inventory Disposition Schedule.

Records (such as reports of analyses and sample receipt forms transmitted by contract analytical laboratories) are dated upon receipt and a copy made for QC review as specified in NES/RES QA/QC Implementation Procedures (WP 02-302). Specific record and data management procedures including the recording and referencing of data manipulations are implemented according to the WIPP Groundwater Monitoring Program Plan and Procedures Manual, RES Data Management Procedure (WP 02-305), and NES Data Management Procedure (WP 02-334).

The WIPP complies with record-keeping requirements as promulgated under 40 CFR Part 61, Subpart H (EPA, 1985b), which pertain to atmospheric radionuclide emissions (WP 02-301). In addition, unless regulations are amended in the future, records development pursuant to these criteria will be maintained at least 30 years, as specified in DOE 1324.2 (DOE, 1982a), Chapter V, Attachment 1, Schedule 25 (Medical, Health and Safety Records).

Consistent record keeping in all aspects of the Environmental Monitoring Programs are a part of QA requirements. Section 10.0 of the OEMP (DOE, 1989) includes a listing of the required records and reports and the laws, regulations, or DOE Orders that contain the requirements. Records are maintained in accordance with WP 15-030, Records Management.

CHAPTER 9

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WSMR, NM 88002-5076

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Roswell, NM 88201

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APPENDIX I

GROSS ALPHA CONCENTRATIONS

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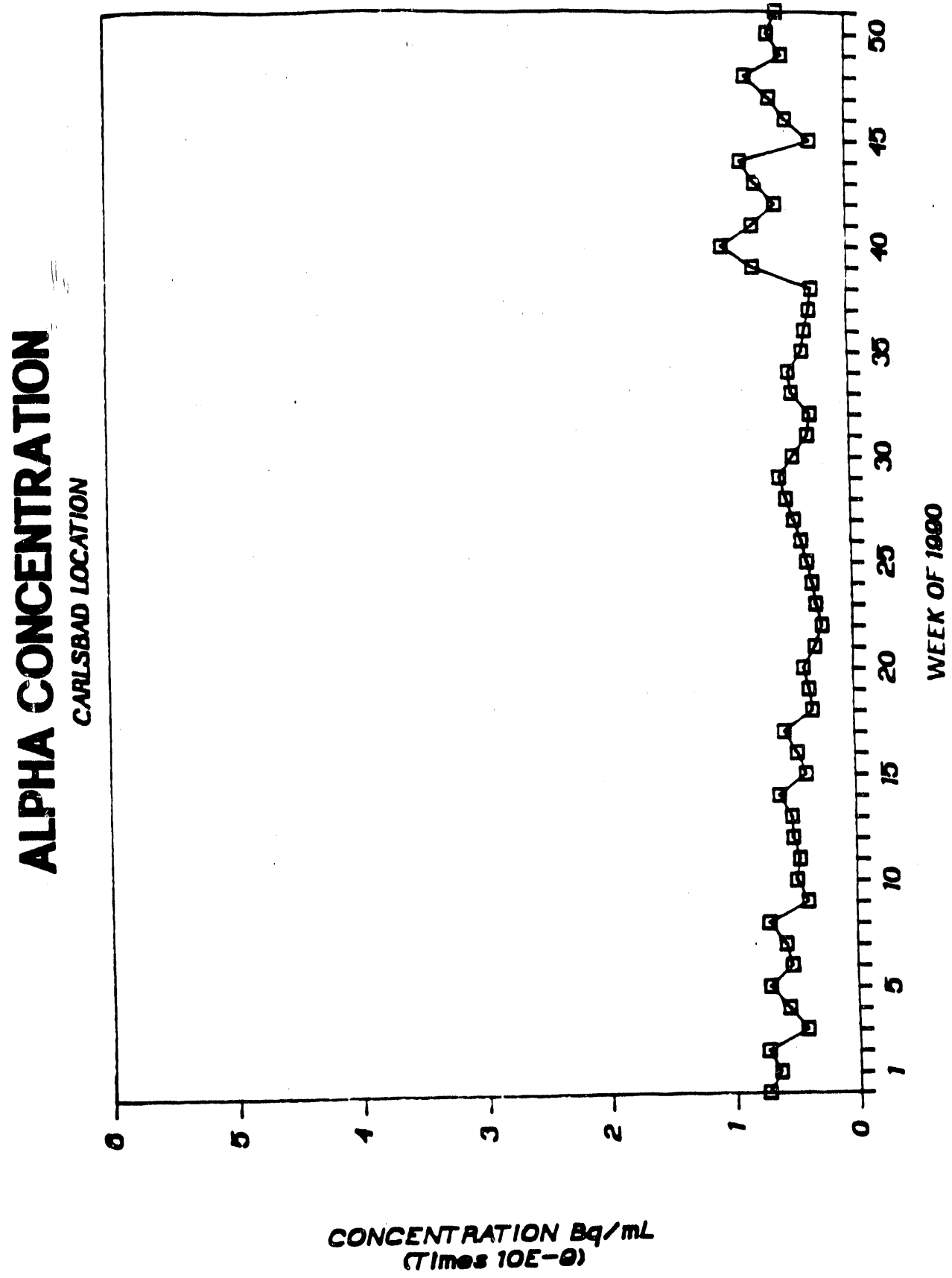
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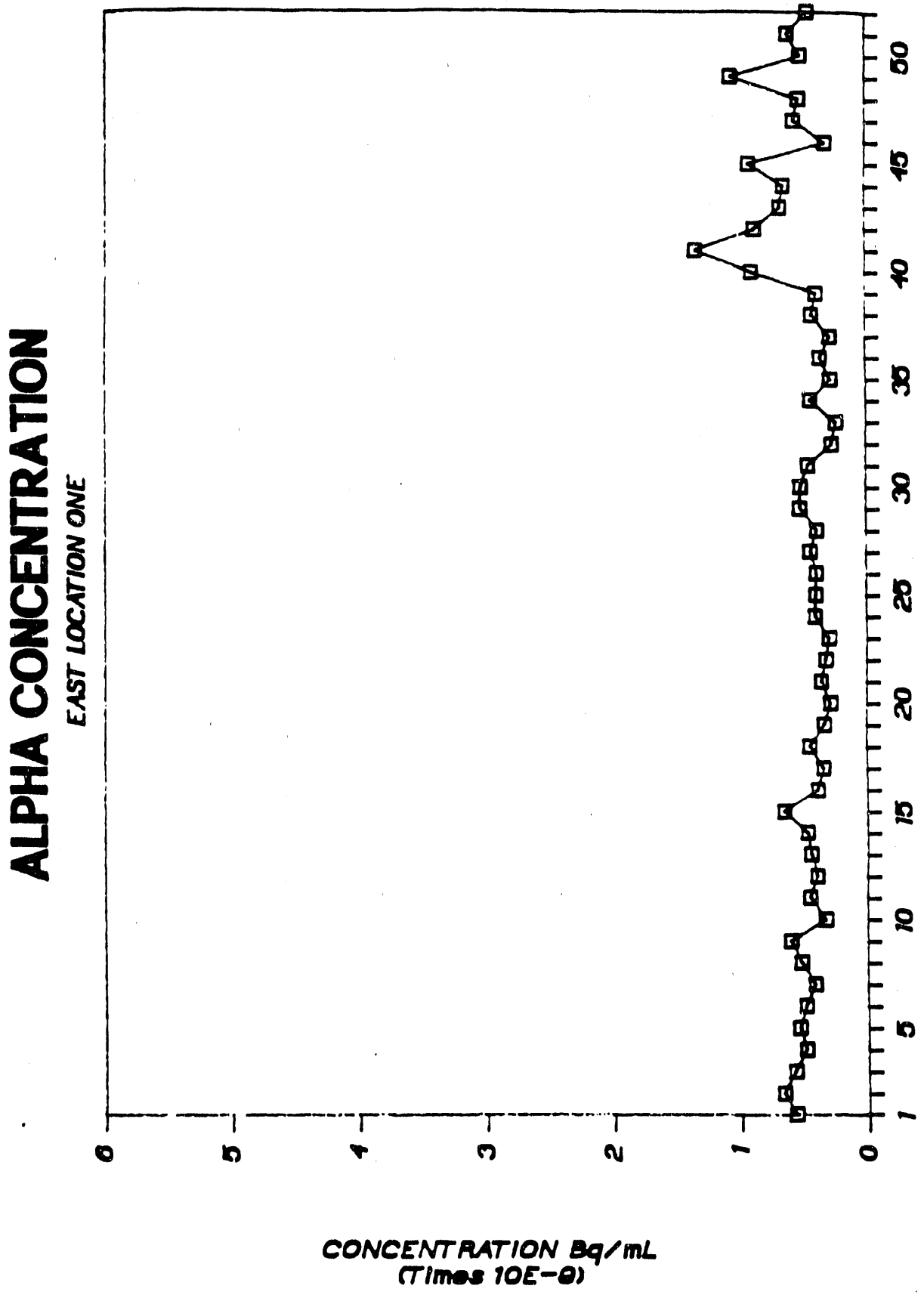
WEEK OF 1990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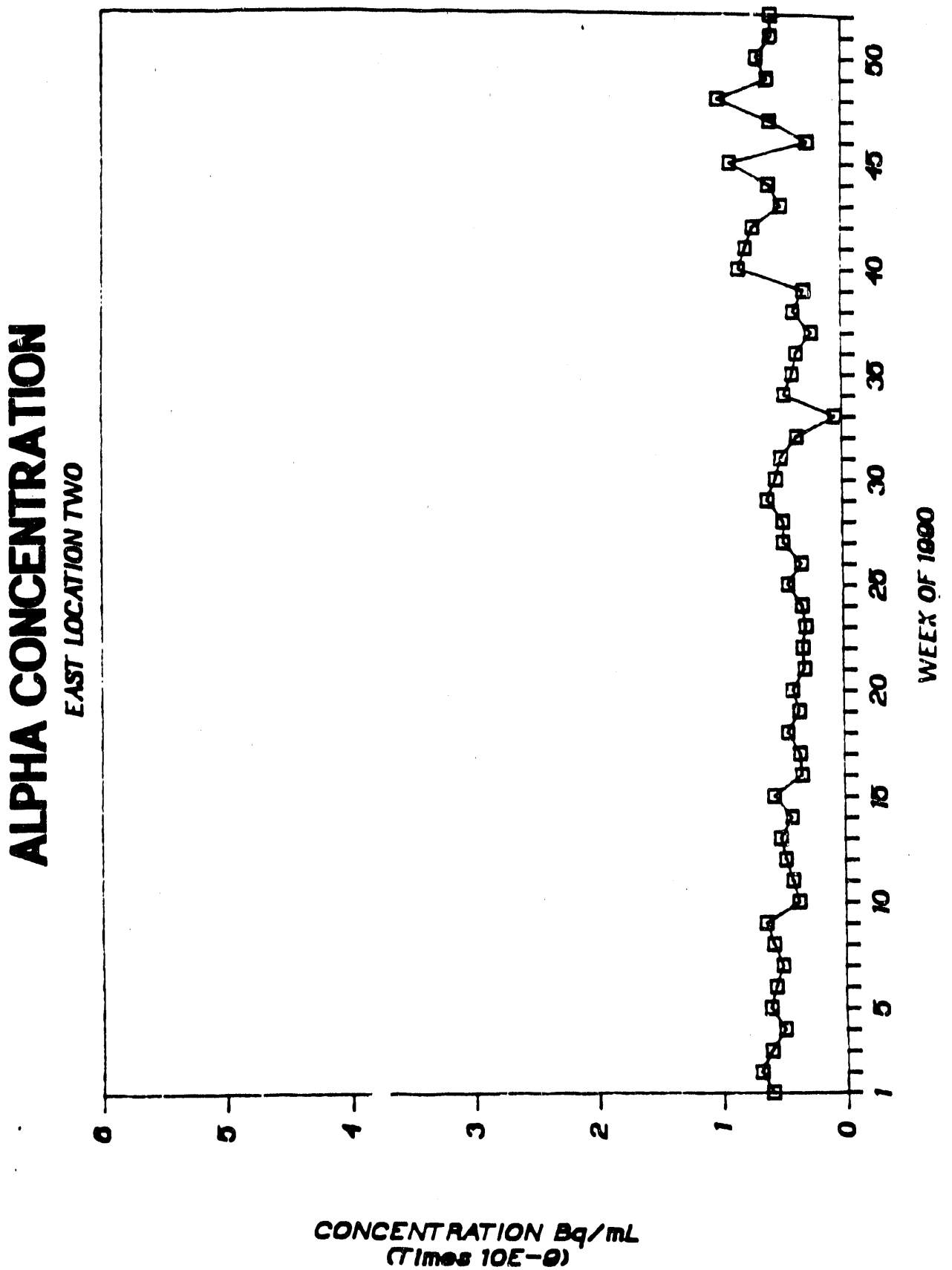
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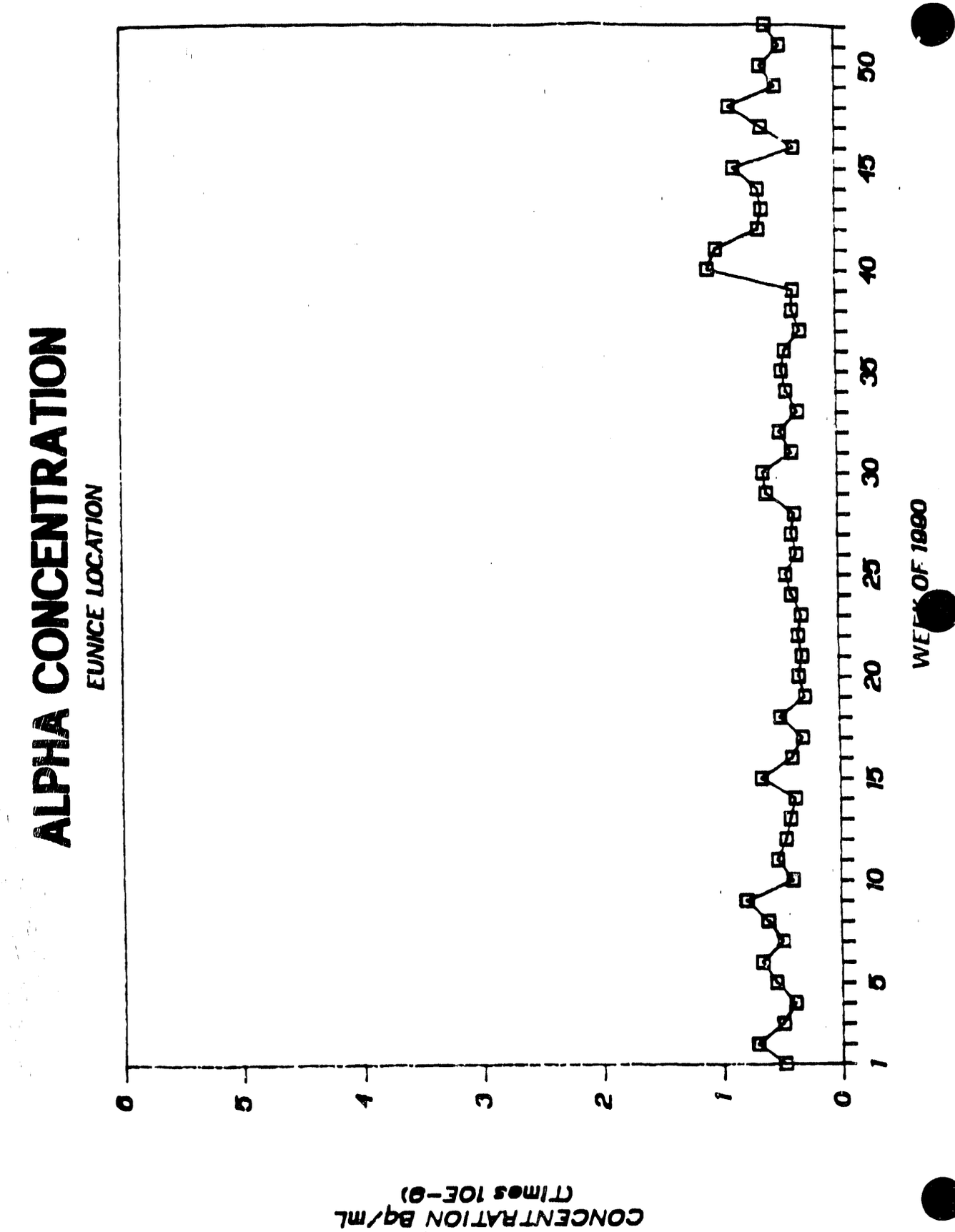
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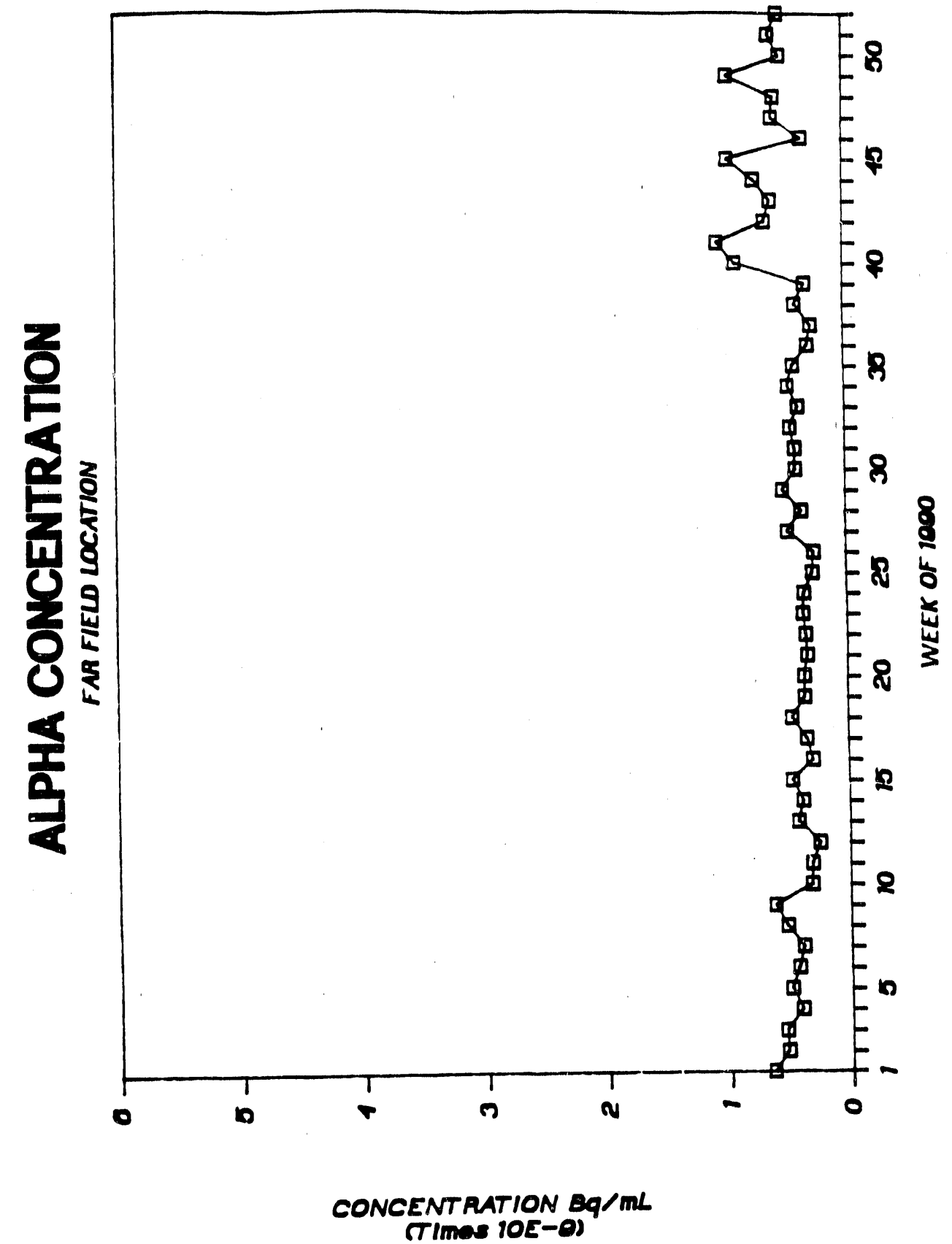
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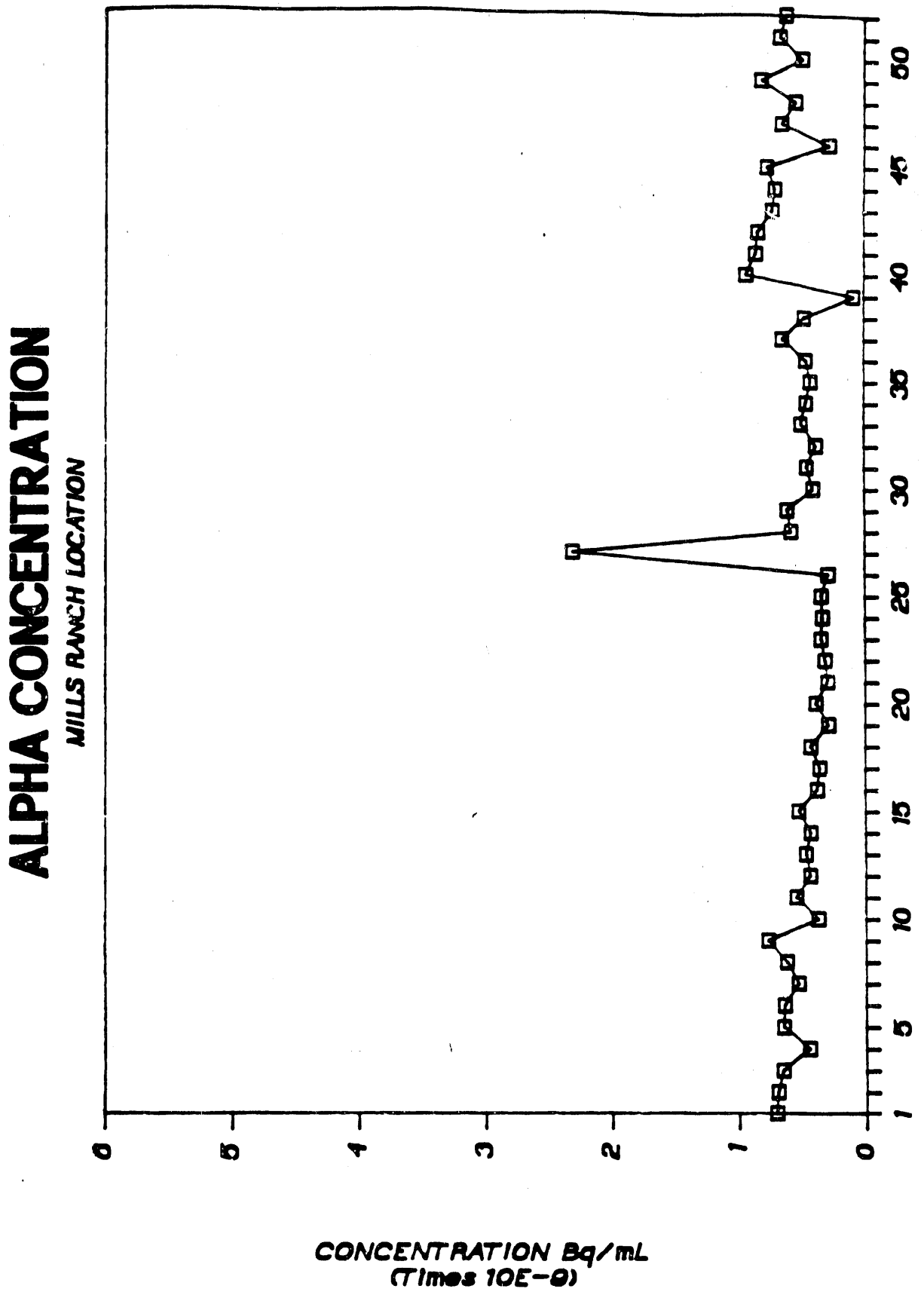
WEEK OF 1990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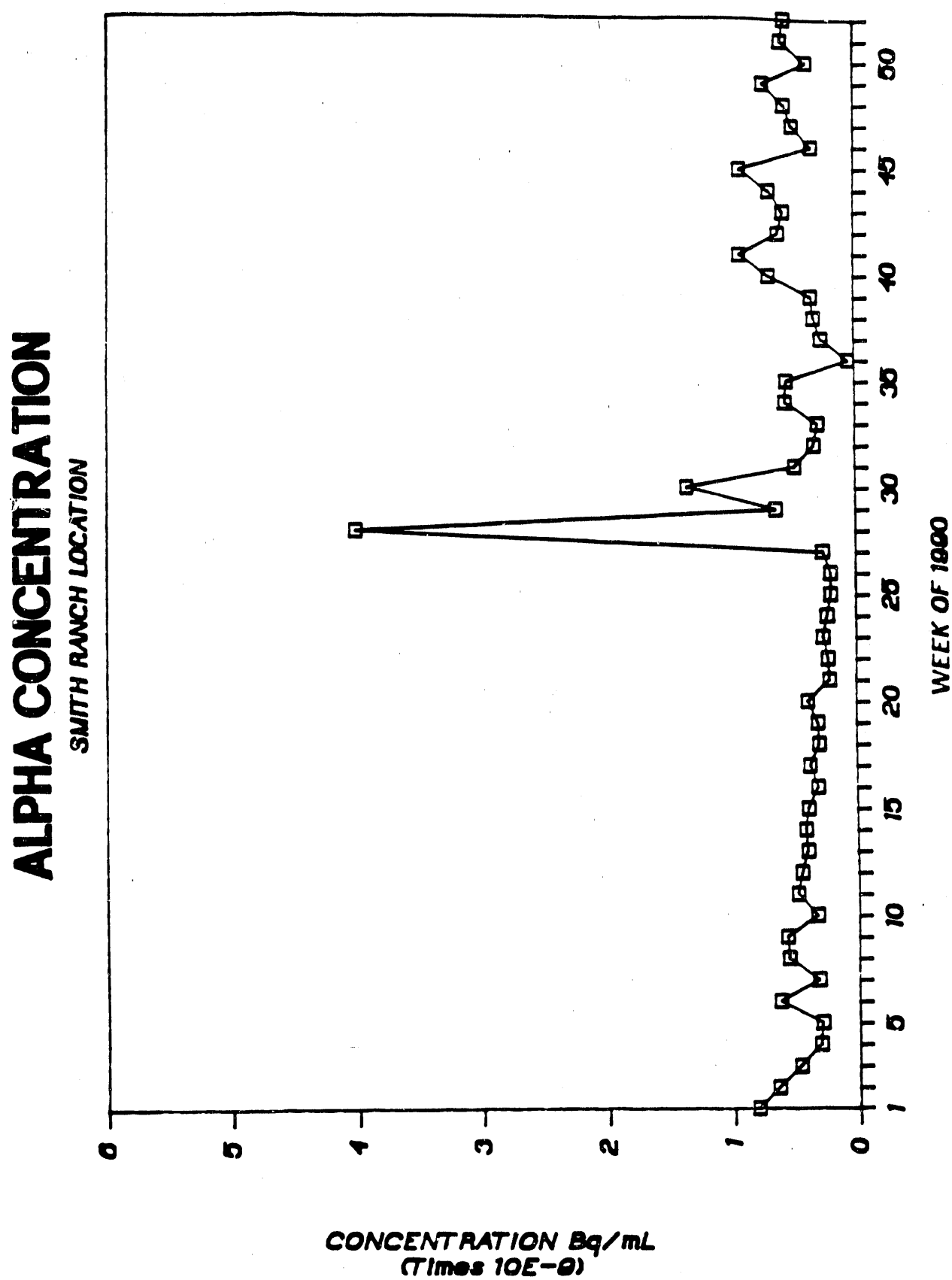
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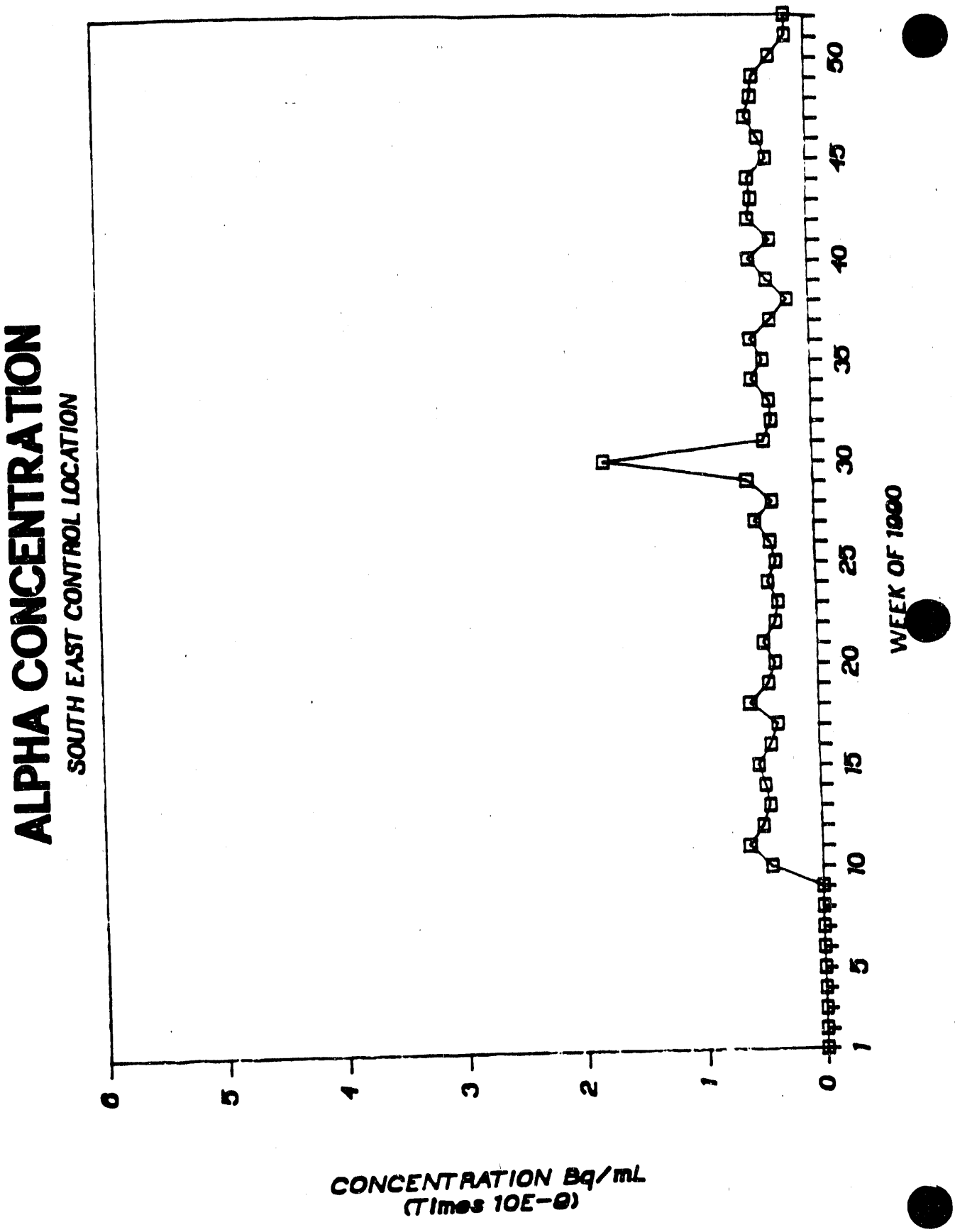
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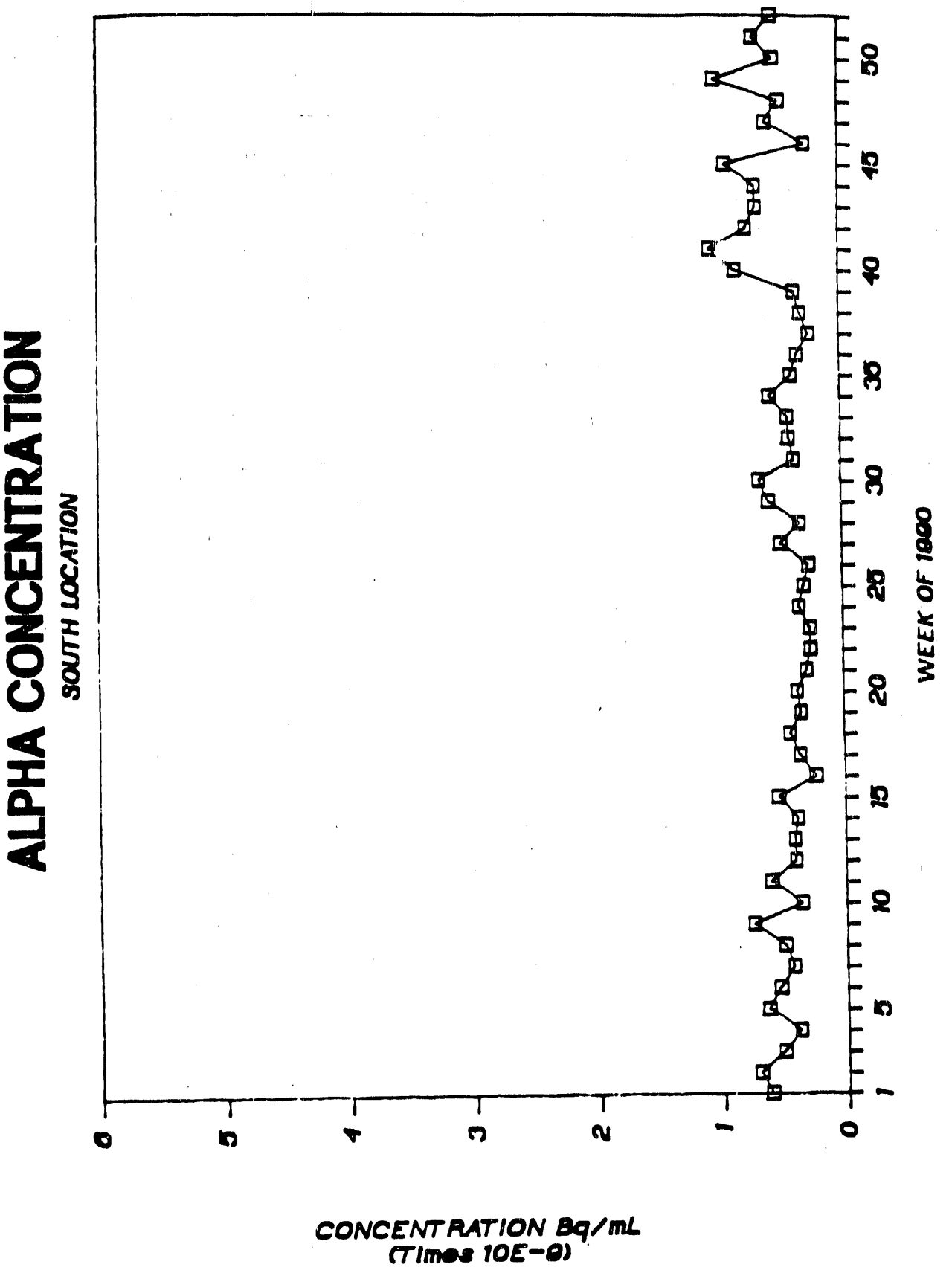
WEEK OF 1990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APPENDIX II

GROSS BETA CONCENTRATIONS

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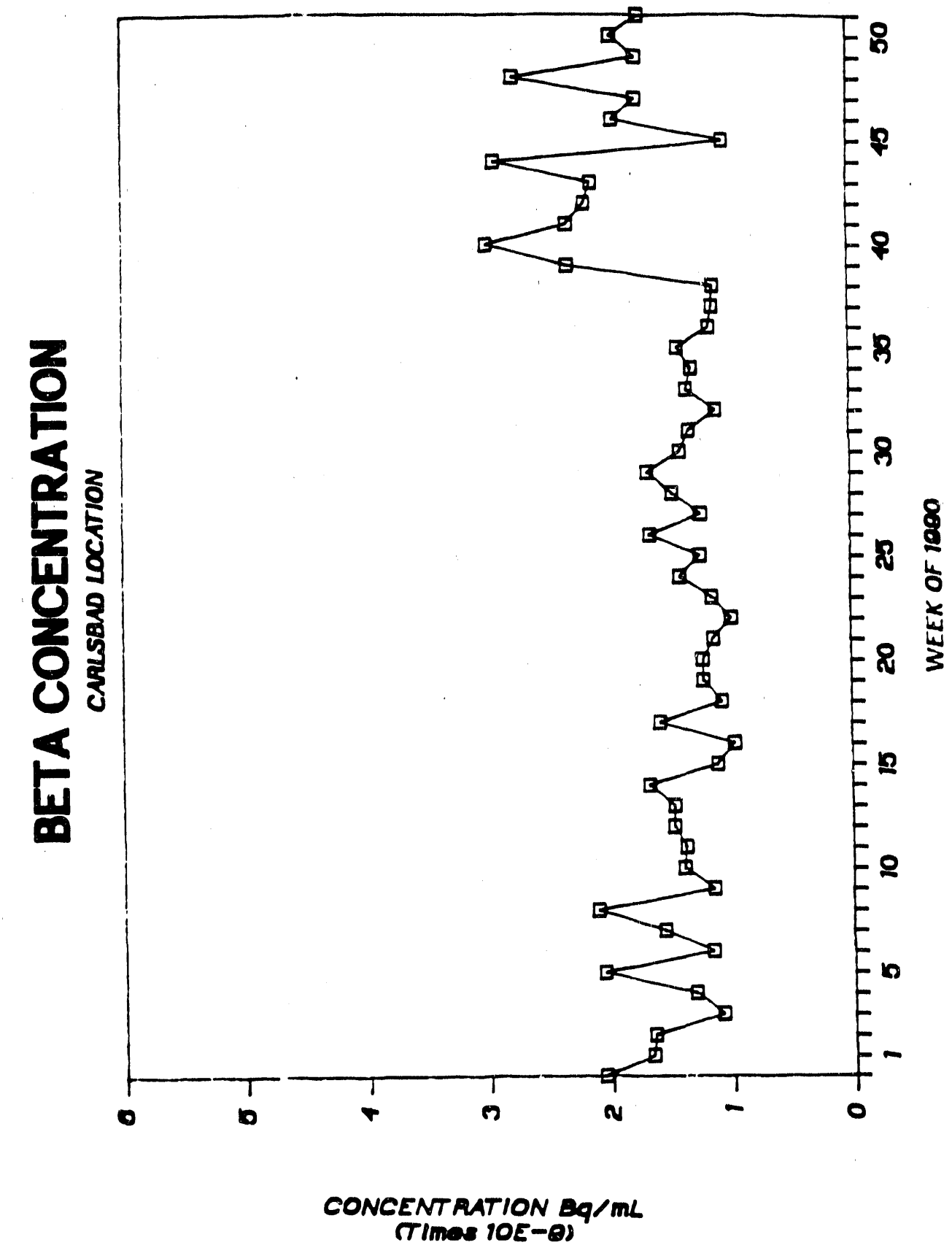
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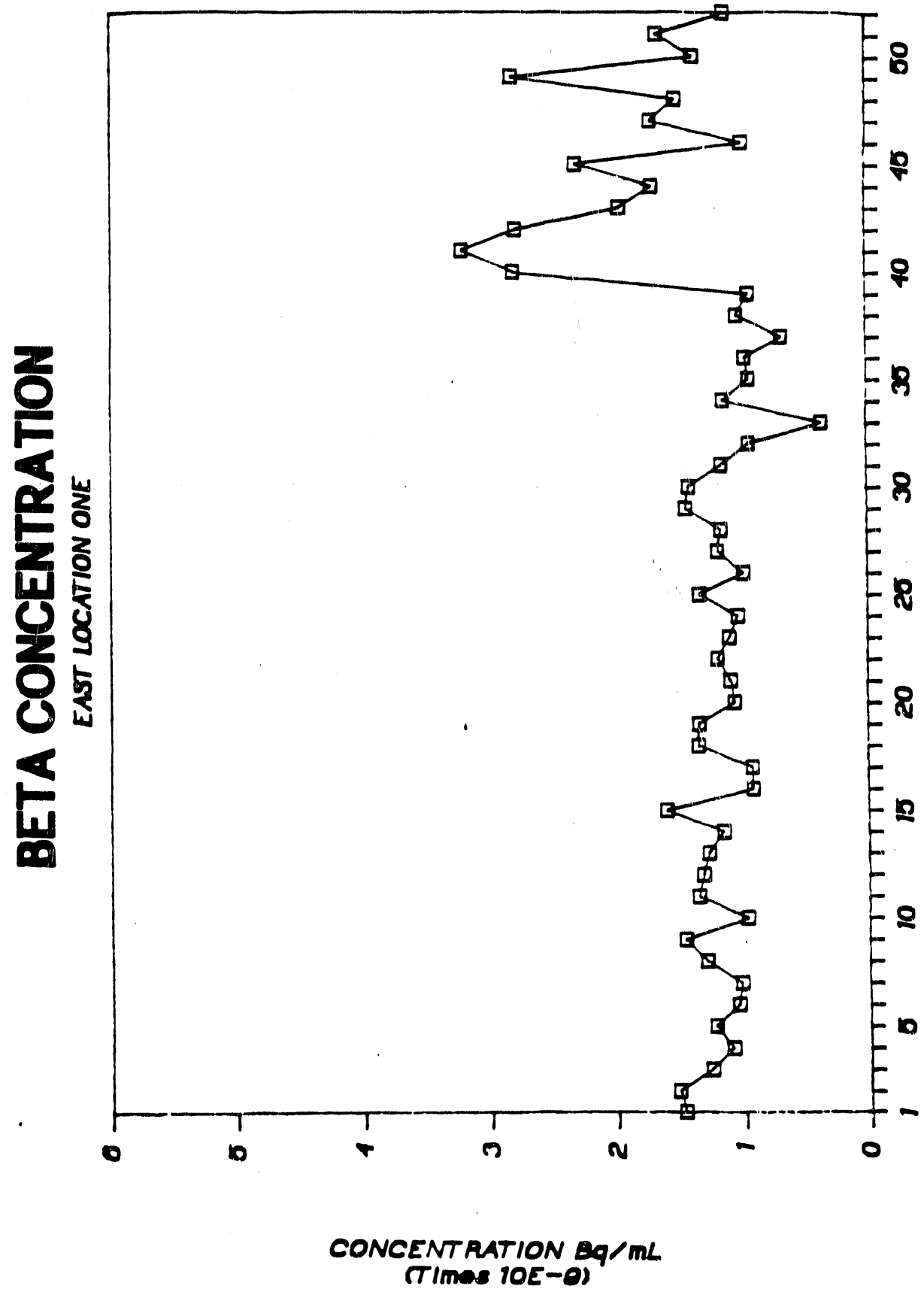
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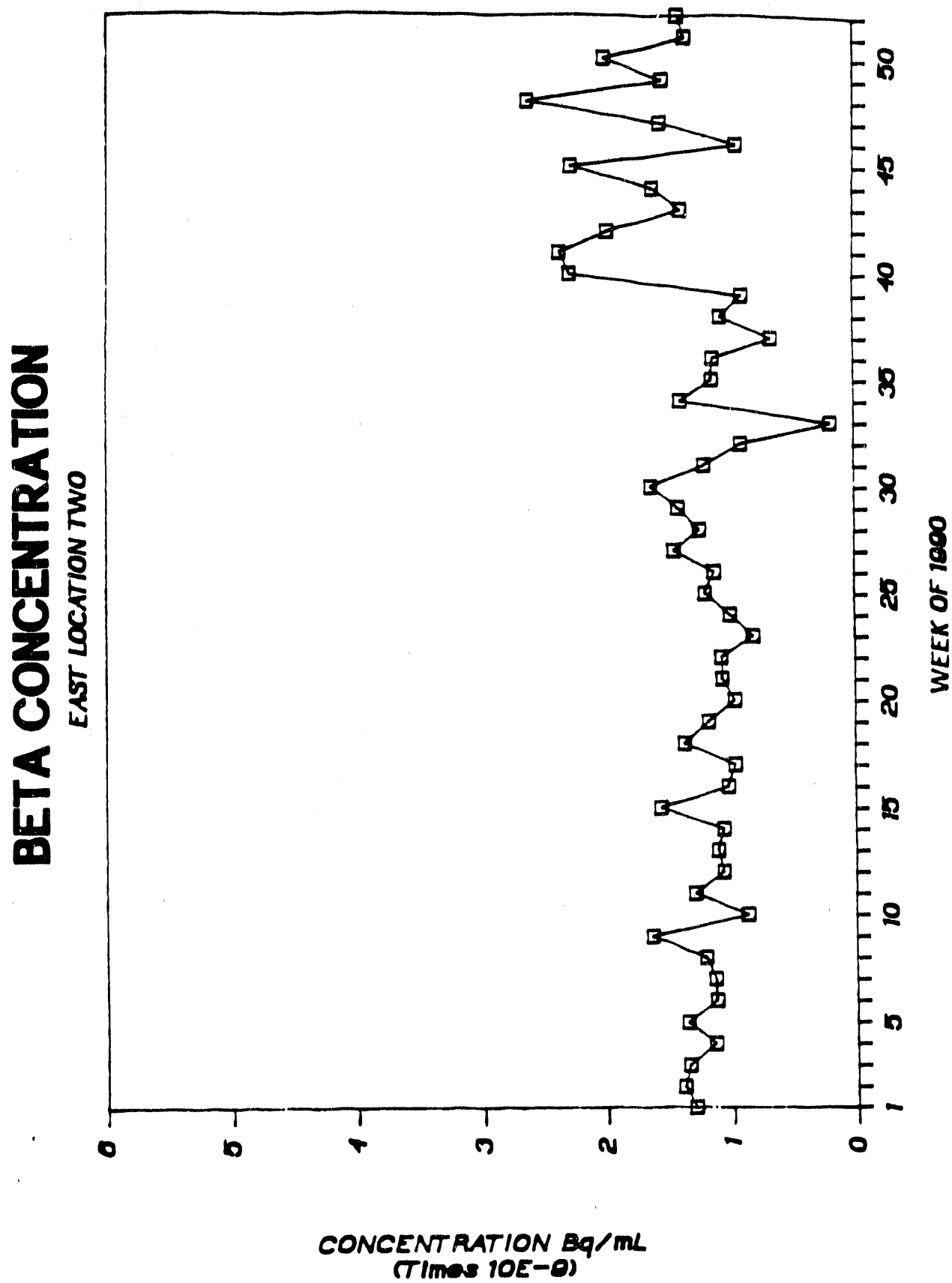
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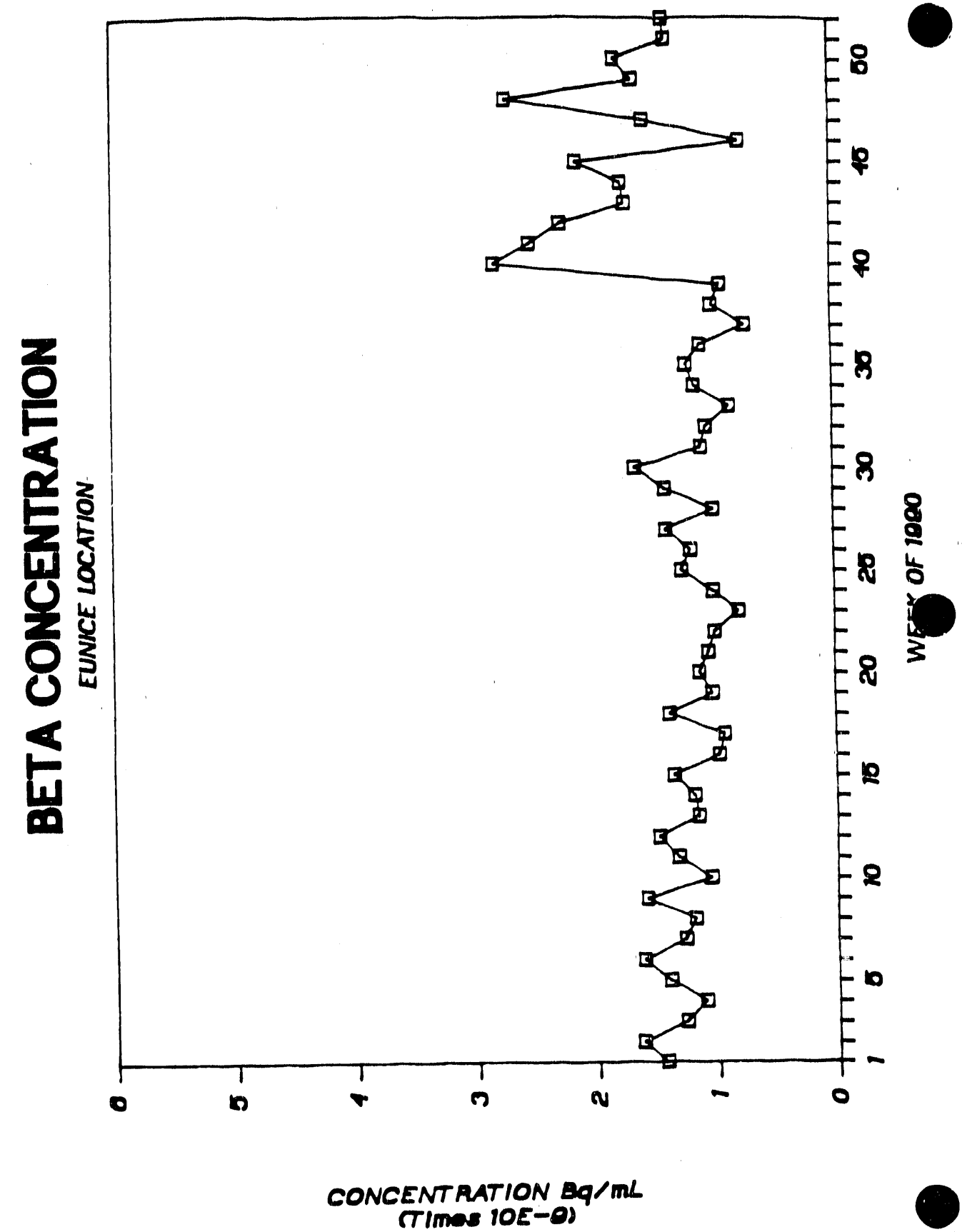
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CONCENTRATION Bq/mL
(Times 10E-9)
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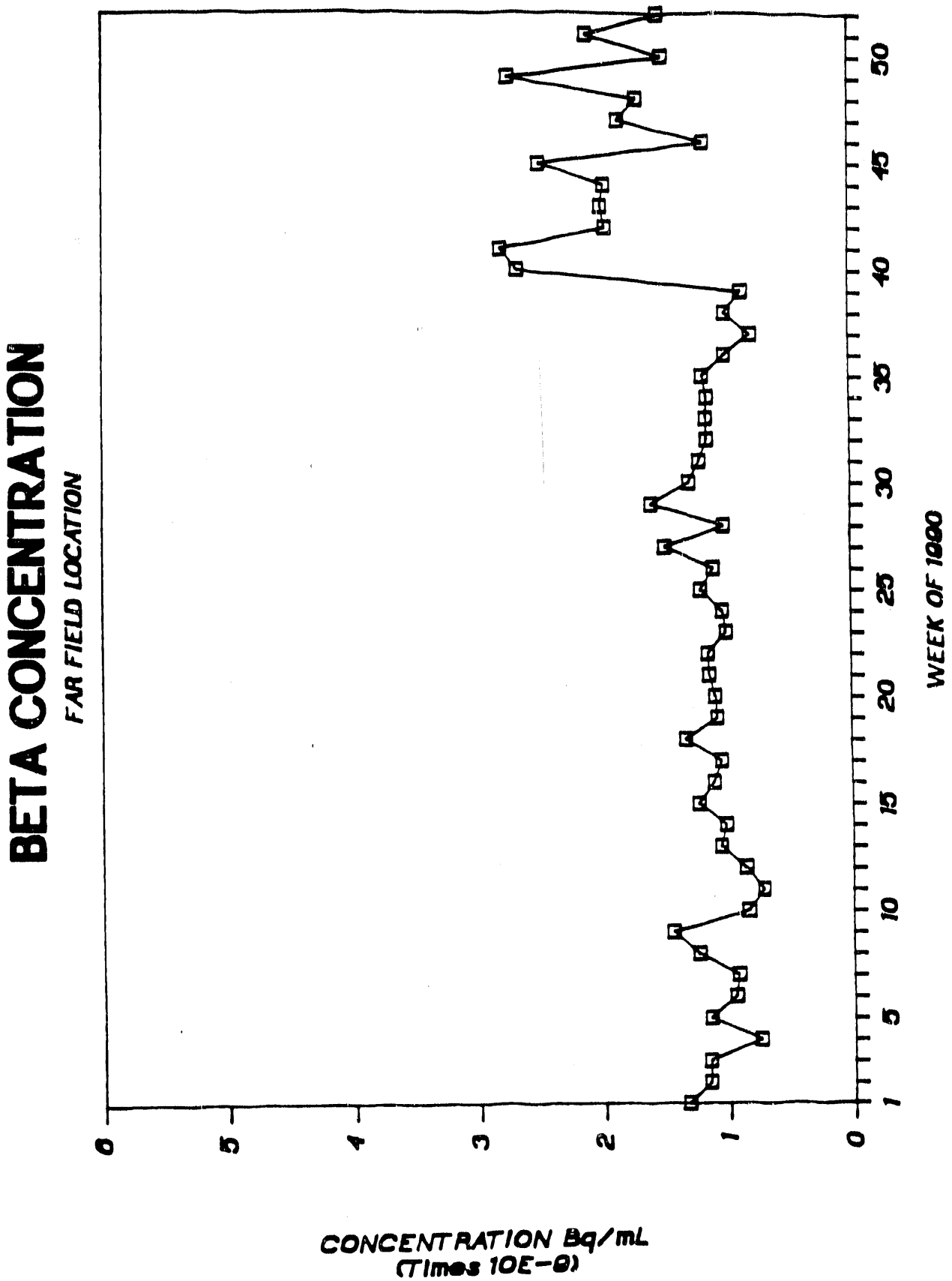
WEEK OF 1990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CONCENTRATION Bq/mL
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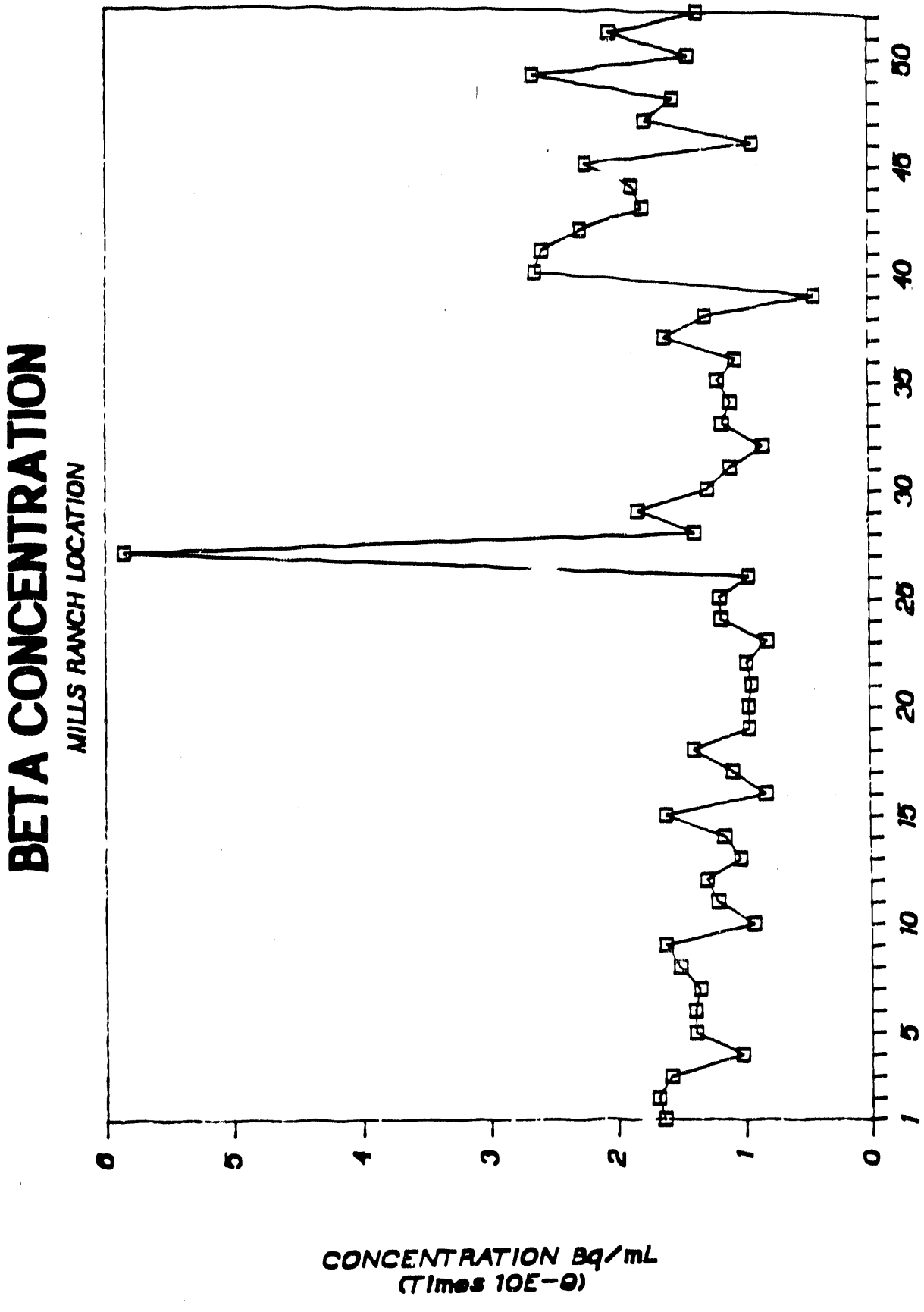
WEEK OF 1990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CONCENTRATION Bq/mL
(Times 10E-9)
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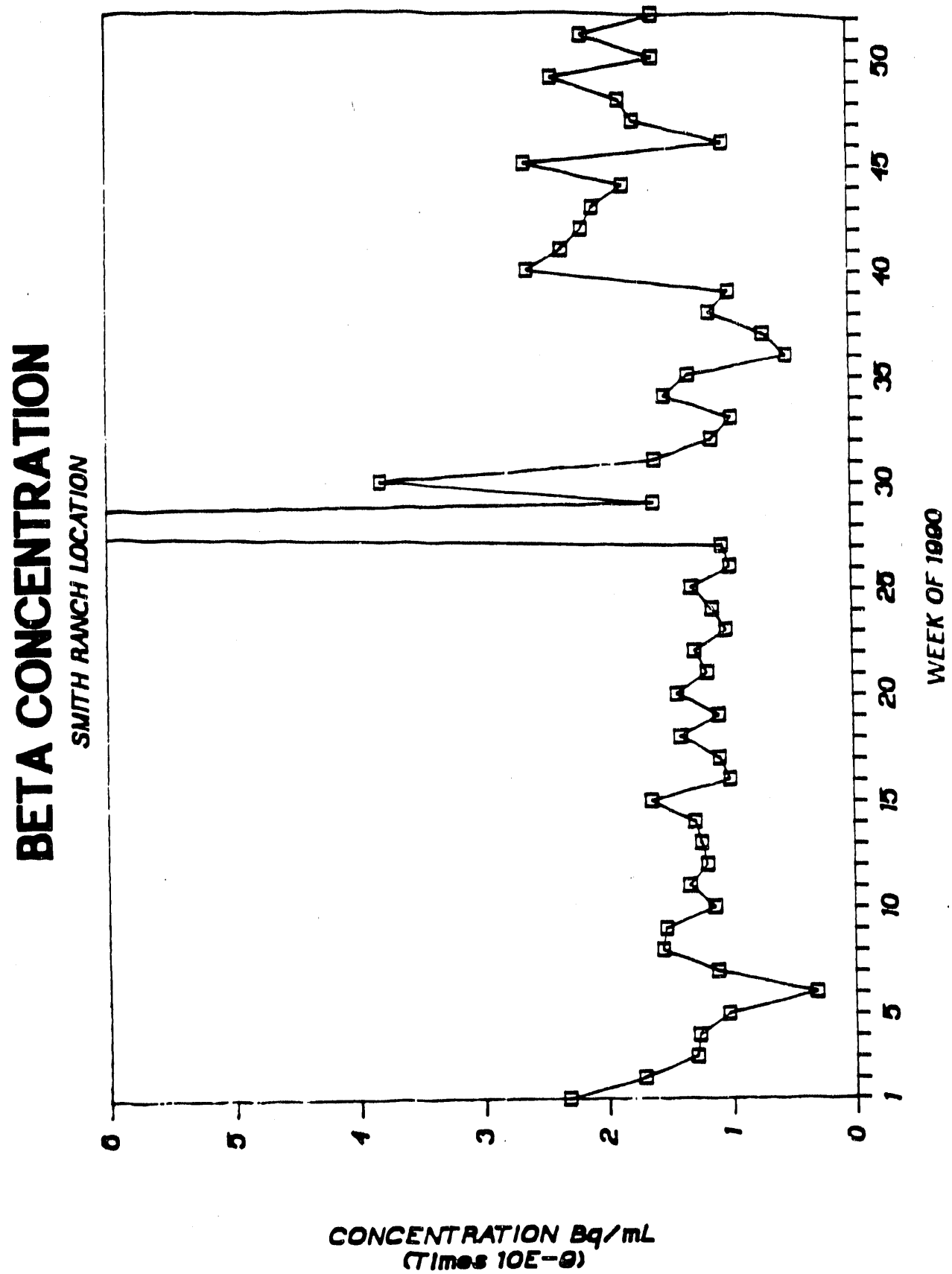
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SMITH RANCH LOCATION
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WEEK OF 1990
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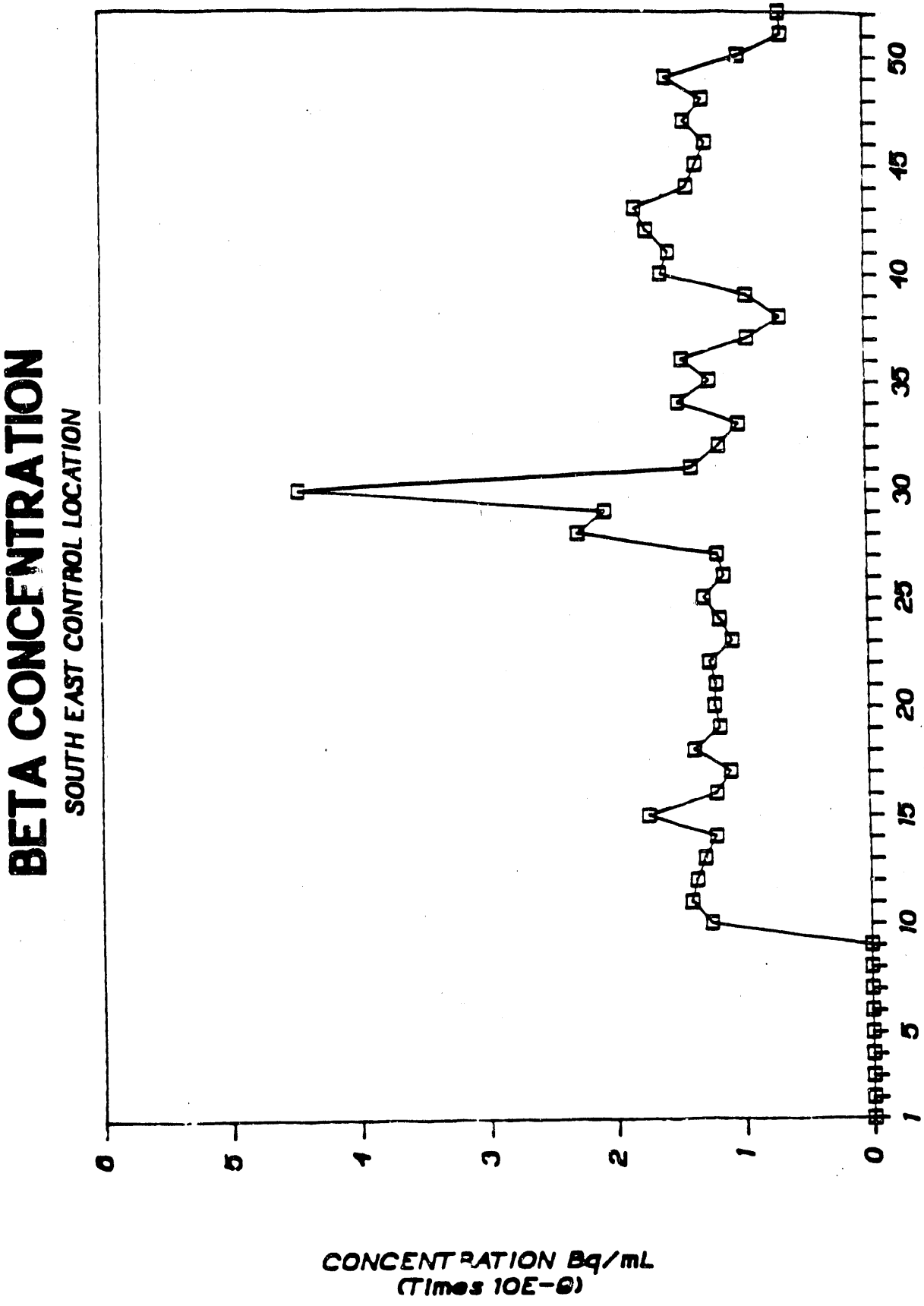
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CONCENTRATION Bq/mL
(Times 10E-8)
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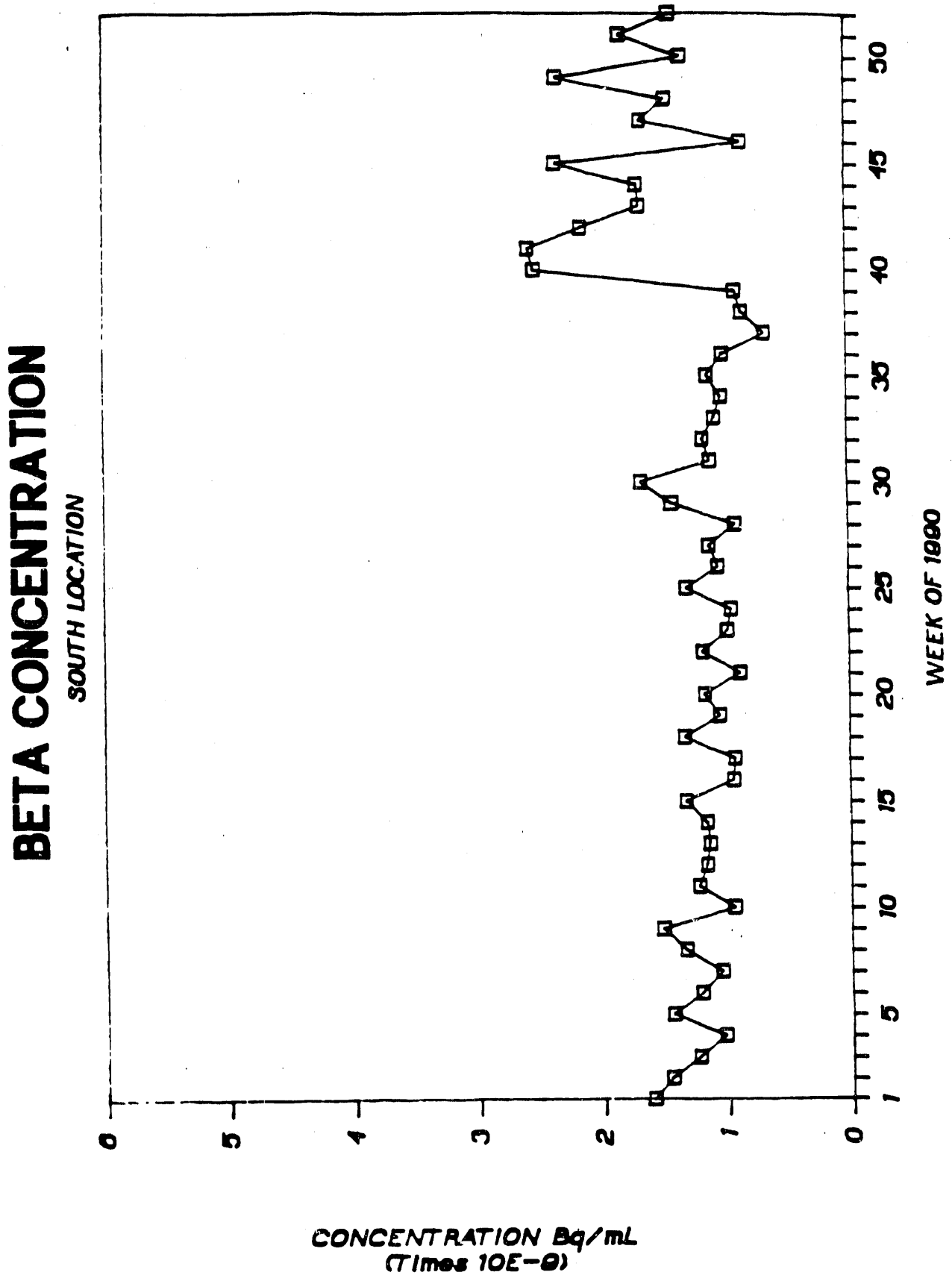
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(Times 10E-8)
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15
20
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WEEK OF 1990

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APPENDIX III

DAILY MAXIMUM, MINIMUM, AND AVERAGE TEMPERATURE

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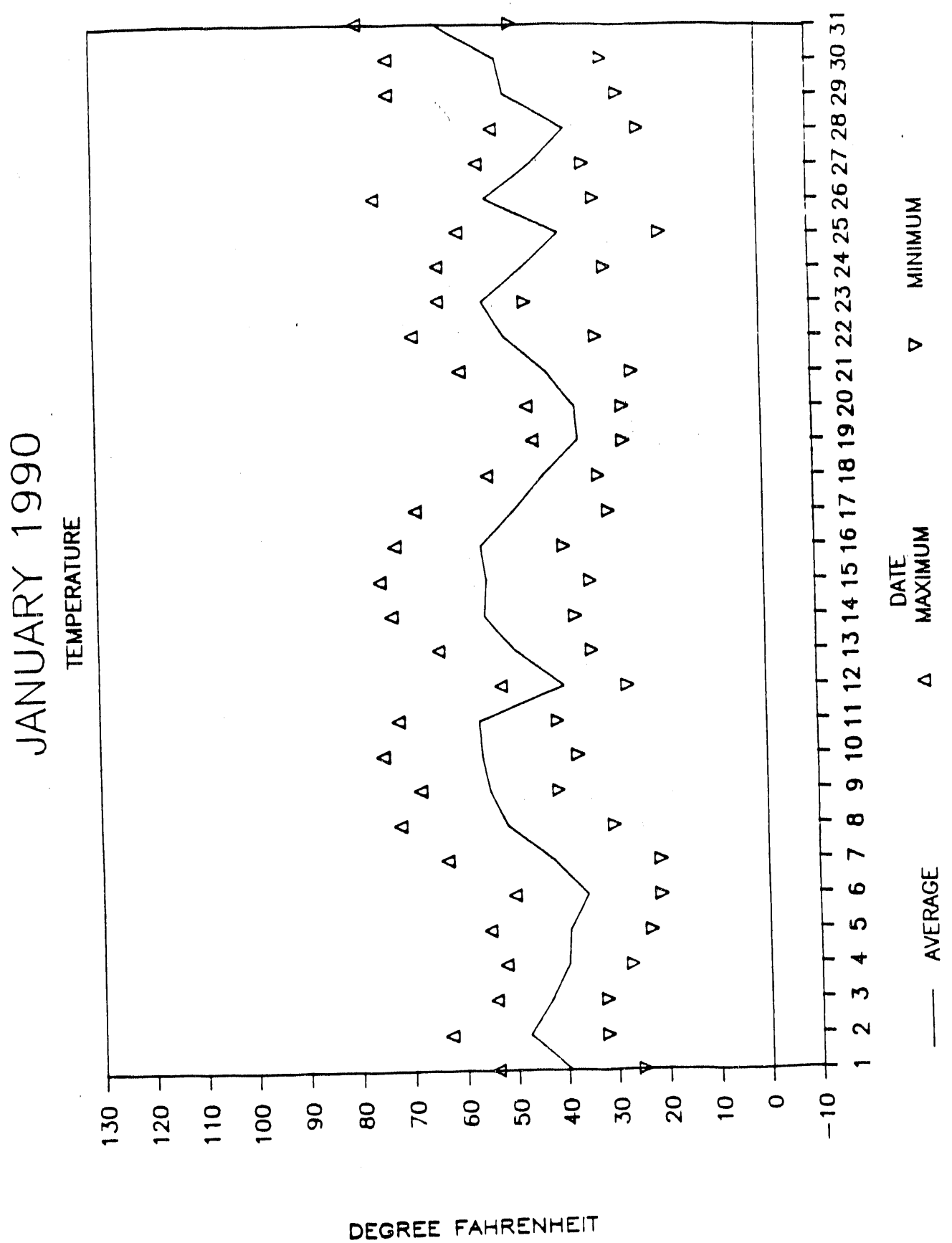
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AVERAGE
MAXIMUM
MINIMUM

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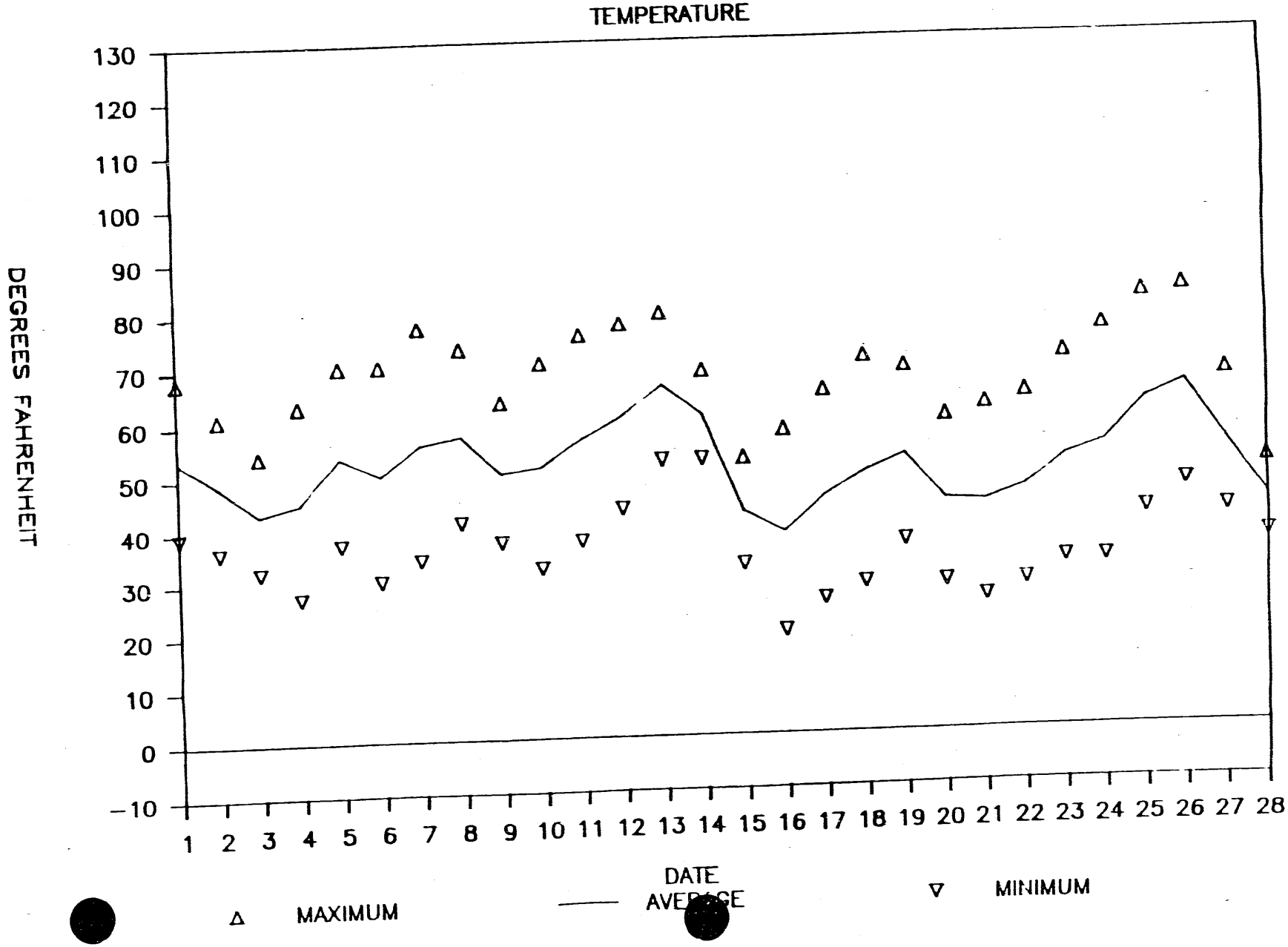

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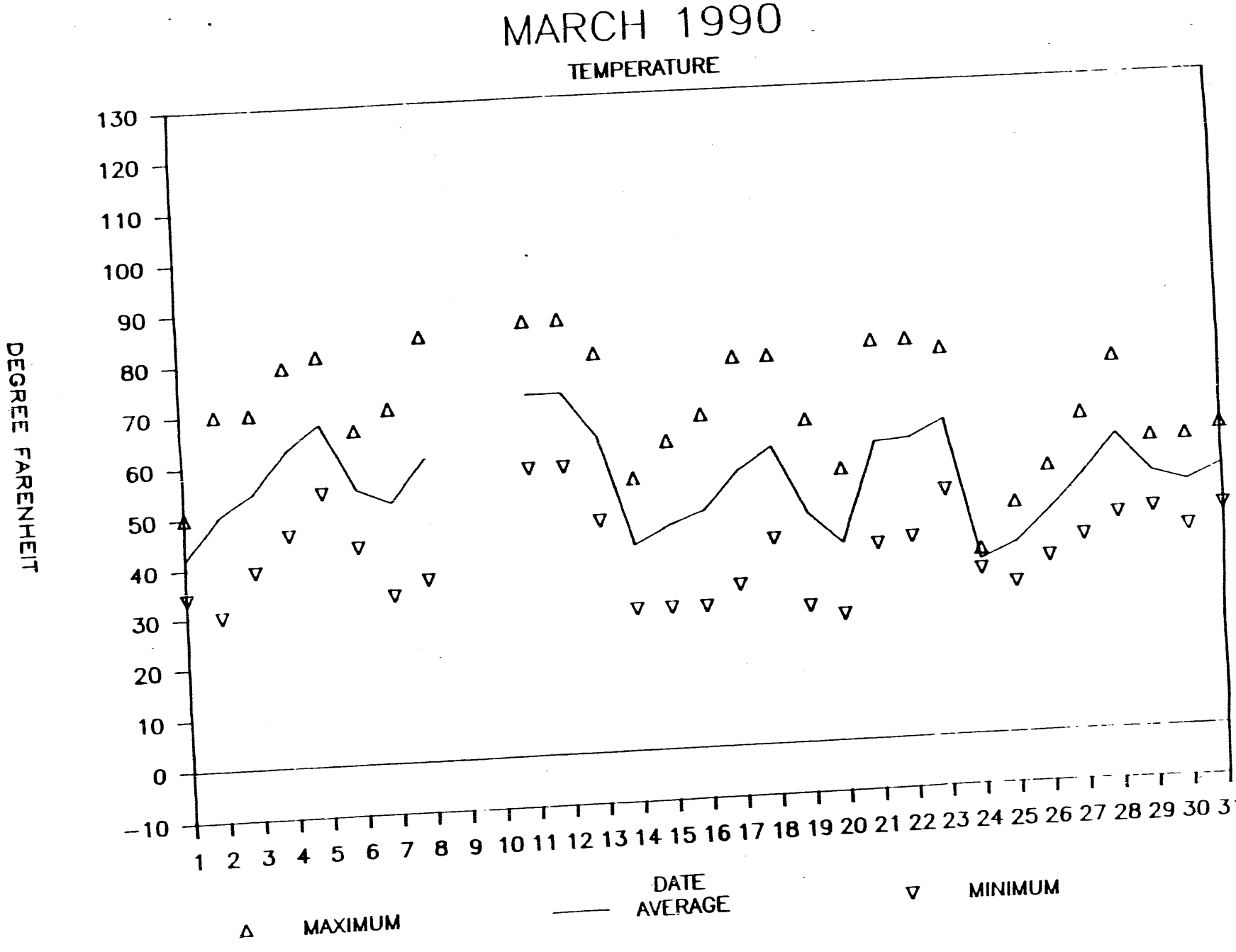
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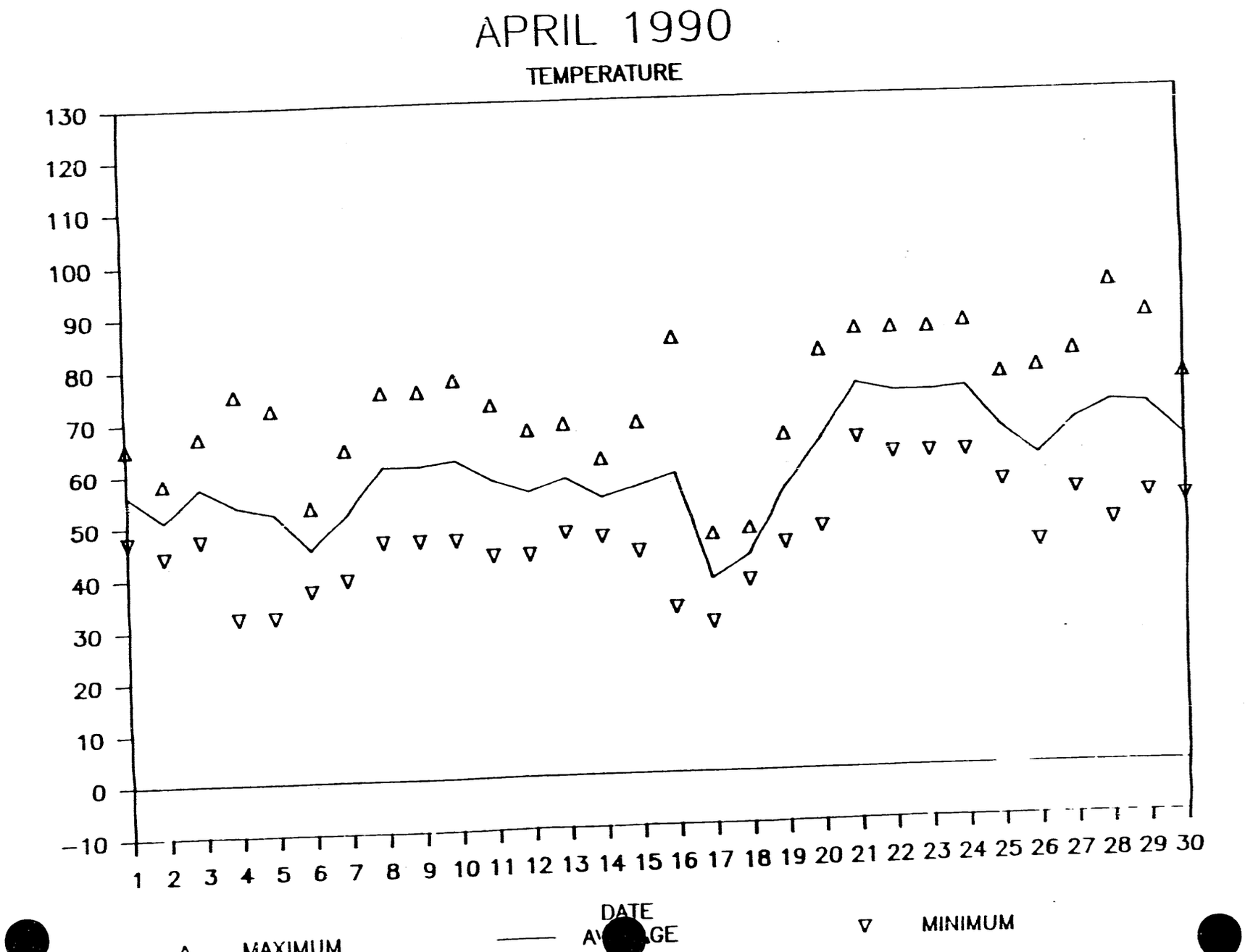
DATE
MAXIMUM
AVERAGE
MINIMUM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DATE
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AVERAGE
MINIMUM

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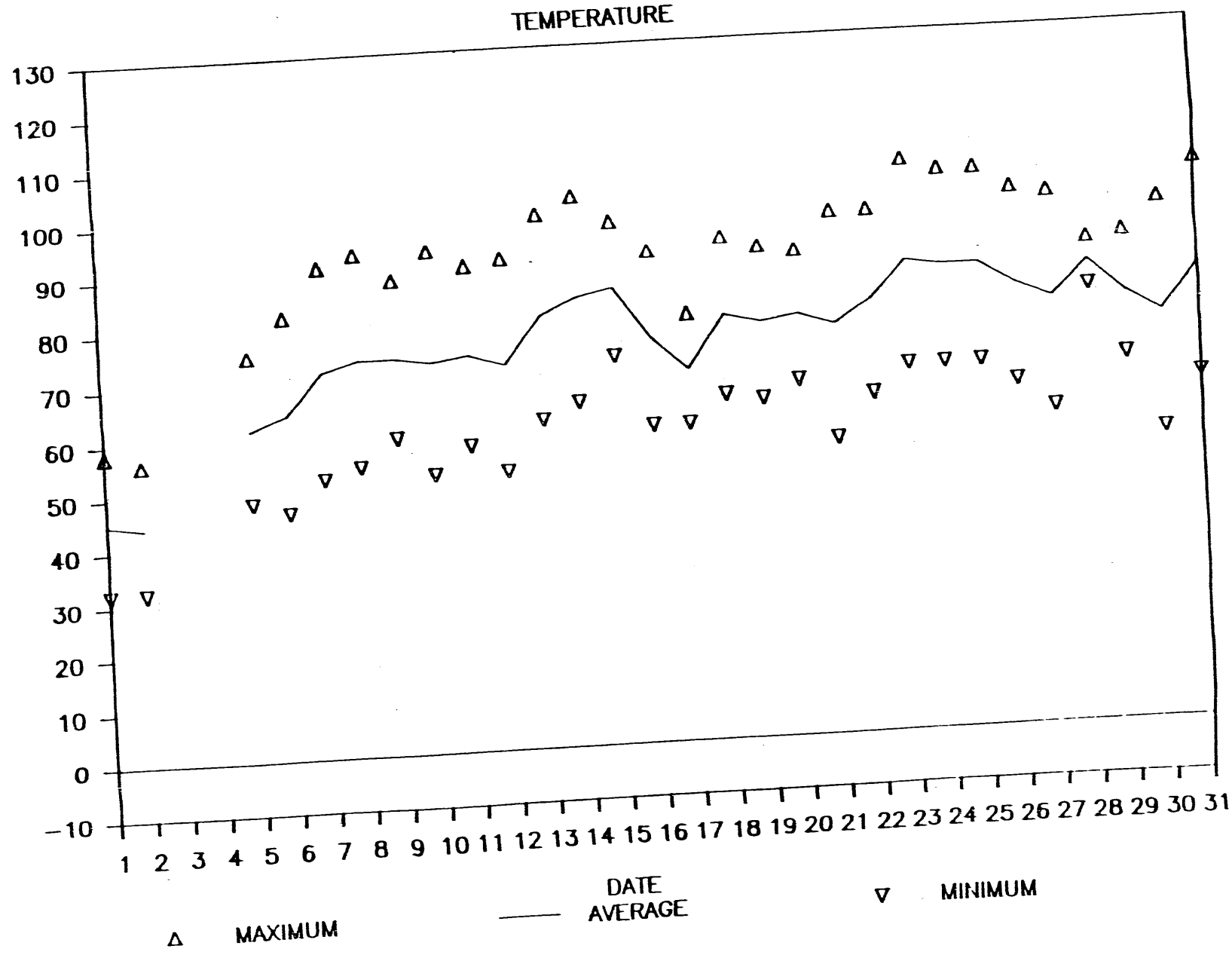
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DEGREE FARENHEIT
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MAXIMUM
AVERAGE
MINIMUM

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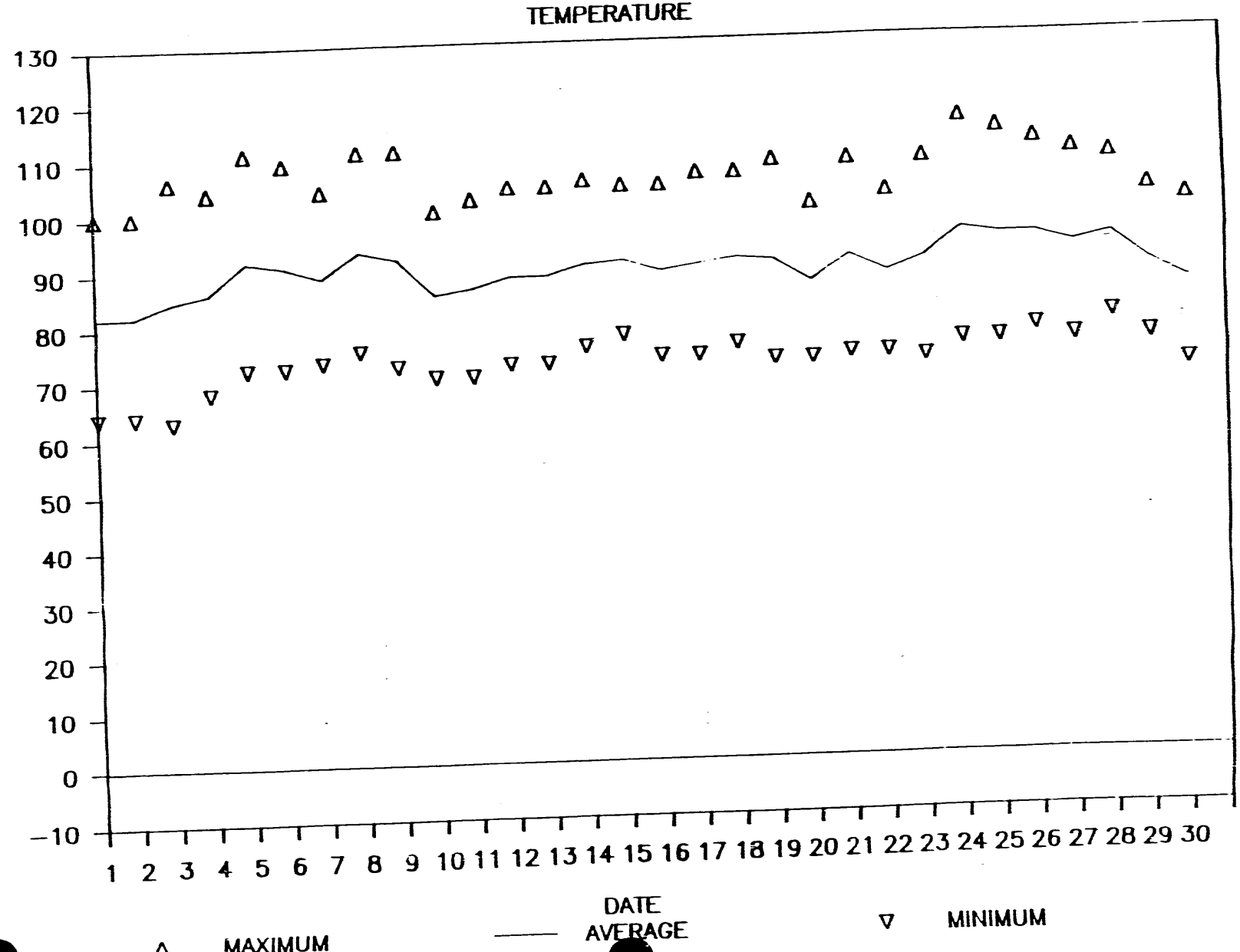

DEGREE FAHRENHEIT

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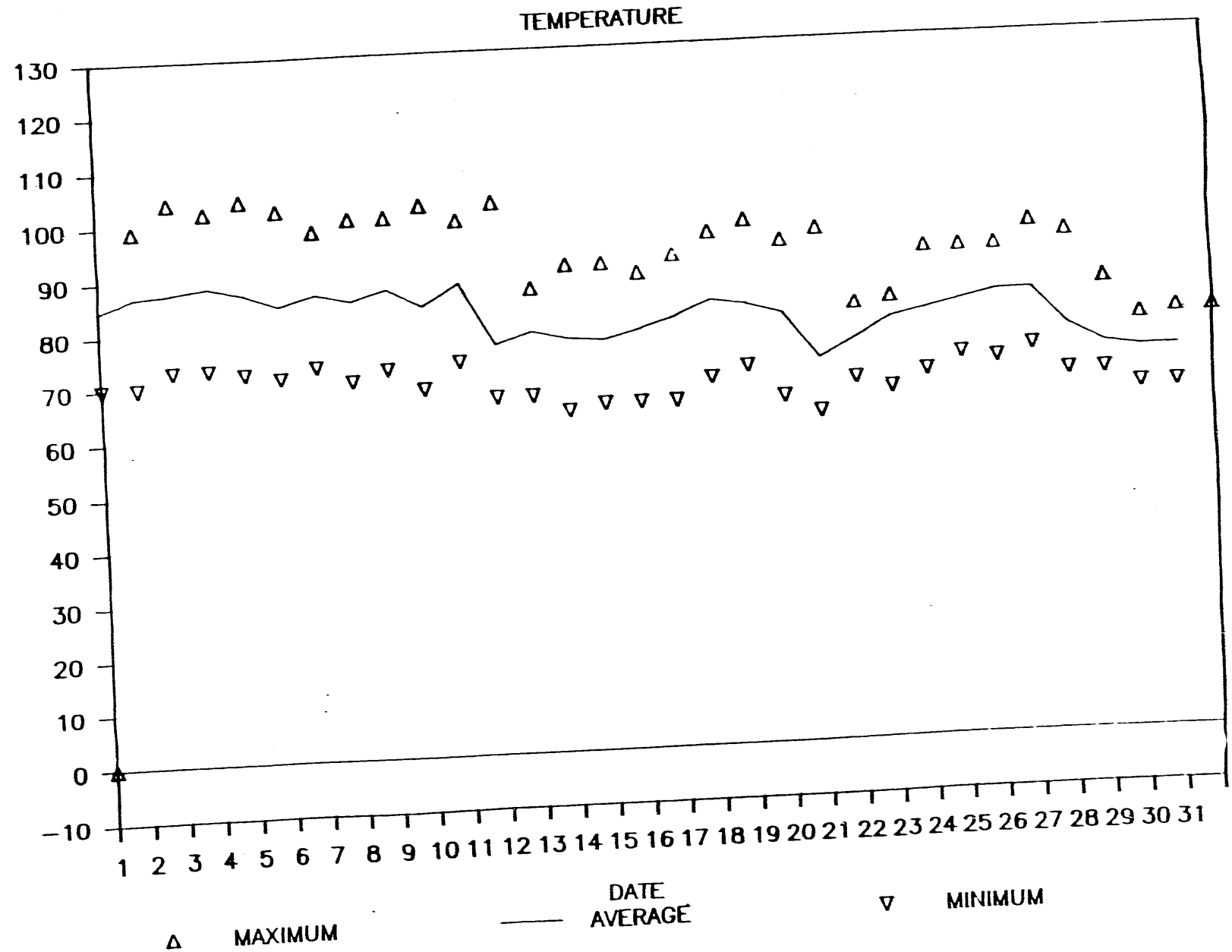

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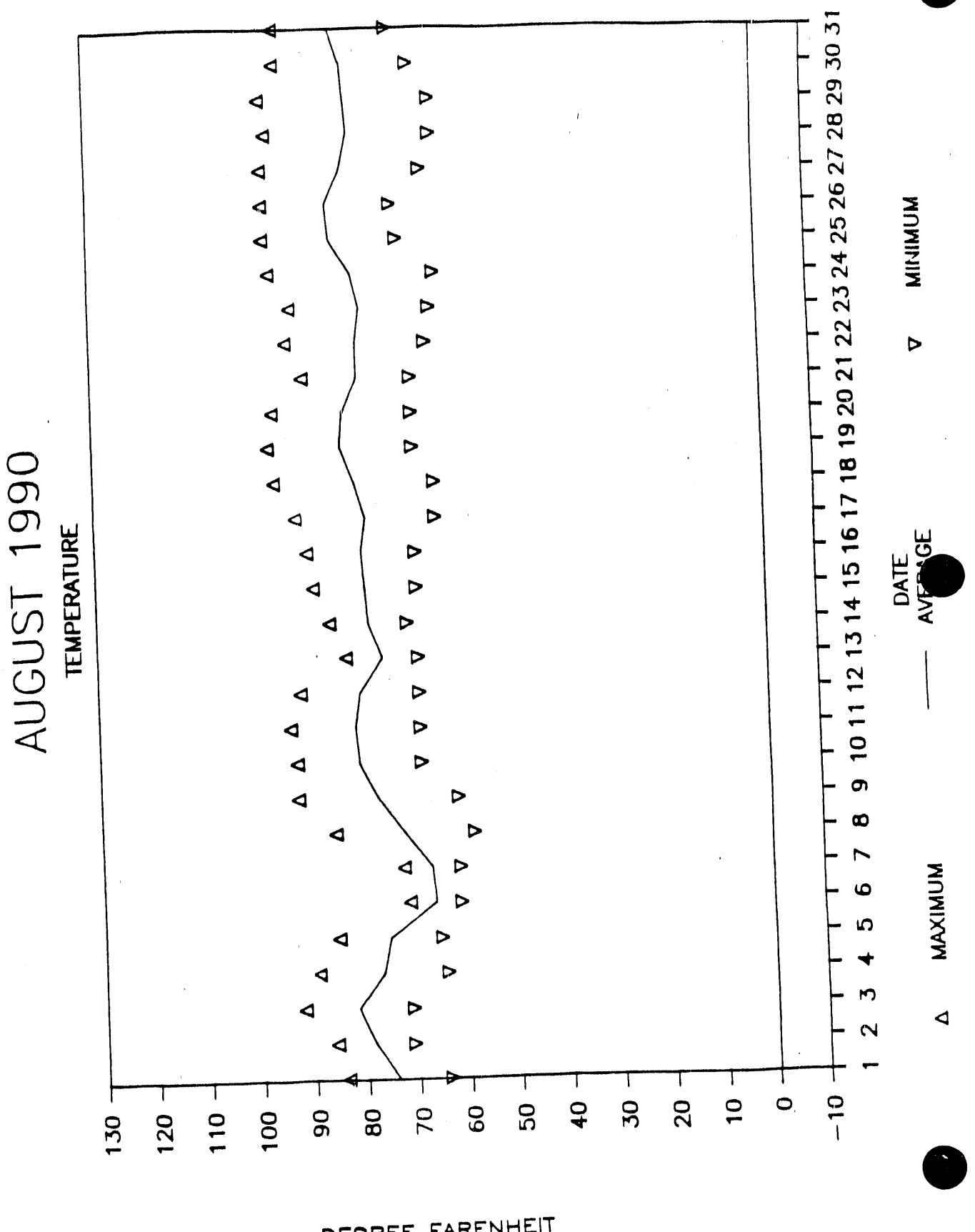
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DATE
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AVERAGE
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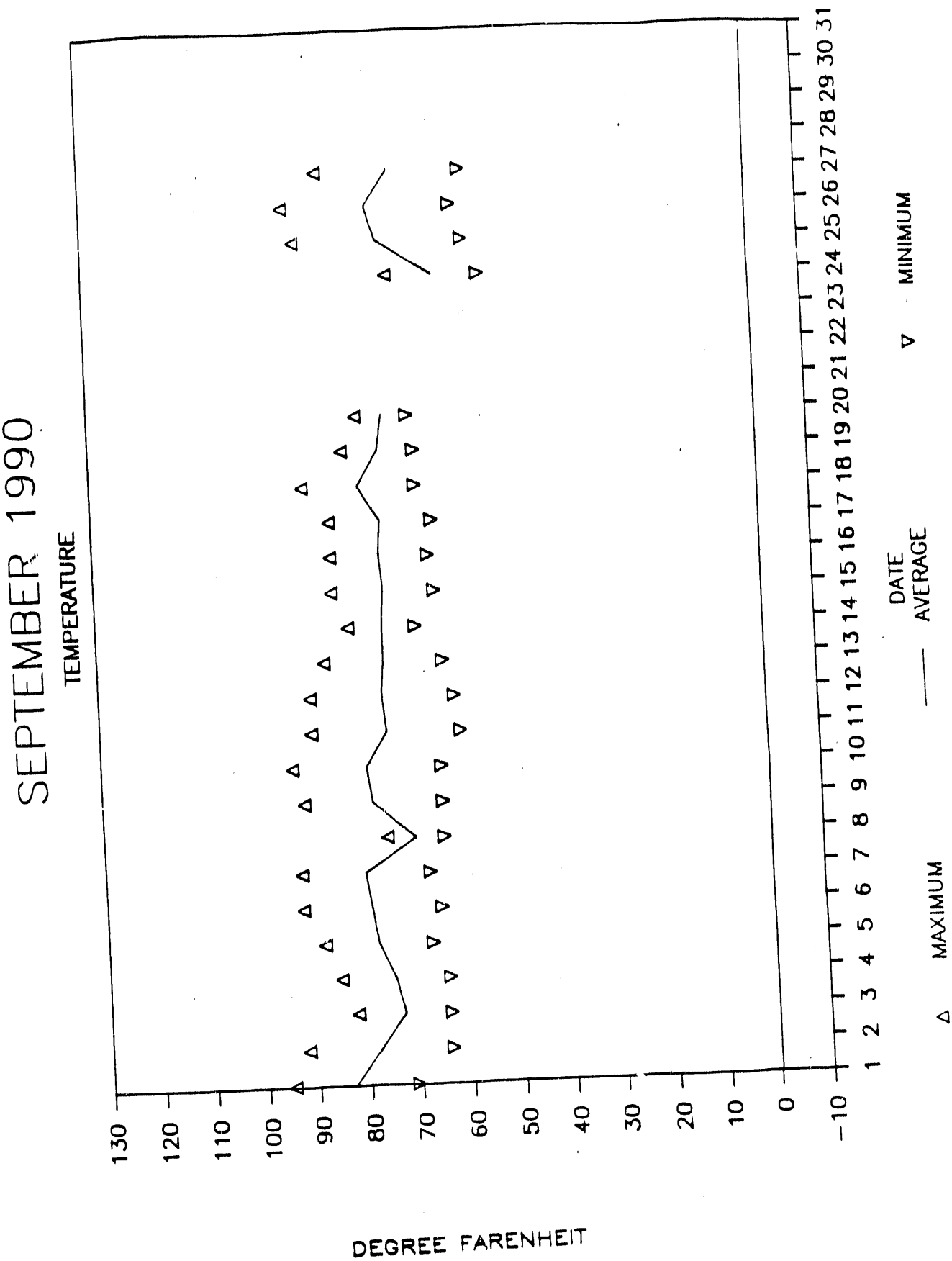
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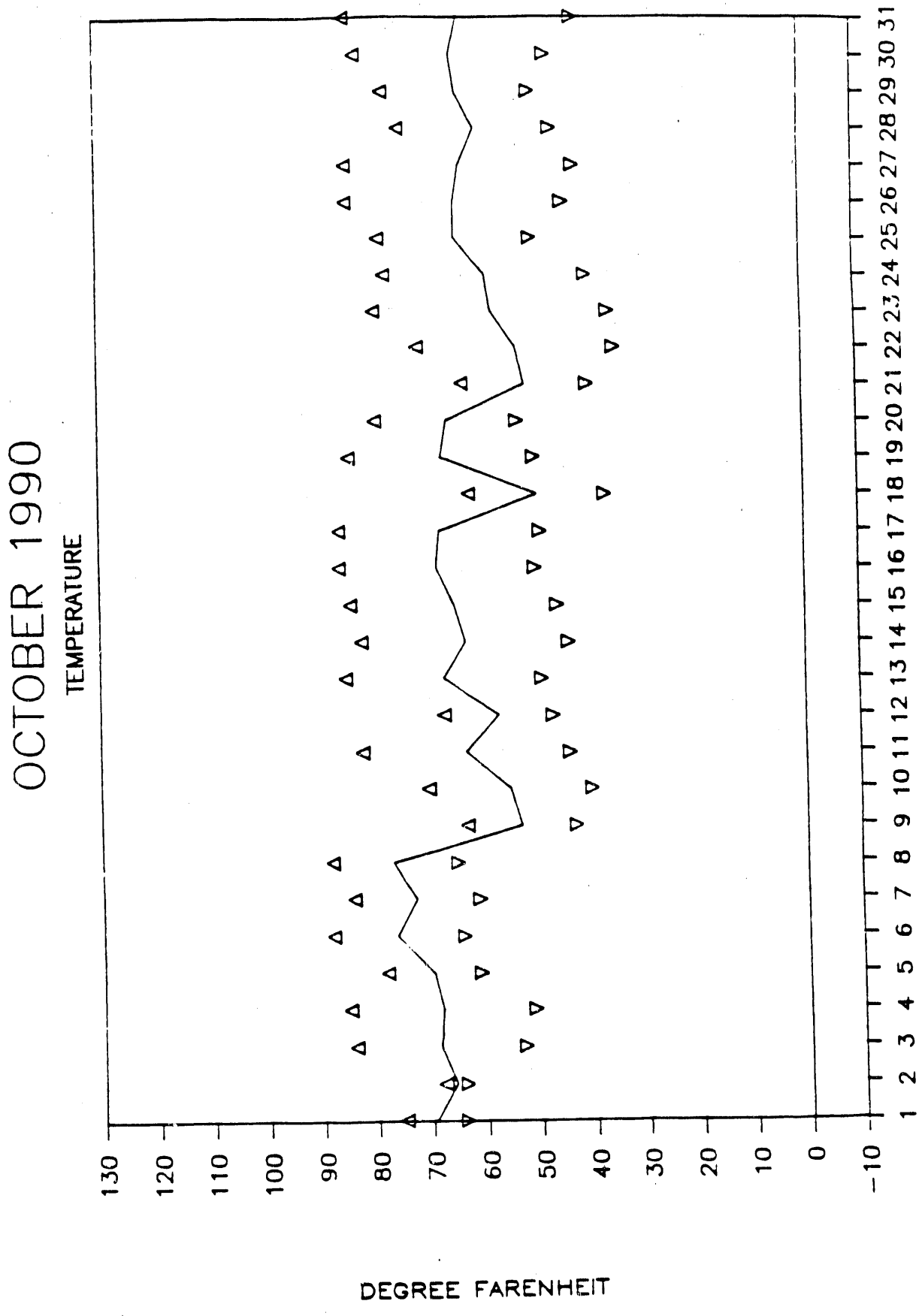
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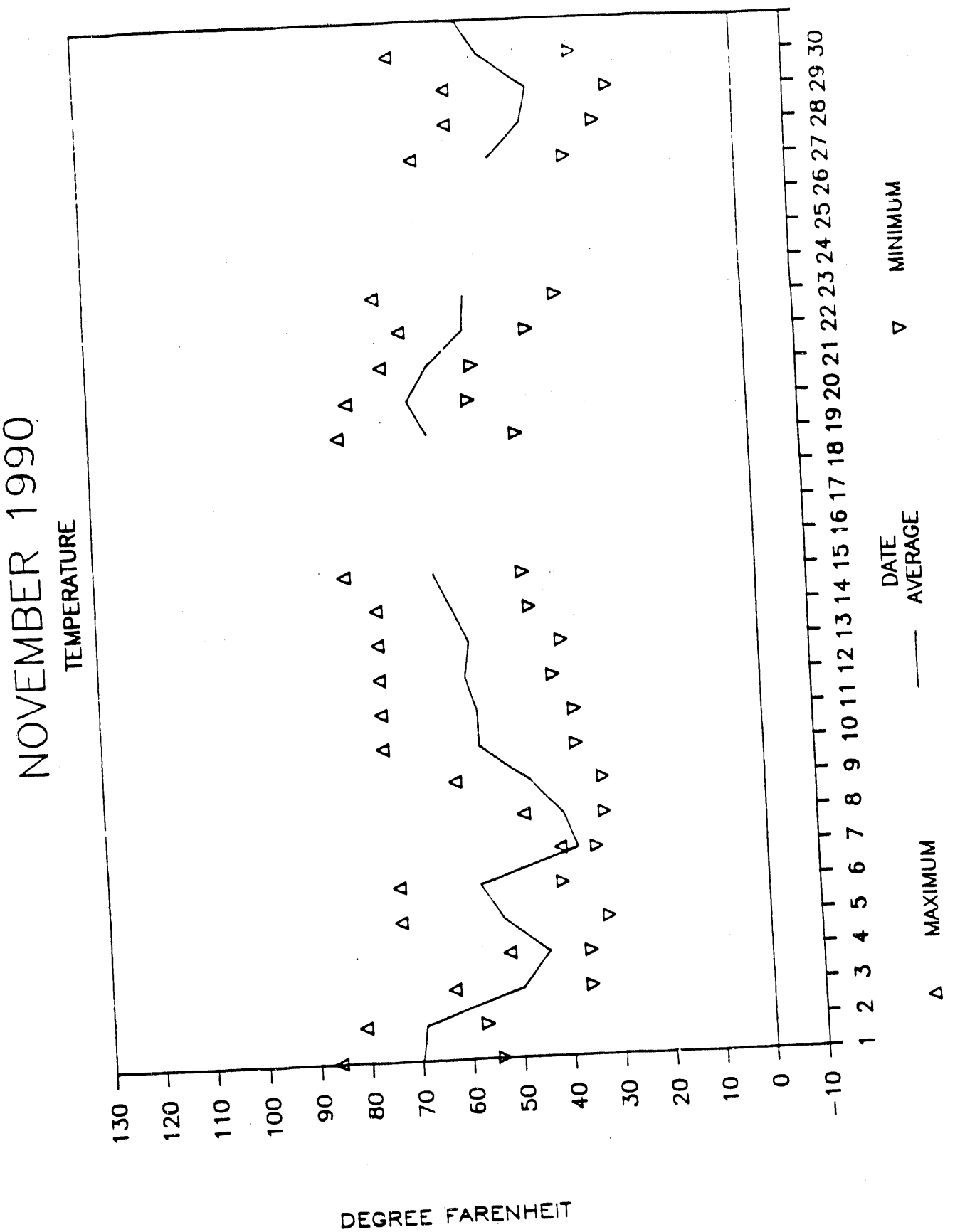
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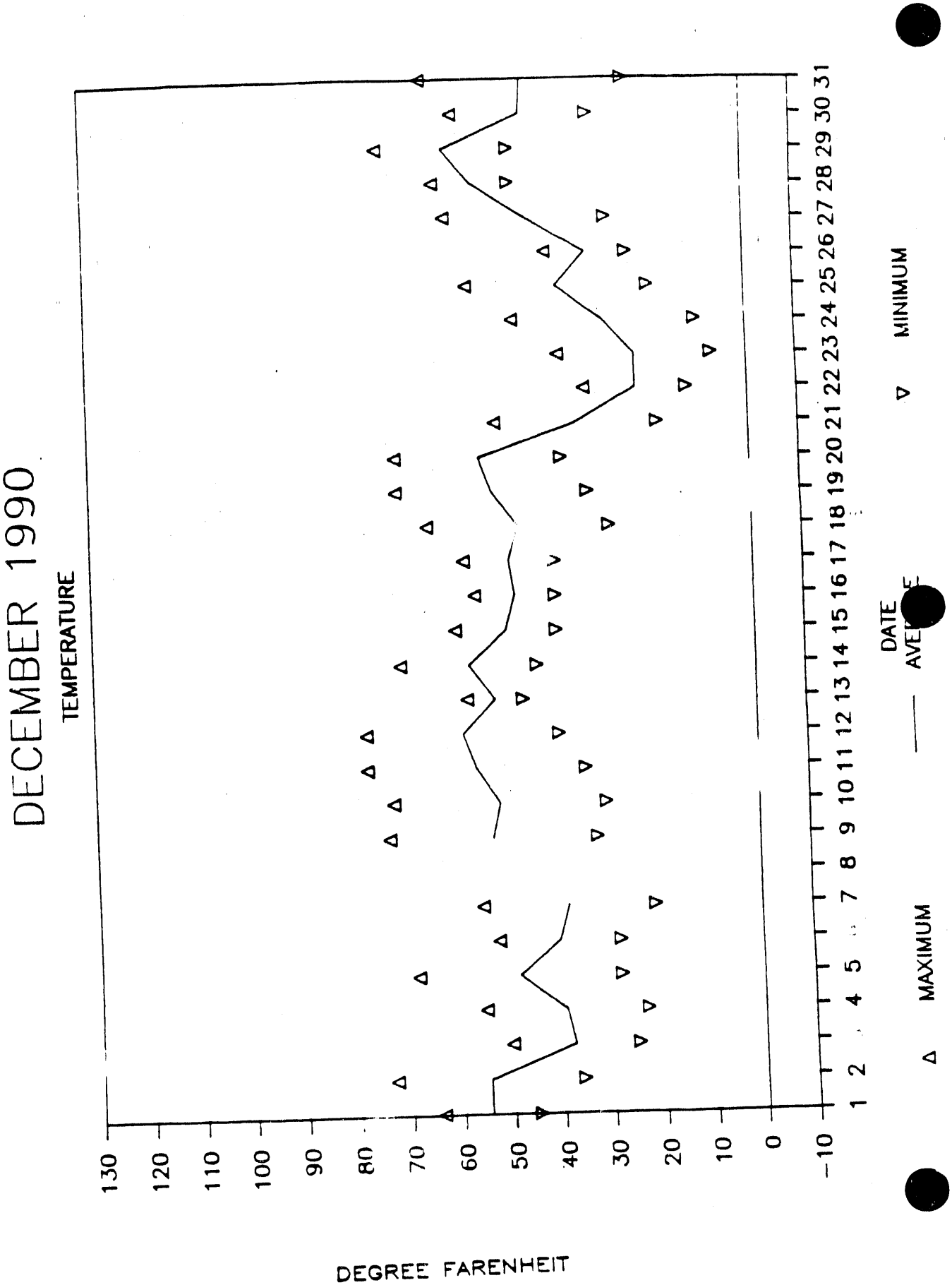
MINIMUM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APPENDIX IV

SUMMARIES OF EACH WELL SAMPLED IN 1990

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SUMMARY OF H-09b, CULEBRA, ROUND-4

WELL CHARACTERISTICS

H-09b drill hole is located T24S, R31E, Section 4, 2391.04 FNL and 238.63 FWL southeast Eddy County, New Mexico. The monument elevation at H-09b is 3406.20 feet amsl. Top Of Casing (TOC) elevation is 3406.86 feet amsl. (SAND88-1065) The well bore was completed on August 28, 1979 to a total depth of 708 feet below ground surface (BGS). Seven inch outside diameter J-55 23 lb/ft casing was installed to a depth of 638 feet BGS leaving the Culebra dolomite member of the Rustler formation exposed to the open bore hole (Winstanley-Carrasco 1985). H-09b has been used for hydrological testing in the WIPP area first for site characterization and most recently for water quality sampling. Well bore caving of the open portion of the wellbore was detected in 1987 bringing the total depth of the well bore up to 670 feet BTOC (Crawley 1987). Westinghouse personnel measured the bottom of the well bore in January 1990 to a depth of 650 ft BTOC with an accuracy deviation of +/- 4 ft.

SAMPLING PROCESS

A Bennett sample pump model 1800-6 Sn 1806-21 and a 3.5 inch Baski sliding end inflatable packer with a 4.5 inch packer sleeve installed over the packer gland was utilized for sampling during this sampling period. A ?.5 X 1.5 inch packer feed through nipple was utilized to facilitate monitoring of formation pressures during the sampling period. The total length of the assembly was approximately 8 feet.

Two Geokon model 4500H vibrating wire transducers were utilized to monitor down hole pressures. The first, 0-100 psi range (Sn 3425) was attached to the tubing bundle at a depth of 600 feet BTOC in order to monitor the integrity of the packer seal. The second transducer Sn (3428), 0-150 psi range was attached to the packer feed through nipple and utilized to monitor pressures below the packer in the formation. Data was collected and stored at regular intervals utilizing a Geokon micro-10 data logger (Sn-18).

The pump/packer assembly was installed on 01-15-90 to a depth of 632 ft BTOC. Static water level was measured just prior to installation at a depth of 417.15 ft BTOC (Solinst # 75-CG-0102). Actual down hole working pressures just prior to the start of pumping was 87 psi. Total drawdown through out the testing period was less than 2.5 feet. The average pumping rate through out the testing period was 33 gallons per hour.

Four serial samples were collected; the first on 01-16-90 after approximately 593 gallons of water had been pumped from the well. Final samples were collected on 01-19-90 after approximately 3058 gallons of water had been pumped from the well. Samples were collected for International Technology Analytical Services Laboratory (ITAS), Westinghouse Advanced Energy Systems Division Analytical Laboratory (WAESD), Sandia National Laboratories (SNL), and the New Mexico Environmental Evaluation Group (EEG). Archival samples were collected for the WIPP project.

ROUND-4 SERIAL SAMPLING RESULTS:

Eh measured +261 mv, +245 mv, +238 mv and +197 mv respectively.

pH remained relatively stable during the testing period measuring 7.31 S.U., 7.31 S.U., 7.35 S.U. and 7.36 S.U. respectively.

Temperature measured 21.1 C on day 1, 21.0 C on day two 21.5 C on day three and 21.0 C on day four.

Specific Gravity and Specific Conductivity were each measured on the first and forth day of sampling, each remained relatively stable. Specific gravity measured 1.004 @21.0 C, and 1.004 @ 21.1 C respectively. Specific conductivity measured 3,460 umhos/cm @ 25.0 C and 3,430 umhos/cm @ 25 C respectively.

Alkalinity averaged 112.9 mg/l, 115.1 mg/l, 115.1 mg/l and 116.2 mg/l.

Chlorides averaged 170.5 mg/l, 169.0 mg/l, 169.5 mg/l and 169.0 mg/l.

Divalent Cations measured 42.9 mg/l, 42.6 mg/l, 42.7 mg/l and 43.0 mg/l.

Total Iron averaged 0.08 mg/l, 0.09 mg/l, 0.08 mg/l and 0.09 mg/l.

Ferrous Iron averaged 0.06 mg/l, 0.05 mg/l 0.06 mg/l and 0.05 mg/l consecutively.

COMPARISON OF ROUND-4 RESULTS WITH PREVIOUS ROUNDS

The amount of water pumped prior to final sampling for the three previous rounds is 9550 gallons, 4300 gallons and 5150 gallons respectively, 3058 gallons were pumped prior to final sampling during round-4. A comparison of the average final day data for the three previous rounds and final day data for round-4 is described in the following table for alkalinity, chlorides, dications, total iron and ferrous iron.

AVG. OF FINAL DAY RESULTS FOR LAST THREE ROUNDS	AVG. OF FINAL DAY FOR ROUND-4
Alkalinity 15.4 mg/l	Alkalinity116.2 mg/l
Chlorides 180.5 mg/l	Chlorides 169.0 mg/l
Dications 42.2 meq/l	Dications 43.0 meq/l
Total Iron 0.14 mg/l	Total Iron 0.09 mg/l
Ferrous Iron 0.05 mg/l	Ferrous Iron 0.05 mg/l

GENERAL OBSERVATIONS/COMMENTS:

A power outage occurred on 01-16-90 and lasted 30 minutes when on site generators were exchanged. The loss of power had no apparent affect on the sampling process or the results obtained.

SUMMARY OF ENGLE WELL, CULEBRA, ROUND-3

WELL CHARACTERISTICS

Engle Well is located in T24S, R31E Section 4, 240 FSL and 1500 FEL in southeastern Eddy County, New Mexico. Top of casing elevation at EngleWell is 3420 feet amsl (SAND88-1065). Engle Well was drilled to a totaldepth of 682 feet below ground surface (BGS) and cased with 6.625" O.D. casing to a depth of 659 feet. The Culebra dolomite member of the RustlerFormation occurring from 659 to 682 feet was left open to the bore holeDOE/WIPP 86-004).

SAMPLING PROCESS

Sampling was performed on 01-30-90 by Gordon Tatro (Westinghouse) and Jim Kinney (New Mexico EEG). A ten gallon water sample was taken from a valve mounted on the discharge pipe at the well-head. The sample was then transported to a mobile field laboratory and filtered through a .45 micronfilter utilizing a peristaltic pump. Samples were collected for ITAS, EEG, SNL, WAESD, and the field chemistry lab.

FIELD ANALYTICAL RESULTS

Round-3 analytical results for Engle Well were as follows; pH 7.46 SU, specific gravity 1.003 at 20.2 C., and specific conductance 2990 umhos/cm at 25 C. Averages for alkalinity, chlorides, and di-valent cations were 79 mg/l, 232 mg/l, and 42 meq/l respectively.

COMPARISON OF ROUND-3 RESULTS WITH PREVIOUS ROUNDS

Round-3 results compare favorably with the results of the previous sampling rounds. Round-1 data for alkalinity was not in agreement andwas omitted from the averages. The results are presented below.

AVERAGE OF PREVIOUS ROUNDS	ROUND-3
Alkalinity 75 mg/l	Alkalinity 79 mg/l
Chlorides 230 mg/l	Chlorides 232 mg/l
Di-Cats 43 meq/l	Di-Cats 42 meq/l

GENERAL OBSERVATIONS/COMMENTS

Engle Well is used primarily to provide water to livestock. A light oil film was noted on some of the samples.

SUMMARY OF H-09b, CULEBRA, ROUND-4

WELL CHARACTERISTICS

H-09b drill hole is located T24S, R31E, Section 4, 2391.04 FNL and 238.63 FWL southeast Eddy County, New Mexico. The monument elevation at H-09b is 3406.20 feet amsl. Top Of Casing (TOC) elevation is 3406.86 feet amsl. (SAND88-1065) The well bore was completed on August 28, 1979 to a total depth of 708 feet below ground surface (BGS). Seven inch outside diameter J-55 23 lb/ft casing was installed to a depth of 638 feet BGS leaving the Culebra dolomite member of the Rustler formation exposed to the open bore hole (Winstanley-Carrasco 1985). H-09b has been used for hydrological testing in the WIPP area first for site characterization and most recently for water quality sampling. Well bore caving of the open portion of the wellbore was detected in 1987 bringing the total depth of the well bore up to 670 feet BTOC (Crawley 1987). Westinghouse personnel measured the bottom of the well bore in January 1990 to a depth of 650 ft BTOC with an accuracy deviation of +/- 4 ft.

SAMPLING PROCESS

A Bennett sample pump model 1800-6 Sn 1806-21 and a 3.5 inch Baski sliding end inflatable packer with a 4.5 inch packer sleeve installed over the packer gland was utilized for sampling during this sampling period. A 3.5 X 1.5 inch packer feed through nipple was utilized to facilitate monitoring of formation pressures during the sampling period. The total length of the assembly was approximately 8 feet.

Two Geokon model 4500H vibrating wire transducers were utilized to monitor down hole pressures. The first, 0-100 psi range (Sn 3425) was attached to the tubing bundle at a depth of 600 feet BTOC in order to monitor the integrity of the packer seal. The second transducer Sn (3428), 0-150 psi range was attached to the packer feed through nipple and utilized to monitor pressures below the packer in the formation. Data was collected and stored at regular intervals utilizing a Geokon micro-10 data logger (Sn-18).

The pump/packer assembly was installed on 01-15-90 to a depth of 632 ft BTOC. Static water level was measured just prior to installation at a depth of 417.15 ft BTOC (Solinst # 75-CG-0102). Actual down hole working pressures just prior to the start of pumping was 87 psi. Total drawdown through out the testing period was less than 2.5 feet. The average pumping rate through out the testing period was 33 gallons per hour.

Four serial samples were collected; the first on 01-16-90 after approximately 593 gallons of water had been pumped from the well. Final samples were collected on 01-19-90 after approximately 3058 gallons of water had been pumped from the well. Samples were collected for International Technology Analytical Services Laboratory (ITAS), Westinghouse Advanced Energy Systems Division Analytical Laboratory (WAESD), Sandia National Laboratories (SNL), and the New Mexico Environmental Evaluation Group (EEG). Archival samples were collected for the WIPP project.

ROUND-4 SERIAL SAMPLING RESULTS:

Eh measured +261 mv, +245 mv, +238 mv and +197 mv respectively.

pH remained relatively stable during the testing period measuring 7.31 S.U., 7.31 S.U., 7.35 S.U. and 7.36 S.U. respectively.

Temperature measured 21.1 C on day 1, 21.0 C on day two 21.5 C on day three and 21.0 C on day four.

Specific Gravity and Specific Conductivity were each measured on the first and forth day of sampling, each remained relatively stable. Specific gravity measured 1.004 @21.0 C, and 1.004 @ 21.5 C respectively. Specific conductivity measured 3,460 umhos/cm @ 25.0 C and 3,430 umhos/cm @ 25 C respectively.

Divalent cations averaged 198.1 mg/l, 196.1 mg/l, 195.3 mg/l, 196.3 mg/l, 194.6 mg/l, 195.3 mg/l and 196.5 mg/l consecutively from day one through day seven of testing.

Total Iron and Ferrous Iron decreased with only slight fluctuations over the sampling period. Total Iron averaged 0.79mg/l, 0.45 mg/l, 0.41 mg/l, 0.43 mg/l, 0.42 mg/l, 0.41 mg/l and 0.36 mg/l. Ferrous Iron averaged 0.71 mg/l, 0.36 mg/l, 0.35 mg/l, 0.39 mg/l, 0.34 mg/l, 0.33 mg/l and 0.29 mg/l respectively.

COMPARISON OF ROUND-5 RESULTS WITH PREVIOUS ROUNDS:

The amount of water pumped prior to final sampling for the four previous rounds is 79,744 gallons, 126,100 gallons, 87,500 gallons and 5142 gallons respectively. 6127 gallons were pumped prior to final sampling during round-5. A comparison of the average final day data for the four previous rounds and final day data for round-5 is described in the following table for alkalinity, chlorides, dications, total iron and ferrous iron.

AVG. OF FINAL DAY RESULTS FOR LAST FOUR ROUNDS	AVG .OF FINAL DAY RESULTS FOR ROUND-5
Alkalinity 94.04 mg/l	Alkalinity 95.40 mg/l
Chlorides 32,040 mg/l	Chlorides 32,218 mg/l
Dications 190.5 meq/l	Dications 196.5 meq/l
Total Iron 0.20 mg/l	Total Iron 0.36 mg/l
Ferrous Iron 0.29 mg/l	Ferrous Iron 0.29 mg/l

GENERAL OBSERVATIONS/COMMENTS:

Approximately seven minutes into the pumping period at 13:43 on 02-05-90 the pump failed and had to be replaced. No other problems or equipment failures occurred duing the period.

SUMMARY FOR H-06c, MAGENTA, ROUND-5

WELL CHARACTERISTICS

H-06c drill hole is located at T22S R31E Section 18 281.06FNL and 374.47FWL in southeastern Eddy County New Mexico. Ground elevation at H-06c is 3347.93 ft amsl and the well casing stick up elevation is 3348.52 ft amsl. The well bore was completed 06-26-'8 to a total depth of 741 feet BGS (Below Ground Surface). Casing, 5.5 inch O.D. type J-55 15.5 lb/ft, was set in the borehole to a depth of 699 ft BGS leaving the Rustler Salado interval open from 700 to 741 ft BGS. After hydrologic testing of the Rustler formation was completed a bridge plug was set below the Culebra dolomite 641 ft BTOC (Below Top Of Casing). The Culebra interval was then perforated from 604-627 ft BTOC. The well bore was left undisturbed until 8-20-86 when a second bridge plug was installed 534 ft BTOC and the casing was again perforated from 490-514 ft BTOC exposing the Magenta Dolomite to facilitate water quality sampling for the WIPP site.

SAMPLING PROCESS

The sampling configuration for H-06c consisted of a Bennett Sample pump model 1800 (Sn 1802) and a 2.8" Ardvark sliding end packer (Sn 3690-435). A 3"X1-1/2" Packer feed through assembly was utilized to facilitate monitoring of formation pressures below the packer. The total length of the pump/packer assembly was approximately 8 ft. Two Geokon Model 4500H vibrating wire transducers were utilized to monitor formation pressures. The first, 0-150 psi range (Sn 3428) was attached to the tubing bundle 25 ft. above the pump/packer assembly in order to monitor the integrity of the packer seal. The second 0-150 psi range (Sn-3431) was attached to the packer feed through assembly to monitor formation pressures in the Magenta dolomite. Data was collected and stored at regular intervals utilizing a micro-10 Geokon data logger (Sn-20).

The pump/packer assembly was installed 03/12/90 to a depth of 483 feet BTOC to the bottom of the pump intake assembly. Static Water Level at H-06c was measured just prior to start of pumping at a depth of 290.50 feet BTOC. Actual working pressure at installation depth just prior to starting the pump was 82.35 psi. Total drawdown throughout the testing period was approximately 142 feet. During the testing period 1453 gallons of water were pumped from the wellbore at an average pumping rate of 20.05 gallons per hour.

Three serial samples were collected; the first was collected on 03-13-90 after approximately 326 gallons of water were pumped and final samples were collected on 03-15-90 after approximately 1308 gallons had been pumped from the well. Samples were collected for International Technology

Analytical Sampling Laboratory (ITAS), Westinghouse Advanced Energy Systems Division Analytical Laboratory (WAESD), Sandia National Laboratory (SNL), and the New Mexico Environmental Evaluation Group (EEG). Archival samples were collected for the WIPP project.

ROUND-5 SERIAL SAMPLING RESULTS:

Eh remained relatively stable from sample 1 to sample 3 measuring + 183 mv, + 221 mv and + 224 mv respectively.

pH remained stable throughout the sampling period measuring 7.82 S.U. at 21.0 C, 7.80 S.U. at 20.0 C and 7.83 S.U. at 21.2 C respectively

Specific gravity was measured at 1.0032 at 20.8 C. for sample number 1 and 1.0034 at 21.2 C. for sample number 3.

Specific conductivity on day 1 measured 4,900 umhos/cm at 25 C. and 5,200 umhos/cm at 25 C. on day three of the testing period.

Daily averages for Alkalinity were 54.0 mg/l, 52.5 mg/l and 51.0 mg/l respectively.

Chlorides averaged 407 mg/l, 408 mg/l and 404 mg/l respectively

Divalent Cations averaged 42.0 meq/l, 42.0 meq/l and 41.5 meq/l.

Total iron averaged 0.15 mg/l, 0.15 mg/l and 0.10 mg/l respectively.

Ferrous iron averaged 0.13 mg/l, 0.11 mg/l and 0.07 mg/l respectively.

COMPARISON OF ROUND-5 RESULTS WITH PREVIOUS ROUNDS:

The average number of gallons pumped prior to final sampling during the previous four rounds was 4073 gallons. A total of 1308 gallons were pumped prior to collecting final samples during round-5. A comparison of the average final day data for the four previous rounds and the final day data for round-5 is described in the following table for alkalinity, chlorides, di-cats, total iron and ferrous iron.

AVG. OF FINAL DAY RESULTS FOR PREVIOUS FOUR ROUNDS	AVERAGE OF FINAL DAY FOR ROUND-5
Alkalinity 51.8 mg/l	Alkalinity 51.0 mg/l
Chlorides 412.5 mg/l	Chlorides 404.0 mg/l
Di-Cats 41.0 meq/l	Di-Cats 41.5 meq/l
Total Iron 0.31 mg/l	Total Iron 0.10 mg/l
Ferrous Iron 0.20 mg/l	Ferrous Iron 0.07 mg/l

GENERAL OBSERVATIONS/COMMENTS

No unusual occurrences or delays to pumping were noted during the testing period.

SUMMARY OF H-18,CULEBRA, ROUND-3

Well Characteristics

Well H-18 is located T22s R31E Section 20 964.8 FNL and 445.6 FWL in south eastern Eddy County, New Mexico, at an elevation of 3,414.21 feet above mean sea level(MSL), to the top of casing. The total depth of the drilled hole was 831 feet below ground surface (BGS). The drill hole was later plugged back to 766 feet BGS. The well is cased to a depth of 673 feet BGS, with 7 inch casing and completed open hole. The source of water sampled from this well is the Culebra Dolomite Member of the Rustler formation located at a depth interval of 689 to 713 feet BGS (Beauhiem, 1987).

Sampling process

The sampling configuration for H-18 consisted of a model 1800 Bennett sample pump (Sn 1806-21) and a 3.5 inch Baski sliding end packer with a 4.5 inch packer sleeve installed over the packer gland. The pump and packer were connected via a specially fabricated packer feed through nipple. The total length of the pump/packer assembly was 7.66 feet. Two geokon transducers were utilized to monitor the pressures in the well bore during testing. The first (Sn 3428) 0-150 psi range was placed at a depth of 625 feet below top of casing (BTOC) to monitor the integrity of the packer seal. The second (Sn 3431) 0-150 psi range was attached to the packer feed through nipple in order to monitor the pressure in the Culebra Dolomite. Data from the transducers was collected and stored at regular intervals utilizing a micro-10 datalogger (Sn-20).

The pump/packer assembly was installed on 03-30-90 to a depth of 658 feet BTOC to the bottom of the pump intake. Static water level was measured just prior to installation at 368.45 ft. BTOC. Actual down hole working pressure prior to the start of pumping was 127.30 psi at the pump intake. Total draw down throughout the testing period was approximately 110 feet. During the testing period 7098 gallons of water were pumped from the well bore at an average pumping rate of 25 gallons per hour.

Eight serial samples were collected; the first was collected on 04-02-90 after approximately 1336 gallons of water were pumped and final samples were collected on 04-10-90 after 6933 gallons of water had been pumped from the well. Samples were collected for International Technology Analytical Services Laboratory (ITAS), Westinghouse Advanced Energy Systems Division Analytical Laboratory (WAESD), Sandia National Laboratory (SNL), and the New Mexico Environmental Evaluation Group (EEG). Archival samples were collected for the WIPP project.

ROUND-3 SERIAL SAMPLING RESULTS:

Eh Measured +235 MV, +208 MV, +208 MV, +239 MV, +227 MV, +171 MV, +169 MV AND +233 MV Respectively.

pH measured 7.83 S.U., 7.83 S.U., 7.79 S.U., 7.78 S.U., 7.72 S.U., 7.75 S.U., 7.70 S.U. and 7.72 S.U. respectively.

Temperature for the eight samples measured; 21.2 C, 20.8 C. [illegible] C, 22.0 C, 21.4 C, 21.4 C, 22.1 C and 21.5 C respectively.

Specific gravity measured 1.0232 at 21.3 C for sample one, 1.0220 at 21.5 C for sample number six and 1.0200 at 21.5 C for sample number eight.

Specific conductance measured 44,500 umhos/cm at 25 C. for sample one, 39,800 umhos/cm at 25 C. for sample six, and 39,300 umhos/cm at 25 C. for samle eight.

Alkalinity average readings over the eight day sampling period were 55.4 mg/l, 53.5 mg/l, 52.0 mg/l, 51.4 mg/l, 52.6 mg/l, 51.2 mg/l 51.3 mg/l and 51.6 mg/l respectively.

Chlorides dropped steadily until the fifth day of sampling, then stabilized, fluctuating only slightly after the fifth day. Average measurements were; 16,619 mg/l, 14,862 mg/l, 14,566 mg/l, 14,186 mg/l, 13,952 mg/l, 13883 mg/l, 13,841 mg/l and 13,966 mg/l respectively.

Di-valent cations averaged 104.2 meq/l, 102.5 meq/l, 100.2 meq/l, 101.4 meq/l, 100.5 meq/l, 100.6 meq/l, 101.6 meq/l and 100.7 meq/l.

Total and Ferrous Iron dropped steadily through the seventh day of testing then increased slightly on the eighth day. Total Iron measured 1.53 mg/l, 0.67 mg/l, 0.51 mg/l, 0.47 mg./l, 0.43 mg/l, 0.37 mg/l, 0.36 mg/l and 0.38 mg/l. Ferrous Iron measured 1.39 mg/l, 0.54 mg/l, 0.38 mg/l, 0.34 mg/l, 0.33 mg/l, 0.30 mg/l, 0.29 mg/l, and 0.33 mg/l respectively.

COMPARISON OF ROUND-3 RESULTS WITH PREVIOUS ROUNDS:

The amount of water pumped prior to final sampling for the two previous rounds were 9,000 gallons and 33,000 gallons respectively. 6,933 gallons were pumped prior to final sampling during round three. A comparison of the average final day data for the two previous rounds and final day data for round-3 is described in the following table for alkalinity, chlorides, di-cats, total iron and ferrous iron.

AVG. OF FINAL DAY RESULTS FOR LAST TWO ROUNDS	AVG. OF FINAL DAY RESULTS FOR ROUND-3
Alkalinity 51.95 mg/l	Alkalinity 51.6 mg/l
Chlorides 12,375 mg/l	Chlorides 13,966 mg/l
Di-cats 98.8 meq/l	Di-cats 100.7 meq/l
Total Iron 0.22 mg/l	Total Iron 0.38 mg/l
Ferrous Iron 0.18 mg/l	Ferrous Iron 0.33 mg/l

GENERAL OBSERVATIONS/COMMENTS

During the evening hours on 04-01-90 at approximately 22:30 hours a failure of the main power generator caused a pump failure that lasted approximately 10 hours. No other problems were encountered during the testing period.

SUMMARY OF H-05b, CULEBRA, ROUND-5

WELL CHARACTERISTICS

H-05b is located approximately 2.7 miles northeast of the center of the WIPP site (1008.30 FNL and 236.22 FEL, Section 15, Township 22S, Range 31E). The ground monument elevation is 3505.38 feet amsl, and top of casing (TOC) is at an elevation of 3506.04 feet amsl, (SAND88-1065).

H-05b was completed on 06-13-78 to a total depth of 925 feet. Well casing (J55 15.5 lb/ft, 5" ID) is installed to a depth of 881 feet below ground surface (BGS). The well is completed open hole in the Culebra which lies at a depth from 897-920 feet BGS.

SAMPLING PROCESS

A Bennett pump/packer assembly was used for this sampling round. The assembly consisted of a model 1800 Bennett Sample Pump (SN 1806-25) and a 2.8 inch Aardvark sliding end packer (SN 3690-435). A 3" to 1-1/2" packer feed through was utilized to facilitate the monitoring of formation pressures below the packer. The total length of the assembly was 7.54 feet.

Two geokon 4500H vibrating wire transducers were utilized to monitor formation pressures. A 0-250 psi pressure range (SN 8317) transducer was attached to the tubing bundle 25 ft above the top of the pump at a depth of 825 feet below top of casing (BTOC) in order to monitor the integrity of the packer seal. A second transducer (0-250 psi, SN 8319) was attached to the packer feed through assembly in order to monitor pressures below the packer. Data was collected and stored on a continuous basis by a Geokon Micro-10 data logger (SN-87).

On 04-23-90 the pump/packer assembly was installed in H-05b. The bottom of the assembly was positioned at a depth of 858 feet BTOC. Static water level just prior to installation measured 485.77 feet BTOC, (Solinst probe 75-CG-0101). The well was pumped for a total of 9 days at an average rate of approximately 9.53 gallons per hour. It was determined that three wellbore volumes was equivalent to 1114 gallons of water.

Four serial samples were collected; the first on 04-24-90 after approximately 278 gallons of water had been pumped from the well. Final samples were collected on 05-02-90 after approximately 2,2 llons of water had been pumped from the well. Final samples were sent to International Technology Analytical Sampling Laboratory (ITAS) and Westinghouse Advanced Energy Systems Division Analytical Lab (WAESD) for analysis. Samples were also provided to Sandia National Laboratories (SNL) and the New Mexico Environmental Evaluation Group (EEG) for independent analysis. Archival samples were collected for the WIPP Project.

ROUND-5 SERIAL SAMPLING RESULTS:

Eh fluctuated during the 4 days of sampling measuring + 140 mv, + 62 mv, + 134 mv, + 144 mv, respectively.

pH remained fairly stable during the 4 days of sampling measuring 7.47 S.U., 7.41 S.U., 7.29 S.U., 7.29 S.U., respectively.

Temperature measured 21.2 C., 20.5 C., 19.8 C., 20.3 C. respectively.

Specific Gravity measured 1.1 at 21.1 C. for sample 1, 1.1028 at 20.6 C. for sample 2, 1.1040 at 19.4 C. for sample 3, and 1.104 at 20.2 C. for sample 4.

Specific Conductance measured 151,900 umhos/cm at 25 C. for sample 1, 153,700 umhos/cm @25 C. for sample 2, and 155,900 umhos/cm at 25 C. for sample 4.

Alkalinity, chlorides and divalent cations fluctuated slightly from sample 1 to sample 4. Alkalinity averaged 55.1 mg/l, 52.2 mg/l, 51.2 mg/l, and 50.9 mg/l respectively. Chlorides averaged 85,027 mg/l, 85,288 mg/l, 85,635 mg/l, and 86,330 mg/l respectively. Divalent cations averaged 264.4 meq/l, 262.4 meq/l, 261.2 meq/l and 262.8 meq/l respectively.

Both iron parameters, (total-iron and ferrous-iron) decreased from sample one to sample four. Total-iron averaged 4.44 mg/l, 2.69 mg/l, 2.25 mg/l and 2.76 mg/l respectively. Ferrous iron averaged 3.97 mg/l, 2.42 mg/l, 2.07 mg/l, 2.44 mg/l respectively. A slight increase in both iron parameters for sample four was caused by packer slippage in the early morning hours of the last day of sampling.

COMPARISON OF ROUND-5 RESULTS WITH PREVIOUS ROUNDS:

The amount of water pumped prior to final sampling for each of the five rounds is as follows; 1,100 gallons, 2,000 gallons, 1,450 gallons, 1,996 and 2,253 gallons respectively. Round 5 results are in good agreement with results obtained from the first four sampling rounds. This comparison was made by comparing chemical parameter averages for the final day of round-5 sampling with the average of the chemical parameter values obtained for the last day of sampling for each of the previous four rounds. The results are presented below.

AVG. OFFINAL DAY RESULTS FOR LAST FOUR ROUNDS	AVG. OF FINAL DAY FOR ROUND-5
Alkalinity 50.0 mg/l	Alkalinity50.9mg/l
Chlorides 84,571 mg/l	Chlorides 84330 mg/l
Di-Cats 256.8 meq/l	Di-Cats 262.8 meq/l
Total Iron 3.01 mg/l	Total Iron 2.76 mg/l
Ferrous Iron 2.73 mg/l	Ferrous Iron 2.44 mg/l

GENERAL OBSERVATIONS/PROBLEMS:

On 04/24/90 at approximately 16:30 hours the pump failed and was replaced on 04/25/90 and pumping resumed at 09:45 am on that date. On 04/27/90 the pressure above the packer began to rise until finally on the morning of 05/02/90 the maximum differential pressure rating of the packer was overcome and the packer was pushed down approximately 25 feet. The lower transducer cable was pulled in two, however the pump continued to operate. After running parameters on Iron and turbidity the decision was made to collect final samples. After the pump had been pulled a post-operational test was preformed on the pump. The cause of the pressure rise above the packer was determined to be a faulty lower-discharge check valve in the pump which caused water to leak from the pump to the well bore above the packer seal.

SUMMARY OF H-05c, MAGENTA, ROUND-5

WELL CHARACTERISTICS

H-O5c is located 2.7 miles northeast of the center of the WIPP site, (1005.55 FNL, 134.95 FEL, Section 15, Township 22S, Range 31 E). Ground monument elevation is 3505.78 feet amsl, and top of casing (TOC) is at an elevation of 3506.04 feet amsl, (SAND88-1065).

H-05c was completed on 06-03-78 to a total depth of 1076 feet BGS. Well casing (J-55, 15.5#/ft.) is installed to a depth of 1024 feet. The well was originally completed open hole in the Rustler/Salado Contact (1041 to 1076 ft) below ground surface (BGS). After testing of the Rustler/Salado Contact was completed, a bridge plug was installed at a depth of 935 ft. BTOC. The well was re-completed in the Culebra from 895 to 925 ft BGS. The Culebra at this location is situated at a depth from 899 to 924 ft. BTOC. On 08-20-86, a bridge plug was installed at a depth of 836 ft BTOC, and the well was re-completed, in the Magenta Dolomite, from 788 to 812 feet BTOC,(SAND85-7206).

SAMPLING PROCESS

A pump/packer assembly was used to sample this well. The assembly consisted of a model 1800 Bennett Sample Pump (SN 1802) and a 2.8 inch Ardvark sliding end packer (SN 3685-133). A 3" X 1-1/2" packer feed through nipple was used to facilitate monitoring of formation pressures. The total length of the assembly was approximately 7.84 feet.

Two geokon 4500H vibrating wire transducers were utilized to monitor formation pressures. A 0-150 psi pressure range (SN 3428) transducer was attached to the tubing bundle and installed at a depth of 675 feet BTOC to monitor the integrity of the packer seal. A second transducer (0-250 psi, SN 9077) was attached to the packer feed through assembly in order to monitor pressures below the packer. Data was collected and stored on a continuous basis by a Geokon Micro-10 data logger (SN-20).

On 05-09-90 the pump/packer assembly was installed in the well. The bottom of the assembly was positioned at a depth of 783 feet BTOC. Static water level just prior to installation measured 353.05 feet BTOC, (Solinst probe 75-CG-0101). The well was pumped for a total of 7 days at an average rate of 13.63 gallons per hour.

Three serial samples were collected: the first on 05-14-90 after approximately 1497 gallons of water had been pumped from the well.

Final samples were collected on 05-16-90 after approximately 1940 gallons of water had been pumped from the well. Final samples were sent to International Technology Analytical Sampling Laboratory (ITAS) and Westinghouse Advanced Energy Systems Division Analytical Lab (WAESD) for analysis. Samples were also provided to Sandia National Laboratories (SNL) and the New Mexico Environmental Evaluation Group (EEG) for independent analysis. Archival samples were collected for the WIPP Project.

ROUND-5 SERIAL SAMPLING RESULTS:

Eh fluctuated during the 3 days of sampling measuring 0 mv, -2 mv, and -4 mv respectively.

pH remained fairly stable during the 4 days of sampling measuring 7.91 S.U., 7.92 S.U. and 7.95 S.U. respectively.

Temperature measured 21.7 C. on day 1, 21.8 C. on day 2 and 21.8 C. on day 3 .

Specific Gravity measured 1.0070 at 21.5 C. on day 1, and 1.0062 at 21.8 C. on day 3.

Specific Conductance measured 8500 umhos/cm at 25 C. on day 1, and 8480 umhos/cm at 25 C. on day 3.

Alkalinity, chlorides and divalent cations remained fairly stable throughout the 4 day sampling period. Alkalinity averaged 57.6 mg/l, 58.2 mg/l and 59.2 mg/l respectively. Chlorides averaged 1037 mg/l, 1031 mg/l and 1028 mg/l respectively. Divalent cations averaged 42.8 meq/l, 42.7 meq/l and 42.6 meq/l respectively.

Both iron parameters, (total-iron and ferrous-iron) decreased from day one to day three during the 3 day sampling period. Total-iron averaged 0.22 mg/l, 0.20 mg/l and 0.18 mg/l respectively. Ferrous iron averaged 0.15 mg/l, 0.13 mg/l and 0.10 mg/l respectively.

COMPARISON OF ROUND-5 RESULTS WITH PREVIOUS ROUNDS:

The amount of water pumped prior to final sampling for each of the five rounds is as follows; 5,800 gallons, 1,900 gallons, 2,500 gallons, 1,997 and 1940 gallons respectively. Comparison of round-5 results with results obtained from the first four rounds, indicate that a representative sample was obtained. This comparison was made by comparing chemical parameter averages for the final day of round-5 sampling with the average of the chemical parameter values obtained for the last day of sampling for each of the previous four rounds. The results are presented below.

AVG. OF FINAL DAY RESULTS FOR LAST FOUR ROUNDS	AVG. OF FINAL DAY FOR ROUND-5
Alkalinity 57.3 mg/l	Alkalinity 59.2 mg/l
Chlorides 1035 mg/l	Chlorides 1028 mg
Di-Cats 42.1 meq/l	Di-Cats 42.6 meq/l
Total Iron 0.86 mg/l	Total Iron 0.18 mg/
Ferrous Iron 0.61 mg/l	Ferrous Iron 0.10 mg/l

The averages for Total iron and Ferrous iron from the first three rounds is misleading because the first round averages are much higher than the other two rounds. Round-5 iron results compare most favorably with round-2 and round-4 results. Iron during rounds-1 and 3 was considerably higher than rounds-2, 4 and 5.

GENERAL OBSERVATIONS/PROBLEMS:

Water from the Magenta at this location is extremely gaseous. On 05-15-90, the second day of sampling the pump began to show early warning signs of failure, running intermittently. Based on the symptoms of the pump final sampling was moved up one day from 05-17-90 to 05-16-90.

SUMMARY OF TWIN WELL (PASTURE), DEWEY LAKE, ROUND-4

WELL CHARACTERISTICS

Twin Well(Pasture) is located approximately ten miles south of the center of the WIPP site. Twin wells consist of two wells in close proximity, the House well and the Pasture well. This sampling was performed in the pasture well. Surface elevation is 3,523 feet above mean sea level (amsl). The total depth of the well is 152 feet below the ground surface (BGS)(Winstanley and Carrasco, 1986). Water is pumped to the surface by a windmill. The well is completed in the Dewey Lake Redbeds.

SAMPLING PROCESS

Samples were collected on 05-30-90, from a discharge pipe at the base of the windmill. Samples were filtered with a portable peristaltic pump. Samples were collected for International Technology Analytical Services (ITAS) and Westinghouse Advanced Energy Systems Division (WAESD) for analysis. Samples were also provided to Sandia National Laboratories (SNL) and the New Mexico Environmental Evaluation Group (EEG).

FIELD ANALYTICAL RESULTS

Round-4 analytical results for Twin Pasture Well were as follows; pH 7.7 SU, secific gravity 1.0028 @ 23.2 degrees C, and specific conductance 614 umhos/cm @ 25 degrees C. Averag for Alkalinity, Chloride and Divalent Cations were 218.9 mg/l, 56 mg/l and 5.5 meq/l respectively.

COMPARISON OF ROUND-4 RESULTS WITH PREVIOUS ROUNDS:

Round-4 results compare favorably with results obtained from the previous sampling rounds. Round-2 data was not in agreement and was not included in the averages. The results are presented below:

AVERAGE OF PREVIOUS ROUNDS	ROUND-4
Alkalinity 222.9 mg/l	Alkalinity 218.9 mg/l
Chlorides 41.5 mg/l	Chlorides 56 mg/l
Di-Cats 7.9 meq/l	Di-Cats 5.5 meq/l

GENERAL OBSERVATIONS/COMMENTS:

This well supplies water for livestock.

SUMMARY OF WIPP-19, CULEBRA, ROUND-5

WELL CHARACTERISTICS

WIPP-19 is located approximately 0.5 miles north of the center of the WIPP site (2286.5 FNL and 12.7 FEL, Section 20, Township 22S, Range 31E). The ground monument elevation is 3433.08 feet amsl, and top of casing (TOC) is at an elevation of 3435.14 feet amsl. (SAND88-1065).

WIPP-19 was drilled in May of 1978 to a total depth of 1038 feet below ground surface (BGS). Following investigations to further characterize the WIPP site geology the well was filled with brine mud and abandoned until October 1985. In October of 1985, the well bore was reamed to 7.875 inches and a 5.5 inch well casing was installed to a depth of 1037 feet BGS. The well casing was perforated in the Culebra Dolomite Member of the Rustler Formation from 754 to 780 feet BGS. The Culebra at this location is located from 756 to 779 feet BGS (SAND87-0039).

SAMPLING PROCESS

A Bennett pump/packer assembly was used for this sampling round. The assembly consisted of a model 1800 Bennett Sample Pump (SN 1806-21) and a 2.8 inch Ardvark sliding end packer (SN 3690-435). A 3" to 1-1/2" packer feed through was utilized to facilitate the monitoring of formation pressures below the packer. The total length of the assembly was 7.52 feet.

Two geokon 4500H vibrating wire transducers were utilized to monitor formation pressures. A 0-150 psi pressure range (SN 3428) transducer was attached to the tubing bundle 25 ft above the top of the pump at a depth of 700 feet below top of casing (BTOC) in order to monitor the integrity of the packer seal. A second transducer (0-150 psi, SN 9075) was attached to the packer feed through assembly in order to monitor pressures below the packer. Data was collected and stored on a continuous basis by a Geokon Micro-10 data logger (SN-20).

On 05-30-90 the pump/packer assembly was installed in WIPP-19. The bottom of the assembly was positioned at a depth of 733 feet BTOC. Static water level just prior to installation measured 434.28 feet BTOC, (Solinst probe 75-CG-0101). The well was pumped for a total of 14 days at an average rate of approximately 17.16 gallons per hour.

Six serial samples were collected; the first on 06-04-90 after approximately 2512 gallons of water had been pumped from the well. Final samples were collected on 06-12-90 after approximately 5516 gallons of water had been pumped from the well. Final samples were sent to International Technology Analytical Sampling Laboratory (ITAS) and Westinghouse Advanced Energy Systems Division Analytical Lab (WAESD) for analysis. Samples were also provided to Sandia National Laboratories (SNL) and the New Mexico Environmental Evaluation Group (EEG) for independent analysis. Archival samples were collected for the WIPP Project.

ROUND-5 SERIAL SAMPLING RESULTS:

Eh fluctuated widely throughout the sampling period from a maximum of +210 to a low of -53. Serial sampling values were +157, +13, -53, +85, +210 and +204 respectively.

pH remained fairly stable during the 6 days of sampling measuring 7.46 S.U., 7.56 S.U., 7.50 S.U. 7.38 S.U., 7.48 S.U. and 7.31 S.U. respectively.

Temperature measured 23.0 C., 22.9 C., 22.8 C., 23.0 C., 22.5 C. and 23.1 C. respectively.

Specific Gravity measured 1.0570 @ 23.4 C. for sample 1, 1.0560 @ 22.9 C. for sample 4 and 1.0546 @ 23.2 C. on day 3.

Specific Conductance measured 94,800 umhos/cm @25 C. for sample 1, and 91,800 umhos/cm @ 25C. for sample 6.

Alkalinity, chlorides and divalent cations decreased from sample 1 to sample 6. Alkalinity averaged [illegible] mg/l, 65.3 mg/l and 63.0 mg/l, 58.1 mg/l, 57.8 mg/l and 59.4 mg/l respectively. Chlorides averaged 41303 mg/l, 40681 mg/l, 41061 mg/l, 40438 mg/l, 40370 mg/l and 40508 mg/l respectively. Divalent cations averaged 191.8 meq/l, 188.2 meq/l, 181.3 meq/l, 184.9 meq/l 178.3 meq/l and 178.9 meq/l respectively.

Both iron parameters, (total-iron and ferrous-iron) decreased dramatically from sample 1 to sample 3. Total-iron averaged 2.19 mg/l, 2.51 mg/l, 2.33 mg/l, 1.08 mg/l, 1.05 mg/l, and .83 mg/l respectively. Ferrous iron averaged 2.16 mg/l, 2.43 mg/l, 2.22 mg/l, 1.01 mg/l 0.99 mg/l and 0.72 mg/l respectively.

COMPARISON OF ROUND-5 RESULTS WITH PREVIOUS ROUNDS:

The amount of water pumped prior to final sampling for each of the five rounds is as follows; 2,400 gallons, 3,050 gallons, 5,300 gallons, 6292 and 5,516 gallons respectively. Round-5 final day results are slightly lower than results obtained from the final day average from the first four sampling rounds. This comparison was made by comparing chemical parameter averages for the final day of round-5 sampling with the average of the chemical parameter values obtained for the last day of sampling for each of the previous four rounds. The results are presented below.

AVG. OF FINAL DAY RESULTS FOR LAST FOUR ROUNDS	AVG. OF FINAL DAY FOR ROUND-5
Alkalinity 68.5 mg/l	Alkalinity 59.4 mg/l
Chlorides 48,848 mg/l	Chlorides 40,508 mg/l
Di-Cats 230.6 meq/l	Di-Cats 178.9 meq/l
Total Iron 1.41 mg/l	Total Iron 0.83 mg/l
Ferrous Iron 1.25 mg/l	Ferrous Iron 0.72 mg/l

GENERAL OBSERVATIONS/PROBLEMS:

During the sampling period a full packer seal was probably not achieved. On 06-04-90 the packer assembly was raised to a total depth of 723 feet BTOC from 733 Btoc in an unsuccessful attempt to seat the packer because of the high iron content of the water samples. During the early morning hours of 06-06-90 at approximately 03:00 pumping was interrupted due to a faulty fuel injector pump on generator # 75-PE-001 pumping was resumed at 05:55. On 06-08-90 pumping was again interrupted when the alternator in generator 75-PE-002 failed at approximately 21:00. Attempts to restart the pump ,after replacing the generator were unsuccessful and the pump was pulled from the wellbore and replaced with and alternate pump. The packer assembly was reinstalled on 06-09-90 to a depth of 745 feet to the bottom of the pump intake. The attempt to achieve a packer seal at this depth was again believed to be unsuccessful however, the iron content of the samples showed favorable trends.

SUMMARY OF BARN WELL, DEWEY LAKE, ROUND-4

WELL CHARACTERISTICS

Barn Well is located approximately three and four tenths of mile south southwest of the center of the WIPP site. Surface elevation is 3,315 feet above mean sea level (amsl). The total depth (TD) of this well is 138 feet below the ground surface (BGS) (Cooper and Glanzman, 1971). Water is pumped using an electric submersible pump.

SAMPLING PROCESS

Water samples were collected on 06-21-90 from a running stream of water from a spigot located in the owner's yard. Samples were filtered (0.45 micron) with a portable peristaltic pump. Samples were collected for International Technology Analytical Services (ITAS), and Westinghouse Advanced Energy System Division (WAESD) for analysis. Samples were also provided to Sandia National Laboratories (SNL) and the New Mexico Environmental Evaluation Group (EEG).

FIELD ANALYTICAL RESULTS

Round four analytical results for Barn Well were as follows: pH 7.58, Specific Gravity 1.0008 @ 25.2 C, Specific Conductivity 1070 umhos/cm @ 25 C. Average readings for Alkalinity, Chlorides and Divalent Cations were 284.1 mg/l, 56 mg/l and 5 meq/l respectively.

COMPARISON OF ROUND-5 RESULTS WITH PREVIOUS ROUNDS:

Round-5 results compare favorably with results obtained from the previous four sampling rounds. This comparison was made by comparing chemical parameter averages for round-5 with the average of the chemical parameter values obtained for the previous rounds. The results are presented below:

AVERAGE OF PREVIOUS FOUR ROUNDS	AVERAGE OF ROUND-5
Alkalinity 281.7 mg/l	Alkalinity 284.1 mg/l
Chlorides 47.2 mg/l	Chlorides 56.0 mg/l
Di-Cats 6.8 meq/l	Di-Cats 5.0 meq/l

GENERAL OBSERVATIONS/COMMENTS:

This well supplies drinking water for a residence located approximately one mile northwest of the well site.

SUMMARY OF RANCH WELL, DEWEY LAKE, ROUND-5

WELL CHARACTERISTICS

Ranch Well is located approximately three and two tenths miles south southeast of the center of the WIPP site. Surface elevation is 3,310 feet above mean sea level (amsl). The total depth of the well is 156 feet below the ground surface (BGS). Water is pumped to the surface by an electric submersible pump (Cooper and Glanzman, 1971).

SAMPLING PROCESS

Samples were collected on 06-19-90, from a discharge pipe above a storage tank located approximately twenty feet north of the well. Samples were filtered with a portable peristaltic pump. Samples were collected for International Technology Analytical Services (ITAS) and Westinghouse Advanced Energy Systems Division (WAESD) for analysis. Samples were also provided to Sandia National Laboratories (SNL) and the New Mexico Environmental Evaluation Group (EEG).

FIELD ANALYTICAL RESULTS

Round-5 analytical results for Ranch Well were as follows; pH 7.24 SU, Specific Gravity 1.0014 @ 23.7 degrees C, Specific Conductivity 3020 umhos/cm @ 25 degrees C. Average readings for Alkalinity, Chlorides and Divalent Cations were; 247.7 mg/l, 358 mg/l, and 38.5 meq/l respectively.

COMPARISON OF ROUND-5 RESULTS WITH PREVIOUS ROUNDS:

Round-5 results compare favorably with results obtained from the previous four sampling rounds. This comparison was made by comparing chemical parameter averages for round-5 with the average of the chemical parameter values obtained for previous four rounds. The results are presented below:

AVERAGE OF PREVIOUS FOUR ROUNDS	AVERAGE OF ROUND-5
Alkalinity 241.8 mg/l	Alkalinity 247.7 mg/l
Chlorides 383.8 mg/l	Chlorides 358 mg/l
Di-Cats 35.2 meq/l	Di-cats 38.5 meq/l

Round-2 alkalinity was measured at 39.8 mg/l. This value was not included in the average above because it is considered to be a suspect value and not representative of other sampling rounds.

GENERAL OBSERVATIONS/COMMENTS

This well supplies water for livestock.

SUMMARY OF H-02c, CULEBRA, ROUND-2

WELL CHARACTERISTICS

H-02c is located approximately 0.5 miles west of the center of the WIPP site (637.15 FNL and 1708.62 FWL, Section 29, Township 22S, Range 31E). The ground monument elevation is 3377.69 feet amsl, and top of casing (TOC) is at an elevation of 3378.41 feet amsl, (SAND88-1065).

H-02c was completed on 02-05-77 to a total depth of 795 feet below ground surface (BGS). Well casing (J55, 24 lb/ft, 6.625" OD) is installed to a depth of 742 feet BGS. The well was originally completed open hole in the Rustler/Salado contact which occurs from 743-795 feet BGS. The well was recompleted to the Culebra through casing perforations (3-holes per foot) from 624-654 feet BGS. A production inflation packer (PIP) was initially installed to isolate the Culebra from the Rustler/Salado. The PIP was later removed and a retrievable bridge plug was installed at a depth of 731 feet BGS, (SAND85-7206).

SAMPLING PROCESS

A Bennett pump/packer assembly was used for this sampling round. The assembly consisted of a model 1800 Bennett Sample Pump and a 3.5 inch Baski sliding end inflatable packer (SN 1981). A 3-1/2" to 1-1/2" packer feed through was utilized to facilitate the monitoring of formation pressures below the packer. A 4-1/2" packer sleeve was installed over the packer gland. The total length of the configuration was 7.7 feet.

Two geokon 4500H vibrating wire transducers were utilized to monitor formation pressures. A 0-150 psi pressure range (SN 3428) transducer was attached to the tubing and installed at a depth of 575 feet BTOC in order to monitor the integrity of the packer seal. A second transducer (0-150 psi, SN 9075) was attached to the packer feed through assembly in order to monitor pressures below the packer. Data was collected and stored on a continuous basis by a Geokon Micro-10 data logger (SN-20).

On 07-09-90 the first pump/packer assembly (Bennett pump SN1806-11) was installed in H-02c. The bottom of the assembly was positioned at a depth of 613 feet BTOC. Static water level just prior to installation measured 376.45 feet BTOC, (Solinst probe 75-CG-0101). This pump operated for five days and then failed on 07-13-90, after pumping approximately 1141 gallons of water.

On 07-13-90 the second pump/packer assembly (Bennett pump 1802) was installed in H-02c. The bottom of the pump assembly was positioned at a depth of 613 BTOC. Pumping continued for a total of 17 days at an average rate of approximately 11.74 gallons per hour.

Final samples were sent to International Technology Analytical Sampling Laboratory (ITAS) and Westinghouse Advanced Energy Systems Division Analytical Lab (WAESD) for analysis. Samples were also provided to Sandia National Laboratories (SNL) and the New Mexico Environmental Evaluation Group (EEG) for independent analysis. Archival samples were collected for the WIPP Project.

ROUND-2 SERIAL SAMPLING RESULTS:

A total of five serial samples were collected during round-2. Five serial samples were collected from 07-19-90 to 07-24-90. The first sample was collected after approximately 2939 gallons of water had been pumped. The final sample was collected after approximately 4294 gallons of water had been pumped.

Eh fluctuated slightly during the sampling period. From 07-19-90 to 07-24-90 five measurements were taken. The measurements were + 229 mv, + 235 mv, + 213 mv, + 274 mv, and + 245 mv, respectively.

pH remained fairly stable during the sampling period. The measurements were 7.71 S.U., 7.78 S.U., 7.78 S.U., 7.88 S.U., 7.72 S.U., respectively.

Temperature fluctuated during the two periods of sampling. From 07-19-90 to 07-24-90 five measurements were taken. The measurements were 22.0 C., 21.0 C., 22.0 C., 21.6 C., 22.2 C. respectively.

Specific gravity measured 1.010 at 22.6 C. on 07-19-90, 1.010 at 20.0 C. on 07-20-90,and 1.010 at 22.3 C. on 07-24-90.

Specific conductance measured 12,600 umhos/cm on 07-19-90, and 12,510 umhos/cm on 07-24-90.

Alkalinity, chlorides and divalent cations remained relatively stable through out the sampling period. For the five samples collected alkalinity averaged 59.6 mg/l, 59.1 mg/l, 60.0 mg/l, 60.5 mg/l,and 60.9 mg/l, respectively. Chlorides averaged 3,037 mg/l, 2,982 mg/l, 2,992 mg/l, 2,975 mg/l,and 2,999 mg/l, respectively. Divalent cations averaged 48.4 meq/l, 48.6 meq/l, 48.6 meq/l, 48.2 meq/l, and 48.7 meq/l respectively.

Both iron parameters, (total-iron and ferrous-iron) remained relatively stable during the sampling period. A spike in the iron parameters occurred on 07-23-90, when the pump stopped for several hours. Total iron averaged 1.46 mg/l, 1.29 mg/l, 1.50 mg/l, 2.06 mg/l, and 1.19 mg/l, respectively. Ferrous iron averaged 1.12 mg/l, 1.05 mg/l, 1.35 mg/l, 1.72 mg/l, and 1.07 mg/l respectively.

COMPARISON OF ROUND-1 RESULTS WITH ROUND-2 RESULTS

The amount of water pumped prior to final sampling during round-1 was 6,660 gallons compared to 4294 gallons for round-2. Alkalinity, Chlorides and Divalent Cations compared favorably with round one final day averages. Both Iron parameters, however, were slightly higher than in round one.

AVERAGE OF FINAL DAY RESULTS FOR ROUND-1	AVERAGE OF FINAL DAY FOR ROUND-2
Alkalinity 58.3 mg/l	Alkalinity 60.9 mg/l
Chlorides 3836 mg/l	Chlorides 2999 mg/l
Di-cats 52.4 meq/l	Di-cats 48.7 meq/l
Total Iron 0.79 mg/l	Total Iron 1.19 mg/l
Ferrous Iron 0.57 mg/l	Ferrous Iron 1.07 mg/l

GENERAL OBSERVATIONS/COMMENTS:

Water at this location is mildly effervescent and exhibits a greenish color tint. Two pump failures occurred during the testing period. The first occurred on 07-13-90 and resulted in pump Sn # 1806-11 being replaced by pump Sn # 1802. The second pump failed the evening of 07-22-90 but technical personnel were able to restart the pump on 07-23-90 and keep it running until final samples had been collected. The pump was left in operation for and extra day to facilitate collection of samples by the University of New Mexico Geology Department. The total gallons of water purged from the well from 07-09-90 until 07-25-90 were approximately 4800.

SUMMARY OF WELL H-3b3, CULEBRA, ROUND-5

WELL CHARACTERISTICS

Well H-3b3 is located approximately 0.8 miles south of the WIPP site, (2022.35 FSL, 217.30 FEL, Section 29, Township 22S, Range 31 E). Surface elevation is 3389.42 feet amsl, and top of casing TOC is at an elevation of 3388.67 feet amsl, (SAND88-1065). A casing stick up is located 0.5 feet above ground surface. The well was completed on 01-30-84 to a total depth of 730 feet below ground surface, (BGS). J-55, (15.5 lb/ft, 5.5 O.D) well casing is installed to a depth of 670.5 feet BGS, leaving the Culebra Dolomite, which is located at a depth of 673 to 696 feet BGS, open hole.

SAMPLING PROCESS

Bennett pump/packer assembly was used for this sampling round. The assembly consisted of a model 1800 Bennett sample pump (Sn 1806-21) and an ardvark 2.8 inch sliding end packer inflatable packer (Sn 3690-435). The total length of the assembly was 7.53 feet.

Two geokon 4500H vibrating wire transducers were utilized to monitor formation pressures. A 0-150 psi transducer (SN 3428) was attached to the tubing bundle 25 feet above the top of the pump/packer assembly. A second 0-150 psi transducer (SN 9075) was attached to the packer feed through assembly in order to monitor pressures below the packer. Data was collected and stored on a continuous basis by a micro-10 geokon data logger (SN-18).

On 08-07-90 the pump/packer assembly was installed in the well. The bottom of the assembly was positioned at a depth of 658 feet BTOC. Static water level just prior to installation measured 404.75 feet BTOC. The well was pumped for a total of 9 days at an average rate of 28.91 gallons per hour.

Four serial samples were collected; the first on 08-12-90 after approximately 3403 gallons of water had been pumped from the well. Final samples were collected on 08-15-90 after approximately 5466 gallons of water had been pumped from the well. Final samples were sent to International Technology Analytical Sampling Laboratory (ITAS), and Westinghouse Advanced Energy Systems Division Analytical Lab (WAESD) for analysis. Samples were also provided to Sandia National Laboratories (SNL) and the New Mexico Environmental Evaluation Group (EEG) for independent analysis. Archival samples were collected for the WIPP Project.

ROUND-5 SERIAL SAMPLING RESULTS:

From day 1 to day 4 Eh measured 206 mv, 190 mv, 212 mv, and 175 mv, respectively.

From day 1 to day 4 pH measured 7.51 S.U., 7.41 S.U., 7.44 S.U., and 7.45 S.U., respectively.

From day 1 to day 4, temperature measured 22.1 C., 22.1 C., 22.2 C., and 22.2 C. respectively.

Specific Gravity measured 1.0420 at 22.3 C. on day 1, and 1.0400 at 22.4C. on day 4.

Specific Conductance measured 69,300 umhos/cm at 25 C. on day 1, and 69,300 umhos/cm at 25 C. on day 4.

Alkalinity remained fairly stable throughout round-5. From day 1 to day 4, alkalinity averaged 50.5 mg/l, 50.6 mg/l, 50.5 mg/l, and 50.5 mg/l, respectively.

Chlorides fluctuated slightly. From day 1 to day 4 chlorides averaged 27,747 mg/l, 27,677 mg/l, 27,781 mg/l, and 27,695 mg/l respectively.

Divalent Cations remained fairly stable throughout round-5. From day 1 to day 4 divalent cations averaged 137.6 meq/l, 136.7 meq/l, 136.7 meq/l, and 137.9 meq/l respectively.

For the four days of sampling total iron averaged 0.22 mg/l, 0.20 mg/l, 0.21 mg/l, and 0.24 mg/l respectively.

From day 1 to day 4 ferrous iron averaged 0.19 mg/l, 0.15 mg/l, 0.19 and 0.19 mg/l respecuvely.

COMPARISON OF ROUND-5 RESULTS WITH PREVIOUS ROUNDS:

The amount of water pumped prior to final sampling for each of the five rounds is as follows; 16,300 gallons, 40,000 gallons, 94,000 gallons, 101,919 and 5,466 gallons respectively. Round-5 parameters compare favorably to all of the previous rounds. This comparison was made by comparing chemical parameter averages for the final day of round-5 sampling with the average of the chemical parameter values obtained for the last day of sampling for each of the previous four rounds. The results are presented below.

AVG. OF FINAL DAY RESULTS FOR LAST FOUR ROUNDS	AVG. OF FINAL DAY FOR ROUND-5
Alkalinity 50.9 mg/l	Alkalinity 50.5 mg/l
Chlorides 28,083 mg/l	Chlorides 27,695 mg/l
Di-Cats 145.1 meq/l	Di-Cats 137.9 meq/l
Total iron 0.17 mg/l	Total Iron 0.24 mg/l
Ferrous Iron 0.14 mg/l	Ferrous Iron 0.19 mg/l

GENERAL OBSERVATIONS/COMMENTS:

This was the first round of sampling where a Bennett sample pump was utilized for the sampling process. In all parameters with the exception of the Iron parameters the results were comparable to other test round parameters. Iron parameters were probably elevated due to the lesser volume of water withdrawn from the aquifer.

SUMMARY OF WELL H-03b1, MAGENTA, ROUND-5

WELL CHARACTERISTICS

Well H-03b1 is located approximately 0.8 miles south of the WIPP

site, (2085.31 FSL, 138.10 FEL, Section 29, Township 22S, Range 31 E).

Surface elevation is 3389.42 feet amsl, and top of casing (TOC) is at an elevation of 3390.64 feet amsl, (SAND88-1065). The well was completed on 08-12-76 to a total depth of 902 feet below ground surface, (BGS).

J-55, (24#/ft., 6.625 O.D.) well casing is installed to a depth of 891 feet BGS. Initial completion was in the Rustler/Salado Contact (813 to 837 feet BGS). The well was next completed in the Magenta and Culebra. A bridge packer was installed at approximately 795 feet BGS. The casing was perforated in the Magenta (562 to 590 feet BGS) and in the Culebra (675 to 703 feet BGS). A Production Inflation Packer (PIP) was installed at a depth of approximately 652 feet BGS, providing access to both intervals.

On 07-08-86 the PIP was removed and a 4.25 inch bridge packer was installed to provide permanent access to the Magenta.

SAMPLING PROCESS

A pump/packer assembly was used to sample H-3b1. The assembly consisted of a Model 1800 Bennett sample pump (SN 1806-25) and a Baski 3.5 inch sliding end packer (SN 1981), with a 4.5 inch packer sleeve (SN 1922) installed over the packer element. The total length of the assembly was 7.66 feet.

Two Geokon 4500h vibrating wire transducers were utilized to monitor formation pressures. The first transducer (SN 3428) was attached to the tubing bundle 25 feet above the pump/packer assembly at a depth of 515 feet BTOC. A second transducer (SN 9075) was attached to the packer feed through assembly in order to monitor pressures below the packer. Data was collected and stored on a continuous basis by a Micro-10 Geokon datalogger (SN 18).

On 08-21-90 the pump/packer assembly was installed in the well. The bottom of the assembly was positioned at a depth of 548 feet BTOC.

Static water level just prior to installation measured 251.49 feet BTOC, (Solinst Probe 75-CG 0102). The well was pumped for a total of seven days at an average rate of 10.86 gallons per hour. Readings from the lower transducer slowly decreased from 130 psi to less than 30 psi.

Five serial samples were collected; the first on 08-23-90 after approximately 475 gallons of water had been pumped from the well.

Final samples were collected on 08-28-90 after approximately 1795 gallons of water had been pumped from the well. Final samples were sent to International Technology Analytical Sampling Laboratory (ITAS), and Westinghouse Advanced Energy Systems Division Analytical Lab (WAESD) for analysis. Samples were also provided to Sandia National Laboratories (SNL) and the New Mexico Environmental Evaluation Group (EEG) for independent analysis. Archival samples were collected for the WIPP Project.

ROUND-5 SERIAL SAMPLE RESULTS

From sample 1 to sample 5 Eh measured +48 mv, -78 mv, -62 mv, -24 mv and -5 mv respectively.

pH remained fairly stable throughout the testing period. From sample 1 to 5 pH measured 7.86 S.U., 7.78 S.U., 7.76 S.U., 7.81 S.U., and 7.75 S.U. respectively.

From sample 1 to sample 5 temperature measured 22.9 C, 24.4 C, 24.3 C, 23.0 C, and 23.6 C respectively.

Specific gravity measured 1.0084 at 22.9 C on day 1 and 1.0080 at 23.2 C for sample 5.

Specific conductance measured 12,200 umhos/cm at 25 C. on day 1 and 12,200 umhos/cm at 25 C. on day 5.

Alkalinity remained fairly stable throughout round-5. From sample 1 to 5 alkalinity averaged 46.4 mg/l, 47.0 mg/l, 46.9 mg/l, 46.5 mg/l and 45.9 mg/l respectively.

Chlorides for round-5 averaged 3426 mg/l, 3387 mg/l, 3447 mg/l, 3462 mg/l, and 3458 mg/l respectively.

Divalent cations were relatively stable from sample 1 to sample 5. Divalent cations averaged 74.7 meq/l, 73.9 meq/l, 73.8 meq/l, 73.5 meq/l, and 73.7 meq/l respectively.

Both iron parameters (total iron and ferrous iron) were very low. The lower detection limit for measuring iron in the field lab is 0.02 mg/l.

All but the first day of measurements could only be reported as less than 0.02 mg/l. Average iron measurements for the first day were 0.07 mg/l for total iron and 0.05 mg/l for ferrous iron.

COMPARISON OF ROUND-5 RESULTS WITH PREVIOUS ROUNDS:

The amount of water pumped prior to final sampling for each of the five rounds is as follows; 3,800 gallons, 1,500 gallons, 1,700 gallons, 2,280 gallons, and 1,795 gallons respectively. Round-5 parameters compare favorably to all of the previous rounds. This comparison was made by comparing chemical parameter averages for the final day of round-5 sampling with the average of the chemical parameter values obtained for the last day of sampling for each of the previous four rounds. The results are presented below.

AVG. OF FINAL DAY RESULTS FOR LAST FOUR ROUNDS	AVG. OF FINAL DAY FOR ROUND-5
Alkalinity 46.1 mg/l	Alkalinity 45.9 mg/l
Chlorides 3316 mg/l	Chlorides 3458 mg/l
Di-Cats 73.6 meq/l	Di-Cats 73.7 meq/l
Total Iron 0.32 mg/l	Total Iron mg/l
Ferrous Iron 0.21 mg/l	Ferrous Iron mg/l

GENERAL OBSERVATIONS/COMMENTS:

Formation water from the Magenta at this location is slightly effervescent and has a hydro-carbon odor. The water contains a small amount of black particulate matter that can be observed on a 0.45 umfilter.

REFERENCES CITED:

SAND88-1065 Compilation and Comparison fo Test-Hole Location Surveys in the Vicinity of the Waste Isolation Pilot Plant Site, 1989, Mary M. Gonzales, Earth Sciences Division, Sandia National Laboratories, Albuquerque, New Mexico.

SUMMARY OF WELL H-4b CULEBRA, ROUND-5

WELL CHARACTERISTICS

Well H-04b is located two and four tenths miles south southwest of the WIPP site, (498.47 FNL, 632.54 FWL, Section 5, Township 23S, Range 31 E). Surface elevation is 3332.67 feet above mean sea level (amsl), and the top of casing (TOC) is at an elevation of 3333.35 feet amsl, (SAND88-1065). The well was completed on 05-15-78 to a total depth of 529 feet below ground surface, (BGS), (Winstanley/Carrasco, 1986). Well casing (J-55, 15.5 lb/ft) is installed to a depth of 476 feet BGS, with the remaining depth completed open hole. The entire thickness of the Culebra is exposed in the open hole section. At this location the Culebra lies from 498-522 feet BGS (SAND85-7206).

SAMPLING PROCESS

A pump/packer assembly was used to sample H-04b. The assembly consisted of a model 1800 Bennett Sample Pump (SN 1806-11) and a 2.8 inch Ardvark sliding end packer (SN 3690-435). The total length of the assembly was 7.56 feet.

Two geokon 4500H vibrating wire transducers were utilized to monitor formation pressures. A 0-150 psi pressure range (SN 3431) transducer was attached to the tubing bundle 25 feet above the top of the pump/packer assembly at a depth of 425 feet BTOC. A second transducer (0-150 psi, SN 3432) was attached to the packer feed through assembly in order to monitor pressures below the packer. Data was collected and stored on a continuous basis by a CR-10 geokon data logger (SN-22).

On 09-06-90 the pump/packer assembly was installed in the well. The bottom of the assembly was positioned at a depth of 457.56 feet BTOC. Static water level just prior to installation measured 334.80 feet BTOC, (Solinst probe 75-CG-0102). The well was pumped for a total of 7 days at an average rate of 10.81 gallons per hour.

Four serial samples were collected; the first on 09-09-90 after approximately 522 gallons of water had been pumped and final samples were collected on 09-12-90 after approximately 1286 gallons of water had been pumped from the well. Final samples were sent to International Technology Analytical Sampling Laboratory (ITAS), United Nuclear Corporation (UNC), and Westinghouse Advanced Energy Systems Division Analytical Lab (WAESD) for analysis. Samples were also provided to Sandia National Laboratories (SNL) and the New Mexico Environmental Evaluation Group (EEG). Archival samples were collected for the WIPP Project.

ROUND-5 SERIAL SAMPLING RESULTS:

All parameters remained relatively stable throughout the testing period with the exception of the Iron parameters which continued to decrease troughout the period.

Eh measured +95 mv, +113 mv, +112 mv and +114 mv.

pH measured 7.81 S.U., 7.74 S.U., 7.77 S.U. and 7.76 S.U. respectively.

Temperature measured 22.2 C, 21.8 C, 21.5 C and 22.1 C.

Specific gravity measured 1.0168 at 22.3 C on day one and 1.0164 at 21.5 C on day four.

Specific conductivity measured 24,400 umhos at 25 C. on day one and 26,400 umhos at 25 C. on day four.

Alkalinity measurements for each of the four days were 67.8 mg/l, 68.5 mg/l, 68.3 mg/l and 69.1 mg/l respectively.

Chlorides averaged 7,657 mg/l, 7,515 mg/l, 7,568 mg/l and 7,577 mg/l respectively.

Divalent cation from day one to day four 70.8 mg/l, 71.7 mg/l, 71.9 mg/l and 71.4 mg/l respectively.

Both Iron parameters decreased steadily over the four day period. Total Iron averaged 1.26 mg/l, 1.06 mg/l, 1.03 mg/l and 1.01 mg/l. Ferrous Iron Averaged 1.21 mg/l 1.00 mg/l, 0.96 mg/l and 0.89 mg/l respectively.

COMPARISON OF ROUND-5 RESULTS WITH PREVIOUS ROUNDS:

The amount of water pumped prior to final sampling for each of the five rounds is as follows; 4700 gallons, 2450 gallons, 2500 gallons, 1048 gallons, and 1286 respectively. Round-5 parameters compare favorably to all of the previous rounds of testing. This comparison was made by comparing chemical parameter averages for the final day of round-5 sampling with the average of the chemical parameter values obtained for the last day of sampling for each of the previous four rounds. The results are presented below.

AVG. OF FINAL DAY RESULTS FOR LAST FOUR ROUNDS	AVG. OF FINAL DAY FOR ROUND-5
Alkalinity 69.1 mg/l	Chlorides 7445 mg/l
Chlorides 7577mg/l	Di-Cats 71.5 meq/l
Di-Cats 71.4 meq/l	Total iron 0.83 mg/l
Total Iron 1.01 mg/l	Ferrous Iron 0.41 mg/l
Ferrous Iron 0.89 mg/l	

SUMMARY OF WELL H-4c, MAGENTA, ROUND-5

WELL CHARACTERISTICS

Well H-04c is located two and four tenths miles south southwest of the WIPP site, (446.36 FNL, 717.89 FWL, Section 5, Township 23S, Range 31 E). Surface elevation is 3333.45 feet above mean sea level (amsl), and the top of casing (TOC) is at an elevation of 3334.04 feet amsl, (SAND88-1065). The well was completed on 05-09-78 to a total depth of 661 feet below ground surface, (BGS), (Winstanley/Carrasco, 1986). J-55, (15.5 lb/ft, 5.5 O.D) well casing is installed to a depth of 610 feet BGS. Initial completion was in the Culebra. A Lynes bridge packer was installed at a depth of 530 feet BTOC, and the casing was shot perforated from 496 to 520 feet BGS, (SAND85-7206). In August of 1986 the well was recompleted to the Magenta. A second Lynes bridge packer was installed at a depth of 435 feet BTOC and the well casing was shot perforated from 377 to 403 feet BTOC.

SAMPLING PROCESS

A pump/packer assembly was used to sample H-04c. The assembly consisted of a model 1800 Bennett Sample Pump (SN 1802) and a 2.8 inch Ardvark sliding end packer (SN 3690-435). The total length of the assembly was 7.53 feet.

Two geokon 4500H vibrating wire transducers were utilized to monitor formation pressures. A 0-150 psi pressure range (SN 3428) transducer was attached to the tubing bundle 25 feet above the top of the pump/packer assembly at a depth of 340 feet BTOC. A second transducer (0-150 psi, SN 9075) was attached to the packer feed through assembly in order to monitor pressures below the packer. Data was collected and stored on a continuous basis by a CR-10 geokon data logger (SN-20).

On 09-25-90 the pump/packer assembly was installed in the well. The bottom of the assembly was positioned at a depth of 372.53 feet BTOC. Static water level just prior to installation measured 192.31 feet BTOC, (Solinst probe 75-CG-0102). The well was pumped for a total of 7 days at an average rate of 3.72 gallons per hour.

Five serial samples were collected; the first on 09-27-90 after approximately 161 gallons of water had been pumped and final samples were collected on 10-02-90 after approximately 585 gallons of water had been pumped from the well. Final samples were sent to International Technology Analytical Sampling Laboratory (ITAS), United Nuclear Corporation (UNC), and Westinghouse Advanced Energy Systems Division Analytical Lab (WAESD) for analysis. Samples were also provided to Sandia National Laboratories (SNL). The New Mexico Environmental Evaluation Group (EEG) was notified of sampling and elected not to take a sample for analysis. Archival samples were collected for the WIPP Project.

ROUND FIVE SERIAL SAMPLING RESULTS:

Eh measured -86 mv, -82 mv, -58 mv, -81 mv and -61 mv respectively

pH measured 7.98 S.U., 8.00 S.U., 8.03 S.U., 8.00 S.U. and 8.01 S.U.

Temperature measured form day one to day five 23.9 C, 21.7 C, 21.0 C, 21.6 C and 20.6 C.

Specific gravity and Specific Conductivity were measured on day one and day five of the sampling period.

Specific gravity measured 1.02 at 24.1 C. on day one and 1.0202 at 20.4 C. on day five.

Specific conductivity measured 30,900 umhos/cm at 25.0 C. on day one and 30,900 umhos/cm at 25 C. on day five.

Alkalinity averaged 80.6 mg/l, 79.5 mg/l, 82.5 mg/l, 80.9 mg/l and 80.9 mg/l respectively.

Chlorides averaged 8,431 mg/l, 8,516 mg/l, 8,502 mg/l, 8,501 mg/l and 8,492 mg/l respectively.

Divalent Cations reamained relitively stable measureing 70.35 mg/l, 69.25 mg/l, 70.30 mg/l, 70.10 mg/l and 70.10 mg/l daily average readings.

Both iron parameters remained fairly stable throughout the sampling period. Total Iron averaged 0.145 mg/l, 0.165 mg/l, 0.175 mg/l, 0.165 mg/l and 0.165 mg/l. Ferrous Iron averaged 0.125 mg/l, 0.105 mg/l, 0.06 mg/l, 0.085 mg/l and 0.095 mg/l respectively.

COMPARISON OF ROUND-5 RESULTS WITH PREVIOUS ROUNDS:

The amount of water pumped prior to final sampling for each of the our rounds is as follows; 700 gallons, 1,100 gallons, 700 gallons, and 450 gallons and 585 gallons respectively. Round-5 parameters compare favorably to all of the previous rounds even though a smaller amount of water was pumped. This comparison was made by comparing chemical parameter averages for the final day of round-5 sampling with the average of the chemical parameter values obtained for the last day of sampling for each of the previous four rounds. The results are presented below.

AVG. OF FINAL DAY RESULTS FOR LAST FOUR ROUNDS	AVG. OF FINAL DAY FOR ROUND-5
Alkalinity 80.7 mg/l	Alkalinity 80.9 mg/l
Chlorides 8368 mg/l	Chlorides 8493 mg/l
Di-Cats 68.7 meq/l	Di-Cats 70.1 meq/l
Total Iron 0.61 mg/l	Total Iron 0.17 mg/
Ferrous Iron 0.38 mg/l	Ferrous Iron 0.10 mg/l

GENERAL OBSERVATIONS/COMMENTS:

Formation water from the Magenta at this location is slightly effervescent and has a strong sulfurous odor. The water contains a large amount of black particulate matter that can be observed on 0.45 um filters. The Magenta can easily be de-watered at this location so pumping rates must be kept low (i.e., 3.72 gph).

SUMMARY OF WELL H-11b3, CULEBRA, ROUND-5

WELL CHARACTERISTICS

Well H-11B3 is located two and two tenths miles south-southeast of the WIPP site, (1501.7 FSL, 105.2 FEL, Section 33, Township 22S, Range 31 E). Surface elevation is 3412.07 feet above mean sea level (amsl), and the top of casing (TOC) is at an elevation of 3412.42 feet amsl, (SAND88-1065). The well was completed on 12-18-83 to a total depth (TD) of 787 feet below ground surface, (BGS), (Winstanley/Carrasco, 1985). Well casing (J55 15.5 lb/ft, 5 inch I.D.) is installed to a depth of 733 feet BGS. The well is completed open hole in the Culebra which lies at a depth from 734-759 feet BGS (SAND85-7206, Winstanley and Carrasco,1985).

SAMPLING PROCESS

A Bennett pump/packer assembly was used to sample H-11b3. The assembly consisted of a model 1800 Bennett Sample Pump (SN 1806-21) and a 2.8 inch Ardvark sliding end packer (SN 3690-435). The total length of the assembly was 7.54 feet.

Two geokon 4500H vibrating wire transducers were utilized to monitor formation pressures. A 0-150 psi pressure range (SN 3428) transducer was attached to the tubing bundle 25 feet above the top of the pump/packer assembly at a depth of 695 feet BTOC. A second transducer (0-150 psi, SN 9075) was attached to the packer feed through assembly in order to monitor pressures below the packer. Data was collected and stored on a continuous basis by a CR-10 geokon data logger (SN-20).

On 10-10-90 the pump/packer assembly was installed in the well. The bottom of the assembly was positioned at a depth of 727.54 feet BTOC. Static water level just prior to installation measured 436.53 feet BTOC, (Solinst probe 75-CG-0102). The well was pumped for a total of 8 days at an average rate of 26.59 gallons per hour.

Four serial samples were collected; the first on 10-14-90 after approximately 2454 gallons of water had been pumped and final samples were collected on 10-17-90 after approximately 4368 gallons of water had been pumped from the well. Final samples were sent to International Technology Analytical Sampling Laboratory (ITAS), United Nuclear Corporation (UNC), and Westinghouse Advanced Energy Systems Division Analytical Lab (WAESD) for analysis. Samples were also provided to Sandia National Laboratories (SNL). The New Mexico Environmental Evaluation Group (EEG) was notified of sampling and elected not to take a sample for analysis. Archival samples were collected for the WIPP Project.

ROUND-5 SERIAL SAMPLING RESULTS:

Eh measurments fluctuated slightly from sample one thruogh sample 4, measurement were + 118 mv, + 144 mv, + 102 mv and + 119 mv respectively.

pH measurements were 7.37 S.U., 7.38 S.U., 7.36 S.U. and 7.38 S.U. respectively.

Specicic gravity remained constant two measurements were taken the first on day one 1.0804 at 21.6 C. and the second on day four 1.0804 at 21.3 C.

Specific Conductivity measured 133,400 umhos/cm at 25 C. on day one and 133,800 umhos/cm at 25 C. on day four.

Alkalinity average readings were 55.8 mg/l, 55.0 mg/l, 55.3 mg/l and 54.1 mg/l respectively.

Chlorides were relatively stable averaging 66,340 mg/l, 65,184 mg/l, 65,540 mg/l and 65,451 mg/l respectively.

Divalent Cations averaged 186.8 meq/l, 186.2 meq/l, 185.8 meq/l and 185.2 meq/l respectively.

Total Iron and Ferrous Iron remained relatively stable during the four days of testing averaging 0.48 mg/l, 0.44 mg/l, 0.46 mg/l and 0.47 mg/l for Total Iron and 0.37mg/l, 0.35 mg/l, 0.34 mg/l and 0.38 mg/l respectively for Ferrous Iron.

COMPARISON OF ROUND-5 RESULTS WITH PREVIOUS ROUNDS:

The amount of water pumped prior to final sampling for each of the five rounds is as follows; 126,000 gallons, 30,800 gallons, 27,500 gallons, 4,751 gallons and 4,368 gallons respectively. Round five parameters compare favorably to all of the previous rounds. This comparison was made by comparing chemical parameter averages for the final day of round five sampling with the average of the chemical parameter values for the last day of sampling for each of the previous four rounds. The results are presented below.

AVG. OF FINAL DAY RESULTS FOR LAST FOUR ROUNDS	AVG. OF FINAL DAY FOR ROUND-5
Alkalinity 55.3 mg/l	Alkalinity 54.1 mg/l
Chlorides 65,570 mg/l	Chlorides 65,451 mg/l
Di-Cats 187.0 meq/l	Di-Cats 185.2 meq/l
Total Iron 0.36 mg/l	Total Iron 0.47 mg/l
Ferrous Iron 0.24 mg/l	Ferrous Iron 0.38 mg/l

GENERAL OBSERVATIONS/COMMENTS:

Formation water from the Culebra at this location is slightly effervescent.

SUMMARY OF WELL H-7b, CULEBRA, ROUND-5

WELL CHARACTERISTICS

Well H-7b is located 6 miles southwest of the WIPP site, (2565.80 FNL, 2563.45 FWL, Section 14, Township 23S, Range 30 E). Surface elevation is 3163.56 feet amsl, and top of casing (TOC) is at an elevation of 3164.17 feet amsl, (SAND88-1065). The well was completed on 09-18-79 to a total depth of 286 feet below ground surface, (BGS). Well casing (J-55, 23 lb/ft, 7 inch O.D) extends to a depth of 230 feet BGS. The Culebra at this location lies at a depth of 232 feet to 280 feet BTOC, (Winstanley/Carrasco, 1986). The well appears to be obstructed at a depth of 208 feet BTOC. The cause of this obstruction is unknown.

SAMPLING PROCESS

A pump/packer assembly was used to sample H-7b. The assembly consisted of a model 1800 Bennett Sample Pump (SN 1806-25) and a 3.5 inch Baski sliding end packer (SN 1981) with a Baski 4 inch packer sleeve installed around the packer gland (SN 1922). The total length of the assembly was 7.7 feet.

Two geokon 4500H vibrating wire transducers were utilized to monitor formation pressures. A 0-150 psi pressure range (SN 3431) transducer was attached to the tubing bundle and positioned at a depth of 175 feet BTOC to monitor the integrity of the packer seal. A second transducer (0-150 psi, SN 3432) was attached to the packer feed through assembly in order to monitor pressures below the packer. Data was collected and stored on a continuous basis by a micro-10 geokon data logger (SN-20).

On 10-31-90 the pump/packer assembly was installed in the well. The bottom of the assembly was positioned at a depth of 198 feet BTOC. Static water level just prior to installation measured 168.85 feet BTOC, (Solinst probe 75-CG-0101). The well was pumped for a total of 9 days at an average rate of 47.2 gallons per hour. Approximately 9287 gallons were pumped from the well bore through out the pumping period.

Six serial samples were collected; the first on 11-02-90 after approximately 2008 gallons of water had been pumped from the well. Final samples were collected on 11-08-90 after approximately 8878 gallons of water had been pumped from the well. Final samples were sent to International Technology Analytical Services Laboratory (ITAS) and Westinghouse Advanced Energy Systems Division Analytical Lab (WAESD) for analysis. Samples were also provided to Sandia National Laboratories (SNL). New Mexico Environmental Evaluation Group (EEG) were offered samples for independent analysis, however they declined the samples. Archival samples were collected for the WIPP Project.

ROUND-5 SERIAL SAMPLING RESULTS:

Parameters for H-7b, round-5 stabilized very quickly. A total of six samples were collected. Results of daily serial sampling parameters are given below.

Eh fluctuated during the 6 days of sampling measuring +356, +337, +334, +311, +353 and +335 respectively.

pH remained fairly stable during the 6 days of sampling measuring 7.35 S.U., 7.38 S.U., 7.35 S.U.,7.36 S.U., 7.32 S.U. and 7.34 S.U. respectively.

Temperature measured 21.9 C. on day 1, 21.2 C. on day 2, 21.6 C on day 3, 21.4 C on day 4, 20.6 C on day 5 and 20.8 C. on day 6.

Specific Gravity measured 1.0042 at 22.0 C on day 1, and 1.0026 at 20.8 C on day 6.

Specific Conductance measured 3520 at 25 C on day 1, and 3620 at 25 C on day 6.

Alkalinity, chlorides and divalent cations remained fairly stable throughout the 6 day sampling period. Alkalinity averaged 112.6 mg/l, 111.0 mg/l, 113.5 mg/l, 113.3 mg/l, 113.3 mg/l and 112.8 mg/l respectively. Chlorides averaged 278 mg/l, 275 mg/l, 276 mg/l, 276 mg/l, 277 mg/l, and 276 mg/l respectively. Divalent cations averaged 48.7 meq/l, 48.0 meq/l, 46.5 meq/l, 47.6 meq/l, 47.9 meq/l and 47.6 meq/l respectively.

Both iron parameters, (total-iron and ferrous-iron) fluctuated slightly during the 6 day sampling period. Total-iron averaged 0.27 mg/l, 0.60 mg/l, 0.18 mg/l, 0.20 mg/l, 0.18 mg/l, and 0.21 mg/l respectively. Ferrous iron averaged 0.22 mg/l, 0.56 mg/l, 0.15 mg/l, 0.13 mg/l, 0.15 mg/l, and 0.17 mg/l respectively.

COMPARISON OF ROUND-5 RESULTS WITH PREVIOUS ROUNDS:

The amount of water pumped prior to final sampling for each of the five rounds is as follows; 38,900 gallons, 62,600 gallons, 112,400 gallons, 3,909 gallons and 8878 gallons respectively. Round five parameters compare favorably to all of the previous rounds . This comparison was made by comparing chemical parameter averages for the final day of round-5 sampling with the average of the chemical parameter values obtained for the last day of sampling for each of the previous four rounds. The results are presented below.

AVG. OF FINAL DAY RESULTS FOR LAST FOUR ROUNDS	AVG. OF FINAL DAY FOR ROUND-5
Alkalinity 120.5 mg/l	Alkalinity 112.8 mg/l
Chlorides 298 mg/l	Chlorides 276 mg/l
Di-Cats 42.9 meq/l	Di-Cats 47.6 meq/l
Total Iron 0.10 mg/l	Total Iron 0.21 mg/l
Ferrous Iron 0.05 mg/l	Ferrous Iron 0.17 mg/l

GENERAL OBSERVATIONS/COMMENTS:

A spike in the Iron parameters on day two of the serial sampling process was attributable to a pump failure which occurred during the early morning hours of 11/04/90. However there appears to be a long term upward trend in both iron parameters. Given the obstruction in casing discovered during round four this upward trend might be attributed to the continuing deterioration of the well casing.

APPENDIX V

LAST DAY SERIAL SAMPLING RESULTS FROM PREVIOUS ROUNDS

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LAST DAY SAMPLING RESULTS FOR EACH WELL
SAMPLED IN 1985

WELL	ZONE	ROUND	DATE SAMPLED	Eh (mv)	pH (S.U.)	TEMP (C)	SPECIFIC GRAVITY	SPECIFIC CONDUCTANCE (umhos)	ALKALINITY (mg/l)	CHLORIDES (mg/l)	DICATIONS (meq/l)	TOTAL IRON (mg/l)	FERROUS IRON (mg/l)
H-03b3	Culebra	1	02-04-85	62.00	7.40	21.6	NT	63600	51.6	29330	167.8	0.17	0.13
ENGLE	Culebra	1	03-05-85	NT	7.40	20.9	NT	3400	108.1	224	41.8	0.53	0.24
DOE-02	Culebra	1	03-12-85	444.00	7.00	20.7	NT	68000	67.5	32338	186.3	LD	LD
DOE-1	Culebra	1	04-25-85	224.00	7.10	22.6	NT	143000	44.6	73173	208.9	0.35	0.29
H-11b3	Culebra	1	06-04-85	200.00	7.20	23.5	1.0910 @ 22.6 C	116000	53.4	67922	187.6	0.15	0.11
H-04b	Culebra	1	07-25-85	189.00	7.70	21.5	1.0150 @ 21.1 C	26400	70.0	7456	71.4	1.04	0.31
H-12	Culebra	1	08-09-85	229.00	7.20	23.2	1.0960 @ 24.0 C	149000	52.5	80452	242.7	1.18	0.22
H-05b	Culebra	1	08-27-85	91.00	7.40	22.3	1.1050 @ 21.6 C	157000	48.9	83413	256.4	2.81	2.55
H-06b	Culebra	1	09-16-85	290.00	6.90	22.0	1.0420 @ 23.5 C	73300	94.1	32295	190.7	0.21	0.16
H-09b	Culebra	1	11-14-85	280.00	7.50	23.3	1.0030 @ 22.6 C	3300	116.1	194	41.2	0.13	0.05
WIPP-26	Culebra	1	11-25-85	364.00	7.10	21.5	1.0120 @ 21.8 C	26600	118.8	8575	100.4	0.10	LD
WIPP-29	Culebra	1	12-15-85	349.00	5.90	19.9	1.2160 @ 20.8 C	NT	153.9	176019	615.5	1.21	0.89
H-03b1	Magenta	1	07-02-85	-29.00	8.00	24.4	1.0060 @ 21.4 C	12300	46.4	3363	74.3	0.65	0.34
DOE-02	Bell Canyon	1	07-13-89	NT	6.70	NT	NT	NT	NT	89800	397.0	NT	NT

ALKALINITY, CHLORIDE, DICATIONS, TOTAL IRON AND FERROUS IRON ARE AVG. VALUES

LAST DAY SAMPLING RESULTS FOR EACH WELL
SAMPLED IN 1986

WELL	ZONE	ROUND	DATE SAMPLED	Eh (mv)	PH (S.U.)	TEMP (C)	SPECIFIC GRAVITY	SPECIFIC CONDUCTANCE (umhos)	ALKALINITY (mg/l)	CHLORIDES (mg/l)	DICATIONS (meq/l)	TOTAL IRON (mg/l)	FERROUS IRON (mg/l)
H-08b	Culebra	1	01-23-86	338.00	7.60	20.9	1.0020 @ 21.8 C	2900	95.3	33	41.7	0.09	0.02
WIPP-25	Culebra	1	02-13-86	194.00	7.20	21.8	1.0100 @ 21.9 C	20300	126.5	6191	81.5	0.49	0.39
P-14	Culebra	1	02-27-86	174.00	6.80	21.6	1.0190 @ 21.3 C	37400	105.8	15294	254.9	2.08	2.04
P-17	Culebra	1	03-17-86	71.00	7.50	21.7	1.0650 @ 21.2 C	107000	61.1	47482	211.1	4.78	4.18
H-07b1	Culebra	1	03-27-86	261.00	7.20	22.2	1.0010 @ 21.5 C	3700	120.7	309	46.4	0.12	0.06
H-02a	Culebra	1	04-21-86	24.00	8.00	22.0	1.0090 @ 21.7 C	19100	56.3	5243	53.4	1.02	0.80
H-03b3	Culebra	2	05-05-86	160.00	7.40	23.5	1.0380 @ 22.1 C	71900	50.7	27361	136.3	0.23	0.18
H-05b	Culebra	2	05-21-86	53.00	7.60	25.1	1.1050 @ 23.7 C	162200	51.0	84884	253.4	4.01	3.53
H-11b3	Culebra	2	06-04-86	124.00	7.30	23.7	1.0810 @ 24.0 C	140400	54.0	65886	182.8	0.30	0.28
DOE-01	Culebra	2	07-03-86	132.00	7.10	24.2	1.0910 @ 23.0 C	152000	45.3	75335	216.2	1.36	1.24
H-06b	Culebra	2	07-28-86	123.00	7.00	23.3	1.0400 @ 25.6 C	80100	90.7	32228	191.8	0.10	0.07
DOE-02	Culebra	2	08-27-86	336.00	6.20	22.6	1.0430 @ 22.7 C	77900	149.9	32183	187.9	0.21	0.19
H-04b	Culebra	2	11-13-86	126.00	7.60	19.8	1.0210 @ 18.2 C	27800	68.1	7522	72.3	1.22	0.49
P-17	Culebra	2	12-18-86	75.00	7.50	21.1	1.0630 @ 20.9 C	109000	60.9	48033	222.4	4.17	2.21
H-03b1	Magenta	2	09-16-86	-74.00	7.60	21.4	1.0060 @ 21.2 C	12050	45.0	3302	73	0.46	0.40
H-06c	Magenta	1	10-01-86	110.00	7.70	21.3	1.0030 @ 21.4 C	5440	50.5	418	41.1	0.38	0.29
H-05c	Magenta	1	10-24-86	-8.00	8.10	21.9	1.0080 @ 23.1 C	8760	57.3	1045	41.9	2.26	1.42
H-04c	Magenta	1	11-04-86	-47.00	8.30	20.7	1.0190 @ 21.2 C	31600	76.5	8361	69.2	1.85	1.12
Twin Wells Pasture	Dewey Lake	1	01-31-86	433.00	7.70	20.6	0.9980 @ 21.6 C	650	224.7	44	5.9	0.03	LD
Ranch Well	Dewey Lake	1	06-18-86	405.00	6.90	22.1	1.0020 @ 22.1 C	3913	217.3	397	37.8	0.12	0.06

NOTE: DEWEY LAKE WELLS WERE SERIALLY SAMPLED ROUND ONE ONLY.
ALKALINITY, CHLORIDE, DICATIONS, TOTAL IRON AND FERROUS IRON ARE AVG. VALUES

LAST DAY SAMPLING RESULTS FOR EACH WELL SAMPLED IN 1987

WELL	ZONE	ROUND	DATE SAMPLED	Eh (mv)	pH (S.U.)	TEMP (C)	SPECIFIC GRAVITY	SPECIFIC CONDUCTANCE (umhos)	ALKALINITY (mg/L)	CHLORIDES (mg/L)	DICATIONS (meq/L)	TOTAL IRON (mg/L)	FERROUS IRON (mg/L)
M-12	Culebra	2	01-16-87	70.00	7.50	17.8	1.1000 @ 18.5 C	157300	62.0	80000	260.0	2.44	1.54
M-09b	Culebra	2	01-28-87	250.00	7.30	22.1	1.0020 @ 21.9 C	3500	112.0	175	44.0	0.16	LD
M-08b	Culebra	2	02-11-87	220.00	7.20	21.9	1.0020 @ 21.7 C	3060	93.1	36	42.0	0.13	LD
WIPP-13	Culebra	1	02-16-87	280.00	6.70	NT	1.0480 @ 21.4 C	87700	124.0	36000	170.0	NT	NT
M-07b1	Culebra	2	02-25-87	250.00	7.40	21.6	1.0010 @ 20.2 C	3300	121.0	301	44.0	0.08	LD
WIPP-29	Culebra	2	03-11-87	200.00	6.20	20.0	1.1870 @ 21.4 C	223000	162.0	152500	523.5	0.93	0.32
WIPP-26	Culebra	2	04-01-87	320.00	7.00	21.2	1.0100 @ 21.0 C	27800	112.0	5750	85.0	0.06	LD
M-15	Culebra	1	05-11-87	140.00	6.90	20.9	1.1560 @ 22.2 C	300000	41.7	132000	287.0	2.99	2.84
M-14	Culebra	1	05-26-87	70.00	7.70	21.5	1.0120 @ 22.0 C	24000	40.3	8500	126.0	0.53	0.48
Mobely Well	Culebra	1	06-16-87	NT	7.50	25.2	NT	4300	135.5	463	43.5	NT	NT
P-14	Culebra	2	06-18-87	40.00	6.90	21.7	1.0200 @ 21.9 C	38000	103.0	14300	250.5	2.50	2.35
WIPP-19	Culebra	1	07-14-87	150.00	7.00	22.0	1.0720 @ 22.1 C	143500	84.0	62000	286.0	1.75	1.60
DOE-1	Culebra	3	07-28-87	130.00	7.20	23.7	1.0910 @ 23.2 C	148000	44.8	74000	214.0	0.87	0.76
M-02a	Culebra	2	08-12-87	60.00	7.80	22.5	1.0080 @ 22.4 C	15400	53.6	4400	50.0	0.42	0.34
M-03b3	Culebra	3	08-24-87	200.00	7.30	23.2	1.0370 @ 22.4 C	71000	50.8	28000	137.0	0.14	0.10
M-11b3	Culebra	3	09-15-87	70.00	7.30	23.5	1.0800 @ 23.2 C	130900	55.1	65000	185.0	0.43	0.27
M-04b	Culebra	3	09-25-87	100.00	7.60	21.7	1.0150 @ 20.9 C	27200	69.1	7400	70.0	0.60	0.42
P-17	Culebra	3	10-21-87	60.00	7.50	21.0	1.0620 @ 17.6 C	108000	63.1	49000	216.0	3.51	3.25
M-17	Culebra	3	10-27-87	NT	7.00	NT	1.1030 @ 21.3 C	165000	49.8	88500	223.5	0.98	0.78
M-18	Culebra	1	11-10-87	NT	7.60	NT	1.0180 @ 19.0 C	35000	53.4	11750	96.0	0.15	0.10
M-06b	Culebra	3	11-16-87	350.00	6.90	22.2	1.0404 @ 20.9 C	76500	94.0	32000	191.0	0.05	LD
Engle Well	Culebra	2	12-08-87	NT	7.20	NT	1.0020 @ 21.5 C	4330	74.5	237	43.7	NT	NT
Poker Trap	Culebra	1	12-19-87	NT	NT	NT	1.0010 @ 20.0 C	2490	92.2	29	30.4	NT	NT
M-03b1	Magenta	3	09-02-87	-93.00	7.70	23.8	1.0060 @ 23.4 C	12300	46.4	3300	73.0	0.13	0.09
M-04c	Magenta	2	10-05-87	-120.00	8.00	22.6	1.0180 @ 22.6 C	30800	84.6	8400	68.0	0.22	0.15
M-06c	Magenta	2	11-04-87	100.00	7.90	22.1	1.0020 @ 22.1 C	5300	51.9	420	41.0	0.19	0.14
Barn Well	Dewey Lake	1	11-04-87	NT	8.00	18.5	1.0010 @ 21.8 C	983	276.0	52	6.4	NT	NT
Fairview	Dewey Lake	1	11-16-87	NT	6.70	22.8	1.0020 @ 20.4 C	3545	78.9	121	41.6	NT	NT
Unger Well	Dewey Lake	2	11-18-87	NT	7.40	19.2	1.0010 @ 21.6 C	3320	129.0	274	44.9	NT	NT
Ranch Well	Dewey Lake	2	12-20-87	NT	7.50	NT	1.0010 @ 20.2 C	4410	39.8	470	39.1	NT	NT
Commanche	Dockum	1	10-26-87	NT	7.80	20.4	NT	544	228.0	25	3.1	NT	NT
Clifton	Dockum	1	10-28-87	NT	7.70	19.8	1.0020 @ 21.6 C	1510	167.0	52	2.8	NT	NT

NOTE: DEWEY LAKE AND DOCKUM WELLS WERE NOT SERIALLY SAMPLED. ALKALINITY, CHLORIDE, DICATIONS, TOTAL IRON AND FERROUS IRON ARE AVG. VALUES

LAST DAY SAMPLING RESULTS FOR EACH WELL SAMPLED IN 1988

WELL	ZONE	ROUND	DATE SAMPLED	Eh (mv)	PH (S.U.)	TEMP (C)	SPECIFIC GRAVITY	SPECIFIC CONDUCTANCE (umhos)	ALKALINITY (mg/l)	CHLORIDES (mg/l)	DICATIONS (meq/l)	TOTAL IRON (mg/l)	FERROUS IRON (mg/l)
H-15	Culebra	2	01-13-88	108.00	7.01	14.2	1.1526 @ 21.4 C	225000	41.3	133697	298.8	3.60	3.19
H-14	Culebra	2	01-27-88	192.00	7.62	20.8	1.0122 @ 19.7 C	27200	37.0	8510	129.5	0.16	0.09
WIPP-19	Culebra	2	02-12-88	112.00	7.17	21.1	1.0608 @ 21.1 C	113000	68.2	48797	240.8	1.31	1.10
H-05b	Culebra	3	02-24-88	112.00	7.25	19.1	1.1022 @ 19.3 C	172000	47.6	85634	258.7	2.15	1.94
WIPP-30	Culebra	1	03-04-88	NT	7.70	NT	1.0204 @ 19.1 C	NT	37.0	13271	95.9	2.19	1.60
P-14	Culebra	3	03-16-88	182.00	6.90	21.8	1.0200 @ 21.0 C	39500	107.0	14650	256.0	2.00	1.88
WIPP-25	Culebra	3	03-28-88	169.00	7.22	23.2	1.0104 @ 22.0 C	21400	124.7	6407	82.8	0.73	0.69
H-18	Culebra	2	04-07-88	NT	7.49	NT	1.0204 @ 20.2 C	38150	50.5	12962	101.4	0.28	0.25
USGS-1	Culebra	1	04-12-88	NT	7.80	NT	1.0030 @ 20.8 C	4850	107.0	672	41.3	NT	NT
Mobely Well	Culebra	2	04-14-88	NT	7.30	NT	1.0000 @ 25.2 C	4340	133.5	480	43.3	NT	NT
WIPP-26	Culebra	3	04-14-88	428.00	7.11	21.1	1.0092 @ 21.3 C	18500	113.9	5695	87.3	0.04	LD
H-07b1	Culebra	3	04-25-88	343.00	7.21	21.8	1.0015 @ 21.2 C	3680	122.5	293	40.4	0.07	0.04
DOE-2	Culebra	3	05-19-88	307.00	6.68	22.8	1.0442 @ 23.3 C	75500	130.8	31580	184.0	0.35	0.26
H-08b	Culebra	3	06-08-88	297.00	7.30	22.7	1.0014 @ 22.1 C	3000	97.0	39	40.6	0.05	LD
H-09b	Culebra	3	06-21-88	213.00	7.27	22.8	1.0022 @ 22.8 C	3400	117.6	172	41.3	0.12	0.08
USGS-1	Culebra	2	07-07-88	NT	7.50	NT	1.0060 @ 22.8 C	4800	102.5	730	41.1	NT	NT
Poker Trap	Culebra	2	07-07-88	NT	7.70	NT	1.0040 @ 22.7 C	2320	79.8	31	30.3	NT	NT
WIPP-19	Culebra	3	08-29-88	95.00	7.19	21.5	1.0610 @ 22.1 C	98000	60.9	44115	207.6	0.80	0.80
H-01	Culebra	1	10-07-88	42.00	7.79	21.5	1.0242 @ 22.4 C	38900	99.0	12142	83.9	3.22	2.77
AIS	Culebra	1	10-28-88	NT	7.80	NT	1.0370 @ 24.6 C	55100	108.5	19350	92.1	NT	NT
H-15	Culebra	3	11-07-88	131.00	6.86	23.3	1.1596 @ 23.4 C	198800	40.9	134550	281.9	2.88	2.47
H-12	Culebra	3	12-14-88	109.00	7.30	21.5	1.0880 @ 21.2 C	14700	51.1	80100	249.5	2.11	1.95
H-05c	Magenta	2	03-03-88	46.00	7.91	18.8	1.0078 @ 18.1 C	9220	57.2	1037	41.5	0.29	0.25
H-04c	Magenta	3	07-19-88	-63.00	8.08	21.0	1.0202 @ 21.9 C	30600	82.1	8304	68.5	0.18	0.11
H-06c	Magenta	3	07-26-88	111.00	7.84	21.4	1.0026 @ 21.3 C	5300	52.4	408	41.3	0.34	0.16
H-05c	Magenta	3	08-18-88	45.00	8.05	22.0	1.0082 @ 22.1 C	8450	57.5	1030	42.1	0.69	0.5?
Barn Well	Dewey Lake	2	4-20-88	NT	8.00	NT	1.0010 @ 25.1 C	1060	283.5	43	7.5	NT	NT
Ranch Well	Dewey Lake	3	04-20-88	NT	7.30	NT	1.0010 @ 25.1 C	4060	248.5	433	38.9	NT	NT
Unger Well	Dewey Lake	2	07-06-88	NT	7.30	NT	1.0040 @ 22.7 C	3390	134.0	282	41.1	NT	NT
Fairview	Dewey Lake	2	07-06-88	NT	6.70	NT	1.0040 @ 22.7 C	3450	115.5	121	41.7	NT	NT
Twin Well Pasture	Dewey Lake	2	08-03-88	NT	7.10	NT	1.0020 @ 24.9 C	600	215.5	399	39.8	NT	NT
Commanche	Dockum	2	06-28-88	NT	8.00	NT	1.0020 @ 22.8 C	568	227.5	27	3.5	NT	NT
Clifton	Dockum	2	06-29-88	NT	7.50	NT	1.0020 @ 22.9 C	1150	230.5	49	2.8	NT	NT

NOTE: DEWEY LAKE AND DOCKUM WELLS WERE NOT SERIALLY SAMPLED.
ALKALINITY, CHLORIDE, DICATIONS, TOTAL IRON AND FERROUS IRON ARE AVG. VALUES

DOE/WIPP 91-008

LAST DAY SAMPLING RESULTS FOR EACH WELL SAMPLED IN 1989

WELL	ZONE	ROUND	DATE SAMPLED	Eh (mv)	pH (S.U.)	TEMP (C)	SPECIFIC GRAVITY	SPECIFIC CONDUCTANCE (umhos)	ALKALINITY (mg/l)	CHLORIDES (mg/l)	DICATIONS (meq/l)	TOTAL IRON (mg/l)	FERROUS IRON (mg/l)
H-02a	Culebra	3	01-19-89	83.90	7.88	19.2	1.0142 @ 19.4 C	14100	56.9	4129	50.4	1.15	0.99
H-14	Culebra	3	02-14-89	270.00	7.76	20.5	1.0142 @ 20.5 C	24300	38.1	8502	132.9	0.44	0.37
H-03b3	Culebra	4	03-02-89	362.00	7.46	22.2	1.036 @ 22.2 C	68100	50.4	27639	139.1	0.15	0.13
H-04B	Culebra	4	04-06-89	194.00	7.81	21.5	1.0160 @ 21.4 C	24500	68.1	7403	72.5	0.48	0.43
H-07b1	Culebra	4	05-19-89	233.00	7.28	22.0	1.0030 @ 22.0 C	3640	117.8	290	40.6	0.14	0.09
WIPP-25	Culebra	4	06-27-89	188.00	7.28	22.4	1.0110 @ 22.7 C	22000	129.8	6933	89.3	0.72	0.63
H-06b	Culebra	4	07-24-89	284.00	7.01	22.2	1.0444 @ 22.3 C	75000	97.4	31615	188.6	0.44	0.38
H-05b	Culebra	4	08-23-89	182.00	7.35	22.3	1.1022 @ 23.0 C	153000	52.5	84385	258.5	3.06	2.88
WIPP-19	Culebra	4	10-18-89	168.00	7.28	21.2	1.0564 @ 20.9 C	92400	61.1	40440	187.2	1.71	1.49
H-11b3	Culebra	4	10-25-89	187.00	7.34	23.1	1.0804 @ 23.1 C	128900	58.5	63473	192.4	0.46	0.31
H-02c	Culebra	1	12-13-89	173.00	7.84	18.4	1.0202 @ 22.0 C	13500	58.3	3836	52.4	0.79	0.57
H-03b1	Magenta	4	03-16-89	24.00	7.93	22.4	1.0085 @ 21.4 C	12204	46.6	3299	73.9	0.03	LD
H-04c	Magenta	4	04-21-89	-63.00	7.95	19.8	1.0200 @ 26.8 C	30400	79.7	8407	68.9	0.2	0.14
H-06c	Magenta	4	08-04-89	209.00	7.81	22.7	1.0046 @ 22.6 C	5230	52.5	404	40.6	0.31	0.21
H-05c	Magenta	4	09-14-89	206.00	7.95	22.0	1.0080 @ 22.1 C	8460	57.2	1023	42.8	0.21	0.18
Barn Well	Dewey Lake	3	07-13-89	NT	7.71	22.4	1.008 @ 27.8 C	1113	283.4	46.8	6.5	NT	NT
Ranch Well	Dewey Lake	4	07-12-89	NT	7.42	21.2	1.0018 @ 27.8 C	3550	250.8	328	31.8	NT	NT
Twin Wells Pasture	Dewey Lake	3	09-28-89	NT	7.71	NT	1.0016 @ 23.6 C	612	221.0	38.5	4.1	NT	NT

NOTE: DEWEY LAKE WELLS WERE NOT SERIALLY SAMPLED.
ALKALINITY, CHLORIDE, DICATIONS, TOTAL IRON AND FERROUS IRON ARE AVG. VALUES

LAST DAY SAMPLING RESULTS FOR EACH WELL
SAMPLED IN 1990

WELL	ZONE	ROUND	DATE SAMPLED	Eh (mv)	pH (S.U.)	TEMP (C)	SPECIFIC GRAVITY	SPECIFIC CONDUCTANCE (umhos)	ALKALINITY (mg/l)	CHLORIDES (mg/l)	DICATIONS (meq/l)	TOTAL IRON (mg/l)	FERROUS IRON (mg/l)
H-09b	Culebra	4	01-19-90	197.00	7.36	21.0	1.0040 @ 21.1 C	3430	116.2	169	43.0	0.09	0.05
Engle	Culebra	3	01-31-90	NT	7.46	NT	1.0033 @ 20.2 C	2990	79.0	232	42.7	NT	NT
H-06b	Culebra	5	02-12-90	213.00	7.04	21.5	1.0448 @ 21.5 C	75300	95.4	32218	196.5	0.36	0.29
H-18	Culebra	3	04-10-90	233.00	7.72	21.5	1.0200 @ 21.5 C	39300	51.6	13966	100.7	0.38	0.33
H-05b	Culebra	5	05-02-90	144.00	7.29	20.3	1.1040 @ 20.2 C	155900	50.9	86330	262.8	2.76	2.44
WIPP-19	Culebra	5	06-12-90	204.00	7.31	23.1	1.0546 @ 23.2 C	91800	59.4	40508	178.9	0.83	0.72
H-02c	Culebra	2	07-24-90	245.00	7.72	22.2	1.0100 @ 22.3 C	12510	60.9	2999	48.7	1.19	1.07
H-03b3	Culebra	5	08-15-90	175.00	7.45	22.2	1.0400 @ 22.4 C	69300	50.5	27695	137.9	0.24	0.19
H-04b	Culebra	5	09-12-90	114.00	7.76	22.1	1.0164 @ 21.5 C	26400	69.1	7577	71.4	1.01	0.89
H-11b3	Culebra	5	10-17-90	119.00	7.38	21.8	1.0804 @ 21.3 C	133800	54.1	65451	185.2	0.47	0.38
H-07b1	Culebra	5	11-08-90	335.00	7.34	20.8	1.0026 @ 20.8 C	3620	112.8	276	47.6	0.21	0.17
H-06c	Magenta	5	03-15-90	224.00	7.83	21.2	1.0034 @ 21.2	5200	51.0	404	41.5	0.10	0.07
H-05c	Magenta	5	05-16-90	-4.00	7.95	21.8	1.0062 @ 21.8 C	8480	59.2	1028	42.6	0.18	0.10
H-03b1	Magenta	5	08-28-90	-5.00	7.75	23.6	1.0080 @ 23.2 C	12200	45.9	3458	73.7	LD	LD
H-04c	Magenta	5	10-02-90	-61.00	8.01	20.6	1.0202 @ 20.4 C	30900	80.9	8493	70.1	0.17	0.10
Twin Well	Dewey Lake	4	06-01-90	NT	7.70	NT	1.0028 @ 23.2 C	614	218.9	56	5.5	NT	NT
Pasture Ranch Well	Dewey Lake	5	06-20-90	NT	7.24	NT	1.0014 @ 23.7 C	3020	247.7	358	38.5	NT	NT
Barn Well	Dewey Lake	4	06-21-90	NT	7.58	NT	1.0008 @ 25.2 C	1070	284.1	56	5.0	NT	NT

NOTE: DEWEY LAKE WELLS WERE NOT SERIALLY SAMPLED.
ALKALINITY, CHLORIDE, DICATIONS, TOTAL IRON AND FERROUS IRON ARE AVG. VALUES

APPENDIX VI

TABULATED RESULTS

OF

CONTRACT LABORATORY ANALYSIS

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CONTRACT LABORATORY ANALYSIS

H-09b, CULEBRA, ROUND 4

GENERAL CHEMISTRY

PARAMETER	V	VALUE	S	D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
pH		7.4100			7.4200				01-19-90
Specific Conductance		3590.0000			3590.0000			uMhos/cm@25C	01-19-90
Alkalinity (HCO3)		120.0000			0.0000			mg/l	01-19-90
Bromide	<	2.0000		<	2.0000			mg/l	01-19-90
Chloride		160.0000			160.0000			mg/l	01-19-90
Alkalinity (CO3)		0.0000		NA	0.0000			mg/l	01-19-90
Cyanide	<	0.0100		NA	0.0000			mg/l	01-19-90
Fluoride		3.5000		NA	0.0000			mg/l	01-19-90
Iodide	<	2.0000		<	2.0000			mg/l	01-19-90
Nitrate		0.1100			0.1100			mg/l	01-19-90
Total Phenolics		0.0060		NA	0.0000			mg/l	01-19-90
Phosphorus	<	0.0100		<	0.0100			mg/l	01-19-90
Residue, Filterable @ 180 c		3300.0000			3300.0000			mg/l	01-19-90
Residue, Nonfilterable @ 105 c	<	4.0000		<	4.0000			mg/l	01-19-90
Silica		12.0000			12.0000			mg/l	01-19-90
Sulfate		1800.0000			1900.0000			mg/l	01-19-90
Total Organic Carbon		1.0000		<	1.0000			mg/l	01-19-90
Total Organic Halides	<	0.0500		<	0.0500			mg/l	01-19-90

CONTRACT LABORATORY ANALYSIS

H-09b, CULEBRA, ROUND 4

METALS ANALYSIS

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Calcium		650.0000		580.0000			mg/l	01-19-90
Magnesium		160.0000		130.0000			mg/l	01-19-90
Potassium		8.3000		8.2000			mg/l	01-19-90
Sodium		100.0000		100.0000			mg/l	01-19-90
Aluminum	<	0.2000	<	0.2000	< .2	< .2	mg/l	01-19-90
Antimony		0.0900		0.1200	< .06	< .06	mg/l	01-19-90
Arsenic	<	0.0100	NA	0.0000	< .01	< .01	mg/l	01-19-90
Barium	<	0.2000	<	0.2000	< .2	< .2	mg/l	01-19-90
Beryllium	<	0.0050	<	0.0500	< .005	< .005	mg/l	01-19-90
Boron		0.6000		0.5300	< .02	< .02	mg/l	01-19-90
Cadmium		0.0090		0.0140	< .005	< .005	mg/l	01-19-90
Cesium	<	0.2000	<	0.2000	< .2	< .2	mg/l	01-19-90
Chromium		0.0200		0.0400	< .01	< .01	mg/l	01-19-90
Cobalt	<	0.0500	<	0.0500	< .05	< .05	mg/l	01-19-90
Copper	<	0.0250	<	0.0250	< .025	< .025	mg/l	01-19-90
Iron	<	0.1000	<	0.1000	< .1	< .1	mg/l	01-19-90
Lead		0.0600		0.1100	< .05	< .05	mg/l	01-19-90
Lithium		0.2000		0.2000	< .01	< .01	mg/l	01-19-90
Manganese		0.2100		0.0330	< .015	< .015	mg/l	01-19-90
Mercury	<	0.0002	<	0.0002	< .0002	< .0002	mg/l	01-19-90
Molybdenum		0.0500		0.0500	< .02	< .02	mg/l	01-19-90
Nickel	<	0.0400	<	0.0400	< .04	< .04	mg/l	01-19-90
Selenium	<	0.0500	NA	0.0000	< .005	< .005	mg/l	01-19-90
Silver		0.0200		0.0300	< .01	< .01	mg/l	01-19-90
Strontium		7.5000		6.4000	< .01	< .01	mg/l	01-19-90
Thallium	<	10.0000	NA	0.0000	< .01	< .01	mg/l	01-19-90
Titanium		0.0100	<	0.0100	< .01	< .01	mg/l	01-19-90
Vanadium	<	0.0500	<	0.0500	< .05	< .05	mg/l	01-19-90
Zinc	<	0.0200	<	0.0200	< .02	< .02	mg/l	01-19-90

CONTRACT LABORATORY ANALYSIS

H-09b, CULEBRA, ROUND 4

VOLATILE HAZARDOUS SUBSTANCES

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Chloromethane	<	10.0000	NA	0.0000	< 10 T	< 10 M	ug/l	01-19-90
Bromomethane	<	10.0000	NA	0.0000	< 10 T	< 10 M	ug/l	01-19-90
Vinyl chloride	<	10.0000	NA	0.0000	< 10 T	< 10 M	ug/l	01-19-90
Chloroethane	<	10.0000	NA	0.0000	< 10 T	< 10 M	ug/l	01-19-90
Methylene chloride	<	6.0000	NA	0.0000	15 T	< 5 M	ug/l	01-19-90
Acetone	<	10.0000	NA	0.0000	< 10 T	< 10 M	ug/l	01-19-90
Carbon disulfide	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
1,1-Dichloroethene	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
1,1-Dichloroethane	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
1,2-Dichloroethene	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
Chloroform	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
1,2-Dichloroethane	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
2-Butanone	<	10.0000	NA	0.0000	< 10 T	< 10 M	ug/l	01-19-90
1,1,1-Trichloroethane	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
Carbon tetrachloride	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
Vinyl acetate	<	10.0000	NA	0.0000	< 10 T	< 10 M	ug/l	01-19-90
Bromodichloromethane	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
FREON 113	<	50.0000	NA	0.0000	< 50 T	< 50 M	ug/l	01-19-90
1,2-Dichloropropane	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
cis-1,3-Dichloropropene	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
Trichloroethene	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
Dibromochloromethane	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90

T" IN ACID BLANK COLUMN INDICATES TRIP BLANK

M" IN WATER BLANK COLUMN INDICATES METHOD BLANK

1,1,2-TRICHLORO-1,2,2-TRIFLUORETHANE IS FREON 113

CONTRACT LABORATORY ANALYSIS

H-09b, CULEBRA, ROUND 4

VOLATILE HAZARDOUS SUBSTANCES

(CONTINUED)

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
1,1,2-Trichloroethane	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
Benzene	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
trans-1,3-Dichloropropene	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
Bromoform	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
4-Methyl-2-pentanone	<	10.0000	NA	0.0000	< 10 T	< 10 M	ug/l	01-19-90
2-Hexanone	<	10.0000	NA	0.0000	< 10 T	< 10 M	ug/l	01-19-90
Tetrachloroethene	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
1,1,2,2-Tetrachloroethane	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
Toluene	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
Chlorobenzene	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
Ethylbenzene	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
Styrene	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90
Xylene (total)	<	5.0000	NA	0.0000	< 5 T	< 5 M	ug/l	01-19-90

"T" IN ACID BLANK COLUMN INDICATES TRIP BLANK

"M" IN WATER BLANK COLUMN INDICATES METHOD BLANK

CONTRACT LABORATORY ANALYSIS

H-09b, CULEBRA, ROUND 4

SEMIVOLATILE HAZARDOUS SUBSTANCES

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Phenol	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
bis(2-Chloroethyl)ether	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
2-Chlorophenol	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
1-3-Dichlorobenzene		20.0000	NA	0.0000		13 M	ug/l	01-19-90
1-4-Dichlorobenzene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Benzyl alcohol	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
1,2-Dichlorobenzene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
2-Methylphenol	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
bis(2-Chlorisopropyl)ether	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
4-Methylphenol	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
N-Nitroso-di-n-propylamine	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Hexachloroethane	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Nitrobenzene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Isophorone	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
2-Nitrophenol	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
2,4-Dimethylphenol	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Benzoic acid	<	50.0000	NA	0.0000		< 50 M	ug/l	01-19-90
bis(2-Chloroethoxy)methane	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
2,4-Dichlorophenol	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
1,2,4-Trichlorobenzene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Naphthalene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
4-Chloroaniline	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Hexachlorobutadiene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
4-Chloro-3-methylphenol	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
2-Methylnaphthalene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Hexachlorocyclopentadiene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
2,4,6-Trichlorophenol	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
2,4,5-Trichlorophenol	<	50.0000	NA	0.0000		< 50 M	ug/l	01-19-90

T" IN ACID BLANK COLUMN INDICATES TRIP BLANK

H" IN WATER BLANK COLUMN INDICATES METHOD BLANK

CONTRACT LABORATORY ANALYSIS

H-09b, CULEBRA, ROUND 4

SEMIVOLATILE HAZARDOUS SUBSTANCES

(CONTINUED)

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
2-Chloronaphthalene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
2-Nitroaniline	<	50.0000	NA	0.0000		< 50 M	ug/l	01-19-90
Dimethylphthalate	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Acenaphthylene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
2,6-Dinitrotoluene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
3-Nitroaniline	<	50.0000	NA	0.0000		< 50 M	ug/l	01-19-90
Acenaphthene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
2,4-Dinitrophenol	<	50.0000	NA	0.0000		< 50 M	ug/l	01-19-90
4-Nitrophenol	<	50.0000	NA	0.0000		< 50 M	ug/l	01-19-90
Dibenzofuran	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
2,4-Dinitrotoluene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Diethylphthalate	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
4-Chlorophenyl-phenylether	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Fluorene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
4-Nitroaniline	<	50.0000	NA	0.0000		< 50 M	ug/l	01-19-90
4,6-Dinitro-2-methylphenol	<	50.0000	NA	0.0000		< 50 M	ug/l	01-19-90
N-Nitrosodiphenylamine	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
4-Bromophenyl-phenylether	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Hexachlorobenzene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Pentachlorophenol	<	50.0000	NA	0.0000		< 50 M	ug/l	01-19-90
Phenanthrene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Anthracene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Di-n-butylphthalate	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Fluoranthene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Pyrene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Butylbenzylphthalate	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
3,3'-Dichlorobenzidine	<	20.0000	NA	0.0000		< 20 M	ug/l	01-19-90
Benzo(a)anthracene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90

T" IN ACID BLANK COLUMN INDICATES TRIP BLANK

M" IN WATER BLANK COLUMN INDICATES METHOD BLANK

CONTRACT LABORATORY ANALYSIS

H-09b, CULEBRA, ROUND 4

SEMIVOLATILE HAZARDOUS SUBSTANCES

(CONTINUED)

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Chrysene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
bis(2-Ethylhexyl)phthalate	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Di-n-octylphthalate	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Benzo(b)fluoranthene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Benzo(k)fluoranthene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Benzo(a)pyrene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Indeno(1,2,3-cd)pyrene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Dibenzo(a,h,)anthracene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90
Benzo(g,h,i)perylene	<	10.0000	NA	0.0000		< 10 M	ug/l	01-19-90

T" IN ACID BLANK COLUMN INDICATES TRIP BLANK

M" IN WATER BLANK COLUMN INDICATES METHOD BLANK

CONTRACT LABORATORY ANALYSIS

H-09b, CULEBRA, ROUND 4

POLYCHLORINATED BIPHENYLS

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Aroclor 1016	<	0.5000	NA	0.0000		< .5 M	ug/l	01-19-90
Aroclor 1221	<	0.5000	NA	0.0000		< .5 M	ug/l	01-19-90
Aroclor 1232	<	0.5000	NA	0.0000		< .5 M	ug/l	01-19-90
Aroclor 1242	<	0.5000	NA	0.0000		< .5 M	ug/l	01-19-90
Aroclor 1248	<	0.5000	NA	0.0000		< .5 M	ug/l	01-19-90
Aroclor 1254	<	1.0000	NA	0.0000		<1.0 M	ug/l	01-19-90
Aroclor 1260	<	1.0000	NA	0.0000		<1.0 M	ug/l	01-19-90

T= IN ACID BLANK COLUMN INDICATES TRIP BLANK

M= IN WATER BLANK COLUMN INDICATES METHOD BLANK

CONTRACT LABORATORY ANALYSIS

ENGLE WELL, CULEBRA, ROUND 3

GENERAL CHEMISTRY

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK WATERBL/NK	UNITS	DATE
pH		7.1000		7.1100			01-31-90
Specific Conductance		4060.0000		4060.0000		uMhos/cm@25C	01-31-90
Alkalinity (HCO3)		110.0000		110.0000		mg/l	01-31-90
Bromide	<	2.0000	<	2.0000		mg/l	01-31-90
Calcium Hardness		1500.0000		1500.0000		mg/l	01-31-90
Total Hardness		2200.0000	NA	0.0000		mg/l	01-31-90
Chloride		190.0000	NA	0.0000		mg/l	01-31-90
Alkalinity (CO3)		0.0000	NA	0.0000		mg/l	01-31-90
Cyanide	<	0.0100	NA	0.0000		mg/l	01-31-90
Fluoride		2.8000	NA	0.0000		mg/l	01-31-90
Iodide	<	2.0000	<	2.0000		mg/l	01-31-90
Nitrate		0.1100		0.1200		mg/l	01-31-90
Total Phenolics		0.0060		0.0000		mg/l	01-31-90
Phosphorus	<	0.0100	NA	0.0000		mg/l	01-31-90
Residue, Filterable @ 180 c		3600.0000		3600.0000		mg/l	01-31-90
Residue, Nonfilterable @ 105 c	<	4.0000	<	4.0000		mg/l	01-31-90
Silica		12.0000		12.0000		mg/l	01-31-90
Sulfate		1900.0000		2000.0000		mg/l	01-31-90
Total Organic Carbon	<	1.0000	<	1.0000		mg/l	01-31-90
Total Organic Halides	<	0.0500	<	0.0500		mg/l	01-31-90

CONTRACT LABORATORY ANALYSIS

ENGLE WELL, CULEBRA, ROUND 3

METALS ANALYSIS

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Calcium		610.0000		610.0000	< 0.1	< 0.1	mg/l	01-31-90
Magnesium		150.0000		150.0000	< 0.1	< 0.1	mg/l	01-31-90
Potassium		7.6000		7.5000	< 0.1	< 0.1	mg/l	01-31-90
Sodium		220.0000		220.0000	< 0.1	< 0.1	mg/l	01-31-90
Aluminum		0.2000		0.2000	< 0.1	< 0.1	mg/l	01-31-90
Antimony		0.1200		0.1000	< .05	< .05	mg/l	01-31-90
Arsenic	<	0.0020	NA	0.0000	< .002	< .002	mg/l	01-31-90
Barium	<	0.0500	<	0.0500	< .005	< .005	mg/l	01-31-90
Beryllium	<	0.0050	<	0.0050	< .005	< .005	mg/l	01-31-90
Boron		1.2000		1.3000	< 0.02	< 0.02	mg/l	01-31-90
Cadmium		0.0130		0.0110	< .005	< .005	mg/l	01-31-90
Cesium	<	0.2000	<	0.2000	< 0.2	< 0.2	mg/l	01-31-90
Chromium		0.0600		0.0600	< .02	< .01	mg/l	01-31-90
Cobalt		0.0200		0.0200	< .01	< .01	mg/l	01-31-90
Copper	<	0.1000	<	0.1000	< .01	< .01	mg/l	01-31-90
Iron	<	0.0300	<	0.0300	< .03	< .03	mg/l	01-31-90
Lead		0.0900		0.0800	< .05	< .05	mg/l	01-31-90
Lithium		0.1600		0.1600	< .01	< .01	mg/l	01-31-90
Manganese		0.0390		0.0360	< .005	< .005	mg/l	01-31-90
Mercury	<	0.0002	<	0.0002	< .0002	< .0002	mg/l	01-31-90
Molybdenum		0.0500		0.0500	< .02	< .02	mg/l	01-31-90
Nickel		0.0300	<	0.0300	< .03	< .03	mg/l	01-31-90
Selenium	<	0.2000	NA	0.0000	< .002	< .002	mg/l	01-31-90
Silver		0.0200		0.0200	< .01	< .01	mg/l	01-31-90
Strontium		7.9000		8.0000	< .01	< .01	mg/l	01-31-90
Thallium	<	0.0100	NA	0.0000	< .001	< .001	mg/l	01-31-90
Titanium	<	0.0100	<	0.0100	< .01	< .01	mg/l	01-31-90
Vanadium		0.0400		0.0400	< .01	< .01	mg/l	01-31-90
Zinc		2.2000		2.2000	< .02	< .02	mg/l	01-31-90

CONTRACT LABORATORY ANALYSIS

ENGLE WELL, CULEBRA, ROUND 3

VOLATILE HAZARDOUS SUBSTANCES

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Chloromethane	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	01-31-90
Bromomethane	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	01-31-90
Vinyl chloride	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	01-31-90
Chloroethane	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	01-31-90
Methylene chloride	<	5.0000	NA	0.0000	T 6	M 6	ug/l	01-31-90
Acetone	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	01-31-90
Carbon disulfide	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
1,1-Dichloroethene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
1,1-Dichloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
1,2-Dichloroethene(Total)	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
Chloroform	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
1,2-Dichloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
2-Butanone	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	01-31-90
1,1,1-Trichloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
Carbon tetrachloride	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
Vinyl acetate	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	01-31-90
Bromodichloromethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
Freon-113	<	50.0000	NA	0.0000	T< 50	M< 50	ug/l	01-31-90
1,2-Dichloropropane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
cis-1,3-Dichloropropene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
Trichloroethene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
Dibromochloromethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
1,1,2-Trichloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
Benzene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
trans-1,3-Dichloropropene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
Bromoform	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
4-Methyl-2-pentanone	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	01-31-90
2-Hexanone	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	01-31-90
Tetrachloroethene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90

CONTRACT LABORATORY ANALYSIS

ENGLE WELL, CULEBRA, ROUND 3

VOLATILE HAZARDOUS SUBSTANCES

(CONTINUED)

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
1,1,2,2-Tetrachloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
Toluene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
Chlorobenzene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
Ethylbenzene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
Styrene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90
Xylene (total)	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	01-31-90

NOTE: "T" IN ASCID BLANK COLUMN INDICATES TRIP BLANK

"M" IN WATERBLANK COLUMN INDICATES METHOD BLANK

Freon-133 is 1,1,2-Trichloro-1,2,2-Trifluoroethane

CONTRACT LABORATORY ANALYSIS

ENGLE WELL, CULEBRA, ROUND 3

SEMIVOLATILE HAZARDOUS SUBSTANCES

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Phenol	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
bis(2-Chloroethyl)ether	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
2-Chlorophenol	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
1-3-Dichlorobenzene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
1-4-Dichlorobenzene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Benzyl alcohol	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
1,2-Dichlorobenzene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
2-Methylphenol	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
bis(2-Chlorisopropyl)ether	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
4-Methylphenol	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
N-Nitroso-di-n-propylamine	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Hexachloroethane	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Nitrobenzene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Isophorone	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
2-Nitrophenol	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
2,4-Dimethylphenol	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Benzoic acid	<	50.0000	NA	0.0000		M< 50	ug/l	01-31-90
bis(2-Chloroethoxy)methane	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
2,4-Dichlorophenol	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
1,2,4-Trichlorobenzene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Naphthalene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
4-Chloroaniline	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Hexachlorobutadiene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
4-Chloro-3-methylphenol	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
2-Methylnaphthalene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Hexachlorocyclopentadiene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
2,4,6-Trichlorophenol	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
2,4,5-Trichlorophenol	<	50.0000	NA	0.0000		M< 50	ug/l	01-31-90

CONTRACT LABORATORY ANALYSIS

ENGLE WELL, CULEBRA, ROUND 3

SEMIVOLATILE HAZARDOUS SUBSTANCES

(CONTINUED)

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
2-Chloronaphthalene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
2-Nitroaniline	<	50.0000	NA	0.0000		M< 50	ug/l	01-31-90
Dimethylphthalate	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Acenaphthylene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
2,6-Dinitrotoluene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
3-Nitroaniline	<	50.0000	NA	0.0000		M< 50	ug/l	01-31-90
Acenaphthene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
2,4-Dinitrophenol	<	50.0000	NA	0.0000		M< 50	ug/l	01-31-90
4-Nitrophenol	<	50.0000	NA	0.0000		M< 50	ug/l	01-31-90
Dibenzofuran	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
2,4-Dinitrotoluene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Diethylphthalate	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
4-Chlorophenyl-phenylether	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Fluorene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
4-Nitroaniline	<	50.0000	NA	0.0000		M< 50	ug/l	01-31-90
4,6-Dinitro-2-methylphenol	<	50.0000	NA	0.0000		M< 50	ug/l	01-31-90
N-Nitrosodiphenylamine	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
4-Bromophenyl-phenylether	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Hexachlorobenzene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Pentachlorophenol	<	50.0000	NA	0.0000		M< 50	ug/l	01-31-90
Phenanthrene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Anthracene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Di-n-butylphthalate	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Fluoranthene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Pyrene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Butylbenzylphthalate	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
3,3'-Dichlorobenzidine	<	20.0000	NA	0.0000		M< 20	ug/l	01-31-90
Benzo(a)anthracene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90

CONTRACT LABORATORY ANALYSIS

ENGLE WELL, CULEBRA, ROUND 3

SEMIVOLATILE HAZARDOUS SUBSTANCES

(CONTINUED)

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Chrysene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
bis(2-Ethylhexyl)phthalate	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Di-n-octylphthalate	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Benzo(b)fluoranthene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Benzo(k)fluoranthene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Benzo(a)pyrene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Indeno(1,2,3-cd)pyrene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Dibenzo(a,h,)anthracene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90
Benzo(g,h,i)perylene	<	10.0000	NA	0.0000		M< 10	ug/l	01-31-90

NOTE: "T" IN ASCID BLANK COLUMN INDICATES TRIP BLANK

"M" IN WATERBLANK COLUMN INDICATES METHOD BLANK

CONTRACT LABORATORY ANALYSIS

ENGLE WELL, CULEBRA, ROUND 3

PESTICIDE ANALYSIS

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Lindane	<	0.0500	NA	0.0000		M< .05	ug/l	01-31-90
Endrin	<	0.1000	NA	0.0000		M< .10	ug/l	01-31-90
Methoxychlor	<	0.5000	NA	0.0000		M< .50	ug/l	01-31-90
Toxaphene	<	1.0000	NA	0.0000		M< 1.0	ug/l	01-31-90
2,4-D	<	12.0000	NA	0.0000		M< 12	ug/l	01-31-90
2,4,5-TP(Silvex)	<	1.7000	NA	0.0000		M< 1.7	ug/l	01-31-90

NOTE: "T" IN ASCID BLANK COLUMN INDICATES TRIP

"M" IN WATERBLANK COLUMN INDICATES METHO

CONTRACT LABORATORY ANALYSIS

H-06b, CULEBRA, ROUND 5

GENERAL CHEMISTRY

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
pH		6.9000		6.9000				02-12-90
Specific Conductance		77600.0000		77800.0000			uMhos/cm@25C	02-12-90
Alkalinity (HCO3)		93.0000	NA	0.0000			mg/l	02-12-90
Bromide	<	23.0000		22.0000			mg/l	02-12-90
Chloride		28000.0000	NA	0.0000			mg/l	02-12-90
Alkalinity (CO3)		0.0000	NA	0.0000			mg/l	02-12-90
Cyanide	<	0.0100	NA	0.0000			mg/l	02-12-90
Fluoride		1.4000		1.4000			mg/l	02-12-90
Iodide	<	2.0000	<	2.0000			mg/l	02-12-90
Nitrate		0.0800	NA	0.0000			mg/l	02-12-90
Total Phenolics		0.5500	NA	0.0000			mg/l	02-12-90
Total Phosphorus	<	0.0100	NA	0.0000			mg/l	02-12-90
Residue, Filterable @ 180 c		66000.0000		66000.0000			mg/l	02-12-90
Residue, Nonfilterable @ 105 c	<	8.0000		7.0000			mg/l	02-12-90
Silica		8.3000		8.3000			mg/l	02-12-90
Sulfate		3400.0000		3400.0000			mg/l	02-12-90
Total Organic Carbon		7.0000		7.0000			mg/l	02-12-90
Total Organic Halides		0.1800		0.1400			mg/l	02-12-90

CONTRACT LABORATORY ANALYSIS

H-06b, CULEBRA, ROUND 5,

METALS ANALYSIS

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Calcium		2100.0000		2100.0000			mg/l	02-12-90
Magnesium		1000.0000		1000.0000			mg/l	02-12-90
Potassium		600.0000		500.0000			mg/l	02-12-90
Sodium		15000.0000		15500.0000			mg/l	02-12-90
Aluminum	<	2.0000	<	2.0000			mg/l	02-12-90
Antimony	<	0 6000	<	0.6000			mg/l	02-12-90
Arsenic	<	0.0100	NA	0.0000			mg/l	02-12-90
Barium	<	2.0000	<	2.0000			mg/l	02-12-90
Beryllium	<	0.0500	<	0.0500			mg/l	02-12-90
Boron		9.8000		9.7000			mg/l	02-12-90
Cadmium	<	0.0500	<	0.0500			mg/l	02-12-90
Cesium	<	0.1000	<	0.1000			mg/l	02-12-90
Chromium		0.2000		0.3000			mg/l	02-12-90
Cobalt		0.5000	<	0.5000			mg/l	02-12-90
Copper	<	0.2500	<	0.2500			mg/l	02-12-90
Iron	<	1.0000	<	1.0000			mg/l	02-12-90
Lead	<	0.5000	<	0.5000			mg/l	02-12-90
Lithium		0.5000		0.5000			mg/l	02-12-90
Manganese		0.2500		0.2600			mg/l	02-12-90
Mercury	<	0.0002	<	0.0002			mg/l	02-12-90
Molybdenum	<	0.2000	<	0.2000			mg/l	02-12-90
Nickel	<	0.4000	<	0.4000			mg/l	02-12-90
Selenium	<	0.5000	NA	0.0000			mg/l	02-12-90
Silver	<	0.1000		0.1000			mg/l	02-12-90
Strontium		30.0000		30.0000			mg/l	02-12-90
Thallium	<	10.0000	NA	0.0000			mg/l	02-12-90
Titanium	<	0.1000	<	0.1000			mg/l	02-12-90
Vanadium	<	0.5000	<	0.5000			mg/l	02-12-90
Zinc	<	0.2000	<	0.2000			mg/l	02-12-90

CONTRACT LABORATORY ANALYSIS

H-06b, CULEBRA, ROUND 5

VOLATILE HAZARDOUS SUBSTANCES

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Chloromethane	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	02-12-90
Bromomethane	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	02-12-90
Vinyl chloride	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	02-12-90
Chloroethane	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	02-12-90
Methylene chloride	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
Acetone	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	02-12-90
Carbon disulfide	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
1,1-Dichloroethene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
1,1-Dichloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
1,2-Dichloroethene(Total)	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
Chloroform	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
1,2-Dichloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
2-Butanone	<	10.0000	NA	0.0000	T< 10	16	ug/l	02-12-90
1,1,1-Trichloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
Carbon tetrachloride	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
Vinyl acetate	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	02-12-90
Bromodichloromethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
Freon-113	<	50.0000	NA	0.0000	T< 50	M< 50	ug/l	02-12-90
1,2-Dichloropropane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
cis-1,3-Dichloropropene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
Trichloroethene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
Dibromochloromethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90

CONTRACT LABORATORY ANALYSIS

H-06b, CULEBRA, ROUND 5

VOLATILE HAZARDOUS SUBSTANCES

(CONTINUED)

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
1,1,2-Trichloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
Benzene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
trans-1,3-Dichloropropene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
Bromoform	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
4-Methyl-2-pentanone	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	02-12-90
2-Hexanone	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	02-12-90
Tetrachloroethene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
1,1,2,2-Tetrachloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
Toluene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
Chlorobenzene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
Ethylbenzene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
Styrene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90
Xylene (total)	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	02-12-90

NOTE: "T" IN ASCID BLANK COLUMN INDICATES TRIP

"M" IN WATERBLANK COLUMN INDICATES METHO

Freon-133 is 1,1,2-Trichloro-1,2,2-Trifluoroethane

CONTRACT LABORATORY ANALYSIS

H-06c, MAGENTA, ROUND 5

GENERAL CHEMISTRY

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
pH		7.4500		7.4600				03-15-90
Specific Conductance		6600.0000		6600.0000			uMhos/cm@25C	03-15-90
Alkalinity (HCO3)		51.0000		54.0000			mg/l	03-15-90
Bromide	<	2.0000	<	2.0000			mg/l	03-15-90
Calcium Hardness		0.0000		0 0000			mg/l	03-15-90
Total Hardness		0.0000	NA	0.0000			mg/l	03-15-90
Chloride		390.0000	NA	0.0000			mg/l	03-15-90
Alkalinity (CO3)		0.0000	NA	0.0000			mg/l	03-15-90
Cyanide	<	0.0100	<	0.0200			mg/l	03-15-90
Fluoride		1.9000		1.9000			mg/l	03-15-90
Iodide	<	2.0000	<	2.0000			mg/l	03-15-90
Nitrate	<	0.0200	<	0.0200			mg/l	03-15-90
Total Phenolics	<	0.0050		0.0000			mg/l	03-15-90
Phosphorus	<	0.0100	NA	0.0000			mg/l	03-15-90
Residue, Filterable @ 180 c		4800.0000		4800.0000			mg/l	03-15-90
Residue, Nonfilterable @ 105 c		10.0000		7.0000			mg/l	03-15-90
Silica		5.1000		5.1000			mg/l	03-15-90
Sulfate		2600.0000		2500.0000			mg/l	03-15-90
Total Organic Carbon		1.0000		1.0000			mg/l	03-15-90
Total Organic Halides	<	0.0500	<	0.0500			mg/l	03-15-90

CONTRACT LABORATORY ANALYSIS

H-06c, MAGENTA, ROUND 5

METALS ANALYSIS

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Calcium		570.0000		570.0000			mg/l	03-15-90
Magnesium		170.0000		170.0000			mg/l	03-15-90
Potassium		20.0000		20.0000			mg/l	03-15-90
Sodium		570.0000		590.0000			mg/l	03-15-90
Aluminum	<	2.0000	<	2.0000			mg/l	03-15-90
Antimony	<	0.6000	<	0.6000			mg/l	03-15-90
Arsenic	<	0.0100	NA	0.0000			mg/l	03-15-90
Barium	<	2.0000	<	2.0000			mg/l	03-15-90
Beryllium	<	0.0500	<	0.0500			mg/l	03-15-90
Boron		2.3000		2.4000			mg/l	03-15-90
Cadmium	<	0.0500	<	0.0500			mg/l	03-15-90
Cesium	<	0.2000	<	0.2000			mg/l	03-15-90
Chromium	<	0.1000	<	0.1000			mg/l	03-15-90
Cobalt	<	0.5000	<	0.5000			mg/l	03-15-90
Copper	<	0.2500	<	0.2500			mg/l	03-15-90
Iron	<	1.0000	<	1.0000			mg/l	03-15-90
Lead	<	0.5000	<	0.5000			mg/l	03-15-90
Lithium		0.2100		0.2100			mg/l	03-15-90
Manganese	<	0.1500	<	0.1500			mg/l	03-15-90
Mercury	<	0.0004	<	0.0004			mg/l	03-15-90
Molybdenum	<	0.2000	<	0.2000			mg/l	03-15-90
Nickel	<	0.4000	<	0.4000			mg/l	03-15-90
Selenium	<	0.5000	NA	0.0000			mg/l	03-15-90
Silver	<	0.1000	<	0.1000			mg/l	03-15-90
Strontium		10.0000		10.0000			mg/l	03-15-90
Thallium	<	0.1000	NA	0.0000			mg/l	03-15-90
Titanium	<	0.1000	<	0.1000			mg/l	03-15-90
Vanadium	<	0.5000	<	0.5000			mg/l	03-15-90
Zinc	<	0.2000	<	0.2000			mg/l	03-15-90

CONTRACT LABORATORY ANALYSIS

H-06c, MAGENTA, ROUND 5

VOLATILE HAZARDOUS SUBSTANCES

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Chloromethane	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	03-15-90
Bromomethane	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	03-15-90
Vinyl chloride	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	03-15-90
Chloroethane	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	03-15-90
Methylene chloride	<	5.0000	NA	0.0000	T < 5	M< 5	ug/l	03-15-90
Acetone	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	03-15-90
Carbon disulfide	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
1,1-Dichloroethene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
1,1-Dichloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
1,2-Dichloroethene(Total)	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
Chloroform	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
1,2-Dichloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
2-Butanone	<	10.0000	NA	0.0000	T< 10	M 13	ug/l	03-15-90
1,1,1-Trichloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
Carbon tetrachloride	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
Vinyl acetate	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	03-15-90
Bromodichloromethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
1,2-Dichloropropane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
cis-1,3-Dichloropropene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
Trichloroethene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
Dibromochloromethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90

CONTRACT LABORATORY ANALYSIS

H-06c, MAGENTA, ROUND 5

VOLATILE HAZARDOUS SUBSTANCES

(CONTINUED)

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
1,1,2-Trichloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
Benzene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
trans-1,3-Dichloropropene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
Bromoform	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
4-Methyl-2-pentanone	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	03-15-90
2-Hexanone	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	03-15-90
Tetrachloroethene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
1,1,2,2-Tetrachloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
Toluene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
Chlorobenzene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
Ethylbenzene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
Styrene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90
Xylene (total)	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	03-15-90

NOTE: "T" IN ASCID BLANK COLUMN INDICATES TRIP

"M" IN WATERBLANK COLUMN INDICATES METHO

CONTRACT LABORATORY ANALYSIS

H-18, CULEBRA, ROUND 3

GENERAL CHEMISTRY

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
pH		7.5900		7.6000				04-10-90
Specific Conductance		39300.0000		39300.0000			umhos/cm@25C	04-10-90
Alkalinity (HCO3)		56.0000	NA	0.0000			mg/l	04-10-90
Bromide		14.0000		14.0000			mg/l	04-10-90
Calcium Hardness		0.0000		0.0000			mg/l	04-10-90
Total Hardness		0.0000	NA	0.0000			mg/l	04-10-90
Chloride		13000.0000		13000.0000			mg/l	04-10-90
Alkalinity (CO3)		0.0000	NA	0.0000			mg/l	04-10-90
Cyanide	<	0.0100	NA	0.0000			mg/l	04-10-90
Fluoride		1.7000		1.7000			mg/l	04-10-90
Iodide	<	2.0000	<	2.0000			mg/l	04-10-90
Nitrate	<	0.2000	NA	0.0000			mg/l	04-10-90
Total Phenolics		0.1200	NA	0.0000			mg/l	04-10-90
Phosphorus	<	0.0100	NA	0.0000			mg/l	04-10-90
Residue, Filterable @ 180 c		31000.0000		31000.0000			mg/l	04-10-90
Residue, Nonfilterable @ 105 c	<	4.0000		7.0000			mg/l	04-10-90
Silica		5.1000	NA	0.0000			mg/l	04-10-90
Sulfate		5200.0000	NA	0.0000			mg/l	04-10-90
Total Organic Carbon		4.0000		5.0000			mg/l	04-10-90
Total Organic Halides		0.4300		0.4100			mg/l	04-10-90

CONTRACT LABORATORY ANALYSIS

H-18, CULEBRA, ROUND 3

METALS ANALYSIS

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Calcium		1200.0000		1200.0000			mg/l	04-10-90
Magnesium		520.0000		520.0000			mg/l	04-10-90
Potassium		300.0000		200.0000			mg/l	04-10-90
Sodium		8000.0000		8000.0000			mg/l	04-10-90
Aluminum	<	2.0000	<	2.0000			mg/l	04-10-90
Antimony	<	0.6000	<	0.6000			mg/l	04-10-90
Arsenic	<	0.1000	NA	0.0000			mg/l	04-10-90
Barium	<	2.0000	<	2.0000			mg/l	04-10-90
Beryllium	<	0.0500	<	0.0500			mg/l	04-10-90
Boron		16.0000		16.0000			mg/l	04-10-90
Cadmium	<	0.0500	<	0.0500			mg/l	04-10-90
Cesium		0.7000		0.8000			mg/l	04-10-90
Chromium		0.2000		0.2000			mg/l	04-10-90
Cobalt	<	0.5000	<	0.5000			mg/l	04-10-90
Copper	<	0.2500	<	0.2500			mg/l	04-10-90
Iron	<	1.0000	<	1.0000			mg/l	04-10-90
Lead	<	0.5000	<	0.5000			mg/l	04-10-90
Lithium		0.2000		0.1000			mg/l	04-10-90
Manganese		0.2100		0.2000			mg/l	04-10-90
Mercury	<	0.0002	<	0.0002			mg/l	04-10-90
Molybdenum	<	0.2000	<	0.2000			mg/l	04-10-90
Nickel	<	0.4000	<	0.4000			mg/l	04-10-90
Selenium	<	0.5000	NA	0.0000			mg/l	04-10-90
Silver	<	0.1000	<	0.1000			mg/l	04-10-90
Strontium		15.0000		15.0000			mg/l	04-10-90
Thallium	<	0.5000	NA	0.0000			mg/l	04-10-90
Titanium	<	0.1000	<	0.1000			mg/l	04-10-90
Vanadium	<	0.5000	<	0.5000			mg/l	04-10-90
Zinc	<	0.2000	<	0.2000			mg/l	04-10-90

CONTRACT LABORATORY ANALYSIS
H-18, CULEBRA, ROUND 3
VOLATILE HAZADROUS SUBSTANCES

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Chloromethane	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	04-10-90
Bromomethane	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	04-10-90
Vinyl chloride	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	04-10-90
Chloroethane	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	04-10-90
Methylene chloride	<	5.0000	NA	0.0000	T 6	M< 5	ug/l	04-10-90
Acetone	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	04-10-90
Carbon disulfide	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
1,1-Dichloroethene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
1,1-Dichloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
1,2-Dichloroethene(Total)	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
Chloroform	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
1,2-Dichloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
2-Butanone	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	04-10-90
1,1,1-Trichloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
Carbon tetrachloride	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
Vinyl acetate	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	04-10-90
Bromodichloromethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
1,2-Dichloropropane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
cis-1,3-Dichloropropene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
Trichloroethene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
Dibromochloromethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
1,1,2-Trichloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
Benzene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
trans-1,3-Dichloropropene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
Bromoform	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
4-Methyl-2-pentanone	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	04-10-90
2-Hexanone	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	04-10-90
Tetrachloroethene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
1,1,2,2-Tetrachloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
Toluene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
Chlorobenzene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
Ethylbenzene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
Styrene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90
Xylene (total)	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	04-10-90

NOTE: "T" IN ACID BLANK COLUMN INDICATES TRIP
"M" IN WATERBLANK COLUMN INDICATES METHO

CONTRACT LABORATORY ANALYSIS

H-05b, CULEBRA, ROUND 5

GENERAL CHEMISTRY

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
pH		8.3300		8.3300				05-02-90
Specific Conductance		153000.0000		153000.0000			uMhos/cm@25C	05-02-90
Alkalinity (HCO3)		41.0000		41.0000			mg/l	05-02-90
Bromide		69.0000	NA	0.0000			mg/l	05-02-90
Chloride		92100.0000	NA	0.0000			mg/l	05-02-90
Alkalinity (CO3)		0.0000	NA	0.0000			mg/l	05-02-90
Cyanide	<	0.0100	NA	0.0000			mg/l	05-02-90
Fluoride		0.9000		0.9000			mg/l	05-02-90
Iodide	<	2.0000	<	2.0000			mg/l	05-02-90
Nitrate		0.0300		0.0400			mg/l	05-02-90
Total Phenolics		0.1600	NA	0.0000			mg/l	05-02-90
Phosphorus		0.0200	NA	0.0000			mg/l	05-02-90
Residue, Filterable @ 180 c		160000.0000		173000.0000			mg/l	05-02-90
Residue, Nonfilterable @ 105 c		38.0000		34.0000			mg/l	05-02-90
Silica		2.7000		3.2000			mg/l	05-02-90
Sulfate		7900.0000		7500.0000			mg/l	05-02-90
Total Organic Carbon		9.0000	NA	0.0000			mg/l	05-02-90
Total Organic Halides		0.8900	NA	0.0000			mg/l	05-02-90

CONTRACT LABORATORY ANALYSIS

H-05b, CULEBRA, ROUND 5

METALS ANALYSIS

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Calcium		1500.0000		1500.0000			mg/l	05-02-90
Magnesium		1800.0000		1700.0000			mg/l	05-02-90
Potassium		1200.0000		1200.0000			mg/l	05-02-90
Sodium		55200.0000		55200.0000			mg/l	05-02-90
Aluminum	<	2.0000	<	2.0000	< .2	< .2	mg/l	05-02-90
Antimony		0.6000		0.6000	< .06	< .06	mg/l	05-02-90
Arsenic	<	0.1000	NA	0.0000	< .01	< .01	mg/l	05-02-90
Barium	<	2.0000	<	2.0000	< .2	< .2	mg/l	05-02-90
Beryllium	<	0.0500	<	0.0500	< .005	< .005	mg/l	05-02-90
Boron		30.0000		30.0000	< .02	< .02	mg/l	05-02-90
Cadmium		0.1000		0.1000	< .005	< .005	mg/l	05-02-90
Cesium	<	0.2000	<	2.0000	< .2	< .2	mg/l	05-02-90
Chromium		0.3000		0.3000	.01	.01	mg/l	05-02-90
Cobalt	<	0.5000	<	0.5000	< .05	< .05	mg/l	05-02-90
Copper	<	0.2500	<	0.2500	< .025	< .025	mg/l	05-02-90
Iron		2.0000		2.0000	< .1	< .1	mg/l	05-02-90
Lead	<	0.5000	<	0.5000	< .05	< .05	mg/l	05-02-90
Lithium		1.0000		1.0000	< .01	< .01	mg/l	05-02-90
Manganese		0.2300		0.2400	< .015	< .015	mg/l	05-02-90
Mercury	<	0.0002	<	0.0002	< .0002	< .0002	mg/l	05-02-90
Molybdenum		0.3000		0.3000	< .02	< .02	mg/l	05-02-90
Nickel	<	0.4000	<	0.4000	< .04	< .04	mg/l	05-02-90
Selenium	<	5.0000	NA	0.0000	< .005	< .005	mg/l	05-02-90
Silver		0.1000		0.1000	< .01	< .01	mg/l	05-02-90
Strontium		26.0000		26.0000	< .01	< .01	mg/l	05-02-90
Thallium	<	10.0000	NA	0.0000	< .01	< .01	mg/l	05-02-90
Titanium	<	0.1000	<	0.1000	< .01	< .01	mg/l	05-02-90
Vanadium	<	0.0500	<	0.0500	< .05	< .05	mg/l	05-02-90
Zinc		0.8000		0.8000	< .02	< .02	mg/l	05-02-90

CONTRACT LABORATORY ANALYSIS

H-05b, CULEBRA, ROUND 5

VOLATILE HAZARDOUS SUBSTANCES

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Chloromethane	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	05-02-90
Bromomethane	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	05-02-90
Vinyl chloride	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	05-02-90
Chloroethane	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	05-02-90
Methylene chloride		6.0000	NA	0.0000	T 10	M< 5	ug/l	05-02-90
Acetone	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	05-02-90
Carbon disulfide	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
1,1-Dichloroethene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
1,1-Dichloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
1,2-Dichloroethene (TOTAL)	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
Chloroform	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
1,2-Dichloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
2-Butanone	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	05-02-90
1,1,1-Trichloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
Carbon tetrachloride	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
Vinyl acetate	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	05-02-90
Bromodichloromethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
1,2-Dichloropropane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
cis-1,3-Dichloropropene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
Trichloroethene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
Dibromochloromethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
1,1,2-Trichloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
Benzene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
trans-1,3-Dichloropropene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
Bromoform	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
4-Methyl-2-pentanone	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	05-02-90
2-Hexanone	<	10.0000	NA	0.0000	T< 10	M< 10	ug/l	05-02-90
Tetrachloroethene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
1,1,2,2-Tetrachloroethane	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
Toluene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
Chlorobenzene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
Ethylbenzene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
Styrene	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90
Xylene (total)	<	5.0000	NA	0.0000	T< 5	M< 5	ug/l	05-02-90

T" IN ACID BLANK COLUMN INDICATES TRIP BLANK

M" IN WATER BLANK COLUMN INDICATES METHOD BLANK

CONTRACT LABORATORY ANALYSIS

H-05c, MAGENTA, ROUND 5

GENERAL CHEMISTRY

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
pH		8.3300		8.3300				05-16-90
Specific Conductance		9100.0000		9100.0000			uMhos/cm@25C	05-16-90
Alkalinity (HCO3)		46.0000		49.0000			mg/l	05-16-90
Bromide	<	2.0000	<	2.0000			mg/l	05-16-90
Chloride		870.0000		860.0000			mg/l	05-16-90
Alkalinity (CO3)		0.0000	NA	0.0000			mg/l	05-16-90
Cyanide	<	0.0100	<	0.0100			mg/l	05-16-90
Fluoride		2.9000		0.0000			mg/l	05-16-90
Iodide	<	2.0000	<	2.0000			mg/l	05-16-90
Nitrate	<	0.0200	<	0.0200			mg/l	05-16-90
Total Phenolics		0.0100		0.0000			mg/l	05-16-90
Phosphorus	<	0.0100	NA	0.0000			mg/l	05-16-90
Residue, Filterable @ 180 c		7200.0000		0.0000			mg/l	05-16-90
Residue, Nonfilterable @ 105 c<		4.0000		0.0000			mg/l	05-16-90
Silica		4.9000		4.4000			mg/l	05-16-90
Sulfate		3300.0000	NA	3300.0000			mg/l	05-16-90
Total Organic Carbon		2.0000		2.0000			mg/l	05-16-90
Total Organic Halides		0.0700	<	0.0500			mg/l	05-16-90

CONTRACT LABORATORY ANALYSIS

H-05c, MAGENTA, ROUND 5

METALS ANALYSIS

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Calcium		560.0000		560.0000			mg/l	05-16-90
Magnesium		180.0000		180.0000			mg/l	05-16-90
Potassium		36.0000		36.0000			mg/l	05-16-90
Sodium		1000.0000		1000.0000			mg/l	05-16-90
Aluminum	<	2.0000	<	2.0000			mg/l	05-16-90
Antimony	<	0.6000	<	0.6000			mg/l	05-16-90
Arsenic	<	0.1000	NA	0.0000			mg/l	05-16-90
Barium	<	2.0000	<	2.0000			mg/l	05-16-90
Beryllium	<	0.0500	<	0.0500			mg/l	05-16-90
Boron		10.0000		10.0000			mg/l	05-16-90
Cadmium	<	0.0500	<	0.0500			mg/l	05-16-90
Cesium	<	0.2000	<	0.2000			mg/l	05-16-90
Chromium	<	0.1000	<	0.1000			mg/l	05-16-90
Cobalt	<	0.5000	<	0.5000			mg/l	05-16-90
Copper	<	0.2500	<	0.2500			mg/l	05-16-90
Iron	<	1.0000	<	1.0000			mg/l	05-16-90
Lead	<	0.5000	<	0.5000			mg/l	05-16-90
Lithium		0.2000		0.2000			mg/l	05-16-90
Manganese	<	0.1500	<	0.1500			mg/l	05-16-90
Mercury	<	0.0002	<	0.0002			mg/l	05-16-90
Molybdenum	<	0.2000	<	0.2000			mg/l	05-16-90
Nickel	<	0.4000	<	0.4000			mg/l	05-16-90
Selenium	<	0.0050	NA	0.0000			mg/l	05-16-90
Silver	<	0.1000	<	0.1000			mg/l	05-16-90
Strontium		9.8000		9.8000			mg/l	05-16-90
Thallium	<	0.2500	NA	0.0000			mg/l	05-16-90
Titanium	<	0.1000	<	0.1000			mg/l	05-16-90
Vanadium	<	0.5000	<	0.5000			mg/l	05-16-90
Zinc	<	0.2000	<	0.2000			mg/l	05-16-90

CONTRACT LABORATORY ANALYSIS

TWIN WELL, DEWEY LAKE, ROUND 4

GENERAL CHEMISTRY

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
pH		7.5400		7.5500				05-30-90
Specific Conductance		1030.0000		1030.0000			uMhos/cm@25C	05-30-90
Calcium Hardness (mg/L CaCO3)		268.0000	NA	0.0000			mg/l	05-30-90
Langelier Saturation Index		0.2600	NA	0.0000			NA	05-30-90
Alkalinity (HCO3)		210.0000		220.0000			mg/l	05-30-90
Bromide		3.0000		0.0000			mg/l	05-30-90
Chloride		35.0000		0.0000			mg/l	05-30-90
Alkalinity (CO3)		0.0000	NA	0.0000			mg/l	05-30-90
Cyanide	<	0.0100	<	0.0200			mg/l	05-30-90
Fluoride		0.6000		0.0000			mg/l	05-30-90
Iodide	<	2.0000	<	2.0000			mg/l	05-30-90
Nitrate		9.2000		0.0000			mg/l	05-30-90
Total Phenolics	<	0.0050		0.0000			mg/l	05-30-90
Phosphorus	<	0.0100	<	0.0100			mg/l	05-30-90
Residue, Filterable @ 180 c		410.0000		0.0000			mg/l	05-30-90
Residue, Nonfilterable @ 105 c<		9.0000		6.0000			mg/l	05-30-90
Silica		18.0000		18.0000			mg/l	05-30-90
Sulfate		59.0000	NA	0.0000			mg/l	05-30-90
Total Organic Carbon		2.0000		2.0000			mg/l	05-30-90
Total Organic Halides	<	0.0500	<	0.0500			mg/l	05-30-90

CONTRACT LABORATORY ANALYSIS

TWIN WELL, DEWEY LAKE, ROUND 4

METALS ANALYSIS

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Calcium		77.0000		77.0000			mg/l	05-30-90
Magnesium		24.0000		24.0000			mg/l	05-30-90
Potassium	<	5.0000	<	5.0000			mg/l	05-30-90
Sodium		23.0000		22.0000			mg/l	05-30-90
Aluminum	<	0.2000	<	0.2000			mg/l	05-30-90
Antimony	<	0.0600	<	0.0600			mg/l	05-30-90
Arsenic	<	0.0100	NA	0.0000			mg/l	05-30-90
Barium	<	0.2000	<	0.2000			mg/l	05-30-90
Beryllium	<	0.0050	<	0.0050			mg/l	05-30-90
Boron		0.1500		0.1600			mg/l	05-30-90
Cadmium	<	0.0050	<	0.0050			mg/l	05-30-90
Cesium	<	0.2000	<	0.2000			mg/l	05-30-90
Chromium		0.0200		0.0200			mg/l	05-30-90
Cobalt		0.0500		0.0500			mg/l	05-30-90
Copper		0.0480		0.0470			mg/l	05-30-90
Iron	<	0.1000	<	0.1000			mg/l	05-30-90
Lead	<	0.0500	<	0.0500			mg/l	05-30-90
Lithium	<	0.1000	<	0.1000			mg/l	05-30-90
Manganese		0.0190		0.0190			mg/l	05-30-90
Mercury		0.0002	<	0.0002			mg/l	05-30-90
Molybdenum	<	0.0200	<	0.0200			mg/l	05-30-90
Nickel	<	0.0400	<	0.0400			mg/l	05-30-90
Selenium	<	0.0500	NA	0.0000			mg/l	05-30-90
Silver	<	0.0100	<	0.0100			mg/l	05-30-90
Strontium		1.0000		1.0000			mg/l	05-30-90
Thallium	<	0.0100	NA	0.0000			mg/l	05-30-90
Titanium	<	0.0100	<	0.0100			mg/l	05-30-90
Vanadium	<	0.0500	<	0.0500			mg/l	05-30-90
Zinc		0.5200		0.5200			mg/l	05-30-90

CONTRAC LABORATORY ANALYSIS

WIPP-19, CULEBRA, ROUND 5

GENERAL CHEMISTRY

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
pH		7.2400		7.2400				06-13-90
Specific Conductance		90800.0000		91100.0000			uMhos/cm@25C	06-13-90
Alkalinity (HCO3)		56.0000	NA	0.0000			mg/l	06-13-90
Bromide		49.0000		48.0000			mg/l	06-13-90
Chloride		37900.0000	NA	0.0000			mg/l	06-13-90
Alkalinity (CO3)		0.0000	NA	0.0000			mg/l	06-13-90
Cyanide	<	0.0100	NA	0.0000			mg/l	06-13-90
Fluoride		1.0000		1.0000			mg/l	06-13-90
Iodide	<	2.0000	<	2.0000			mg/l	06-13-90
Nitrate	<	0.0200	<	0.0200			mg/l	06-13-90
Total Phenolics	<	0.0050	<	0.0100			mg/l	06-13-90
Phosphorus	<	0.0100	NA	0.0000			mg/l	06-13-90
Residue, Filterable @ 180 c		77200.0000		74500.0000			mg/l	06-13-90
Residue, Nonfilterable @ 105 c		19.0000		16.0000			mg/l	06-13-90
Silica		4.3000	NA	0.0000			mg/l	06-13-90
Sulfate		5000.0000	NA	0.0000			mg/l	06-13-90
Total Organic Carbon		7.0000		5.0000			mg/l	06-13-90
Total Organic Halides		0.5900		0.5400			mg/l	06-13-90

CONTRAC LABORATORY ANALYSIS

WIPP-19, CULEBRA, ROUND 5

METALS ANALYSIS

PARAMETER	V	VALUE	S	D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Calcium		1400.0000			1400.0000			mg/l	06-13-90
Magnesium		1000.0000			1000.0000			mg/l	06-13-90
Potassium		600.0000			580.0000			mg/l	06-13-90
Sodium		31000.0000			31000.0000			mg/l	06-13-90
Aluminum	<	0.2000		<	0.2000			mg/l	06-13-90
Antimony	<	0.6000		<	0.6000			mg/l	06-13-90
Arsenic	<	0.0200		NA	0.0000			mg/l	06-13-90
Barium	<	2.0000		<	2.0000			mg/l	06-13-90
Beryllium	<	0.0500		<	0.0500			mg/l	06-13-90
Boron		26.0000			26.0000			mg/l	06-13-90
Cadmium	<	0.0500		<	0.0500			mg/l	06-13-90
Cesium	<	0.2000		<	0.2000			mg/l	06-13-90
Chromium		0.1000			0.1000			mg/l	06-13-90
Cobalt	<	0.5000		<	0.5000			mg/l	06-13-90
Copper	<	0.2500		<	0.2500			mg/l	06-13-90
Iron	<	1.0000		<	1.0000			mg/l	06-13-90
Lead	<	0.5000		<	0.5000			mg/l	06-13-90
Lithium		0.6000			0.5000			mg/l	06-13-90
Manganese		0.8000			0.8000			mg/l	06-13-90
Mercury	<	0.0002		<	0.0002			mg/l	06-13-90
Molybdenum	<	0.2000		<	0.2000			mg/l	06-13-90
Nickel	<	0.4000		<	0.4000			mg/l	06-13-90
Selenium	<	0.5000		NA	0.0000			mg/l	06-13-90
Silver	<	0.1000		<	0.1000			mg/l	06-13-90
Strontium		22.0000			22.0000			mg/l	06-13-90
Thallium	<	0.1000		NA	0.0000			mg/l	06-13-90
Titanium	<	0.1000		<	0.1000			mg/l	06-13-90
Vanadium	<	0.5000		<	0.5000			mg/l	06-13-90
Zinc	<	0.2000		<	0.2000			mg/l	06-13-90

CONTRACT LABORATORY ANALYSIS

RANCH WELL, DEWEY LAKE, ROUND 5

GENERAL CHEMISTRY

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
pH		7.2000		7.2000				06-20-90
Specific Conductance		3650.0000		3670.0000			uMhos/cm@25C	06-20-90
Langelier Saturation Index		0.1700	NA	0.0000				06-20-90
Alkalinity (HCO3)		230.0000		230.0000			mg/l	06-20-90
Bromide	<	2.0000		0.0000			mg/l	06-20-90
Chloride		340.0000		0.0000			mg/l	06-20-90
Alkalinity (CO3)		0.0000	NA	0.0000			mg/l	06-20-90
Cyanide	<	0.0100		0.0000			mg/l	06-20-90
Fluoride		1.0000		0.0000			mg/l	06-20-90
Iodide	<	2.0000	<	2.0000			mg/l	06-20-90
Nitrate		71.0000		71.0000			mg/l	06-20-90
Total Phenolics	<	0.0050		0.0000			mg/l	06-20-90
Phosphorus	<	0.0100	<	0.0100			mg/l	06-20-90
Residue, Filterable @ 180 c		3000.0000		3000.0000			mg/l	06-20-90
Residue, Nonfilterable @ 105 c	<	4.0000	<	4.0000			mg/l	06-20-90
Silica		20.0000		0.0000			mg/l	06-20-90
Sulfate		1400.0000		1400.0000			mg/l	06-20-90
Total Organic Carbon		3.0000		2.0000			mg/l	06-20-90
Total Organic Halides	<	0.0500	<	0.0500			mg/l	06-20-90

CONTRACT LABORATORY ANALYSIS

RANCH WELL, DEWEY LAKE, ROUND 5

METALS ANALYSIS

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Calcium		550.0000		550.0000			mg/l	06-20-90
Magnesium		150.0000		150.0000			mg/l	06-20-90
Potassium	<	5.0000	<	5.0000			mg/l	06-20-90
Sodium		220.0000		220.0000			mg/l	06-20-90
Aluminum	<	2.0000	<	2.0000			mg/l	06-20-90
Antimony		0.1100		0.1100			mg/l	06-20-90
Arsenic	<	0.0100	NA	0.0000			mg/l	06-20-90
Barium	<	0.2000	<	0.2000			mg/l	06-20-90
Beryllium	<	0.0050	<	0.0050			mg/l	06-20-90
Boron		0.3300		0.3200			mg/l	06-20-90
Cadmium		0.0090		0.0100			mg/l	06-20-90
Cesium	<	0.2000	<	0.2000			mg/l	06-20-90
Chromium	<	0.0100		0.0100			mg/l	06-20-90
Cobalt	<	0.0500	<	0.0500			mg/l	06-20-90
Copper	<	0.0250	<	0.0250			mg/l	06-20-90
Iron	<	0.1000	<	0.1000			mg/l	06-20-90
Lead		0.0600		0.0600			mg/l	06-20-90
Lithium	<	0.1000	<	0.1000			mg/l	06-20-90
Manganese	<	0.0150	<	0.0150			mg/l	06-20-90
Mercury	<	0.0002	<	0.0002			mg/l	06-20-90
Molybdenum		0.0400		0.0400			mg/l	06-20-90
Nickel	<	0.0400	<	0.0400			mg/l	06-20-90
Selenium	<	0.0500	NA	0.0000			mg/l	06-20-90
Silver		0.0200		0.0200			mg/l	06-20-90
Strontium		5.1000		5.1000			mg/l	06-20-90
Thallium	<	1.0000	NA	0.0000			mg/l	06-20-90
Titanium		0.0100		0.0100			mg/l	06-20-90
Vanadium		0.0500		0.0500			mg/l	06-20-90
Zinc		0.0200		0.0200			mg/l	06-20-90

CONTRACT LABORATORY ANALYSIS

BARN WELL, DEWEY LAKE, ROUND 4

GENERAL CHEMISTRY

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
pH		7.6900		7.6800				06-21-90
Specific Conductance		1048.0000		1049.0000			uMhos/cm@25C	06-21-90
Langelier Saturation Index		0.2500	NA	0.0000				06-21-90
Alkalinity (HCO3)		280.0000	NA	0.0000			mg/l	06-21-90
Bromide	<	2.0000	<	2.0000			mg/l	06-21-90
Calcium Hardness (CaCO3)		150	NA	0.0000			mg/l	06-21-90
Chloride		41.0000	NA	0.0000			mg/l	06-21-90
Alkalinity (CO3)		0.0000	NA	0.0000			mg/l	06-21-90
Cyanide	<	0.0100	NA	0.0000			mg/l	06-21-90
Fluoride		2.6000	NA	0.0000			mg/l	06-21-90
Iodide	<	2.0000	<	2.0000			mg/l	06-21-90
Nitrate		8.9000	NA	0.0000			mg/l	06-21-90
Total Phenolics	<	0.0050	NA	0.0000			mg/l	06-21-90
Phosphorus	<	0.0100	NA	0.0000			mg/l	06-21-90
Residue, Filterable @ 180 c		650.0000		650.0000			mg/l	06-21-90
Residue, Nonfilterable @ 105 c	<	4.0000	<	4.0000			mg/l	06-21-90
Silica		25.0000	NA	0.0000			mg/l	06-21-90
Sulfate		180.0000	NA	0.0000			mg/l	06-21-90
Total Organic Carbon	<	1.0000	<	1.0000			mg/l	06-21-90
Total Organic Halides		0.1800		0.1200			mg/l	06-21-90

CONTRACT LABORATORY ANALYSIS

BARN WELL, DEWEY LAKE, ROUND 4

METALS ANALYSIS

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Calcium		64.0000		64.0000			mg/l	06-21-90
Magnesium		33.0000		33.0000			mg/l	06-21-90
Potassium	<	5.0000	<	5.0000			mg/l	06-21-90
Sodium		120.0000		120.0000			mg/l	06-21-90
Aluminum	<	2.0000	<	2.0000			mg/l	06-21-90
Antimony	<	0.0600	<	0.0600			mg/l	06-21-90
Arsenic	<	0.0100	NA	0.0000			mg/l	06-21-90
Barium	<	0.2000	<	0.2000			mg/l	06-21-90
Beryllium	<	0.0050	<	0.0050			mg/l	06-21-90
Boron		0.3600		0.3600			mg/l	06-21-90
Cadmium	<	0.0050	<	0.0050			mg/l	06-21-90
Cesium	<	0.2000	<	0.2000			mg/l	06-21-90
Chromium	<	0.0100	<	0.0100			mg/l	06-21-90
Cobalt	<	0.0500	<	0.0500			mg/l	06-21-90
Copper	<	0.0250	<	0.0250			mg/l	06-21-90
Iron	<	0.1000	<	0.1000			mg/l	06-21-90
Lead	<	0.0500	<	0.0500			mg/l	06-21-90
Lithium		0.0400		0.0400			mg/l	06-21-90
Manganese	<	0.0150	<	0.0150			mg/l	06-21-90
Mercury	<	0.0002	<	0.0002			mg/l	06-21-90
Molybdenum	<	0.0200	<	0.0200			mg/l	06-21-90
Nickel	<	0.0400	<	0.0400			mg/l	06-21-90
Selenium	<	0.0500	NA	0.0000			mg/l	06-21-90
Silver	<	0.0100	<	0.0100			mg/l	06-21-90
Strontium		0.9400		0.9400			mg/l	06-21-90
Thallium	<	0.0100	NA	0.0000			mg/l	06-21-90
Titanium	<	0.0100	<	0.0100			mg/l	06-21-90
Vanadium		0.0600		0.0600			mg/l	06-21-90
Zinc	<	0.0200	<	0.0200			mg/l	06-21-90

CONTRACT LABORATORY ANALYSIS

H-02c, CULEBRA, ROUND 2

GENERAL CHEMISTRY

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
pH		7.4400		7.4400				07-25-90
Specific Conductance		13900.0000		14000.0000			uMhos/cm@25C	07-25-90
Alkalinity (HCO3)		60.0000		0.0000			mg/l	07-25-90
Bromide		12.0000		12.0000			mg/l	07-25-90
Chloride		2700.0000		0.0000			mg/l	07-25-90
Alkalinity (CO3)		0.0000	NA	0.0000			mg/l	07-25-90
Cyanide	<	0.0100	NA	0.0000			mg/l	07-25-90
Fluorescein		4.4000		4.6000			mg/l	07-25-90
Fluoride		2.5000		0.0000			mg/l	07-25-90
Iodide		4.0000		5.0000			mg/l	07-25-90
Nitrate	<	0.0200		0.0000			mg/l	07-25-90
Total Phenolics	<	0.0050		0.0000			mg/l	07-25-90
Phosphorus		0.0200		0.0000			mg/l	07-25-90
Residue, Filterable @ 180 c		9300.0000		0.0000			mg/l	07-25-90
Residue, Nonfilterable @ 105 c		62.0000		0.0000			mg/l	07-25-90
Silica		6.2000		0.0000			mg/l	07-25-90
Sulfate		2900.0000		0.0000			mg/l	07-25-90
Total Organic Carbon		2.0000		2.0000			mg/l	07-25-90
Total Organic Halides		0.1100		0.0700			mg/l	07-25-90

CONTRACT LABORATORY ANALYSIS

H-02c, CULEBRA, ROUND 2

METALS ANALYSIS

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Calcium		680.0000		680.0000			mg/l	07-25-90
Magnesium		160.0000		160.0000			mg/l	07-25-90
Potassium		100.0000		100.0000			mg/l	07-25-90
Sodium		2000.0000		2000.0000			mg/l	07-25-90
Aluminum	<	2.0000	<	2.0000	< .2	< .2	mg/l	07-25-90
Antimony	<	0.6000	<	0.6000	< .06	< .06	mg/l	07-25-90
Arsenic	<	0.0100	NA	0.0000	< .01	< .01	mg/l	07-25-90
Barium	<	2.0000	<	2.0000	< .2	< .2	mg/l	07-25-90
Beryllium	<	0.0500	<	0.0500	< .005	< .005	mg/l	07-25-90
Boron		11.0000		11.0000	< .02	< .02	mg/l	07-25-90
Cadmium	<	0.0500	<	0.0500	< .005	< .005	mg/l	07-25-90
Cesium	<	0.2000	<	0.2000	< .2	< .2	mg/l	07-25-90
Chromium		0.1000		0.1000	< .01	< .02	mg/l	07-25-90
Cobalt	<	0.5000	<	0.5000	< .05	< .05	mg/l	07-25-90
Copper	<	0.2500	<	0.2500	< .025	< .025	mg/l	07-25-90
Iron		1.0000		1.0000	< .1	< .1	mg/l	07-25-90
Lead	<	0.5000	<	0.5000	< .05	< .05	mg/l	07-25-90
Lithium		0.2000		0.2000	< .01	< .01	mg/l	07-25-90
Manganese	<	0.1500	<	0.1500	< .015	< .015	mg/l	07-25-90
Mercury	<	0.0002	<	0.0002	< .0002	< .0002	mg/l	07-25-90
Molybdenum	<	0.2000	<	0.2000	< .02	< .02	mg/l	07-25-90
Nickel	<	0.4000	<	0.4000	< .04	< .04	mg/l	07-25-90
Selenium	<	0.0500	NA	0.0000	< .005	< .005	mg/l	07-25-90
Silver	<	0.1000	<	0.1000	< .01	< .01	mg/l	07-25-90
Strontium		8.7000		8.8000	< .01	< .01	mg/l	07-25-90
Thallium	<	0.0100	NA	0.0000	< .01	< .01	mg/l	07-25-90
Titanium	<	0.1000	<	0.1000	< .01	< .01	mg/l	07-25-90
Vanadium	<	0.5000	<	0.5000	< .05	< .05	mg/l	07-25-90
Zinc	<	0.2000	<	0.2000	< .02	< .02	mg/l	07-25-90

CONTRACT LABORATORY ANALYSIS

H-03b3, CULEBRA, ROUND 5

GENERAL CHEMISTRY

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
pH		7.1600		7.1600				08-15-90
Specific Conductance		66000.0000		66000.0000			uMhos/cm@25C	08-15-90
Alkalinity (HCO3)		49.0000	NA	0.0000			mg/l	08-15-90
Bromide		27.0000		27.0000			mg/l	08-15-90
Chloride		27000.0000		27000.0000			mg/l	08-15-90
Alkalinity (CO3)		0.0000	NA	0.0000			mg/l	08-15-90
Cyanide	<	0.0100		0.0000			mg/l	08-15-90
Fluoride		1.5000		0.0000			mg/l	08-15-90
Iodide	<	2.0000	<	2.0000			mg/l	08-15-90
Nitrate	<	0.0200		0.0000			mg/l	08-15-90
Total Phenolics	<	0.0050	<	0.0100			mg/l	08-15-90
Phosphorus	<	0.0100		0.0000			mg/l	08-15-90
Residue, Filterable @ 180 c		55000.0000		0.0000			mg/l	08-15-90
Residue, Nonfilterable @ 105 c		100.0000		0.0000			mg/l	08-15-90
Silica		4.5000		0.0000			mg/l	08-15-90
Sulfate		4700.0000		0.0000			mg/l	08-15-90
Total Organic Carbon	<	1.0000		1.0000			mg/l	08-15-90
Total Organic Halides		0.1300		0.1400			mg/l	08-15-90

CONTRACT LABORATORY ANALYSIS

H-03b3, CULEBRA, ROUND 5

METALS ANALYSIS

PARAMETER	V	VALUE	S	D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Calcium		1300.0000			1300.0000			mg/l	08-15-90
Magnesium		700.0000			710.0000			mg/l	08-15-90
Potassium		450.0000			450.0000			mg/l	08-15-90
Sodium		16000.0000			16000.0000			mg/l	08-15-90
Aluminum	<	2.0000	<		2.0000			mg/l	08-15-90
Antimony	<	0.6000	<		0.6000			mg/l	08-15-90
Arsenic	<	0.1000	NA		0.0000			mg/l	08-15-90
Barium	<	2.0000	<		2.0000			mg/l	08-15-90
Beryllium	<	0.0500	<		0.0500			mg/l	08-15-90
Boron		22.0000			22.0000			mg/l	08-15-90
Cadmium	<	0.0500	<		0.0500			mg/l	08-15-90
Cesium	<	0.2000	<		0.2000			mg/l	08-15-90
Chromium		0.1000			0.2000			mg/l	08-15-90
Cobalt	<	0.5000	<		0.5000			mg/l	08-15-90
Copper	<	0.2500	<		0.2500			mg/l	08-15-90
Iron	<	1.0000	<		1.0000			mg/l	08-15-90
Lead	<	0.5000	<		0.5000			mg/l	08-15-90
Lithium		0.4000			0.4000			mg/l	08-15-90
Manganese	<	0.1500	<		0.1500			mg/l	08-15-90
Mercury	<	0.0002	<		0.0002			mg/l	08-15-90
Molybdenum	<	0.2000	<		0.2000			mg/l	08-15-90
Nickel	<	0.4000	<		0.4000			mg/l	08-15-90
Selenium	<	0.5000	NA		0.0000			mg/l	08-15-90
Silver	<	0.1000	<		0.1000			mg/l	08-15-90
Strontium		23.0000			23.0000			mg/l	08-15-90
Thallium	<	10.0000	NA		0.0000			mg/l	08-15-90
Titanium	<	0.1000	<		0.1000			mg/l	08-15-90
Vanadium	<	0.5000	<		0.5000			mg/l	08-15-90
Zinc	<	0.2000	<		0.2000			mg/l	08-15-90

CONTRACT LABORATORY ANALYSIS

H-03b1, MAGENTA, ROUND 5

GENERAL CHEMISTRY

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
pH		6.5000		6.5100				08-28-90
Specific Conductance		10300.0000		10310.0000			uMhos/cm@25C	08-28-90
Alkalinity (HCO3)		36.0000		0.0000			mg/l	08-28-90
Bromide		6.0000		6.0000			mg/l	08-28-90
Chloride		3200.0000		3200.0000			mg/l	08-28-90
Alkalinity (CO3)		0.0000	NA	0.0000			mg/l	08-28-90
Cyanide	<	0.0100		0.0000			mg/l	08-28-90
Fluoride		2.2000		0.0000			mg/l	08-28-90
Iodide	<	2.0000	<	2.0000			mg/l	08-28-90
Nitrate	<	0.0200	<	0.0200			mg/l	08-28-90
Total Phenolics	<	0.0050		0.0000			mg/l	08-28-90
Phosphorus		0.0300		0.0000			mg/l	08-28-90
Residue, Filterable @ 180 c		9300.0000		0.0000			mg/l	08-28-90
Residue, Nonfilterable @ 105 c		18.0000		0.0000			mg/l	08-28-90
Silica		5.5000		0.0000			mg/l	08-28-90
Sulfate		2100.0000		0.0000			mg/l	08-28-90
Total Organic Carbon	<	1.0000	<	1.0000			mg/l	08-28-90
Total Organic Halides	<	0.0500	<	0.0500			mg/l	08-28-90

CONTRACT LABORATORY ANALYSIS

H-03b1, MAGENTA, ROUND 5

METALS ANALYSIS

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Calcium		1100.0000		1100.0000			mg/l	08-28-90
Magnesium		270.0000		270.0000			mg/l	08-28-90
Potassium		30.0000		30.0000			mg/l	08-28-90
Sodium		1400.0000		1400.0000			mg/l	08-28-90
Aluminum		0.3000		0.3000			mg/l	08-28-90
Antimony		0.1100		0.1000			mg/l	08-28-90
Arsenic	<	0.0100	NA	0.0000			mg/l	08-28-90
Barium	<	0.2000	<	0.2000			mg/l	08-28-90
Beryllium	<	0.0050	<	0.0050			mg/l	08-28-90
Boron		3.3000		3.3000			mg/l	08-28-90
Cadmium	<	0.0170	<	0.0180			mg/l	08-28-90
Cesium	<	0.2000	<	0.2000			mg/l	08-28-90
Chromium		0.1200		0.1200			mg/l	08-28-90
Cobalt	<	0.0500	<	0.0500			mg/l	08-28-90
Copper	<	0.0250	<	0.0250			mg/l	08-28-90
Iron	<	0.1000	<	0.1000			mg/l	08-28-90
Lead		0.1400		0.1400			mg/l	08-28-90
Lithium		0.3000		0.3000			mg/l	08-28-90
Manganese		0.0310		0.0300			mg/l	08-28-90
Mercury	<	0.0004	<	0.0004			mg/l	08-28-90
Molybdenum		0.0500		0.0500			mg/l	08-28-90
Nickel		0.0600		0.0600			mg/l	08-28-90
Selenium	<	0.0500	NA	0.0000			mg/l	08-28-90
Silver		0.0300		0.0300			mg/l	08-28-90
Strontium		16.0000		16.0000			mg/l	08-28-90
Thallium	<	1.0000	NA	0.0000			mg/l	08-28-90
Titanium		0.0200		0.0200			mg/l	08-28-90
Vanadium		0.0700		0.0700			mg/l	08-28-90
Zinc	<	0.0200	<	0.0200			mg/l	08-28-90

CONTRACT LABORATORY ANALYSIS

H-04b, CULEBRA, ROUND 5

GENERAL CHEMISTRY

PARAMETER	V	VALUE	S	D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
pH		6.6800			6.7100				09-11-90
Specific Conductance		21900.0000			22000.0000			uMhos/cm@25C	09-11-90
Alkalinity (HCO3)		54.0000			0.0000			mg/l	09-11-90
Bromide		44.0000			44.0000			mg/l	09-11-90
Chloride		650.0000			580.0000			mg/l	09-11-90
Alkalinity (CO3)		0.0000		NA	0.0000			mg/l	09-11-90
Cyanide	<	0.0100			0.0000			mg/l	09-11-90
Fluoride		2.1000			0.0000			mg/l	09-11-90
Iodide	<	2.0000		<	2.0000			mg/l	09-11-90
Nitrate	<	0.0200		<	0.0200			mg/l	09-11-90
Total Phenolics	<	0.0050			0.0000			mg/l	09-11-90
Phosphorus	<	0.0100			0.0000			mg/l	09-11-90
Residue, Filterable @ 180 c		21000.0000			0.0000			mg/l	09-11-90
Residue, Nonfilterable @ 105 c		48.0000			0.0000			mg/l	09-11-90
Silica		5.9000			0.0000			mg/l	09-11-90
Sulfate		4800.0000			0.0000			mg/l	09-11-90
Total Organic Carbon		5.0000			4.0000			mg/l	09-11-90
Total Organic Halides		0.0800			0.0600			mg/l	09-11-90

CONTRACT LABORATORY ANALYSIS

H-04b, CULEBRA, ROUND 5

METALS ANALYSIS

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Calcium		630.0000		640.0000			mg/l	09-11-90
Magnesium		390.0000		390.0000			mg/l	09-11-90
Potassium		170.0000		170.0000			mg/l	09-11-90
Sodium		6000.0000		6000.0000			mg/l	09-11-90
Aluminum	<	2.0000	<	2.0000			mg/l	09-11-90
Antimony	<	0.6000	<	0.6000			mg/l	09-11-90
Arsenic	<	0.1000	NA	0.0000			mg/l	09-11-90
Barium	<	2.0000	<	2.0000			mg/l	09-11-90
Beryllium	<	0.0500	<	0.0500			mg/l	09-11-90
Boron		17.0000		17.0000			mg/l	09-11-90
Cadmium	<	0.0500	<	0.0500			mg/l	09-11-90
Cesium	<	0.2000	<	0.2000			mg/l	09-11-90
Chromium		0.2000		0.2000			mg/l	09-11-90
Cobalt	<	0.5000	<	0.5000			mg/l	09-11-90
Copper	<	0.2500	<	0.2500			mg/l	09-11-90
Iron	<	1.0000	<	1.0000			mg/l	09-11-90
Lead	<	0.5000	<	0.5000			mg/l	09-11-90
Lithium		0.3000		0.3000			mg/l	09-11-90
Manganese	<	0.1900	<	0.1900			mg/l	09-11-90
Mercury	<	0.0004	<	0.0004			mg/l	09-11-90
Molybdenum	<	0.2000	<	0.2000			mg/l	09-11-90
Nickel	<	0.4000	<	0.4000			mg/l	09-11-90
Selenium	<	0.0500	NA	0.0000			mg/l	09-11-90
Silver	<	0.1000	<	0.1000			mg/l	09-11-90
Strontium		13.0000		13.0000			mg/l	09-11-90
Thallium	<	0.1000	NA	0.0000			mg/l	09-11-90
Titanium	<	0.1000	<	0.1000			mg/l	09-11-90
Vanadium	<	0.5000	<	0.5000			mg/l	09-11-90
Zinc	<	0.2000	<	0.2000			mg/l	09-11-90

CONTRACT LABORATORY ANALYSIS

H-04c, MAGENTA, ROUND 5

GENERAL CHEMISTRY

PARAMETER	V	VALUE	S	D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
pH		7.4300			7.4300				10-2-90
Specific Conductance		28800.0000			28800.0000			uMhos/cm@25C	10-2-90
Alkalinity (HCO3)		62.0000			0.0000			mg/l	10-2-90
Bromide		6.0000			6.0000			mg/l	10-2-90
Chloride		9000.0000			8900.0000			mg/l	10-2-90
Alkalinity (CO3)		0.0000	NA		0.0000			mg/l	10-2-90
Cyanide	<	0.0100	NA		0.0000			mg/l	10-2-90
Fluoride		2.8000			0.0000			mg/l	10-2-90
Iodide	<	2.0000	<		2.0000			mg/l	10-2-90
Nitrate	<	0.0200	<		0.0200			mg/l	10-2-90
Total Phenolics		0.0290	NA		0.0000			mg/l	10-2-90
Phosphorus	<	0.0100	NA		0.0000			mg/l	10-2-90
Residue, Filterable @ 180 c		24600.0000	NA		0.0000			mg/l	10-2-90
Residue, Nonfilterable @ 105 c		59.0000	NA		0.0000			mg/l	10-2-90
Silica		4.7000	NA		0.0000			mg/l	10-2-90
Sulfate		7600.0000	NA		0.0000			mg/l	10-2-90
Total Organic Carbon	<	1.0000	<		1.0000			mg/l	10-2-90
Total Organic Halides	<	0.1000	<		0.0500			mg/l	10-2-90

CONTRACT LABORATORY ANALYSIS

H-04c, MAGENTA, ROUND 5

METALS ANALYSIS

PARAMETER	V	VALUE	S	D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Calcium		630.0000			630.0000			mg/l	10-2-90
Magnesium		400.0000			410.0000			mg/l	10-2-90
Potassium		70.0000			70.0000			mg/l	10-2-90
Sodium		3600.0000			3600.0000			mg/l	10-2-90
Aluminum	<	2.0000		<	2.0000			mg/l	10-2-90
Antimony	<	0.6000		<	0.6000			mg/l	10-2-90
Arsenic	<	0.1000		NA	0.0000			mg/l	10-2-90
Barium	<	0.2000		<	0.2000			mg/l	10-2-90
Beryllium	<	0.0500		<	0.0500			mg/l	10-2-90
Boron		12.0000			12.0000			mg/l	10-2-90
Cadmium	<	0.0500		<	0.0500			mg/l	10-2-90
Cesium	<	0.1000		<	0.1000			mg/l	10-2-90
Chromium	<	0.1000		<	0.1000			mg/l	10-2-90
Cobalt	<	0.5000		<	0.5000			mg/l	10-2-90
Copper	<	0.2500		<	0.2500			mg/l	10-2-90
Iron	<	1.0000		<	1.0000			mg/l	10-2-90
Lead	<	0.5000		<	0.5000			mg/l	10-2-90
Lithium		0.3900			0.3900			mg/l	10-2-90
Manganese	<	0.1500		<	0.1500			mg/l	10-2-90
Mercury	<	0.0002		<	0.0002			mg/l	10-2-90
Molybdenum	<	0.2000		<	0.2000			mg/l	10-2-90
Nickel	<	0.4000		<	0.4000			mg/l	10-2-90
Selenium	<	0.0500		NA	0.0000			mg/l	10-2-90
Silver	<	0.1000		<	0.1000			mg/l	10-2-90
Strontium		11.0000			11.0000			mg/l	10-2-90
Thallium	<	0.1000		NA	0.0000			mg/l	10-2-90
Titanium	<	0.1000		<	0.1000			mg/l	10-2-90
Vanadium	<	0.5000		<	0.5000			mg/l	10-2-90
Zinc	<	0.2000		<	0.2000			mg/l	10-2-90

CONTRACT LABORATORY ANALYSIS

H-11b3, CULEBRA, ROUND 5

GENERAL CHEMISTRY

PARAMETER	V	VALUE	S	D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
pH		7.0600			7.0600				10-17-90
Specific Conductance		112000.0000			112000.0000			uMhos/cm@25C	10-17-90
Alkalinity (HCO3)		44.0000			0.0000			mg/l	10-17-90
Bromide		51.0000		NA	0.0000			mg/l	10-17-90
Chloride		56000.0000			56000.0000			mg/l	10-17-90
Alkalinity (CO3)		0.0000		NA	0.0000			mg/l	10-17-90
Cyanide	<	0.0100			0.0000			mg/l	10-17-90
Fluoride		1.1000			0.0000			mg/l	10-17-90
Iodide	<	2.0000		<	2.0000			mg/l	10-17-90
Nitrate	<	0.0200			0.0000			mg/l	10-17-90
Total Phenolics	<	0.0050			0.0000			mg/l	10-17-90
Phosphorus	<	0.0100			0.0000			mg/l	10-17-90
Residue, Filterable @ 180 c		113000.0000			0.0000			mg/l	10-17-90
Residue, Nonfilterable @ 105 c		640.0000			0.0000			mg/l	10-17-90
Silica		4.1000			0.0000			mg/l	10-17-90
Sulfate		7400.0000			0.0000			mg/l	10-17-90
Total Organic Carbon		3.0000			2.0000			mg/l	10-17-90
Total Organic Halides		0.0600		<	0.0500			mg/l	10-17-90

CONTRACT LABORATORY ANALYSIS

H-11b3, CULEBRA, ROUND 5

METALS ANALYSIS

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Calcium		1500.0000		1500.0000			mg/l	10-17-90
Magnesium		1100.0000		1100.0000			mg/l	10-17-90
Potassium		680.0000		670.0000			mg/l	10-17-90
Sodium		40000.0000		41000.0000			mg/l	10-17-90
Aluminum	<	2.0000	<	2.0000			mg/l	10-17-90
Antimony	<	0.6000	<	0.6000			mg/l	10-17-90
Arsenic	<	0.1000	NA	0.0000			mg/l	10-17-90
Barium	<	2.0000	<	2.0000			mg/l	10-17-90
Beryllium	<	0.0500	<	0.0500			mg/l	10-17-90
Boron		31.0000		31.0000			mg/l	10-17-90
Cadmium		0.0600		0.0600			mg/l	10-17-90
Cesium	<	0.1000	<	0.1000			mg/l	10-17-90
Chromium		0.4000		0.4000			mg/l	10-17-90
Cobalt	<	0.5000	<	0.5000			mg/l	10-17-90
Copper	<	0.2500	<	0.2500			mg/l	10-17-90
Iron	<	1.0000	<	1.0000			mg/l	10-17-90
Lead		0.6000		0.6000			mg/l	10-17-90
Lithium		0.5000		0.5000			mg/l	10-17-90
Manganese		0.2200		0.2300			mg/l	10-17-90
Mercury	<	0.0002	<	0.0002			mg/l	10-17-90
Molybdenum		0.3000		0.3000			mg/l	10-17-90
Nickel	<	0.4000	<	0.4000			mg/l	10-17-90
Selenium	<	0.0500	NA	0.0000			mg/l	10-17-90
Silver		0.1000		0.1000			mg/l	10-17-90
Strontium		21.0000		21.0000			mg/l	10-17-90
Thallium	<	10.0000	NA	0.0000			mg/l	10-17-90
Titanium		0.1000		0.1000			mg/l	10-17-90
Vanadium	<	0.5000	<	0.5000			mg/l	10-17-90
Zinc	<	0.2000	<	0.2000			mg/l	10-17-90

CONTRACT LABORATORY ANALYSIS

H-07b1, CULEBRA, ROUND 5

GENERAL CHEMISTRY

PARAMETER	V	VALUE	S D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
pH		7.1400		7.1200				11-09-90
Specific Conductance		3760.0000		3760.0000			uMhos/cm@25C	11-09-90
Alkalinity (HCO3)		92.0000	NA	0.0000			mg/l	11-09-90
Bromide	<	2.0000	<	2.0000			mg/l	11-09-90
Chloride		280.0000		280.0000			mg/l	11-09-90
Alkalinity (CO3)		0.0000	NA	0.0000			mg/l	11-09-90
Cyanide	<	0.0100	NA	0.0000			mg/l	11-09-90
Fluoride		1.5000	NA	0.0000			mg/l	11-09-90
Iodide	<	2.0000	<	2.0000			mg/l	11-09-90
Nitrate		0.9000		0.9000			mg/l	11-09-90
Total Phenolics	<	0.0050	NA	0.0000			mg/l	11-09-90
Phosphorus	<	0.0100	NA	0.0000			mg/l	11-09-90
Residue, Filterable @ 180 c		3500.0000	NA	0.0000			mg/l	11-09-90
Residue, Nonfilterable @ 105 c	<	4.0000	NA	0.0000			mg/l	11-09-90
Silica		23.0000	NA	0.0000			mg/l	11-09-90
Sulfate		2100.0000		2100.0000			mg/l	11-09-90
Total Organic Carbon		8.0000		8.0000			mg/l	11-09-90
Total Organic Halides	<	0.0500		0.0600			mg/l	11-09-90

CONTRACT LABORATORY ANALYSIS

H-07b1, CULEBRA, ROUND 5

METALS ANALYSIS

PARAMETER	V	VALUE	S	D	VALUE_DUP	ACIDBLANK	WATERBLANK	UNITS	DATE
Calcium		670.0000			660.0000			mg/l	11-09-90
Magnesium		140.0000			140.0000			mg/l	11-09-90
Potassium	<	50.0000	<		50.0000			mg/l	11-09-90
Sodium		100.0000			100.0000			mg/l	11-09-90
Aluminum	<	2.0000	<		2.0000	< .2	< .2	mg/l	11-09-90
Antimony	<	0.6000	<		0.6000	< .06	< .06	mg/l	11-09-90
Arsenic	<	0.0100	NA		0.0000	< .01	< .01	mg/l	11-09-90
Barium	<	2.0000	<		2.0000	< .2	< .2	mg/l	11-09-90
Beryllium	<	0.0500	<		0.0500	< .005	< .005	mg/l	11-09-90
Boron		0.9000			0.9000	0.04	0.03	mg/l	11-09-90
Cadmium	<	0.0500	<		0.0500	< .005	< .005	mg/l	11-09-90
Cesium	<	0.1000	<		0.1000	< .1	< .1	mg/l	11-09-90
Chromium		0.2000			0.2000	0.01	0.01	mg/l	11-09-90
Cobalt	<	0.5000	<		0.5000	< .05	< .05	mg/l	11-09-90
Copper	<	0.2500	<		0.2500	< .025	< .025	mg/l	11-09-90
Iron	<	1.0000			1.0000	< .1	< .1	mg/l	11-09-90
Lead	<	0.5000	<		0.5000	< .05	< .05	mg/l	11-09-90
Lithium	<	0.1000	<		0.1000	< .01	< .01	mg/l	11-09-90
Manganese	<	0.1500	<		0.1500	< .015	< .015	mg/l	11-09-90
Mercury	<	0.0020	<		0.0020	< .0002	< .0002	mg/l	11-09-90
Molybdenum	<	0.2000	<		0.2000	< .02	< .02	mg/l	11-09-90
Nickel	<	0.4000	<		0.4000	< .04	< .04	mg/l	11-09-90
Selenium	<	0.0500	NA		0.0000	< .005	< .005	mg/l	11-09-90
Silver	<	0.1000	<		0.1000	< .01	< .01	mg/l	11-09-90
Strontium		8.5000			8.5000	< .01	< .01	mg/l	11-09-90
Thallium	<	0.1000			0.0000	< .01	< .01	mg/l	11-09-90
Titanium	<	0.1000	<		0.1000	< .01	< .01	mg/l	11-09-90
Vanadium	<	0.5000	<		0.5000	< .05	< .05	mg/l	11-09-90
Zinc	<	0.2000	<		0.2000	< .02	< .02	mg/l	11-09-90

APPENDIX VII
TABULATED RESULTS
OF
SERIAL SAMPLING ANALYSIS

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SERIAL SAMPLE FIELD ANALYSIS
H-09b, CULEBRA
ROUND 4

NO	PARAMETER	V	VALUE	S	D	VALUE_DUP	UNITS	DATE	FLOW
1	Eh		261.0000	NA		0.0000	mV	01-16-90	593
2	Eh		245.0000	NA		0.0000	mV	01-17-90	1416
3	Eh		238.0000	NA		0.0000	mV	01-18-90	2236
4	Eh		197.0000	NA		0.0000	mV	01-19-90	3058
1	pH		7.3100	NA		0.0000	S.U.	01-16-90	593
2	pH		7.3100	NA		0.0000	S.U.	01-17-90	1416
3	pH		7.3500	NA		0.0000	S.U.	01-18-90	2236
4	pH		7.3600	NA		0.0000	S.U.	01-19-90	3058
1	TEMPERATURE		21.1000	NA		0.0000	C	01-16-90	593
2	TEMPERATURE		21.0000	NA		0.0000	C	01-17-90	1416
3	TEMPERATURE		21.5000	NA		0.0000	C	01-18-90	2236
4	TEMPERATURE		21.0000	NA		0.0000	C	01-19-90	3058
1	Sp.GRAVITY		1.0040	NA		0.0000	@ 21.0 C	01-16-90	593
4	Sp.GRAVITY		1.0040	NA		0.0000	@ 21.1 C	01-19-90	3058
1	Sp.CONDUCTANCE		3460.0000	NA		0.0000	umhos/cm@25C	01-16-90	593
4	Sp.CONDUCTANCE		3430.0000	NA		0.0000	umhos/cm@25C	01-19-90	3058
1	ALKALINITY		112.4000			113.4000	mg/l	01-16-90	593
2	ALKALINITY		114.6000			115.6000	mg/l	01-17-90	1416
3	ALKALINITY		115.1000			115.1000	mg/l	01-18-90	2236
4	ALKALINITY		116.4000			115.9000	mg/l	01-19-90	3058
1	CHLORIDE		170.0000			171.0000	mg/l	01-16-90	593
2	CHLORIDE		169.0000			169.0000	mg/l	01-17-90	1416
3	CHLORIDE		170.0000			169.0000	mg/l	01-18-90	2236
4	CHLORIDE		169.0000			169.0000	mg/l	01-19-90	3058
1	DIVALENT CATIONS		42.9000			42.8000	meq/l	01-16-90	593
2	DIVALENT CATIONS		42.5000			42.7000	meq/l	01-17-90	1416
3	DIVALENT CATIONS		42.6000			42.7000	meq/l	01-18-90	2236
4	DIVALENT CATIONS		43.1000			42.9000	meq/l	01-19-90	3058
1	TOTAL IRON		0.0900			0.0700	mg/l	01-16-90	593
2	TOTAL IRON		0.1000			0.0800	mg/l	01-17-90	1416
3	TOTAL IRON		0.0700			0.0800	mg/l	01-18-90	2236
4	TOTAL IRON		0.0900			0.0800	mg/l	01-19-90	3058
1	FERROUS IRON		0.0600			0.0600	mg/l	01-16-90	593
2	FERROUS IRON		0.0600			0.0400	mg/l	01-17-90	1416
3	FERROUS IRON		0.0500			0.0600	mg/l	01-18-90	2236
4	FERROUS IRON		0.0500			0.0500	mg/l	01-19-90	3058

SERIAL SAMPLE FIELD ANALYSIS
H-04b, CULEBRA
ROUND 5

NO	PARAMETER	V	VALUE	S D	VALUE_DUP	UNITS	DATE	FLOW
1	Eh		227.0000	NA	0.0000	mV	02-06-90	579
2	Eh		203.0000	NA	0.0000	mV	02-07-90	1452
3	Eh		217.0000	NA	0.0000	mV	02-08-90	2375
4	Eh		190.0000	NA	0.0000	mV	02-09-90	3282
5	Eh		208.0000	NA	0.0000	mV	02-10-90	4518
6	Eh		208.0000	NA	0.0000	mV	02-11-90	5326
7	Eh		213.0000	NA	0.0000	mV	02-12-90	6127
1	pH		6.9800	NA	0.0000	S.U.	02-06-90	579
2	pH		6.9600	NA	0.0000	S.U.	02-07-90	1452
3	pH		7.0100	NA	0.0000	S.U.	02-08-90	2375
4	pH		7.0000	NA	0.0000	S.U.	02-09-90	3282
5	pH		7.0100	NA	0.0000	S.U.	02-10-90	4518
6	pH		7.0400	NA	0.0000	S.U.	02-11-90	5326
7	pH		7.0400	NA	0.0000	S.U.	02-12-90	6127
1	TEMPERATURE		21.3000	NA	0.0000	C	02-06-90	579
2	TEMPERATURE		21.4000	NA	0.0000	C	02-07-90	1452
3	TEMPERATURE		21.3000	NA	0.0000	C	02-08-90	2375
4	TEMPERATURE		21.2000	NA	0.0000	C	02-09-90	3282
5	TEMPERATURE		21.3000	NA	0.0000	C	02-10-90	4518
6	TEMPERATURE		21.5000	NA	0.0000	C	02-11-90	5326
7	TEMPERATURE		21.5000	NA	0.0000	C	02-12-90	6127
1	Sp.GRAVITY		1.0422	NA	0.0000	@ 21.2 C	02-06-90	579
7	Sp.GRAVITY		1.0448	NA	0.0000	@ 21.5 C	02-12-90	6127
1	Sp.CONDUCTANCE		73400.0000	NA	0.0000	umhos/cm@25C	02-06-90	579
7	Sp.CONDUCTANCE		75300.0000	NA	0.0000	umhos/cm@25C	02-12-90	6127
1	ALKALINITY		96.0000		95.0000	mg/l	02-06-90	579
2	ALKALINITY		94.0000		93.1000	mg/l	02-07-90	1452
3	ALKALINITY		94.5000		94.5000	mg/l	02-08-90	2375
4	ALKALINITY		94.0000		94.5000	mg/l	02-09-90	3282
5	ALKALINITY		93.5000		94.3000	mg/l	02-10-90	4518
6	ALKALINITY		94.5000		94.5000	mg/l	02-11-90	5326
7	ALKALINITY		95.3000		95.5000	mg/l	02-12-90	6127
1	CHLORIDE		31835.0000		31974.0000	mg/l	02-06-90	579
2	CHLORIDE		32044.0000		31905.0000	mg/l	02-07-90	1452
3	CHLORIDE		32113.0000		31905.0000	mg/l	02-08-90	2375
4	CHLORIDE		31557.0000		31905.0000	mg/l	02-09-90	3282
5	CHLORIDE		31974.0000		32113.0000	mg/l	02-10-90	4518
6	CHLORIDE		32113.0000		32322.0000	mg/l	02-11-90	5326
7	CHLORIDE		32322.0000		32113.0000	mg/l	02-12-90	6127
1	DIVALENT CATIONS		197.3000		198.9000	meq/l	02-06-90	579
2	DIVALENT CATIONS		196.5000		195.7000	meq/l	02-07-90	1452
3	DIVALENT CATIONS		195.7000		194.8000	meq/l	02-08-90	2375
4	DIVALENT CATIONS		196.9000		195.7000	meq/l	02-09-90	3282
5	DIVALENT CATIONS		195.2000		194.0000	meq/l	02-10-90	4518
6	DIVALENT CATIONS		194.8000		195.7000	meq/l	02-11-90	5326
7	DIVALENT CATIONS		196.9000		196.1000	meq/l	02-12-90	6127
1	TOTAL IRON		0.8000		0.7800	mg/l	02-06-90	579
2	TOTAL IRON		0.4600		0.4300	mg/l	02-07-90	1452
3	TOTAL IRON		0.4200		0.4000	mg/l	02-08-90	2375
4	TOTAL IRON		0.4200		0.4400	mg/l	02-09-90	3282
5	TOTAL IRON		0.4300		0.4100	mg/l	02-10-90	4518
6	TOTAL IRON		0.4000		0.4100	mg/l	02-11-90	5326
7	TOTAL IRON		0.3400		0.3700	mg/l	02-12-90	6127
1	FERROUS IRON		0.7100		0.7000	mg/l	02-06-90	579
2	FERROUS IRON		0.3500		0.3600	mg/l	02-07-90	1452
3	FERROUS IRON		0.3400		0.3500	mg/l	02-08-90	2375
4	FERROUS IRON		0.4000		0.3700	mg/l	02-09-90	3282
5	FERROUS IRON		0.3400		0.3400	mg/l	02-10-90	4518
6	FERROUS IRON		0.3400		0.3200	mg/l	02-11-90	5326
7	FERROUS IRON		0.2900		0.2800	mg/l	02-12-90	6127

H-06c, MAGENTA
SERIAL SAMPLE FIELD AMALYSIS
H-06c, MAGENTA
ROUND 5

NO	PARAMETER	V	VALUE	S	D	VALUE_DUP	UNITS	DATE	FLOW
1	Eh		183.0000		NA	0.0000	mV	03-13-90	326
2	Eh		221.0000		NA	0.0000	mV	03-14-90	811
3	Eh		224.0000		NA	0.0000	mV	03-15-90	1308
1	pH		7.8200		NA	0.0000	S.U.	03-13-90	326
2	pH		7.8000		NA	0.0000	S.U.	03-14-90	811
3	pH		7.8300		NA	0.0000	S.U.	03-15-90	1308
1	TEMPERATURE		21.0000		NA	0.0000	C	03-13-90	326
2	TEMPERATURE		20.0000		NA	0.0000	C	03-14-90	811
3	TEMPERATURE		21.2000		NA	0.0000	C	03-15-90	1308
1	Sp.GRAVITY		1.0032		NA	0.0000	@ 20.8 C	03-13-90	326
3	Sp.GRAVITY		1.0034		NA	0.0000	@ 21.2 C	03-15-90	1308
1	Sp.CONDUCTANCE		4900.0000		NA	0.0000	umhos/cm@25C	03-13-90	326
3	Sp.CONDUCTANCE		5200.0000		NA	0.0000	umhos/cm@25C	03-15-90	1308
1	ALKALINITY		54.3000			53.6000	mg/l	03-13-90	326
2	ALKALINITY		52.6000			52.3000	mg/l	03-14-90	811
3	ALKALINITY		51.4000			50.6000	mg/l	03-15-90	1308
1	CHLORIDE		405.0000			408.0000	mg/l	03-13-90	326
2	CHLORIDE		407.0000			408.0000	mg/l	03-14-90	811
3	CHLORIDE		405.0000			403.0000	mg/l	03-15-90	1308
1	DIVALENT CATIONS		42.1000			41.8000	meq/l	03-13-90	326
2	DIVALENT CATIONS		41.9000			42.0800	meq/l	03-14-90	811
3	DIVALENT CATIONS		41.5000			41.5000	meq/l	03-15-90	1308
1	TOTAL IRON		0.1400			0.1500	mg/l	03-13-90	326
2	TOTAL IRON		0.1500			0.1500	mg/l	03-14-90	811
3	TOTAL IRON		0.1000			0.0900	mg/l	03-15-90	1308
1	FERROUS IRON		0.1300			0.1200	mg/l	03-13-90	326
2	FERROUS IRON		0.1200			0.0900	mg/l	03-14-90	811
3	FERROUS IRON		0.0700			0.0600	mg/l	03-15-90	1308

SERIAL SAMPLE FIELD ANALYSIS
H-18, CULEBRA
ROUND 3

NO	PARAMETER	V	VALUE	S	D	VALUE_DUP	UNITS	DATE	FLOW
1	Eh		235.0000	NA		0.0000	mV	04-02-90	1336
2	Eh		208.0000	NA		0.0000	mV	04-03-90	1987
3	Eh		208.0000	NA		0.0000	mV	04-04-90	2688
4	Eh		239.0000	NA		0.0000	mV	04-05-90	3408
5	Eh		227.0000	NA		0.0000	mV	04-06-90	4126
6	Eh		171.0000	NA		0.0000	mV	04-08-90	5609
7	Eh		169.0000	NA		0.0000	mV	04-09-90	6243
8	Eh		233.0000	NA		0.0000	mV	04-10-90	6933
1	pH		7.8300	NA		0.0000	S.U.	04-02-90	1336
2	pH		7.8300	NA		0.0000	S.U.	04-03-90	1987
3	pH		7.7900	NA		0.0000	S.U.	04-04-90	2688
4	pH		7.7800	NA		0.0000	S.U.	04-05-90	3408
5	pH		7.7200	NA		0.0000	S.U.	04-06-90	4126
6	pH		7.7500	NA		0.0000	S.U.	04-08-90	5609
7	pH		7.7000	NA		0.0000	S.U.	04-09-90	6243
8	pH		7.7200	NA		0.0000	S.U.	04-10-90	6933
1	TEMPERATURE		21.2000	NA		0.0000	C	04-02-90	1336
2	TEMPERATURE		20.8000	NA		0.0000	C	04-03-90	1987
3	TEMPERATURE		21.2000	NA		0.0000	C	04-04-90	2688
4	TEMPERATURE		22.0000	NA		0.0000	C	04-05-90	3408
5	TEMPERATURE		21.4000	NA		0.0000	C	04-06-90	4126
6	TEMPERATURE		21.4000	NA		0.0000	C	04-08-90	5609
7	TEMPERATURE		22.1000	NA		0.0000	C	04-09-90	6243
8	TEMPERATURE		21.5000	NA		0.0000	C	04-10-90	6933
1	Sp.GRAVITY		1.0232	NA		0.0000	@ 21.3 C	04-02-90	1336
6	Sp.GRAVITY		1.0220	NA		0.0000	@ 21.5 C	04-08-90	5609
8	Sp.GRAVITY		1.0200	NA		0.0000	@ 21.5 C	04-10-90	6933
1	Sp.CONDUCTANCE		44500.0000	NA		0.0000	umhos/cm@25C	04-02-90	1336
6	Sp.CONDUCTANCE		39800.0000	NA		0.0000	umhos/cm@25C	04-08-90	5609
8	Sp.CONDUCTANCE		39300.0000	NA		0.0000	umhos/cm@25C	04-10-90	6933
1	ALKALINITY		55.0000			55.7000	mg/l	04-02-90	1336
2	ALKALINITY		53.7000			53.2000	mg/l	04-03-90	1987
3	ALKALINITY		51.5000			52.5000	mg/l	04-04-90	2688
4	ALKALINITY		51.0000			51.8000	mg/l	04-05-90	3408
5	ALKALINITY		52.9000			52.2000	mg/l	04-06-90	4126
6	ALKALINITY		51.2000			51.2000	mg/l	04-08-90	5609
7	ALKALINITY		50.9000			51.7000	mg/l	04-09-90	6243
8	ALKALINITY		51.9000			51.2000	mg/l	04-10-90	6933
1	CHLORIDE		16567.0000			16671.0000	mg/l	04-02-90	1336
2	CHLORIDE		14792.0000			14931.0000	mg/l	04-03-90	1987
3	CHLORIDE		14513.0000			14618.0000	mg/l	04-04-90	2688
4	CHLORIDE		14228.0000			14144.0000	mg/l	04-05-90	3408
5	CHLORIDE		14007.0000			13896.0000	mg/l	04-06-90	4126
6	CHLORIDE		13924.0000			13841.0000	mg/l	04-08-90	5609
7	CHLORIDE		13813.0000			13868.0000	mg/l	04-09-90	6243
8	CHLORIDE		13924.0000			14007.0000	mg/l	04-10-90	6933
1	DIVALENT CATIONS		104.4000			104.0000	meq/l	04-02-90	1336
2	DIVALENT CATIONS		102.6000			102.4000	meq/l	04-03-90	1987
3	DIVALENT CATIONS		99.6000			100.8000	meq/l	04-04-90	2688
4	DIVALENT CATIONS		101.2000			101.6000	meq/l	04-05-90	3408
5	DIVALENT CATIONS		100.5000			100.5000	meq/l	04-06-90	4126
6	DIVALENT CATIONS		101.3000			100.9000	meq/l	04-08-90	5609
7	DIVALENT CATIONS		101.7000			101.5000	meq/l	04-09-90	6243
8	DIVALENT CATIONS		100.7000			100.7000	meq/l	04-10-90	6933
1	TOTAL IRON		1.5200			1.5300	mg/l	04-02-90	1336
2	TOTAL IRON		0.6900			0.6400	mg/l	04-03-90	1987
3	TOTAL IRON		0.5000			0.5200	mg/l	04-04-90	2688
4	TOTAL IRON		0.4800			0.4600	mg/l	04-05-90	3408
5	TOTAL IRON		0.4200			0.4400	mg/l	04-06-90	4126
6	TOTAL IRON		0.3800			0.3500	mg/l	04-08-90	5609
7	TOTAL IRON		0.3600			0.3600	mg/l	04-09-90	6243
8	TOTAL IRON		0.3700			0.3900	mg/l	04-10-90	6933
1	FERROUS IRON		1.3900			1.3800	mg/l	04-02-90	1336
2	FERROUS IRON		0.5300			0.5500	mg/l	04-03-90	1987
3	FERROUS IRON		0.3700			0.3800	mg/l	04-04-90	2688
4	FERROUS IRON		0.3200			0.3600	mg/l	04-05-90	3408
5	FERROUS IRON		0.3500			0.3100	mg/l	04-06-90	4126
6	FERROUS IRON		0.2800			0.3100	mg/l	04-08-90	5609
7	FERROUS IRON		0.2700			0.3000	mg/l	04-09-90	6243
8	FERROUS IRON		0.3400			0.3100	mg/l	04-10-90	6933

SERIAL SAMPLE FIELD ANALYSIS
WIPP-19, CULEBRA
ROUND 5

NO	PARAMETER	V	VALUE	S	D	VALUE_DUP	UNITS	DATE	FLOW
1	Eh		157.0000		NA	0.0000	mV	06-04-90	2512
2	Eh		13.0000		NA	0.0000	mV	06-06-90	3156
3	Eh		-53.0000		NA	0.0000	mV	06-07-90	3579
4	Eh		85.0000		NA	0.0000	mV	06-10-90	4602
5	Eh		210.0000		NA	0.0000	mV	06-11-90	5050
6	Eh		204.0000		NA	0.0000	mV	06-12-90	5516
1	PH		7.4600		NA	0.0000	S.U.	06-04-90	2512
2	PH		7.5600		NA	0.0000	S.U.	06-06-90	3156
3	PH		7.5000		NA	0.0000	S.U.	06-07-90	3579
4	PH		7.3800		NA	0.0000	S.U.	06-10-90	4602
5	PH		7.4800		NA	0.0000	S.U.	06-11-90	5050
6	PH		7.3100		NA	0.0000	S.U.	06-12-90	5516
1	TEMPERATURE		23.0000		NA	0.0000	C	06-04-90	2512
2	TEMPERATURE		22.9000		NA	0.0000	C	06-06-90	3156
3	TEMPERATURE		22.8000		NA	0.0000	C	06-07-90	3579
4	TEMPERATURE		23.0000		NA	0.0000	C	06-10-90	4602
5	TEMPERATURE		22.5000		NA	0.0000	C	06-11-90	5050
6	TEMPERATURE		23.1000		NA	0.0000	C	06-12-90	5516
1	Sp.GRAVITY		1.0570		NA	0.0000	@ 23.4 C	06-04-90	2512
4	Sp.GRAVITY		1.0560		NA	0.0000	@ 22.9 C	06-10-90	4602
6	Sp.GRAVITY		1.0546		NA	0.0000	@ 23.2 C	06-12-90	5516
1	Sp.CONDUCTANCE		94800.0000		NA	0.0000	umhos/cm@25C	06-04-90	2512
6	Sp.CONDUCTANCE		91800.0000		NA	0.0000	umhos/cm@25C	06-12-90	5516
1	ALKALINITY		74.8000			75.5000	mg/l	06-04-90	2512
2	ALKALINITY		65.8000			64.8000	mg/l	06-06-90	3156
3	ALKALINITY		62.6000			63.3000	mg/l	06-07-90	3579
4	ALKALINITY		57.5000			58.7000	mg/l	06-10-90	4602
5	ALKALINITY		57.3000			58.2000	mg/l	06-11-90	5050
6	ALKALINITY		59.7000			59.0000	mg/l	06-12-90	5516
1	CHLORIDE		41130.0000			41475.0000	mg/l	06-04-90	2512
2	CHLORIDE		40784.0000			40577.0000	mg/l	06-06-90	3156
3	CHLORIDE		40922.0000			41199.0000	mg/l	06-07-90	3579
4	CHLORIDE		40438.0000			40438.0000	mg/l	06-10-90	4602
5	CHLORIDE		40231.0000			40508.0000	mg/l	06-11-90	5050
6	CHLORIDE		40438.0000			40577.0000	mg/l	06-12-90	5516
1	DIVALENT CATIONS		191.0000			192.6000	mg/l	06-04-90	2512
2	DIVALENT CATIONS		188.6000			187.8000	mg/l	06-06-90	3156
3	DIVALENT CATIONS		180.5000			182.1000	mg/l	06-07-90	3579
4	DIVALENT CATIONS		184.5000			185.3000	mg/l	06-10-90	4602
5	DIVALENT CATIONS		177.7000			178.9000	mg/l	06-11-90	5050
6	DIVALENT CATIONS		178.5000			179.3000	mg/l	06-12-90	5516
1	TOTAL IRON		2.1800			2.1900	mg/l	06-04-90	2512
2	TOTAL IRON		2.4900			2.5200	mg/l	06-06-90	3156
3	TOTAL IRON		2.3200			2.3400	mg/l	06-07-90	3579
4	TOTAL IRON		1.0600			1.0900	mg/l	06-10-90	4602
5	TOTAL IRON		1.0300			1.0600	mg/l	06-11-90	5050
6	TOTAL IRON		0.8200			0.8300	mg/l	06-12-90	5516
1	FERROUS IRON		2.1800			2.1300	mg/l	06-04-90	2512
2	FERROUS IRON		2.4500			2.4100	mg/l	06-06-90	3156
3	FERROUS IRON		2.2000			2.2300	mg/l	06-07-90	3579
4	FERROUS IRON		1.0200			1.0000	mg/l	06-10-90	4602
5	FERROUS IRON		0.9800			0.9900	mg/l	06-11-90	5050
6	FERROUS IRON		0.7100			0.7200	mg/l	06-12-90	5516

SERIAL SAMPLE FIELD ANALYSIS
H-05c, MAGENTA
ROUND 5

NO	PARAMETER	V	VALUE	S	D	VALUE_DUP	UNITS	DATE	FLOW
1	Eh		0.0000	NA		0.0000	mV	05-14-90	1497
2	Eh		-2.0000	NA		0.0000	mV	05-15-90	1705
3	Eh		-4.0000	NA		0.0000	mV	05-16-90	1940
1	pH		7.9100	NA		0.0000	S.U.	05-14-90	1497
2	pH		7.9200	NA		0.0000	S.U.	05-15-90	1705
3	pH		7.9500	NA		0.0000	S.U.	05-16-90	1940
1	TEMPERATURE		21.7000	NA		0.0000	C	05-14-90	1497
2	TEMPERATURE		21.8000	NA		0.0000	C	05-15-90	1705
3	TEMPERATURE		21.8000	NA		0.0000	C	05-16-90	1940
1	Sp.GRAVITY		1.0070	NA		0.0000	@ 21.5 C	05-14-90	1497
3	Sp.GRAVITY		1.0062	NA		0.0000	@ 21.8 C	05-16-90	1940
1	Sp.CONDUCTANCE		8500.0000	NA		0.0000	umhos/cm@25C	05-14-90	1497
3	Sp.CONDUCTANCE		8480.0000	NA		0.0000	umhos/cm@25C	05-16-90	1940
1	ALKALINITY		58.0000			57.2000	mg/l	05-14-90	1497
2	ALKALINITY		58.0000			58.4000	mg/l	05-15-90	1705
3	ALKALINITY		59.7000			58.7000	mg/l	05-16-90	1940
1	CHLORIDE		1035.0000			1038.0000	mg/l	05-14-90	1497
2	CHLORIDE		1033.0000			1028.0000	mg/l	05-15-90	1705
3	CHLORIDE		1030.0000			1025.0000	mg/l	05-16-90	1940
1	DIVALENT CATIONS		42.9000			42.6000	meq/l	05-14-90	1497
2	DIVALENT CATIONS		42.9000			42.5000	meq/l	05-15-90	1705
3	DIVALENT CATIONS		42.6000			42.6000	meq/l	05-16-90	1940
1	TOTAL IRON		0.2200			0.2200	mg/l	05-14-90	1497
2	TOTAL IRON		0.1900			0.2100	mg/l	05-15-90	1705
3	TOTAL IRON		0.1800			0.1700	mg/l	05-16-90	1940
1	FERROUS IRON		0.1500			0.1400	mg/l	05-14-90	1497
2	FERROUS IRON		0.1300			0.1200	mg/l	05-15-90	1705
3	FERROUS IRON		0.1000			0.0900	mg/l	05-16-90	1940

SERIAL SAMPLING FIELD ANALYSIS
H-05b, CULEBRA
ROUND 5

NO	PARAMETER	V	VALUE	S D	VALUE_DUP	UNITS	DATE	FLOW
1	Eh		140.0000	NA	0.0000	mV	04-24-90	278
2	Eh		62.0000	NA	0.0000	mV	04-30-90	1753
3	Eh		134.0000	NA	0.0000	mV	05-01-90	2010
4	Eh		144.0000	NA	0.0000	mV	05-02-90	2253
1	pH		7.4700	NA	0.0000	S.U.	04-24-90	278
2	pH		7.4100	NA	0.0000	S.U.	04-30-90	1753
3	pH		7.2900	NA	0.0000	S.U.	05-01-90	2010
4	pH		7.2900	NA	0.0000	S.U.	05-02-90	2253
1	TEMPERATURE		21.2000	NA	0.0000	C	04-24-90	278
2	TEMPERATURE		20.5000	NA	0.0000	C	04-30-90	1753
3	TEMPERATURE		19.8000	NA	0.0000	C	05-01-90	2010
4	TEMPERATURE		20.3000	NA	0.0000	C	05-02-90	2253
1	Sp.GRAVITY		1.1040	NA	0.0000	@ 21.1 C	04-24-90	278
2	Sp.GRAVITY		1.1028	NA	0.0000	@ 20.6 C	04-30-90	1753
3	Sp.GRAVITY		1.1040	NA	0.0000	@ 19.4 C	05-01-90	2010
4	Sp.GRAVITY		1.1040	NA	0.0000	@ 20.2 C	05-02-90	2253
1	Sp.CONDUCTANCE		151900.0000	NA	0.0000	umhos/cm@25C	04-24-90	278
2	Sp.CONDUCTANCE		153700.0000	NA	0.0000	umhos/cm@25C	04-30-90	1753
4	Sp.CONDUCTANCE		155900.0000	NA	0.0000	umhos/cm@25C	05-02-90	2253
1	ALKALINITY		54.6000		55.6000	mg/l	04-24-90	278
2	ALKALINITY		51.7000		52.7000	mg/l	04-30-90	1753
3	ALKALINITY		51.2000		51.2000	mg/l	05-01-90	2010
4	ALKALINITY		50.5000		51.2000	mg/l	05-02-90	2253
1	CHLORIDE		84593.0000		85461.0000	mg/l	04-24-90	278
2	CHLORIDE		85635.0000		84940.0000	mg/l	04-30-90	1753
3	CHLORIDE		85809.0000		85461.0000	mg/l	05-01-90	2010
4	CHLORIDE		86330.0000		86330.0000	mg/l	05-02-90	2253
1	DIVALENT CATIONS		265.8000		263.0000	meq/l	04-24-90	278
2	DIVALENT CATIONS		263.4000		261.4000	meq/l	04-30-90	1753
3	DIVALENT CATIONS		261.8000		260.6000	meq/l	05-01-90	2010
4	DIVALENT CATIONS		263.4000		262.2000	meq/l	05-02-90	2253
1	TOTAL IRON		4.3900		4.4900	mg/l	04-24-90	278
2	TOTAL IRON		2.7600		2.6100	mg/l	04-30-90	1753
3	TOTAL IRON		2.3200		2.1800	mg/l	05-01-90	2010
4	TOTAL IRON		2.7200		2.7900	mg/l	05-02-90	2253
1	FERROUS IRON		3.8300		4.1100	mg/l	04-24-90	278
2	FERROUS IRON		2.3806		2.4500	mg/l	04-30-90	1753
3	FERROUS IRON		2.1100		2.0200	mg/l	05-01-90	2010
4	FERROUS IRON		2.4700		2.4100	mg/l	05-02-90	2253

SERIAL SAMPLE FIELD ANALYSIS
H-02c, CULEBRA
ROUND 2

NO	PARAMETER	V	VALUE	S	D	VALUE_DUP	UNITS	DATE	FLOW
1	Eh		229.0000	NA		0.0000	mV	07-19-90	2939
2	Eh		235.0000	NA		0.0000	mV	07-20-90	3253
3	Eh		213.0000	NA		0.0000	mV	07-22-90	3871
4	Eh		274.0000	NA		0.0000	mV	07-23-90	3957
5	Eh		245.0000	NA		0.0000	mV	07-24-90	4294
1	pH		7.7100	NA		0.0000	S.U.	07-19-90	2939
2	pH		7.7800	NA		0.0000	S.U.	07-20-90	3253
3	pH		7.7800	NA		0.0000	S.U.	07-22-90	3871
4	pH		7.8800	NA		0.0000	S.U.	07-23-90	3957
5	pH		7.7200	NA		0.0000	S.U.	07-24-90	4294
1	TEMPERATURE		22.0000	NA		0.0000	C	07-19-90	2939
2	TEMPERATURE		21.0000	NA		0.0000	C	07-20-90	3253
3	TEMPERATURE		22.0000	NA		0.0000	C	07-22-90	3871
4	TEMPERATURE		21.6000	NA		0.0000	C	07-23-90	3957
5	TEMPERATURE		22.2000	NA		0.0000	C	07-24-90	4294
1	Sp.GRAVITY		1.0100	NA		0.0000	@ 22.6 C	07-19-90	2939
2	Sp.GRAVITY		1.0100	NA		0.0000	@ 20.0 C	07-20-90	3253
5	Sp.GRAVITY		1.0100	NA		0.0000	@ 22.3 C	07-24-90	4294
1	Sp.CONDUCTANCE		12600.0000	NA		0.0000	umhos/cm@25C	07-19-90	2939
5	Sp.CONDUCTANCE		12510.0000	NA		0.0000	umhos/cm@25C	07-24-90	4294
1	ALKALINITY		60.0000			59.1000	mg/l	07-19-90	2939
2	ALKALINITY		59.6000			58.5000	mg/l	07-20-90	3253
3	ALKALINITY		60.4000			59.5000	mg/l	07-22-90	3871
4	ALKALINITY		60.7000			60.2000	mg/l	07-23-90	3957
5	ALKALINITY		61.4000			60.4000	mg/l	07-24-90	4294
1	CHLORIDE		3061.0000			3013.0000	mg/l	07-19-90	2939
2	CHLORIDE		2999.0000			2964.0000	mg/l	07-20-90	3253
3	CHLORIDE		2978.0000			3006.0000	mg/l	07-22-90	3871
4	CHLORIDE		2992.0000			2957.0000	mg/l	07-23-90	3957
5	CHLORIDE		2992.0000			3006.0000	mg/l	07-24-90	4294
1	DIVALENT CATIONS		48.5000			48.3000	mg/l	07-19-90	2939
2	DIVALENT CATIONS		48.8000			48.4000	mg/l	07-20-90	3253
3	DIVALENT CATIONS		48.6000			48.6000	mg/l	07-22-90	3871
4	DIVALENT CATIONS		48.0000			48.3000	mg/l	07-23-90	3957
5	DIVALENT CATIONS		48.7000			48.6000	mg/l	07-24-90	4294
1	TOTAL IRON		1.4800			1.4400	mg/l	07-19-90	2939
2	TOTAL IRON		1.2600			1.3100	mg/l	07-20-90	3253
3	TOTAL IRON		1.4900			1.5100	mg/l	07-22-90	3871
4	TOTAL IRON		2.0400			2.0800	mg/l	07-23-90	3957
5	TOTAL IRON		1.1800			1.2000	mg/l	07-24-90	4294
1	FERROUS IRON		1.1300			1.1000	mg/l	07-19-90	2939
2	FERROUS IRON		1.0200			1.0800	mg/l	07-20-90	3253
3	FERROUS IRON		1.3400			1.3600	mg/l	07-22-90	3871
4	FERROUS IRON		1.7000			1.7300	mg/l	07-23-90	3957
5	FERROUS IRON		1.0800			1.0600	mg/l	07-24-90	4294

SERIAL SAMPLE FIELD ANALYSIS
H-03b1, MAGENTA
ROUND 5

NO	PARAMETER	V	VALUE	S	D	VALUE_DUP	UNITS	DATE	FLOW
1	Eh		48.0000		NA	0.0000	mV	08-23-90	475
2	Eh		-78.0000		NA	0.0000	mV	08-24-90	741
3	Eh		-62.0000		NA	0.0000	mV	08-26-90	1298
4	Eh		-24.0000		NA	0.0000	mV	08-27-90	1530
5	Eh		-5.0000		NA	0.0000	mV	08-28-90	1795
1	pH		7.8600		NA	0.0000	S.U.	08-23-90	475
2	pH		7.7800		NA	0.0000	S.U.	08-24-90	741
3	pH		7.7600		NA	0.0000	S.U.	08-26-90	1298
4	pH		7.8100		NA	0.0000	S.U.	08-27-90	1530
5	pH		7.7500		NA	0.0000	S.U.	08-28-90	1795
1	TEMPERATURE		22.9000		NA	0.0000	C	08-23-90	475
2	TEMPERATURE		24.4000		NA	0.0000	C	08-24-90	741
3	TEMPERATURE		24.3000		NA	0.0000	C	08-26-90	1298
4	TEMPERATURE		23.0000		NA	0.0000	C	08-27-90	1530
5	TEMPERATURE		23.6000		NA	0.0000	C	08-28-90	1795
1	Sp.GRAVITY		1.0084		NA	0.0000	@ 22.9 C	08-23-90	475
5	Sp.GRAVITY		1.0080		NA	0.0000	@ 23.2 C	08-28-90	1795
1	Sp.CONDUCTANCE		12200.0000		NA	0.0000	umhos/cm@25C	08-23-90	475
5	Sp.CONDUCTANCE		12200.0000		NA	0.0000	umhos/cm@25C	08-28-90	1795
1	ALKALINITY		46.0000			46.7000	mg/l	08-23-90	475
2	ALKALINITY		46.7000			47.2000	mg/l	08-24-90	741
3	ALKALINITY		47.6000			46.2000	mg/l	08-26-90	1298
4	ALKALINITY		46.5000			46.5000	mg/l	08-27-90	1530
5	ALKALINITY		46.0000			45.7000	mg/l	08-28-90	1795
1	CHLORIDE		3436.0000			3415.0000	mg/l	08-23-90	475
2	CHLORIDE		3401.0000			3372.0000	mg/l	08-24-90	741
3	CHLORIDE		3458.0000			3436.0000	mg/l	08-26-90	1298
4	CHLORIDE		3458.0000			3465.0000	mg/l	08-27-90	1530
5	CHLORIDE		3465.0000			3450.0000	mg/l	08-28-90	1795
1	DIVALENT CATIONS		74.3000			73.1600	mg/l	08-23-90	475
2	DIVALENT CATIONS		73.8000			73.9000	mg/l	08-24-90	741
3	DIVALENT CATIONS		74.1000			73.5000	mg/l	08-26-90	1298
4	DIVALENT CATIONS		73.6000			73.3000	mg/l	08-27-90	1530
5	DIVALENT CATIONS		73.5000			73.9000	mg/l	08-28-90	1795
1	TOTAL IRON		0.0700			0.0600	mg/l	08-23-90	475
2	TOTAL IRON	<	0.0200		<	0.0200	mg/l	08-24-90	741
3	TOTAL IRON	<	0.0200		<	0.0200	mg/l	08-26-90	1298
4	TOTAL IRON	<	0.0200		<	0.0200	mg/l	08-27-90	1530
5	TOTAL IRON	<	0.0200		<	0.0200	mg/l	08-28-90	1795
1	FERROUS IRON		0.0500			0.0400	mg/l	08-23-90	475
2	FERROUS IRON	<	0.0200		<	0.0200	mg/l	08-24-90	741
3	FERROUS IRON	<	0.0200		<	0.0200	mg/l	08-26-90	1298
4	FERROUS IRON	<	0.0200		<	0.0200	mg/l	08-27-90	1530
5	FERROUS IRON	<	0.0200		<	0.0200	mg/l	08-28-90	1795

SERIAL SAMPLING FIELD ANALYSIS
H-03b3, CULEBRA
ROUND 5

NO	PARAMETER	V	VALUE	S D	VALUE_DUP	UNITS	DATE	FLOW
1	Eh		206.0000	NA	0.0000	mV	08-12-90	3403
2	Eh		190.0000	NA	0.0000	mV	08-13-90	4063
3	Eh		212.0000	NA	0.0000	mV	08-14-90	4718
4	Eh		175.0000	NA	0.0000	mV	08-15-90	5466
1	pH		7.5100	NA	0.0000	S.U.	08-12-90	3403
2	pH		7.4100	NA	0.0000	S.U.	08-13-90	4063
3	pH		7.4400	NA	0.0000	S.U.	08-14-90	4718
4	pH		7.4500	NA	0.0000	S.U.	08-15-90	5466
1	TEMPERATURE		22.1000	NA	0.0000	C	08-12-90	3403
2	TEMPERATURE		22.1000	NA	0.0000	C	08-13-90	4063
3	TEMPERATURE		22.2000	NA	0.0000	C	08-14-90	4718
4	TEMPERATURE		22.2000	NA	0.0000	C	08-15-90	5466
1	Sp.GRAVITY		1.0420	NA	0.0000	@ 22.6 C	08-12-90	3403
4	Sp.GRAVITY		1.0400	NA	0.0000	@ 22.3 C	08-15-90	5466
1	Sp.CONDUCTANCE		69300.0000	NA	0.0000	umhos/cm@25C	08-12-90	3403
4	Sp.CONDUCTANCE		69300.0000	NA	0.0000	umhos/cm@25C	08-15-90	5466
1	ALKALINITY		50.7000		50.2000	mg/l	08-12-90	3403
2	ALKALINITY		51.0000		50.2000	mg/l	08-13-90	4063
3	ALKALINITY		50.5000		50.5000	mg/l	08-14-90	4718
4	ALKALINITY		50.7000		50.2000	mg/l	08-15-90	5466
1	CHLORIDE		27799.0000		27694.0000	mg/l	08-12-90	3403
2	CHLORIDE		27625.0000		27729.0000	mg/l	08-13-90	4063
3	CHLORIDE		27833.0000		27729.0000	mg/l	08-14-90	4718
4	CHLORIDE		27729.0000		27660.0000	mg/l	08-15-90	5466
1	DIVALENT CATIONS		137.6000		137.6000	mg/l	08-12-90	3403
2	DIVALENT CATIONS		136.6000		136.8000	mg/l	08-13-90	4063
3	DIVALENT CATIONS		136.2000		137.2000	mg/l	08-14-90	4718
4	DIVALENT CATIONS		137.8000		138.0000	mg/l	08-15-90	5466
1	TOTAL IRON		0.2200		0.2100	mg/l	08-12-90	3403
2	TOTAL IRON		0.2100		0.1900	mg/l	08-13-90	4063
3	TOTAL IRON		0.2000		0.2100	mg/l	08-14-90	4718
4	TOTAL IRON		0.2500		0.2200	mg/l	08-15-90	5466
1	FERROUS IRON		0.1900		0.1900	mg/l	08-12-90	3403
2	FERROUS IRON		0.1600		0.1300	mg/l	08-13-90	4063
3	FERROUS IRON		0.1900		0.1800	mg/l	08-14-90	4718
4	FERROUS IRON		0.1800		0.1900	mg/l	08-15-90	5466

SERIAL SAMPLE FIELD ANALYSIS
H-04b, CULEBRA
ROUND 5

NO	PARAMETER	V	VALUE	S D	VALUE_DUP	UNITS	DATE	FLOW
1	Eh		95.0000	NA	0.0000	mV	09-09-90	522
2	Eh		113.0000	NA	0.0000	mV	09-10-90	764
3	Eh		112.0000	NA	0.0000	mV	09-11-90	1018
4	Eh		114.0000	NA	0.0000	mV	09-12-90	1286
1	pH		7.8100	NA	0.0000	S.U.	09-09-90	522
2	pH		7.7400	NA	0.0000	S.U.	09-10-90	764
3	pH		7.7700	NA	0.0000	S.U.	09-11-90	1018
4	pH		7.7600	NA	0.0000	S.U.	09-12-90	1286
1	TEMPERATURE		22.2000	NA	0.0000	C	09-09-90	522
2	TEMPERATURE		21.8000	NA	0.0000	C	09-10-90	764
3	TEMPERATURE		21.5000	NA	0.0000	C	09-11-90	1018
4	TEMPERATURE		22.1000	NA	0.0000	C	09-12-90	1286
1	Sp.GRAVITY		1.0168	NA	0.0000	@ 22.3 C	09-09-90	522
4	Sp.GRAVITY		1.0164	NA	0.0000	@ 21.5 C	09-12-90	1286
1	Sp.CONDUCTANCE		24400.0000	NA	0.0000	umhos/cm@25C	09-09-90	522
4	Sp.CONDUCTANCE		26400.0000	NA	0.0000	umhos/cm@25C	09-12-90	1286
1	ALKALINITY		66.8000		68.7000	mg/l	09-09-90	522
2	ALKALINITY		68.5000		68.5000	mg/l	09-10-90	764
3	ALKALINITY		68.7000		67.8000	mg/l	09-11-90	1018
4	ALKALINITY		69.5000		68.7000	mg/l	09-12-90	1286
1	CHLORIDE		7683.0000		7630.0000	mg/l	09-09-90	522
2	CHLORIDE		7541.0000		7488.0000	mg/l	09-10-90	764
3	CHLORIDE		7541.0000		7594.0000	mg/l	09-11-90	1018
4	CHLORIDE		7577.0000		7577.0000	mg/l	09-12-90	1286
1	DIVALENT CATIONS		70.6000		70.9000	mg/l	09-09-90	522
2	DIVALENT CATIONS		72.0000		71.4000	mg/l	09-10-90	764
3	DIVALENT CATIONS		72.0000		71.8000	mg/l	09-11-90	1018
4	DIVALENT CATIONS		71.0000		71.7000	mg/l	09-12-90	1286
1	TOTAL IRON		1.2400		1.2700	mg/l	09-09-90	522
2	TOTAL IRON		1.0700		1.0500	mg/l	09-10-90	764
3	TOTAL IRON		1.0200		1.0300	mg/l	09-11-90	1018
4	TOTAL IRON		0.9900		1.0300	mg/l	09-12-90	1286
1	FERROUS IRON		1.2100		1.2000	mg/l	09-09-90	522
2	FERROUS IRON		0.9800		1.0100	mg/l	09-10-90	764
3	FERROUS IRON		0.9400		0.9700	mg/l	09-11-90	1018
4	FERROUS IRON		0.8900		0.8900	mg/l	09-12-90	1286

SERIAL SAMPLE FIELD ANALYSIS
H-04c, MAGENTA
ROUND 5

NO	PARAMETER	V	VALUE	S D	VALUE_DUP	UNITS	DATE	FLOW
1	Eh		-86.0000	NA	0.0000	mV	09-27-90	161
2	Eh		-82.0000	NA	0.0000	mV	09-28-90	248
3	Eh		-58.0000	NA	0.0000	mV	09-30-90	422
4	Eh		-81.0000	NA	0.0000	mV	10-01-90	502
5	Eh		-61.0000	NA	0.0000	mV	10-02-90	585
1	pH		7.9800	NA	0.0000	S.U.	09-27-90	161
2	pH		8.0000	NA	0.0000	S.U.	09-28-90	248
3	pH		8.0300	NA	0.0000	S.U.	09-30-90	422
4	pH		8.0000	NA	0.0000	S.U.	10-01-90	502
5	pH		8.0100	NA	0.0000	S.U.	10-02-90	585
1	TEMPERATURE		23.9000	NA	0.0000	C	09-27-90	161
2	TEMPERATURE		21.7000	NA	0.0000	C	09-28-90	248
3	TEMPERATURE		21.0000	NA	0.0000	C	09-30-90	422
4	TEMPERATURE		21.6000	NA	0.0000	C	10-01-90	502
5	TEMPERATURE		20.6000	NA	0.0000	C	10-02-90	585
1	Sp.GRAVITY		1.0200	NA	0.0000	@24.1	09-27-90	161
5	Sp.GRAVITY		1.0202	NA	0.0000	@20.4	10-02-90	585
1	Sp.CONDUCTANCE		30900.0000	NA	0.0000	umhos/cm@25C	09-27-90	161
5	Sp.CONDUCTANCE		30900.0000	NA	0.0000	umhos/cm@25C	10-02-90	585
1	ALKALINITY		79.7000		81.5000	mg/l	09-27-90	161
2	ALKALINITY		79.5000		79.5000	mg/l	09-28-90	248
3	ALKALINITY		82.2000		82.1000	mg/l	09-30-90	422
4	ALKALINITY		80.7000		81.0000	mg/l	10-01-90	502
5	ALKALINITY		81.2000		80.5000	mg/l	10-02-90	585
1	CHLORIDE		8395.0000		8466.0000	mg/l	09-27-90	161
2	CHLORIDE		8501.0000		8430.0000	mg/l	09-28-90	248
3	CHLORIDE		8519.0000		8484.0000	mg/l	09-30-90	422
4	CHLORIDE		8501.0000		8501.0000	mg/l	10-01-90	502
5	CHLORIDE		8519.0000		8466.0000	mg/l	10-02-90	585
1	DIVALENT CATIONS		70.6000		70.1000	meq/l	09-27-90	161
2	DIVALENT CATIONS		69.5000		69.0000	meq/l	09-28-90	248
3	DIVALENT CATIONS		70.3000		70.3000	meq/l	09-30-90	422
4	DIVALENT CATIONS		69.8000		70.4000	meq/l	10-01-90	502
5	DIVALENT CATIONS		70.1000		70.1000	meq/l	10-02-90	585
1	TOTAL IRON		0.1400		0.1500	mg/l	09-27-90	161
2	TOTAL IRON		0.1600		0.1700	mg/l	09-28-90	248
3	TOTAL IRON		0.1900		0.1600	mg/l	09-30-90	422
4	TOTAL IRON		0.1600		0.1700	mg/l	10-01-90	502
5	TOTAL IRON		0.1800		0.1500	mg/l	10-02-90	585
1	FERROUS IRON		0.1200		0.1300	mg/l	09-27-90	161
2	FERROUS IRON		0.0900		0.1200	mg/l	09-28-90	248
3	FERROUS IRON		0.0500		0.0700	mg/l	09-30-90	422
4	FERROUS IRON		0.0900		0.0800	mg/l	10-01-90	502
5	FERROUS IRON		0.0900		0.1000	mg/l	10-02-90	585

SERIAL SAMPLE FIELD ANALYSIS
H-11b3, CULEBRA
ROUND 5

NO	PARAMETER	V	VALUE	S	D	VALUE_DUP	UNITS	DATE	FLOW
1	Eh		118.0000		NA	0.0000	mV	10-14-90	161
2	Eh		144.0000		NA	0.0000	mV	10-15-90	248
3	Eh		102.0000		NA	0.0000	mV	10-16-90	422
4	Eh		119.0000		NA	0.0000	mV	10-17-90	502
1	pH		7.3700		NA	0.0000	S.U.	10-14-90	161
2	pH		7.3800		NA	0.0000	S.U.	10-15-90	248
3	pH		7.3600		NA	0.0000	S.U.	10-16-90	422
4	pH		7.3800		NA	0.0000	S.U.	10-17-90	502
1	TEMPERATURE		22.0000		NA	0.0000	C	10-14-90	161
2	TEMPERATURE		22.0000		NA	0.0000	C	10-15-90	248
3	TEMPERATURE		21.8000		NA	0.0000	C	10-16-90	422
4	TEMPERATURE		21.8000		NA	0.0000	C	10-17-90	502
1	Sp.GRAVITY		1.0804		NA	0.0000	@24.1	10-14-90	161
4	Sp.GRAVITY		1.0804		NA	0.0000	@20.4	10-17-90	585
1	Sp.CONDUCTANCE		133400.0000		NA	0.0000	umhos/cm@25C	10-14-90	161
4	Sp.CONDUCTANCE		133800.0000		NA	0.0000	umhos/cm@25C	10-17-90	585
1	ALKALINITY		56.3000			55.3000	mg/l	10-14-90	161
2	ALKALINITY		55.5000			54.5000	mg/l	10-15-90	248
3	ALKALINITY		55.3000			55.3000	mg/l	10-16-90	422
4	ALKALINITY		54.5000			53.8000	mg/l	10-17-90	502
1	CHLORIDE		66696.0000			65984.0000	mg/l	10-14-90	161
2	CHLORIDE		65451.0000			64917.0000	mg/l	10-15-90	248
3	CHLORIDE		65806.0000			65273.0000	mg/l	10-16-90	422
4	CHLORIDE		65451.0000			65451.0000	mg/l	10-17-90	502
1	DIVALENT CATIONS		187.2000			186.4000	meq/l	10-14-90	161
2	DIVALENT CATIONS		186.8000			185.6000	meq/l	10-15-90	248
3	DIVALENT CATIONS		186.4000			185.2000	meq/l	10-16-90	422
4	DIVALENT CATIONS		184.8000			185.6000	meq/l	10-17-90	502
1	TOTAL IRON		0.4700			0.4800	mg/l	10-14-90	161
2	TOTAL IRON		0.4300			0.4500	mg/l	10-15-90	248
3	TOTAL IRON		0.4600			0.4600	mg/l	10-16-90	422
4	TOTAL IRON		0.4700			0.4600	mg/l	10-17-90	502
1	FERROUS IRON		0.3600			0.3700	mg/l	10-14-90	161
2	FERROUS IRON		0.3400			0.3600	mg/l	10-15-90	248
3	FERROUS IRON		0.3500			0.3300	mg/l	10-16-90	422
4	FERROUS IRON		0.3600			0.3900	mg/l	10-17-90	502

SERIAL SAMPLE FIELD ANALYSIS
H-07b1, CULEBRA
ROUND 5

NO	PARAMETER	V	VALUE	S D	VALUE_DUP	UNITS	DATE	FLOW
1	Eh		356.0000	NA	0.0000	mV	11-02-90	2008
2	Eh		337.0000	NA	0.0000	mV	11-04-90	4397
3	Eh		334.0000	NA	0.0000	mV	11-05-90	5489
4	Eh		311.0000	NA	0.0000	mV	11-06-90	6619
5	Eh		353.0000	NA	0.0000	mV	11-07-90	7750
6	Eh		335.0000	NA	0.0000	mV	11-08-90	8878
1	pH		7.3500	NA	0.0000	S.U.	11-02-90	2008
2	pH		7.3800	NA	0.0000	S.U.	11-04-90	4397
3	pH		7.3500	NA	0.0000	S.U.	11-05-90	5489
4	pH		7.3600	NA	0.0000	S.U.	11-06-90	6619
5	pH		7.3200	NA	0.0000	S.U.	11-07-90	7750
6	pH		7.3400	NA	0.0000	S.U.	11-08-90	8878
1	TEMPERATURE		21.9000	NA	0.0000	C	11-02-90	2008
2	TEMPERATURE		21.2000	NA	0.0000	C	11-04-90	4397
3	TEMPERATURE		21.6000	NA	0.0000	C	11-05-90	5489
4	TEMPERATURE		21.4000	NA	0.0000	C	11-06-90	6619
5	TEMPERATURE		20.6000	NA	0.0000	C	11-07-90	7750
6	TEMPERATURE		20.8000	NA	0.0000	C	11-08-90	8878
1	Sp.GRAVITY		1.0042	NA	0.0000	@22.0	11-02-90	2008
6	Sp.GRAVITY		1.0026	NA	0.0000	@20.8	11-08-90	8878
1	Sp.CONDUCTANCE		3520.0000	NA	0.0000	umhos/cm@25C	11-02-90	2008
6	Sp.CONDUCTANCE		3620.0000	NA	0.0000	umhos/cm@25C	11-08-90	8878
1	ALKALINITY		112.2000		113.0000	mg/l	11-02-90	2008
2	ALKALINITY		111.1000		110.9000	mg/l	11-04-90	4397
3	ALKALINITY		113.5000		113.4000	mg/l	11-05-90	5489
4	ALKALINITY		113.7000		112.8000	mg/l	11-06-90	6619
5	ALKALINITY		113.3000		113.3000	mg/l	11-07-90	7750
6	ALKALINITY		112.5000		113.0000	mg/l	11-08-90	8878
1	CHLORIDE		277.0000		279.0000	mg/l	11-02-90	2008
2	CHLORIDE		277.0000		272.0000	mg/l	11-04-90	4397
3	CHLORIDE		276.0000		275.0000	mg/l	11-05-90	5489
4	CHLORIDE		276.0000		276.0000	mg/l	11-06-90	6619
5	CHLORIDE		277.0000		277.0000	mg/l	11-07-90	7750
6	CHLORIDE		275.0000		277.0000	mg/l	11-08-90	8878
1	DIVALENT CATIONS		49.8000		47.6000	meq/l	11-02-90	2008
2	DIVALENT CATIONS		48.0000		47.9000	meq/l	11-04-90	4397
3	DIVALENT CATIONS		46.1000		46.8000	meq/l	11-05-90	5489
4	DIVALENT CATIONS		47.9000		47.3000	meq/l	11-06-90	6619
5	DIVALENT CATIONS		47.8000		47.9000	meq/l	11-07-90	7750
6	DIVALENT CATIONS		47.8000		47.4000	meq/l	11-08-90	8878
1	TOTAL IRON		0.2500		0.2800	mg/l	11-02-90	2008
2	TOTAL IRON		0.5900		0.6000	mg/l	11-04-90	4397
3	TOTAL IRON		0.1800		0.1800	mg/l	11-05-90	5489
4	TOTAL IRON		0.2000		0.1900	mg/l	11-06-90	6619
5	TOTAL IRON		0.1800		0.1800	mg/l	11-07-90	7750
6	TOTAL IRON		0.1900		0.2200	mg/l	11-08-90	8878
1	FERROUS IRON		0.2200		0.2200	mg/l	11-02-90	2008
2	FERROUS IRON		0.5500		0.5600	mg/l	11-04-90	4397
3	FERROUS IRON		0.1500		0.1500	mg/l	11-05-90	5489
4	FERROUS IRON		0.1200		0.1300	mg/l	11-06-90	6619
5	FERROUS IRON		0.1400		0.1500	mg/l	11-07-90	7750
6	FERROUS IRON		0.1700		0.1700	mg/l	11-08-90	8878

FIELD ANALYSIS FOR PRIVATE WELLS SAMPLED IN 1990

FIELD ANALYSIS ENGLE WELL, CULEBRA ROUND 3

NO	PARAMETER	V	VALUE	S	D	VALUE_DUP	UNITS	DATE	FLOW
1	pH		7.4600		NA	0.0000	S.U.	01-31-90	N/A
1	Sp.GRAVITY		1.0033		NA	0.0000	@ 20.2 C	01-31-90	N/A
1	Sp.CONDUCTANCE		2990.0000		NA	0.0000	umhos/cm@25C	01-31-90	N/A
1	ALKALINITY		79.6000			78.4000	mg/l	01-31-90	N/A
1	CHLORIDE		230.0000			233.0000	mg/l	01-31-90	N/A
1	DIVALENT CATIONS		42.6000			42.8000	meq/l	01-31-90	N/A

FIELD ANALYSIS BARN WELL, DEWEY LAKE ROUND 4

NO	PARAMETER	V	VALUE	S	D	VALUE_DUP	UNITS	DATE	FLOW
1	pH		7.5800		NA	0.0000	S.U.	06-21-90	N/A
1	Sp.GRAVITY		1.0008		NA	0.0000	@ 25.2 C	06-21-90	N/A
1	Sp.CONDUCTANCE		1070.0000		NA	0.0000	umhos/cm@25C	06-21-90	N/A
1	ALKALINITY		282.6000			285.5000	mg/l	06-21-90	N/A
1	CHLORIDE		55.0000			57.0000	mg/l	06-21-90	N/A
1	DIVALENT CATIONS		5.0000			5.0000	meq/l	06-21-90	N/A

FIELD ANALYSIS RANCH WELL, DEWEY LAKE ROUND 5

NO	PARAMETER	V	VALUE	S	D	VALUE_DUP	UNITS	DATE	FLOW
1	pH		7.2400		NA	0.0000	S.U.	06-20-90	N/A
1	Sp.GRAVITY		1.0014		NA	0.0000	@ 23.7 C	06-20-90	N/A
1	Sp.CONDUCTANCE		3020.0000		NA	0.0000	umhos/cm@25C	06-20-90	N/A
1	ALKALINITY		246.8000			248.5000	mg/l	06-20-90	N/A
1	CHLORIDE		354.0000			361.0000	mg/l	06-20-90	N/A
1	DIVALENT CATIONS		38.5000			38.5000	meq/l	06-20-90	N/A

FIELD ANALYSIS TWIN WELL, DEWEY LAKE ROUND 4

NO	PARAMETER	V	VALUE	S	D	VALUE_DUP	UNITS	DATE	FLOW
1	pH		7.7000		NA	0.0000	S.U.	06-01-90	N/A
1	Sp.GRAVITY		1.0028		NA	0.0000	@ 23.2 C	06-01-90	N/A
1	Sp.CONDUCTANCE		614.0000		NA	0.0000	umhos/cm@25C	06-01-90	N/A
1	ALKALINITY		220.0000			217.8000	mg/l	06-01-90	N/A
1	CHLORIDE		57.0000			55.0000	mg/l	06-01-90	N/A
1	DIVALENT CATIONS		5.4000			5.5000	meq/l	06-01-90	N/A

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APPENDIX VIII
LAST DAY SERIAL SAMPLING GRAPHS
FOR
PREVIOUS SAMPLING ROUNDS

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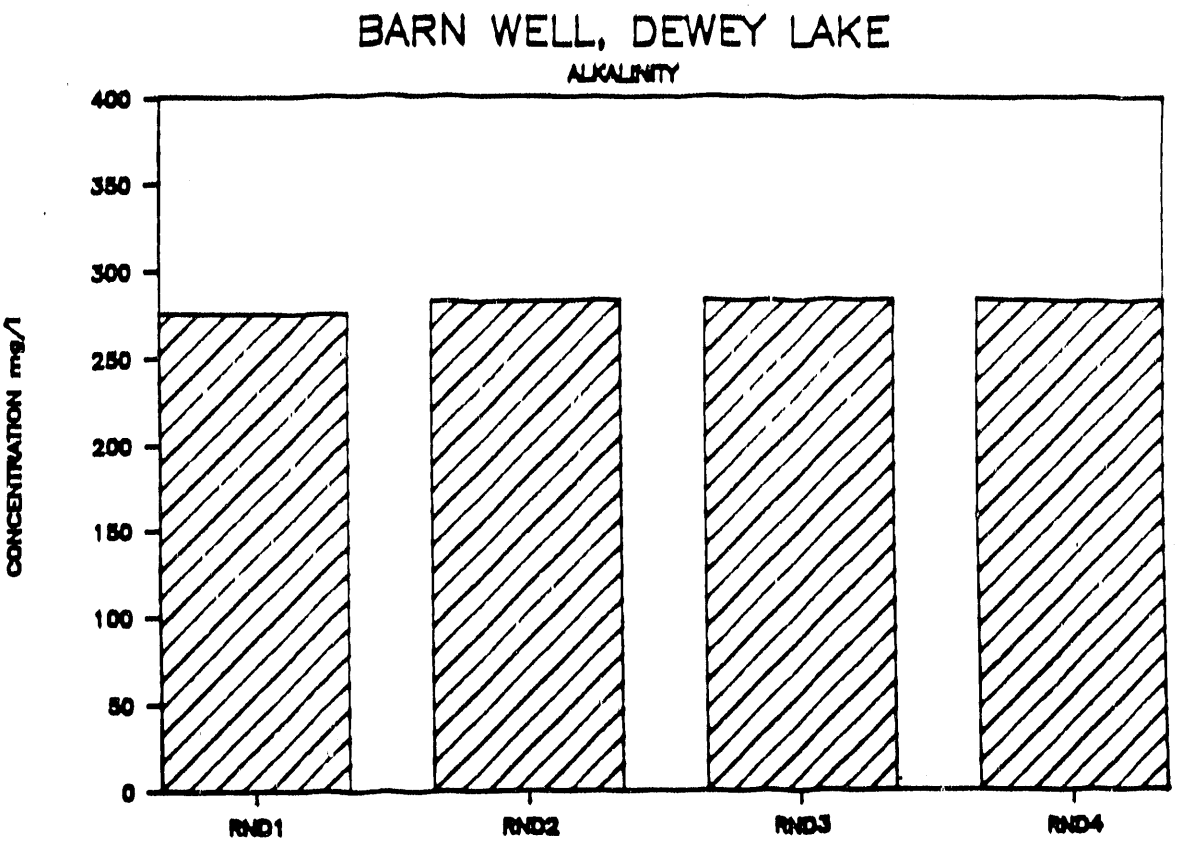
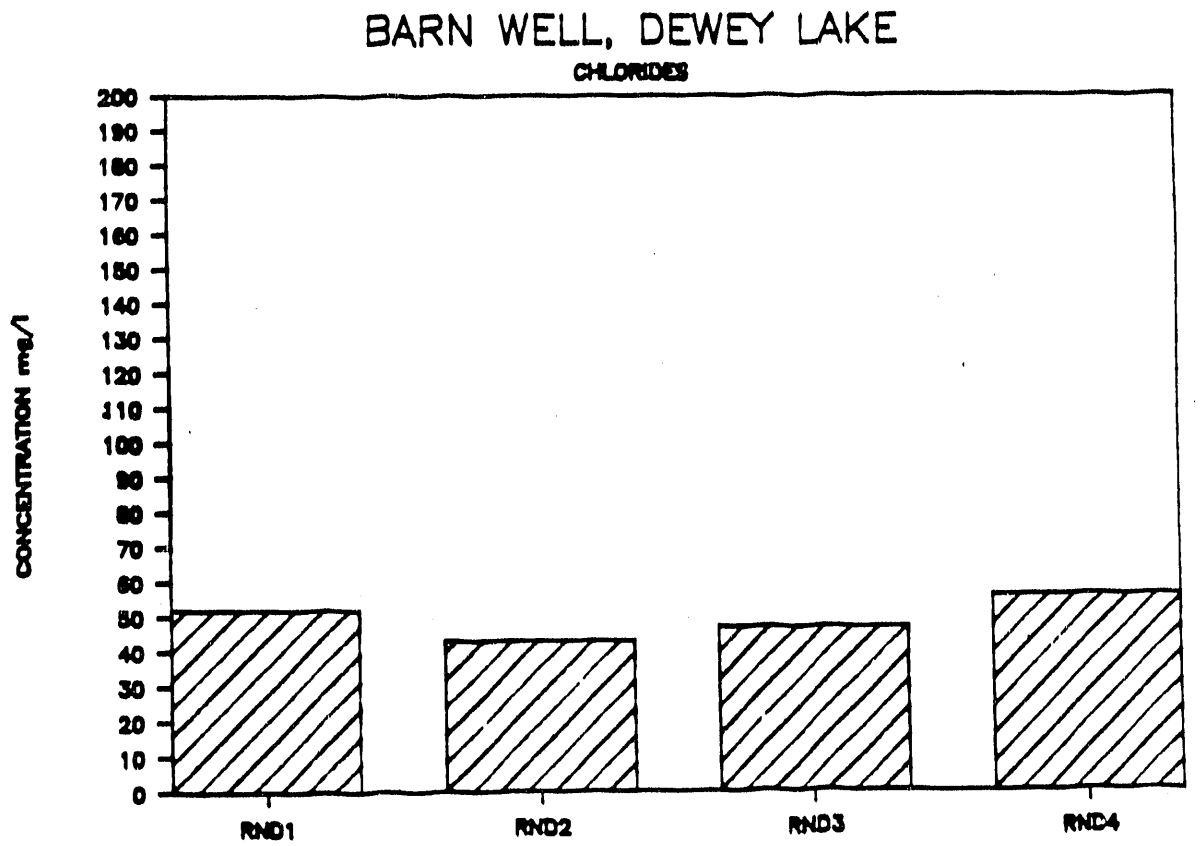
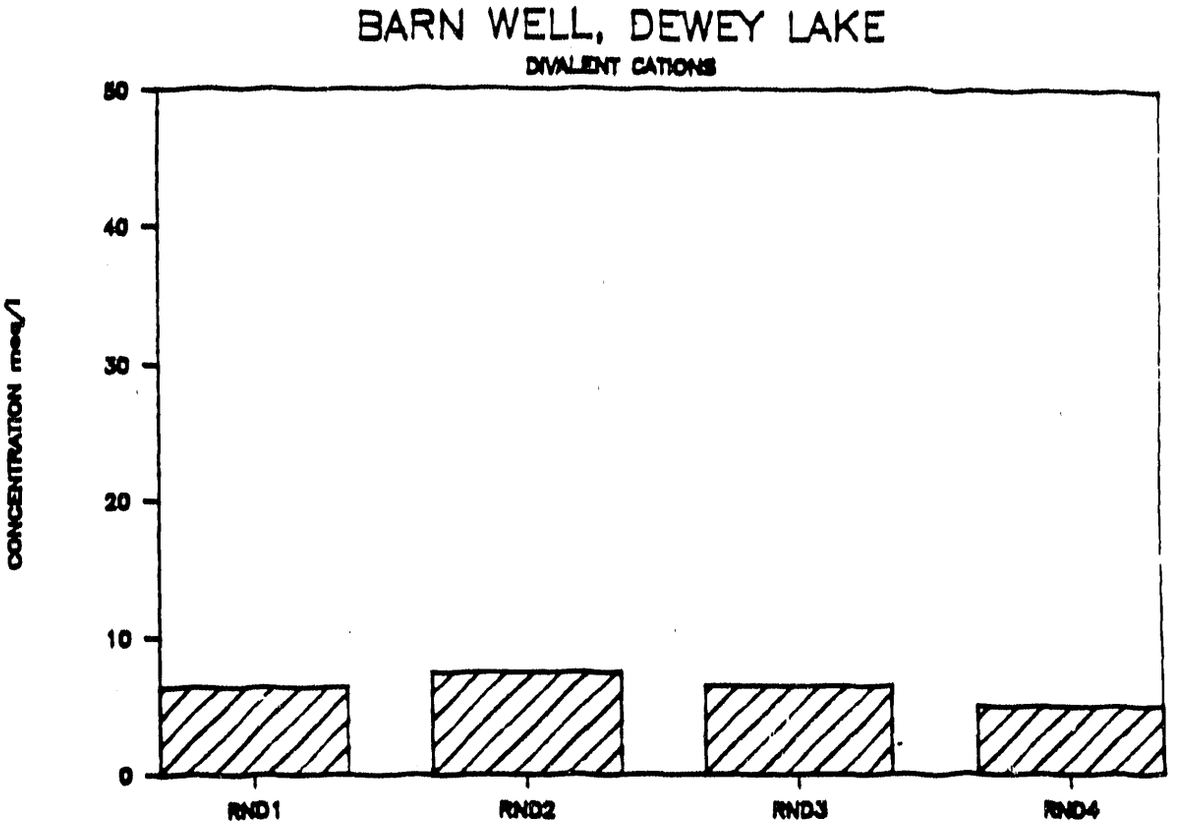
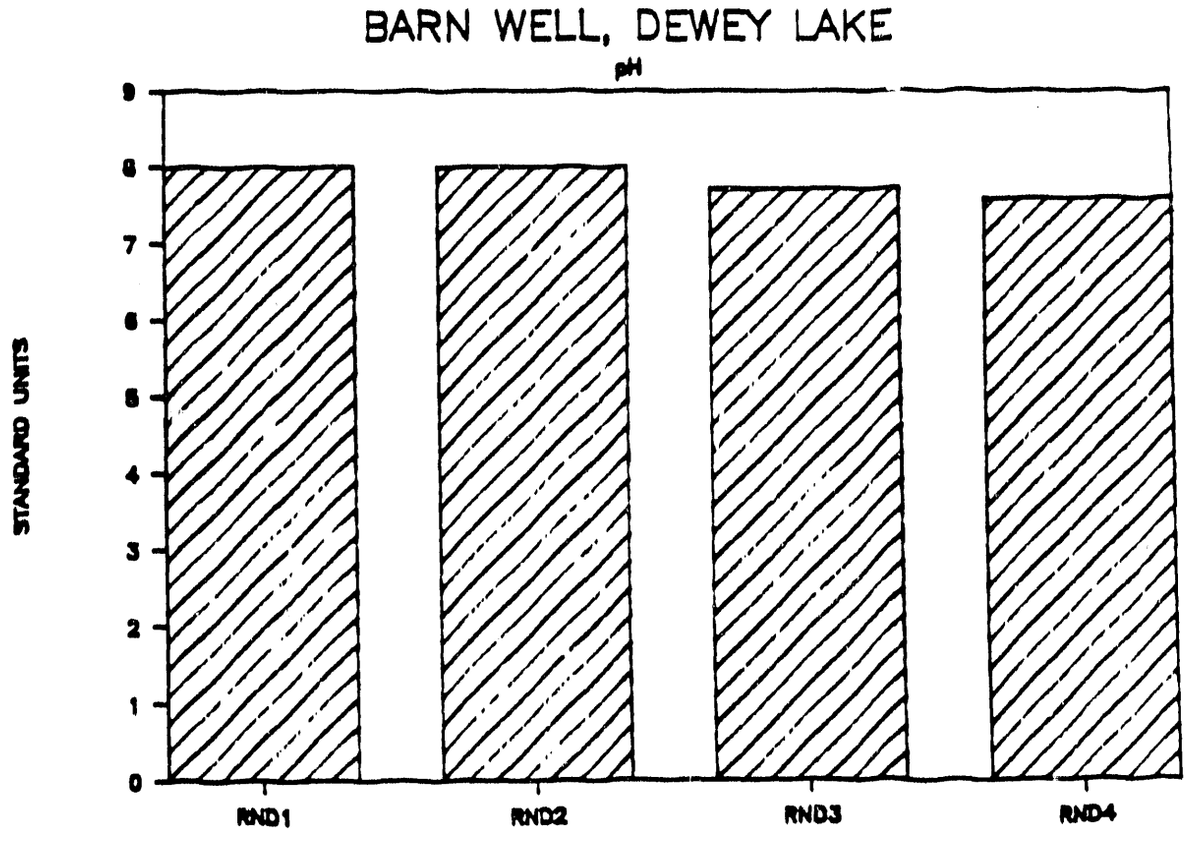
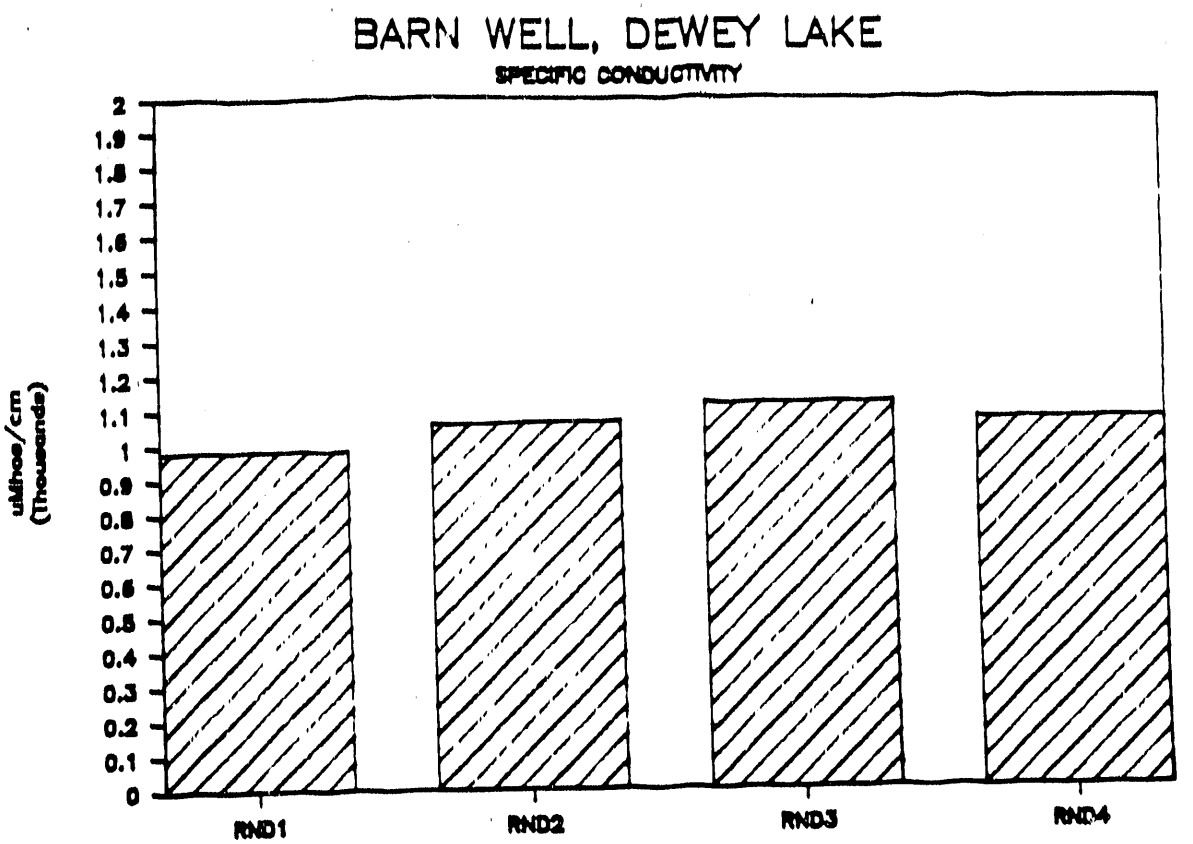
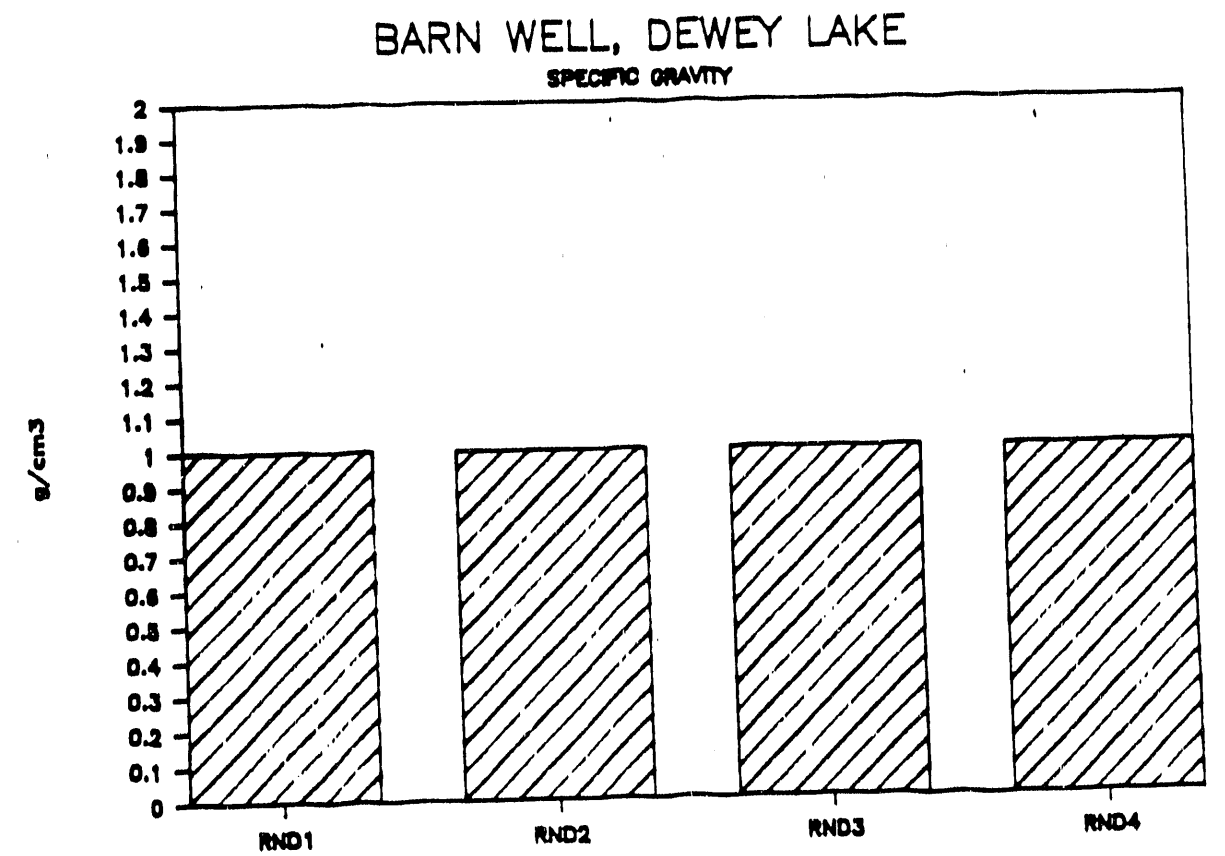

BARN WELL, DEWEY LAKE
ALKALINITY
CONCENTRATION mg/l
400
350
300
250
200
150
100
50
0
RND1
RND2
RND3
RND4

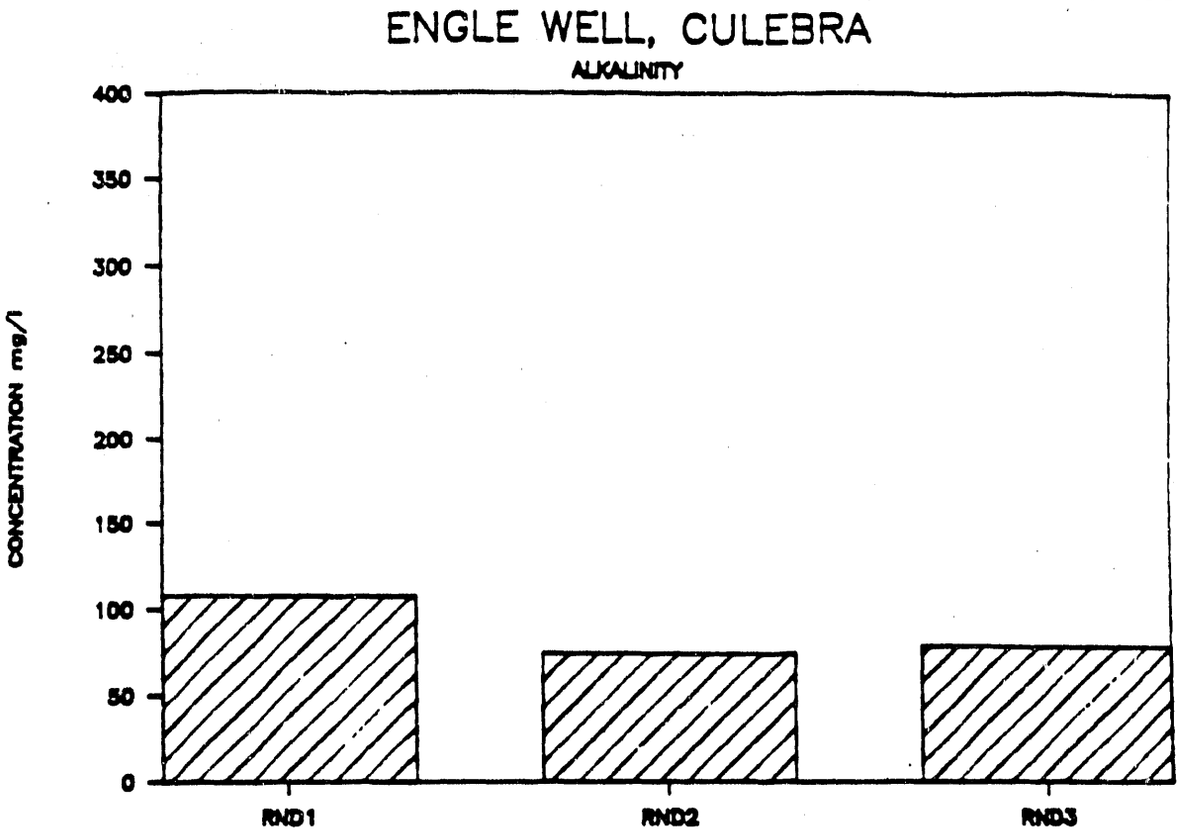

BARN WELL, DEWEY LAKE
CHLORIDES
CONCENTRATION mg/l
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4

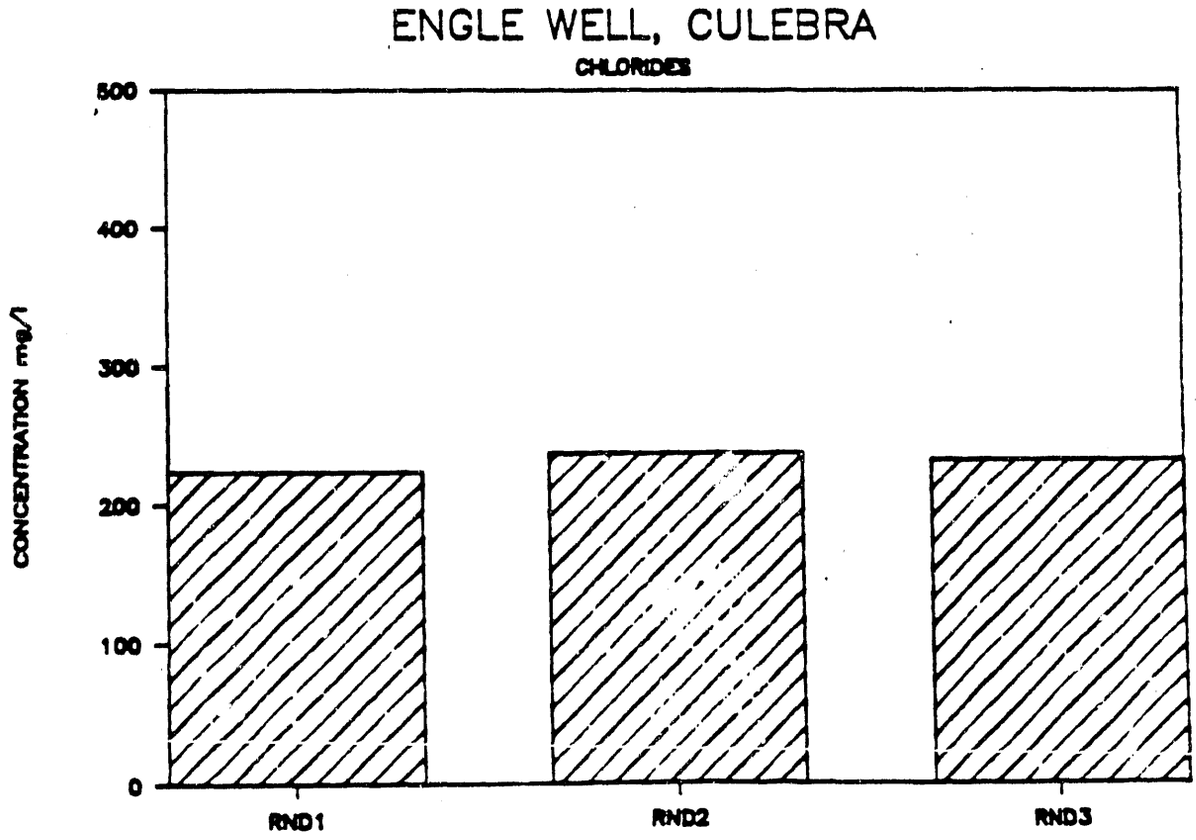

BARN WELL, DEWEY LAKE
DIVALENT CATIONS
CONCENTRATION meq/l
50
40
30
20
10
0
RND1
RND2
RND3
RND4

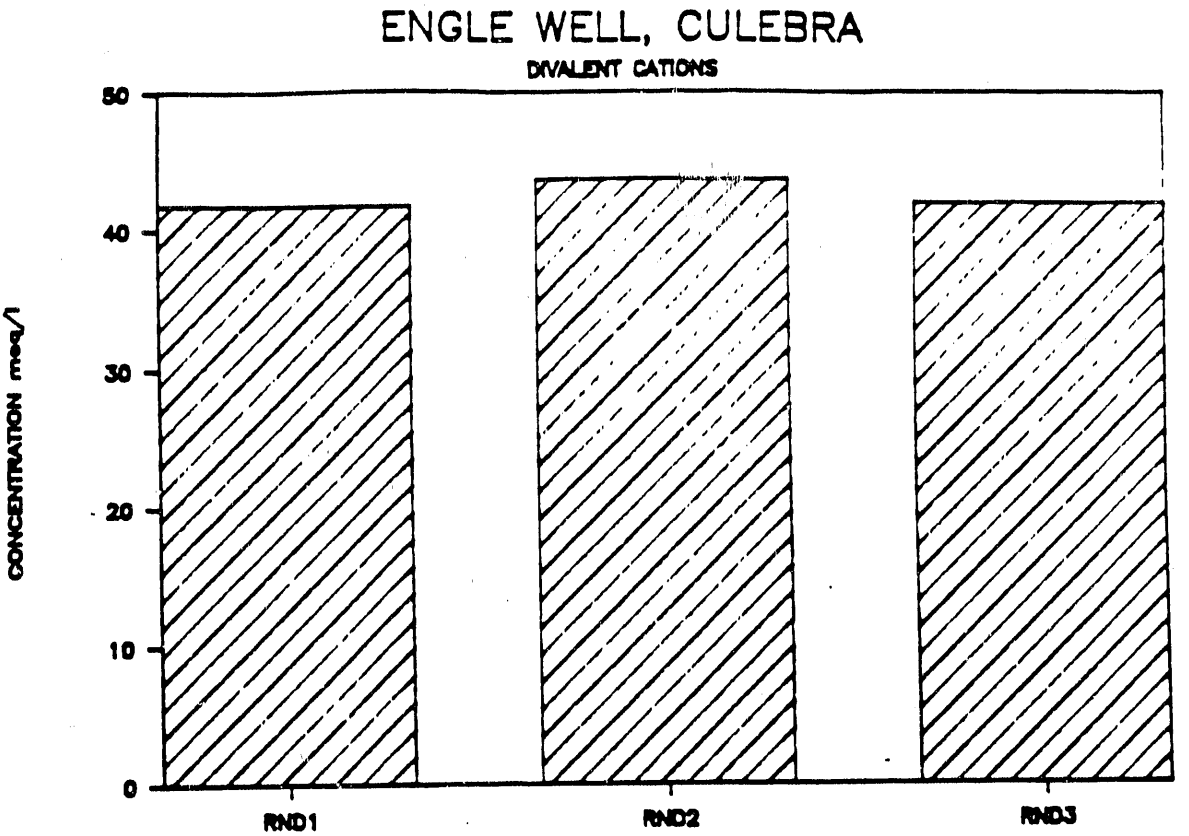

BARN WELL, DEWEY LAKE
pH
STANDARD UNITS
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4

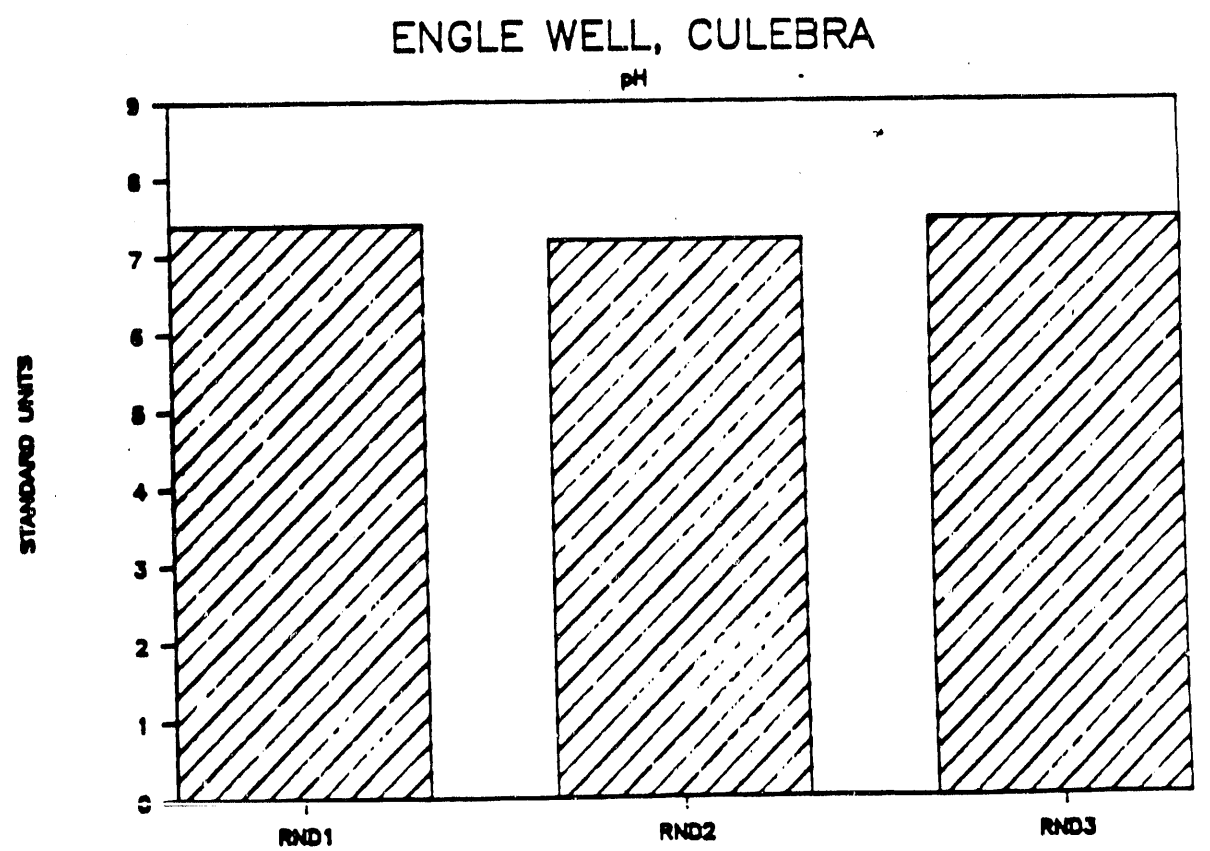

BARN WELL, DEWEY LAKE
SPECIFIC CONDUCTIVITY
umhos/cm
(Thousands)
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4

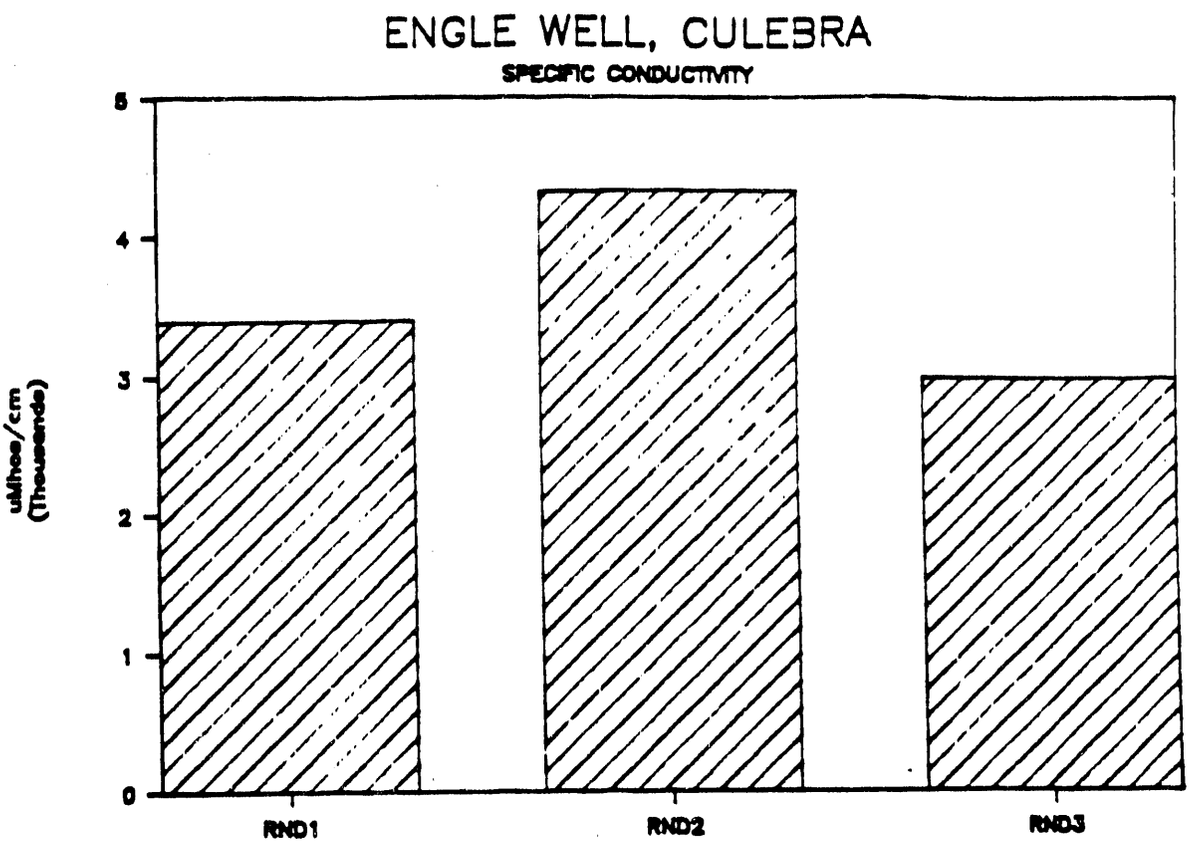

BARN WELL, DEWEY LAKE
SPECIFIC GRAVITY
g/cm3
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4

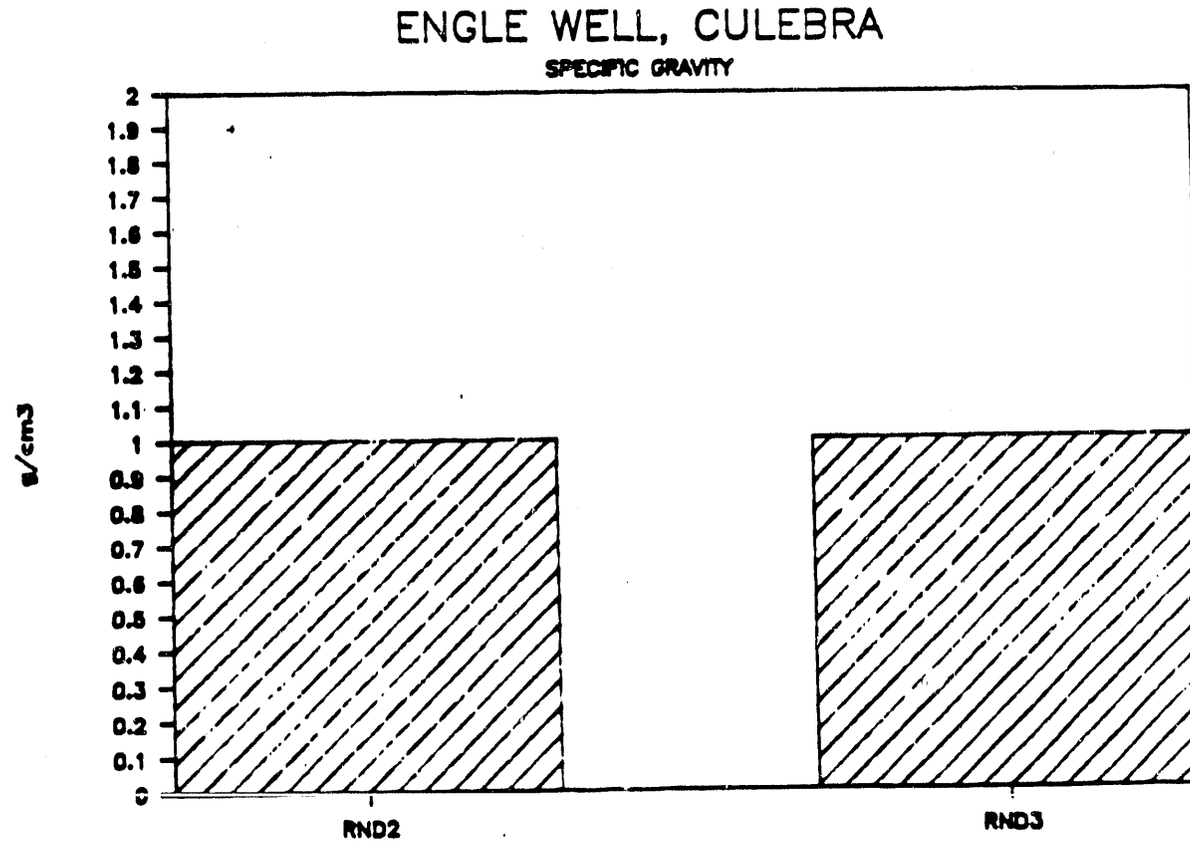

ENGLE WELL, CULEBRA
ALKALINITY
CONCENTRATION mg/l
400
350
300
250
200
150
100
50
0
RND1
RND2
RND3

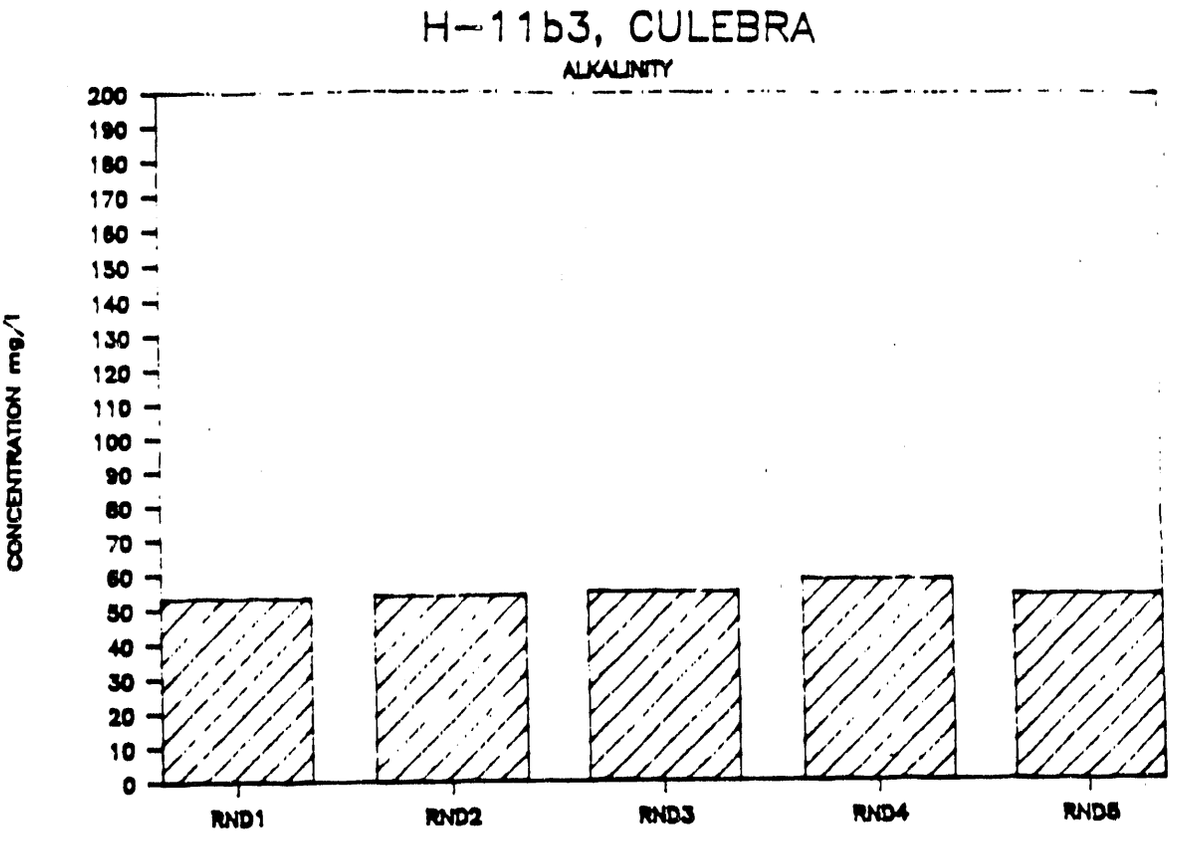

ENGLE WELL, CULEBRA
CHLORIDES
CONCENTRATION mg/l
500
400
300
200
100
0
RND1
RND2
RND3

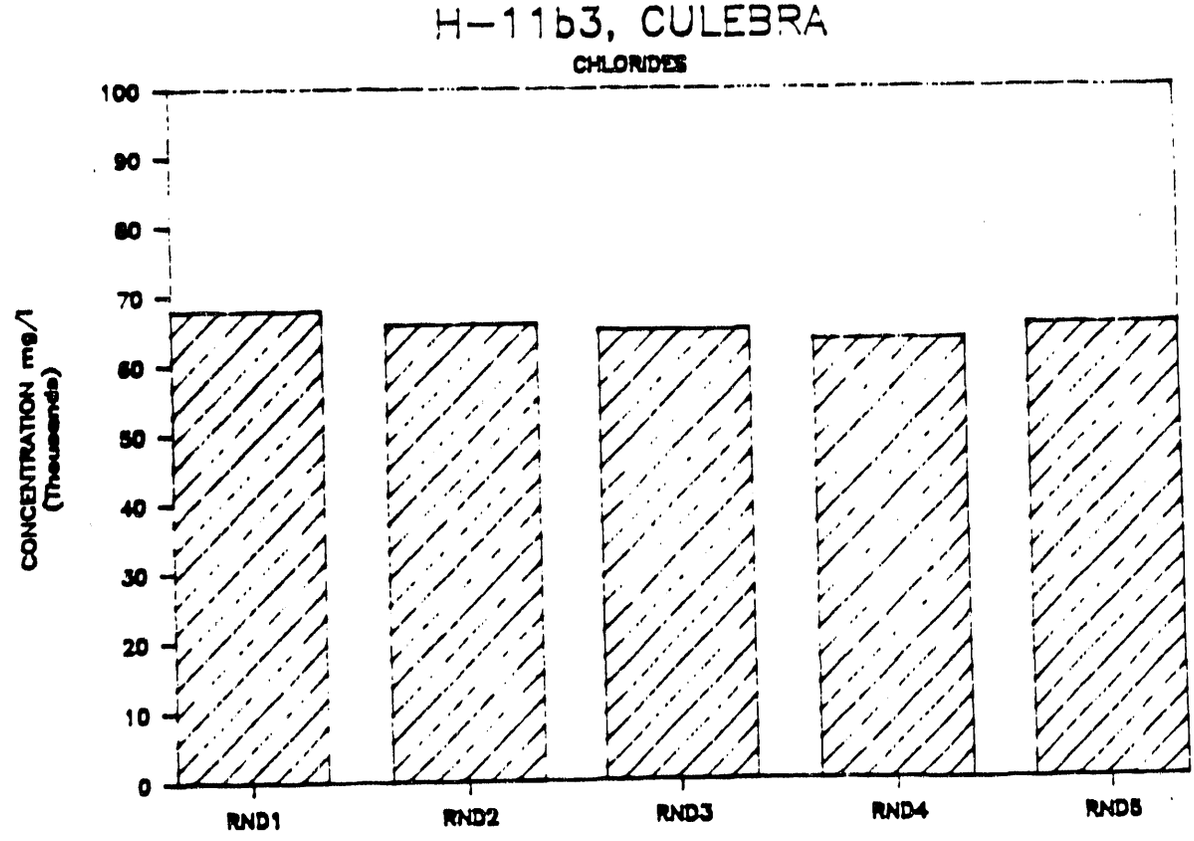

ENGLE WELL, CULEBRA
DIVALENT CATIONS
CONCENTRATION meq/l
50
40
30
20
10
0
RND1
RND2
RND3

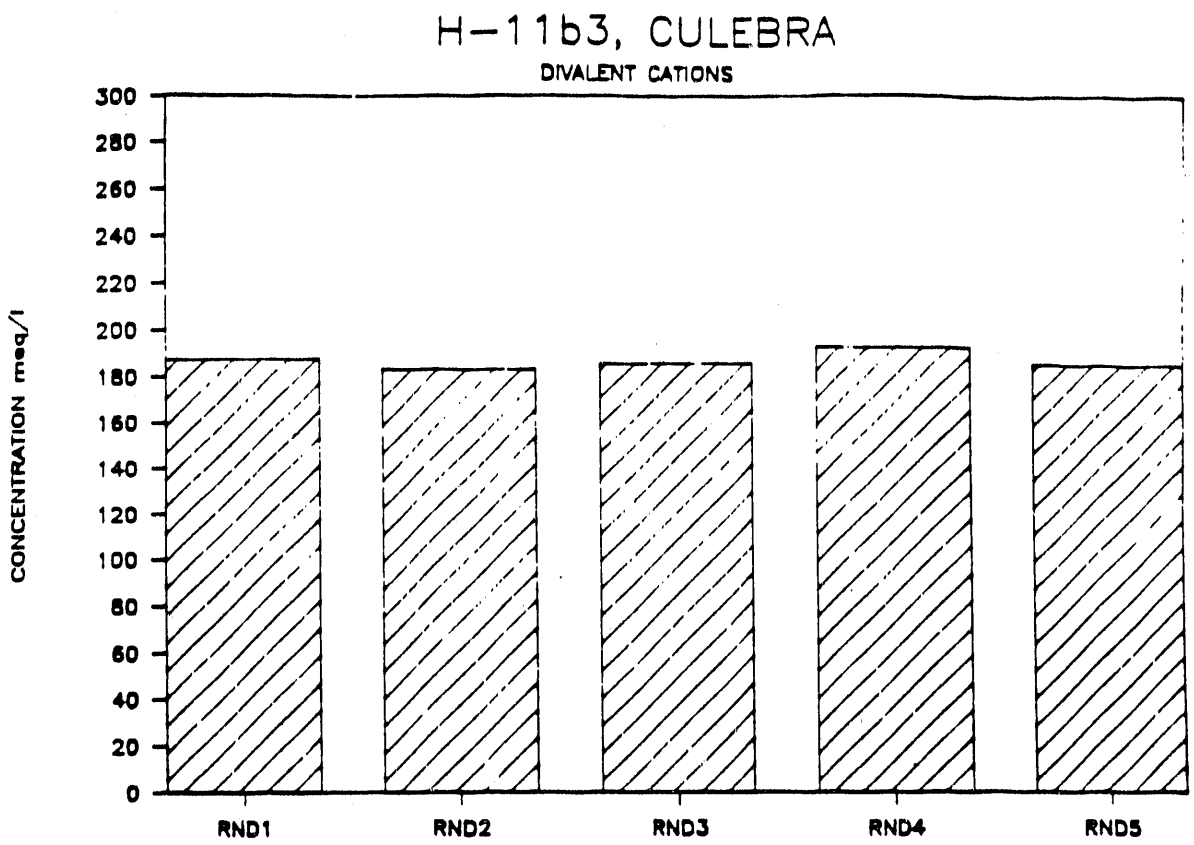

ENGLE WELL, CULEBRA
pH
STANDARD UNITS
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3

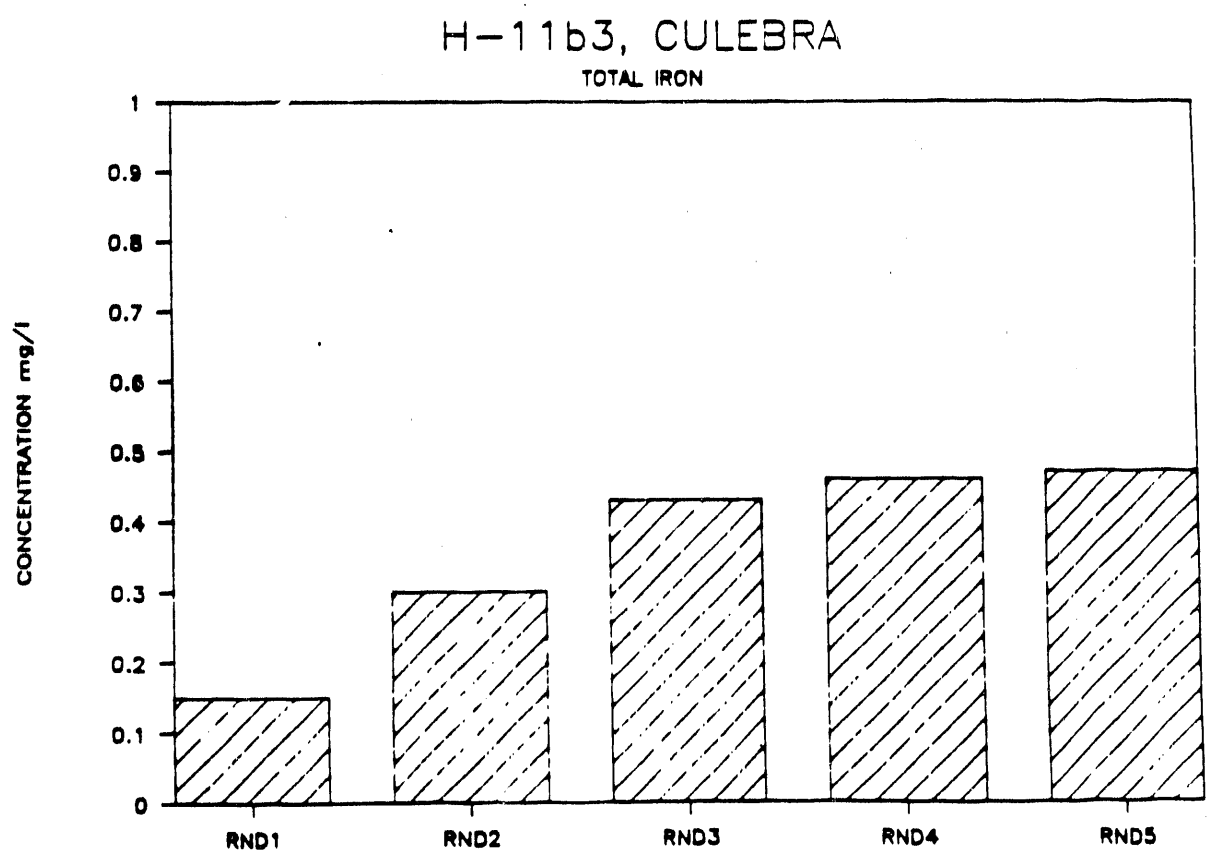

ENGLE WELL, CULEBRA
SPECIFIC CONDUCTIVITY
uMhos/cm
(Thousands)
5
4
3
2
1
0
RND1
RND2
RND3


ENGLE WELL, CULEBRA
SPECIFIC GRAVITY
g/cm3
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND2
RND3

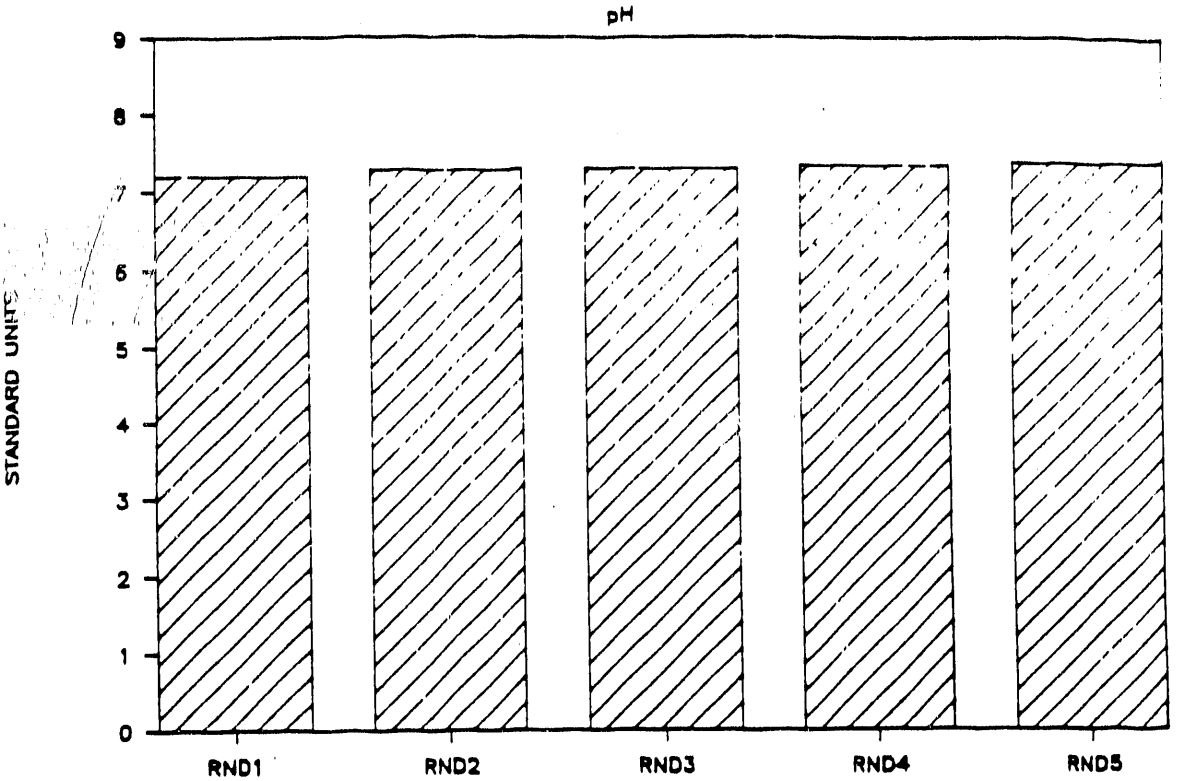

H-11b3, CULEBRA
ALKALINITY
CONCENTRATION mg/l
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5


H-11b3, CULEBRA
CHLORIDES
CONCENTRATION mg/l
(Thousands)
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

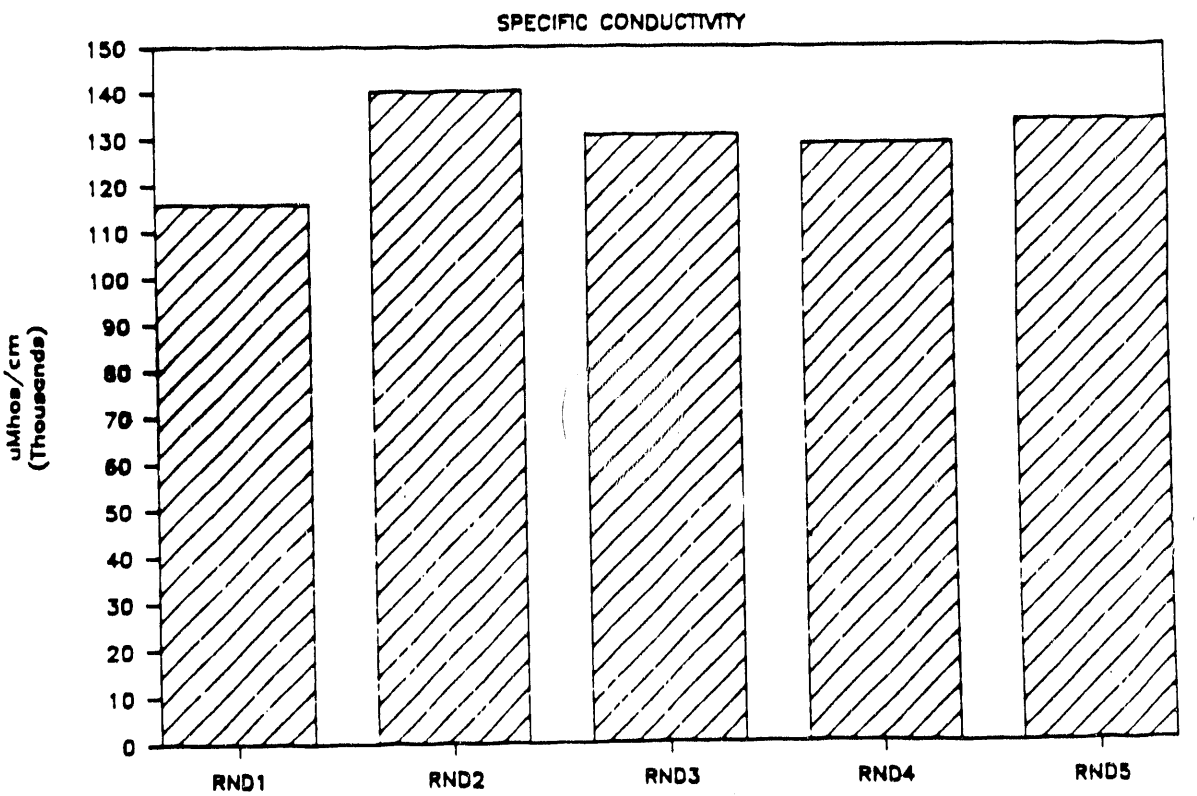

H-11b3, CULEBRA
DIVALENT CATIONS
CONCENTRATION meq/l
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
RND1
RND2
RND3
RND4
RND5

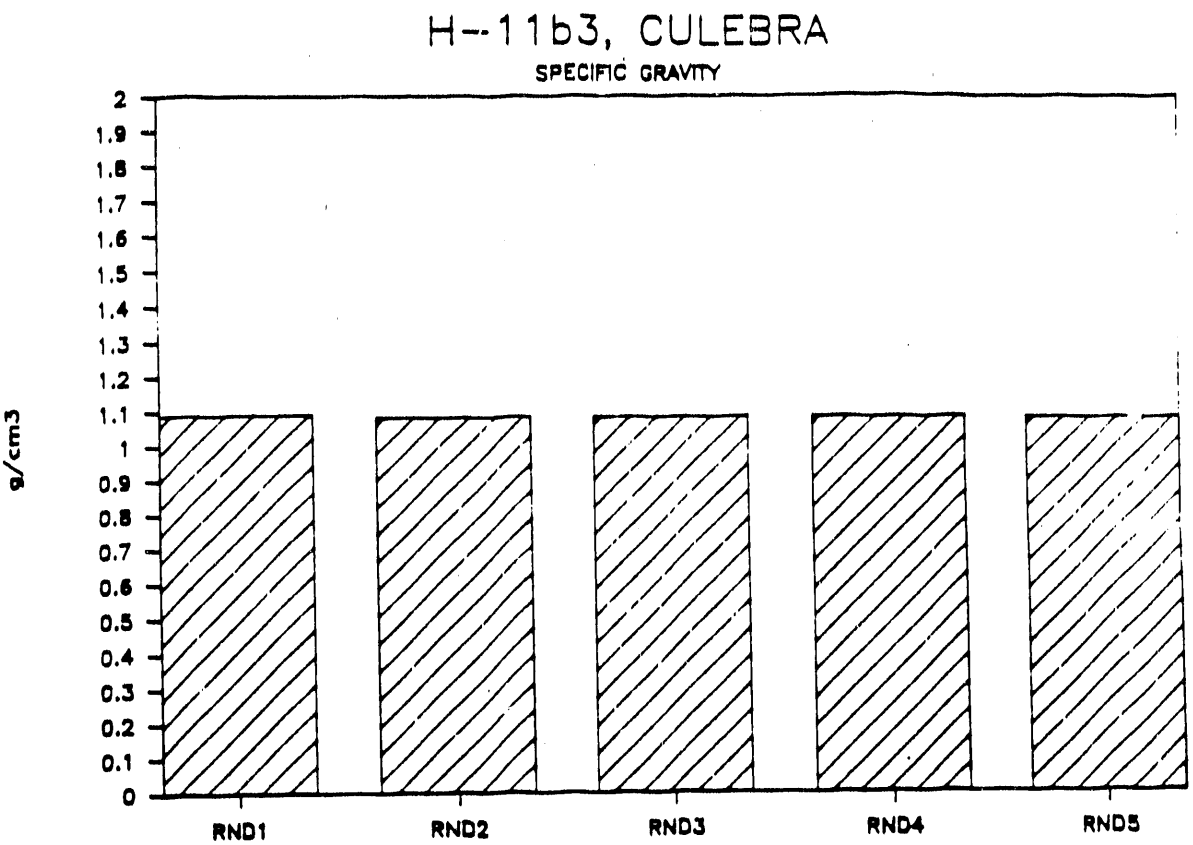

H-11b3, CULEBRA
TOTAL IRON
CONCENTRATION mg/l
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5

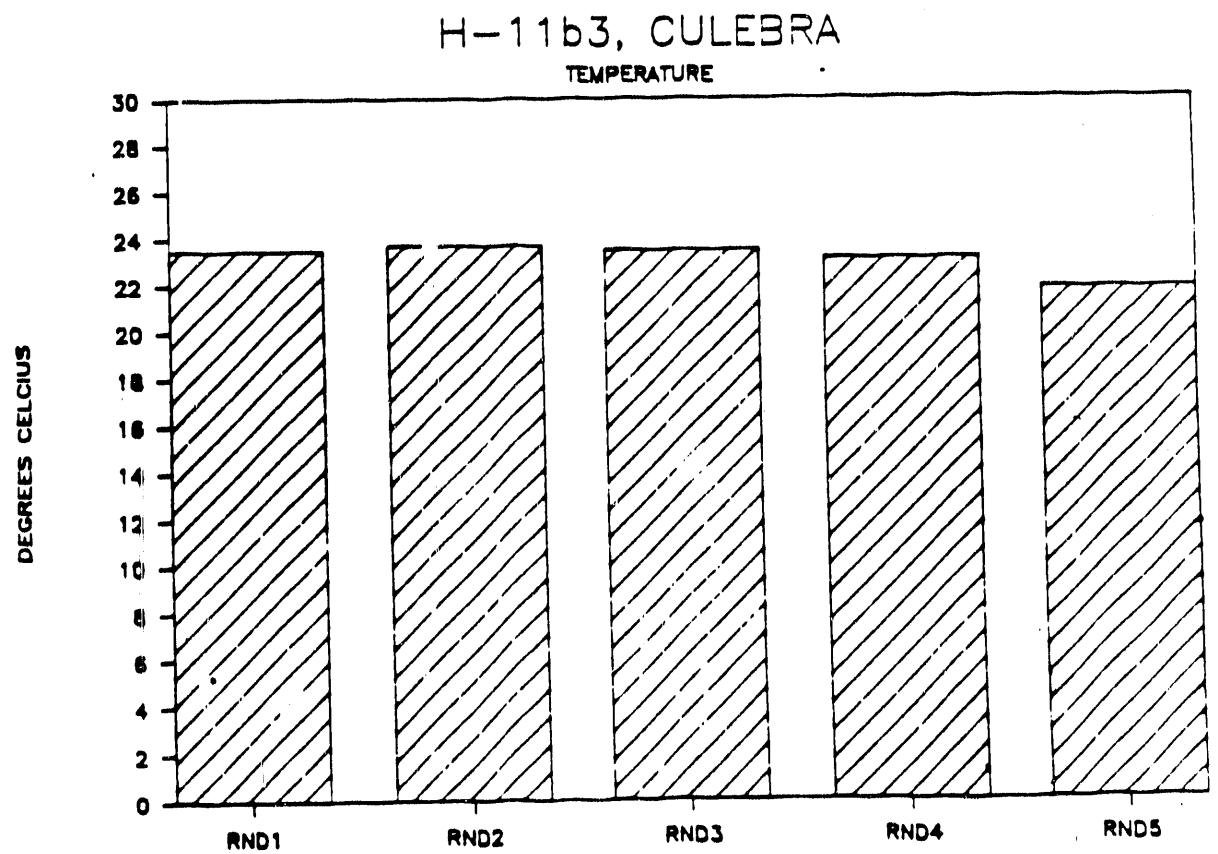
H-11b3, CULEBRA

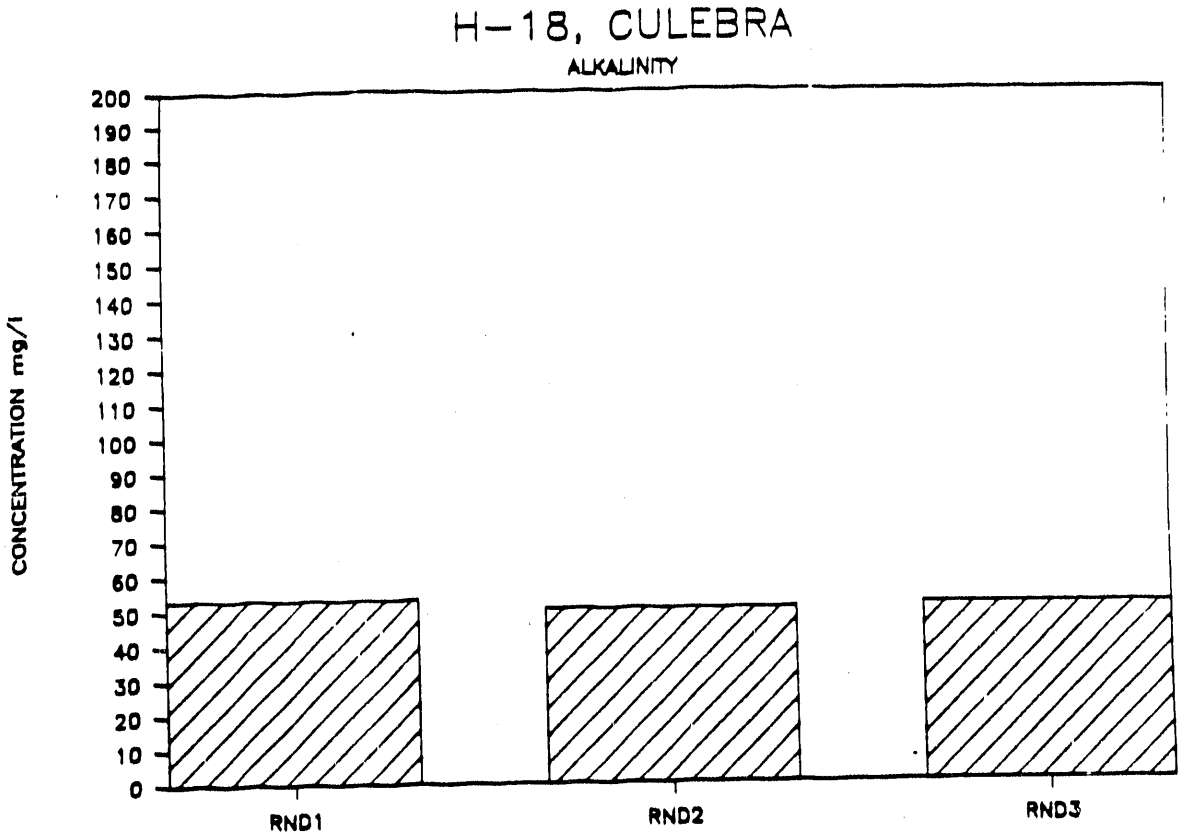


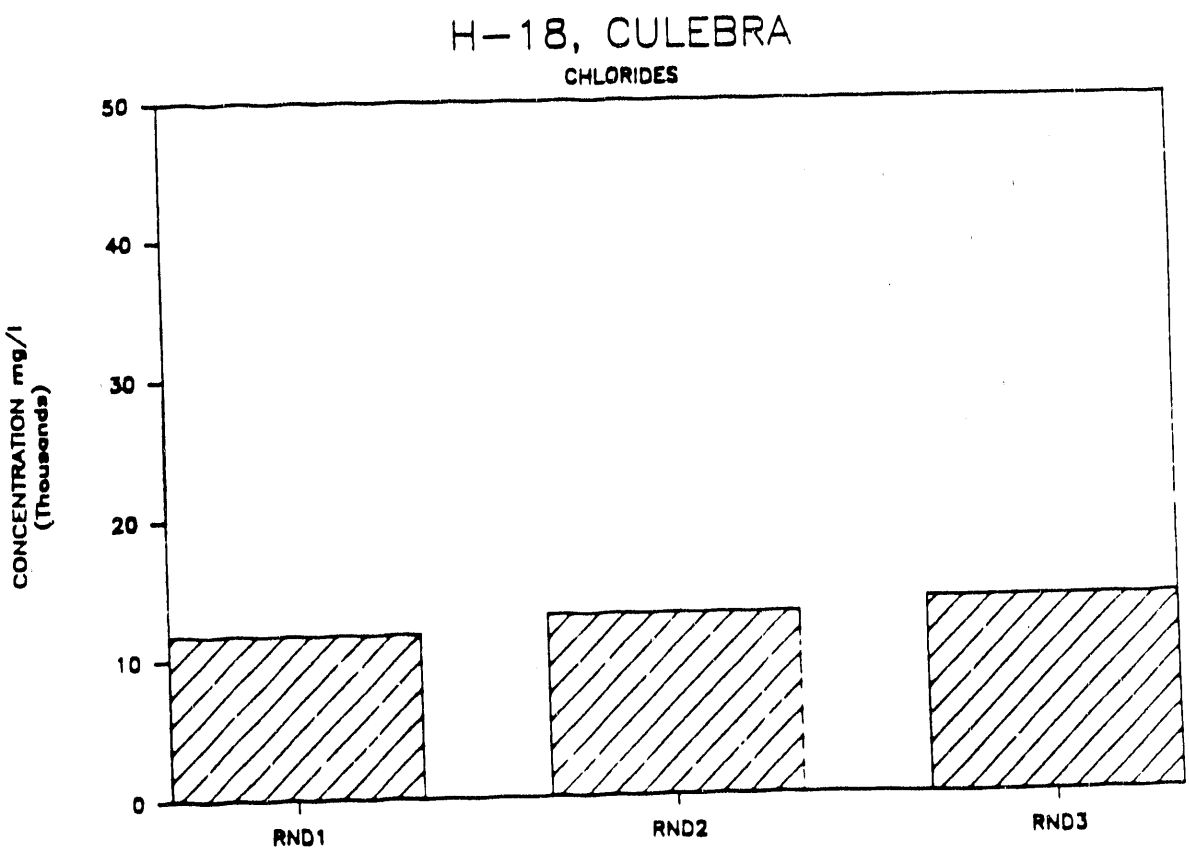
H-11b3, CULEBRA

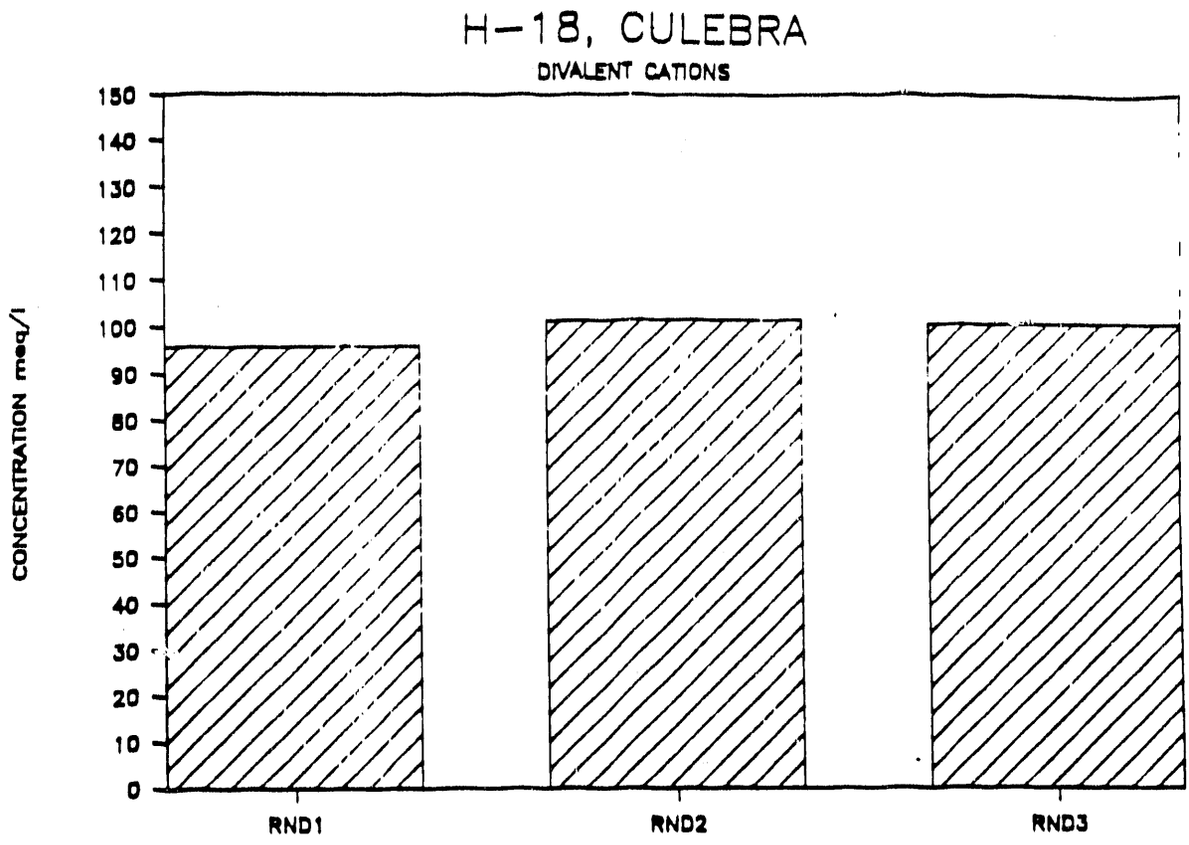


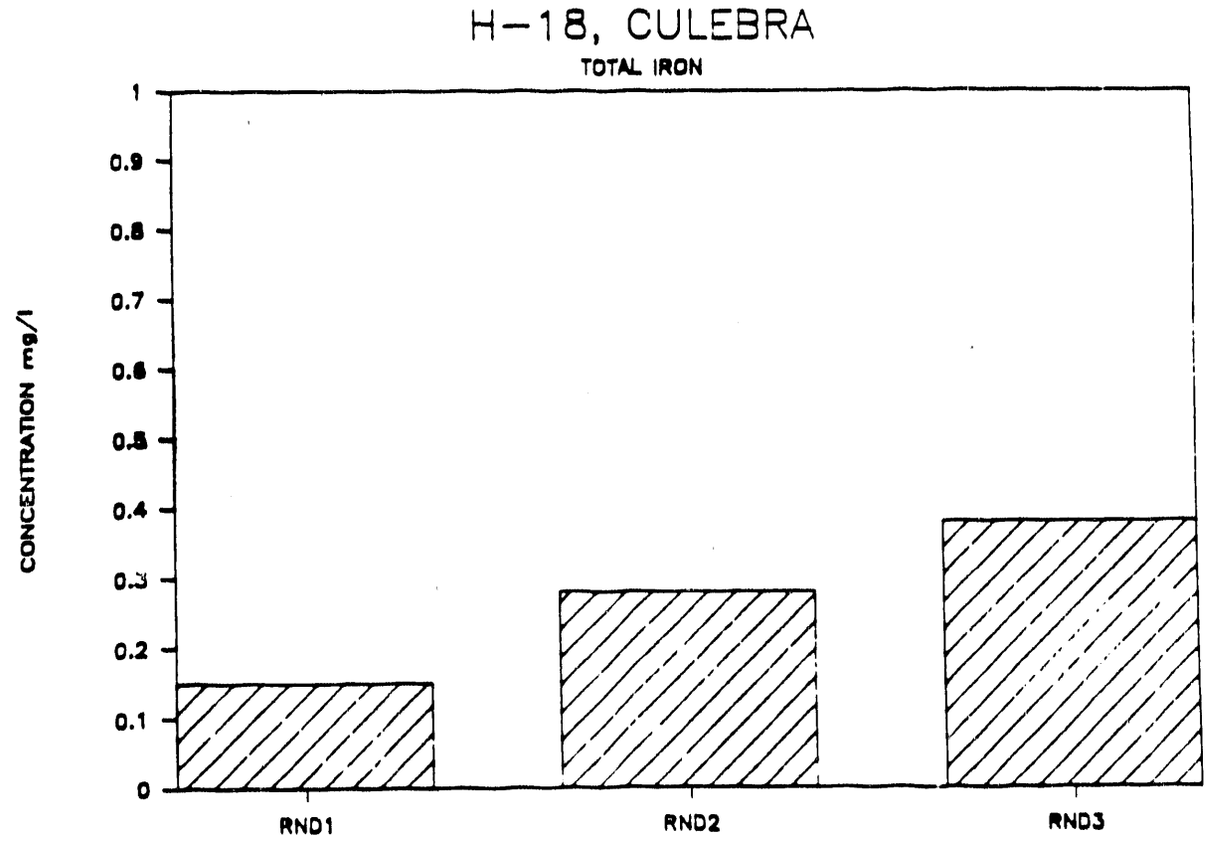

H--11b3, CULEBRA
SPECIFIC GRAVITY
g/cm3
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5

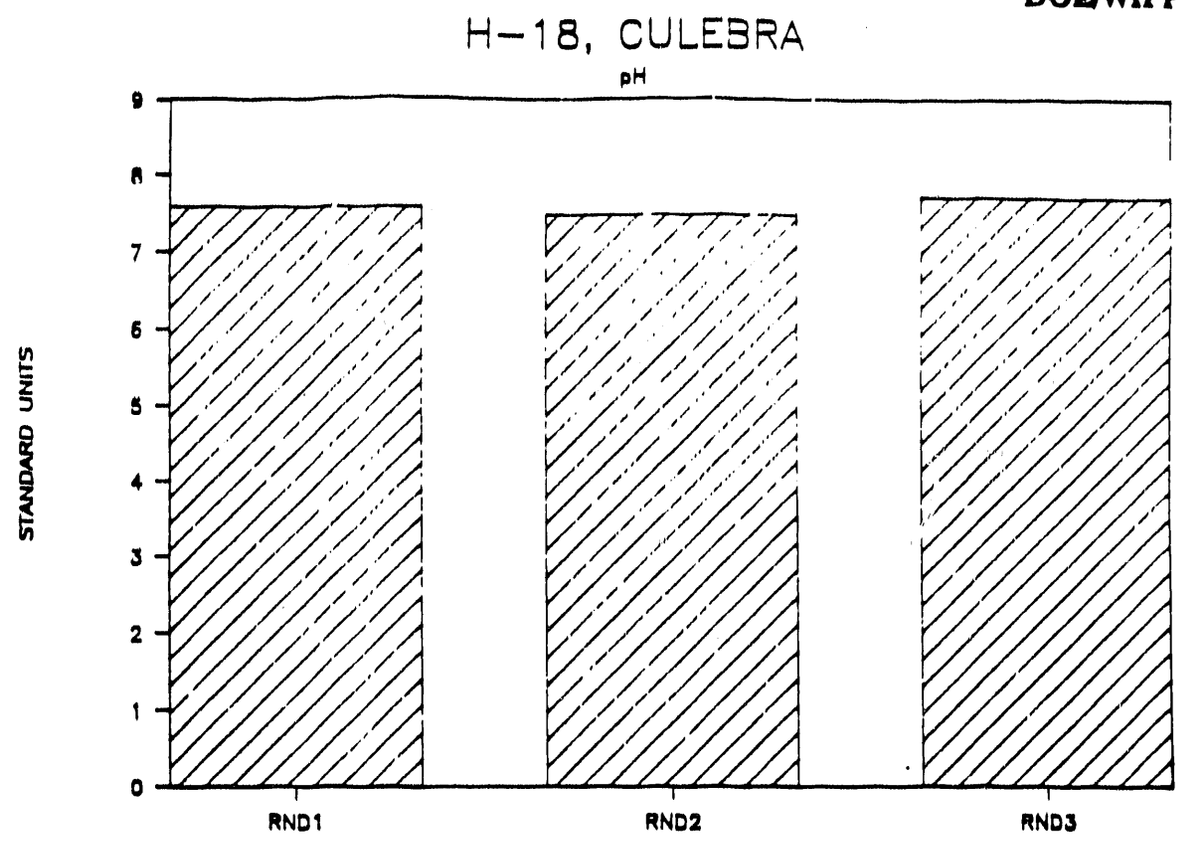

H-11b3, CULEBRA
TEMPERATURE
DEGREES CELCIUS
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
RND1
RND2
RND3
RND4
RND5

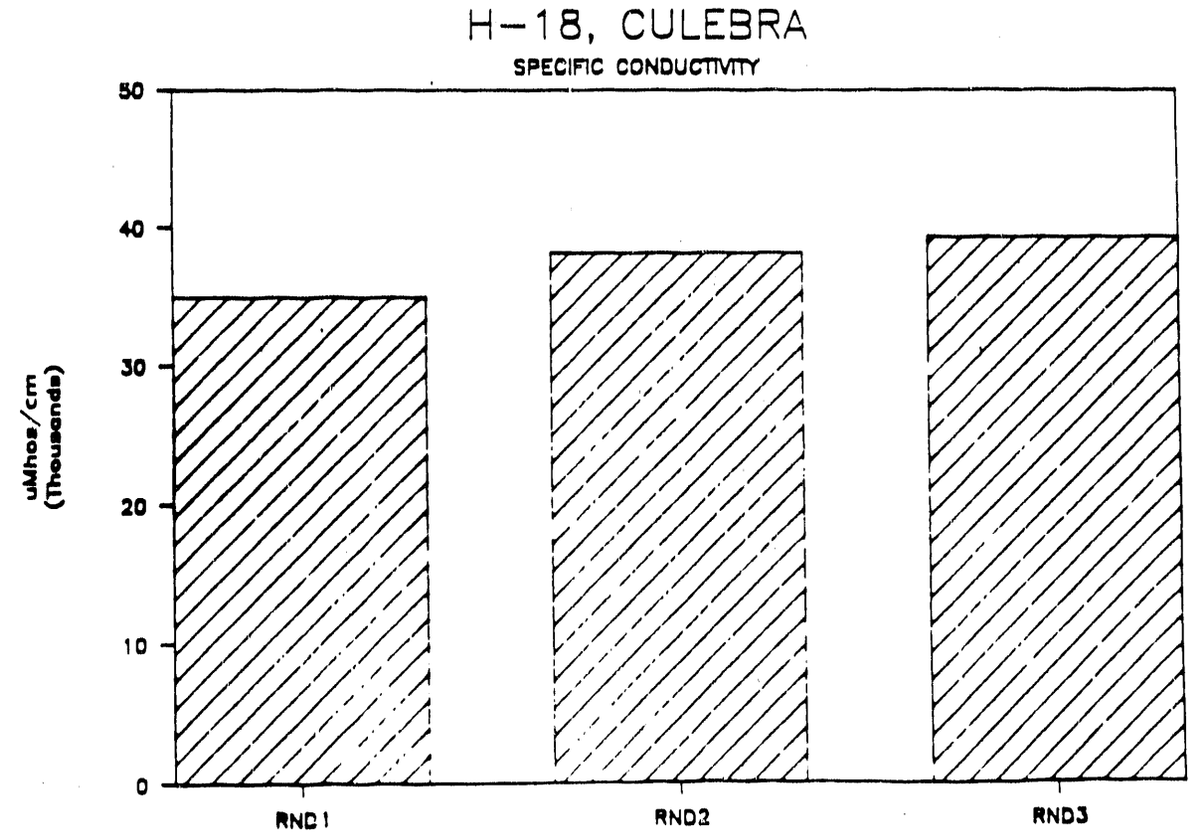

H-18, CULEBRA
ALKALINITY
CONCENTRATION mg/l
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3

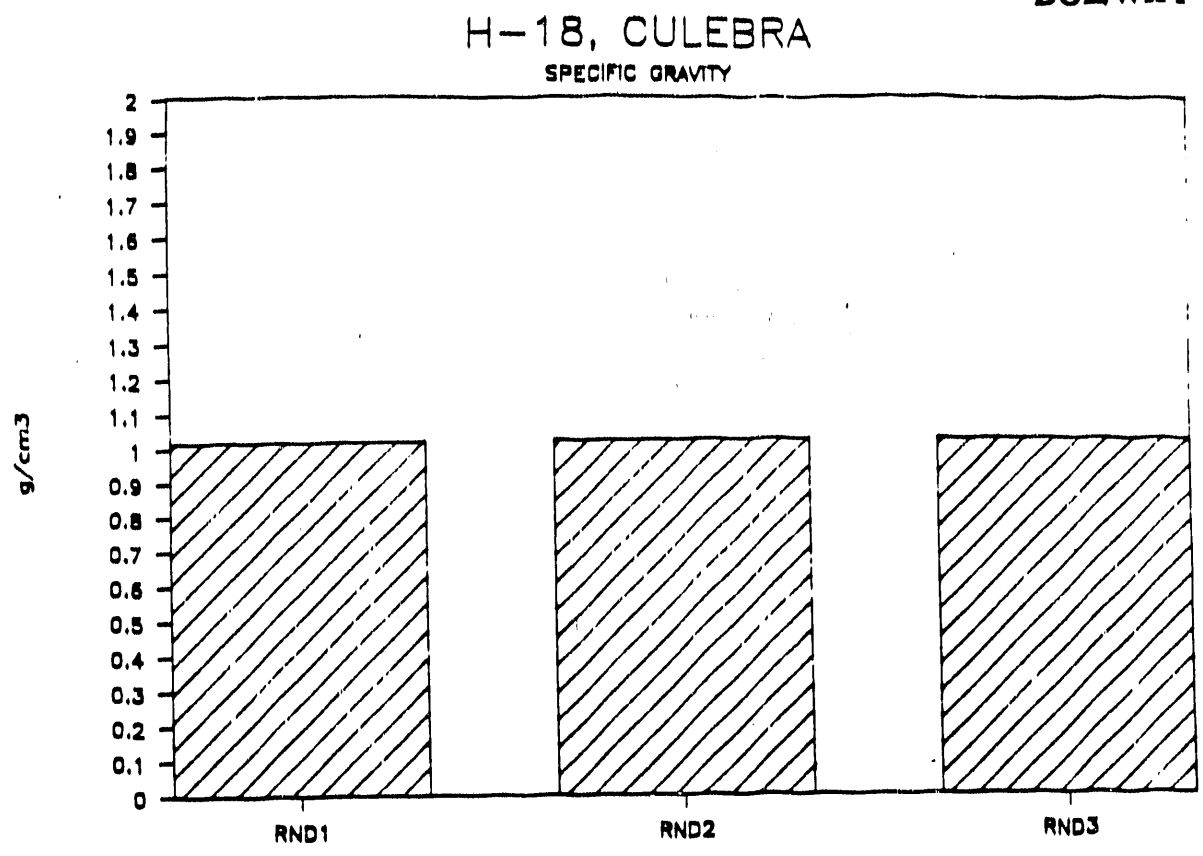

H-18, CULEBRA
CHLORIDES
CONCENTRATION mg/l
(Thousands)
50
40
30
20
10
0
RND1
RND2
RND3

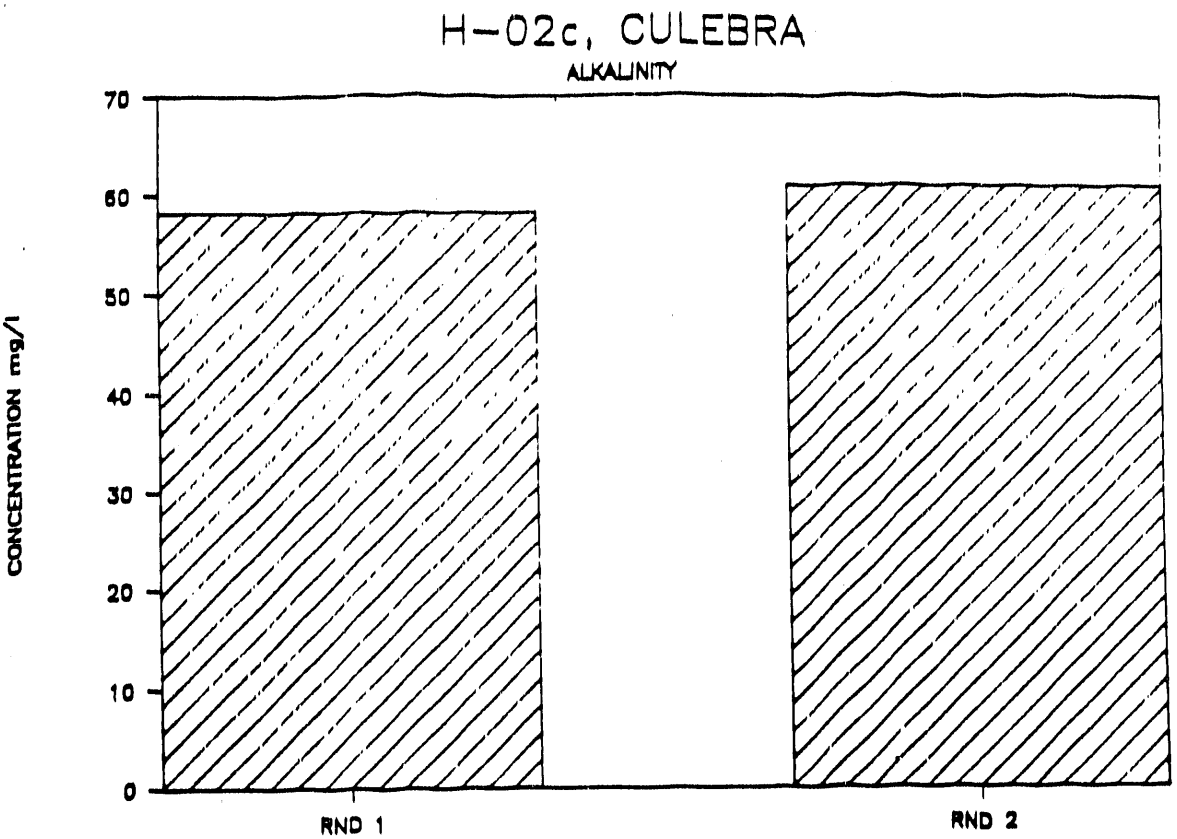

H-18, CULEBRA
DIVALENT CATIONS
CONCENTRATION meq/l
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3

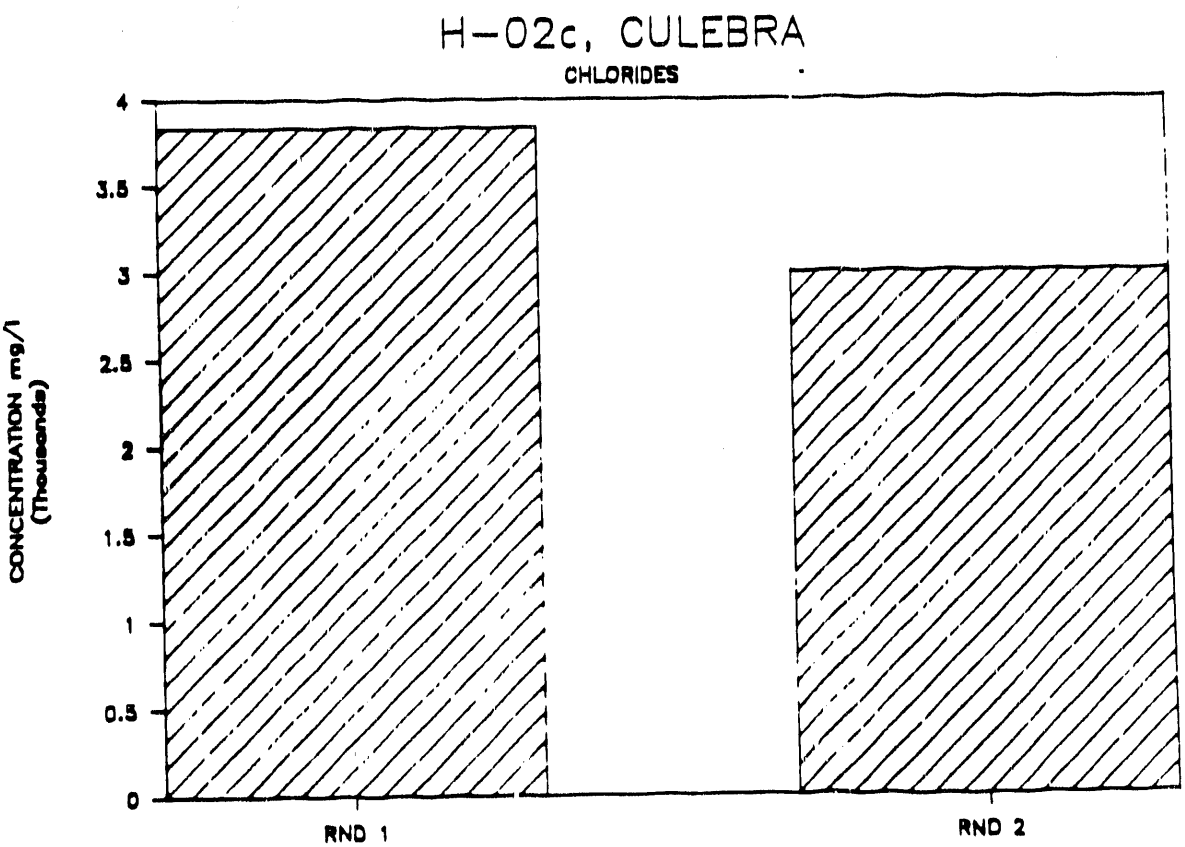

H-18, CULEBRA
TOTAL IRON
CONCENTRATION mg/l
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3

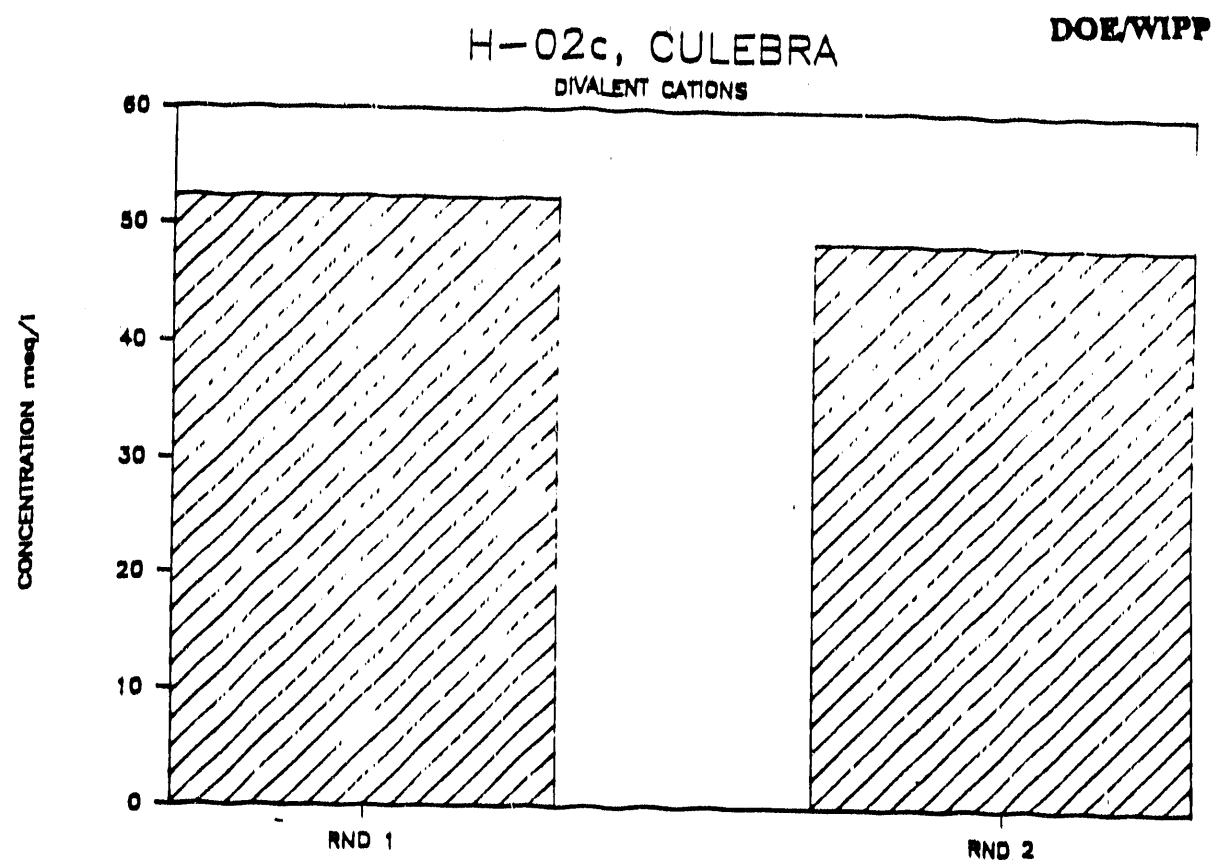

H-18, CULEBRA
pH
STANDARD UNITS
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3

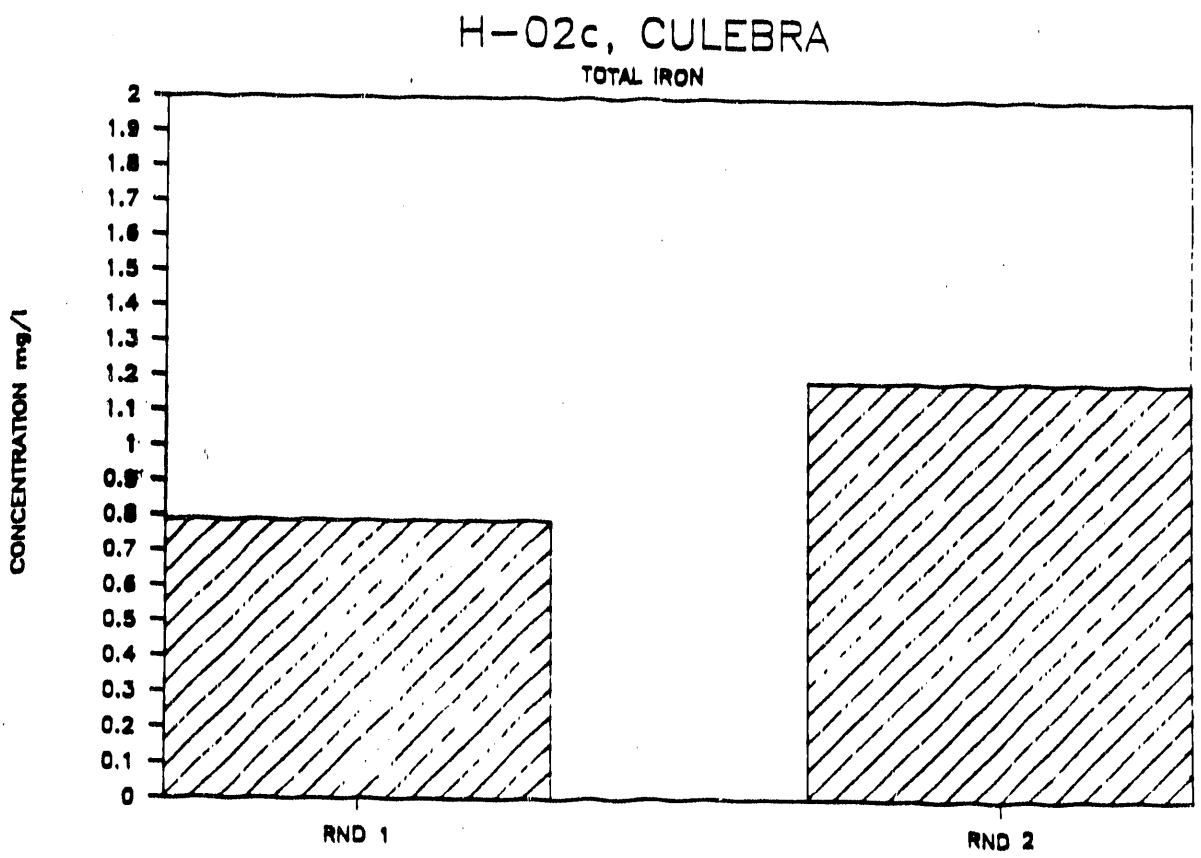

H-18, CULEBRA
SPECIFIC CONDUCTIVITY
uMhos/cm
(Thousands)
50
40
30
20
10
0
RND1
RND2
RND3

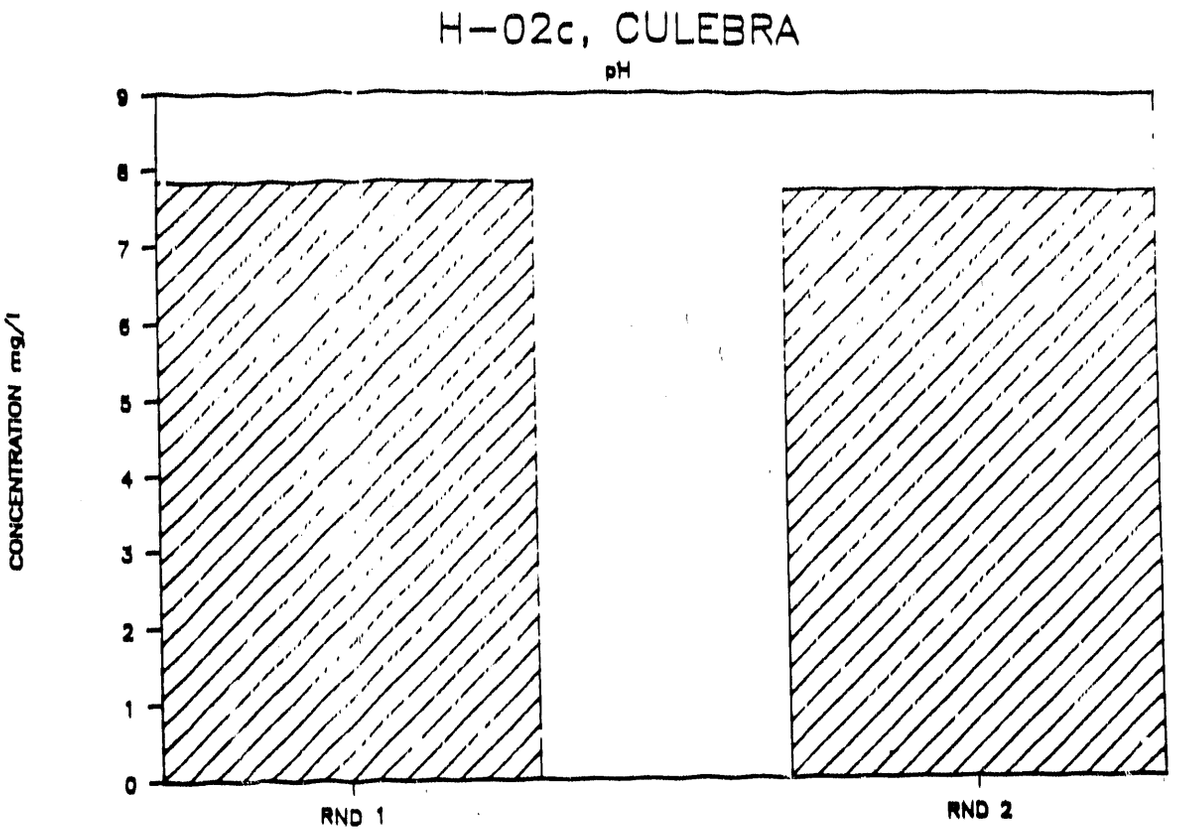

H-18, CULEBRA
SPECIFIC GRAVITY
g/cm3
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3

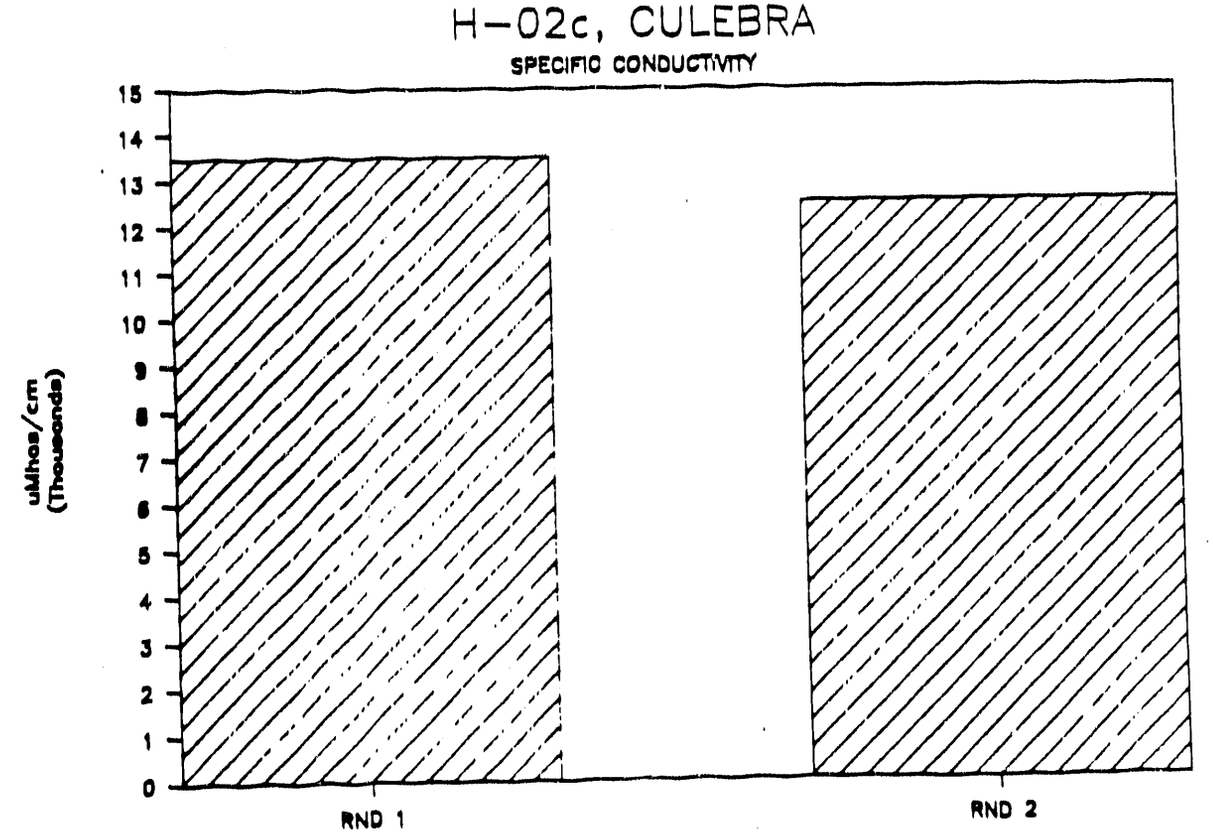

H-02c, CULEBRA
ALKALINITY
CONCENTRATION mg/l
70
60
50
40
30
20
10
0
RND 1
RND 2

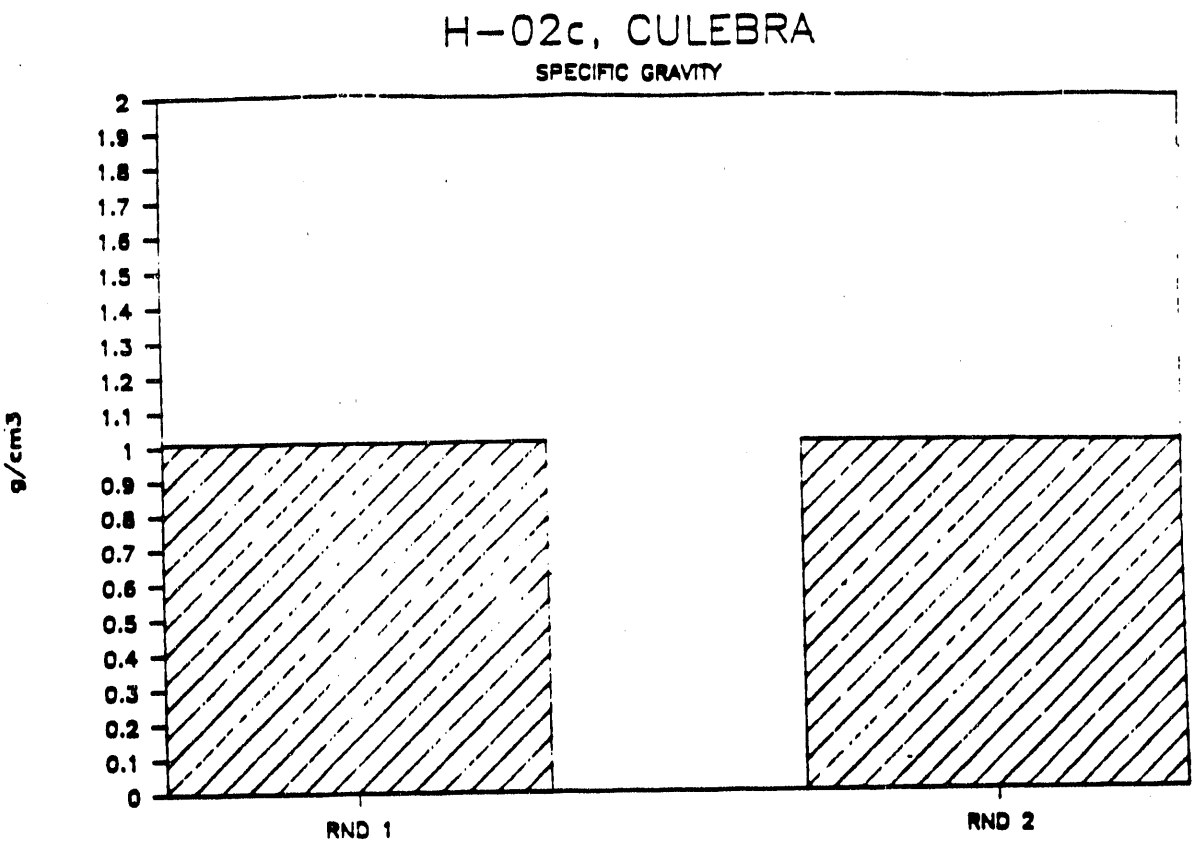

H-02c, CULEBRA
CHLORIDES
CONCENTRATION mg/l (Thousands)
4
3.5
3
2.5
2
1.5
1
0.5
0
RND 1
RND 2

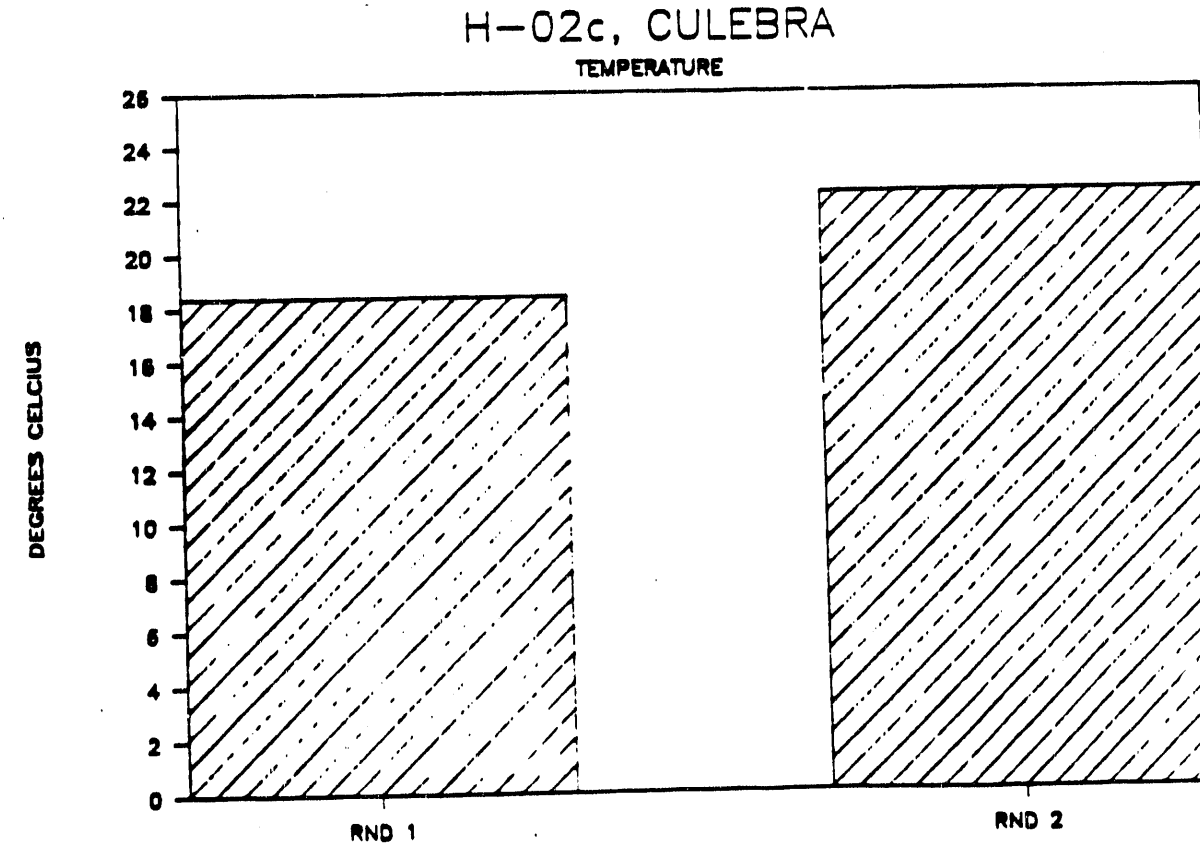

H-02c, CULEBRA
DIVALENT CATIONS
CONCENTRATION meq/l
60
50
40
30
20
10
0
RND 1
RND 2

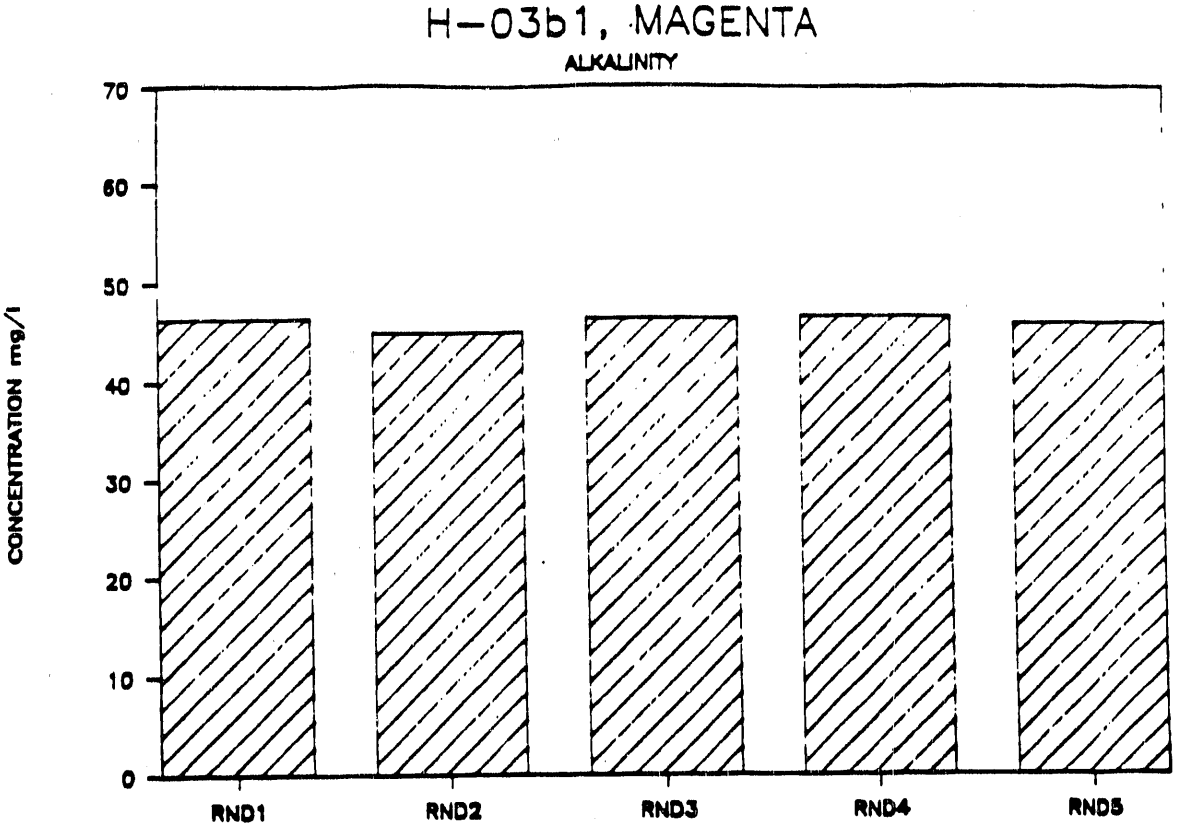

H-02c, CULEBRA
TOTAL IRON
CONCENTRATION mg/l
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND 1
RND 2

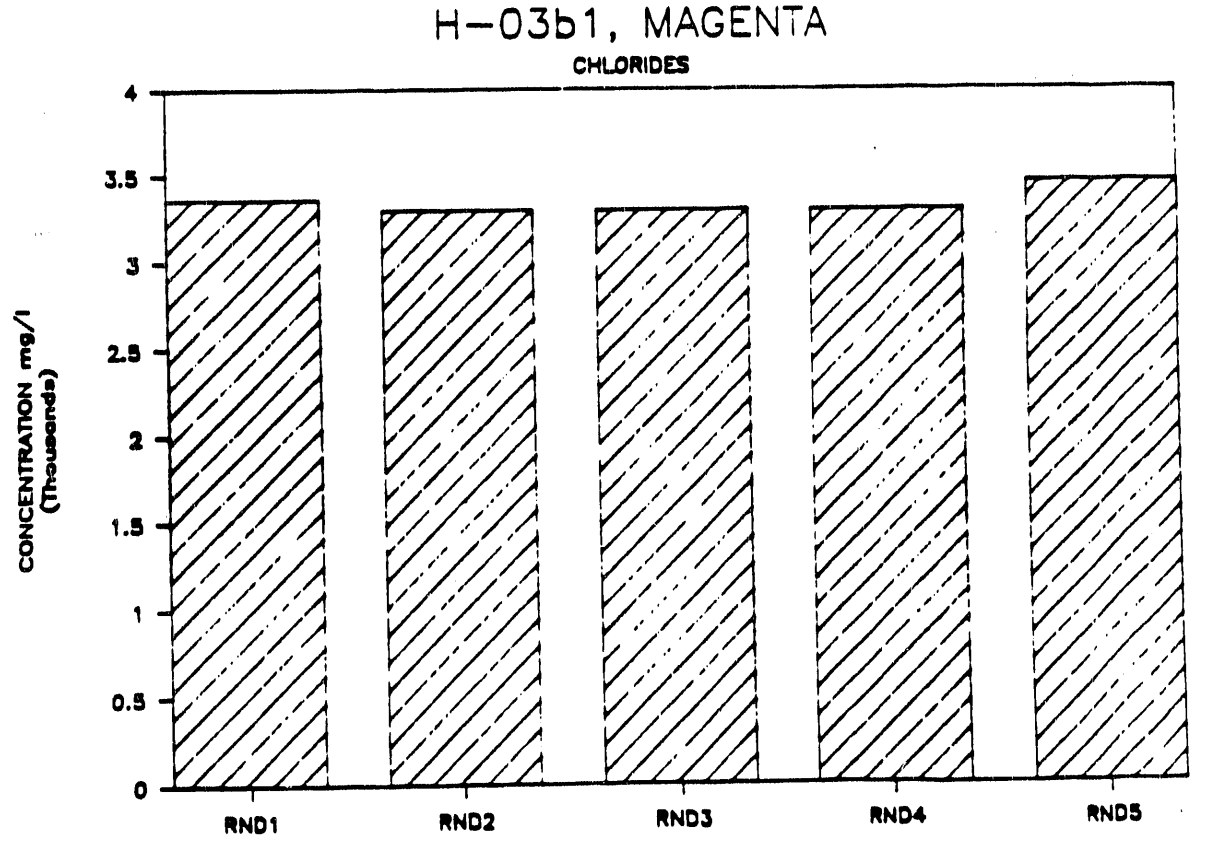

H-02c, CULEBRA
pH
CONCENTRATION mg/l
9
8
7
6
5
4
3
2
1
0
RND 1
RND 2

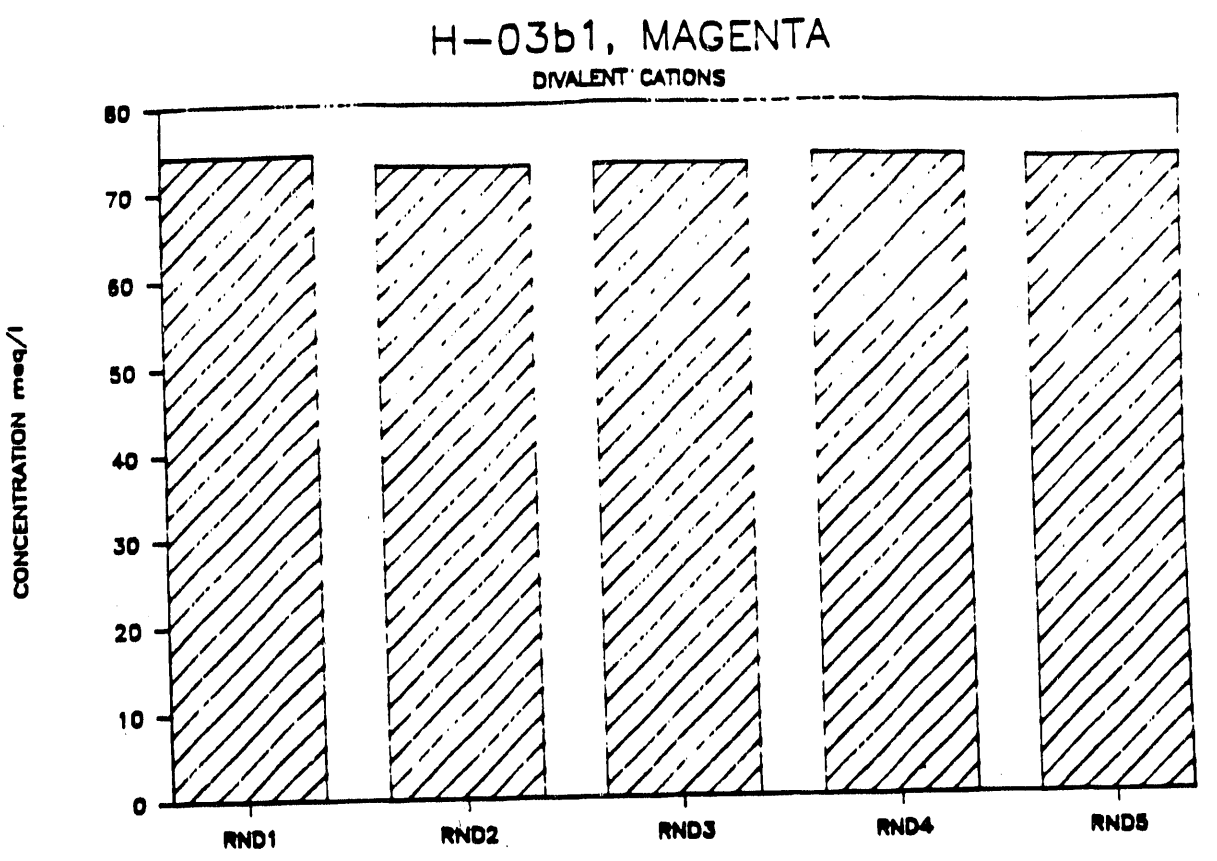

H-02c, CULEBRA
SPECIFIC CONDUCTIVITY
uMhos/cm
(Thousands)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
RND 1
RND 2

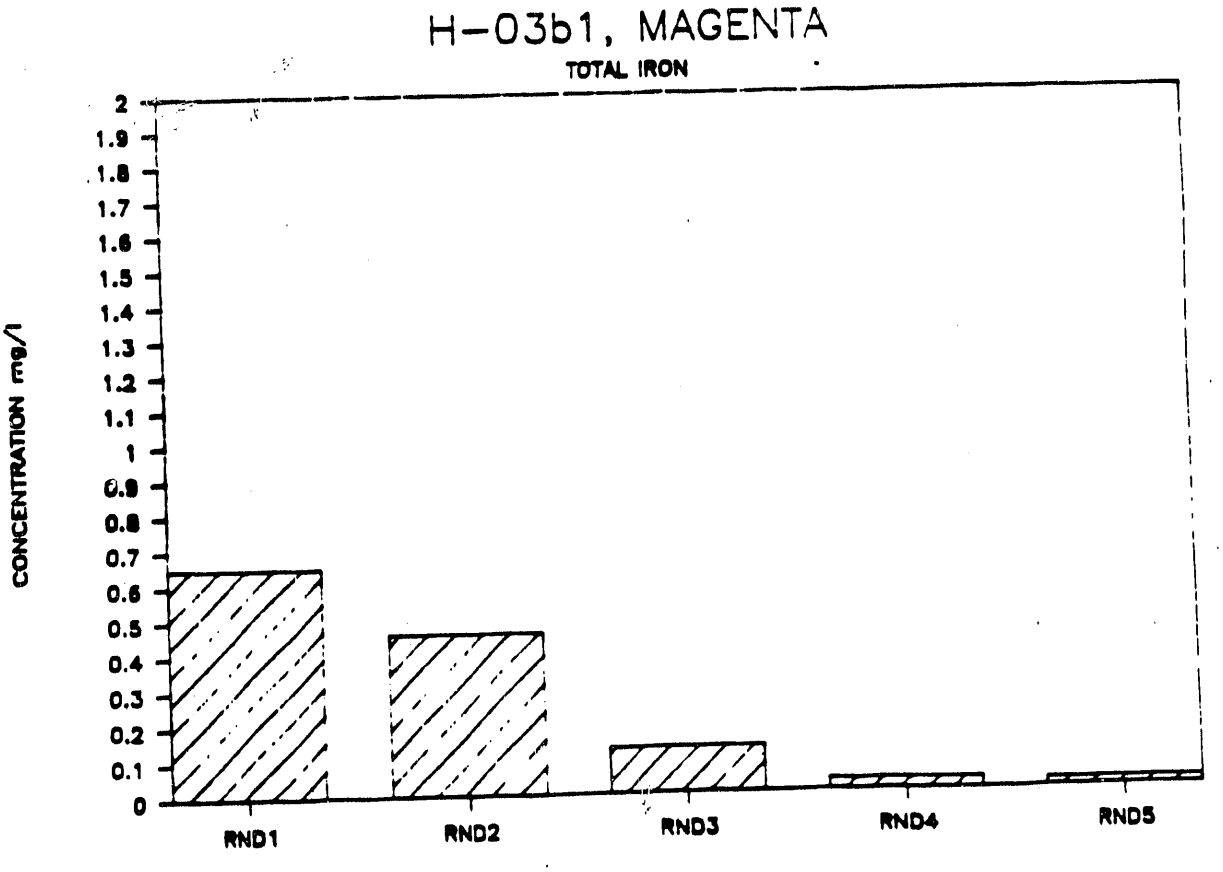

H-02c, CULEBRA
SPECIFIC GRAVITY
g/cm3
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND 1
RND 2

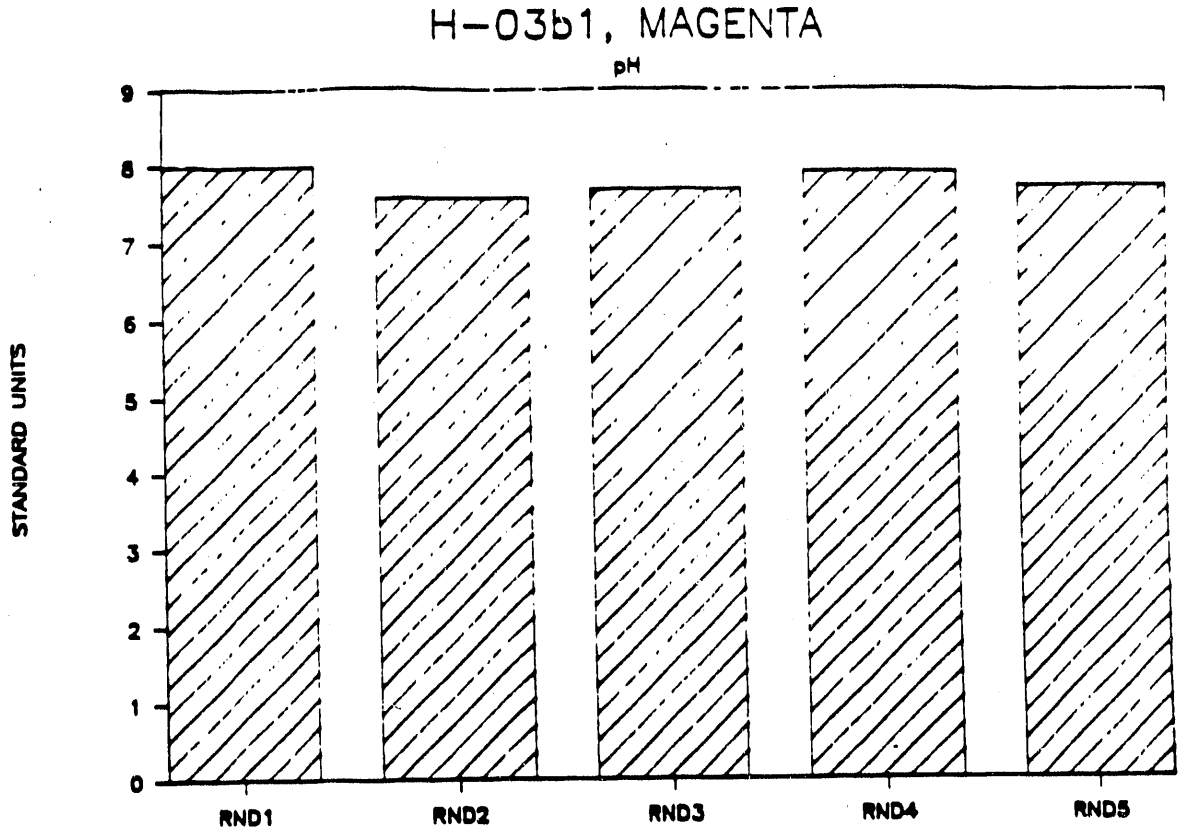

H-02c, CULEBRA
TEMPERATURE
DEGREES CELCIUS
26
24
22
20
18
16
14
12
10
8
6
4
2
0
RND 1
RND 2

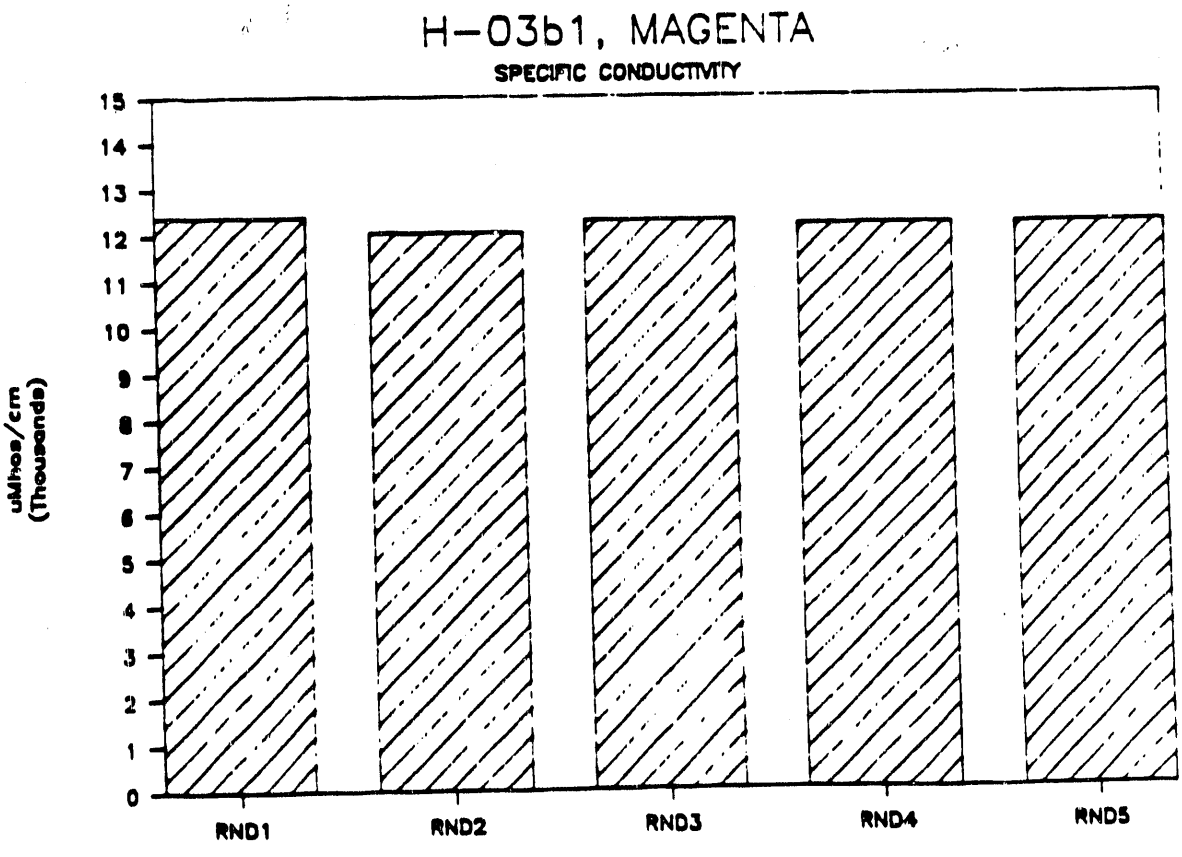

H-03b1, MAGENTA
ALKALINITY
CONCENTRATION mg/l
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

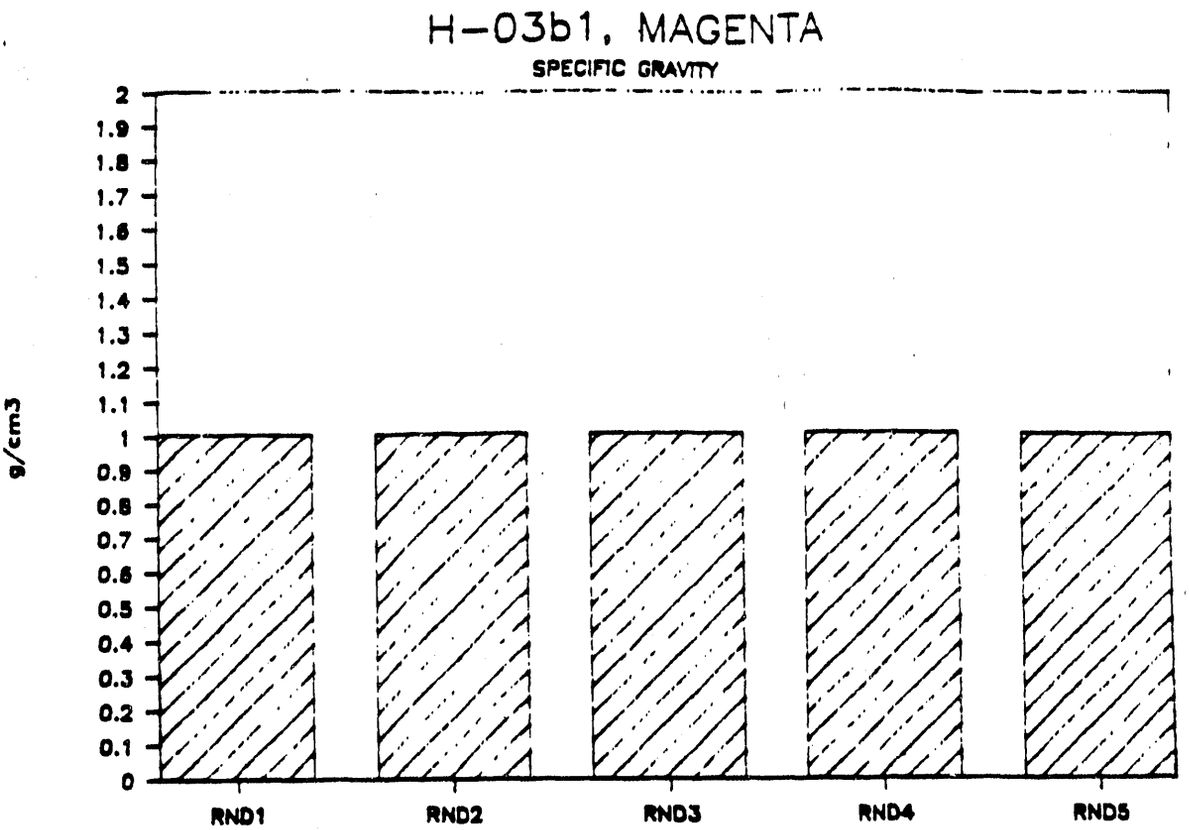

H-03b1, MAGENTA
CHLORIDES
CONCENTRATION mg/l
(Thousands)
4
3.5
3
2.5
2
1.5
1
0.5
0
RND1
RND2
RND3
RND4
RND5

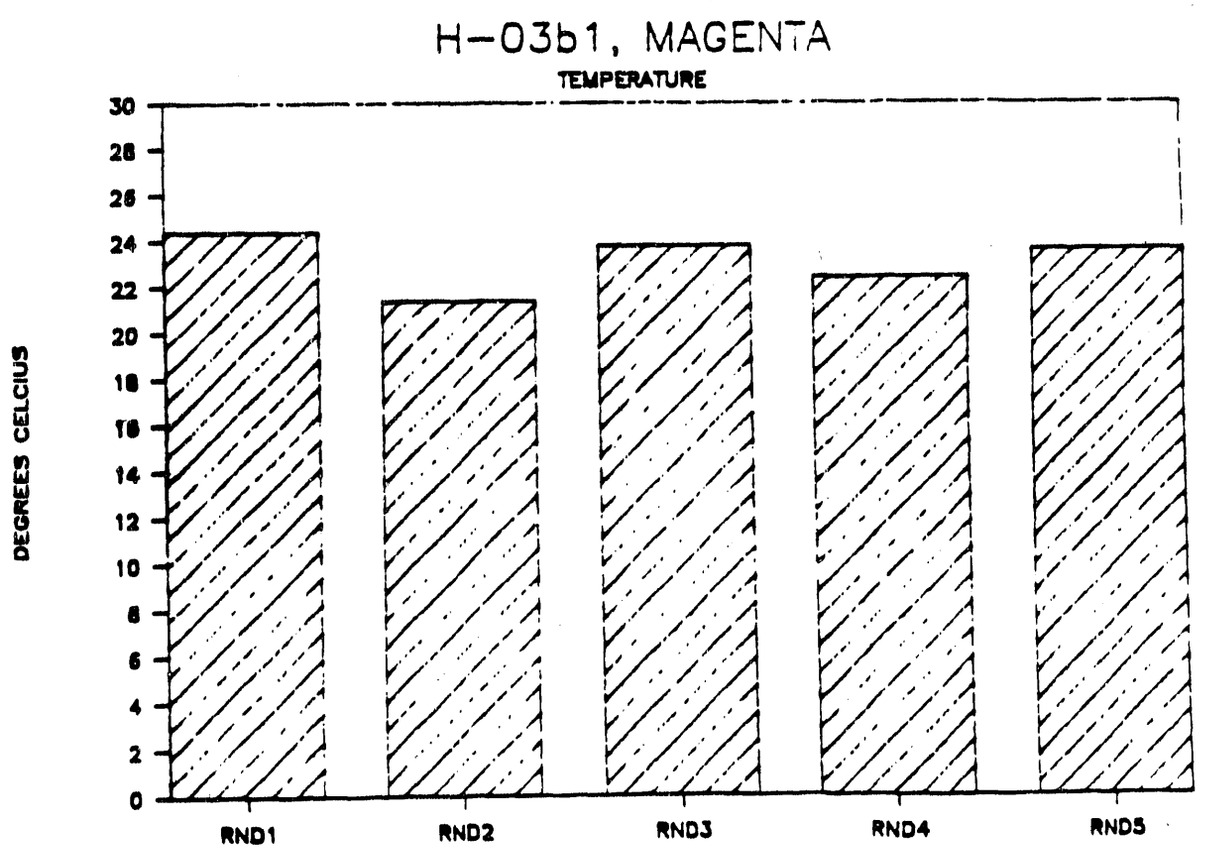

H-03b1, MAGENTA
DIVALENT CATIONS
CONCENTRATION meq/l
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

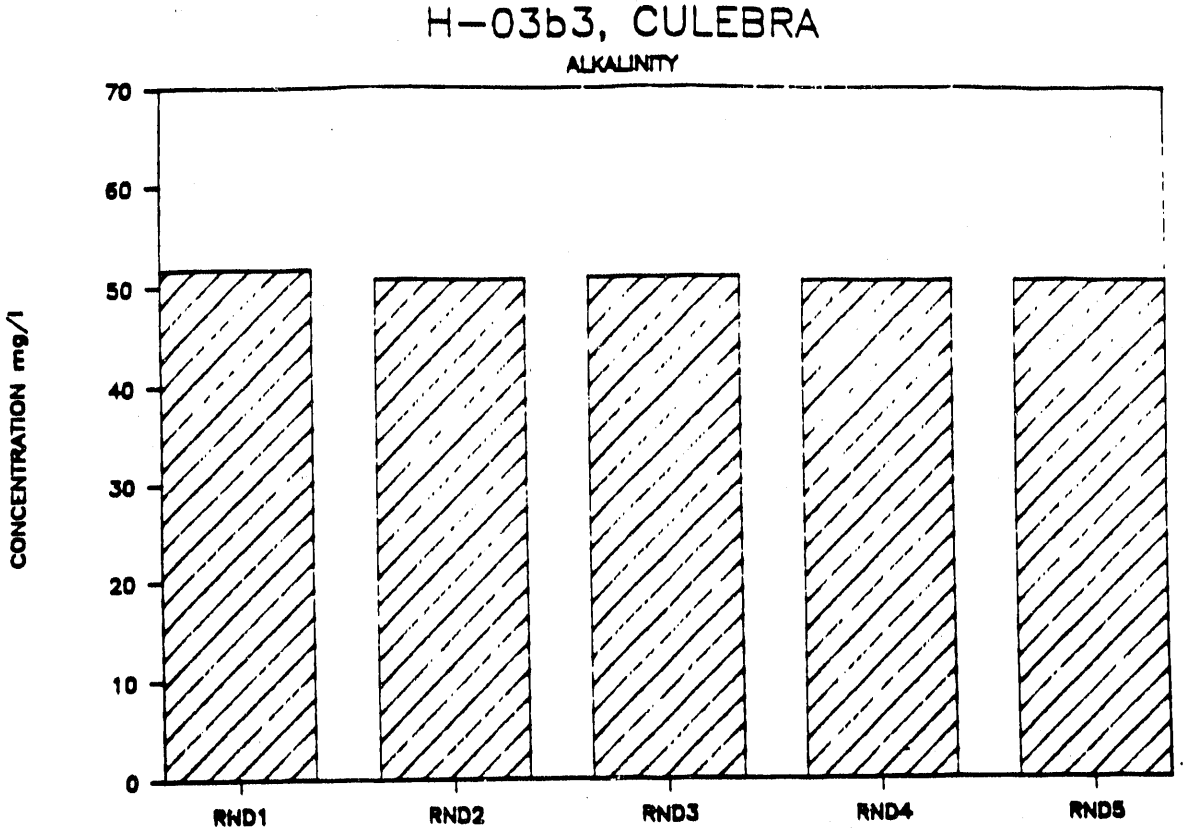

H-03b1, MAGENTA
TOTAL IRON
CONCENTRATION mg/l
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5

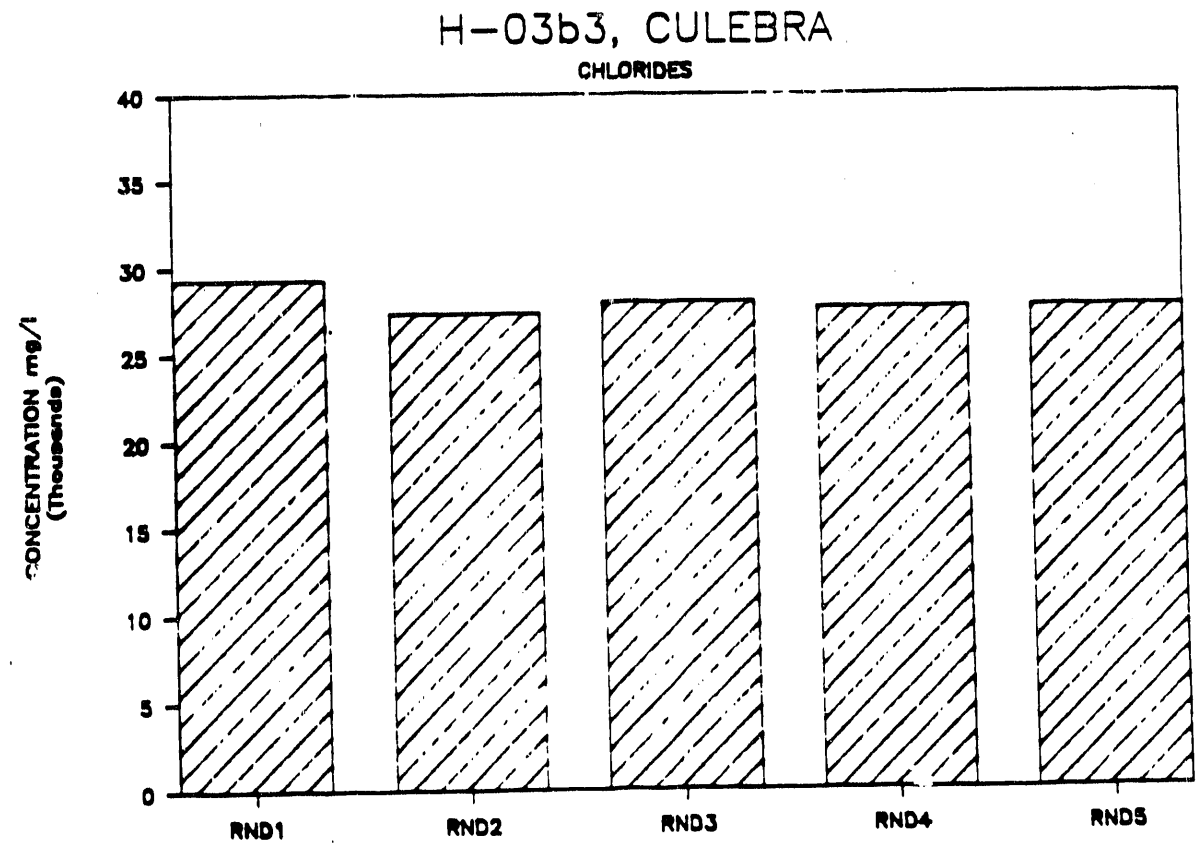

H-03b1, MAGENTA
pH
STANDARD UNITS
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5

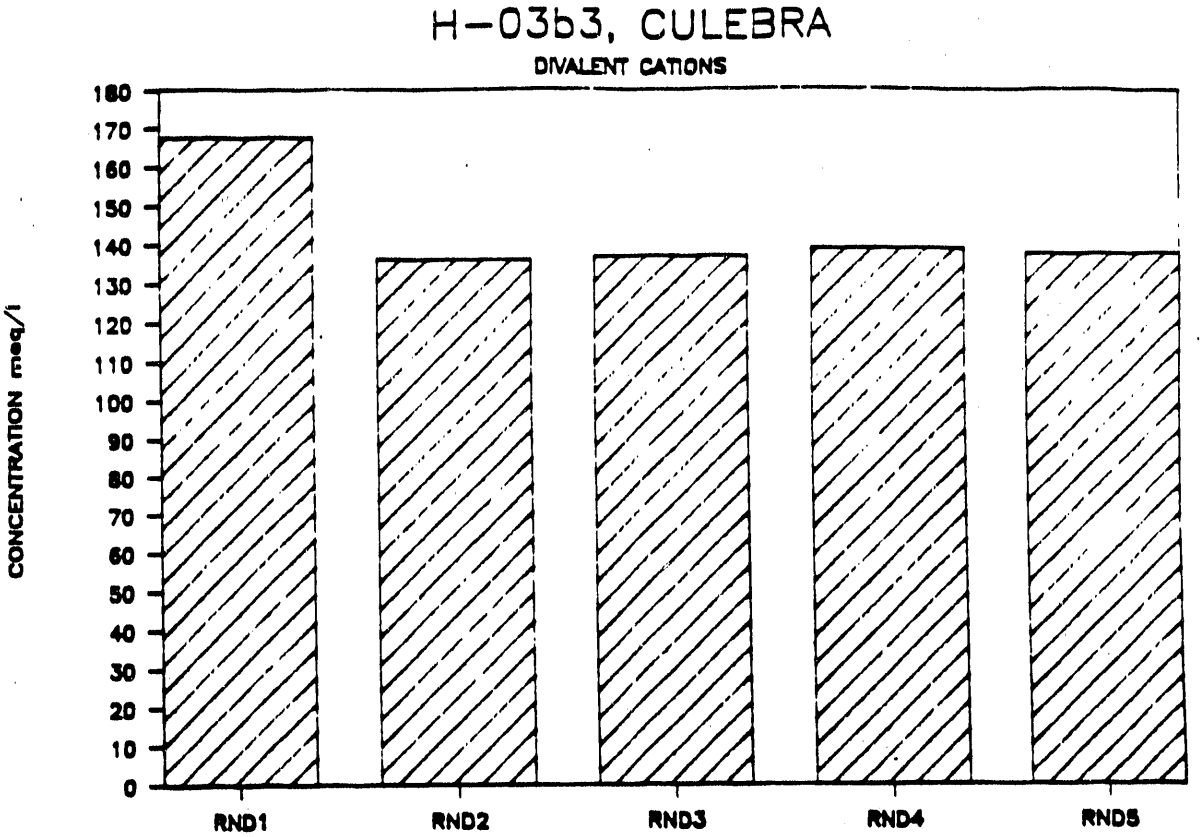

H-03b1, MAGENTA
SPECIFIC CONDUCTIVITY
uMhos/cm (Thousands)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5

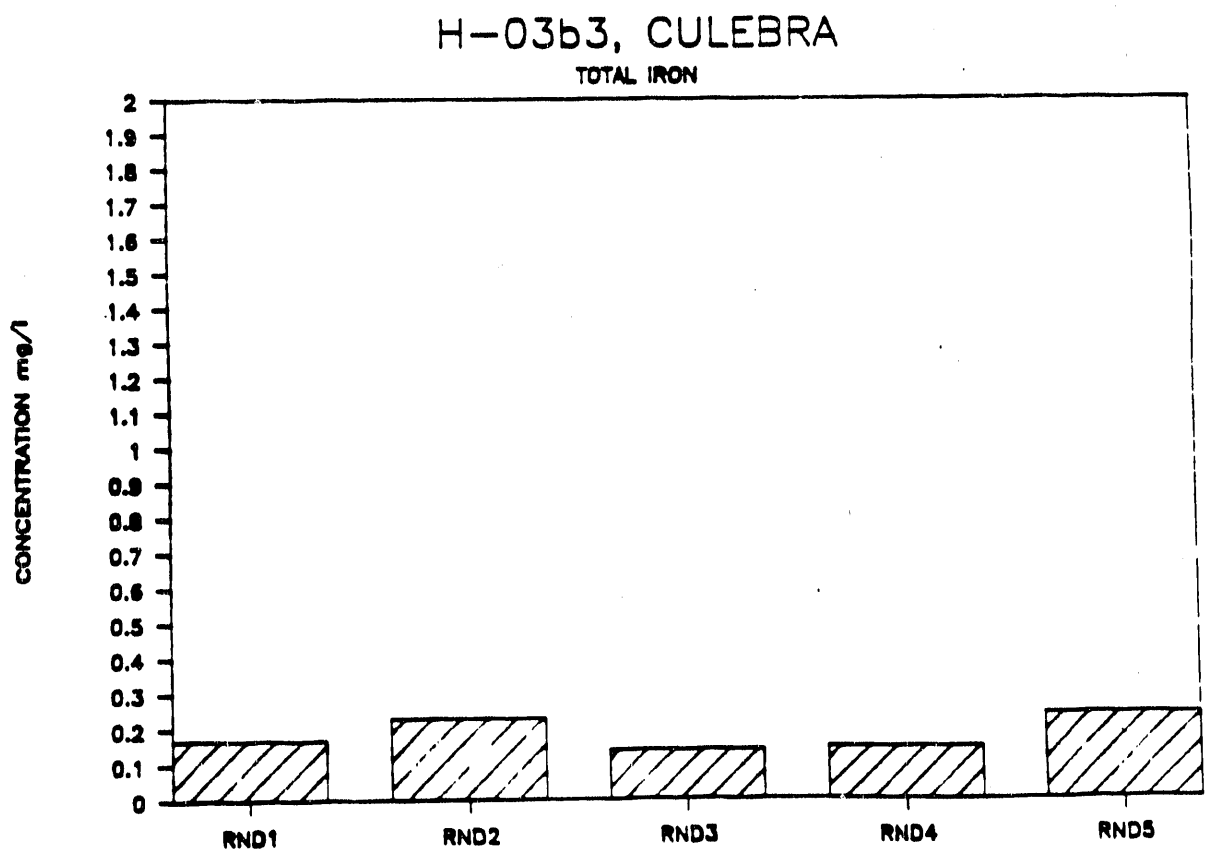

H-03b1, MAGENTA
SPECIFIC GRAVITY
g/cm3
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5

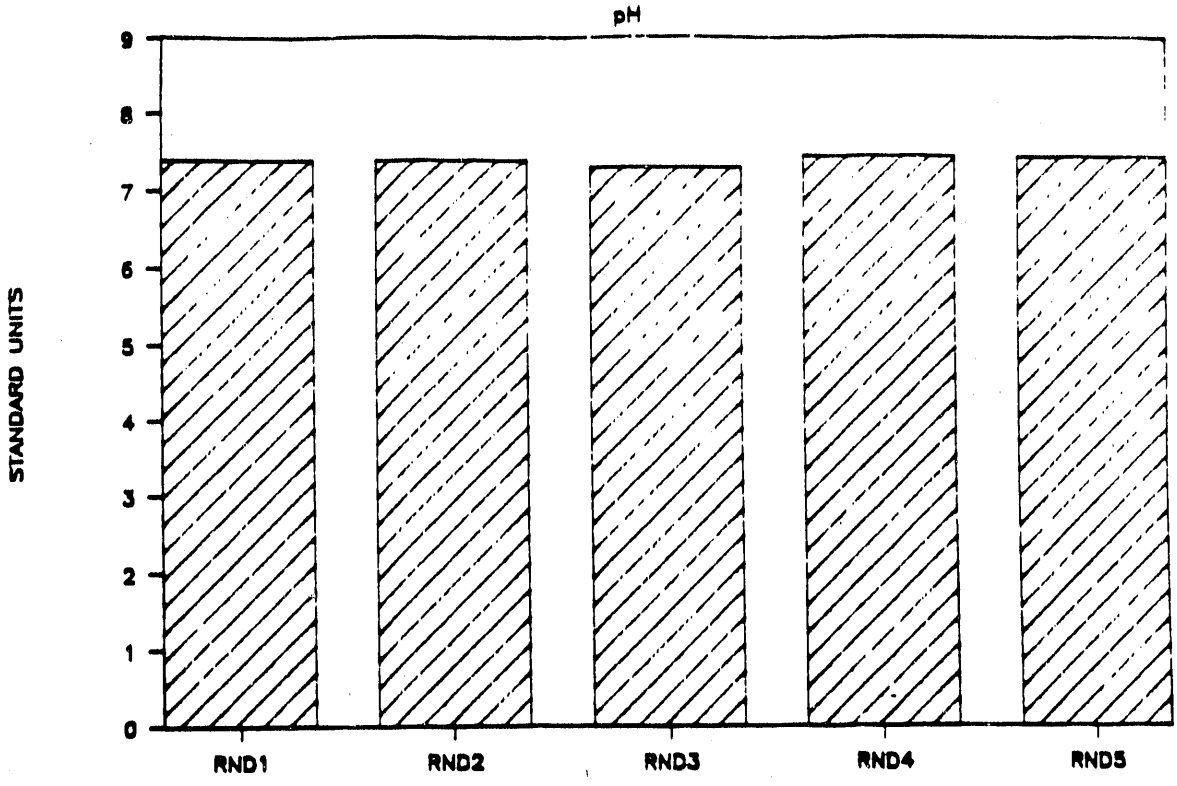

H-03b1, MAGENTA
TEMPERATURE
DEGREES CELCIUS
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
RND1
RND2
RND3
RND4
RND5

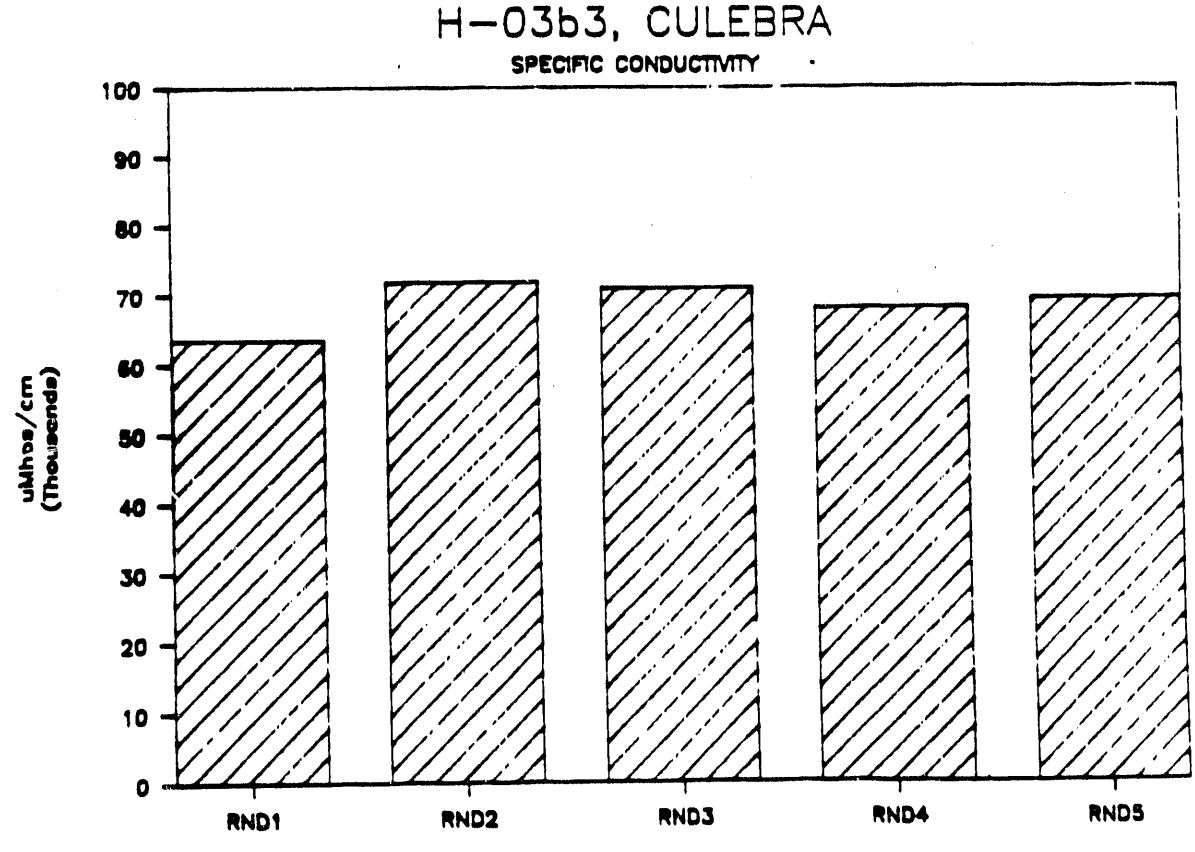

H-03b3, CULEBRA
ALKALINITY
CONCENTRATION mg/l
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

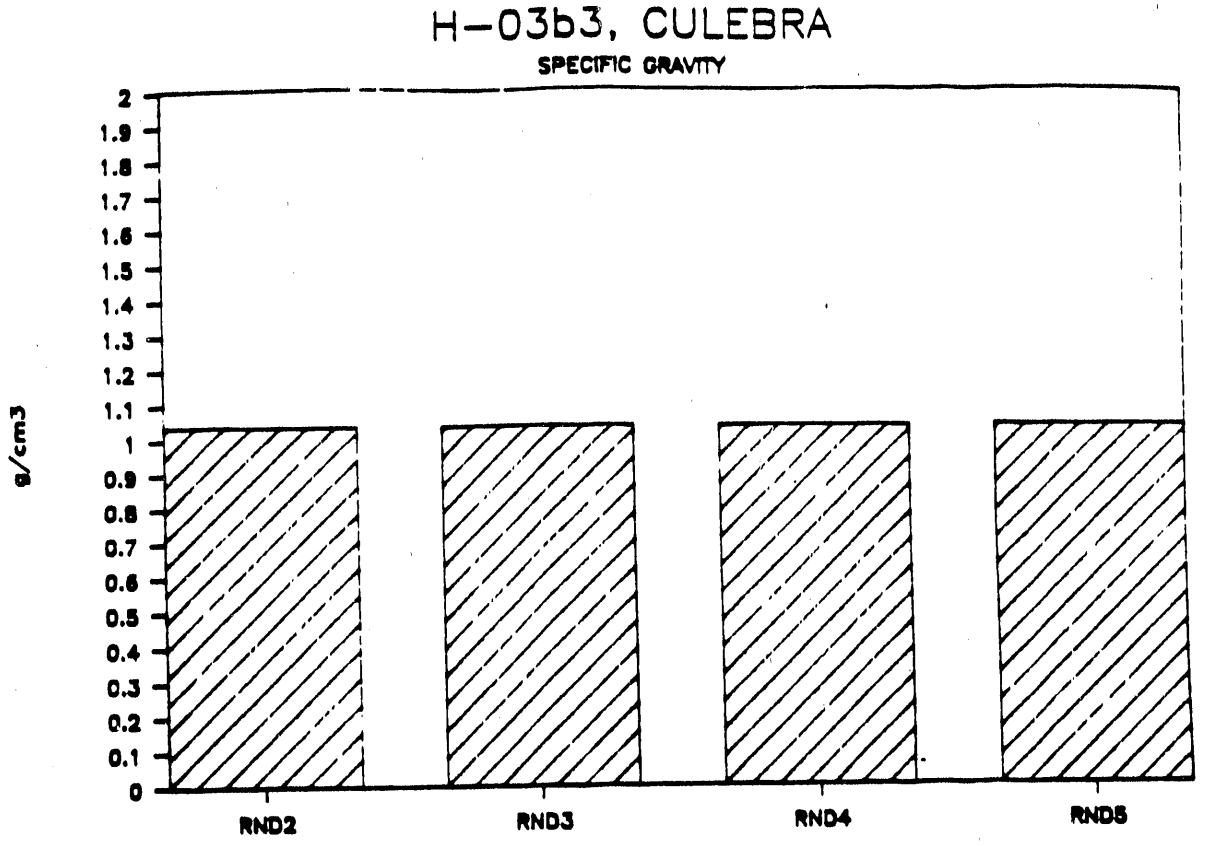

H-03b3, CULEBRA
CHLORIDES
CONCENTRATION mg/l
(Thousands)
40
35
30
25
20
15
10
5
0
RND1
RND2
RND3
RND4
RND5

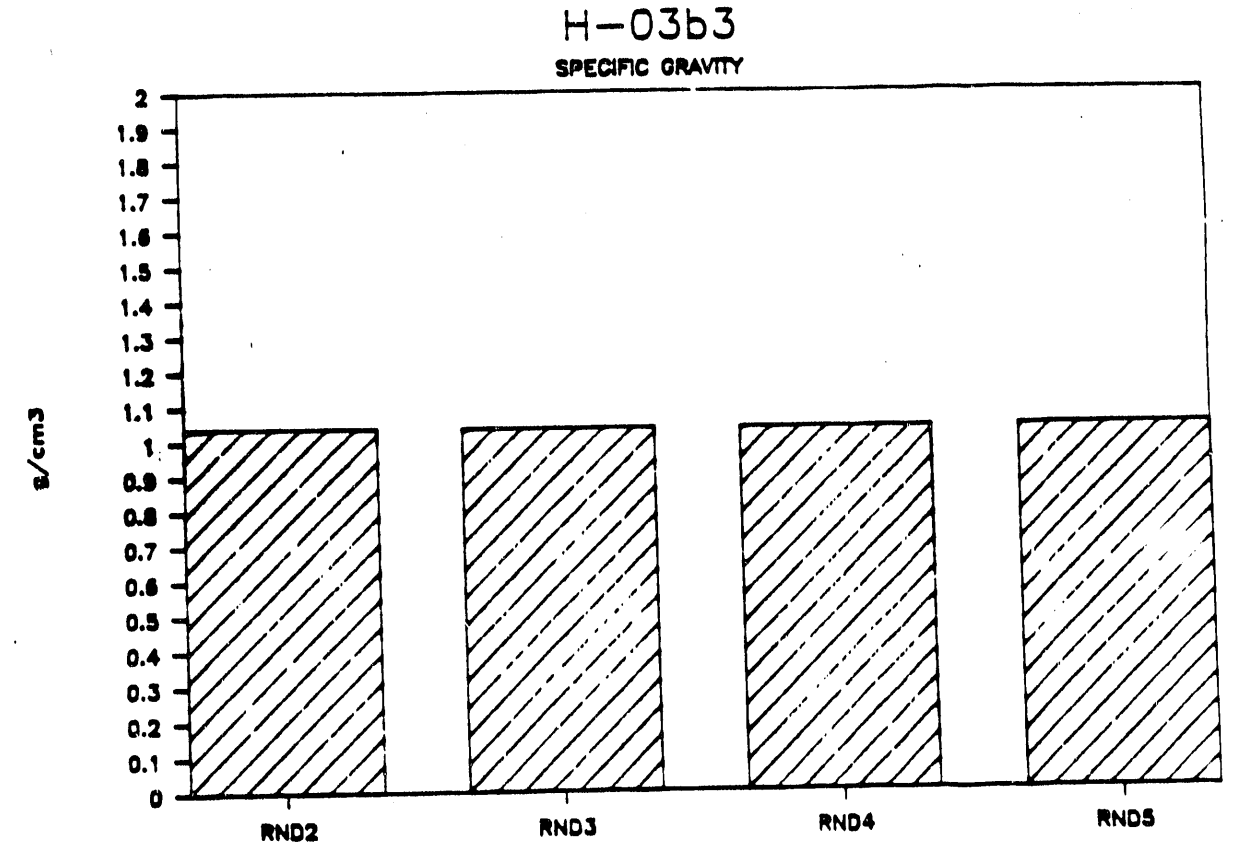

H-03b3, CULEBRA
DIVALENT CATIONS
CONCENTRATION meq/l
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

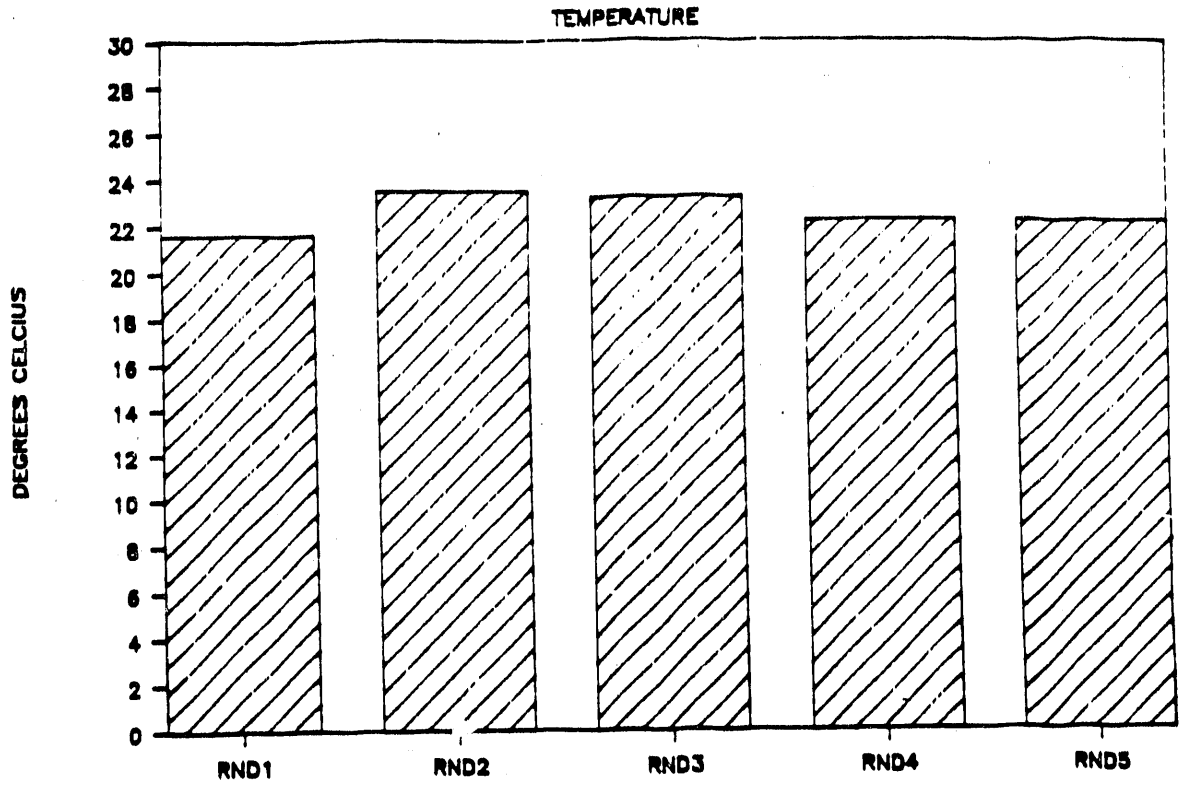

H-03b3, CULEBRA
TOTAL IRON
CONCENTRATION mg/l
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5

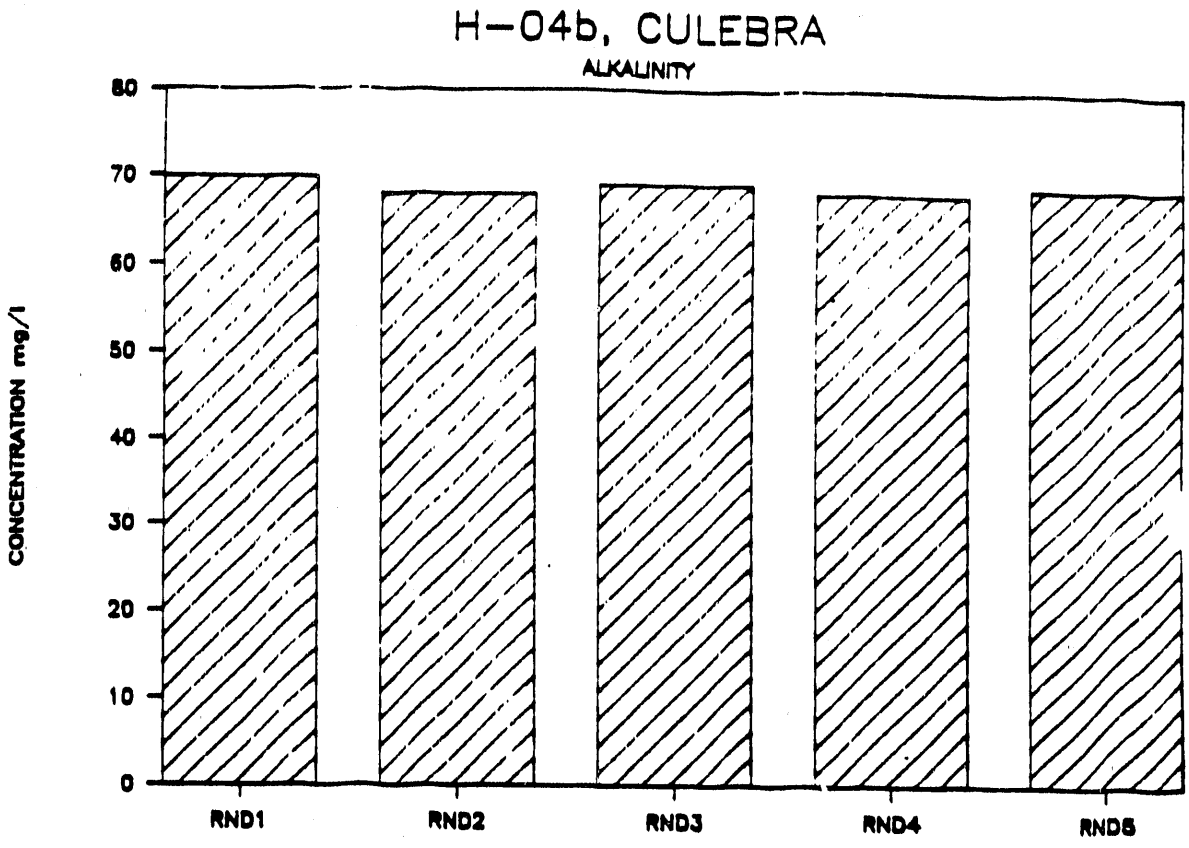

H-03b3, CULEBRA
pH
STANDARD UNITS
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5

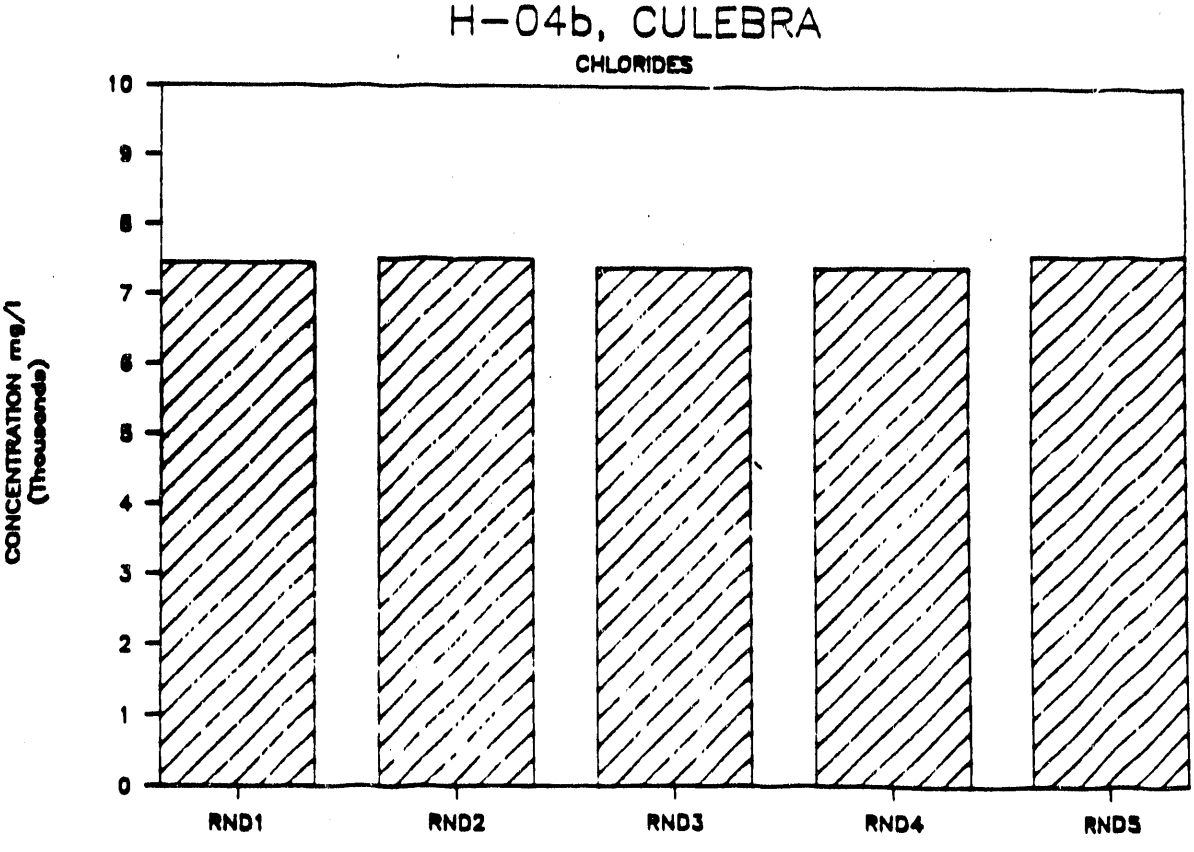

H-03b3, CULEBRA
SPECIFIC CONDUCTIVITY
uMhos/cm
(Thousands)
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

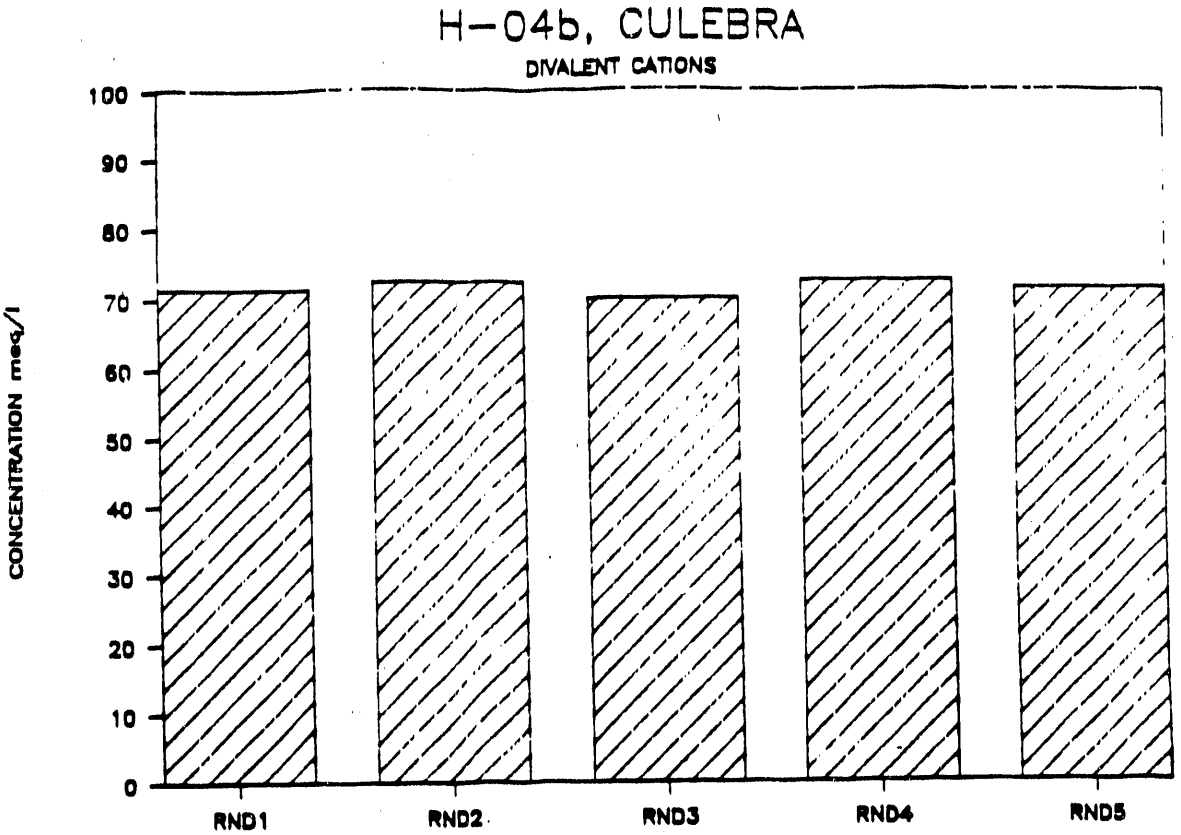

H-03b3, CULEBRA
SPECIFIC GRAVITY
g/cm3
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND2
RND3
RND4
RND5

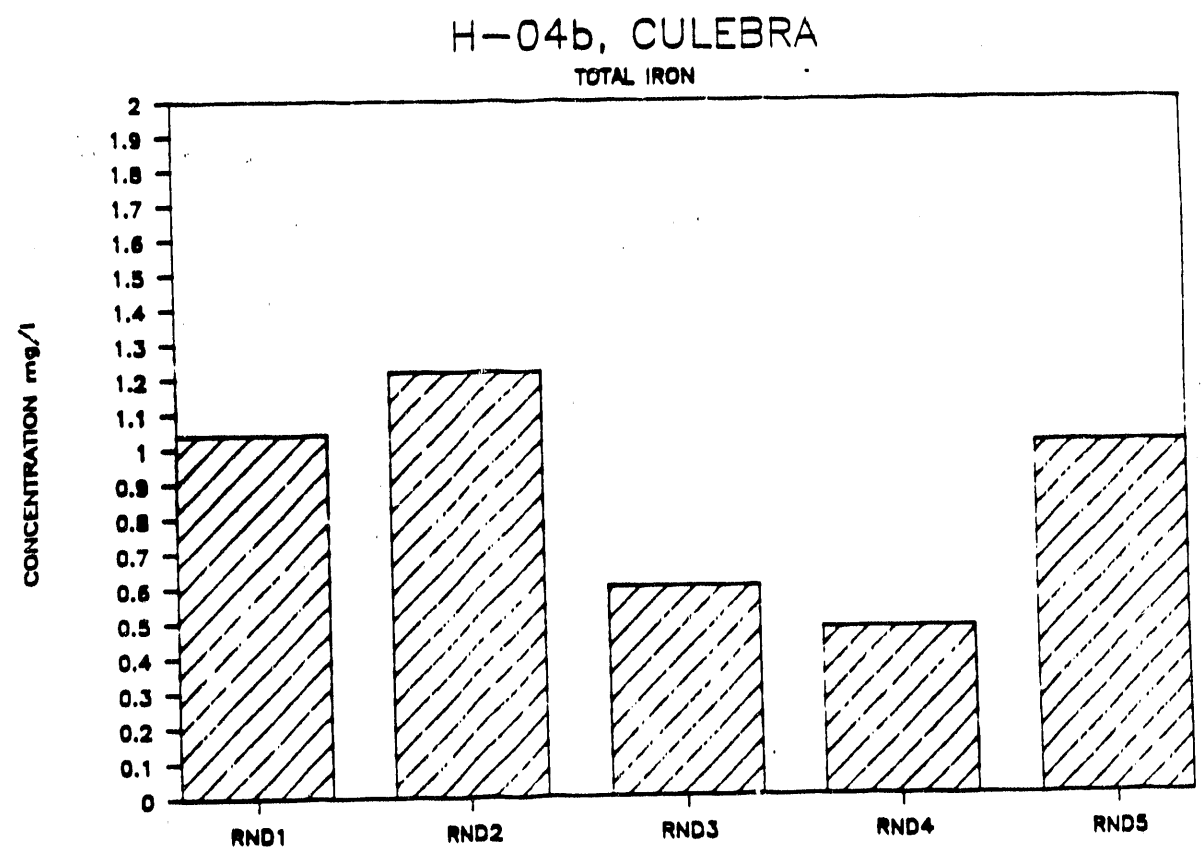

H-03b3
SPECIFIC GRAVITY
g/cm3
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND2
RND3
RND4
RND5

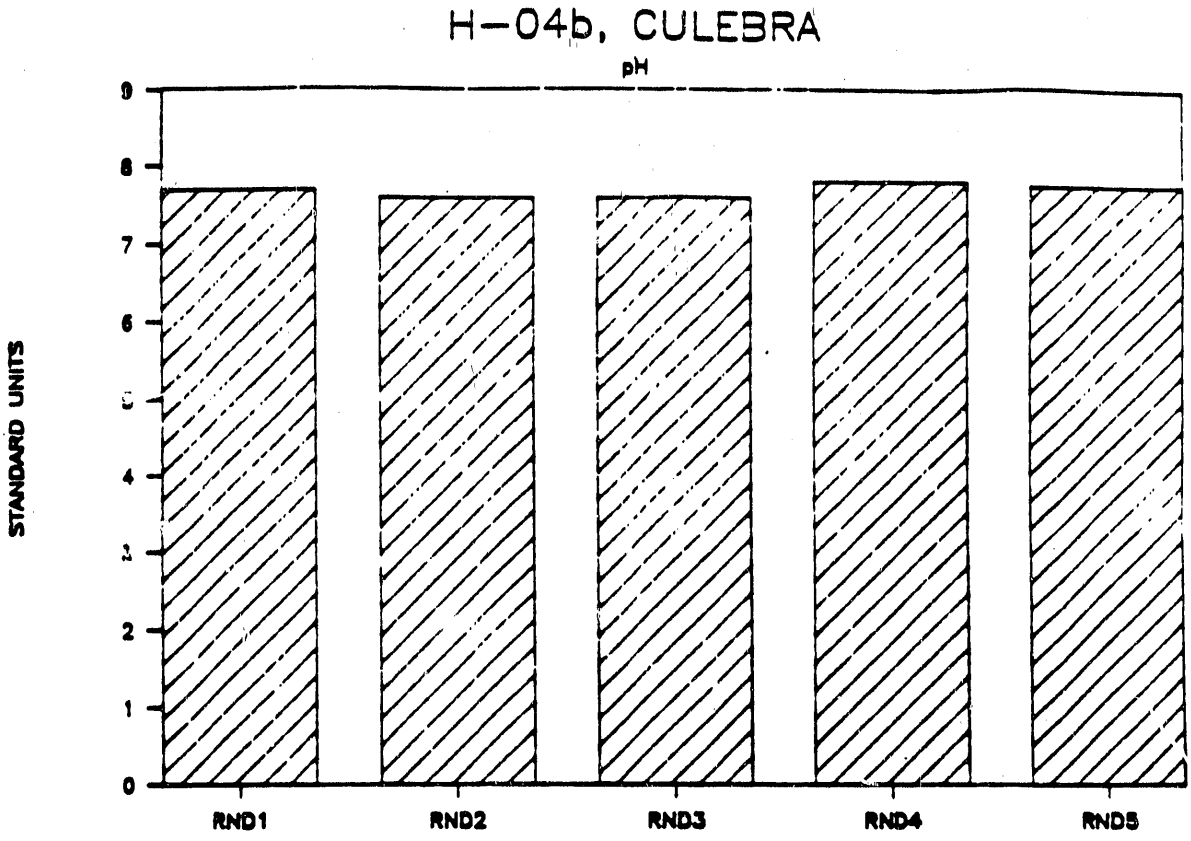

H-03b3, CULEBRA
TEMPERATURE
DEGREES CELCIUS
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
RND1
RND2
RND3
RND4
RND5

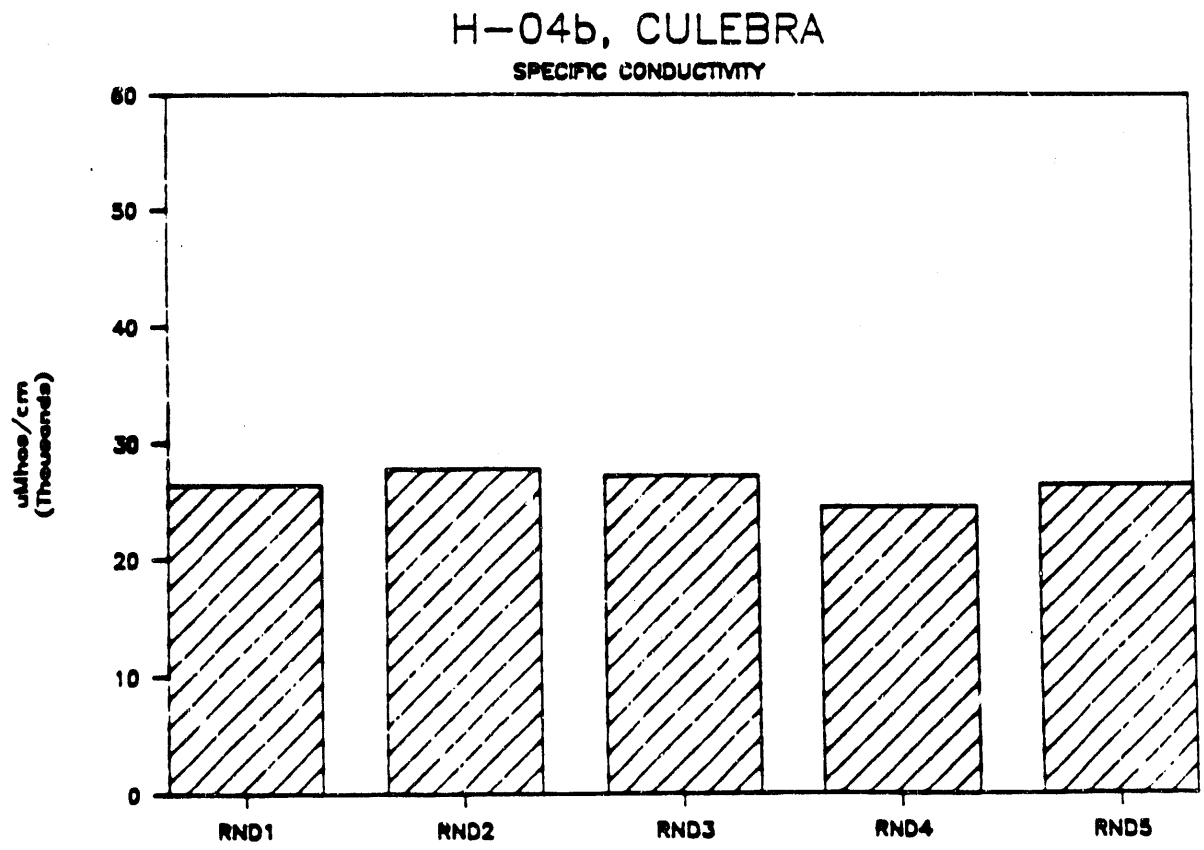

H-04b, CULEBRA
ALKALINITY
CONCENTRATION mg/l
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

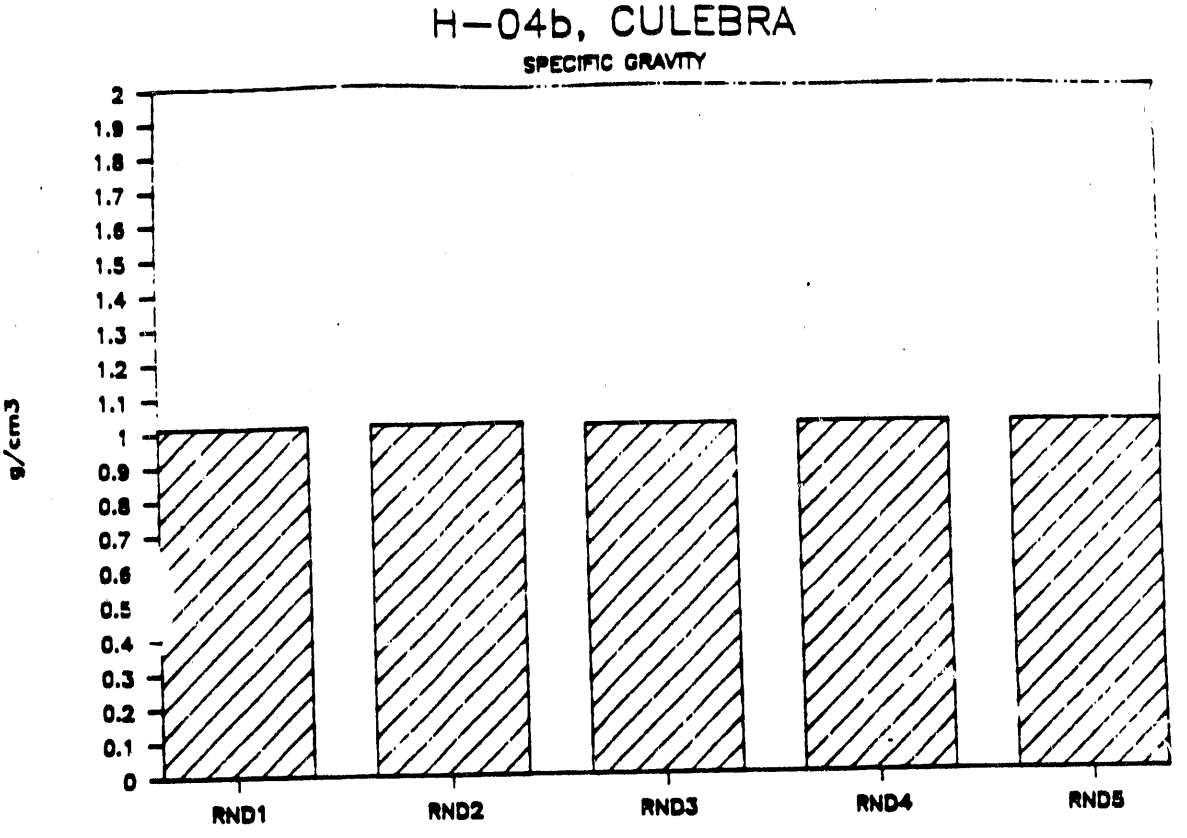

H-04b, CULEBRA
CHLORIDES
CONCENTRATION mg/l
(Thousands)
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5

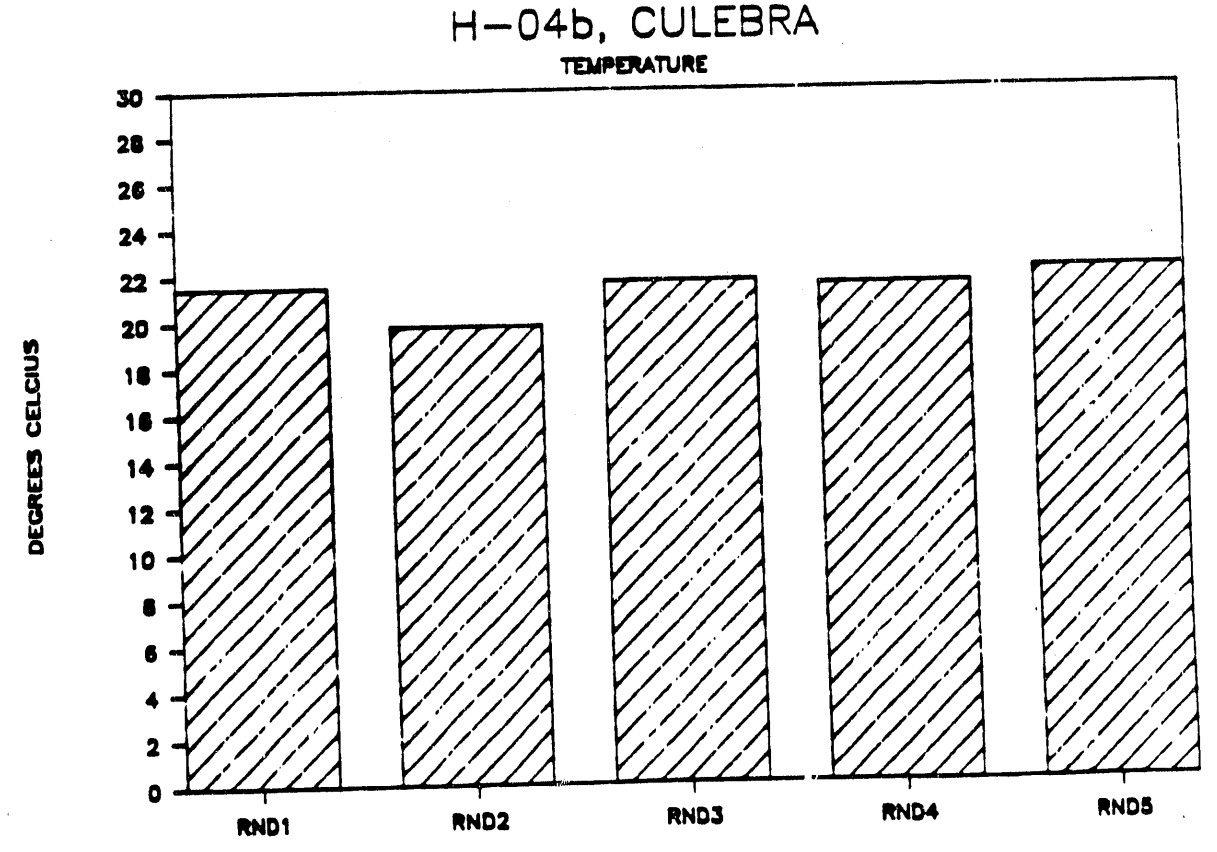

H-04b, CULEBRA
DIVALENT CATIONS
CONCENTRATION meq/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

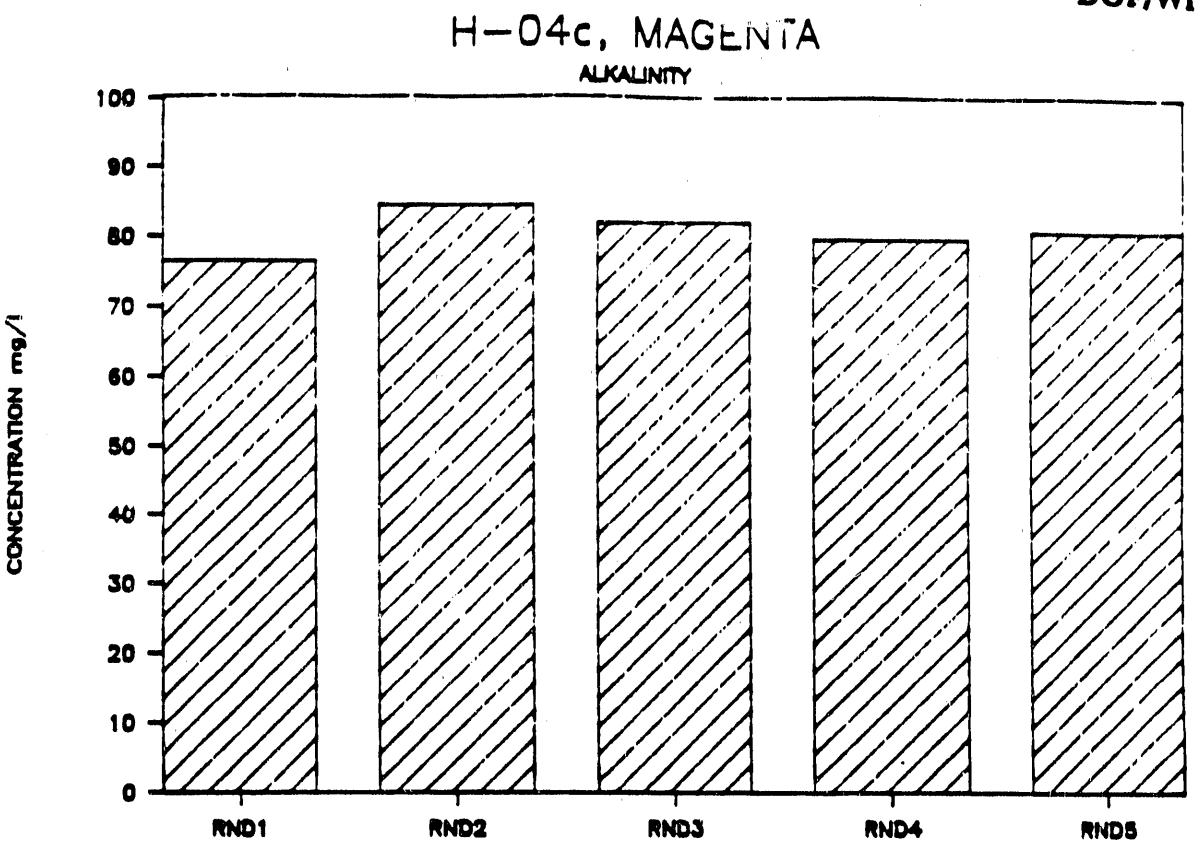

H-04b, CULEBRA
TOTAL IRON
CONCENTRATION mg/l
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5

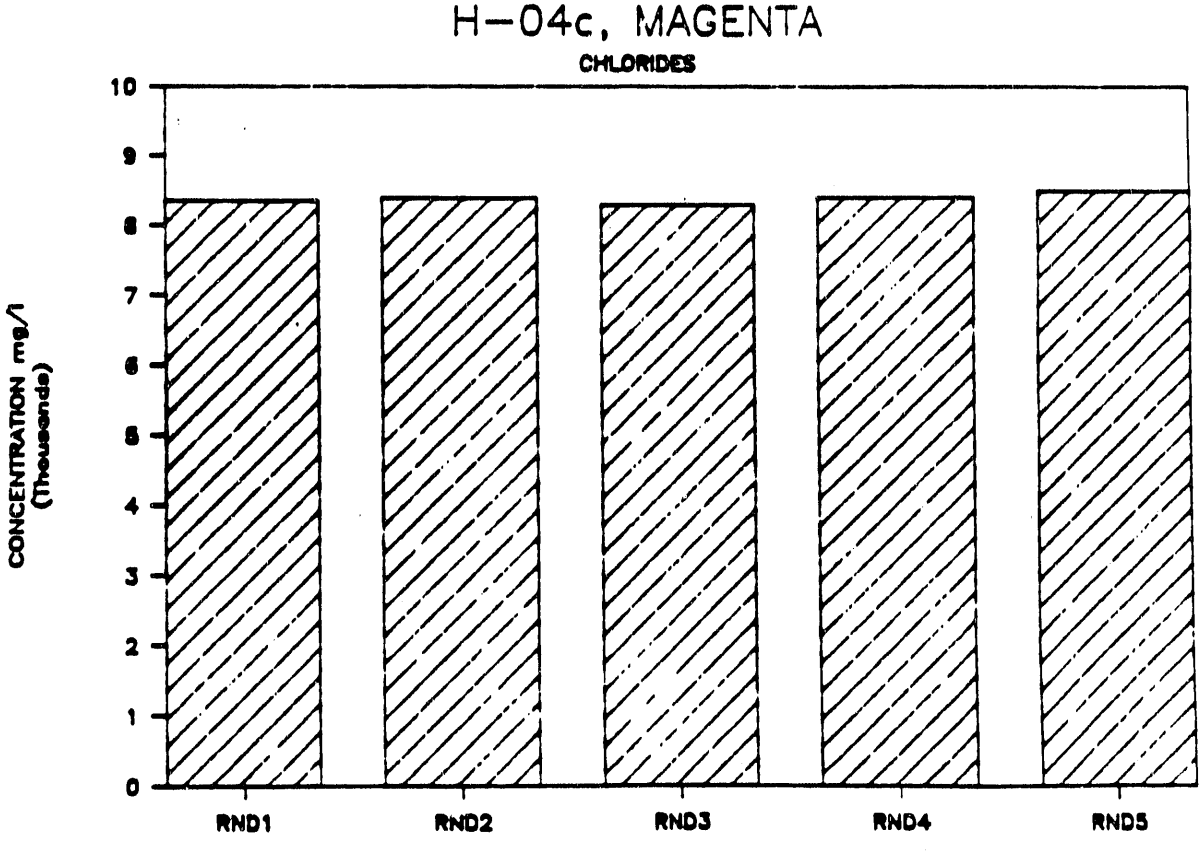

H-04b, CULEBRA
pH
STANDARD UNITS
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5

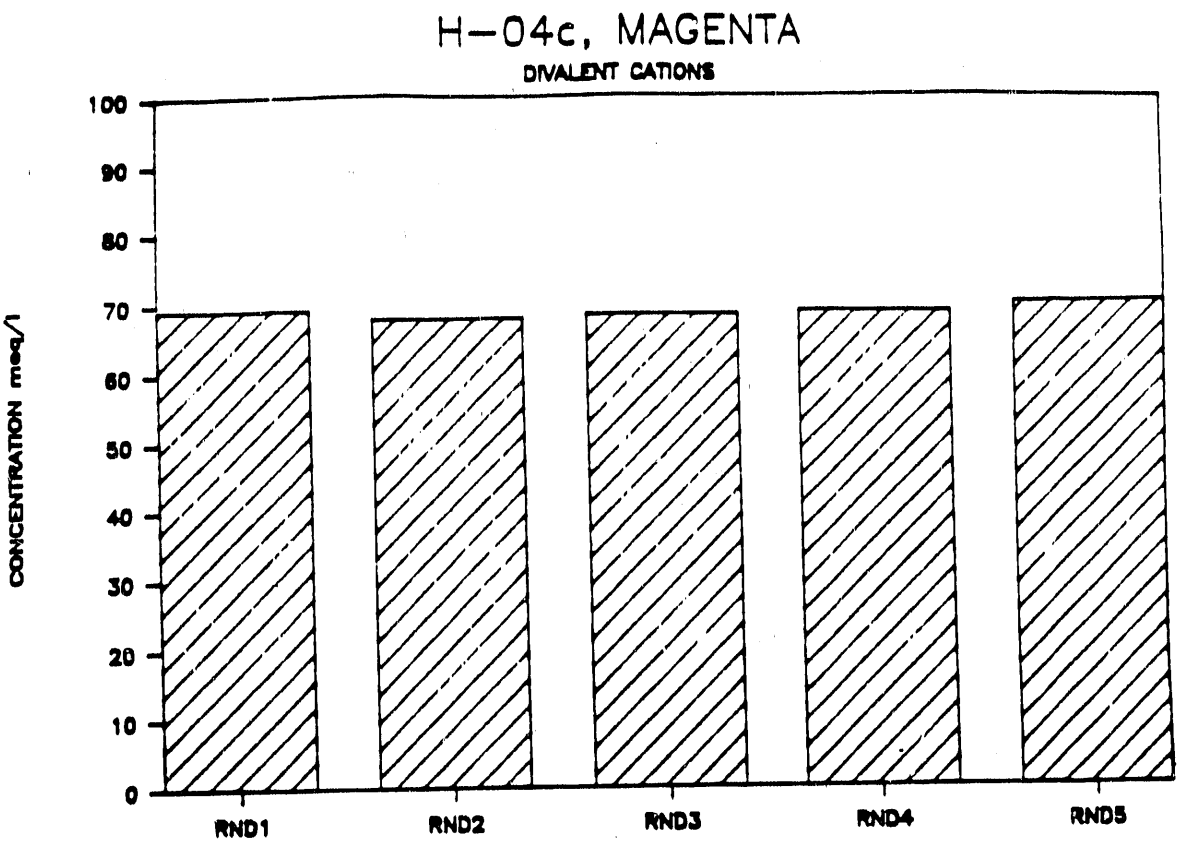

H-04b, CULEBRA
SPECIFIC CONDUCTIVITY
uMhos/cm
(Thousands)
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

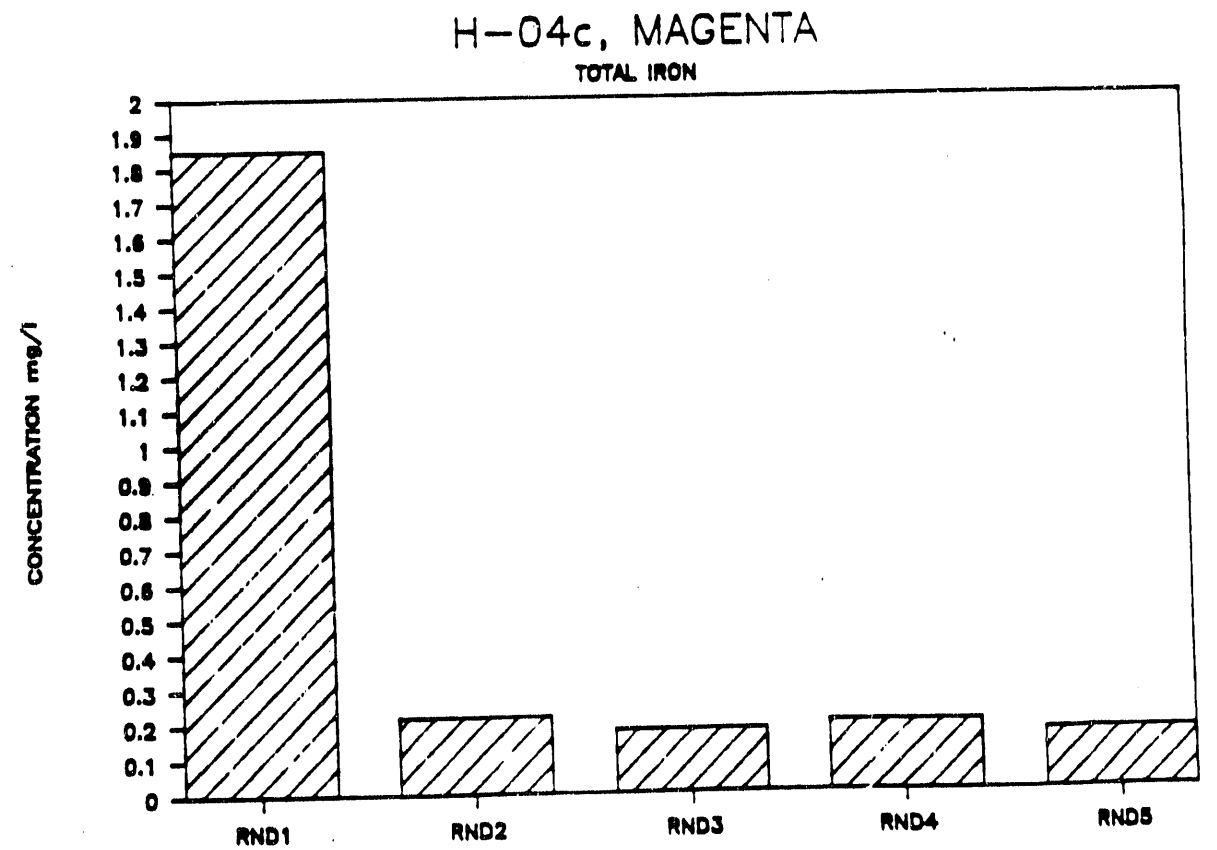

H—04b, CULEBRA
SPECIFIC GRAVITY
g/cm3
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5

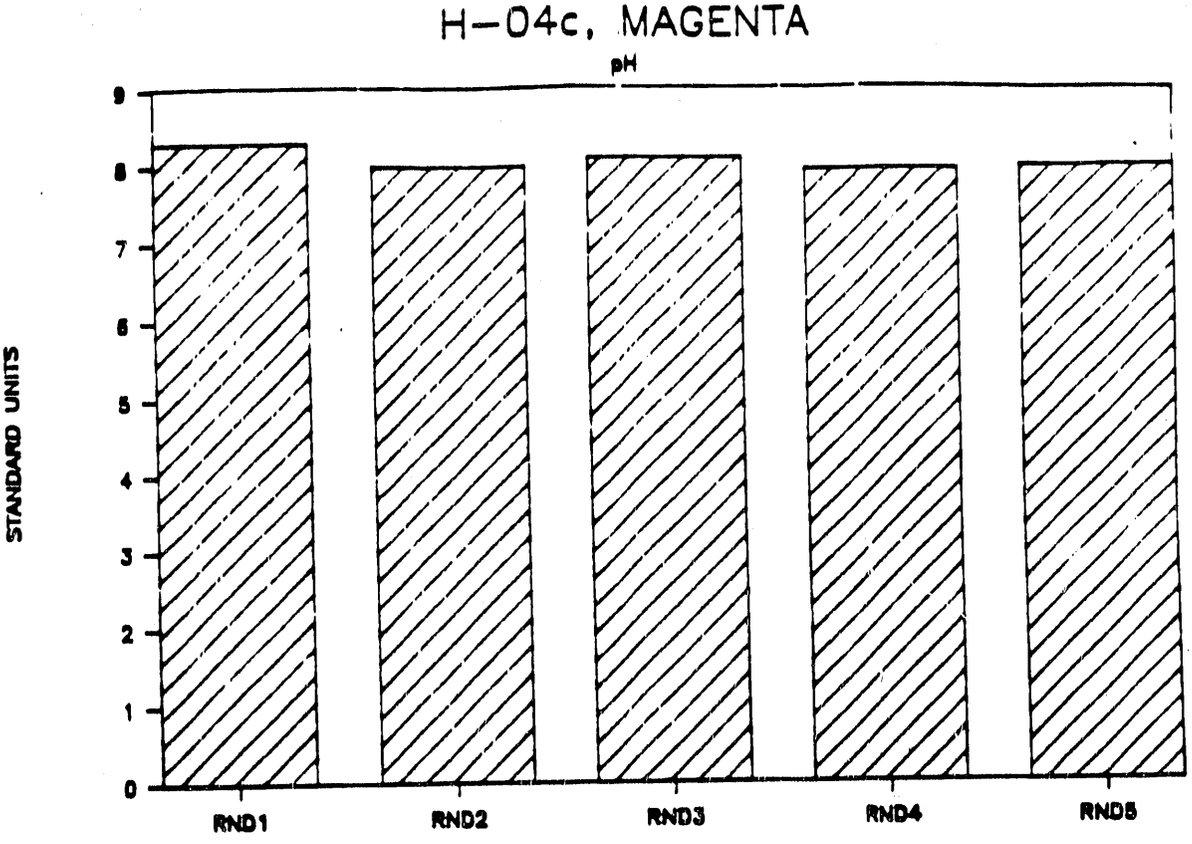

H—04b, CULEBRA
TEMPERATURE
DEGREES CELCIUS
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
RND1
RND2
RND3
RND4
RND5

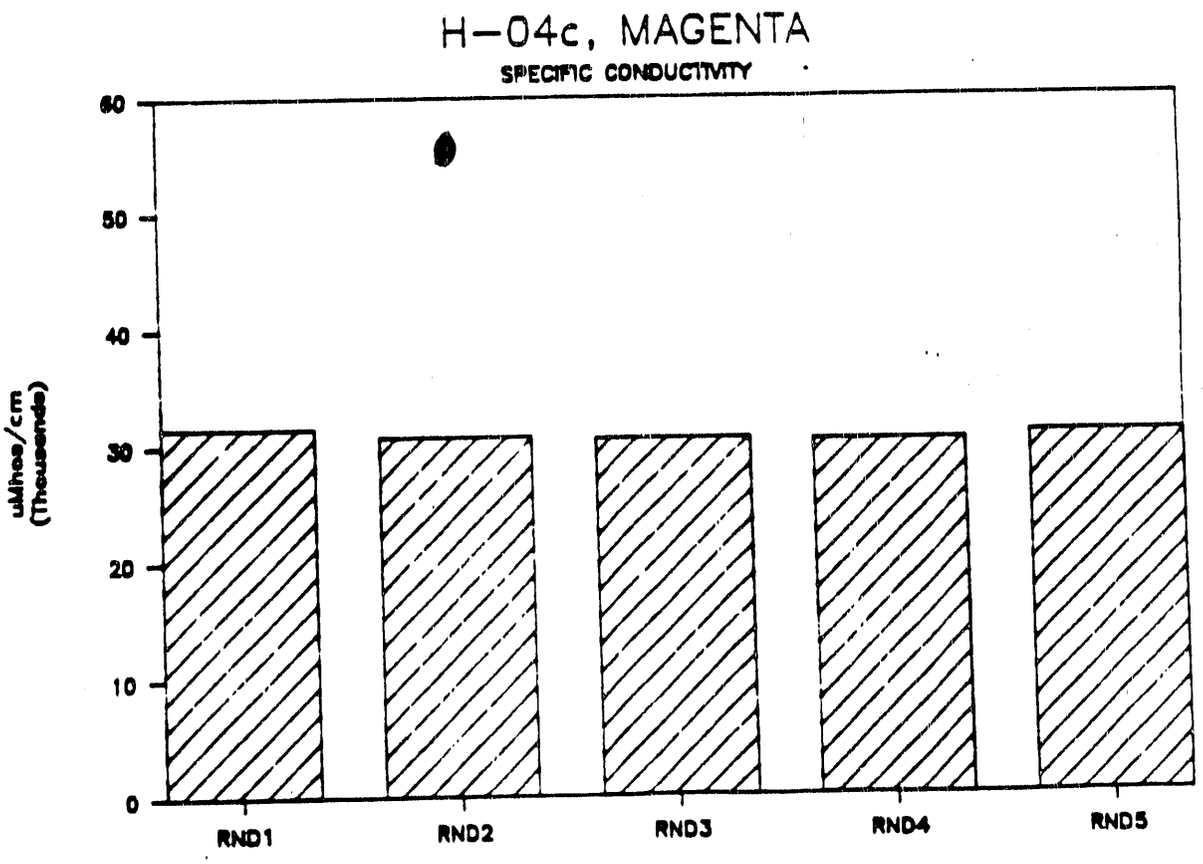

H-04c, MAGENTA
ALKALINITY
CONCENTRATION mg/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

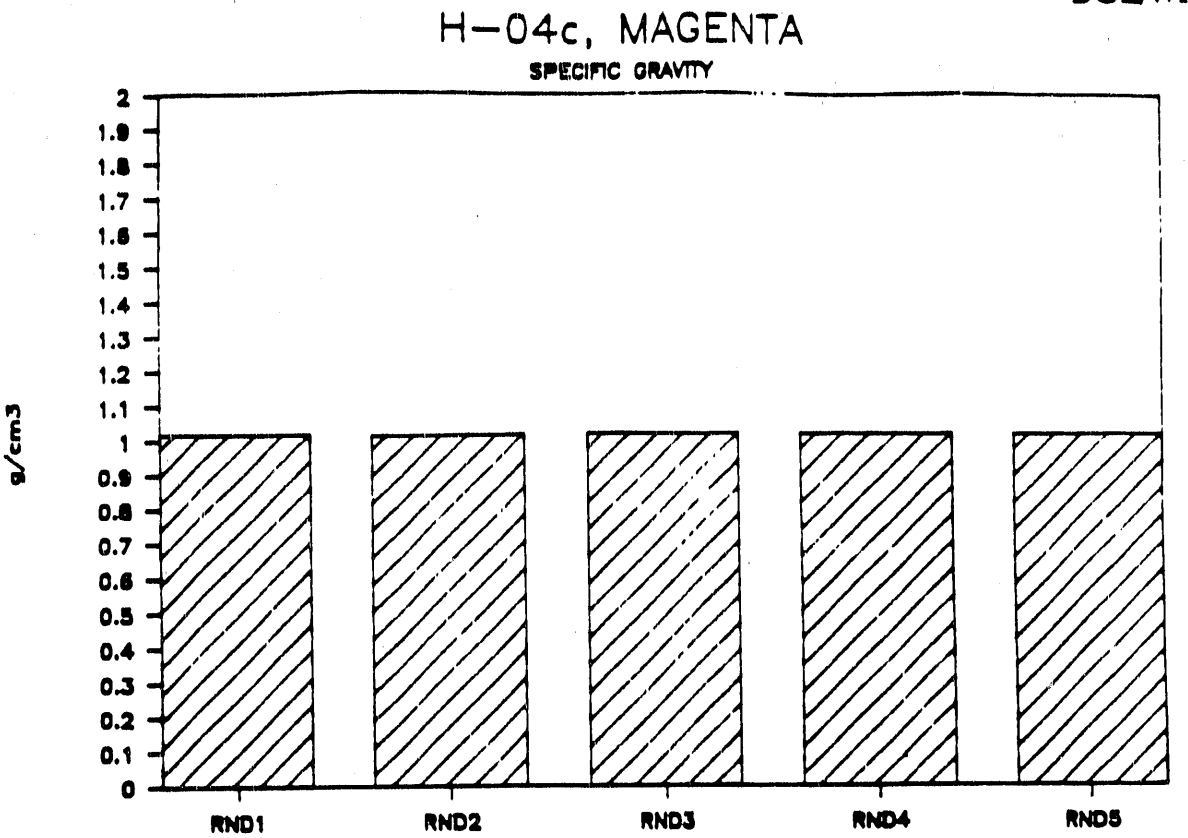

H-04c, MAGENTA
CHLORIDES
CONCENTRATION mg/l
(Thousands)
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5

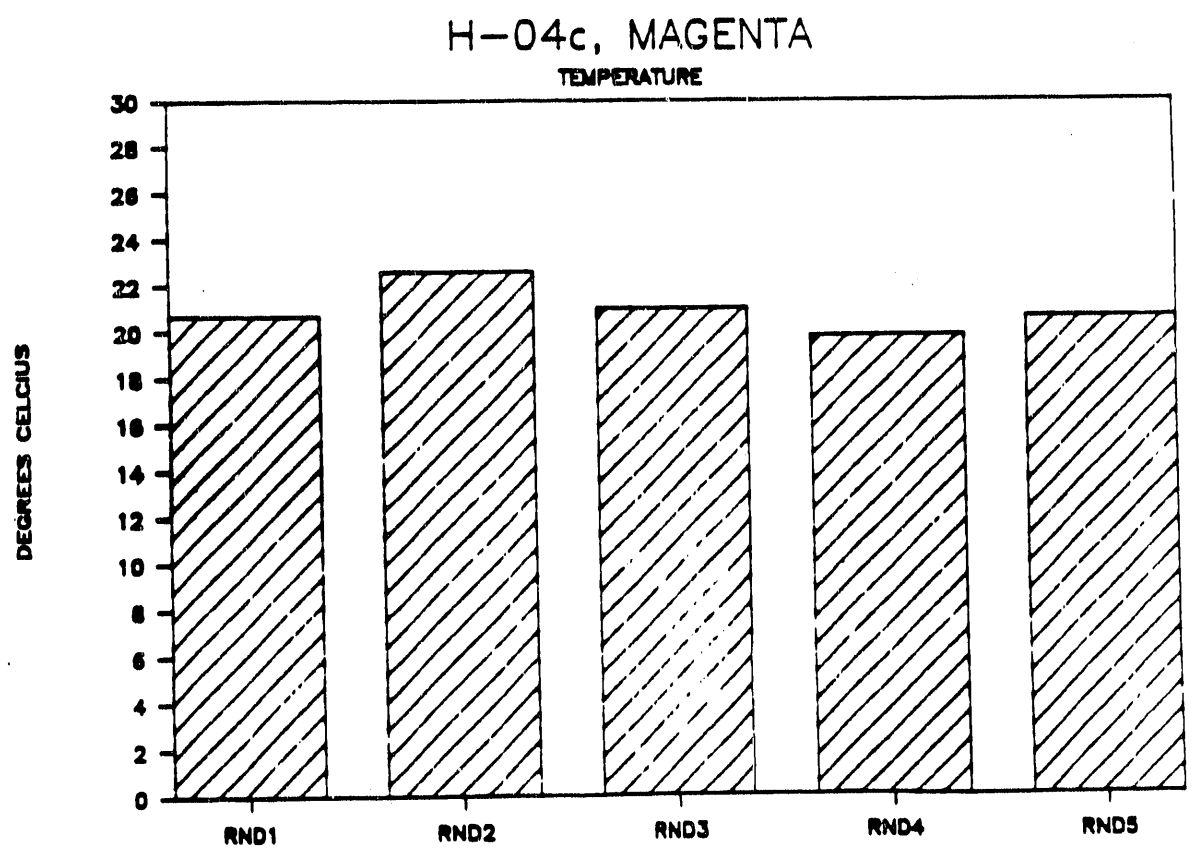

H-04c, MAGENTA
DIVALENT CATIONS
CONCENTRATION meq/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

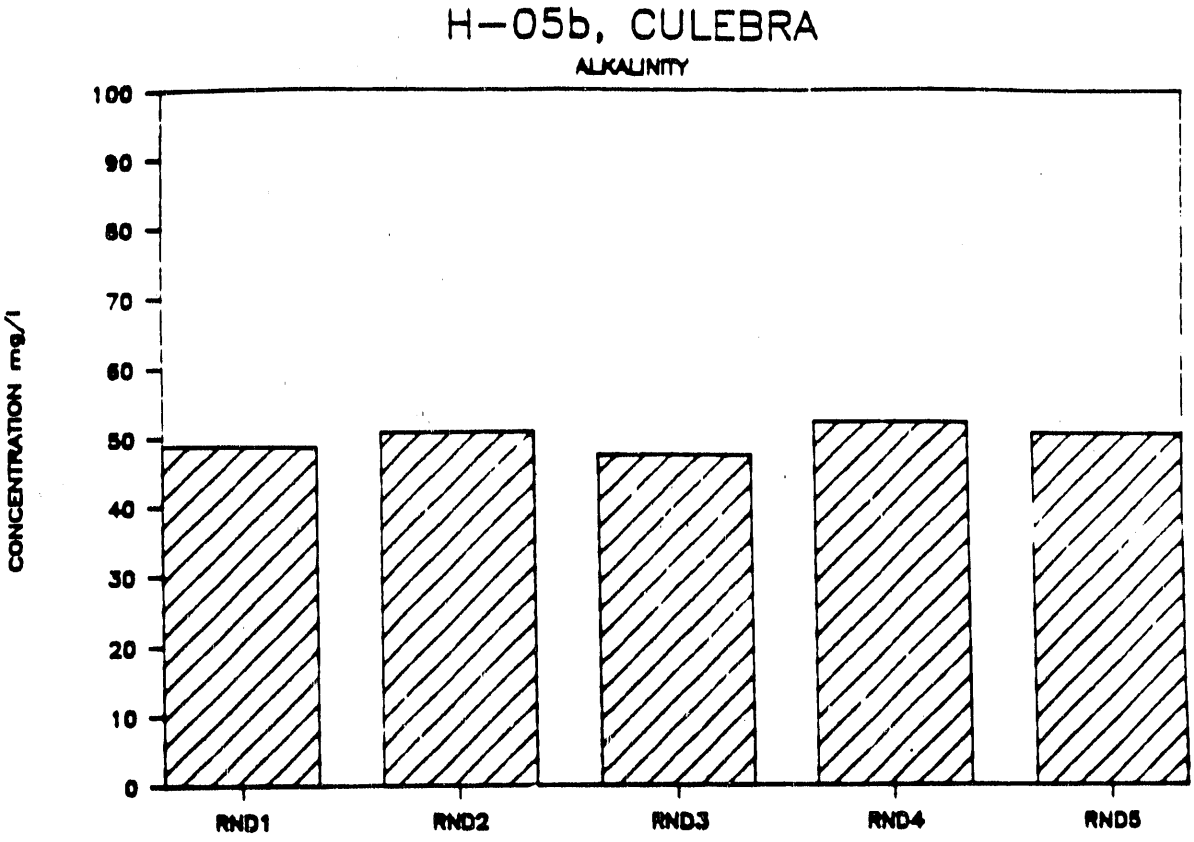

H-04c, MAGENTA
TOTAL IRON
CONCENTRATION mg/l
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5

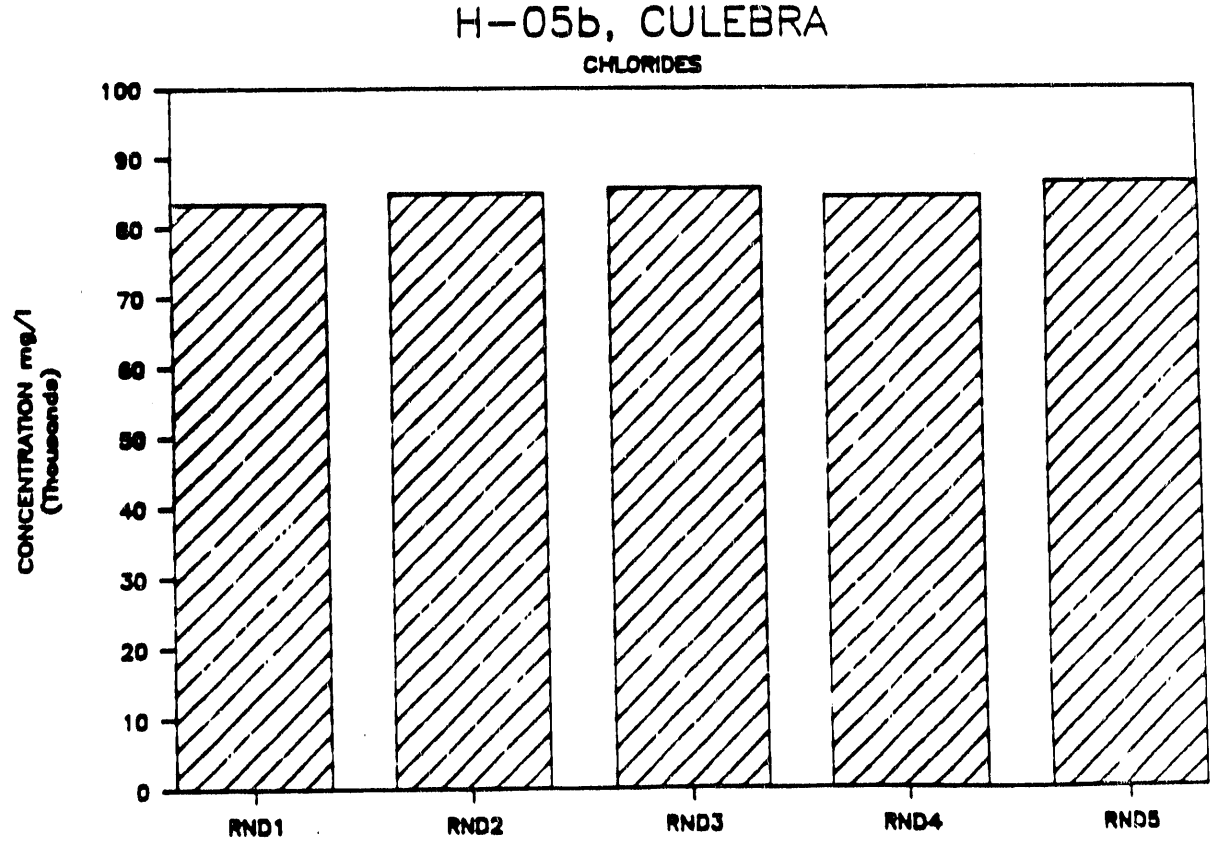

H-04c, MAGENTA
pH
STANDARD UNITS
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5

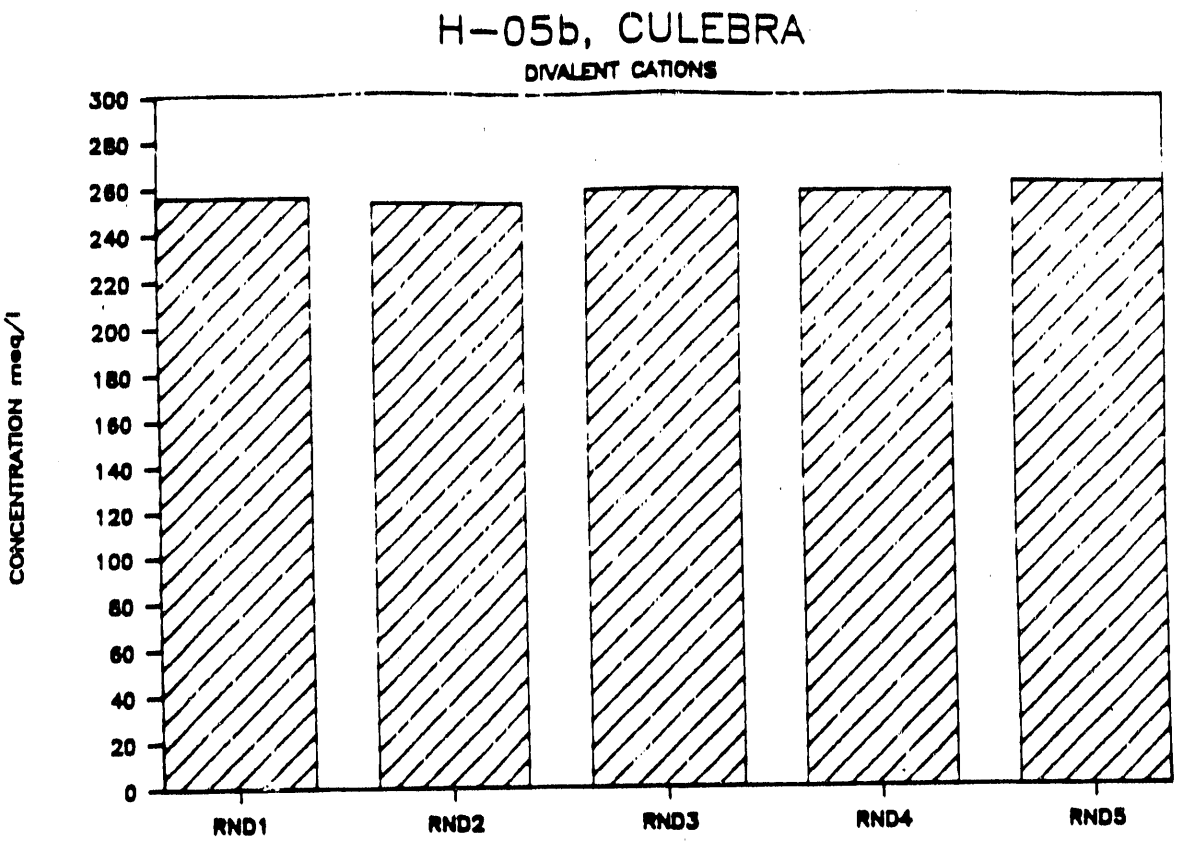

H-04c, MAGENTA
SPECIFIC CONDUCTIVITY
uMhos/cm
(Thousands)
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

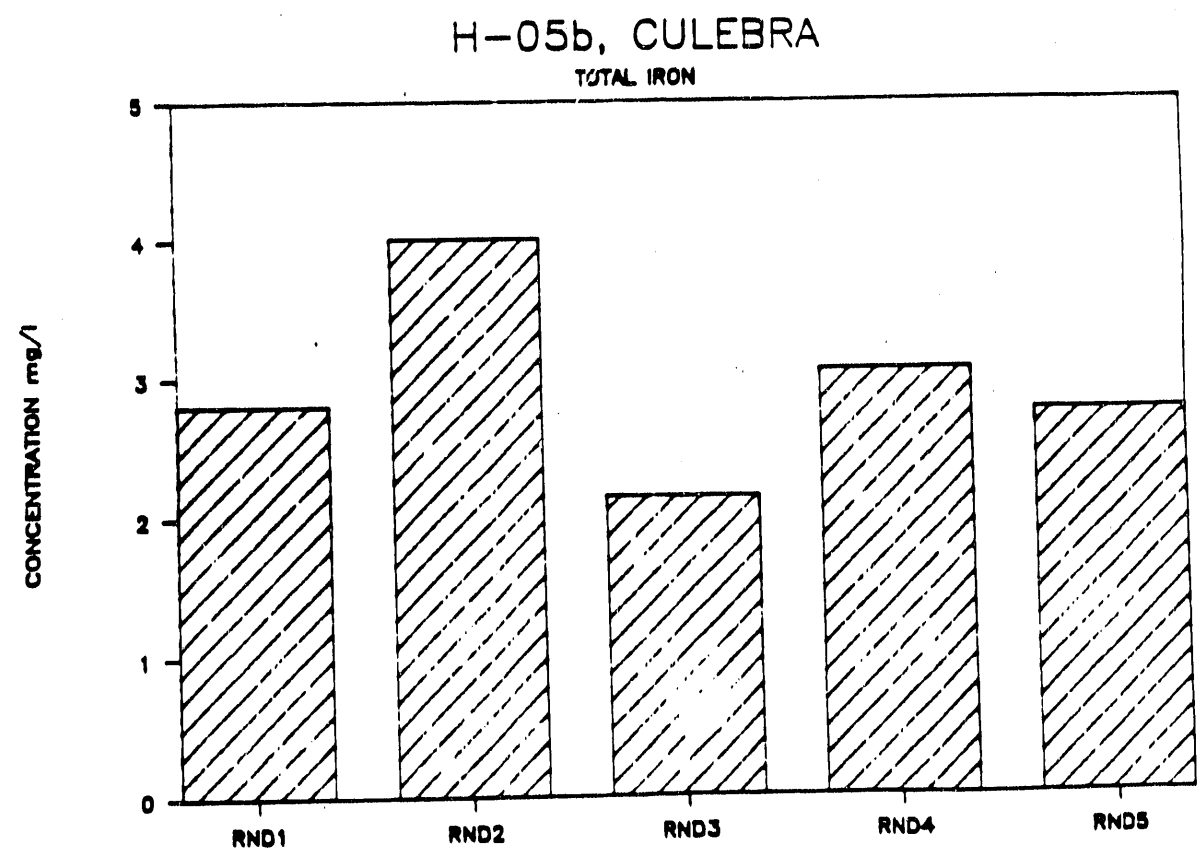

H-04c, MAGENTA
SPECIFIC GRAVITY
g/cm3
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5

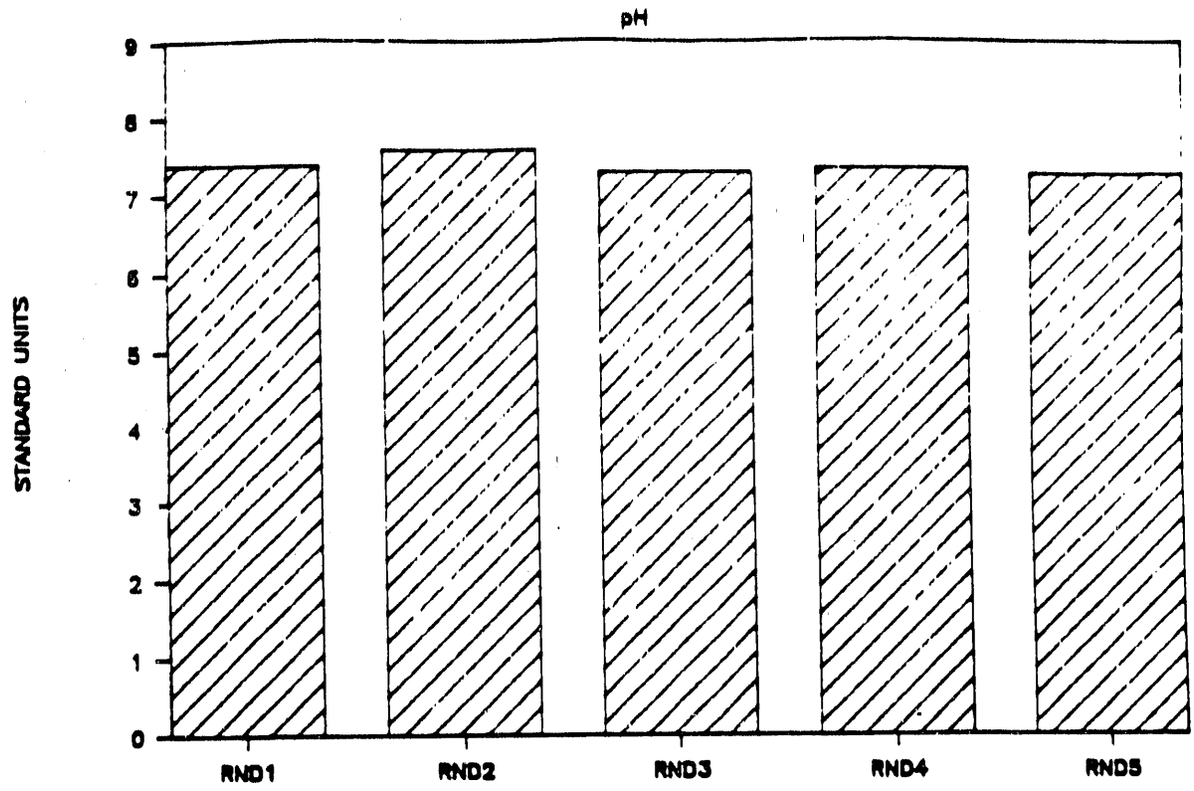

H-04c, MAGENTA
TEMPERATURE
DEGREES CELCIUS
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
RND1
RND2
RND3
RND4
RND5

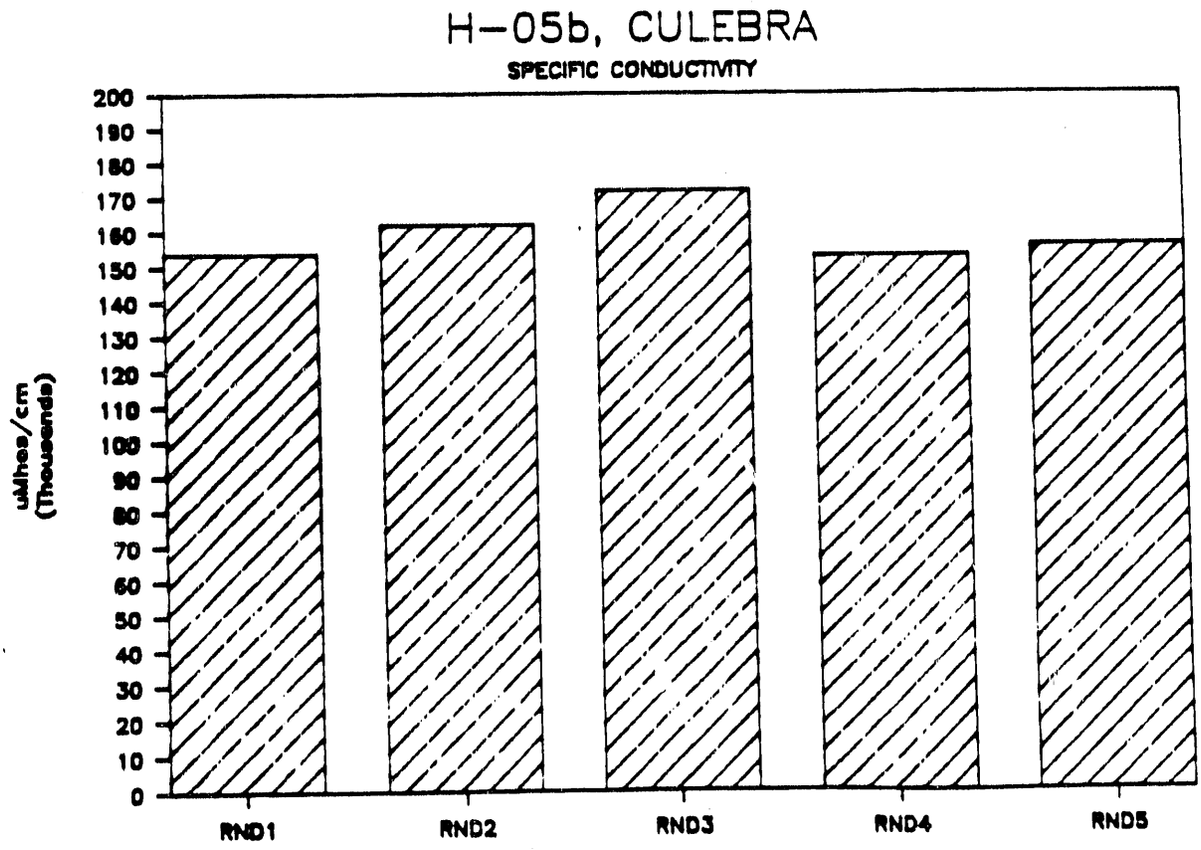

H-05b, CULEBRA
ALKALINITY
CONCENTRATION mg/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

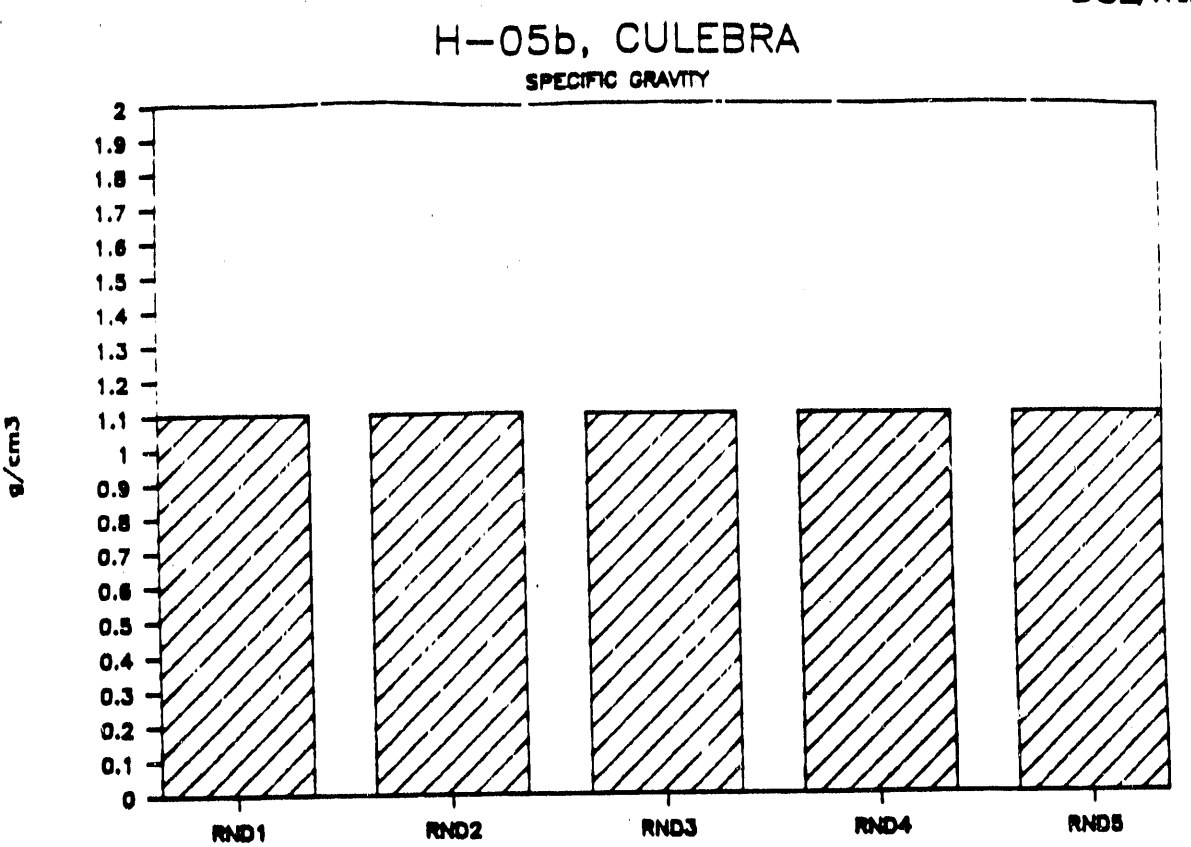

H-05b, CULEBRA
CHLORIDES
CONCENTRATION mg/l
(Thousands)
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

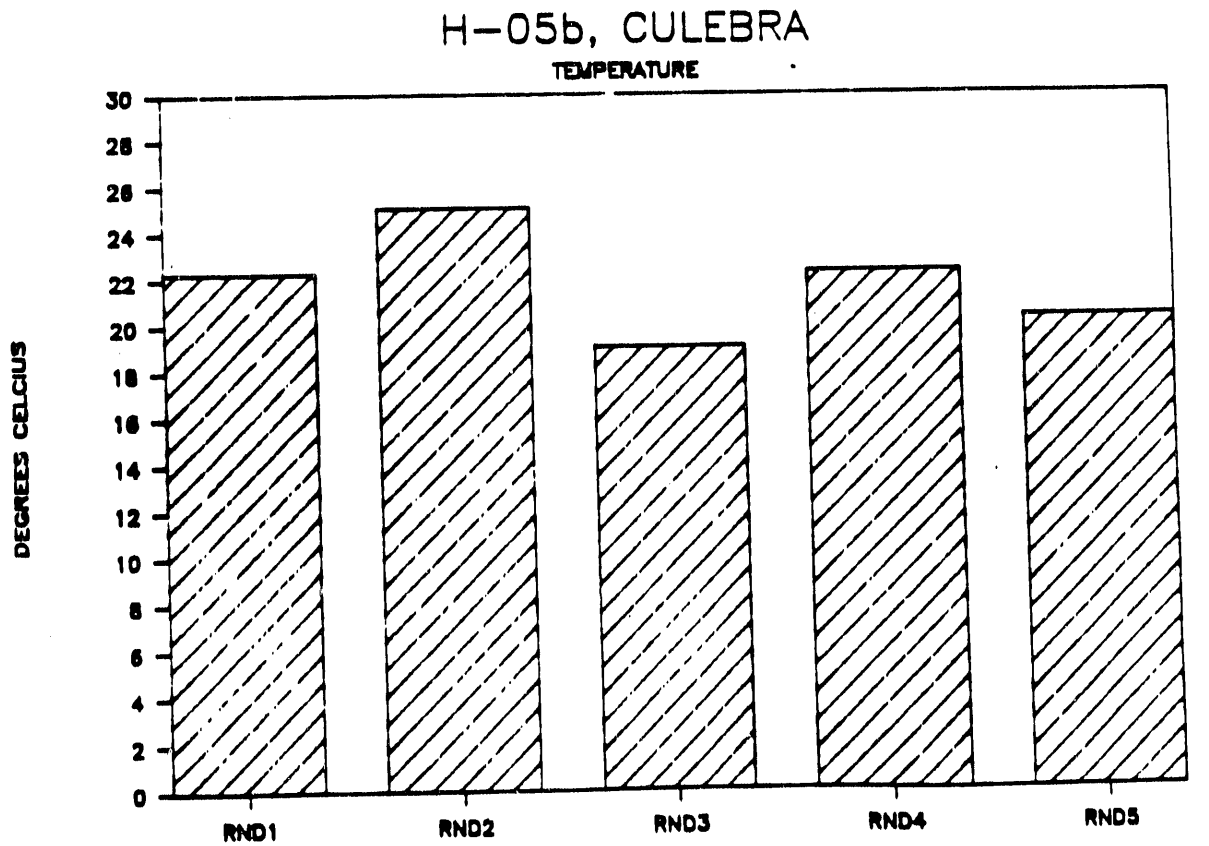

H-05b, CULEBRA
DIVALENT CATIONS
CONCENTRATION meq/l
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
RND1
RND2
RND3
RND4
RND5

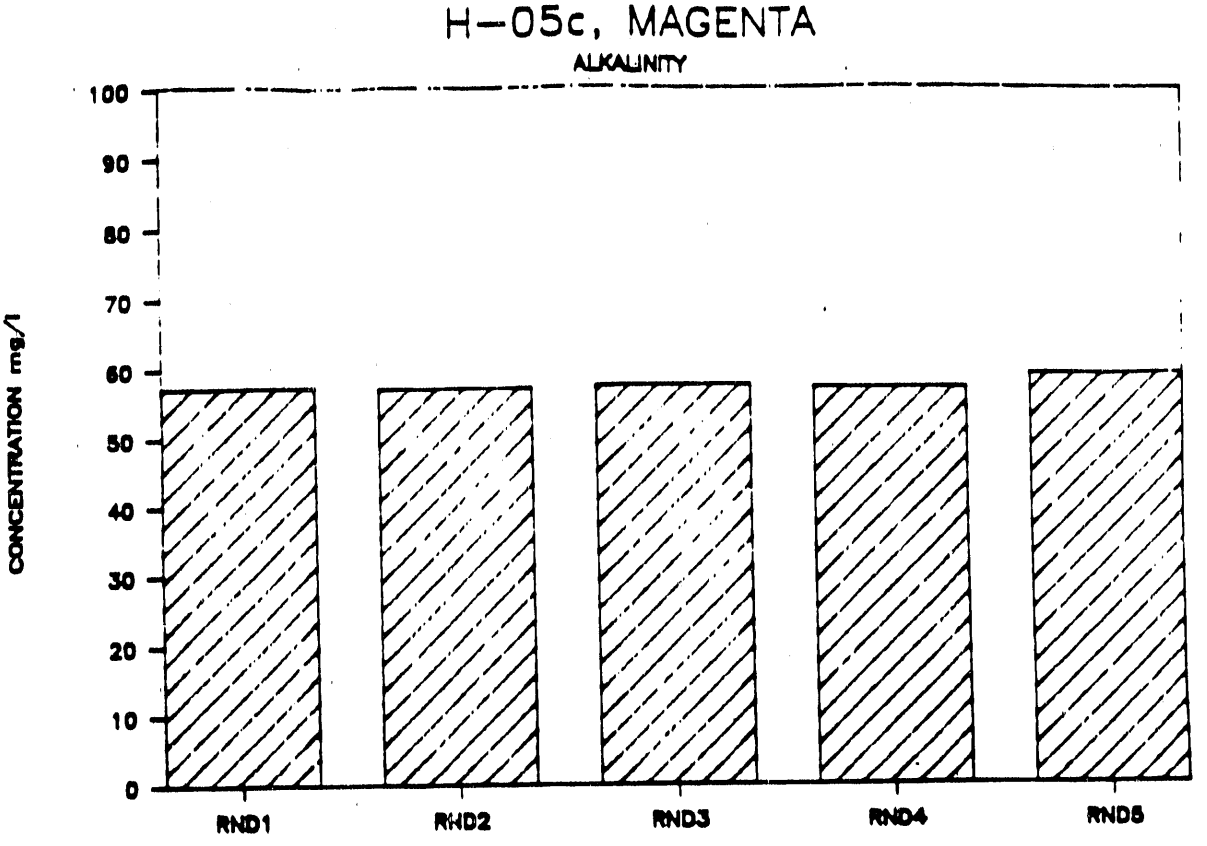

H-05b, CULEBRA
TOTAL IRON
CONCENTRATION mg/l
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5

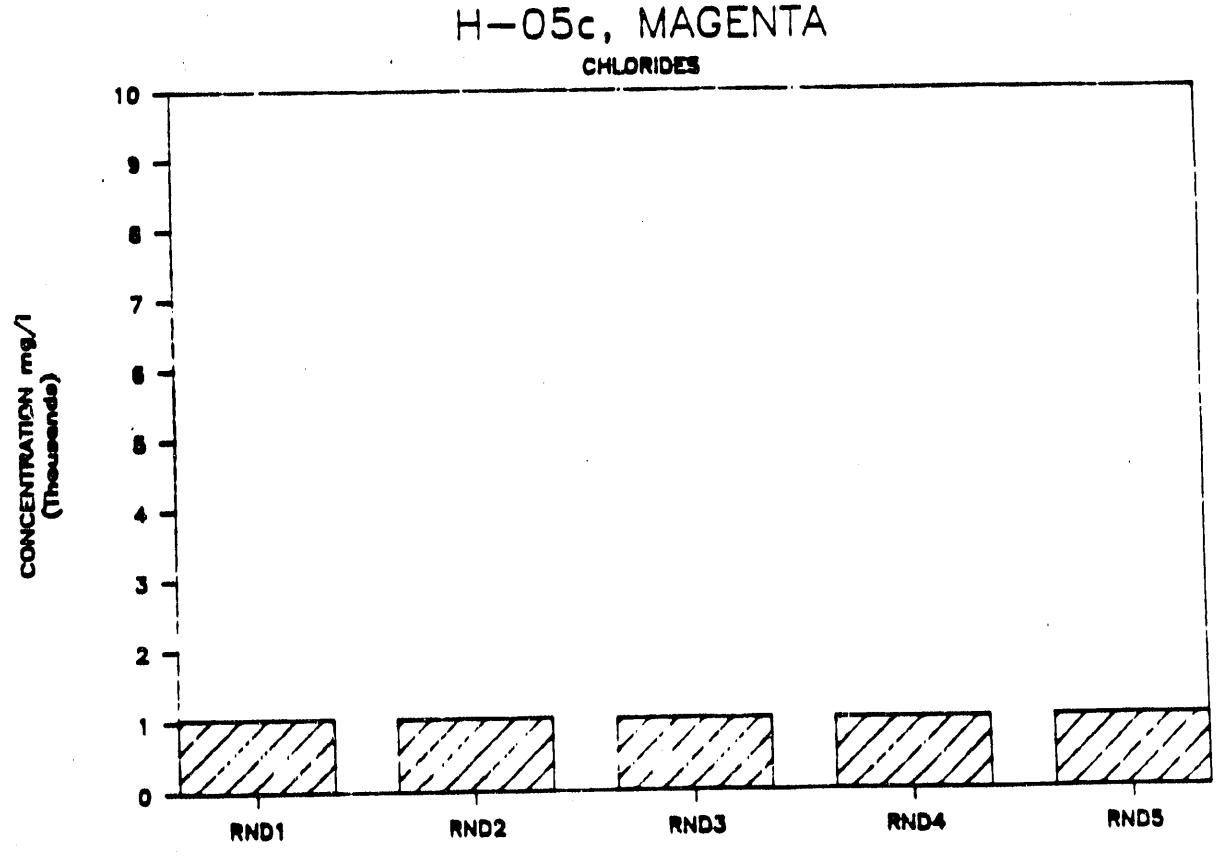

H-05b, CULEBRA
pH
STANDARD UNITS
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5

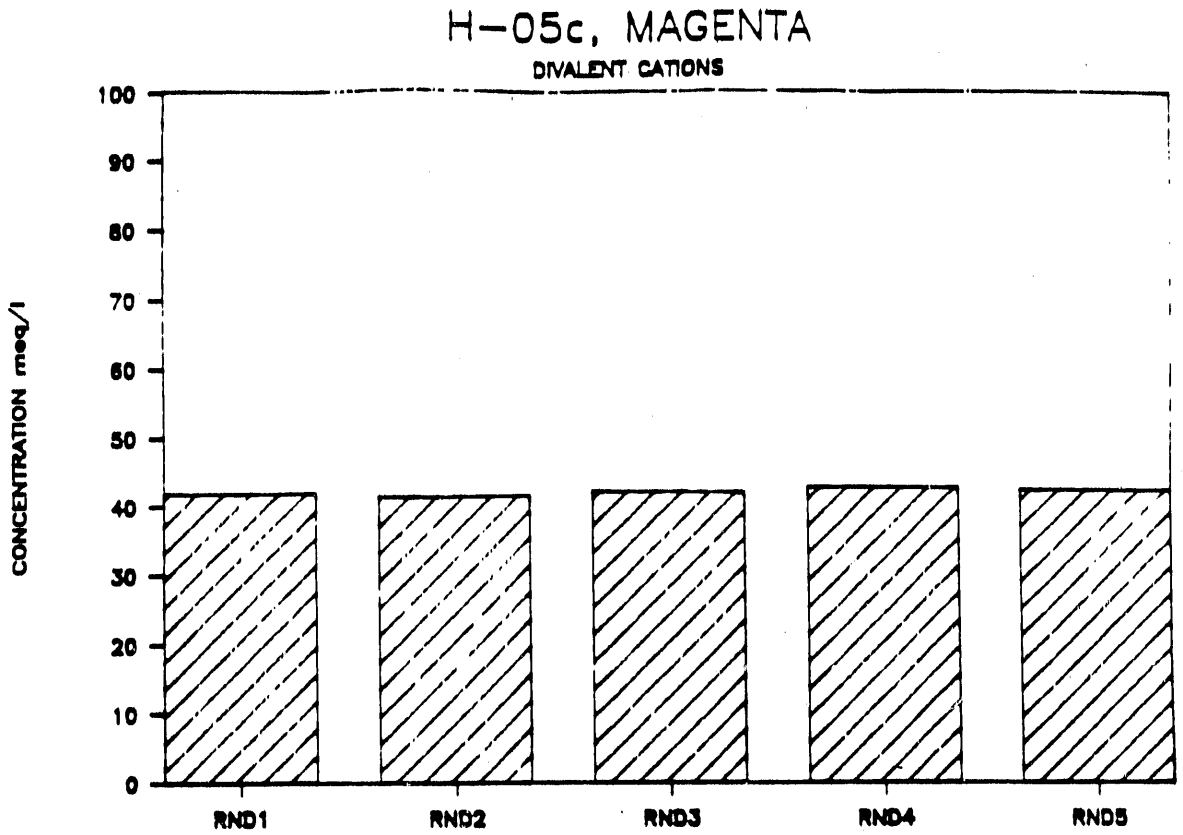

H-05b, CULEBRA
SPECIFIC CONDUCTIVITY
uMhos/cm
(Thousands)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

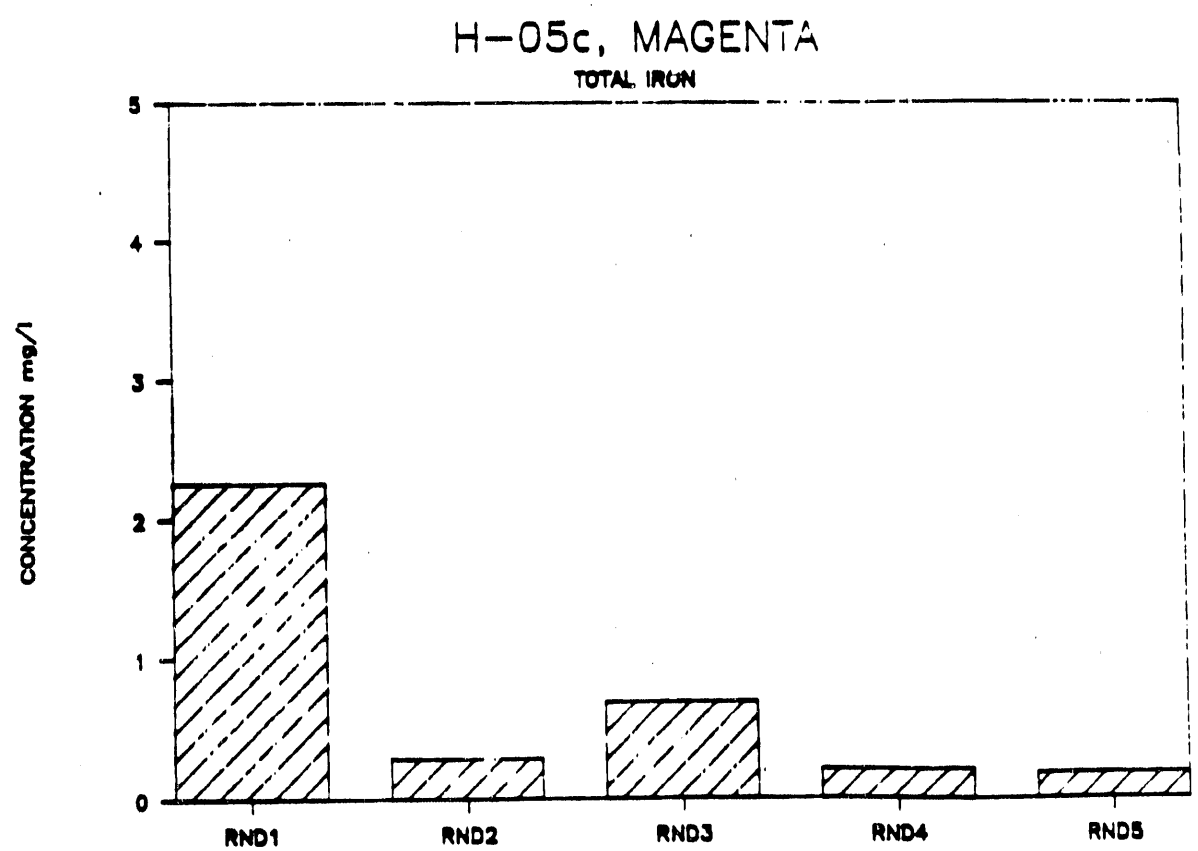

H-05b, CULEBRA
SPECIFIC GRAVITY
g/cm3
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5

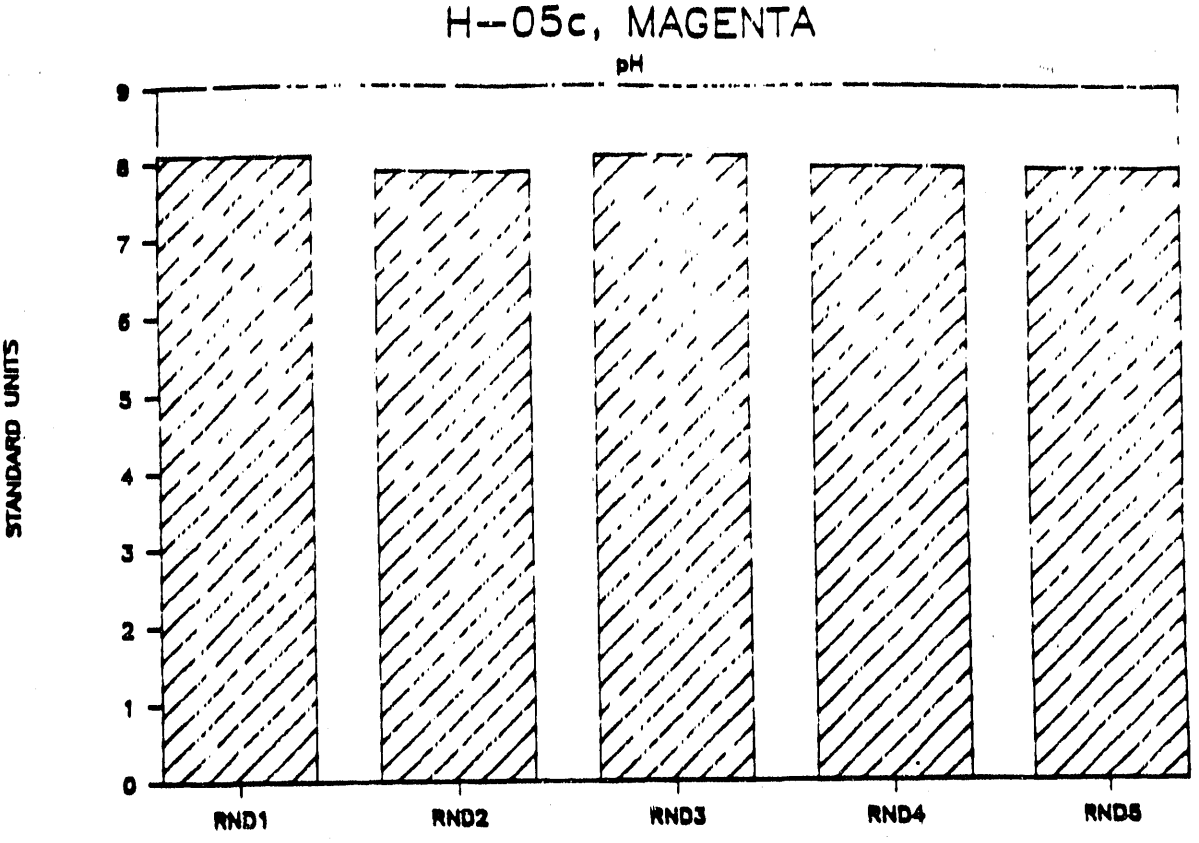

H-05b, CULEBRA
TEMPERATURE
DEGREES CELCIUS
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
RND1
RND2
RND3
RND4
RND5

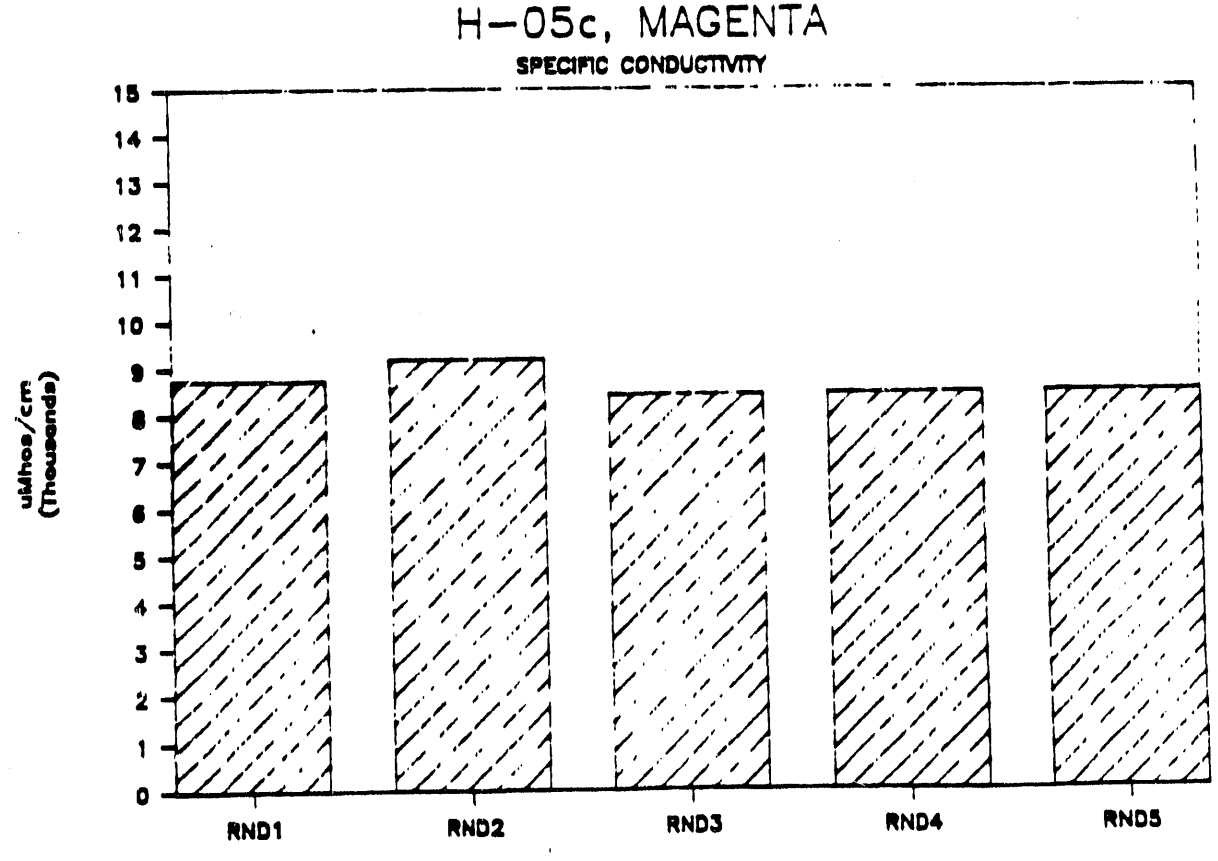

H-05c, MAGENTA
ALKALINITY
CONCENTRATION mg/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

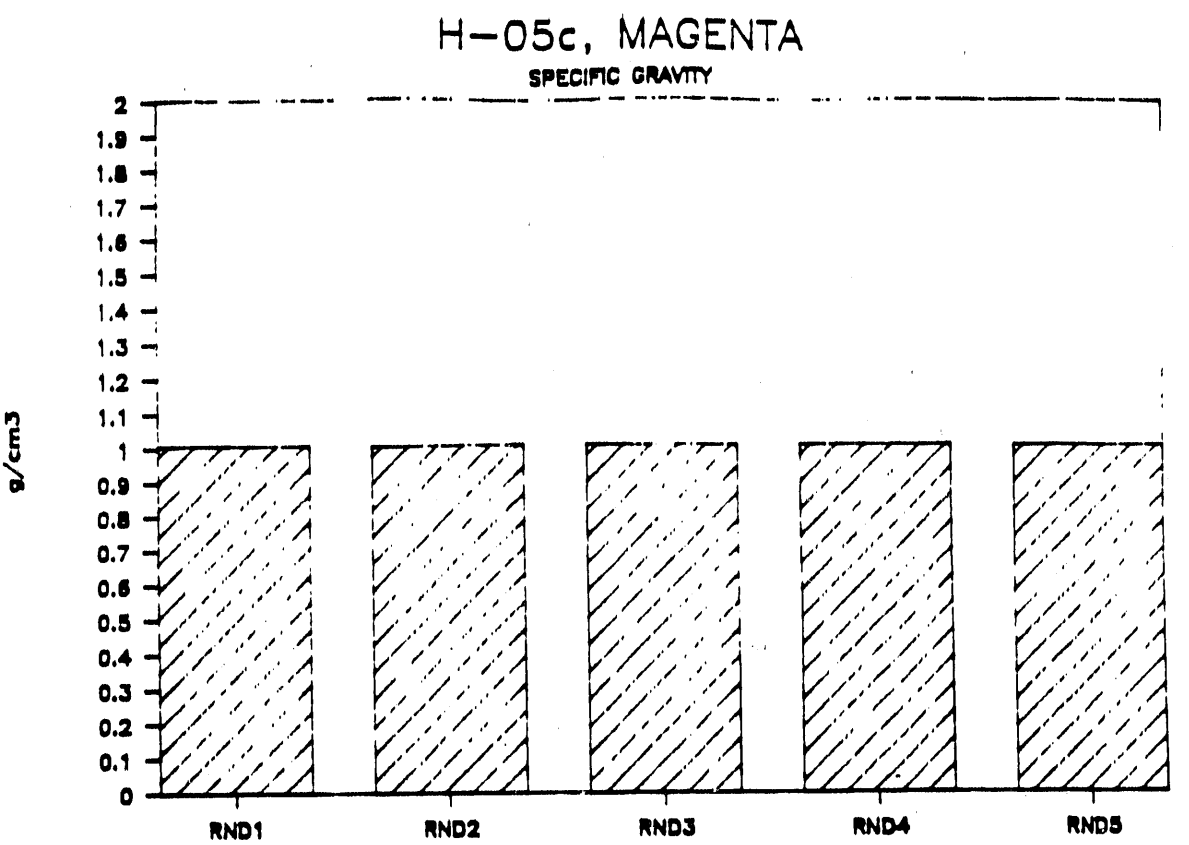

H-05c, MAGENTA
CHLORIDES
CONCENTRATION mg/l
(Thousands)
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5

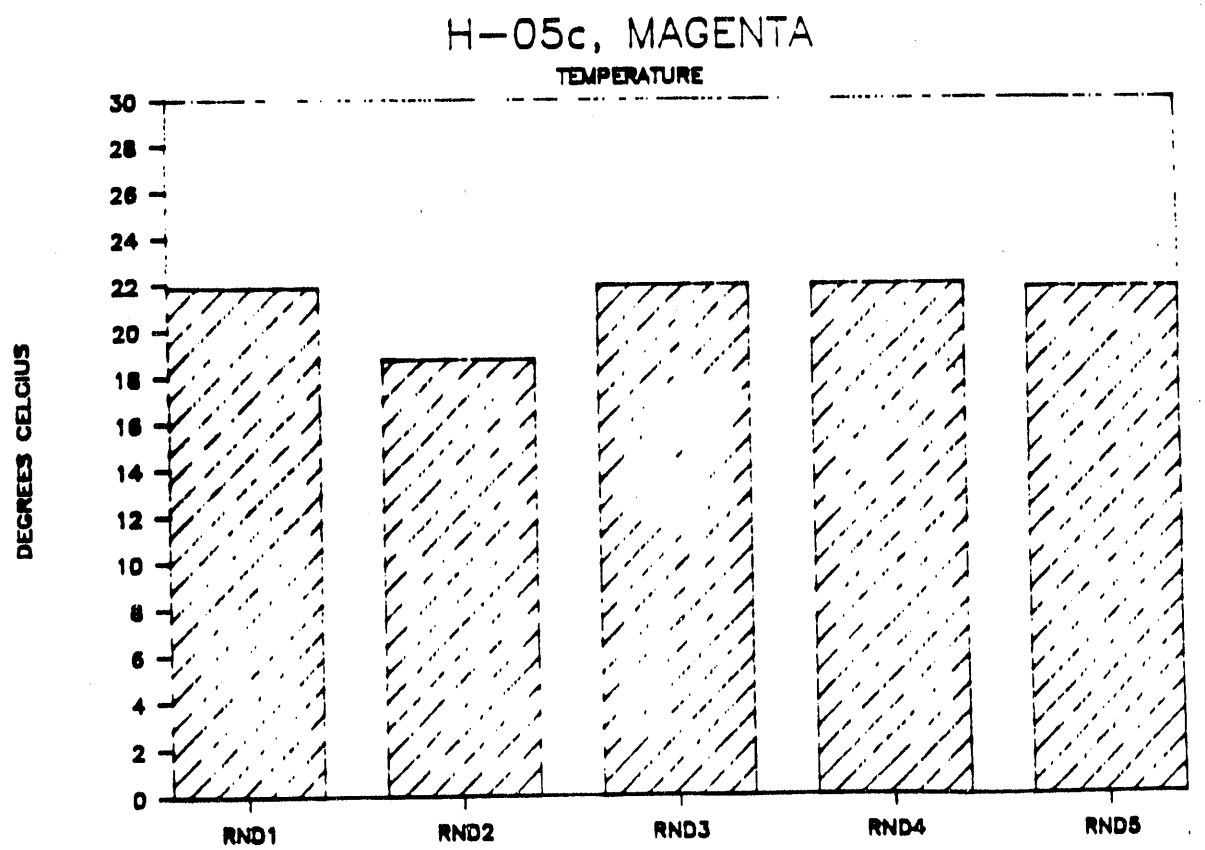

H–05c, MAGENTA
DIVALENT CATIONS
CONCENTRATION meq/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

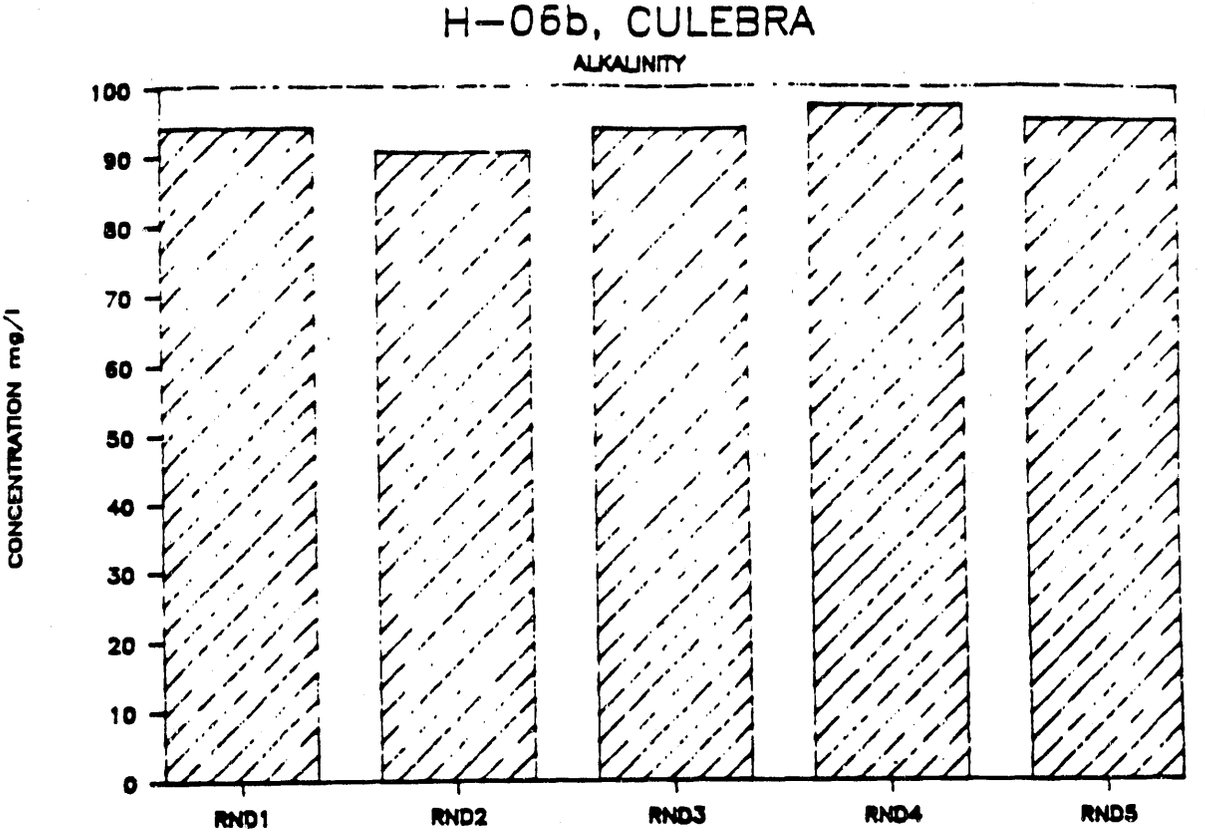

H–05c, MAGENTA
TOTAL IRON
CONCENTRATION mg/l
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5

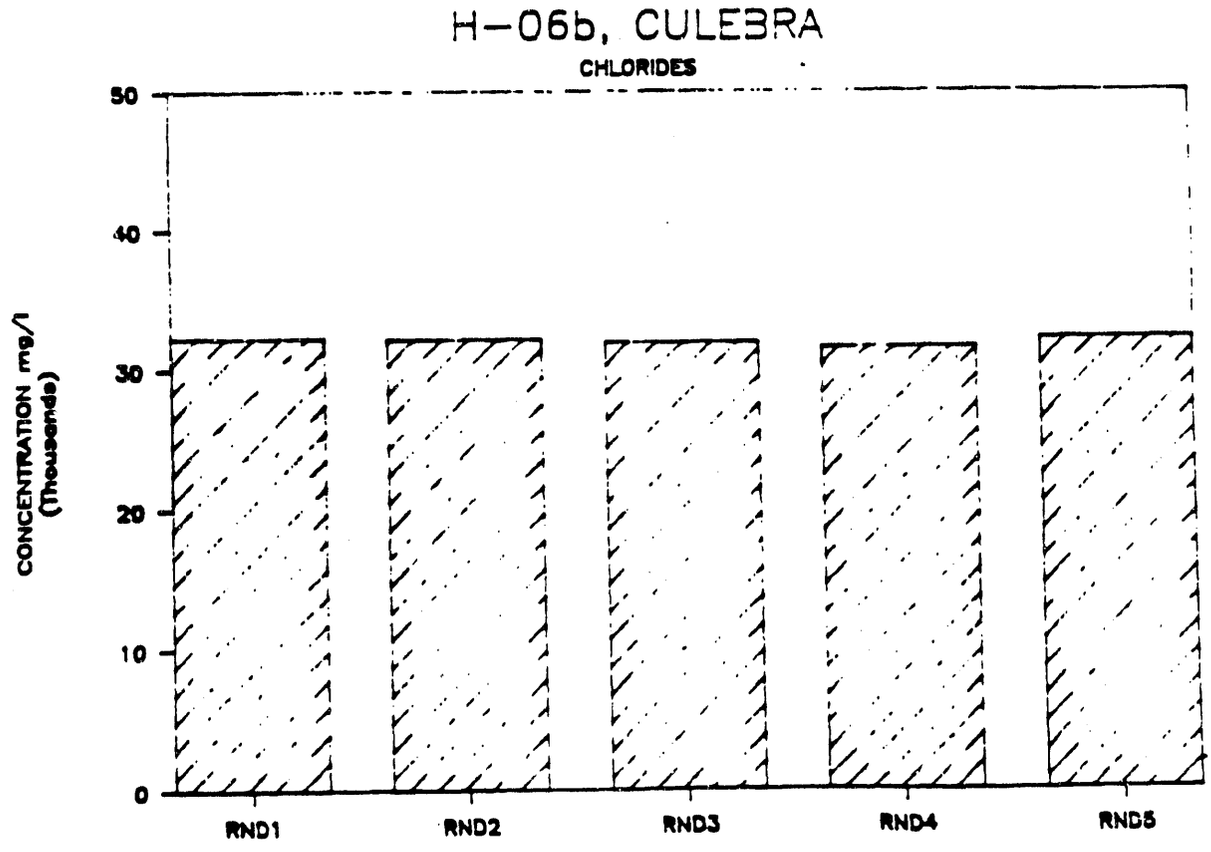

H-05c, MAGENTA
pH
STANDARD UNITS
0
1
2
3
4
5
6
7
8
9
RND1
RND2
RND3
RND4
RND5

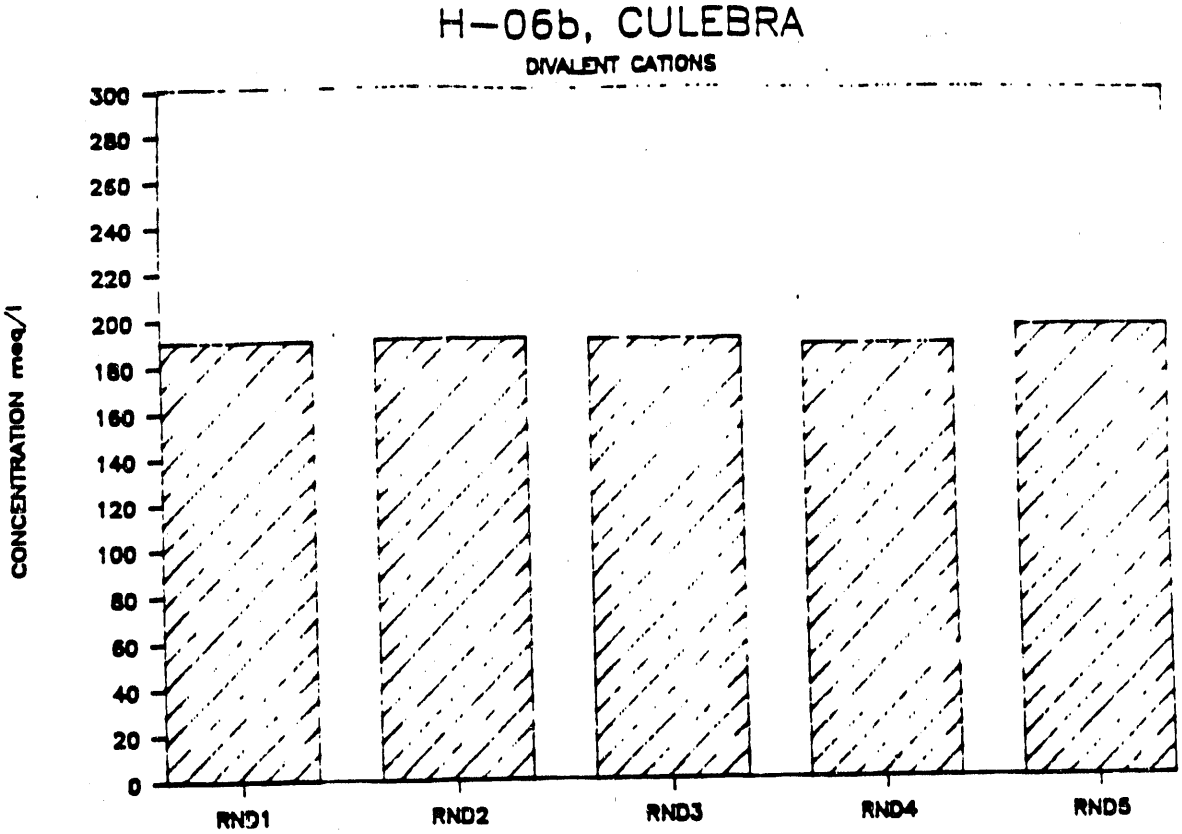

H-05c, MAGENTA
SPECIFIC CONDUCTIVITY
umhos/cm (Thousands)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
RND1
RND2
RND3
RND4
RND5

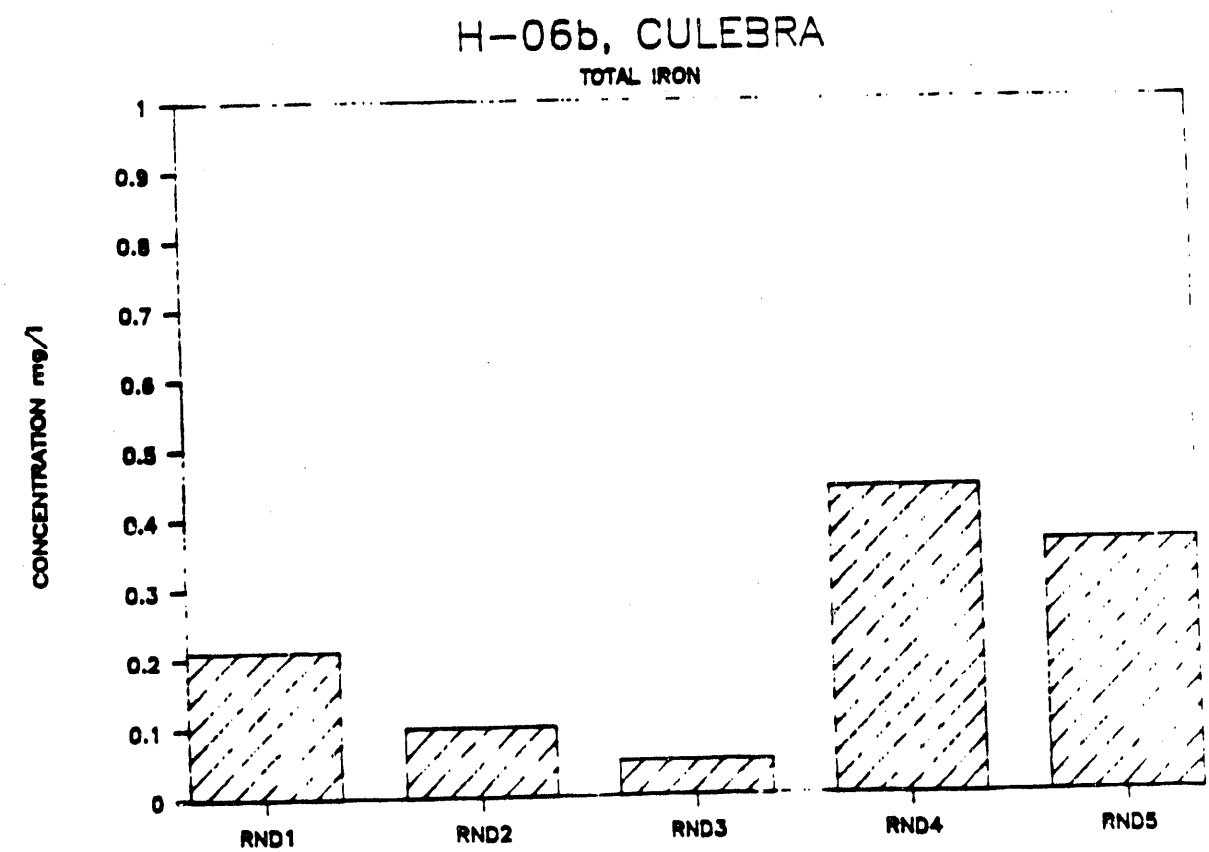

H-05c, MAGENTA
SPECIFIC GRAVITY
g/cm3
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5

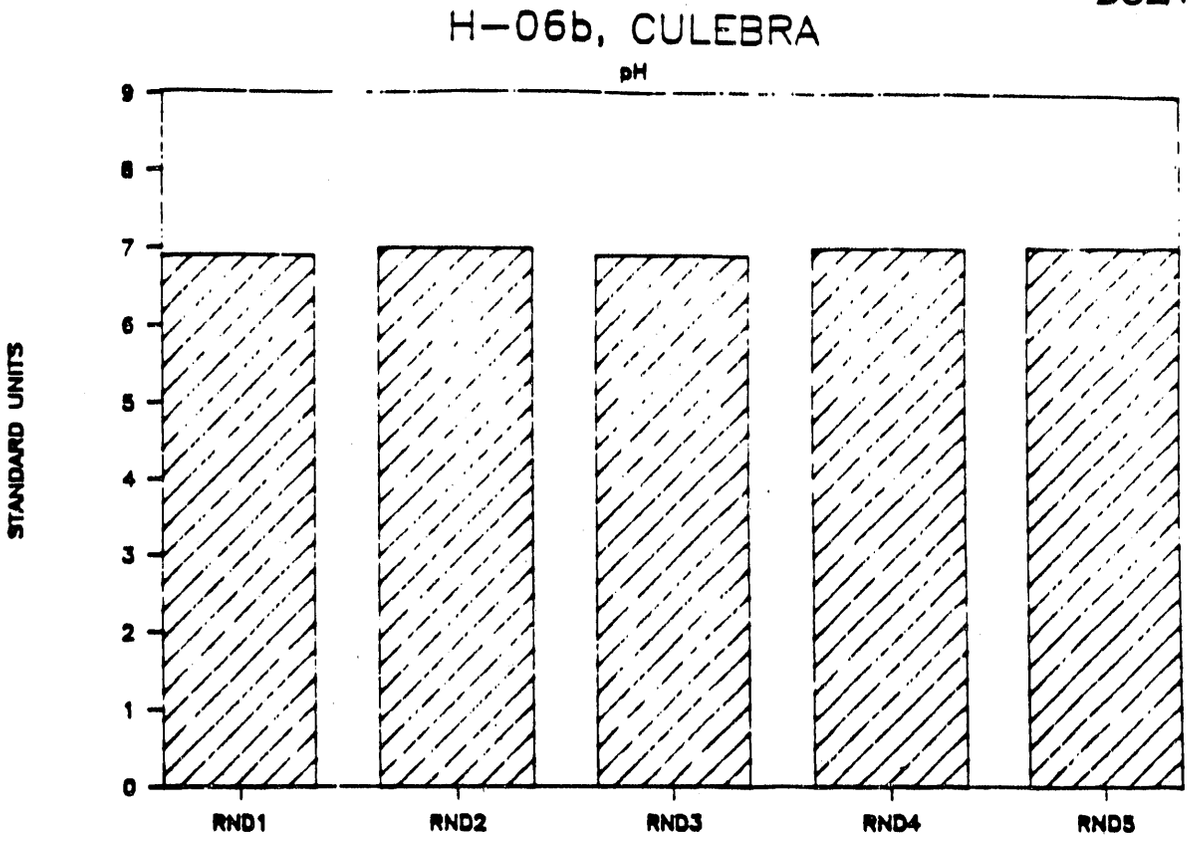

H-05c, MAGENTA
TEMPERATURE
DEGREES CELCIUS
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
RND1
RND2
RND3
RND4
RND5

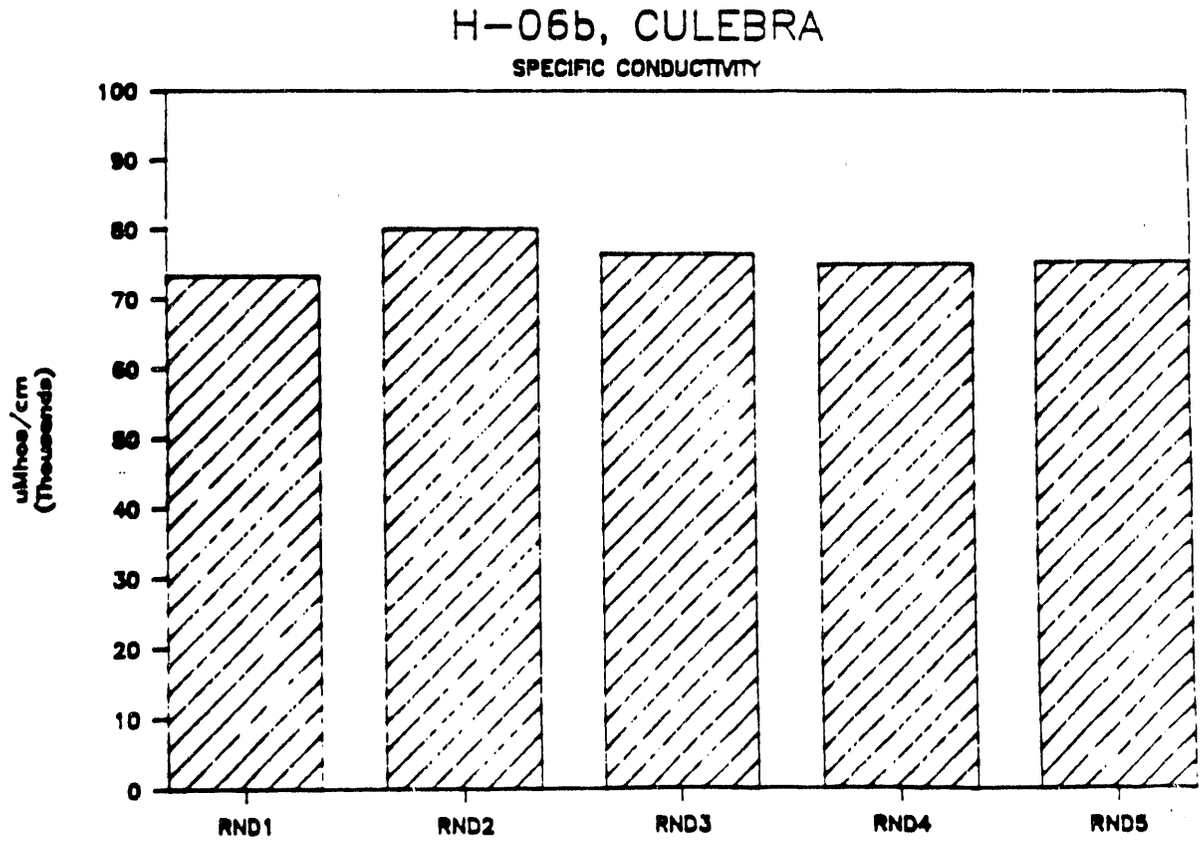

H-06b, CULEBRA
ALKALINITY
CONCENTRATION mg/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

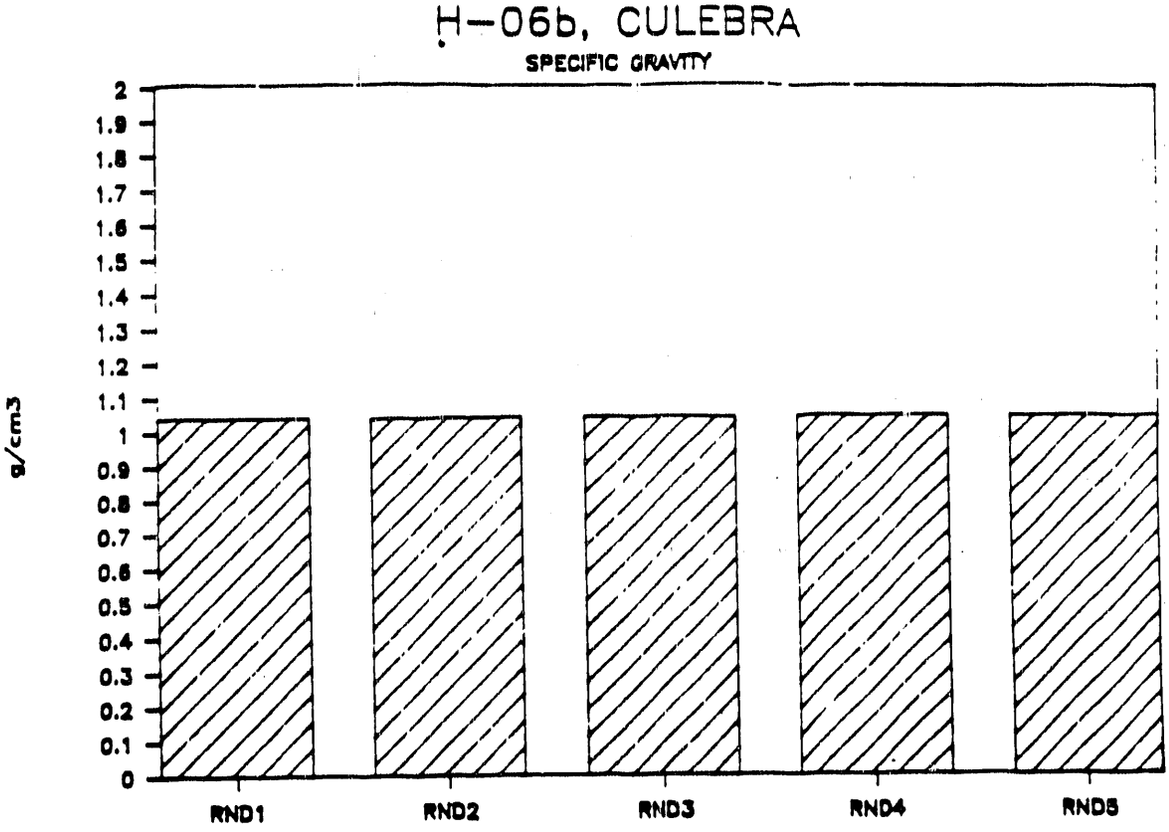

H-06b, CULEBRA
CHLORIDES
CONCENTRATION mg/l
(Thousands)
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

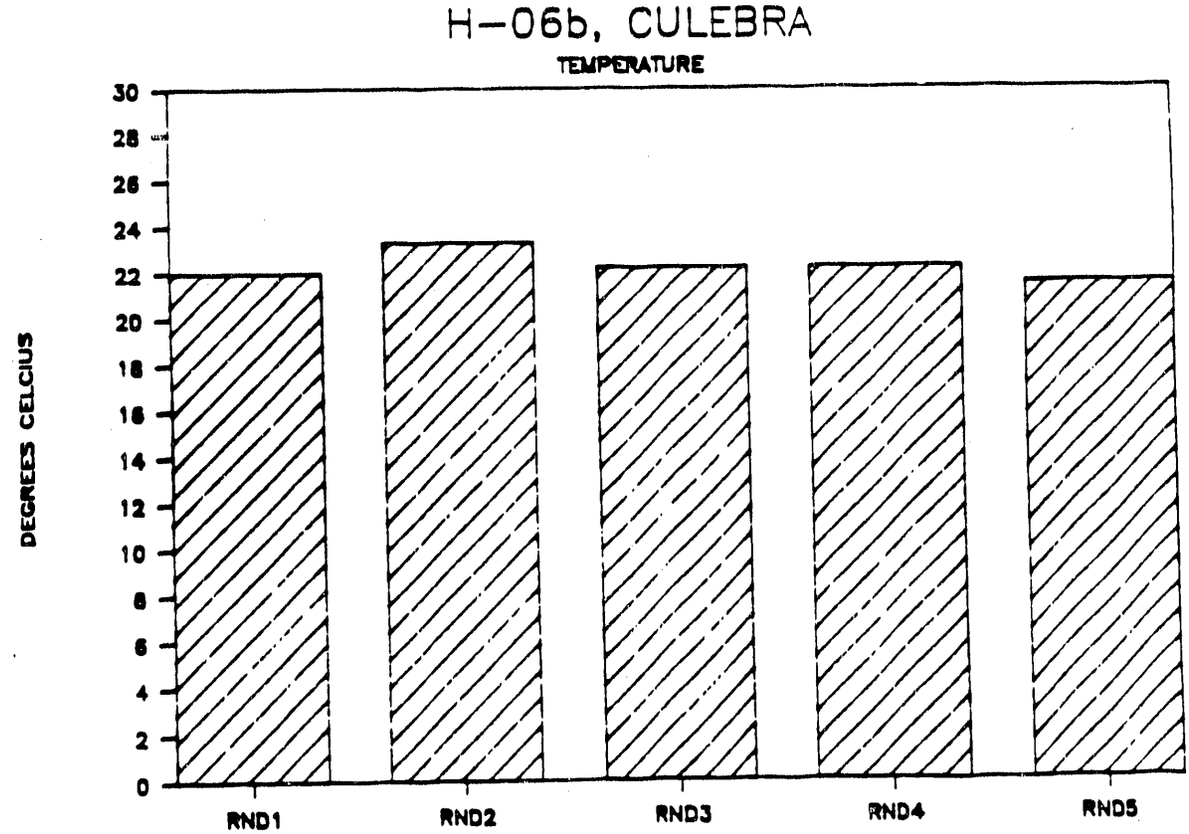

H-06b, CULEBRA
DIVALENT CATIONS
CONCENTRATION meq/l
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
RND1
RND2
RND3
RND4
RND5

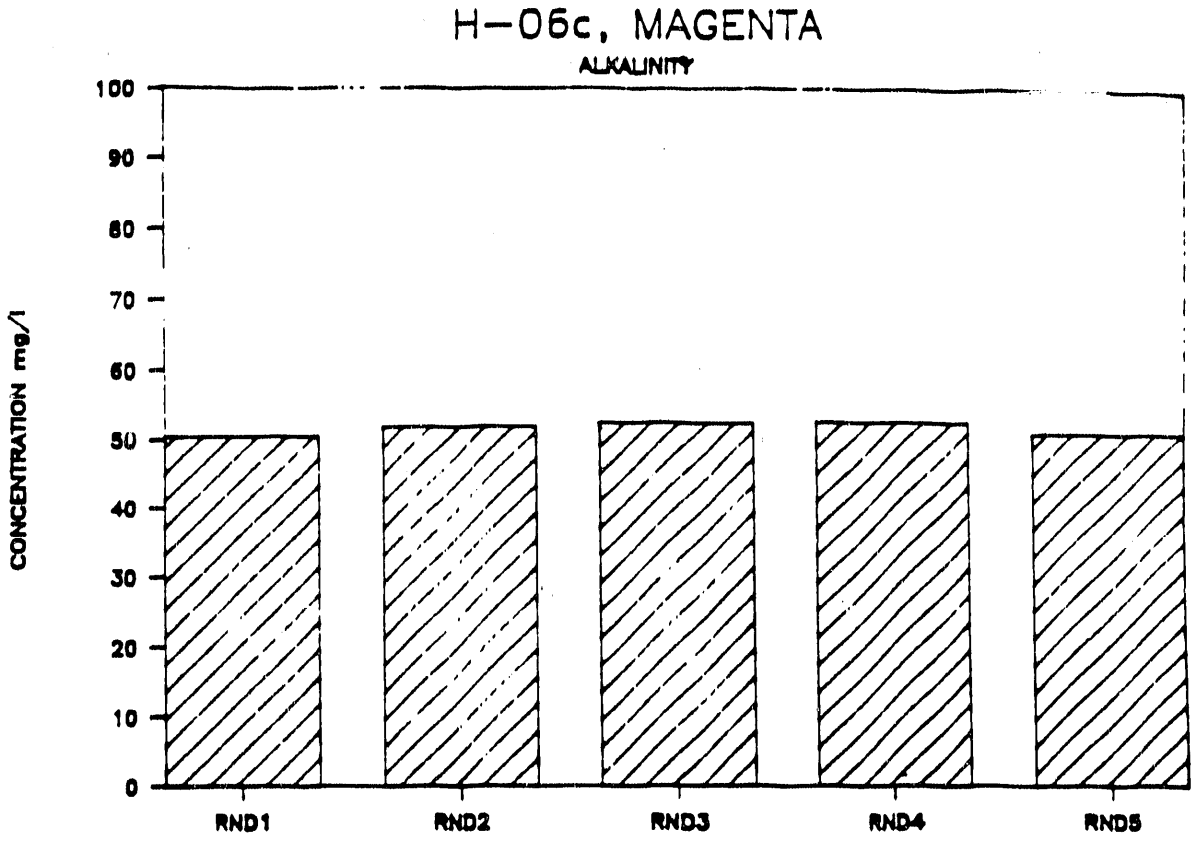

H-06b, CULEBRA
TOTAL IRON
CONCENTRATION mg/l
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5

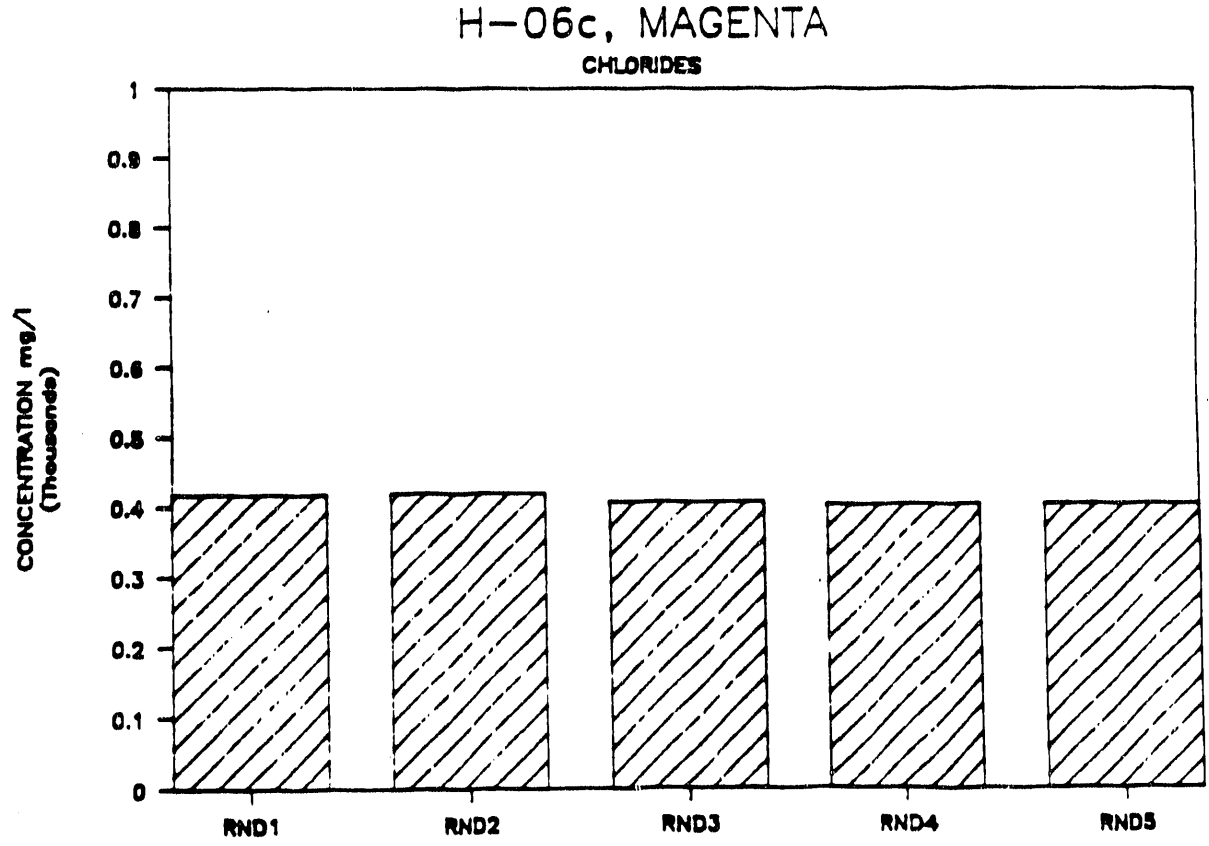

H-06b, CULEBRA
pH
STANDARD UNITS
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5

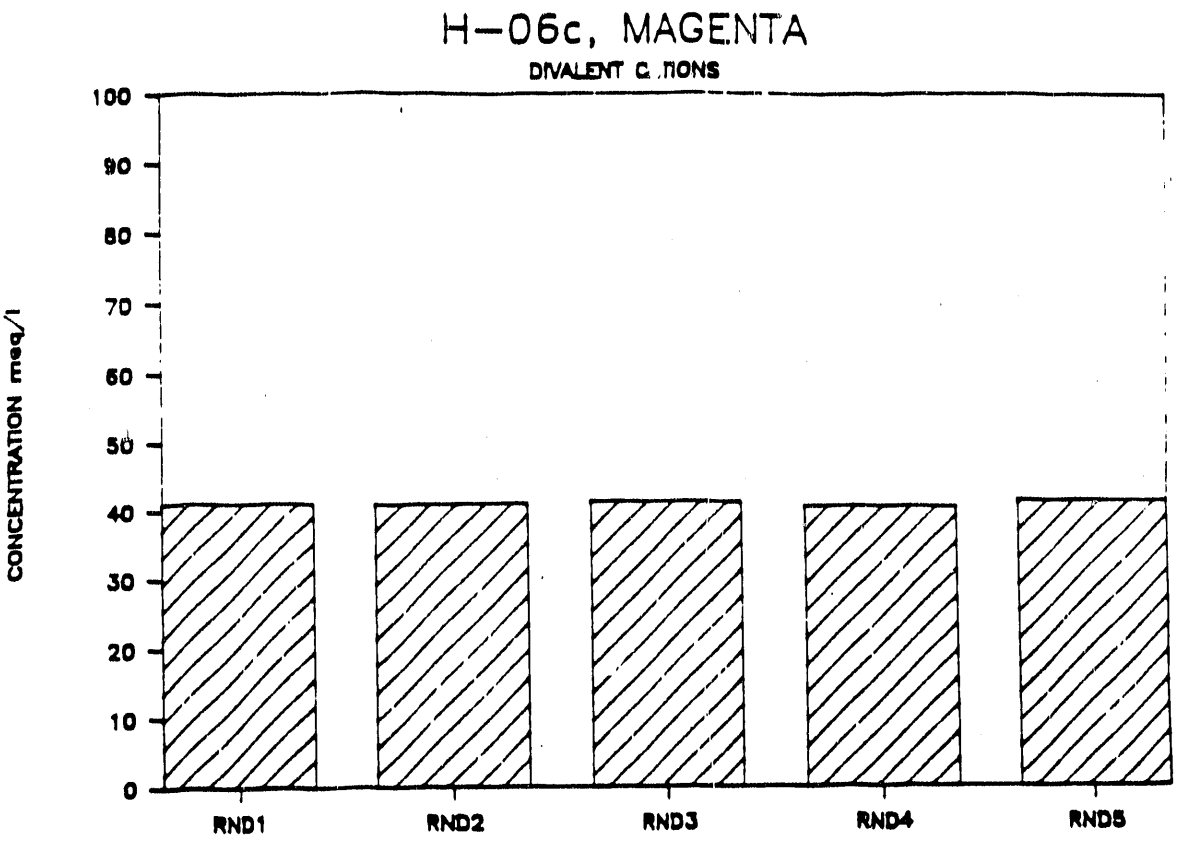

H-06b, CULEBRA
SPECIFIC CONDUCTIVITY
uMhos/cm
(Thousands)
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

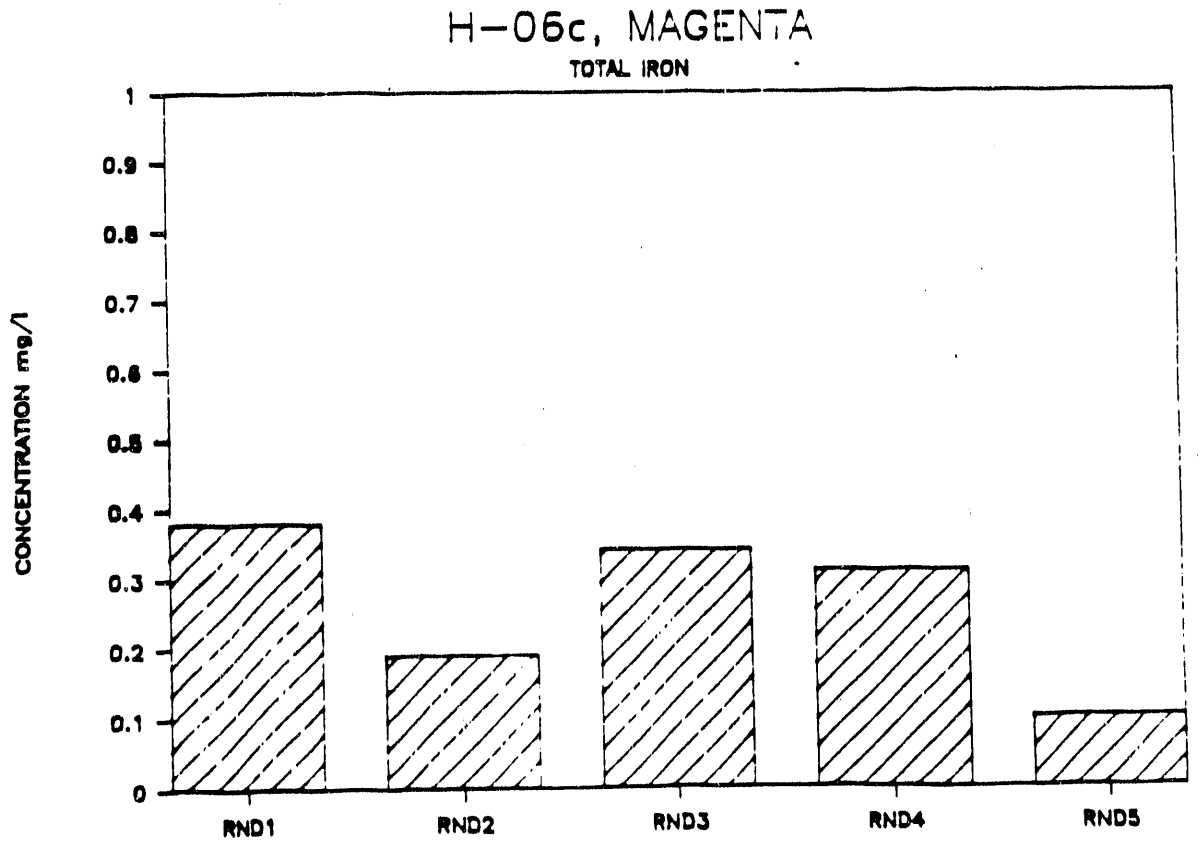

H-06b, CULEBRA
SPECIFIC GRAVITY
g/cm3
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5

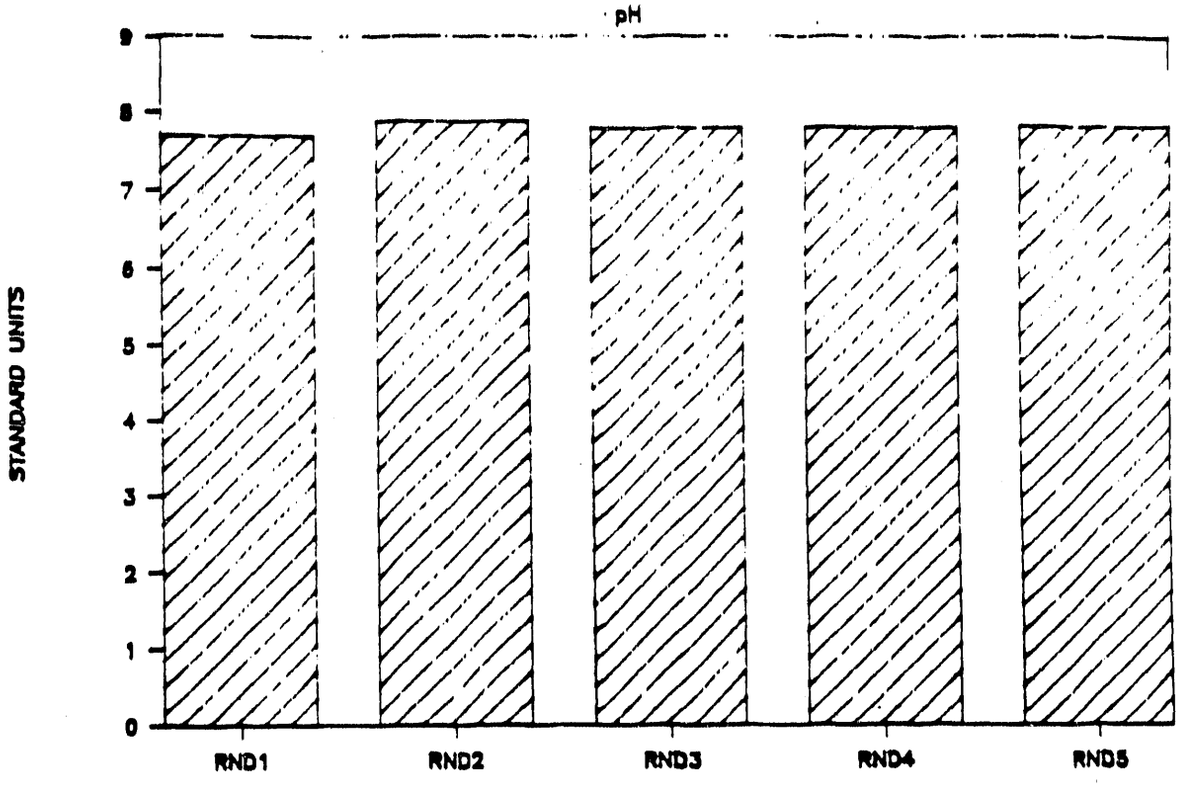

H-06b, CULEBRA
TEMPERATURE
DEGREES CELCIUS
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
RND1
RND2
RND3
RND4
RND5

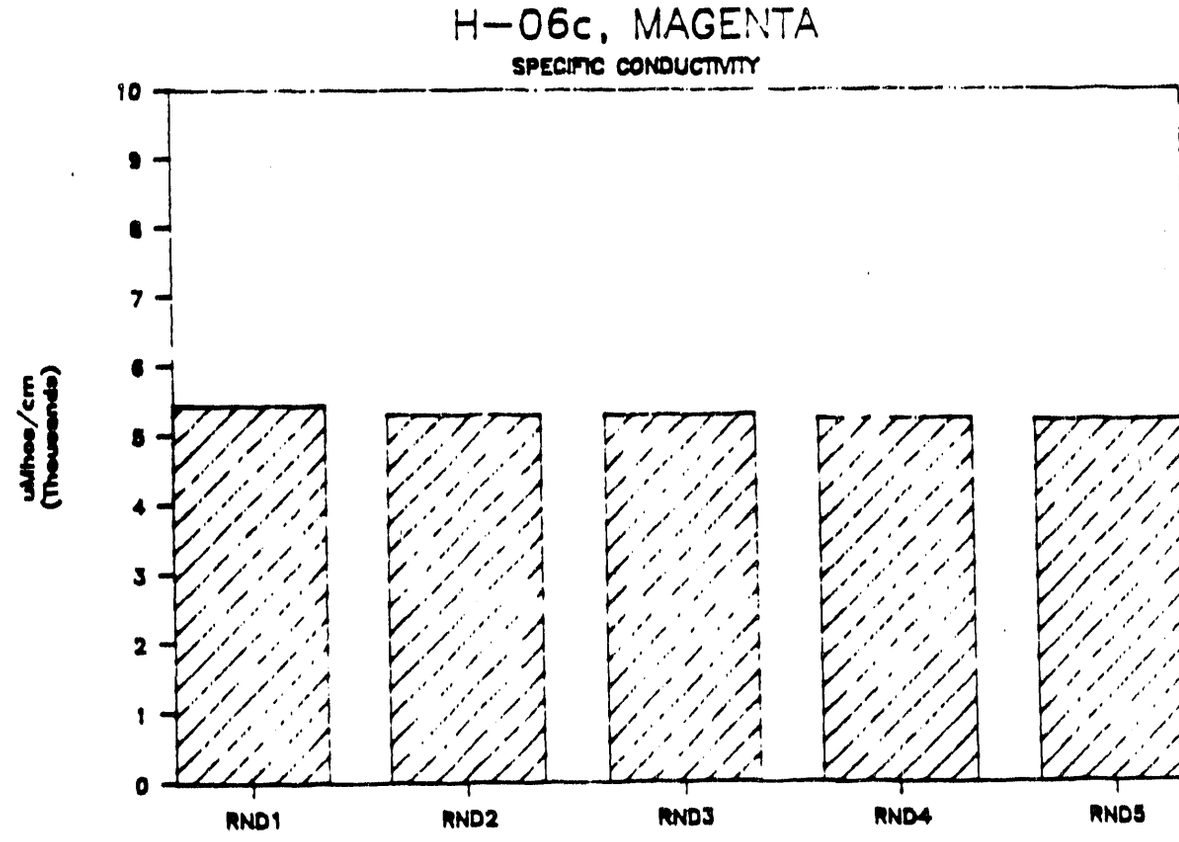

H-06c, MAGENTA
ALKALINITY
CONCENTRATION mg/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

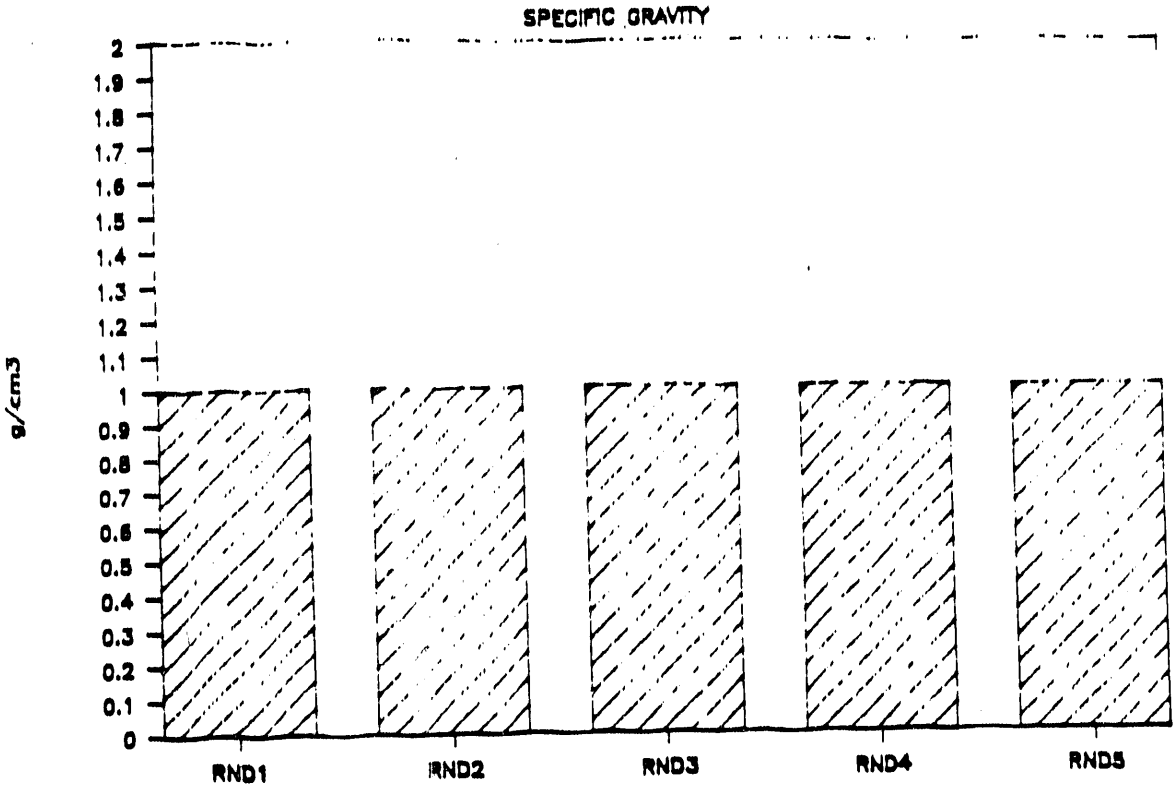

H-06c, MAGENTA
CHLORIDES
CONCENTRATION mg/l
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5

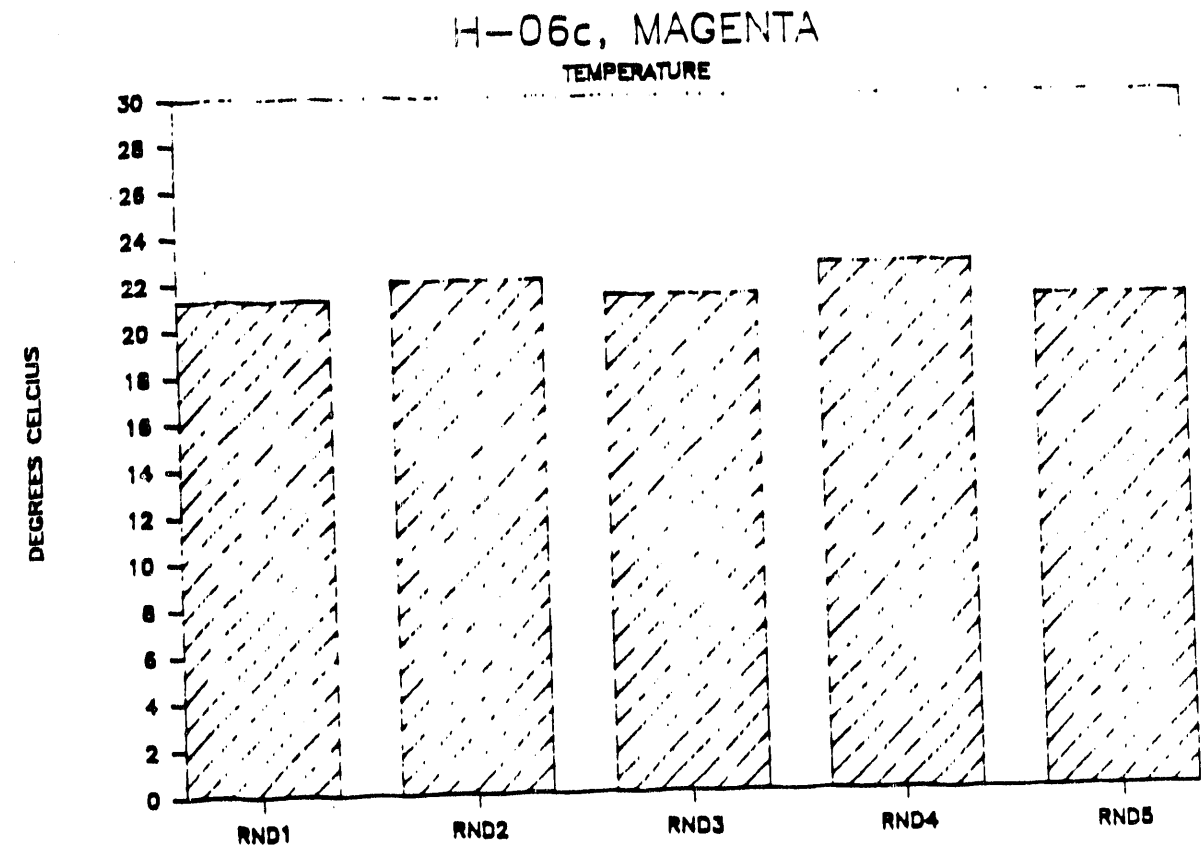

H-06c, MAGENTA
DIVALENT CATIONS
CONCENTRATION meq/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

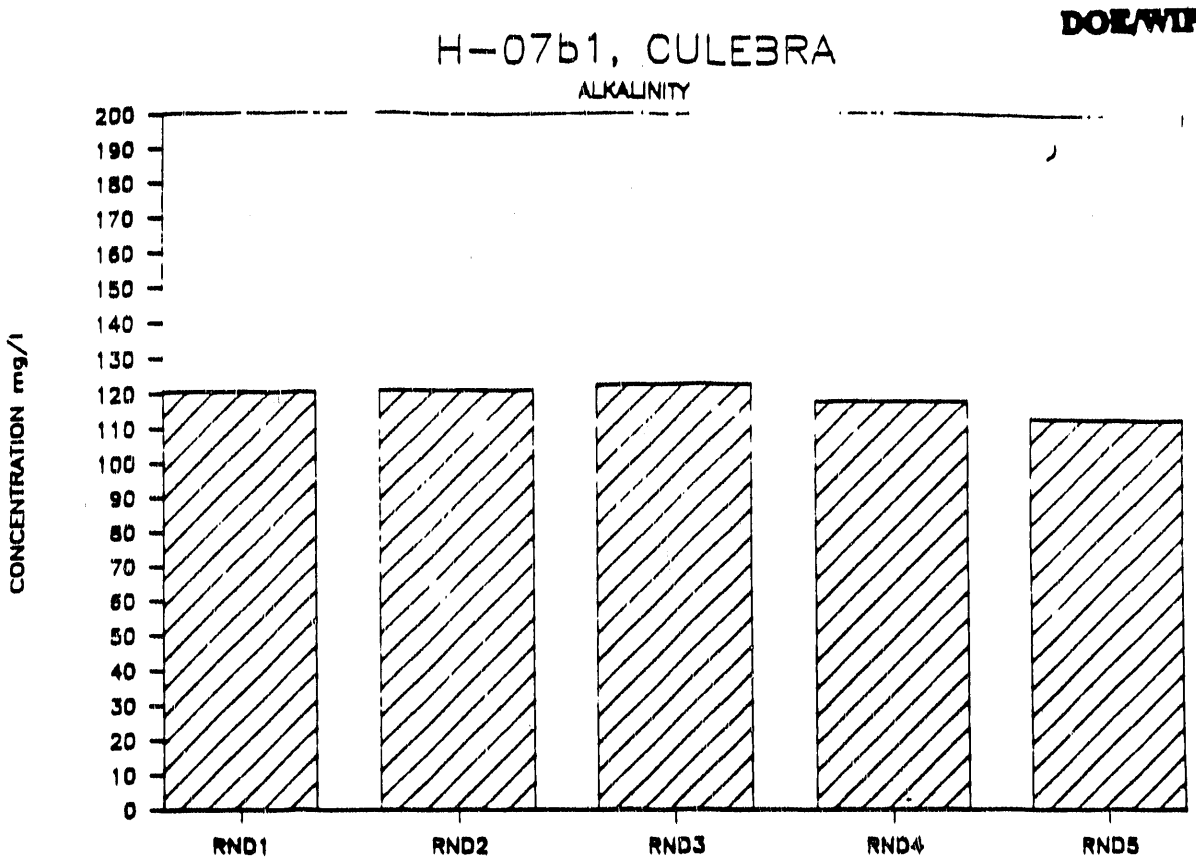

H-06c, MAGENTA
TOTAL IRON
CONCENTRATION mg/l
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5

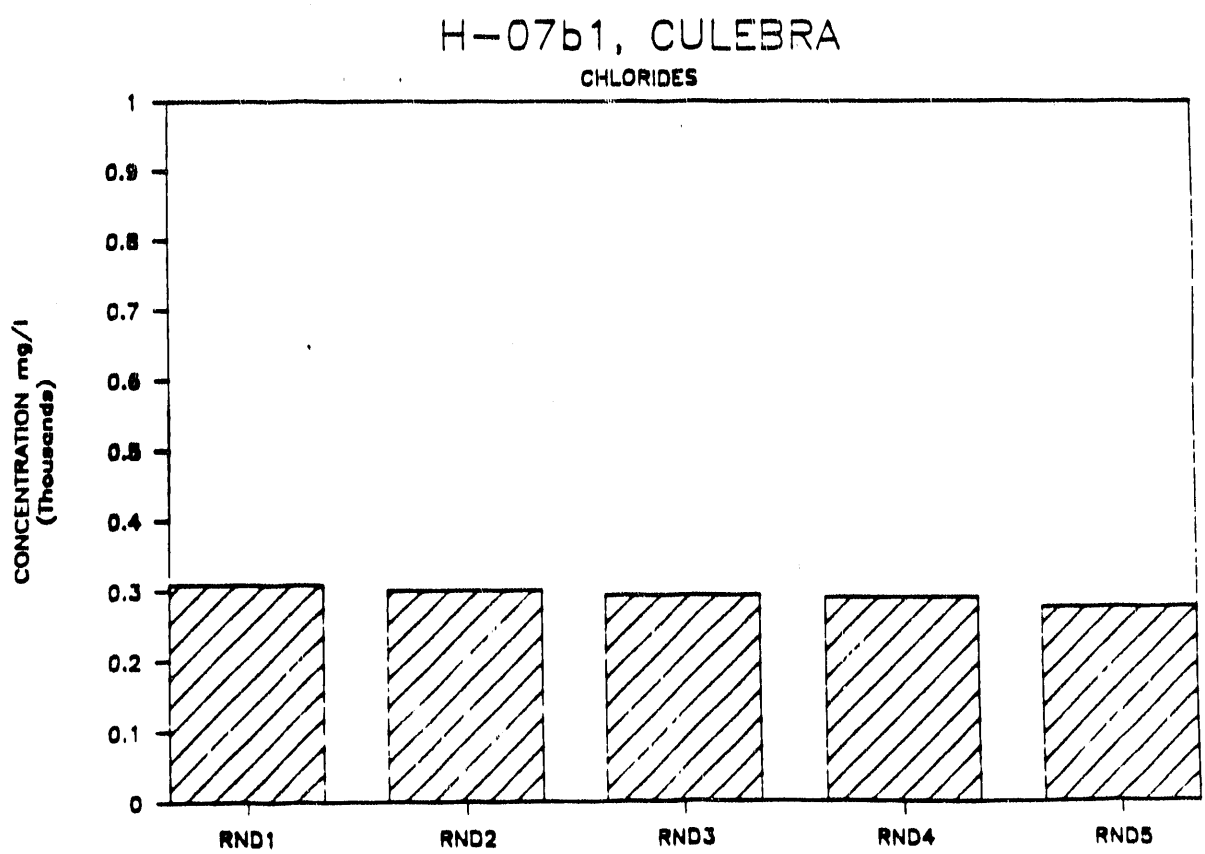

H-06c, MAGENTA
pH
STANDARD UNITS
0
1
2
3
4
5
6
7
8
9
RND1
RND2
RND3
RND4
RND5

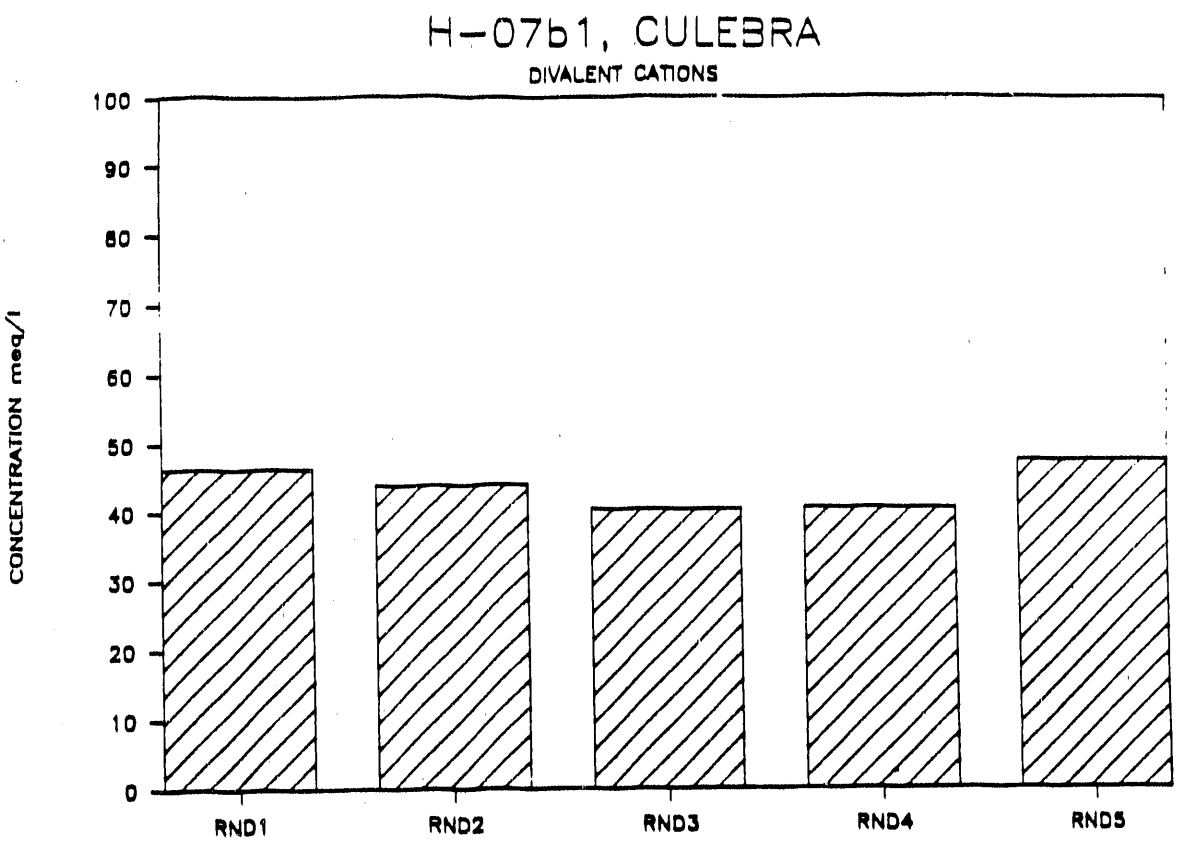

H-06c, MAGENTA
SPECIFIC CONDUCTIVITY
uMhos/cm
(Thousands)
0
1
2
3
4
5
6
7
8
9
10
RND1
RND2
RND3
RND4
RND5

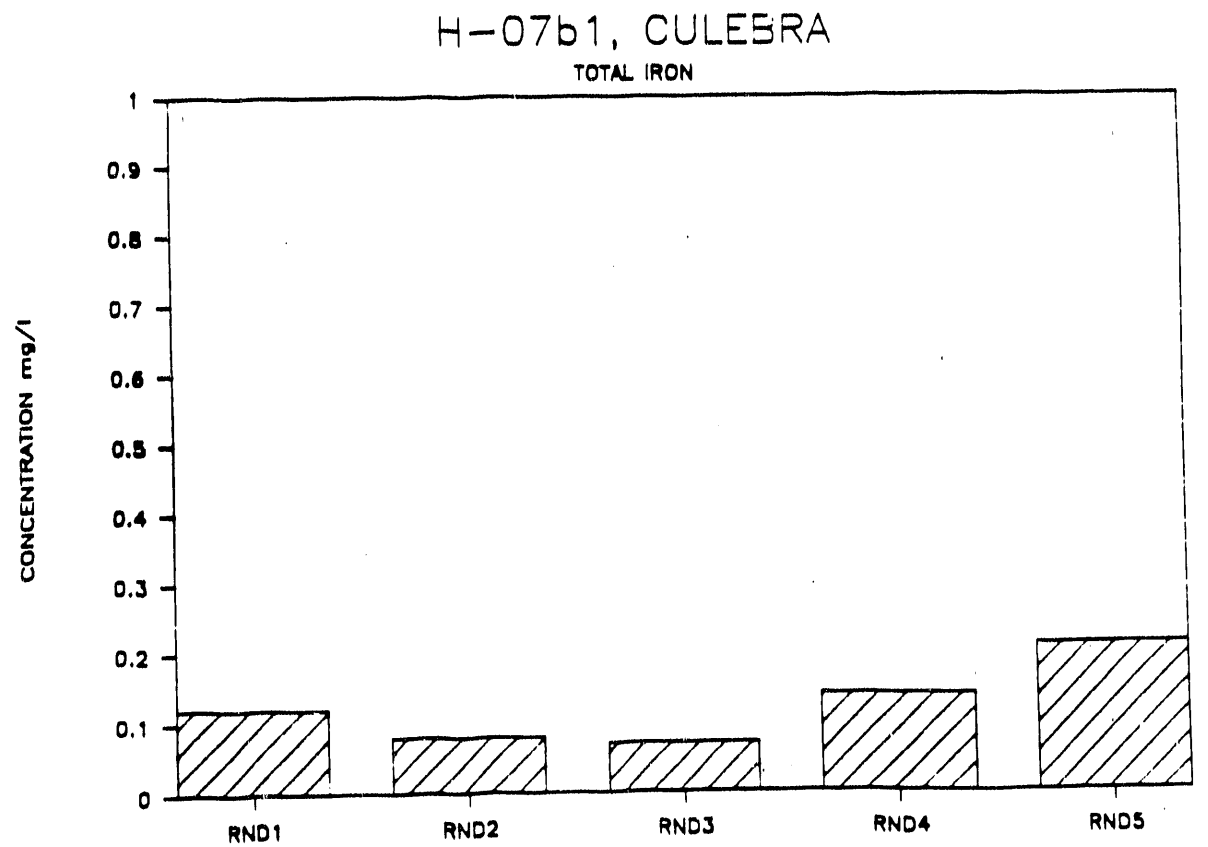

H-06c, MAGENTA
SPECIFIC GRAVITY
g/cm3
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5

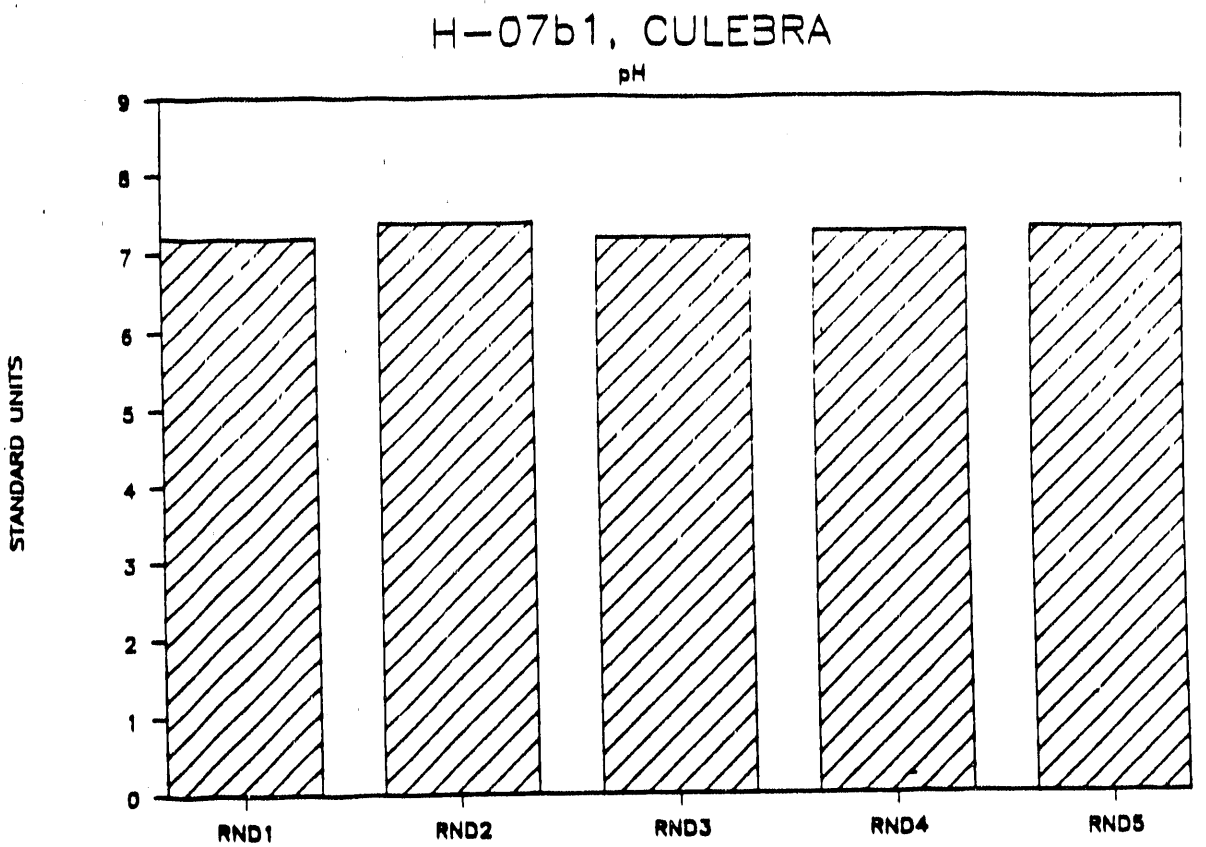

H-06c, MAGENTA
TEMPERATURE
DEGREES CELCIUS
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
RND1
RND2
RND3
RND4
RND5

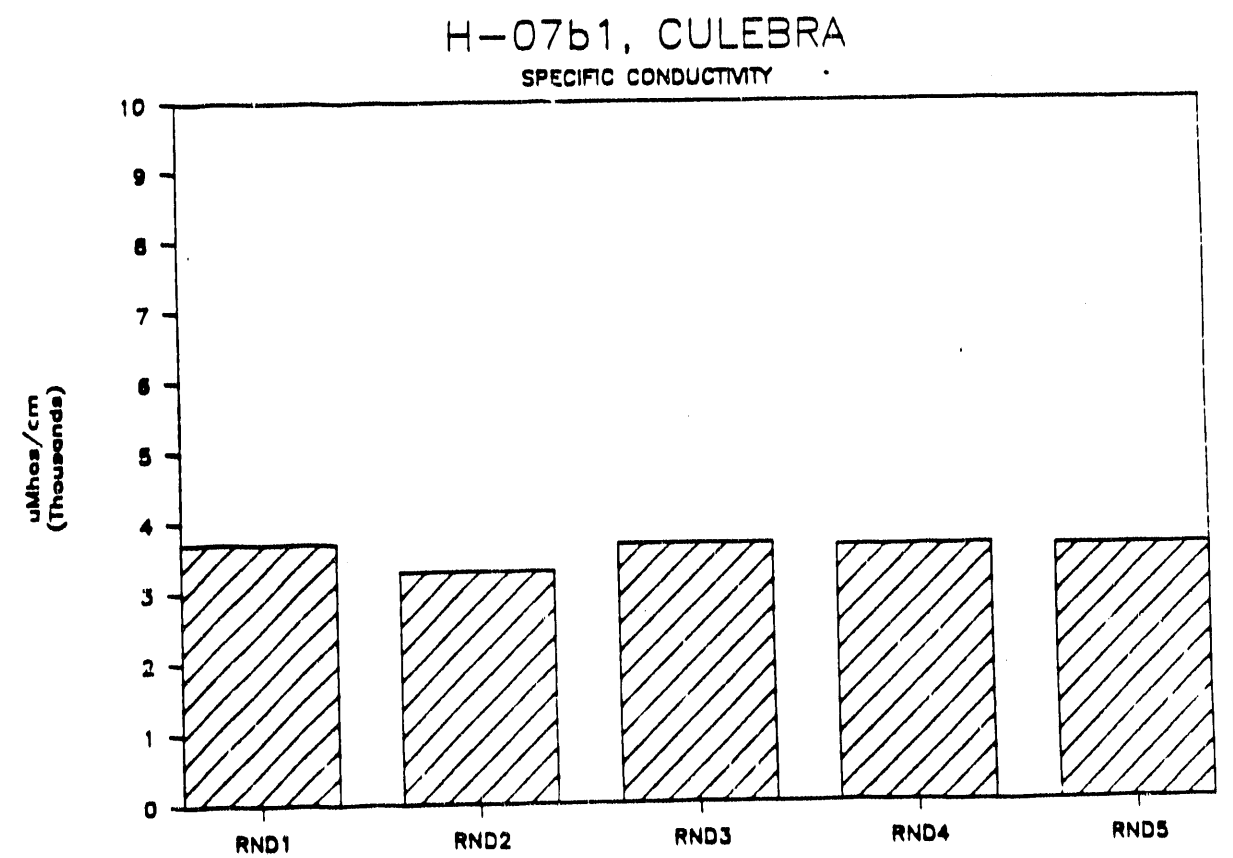

H-07b1, CULEBRA
ALKALINITY
CONCENTRATION mg/l
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

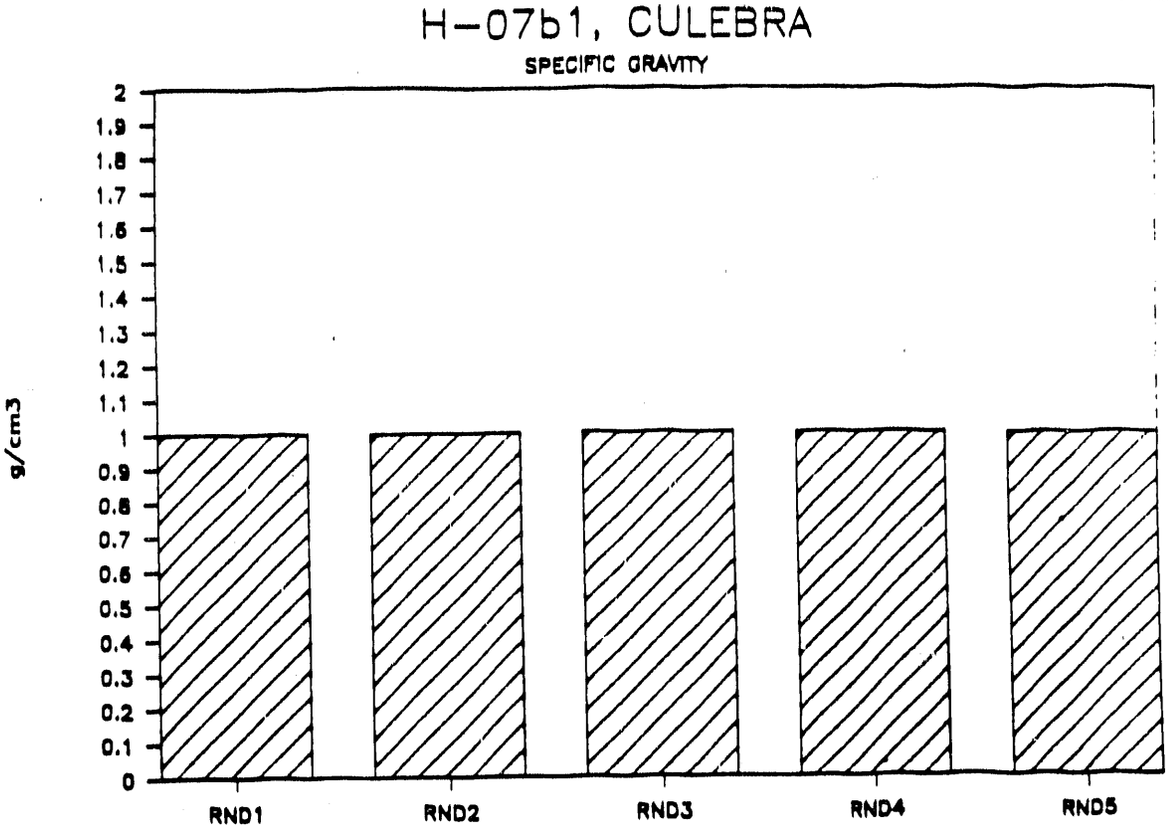

H-07b1, CULEBRA
CHLORIDES
CONCENTRATION mg/l
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5

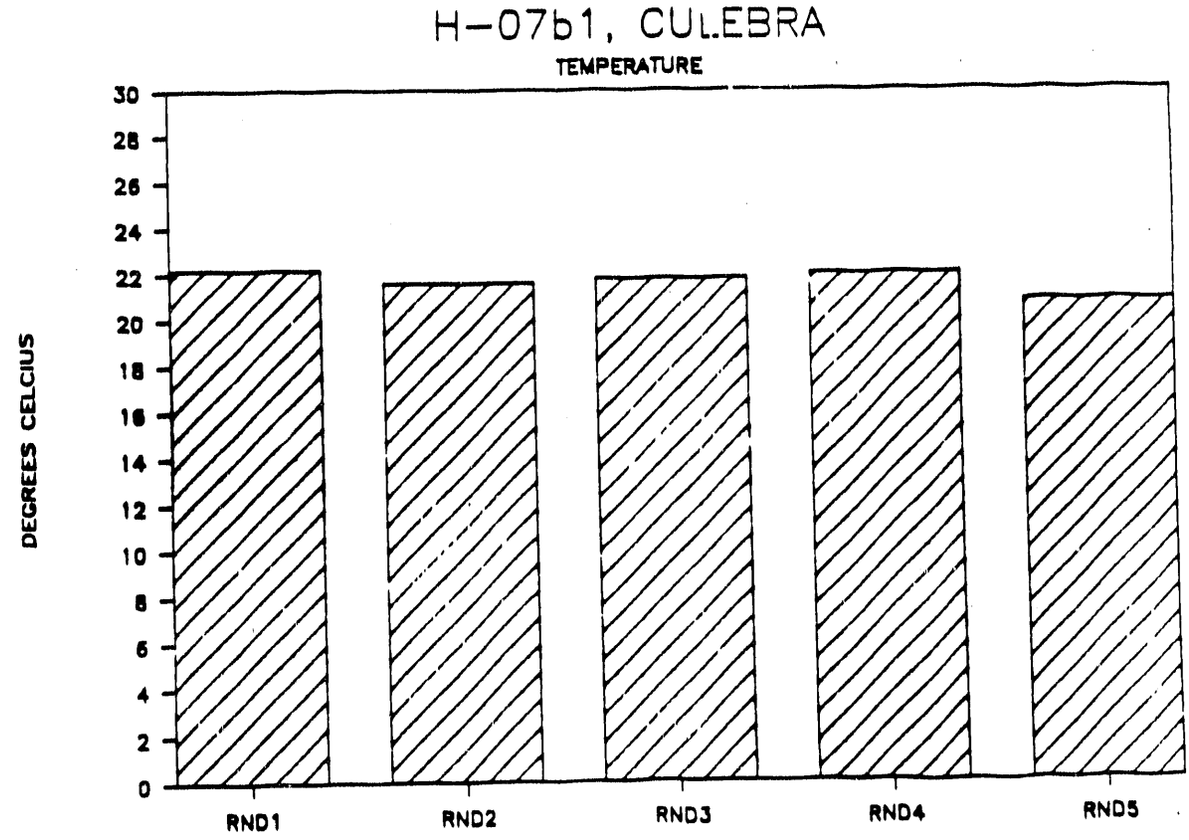

H-07b1, CULEBRA
DIVALENT CATIONS
CONCENTRATION meq/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

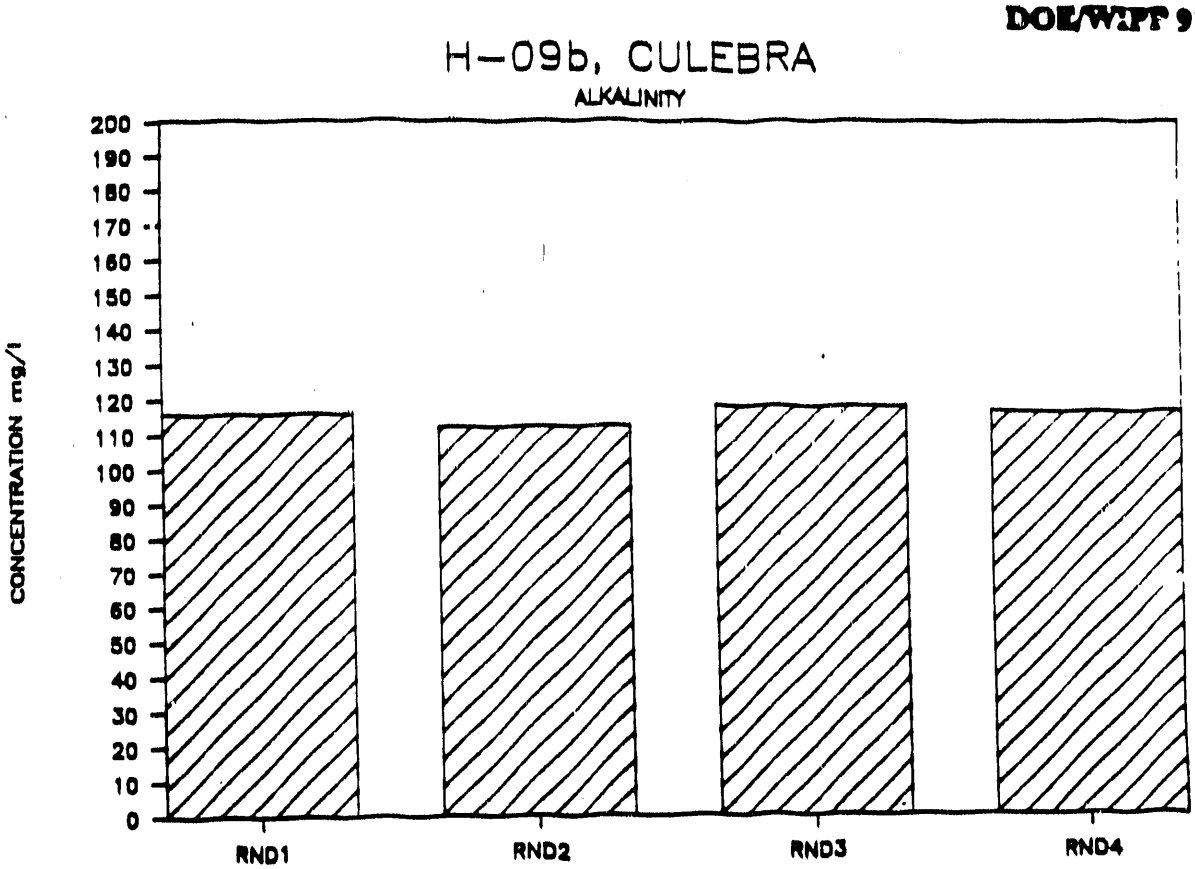

H-07b1, CULEBRA
TOTAL IRON
CONCENTRATION mg/l
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5

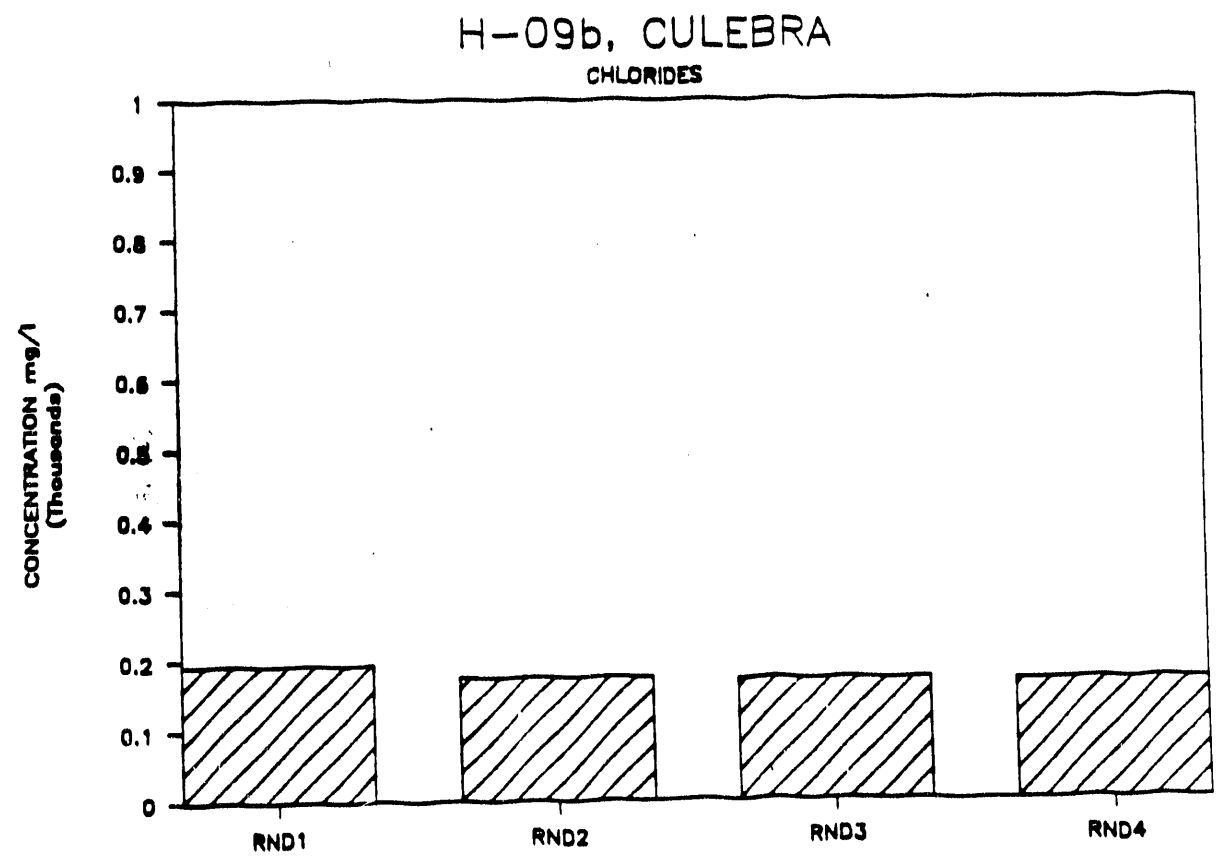

H-07b1, CULEBRA
pH
STANDARD UNITS
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5

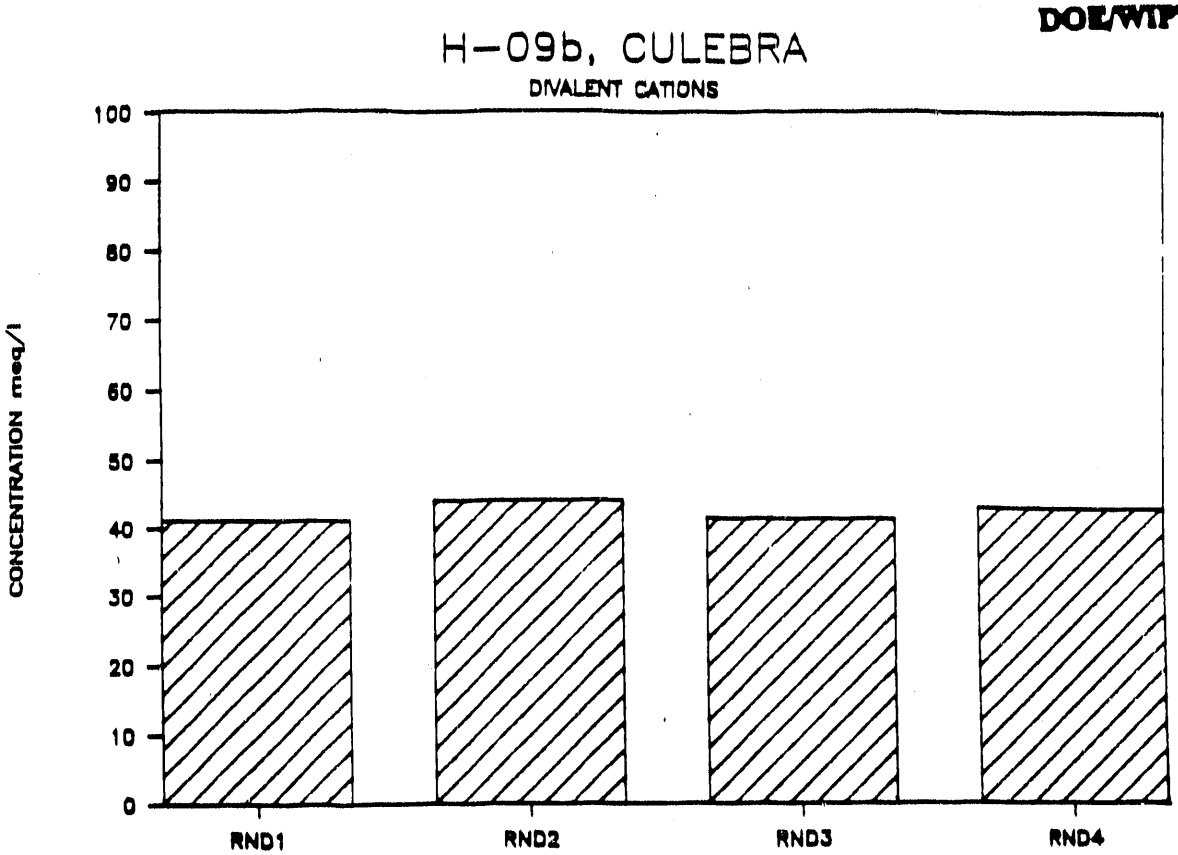

H-07b1, CULEBRA
SPECIFIC CONDUCTIVITY
uMhos/cm
(Thousands)
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5

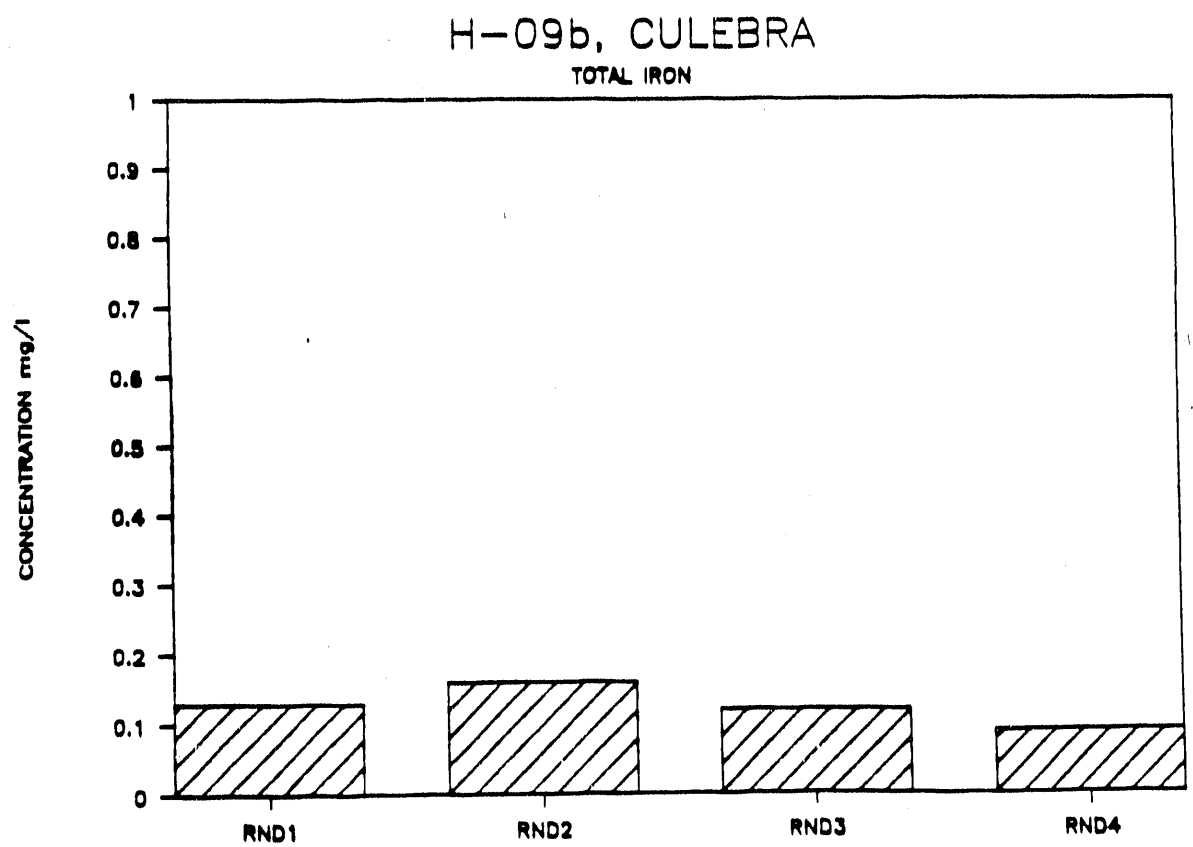

H-07b1, CULEBRA
SPECIFIC GRAVITY
g/cm3
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5

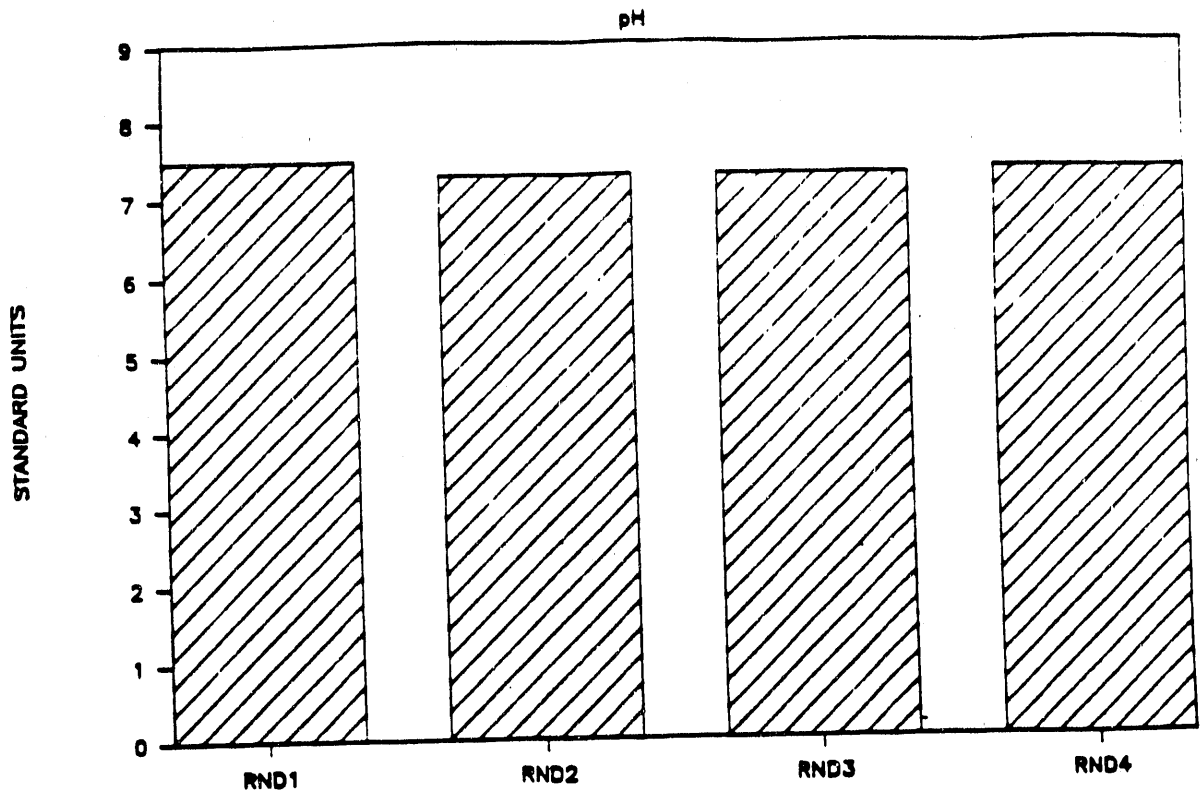

H-07b1, CULEBRA
TEMPERATURE
DEGREES CELCIUS
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
RND1
RND2
RND3
RND4
RND5

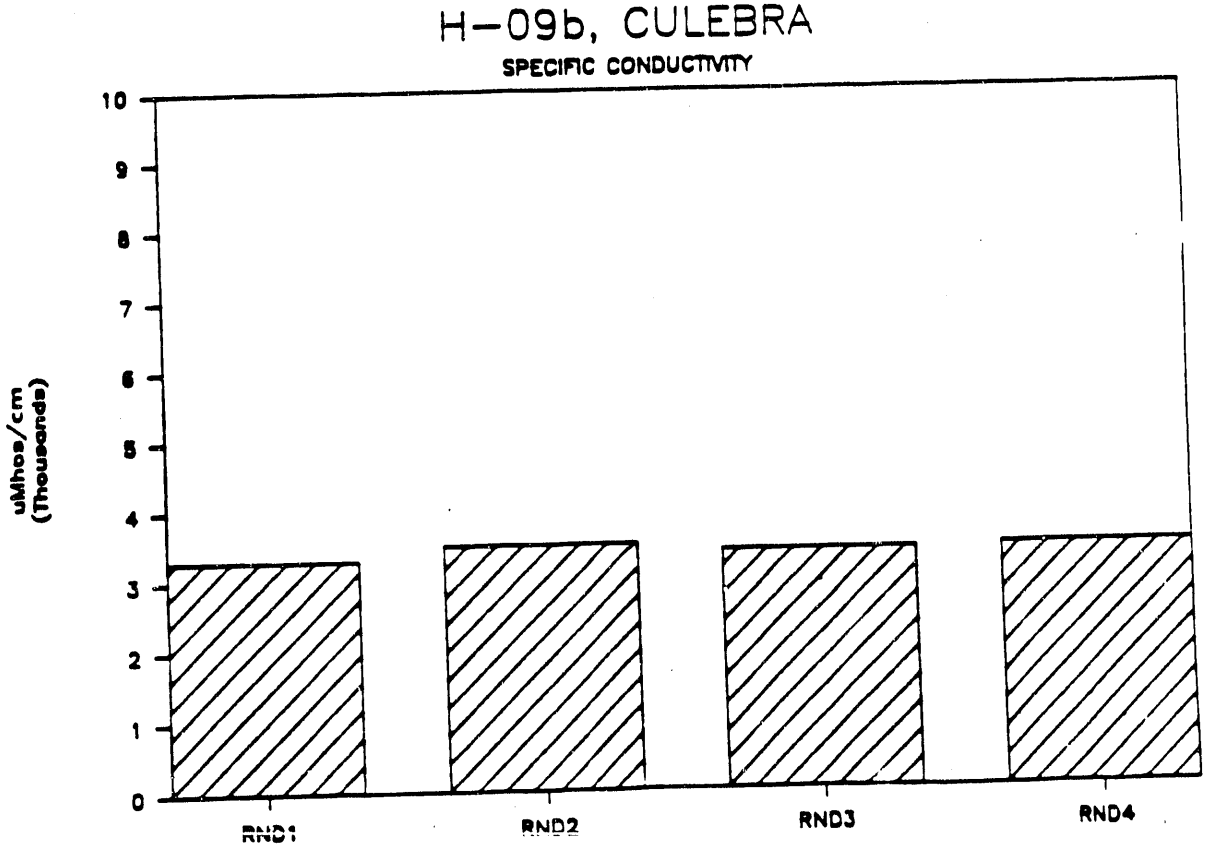

H-09b, CULEBRA
ALKALINITY
CONCENTRATION mg/l
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4

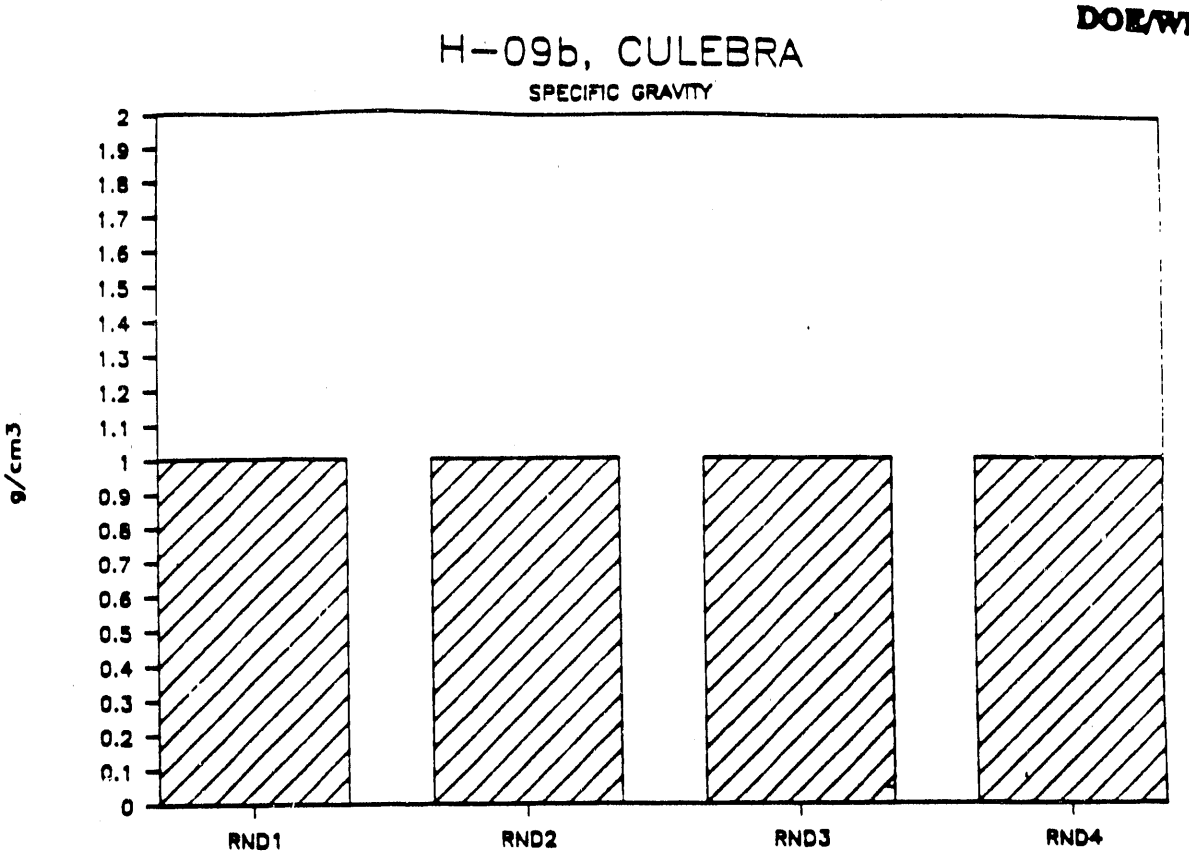

H-09b, CULEBRA
CHLORIDES
CONCENTRATION mg/l
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4

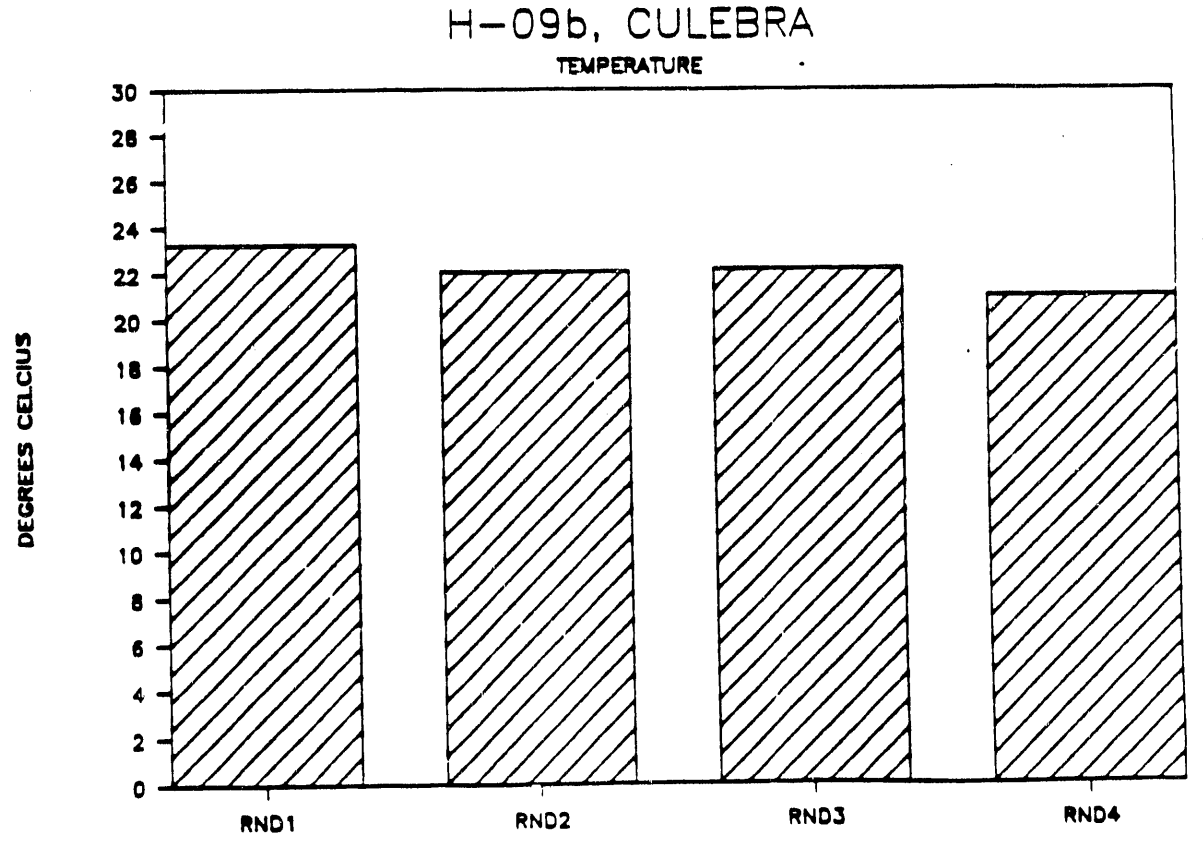

H-09b, CULEBRA
DIVALENT CATIONS
CONCENTRATION meq/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4

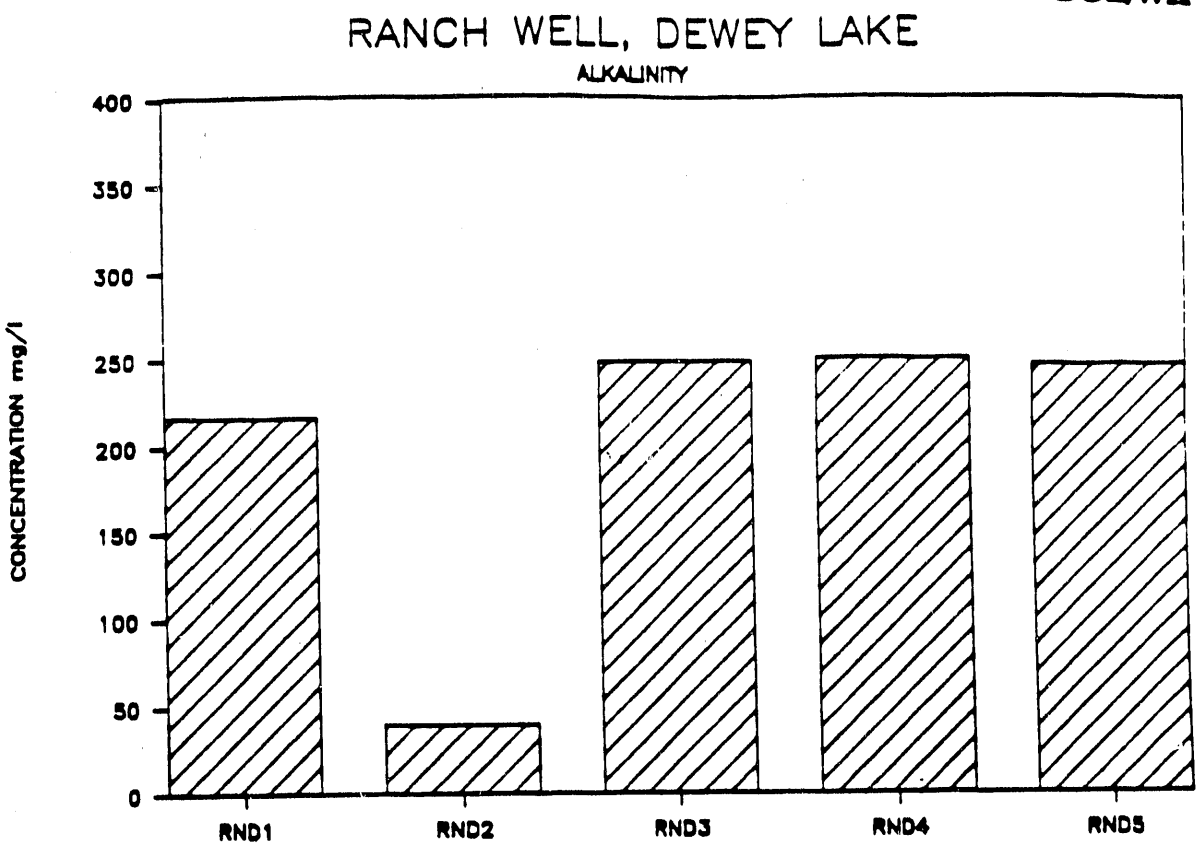

H-09b, CULEBRA
TOTAL IRON
CONCENTRATION mg/l
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4

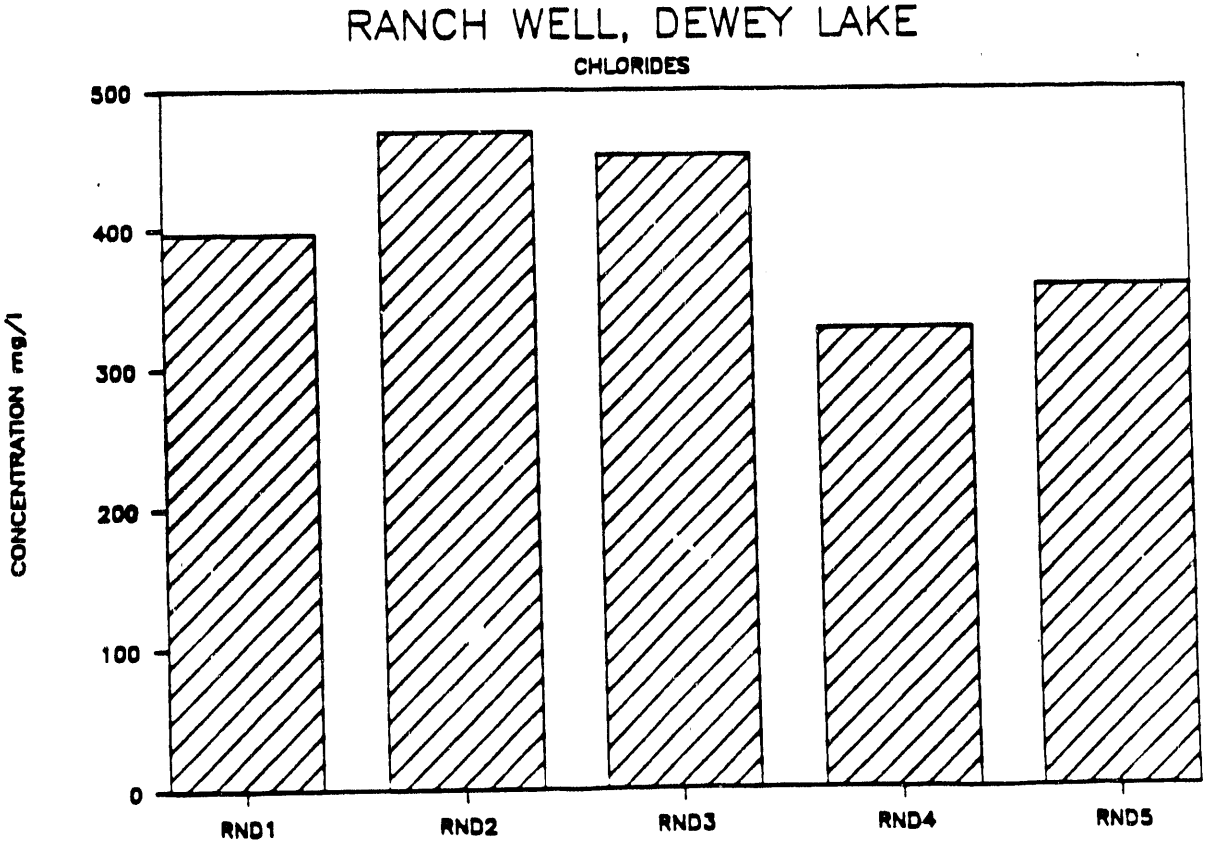

H-09b, CULEBRA
pH
STANDARD UNITS
0
1
2
3
4
5
6
7
8
9
RND1
RND2
RND3
RND4

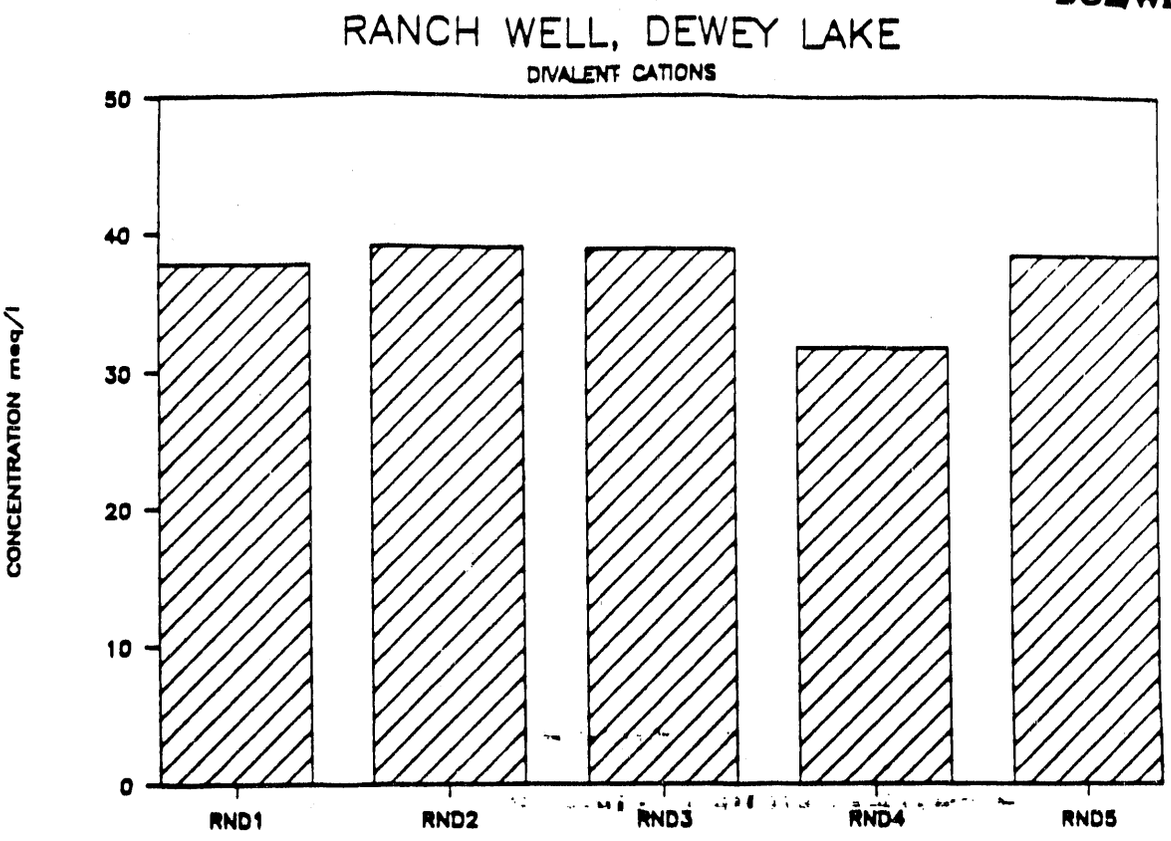

H-09b, CULEBRA
SPECIFIC CONDUCTIVITY
uMhos/cm
(Thousands)
0
1
2
3
4
5
6
7
8
9
10
RND1
RND2
RND3
RND4

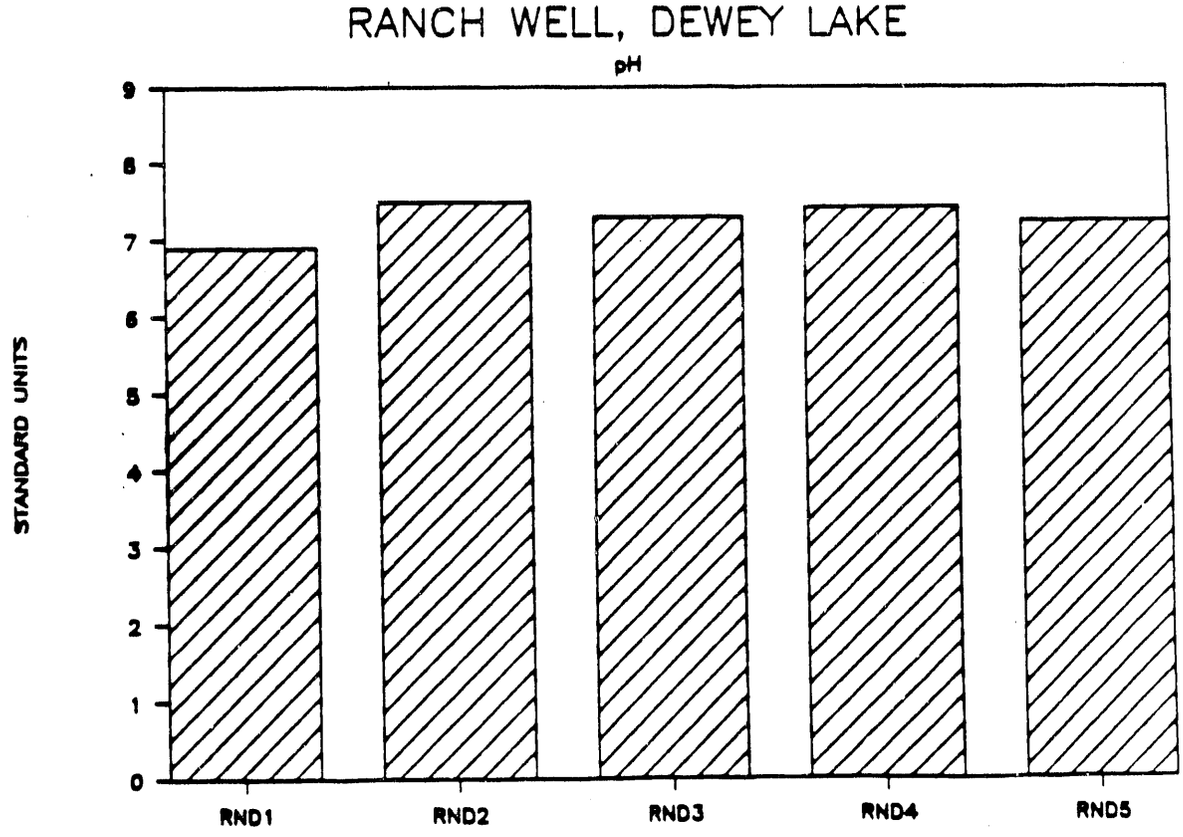

H-09b, CULEBRA
SPECIFIC GRAVITY
g/cm3
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4

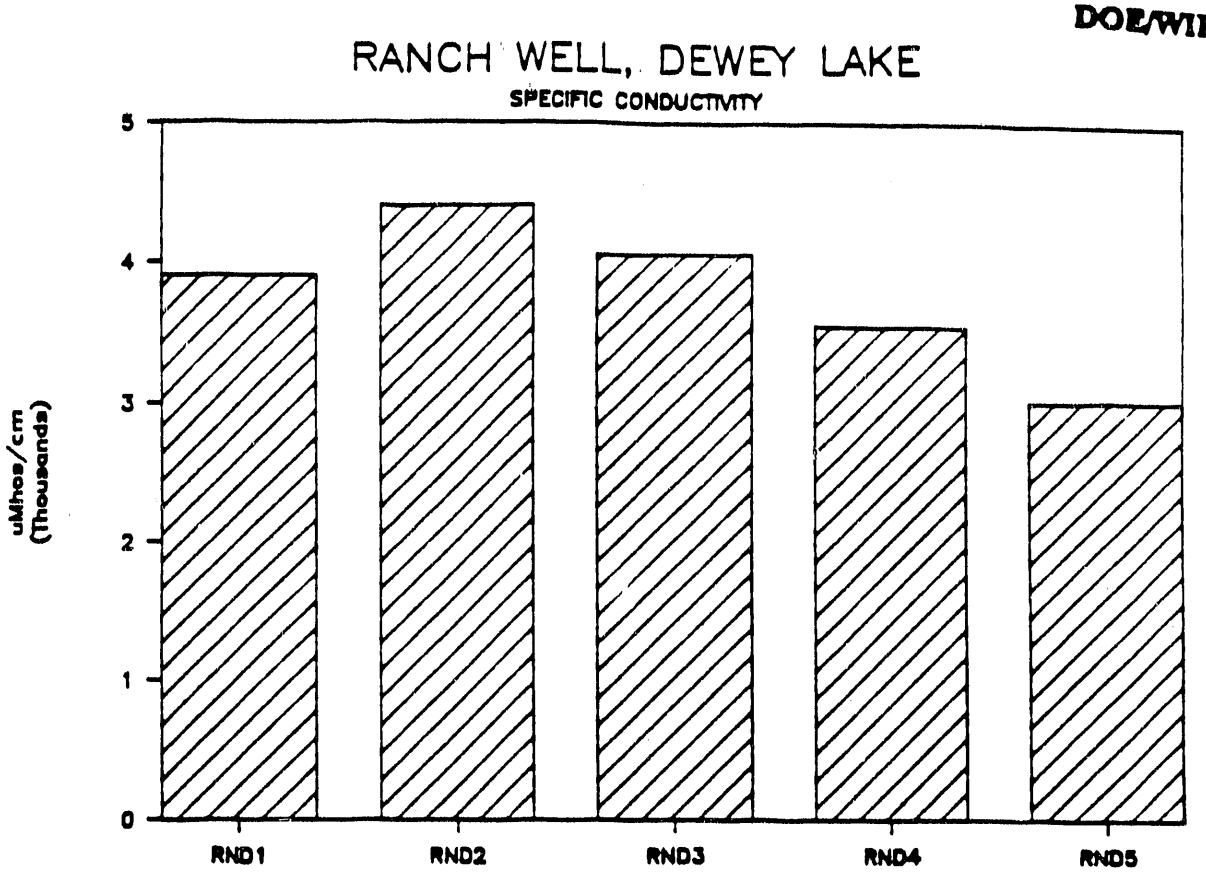

H-09b, CULEBRA
TEMPERATURE
DEGREES CELCIUS
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
RND1
RND2
RND3
RND4

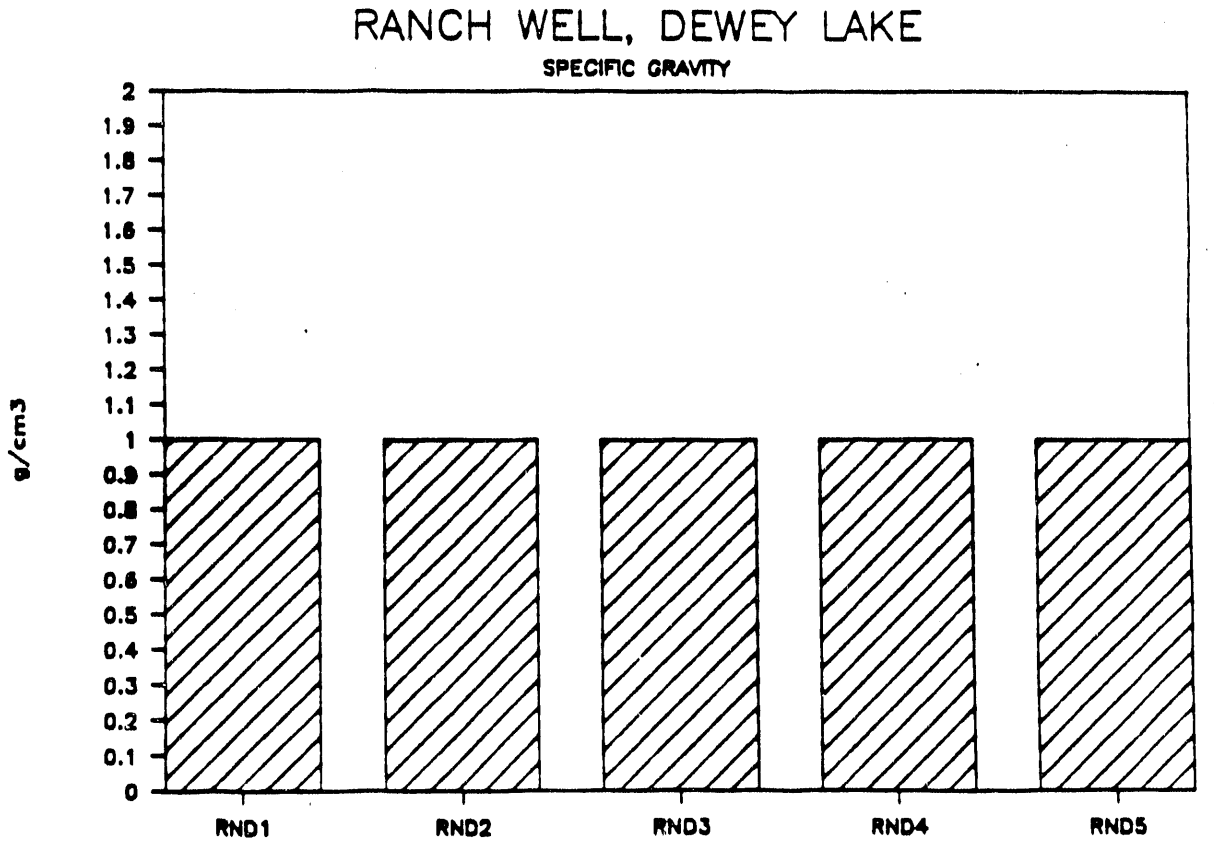

RANCH WELL, DEWEY LAKE
ALKALINITY
CONCENTRATION mg/l
400
350
300
250
200
150
100
50
0
RND1
RND2
RND3
RND4
RND5

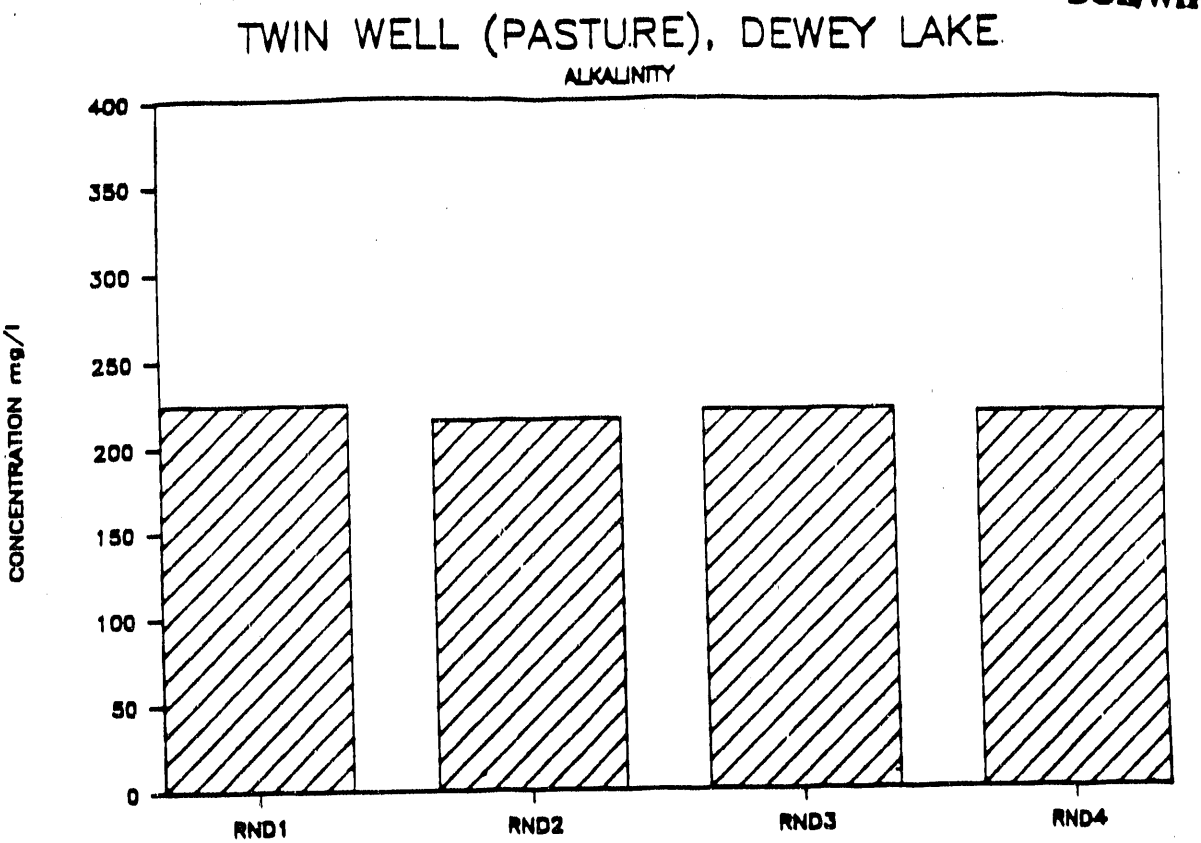

RANCH WELL, DEWEY LAKE
CHLORIDES
CONCENTRATION mg/l
500
400
300
200
100
0
RND1
RND2
RND3
RND4
RND5

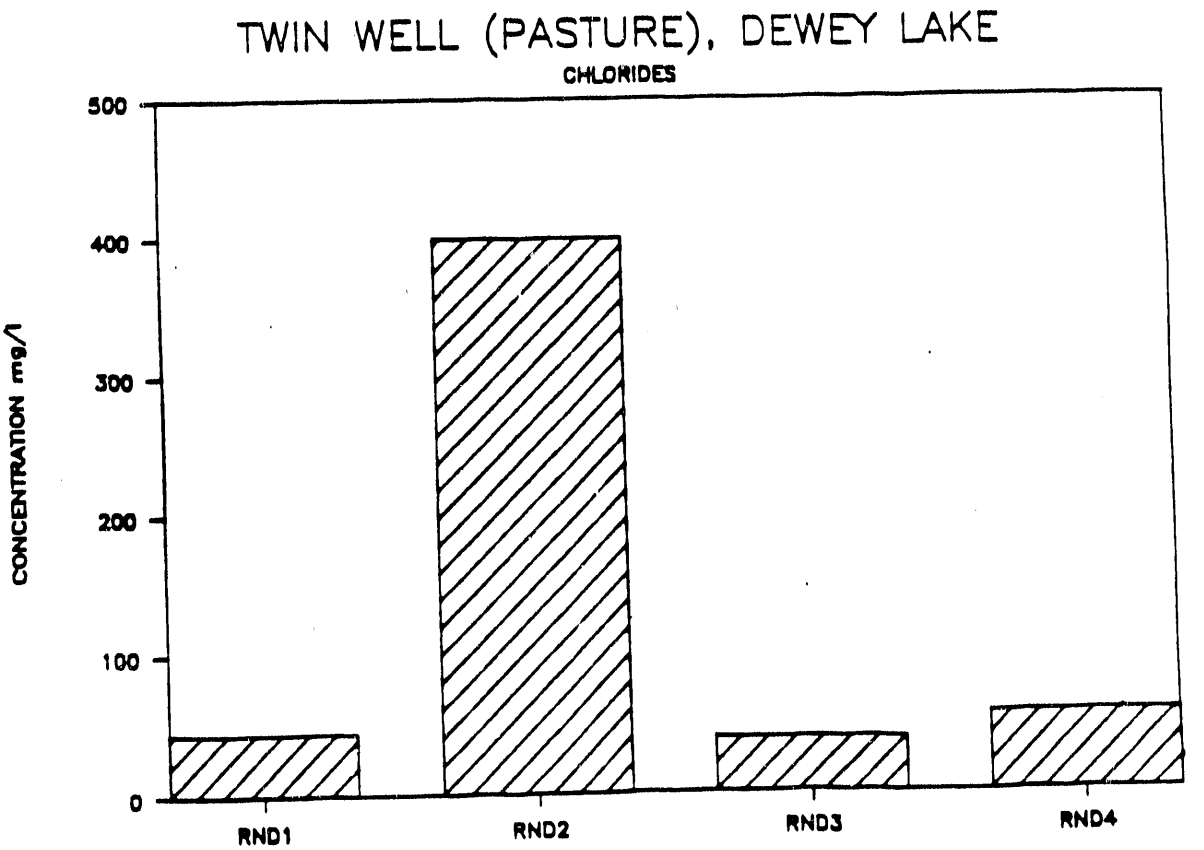

RANCH WELL, DEWEY LAKE
DIVALENT CATIONS
CONCENTRATION meq/l
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

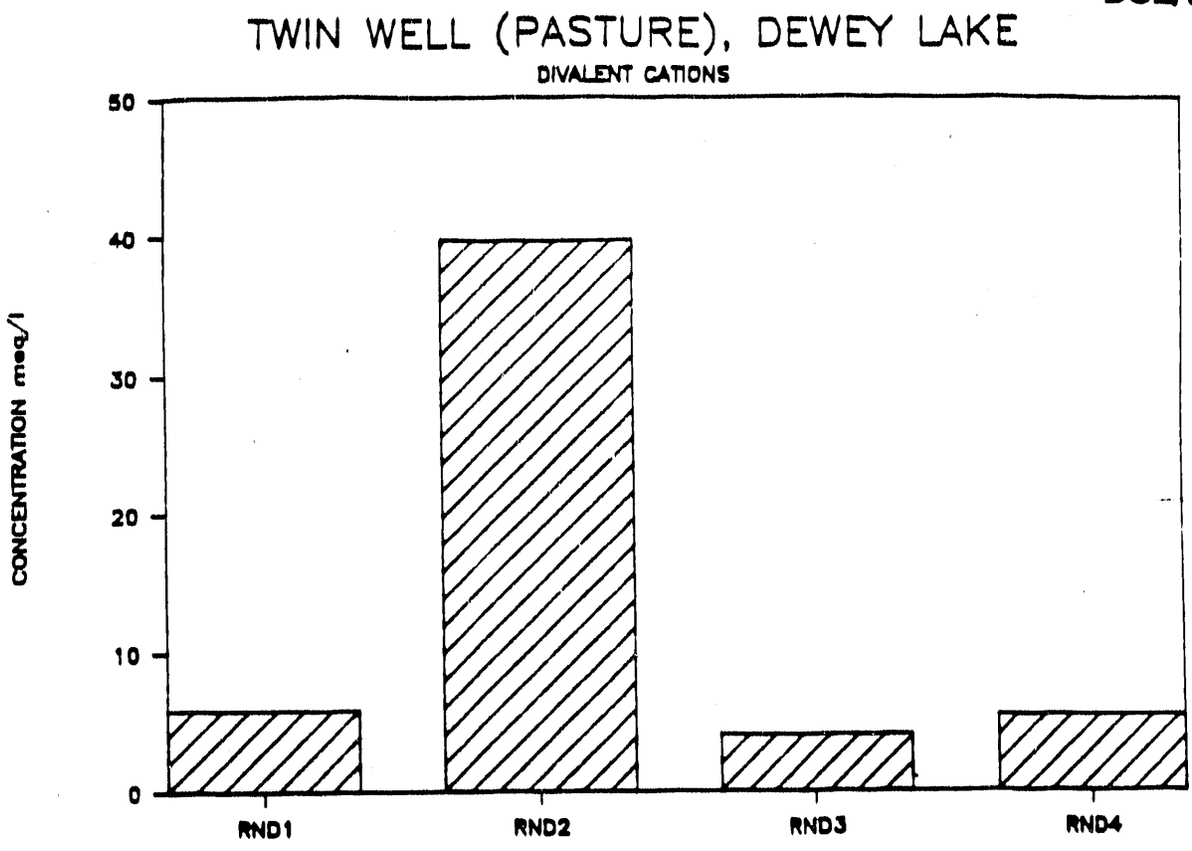

RANCH WELL, DEWEY LAKE
pH
STANDARD UNITS
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5

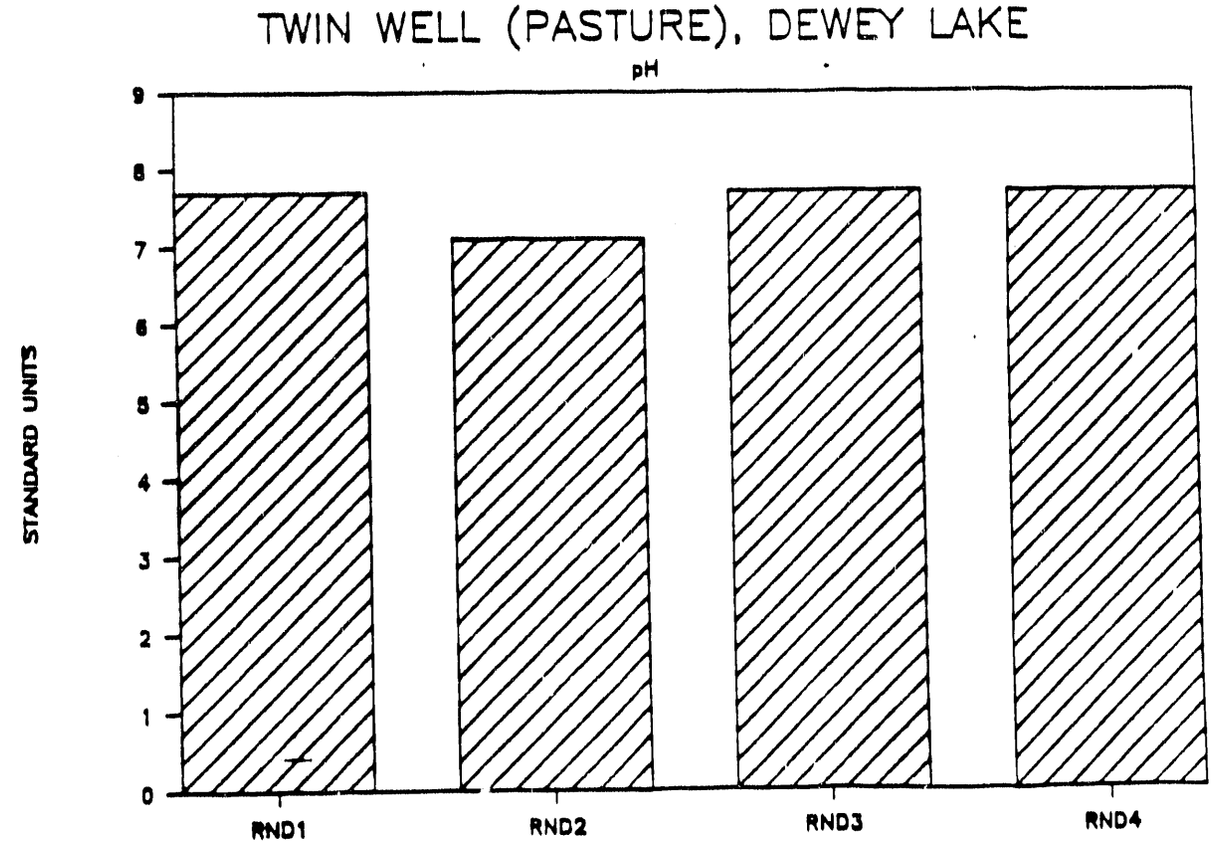

RANCH WELL, DEWEY LAKE
SPECIFIC CONDUCTIVITY
uMhos/cm
(Thousands)
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5


RANCH WELL, DEWEY LAKE
SPECIFIC GRAVITY
g/cm3
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5


TWIN WELL (PASTURE), DEWEY LAKE
ALKALINITY
CONCENTRATION mg/l
400
350
300
250
200
150
100
50
0
RND1
RND2
RND3
RND4

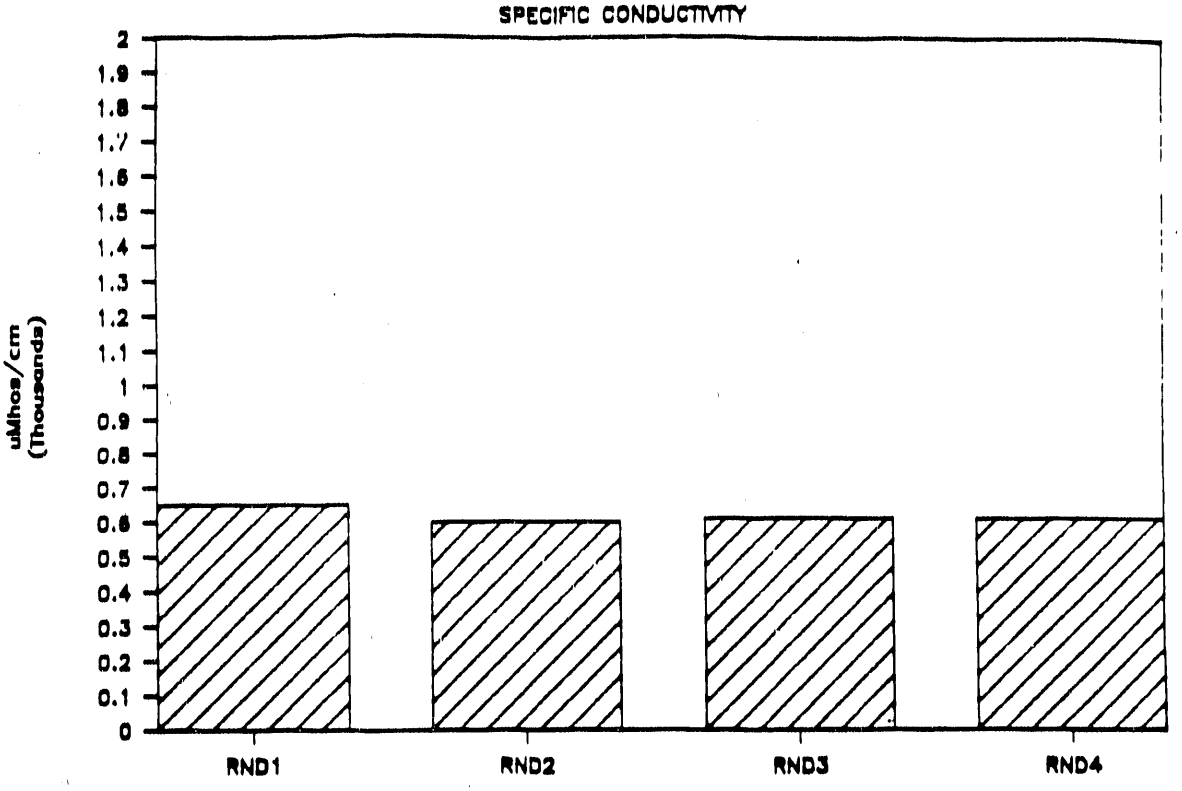

TWIN WELL (PASTURE), DEWEY LAKE
CHLORIDES
CONCENTRATION mg/l
500
400
300
200
100
0
RND1
RND2
RND3
RND4


TWIN WELL (PASTURE), DEWEY LAKE
DIVALENT CATIONS
CONCENTRATION meq/l
50
40
30
20
10
0
RND1
RND2
RND3
RND4


TWIN WELL (PASTURE), DEWEY LAKE
pH
STANDARD UNITS
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4

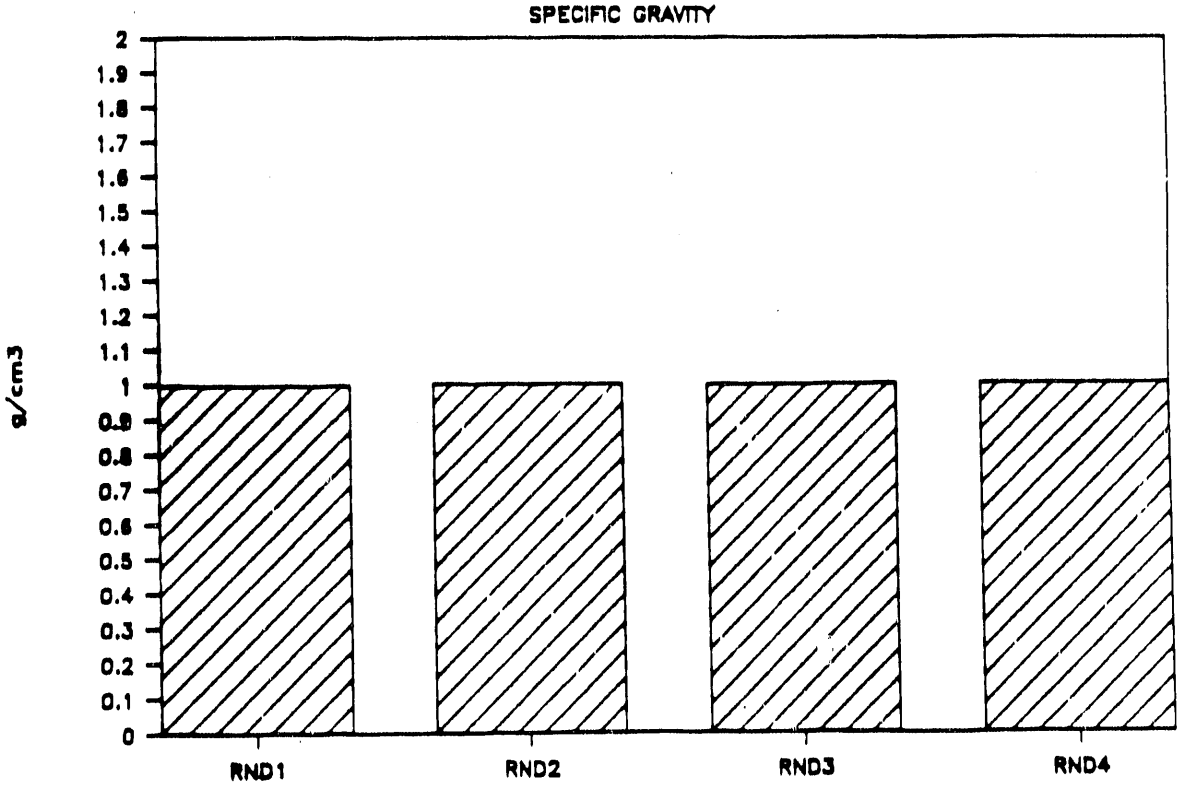
TWIN WELL (PASTURE), DEWEY LAKE

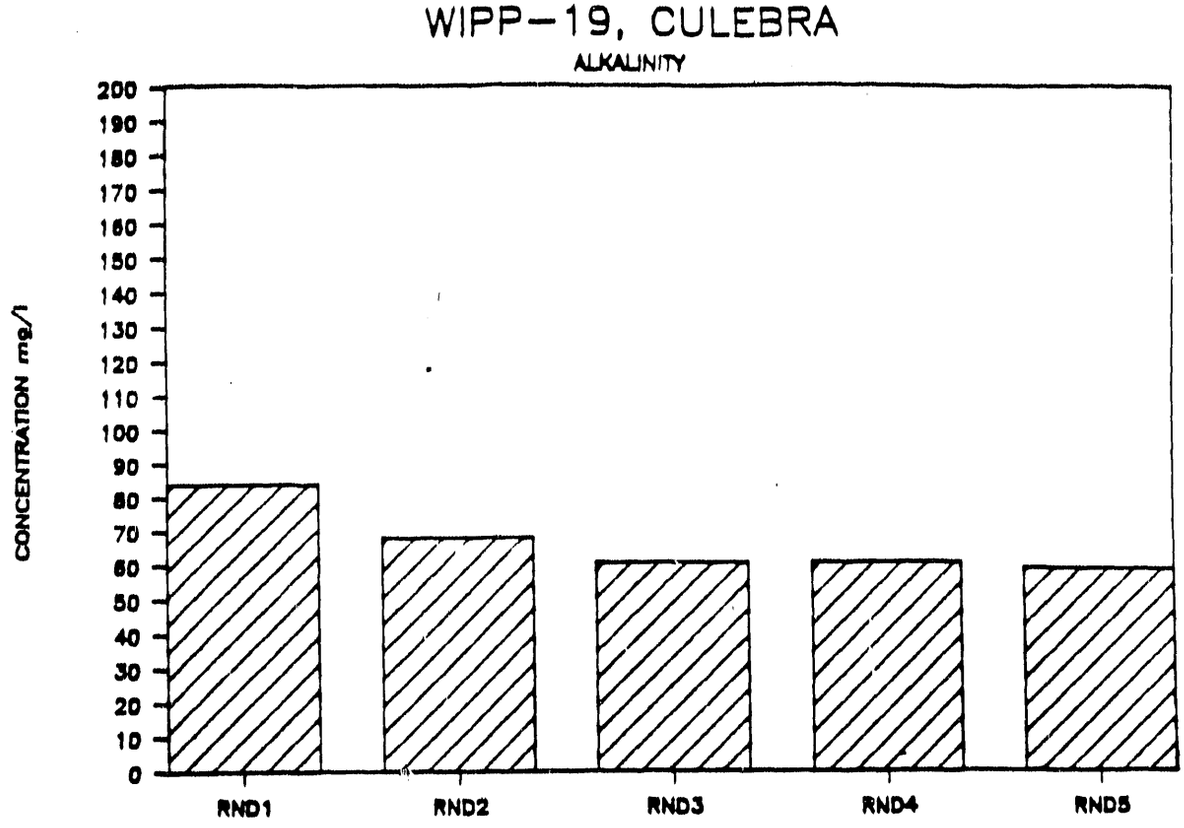
SPECIFIC CONDUCTIVITY

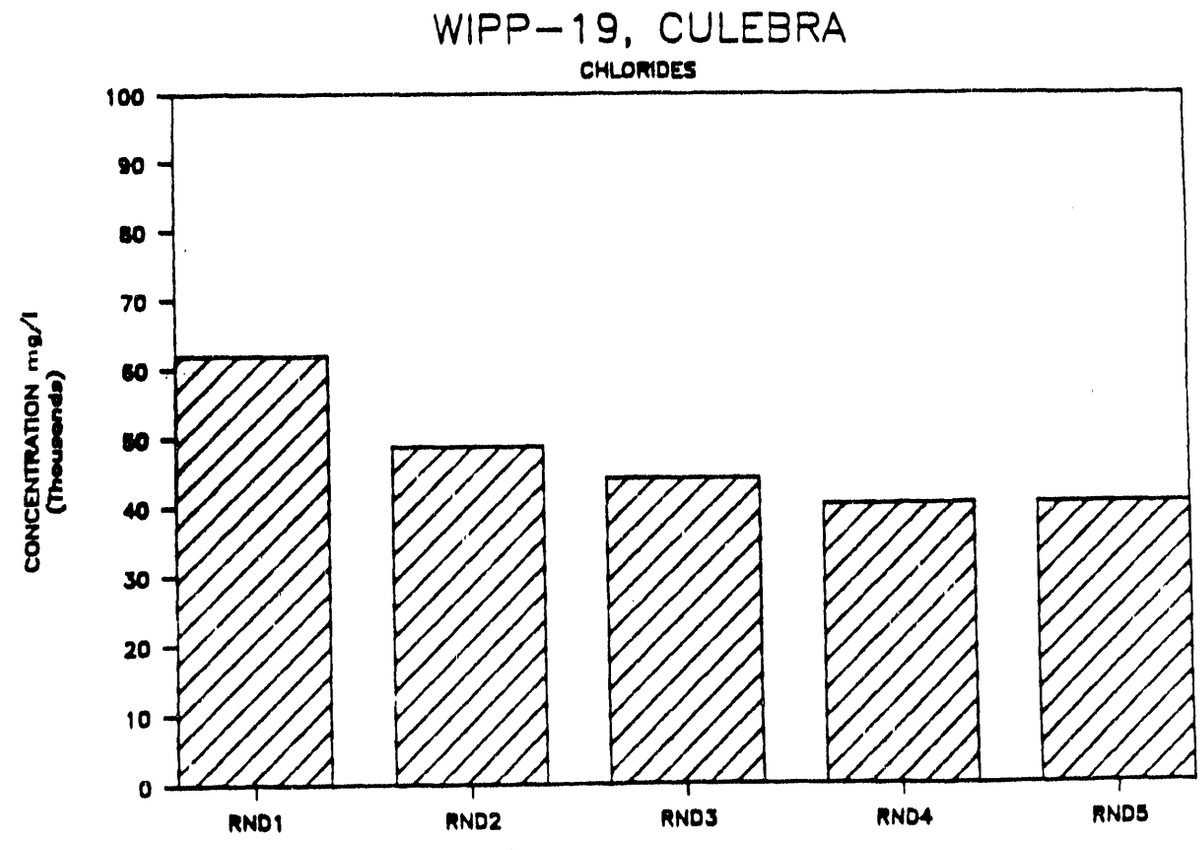


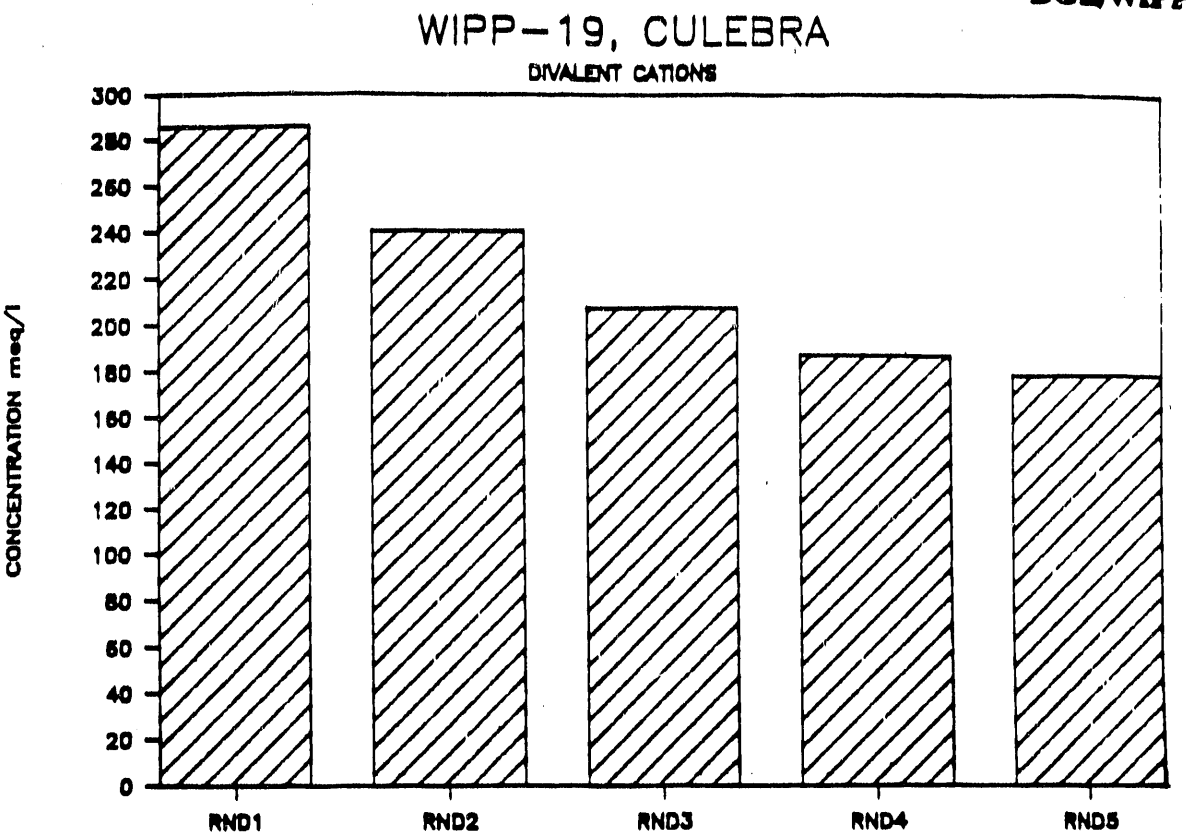
TWIN WELL (PASTURE), DEWEY LAKE

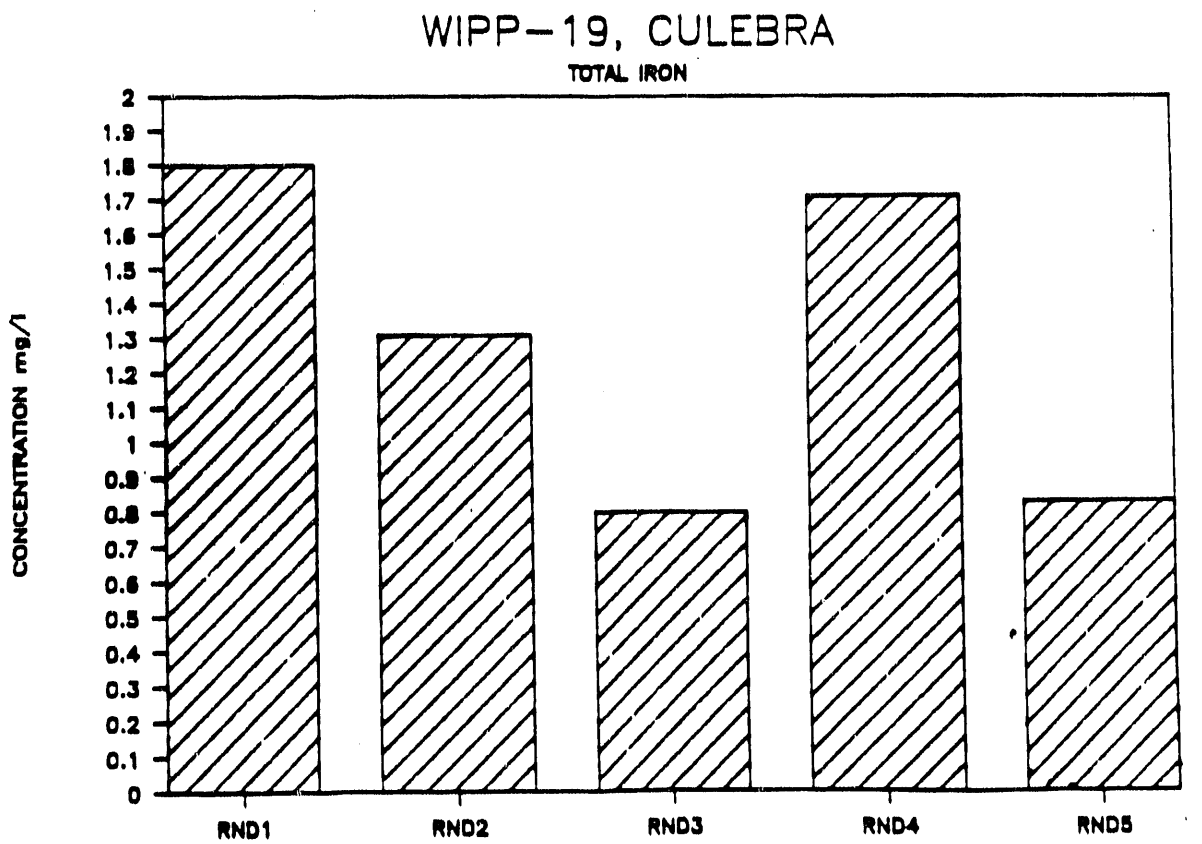
SPECIFIC GRAVITY

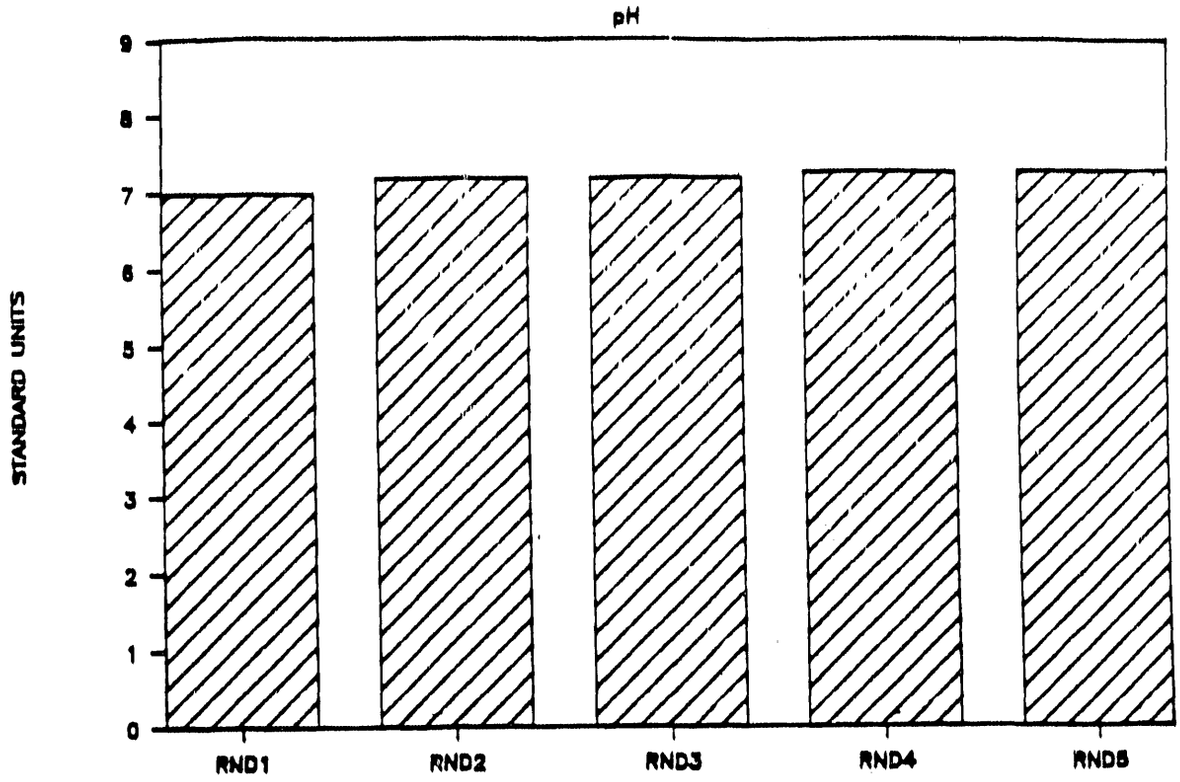


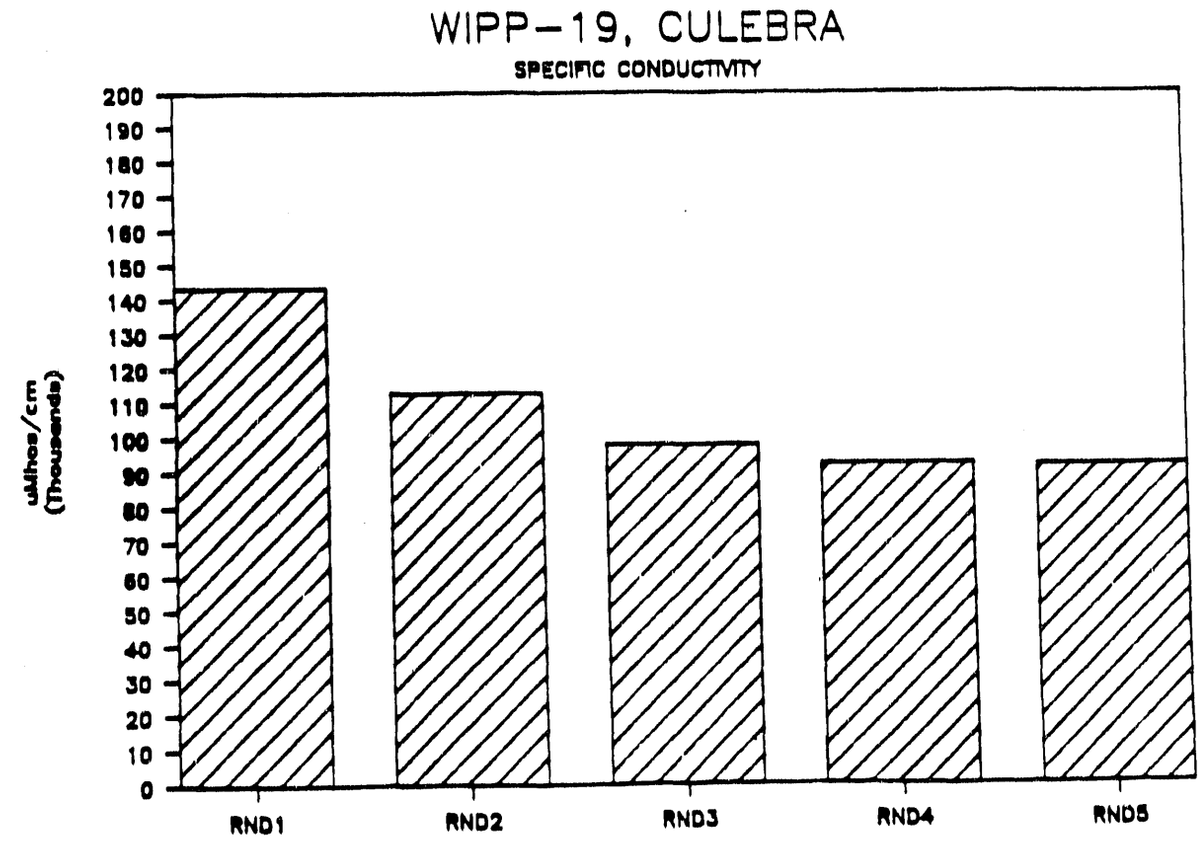

WIPP–19, CULEBRA
ALKALINITY
CONCENTRATION mg/l
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

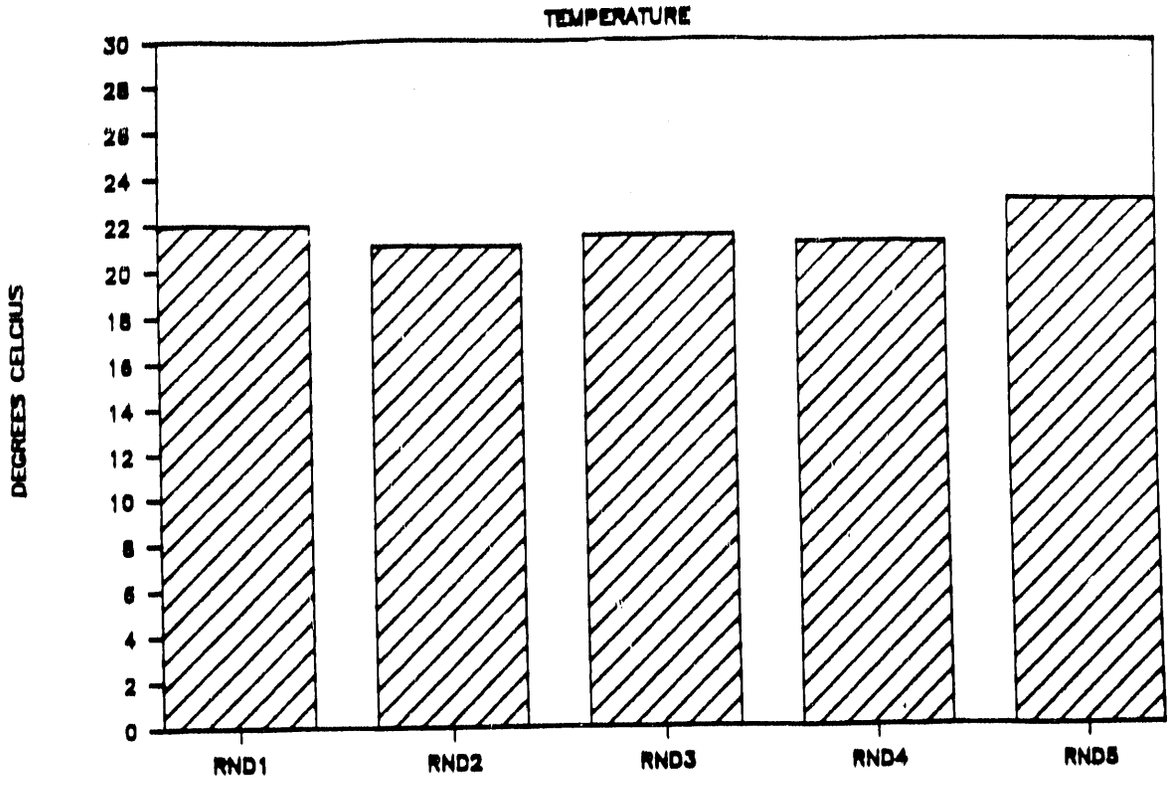

WIPP–19, CULEBRA
CHLORIDES
CONCENTRATION mg/l
(Thousands)
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5

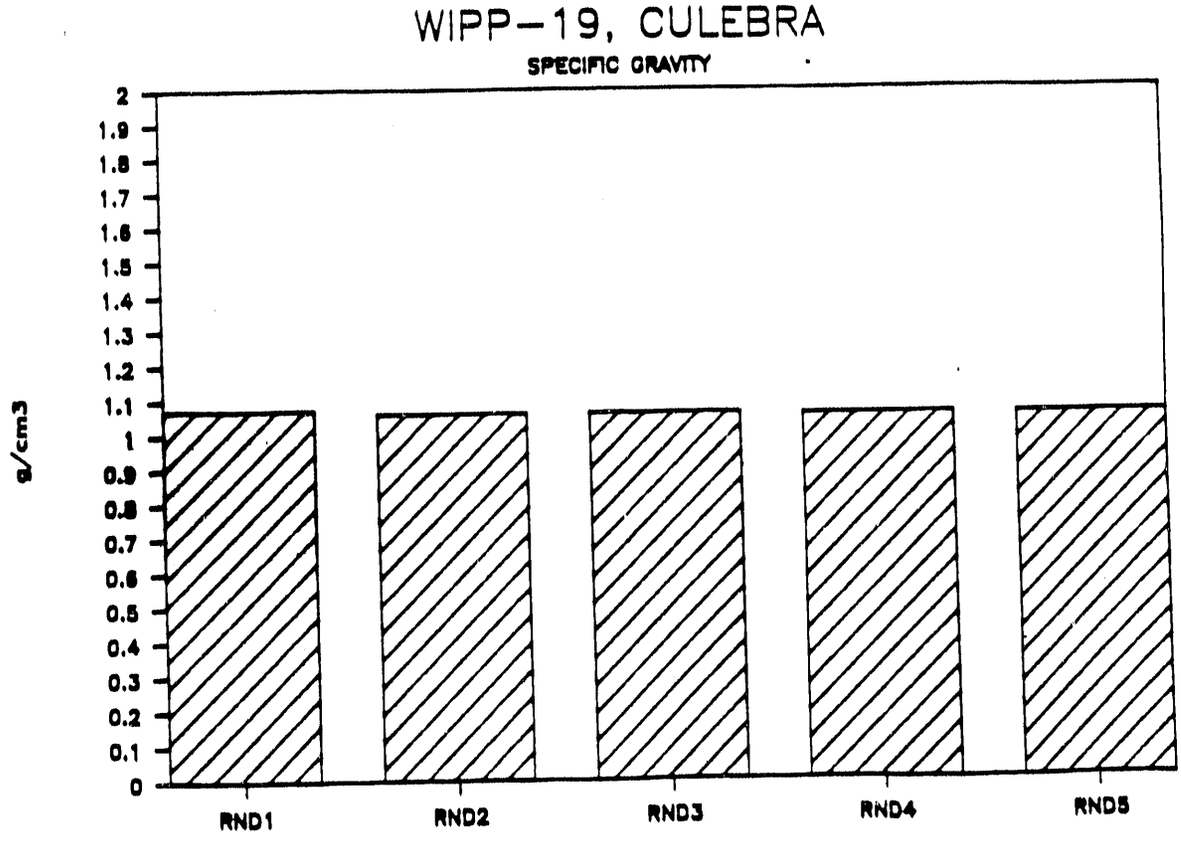

WIPP–19, CULEBRA
DIVALENT CATIONS
CONCENTRATION meq/l
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
RND1
RND2
RND3
RND4
RND5


WIPP–19, CULEBRA
TOTAL IRON
CONCENTRATION mg/l
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5


WIPP–19, CULEBRA
pH
STANDARD UNITS
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5


WIPP–19, CULEBRA
SPECIFIC CONDUCTIVITY
uMhos/cm
(Thousands)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5


WIPP-19, CULEBRA
TEMPERATURE
DEGREES CELCIUS
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
RND1
RND2
RND3
RND4
RND5


WIPP-19, CULEBRA
SPECIFIC GRAVITY
g/cm3
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5

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APPENDIX IX
MAJOR CATION AND ANION GRAPHS

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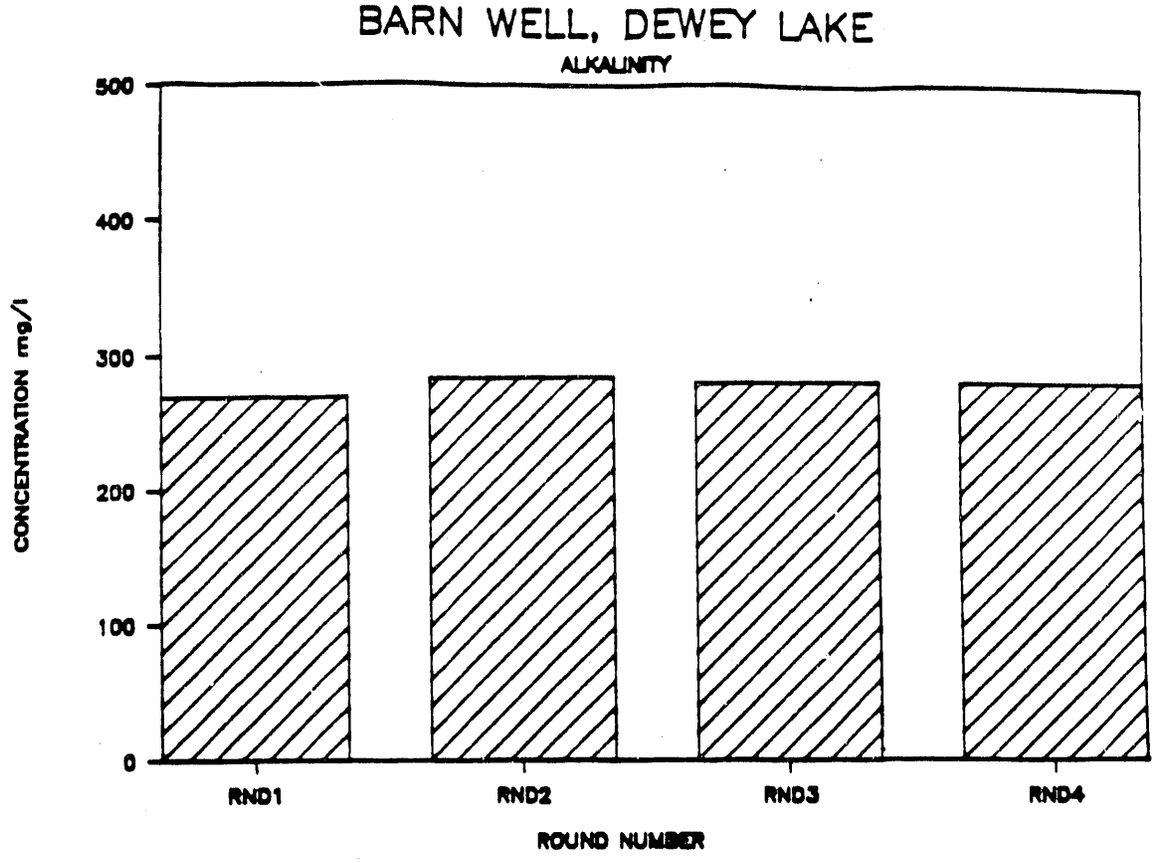
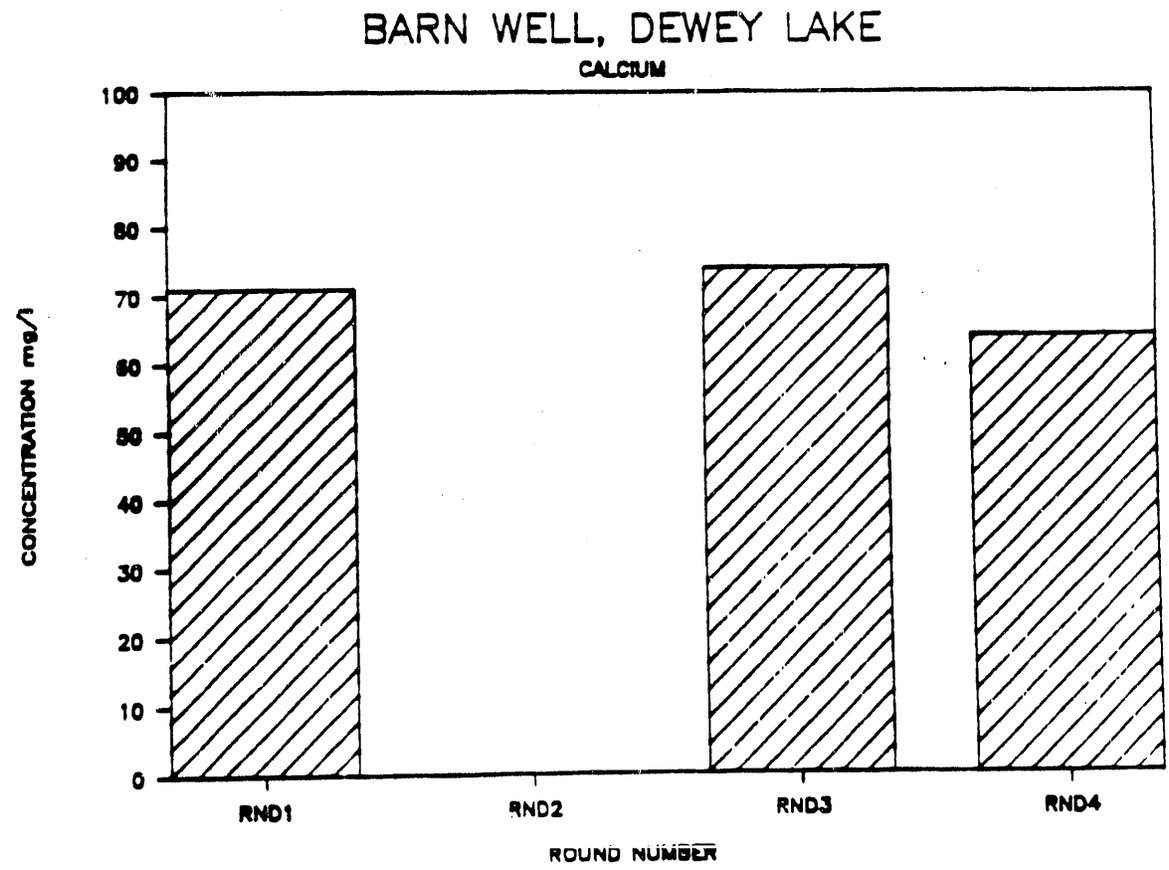
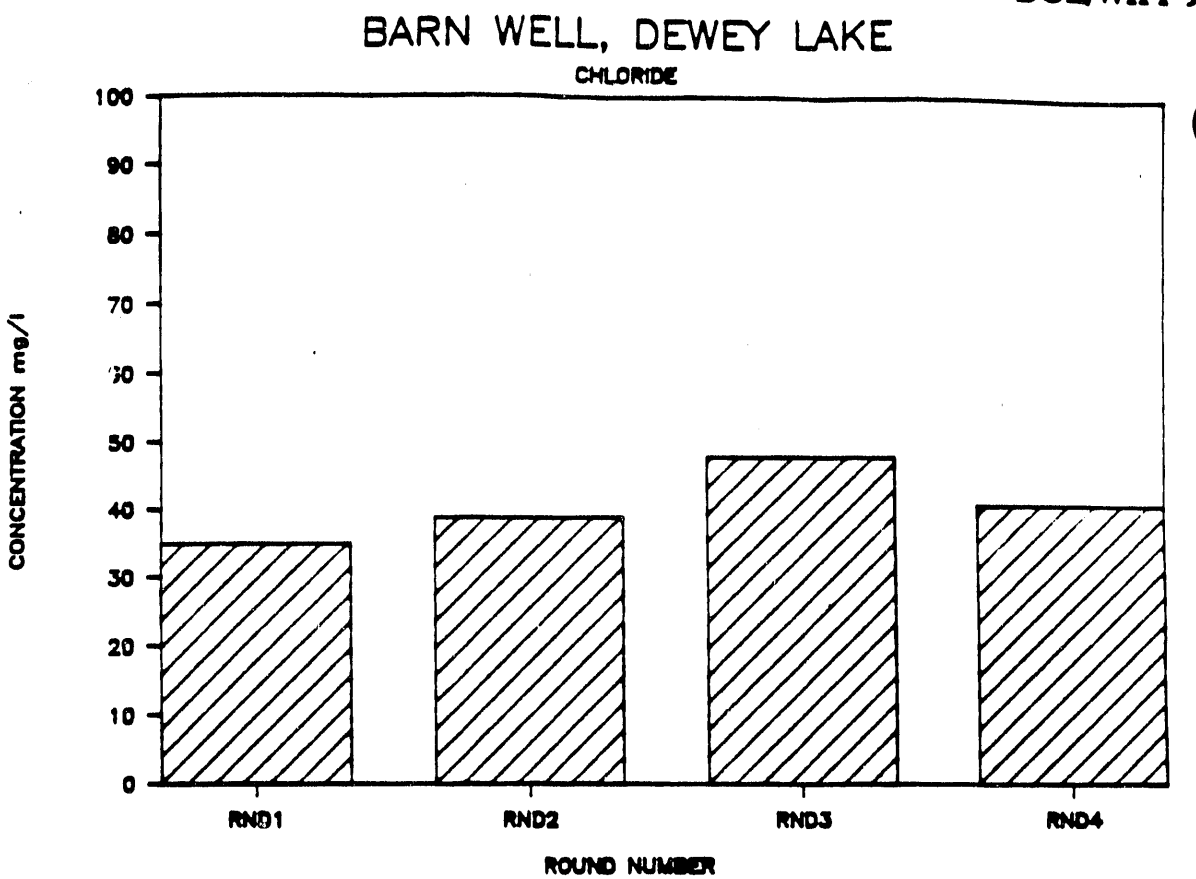
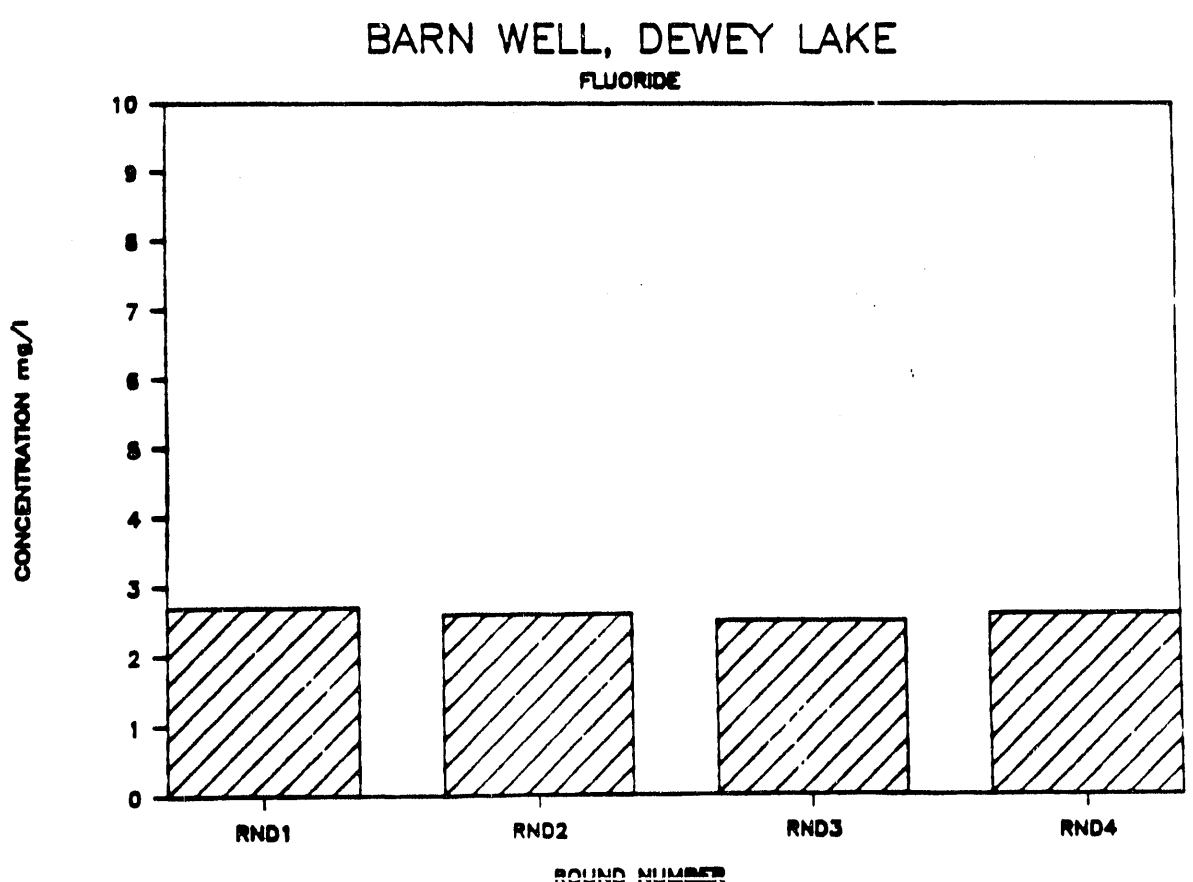
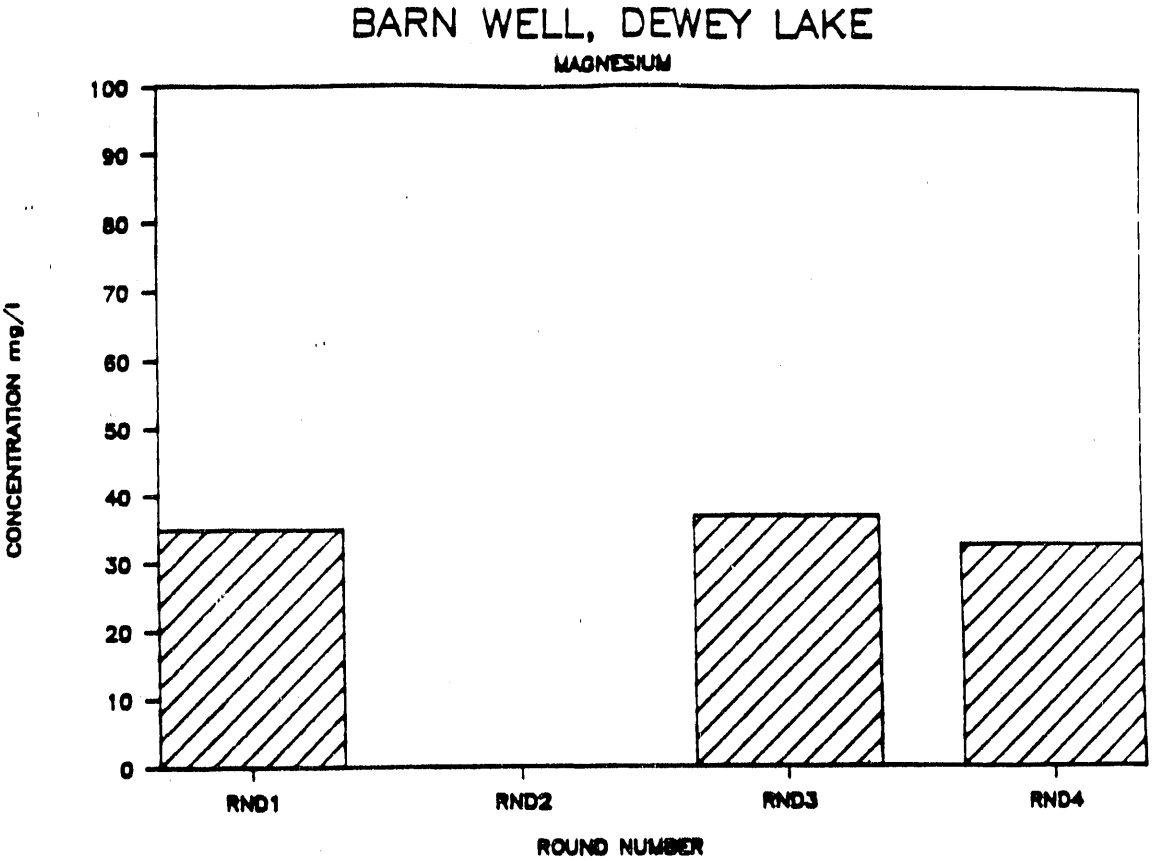
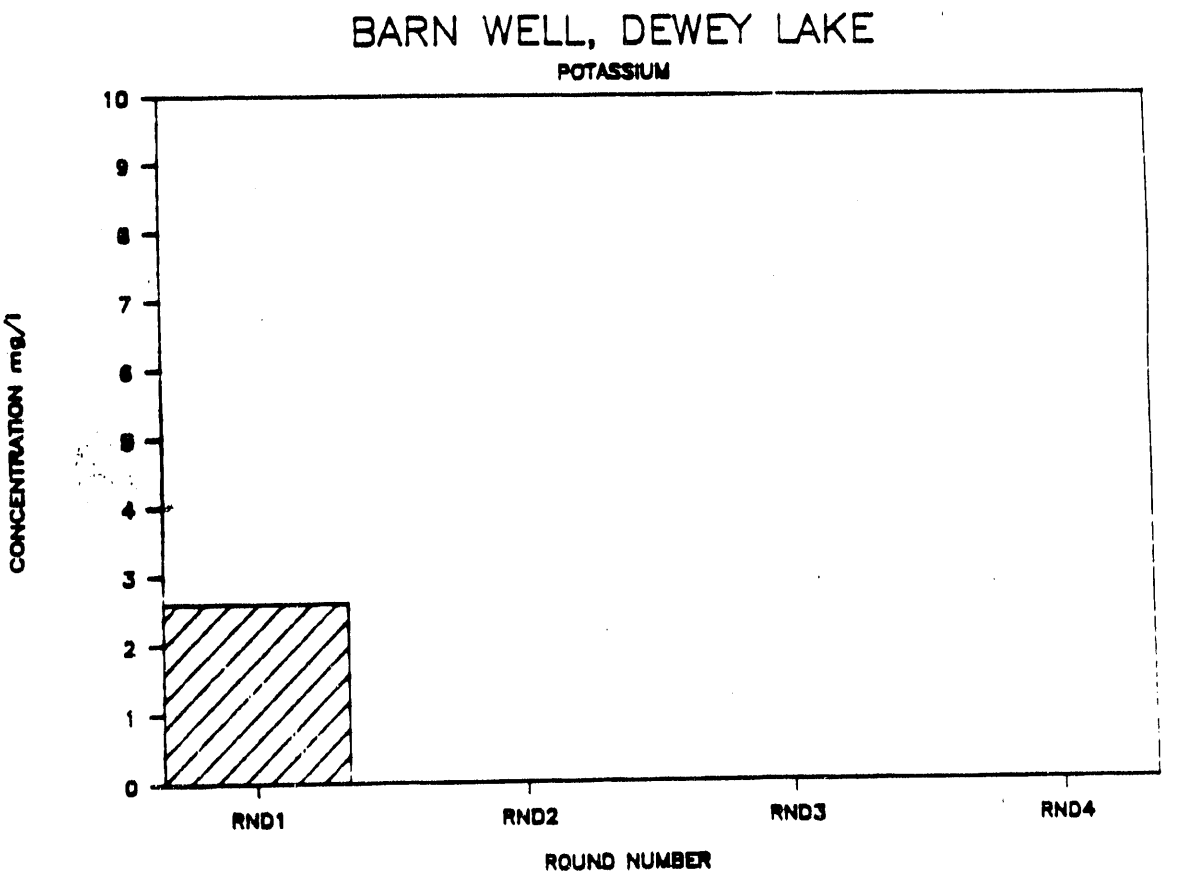

BARN WELL, DEWEY LAKE
ALKALINITY
CONCENTRATION mg/l
500
400
300
200
100
0
RND1
RND2
RND3
RND4
ROUND NUMBER

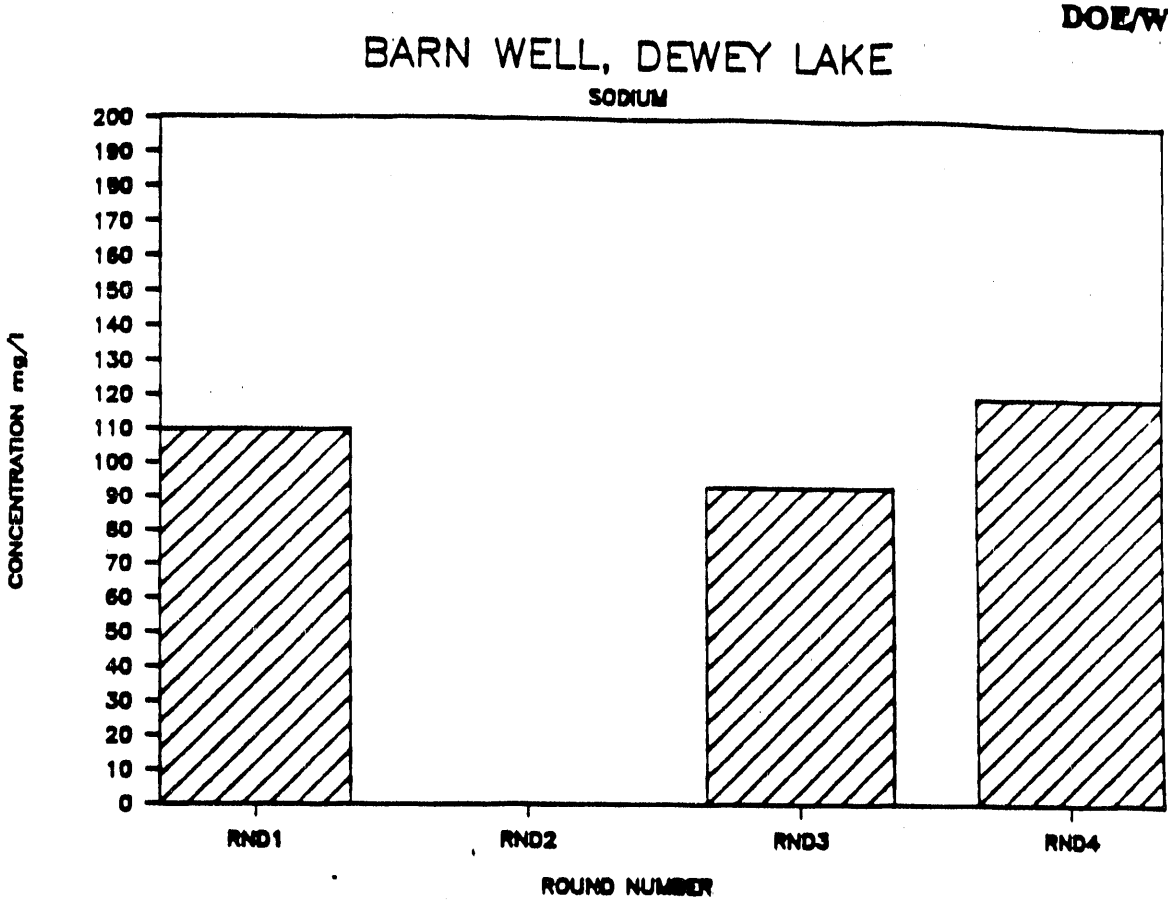

BARN WELL, DEWEY LAKE
CALCIUM
CONCENTRATION mg/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
ROUND NUMBER

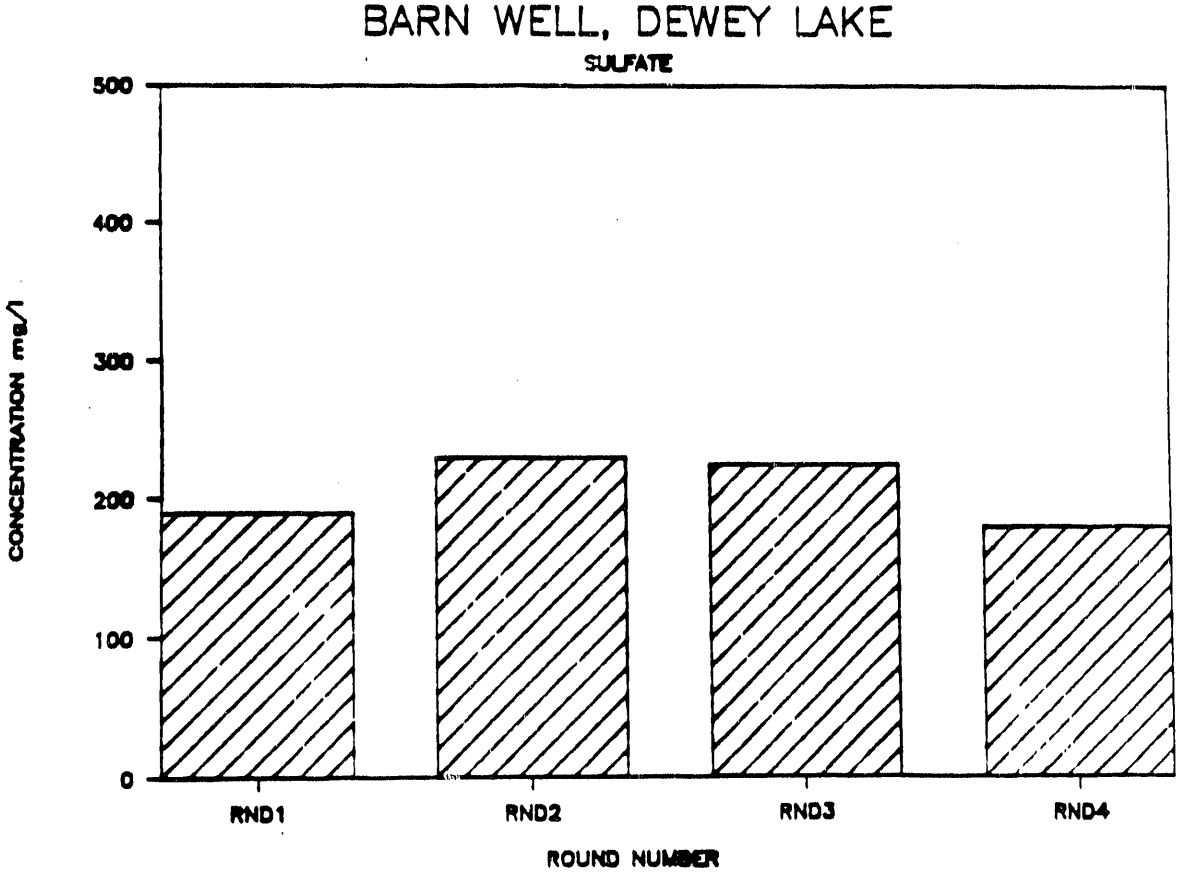

BARN WELL, DEWEY LAKE
CHLORIDE
CONCENTRATION mg/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
ROUND NUMBER

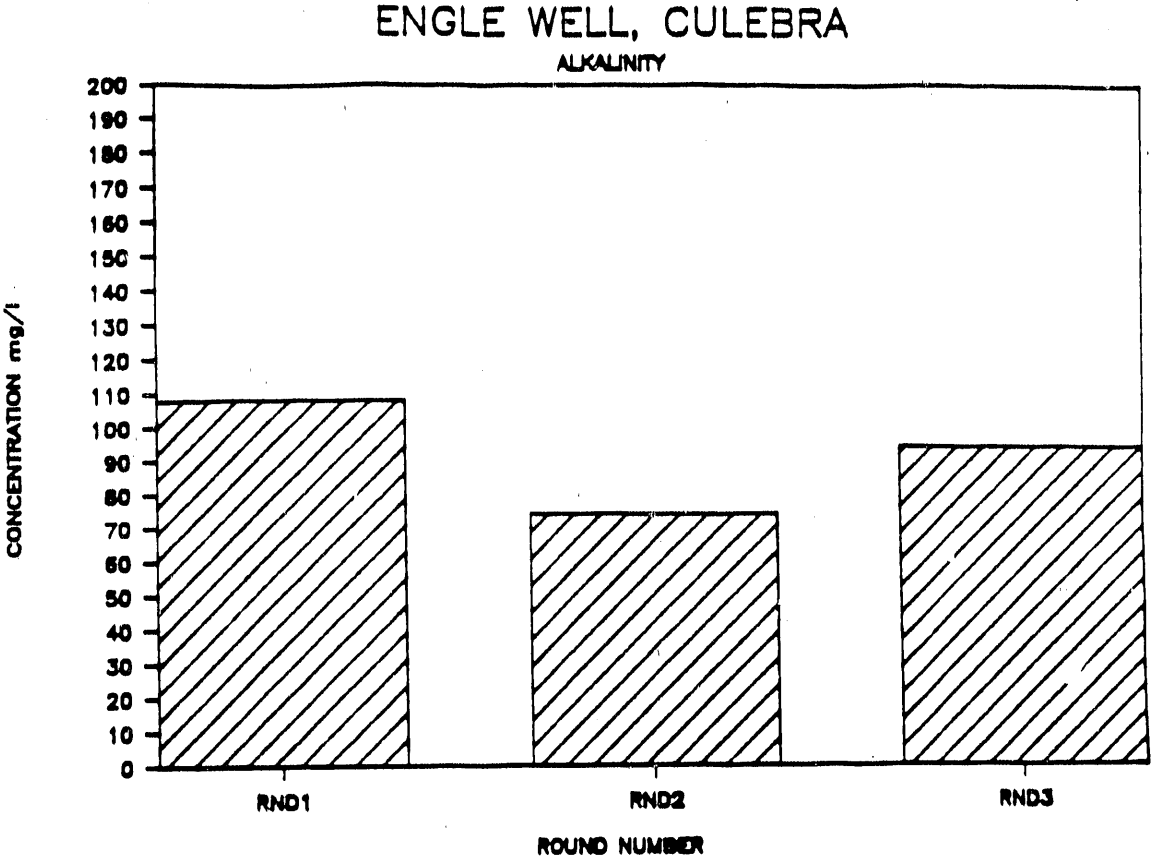

BARN WELL, DEWEY LAKE
FLUORIDE
CONCENTRATION mg/l
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
ROUND NUMBER

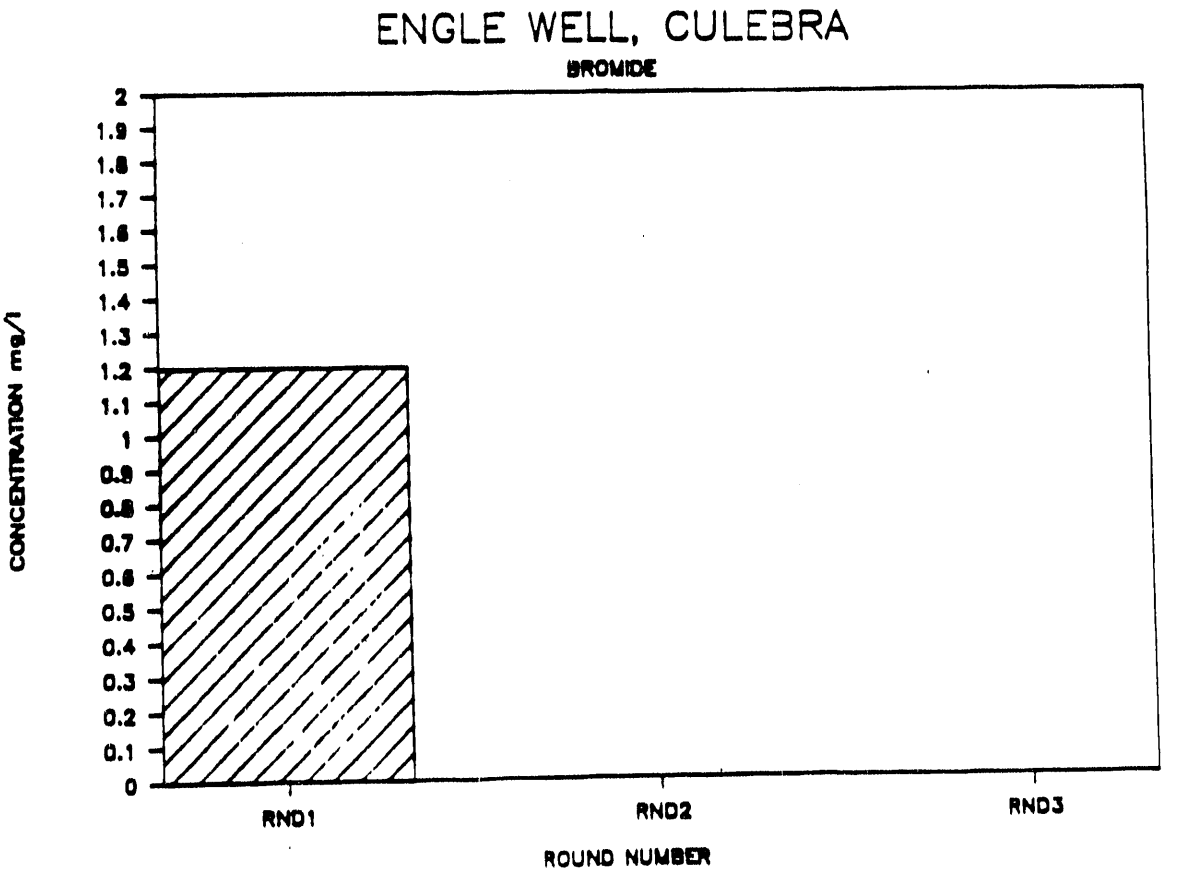

BARN WELL, DEWEY LAKE
MAGNESIUM
CONCENTRATION mg/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
ROUND NUMBER

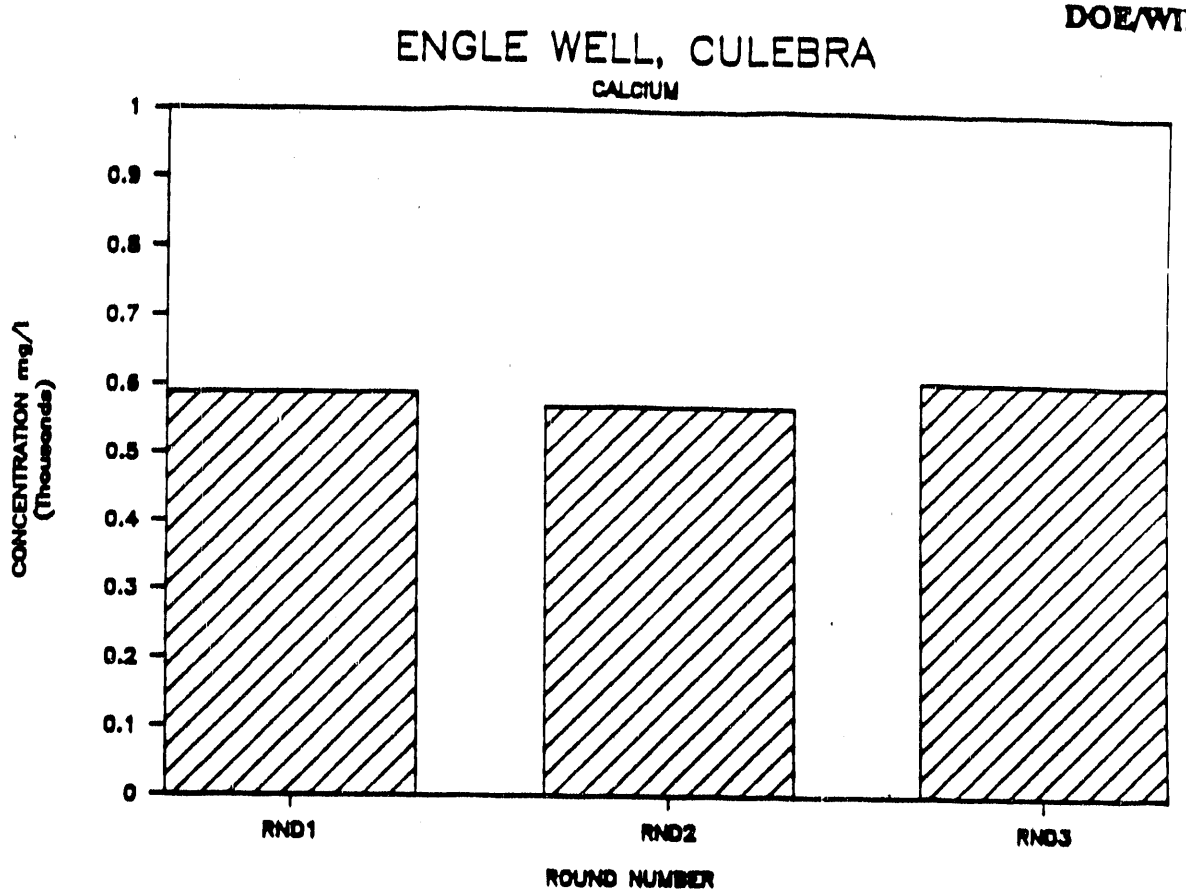

BARN WELL, DEWEY LAKE
POTASSIUM
CONCENTRATION mg/l
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
ROUND NUMBER

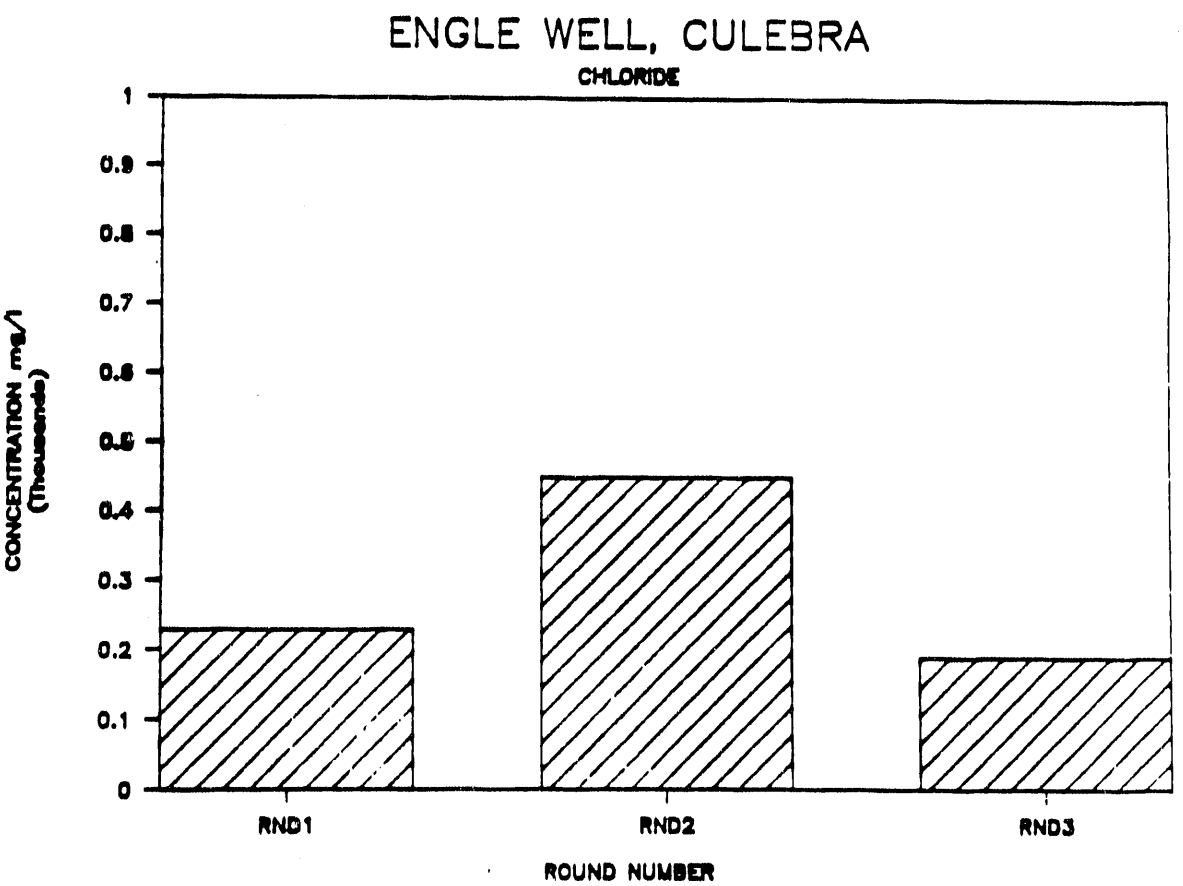

BARN WELL, DEWEY LAKE
SODIUM
CONCENTRATION mg/l
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
ROUND NUMBER

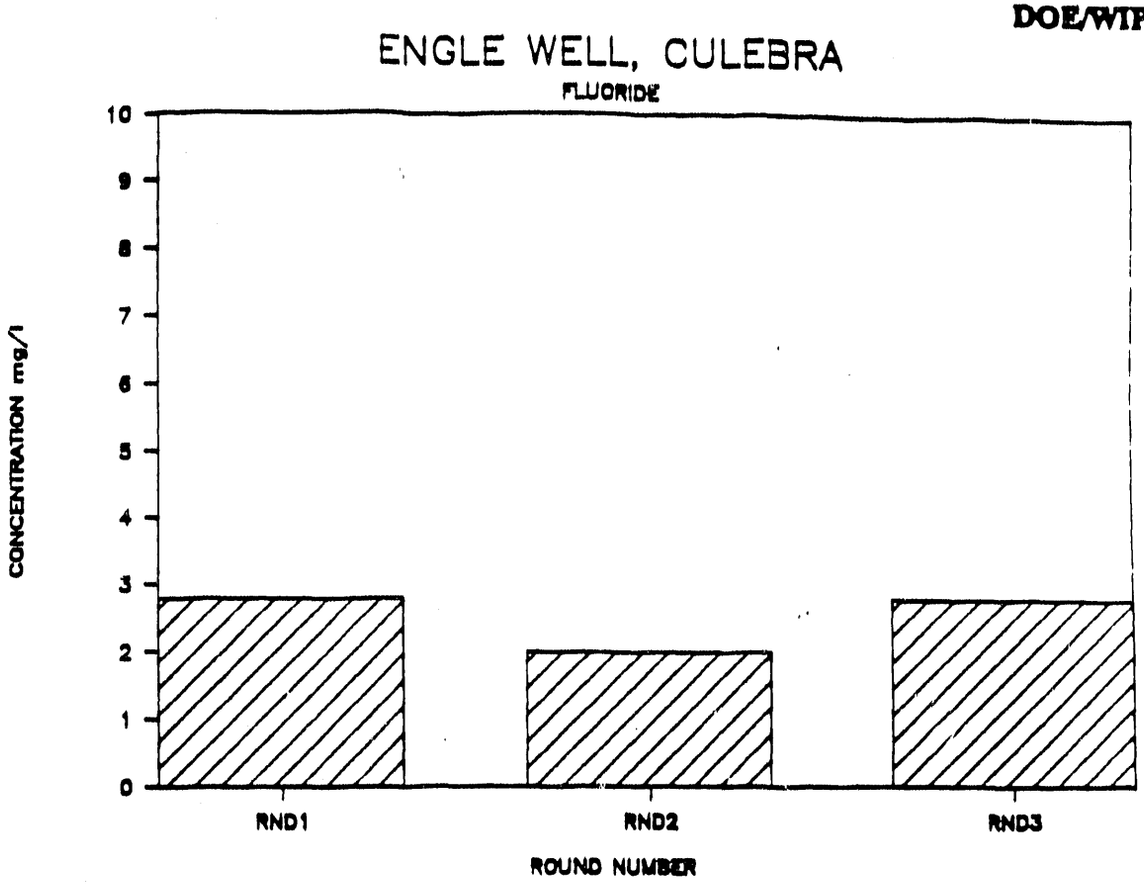

BARN WELL, DEWEY LAKE
SULFATE
CONCENTRATION mg/l
500
400
300
200
100
0
RND1
RND2
RND3
RND4
ROUND NUMBER

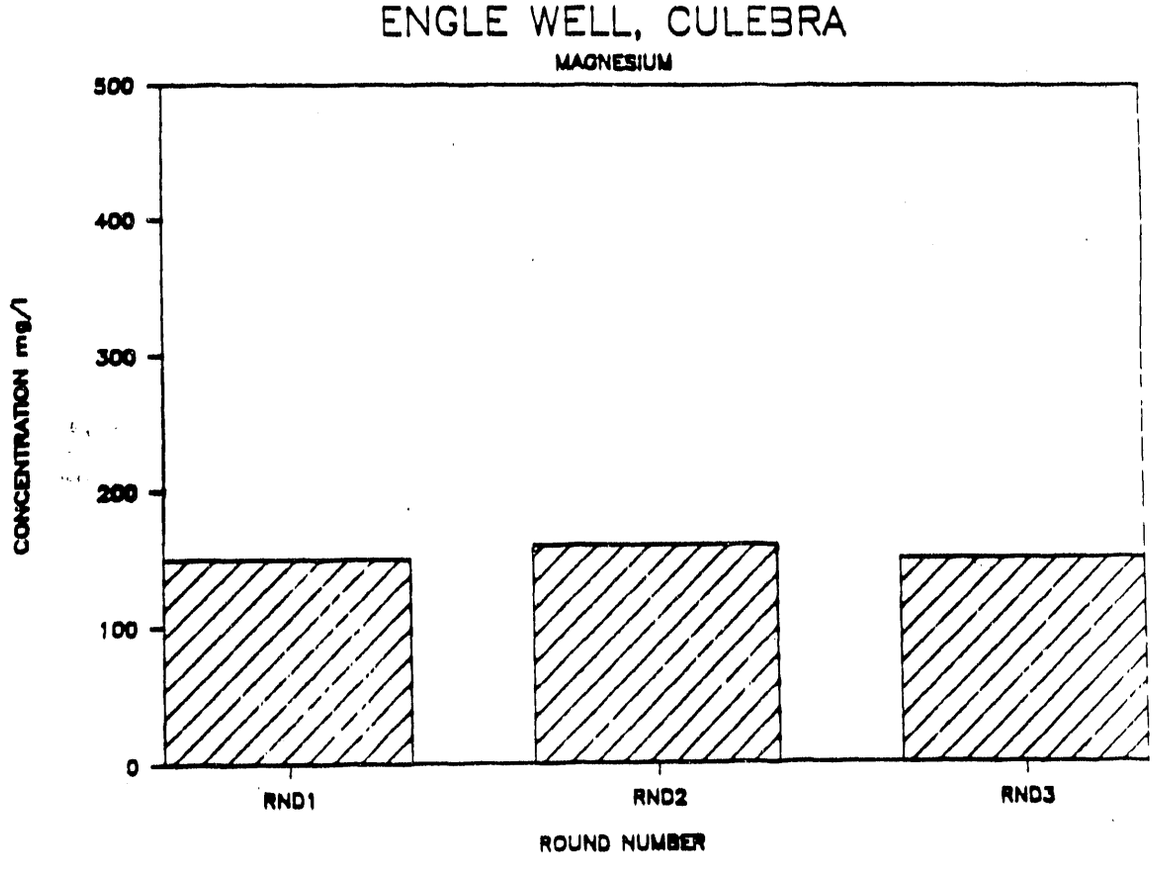

ENGLE WELL, CULEBRA
ALKALINITY
CONCENTRATION mg/l
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
ROUND NUMBER

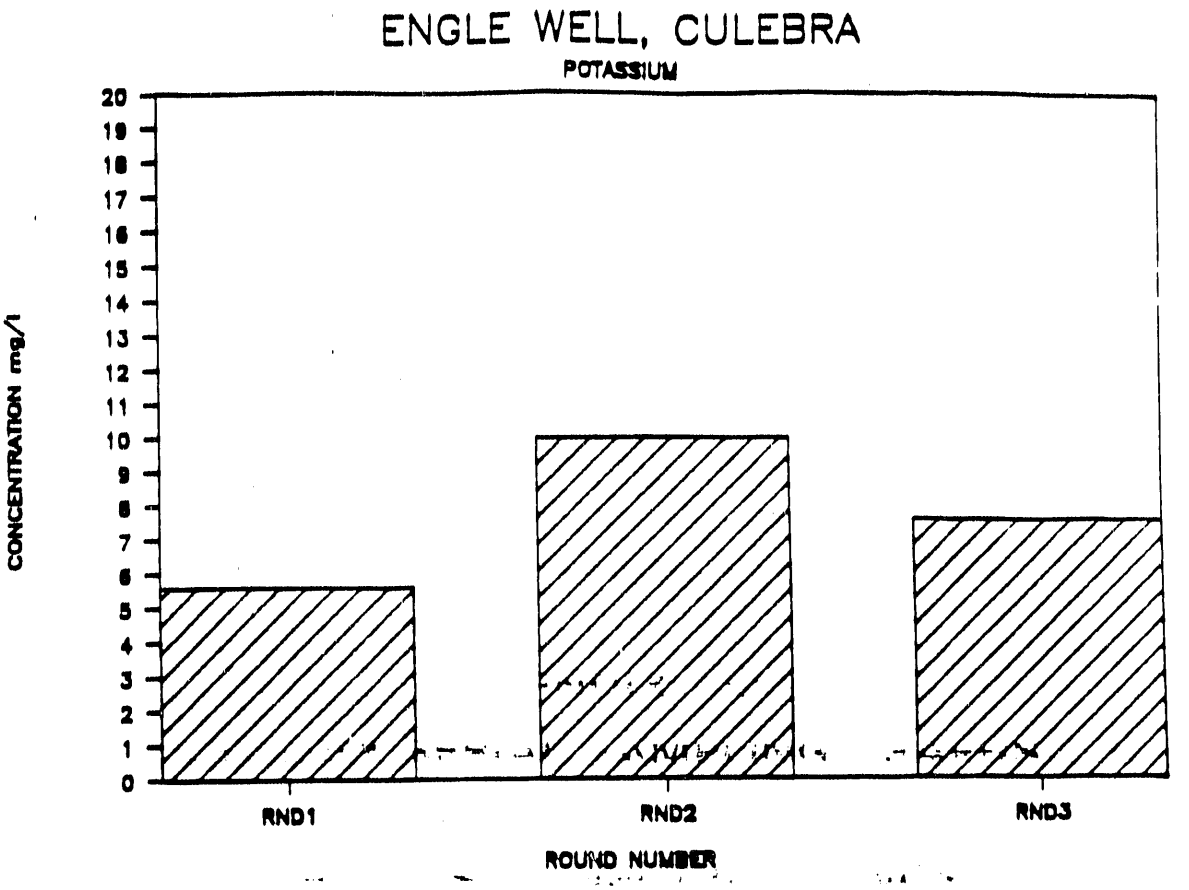

ENGLE WELL, CULEBRA
BROMIDE
CONCENTRATION mg/l
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
ROUND NUMBER

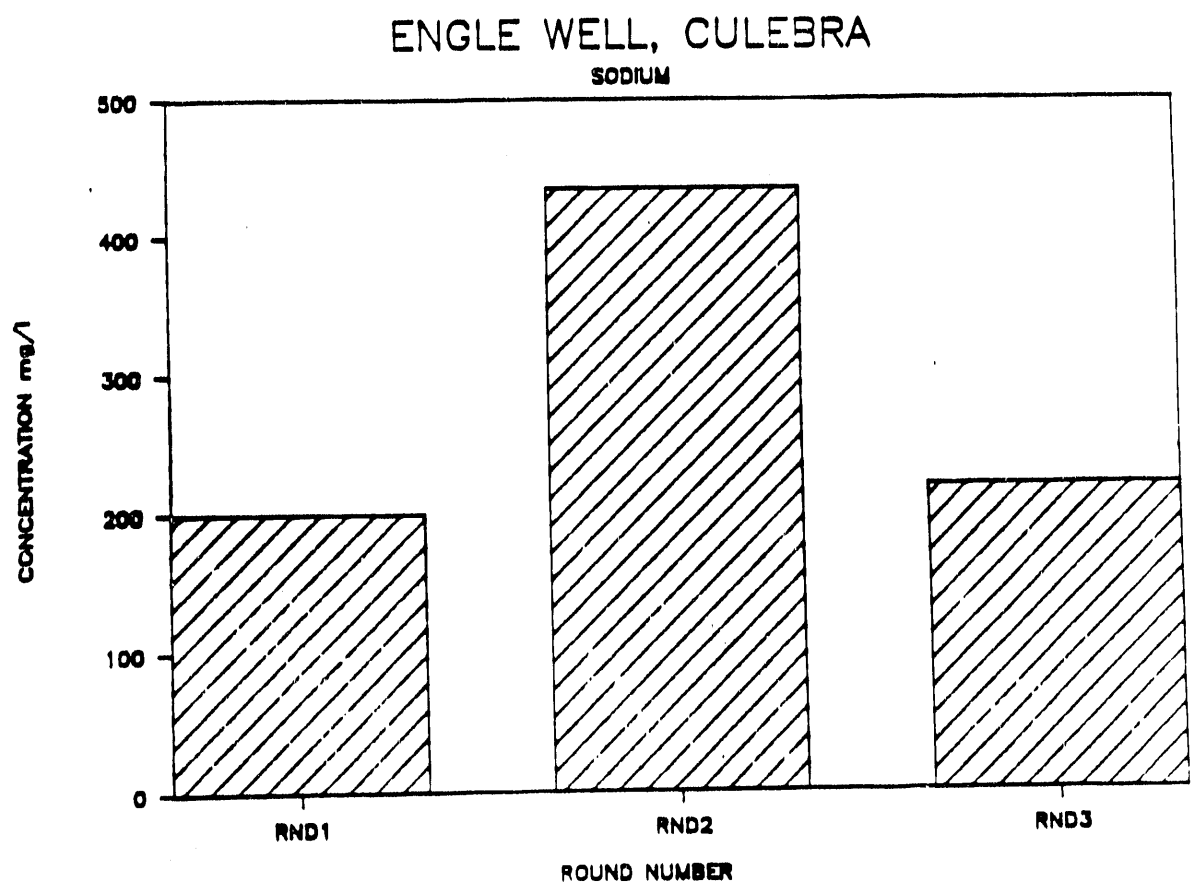

ENGLE WELL, CULEBRA
CALCIUM
CONCENTRATION mg/l
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
ROUND NUMBER

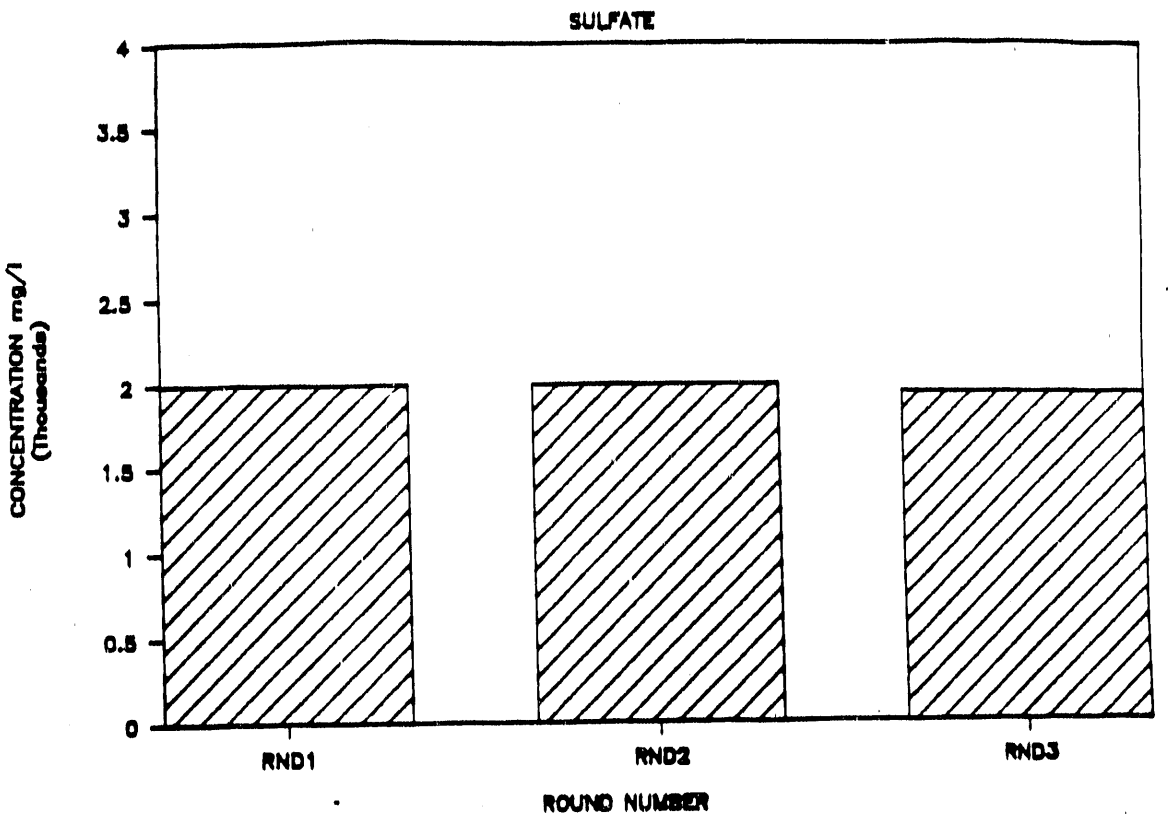

ENGLE WELL, CULEBRA
CHLORIDE
CONCENTRATION mg/l
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
ROUND NUMBER

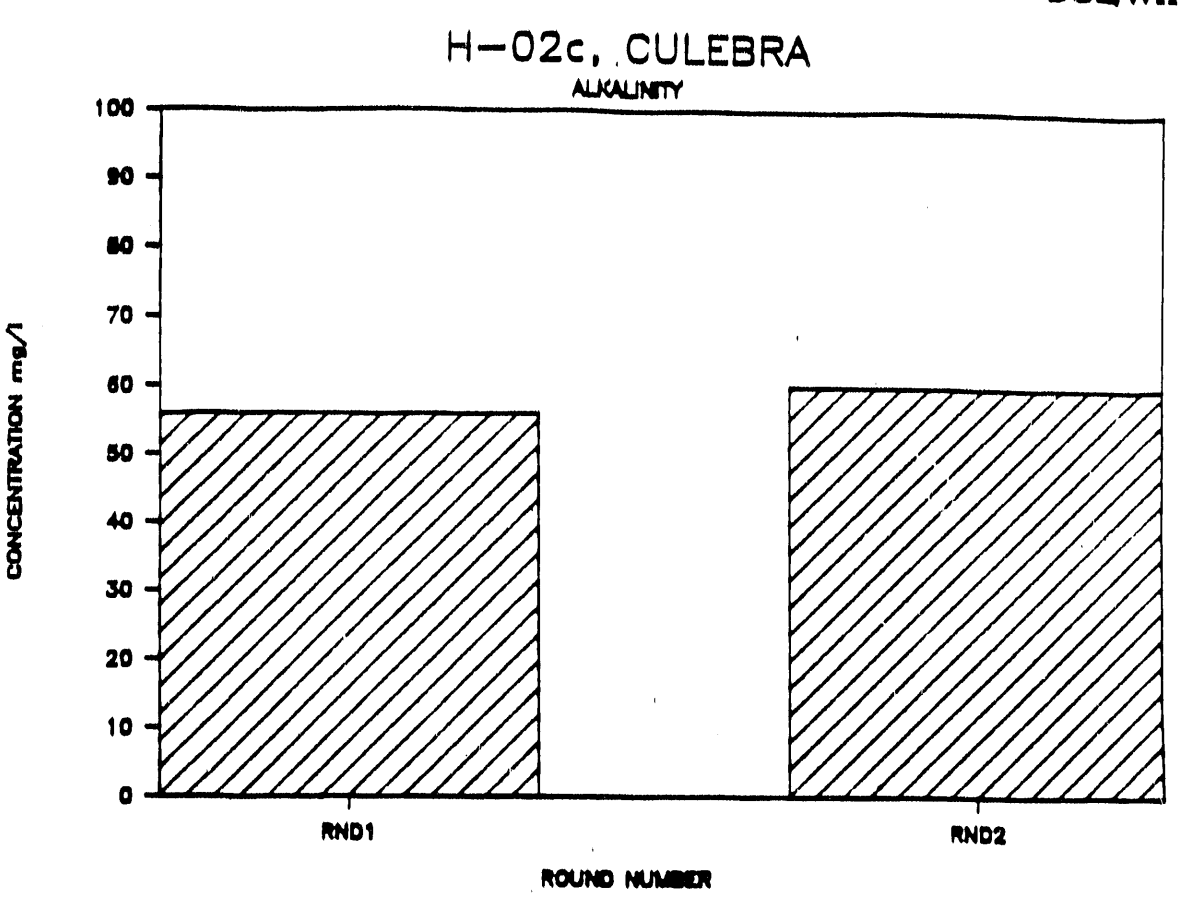

ENGLE WELL, CULEBRA
FLUORIDE
CONCENTRATION mg/l
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
ROUND NUMBER

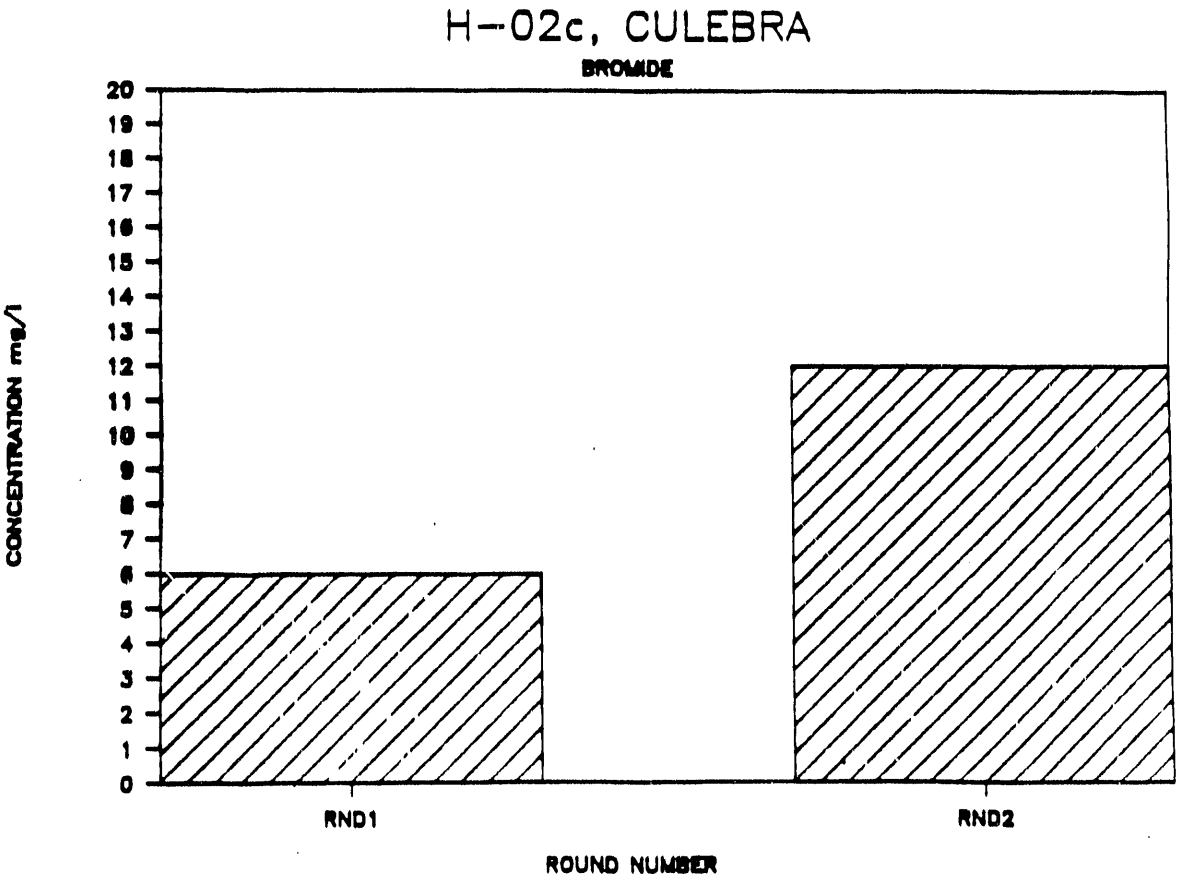

ENGLE WELL, CULEBRA
MAGNESIUM
CONCENTRATION mg/l
500
400
300
200
100
0
RND1
RND2
RND3
ROUND NUMBER

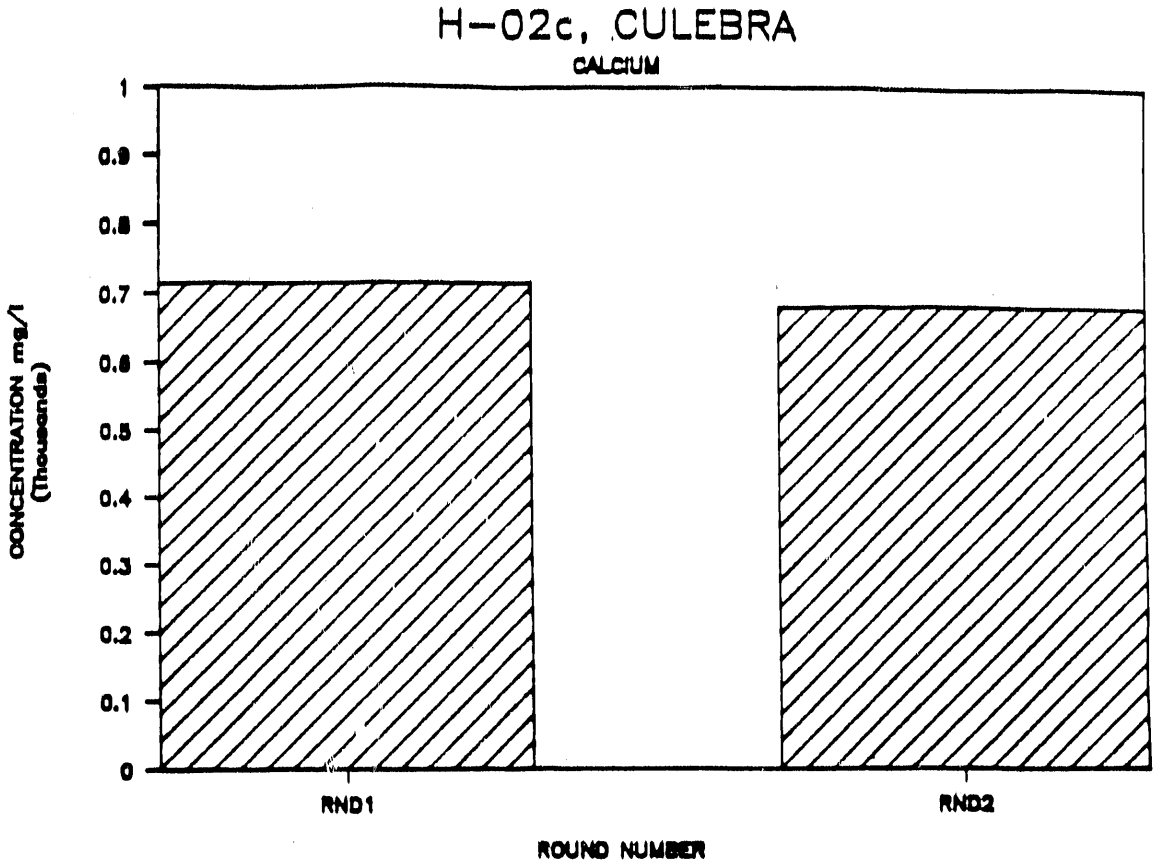

ENGLE WELL, CULEBRA
POTASSIUM
CONCENTRATION mg/l
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
ROUND NUMBER

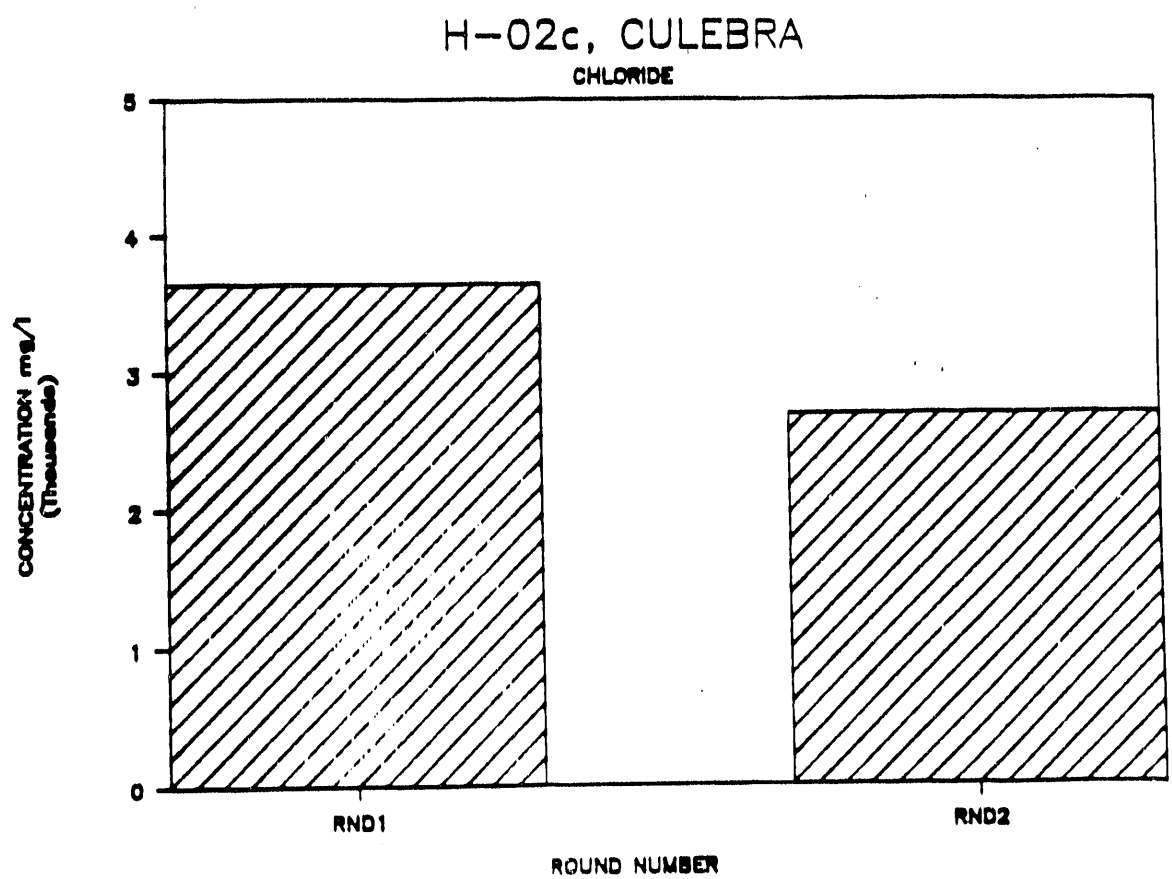

ENGLE WELL, CULEBRA
SODIUM
CONCENTRATION mg/l
500
400
300
200
100
0
RND1
RND2
RND3
ROUND NUMBER

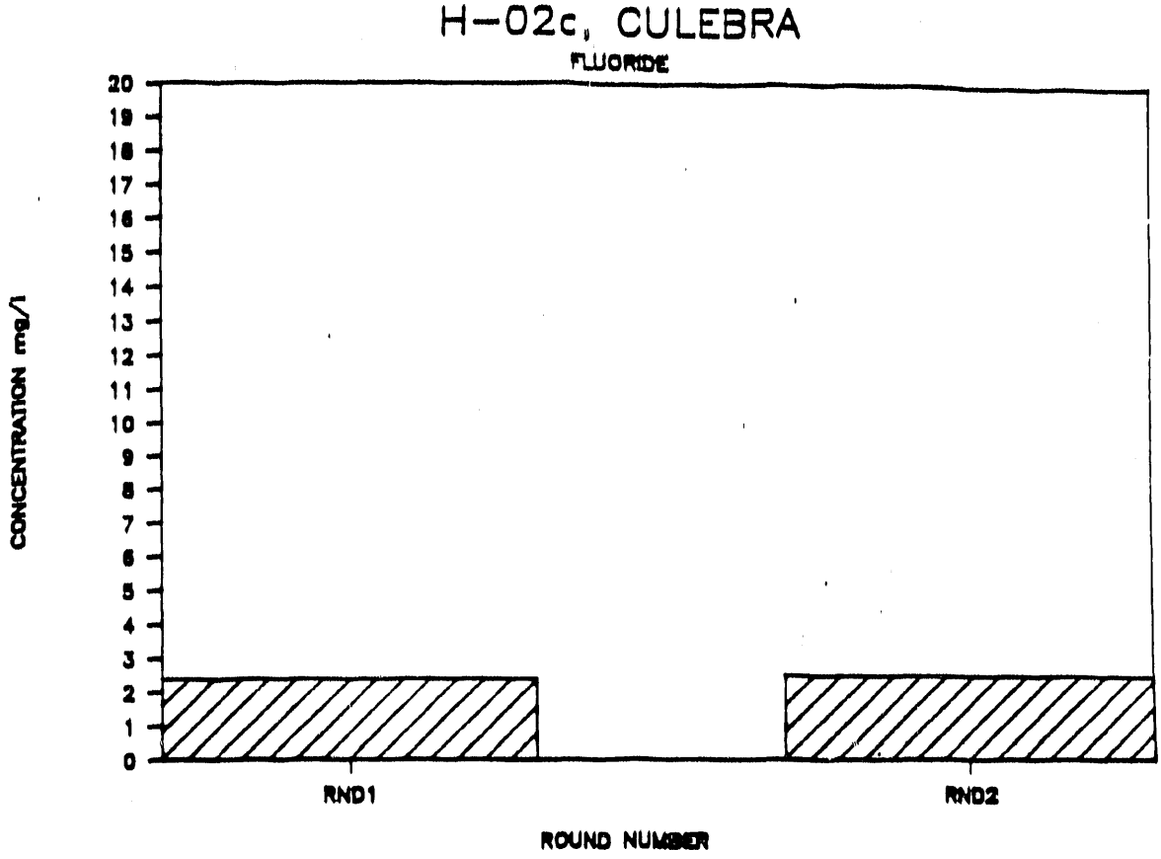

ENGLE WELL, CULEBRA
SULFATE
CONCENTRATION mg/l
(Thousands)
4
3.5
3
2.5
2
1.5
1
0.5
0
RND1
RND2
RND3
ROUND NUMBER

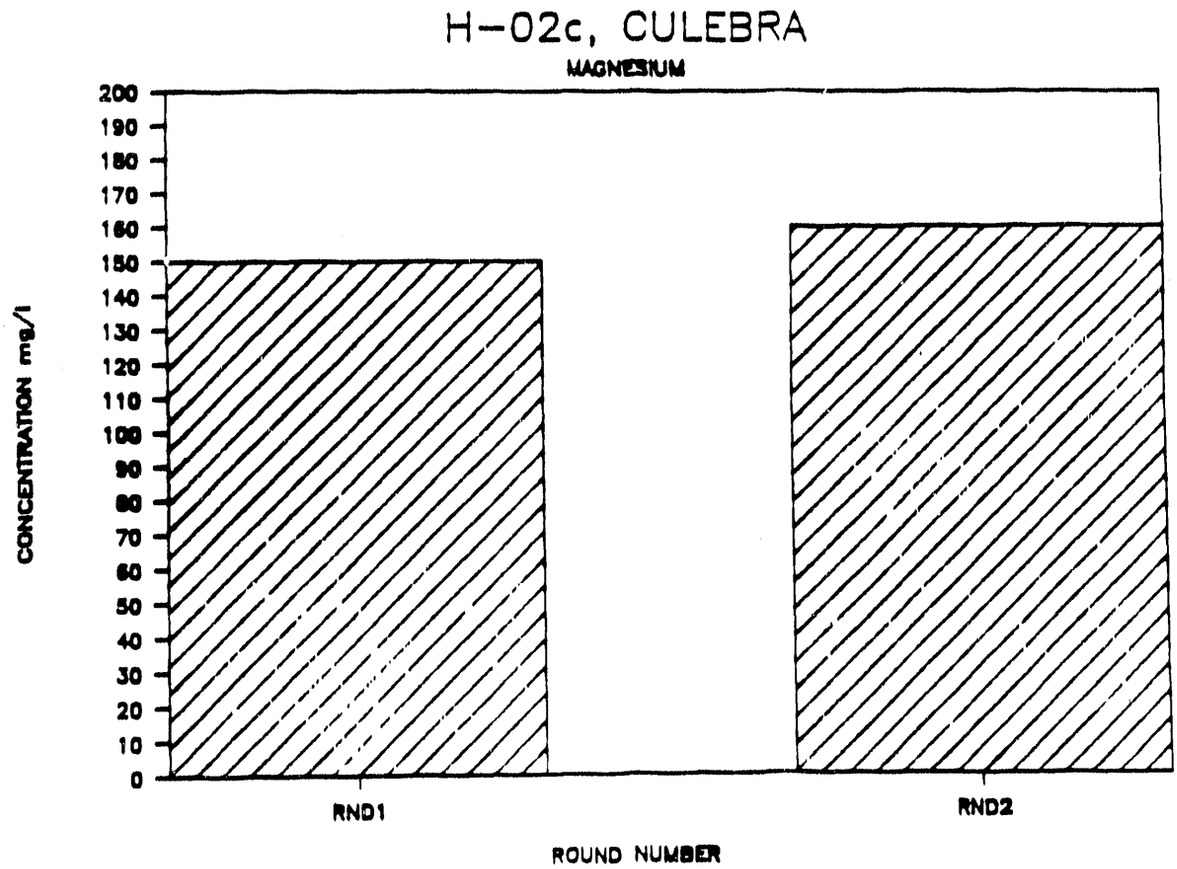

H-02c, CULEBRA
ALKALINITY
CONCENTRATION mg/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
ROUND NUMBER

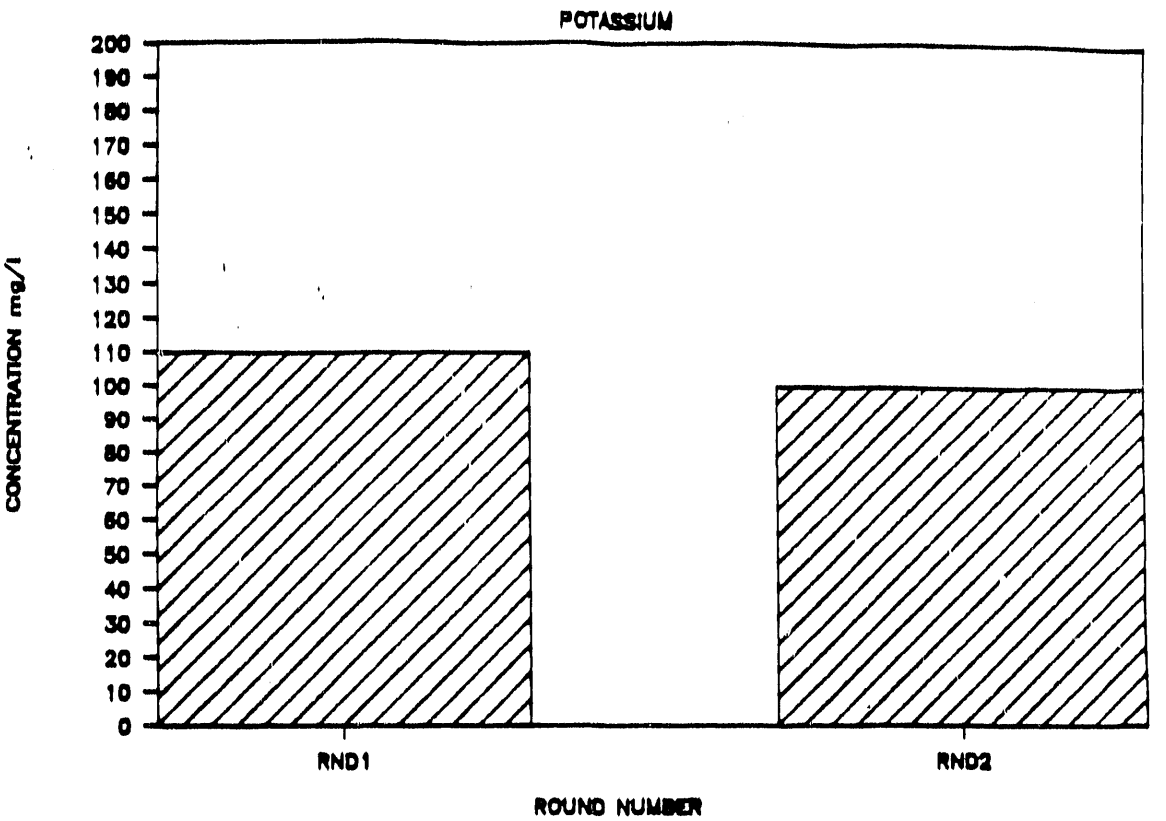

H-02c, CULEBRA
BROMIDE
CONCENTRATION mg/l
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
ROUND NUMBER

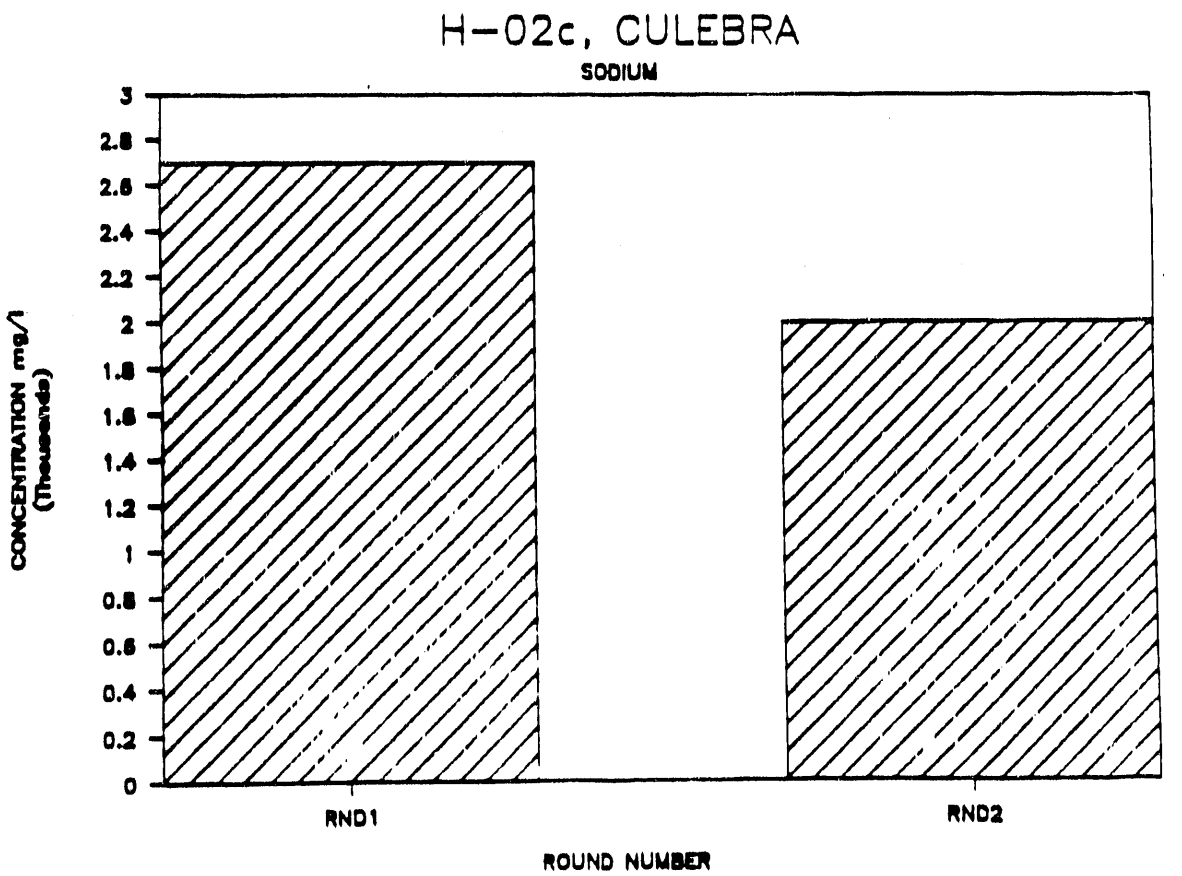

H-02c, CULEBRA
CALCIUM
CONCENTRATION mg/l
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
ROUND NUMBER

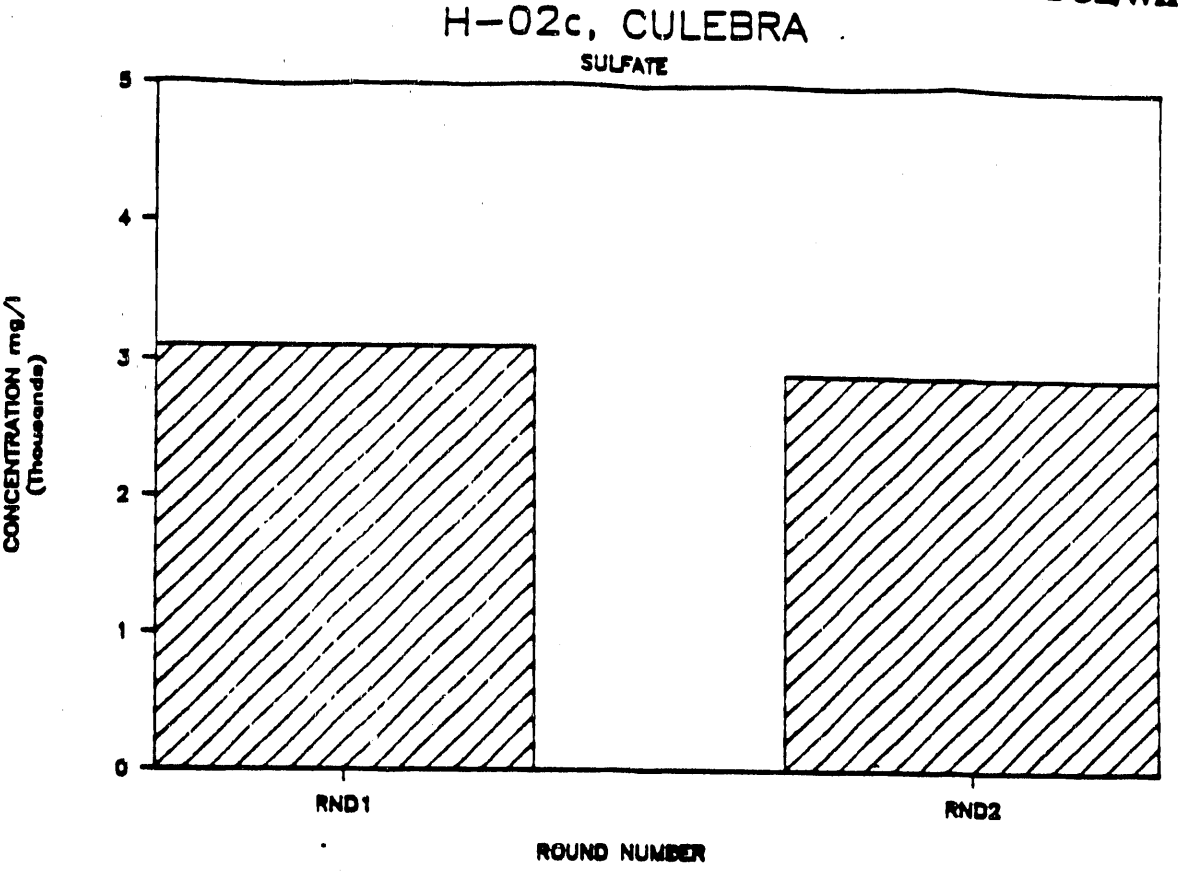

H-02c, CULEBRA
CHLORIDE
CONCENTRATION mg/l
(Thousands)
5
4
3
2
1
0
RND1
RND2
ROUND NUMBER

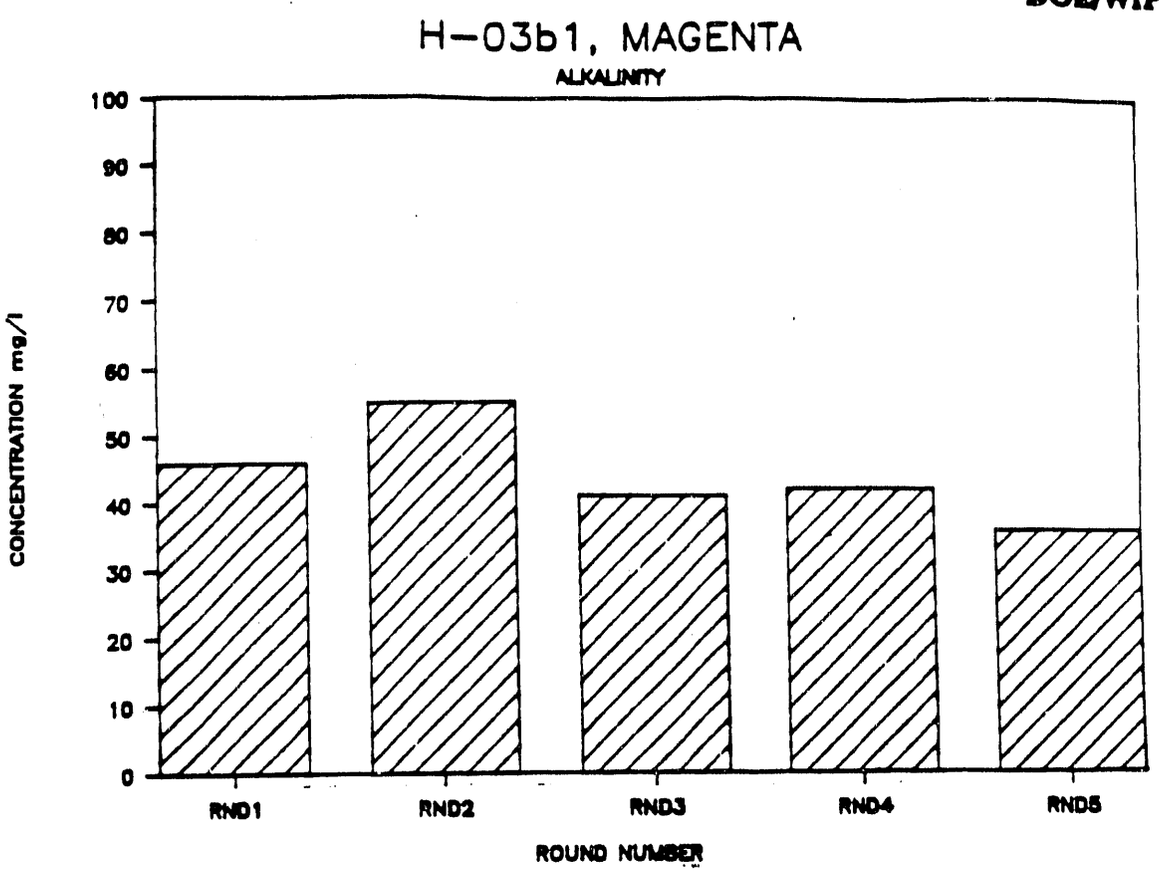

H-02c, CULEBRA
FLUORIDE
CONCENTRATION mg/l
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
ROUND NUMBER

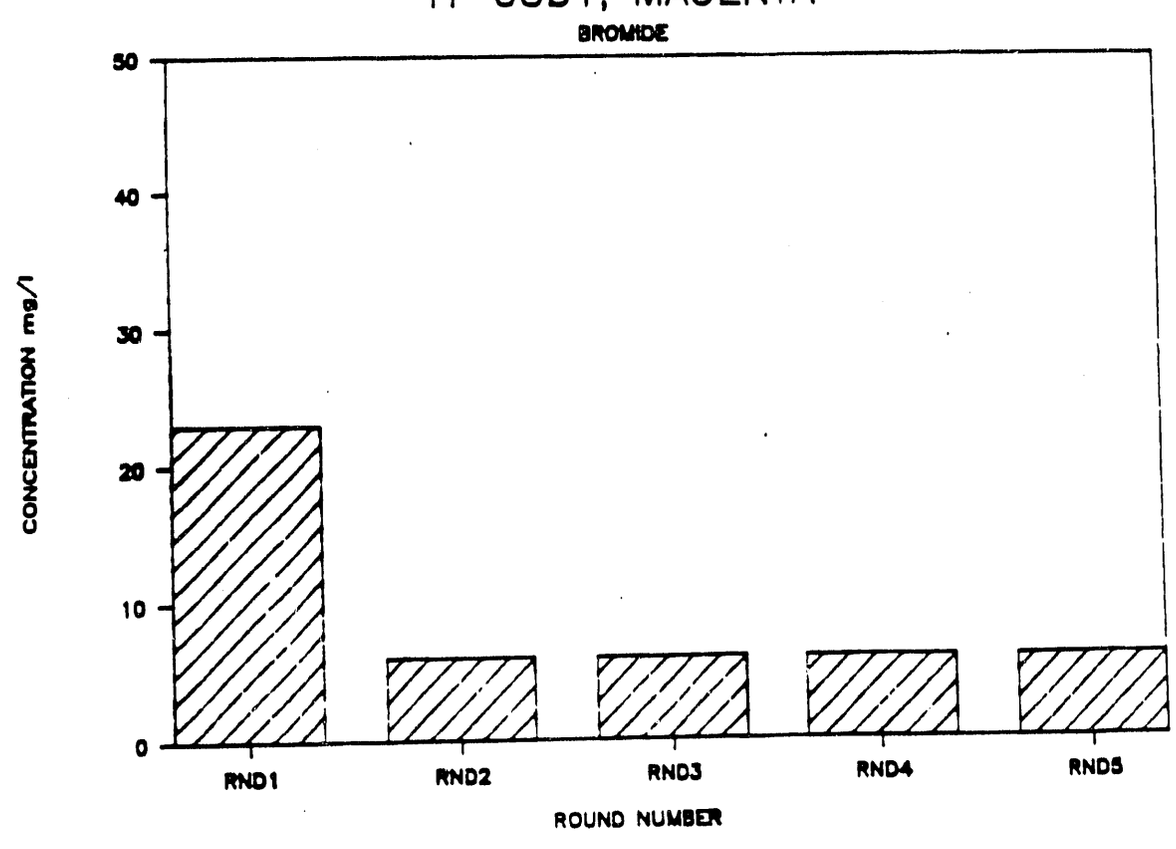

H-02c, CULEBRA
MAGNESIUM
CONCENTRATION mg/l
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
ROUND NUMBER

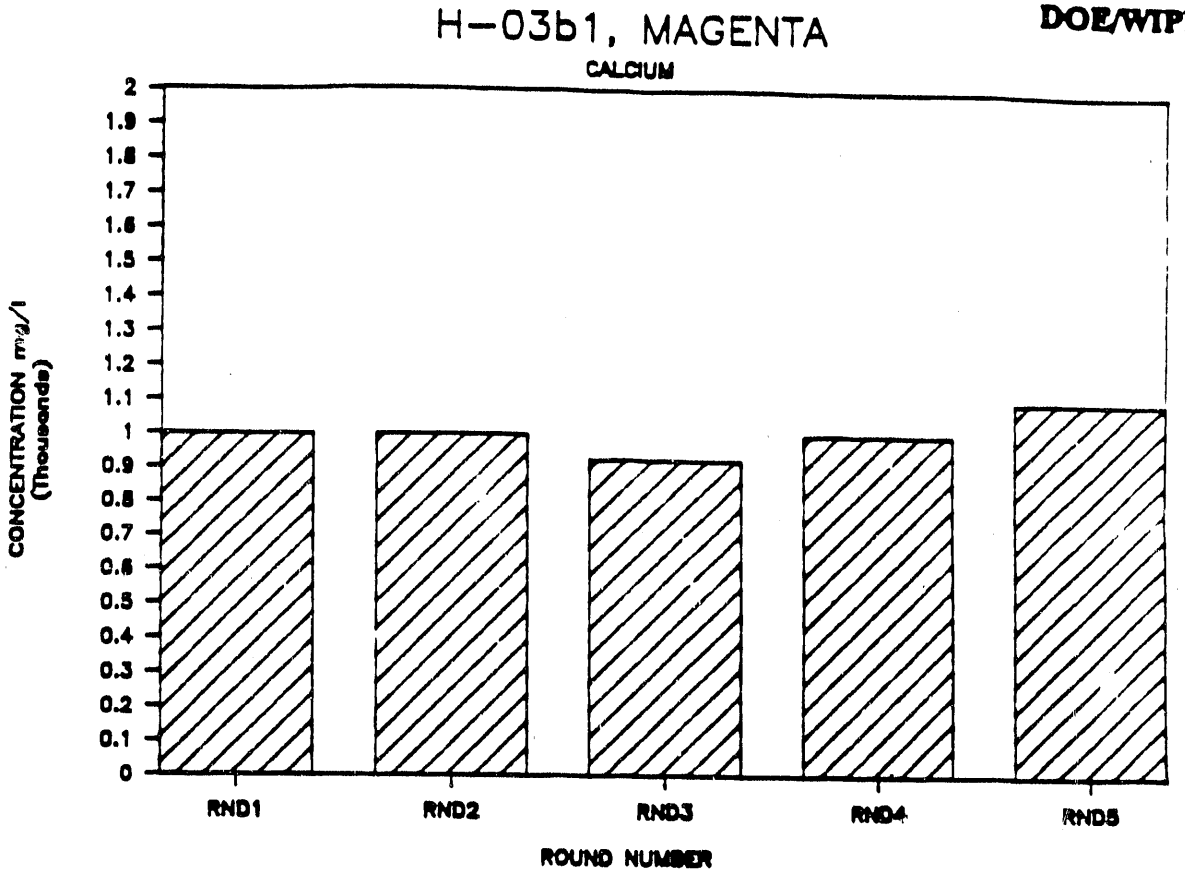

H-02c, CULEBRA
POTASSIUM
CONCENTRATION mg/l
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
ROUND NUMBER

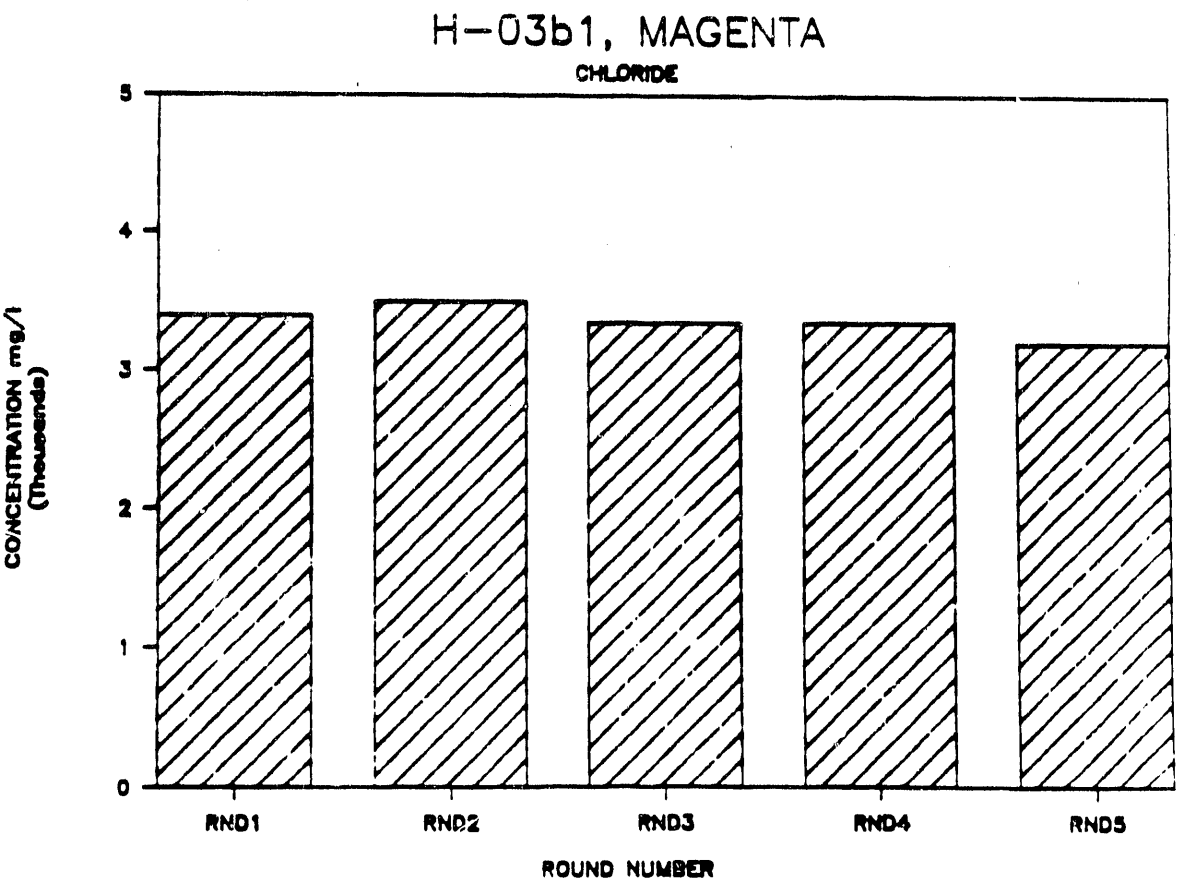

H-02c, CULEBRA
SODIUM
CONCENTRATION mg/l
(Thousands)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
RND1
RND2
ROUND NUMBER

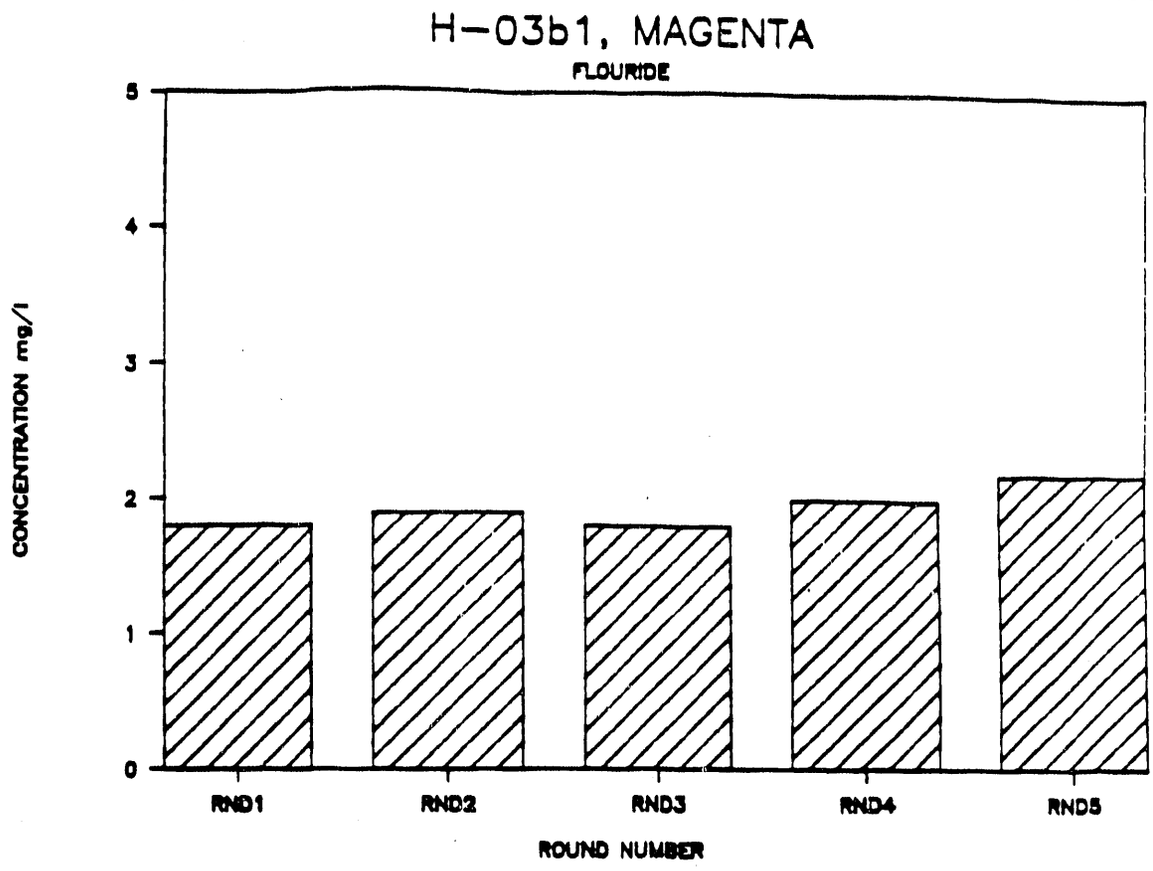

H-02c, CULEBRA
SULFATE
CONCENTRATION mg/l
(Thousands)
5
4
3
2
1
0
RND1
RND2
ROUND NUMBER

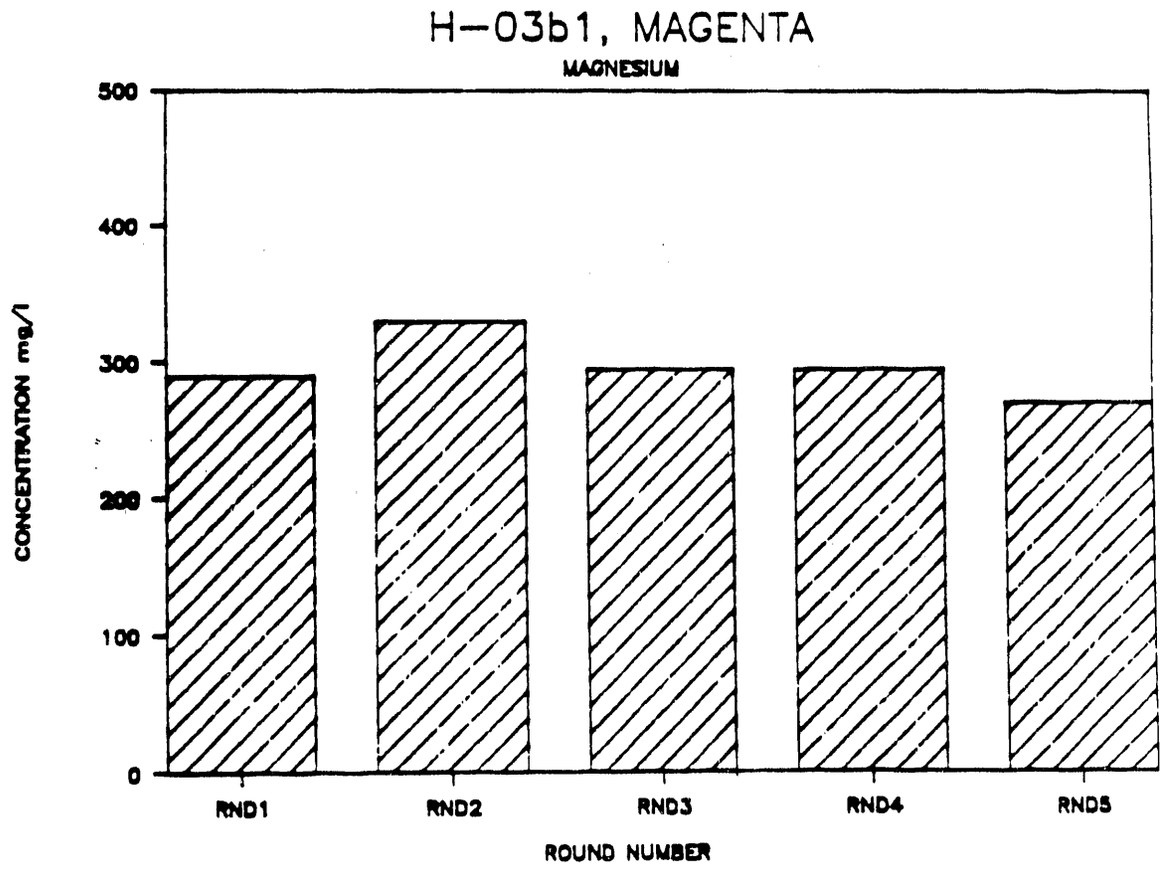

H-03b1, MAGENTA
ALKALINITY
CONCENTRATION mg/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

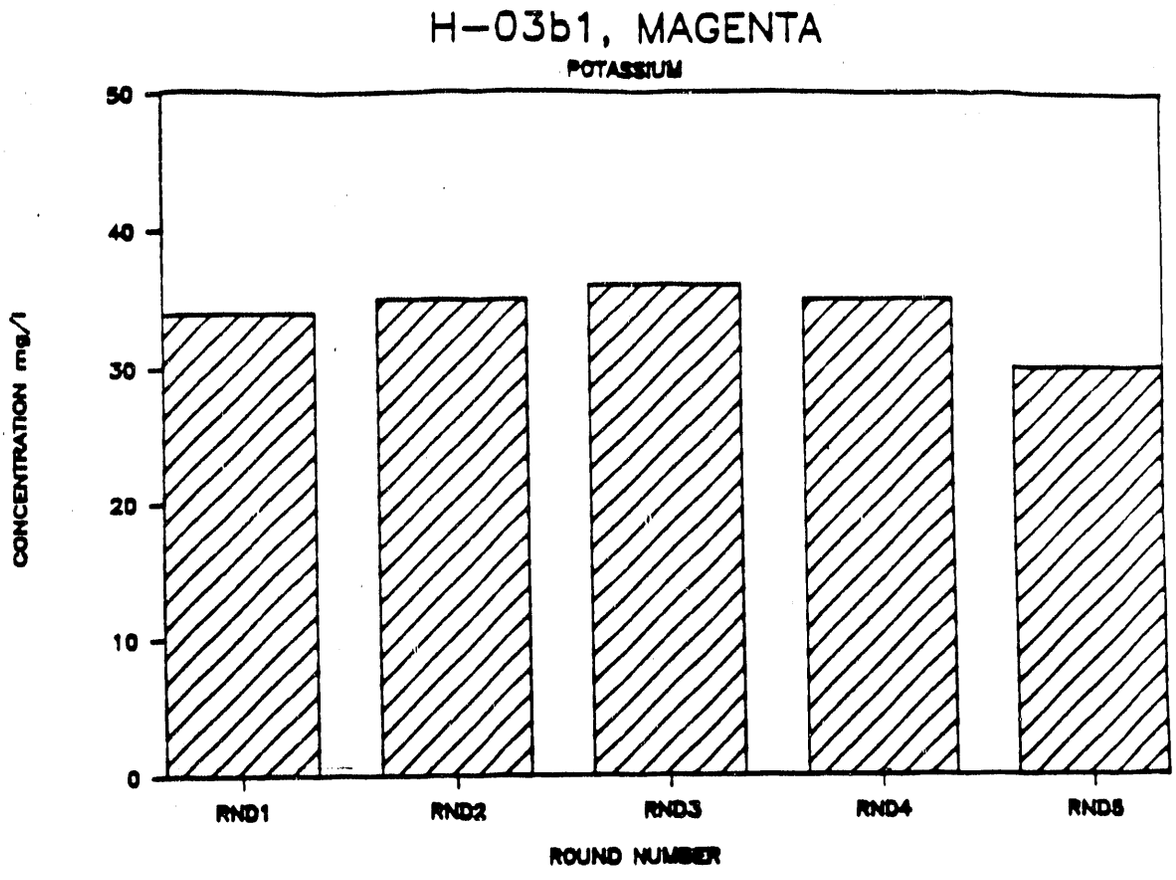

H-03b1, MAGENTA
BROMIDE
CONCENTRATION mg/l
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

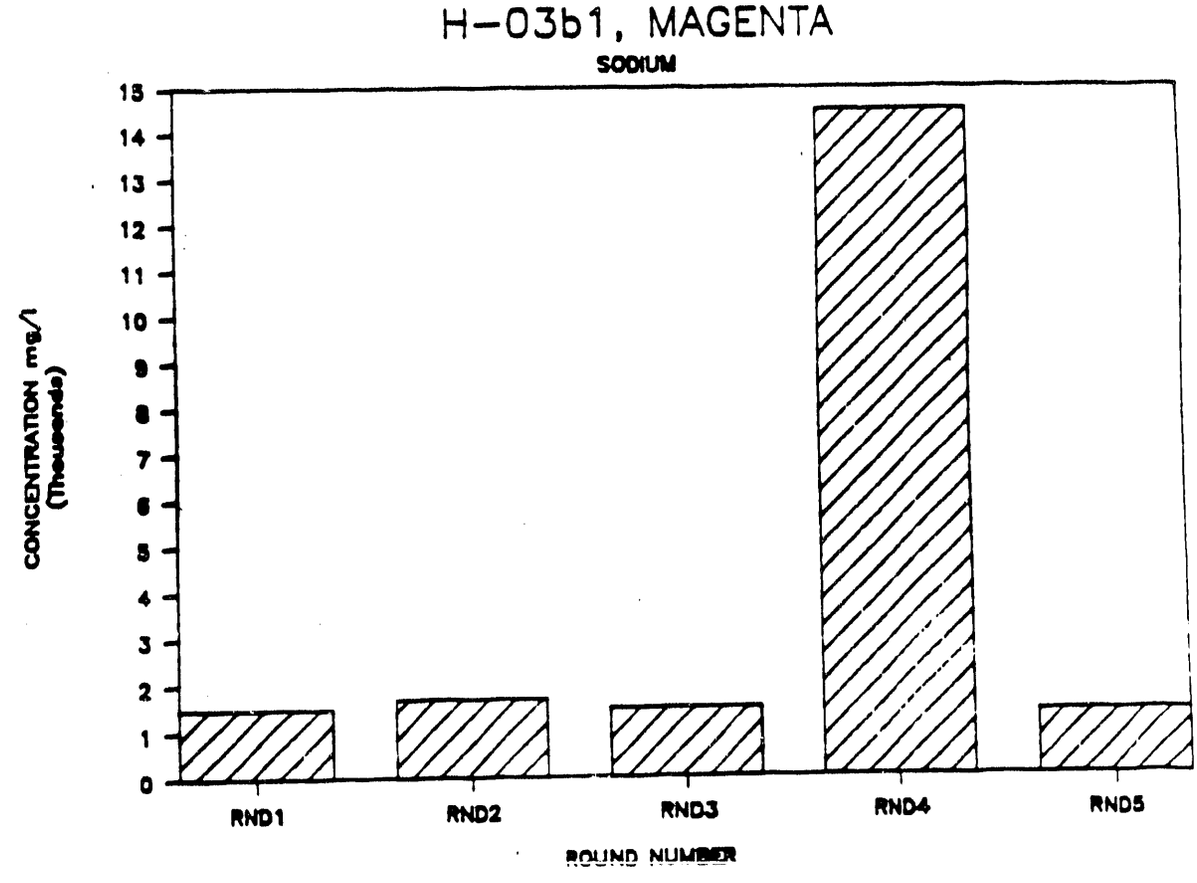

H-03b1, MAGENTA
CALCIUM
CONCENTRATION mg/l
(Thousands)
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

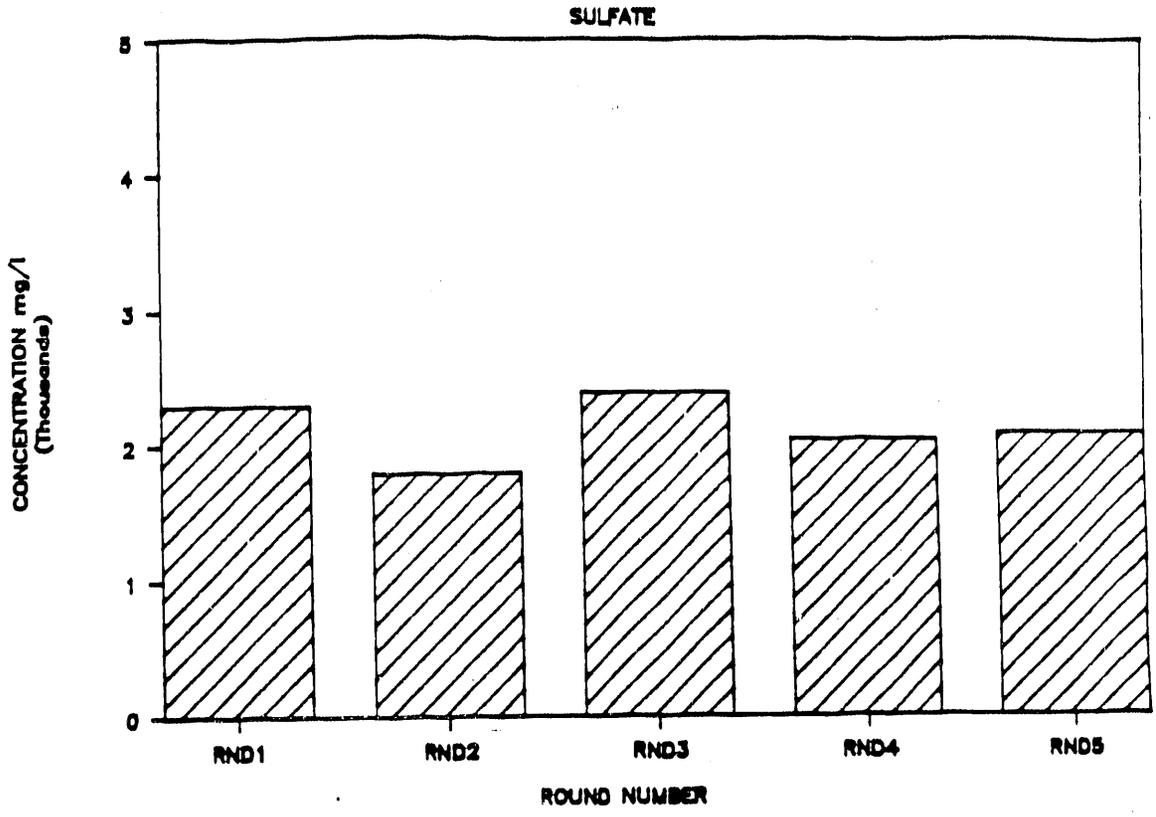

H-03b1, MAGENTA
CHLORIDE
CONCENTRATION mg/l
(Thousands)
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

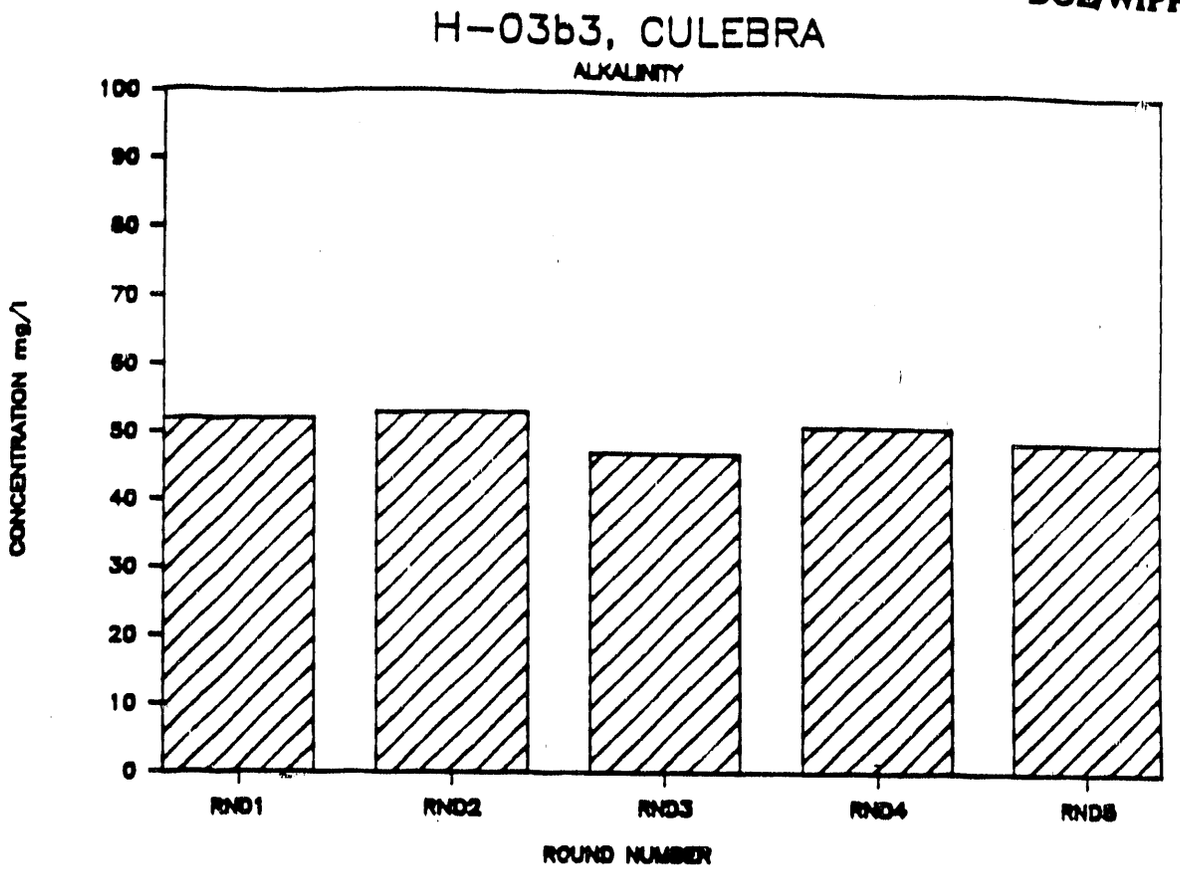

H-03b1, MAGENTA
FLOURIDE
CONCENTRATION mg/l
0
1
2
3
4
5
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

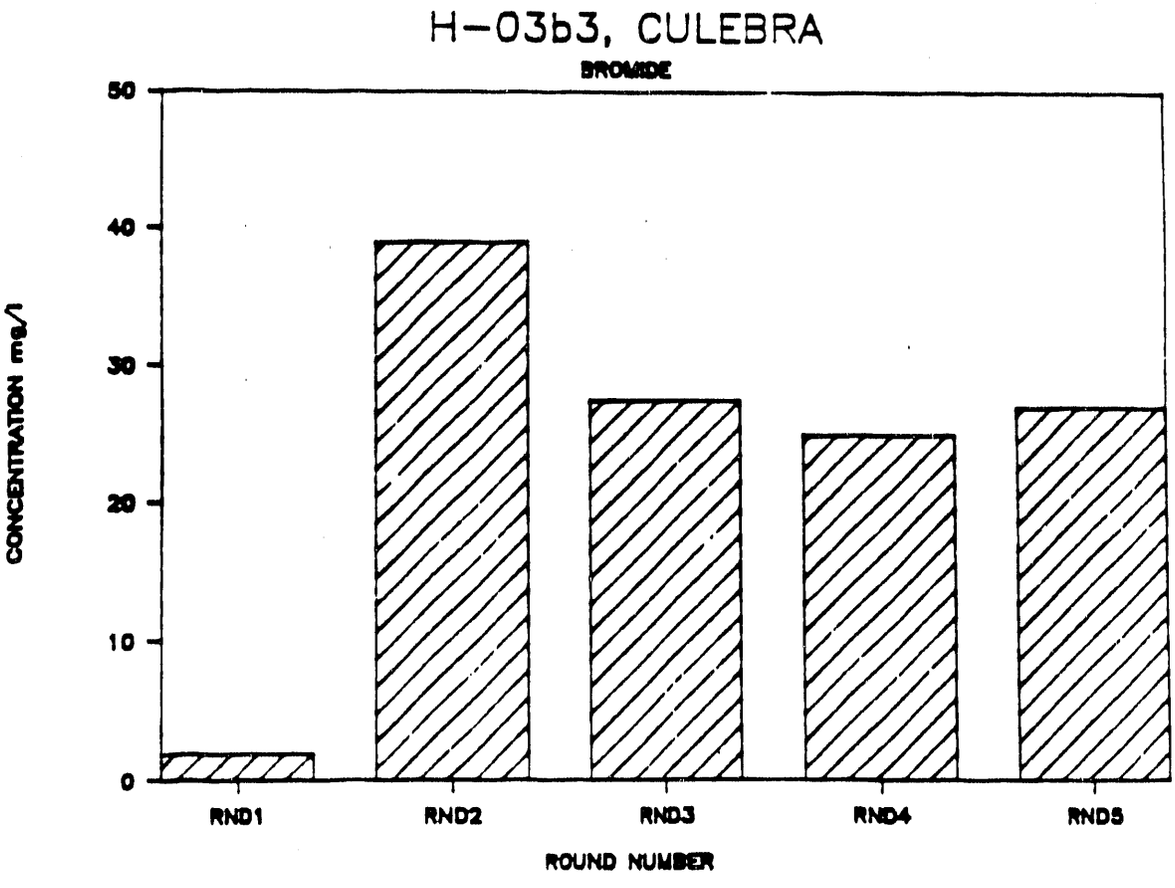

H-03b1, MAGENTA
MAGNESIUM
CONCENTRATION mg/l
0
100
200
300
400
500
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

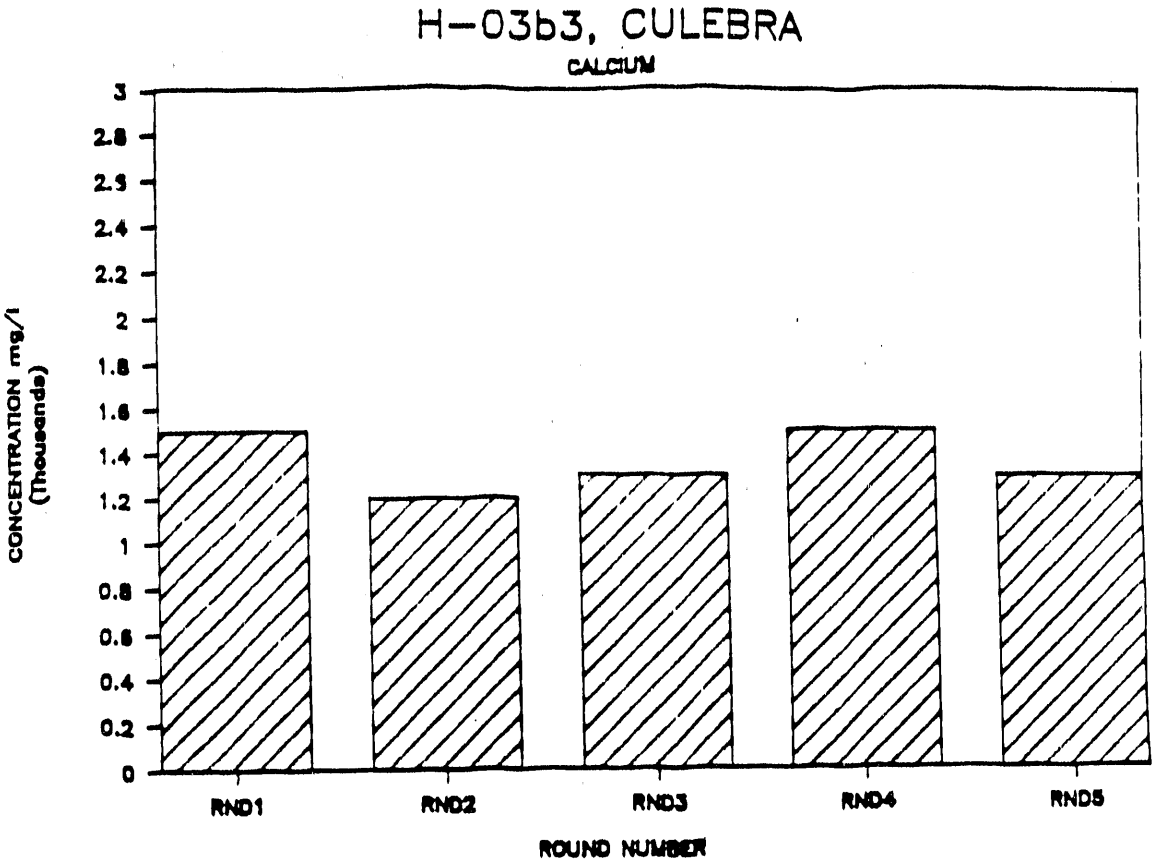

H-03b1, MAGENTA
POTASSIUM
CONCENTRATION mg/l
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

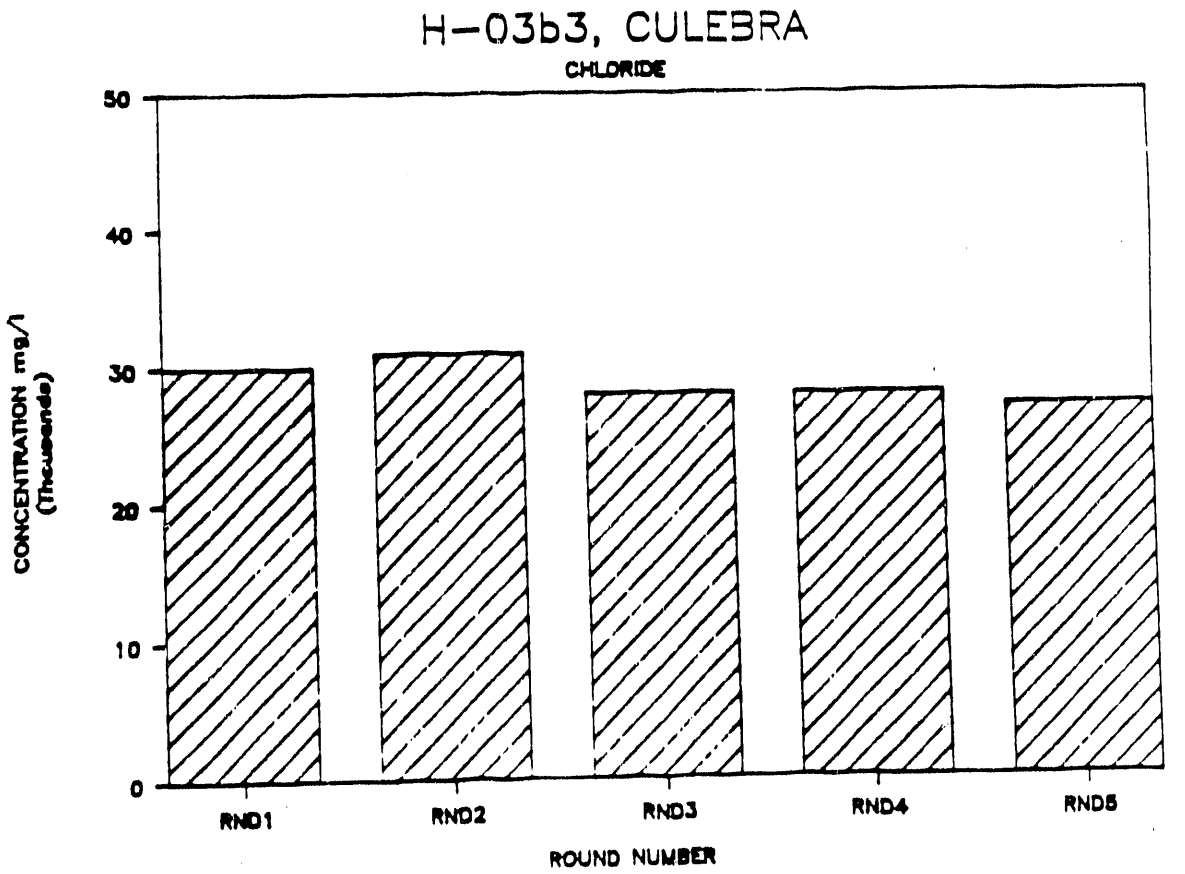

H-03b1, MAGENTA
SODIUM
CONCENTRATION mg/l
(Thousands)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

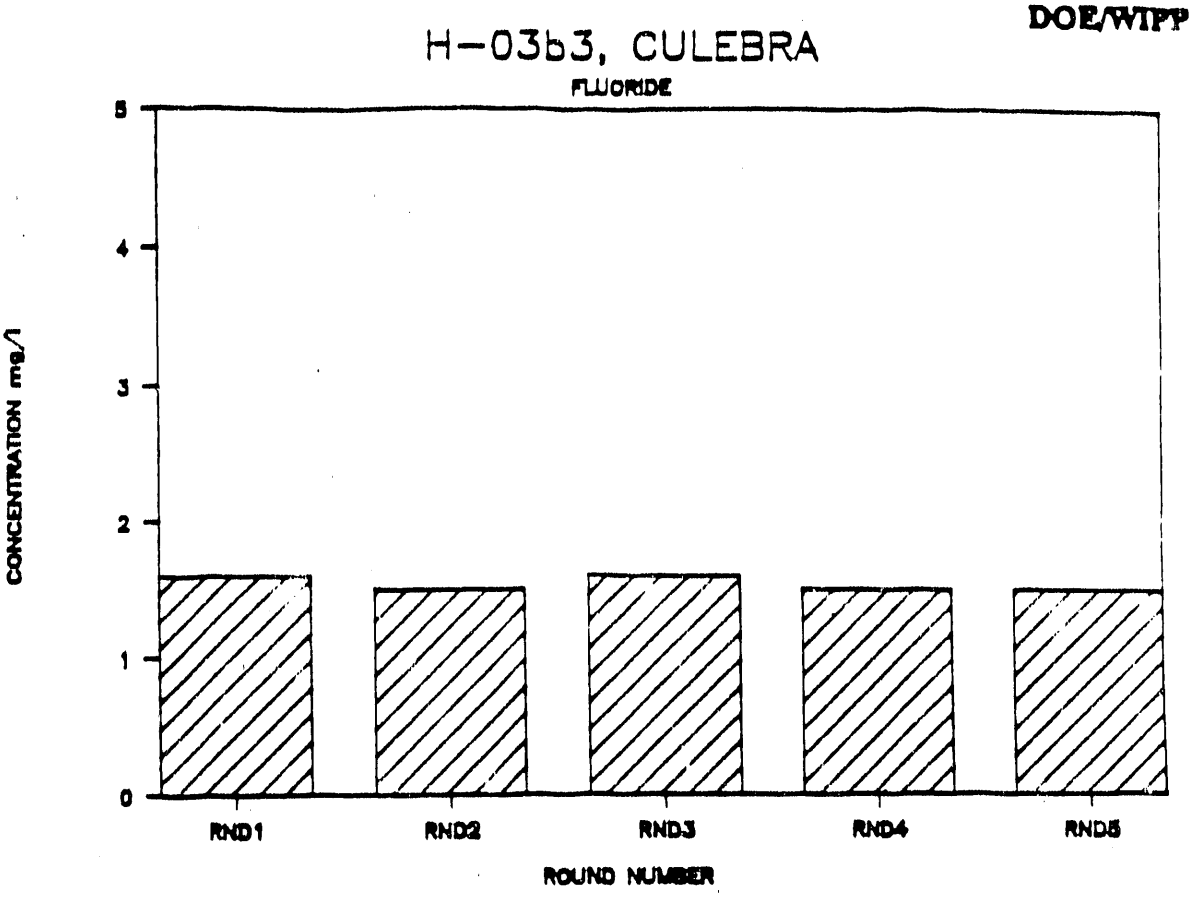

H-03b1, MAGENTA
SULFATE
CONCENTRATION mg/l
(Thousands)
0
1
2
3
4
5
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

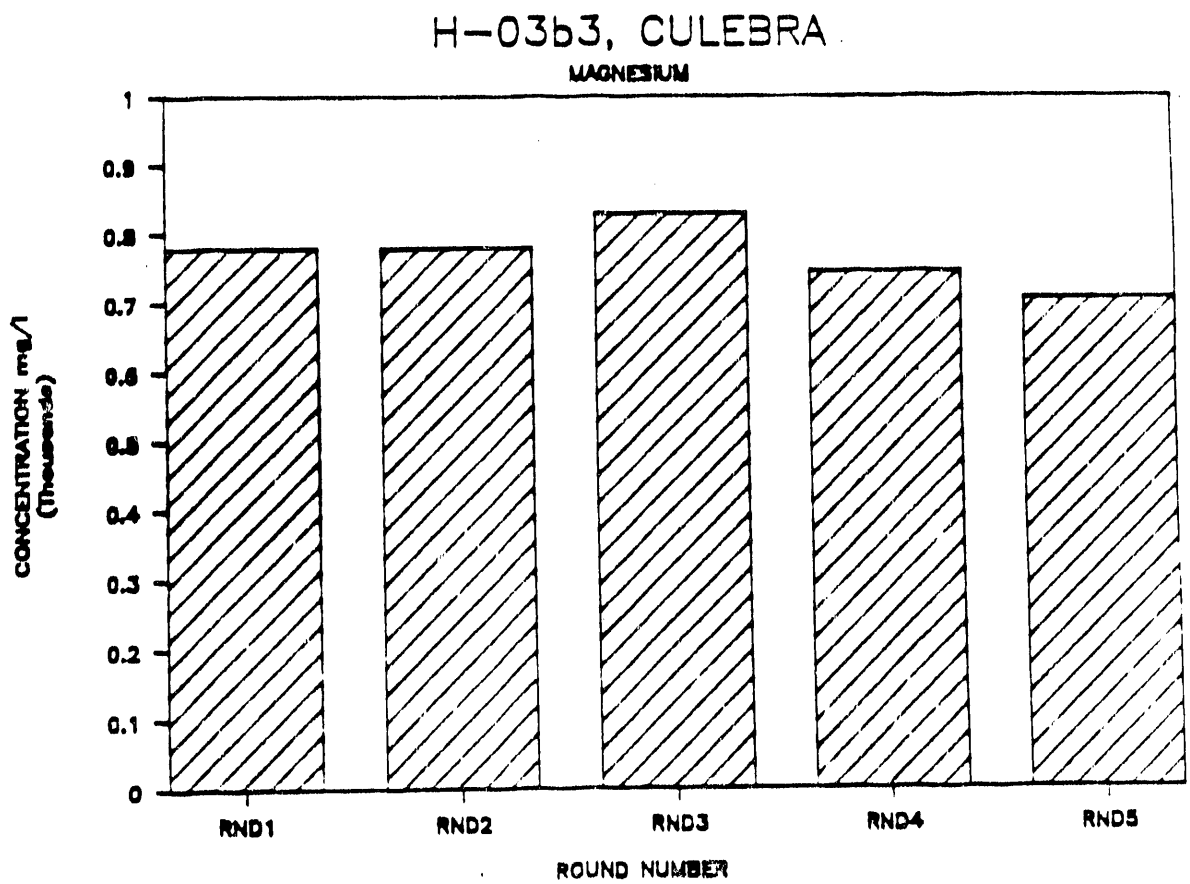

H-03b3, CULEBRA
ALKALINITY
CONCENTRATION mg/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

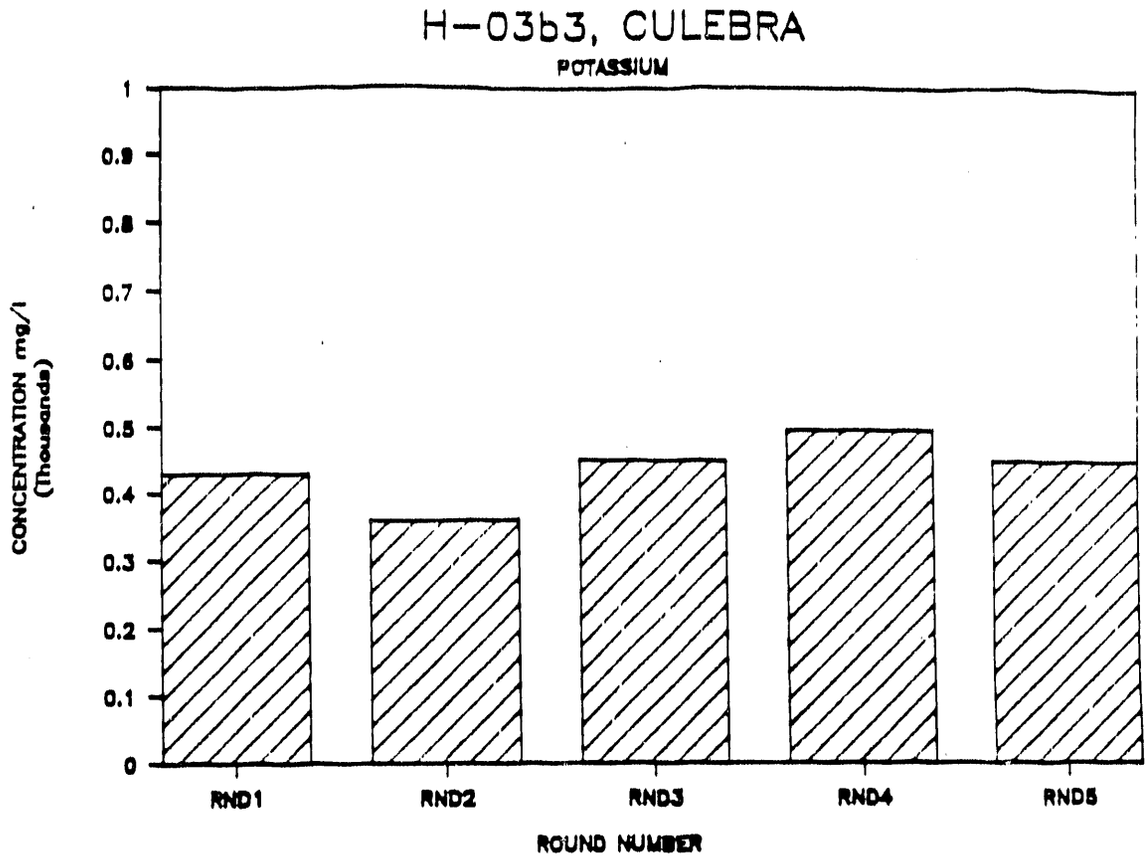

H-03b3, CULEBRA
BROMIDE
CONCENTRATION mg/l
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

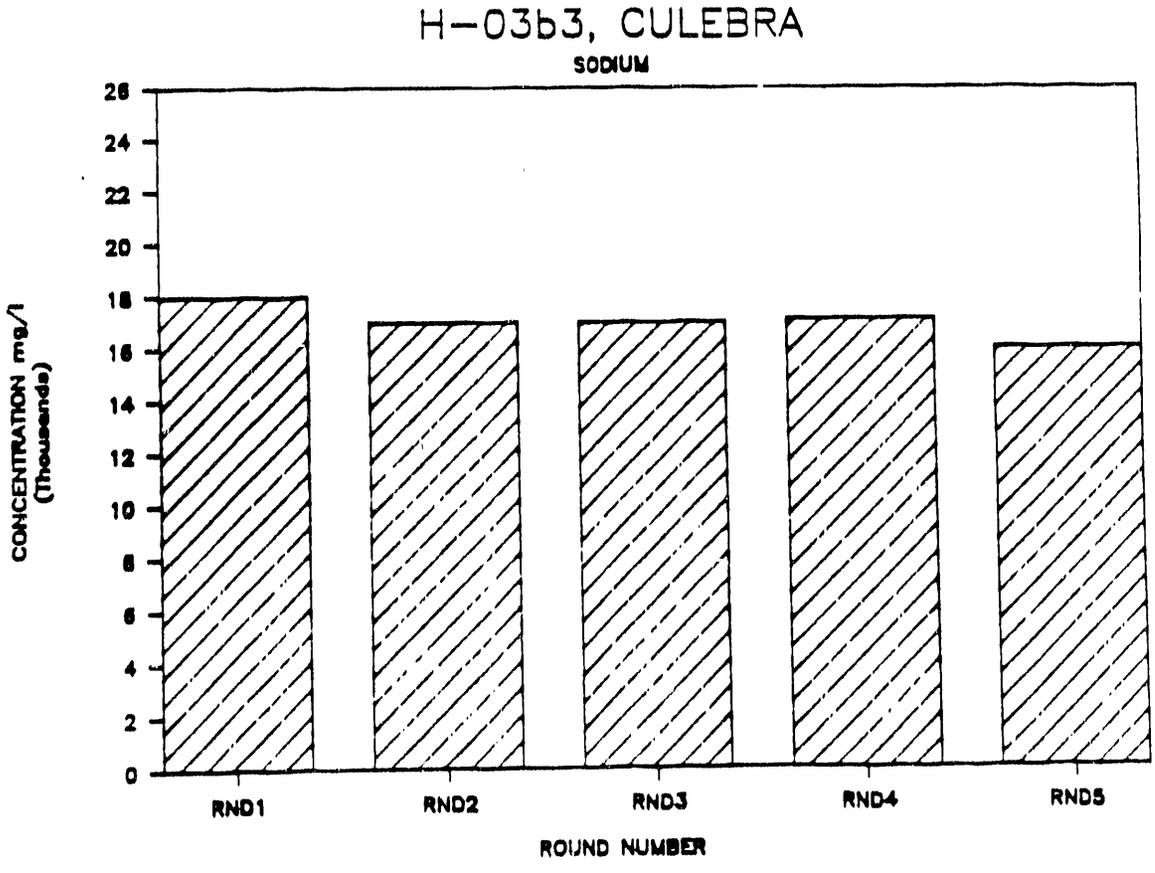

H-03b3, CULEBRA
CALCIUM
CONCENTRATION mg/l (Thousands)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

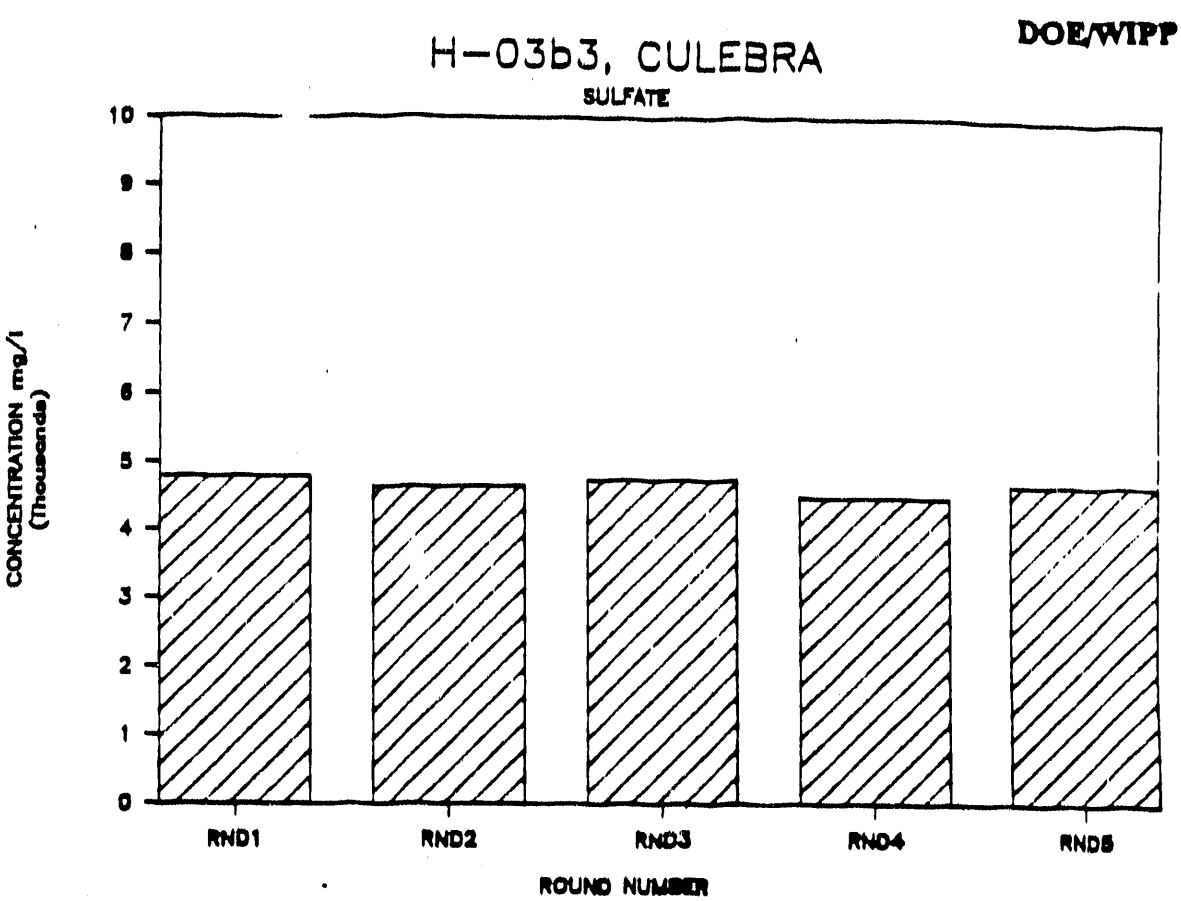

H-03b3, CULEBRA
CHLORIDE
CONCENTRATION mg/l (Thousands)
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

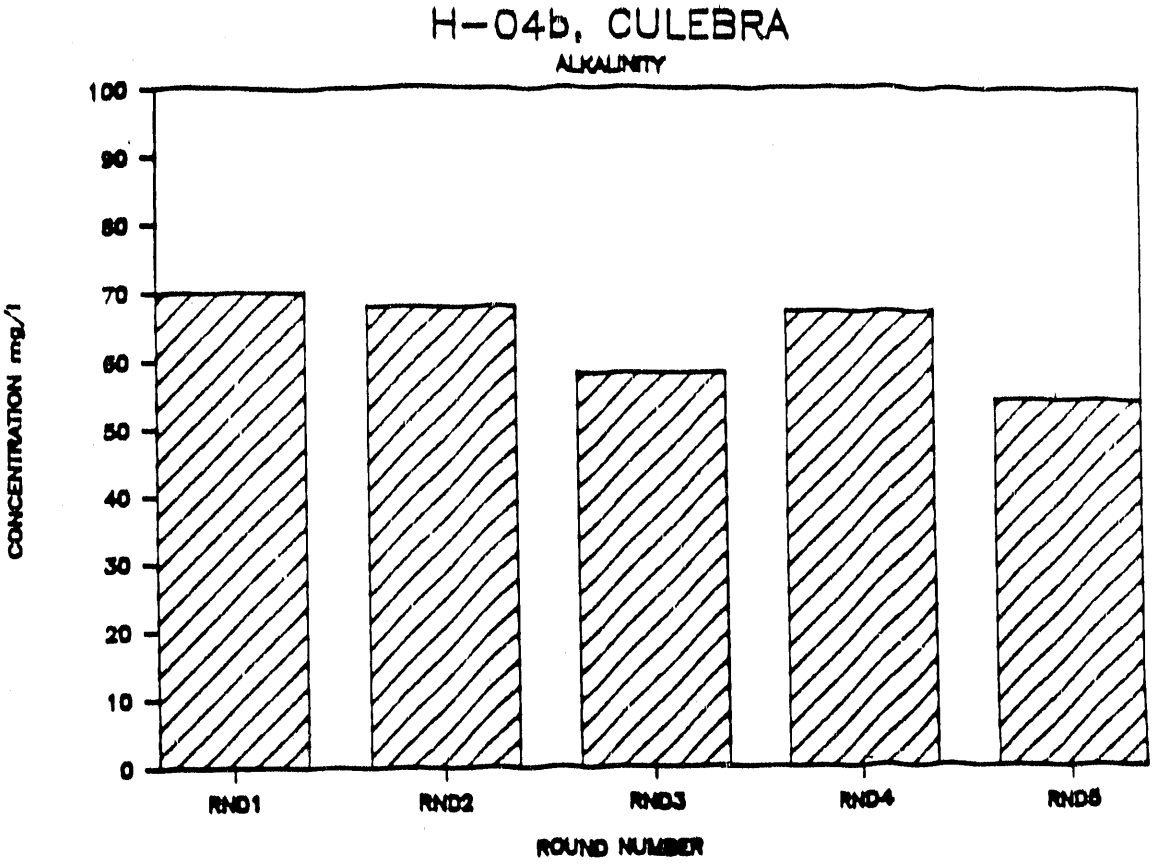

H-03b3, CULEBRA
FLUORIDE
CONCENTRATION mg/l
0
1
2
3
4
5
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

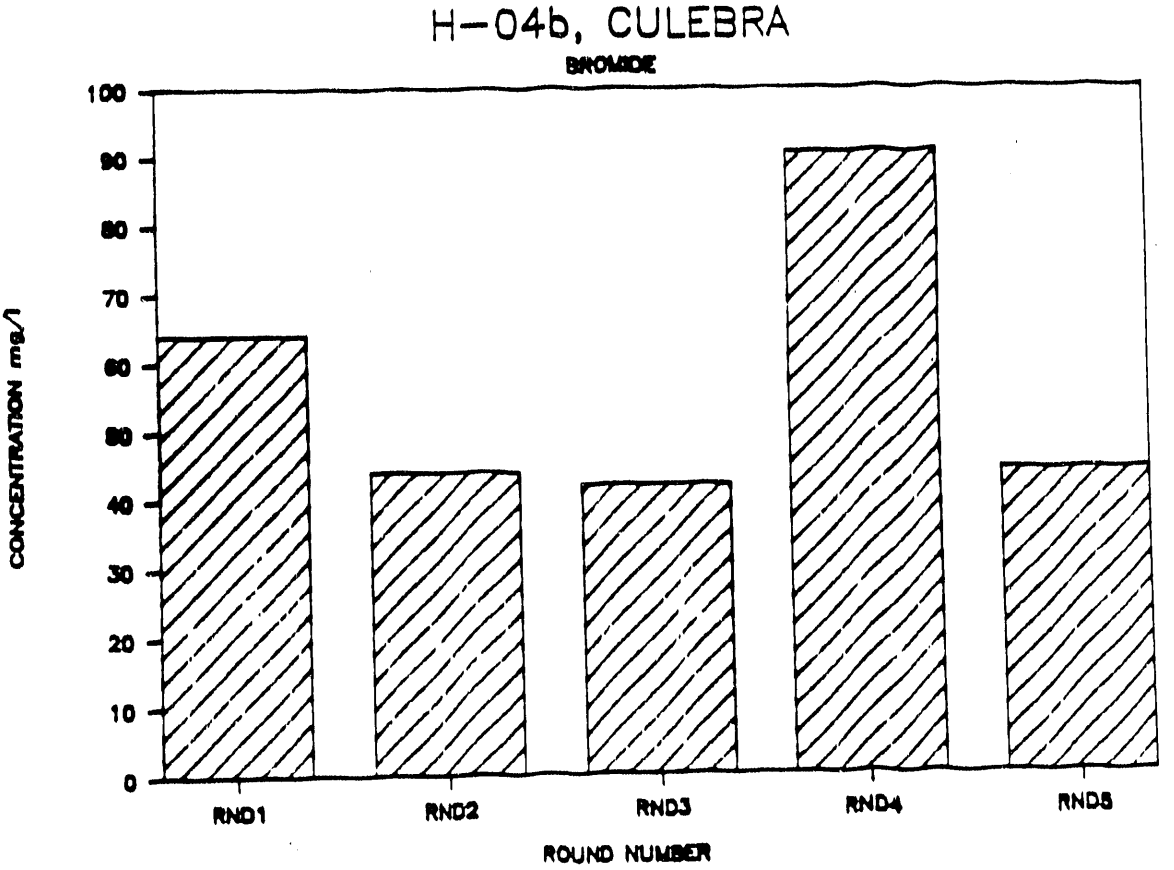

H-03b3, CULEBRA
MAGNESIUM
CONCENTRATION mg/l
0
0.1
0.2
0.3
0.4
0.7
0.9
1
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

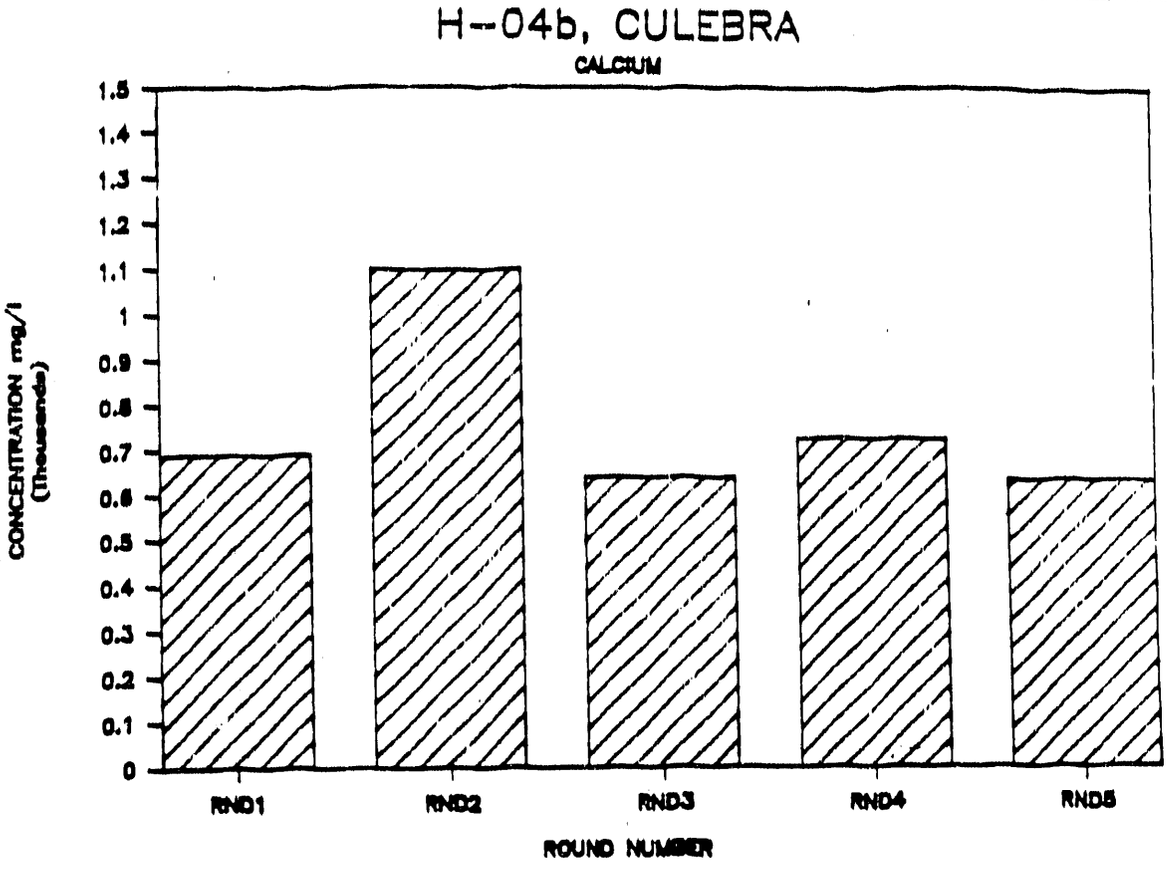

H-03b3, CULEBRA
POTASSIUM
CONCENTRATION mg/l
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

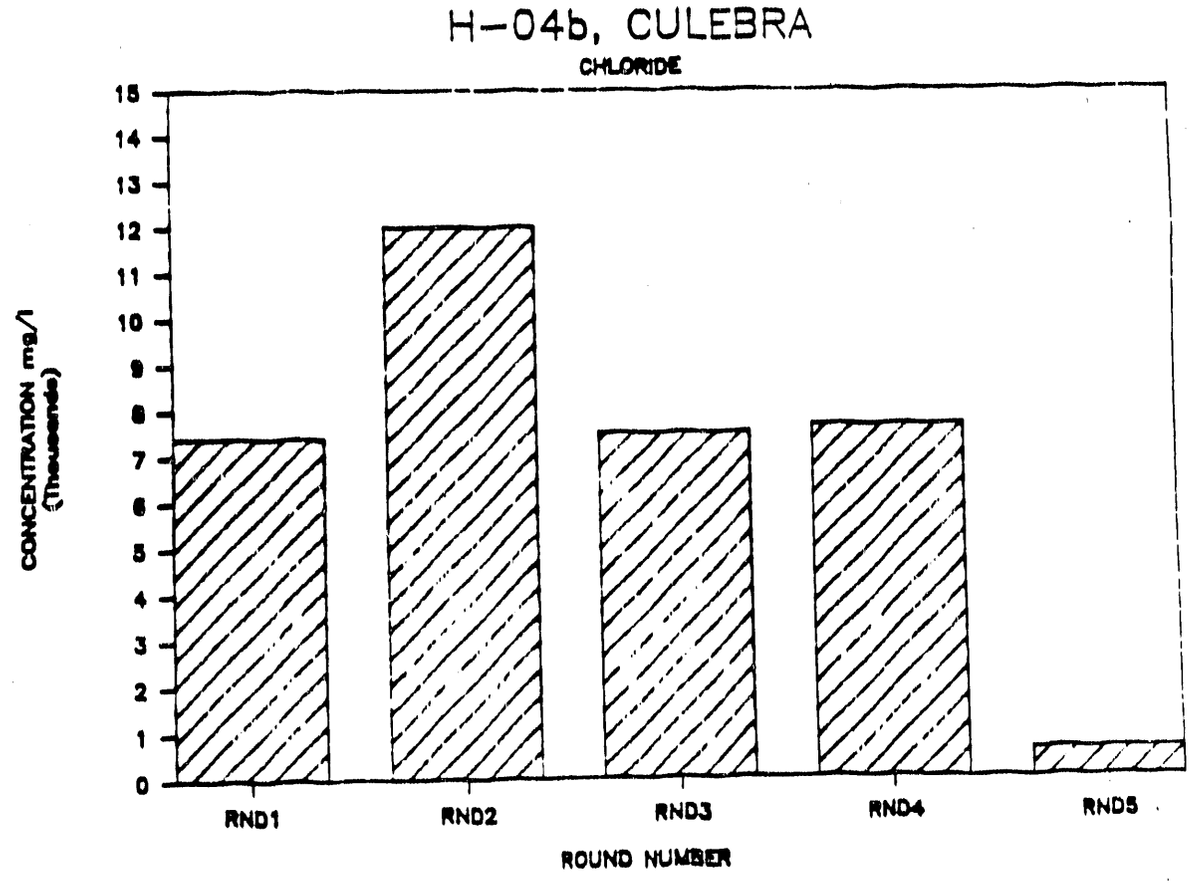

H-03b3, CULEBRA
SODIUM
CONCENTRATION mg/l
(Thousands)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

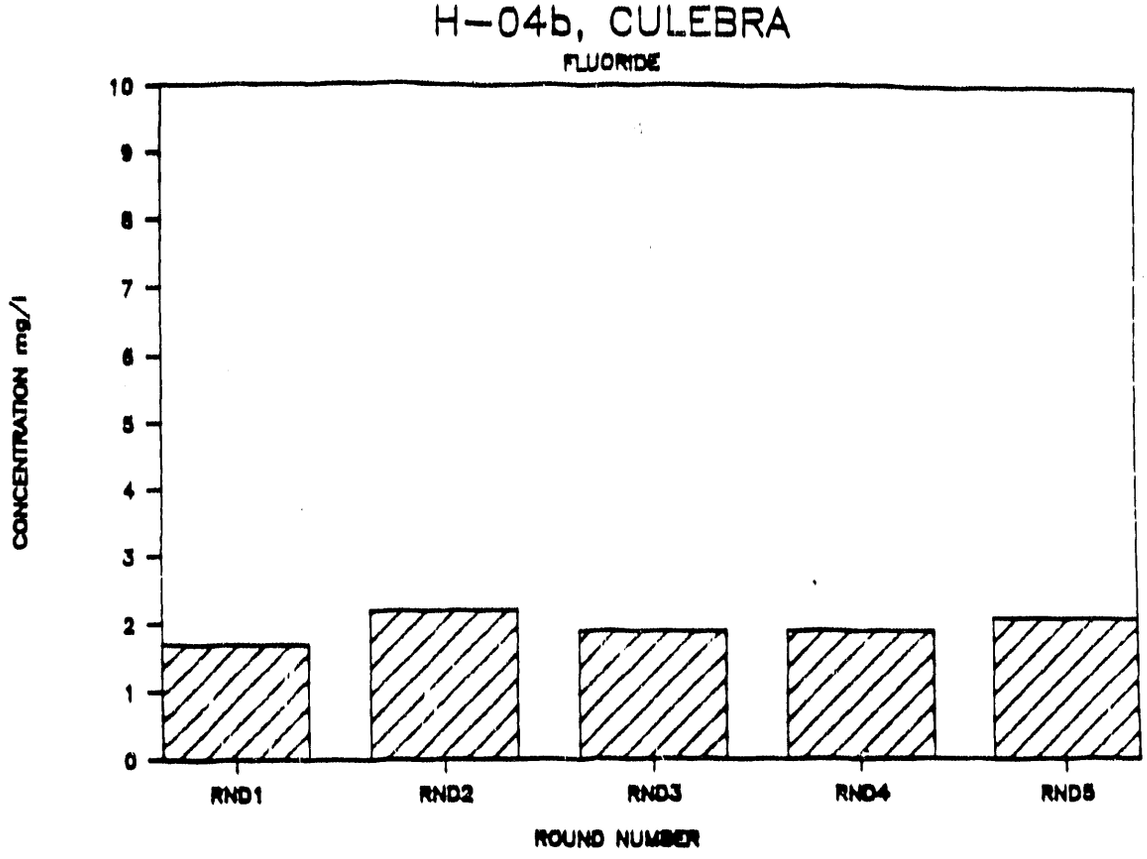

H-03b3, CULEBRA
SULFATE
CONCENTRATION mg/l
(Thousands)
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

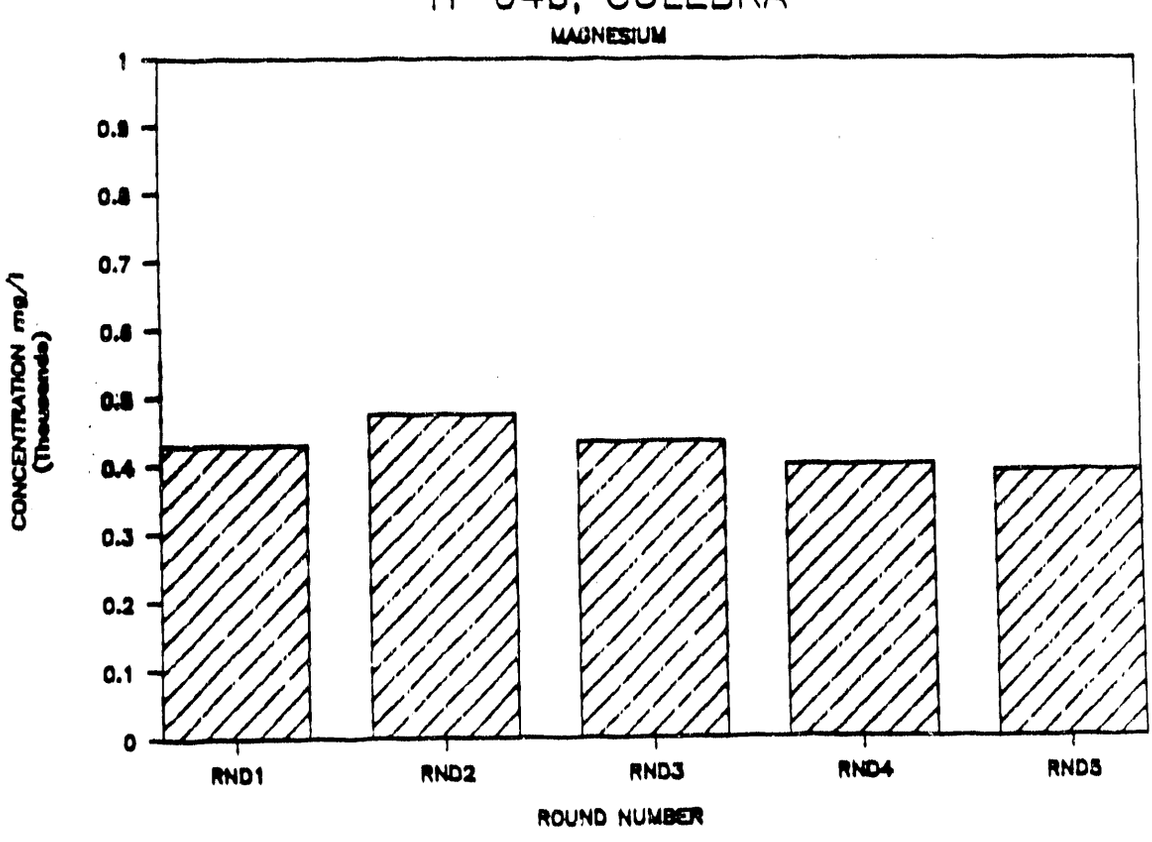

H-04b, CULEBRA
ALKALINITY
CONCENTRATION mg/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

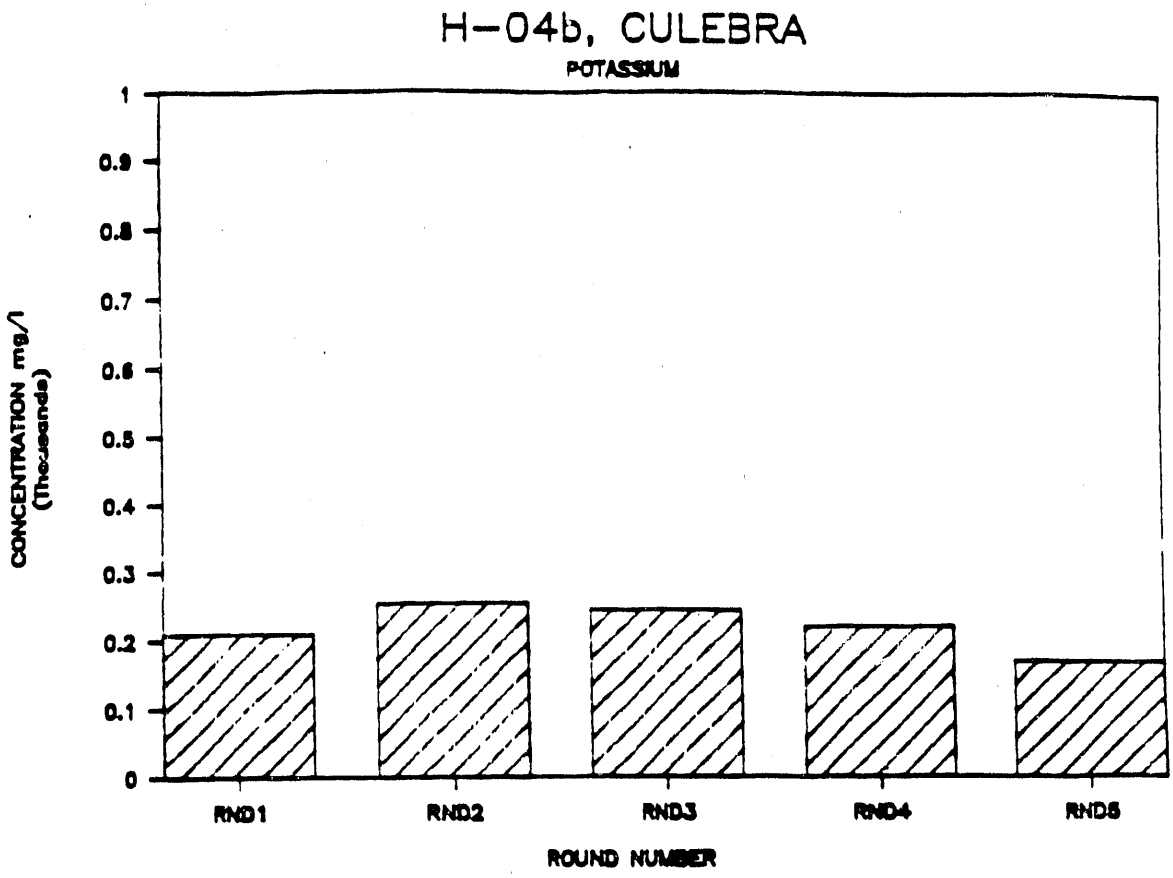

H-04b, CULEBRA
BROMIDE
CONCENTRATION mg/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

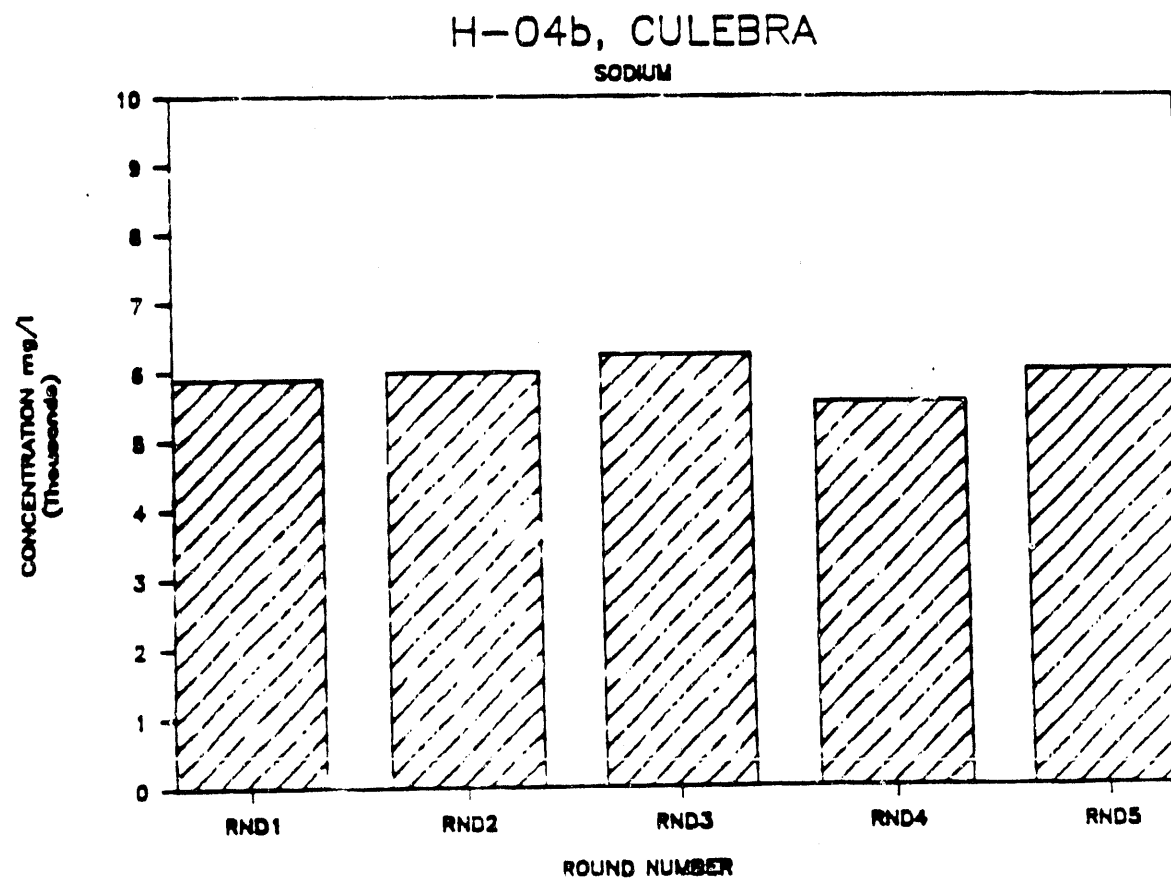

H--04b, CULEBRA
CALCIUM
CONCENTRATION mg/l (Thousands)
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

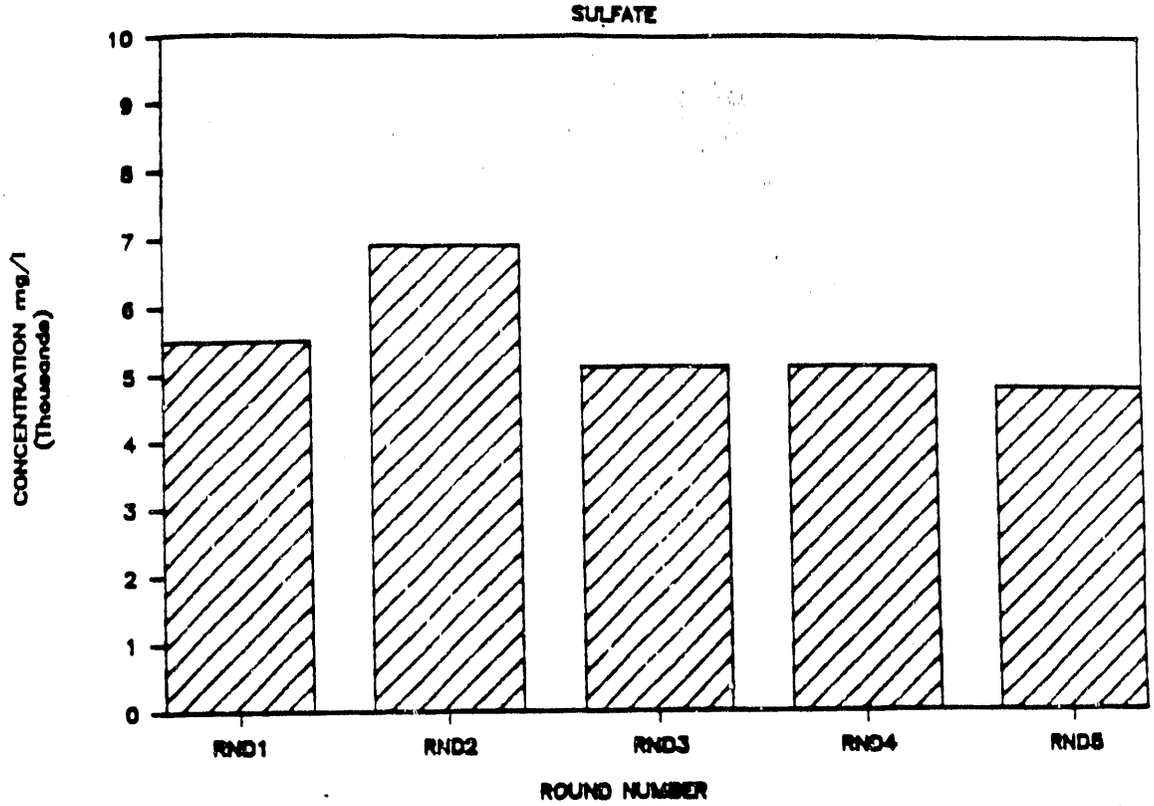

H-04b, CULEBRA
CHLORIDE
CONCENTRATION mg/l (Thousands)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

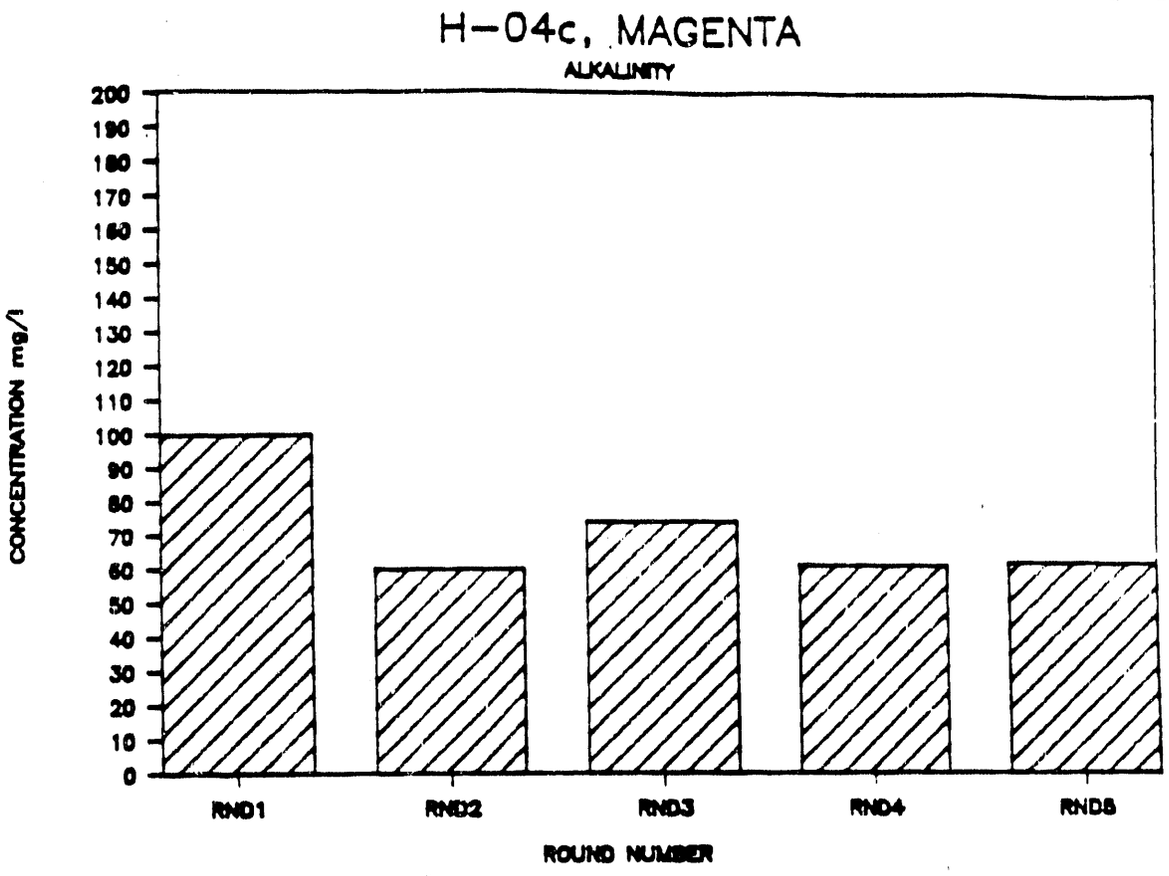

H-04b, CULEBRA
FLUORIDE
CONCENTRATION mg/l
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

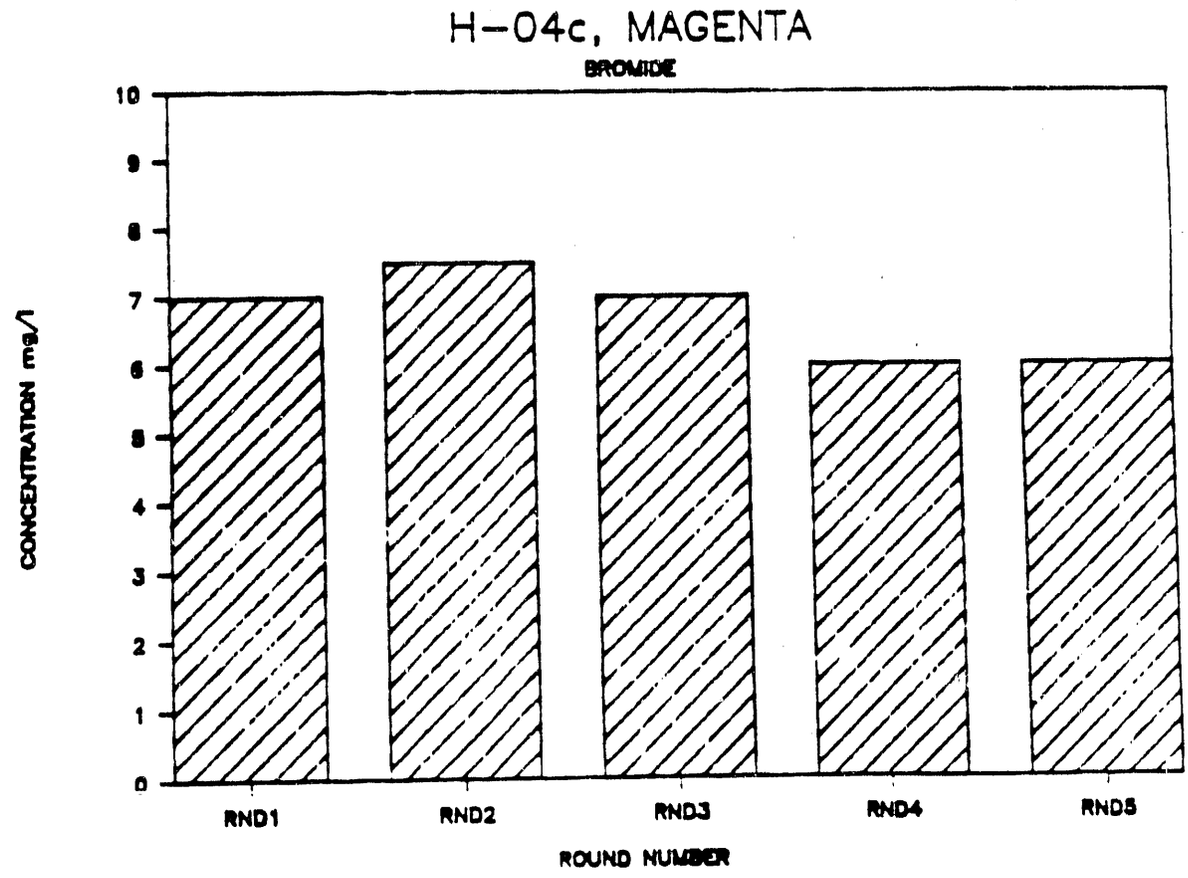

H-04b, CULEBRA
MAGNESIUM
CONCENTRATION mg/l
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

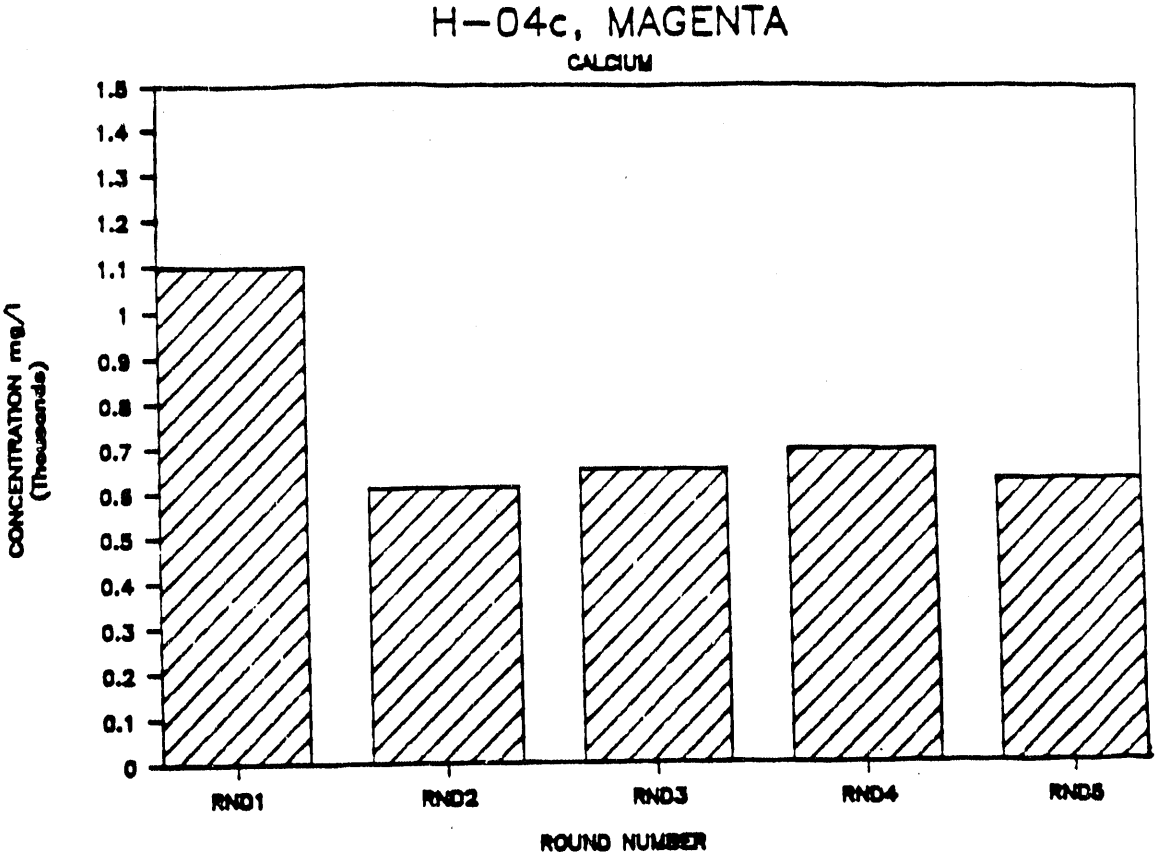

H-04b, CULEBRA
POTASSIUM
CONCENTRATION mg/l
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

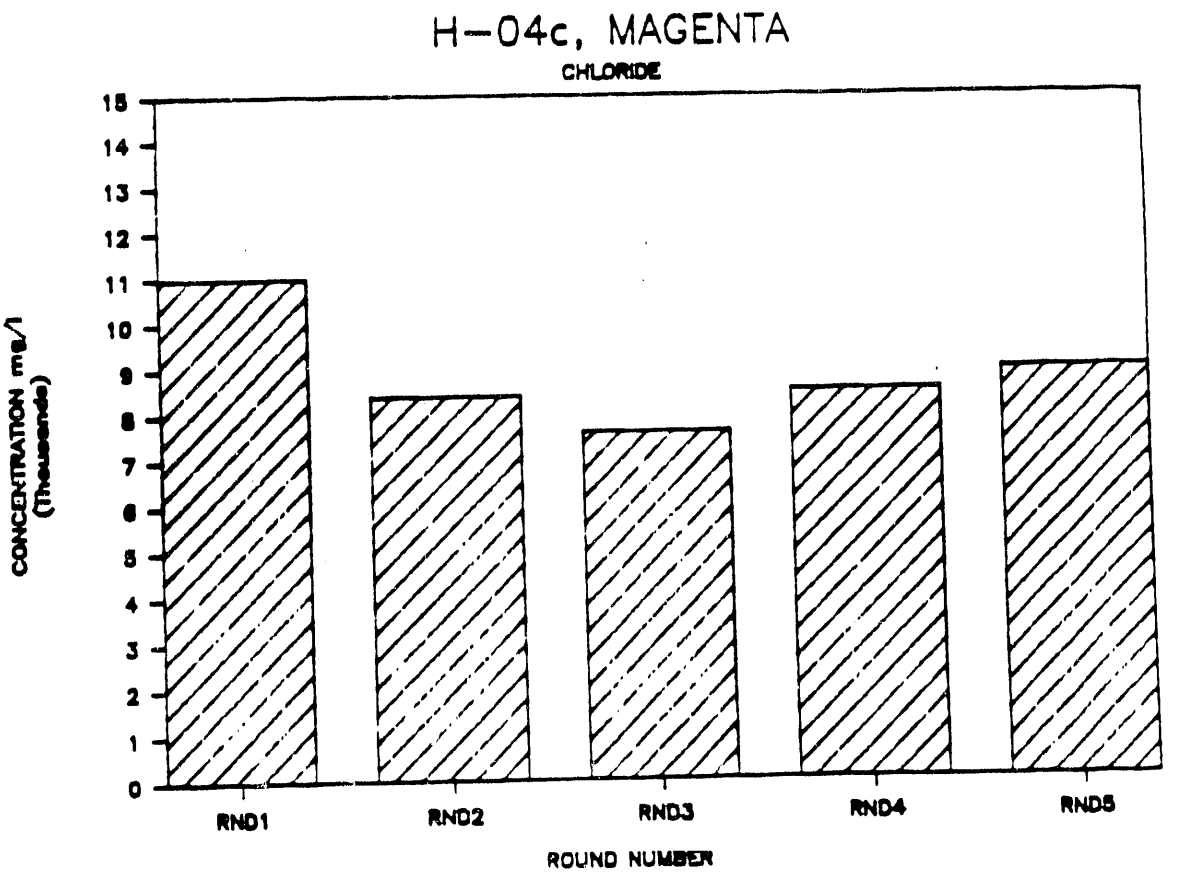

H-04b, CULEBRA
SODIUM
CONCENTRATION mg/l
(Thousands)
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

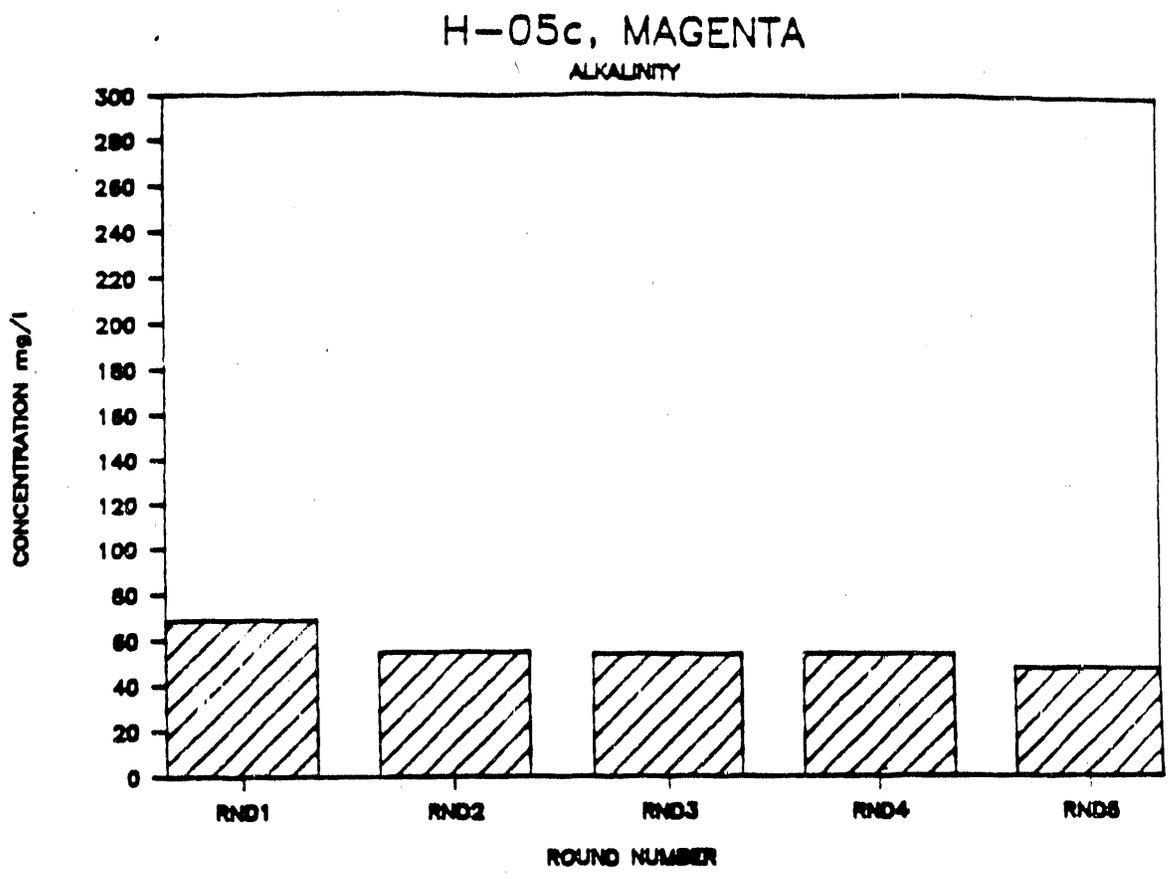

H-04b, CULEBRA
SULFATE
CONCENTRATION mg/l
(Thousands)
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

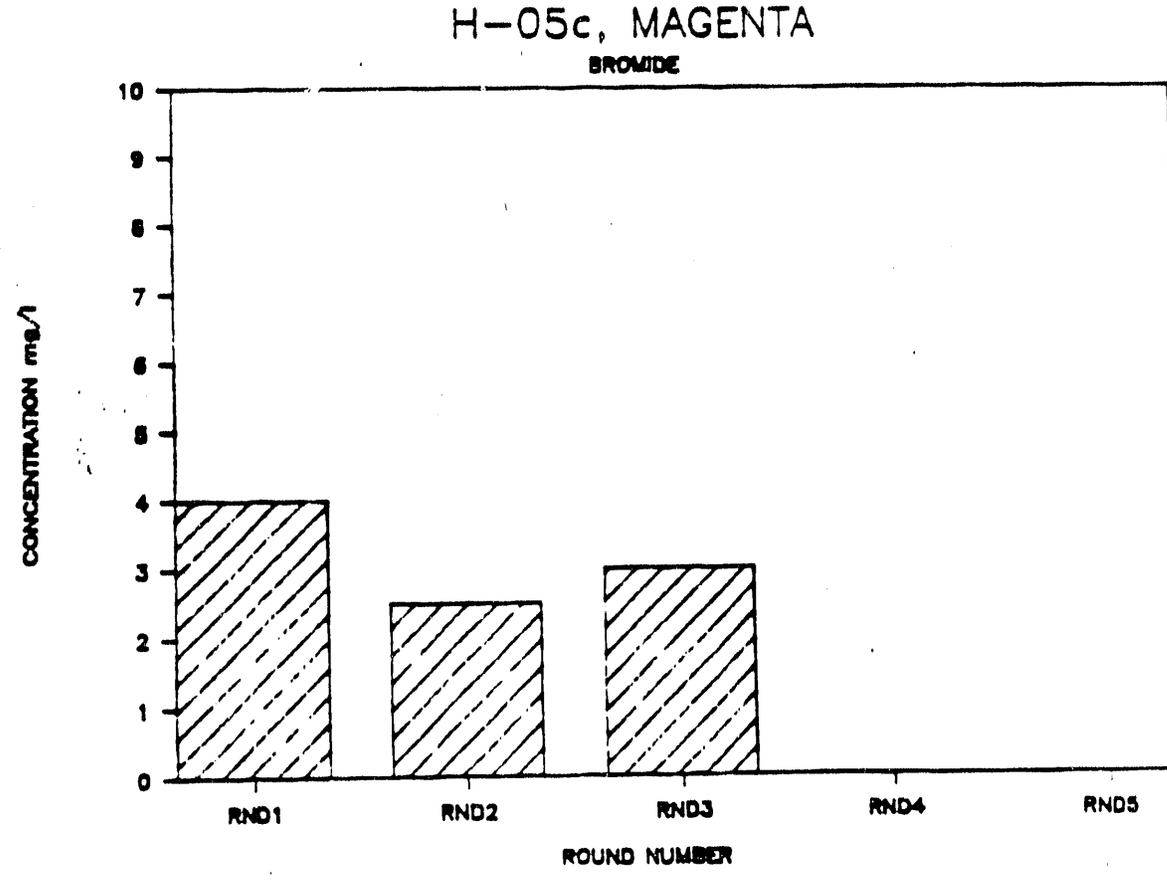

H-04c, MAGENTA
ALKALINITY
CONCENTRATION mg/l
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

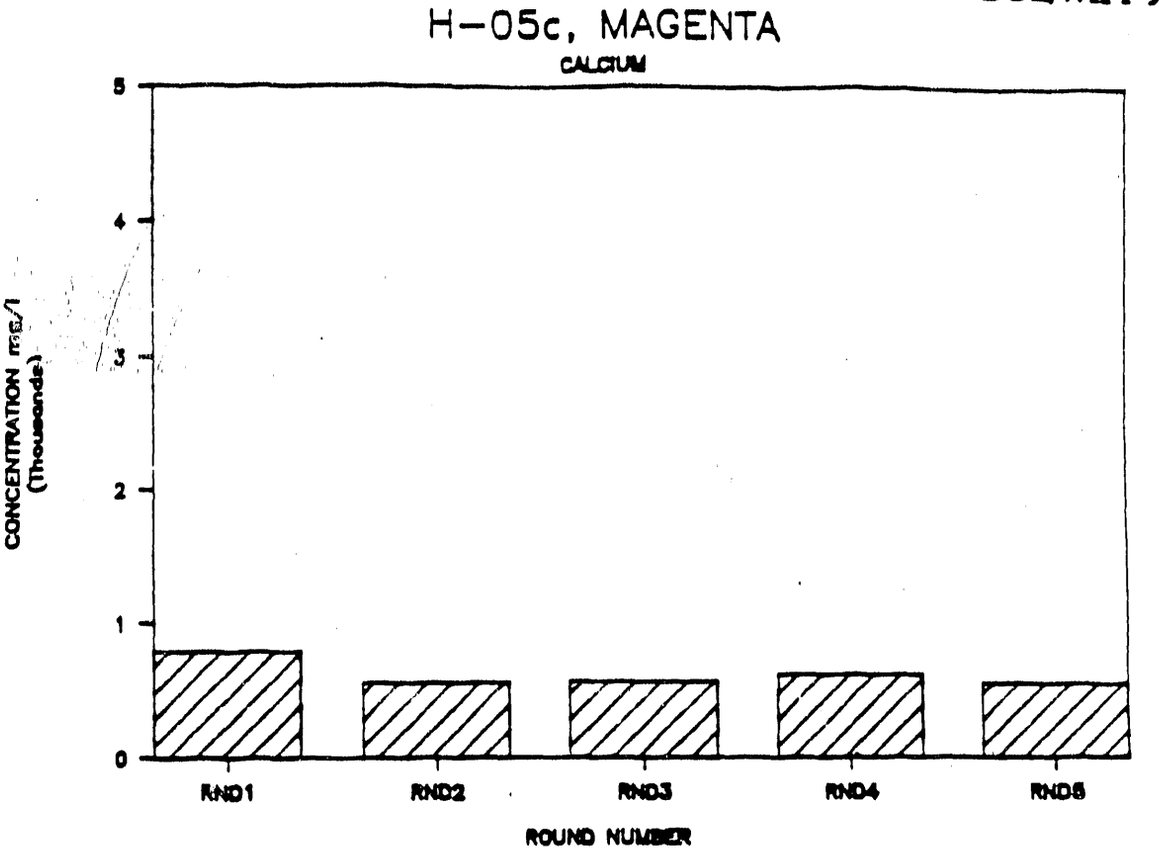

H-04c, MAGENTA
BROMIDE
CONCENTRATION mg/l
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

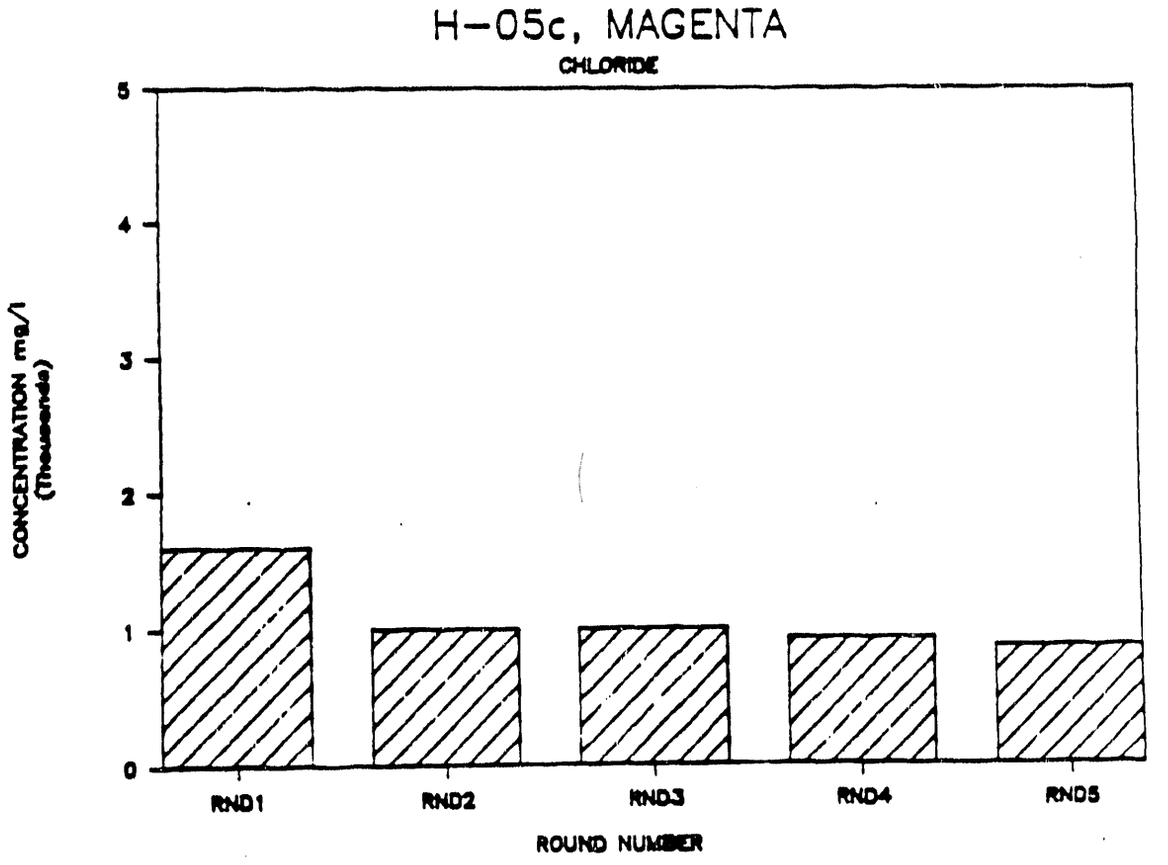

H-04c, MAGENTA
CALCIUM
CONCENTRATION mg/l
(Thousands)
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

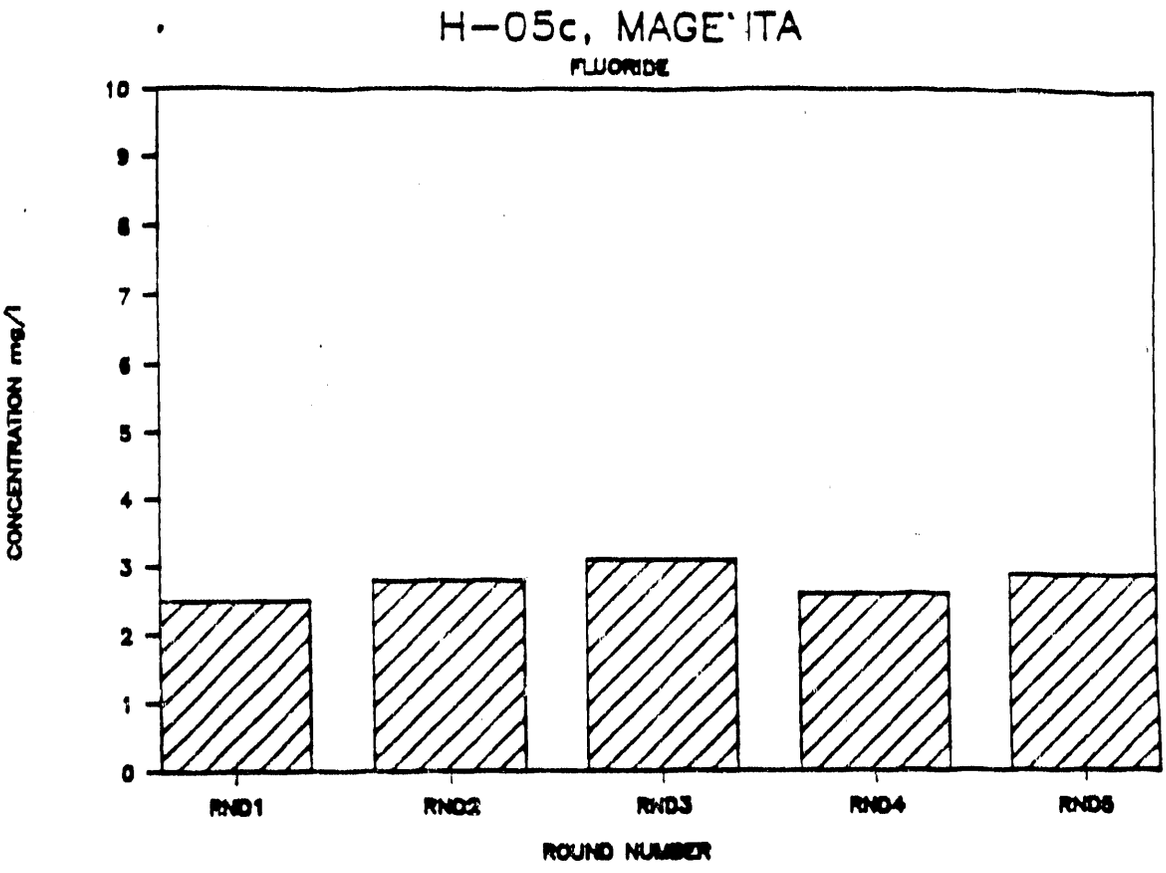

H-04c, MAGENTA
CHLORIDE
CONCENTRATION mg/l
(Thousands)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

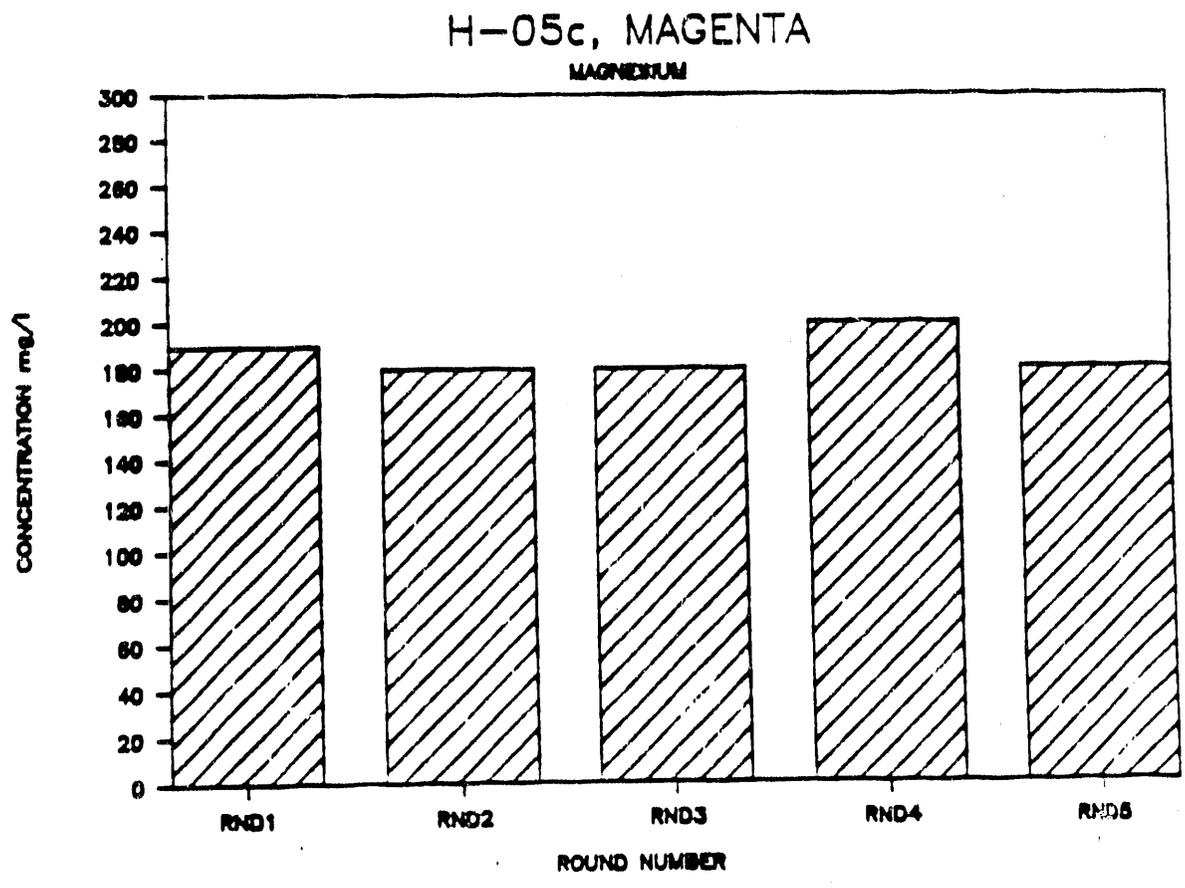

H-05c, MAGENTA
ALKALINITY
CONCENTRATION mg/l
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

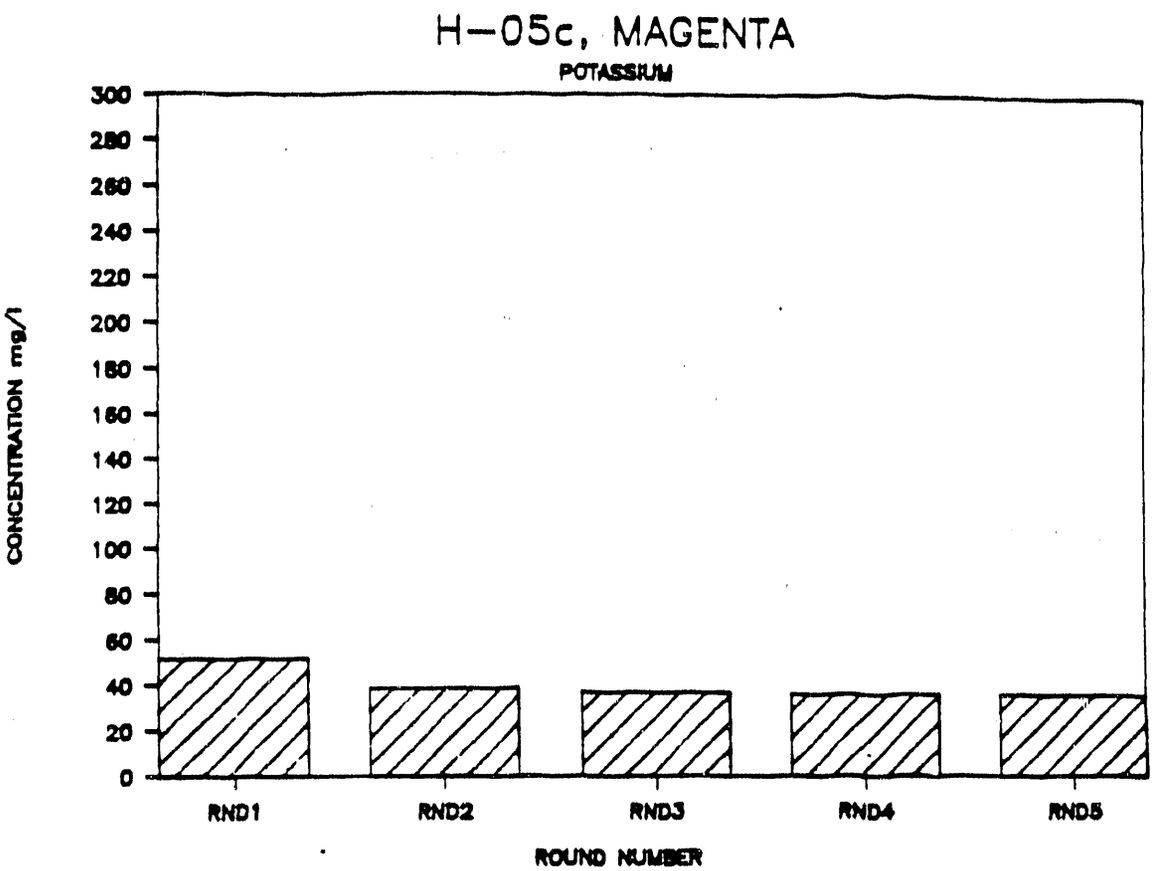

H-05c, MAGENTA
BROMIDE
CONCENTRATION mg/l
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

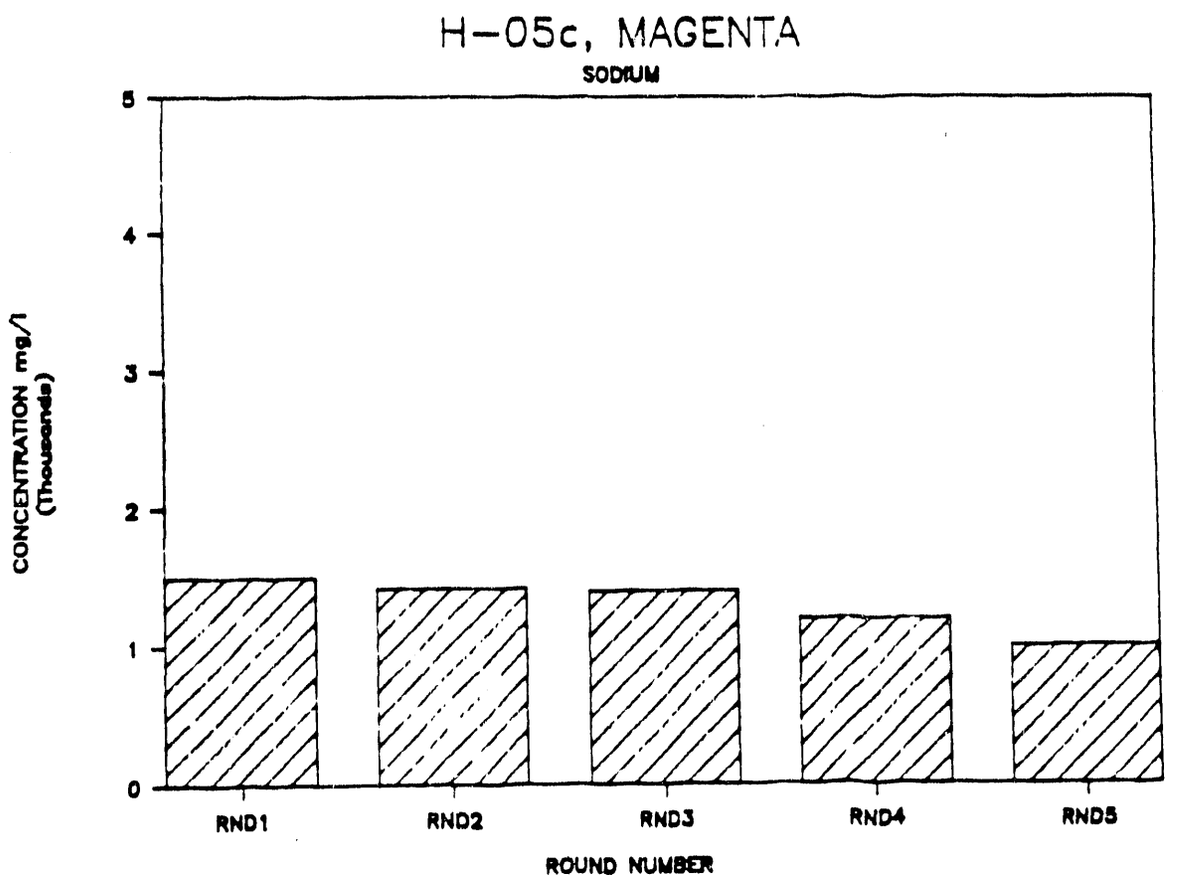

H-05c, MAGENTA
CALCIUM
CONCENTRATION mg/l
(Thousands)
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

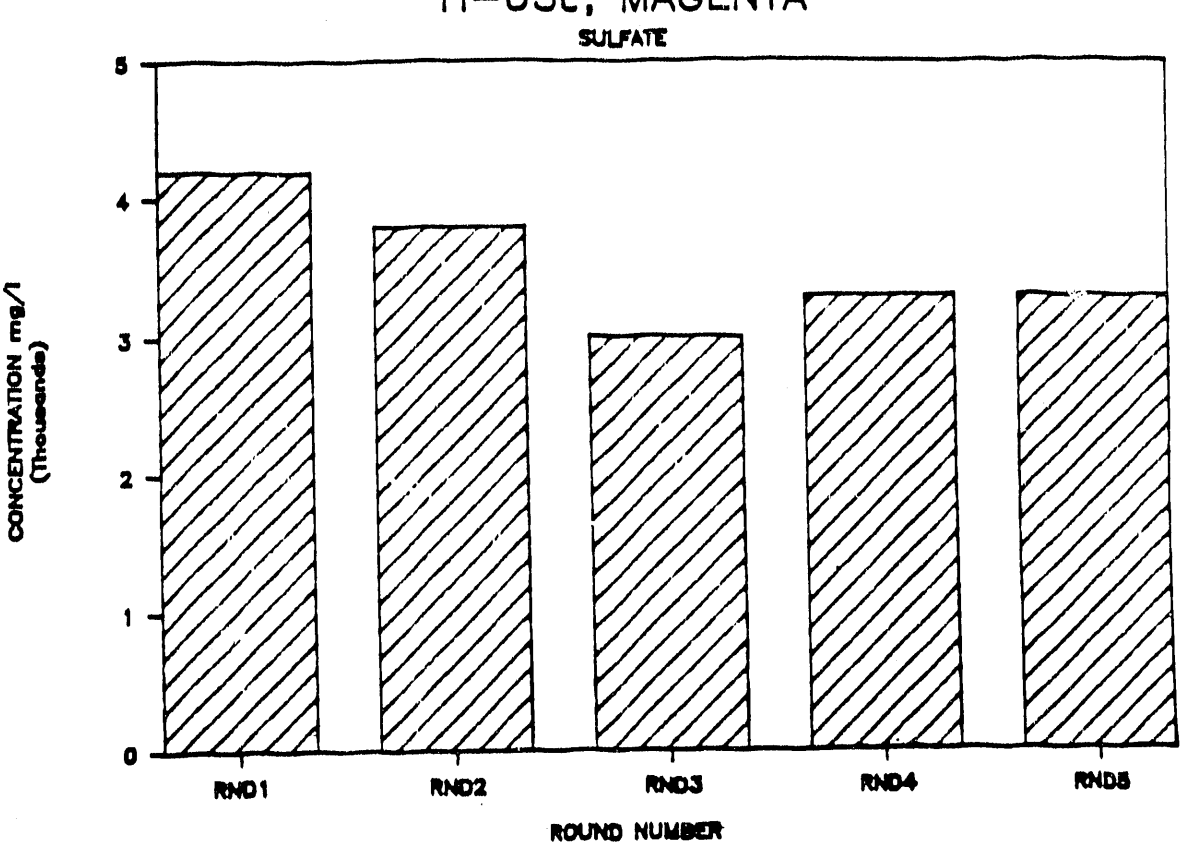

H-05c, MAGENTA
CHLORIDE
CONCENTRATION mg/l
(Thousands)
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

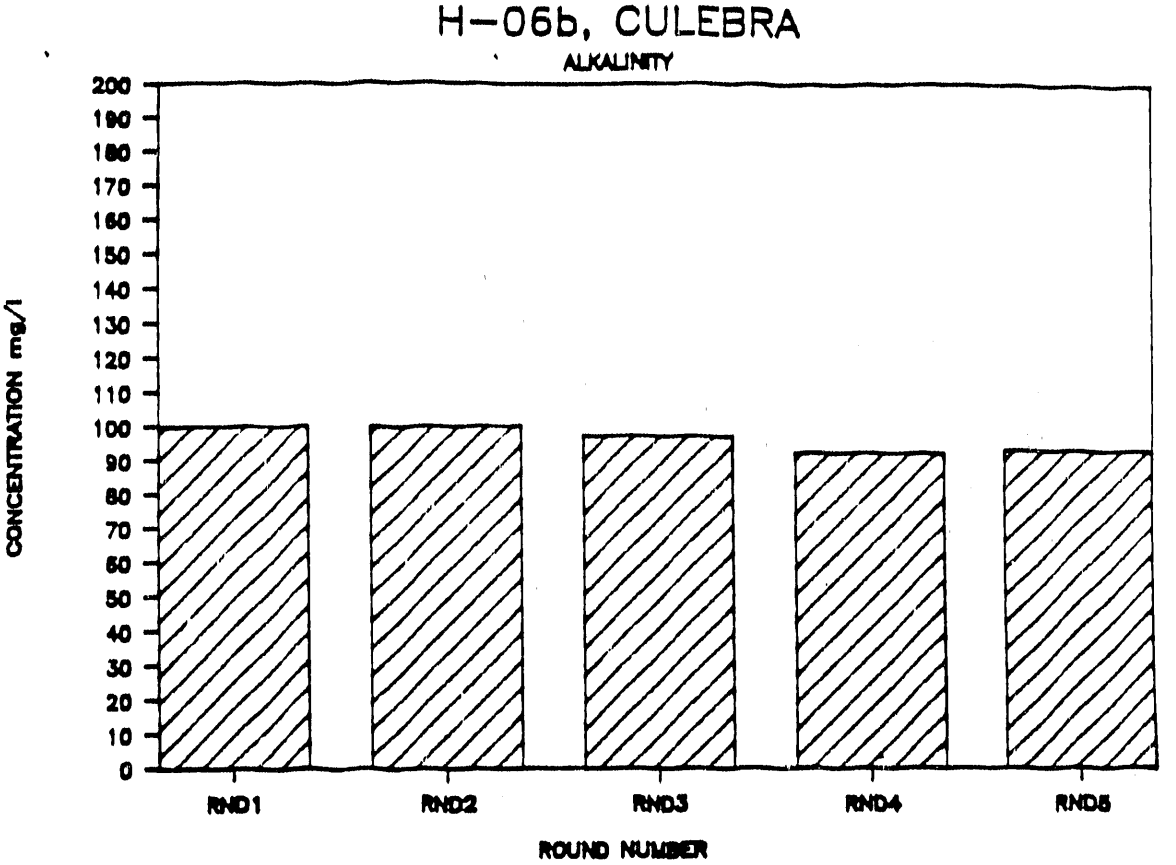

H-05c, MAGENTA
FLUORIDE
CONCENTRATION mg/l
0
1
2
3
4
5
6
7
8
9
10
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

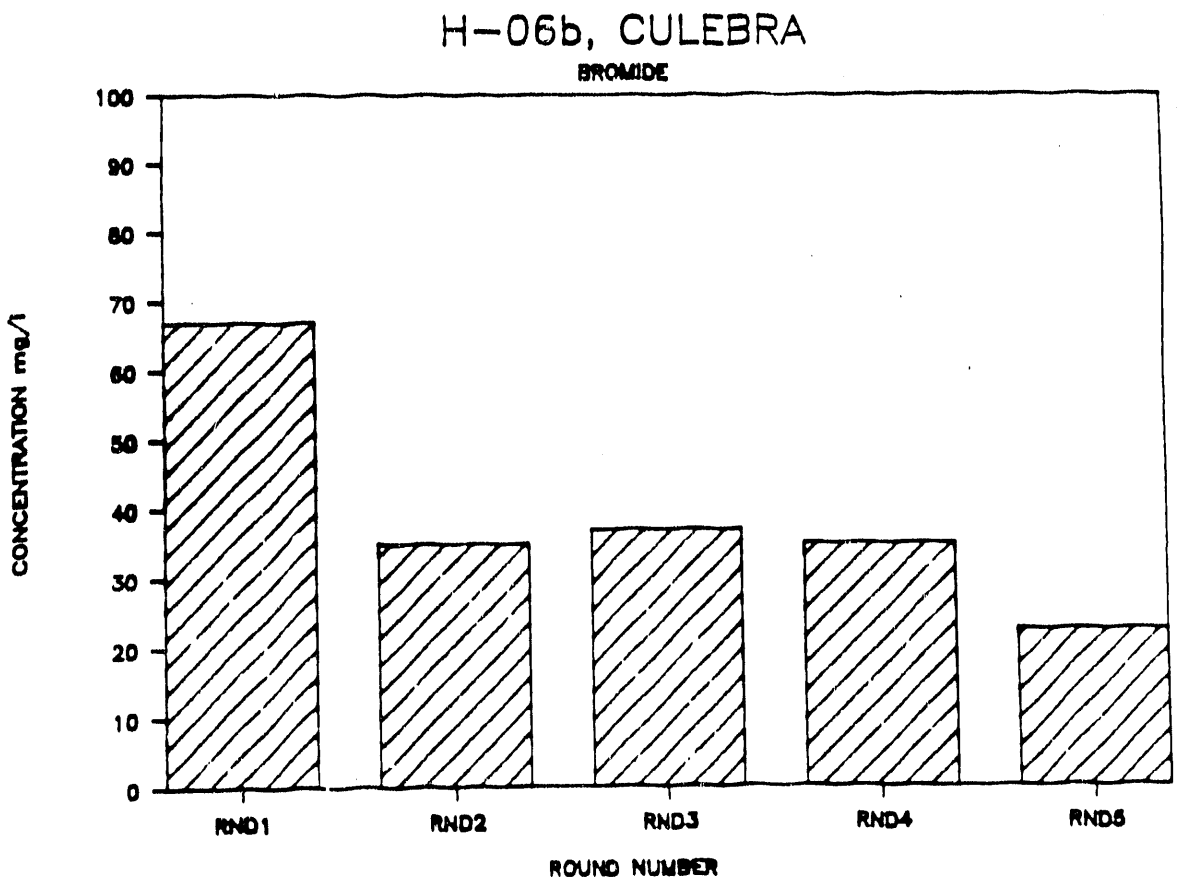

H-05c, MAGENTA
MAGNESIUM
CONCENTRATION mg/l
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

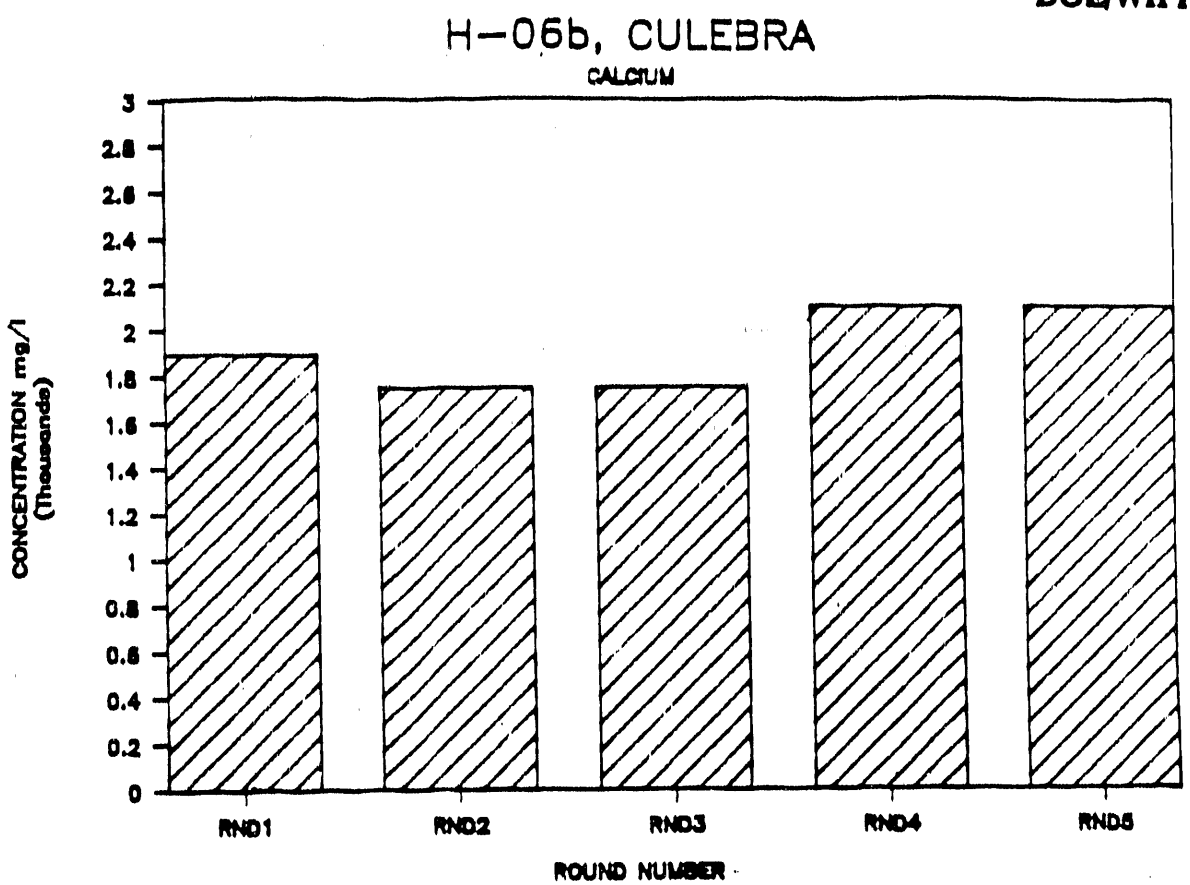

H-05c, MAGENTA
POTASSIUM
CONCENTRATION mg/l
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

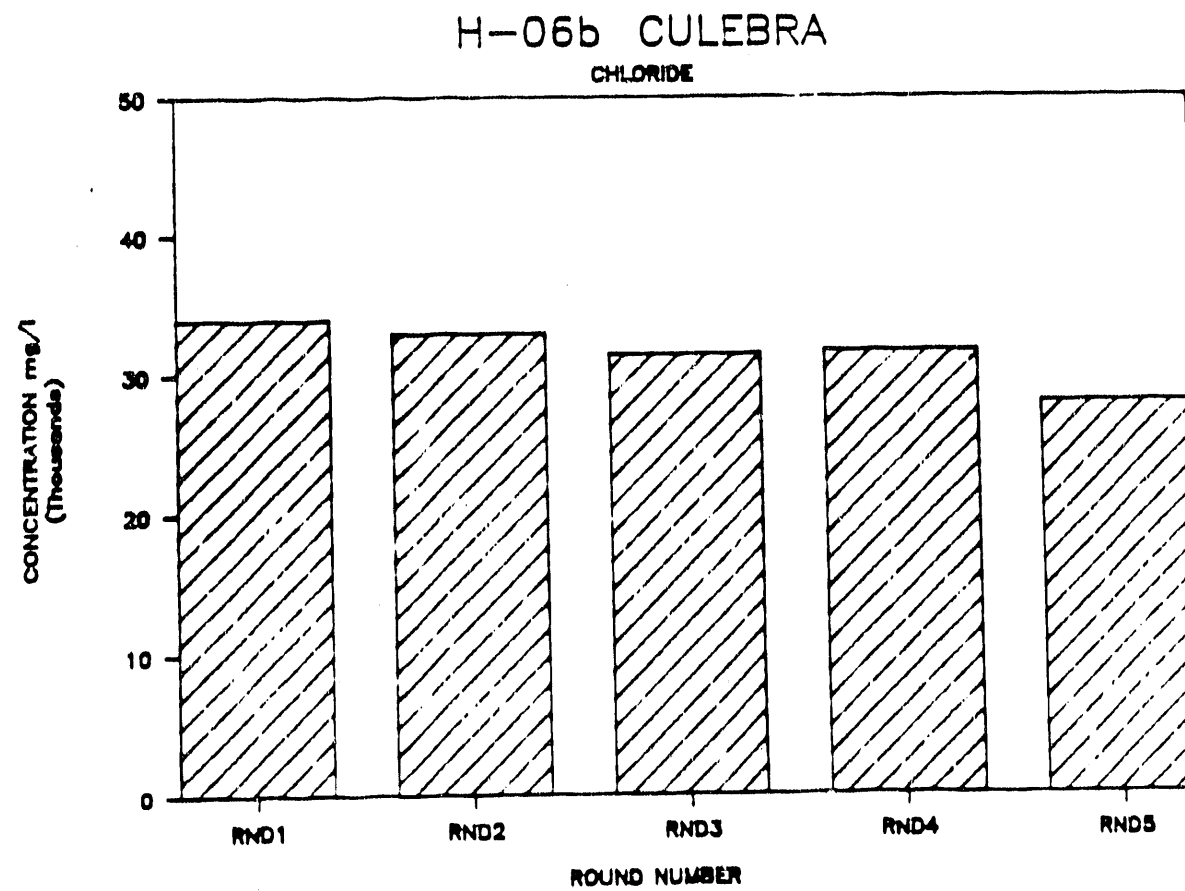

H-05c, MAGENTA
SODIUM
CONCENTRATION mg/l
(Thousands)
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

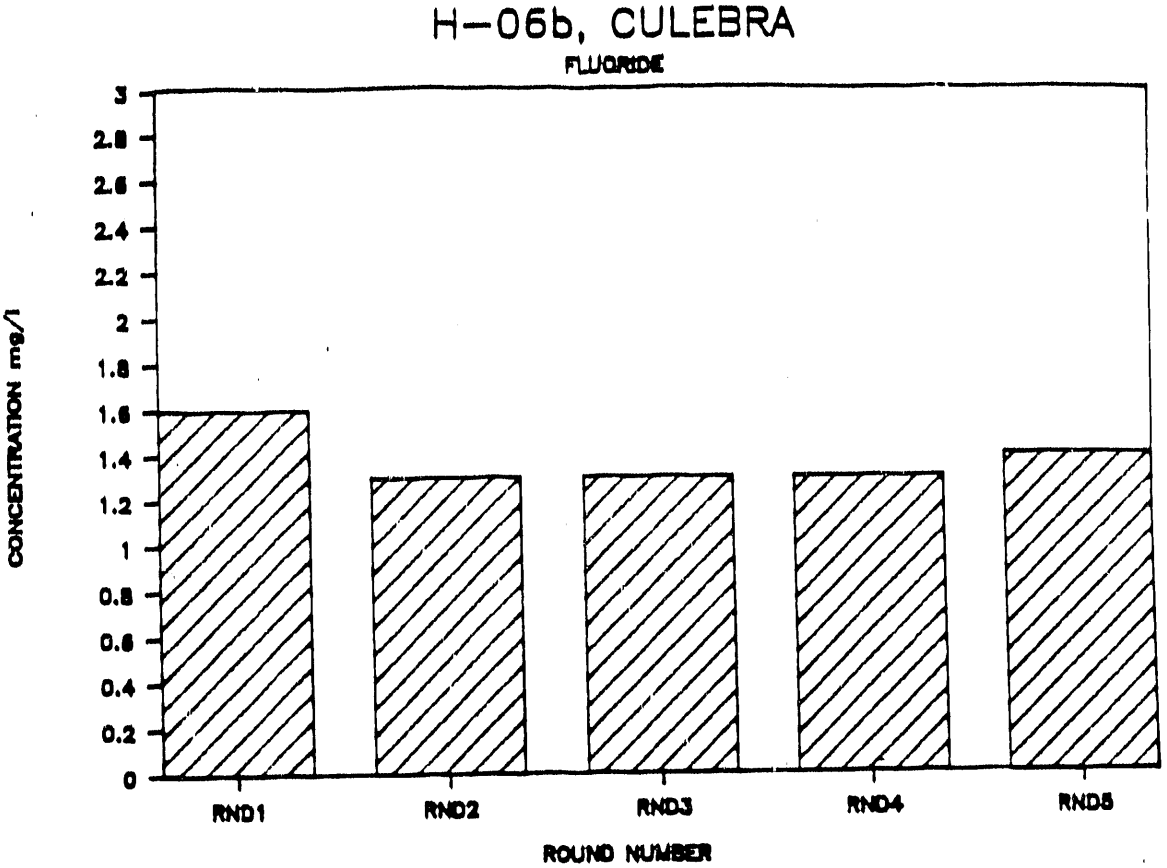

H-05c, MAGENTA
SULFATE
CONCENTRATION mg/l
(Thousands)
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

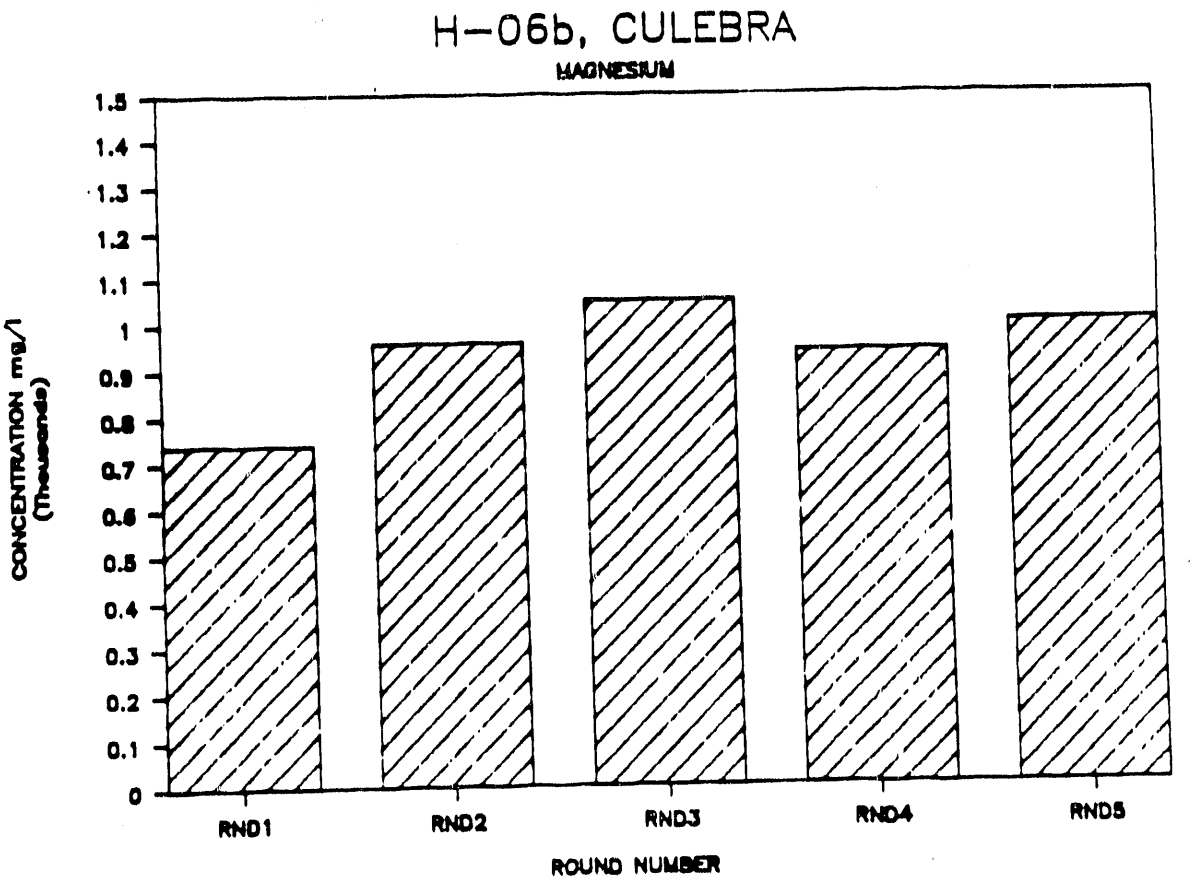

H-06b, CULEBRA
ALKALINITY
CONCENTRATION mg/l
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

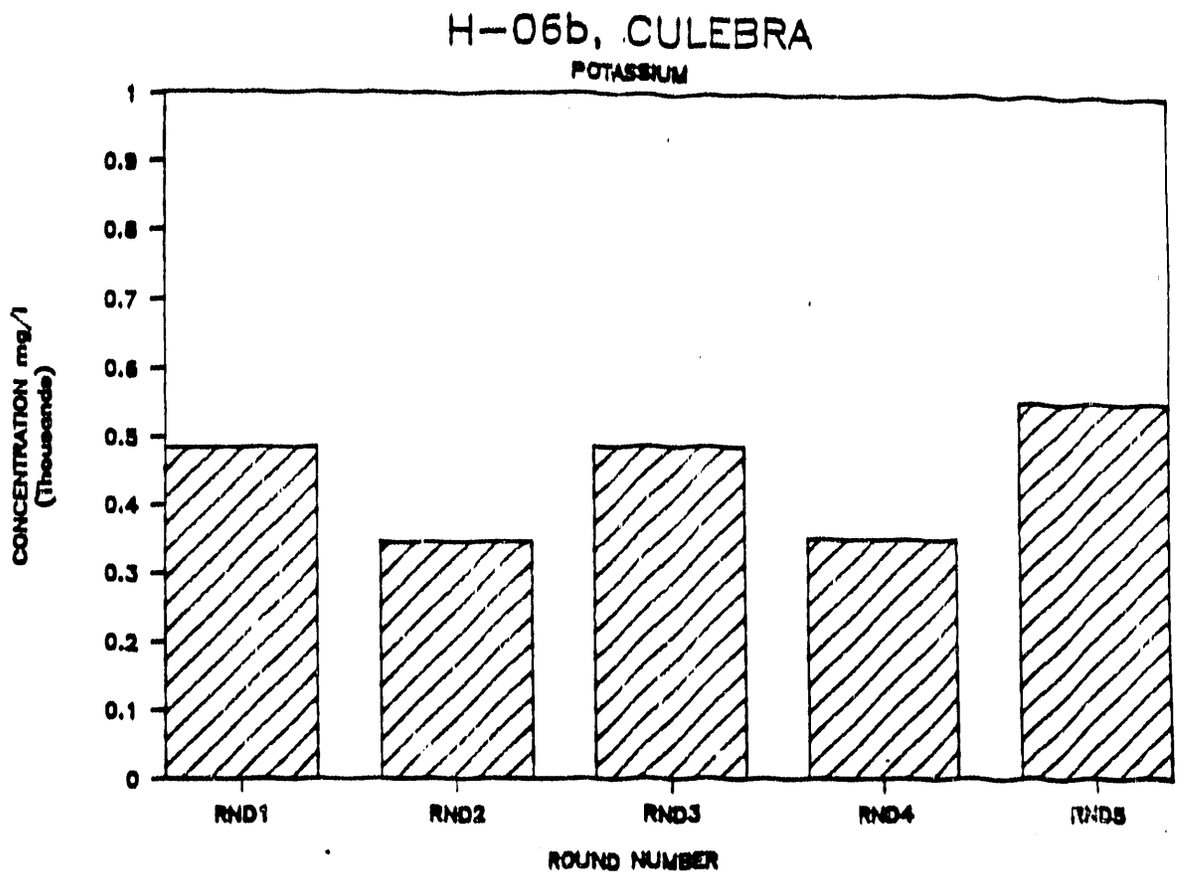

H-06b, CULEBRA
BROMIDE
CONCENTRATION mg/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

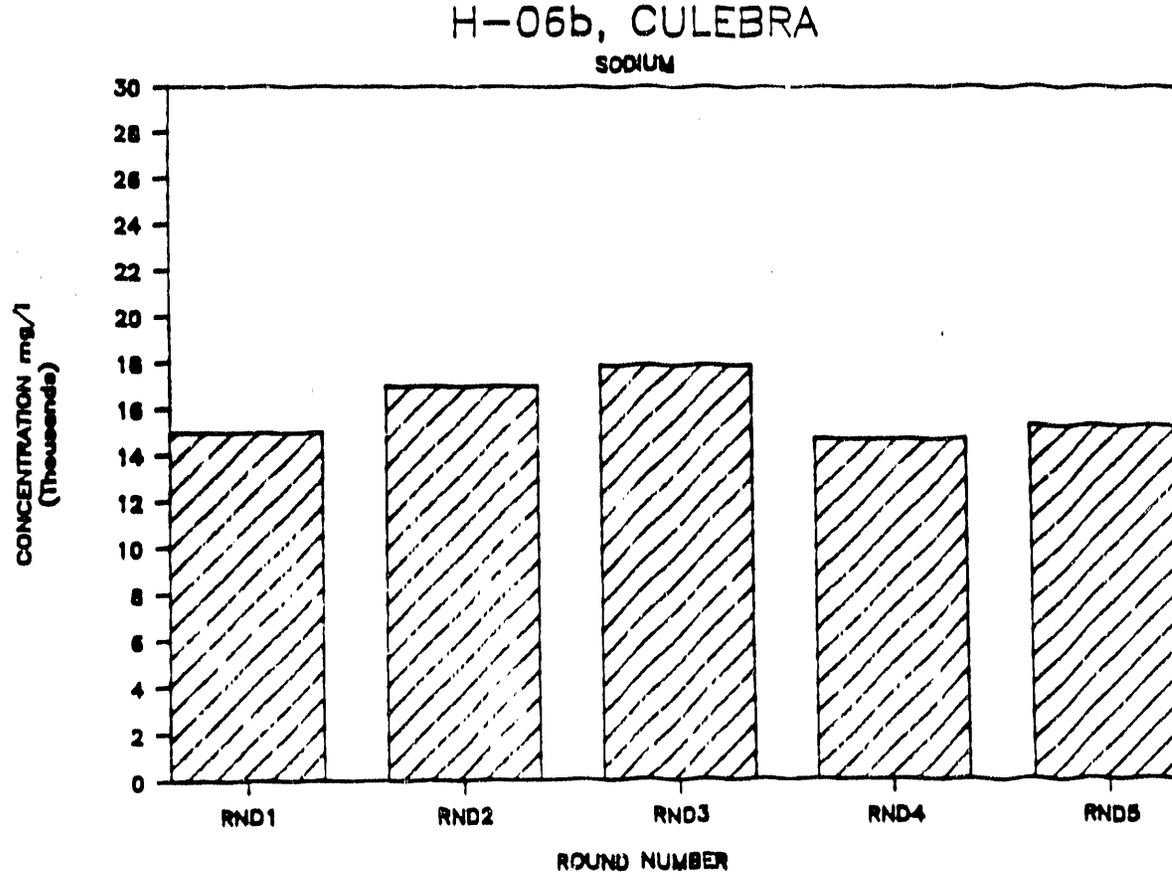

H-06b, CULEBRA
CALCIUM
CONCENTRATION mg/l
(Thousands)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

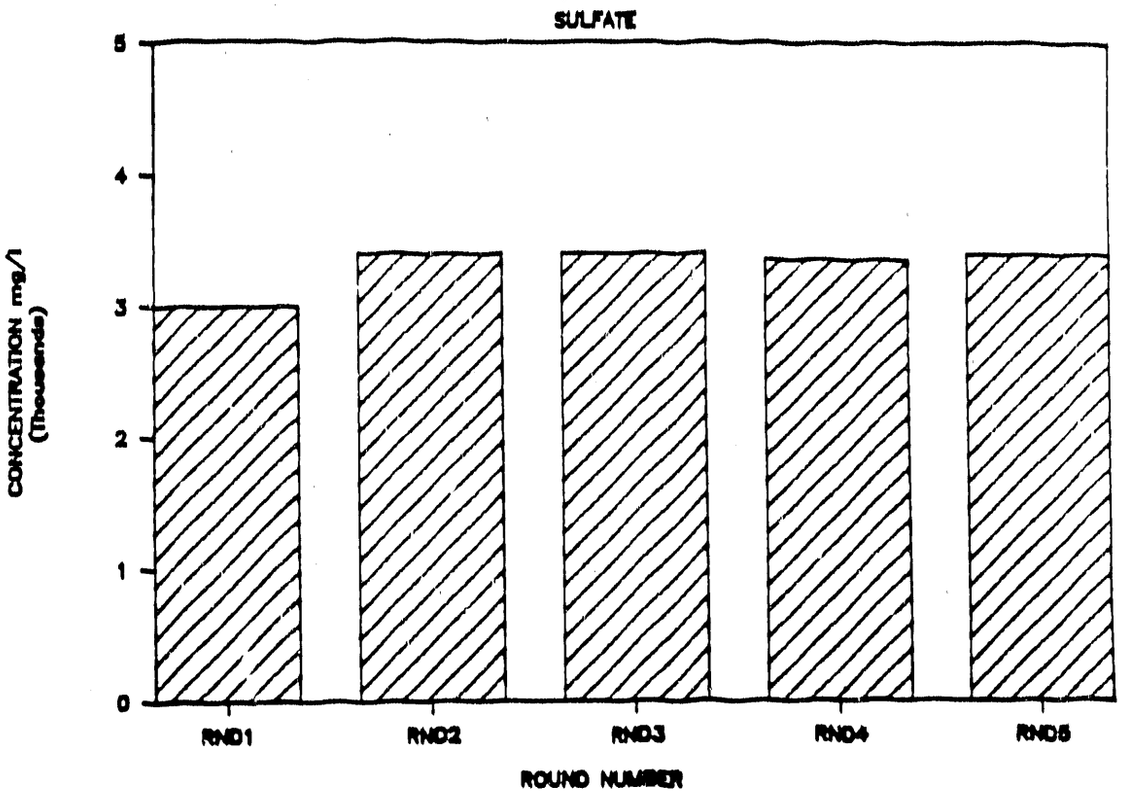

H-06b CULEBRA
CHLORIDE
CONCENTRATION mg/l
(Thousands)
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

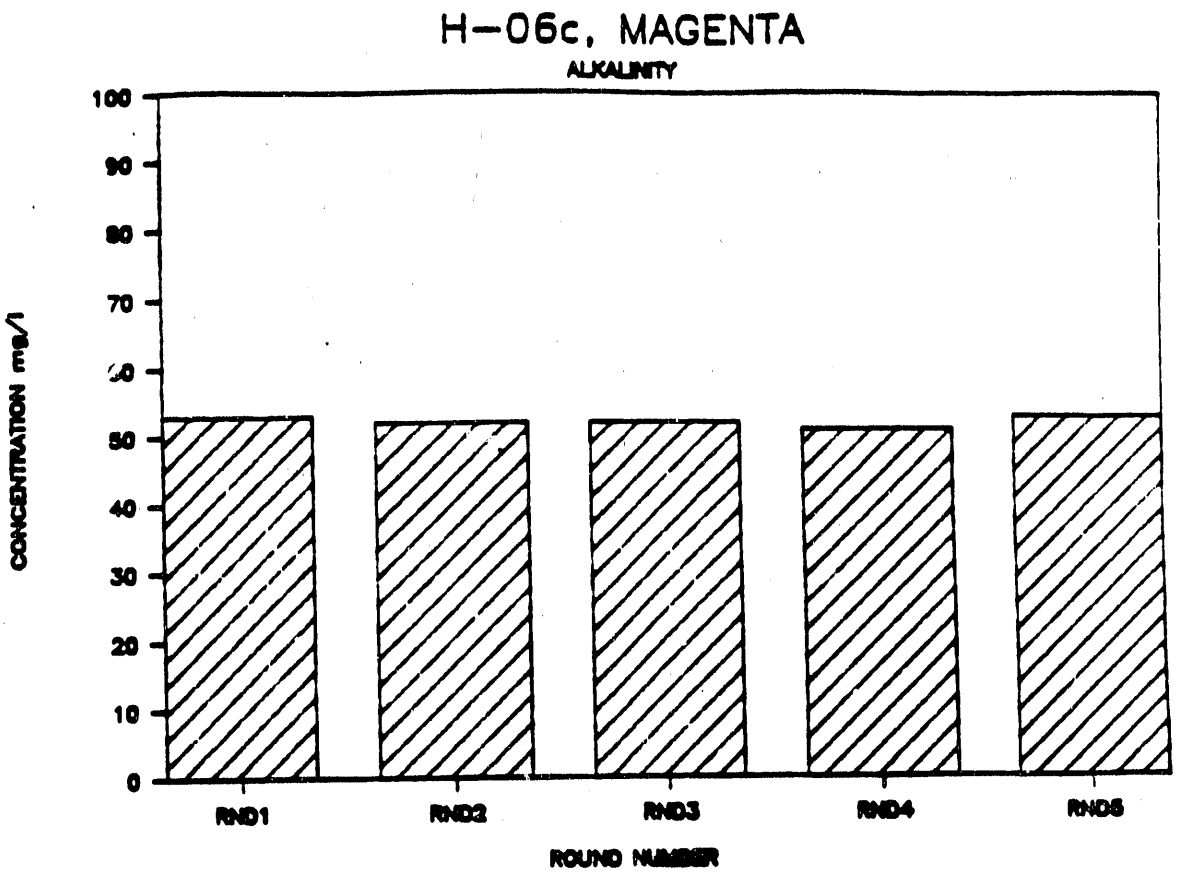

H-06b, CULEBRA
FLUORIDE
CONCENTRATION mg/l
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

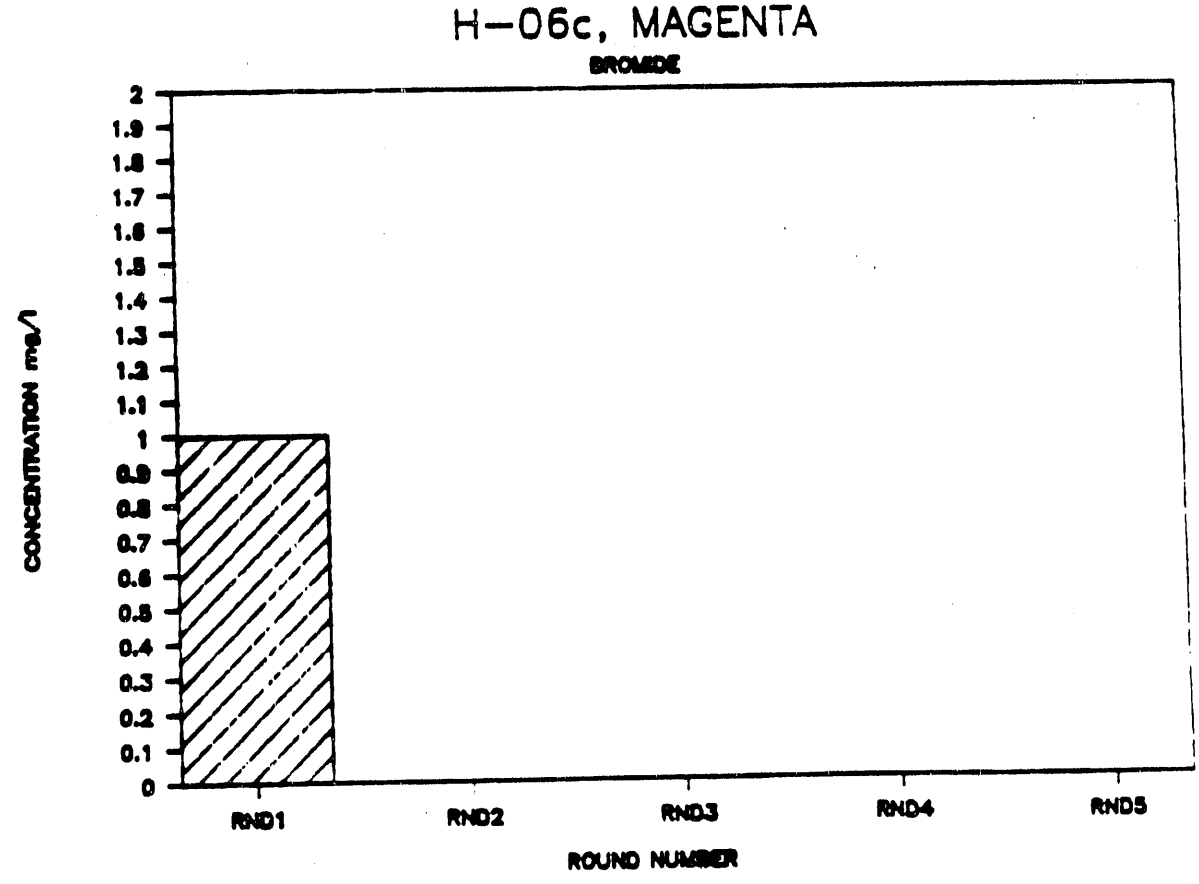

H-06b, CULEBRA
MAGNESIUM
CONCENTRATION mg/l
(Thousands)
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

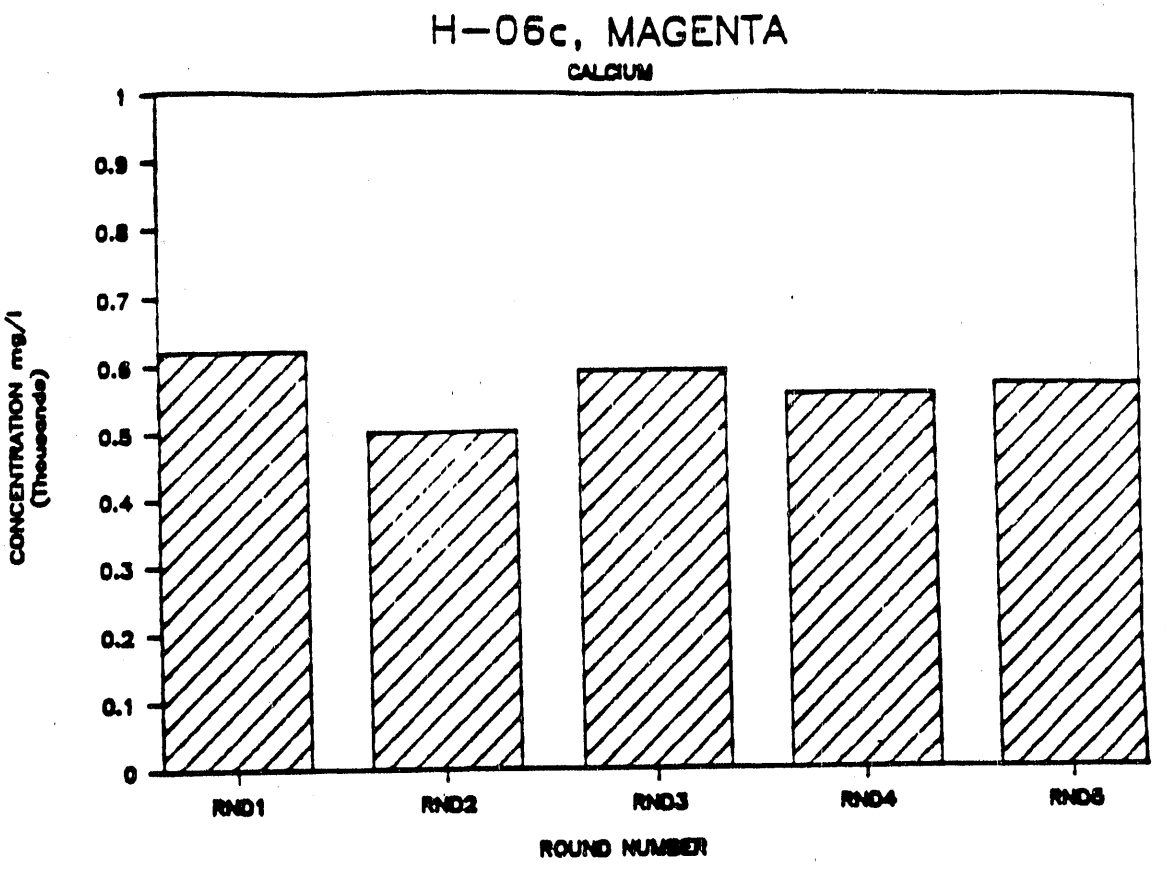

H-06b, CULEBRA
POTASSIUM
CONCENTRATION mg/l
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

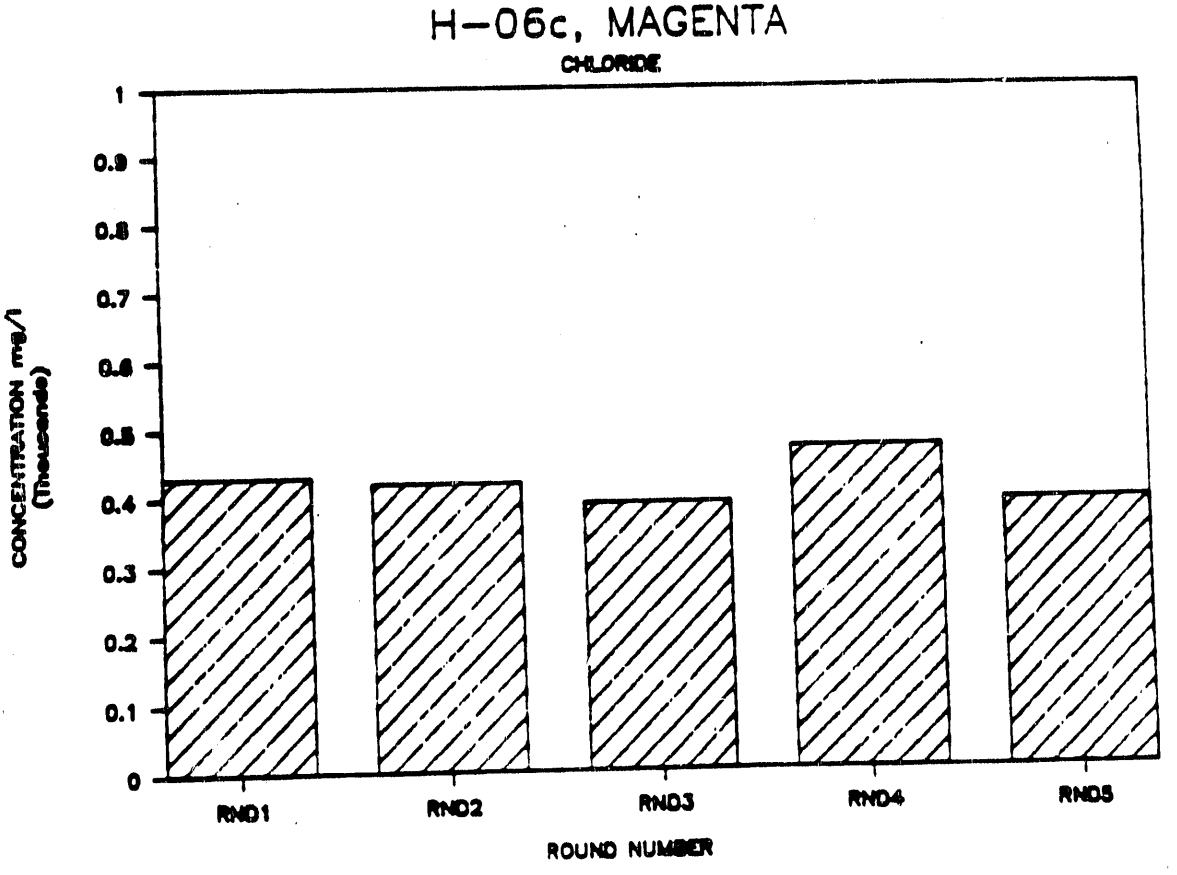

H-06b, CULEBRA
SODIUM
CONCENTRATION mg/l
(Thousands)
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

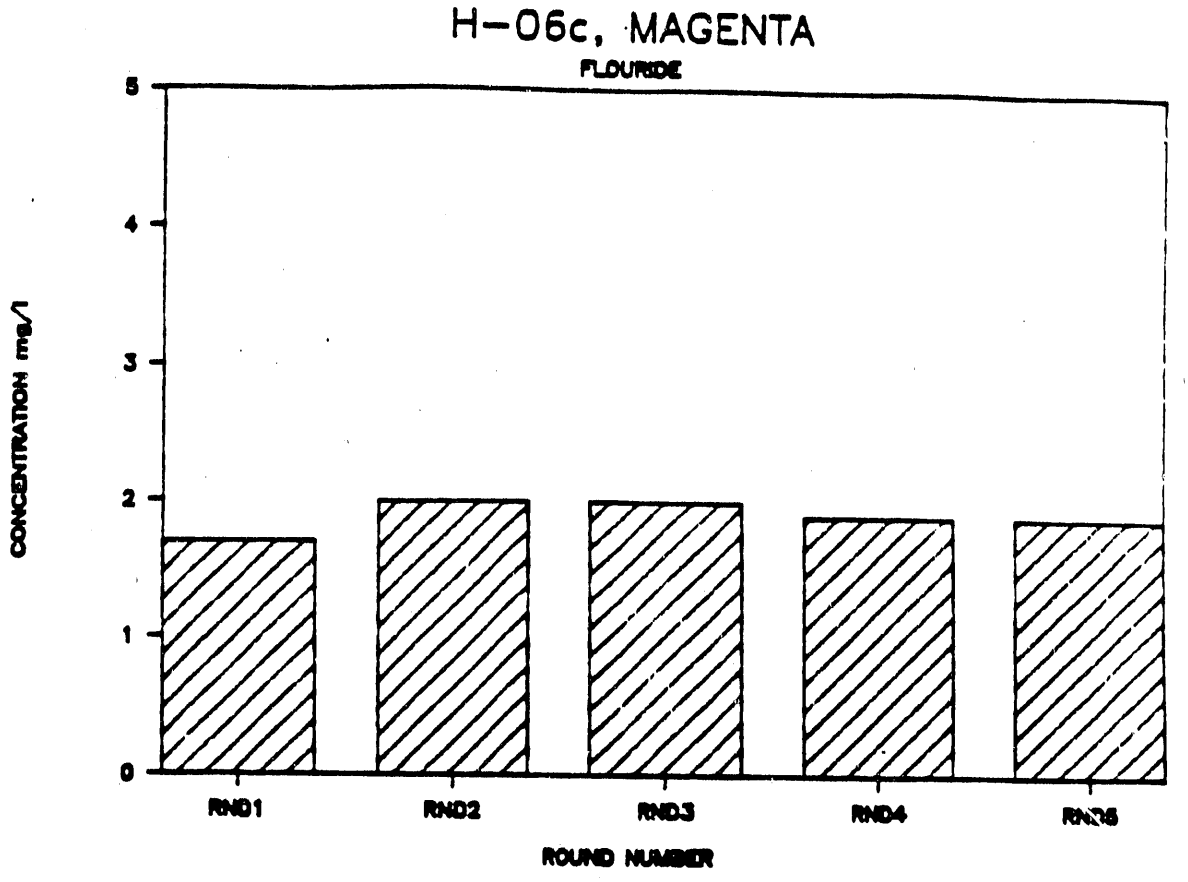

H-06b, CULEBRA
SULFATE
CONCENTRATION mg/l
(Thousands)
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

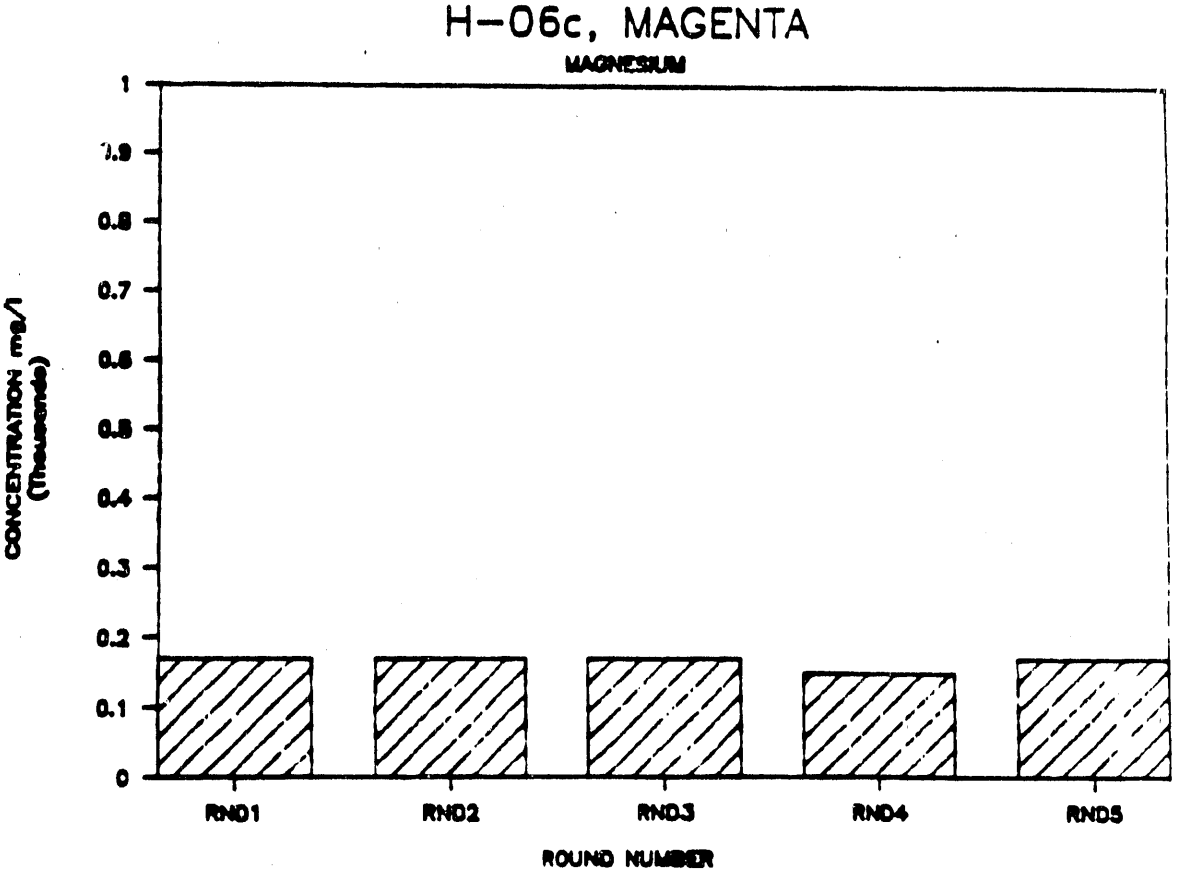

H-06c, MAGENTA
ALKALINITY
CONCENTRATION mg/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

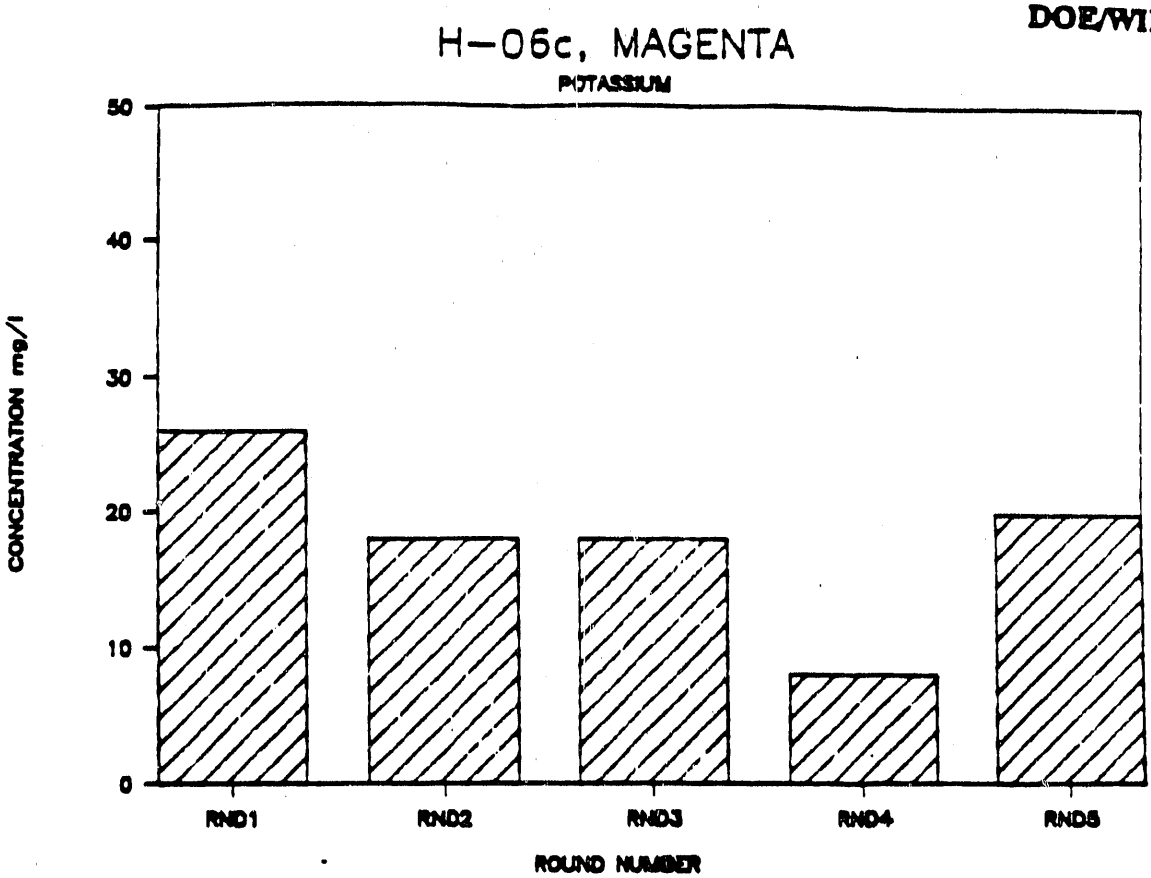

H-06c, MAGENTA
BROMIDE
CONCENTRATION mg/l
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

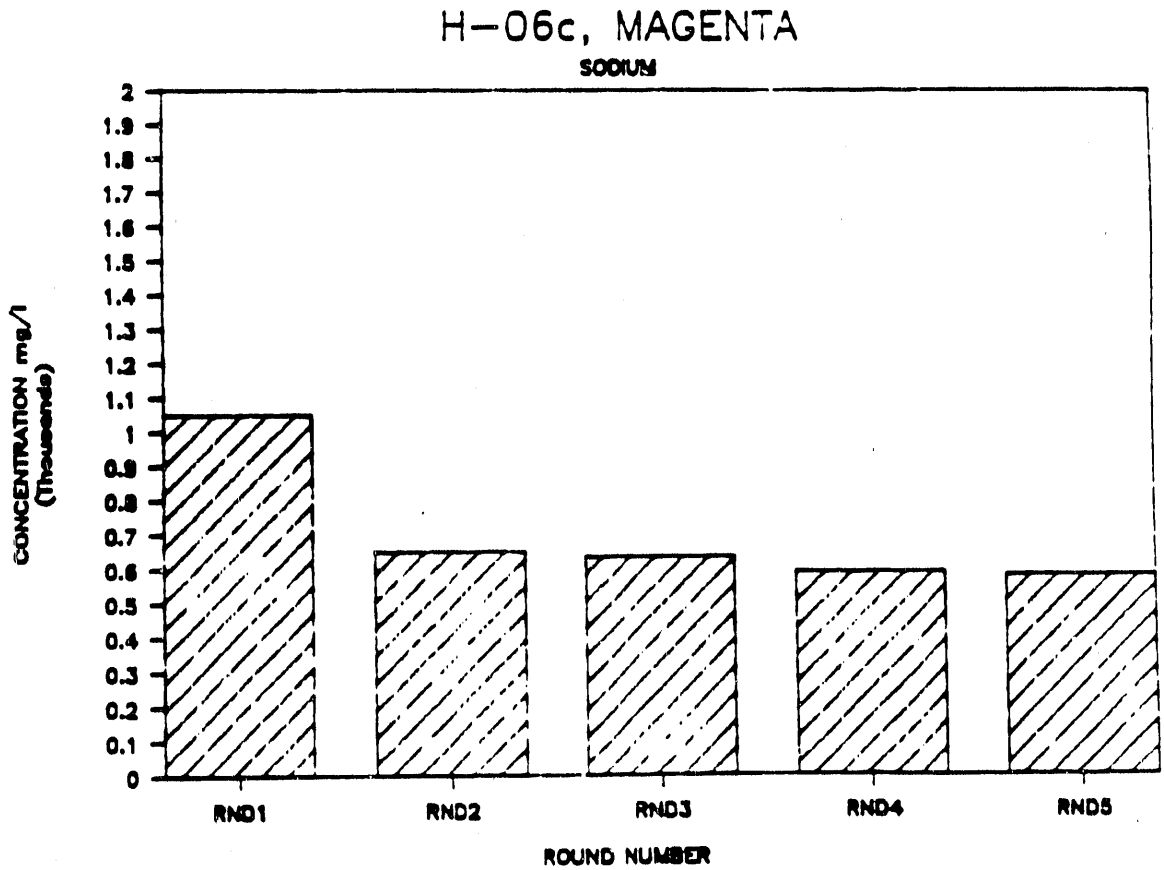

H-06c, MAGENTA
CALCIUM
CONCENTRATION mg/l
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

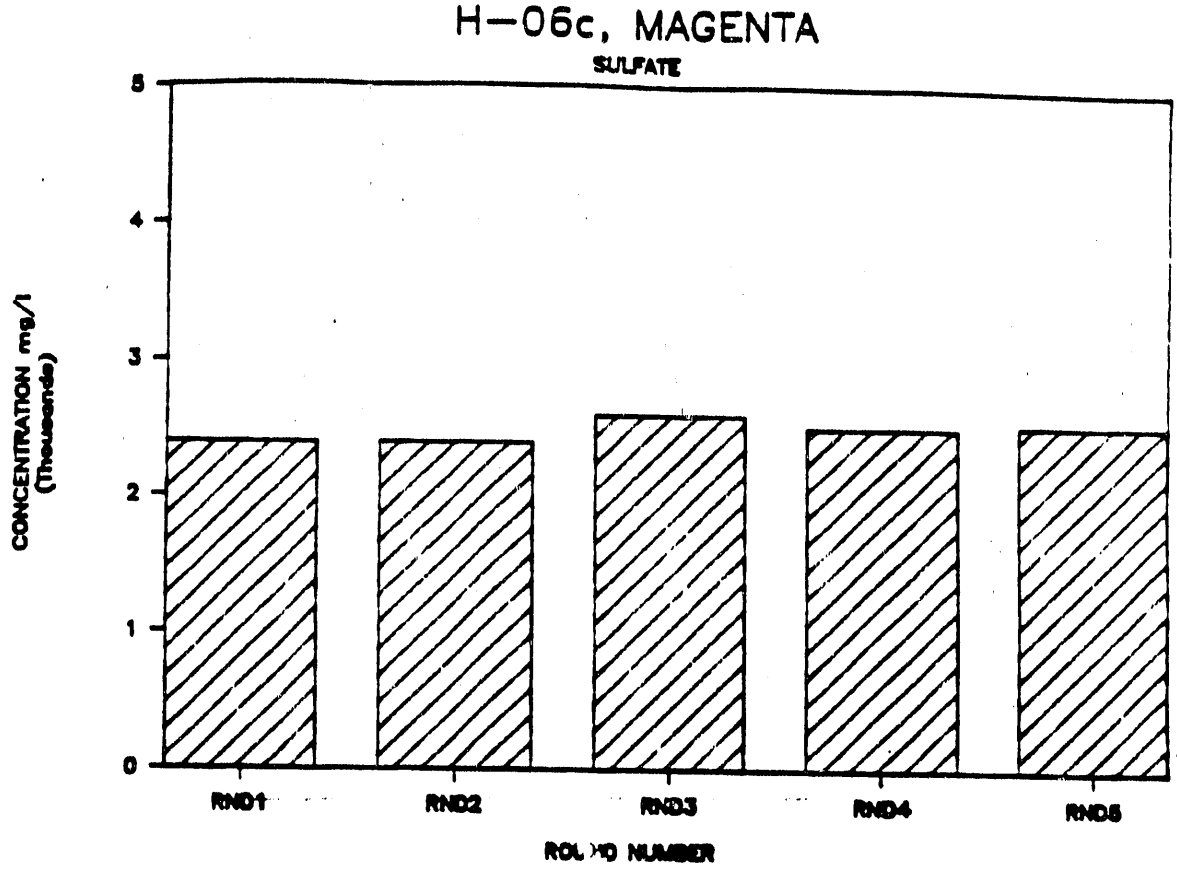

H-06c, MAGENTA
CHLORIDE
CONCENTRATION mg/l
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

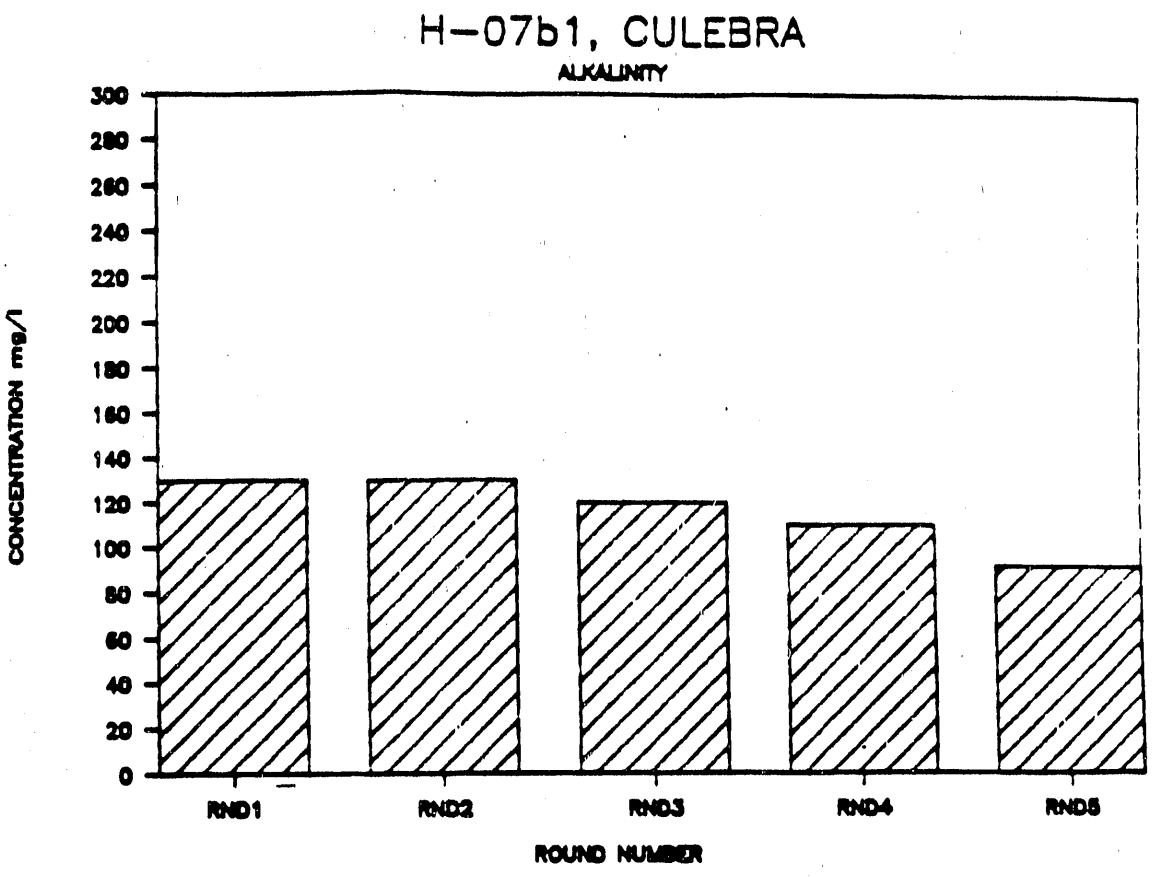

H-06c, MAGENTA
FLOURIDE
CONCENTRATION mg/l
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

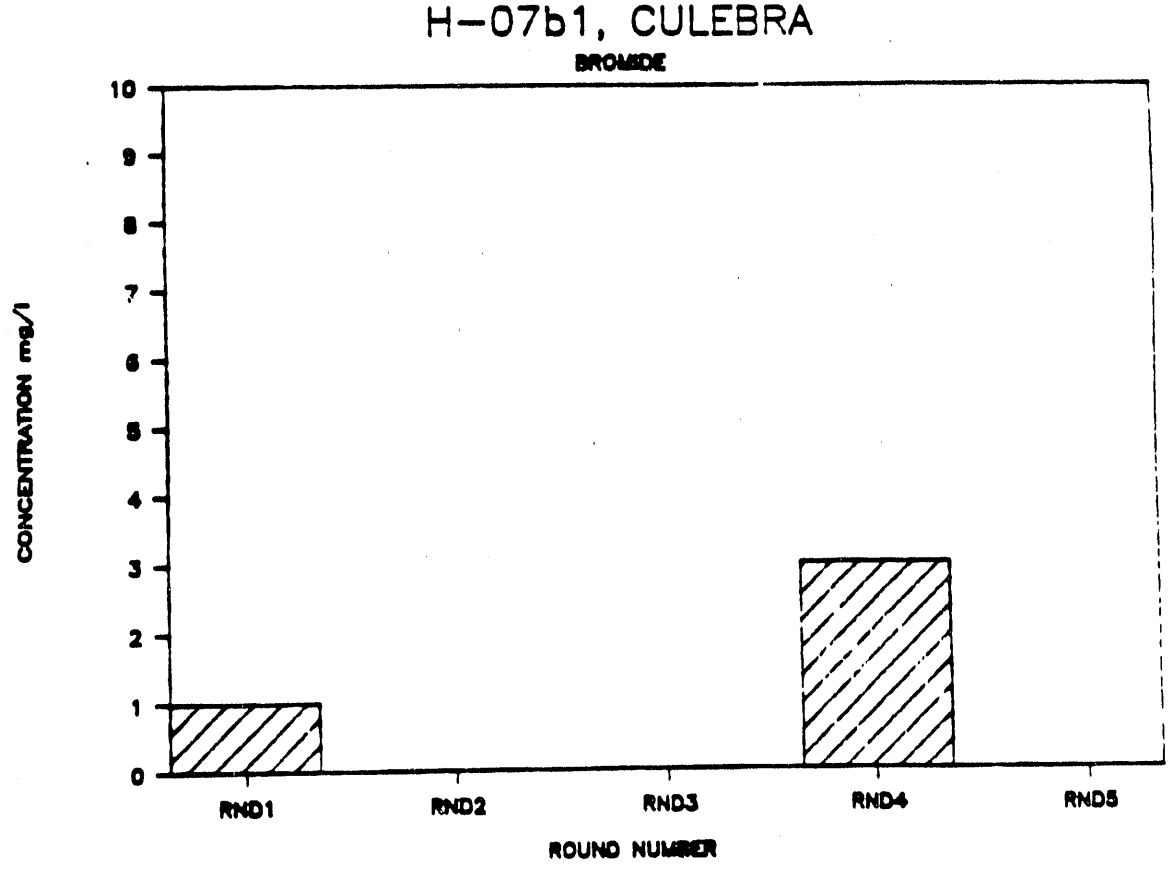

H-06c, MAGENTA
MAGNESIUM
CONCENTRATION mg/l
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

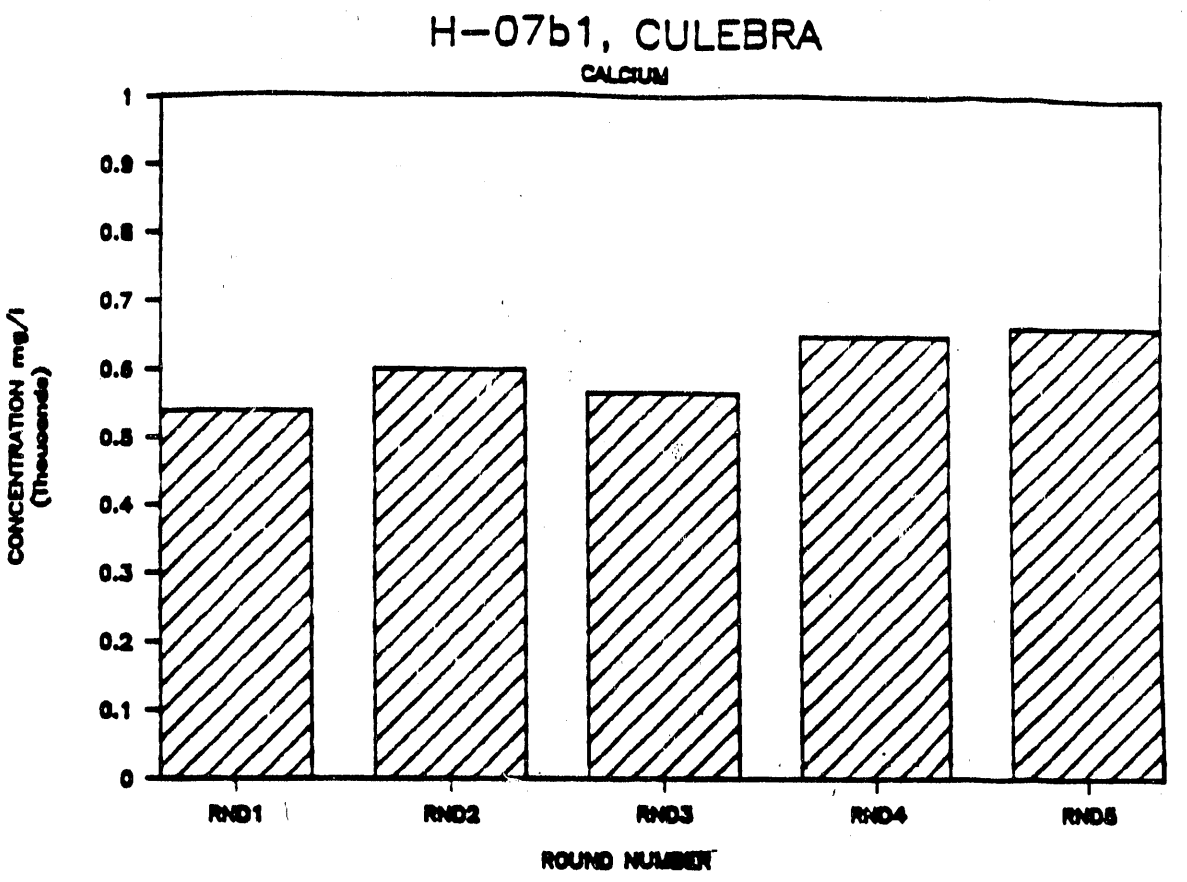

H-06c, MAGENTA
POTASSIUM
CONCENTRATION mg/l
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

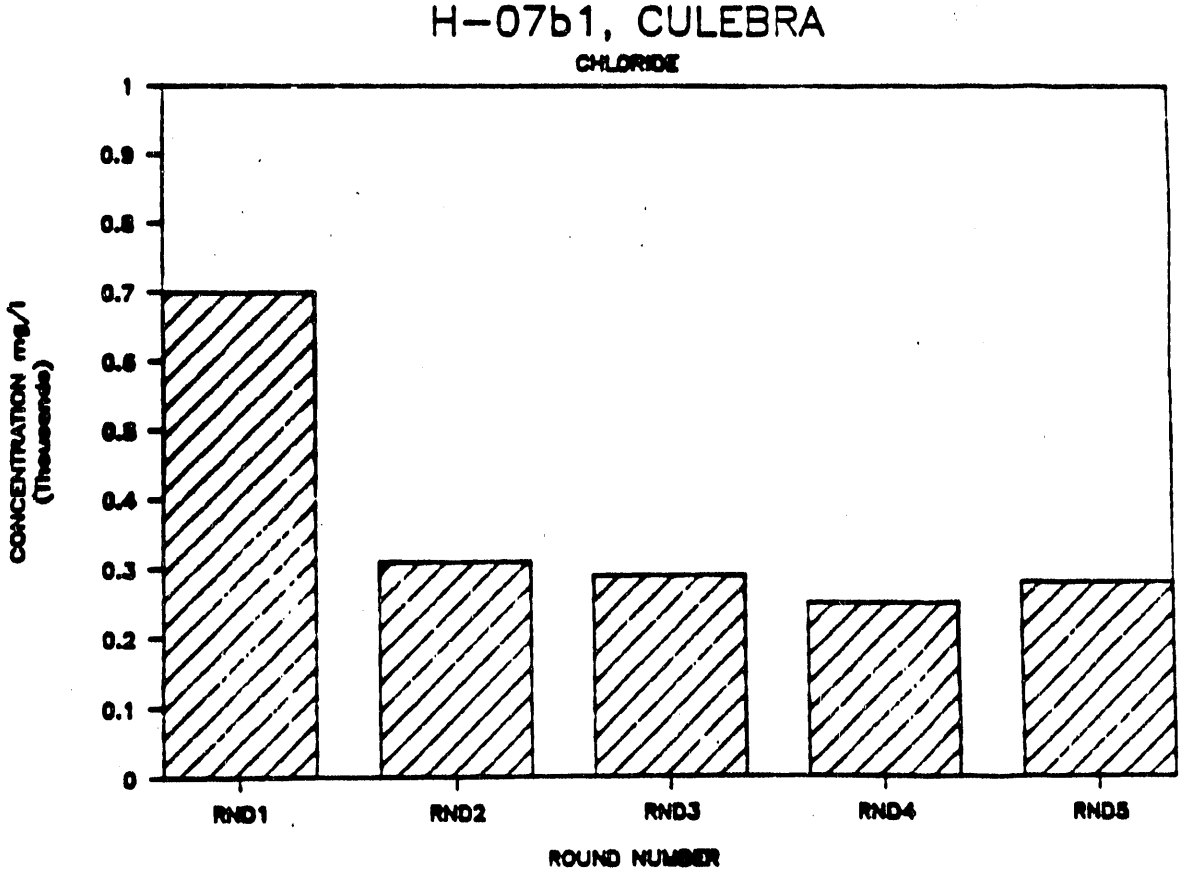

H-06c, MAGENTA
SODIUM
CONCENTRATION mg/l
(Thousands)
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

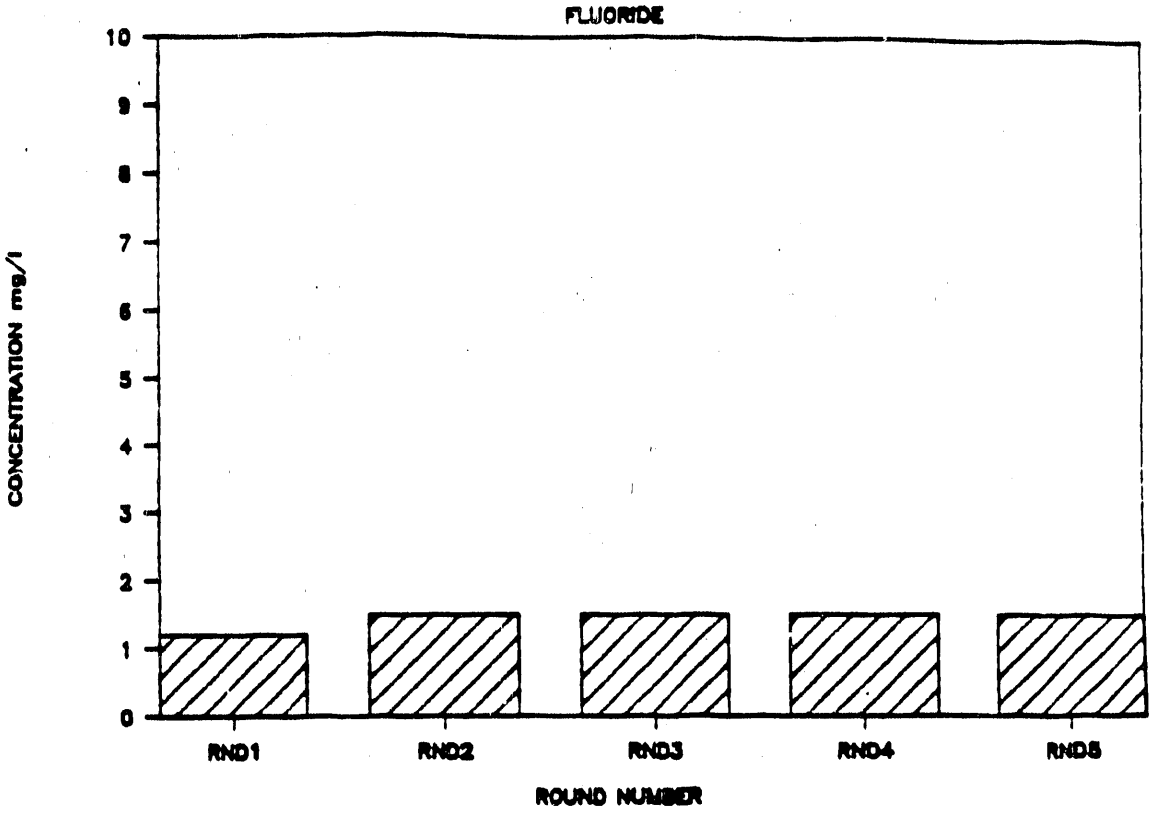

H—06c, MAGENTA
SULFATE
CONCENTRATION mg/l
(Thousands)
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

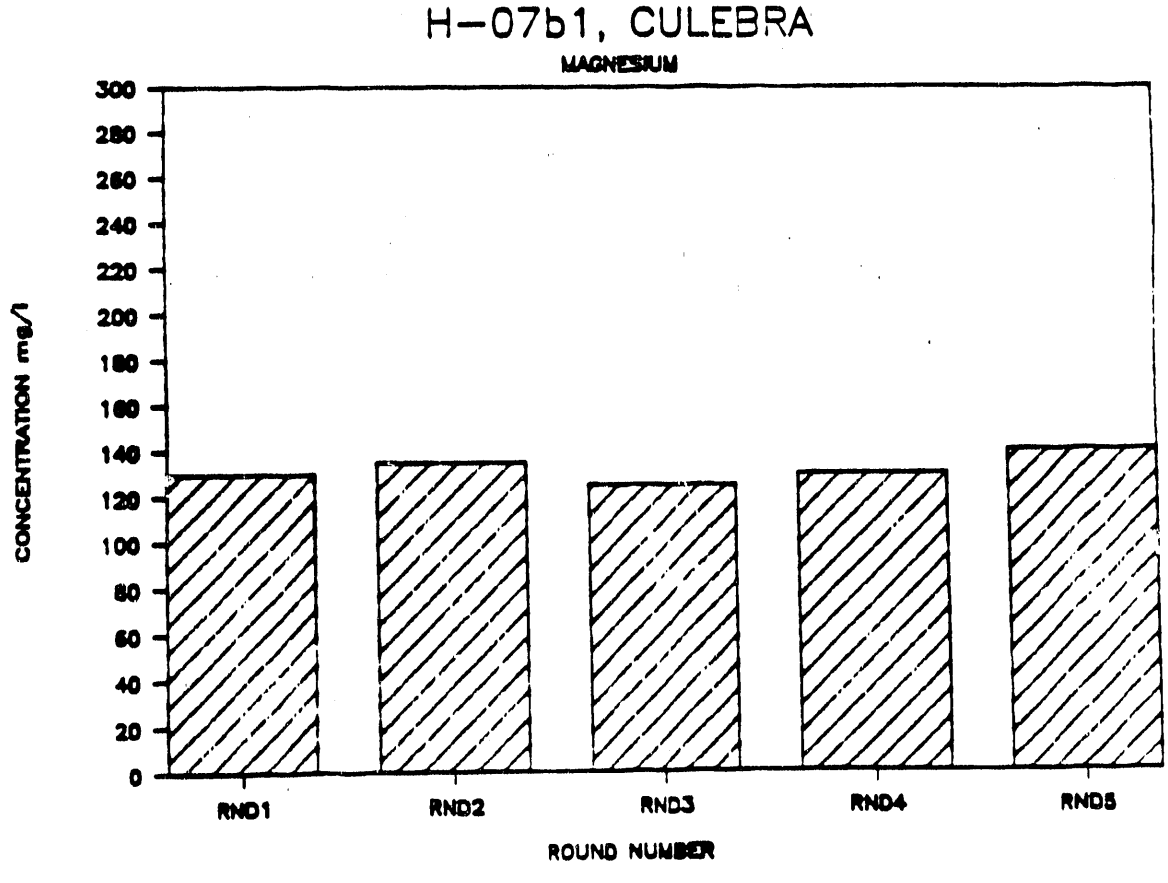

H-07b1, CULEBRA
ALKALINITY
CONCENTRATION mg/l
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

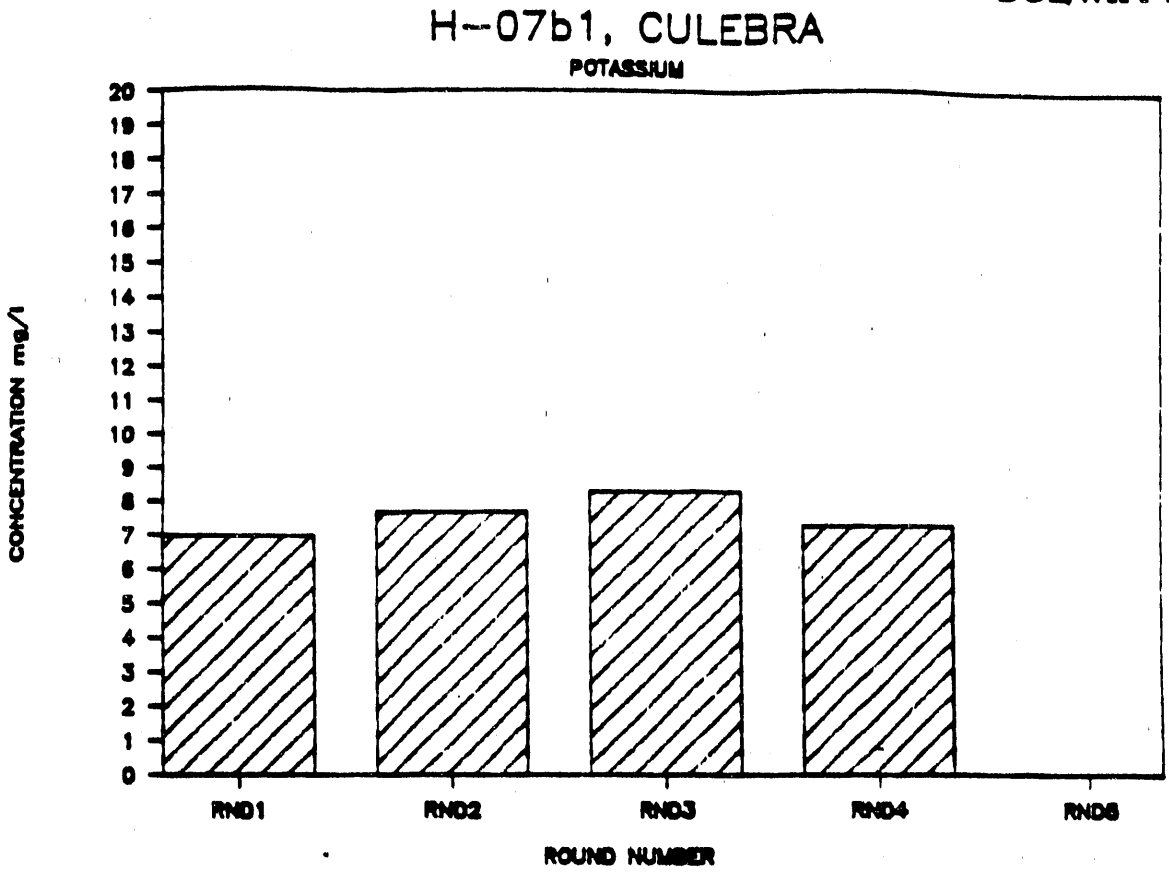

H-07b1, CULEBRA
BROMIDE
CONCENTRATION mg/l
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

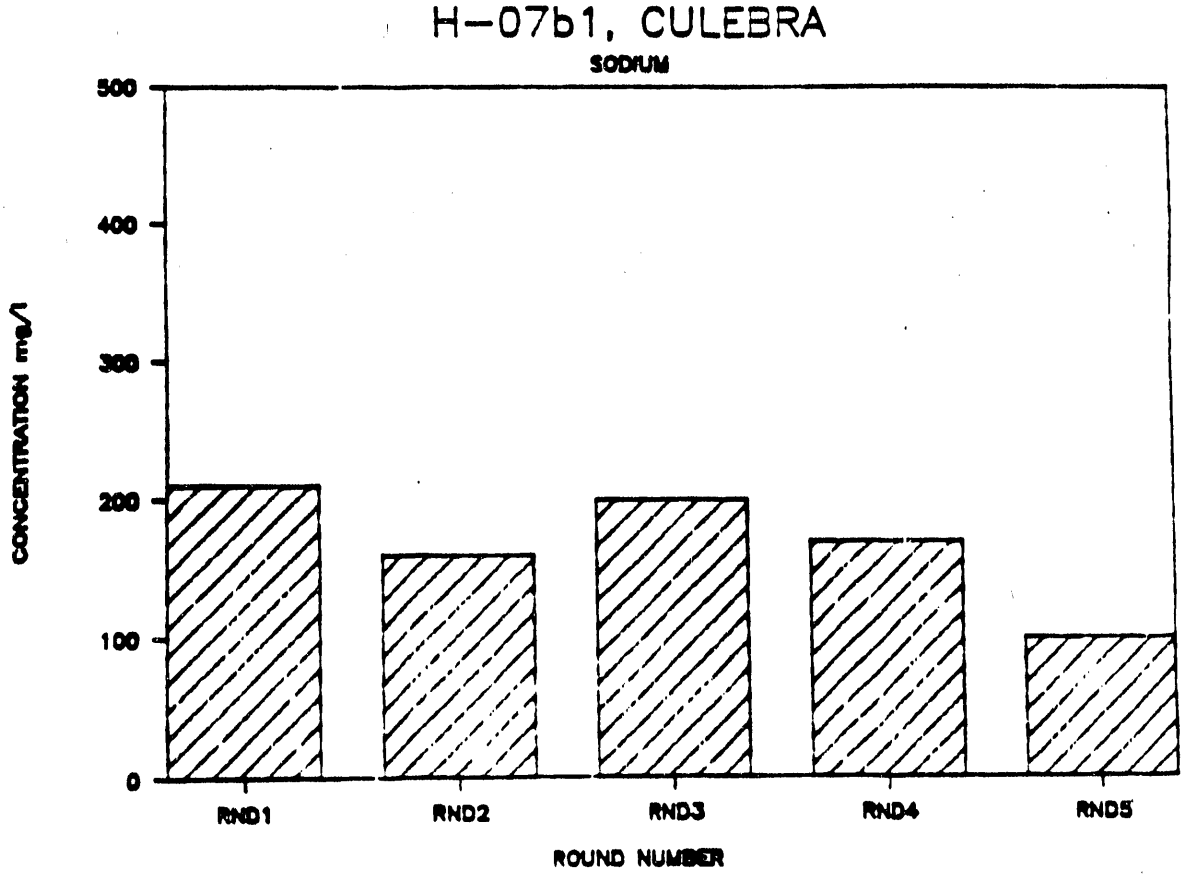

H-07b1, CULEBRA
CALCIUM
CONCENTRATION mg/l
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

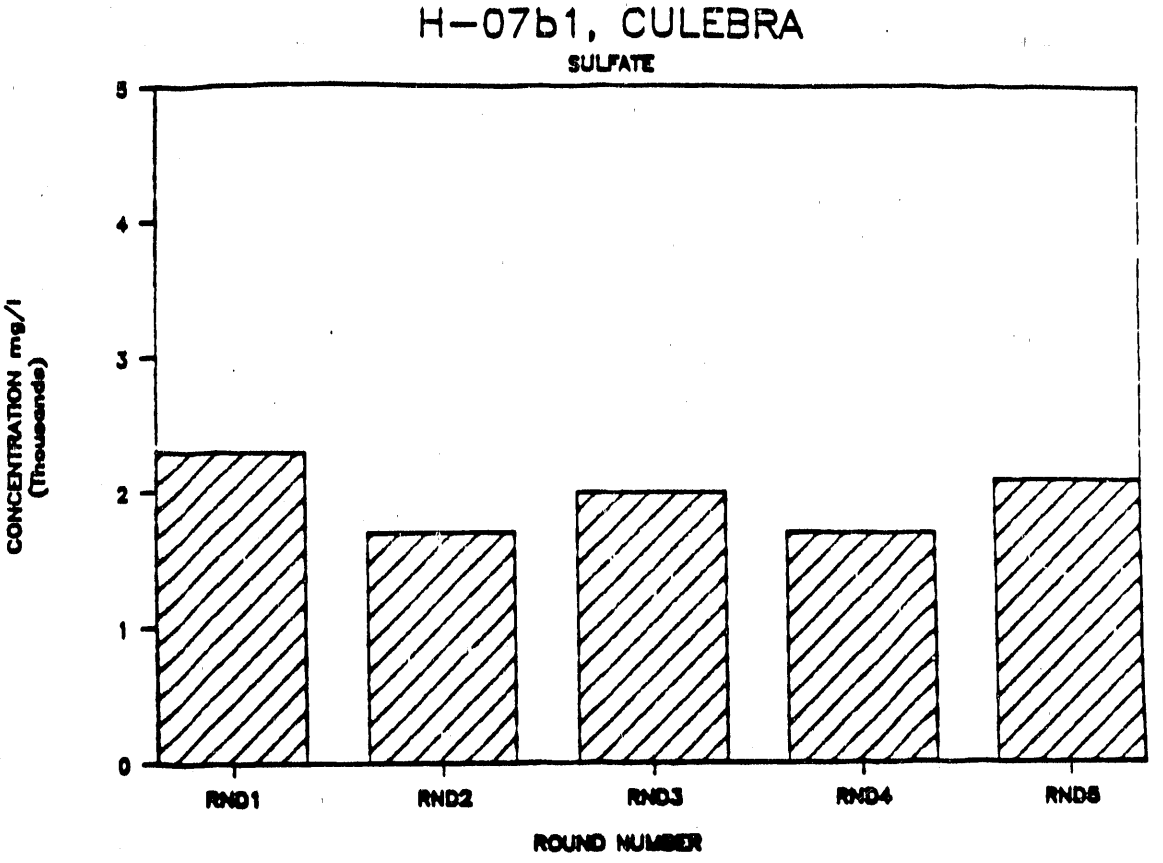

H-07b1, CULEBRA
CHLORIDE
CONCENTRATION mg/l
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

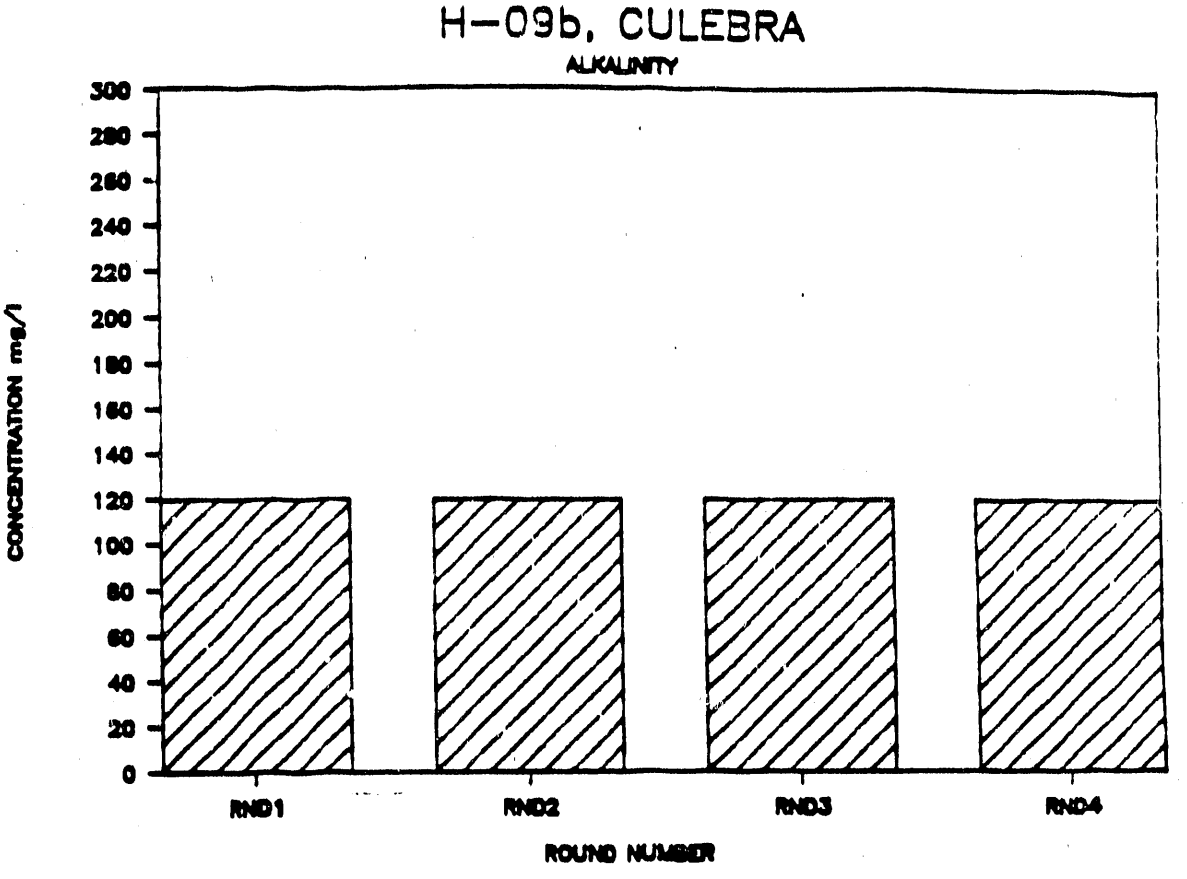

H-07b1, CULEBRA
FLUORIDE
CONCENTRATION mg/l
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

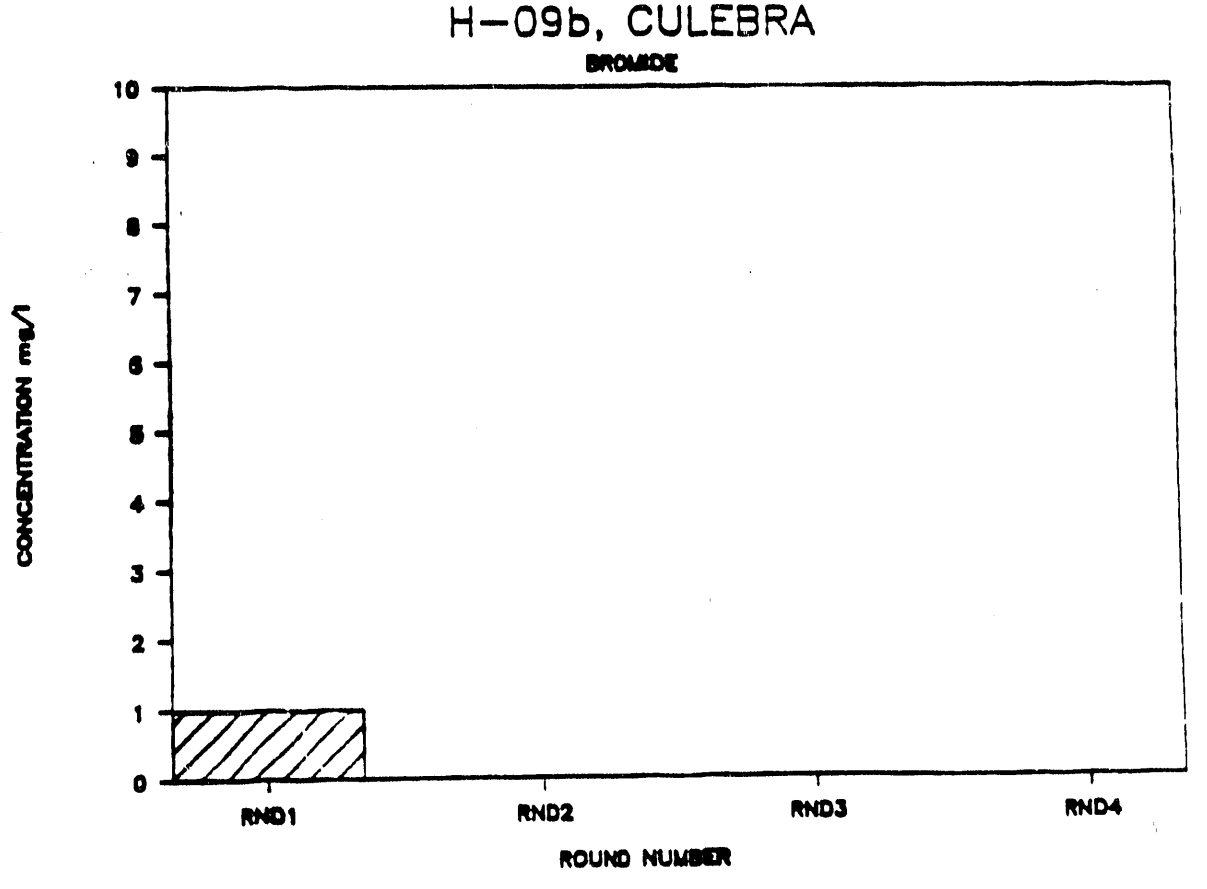

H-07b1, CULEBRA
MAGNESIUM
CONCENTRATION mg/l
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

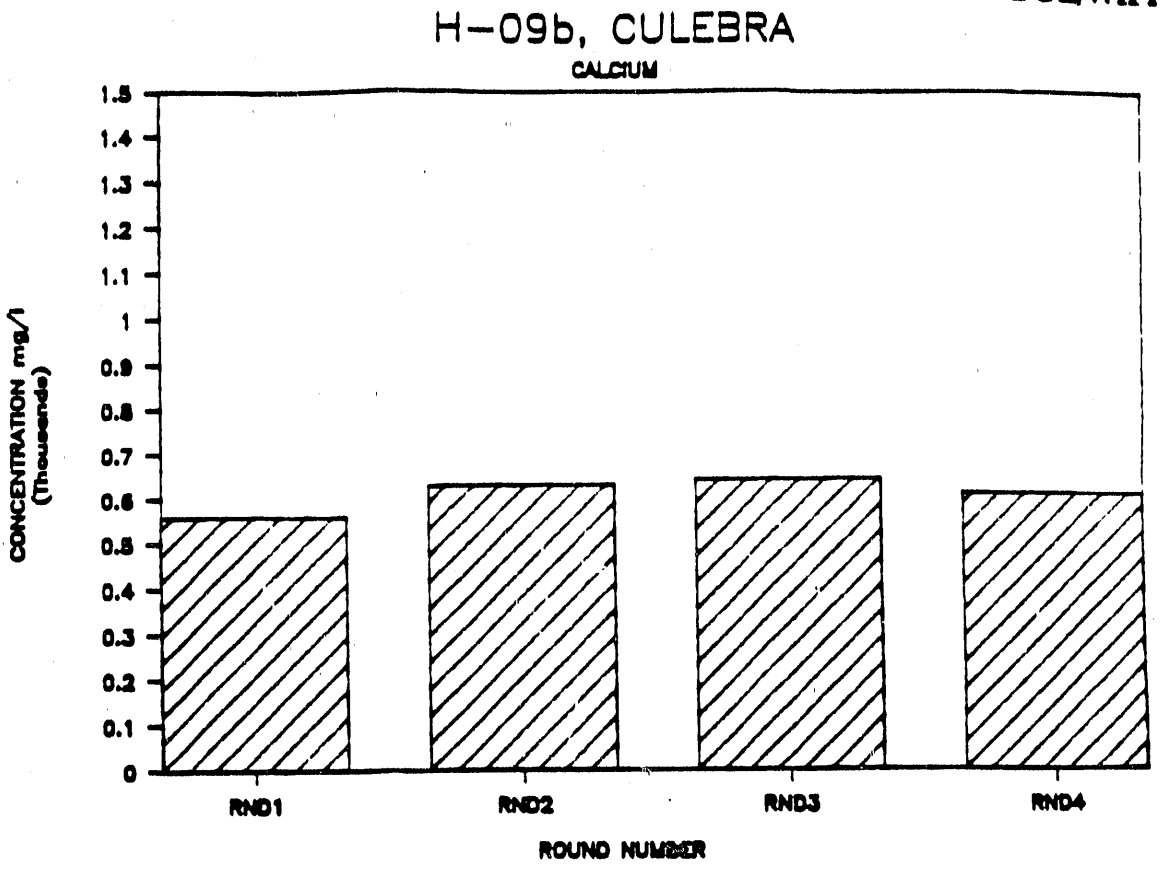

H-07b1, CULEBRA
POTASSIUM
CONCENTRATION mg/l
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

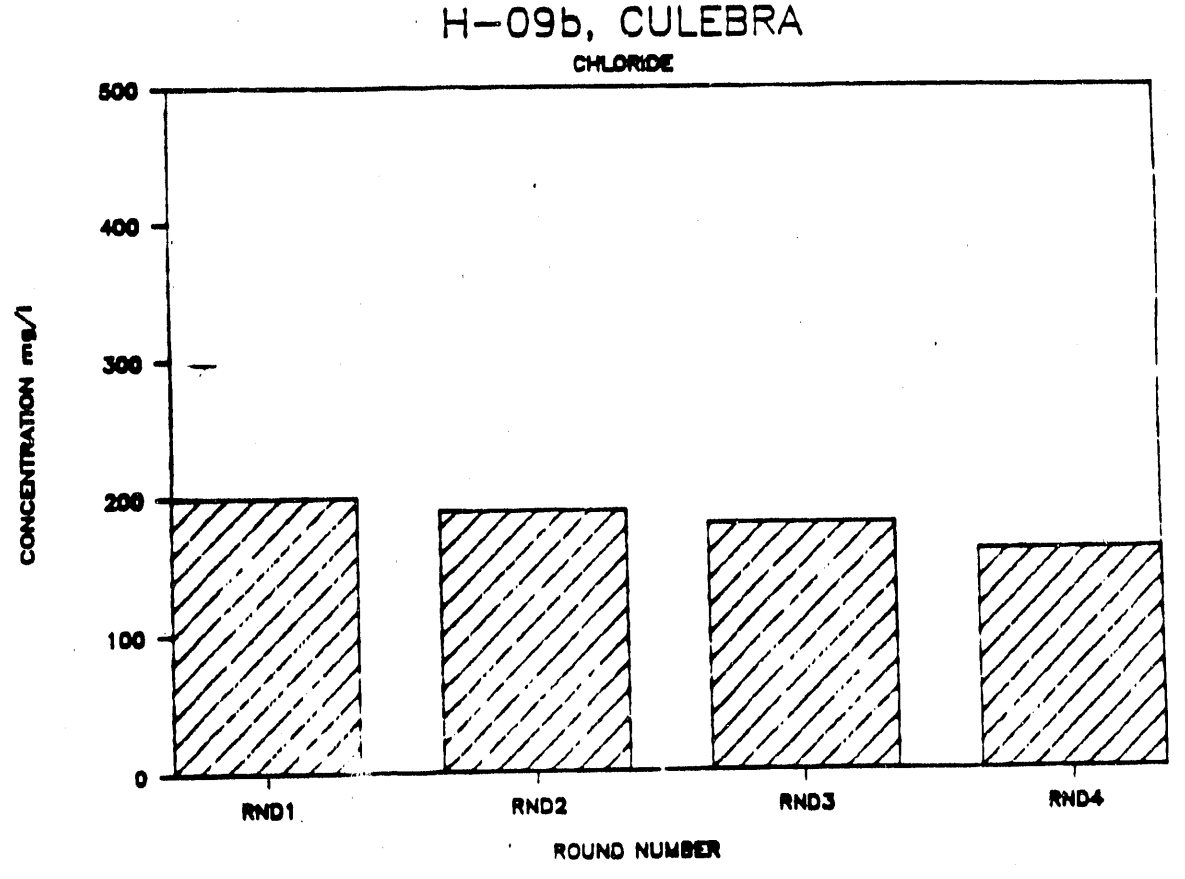

H-07b1, CULEBRA
SODIUM
CONCENTRATION mg/l
500
400
300
200
100
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

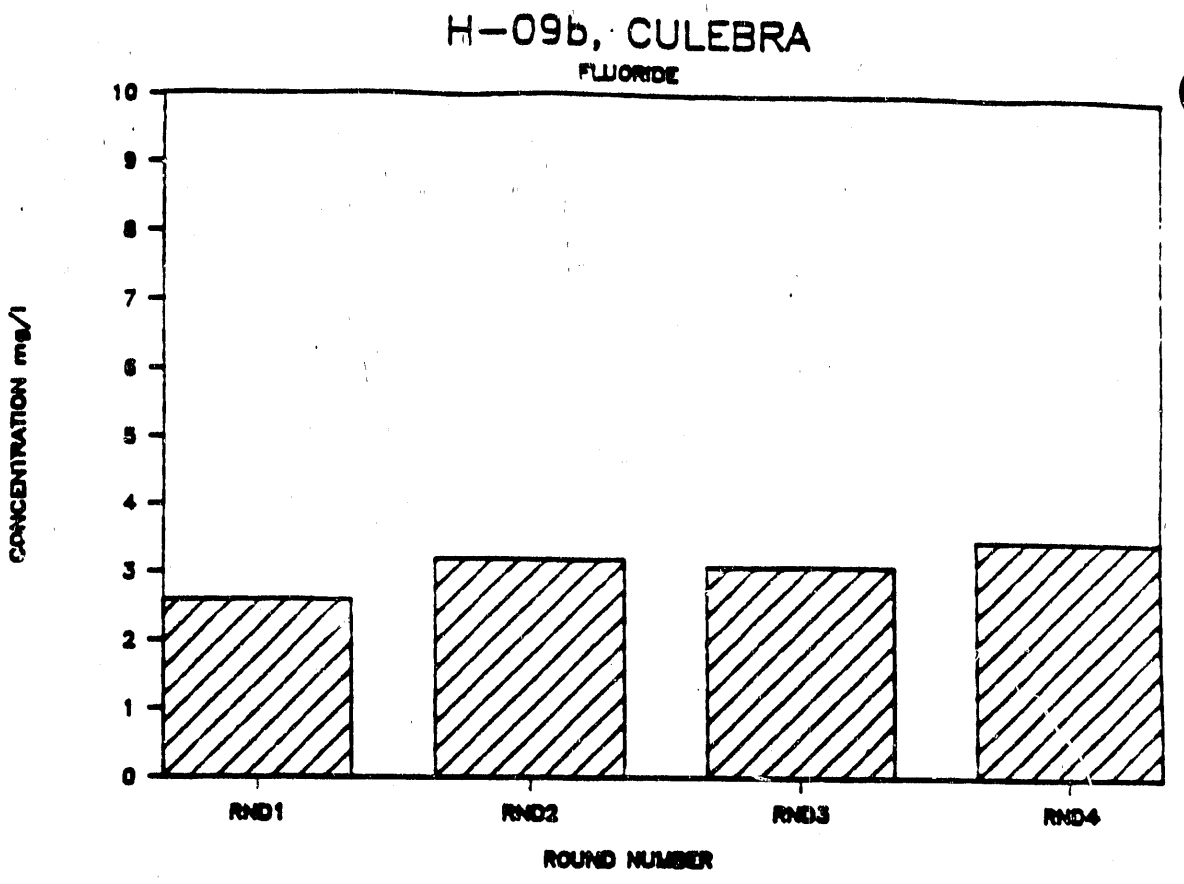

H-07b1, CULEBRA
SULFATE
CONCENTRATION mg/l
(Thousands)
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

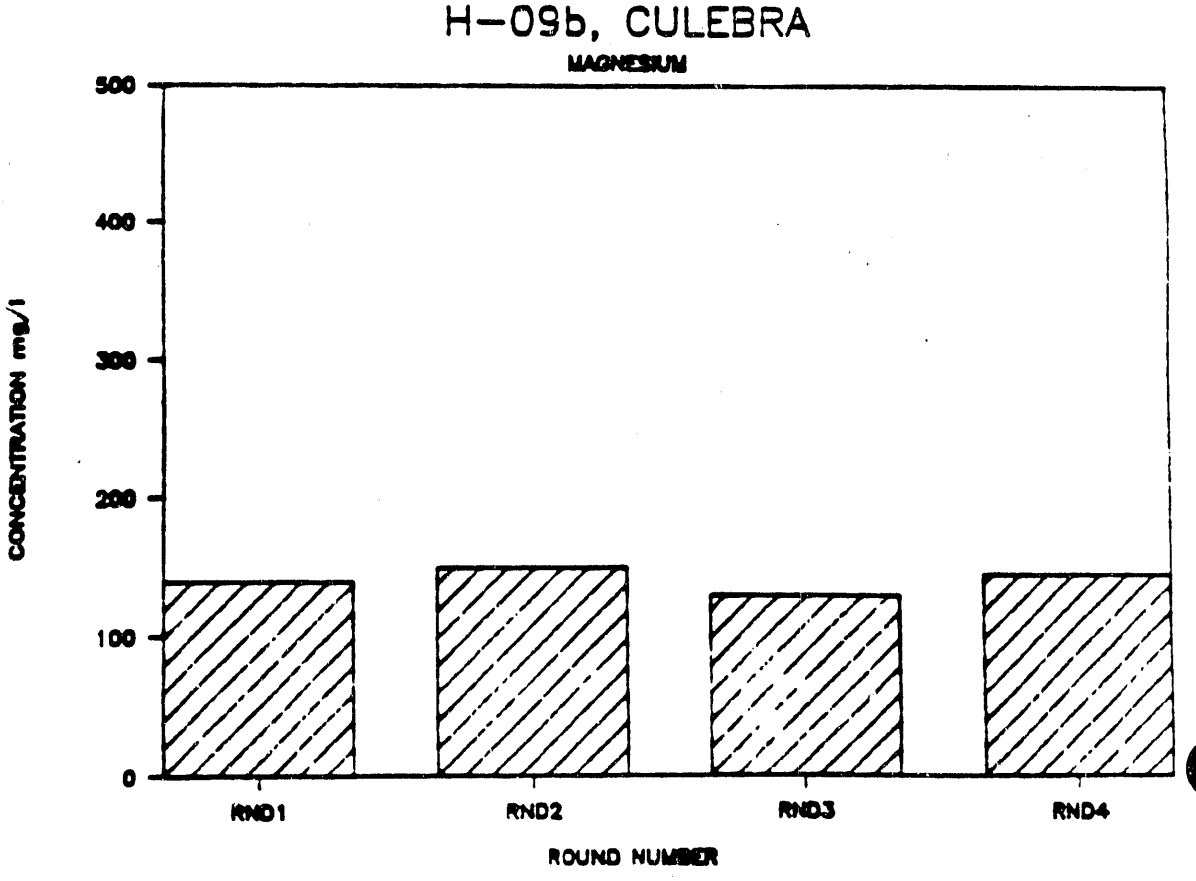

H-09b, CULEBRA
ALKALINITY
CONCENTRATION mg/l
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
RND1
RND2
RND3
RND4
ROUND NUMBER

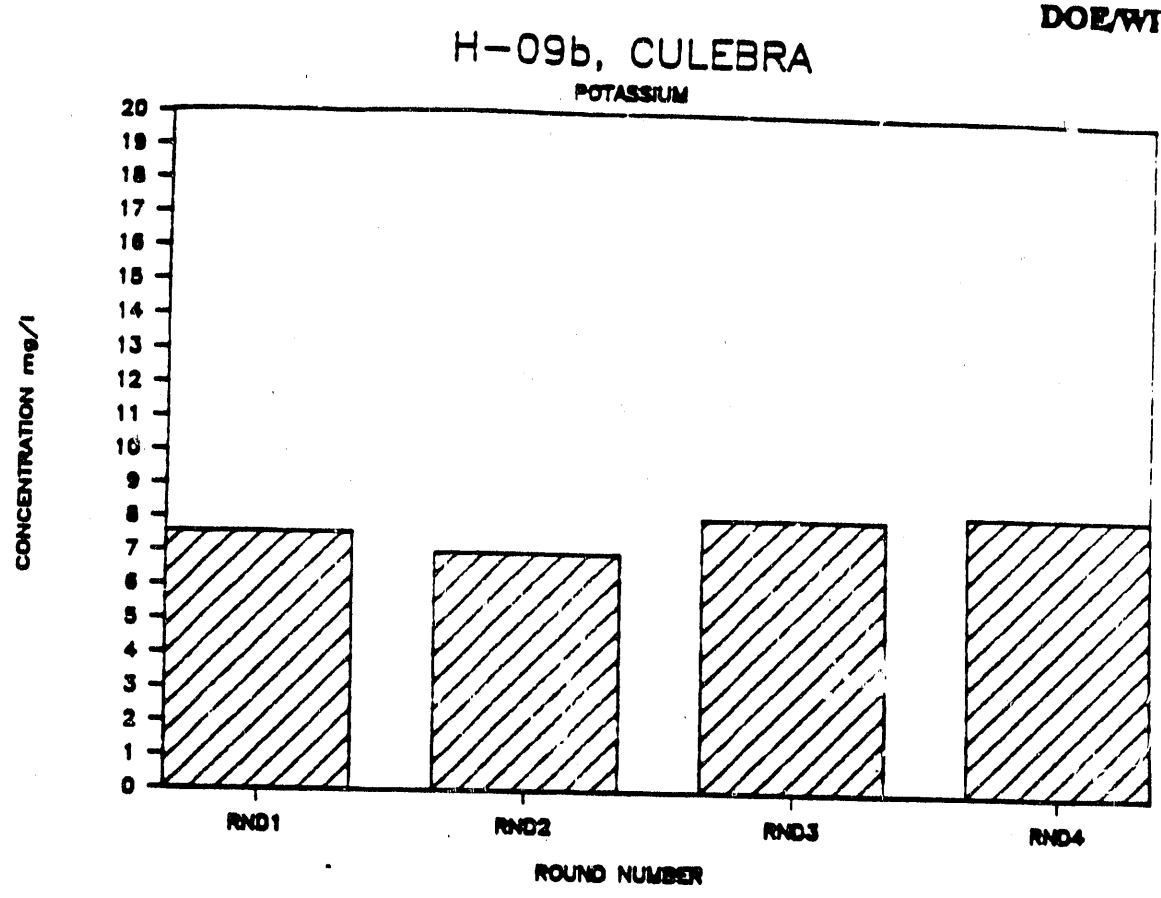

H-09b, CULEBRA
BROMIDE
CONCENTRATION mg/l
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
ROUND NUMBER

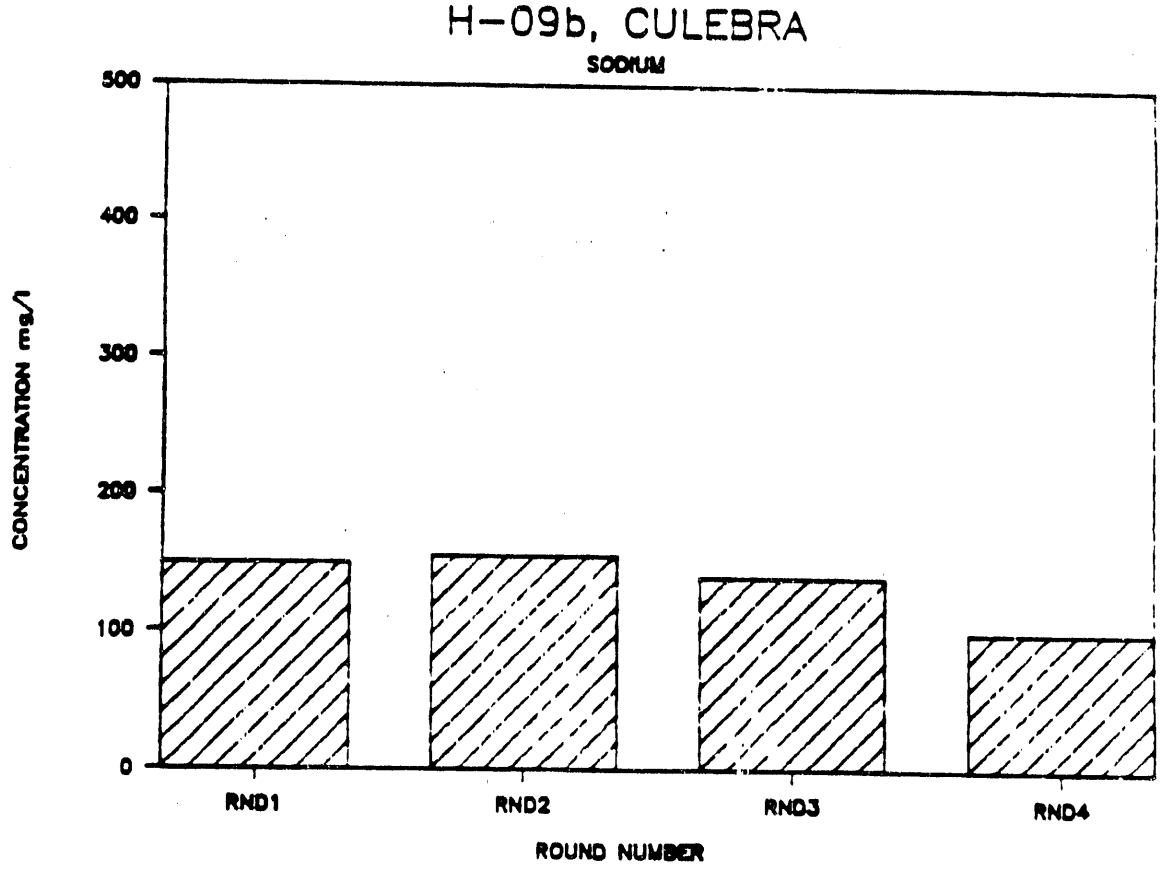

H-09b, CULEBRA
CALCIUM
CONCENTRATION mg/l (Thousands)
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
ROUND NUMBER

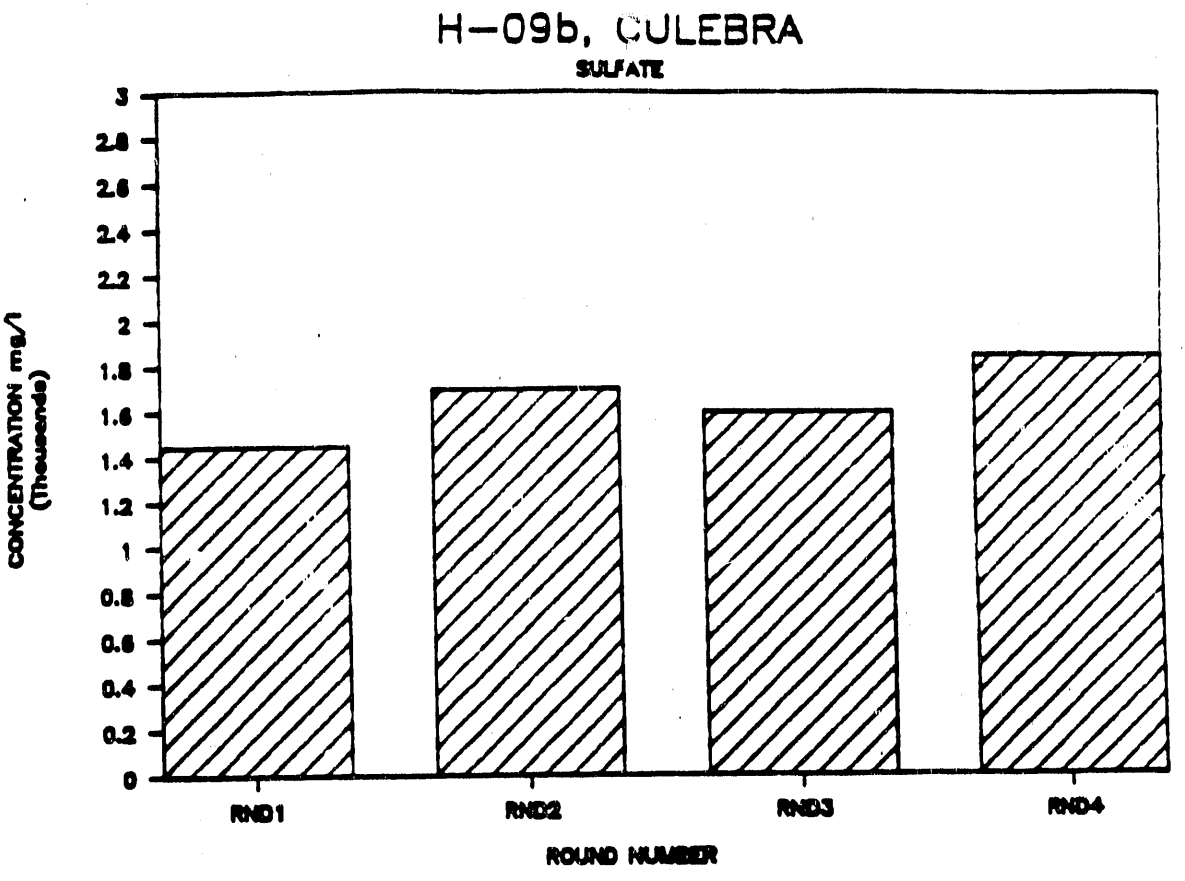

H-09b, CULEBRA
CHLORIDE
CONCENTRATION mg/l
500
400
300
200
100
0
RND1
RND2
RND3
RND4
ROUND NUMBER

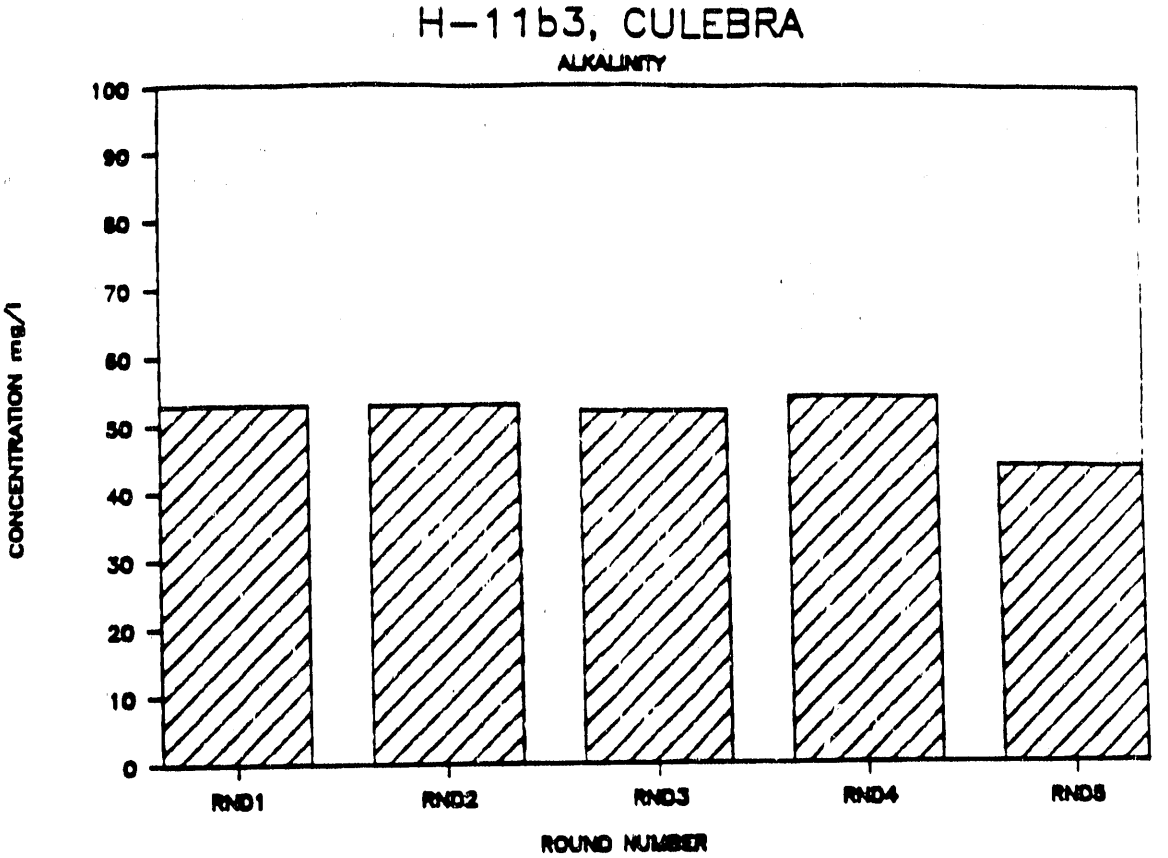

H-09b, CULEBRA
FLUORIDE
CONCENTRATION mg/l
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
ROUND NUMBER

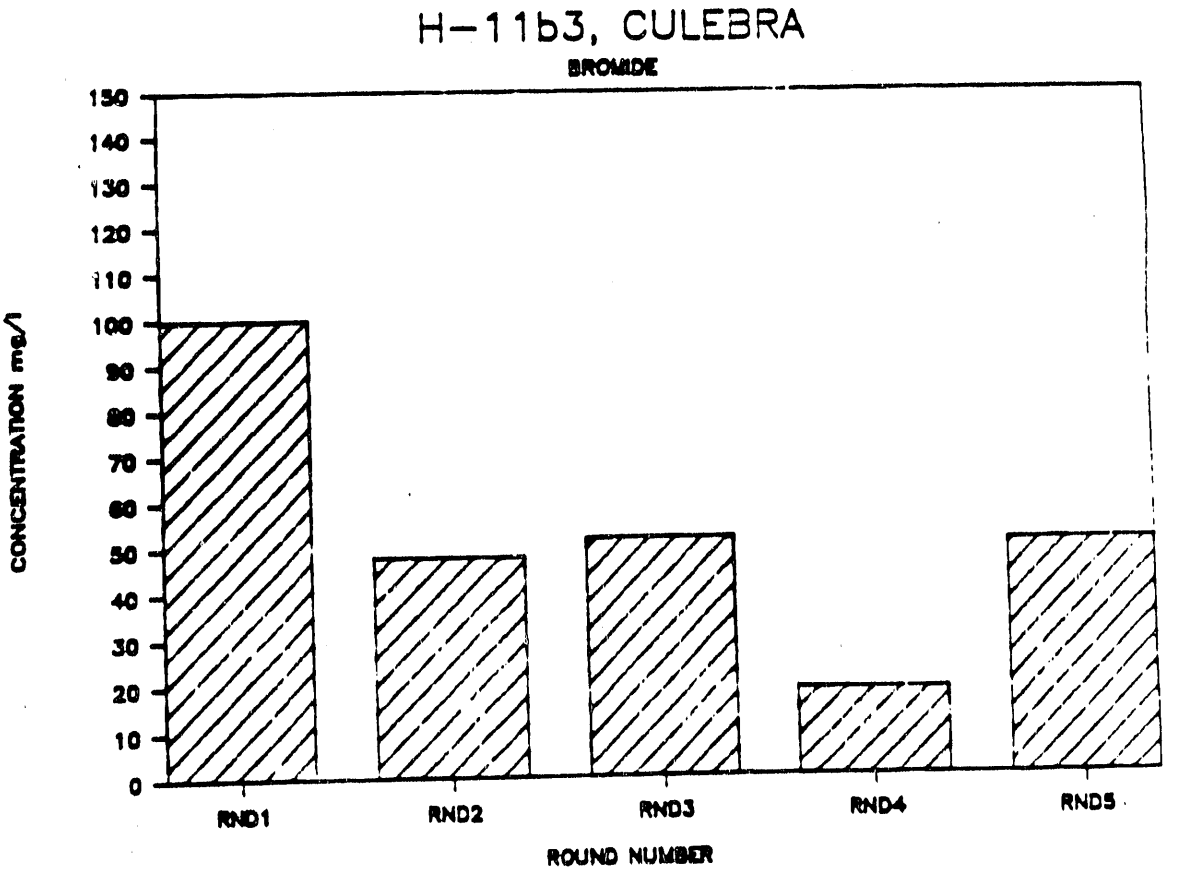

H-09b, CULEBRA
MAGNESIUM
CONCENTRATION mg/l
500
400
300
200
100
0
RND1
RND2
RND3
RND4
ROUND NUMBER

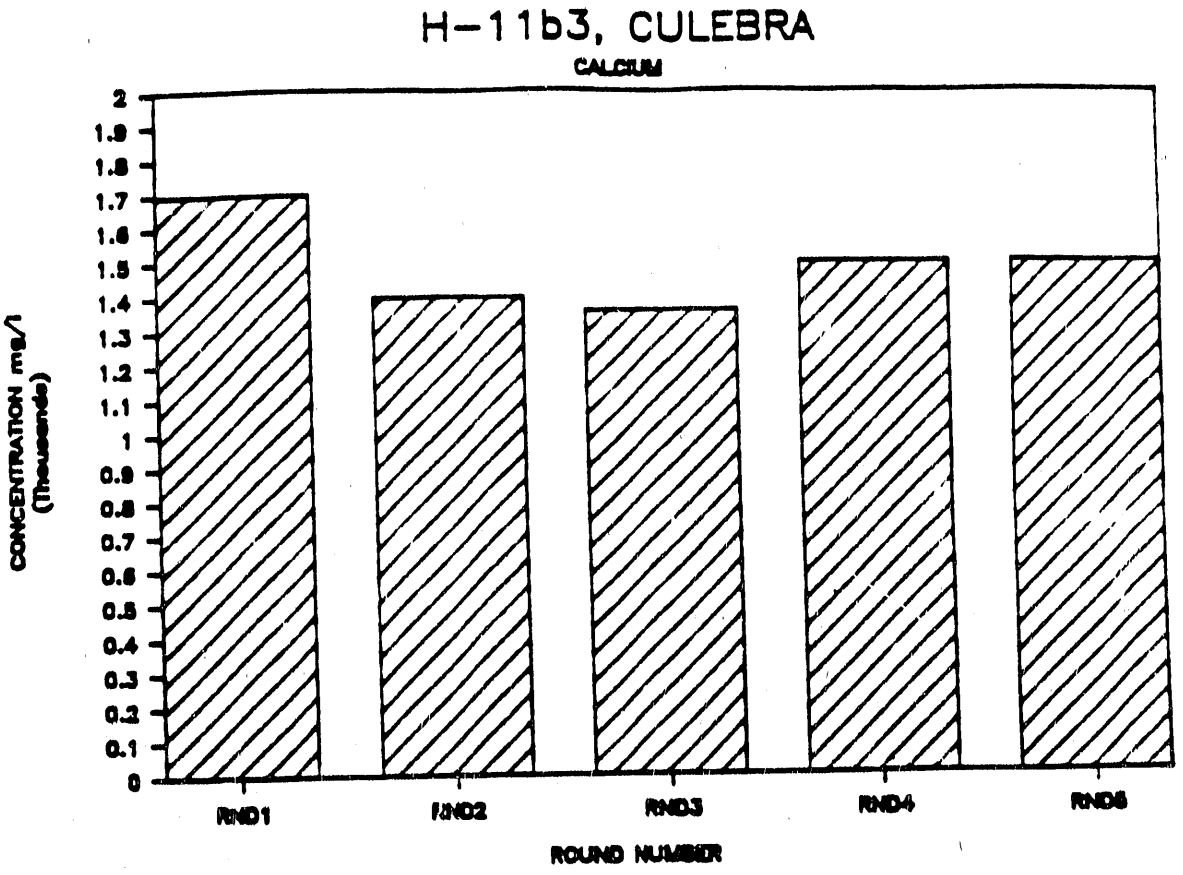

H-09b, CULEBRA
POTASSIUM
CONCENTRATION mg/l
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
ROUND NUMBER

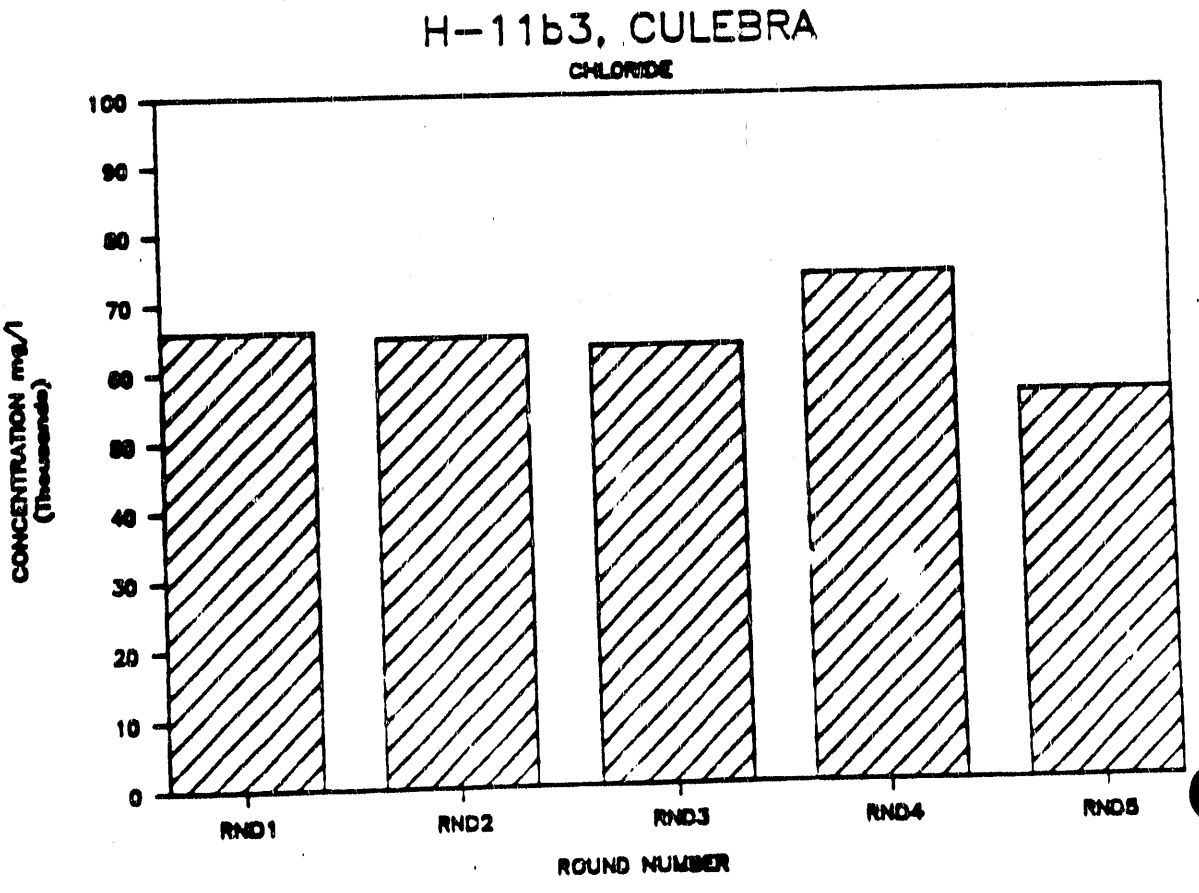

H-09b, CULEBRA
SODIUM
CONCENTRATION mg/l
500
400
300
200
100
0
RND1
RND2
RND3
RND4
ROUND NUMBER

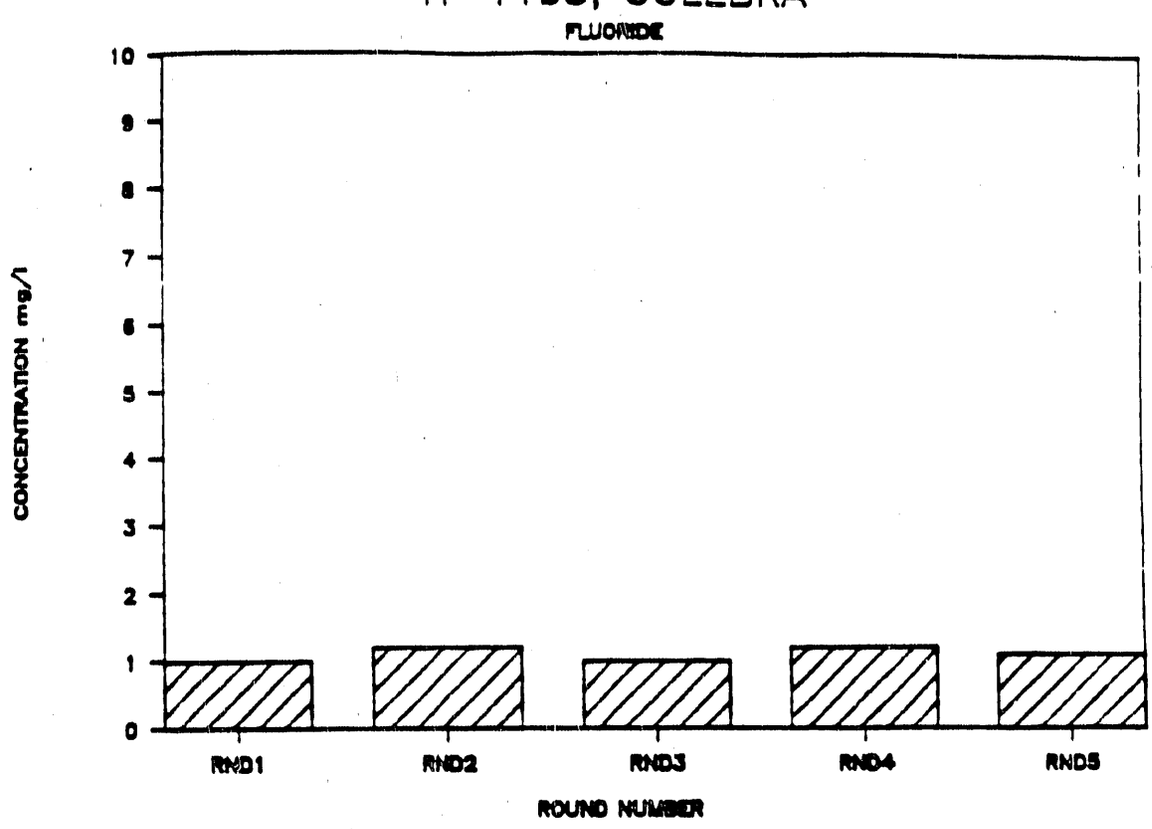

H-09b, CULEBRA
SULFATE
CONCENTRATION mg/l
(Thousands)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
RND1
RND2
RND3
RND4
ROUND NUMBER

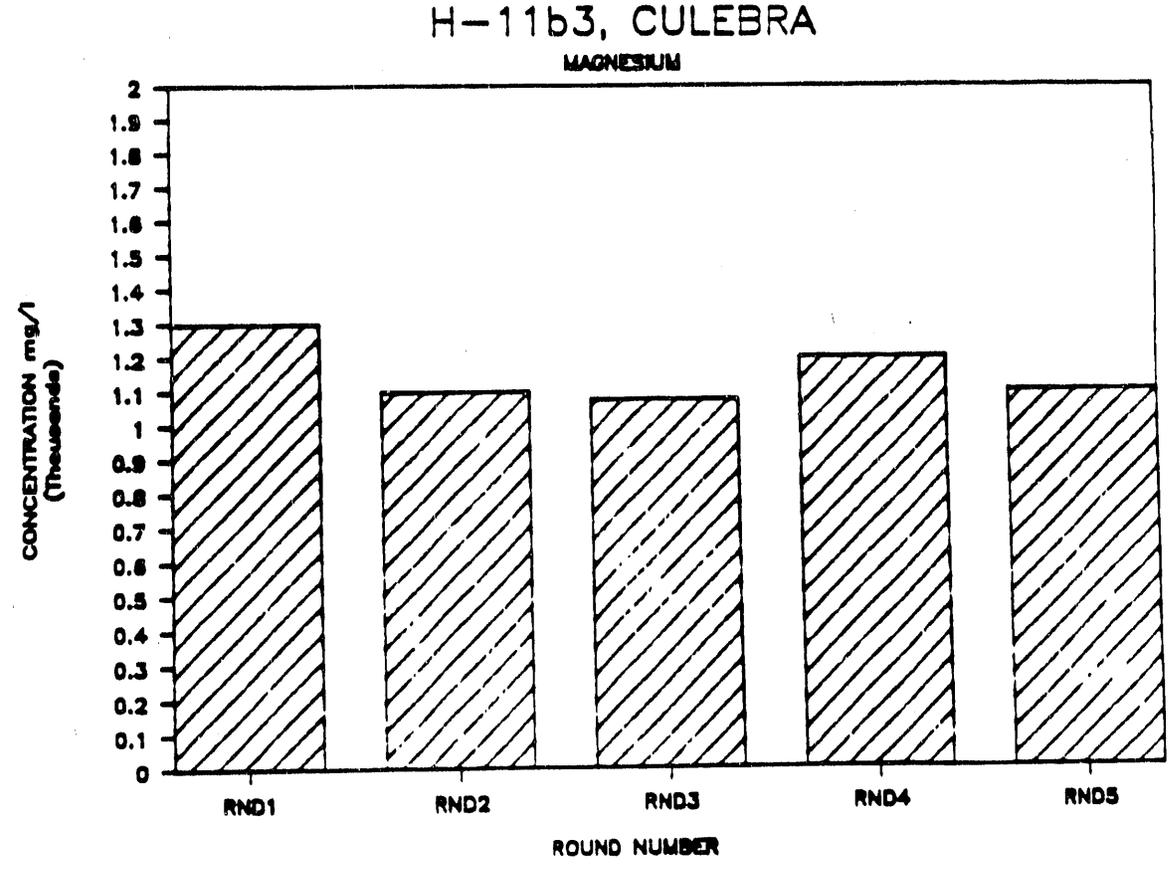

H-11b3, CULEBRA
ALKALINITY
CONCENTRATION mg/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

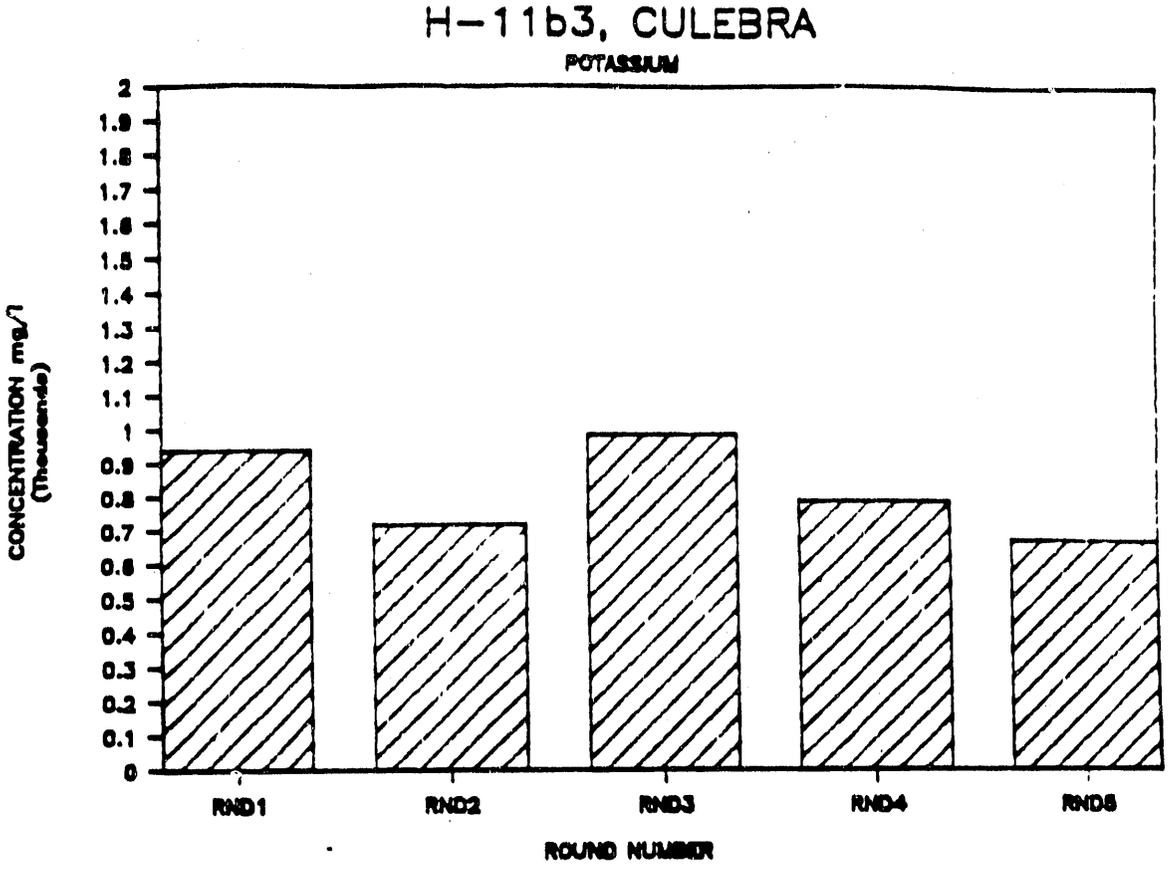

H-11b3, CULEBRA
BROMIDE
CONCENTRATION mg/l
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

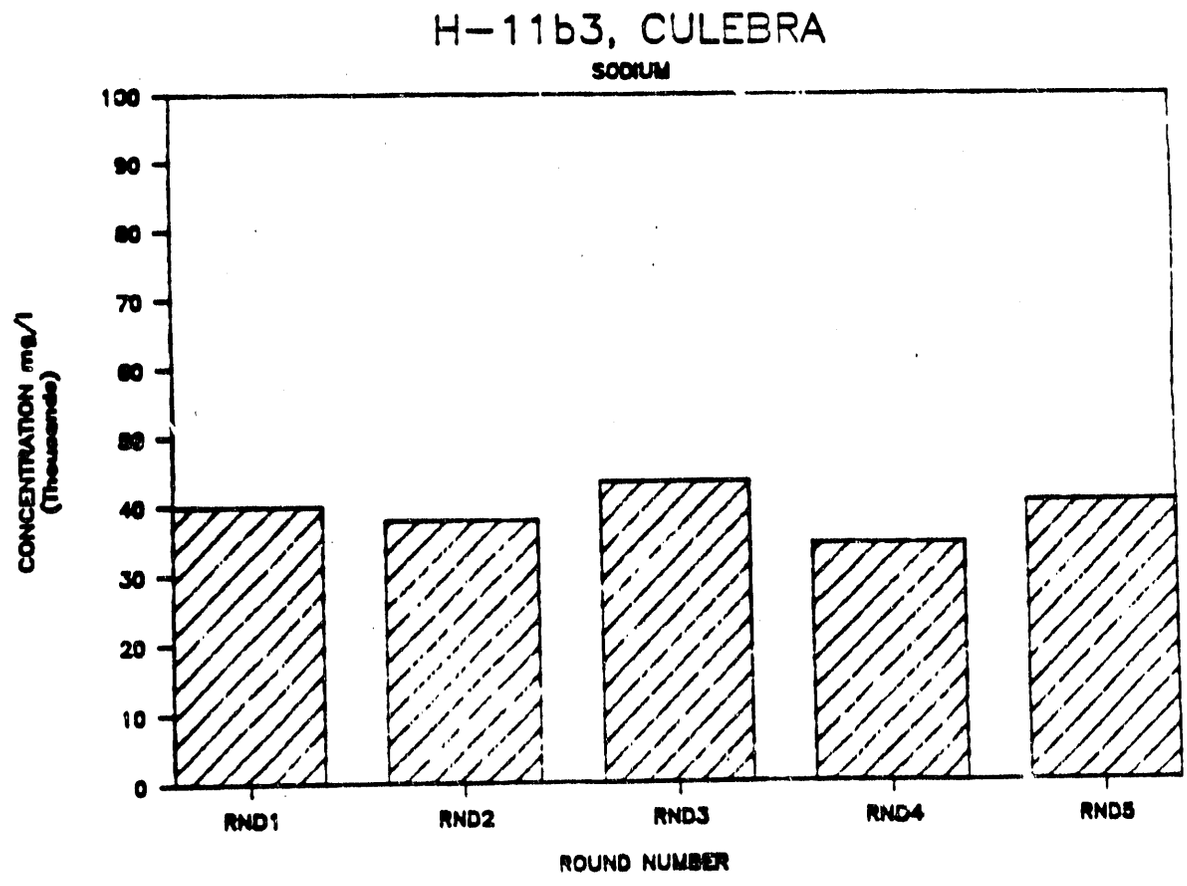

H-11b3, CULEBRA
CALCIUM
CONCENTRATION mg/l
(Thousands)
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

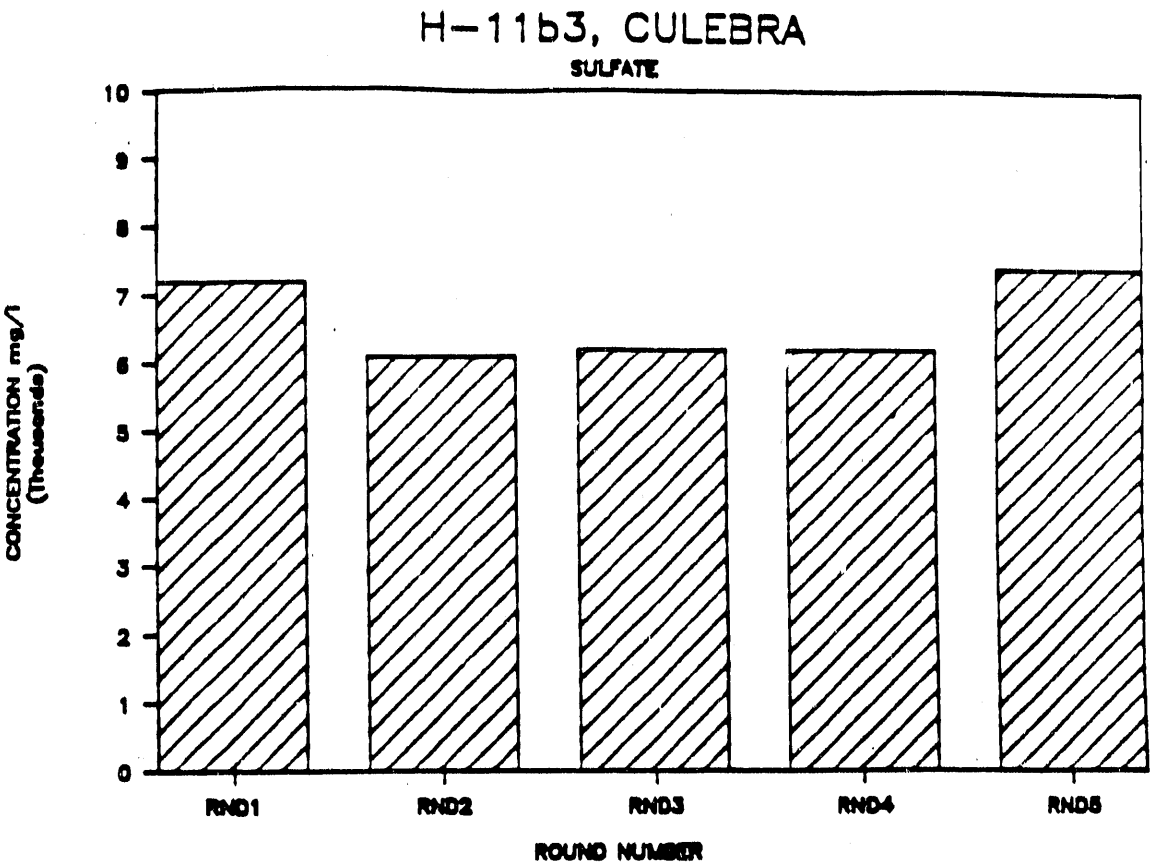

H-11b3, CULEBRA
CHLORIDE
CONCENTRATION mg/l
(Thousands)
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

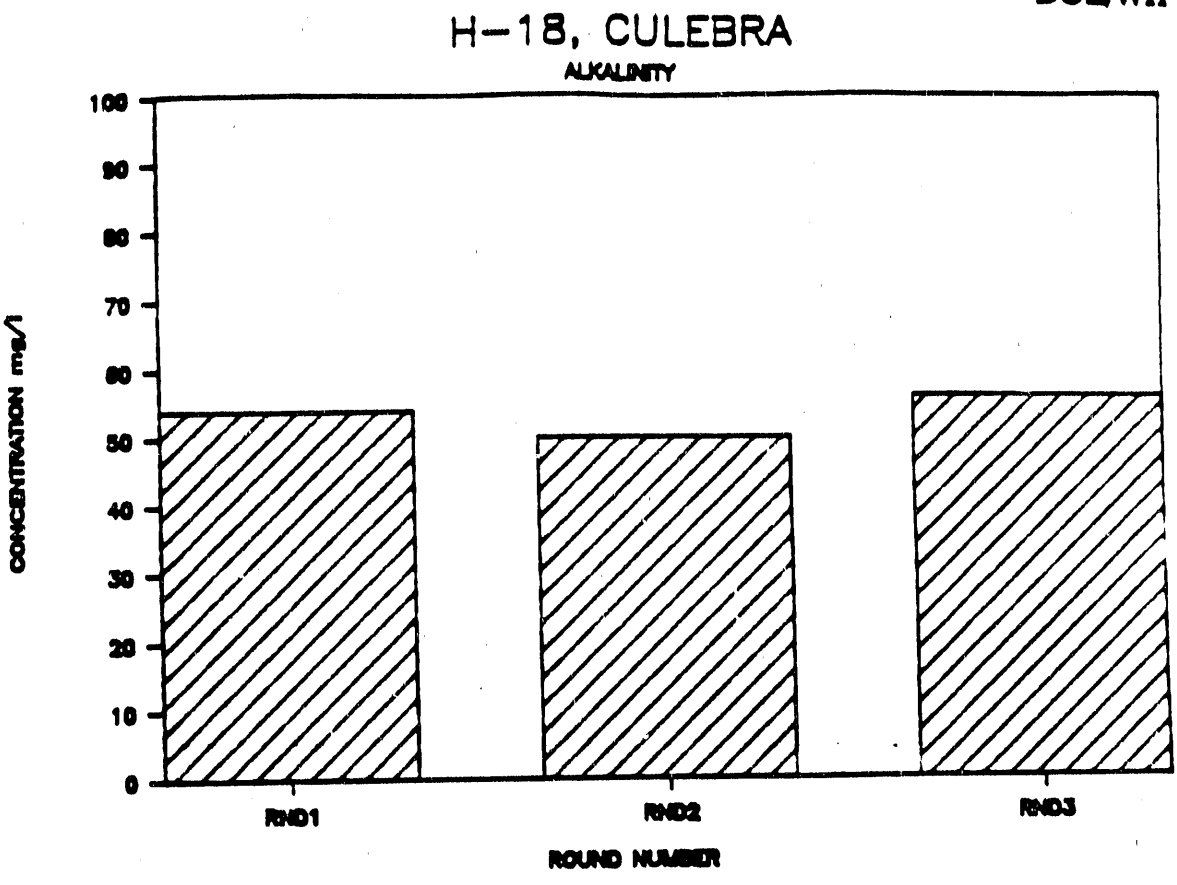

H-11b3, CULEBRA
FLUORIDE
CONCENTRATION mg/l
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

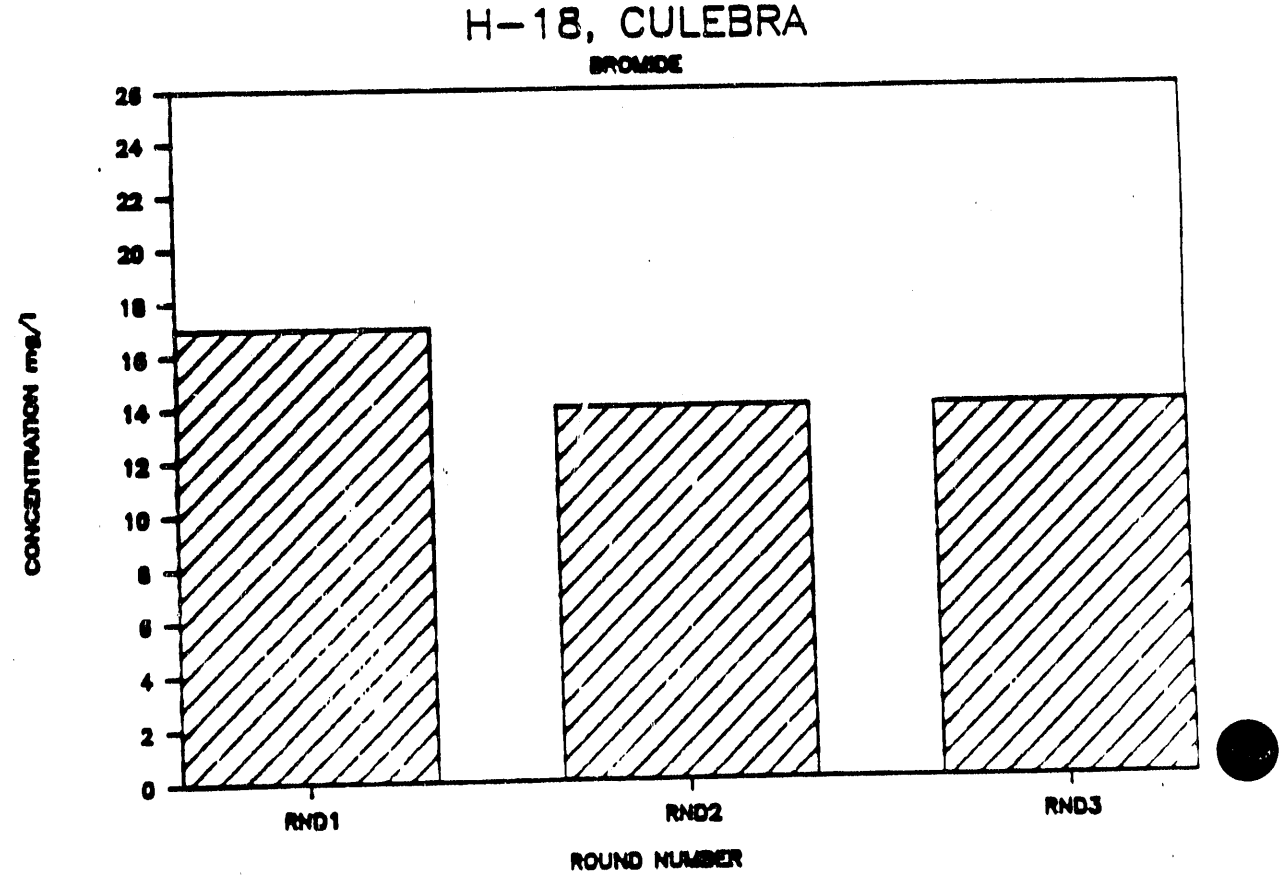

H-11b3, CULEBRA
MAGNESIUM
CONCENTRATION mg/l
(Thousands)
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

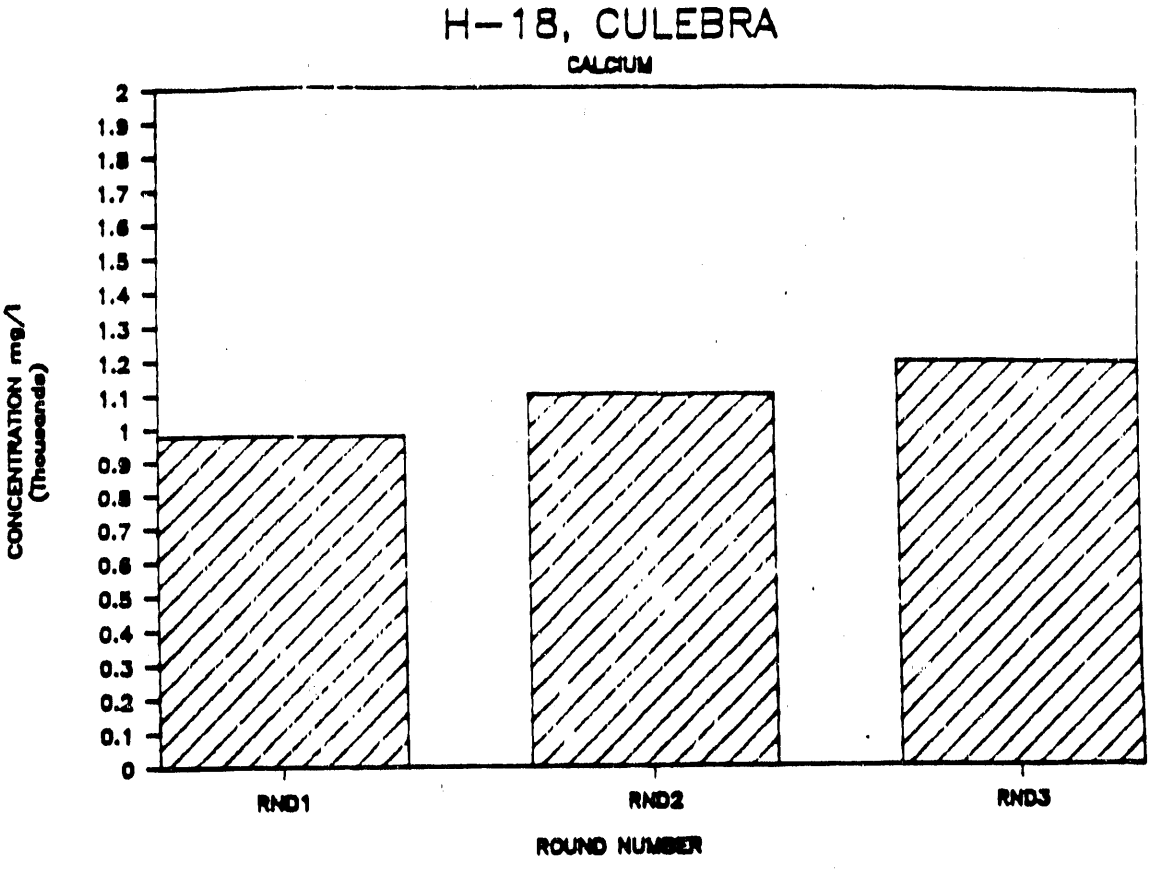

H-11b3, CULEBRA
POTASSIUM
CONCENTRATION mg/l (Thousands)
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

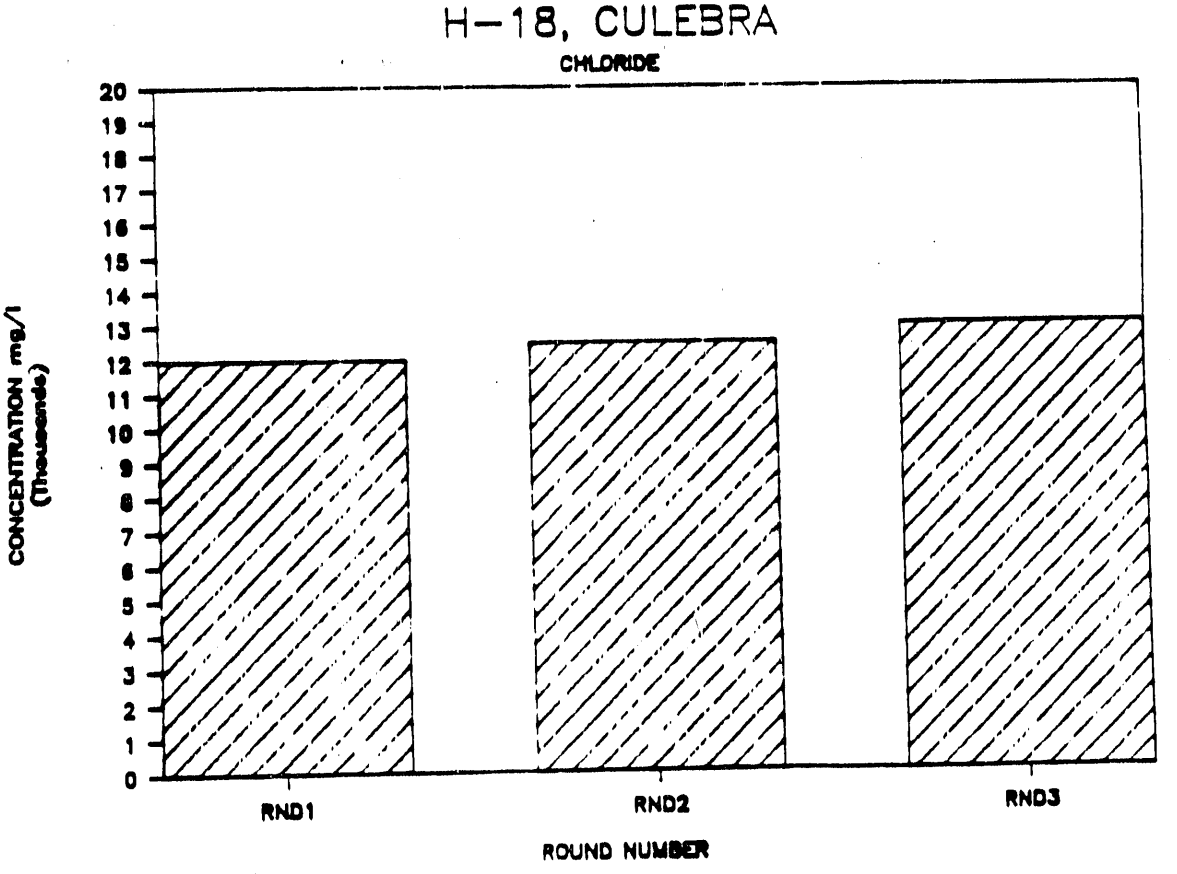

H-11b3, CULEBRA
SODIUM
CONCENTRATION mg/l (Thousands)
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

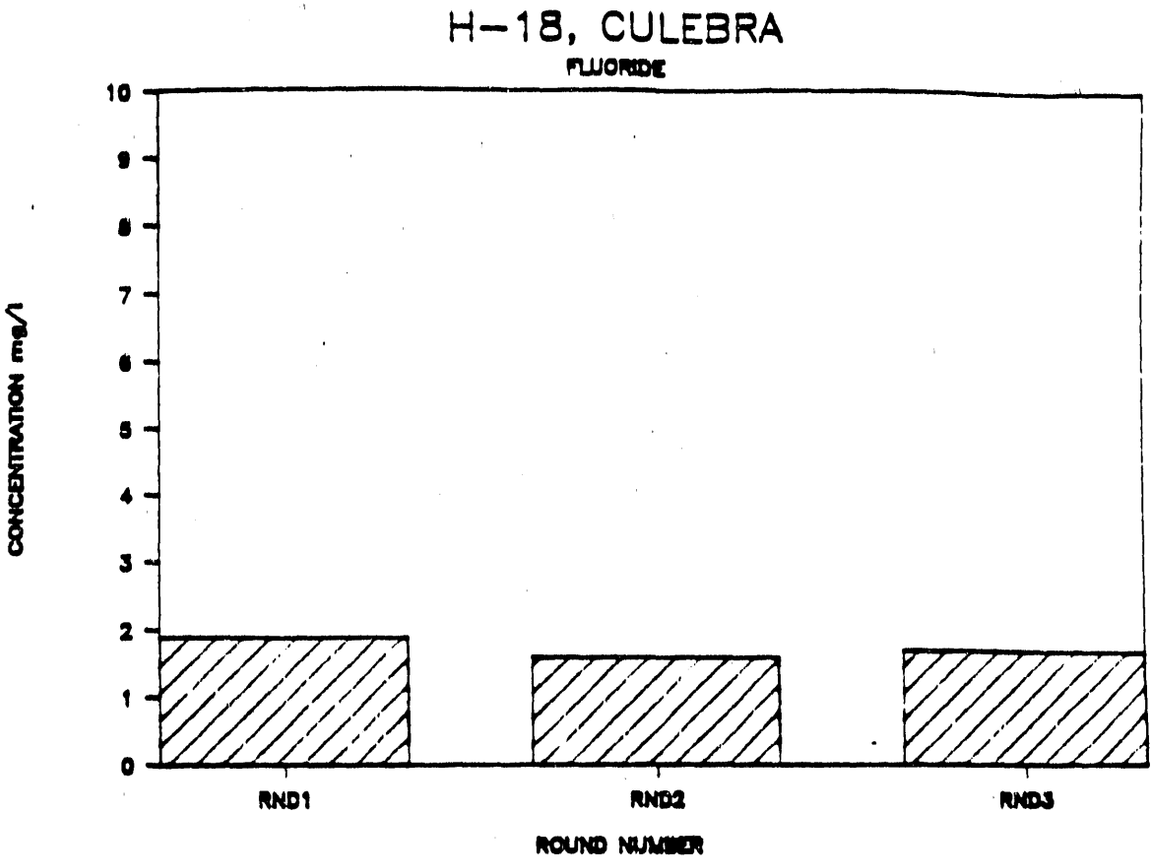

H-11b3, CULEBRA
SULFATE
CONCENTRATION mg/l
(Thousands)
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

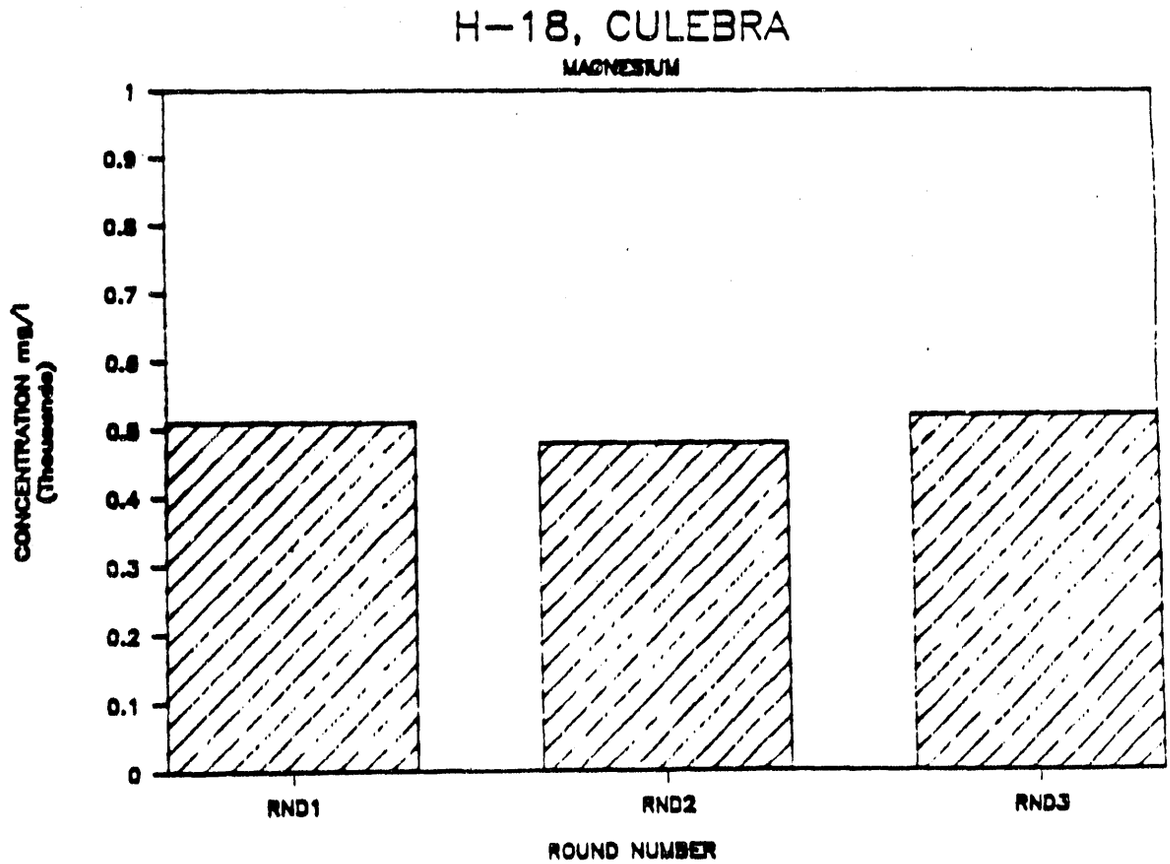

H-18, CULEBRA
ALKALINITY
CONCENTRATION mg/l
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
ROUND NUMBER

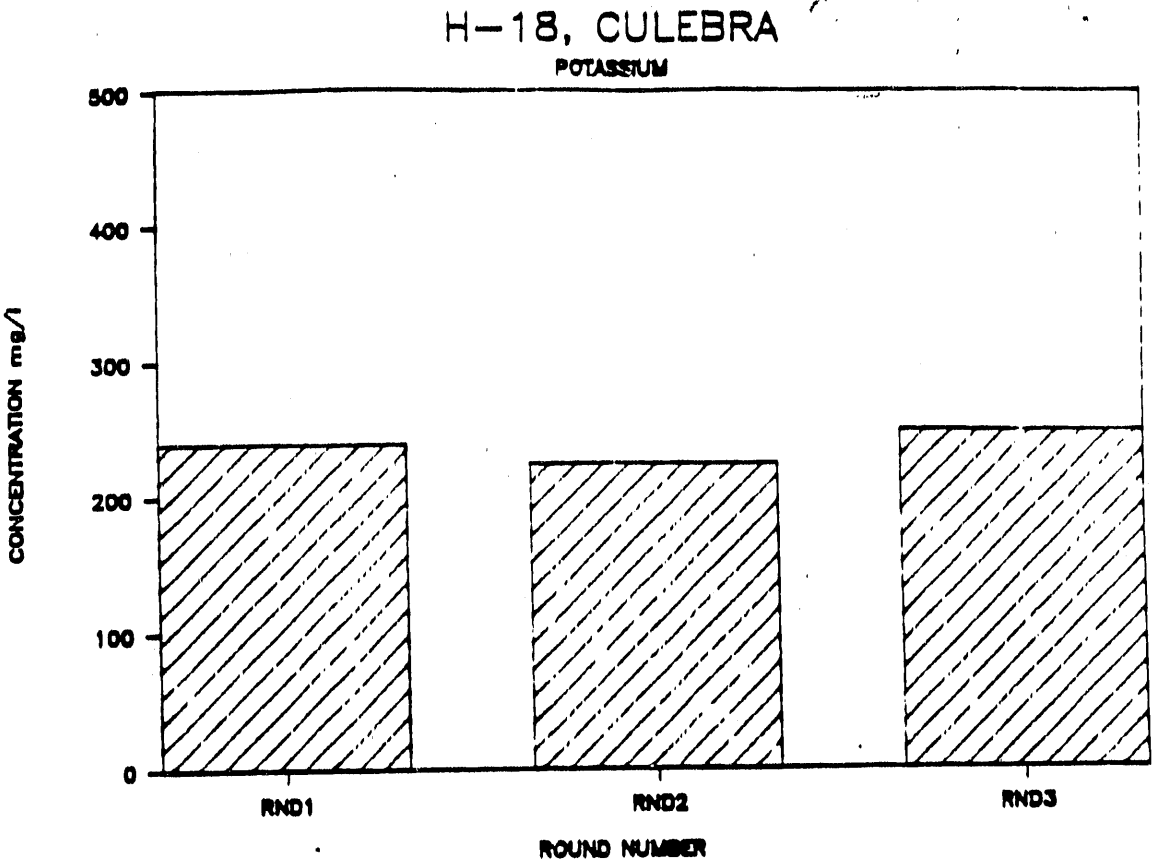

H-18, CULEBRA
BROMIDE
CONCENTRATION mg/l
26
24
22
20
18
16
14
12
10
8
6
4
2
0
RND1
RND2
RND3
ROUND NUMBER

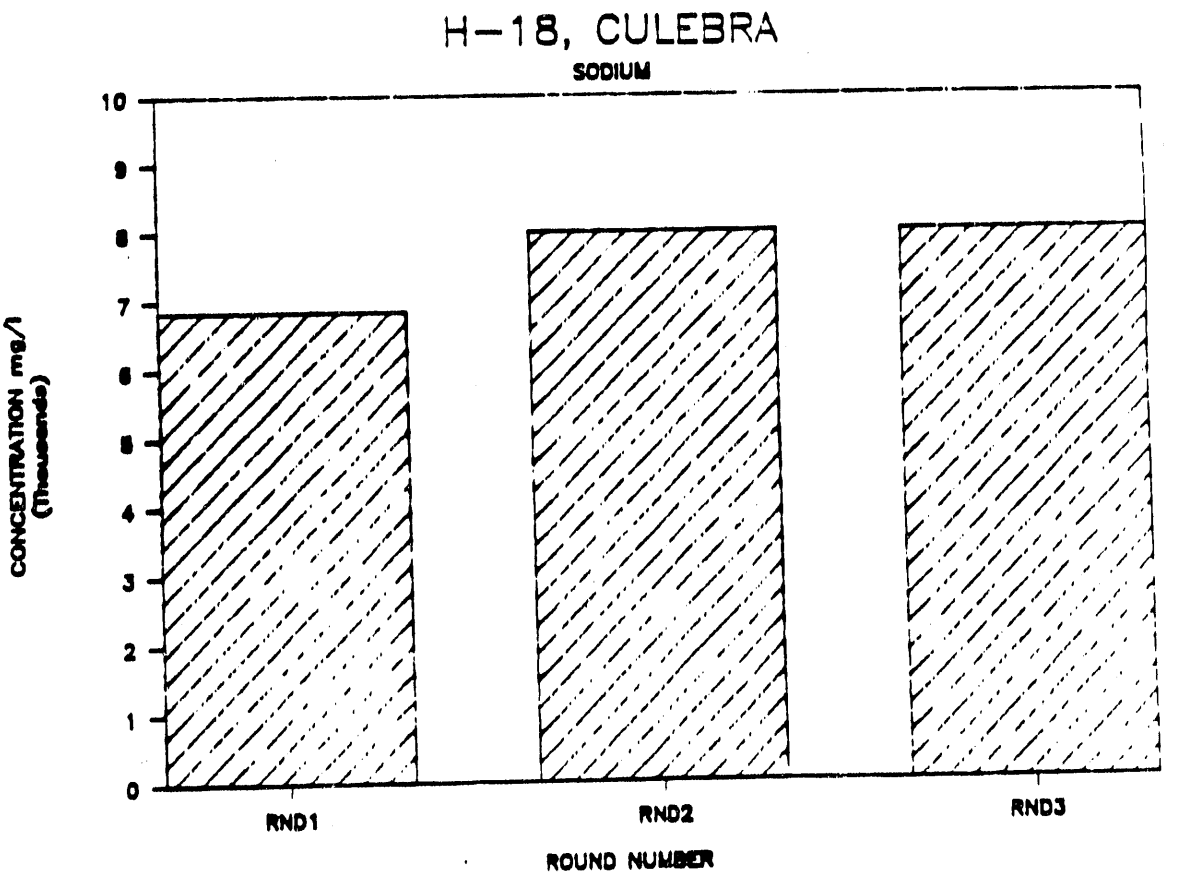

H-18, CULEBRA
CALCIUM
CONCENTRATION mg/l
(Thousands)
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
ROUND NUMBER

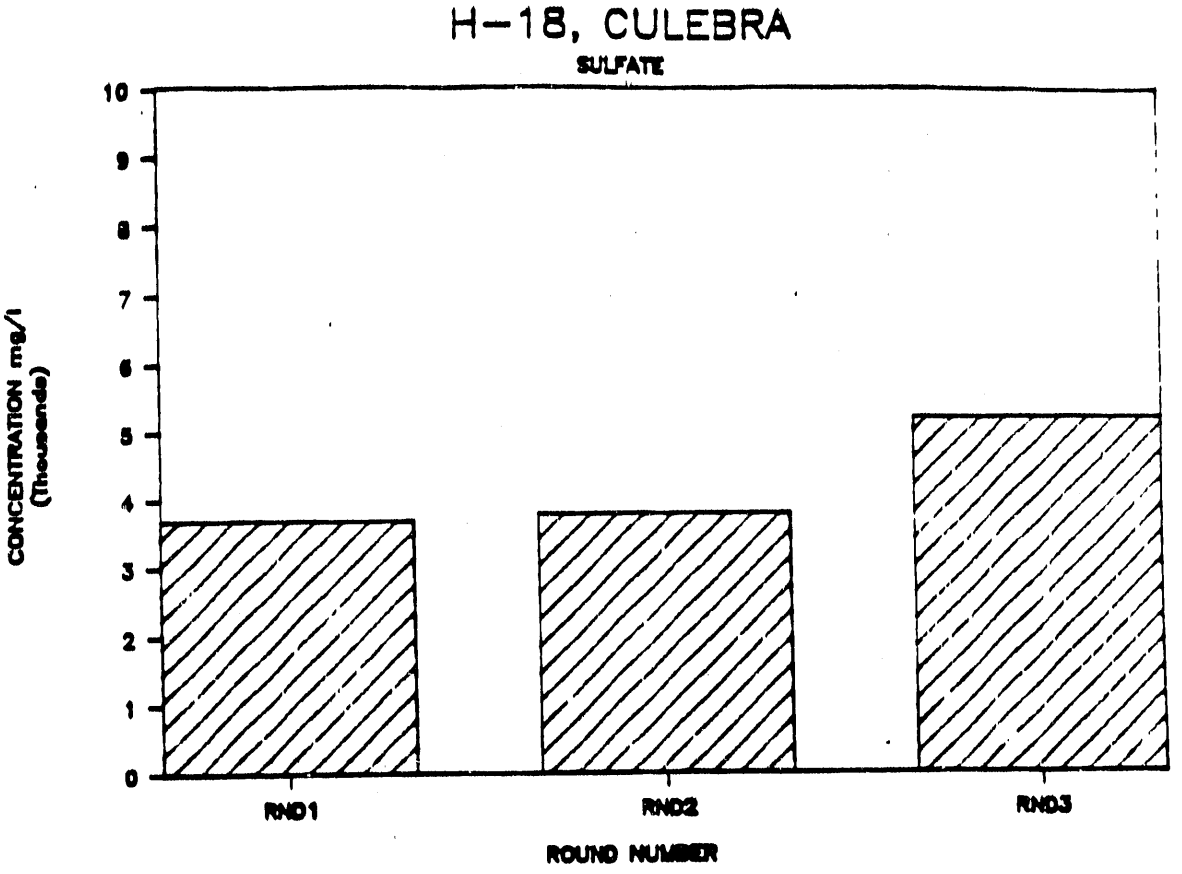

H-18, CULEBRA
CHLORIDE
CONCENTRATION mg/l
(Thousands)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
ROUND NUMBER

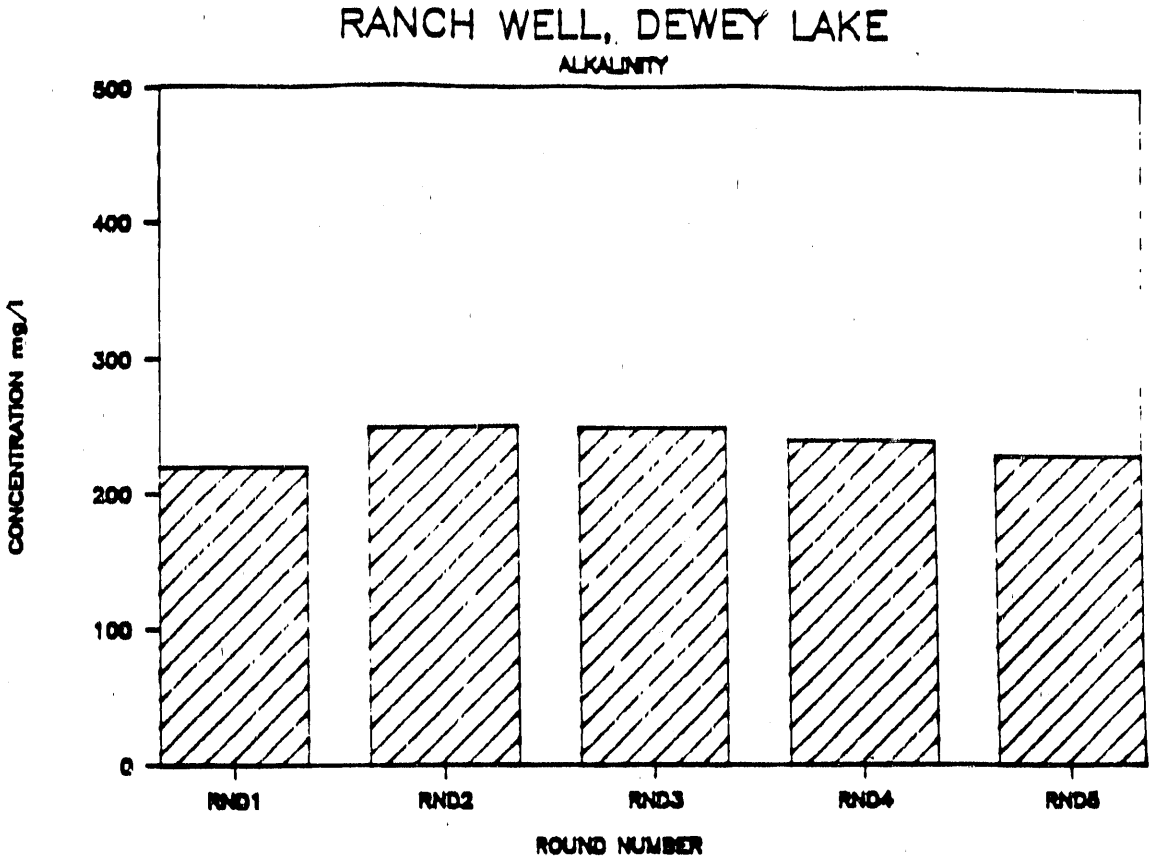

H-18, CULEBRA
FLUORIDE
CONCENTRATION mg/l
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
ROUND NUMBER

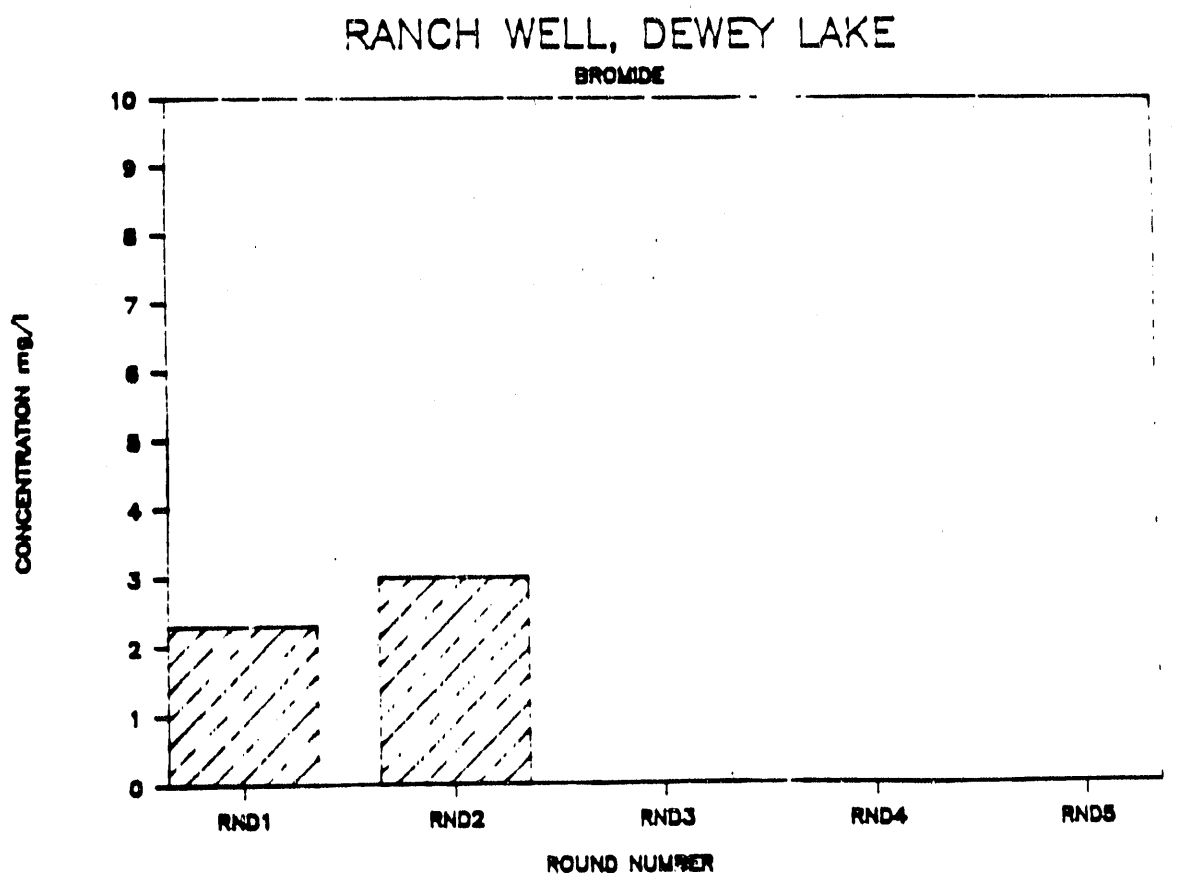

H-18, CULEBRA
MAGNESIUM
CONCENTRATION mg/l
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
ROUND NUMBER

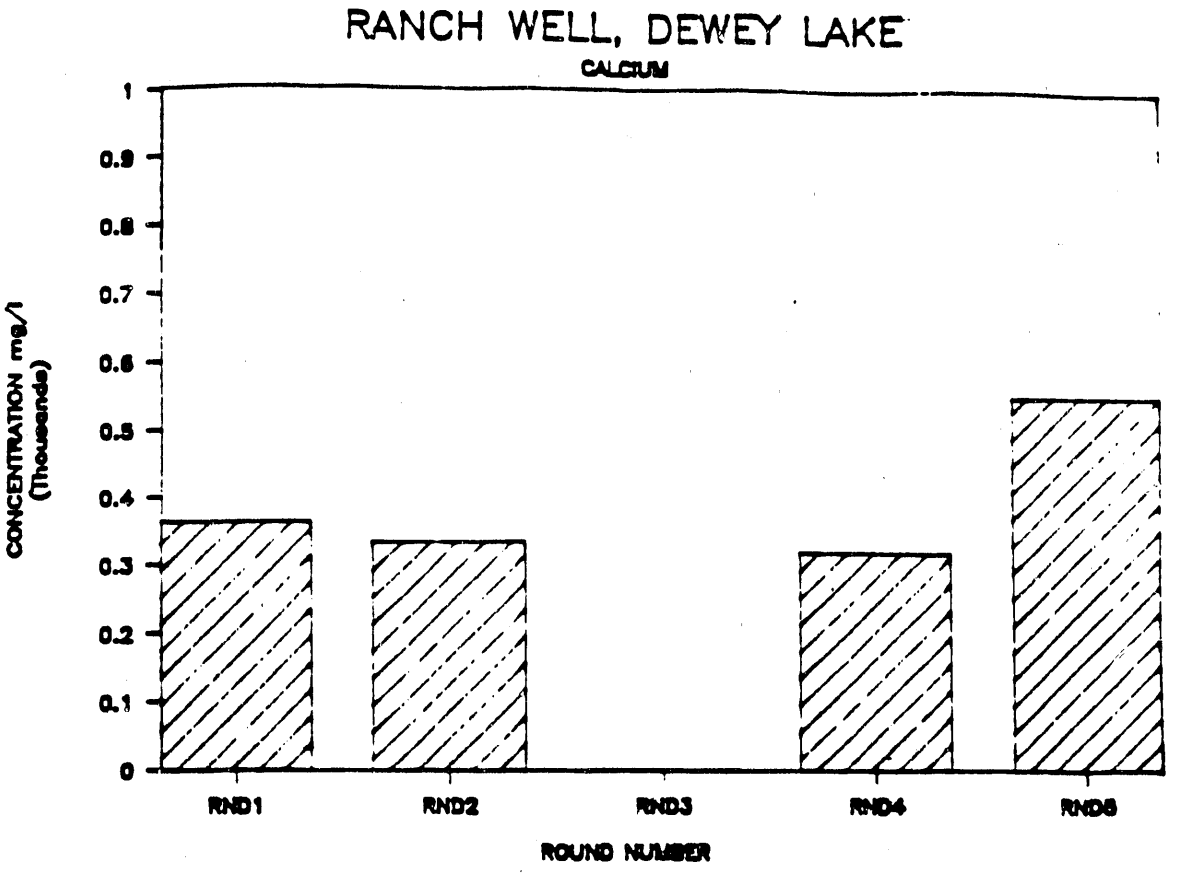

H-18, CULEBRA
POTASSIUM
CONCENTRATION mg/l
500
400
300
200
100
0
RND1
RND2
RND3
ROUND NUMBER

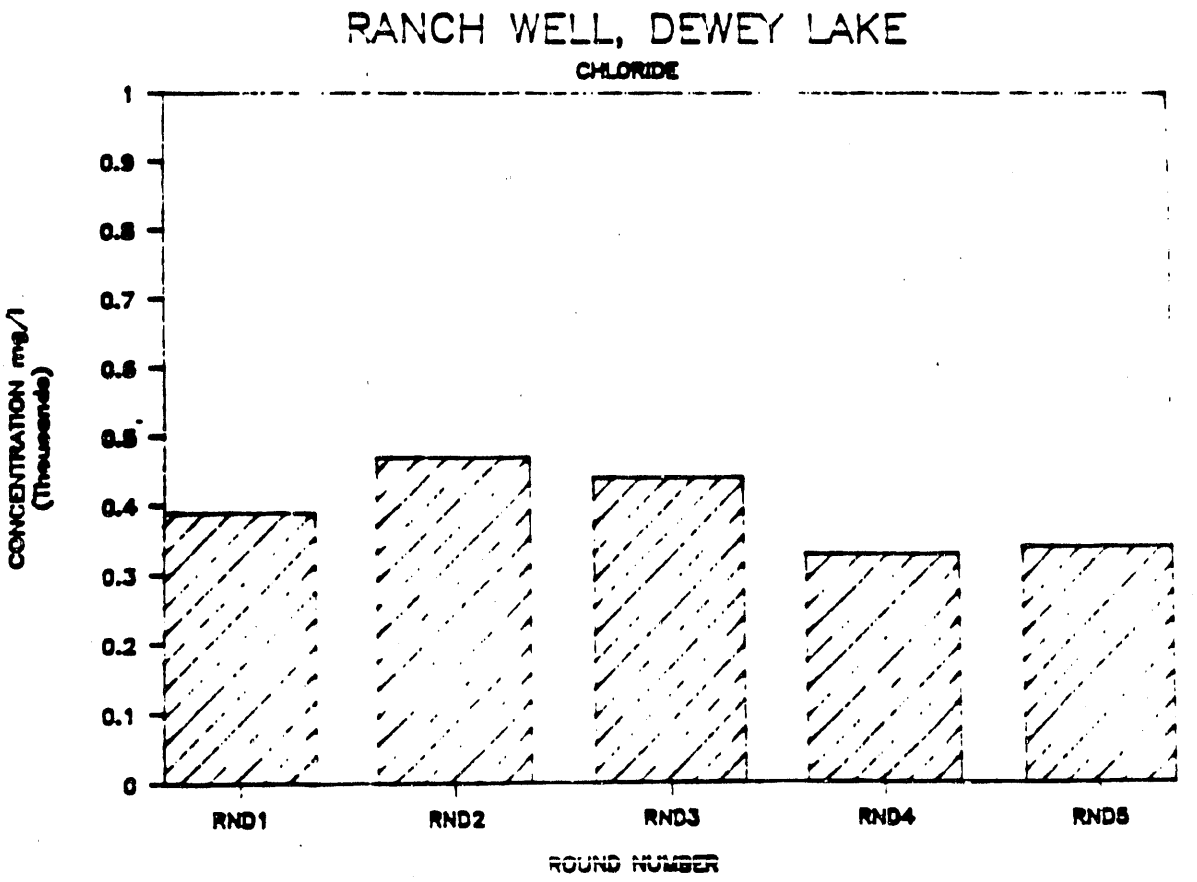

H-18, CULEBRA
SODIUM
CONCENTRATION mg/l
(Thousands)
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
ROUND NUMBER

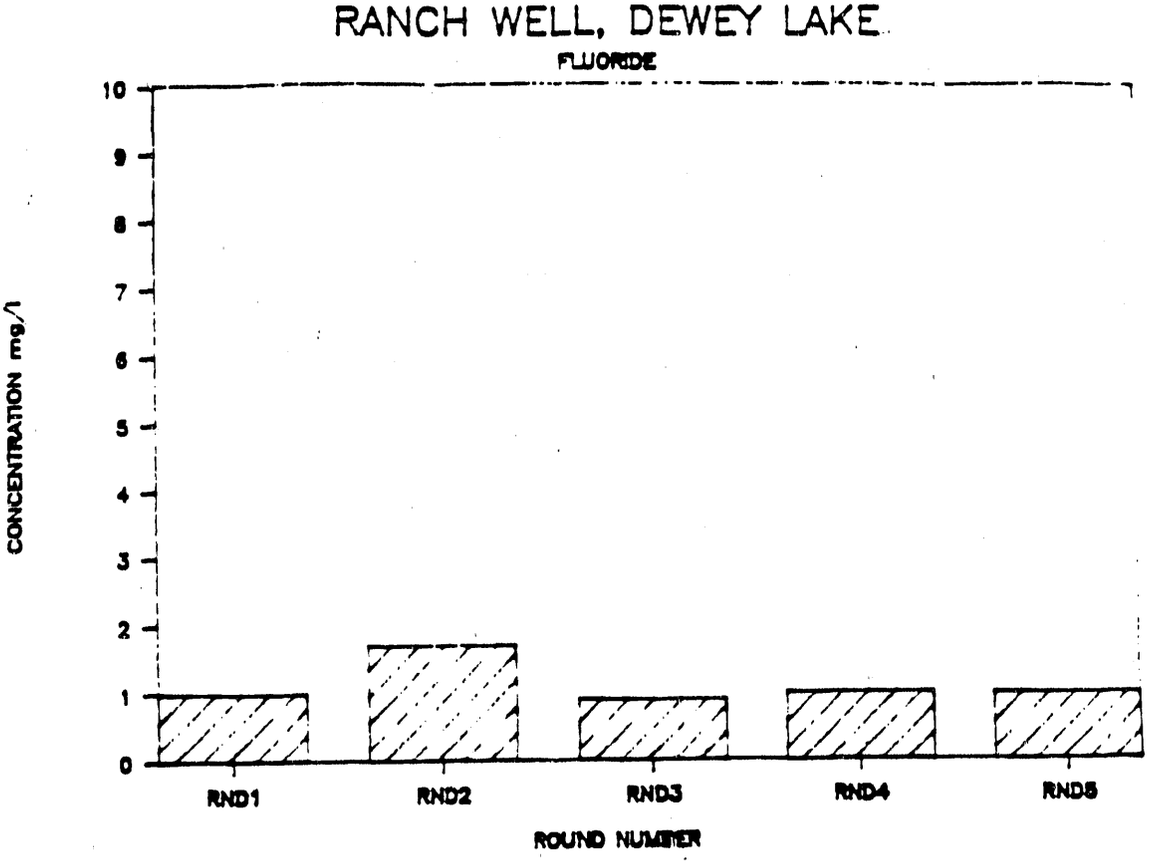

H-18, CULEBRA
SULFATE
CONCENTRATION mg/l
(Thousands)
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
ROUND NUMBER

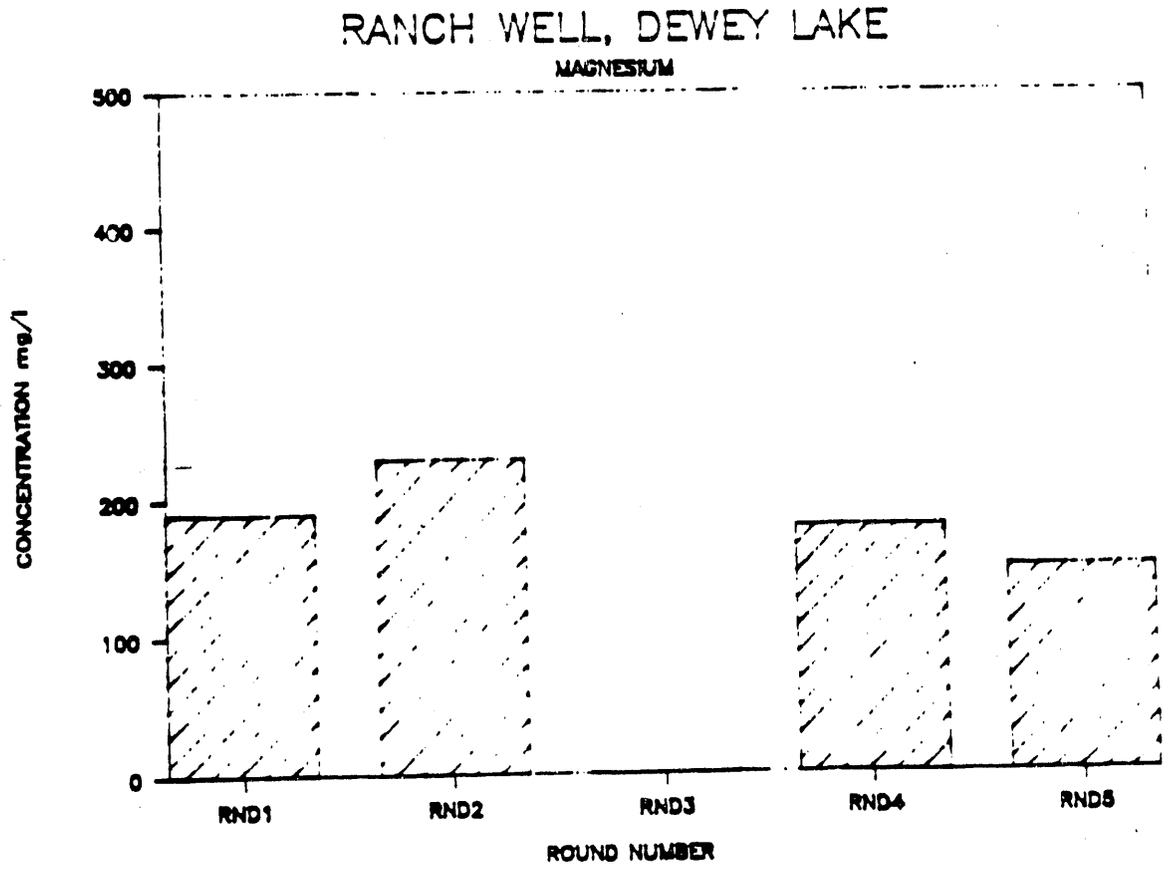

RANCH WELL, DEWEY LAKE
ALKALINITY
CONCENTRATION mg/l
500
400
300
200
100
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

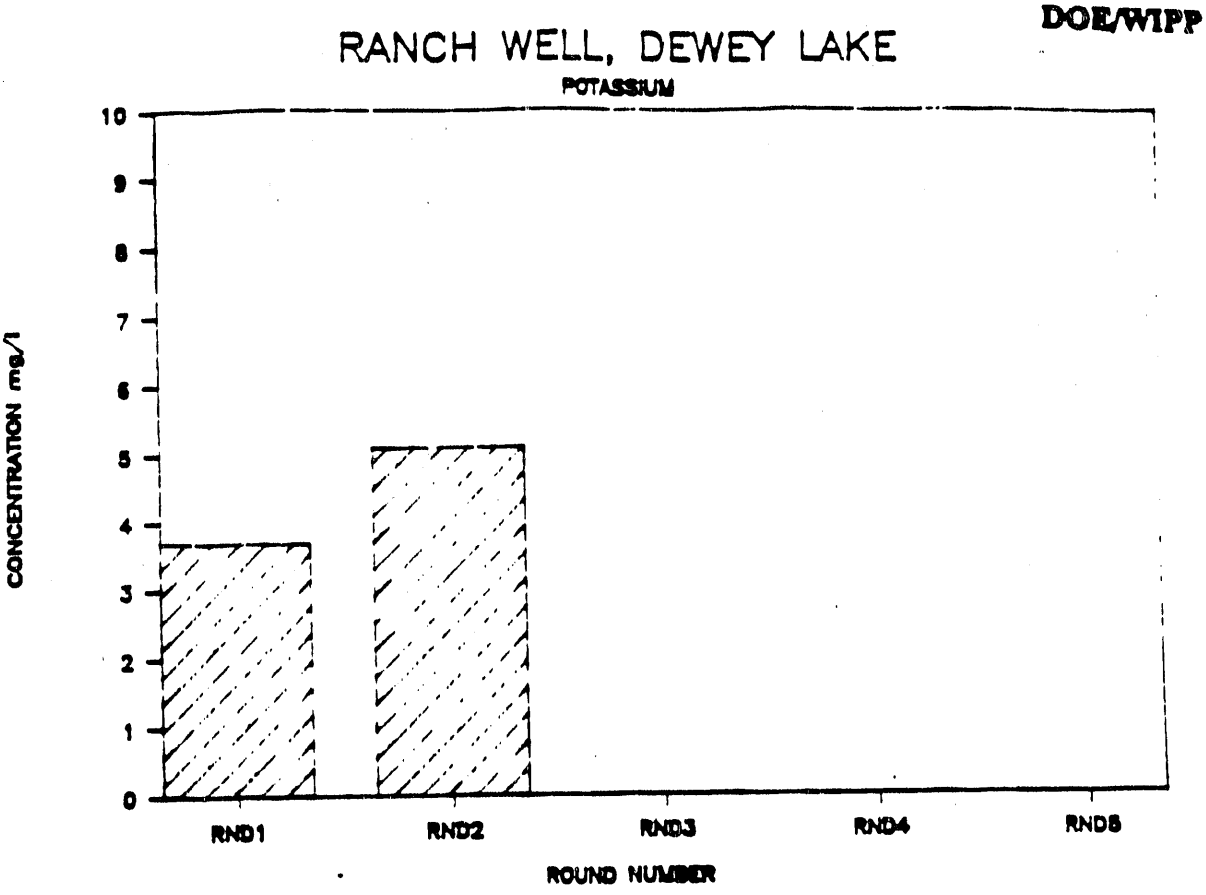

RANCH WELL, DEWEY LAKE
BROMIDE
CONCENTRATION mg/l
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

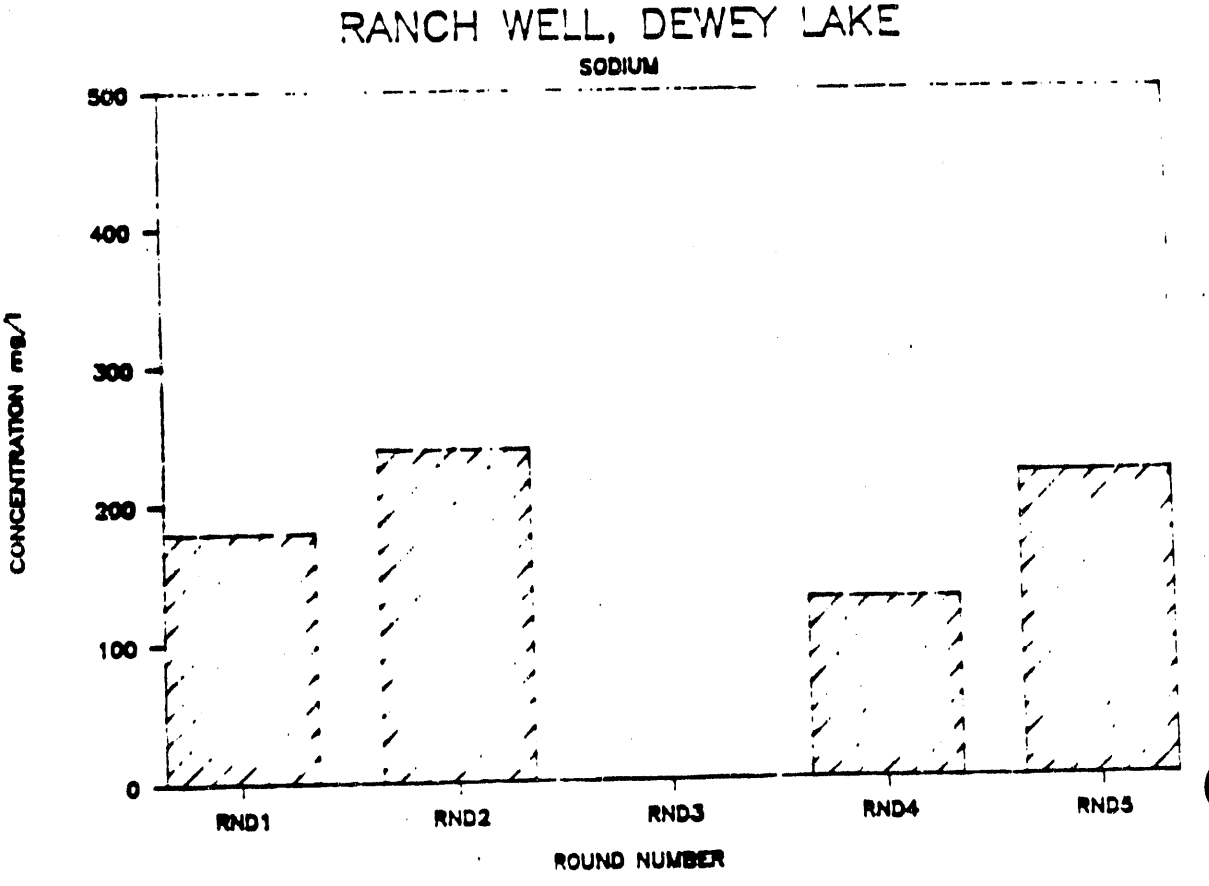

RANCH WELL, DEWEY LAKE
CALCIUM
CONCENTRATION mg/l
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

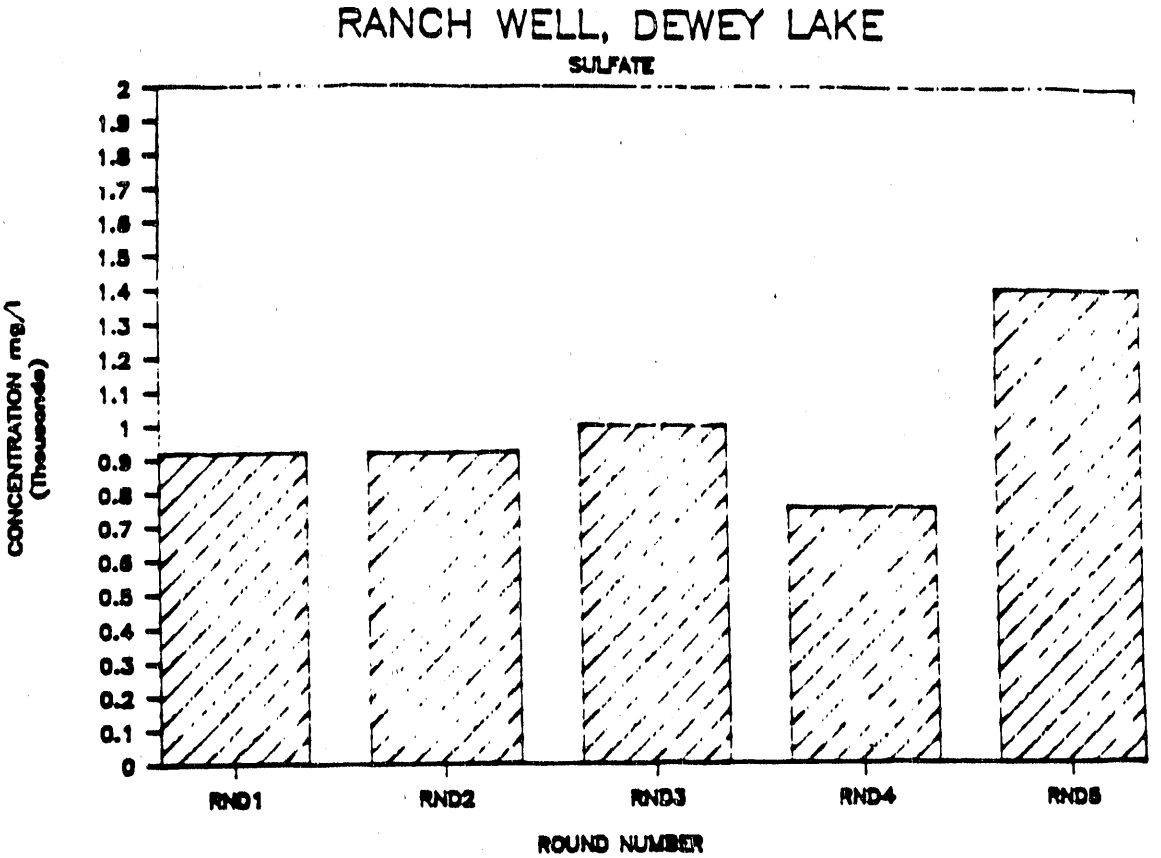

RANCH WELL, DEWEY LAKE
CHLORIDE
CONCENTRATION mg/l
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

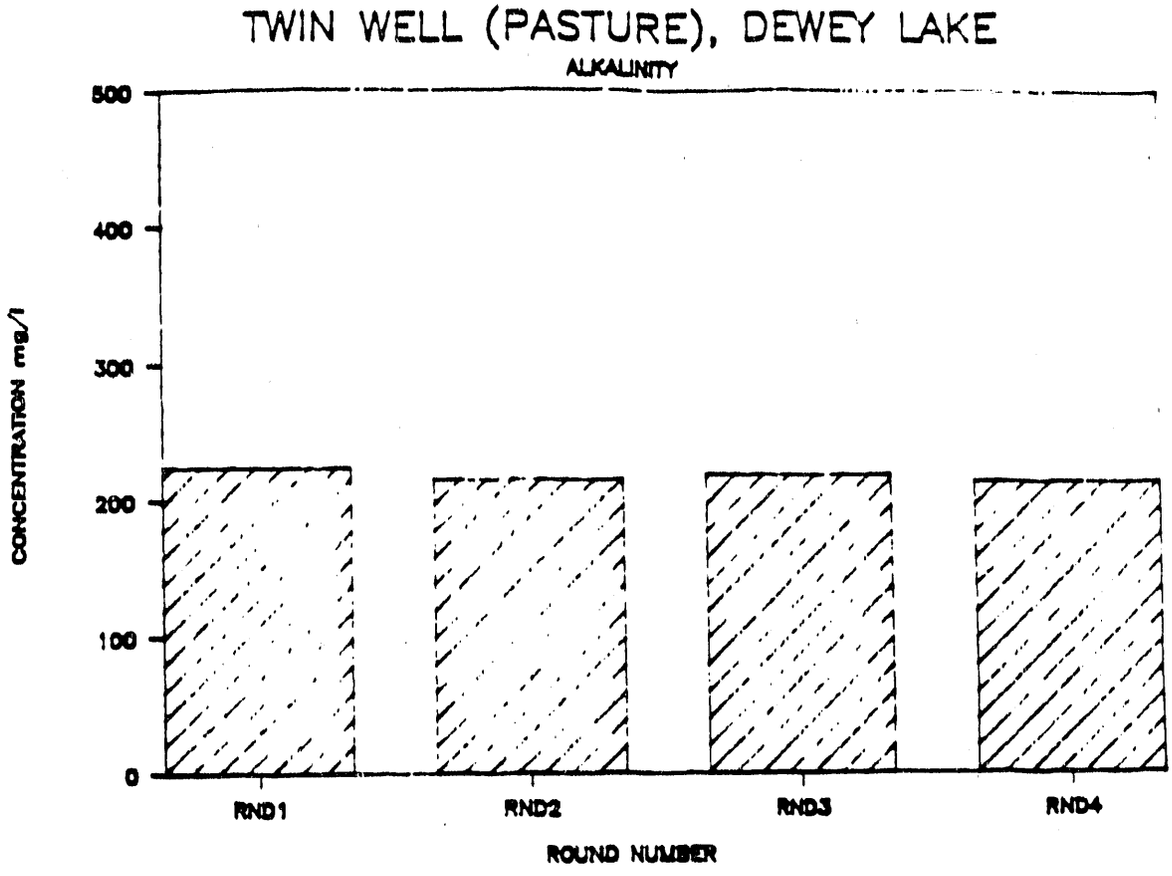

RANCH WELL, DEWEY LAKE
FLUORIDE
CONCENTRATION mg/l
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

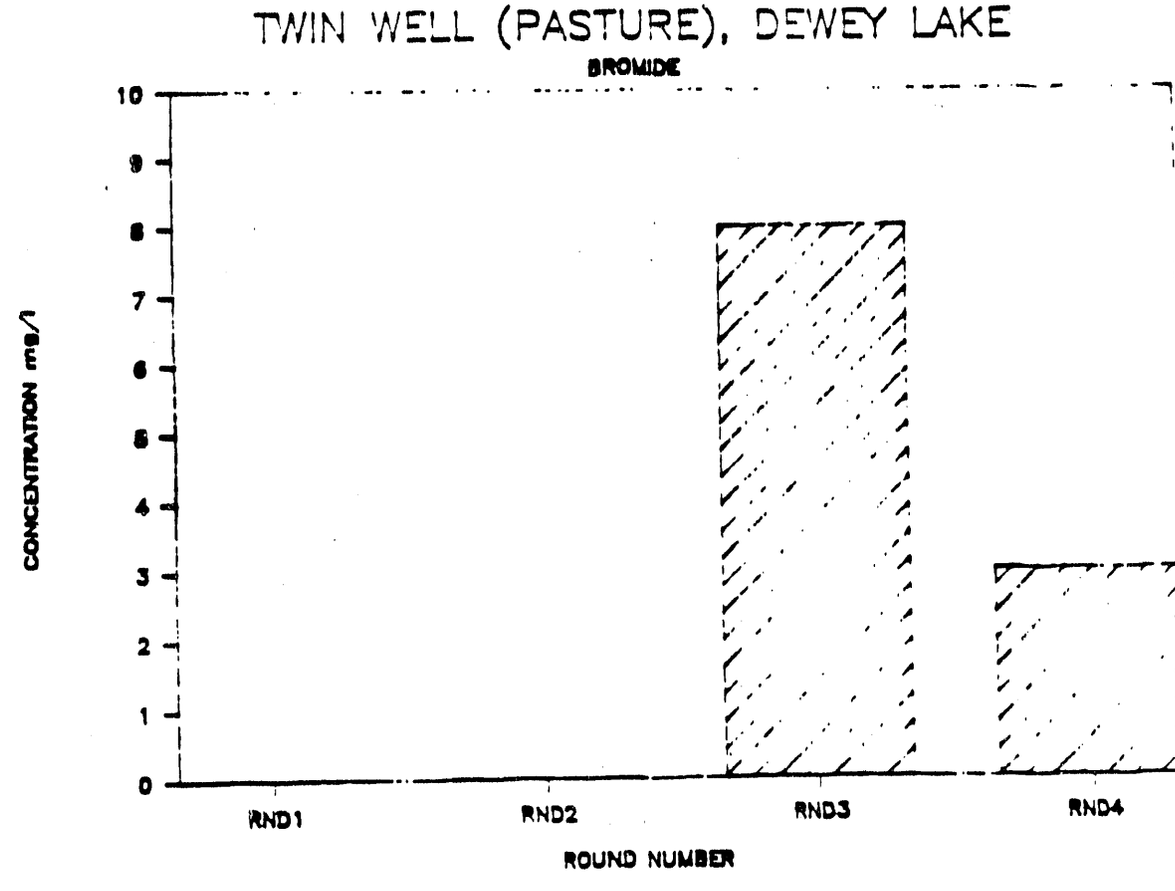

RANCH WELL, DEWEY LAKE
MAGNESIUM
CONCENTRATION mg/l
500
400
300
200
100
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER


RANCH WELL, DEWEY LAKE
POTASSIUM
CONCENTRATION mg/l
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER


RANCH WELL, DEWEY LAKE
SODIUM
CONCENTRATION mg/l
500
400
300
200
100
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

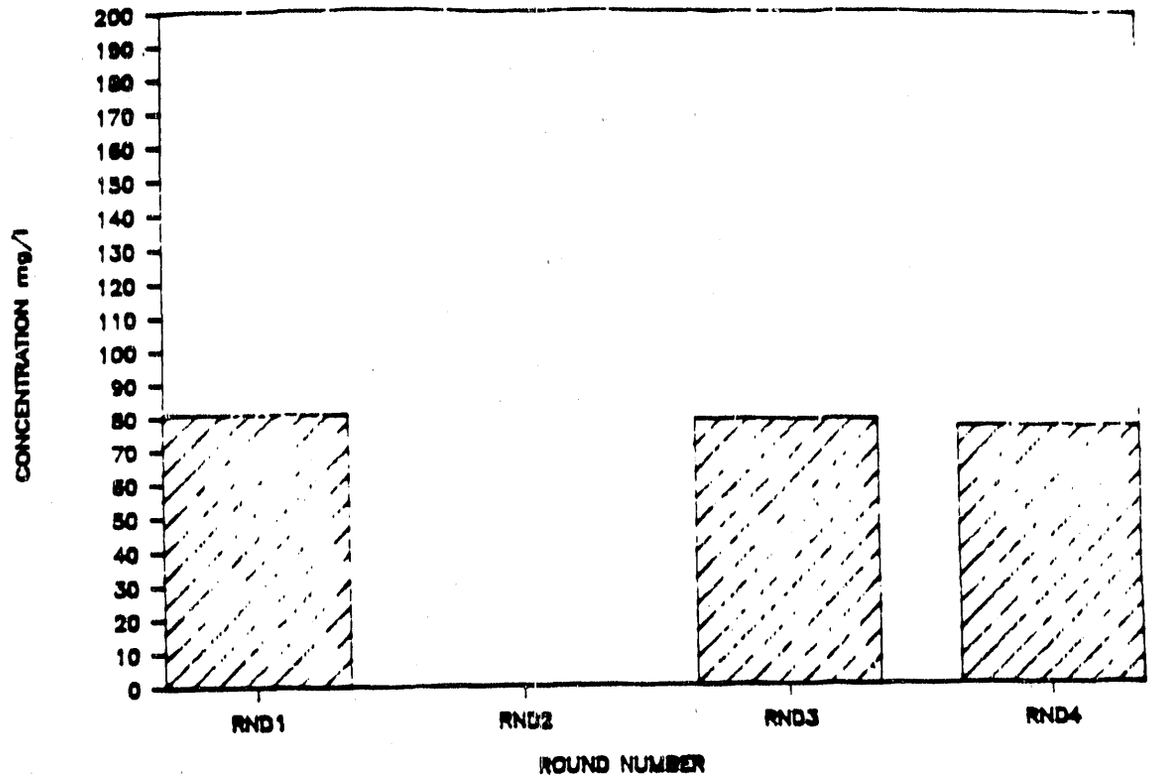

RANCH WELL, DEWEY LAKE
SULFATE
CONCENTRATION mg/l
(Thousands)
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER


TWIN WELL (PASTURE), DEWEY LAKE
ALKALINITY
CONCENTRATION mg/l
500
400
300
200
100
0
RND1
RND2
RND3
RND4
ROUND NUMBER


TWIN WELL (PASTURE), DEWEY LAKE
BROMIDE
CONCENTRATION mg/l
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
ROUND NUMBER

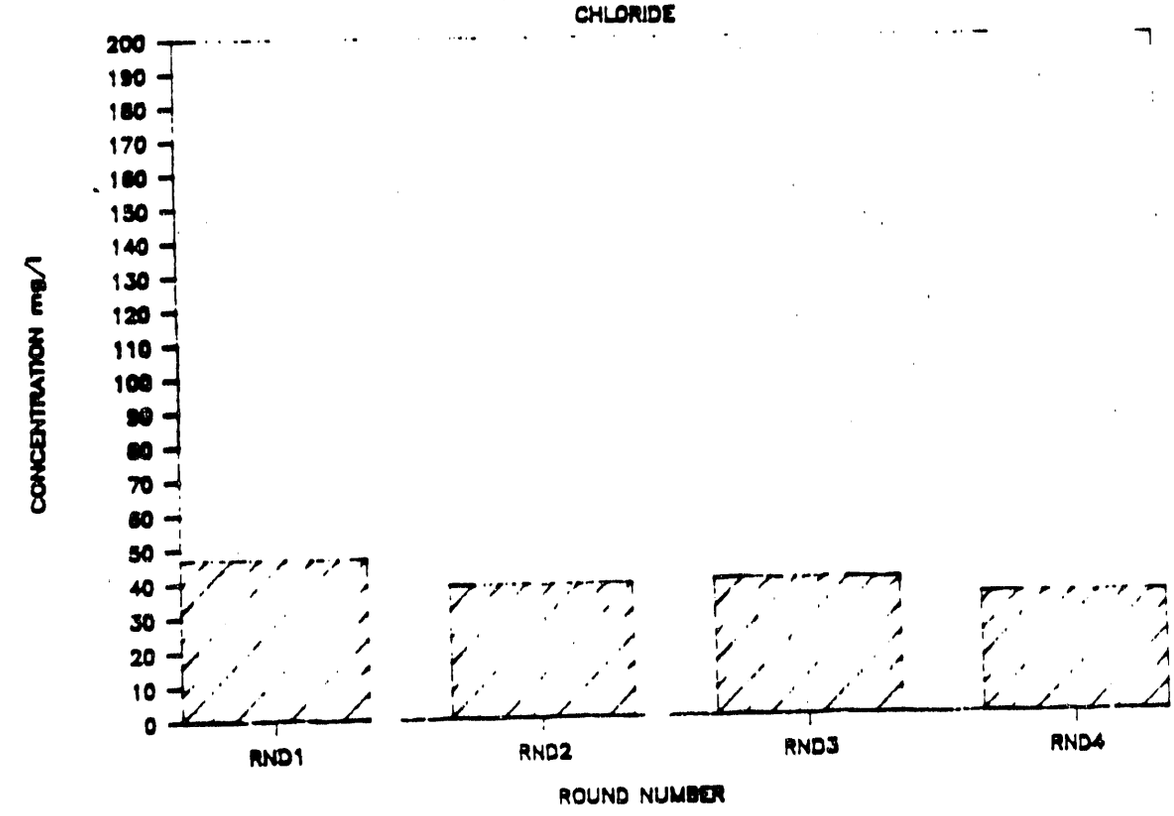
TWIN WELL (PASTURE), DEWEY LAKE

CALCIUM



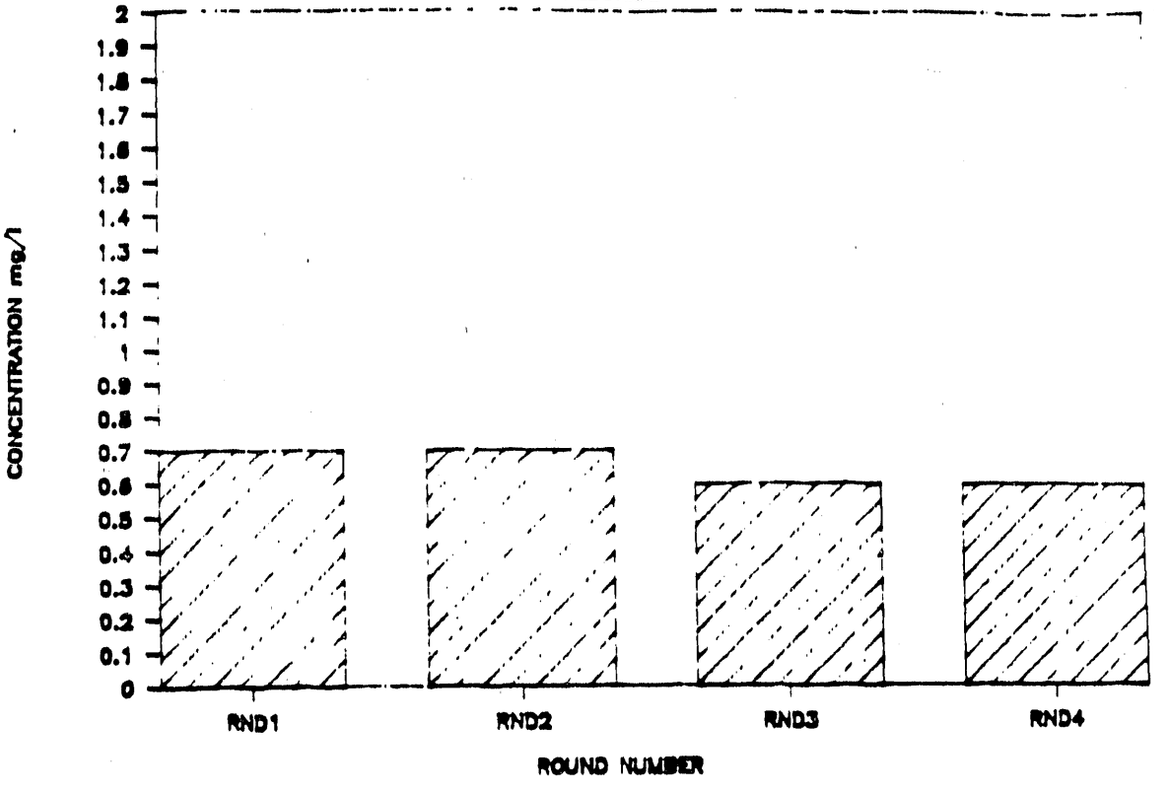
TWIN WELL (PASTURE), DEWEY LAKE

CHLORIDE



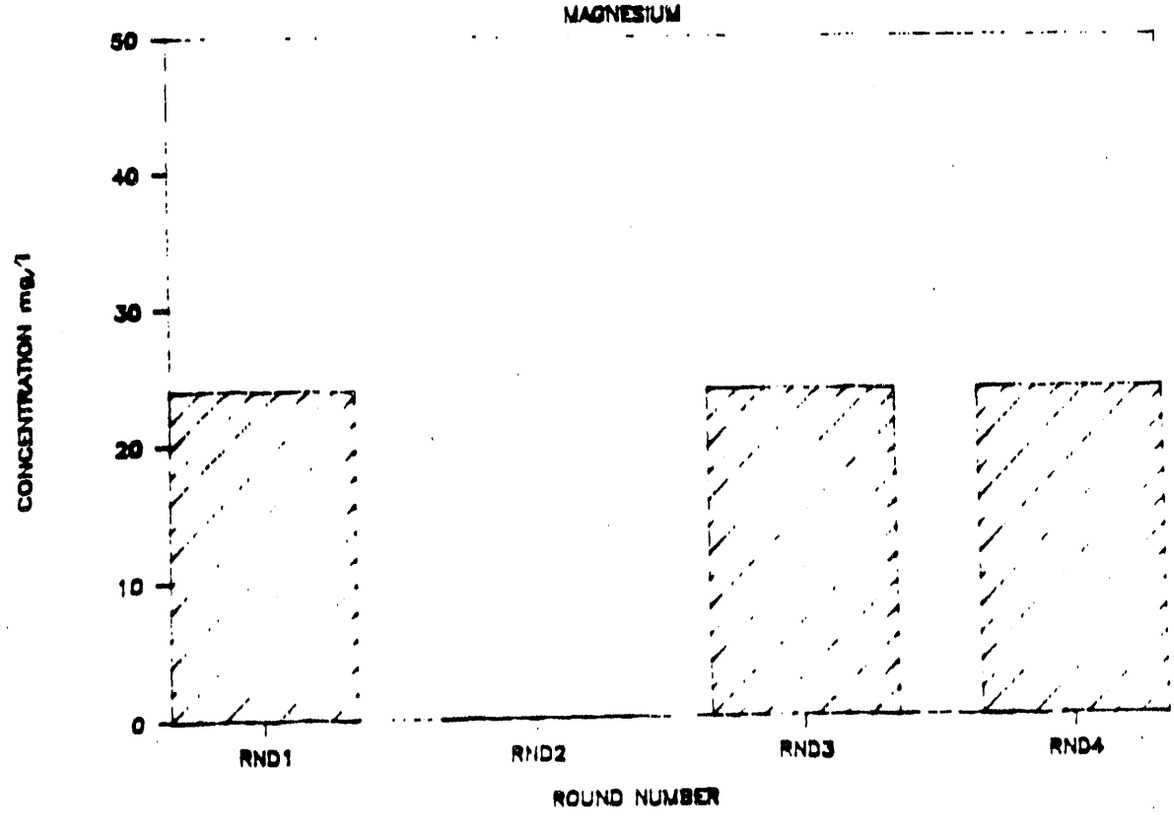
TWIN WELL (PASTURE), DEWEY LAKE

FLUORIDE

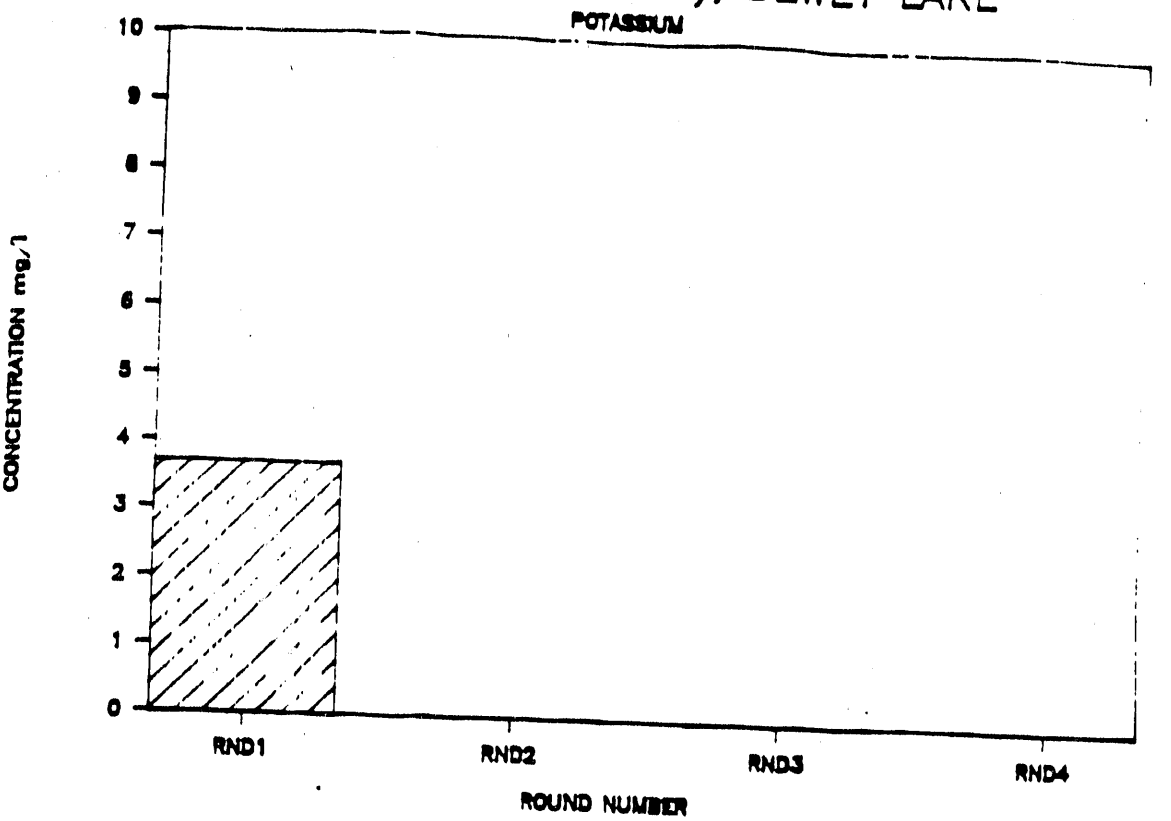


TWIN WELL (PASTURE), DEWEY LAKE

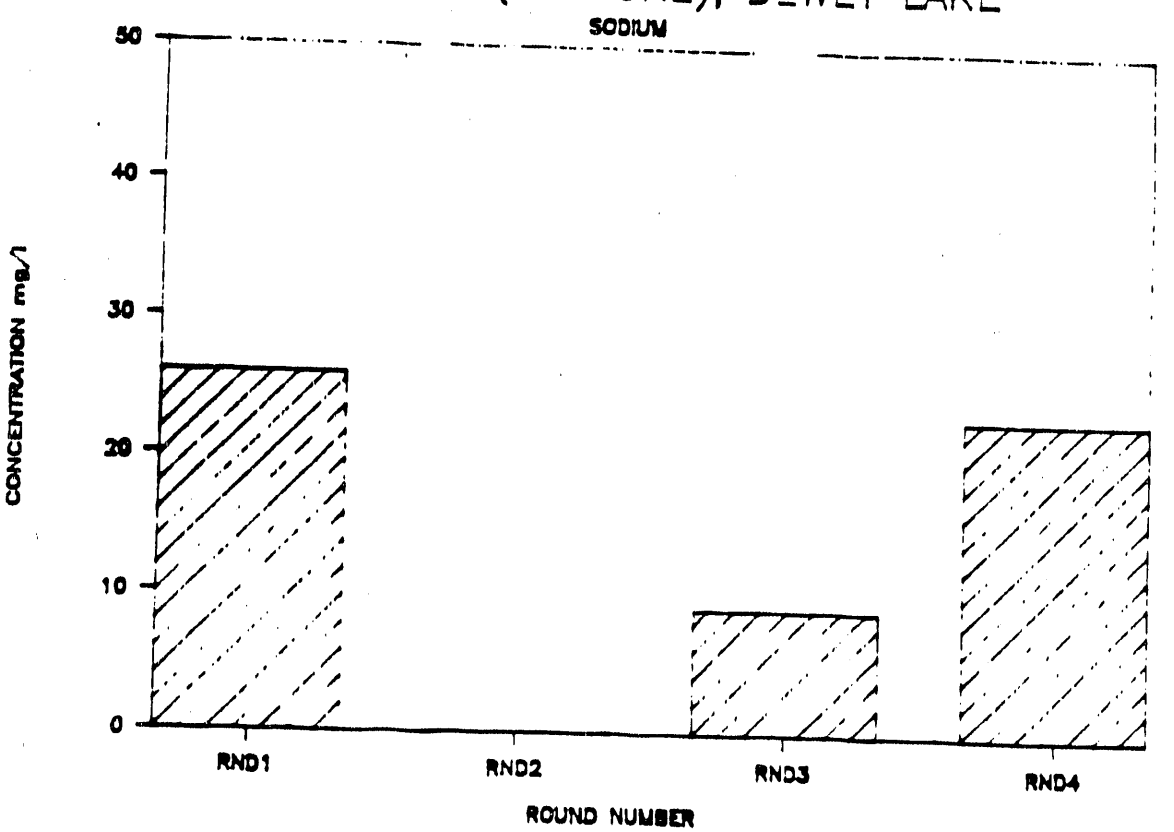
MAGNESIUM

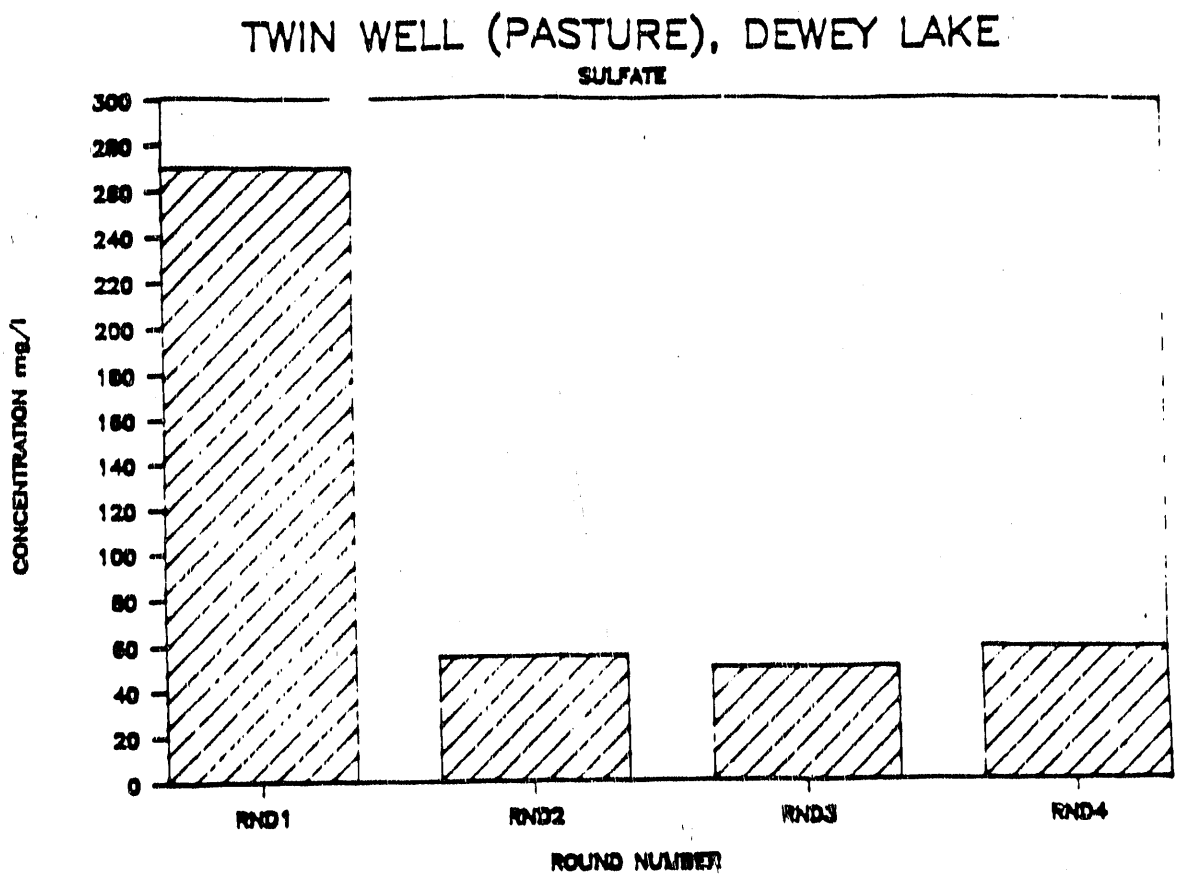


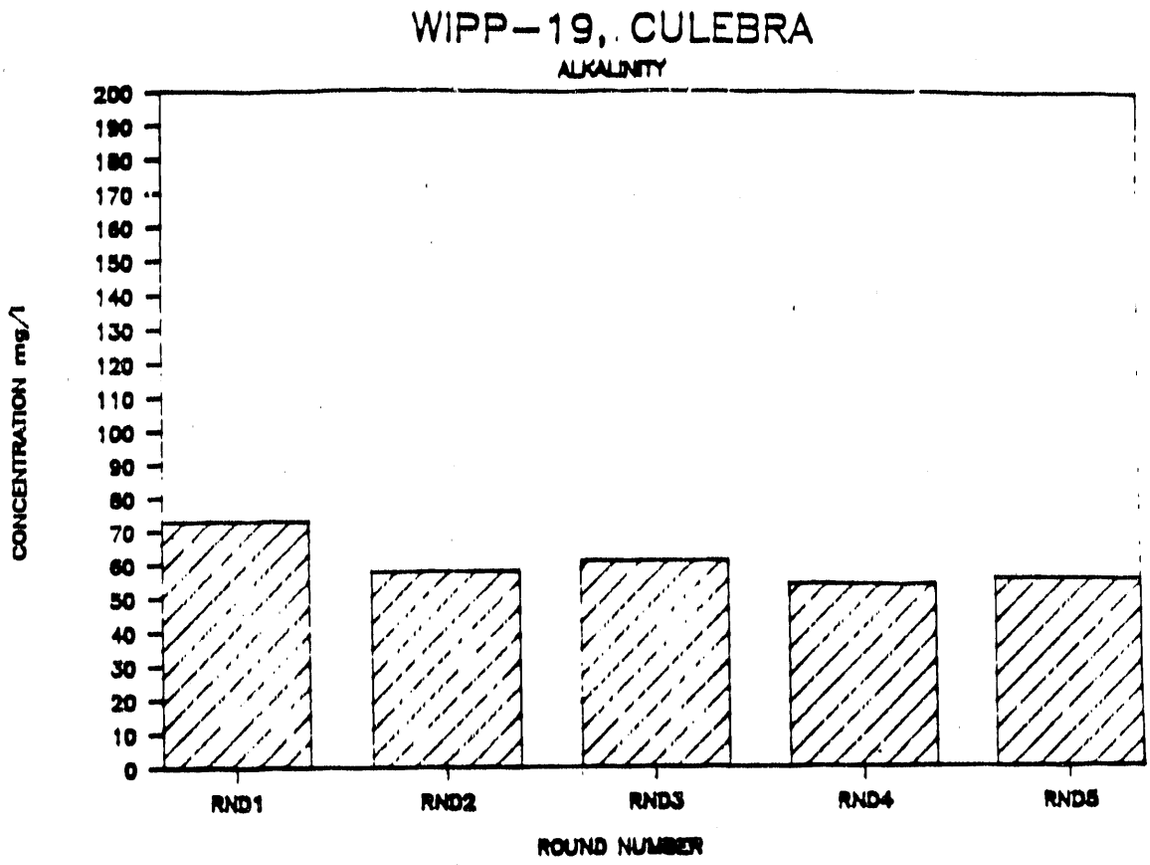
TWIN WELL (PASTURE), DEWEY LAKE

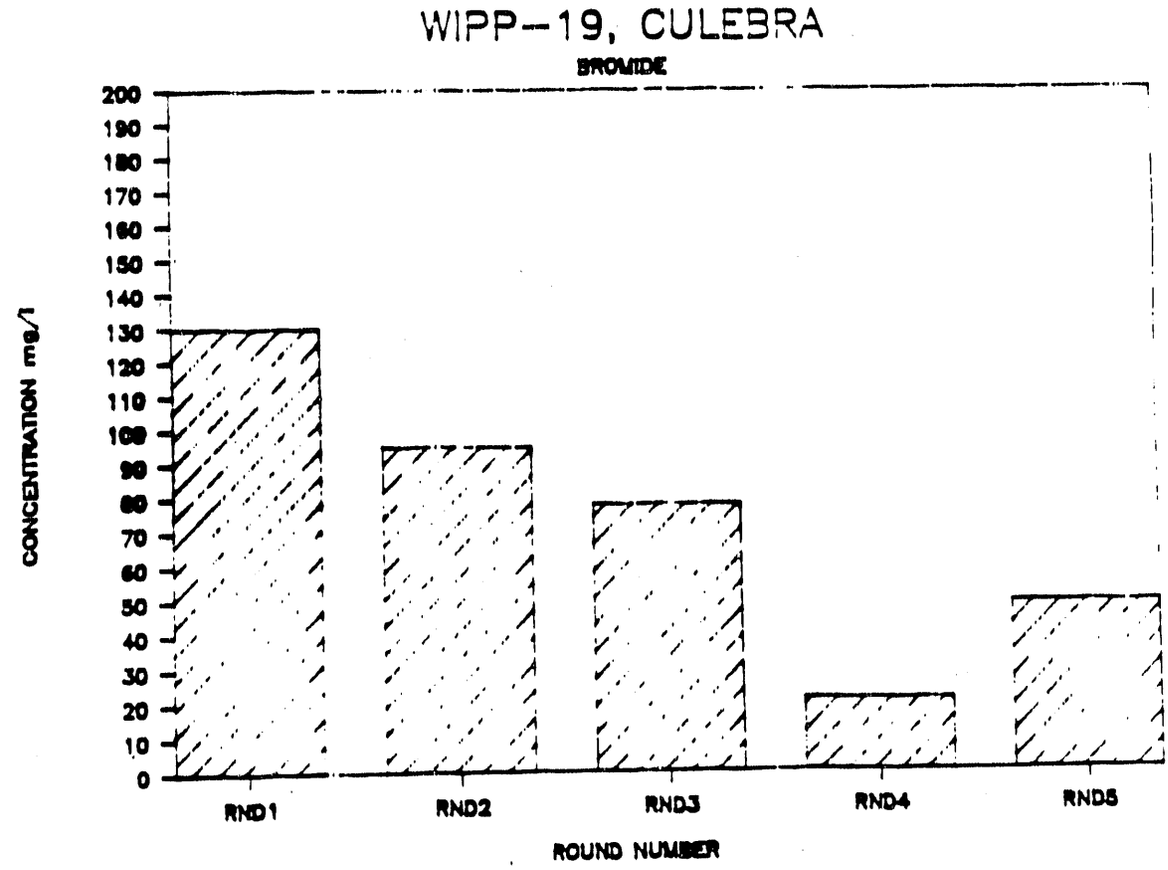


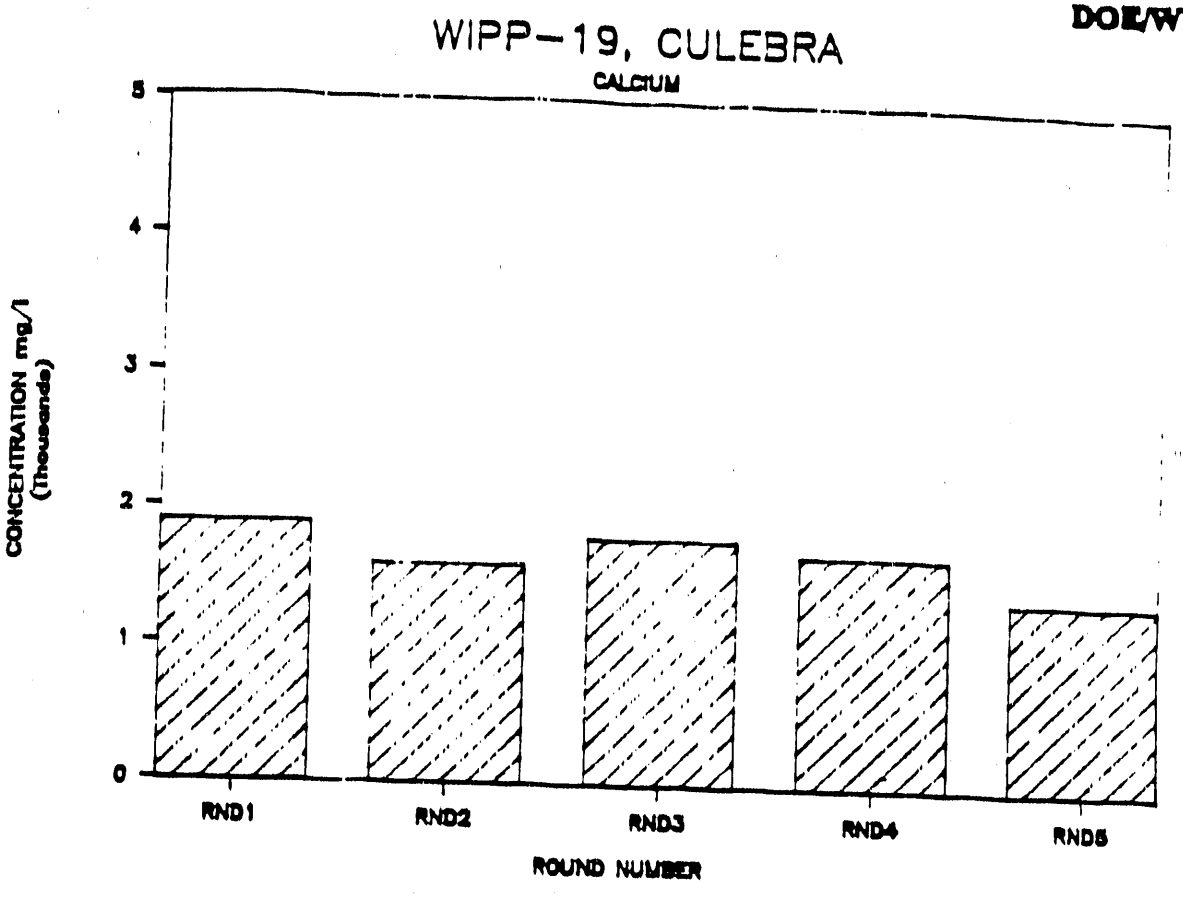
TWIN WELL (PASTURE), DEWEY LAKE

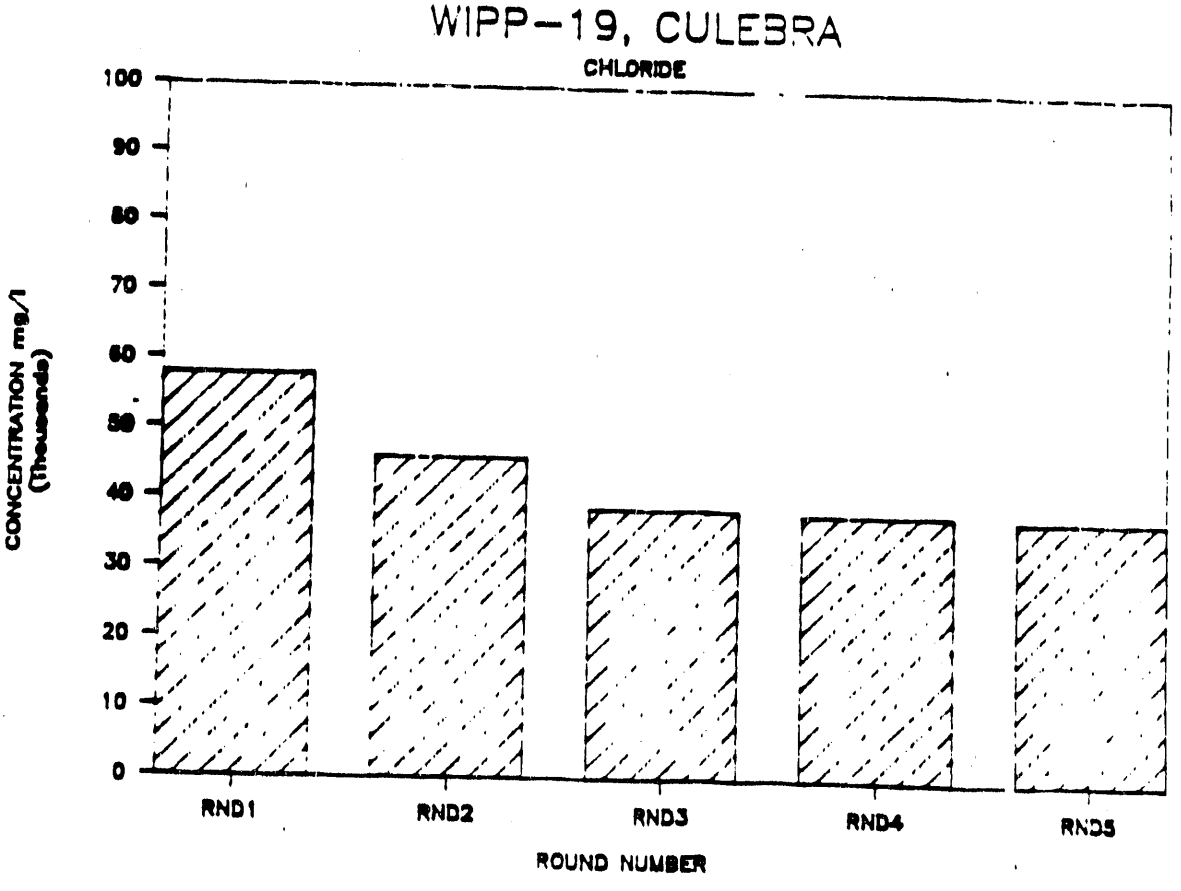


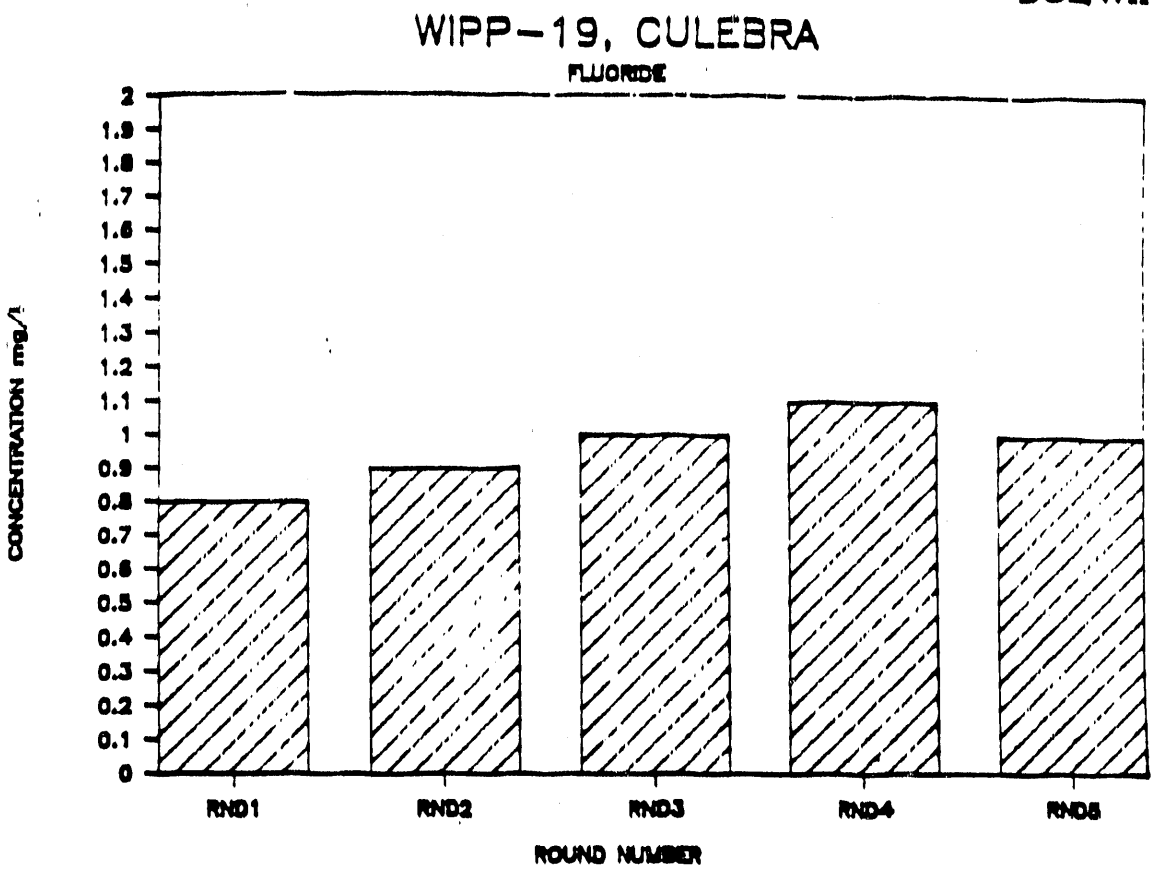

TWIN WELL (PASTURE), DEWEY LAKE
SULFATE
CONCENTRATION mg/l
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
RND1
RND2
RND3
RND4
ROUND NUMBER

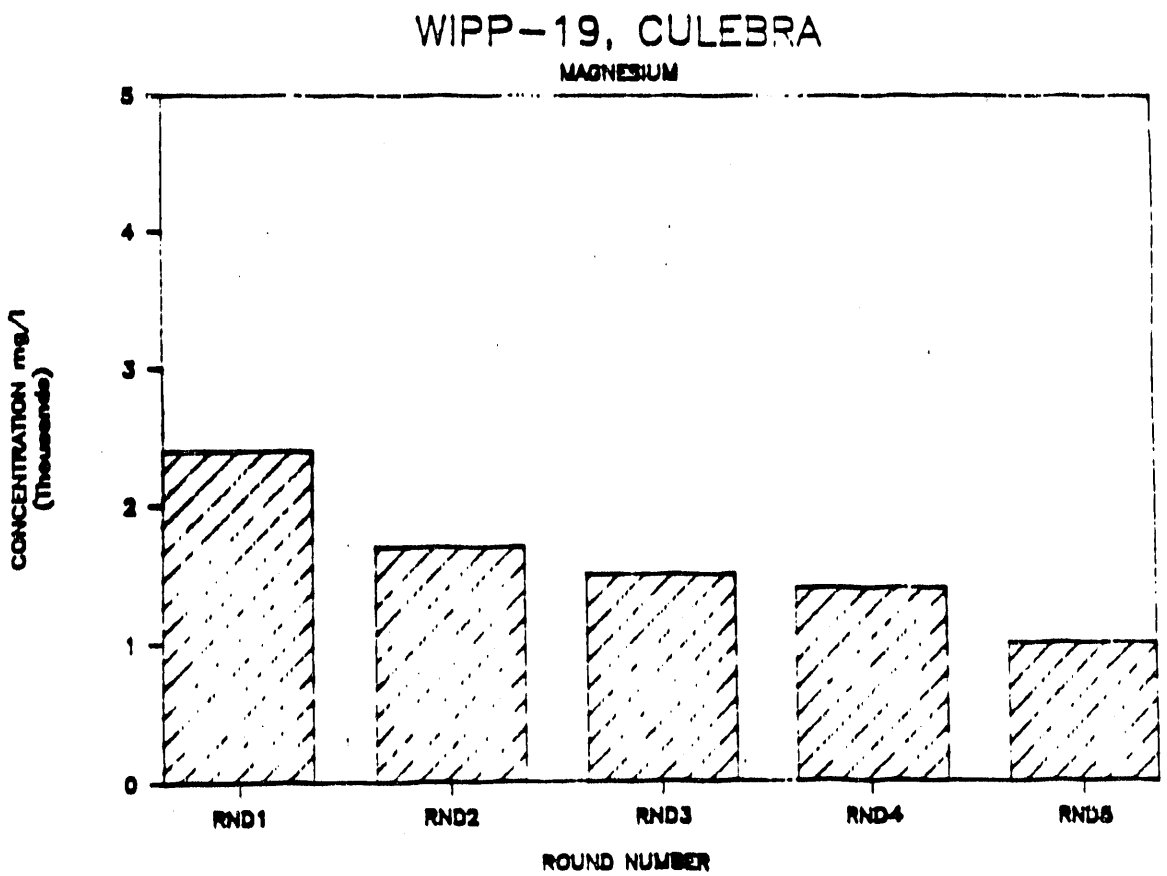

WIPP–19, CULEBRA
ALKALINITY
CONCENTRATION mg/l
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

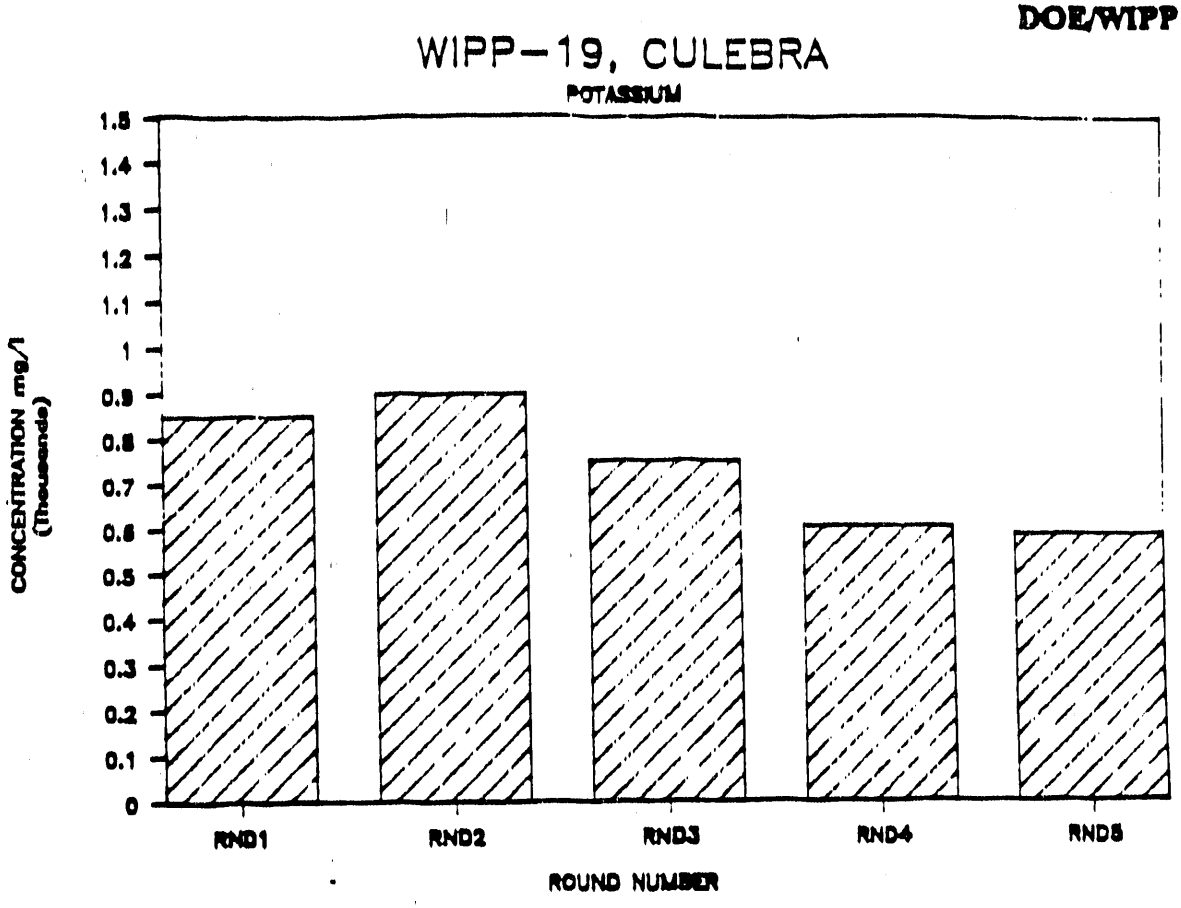

WIPP–19, CULEBRA
BROMIDE
CONCENTRATION mg/l
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

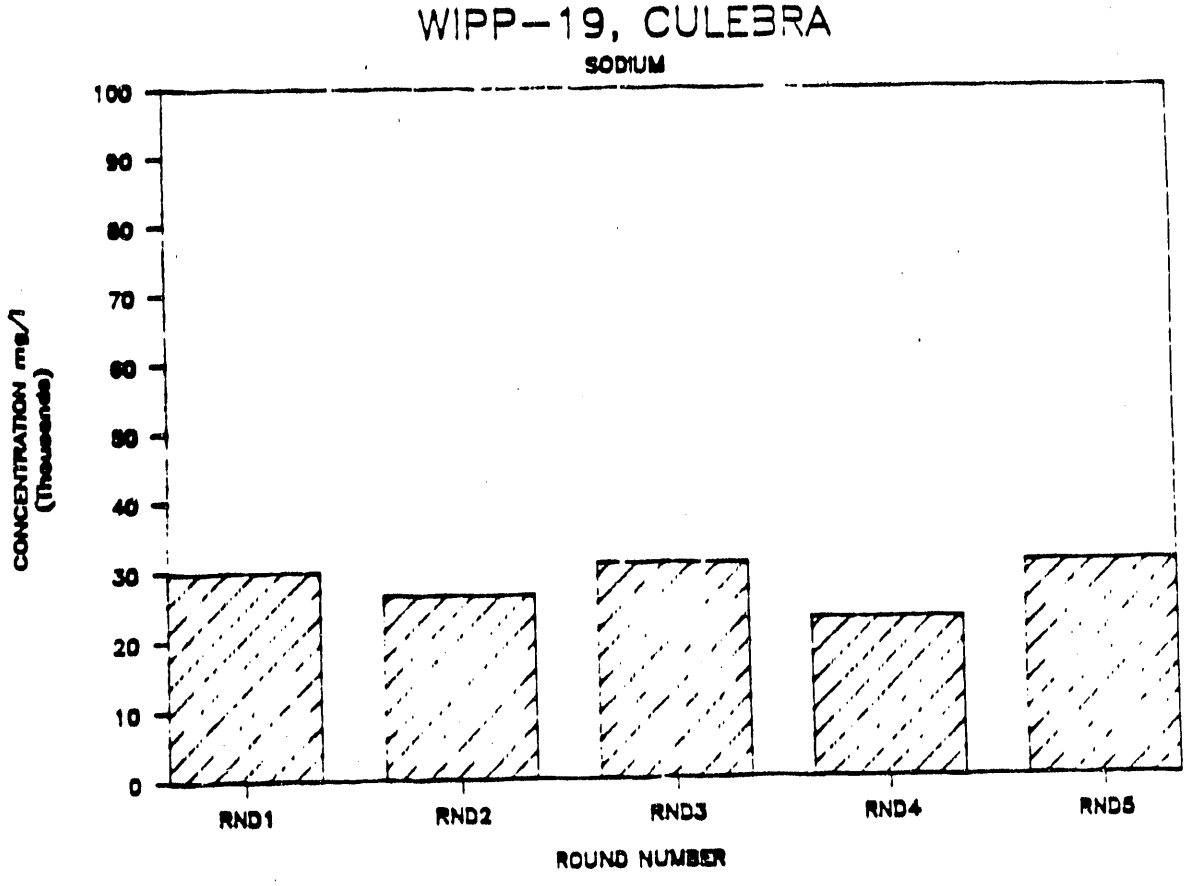

WIPP–19, CULEBRA
CALCIUM
CONCENTRATION mg/l
(thousands)
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

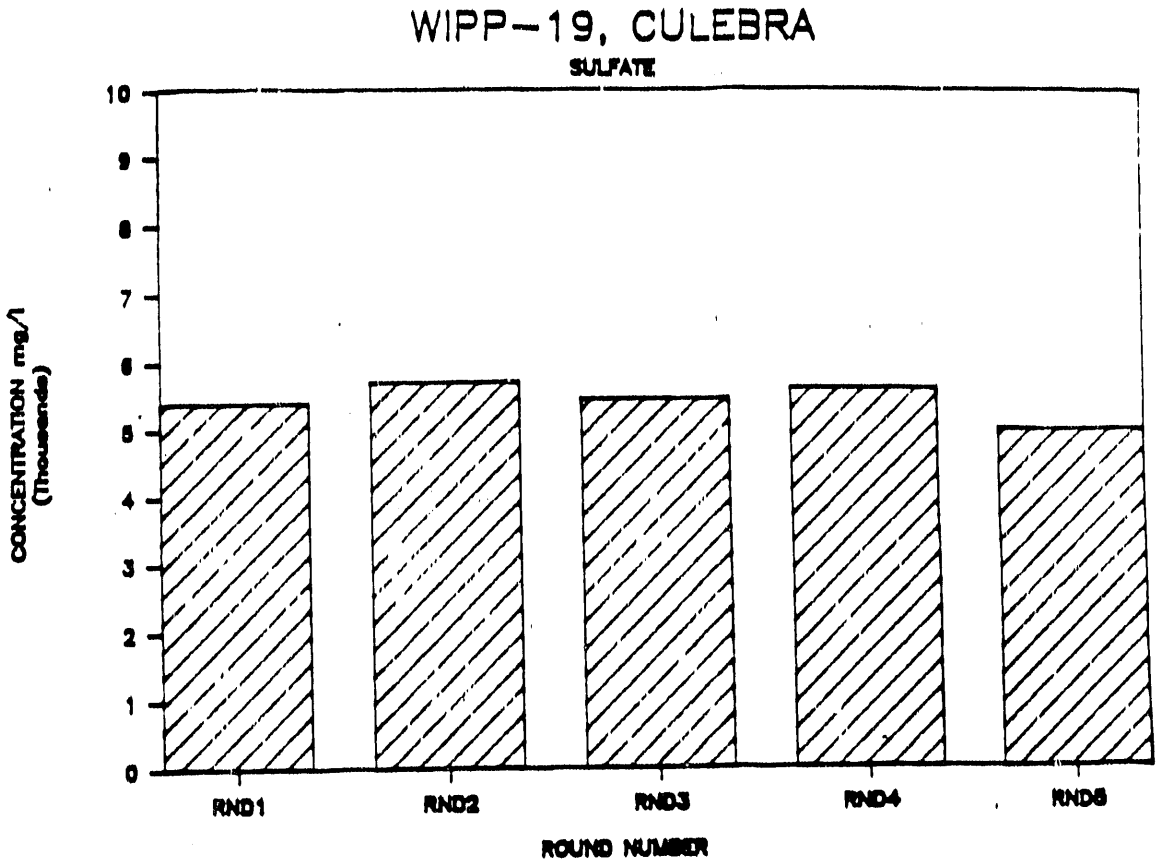

WIPP–19, CULEBRA
CHLORIDE
CONCENTRATION mg/l
(thousands)
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER


WIPP-19, CULEBRA
FLUORIDE
CONCENTRATION mg/l
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER


WIPP-19, CULEBRA
MAGNESIUM
CONCENTRATION mg/l
(Thousands)
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER


WIPP-19, CULEBRA
POTASSIUM
CONCENTRATION mg/l (Thousands)
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER


WIPP-19, CULEBRA
SODIUM
CONCENTRATION mg/l (Thousands)
100
90
80
70
60
50
40
30
20
10
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER


WIPP-19, CULEBRA
SULFATE
CONCENTRATION mg/l
(Thousands)
10
9
8
7
6
5
4
3
2
1
0
RND1
RND2
RND3
RND4
RND5
ROUND NUMBER

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APPENDIX X
GROUNDWATER LEVEL DATA FOR 1990

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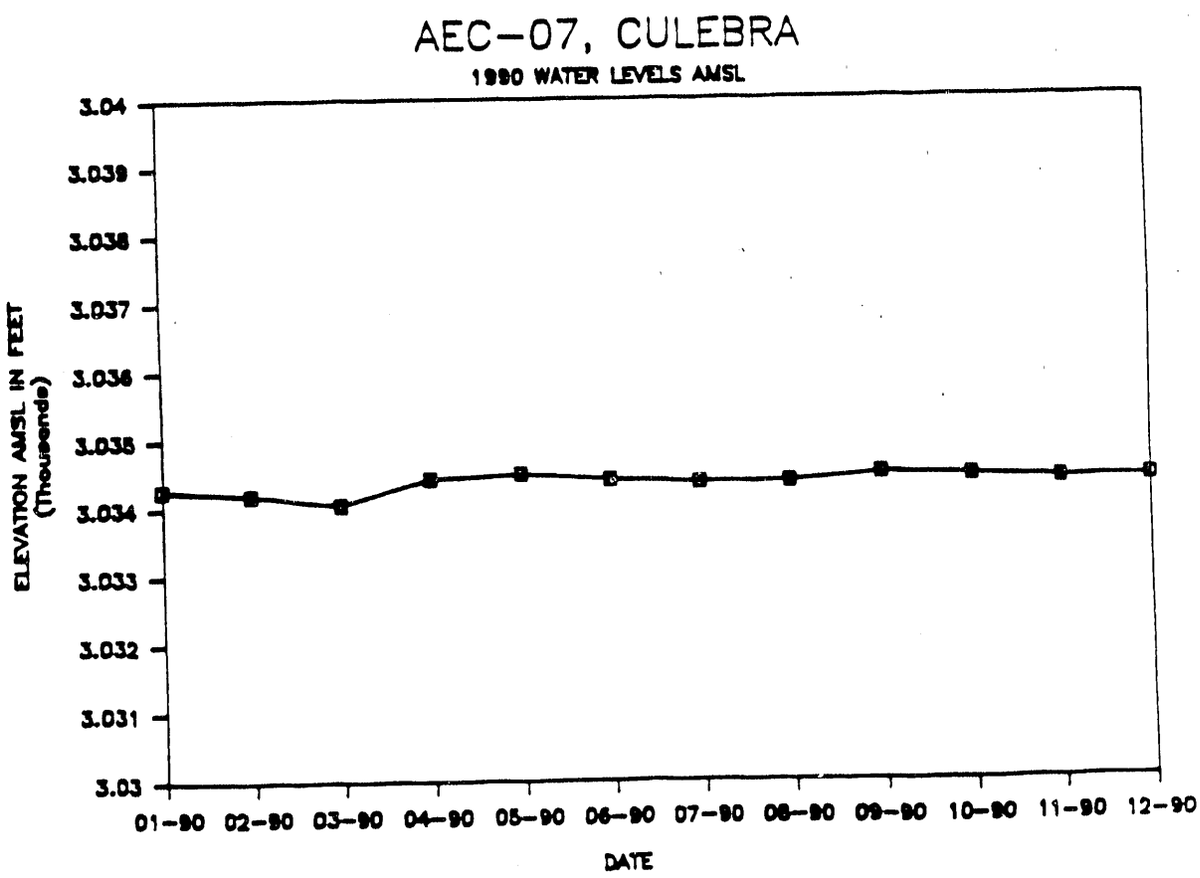
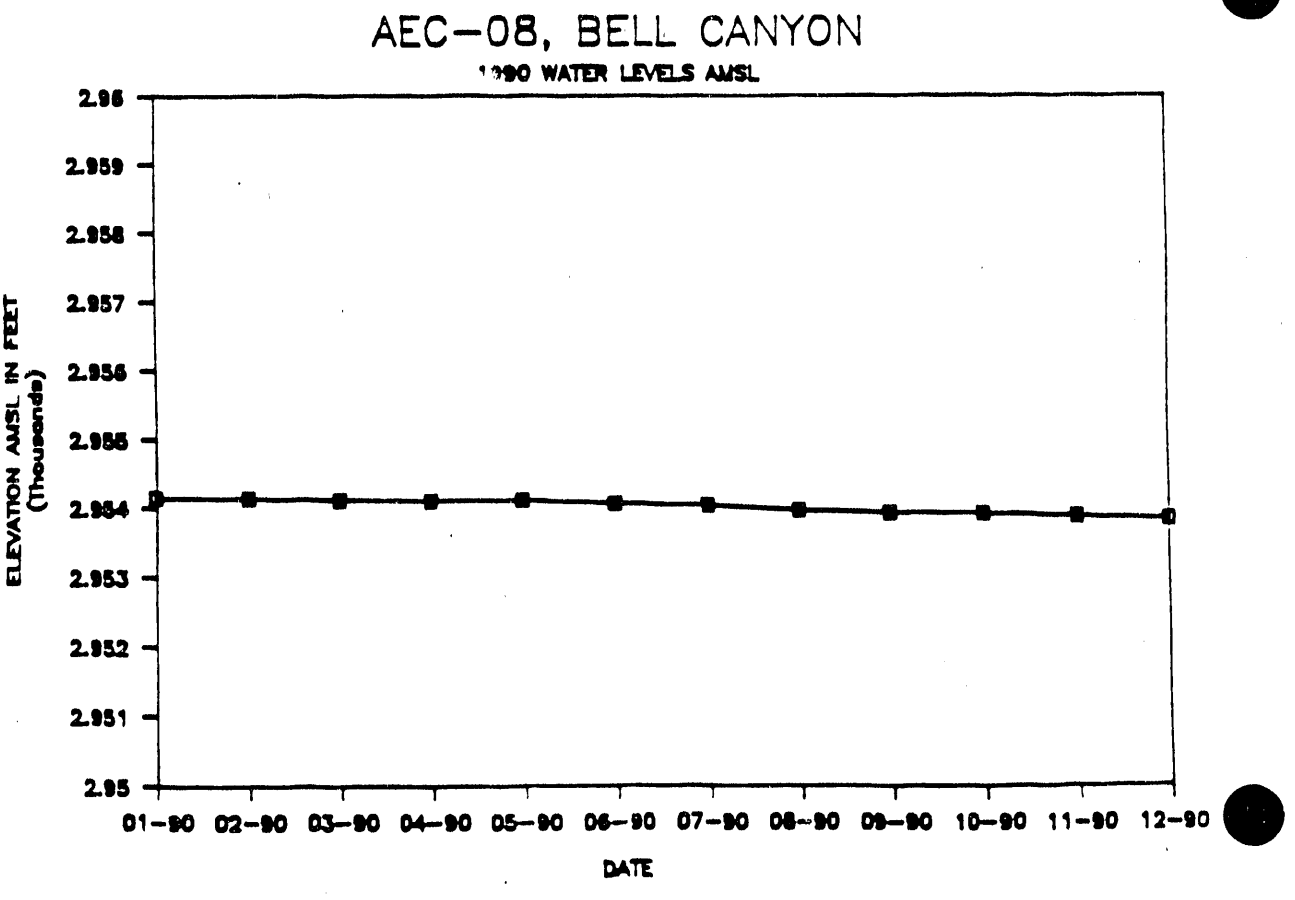
GROUND WATER-LEVELS
CALENDAR YEAR 1990
AEC-07, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_
AEC-7	CUL	3657.25	01-90	09:54	623.96	0.98	622.98	189.88	3034.27	924.85
AEC-7	CUL	3657.25	02-90	09:36	624.03	0.98	623.05	189.91	3034.20	924.82
AEC-7	CUL	3657.25	03-90	08:21	624.18	0.98	623.20	189.95	3034.05	924.78
AEC-7	CUL	3657.25	04-90	08:00	623.80	0.98	622.82	189.84	3034.43	924.89
AEC-7	CUL	3657.25	05-90	08:25	623.73	0.98	622.75	189.81	3034.50	924.92
AEC-7	CUL	3657.25	06-90	07:49	623.82	0.98	622.84	189.84	3034.41	924.89
AEC-7	CUL	3657.25	07-90	08:20	623.86	0.98	622.88	189.85	3034.37	924.88
AEC-7	CUL	3657.25	08-90	07:37	623.86	0.98	622.88	189.85	3034.37	924.88
AEC-7	CUL	3657.25	09-90	08:35	623.75	0.98	622.77	189.82	3034.48	924.91
AEC-7	CUL	3657.25	10-90	08:45	623.79	0.98	622.81	189.83	3034.44	924.90
AEC-7	CUL	3657.25	11-90	09:02	623.84	0.98	622.86	189.85	3034.39	924.88
AEC-7	CUL	3657.25	12-90	08:20	623.83	0.98	622.85	189.84	3034.40	924.89



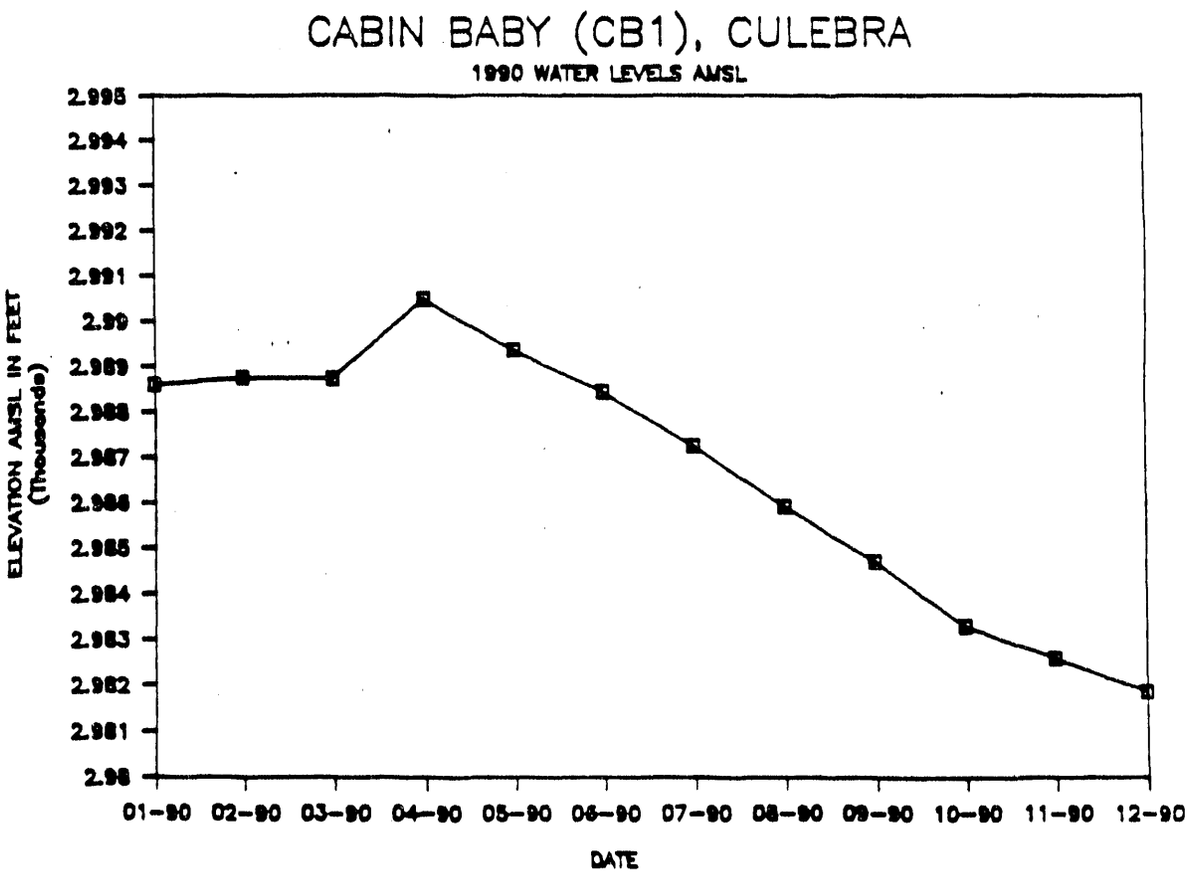
GROUND WATER-LEVELS
CALENDAR YEAR 1990
AEC-08, BELL CANYON

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL
AEC-8	B/C	3537.10	01-90	14:10	582.95	0.00	582.95	177.68	2954.15	900.4
AEC-8	B/C	3537.10	02-90	12:30	582.95	0.00	582.95	177.68	2954.15	900.4
AEC-8	B/C	3537.10	03-90	08:50	582.97	0.00	582.97	177.69	2954.13	900.4
AEC-8	B/C	3537.10	04-90	08:31	582.98	0.00	582.98	177.69	2954.12	900.4
AEC-8	B/C	3537.10	05-90	08:58	582.97	0.00	582.97	177.69	2954.13	900.4
AEC-8	B/C	3537.10	06-90	08:10	583.02	0.00	583.02	177.70	2954.08	900.4
AEC-8	B/C	3537.10	07-90	08:45	583.05	0.00	583.05	177.71	2954.05	900.3
AEC-8	B/C	3537.10	08-90	15:20	583.13	0.00	583.13	177.74	2953.97	900.3
AEC-8	B/C	3537.10	09-90	08:58	583.17	0.00	583.17	177.75	2953.93	900.3
AEC-8	B/C	3537.10	10-90	09:09	583.18	0.00	583.18	177.75	2953.92	900.3
AEC-8	B/C	3537.10	11-90	09:30	583.21	0.00	583.21	177.76	2953.89	900.3
AEC-8	B/C	3537.10	12-90	08:45	583.25	0.00	583.25	177.77	2953.85	900.3



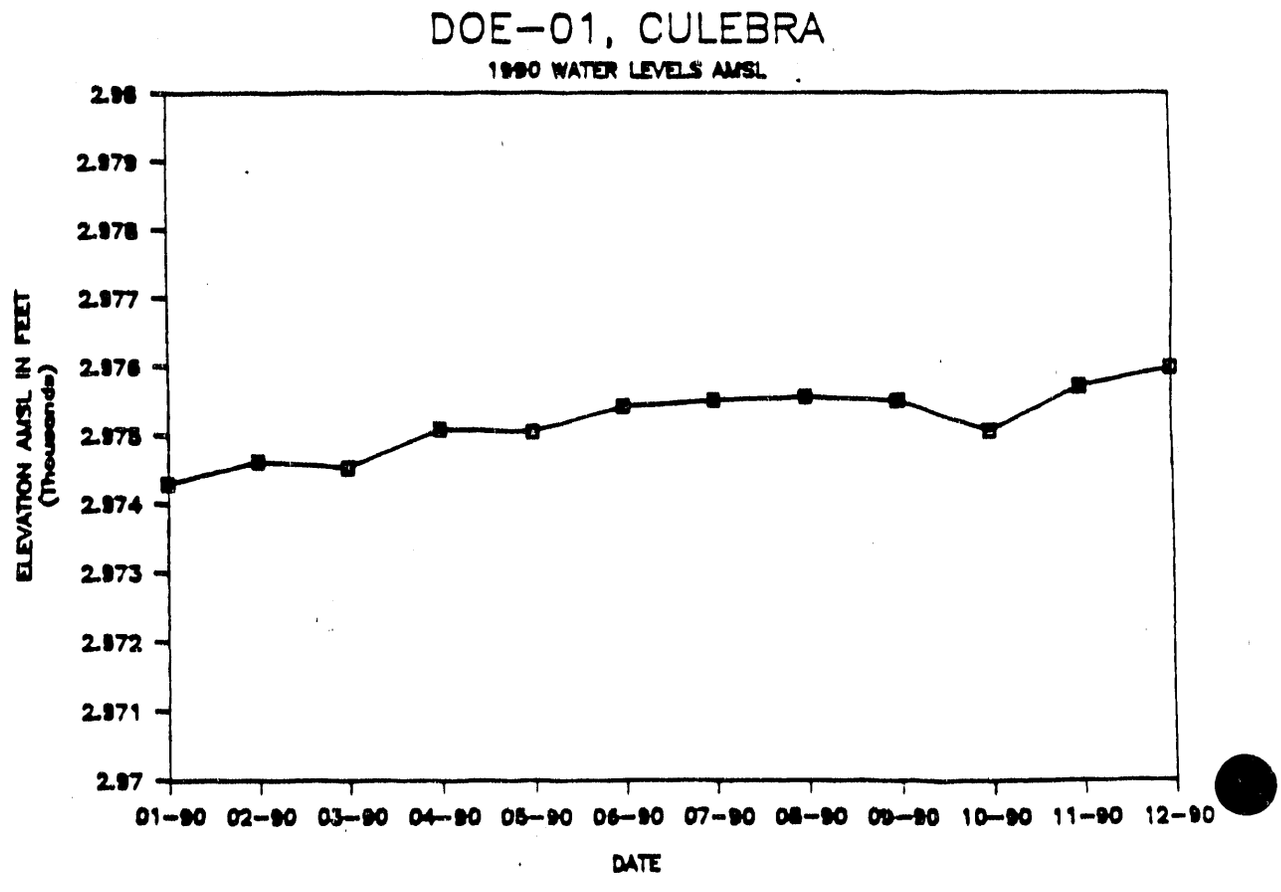
GROUND WATER-LEVELS
CALENDAR YEAR 1990
CABIN BABY, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_
CABIN BABY	CUL	3328.38	01-90	13:23	339.76	0.00	339.76	103.56	2988.62	910.93
CABIN BABY	CUL	3328.38	02-90	09:11	339.59	0.00	339.59	103.51	2988.79	910.98
CABIN BABY	CUL	3328.38	03-90	14:06	339.61	0.00	339.61	103.51	2988.77	910.98
CABIN BABY	CUL	3328.38	04-90	11:38	337.86	0.00	337.86	102.98	2990.52	911.51
CABIN BABY	CUL	3328.38	05-90	09:50	338.98	0.00	338.98	103.32	2989.40	911.17
CABIN BABY	CUL	3328.38	06-90	16:06	339.90	0.00	339.90	103.60	2988.48	910.89
CABIN BABY	CUL	3328.38	07-90	08:55	341.10	0.00	341.10	103.97	2987.28	910.52
CABIN BABY	CUL	3328.38	08-90	10:55	342.44	0.00	342.44	104.38	2985.94	910.11
CABIN BABY	CUL	3328.38	09-90	15:16	343.68	0.00	343.68	104.75	2984.70	909.74
CABIN BABY	CUL	3328.38	10-90	07:06	345.09	0.00	345.09	105.18	2983.29	909.31
CABIN BABY	CUL	3328.38	11-90	16:25	345.79	0.00	345.79	105.40	2982.59	909.09
CABIN BABY	CUL	3328.38	12-90	06:50	346.53	0.00	346.53	105.62	2981.85	908.87



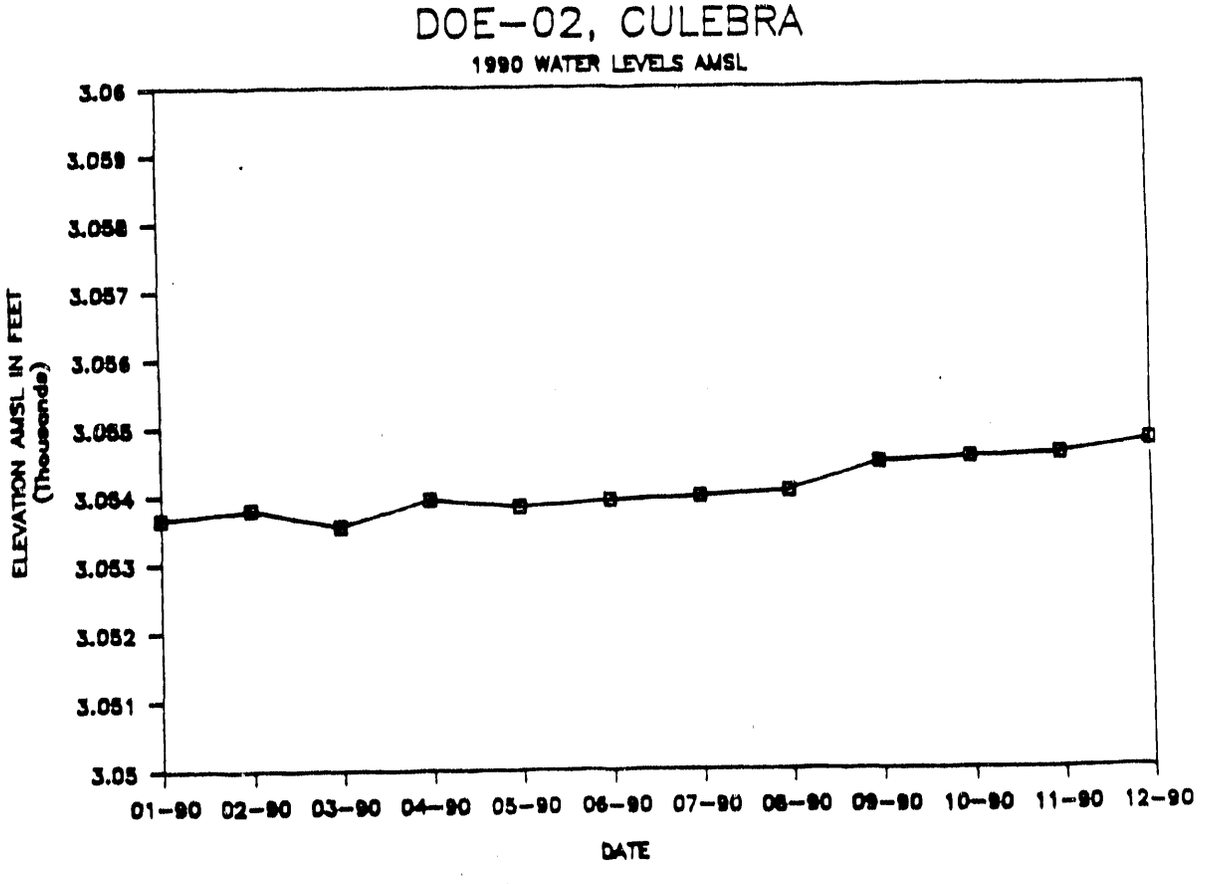
GROUND WATER-LEVELS
CALENDAR YEAR 1990
DOE-01, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MS
DOE-1	CUL	3465.22	01-90	07:24	490.93	0.00	490.93	149.64	2974.29	906.
DOE-1	CUL	3465.22	02-90	10:50	490.59	0.00	490.59	149.53	2974.63	906.
DOE-1	CUL	3465.22	03-90	12:38	490.68	0.00	490.68	149.56	2974.54	906.
DOE-1	CUL	3465.22	04-90	17:45	490.12	0.00	490.12	149.39	2975.10	906.
DOE-1	CUL	3465.22	05-90	12:45	490.15	0.00	490.15	149.40	2975.07	906.
DOE-1	CUL	3465.22	06-90	17:20	489.78	0.00	489.78	149.28	2975.44	906.
DOE-1	CUL	3465.22	07-90	15:03	489.70	0.00	489.70	149.26	2975.52	906.
DOE-1	CUL	3465.22	08-90	14:00	489.65	0.00	489.65	149.25	2975.57	906.
DOE-1	CUL	3465.22	09-90	14:55	489.71	0.00	489.71	149.26	2975.51	906.
DOE-1	CUL	3465.22	10-90	13:41	490.15	0.00	490.15	149.40	2975.07	906.
DOE-1	CUL	3465.22	11-90	13:40	489.50	0.00	489.50	149.20	2975.72	907.
DOE-1	CUL	3465.22	12-90	12:35	489.23	0.00	489.23	149.12	2975.99	907.



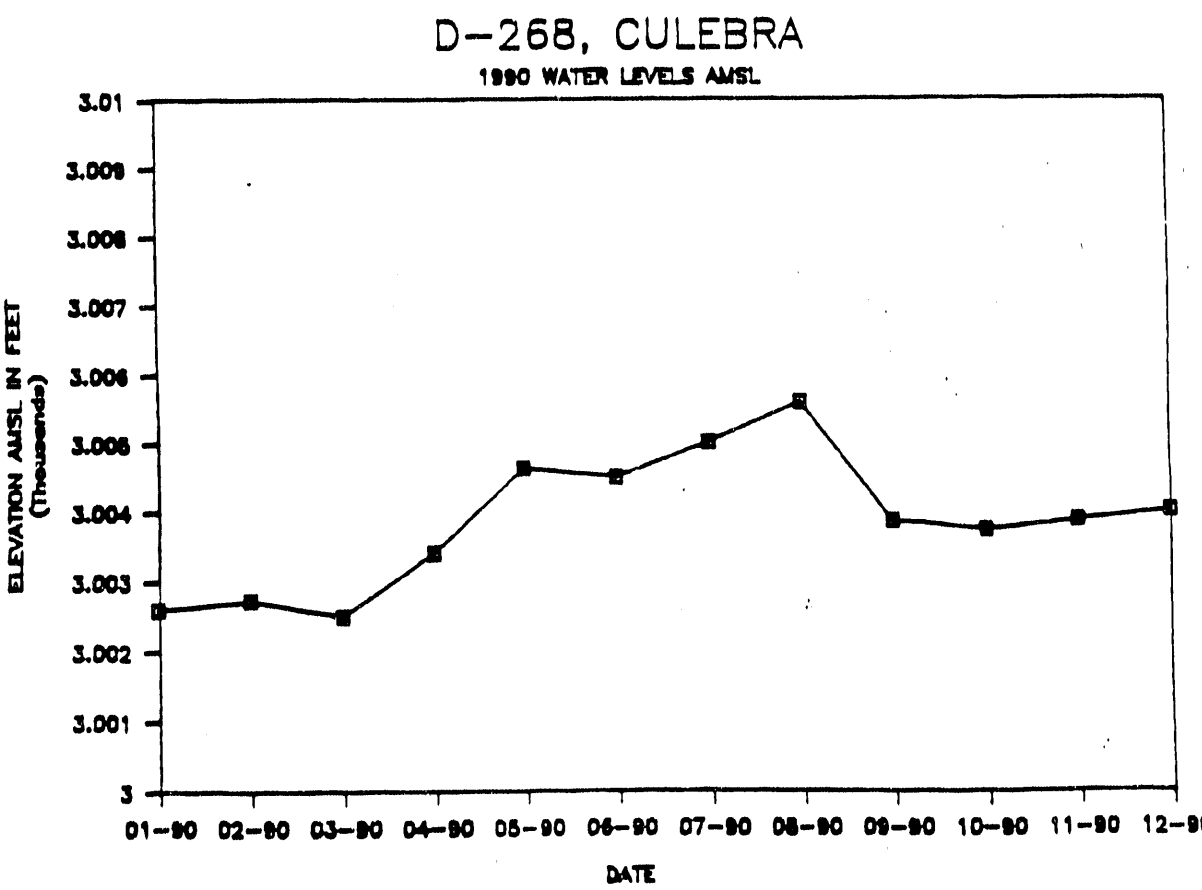
GROUND WATER-LEVELS
CALENDAR YEAR 1990
DOE-02, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_M
DOE-2	CUL	3419.09	01-90	10:44	365.43	0.00	365.43	111.38	3053.66	930.76
DOE-2	CUL	3419.09	02-90	14:44	365.28	0.00	365.28	111.34	3053.81	930.80
DOE-2	CUL	3419.09	03-90	08:55	365.53	0.00	365.53	111.41	3053.56	930.73
DOE-2	CUL	3419.09	04-90	12:21	365.14	0.00	365.14	111.29	3053.95	930.84
DOE-2	CUL	3419.09	05-90	11:50	365.24	0.00	365.24	111.33	3053.85	930.81
DOE-2	CUL	3419.09	06-90	09:23	365.15	0.00	365.15	111.30	3053.94	930.84
DOE-2	CUL	3419.09	07-90	10:00	365.10	0.00	365.10	111.28	3053.99	930.86
DOE-2	CUL	3419.09	08-90	12:08	365.02	0.00	365.02	111.26	3054.07	930.88
DOE-2	CUL	3419.09	09-90	16:37	364.62	0.00	364.62	111.14	3054.47	931.00
DOE-2	CUL	3419.09	10-90	15:58	364.55	0.00	364.55	111.11	3054.54	931.02
DOE-2	CUL	3419.09	11-90	14:55	364.50	0.00	364.50	111.10	3054.59	931.04
DOE-2	CUL	3419.09	12-90	15:05	364.32	0.00	364.32	111.04	3054.77	931.09



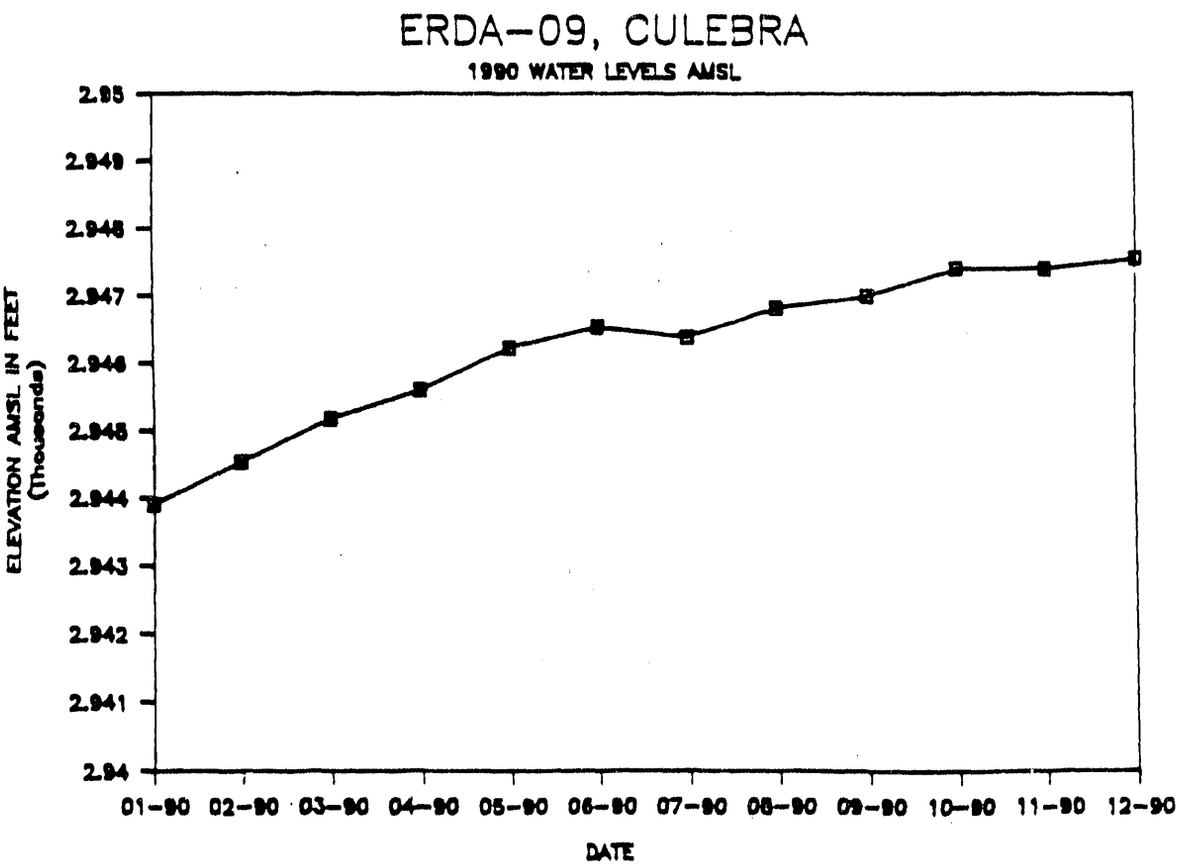
GROUND WATER-LEVELS
CALENDAR YEAR 1990
D-268, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL
D-268	CUL	3280.70	01-90	09:16	278.85	0.75	278.10	84.76	3002.60	9
D-268	CUL	3280.70	02-90	09:41	278.70	0.75	277.95	84.72	3002.75	9
D-268	CUL	3280.70	03-90	11:10	278.94	0.75	278.19	84.79	3002.51	91
D-268	CUL	3280.70	04-90	13:49	278.03	0.75	277.28	84.51	3003.42	915
D-268	CUL	3280.70	05-90	10:50	276.79	0.75	276.04	84.14	3004.66	91
D-268	CUL	3280.70	06-90	13:06	276.93	0.75	276.18	84.18	3004.52	9
D-268	CUL	3280.70	07-90	07:40	276.42	0.75	275.67	84.02	3005.03	91
D-268	CUL	3280.70	08-90	07:25	275.84	0.75	275.09	83.85	3005.61	916.1
D-268	CUL	3280.70	09-90	13:50	277.57	0.75	276.82	84.37	3003.88	915.5
D-268	CUL	3280.70	10-90	07:38	277.70	0.75	276.95	84.41	3003.75	915.5
D-268	CUL	3280.70	11-90	12:35	277.55	0.75	276.80	84.37	3003.90	915.5
D-268	CUL	3280.70	12-90	14:20	277.41	0.75	276.66	84.33	3004.04	915.6



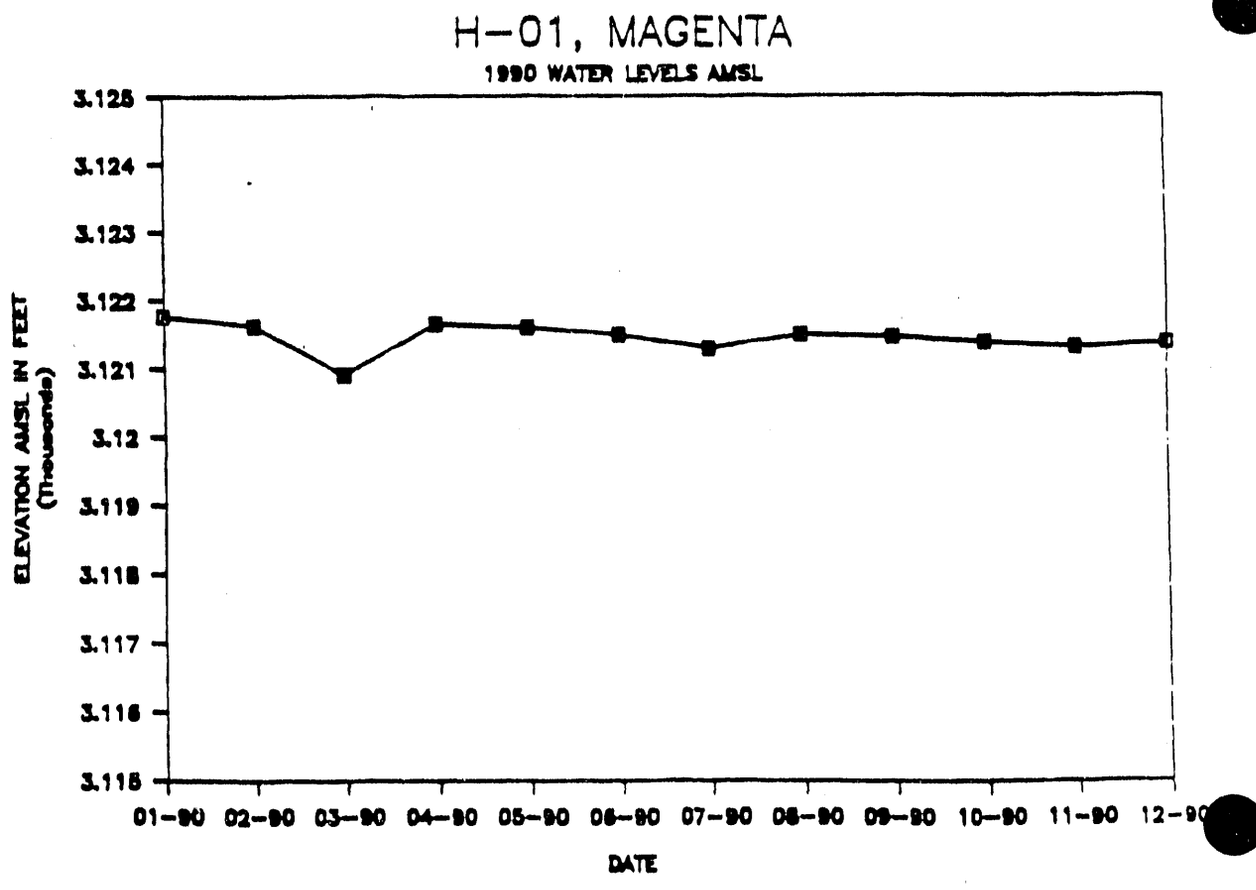
GROUND WATER-LEVELS
CALENDAR YEAR 1990
ERDA-09, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_M
ERDA-9	CUL	3410.10	01-90	13:51	467.11	0.92	466.19	142.09	2943.91	897.30
ERDA-9	CUL	3410.10	02-90	11:38	466.47	0.92	465.55	141.90	2944.55	897.50
ERDA-9	CUL	3410.10	03-90	15:00	465.83	0.92	464.91	141.70	2945.19	897.69
ERDA-9	CUL	3410.10	04-90	16:20	465.40	0.92	464.48	141.57	2945.62	897.82
ERDA-9	CUL	3410.10	05-90	14:35	464.77	0.92	463.85	141.38	2946.25	898.02
ERDA-9	CUL	3410.10	06-90	06:51	464.47	0.92	463.55	141.29	2946.55	898.11
ERDA-9	CUL	3410.10	07-90	07:23	464.62	0.92	463.70	141.34	2946.40	898.06
ERDA-9	CUL	3410.10	08-90	13:08	464.19	0.92	463.27	141.20	2946.83	898.19
ERDA-9	CUL	3410.10	09-90	13:34	464.02	0.92	463.10	141.15	2947.00	898.25
ERDA-9	CUL	3410.10	10-90	13:08	463.61	0.92	462.69	141.03	2947.41	898.37
ERDA-9	CUL	3410.10	11-90	10:41	463.61	0.92	462.69	141.03	2947.41	898.37
ERDA-9	CUL	3410.10	12-90	10:20	463.45	0.92	462.53	140.98	2947.57	898.42



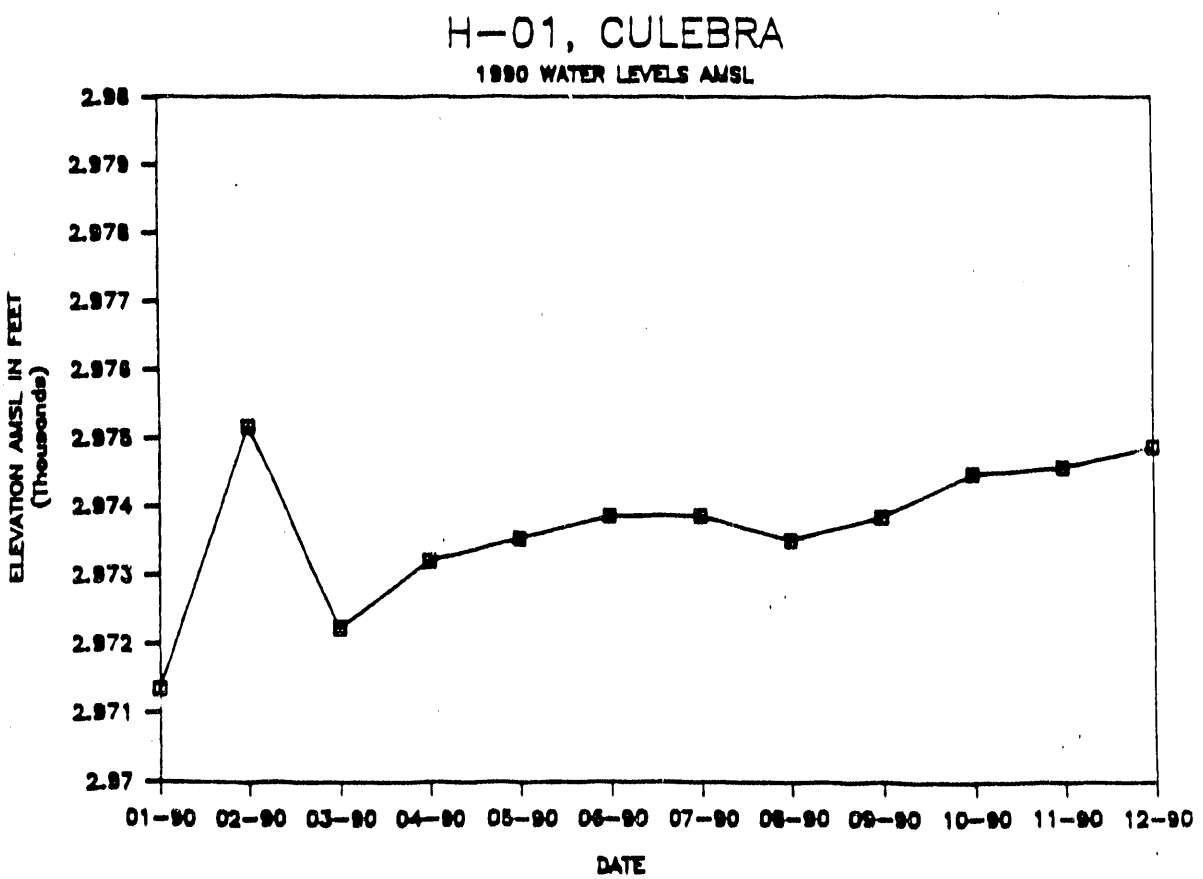
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-01, MAGENTA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL
H-01 (ANNULUS)	MAG	3399.53	01-90	14:10	278.74	0.98	277.76	84.66	3121.77	951.9
H-01 (ANNULUS)	MAG	3399.53	02-90	12:00	278.87	0.98	277.89	84.70	3121.64	951.4
H-01 (ANNULUS)	MAG	3399.53	03-90	14:45	279.59	0.98	278.61	84.92	3120.92	951.2
H-01 (ANNULUS)	MAG	3399.53	04-90	16:35	278.84	0.98	277.86	84.69	3121.67	951.4
H-01 (ANNULUS)	MAG	3399.53	05-90	14:46	278.90	0.98	277.92	84.71	3121.61	951.4
H-01 (ANNULUS)	MAG	3399.53	06-90	06:45	279.00	0.98	278.02	84.74	3121.51	951.4
H-01 (ANNULUS)	MAG	3399.53	07-90	07:40	279.20	0.98	278.22	84.80	3121.31	951.3
H-01 (ANNULUS)	MAG	3399.53	08-90	13:18	279.00	0.98	278.02	84.74	3121.51	951.
H-01 (ANNULUS)	MAG	3399.53	09-90	13:49	279.04	0.98	278.06	84.75	3121.47	951.4
H-01 (ANNULUS)	MAG	3399.53	10-90	13:24	279.12	0.98	278.14	84.78	3121.39	951.4
H-01 (ANNULUS)	MAG	3399.53	11-90	10:32	279.19	0.98	278.21	84.80	3121.32	951.3
H-01 (ANNULUS)	MAG	3399.53	12-90	10:32	279.13	0.98	278.15	84.78	3121.38	951.4



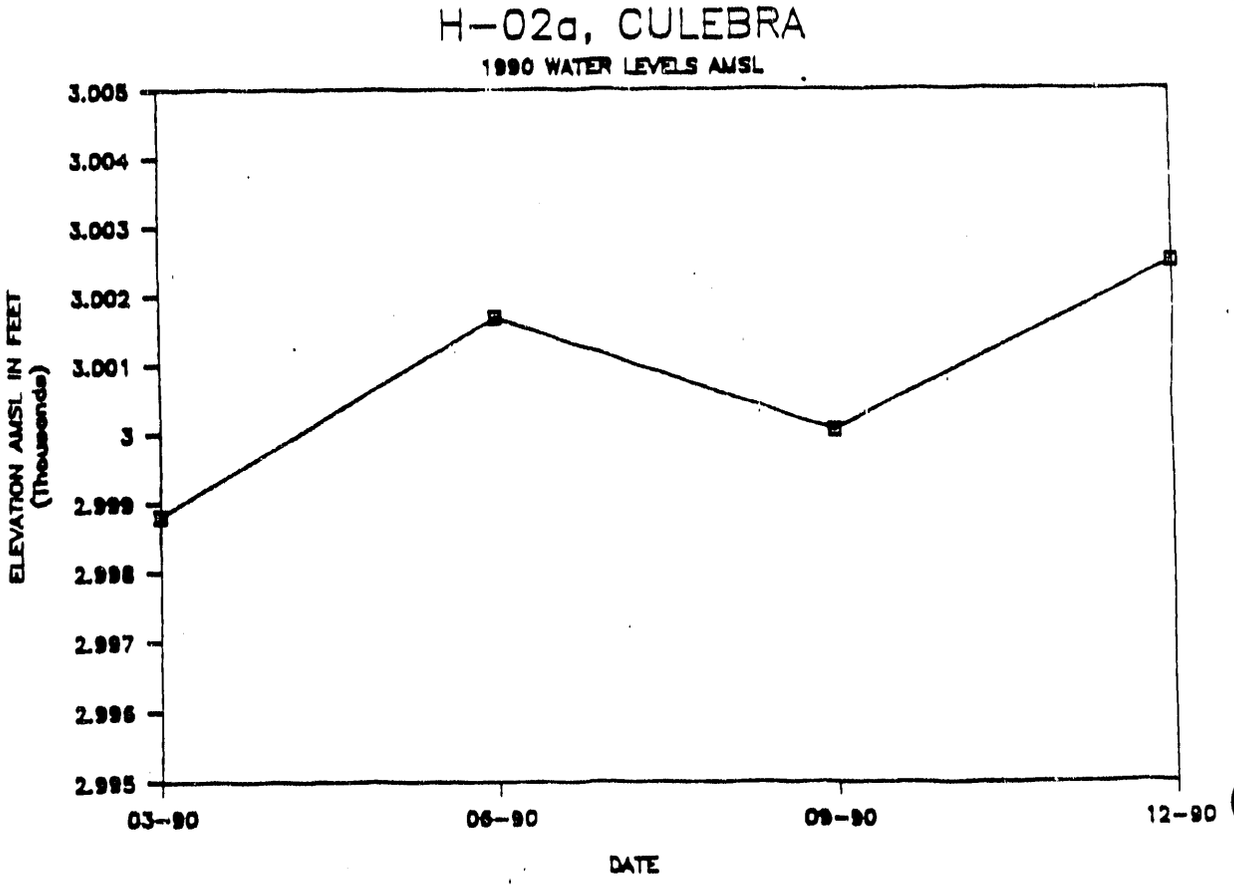
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-01, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_
H-01 (PIP)	CUL	3399.53	01-90	14:18	429.17	0.98	428.19	130.51	2971.34	905.66
H-01 (PIP)	CUL	3399.53	02-90	11:51	425.33	0.98	424.35	129.34	2975.18	906.83
H-01 (PIP)	CUL	3399.53	03-90	14:38	428.28	0.98	427.30	130.24	2972.23	905.94
H-01 (PIP)	CUL	3399.53	04-90	16:29	427.30	0.98	426.32	129.94	2973.21	906.23
H-01 (PIP)	CUL	3399.53	05-90	14:41	426.97	0.98	425.99	129.84	2973.54	906.33
H-01 (PIP)	CUL	3399.53	06-90	06:36	426.64	0.98	425.66	129.74	2973.87	906.44
H-01 (PIP)	CUL	3399.53	07-90	07:30	426.64	0.98	425.66	129.74	2973.87	906.44
H-01 (PIP)	CUL	3399.53	08-90	13:12	427.00	0.98	426.02	129.85	2973.51	906.33
H-01 (PIP)	CUL	3399.53	09-90	13:41	426.67	0.98	425.69	129.75	2973.84	906.43
H-01 (PIP)	CUL	3399.53	10-90	13:19	426.03	0.98	425.05	129.56	2974.48	906.62
H-01 (PIP)	CUL	3399.53	11-90	10:23	425.93	0.98	424.95	129.52	2974.58	906.65
H-01 (PIP)	CUL	3399.53	12-90	10:30	425.63	0.98	424.65	129.43	2974.88	906.74



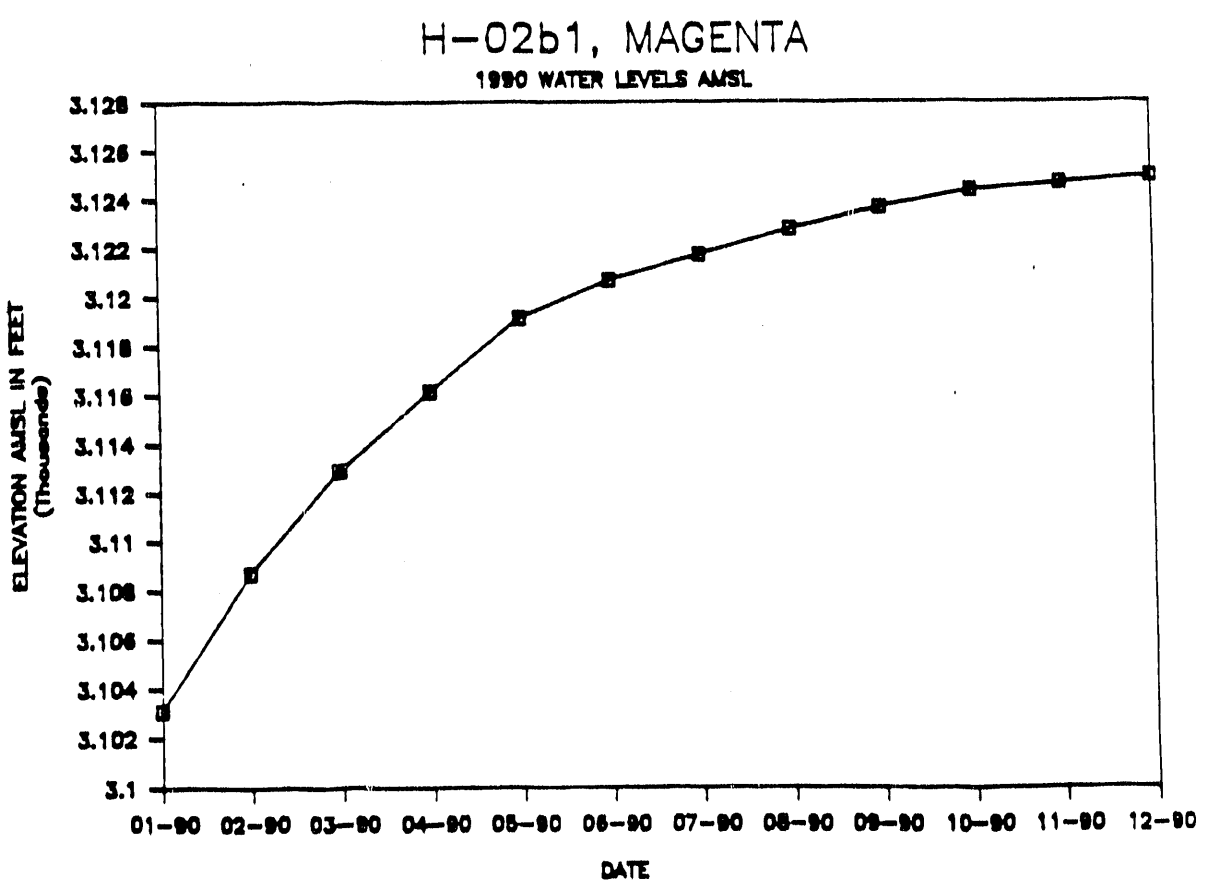
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-02a, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL
H-02a	CUL	3378.09	03-90	13:50	379.28	0.00	379.28	115.60	2998.81	914.
H-02a	CUL	3378.09	06-90	12:36	376.38	0.00	376.38	114.72	3001.71	914.
H-02a	CUL	3378.09	09-90	15:53	378.02	0.00	378.02	115.22	3000.07	914.
H-02a	CUL	3378.09	12-90	12:55	375.59	0.00	375.59	114.48	3002.50	915.



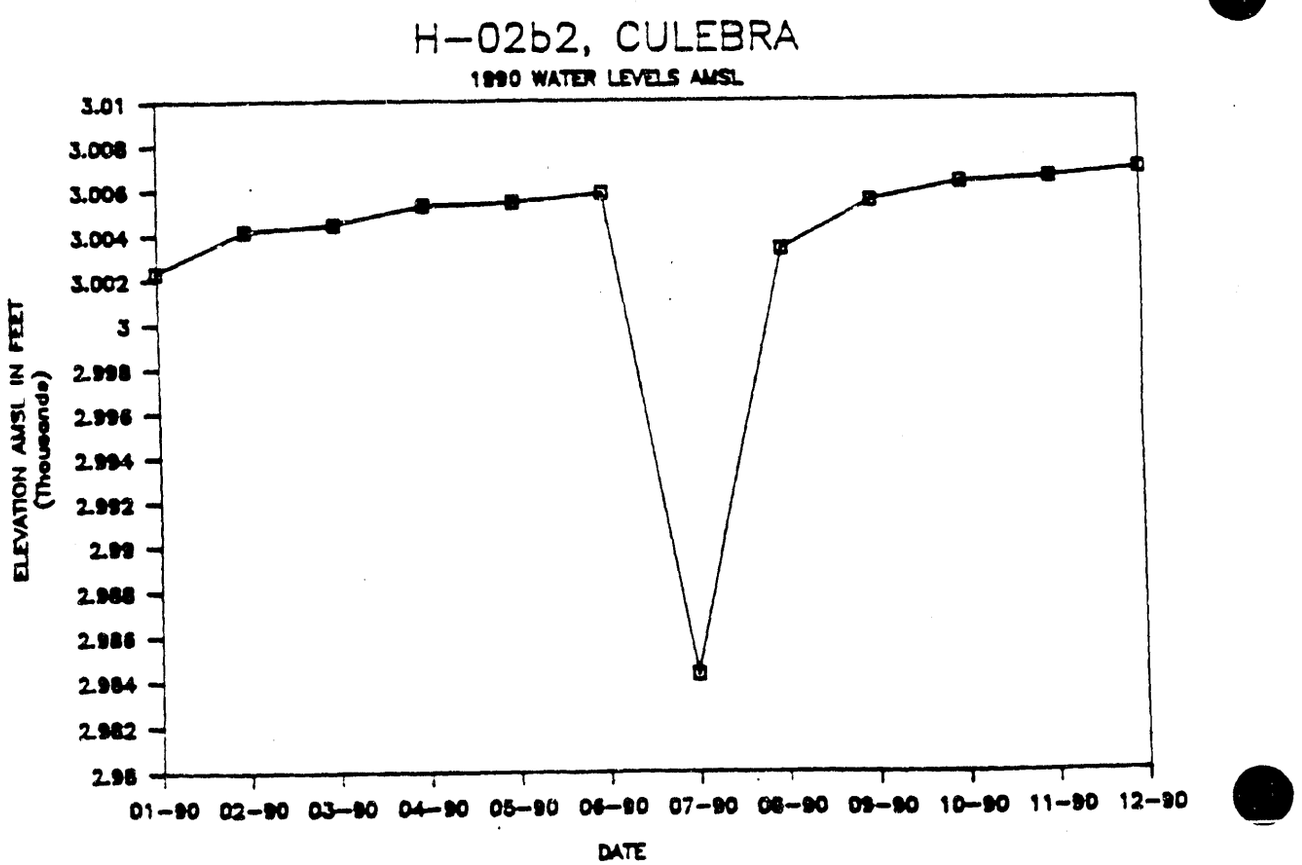
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-02b1, MAGENTA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_M
H-02b1	MAG	3378.46	01-90	14:38	275.33	0.00	275.33	83.92	3103.13	945.83
H-02b1	MAG	3378.46	02-90	12:16	269.72	0.00	269.72	82.21	3108.74	947.54
H-02b1	MAG	3378.46	03-90	14:00	265.53	0.00	265.53	80.93	3112.93	948.82
H-02b1	MAG	3378.46	04-90	17:00	262.28	0.00	262.28	79.94	3116.18	949.81
H-02b1	MAG	3378.46	05-90	13:05	259.28	0.00	259.28	79.03	3119.18	950.73
H-02b1	MAG	3378.46	06-90	12:23	257.72	0.00	257.72	78.55	3120.74	951.20
H-02b1	MAG	3378.46	07-90	07:15	256.69	0.00	256.69	78.24	3121.77	951.52
H-02b1	MAG	3378.46	08-90	13:48	255.66	0.00	255.66	77.93	3122.80	951.83
H-02b1	MAG	3378.46	09-90	14:06	254.78	0.00	254.78	77.66	3123.68	952.10
H-02b1	MAG	3378.46	10-90	15:09	254.08	0.00	254.08	77.44	3124.38	952.31
H-02b1	MAG	3378.46	11-90	11:40	253.78	0.00	253.78	77.35	3124.68	952.40
H-02b1	MAG	3378.46	12-90	13:05	253.51	0.00	253.51	77.27	3124.95	952.48



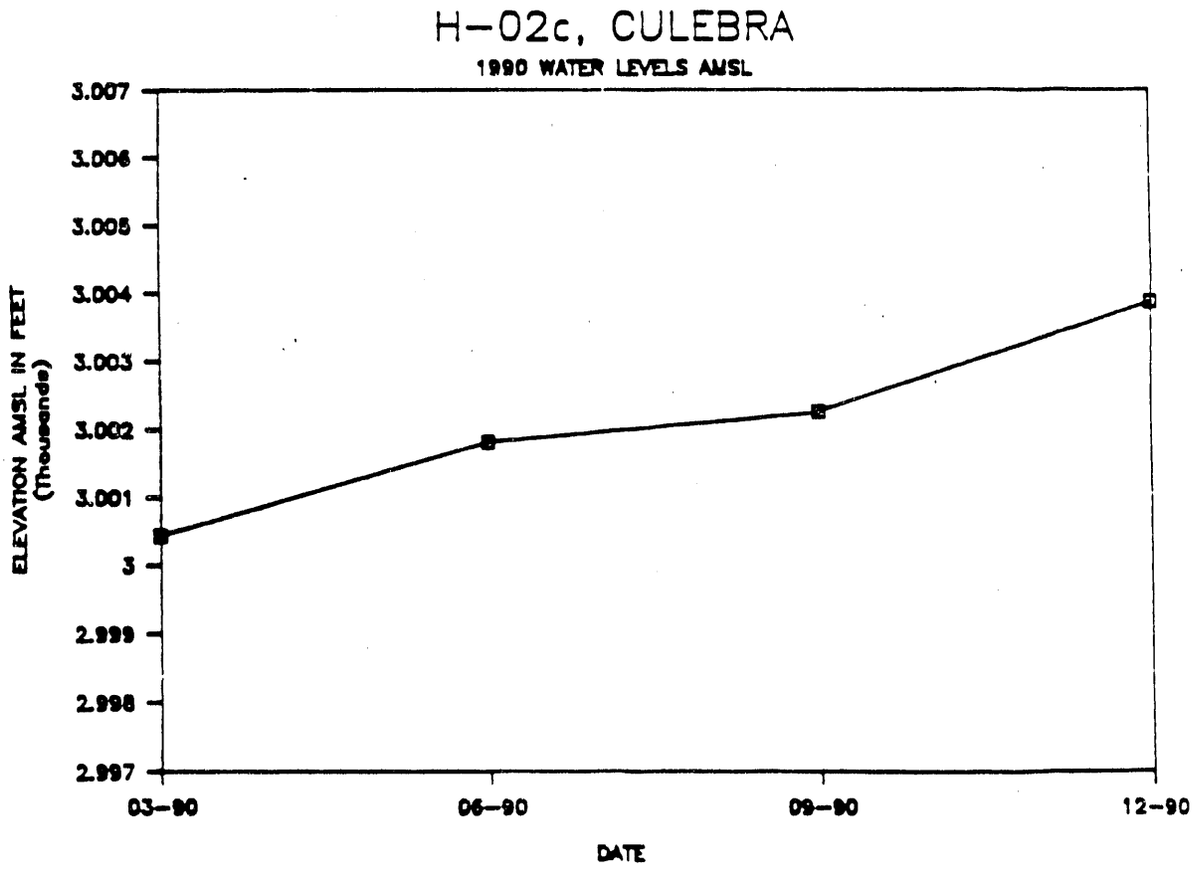
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-02b2, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MS
H-02b2	CUL	3378.31	01-90	14:41	375.98	0.00	375.98	114.60	3002.33	915.
H-02b2	CUL	3378.31	02-90	12:24	374.10	0.00	374.10	114.03	3004.21	915.
H-02b2	CUL	3378.31	03-90	14:10	373.82	0.00	373.82	113.94	3004.49	915.
H-02b2	CUL	3378.31	04-90	16:50	372.98	0.00	372.98	113.68	3005.33	916.
H-02b2	CUL	3378.31	05-90	13:20	372.84	0.00	372.84	113.64	3005.47	916.
H-02b2	CUL	3378.31	06-90	12:30	372.44	0.00	372.44	113.52	3005.87	916.
H-02b2	CUL	3378.31	07-90	07:05	394.00	0.00	394.00	120.09	2984.31	909.
H-02b2	CUL	3378.31	08-90	13:33	374.97	0.00	374.97	114.29	3003.34	915.
H-02b2	CUL	3378.31	09-90	16:02	372.83	0.00	372.83	113.64	3005.48	916.
H-02b2	CUL	3378.31	10-90	15:14	372.02	0.00	372.02	113.39	3006.29	916.
H-02b2	CUL	3378.31	11-90	11:35	371.80	0.00	371.80	113.32	3006.51	916.
H-02b2	CUL	3378.31	12-90	13:10	371.42	0.00	371.42	113.21	3006.89	916.



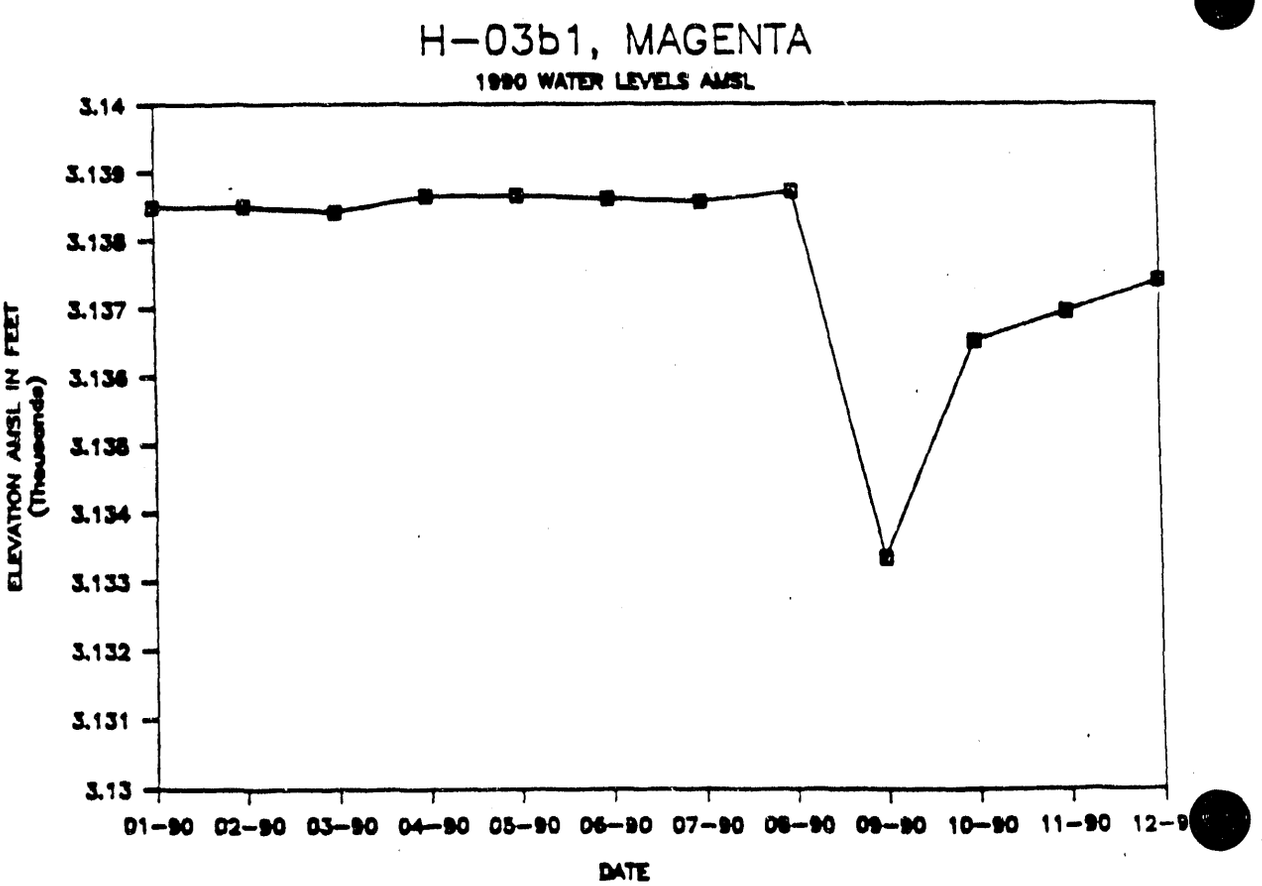
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-02c, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_
H-02c	CUL	3378.41	03-90	14:19	377.97	0.00	377.97	115.21	3000.44	914.53
H-02c	CUL	3378.41	06-90	12:16	376.58	0.00	376.58	114.78	3001.83	914.96
H-02c	CUL	3378.41	09-90	16:14	376.14	0.00	376.14	114.65	3002.27	915.09
H-02c	CUL	3378.41	12-90	13:15	374.53	0.00	374.53	114.16	3003.88	915.58



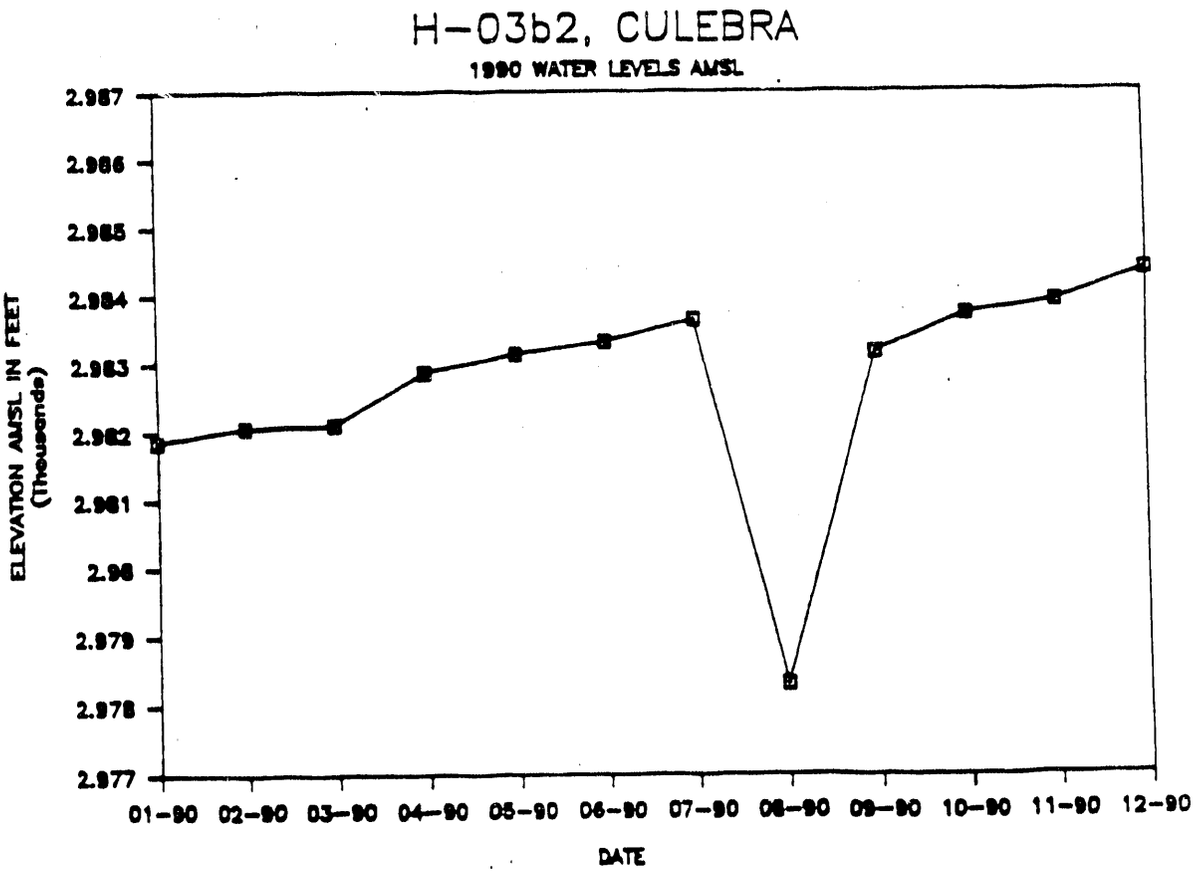
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-03b1, MAGENTA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL
H-03b1	MAG	3390.64	01-90	14:52	252.15	0.00	252.15	76.86	3138.49	956.[illegible]
H-03b1	MAG	3390.64	02-90	11:00	252.14	0.00	252.14	76.85	3138.50	956.[illegible]
H-03b1	MAG	3390.64	03-90	12:53	252.22	0.00	252.22	76.88	3138.42	956.[illegible]
H-03b1	MAG	3390.64	04-90	17:09	251.99	0.00	251.99	76.81	3138.65	956.[illegible]
H-03b1	MAG	3390.64	05-90	15:02	251.98	0.00	251.98	76.80	3138.66	956.[illegible]
H-03b1	MAG	3390.64	06-90	05:55	252.03	0.00	252.03	76.82	3138.61	956.[illegible]
H-03b1	MAG	3390.64	07-90	14:17	252.07	0.00	252.07	76.83	3138.57	956.[illegible]
H-03b1	MAG	3390.64	08-90	14:15	251.92	0.00	251.92	76.79	3138.72	956.[illegible]
H-03b1	MAG	3390.64	09-90	14:03	257.30	0.00	257.30	78.43	3133.34	955.[illegible]
H-03b1	MAG	3390.64	10-90	14:21	254.12	0.00	254.12	77.46	3136.52	956.[illegible]
H-03b1	MAG	3390.64	11-90	12:52	253.68	0.00	253.68	77.32	3136.96	956.[illegible]
H-03b1	MAG	3390.64	12-90	11:52	253.23	0.00	253.23	77.18	3137.41	956.[illegible]



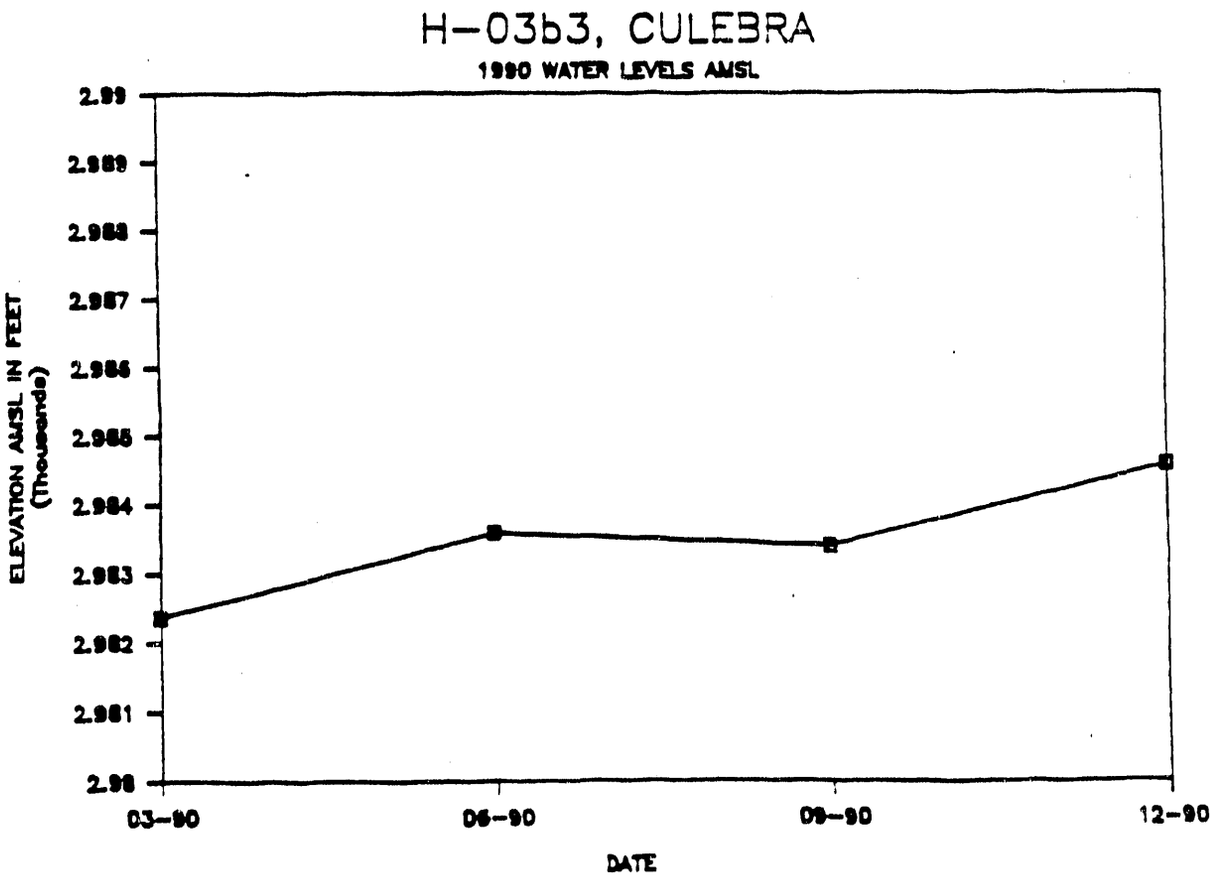
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-03b2, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_M
H-03b2	CUL	3390.03	01-90	14:58	408.17	0.00	408.17	124.41	2981.86	908.87
H-03b2	CUL	3390.03	02-90	11:10	407.95	0.00	407.95	124.34	2982.08	908.94
H-03b2	CUL	3390.03	03-90	13:00	407.91	0.00	407.91	124.33	2982.12	908.95
H-03b2	CUL	3390.03	04-90	17:25	407.15	0.00	407.15	124.10	2982.88	909.18
H-03b2	CUL	3390.03	05-90	15:25	406.88	0.00	406.88	124.02	2983.15	909.26
H-03b2	CUL	3390.03	06-90	06:21	406.70	0.00	406.70	123.96	2983.33	909.32
H-03b2	CUL	3390.03	07-90	14:25	406.38	0.00	406.38	123.86	2983.65	909.42
H-03b2	CUL	3390.03	08-90	14:30	411.72	0.00	411.72	125.49	2978.31	907.79
H-03b2	CUL	3390.03	09-90	14:38	406.86	0.00	406.86	124.01	2983.17	909.27
H-03b2	CUL	3390.03	10-90	14:12	406.31	0.00	406.31	123.84	2983.72	909.44
H-03b2	CUL	3390.03	11-90	13:00	406.13	0.00	406.13	123.79	2983.90	909.49
H-03b2	CUL	3390.03	12-90	12:20	405.67	0.00	405.67	123.65	2984.36	909.63



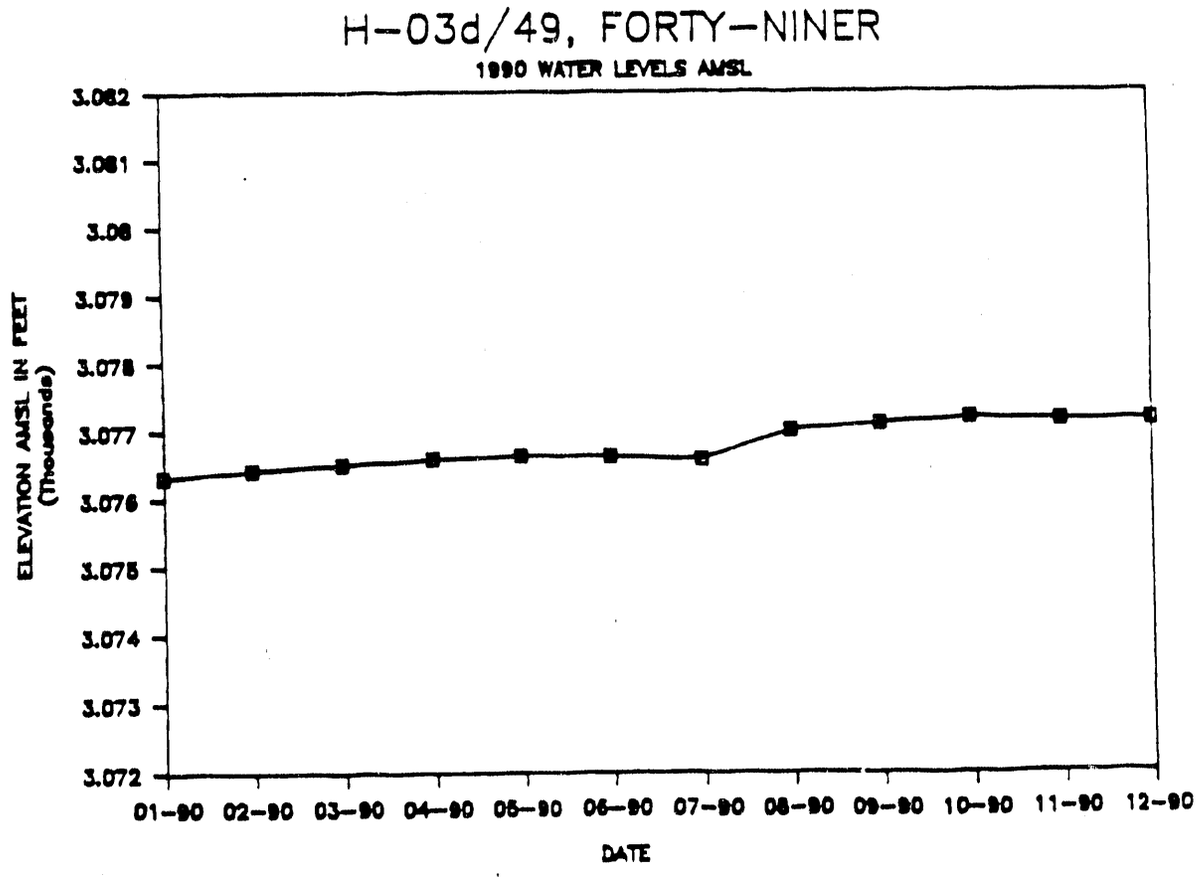
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-03b3, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL
H-03b3	CUL	3388.67	03-90	13:15	406.30	0.00	406.30	123.84	2982.37	909.0
H-03b3	CUL	3388.67	06-90	06:11	405.08	0.00	405.08	123.47	2983.59	909.4
H-03b3	CUL	3388.67	09-90	14:25	405.27	0.00	405.27	123.53	2983.40	909.3
H-03b3	CUL	3388.67	12-90	12:15	404.08	0.00	404.08	123.16	2984.59	909.7



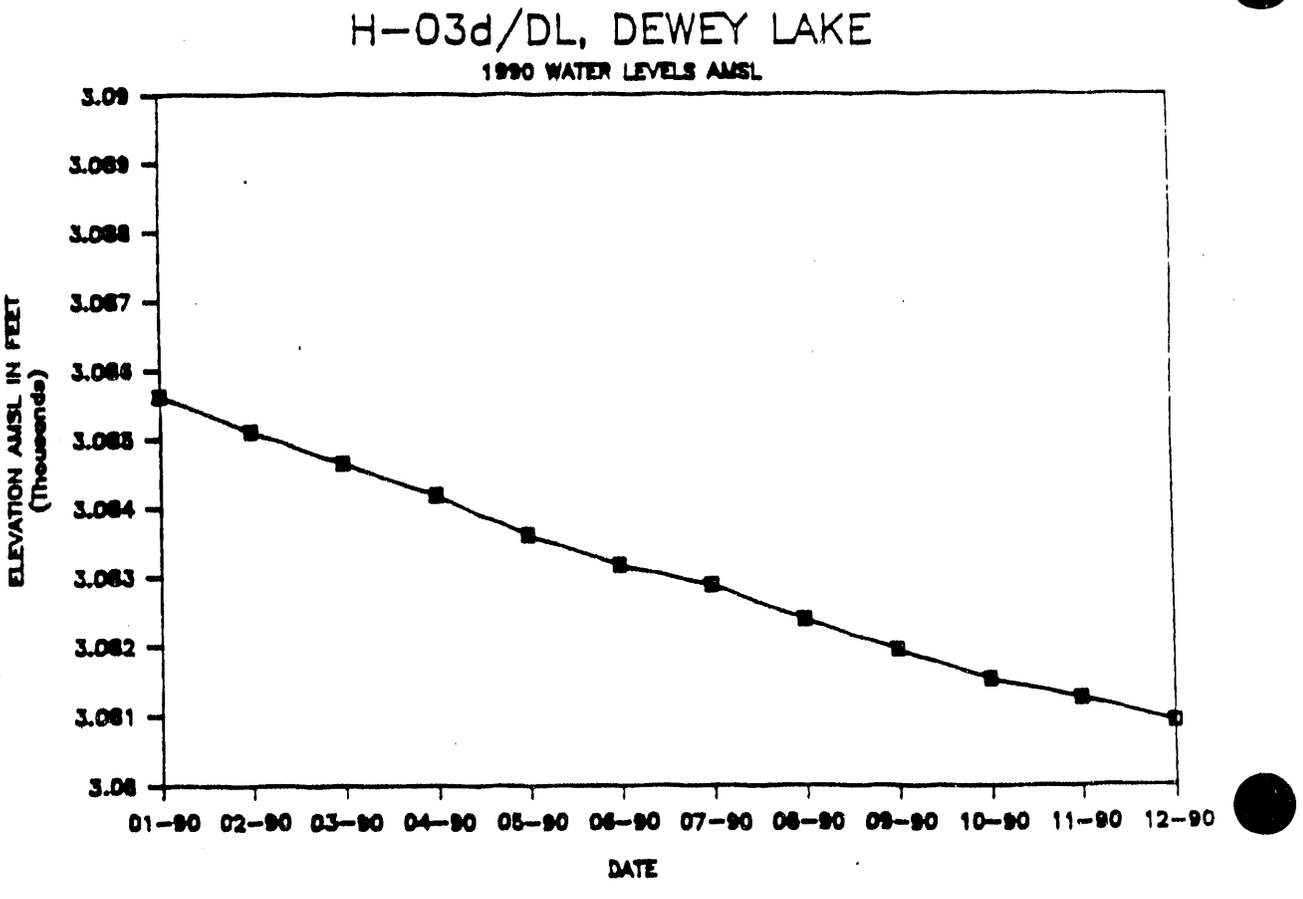
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-03d/49, FORTY-NINER

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_
H-03d/49 (PIP)	49ER	3390.01	01-90	15:09	315.90	2.22	313.68	95.61	3076.33	937.6
H-03d/49 (PIP)	49ER	3390.01	02-90	11:16	315.79	2.22	313.57	95.58	3076.44	937.7
H-03d/49 (PIP)	49ER	3390.01	03-90	13:22	315.71	2.22	313.49	95.55	3076.52	937.7
H-03d/49 (PIP)	49ER	3390.01	04-90	17:14	315.63	2.22	313.41	95.53	3076.60	937.7
H-03d/49 (PIP)	49ER	3390.01	05-90	15:08	315.58	2.22	313.36	95.51	3076.65	937.7
H-03d/49 (PIP)	49ER	3390.01	06-90	06:02	315.59	2.22	313.37	95.52	3076.64	937.7
H-03d/49 (PIP)	49ER	3390.01	07-90	14:35	315.64	2.22	313.42	95.53	3076.59	937.7
H-03d/49 (PIP)	49ER	3390.01	08-90	14:20	315.21	2.22	312.99	95.40	3077.02	937.8
H-03d/49 (PIP)	49ER	3390.01	09-90	14:10	315.12	2.22	312.90	95.37	3077.11	937.9
H-03d/49 (PIP)	49ER	3390.01	10-90	13:58	315.04	2.22	312.82	95.35	3077.19	937.9
H-03d/49 (PIP)	49ER	3390.01	11-90	12:39	315.07	2.22	312.85	95.36	3077.16	937.9
H-03d/49 (PIP)	49ER	3390.01	12-90	12:00	315.06	2.22	312.84	95.35	3077.17	937.9



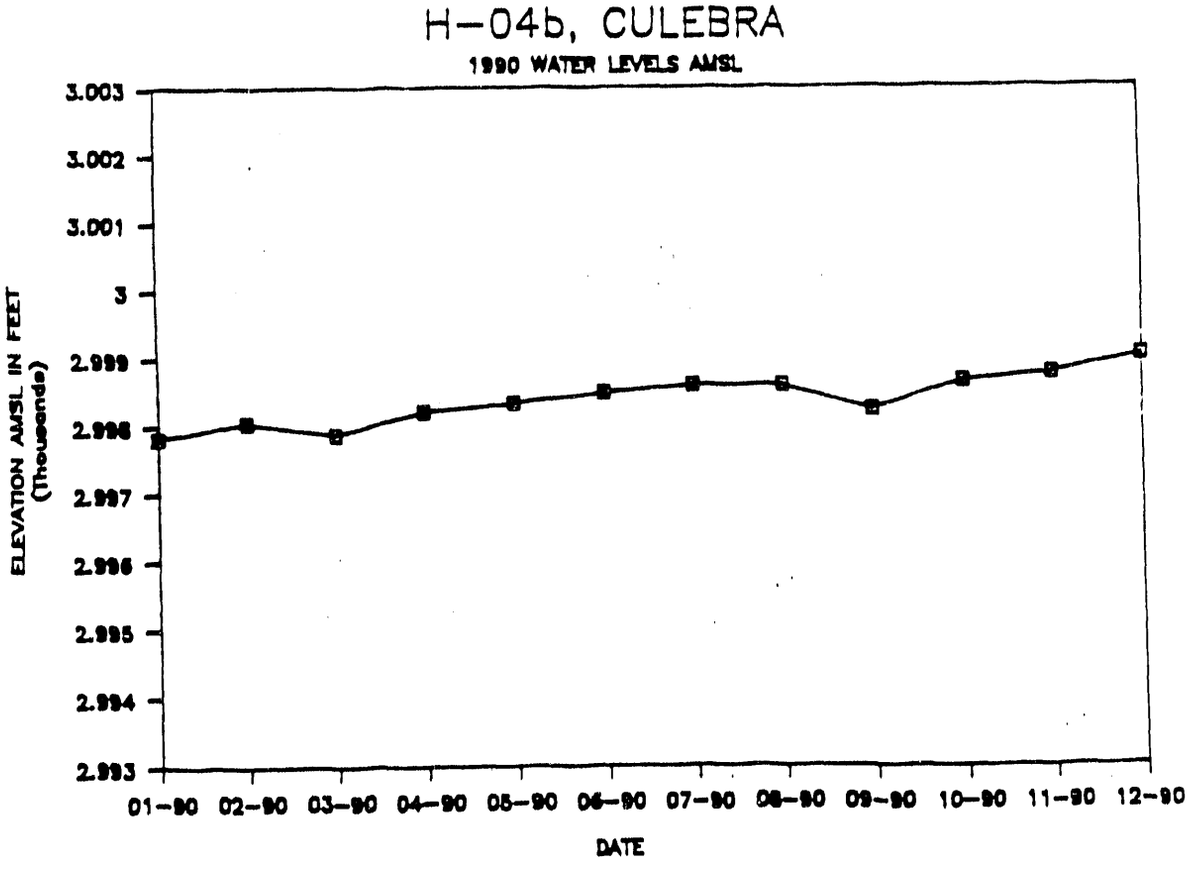
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-03d/DL, DEWEY LAKE

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL
H-03d/DL (PIP)	DL	3390.01	01-90	15:16	306.60	2.22	304.38	92.78	3085.63	940.
H-03d/DL (PIP)	DL	3390.01	02-90	11:29	307.11	2.22	304.89	92.93	3085.12	940
H-03d/DL (PIP)	DL	3390.01	03-90	13:30	307.58	2.22	305.36	93.07	3084.65	940.2
H-03d/DL (PIP)	DL	3390.01	04-90	17:19	308.04	2.22	305.82	93.21	3084.19	940.0
H-03d/DL (PIP)	DL	3390.01	05-90	15:21	308.61	2.22	306.39	93.39	3083.62	939.8
H-03d/DL (PIP)	DL	3390.01	06-90	06:06	309.06	2.22	306.84	93.52	3083.17	939.7
H-03d/DL (PIP)	DL	3390.01	07-90	14:45	309.35	2.22	307.13	93.61	3082.88	939.6
H-03d/DL (PIP)	DL	3390.01	08-90	14:25	309.84	2.22	307.62	93.76	3082.39	939.5
H-03d/DL (PIP)	DL	3390.01	09-90	14:14	310.28	2.22	308.06	93.90	3081.95	939.3
H-03d/DL (PIP)	DL	3390.01	10-90	14:03	310.71	2.22	308.49	94.03	3081.52	939.2
H-03d/DL (PIP)	DL	3390.01	11-90	12:46	310.97	2.22	308.75	94.11	3081.26	939.1
H-03d/DL (PIP)	DL	3390.01	12-90	12:05	311.31	2.22	309.09	94.21	3080.92	939.0



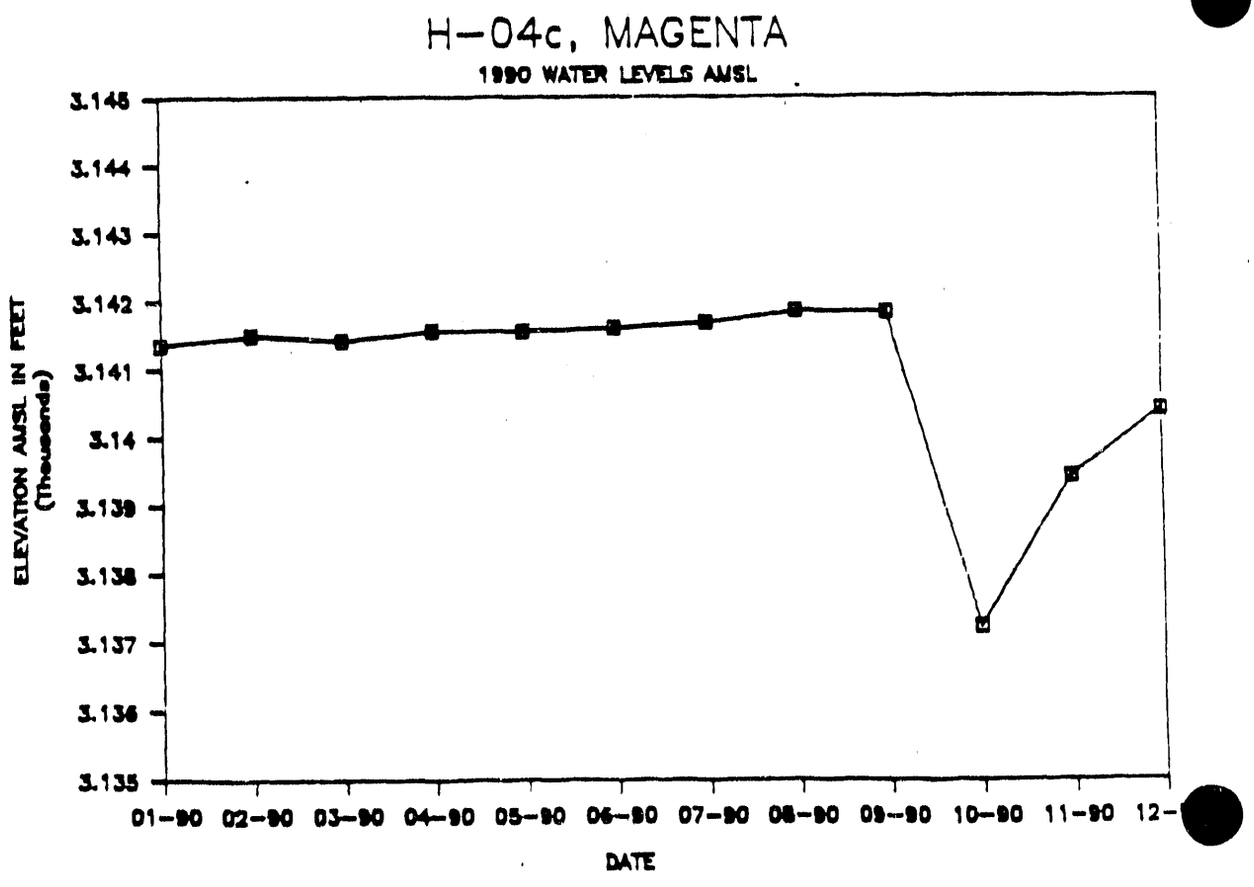
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-04b, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_
H-04b	CUL	3333.35	01-90	08:22	335.53	0.00	335.53	102.27	2997.82	913.74
H-04b	CUL	3333.35	02-90	10:10	335.29	0.00	335.29	102.20	2998.06	913.81
H-04b	CUL	3333.35	03-90	12:00	335.47	0.00	335.47	102.25	2997.88	913.75
H-04b	CUL	3333.35	04-90	12:06	335.13	0.00	335.13	102.15	2998.22	913.86
H-04b	CUL	3333.35	05-90	14:04	335.00	0.00	335.00	102.11	2998.35	913.90
H-04b	CUL	3333.35	06-90	16:40	334.85	0.00	334.85	102.06	2998.50	913.94
H-04b	CUL	3333.35	07-90	07:10	334.74	0.00	334.74	102.03	2998.61	913.98
H-04b	CUL	3333.35	08-90	08:15	334.75	0.00	334.75	102.03	2998.60	913.97
H-04b	CUL	3333.35	09-90	14:50	335.12	0.00	335.12	102.14	2998.23	913.86
H-04b	CUL	3333.35	10-90	16:28	334.70	0.00	334.70	102.02	2998.65	913.99
H-04b	CUL	3333.35	11-90	14:18	334.58	0.00	334.58	101.98	2998.77	914.03
H-04b	CUL	3333.35	12-90	13:55	334.33	0.00	334.33	101.90	2999.02	914.10



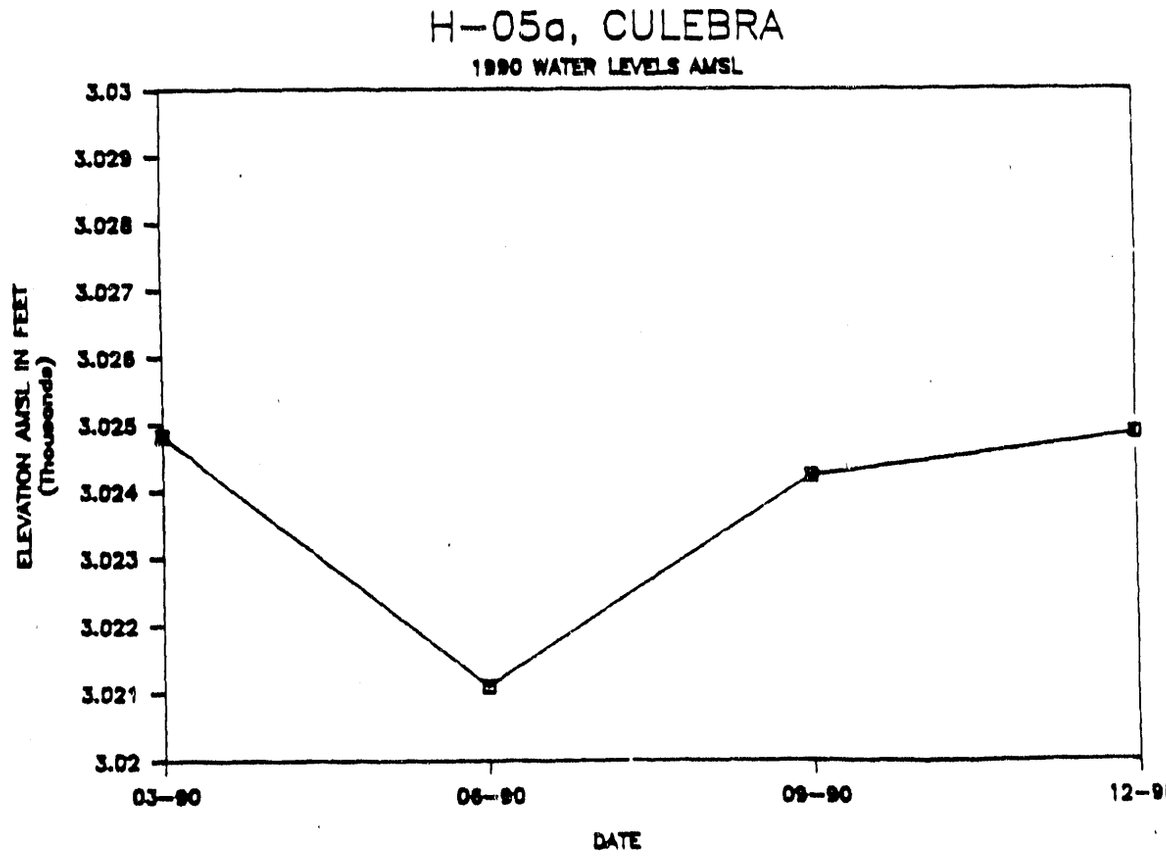
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-04c, MAGENTA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_M
H-04c	MAG	3334.04	01-90	08:37	192.68	0.00	192.68	58.73	3141.36	[illegible]
H-04c	MAG	3334.04	02-90	10:15	192.53	0.00	192.53	58.68	3141.51	9
H-04c	MAG	3334.04	03-90	12:08	192.61	0.00	192.61	58.71	3141.43	9[illegible]
H-04c	MAG	3334.04	04-90	12:13	192.47	0.00	192.47	58.66	3141.57	95[illegible]
H-04c	MAG	3334.04	05-90	13:55	192.47	0.00	192.47	58.66	3141.57	957.[illegible]
H-04c	MAG	3334.04	06-90	16:45	192.43	0.00	192.43	58.65	3141.61	957.[illegible]
H-04c	MAG	3334.04	07-90	07:15	192.35	0.00	192.35	58.63	3141.69	95[illegible]
H-04c	MAG	3334.04	08-90	08:06	192.18	0.00	192.18	58.58	3141.86	9[illegible]
H-04c	MAG	3334.04	09-90	14.56	192.21	0.00	192.21	58.59	3141.83	[illegible]
H-04c	MAG	3334.04	10-90	16:20	196.82	0.00	196.82	59.99	[illegible]37.22	956.[illegible]
H-04c	MAG	3334.04	11-90	14:14	194.62	0.00	194.62	59.32	3139.42	956
H-04c	MAG	3334.04	12-90	13:50	193.64	0.00	193.64	59.02	3140.40	957[illegible]



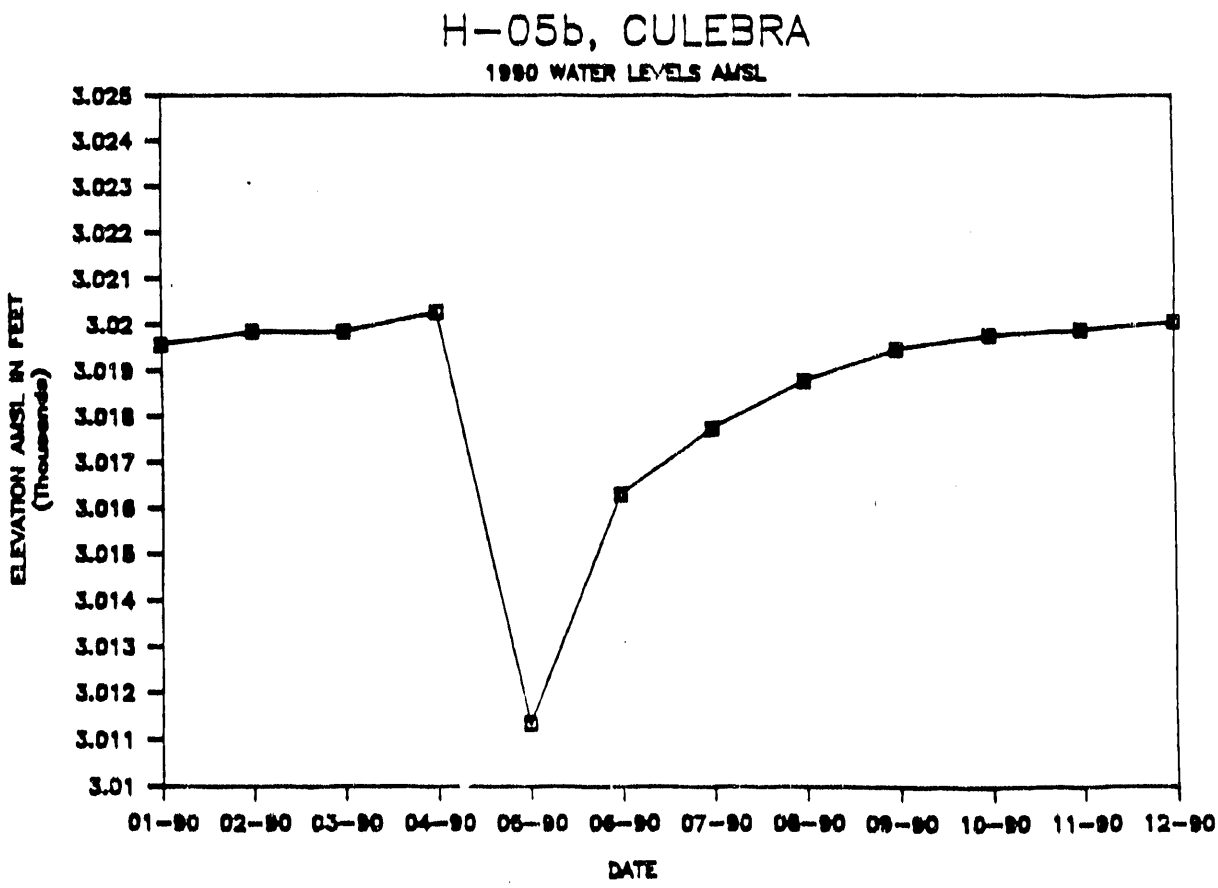
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-05a, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MS
H-05a	CUL	3506.24	03-90	09:30	481.41	0.00	481.41	146.73	3024.83	921.
H-05a	CUL	3506.24	06-90	08:38	485.14	0.00	485.14	147.87	3021.10	920.
H-05a	CUL	3506.24	09-90	09:34	482.00	0.00	482.00	146.91	3024.24	921.
H-05a	CUL	3506.24	12-90	12:05	481.37	0.00	481.37	146.72	3024.87	921.



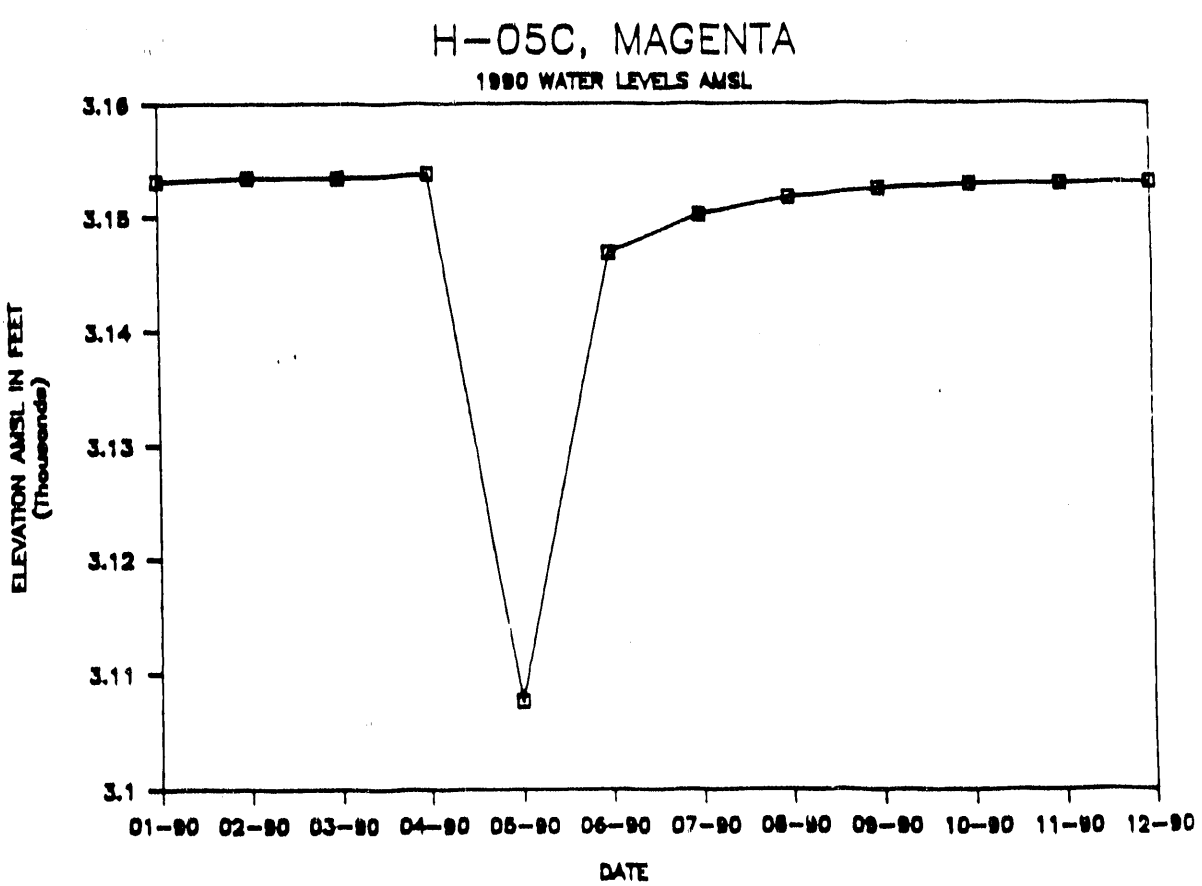
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-05b, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MS
H-05b	CUL	3506.04	01-90	10:11	486.47	0.00	486.47	148.28	3019.57	920.
H-05b	CUL	3506.04	02-90	14:20	486.17	0.00	486.17	148.18	3019.87	920.
H-05b	CUL	3506.04	03-90	09:50	486.18	0.00	486.18	148.19	3019.86	920.
H-05b	CUL	3506.04	04-90	12:55	485.75	0.00	485.75	148.06	3020.29	920.
H-05b	CUL	3506.04	05-90	12:12	494.69	0.00	494.69	150.78	3011.35	917.
H-05b	CUL	3506.04	06-90	08:45	489.72	0.00	489.72	149.27	3016.32	919.
H-05b	CUL	3506.04	07-90	09:05	488.28	0.00	488.28	148.83	3017.76	919.
H-05b	CUL	3506.04	08-90	14:43	487.25	0.00	487.25	148.51	3018.79	920.
H-05b	CUL	3506.04	09-90	09:13	486.58	0.00	486.58	148.31	3019.46	920.
H-05b	CUL	3506.04	10-90	09:22	486.27	0.00	486.27	148.22	3019.77	920.
H-05b	CUL	3506.04	11-90	10:21	486.14	0.00	486.14	148.18	3019.90	920.
H-05b	CUL	3506.04	12-90	11:47	485.97	0.00	485.97	148.12	3020.07	920.



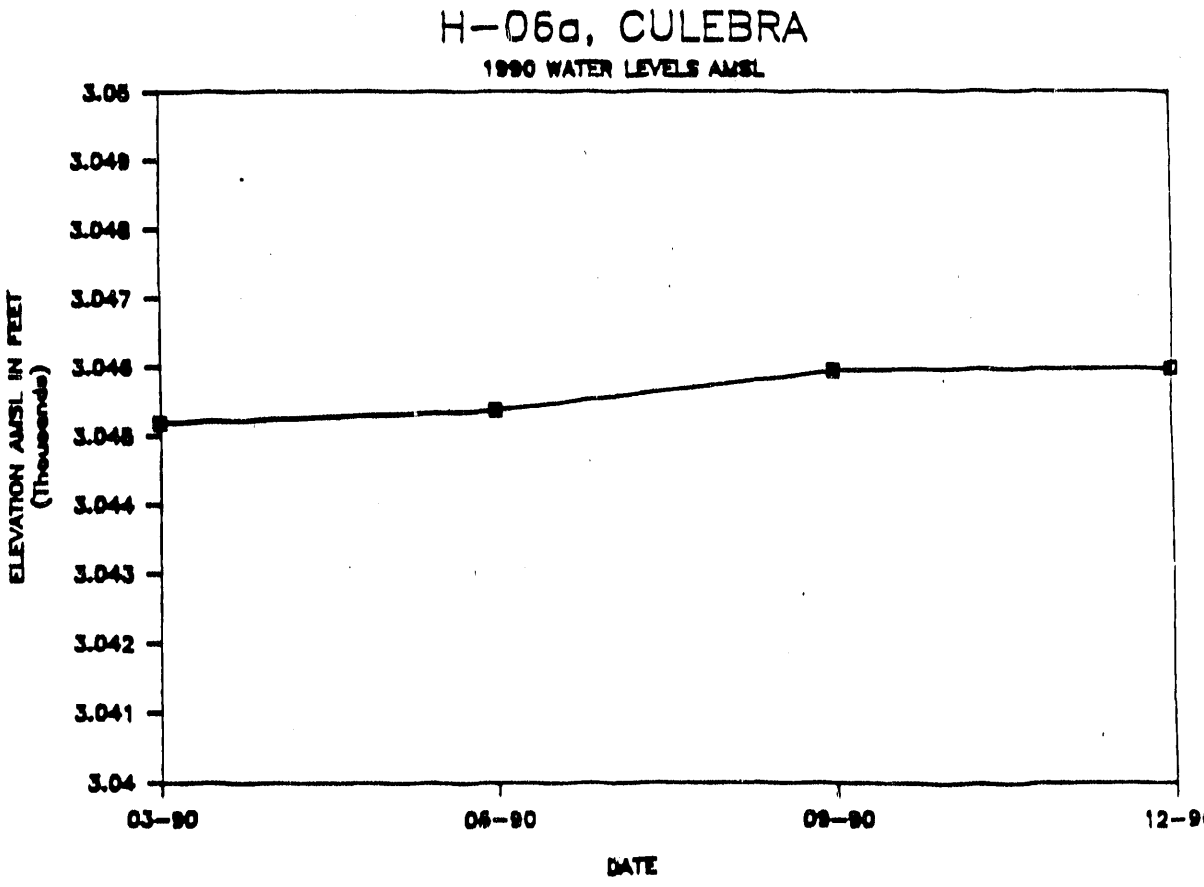
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-05c, MAGENTA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_
H-05c	MAG	3506.04	01-90	10:21	352.84	0.00	352.84	107.55	3153.20	961.10
H-05c	MAG	3506.04	02-90	14:26	352.54	0.00	352.54	107.45	3153.50	961.19
H-05c	MAG	3506.04	03-90	09:55	352.53	0.00	352.53	107.45	3153.51	961.19
H-05c	MAG	3506.04	04-90	13:03	352.18	0.00	352.18	107.34	3153.86	961.30
H-05c	MAG	3506.04	05-90	12:25	398.41	0.00	398.41	121.44	3107.63	947.21
H-05c	MAG	3506.04	06-90	08:53	359.11	0.00	359.11	109.46	3146.93	959.18
H-05c	MAG	3506.04	07-90	09:15	355.74	0.00	355.74	108.43	3150.30	960.21
H-05c	MAG	3506.04	08-90	15:04	354.24	0.00	354.24	107.97	3151.80	960.67
H-05c	MAG	3506.04	09-90	09:26	353.48	0.00	353.48	107.74	3152.56	960.90
H-05c	MAG	3506.04	10-90	09:31	353.15	0.00	353.15	107.64	3152.89	961.00
H-05c	MAG	3506.04	11-90	10:15	353.05	0.00	353.05	107.61	3152.99	961.03
H-05c	MAG	3506.04	12-90	12:20	352.91	0.00	352.91	107.57	3153.13	961.07



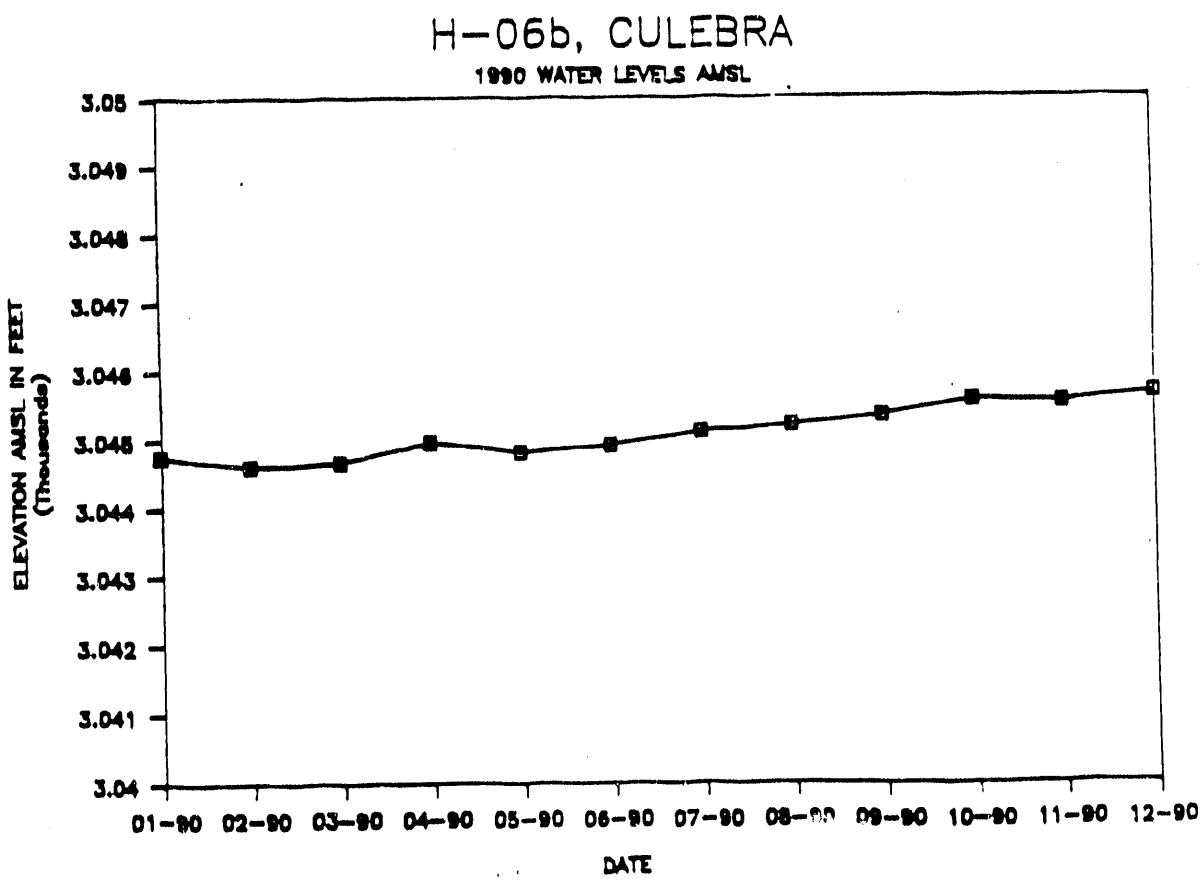
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-06a, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MS
H-06a	CUL	3348.11	03-90	12:15	302.92	0.00	302.92	92.33	3045.19	928.
H-06a	CUL	3348.11	06-90	10:05	302.72	0.00	302.72	92.27	3045.39	928.
H-06a	CUL	3348.11	09-90	12:45	302.15	0.00	302.15	92.10	3045.96	928.
H-06a	CUL	3348.11	12-90	08:30	302.12	0.00	302.12	92.09	3045.99	928.



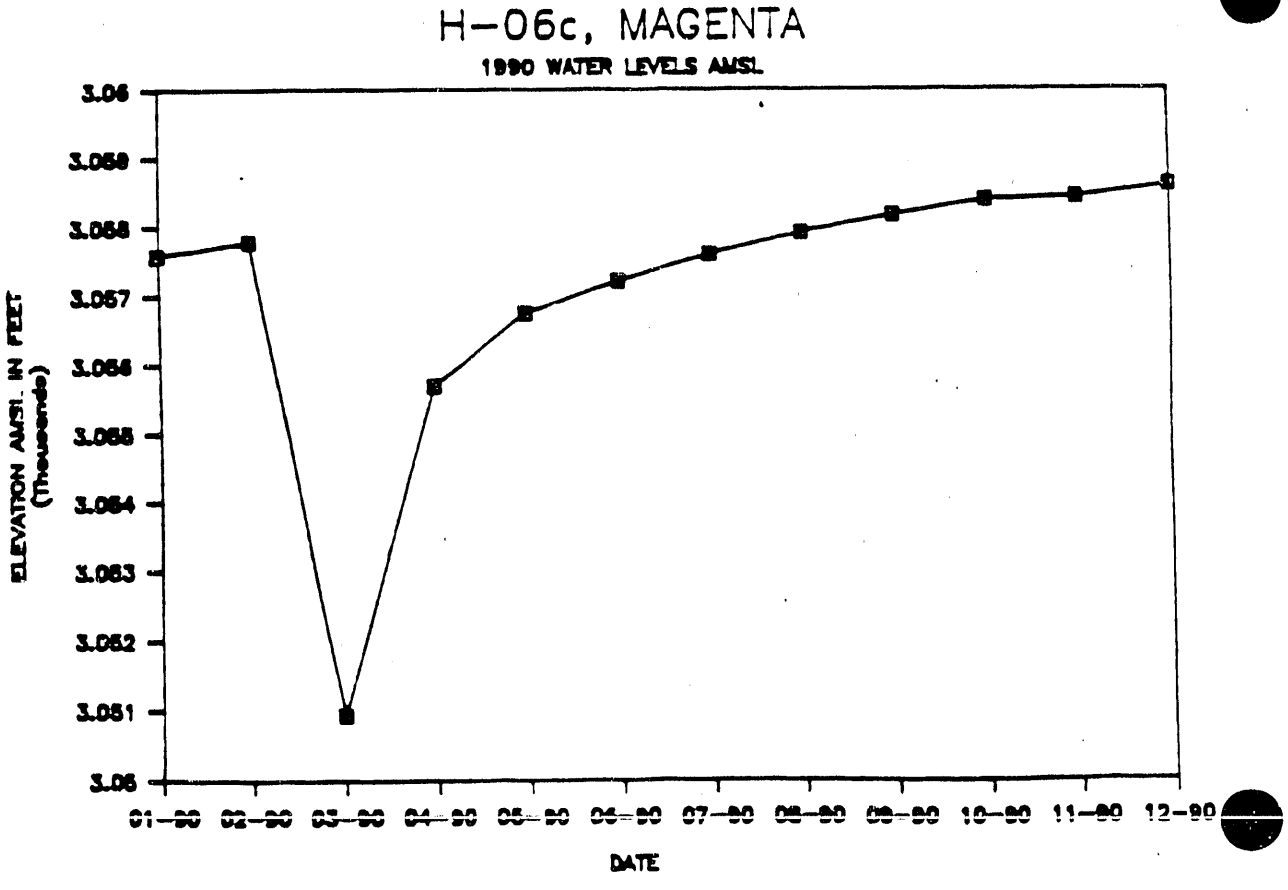
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-06b, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_M
H-06b	CUL	3348.25	01-90	14:28	303.49	0.00	303.49	92.50	3044.76	928.04
H-06b	CUL	3348.25	02-90	12:05	303.63	0.00	303.63	92.55	3044.62	928.00
H-06b	CUL	3348.25	03-90	12:54	303.57	0.00	303.57	92.53	3044.68	928.02
H-06b	CUL	3348.25	04-90	10:35	303.28	0.00	303.28	92.44	3044.97	928.11
H-06b	CUL	3348.25	05-90	10:57	303.42	0.00	303.42	92.48	3044.83	928.06
H-06b	CUL	3348.25	06-90	10:11	303.32	0.00	303.32	92.45	3044.93	928.09
H-06b	CUL	3348.25	07-90	13:30	303.12	0.00	303.12	92.39	3045.13	928.16
H-06b	CUL	3348.25	08-90	13:57	303.03	0.00	303.03	92.36	3045.22	928.18
H-06b	CUL	3348.25	09-90	12:58	302.90	0.00	302.90	92.32	3045.35	928.22
H-06b	CUL	3348.25	10-90	08:26	302.68	0.00	302.68	92.26	3045.57	928.29
H-06b	CUL	3348.25	11-90	09:10	302.71	0.00	302.71	92.27	3045.54	928.28
H-06b	CUL	3348.25	12-90	08:10	302.58	0.00	302.58	92.23	3045.67	928.32



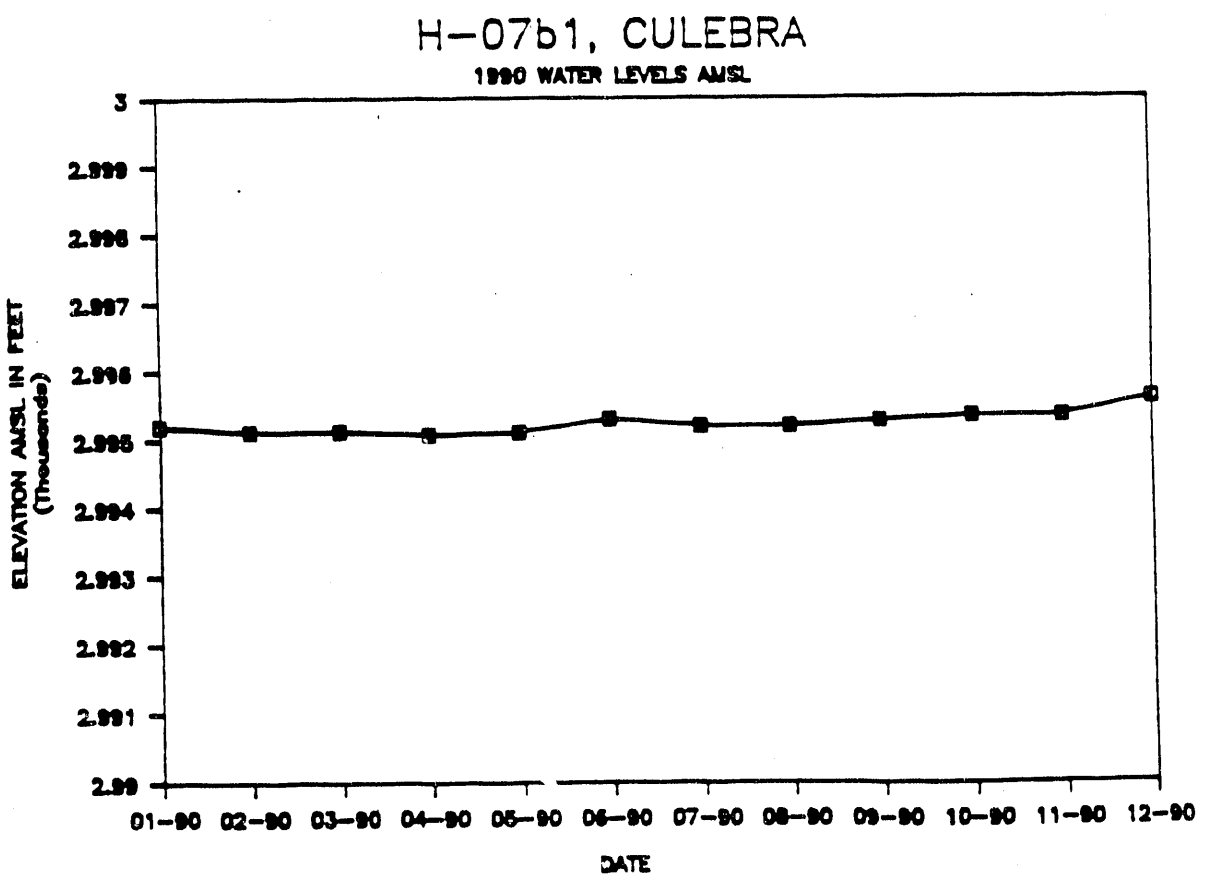
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-06c, MAGENTA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL
H-06c	MAG	3348.52	01-90	14:36	290.93	0.00	290.93	88.68	3057.59	931.9
H-06c	MAG	3348.52	02-90	12:14	290.73	0.00	290.73	88.61	3057.79	932.0
H-06c	MAG	3348.52	03-90	13:04	297.59	0.00	297.59	90.71	3050.93	929.9
H-06c	MAG	3348.52	04-90	10:44	292.82	0.00	292.82	89.25	3055.70	931.7
H-06c	MAG	3348.52	05-90	11:03	291.76	0.00	291.76	88.93	3056.76	93
H-06c	MAG	3348.52	06-90	10:25	291.30	0.00	291.30	88.79	3057.22	93
H-06c	MAG	3348.52	07-90	13:35	290.91	0.00	290.91	88.67	3057.61	93
H-06c	MAG	3348.52	08-90	14:03	290.60	0.00	290.60	88.57	3057.92	932.
H-06c	MAG	3348.52	09-90	12:53	290.35	0.00	290.35	88.50	3058.17	
H-06c	MAG	3348.52	10-90	08:34	290.13	0.00	290.13	88.43	3058.39	932.
H-06c	MAG	3348.52	11-90	09:15	290.09	0.00	290.09	88.42	3058.43	932.2
H-06c	MAG	3348.52	12-90	08:22	289.92	0.00	289.92	88.37	3058.60	932.2



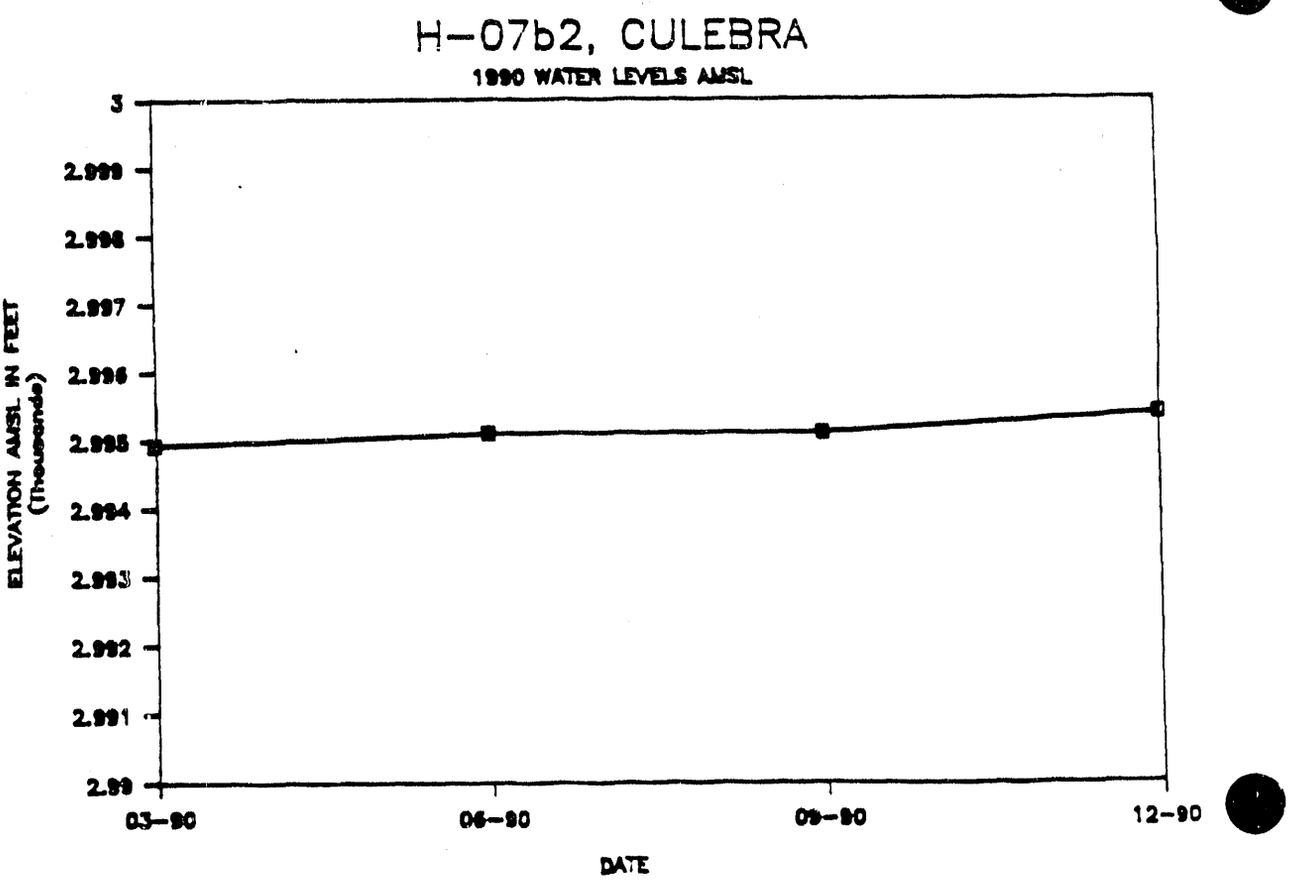
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-07b1, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_
H-07b1	CUL	3164.17	01-90	15:26	168.97	0.00	168.97	51.50	2995.20	912.
H-07b1	CUL	3164.17	02-90	06:36	169.05	0.00	169.05	51.53	2995.12	912.91
H-07b1	CUL	3164.17	03-90	08:10	169.04	0.00	169.04	51.52	2995.13	912.92
H-07b1	CUL	3164.17	04-90	07:27	169.09	0.00	169.09	51.54	2995.08	912.90
H-07b1	CUL	3164.17	05-90	06:45	169.06	0.00	169.06	51.53	2995.11	912.91
H-07b1	CUL	3164.17	06-90	13:32	168.86	0.00	168.86	51.47	2995.31	912.97
H-07b1	CUL	3164.17	07-90	06:50	168.97	0.00	168.97	51.50	2995.20	912.94
H-07b1	CUL	3164.17	08-90	17:05	168.97	0.00	168.97	51.50	2995.20	912.94
H-07b1	CUL	3164.17	09-90	11:35	168.89	0.00	168.89	51.48	2995.28	912.96
H-07b1	CUL	3164.17	10-90	14:15	168.83	0.00	168.83	51.46	2995.34	912.98
H-07b1	CUL	3164.17	11-90	12:45	168.83	0.00	168.83	51.46	2995.34	912.98
H-07b1	CUL	3164.17	12-90	07:20	168.57	0.00	168.57	51.38	2995.60	913.06



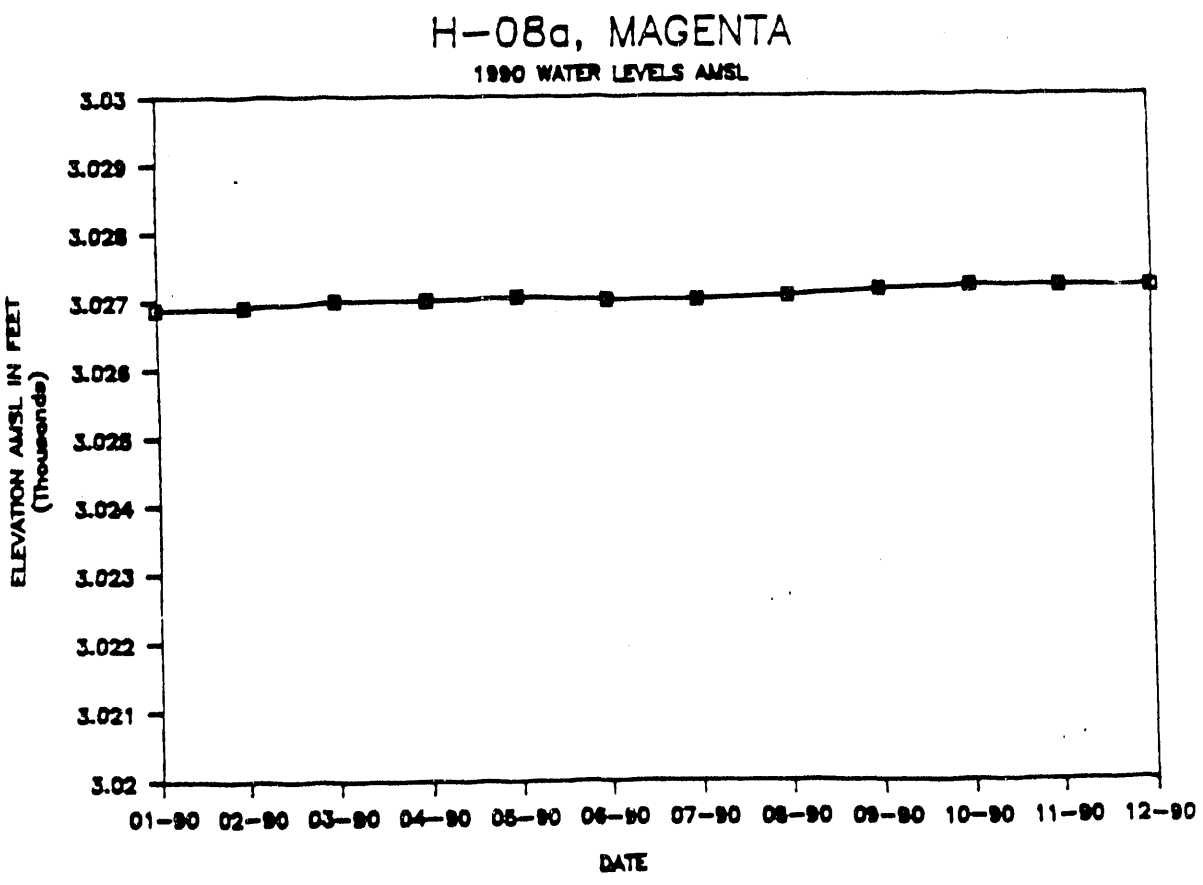
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-07b2, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL
H-07b2	CUL	3164.40	03-90	08:16	169.46	0.00	169.46	51.65	2994.94	912.8
H-07b2	CUL	3164.40	06-90	13:36	169.28	0.00	169.28	51.60	2995.12	912.9
H-07b2	CUL	3164.40	09-90	11:40	169.29	0.00	169.29	51.60	2995.11	912.9
H-07b2	CUL	3164.40	12-90	07:30	169.00	0.00	169.00	51.51	2995.40	913.0



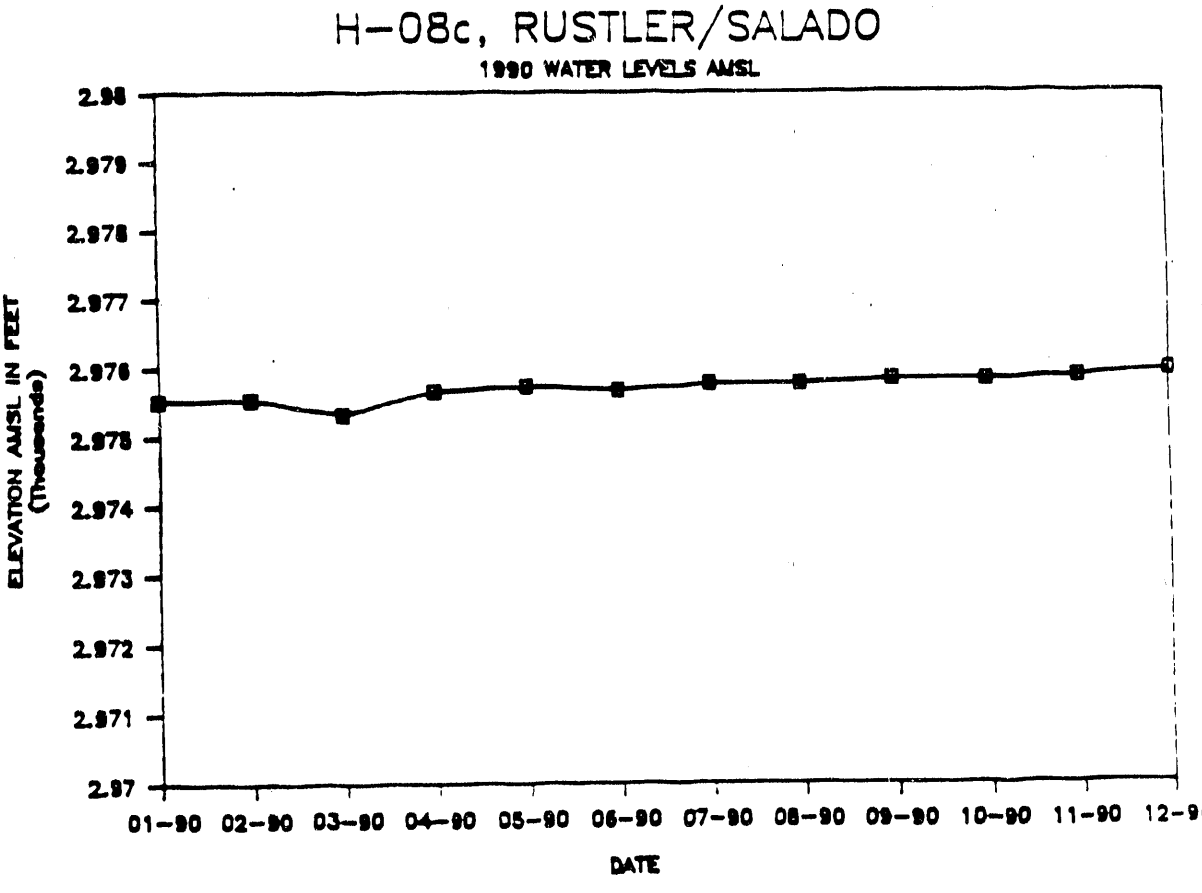
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-08a, MAGENTA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_M
H-08a	MAG	3432.99	01-90	09:15	406.11	0.00	406.11	123.78	3026.88	922.59
H-08a	MAG	3432.99	02-90	07:06	406.07	0.00	406.07	123.77	3026.92	922.61
H-08a	MAG	3432.99	03-90	17:18	405.98	0.00	405.98	123.74	3027.01	922.63
H-08a	MAG	3432.99	04-90	08:00	405.98	0.00	405.98	123.74	3027.01	922.63
H-08a	MAG	3432.99	05-90	14:42	405.92	0.00	405.92	123.72	3027.07	922.65
H-08a	MAG	3432.99	06-90	10:46	405.97	0.00	405.97	123.74	3027.02	922.64
H-08a	MAG	3432.99	07-90	11:35	405.96	0.00	405.96	123.74	3027.03	922.64
H-08a	MAG	3432.99	08-90	16:15	405.91	0.00	405.91	123.72	3027.08	922.65
H-08a	MAG	3432.99	09-90	10:20	405.83	0.00	405.83	123.70	3027.16	922.68
H-08a	MAG	3432.99	10-90	12:56	405.79	0.00	405.79	123.68	3027.20	922.69
H-08a	MAG	3432.99	11-90	11:18	405.79	0.00	405.79	123.68	3027.20	922.69
H-08a	MAG	3432.99	12-90	15:22	405.81	0.00	405.81	123.69	3027.18	922.68



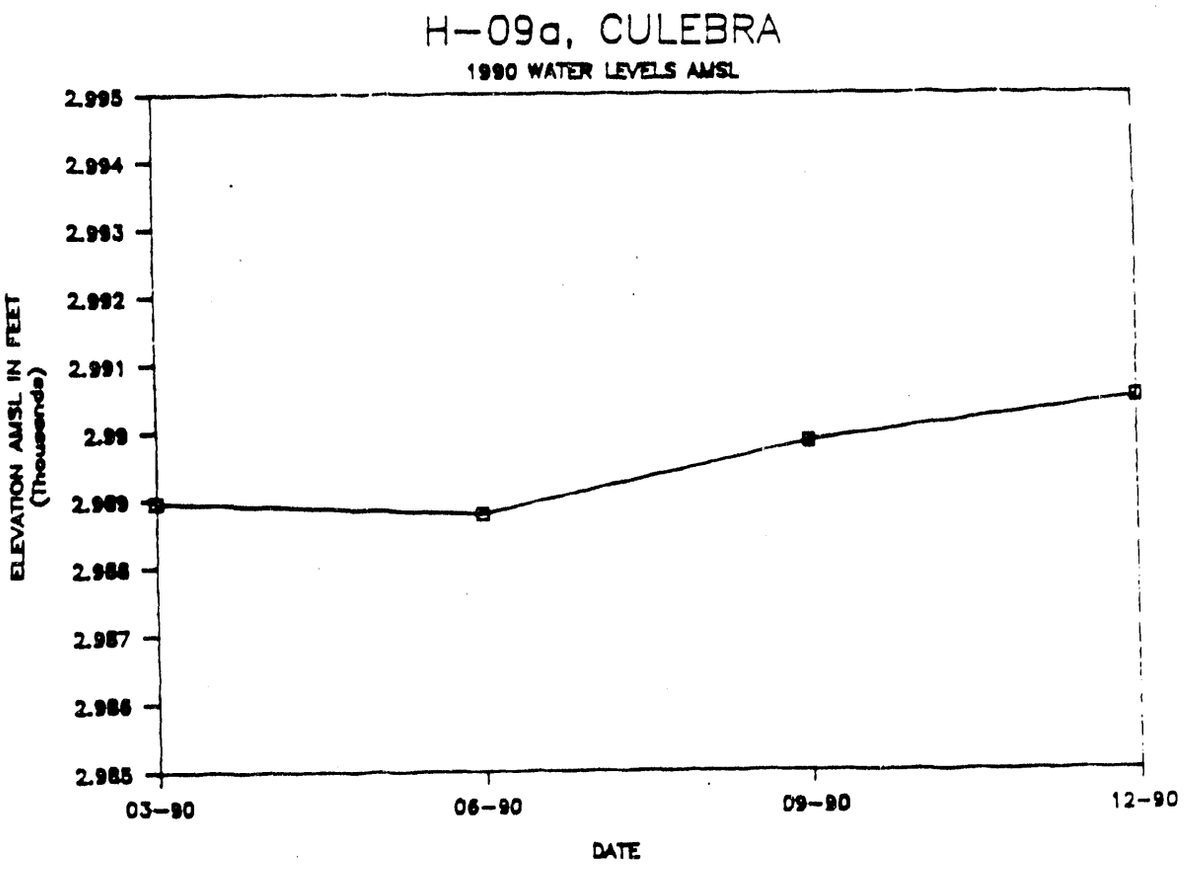
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-08c, RUSTLER/SALADO

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_M
H-08c	RUS/SAL	3432.90	01-90	08:56	457.37	0.00	457.37	139.41	2975.53	90
H-08c	RUS/SAL	3432.90	02-90	07:16	457.35	0.00	457.35	139.40	2975.55	90
H-08c	RUS/SAL	3432.90	03-90	17:25	457.57	0.00	457.57	139.47	2975.33	906.
H-08c	RUS/SAL	3432.90	04-90	08:10	457.23	0.00	457.23	139.36	2975.67	90
H-08c	RUS/SAL	3432.90	05-90	14:35	457.16	0.00	457.16	139.34	2975.74	90
H-08c	RUS/SAL	3432.90	06-90	10:54	457.22	0.00	457.22	139.36	2975.68	90
H-08c	RUS/SAL	3432.90	07-90	11:45	457.13	0.00	457.13	139.33	2975.77	907.0
H-08c	RUS/SAL	3432.90	08-90	16:22	457.13	0.00	457.13	139.33	2975.77	907.0
H-08c	RUS/SAL	3432.90	09-90	10:25	457.07	0.00	457.07	139.31	2975.83	907.0
H-08c	RUS/SAL	3432.90	10-90	13:03	457.08	0.00	457.08	139.32	2975.82	907.0
H-08c	RUS/SAL	3432.90	11-90	11:24	457.03	0.00	457.03	139.30	2975.87	907.0
H-08c	RUS/SAL	3432.90	12-90	15:55	456.94	0.00	456.94	139.28	2975.96	907.0



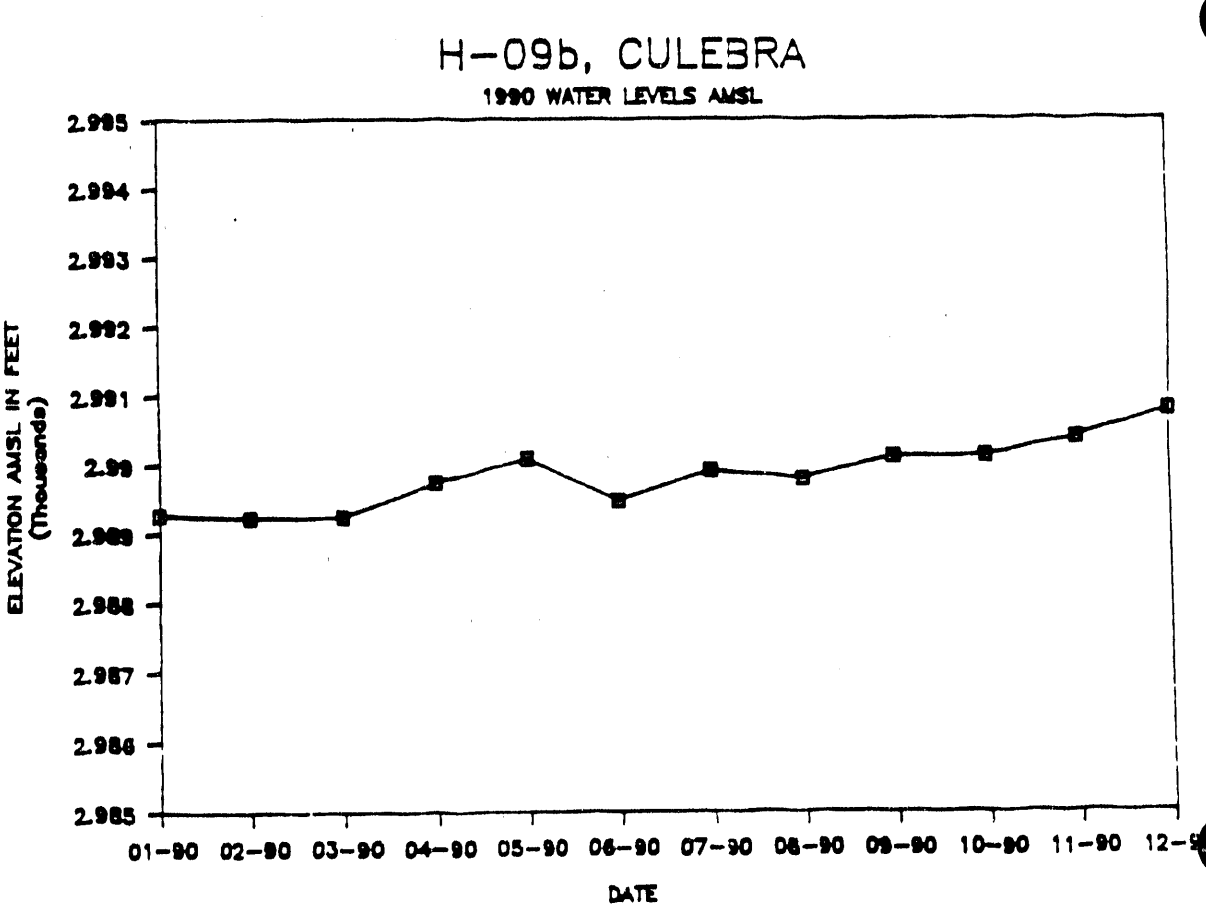
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-09a, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_
H-09a	CUL	3406.68	03-90	16:30	417.72	0.00	417.72	127.32	2988.96	911.0
H-09a	CUL	3406.68	06-90	13:02	417.89	0.00	417.89	127.37	2988.79	910.9
H-09a	CUL	3406.68	09-90	08:40	416.82	0.00	416.82	127.05	2989.86	911.3
H-09a	CUL	3406.68	12-90	14:50	416.18	0.00	416.18	126.85	2990.50	911.5



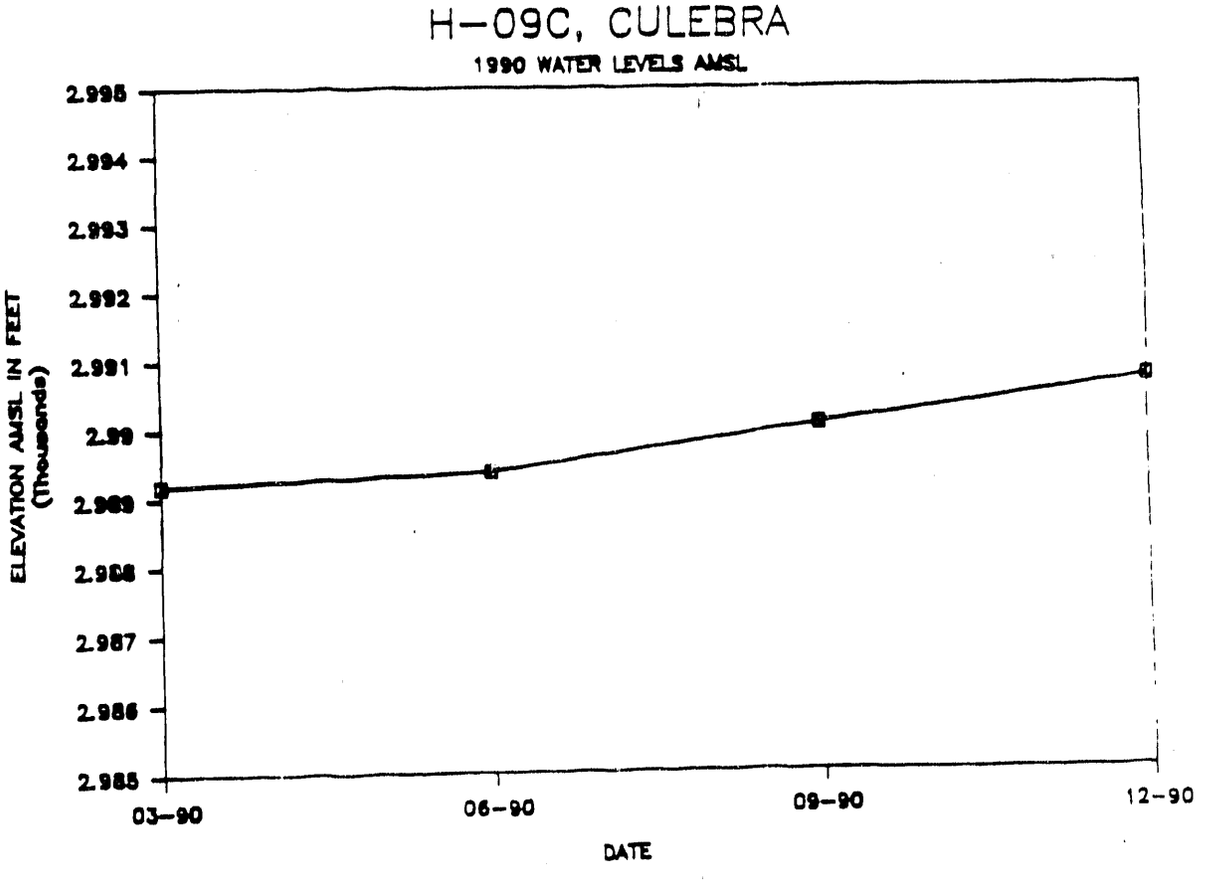
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-09b, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL
H-09b	CUL	3406.86	01-90	09:53	417.59	0.00	417.59	127.28	2989.27	9
H-09b	CUL	3406.86	02-90	07:44	417.63	0.00	417.63	127.29	2989.23	9
H-09b	CUL	3406.86	03-90	16:40	417.61	0.00	417.61	127.29	2989.25	91
H-09b	CUL	3406.86	04-90	08:36	417.12	0.00	417.12	127.14	2989.74	911.
H-09b	CUL	3406.86	05-90	07:14	416.77	0.00	416.77	127.03	2990.09	911.
H-09b	CUL	3406.86	06-90	12:50	417.39	0.00	417.39	127.22	2989.47	911.
H-09b	CUL	3406.86	07-90	11:05	416.95	0.00	416.95	127.09	2989.91	911.
H-09b	CUL	3406.86	08-90	09:00	417.07	0.00	417.07	127.12	2989.79	911.
H-09b	CUL	3406.86	09-90	08:45	416.75	0.00	416.75	127.03	2990.11	911.
H-09b	CUL	3406.86	10-90	12:04	416.75	0.00	416.75	127.03	2990.11	911.
H-09b	CUL	3406.86	11-90	09:36	416.47	0.00	416.47	126.94	2990.39	911.
H-09b	CUL	3406.86	12-90	15:10	416.08	0.00	416.08	126.82	2990.78	911.



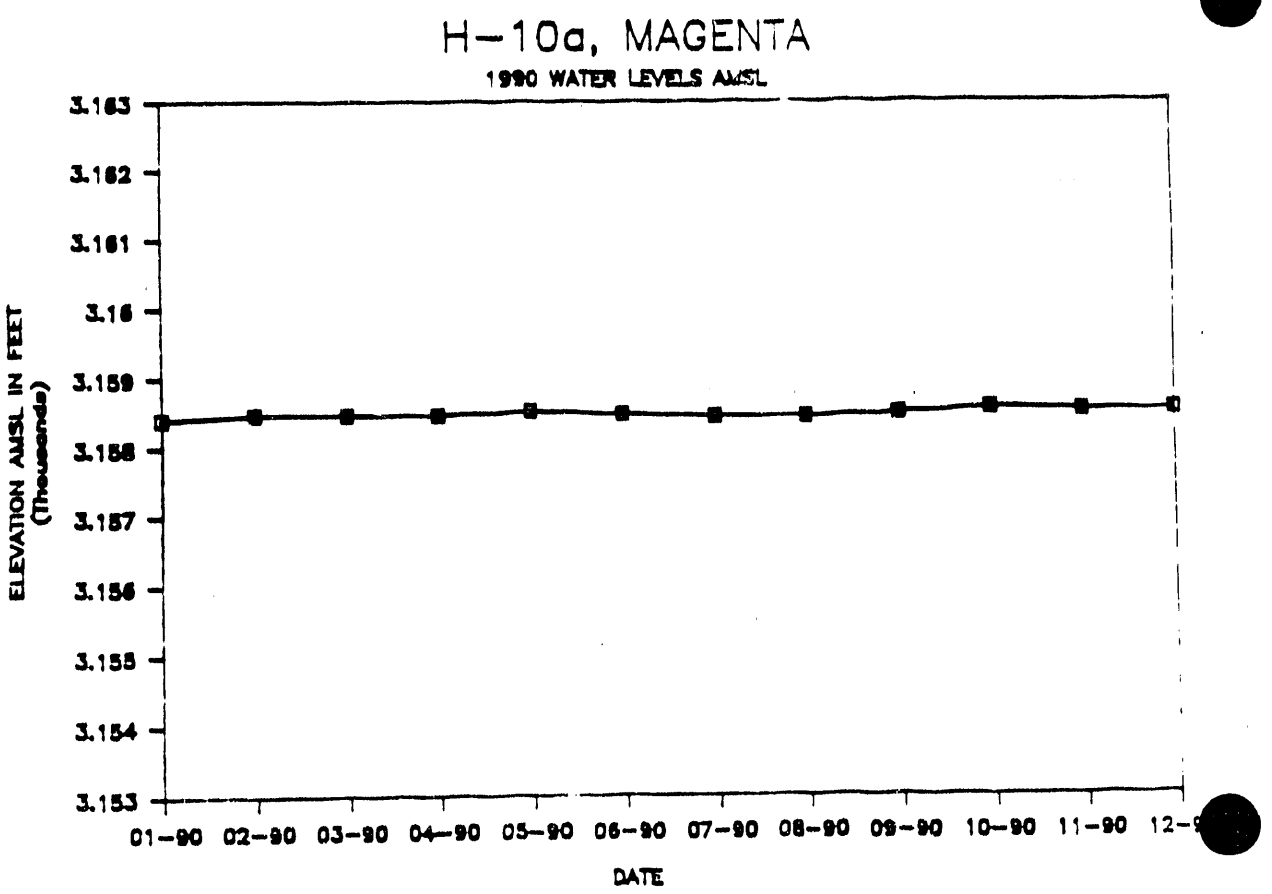
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-09c, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL
H-09c	CUL	3407.30	03-90	16:45	418.11	0.00	418.11	127.44	2989.19	911.1
H-09c	CUL	3407.30	06-90	12:55	417.92	0.00	417.92	127.38	2989.38	911.1
H-09c	CUL	3407.30	09-90	08:56	417.24	0.00	417.24	127.17	2990.06	911.3
H-09c	CUL	3407.30	12-90	15:00	416.60	0.00	416.60	126.98	2990.70	911.5



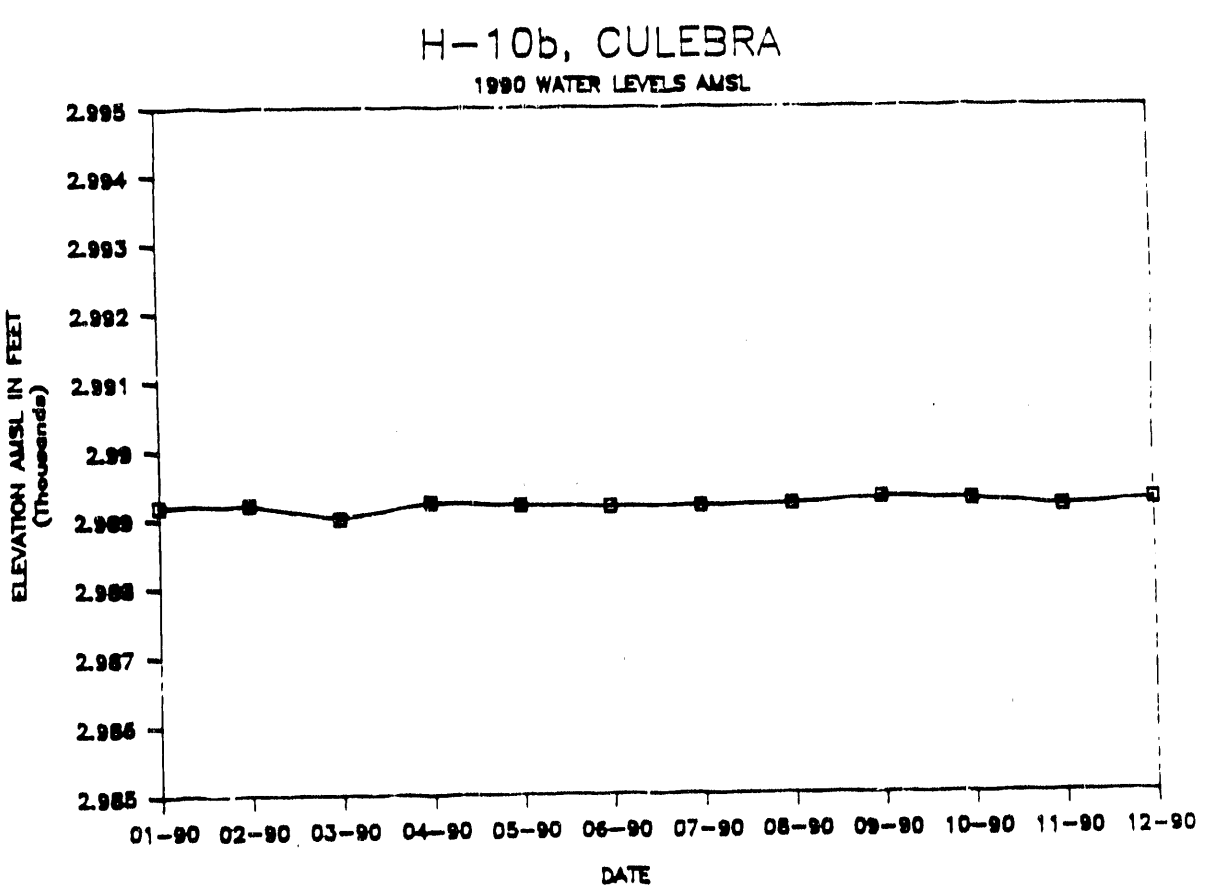
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-10a, MAGENTA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_M
H-10a	MAG	3688.67	01-90	10:55	530.26	0.00	530.26	161.62	3158.41	962.
H-10a	MAG	3688.67	02-90	14:10	530.19	0.00	530.19	161.60	3158.48	962
H-10a	MAG	3688.67	03-90	15:45	530.20	0.00	530.20	161.60	3158.47	962
H-10a	MAG	3688.67	04-90	09:06	530.20	0.00	530.20	161.60	3158.47	962
H-10a	MAG	3688.67	05-90	07:47	530.14	0.00	530.14	161.59	3158.53	962
H-10a	MAG	3688.67	06-90	13:49	530.19	0.00	530.19	161.60	3158.48	962.
H-10a	MAG	3688.67	07-90	10:25	530.22	0.00	530.22	161.61	3158.45	962
H-10a	MAG	3688.67	08-90	08:30	530.22	0.00	530.22	161.61	3158.45	
H-10a	MAG	3688.67	09-90	07:40	530.18	0.00	530.18	161.60	3158.49	962
H-10a	MAG	3688.67	10-90	11:24	530.11	0.00	530.11	161.58	3158.56	962
H-10a	MAG	3688.67	11-90	08:55	530.14	0.00	530.14	161.59	3158.53	962
H-10a	MAG	3688.67	12-90	14:08	530.14	0.00	530.14	161.59	3158.53	962



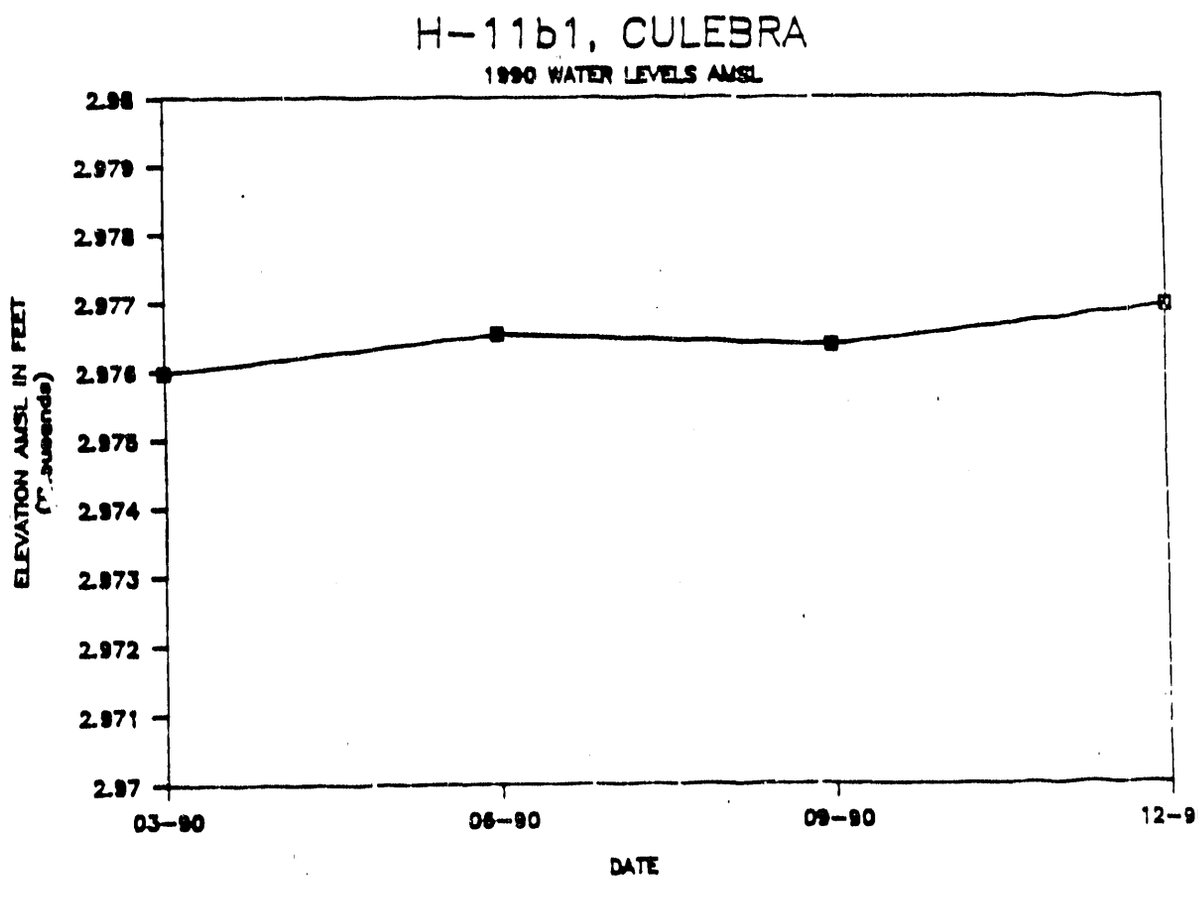
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-10b, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_
H-10b	CUL	3689.47	01-90	10:42	700.28	0.00	700.28	213.45	2989.19	911.11
H-10b	CUL	3689.47	02-90	14:24	700.26	0.00	700.26	213.44	2989.21	911.11
H-10b	CUL	3689.47	03-90	15:46	700.46	0.00	700.46	213.50	2989.01	911.05
H-10b	CUL	3689.47	04-90	09:14	700.22	0.00	700.22	213.43	2989.25	911.12
H-10b	CUL	3689.47	05-90	07:57	700.27	0.00	700.27	213.44	2989.20	911.11
H-10b	CUL	3689.47	06-90	13:57	700.29	0.00	700.29	213.45	2989.18	911.10
H-10b	CUL	3689.47	07-90	10:34	700.29	0.00	700.29	213.45	2989.18	911.10
H-10b	CUL	3689.47	08-90	08:17	700.26	0.00	700.26	213.44	2989.21	911.11
H-10b	CUL	3689.47	09-90	07:59	700.17	0.00	700.17	213.41	2989.30	911.14
H-10b	CUL	3689.47	10-90	11:16	700.21	0.00	700.21	213.42	2989.26	911.13
H-10b	CUL	3689.47	11-90	09:06	700.31	0.00	700.31	213.45	2989.16	911.10
H-10b	CUL	3689.47	12-90	14:15	700.22	0.00	700.22	213.43	2989.25	911.12



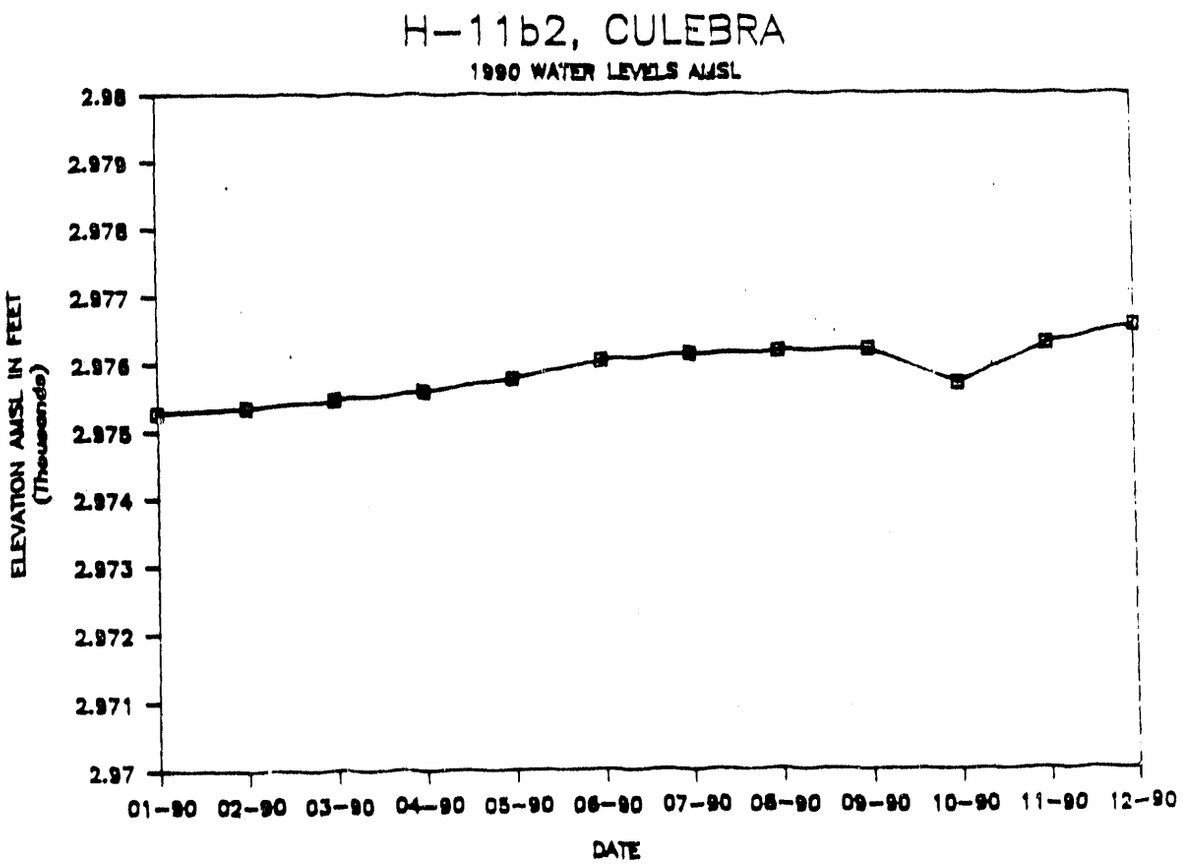
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-11b1, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MS.
H-11b1	CUL	3411.62	03-90	14:35	435.63	0.00	435.63	132.78	2975.99	907.0
H-11b1	CUL	3411.62	06-90	15:30	435.07	0.00	435.07	132.61	2976.55	907.2
H-11b1	CUL	3411.62	09-90	15:35	435.24	0.00	435.24	132.66	2976.38	907.2
H-11b1	CUL	3411.62	12-90	07:05	434.67	0.00	434.67	132.49	2976.95	907.3



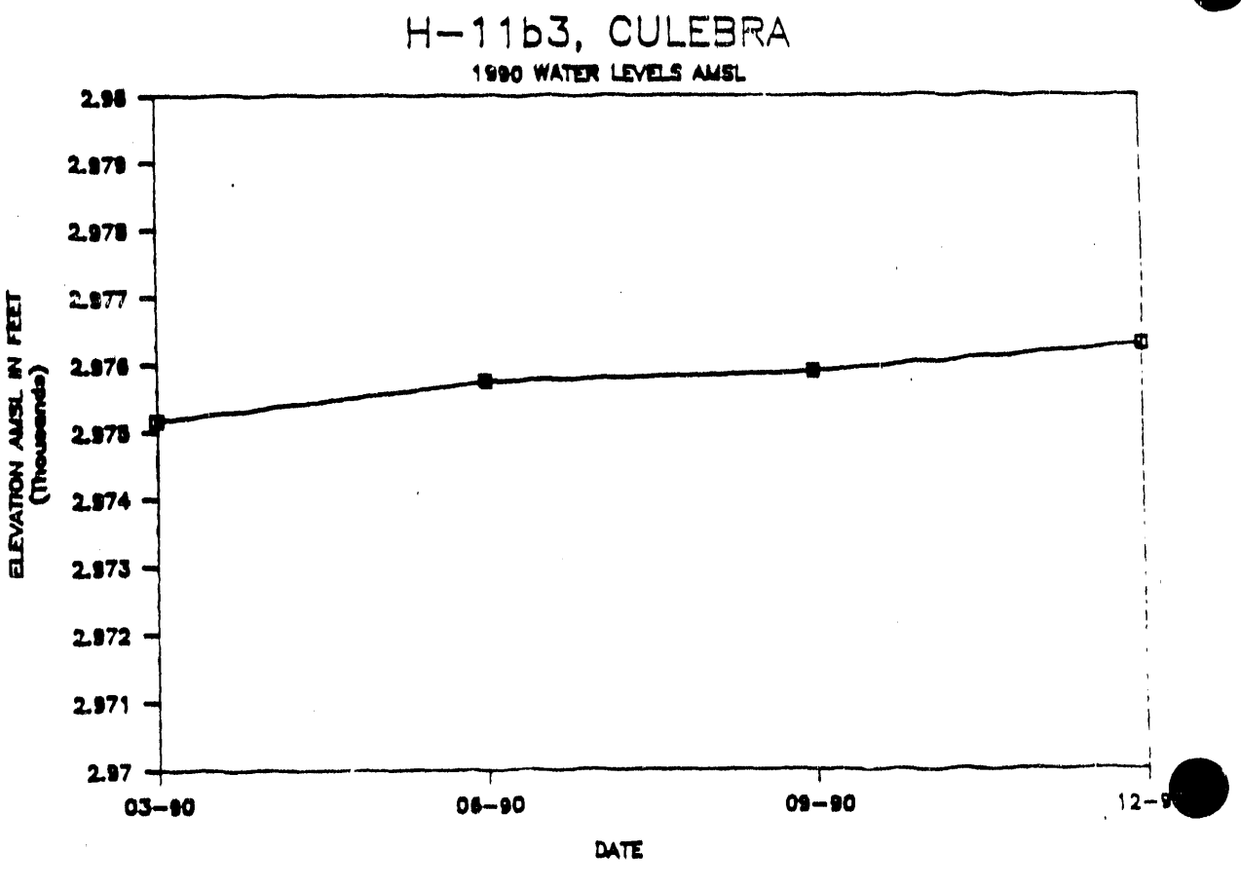
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-11b2, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL
H-11b2	CUL	3411.64	01-90	13:11	436.36	0.00	436.36	133.00	2975.28	906.8
H-11b2	CUL	3411.64	02-90	08:42	436.28	0.00	436.28	132.98	2975.36	906.8
H-11b2	CUL	3411.64	03-90	14:42	436.16	0.00	436.16	132.94	2975.48	906.9
H-11b2	CUL	3411.64	04-90	11:09	436.04	0.00	436.04	132.90	2975.60	906.9
H-11b2	CUL	3411.64	05-90	09:15	435.85	0.00	435.85	132.85	2975.79	907.0
H-11b2	CUL	3411.64	06-90	15:40	435.58	0.00	435.58	132.76	2976.06	907.1
H-11b2	CUL	3411.64	07-90	09:35	435.49	0.00	435.49	132.74	2976.15	907.1
H-11b2	CUL	3411.64	08-90	11:35	435.46	0.00	435.46	132.73	2976.18	907.1
H-11b2	CUL	3411.64	09-90	11:53	435.43	0.00	435.43	132.72	2976.21	907.1
H-11b2	CUL	3411.64	10-90	07:45	435.95	0.00	435.95	132.88	2975.69	906.9
H-11b2	CUL	3411.64	11-90	16:58	435.36	0.00	435.36	132.70	2976.28	907.1
H-11b2	CUL	3411.64	12-90	07:25	435.08	0.00	435.08	132.61	2976.56	907.2



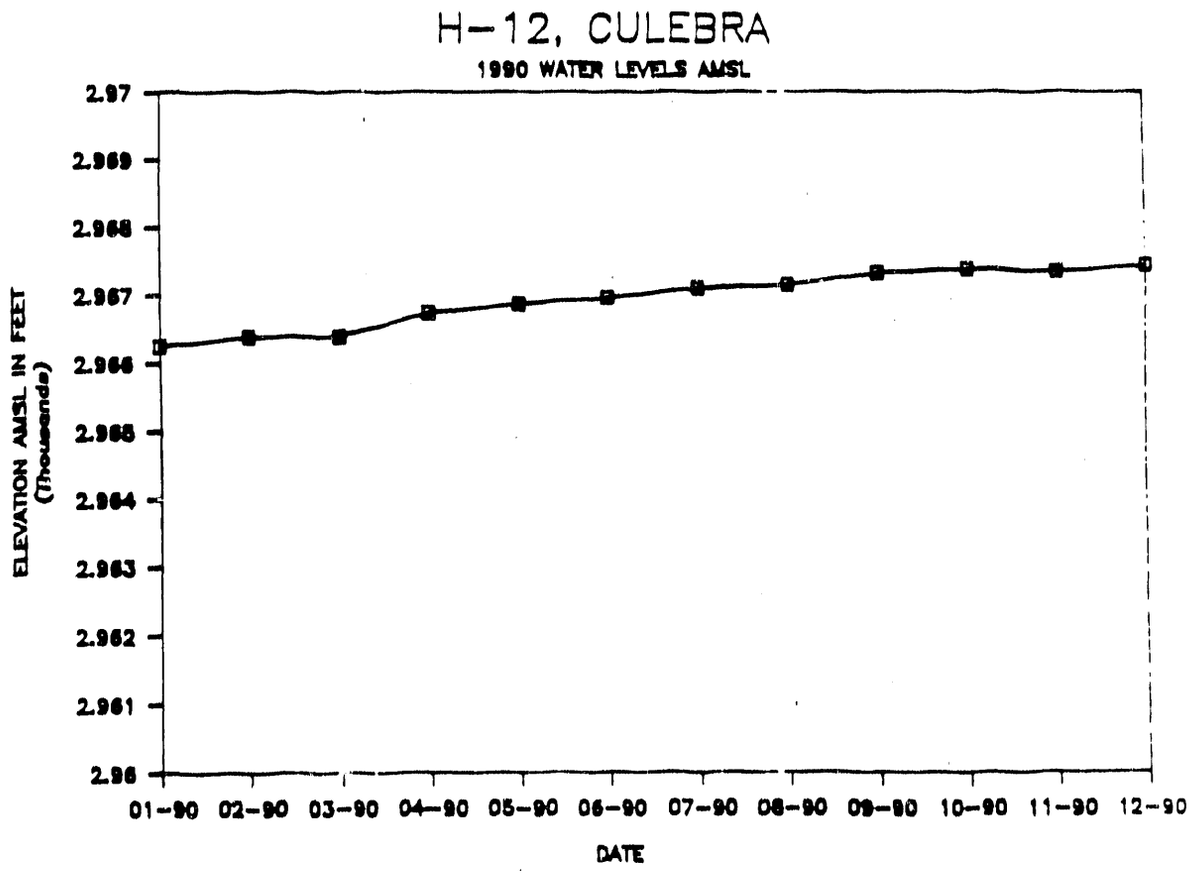
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-11b3, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL
H-11b3	CUL	3412.42	03-90	14:50	437.25	0.00	437.25	133.27	2975.17	906.8
H-11b3	CUL	3412.42	06-90	15:19	436.66	0.00	436.66	133.09	2975.76	907.0
H-11b3	CUL	3412.42	09-90	15:45	436.52	0.00	436.52	133.05	2975.90	907.0
H-11b3	CUL	3412.42	12-90	07:30	436.12	0.00	436.12	132.93	2976.30	907.1



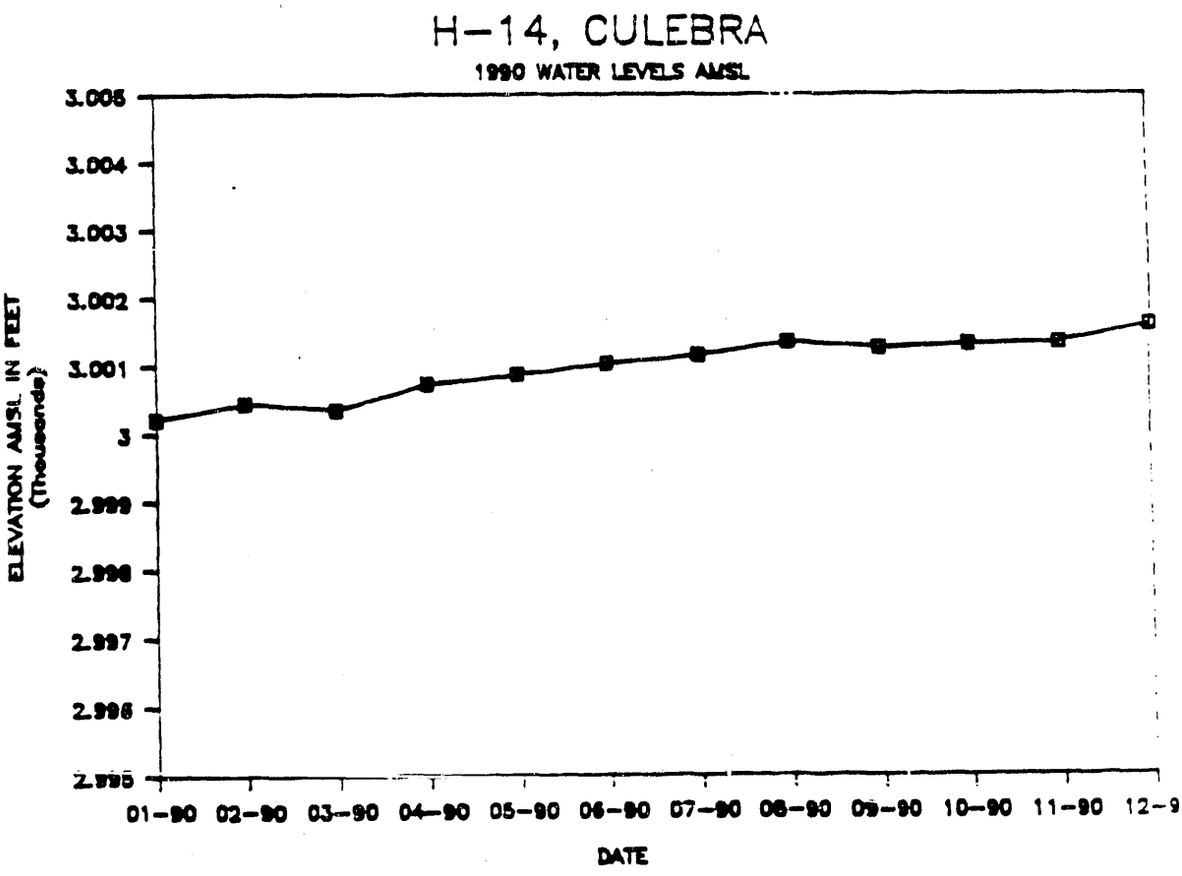
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-12, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MS.
H-12	CUL	3427.19	01-90	11:44	460.93	0.00	460.93	140.49	2966.26	904.
H-12	CUL	3427.19	02-90	08:13	460.79	0.00	460.79	140.45	2966.40	904.
H-12	CUL	3427.19	03-90	15:20	460.79	0.00	460.79	140.45	2966.40	904.
H-12	CUL	3427.19	04-90	09:45	460.44	0.00	460.44	140.34	2966.75	904.
H-12	CUL	3427.19	05-90	08:35	460.31	0.00	460.31	140.30	2966.88	904.
H-12	CUL	3427.19	06-90	14:45	460.22	0.00	460.22	140.28	2966.97	904.
H-12	CUL	3427.19	07-90	09:50	460.08	0.00	460.08	140.23	2967.11	904.
H-12	CUL	3427.19	08-90	09:25	460.03	0.00	460.03	140.22	2967.16	904.
H-12	CUL	3427.19	09-90	07:05	459.86	0.00	459.86	140.17	2967.33	904.
H-12	CUL	3427.19	10-90	10:10	459.80	0.00	459.80	140.15	2967.39	904.
H-12	CUL	3427.19	11-90	15:20	459.85	0.00	459.85	140.16	2967.34	904.
H-12	CUL	3427.19	12-90	13:25	459.75	0.00	459.75	140.13	2967.44	904.



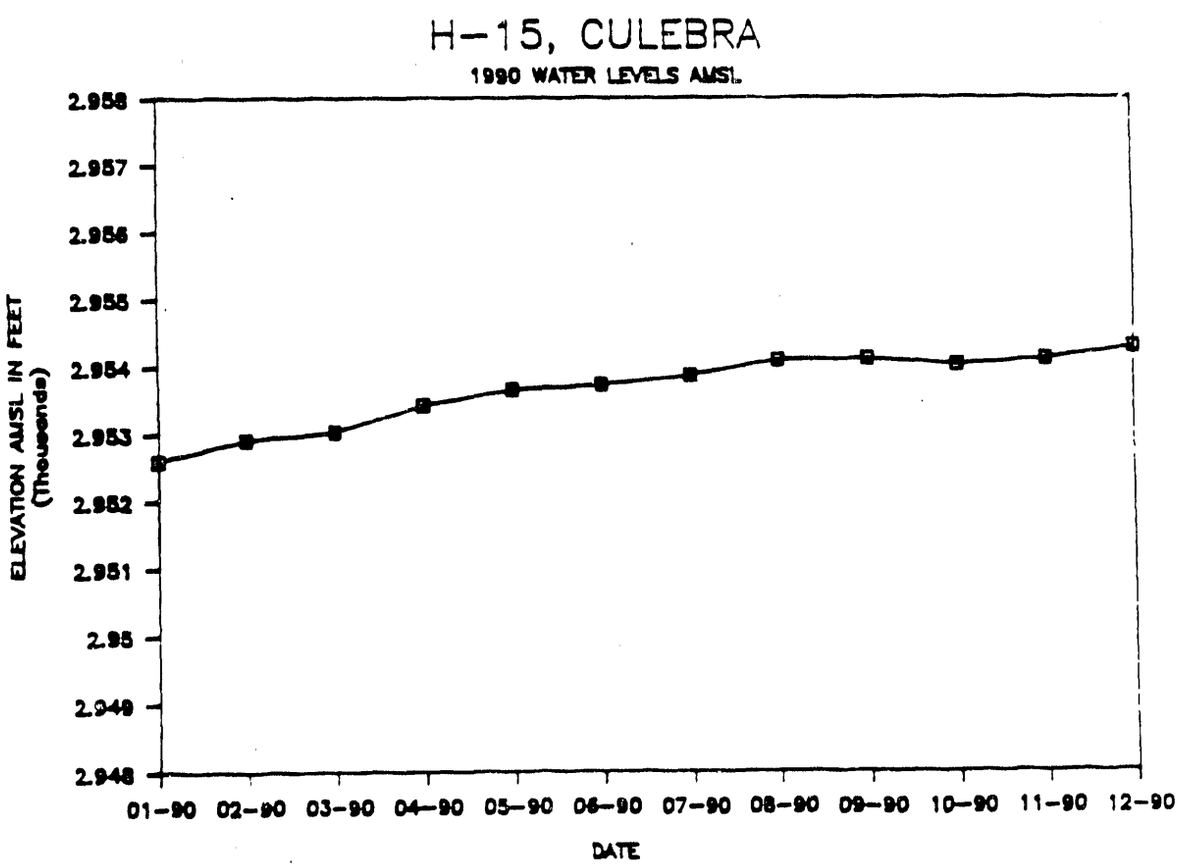
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-14, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL
H-14	CUL	3347.11	01-90	08:00	346.89	0.00	346.89	105.73	3000.22	914.4
H-14	CUL	3347.11	02-90	10:30	346.65	0.00	346.65	105.66	3000.46	914.5
H-14	CUL	3347.11	03-90	12:23	346.75	0.00	346.75	105.69	3000.36	914.5
H-14	CUL	3347.11	04-90	12:25	346.37	0.00	346.37	105.57	3000.74	914.6
H-14	CUL	3347.11	05-90	13:33	346.23	0.00	346.23	105.53	3000.88	914.6
H-14	CUL	3347.11	06-90	17:00	346.07	0.00	346.07	105.48	3001.04	914.7
H-14	CUL	3347.11	07-90	15:15	345.95	0.00	345.95	105.45	3001.16	914.
H-14	CUL	3347.11	08-90	08:27	345.76	0.00	345.76	105.39	3001.35	9
H-14	CUL	3347.11	09-90	15:11	345.85	0.00	345.85	105.42	3001.26	9
H-14	CUL	3347.11	10-90	14:34	345.80	0.00	345.80	105.40	3001.31	9
H-14	CUL	3347.11	11-90	13:50	345.78	0.00	345.78	105.39	3001.33	914.
H-14	CUL	3347.11	12-90	13:30	345.52	0.00	345.52	105.31	3001.59	914.



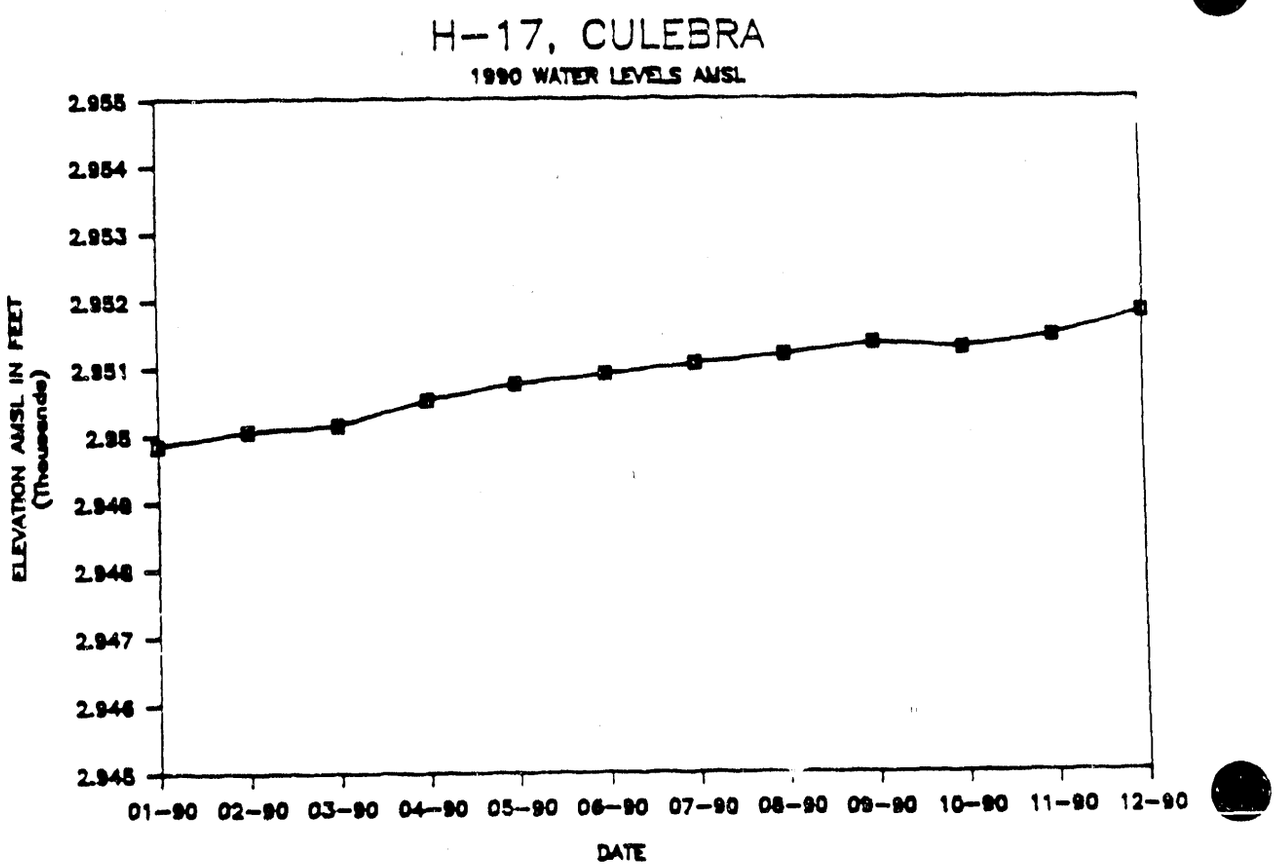
GROUND WATER LEVELS
CALENDAR YEAR 1990
H-15, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL
H-15	CUL	3481.63	01-90	09:44	529.03	0.00	529.03	161.25	2952.60	899.9
H-15	CUL	3481.63	02-90	13:56	528.71	0.00	528.71	161.15	2952.92	900.0
H-15	CUL	3481.63	03-90	10:20	528.59	0.00	528.59	161.11	2953.04	900.0
H-15	CUL	3481.63	04-90	13:25	528.20	0.00	528.20	161.00	2953.43	900.2
H-15	CUL	3481.63	05-90	12:44	527.96	0.00	527.96	160.92	2953.67	900.2
H-15	CUL	3481.63	06-90	08:12	527.89	0.00	527.89	160.90	2953.74	900.3
H-15	CUL	3481.63	07-90	07:55	527.76	0.00	527.76	160.86	2953.87	900.3
H-15	CUL	3481.63	08-90	15:41	527.53	0.00	527.53	160.79	2954.10	900.4
H-15	CUL	3481.63	09-90	09:52	527.52	0.00	527.52	160.79	2954.11	900.4
H-15	CUL	3481.63	10-90	10:35	527.61	0.00	527.61	160.82	2954.02	900.3
H-15	CUL	3481.63	11-90	10:40	527.52	0.00	527.52	160.79	2954.11	900.4
H-15	CUL	3481.63	12-90	09:20	527.35	0.00	527.35	160.74	2954.28	900.4



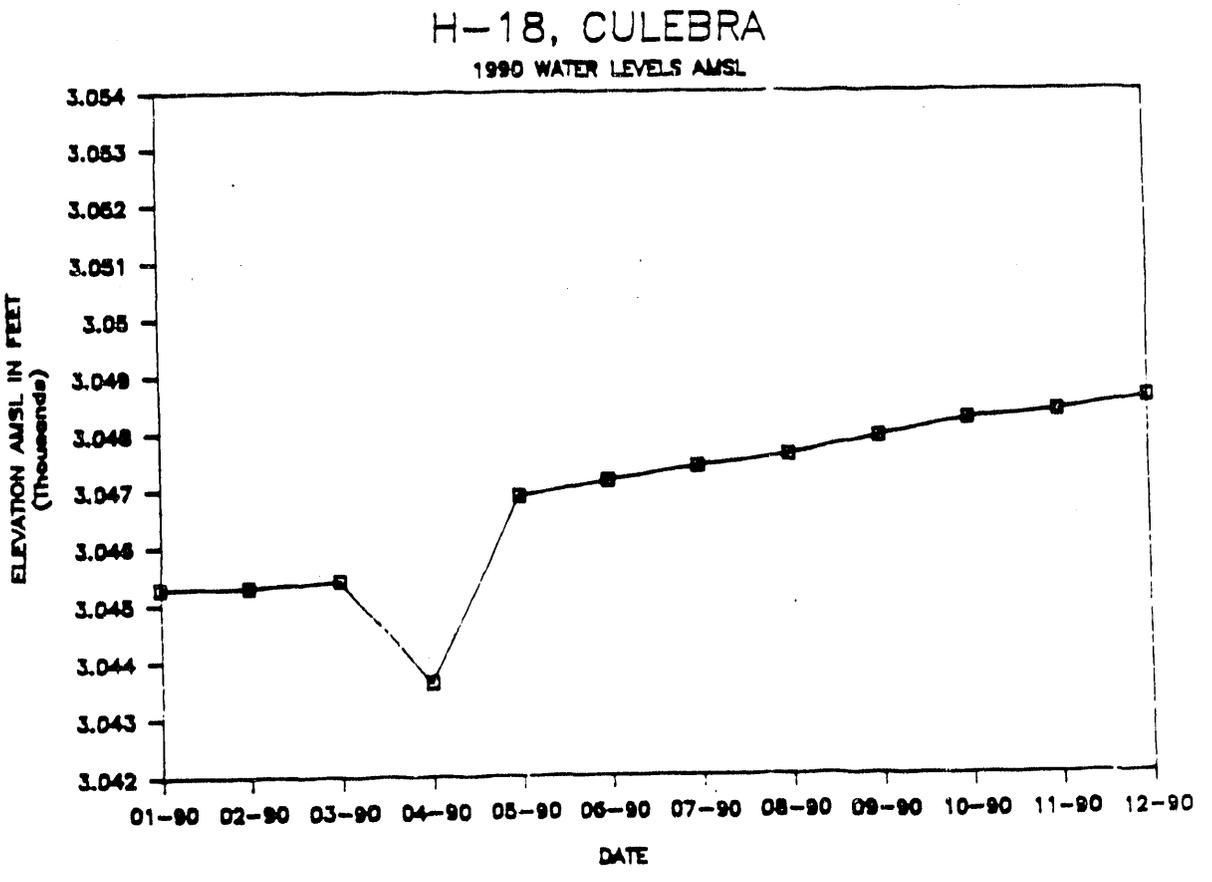
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-17, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_
H-17	CUL	3385.31	01-90	12:46	435.46	0.00	435.46	132.73	2949.85	8
H-17	CUL	3385.31	02-90	08:54	435.25	0.00	435.25	132.66	2950.06	8
H-17	CUL	3385.31	03-90	14:19	435.16	0.00	435.16	132.64	2950.15	8
H-17	CUL	3385.31	04-90	11:20	434.78	0.00	434.78	132.52	2950.53	899.3
H-17	CUL	3385.31	05-90	09:35	434.54	0.00	434.54	132.45	2950.77	899.3
H-17	CUL	3385.31	06-90	15:50	434.40	0.00	434.40	132.41	2950.91	899.4
H-17	CUL	3385.31	07-90	09:15	434.25	0.00	434.25	132.36	2951.06	899.
H-17	CUL	3385.31	08-90	11:15	434.12	0.00	434.12	132.32	2951.19	8
H-17	CUL	3385.31	09-90	16:07	433.95	0.00	433.95	132.27	2951.36	
H-17	CUL	3385.31	10-90	07:23	434.04	0.00	434.04	132.30	2951.	
H-17	CUL	3385.31	11-90	16:38	433.86	0.00	433.86	132.24	2951.45	899.6
H-17	CUL	3385.31	12-90	07:45	433.51	0.00	433.51	132.13	2951.80	899.7



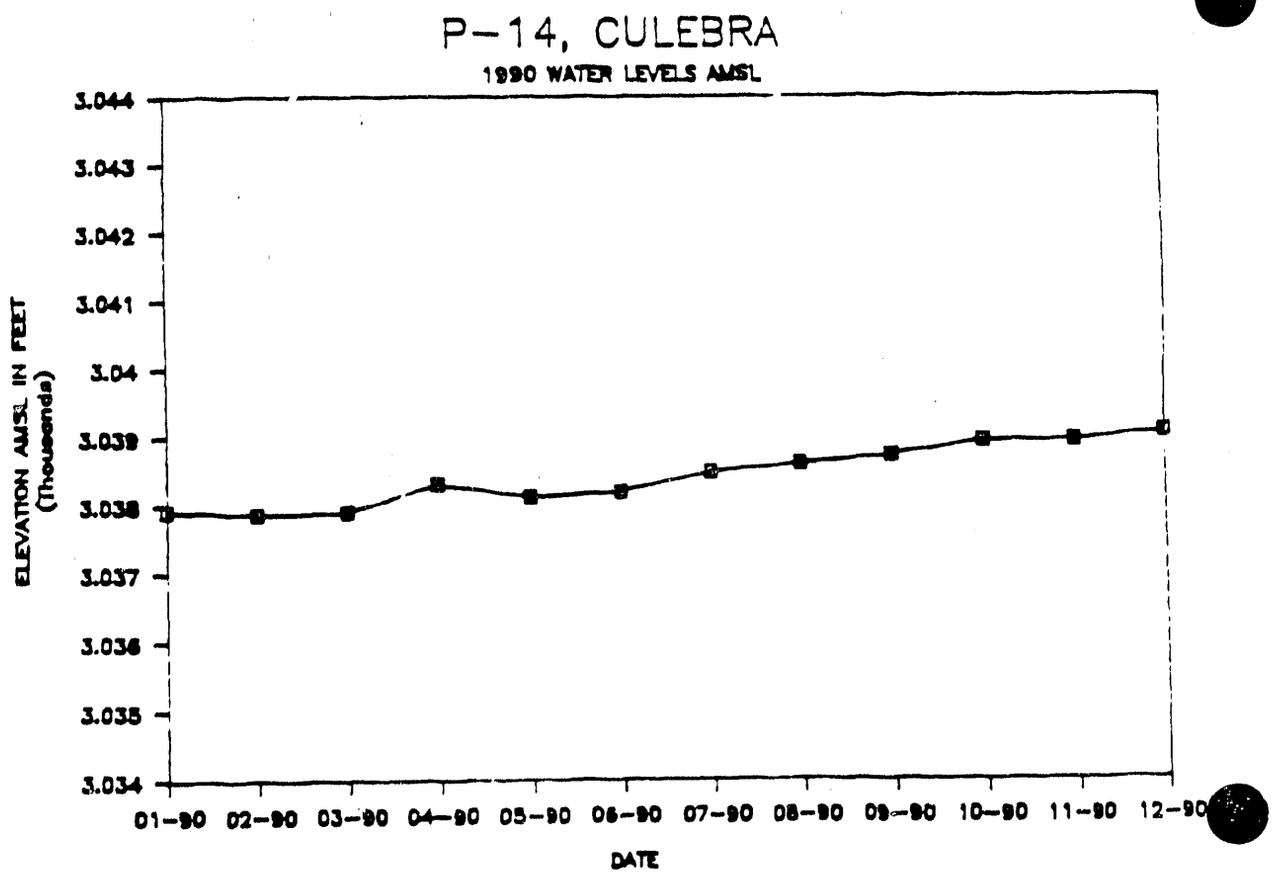
GROUND WATER-LEVELS
CALENDAR YEAR 1990
H-18, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL
H-18	CUL	3414.21	01-90	14:02	368.92	0.00	368.92	112.45	3045.29	928.2
H-18	CUL	3414.21	02-90	12:36	368.90	0.00	368.90	112.44	3045.31	928.2
H-18	CUL	3414.21	03-90	13:30	368.79	0.00	368.79	112.41	3045.42	928.2
H-18	CUL	3414.21	04-90	11:05	370.58	0.00	370.58	112.95	3043.63	927.7
H-18	CUL	3414.21	05-90	11:17	367.31	0.00	367.31	111.96	3046.90	928.7
H-18	CUL	3414.21	06-90	10:44	367.05	0.00	367.05	111.88	3047.16	928.7
H-18	CUL	3414.21	07-90	13:50	366.80	0.00	366.80	111.80	3047.41	928.8
H-18	CUL	3414.21	08-90	14:20	366.61	0.00	366.61	111.74	3047.60	928.9
H-18	CUL	3414.21	09-90	12:25	366.30	0.00	366.30	111.65	3047.91	929.0
H-18	CUL	3414.21	10-90	08:50	365.99	0.00	365.99	111.55	3048.22	929.1
H-18	CUL	3414.21	11-90	09:56	365.86	0.00	365.86	111.51	3048.35	929.1
H-18	CUL	3414.21	12-90	08:50	365.63	0.00	365.63	111.44	3048.58	929.2



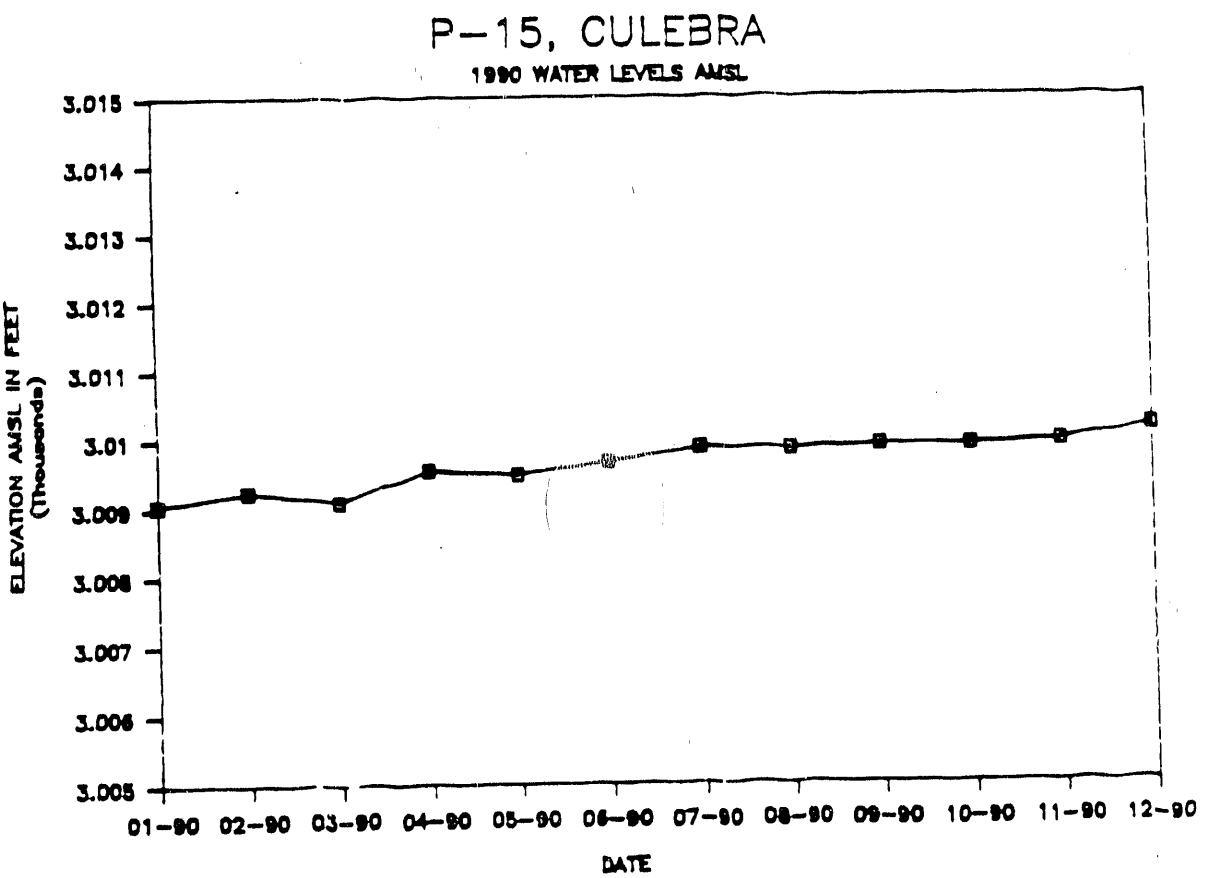
GROUND WATER-LEVELS
CALENDAR YEAR 1990
P-14, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_
P-14	CUL	3361.06	01-90	14:56	323.14	0.00	323.14	98.49	3037.92	92
P-14	CUL	3361.06	02-90	11:42	323.19	0.00	323.19	98.51	3037.87	925
P-14	CUL	3361.06	03-90	12:25	323.15	0.00	323.15	98.50	3037.91	92
P-14	CUL	3361.06	04-90	10:13	322.74	0.00	322.74	98.37	3038.32	926
P-14	CUL	3361.06	05-90	10:37	322.93	0.00	322.93	98.43	3038.13	92
P-14	CUL	3361.06	06-90	09:38	322.86	0.00	322.86	98.41	3038.20	
P-14	CUL	3361.06	07-90	13:15	322.57	0.00	322.57	98.32	3038.49	926
P-14	CUL	3361.06	08-90	13:37	322.45	0.00	322.45	98.28	3038.61	92
P-14	CUL	3361.06	09-90	13:19	322.33	0.00	322.33	98.25	3038.73	
P-14	CUL	3361.06	10-90	08:00	322.12	0.00	322.12	98.18	3038.74	
P-14	CUL	3361.06	11-90	08:45	322.12	0.00	322.12	98.18	3038.94	9
P-14	CUL	3361.06	12-90	07:50	321.99	0.00	321.99	98.14	3039.07	926.



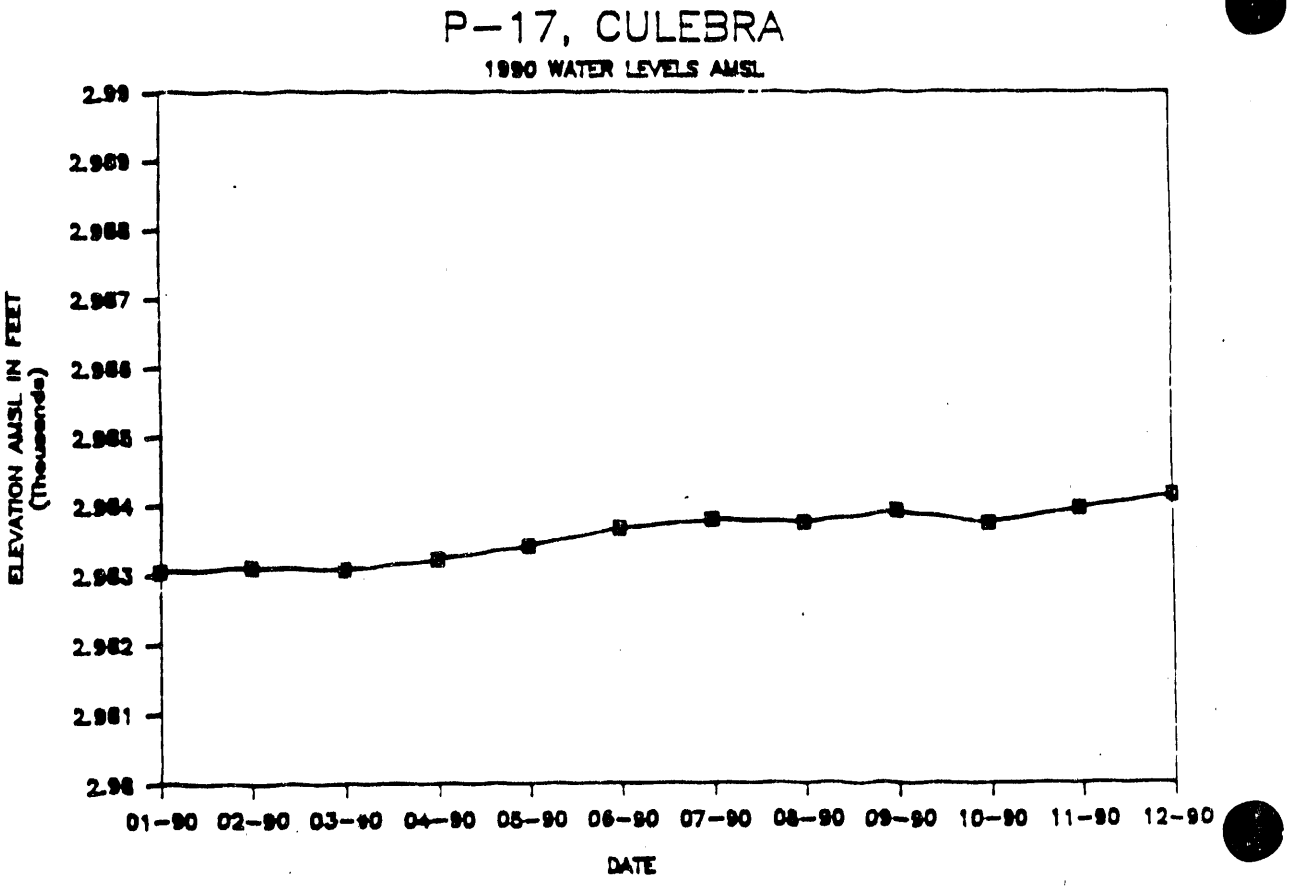
GROUND WATER-LEVELS
CALENDAR YEAR 1990
P-15, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_
P-15	CUL	3311.38	01-90	08:55	302.33	0.00	302.33	92.15	3009.05	917.1
P-15	CUL	3311.38	02-90	09:56	302.13	0.00	302.13	92.09	3009.25	917.2
P-15	CUL	3311.38	03-90	11:17	302.27	0.00	302.27	92.13	3009.11	917.1
P-15	CUL	3311.38	04-90	14:06	301.82	0.00	301.82	91.99	3009.56	917.3
P-15	CUL	3311.38	05-90	11:07	301.88	0.00	301.88	92.01	3009.50	917.3
P-15	CUL	3311.38	06-90	12:50	301.70	0.00	301.70	91.96	3009.68	917.3
P-15	CUL	3311.38	07-90	07:28	301.50	0.00	301.50	91.90	3009.88	917.4
P-15	CUL	3311.38	08-90	07:47	301.51	0.00	301.51	91.90	3009.87	917.4
P-15	CUL	3311.38	09-90	14:15	301.47	0.00	301.47	91.89	3009.91	917.4
P-15	CUL	3311.38	10-90	07:57	301.48	0.00	301.48	91.89	3009.90	917.4
P-15	CUL	3311.38	11-90	11:58	301.42	0.00	301.42	91.87	3009.96	917.4
P-15	CUL	3311.38	12-90	14:05	301.23	0.00	301.23	91.81	3010.15	917.4



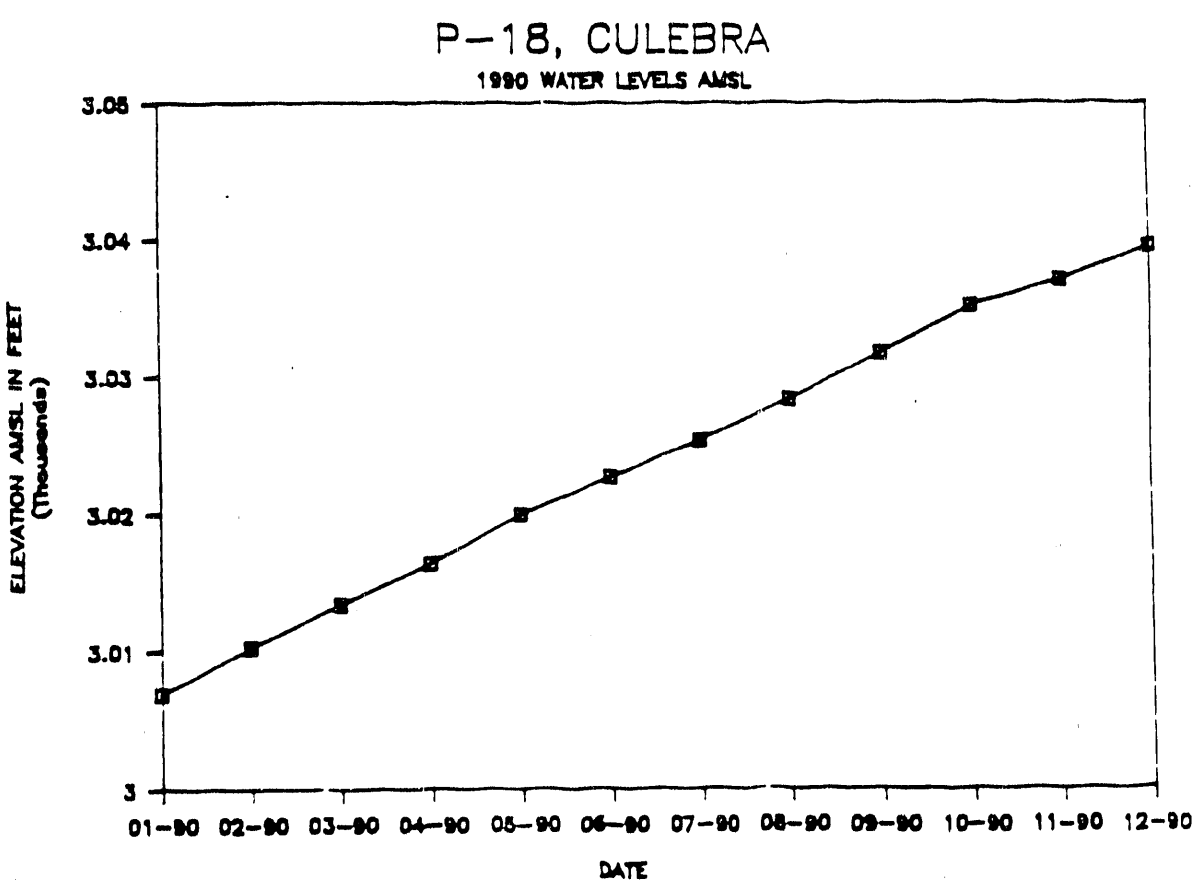
GROUND WATER-LEVELS
CALE AR YEAR 1990
P-17, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL
P-17	CUL	3337.24	01-90	13:45	354.19	0.00	354.19	107.96	2983.05	909.2
P-17	CUL	3337.24	02-90	09:21	354.13	0.00	354.13	107.94	2983.11	[illegible]
P-17	CUL	3337.24	03-90	13:55	354.16	0.00	354.16	107.95	2983.08	909.2
P-17	CUL	3337.24	04-90	11:49	354.01	0.00	354.01	107.90	2983.23	909.2
P-17	CUL	3337.24	05-90	10:11	353.82	0.00	353.82	107.84	2983.42	909.3
P-17	CUL	3337.24	06-90	16:18	353.57	0.00	353.57	107.77	2983.67	909.4
P-17	CUL	3337.24	07-90	08:35	353.44	0.00	353.44	107.73	2983.80	909.46
P-17	CUL	3337.24	08-90	09:13	353.48	0.00	353.48	107.74	2983.76	909.45
P-17	CUL	3337.24	09-90	06:20	353.32	0.00	353.32	107.69	2983.92	909.5
P-17	CUL	3337.24	10-90	06:50	353.50	0.00	353.50	107.75	2983.74	909.4
P-17	CUL	3337.24	11-90	16:06	353.28	0.00	353.28	107.68	2983.96	909.5
P-17	CUL	3337.24	12-90	06:30	353.08	0.00	353.08	107.62	2984.16	909.5



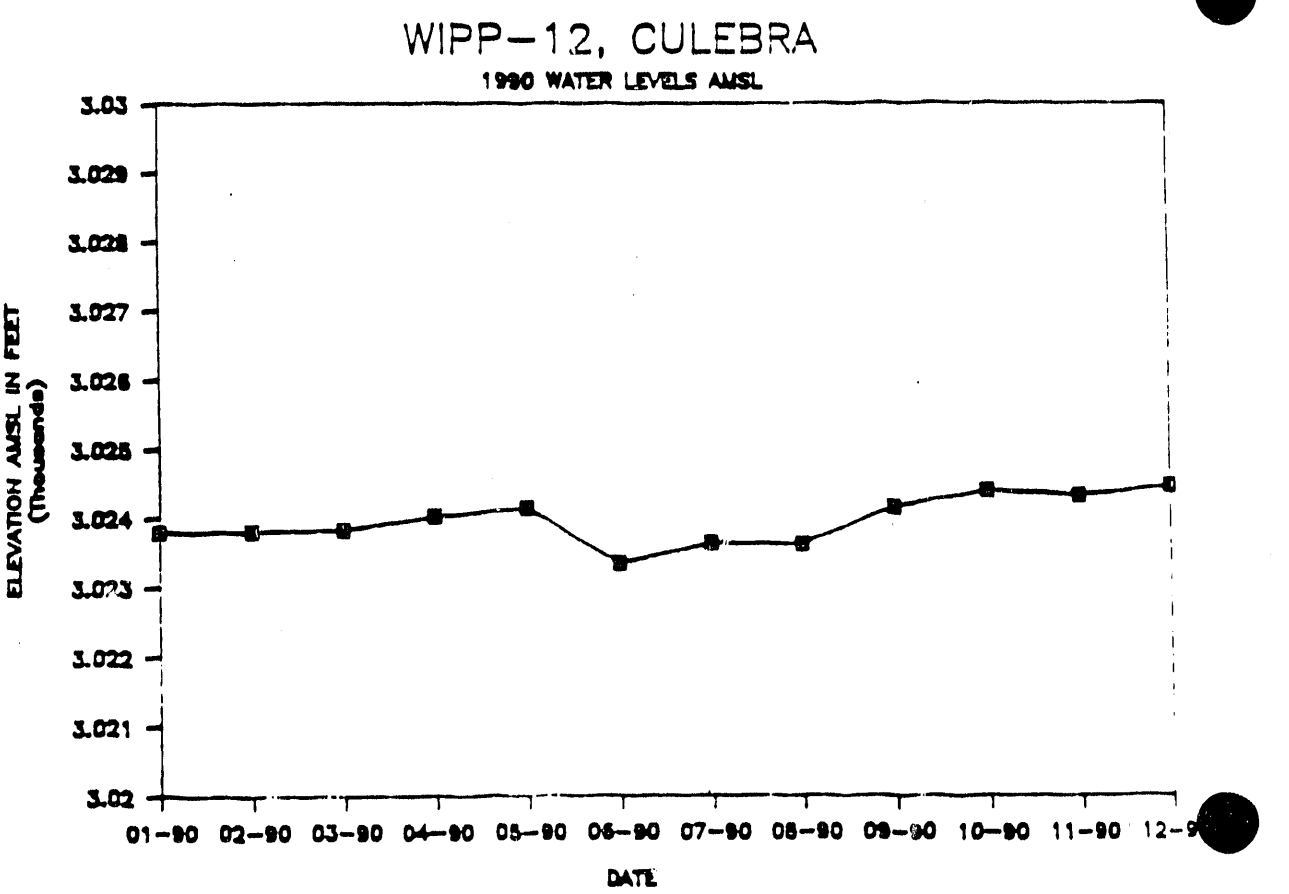
GROUND WATER-LEVELS
CALENDAR YEAR 1990
P-18, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_
P-18	CUL	3478.42	01-90	12:15	472.18	0.68	471.50	143.71	3006.92	916.5
P-18	CUL	3478.42	02-90	08:29	468.82	0.68	468.14	142.69	3010.28	917.5
P-18	CUL	3478.42	03-90	15:04	465.71	0.68	465.03	141.74	3013.39	918.4
P-18	CUL	3478.42	04-90	10:01	462.75	0.68	462.07	140.84	3016.35	919.3
P-18	CUL	3478.42	05-90	09:00	459.13	0.68	458.45	139.74	3019.97	920.4
P-18	CUL	3478.42	06-90	15:07	456.42	0.68	455.74	138.91	3022.68	921.3
P-18	CUL	3478.42	07-90	09:35	453.74	0.68	453.06	138.09	3025.36	922.1
P-18	CUL	3478.42	08-90	09:42	450.77	0.68	450.09	137.19	3028.33	923.03
P-18	CUL	3478.42	09-90	16:30	447.42	0.68	446.74	136.17	3031.68	924.06
P-18	CUL	3478.42	10-90	10:32	444.00	0.68	443.32	135.12	3035.10	925.1
P-18	CUL	3478.42	11-90	15:45	442.07	0.68	441.39	134.54	3037.03	925.6
P-18	CUL	3478.42	12-90	12:50	439.67	0.68	438.99	133.80	3039.43	926.42



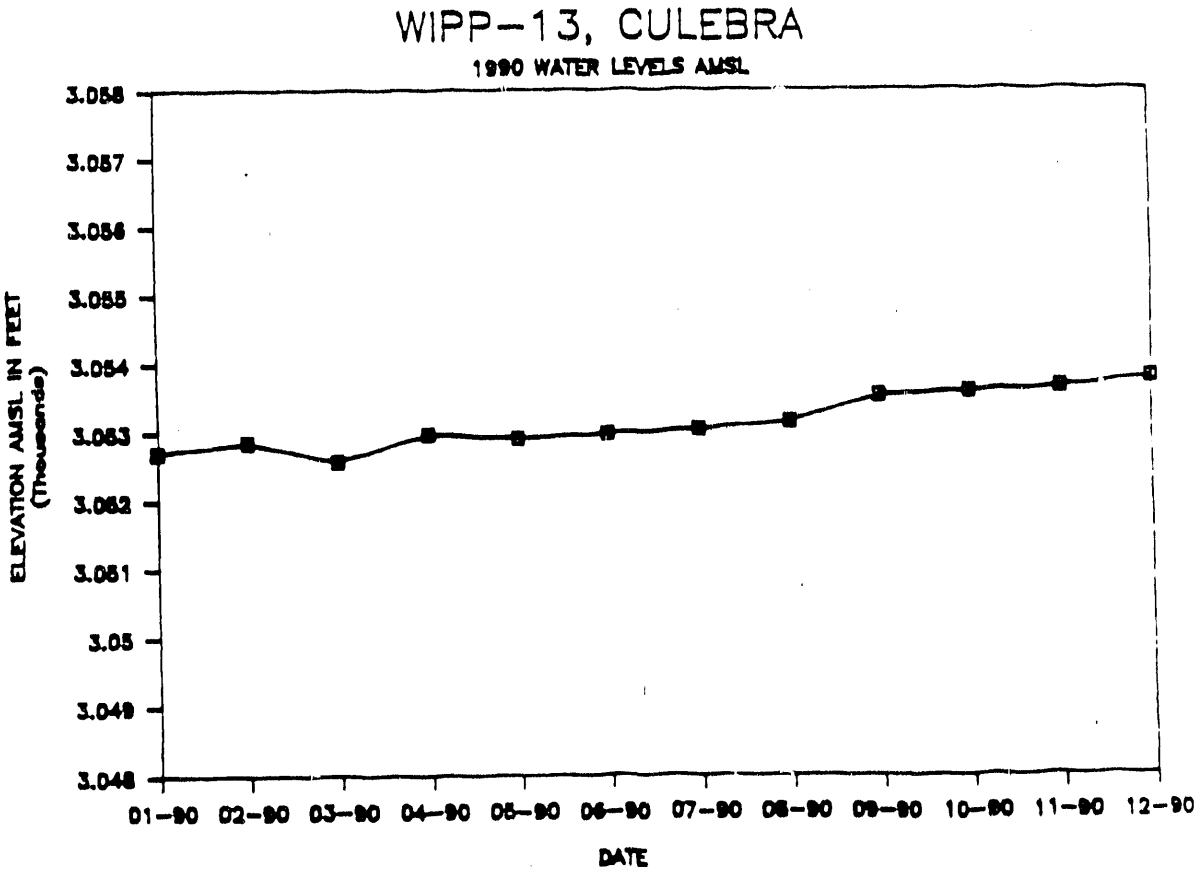
GROUND WATER-LEVELS
CALENDAR YEAR 1990
WIPP-12, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_M
WIPP-12	CUL	3472.06	01-90	13:33	448.27	0.00	448.27	136.63	3023.79	921
WIPP-12	CUL	3472.06	02-90	13:33	448.25	0.00	448.25	136.63	3023.81	921
WIPP-12	CUL	3472.06	03-90	15:40	448.23	0.00	448.23	136.62	3023.83	921
WIPP-12	CUL	3472.06	04-90	16:09	448.03	0.00	448.03	136.56	3024.03	921.
WIPP-12	CUL	3472.06	05-90	14:17	447.90	0.00	447.90	136.52	3024.16	921.
WIPP-12	CUL	3472.06	06-90	07:53	448.72	0.00	448.72	136.77	3023.34	921.
WIPP-12	CUL	3472.06	07-90	14:15	448.42	0.00	448.42	136.68	3023.64	921.
WIPP-12	CUL	3472.06	08-90	12:55	448.44	0.00	448.44	136.68	3023.62	921.
WIPP-12	CUL	3472.06	09-90	13:15	447.90	0.00	447.90	136.52	3024.16	921.
WIPP-12	CUL	3472.06	10-90	11:25	447.67	0.00	447.67	136.45	3024.39	921.
WIPP-12	CUL	3472.06	11-90	11:20	447.74	0.00	447.74	136.47	3024.32	921.
WIPP-12	CUL	3472.06	12-90	10:08	447.60	0.00	447.60	136.43	3024.46	921.



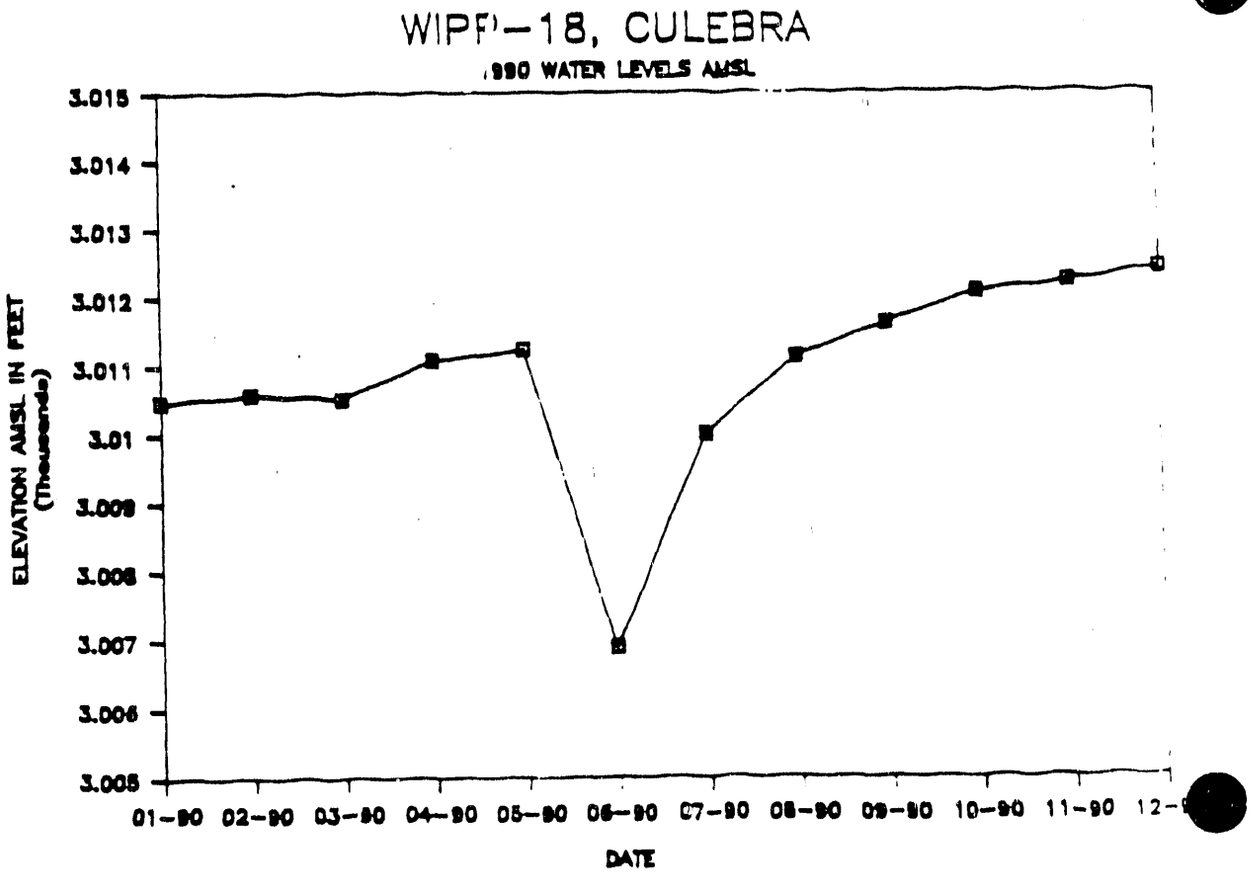
GROUND WATER-LEVELS
CALANDER YEAR 1990
WIPP-13, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_
WIPP-13	CUL	3405.71	01-90	10:58	353.00	0.00	353.00	107.59	3052.71	930.4
WIPP-13	CUL	3405.71	02-90	14:56	352.85	0.00	352.85	107.55	3052.86	930.5
WIPP-13	CUL	3405.71	03-90	08:40	353.13	0.00	353.13	107.63	3052.58	930.43
WIPP-13	CUL	3405.71	04-90	12:33	352.73	0.00	352.73	107.51	3052.98	930.55
WIPP-13	CUL	3405.71	05-90	11:38	352.79	0.00	352.79	107.53	3052.92	930.53
WIPP-13	CUL	3405.71	06-90	09:36	352.72	0.00	352.72	107.51	3052.99	930.55
WIPP-13	CUL	3405.71	07-90	09:45	352.66	0.00	352.66	107.49	3053.05	930.57
WIPP-13	CUL	3405.71	08-90	11:57	352.56	0.00	352.56	107.46	3053.15	930.60
WIPP-13	CUL	3405.71	09-90	16:25	352.18	0.00	352.18	107.34	3053.53	930.72
WIPP-13	CUL	3405.71	10-90	15:30	352.12	0.00	352.12	107.33	3053.59	930.73
WIPP-13	CUL	3405.71	11-90	16:10	352.07	0.00	352.07	107.31	3053.64	930.75
WIPP-13	CUL	3405.71	12-90	14:43	351.92	0.00	351.92	107.27	3053.79	930.80



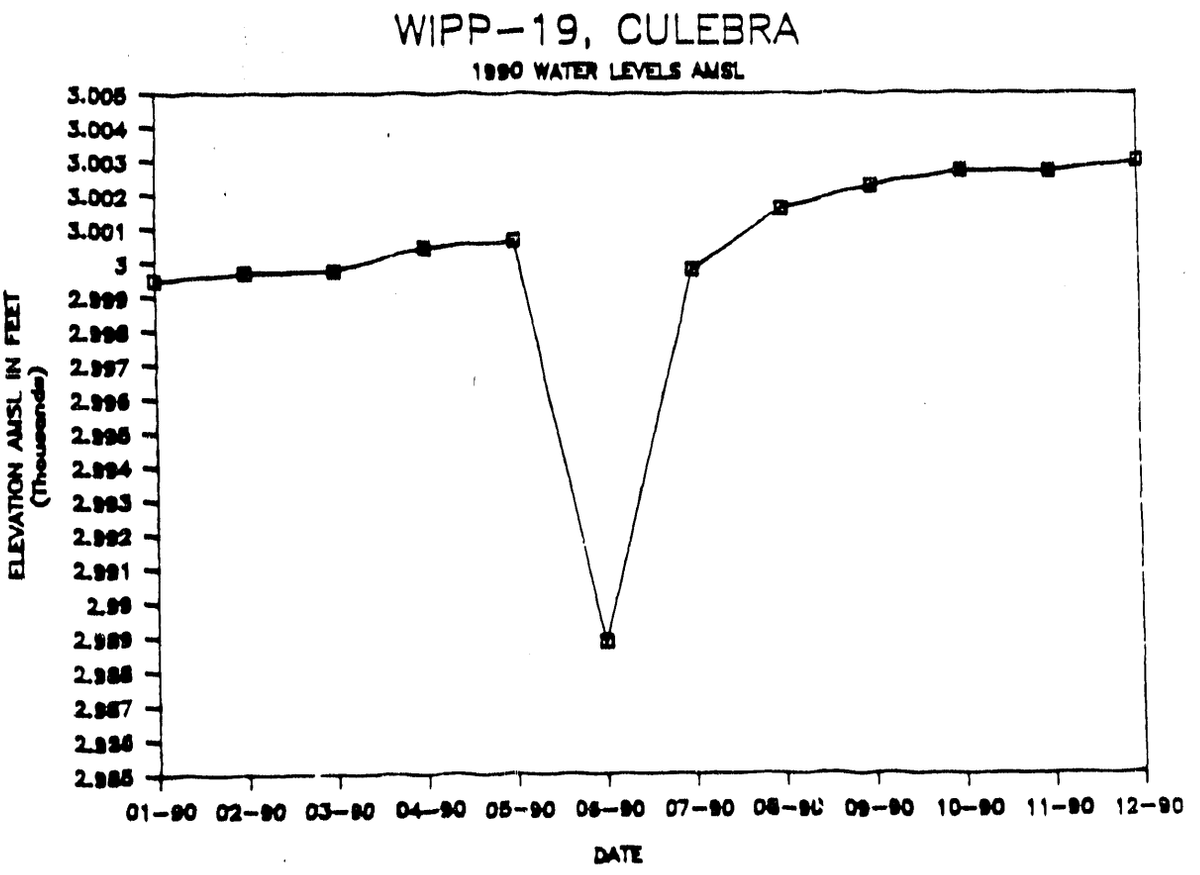
GROUND WATER-LEVELS
CALENDAR YEAR 1990
WIPP-18, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MS.
WIPP-18	CUL	3458.76	01-90	13:22	448.27	0.00	448.27	136.63	3010.49	917.
WIPP-18	CUL	3458.76	02-90	13:20	448.17	0.00	448.17	136.60	3010.59	917.
WIPP-18	CUL	3458.76	03-90	15:30	448.22	0.00	448.22	136.62	3010.54	917.
WIPP-18	CUL	3458.76	04-90	16:00	447.67	0.00	447.67	136.45	3011.09	917.
WIPP-18	CUL	3458.76	05-90	14:06	447.51	0.00	447.51	136.40	3011.25	917.
WIPP-18	CUL	3458.76	06-90	07:41	451.88	0.00	451.88	137.73	3006.88	916.
WIPP-18	CUL	3458.76	07-90	14:00	448.75	0.00	448.75	136.78	3010.01	91
WIPP-18	CUL	3458.76	08-90	12:45	447.63	0.00	447.63	136.45	3011.13	9
WIPP-18	CUL	3458.76	09-90	13:08	447.14	0.00	447.14	136.29	3011.62	9
WIPP-18	CUL	3458.76	10-90	11:15	446.69	0.00	446.69	136.15	3012.07	9
WIPP-18	CUL	3458.76	11-90	11:11	446.56	0.00	446.56	136.11	3012.20	9
WIPP-18	CUL	3458.76	12-90	10:00	446.35	0.00	446.35	136.05	3012.41	918.



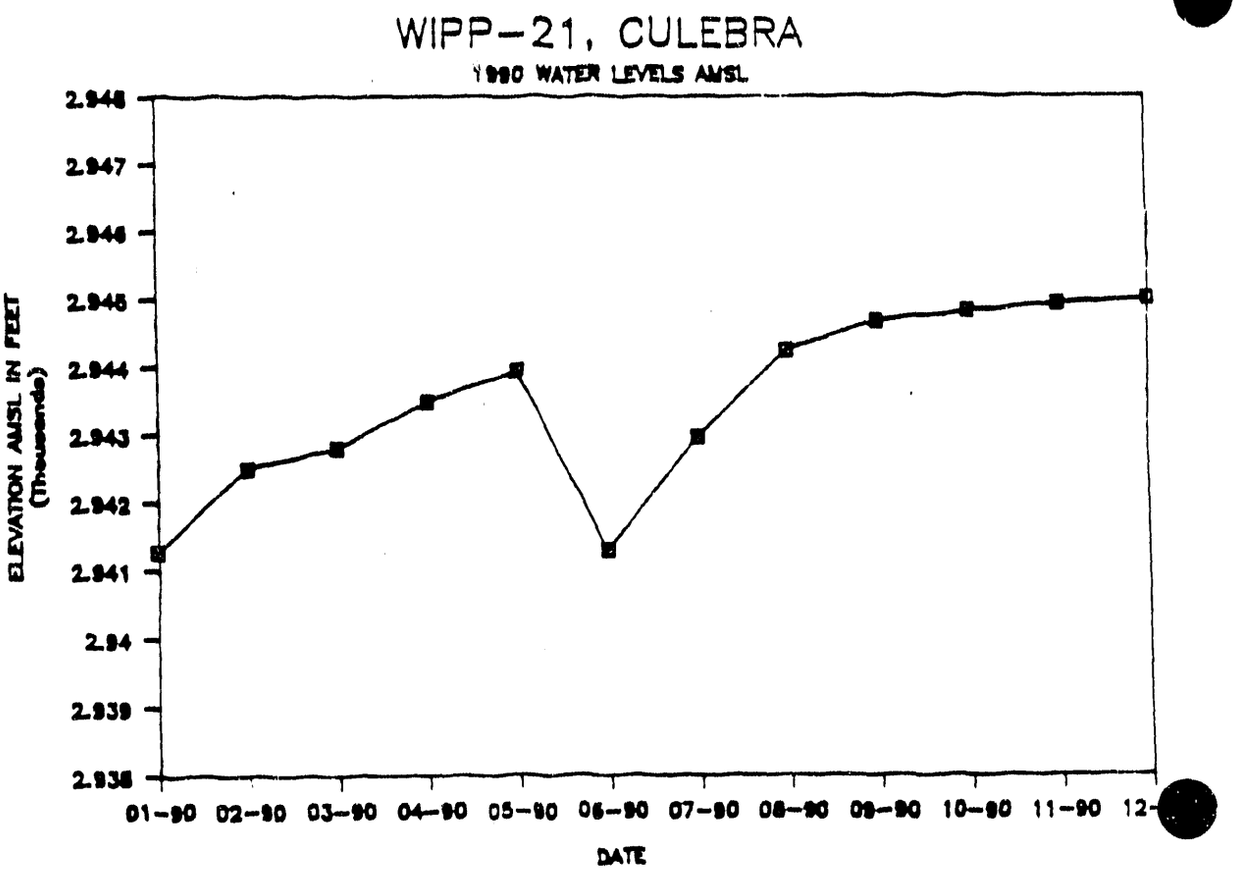
GROUND WATER-LEVELS
CALENDAR YEAR 1990
WIPP-19, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_M
WIPP-19	CUL	3435.14	01-90	13:12	435.65	0.00	435.65	132.79	2999.49	914.24
WIPP-19	CUL	3435.14	02-90	13:12	435.42	0.00	435.42	132.72	2999.72	914.31
WIPP-19	CUL	3435.14	03-90	15:22	435.37	0.00	435.37	132.70	2999.77	914.33
WIPP-19	CUL	3435.14	04-90	15:51	434.67	0.00	434.67	132.49	3000.47	914.54
WIPP-19	CUL	3435.14	05-90	13:53	434.48	0.00	434.48	132.43	3000.66	914.60
WIPP-19	CUL	3435.14	06-90	07:25	446.28	0.00	446.28	136.03	2988.86	911.00
WIPP-19	CUL	3435.14	07-90	13:50	435.33	0.00	435.33	132.69	2999.81	914.34
WIPP-19	CUL	3435.14	08-90	12:34	433.54	0.00	433.54	132.14	3001.60	914.89
WIPP-19	CUL	3435.14	09-90	13:01	432.86	0.00	432.86	131.94	3002.28	915.09
WIPP-19	CUL	3435.14	10-90	11:04	432.44	0.00	432.44	131.81	3002.70	915.22
WIPP-19	CUL	3435.14	11-90	11:05	432.44	0.00	432.44	131.81	3002.70	915.22
WIPP-19	CUL	3435.14	12-90	09:45	432.14	0.00	432.14	131.72	3003.00	915.31



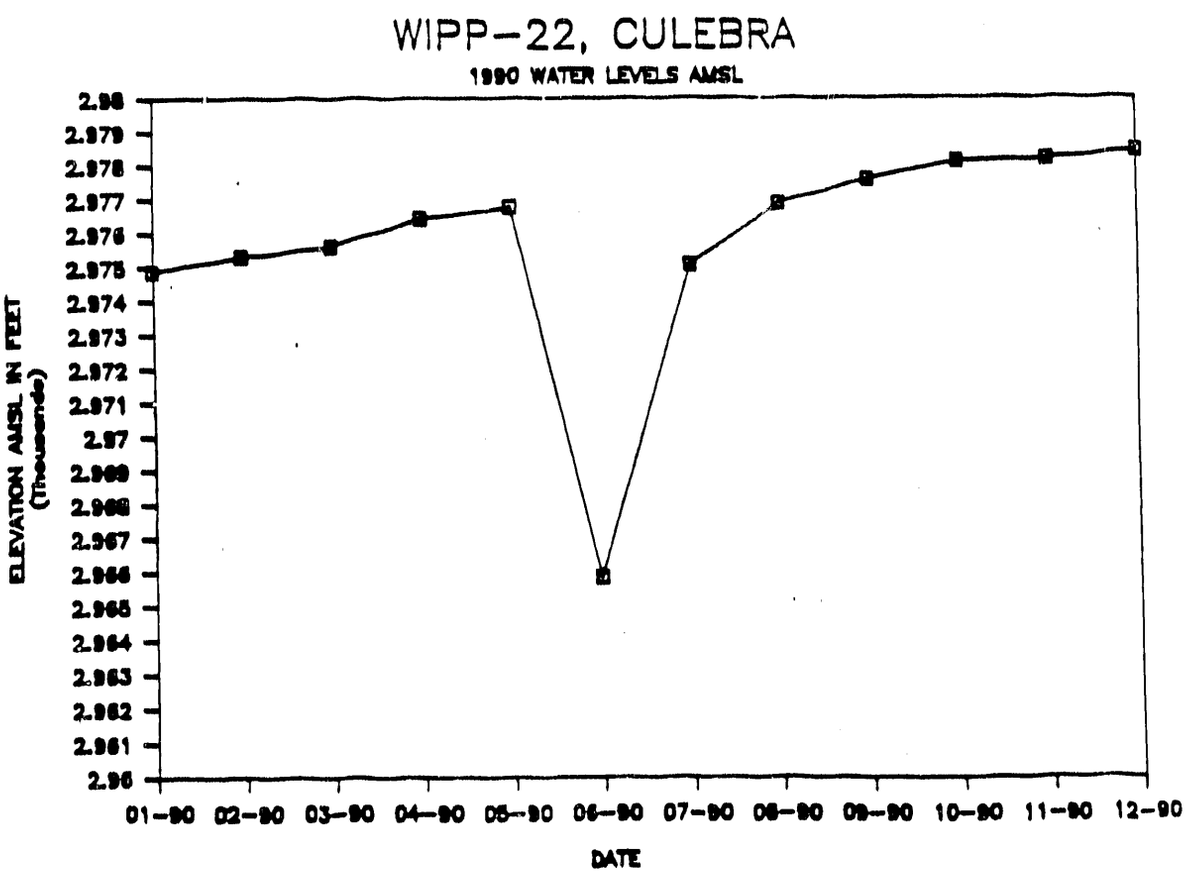
GROUND WATER-LEVELS
CALENDAR YEAR 1990
WIPP-21, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MS
WIPP-21	CUL	3418.96	01-90	12:50	478.31	0.62	477.69	145.60	2941.27	896.
WIPP-21	CUL	3418.96	02-90	12:50	477.07	0.62	476.45	145.22	2942.51	896.
WIPP-21	CUL	3418.96	03-90	15:08	476.77	0.62	476.15	145.13	2942.81	896
WIPP-21	CUL	3418.96	04-90	15:34	476.08	0.62	475.46	144.92	2943.50	897
WIPP-21	CUL	3418.96	05-90	13:32	475.62	0.62	475.00	144.78	2943.96	897.
WIPP-21	CUL	3418.96	06-90	06:58	478.28	0.62	477.66	145.59	2941.30	896.
WIPP-21	CUL	3418.96	07-90	13:00	476.61	0.62	475.99	145.08	2942.97	897.
WIPP-21	CUL	3418.96	08-90	12:12	475.33	0.62	474.71	144.69	2944.25	89
WIPP-21	CUL	3418.96	09-90	12:35	474.90	0.62	474.28	144.56	2944.68	8
WIPP-21	CUL	3418.96	10-90	10:44	474.77	0.62	474.15	144.52	2944.81	8
WIPP-21	CUL	3418.96	11-90	10:51	474.65	0.62	474.03	144.48	2944.93	89
WIPP-21	CUL	3418.96	12-90	09:00	474.58	0.62	473.96	144.46	2945.00	897.



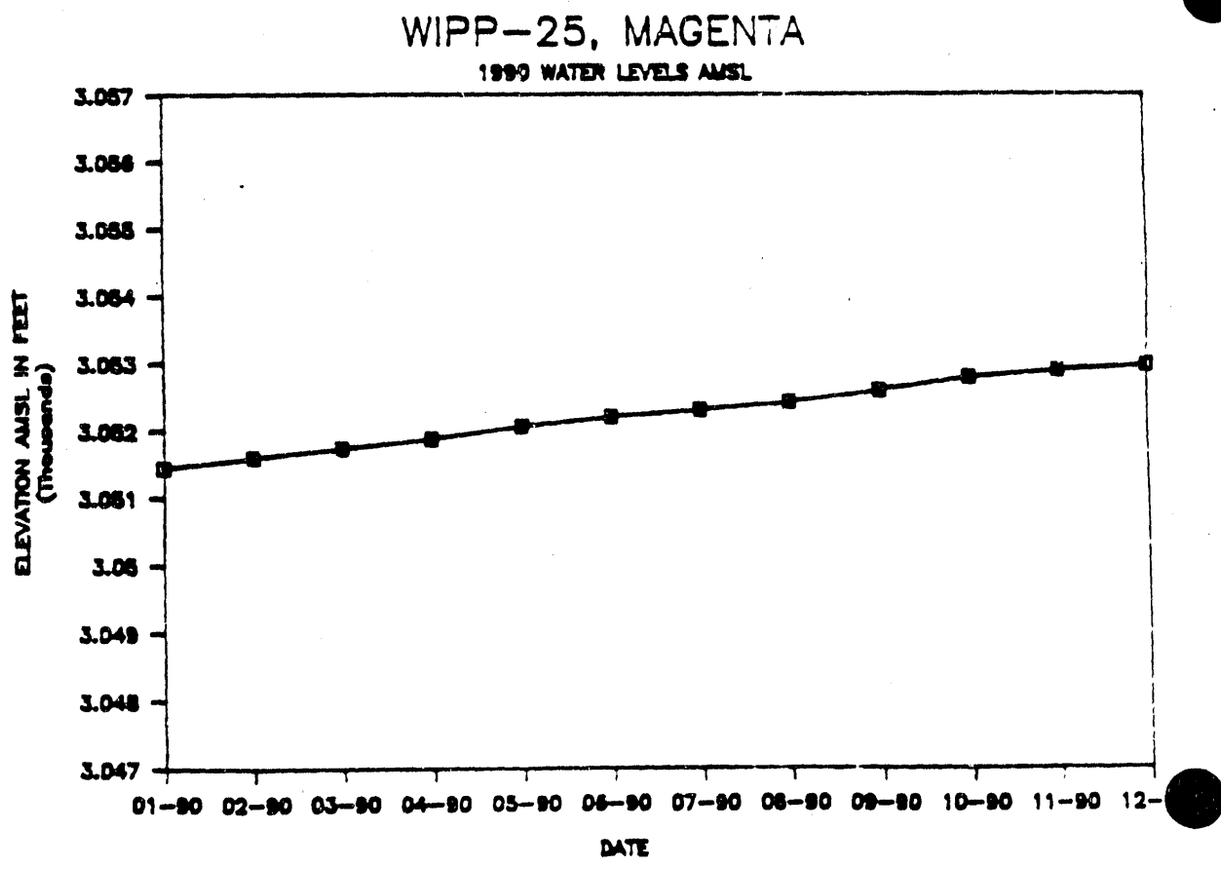
GROUND WATER-LEVELS
CALENDAR YEAR 1990
WIPP-22, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL
WIPP-22	CUL	3428.12	01-90	12:25	453.23	0.00	453.23	138.14	2974.89	906.7
WIPP-22	CUL	3428.12	02-90	13:03	452.79	0.00	452.79	138.01	2975.33	906.8
WIPP-22	CUL	3428.12	03-90	15:15	452.48	0.00	452.48	137.92	2975.64	906.9
WIPP-22	CUL	3428.12	04-90	15:41	451.68	0.00	451.68	137.67	2976.44	907.2
WIPP-22	CUL	3428.12	05-90	13:44	451.33	0.00	451.33	137.57	2976.79	907.3
WIPP-22	CUL	3428.12	06-90	07:15	462.27	0.00	462.27	140.90	2965.85	903.9
WIPP-22	CUL	3428.12	07-90	13:20	453.04	0.00	453.04	138.09	2975.08	906.8
WIPP-22	CUL	3428.12	08-90	12:20	451.24	0.00	451.24	137.54	2976.88	907.3
WIPP-22	CUL	3428.12	09-90	12:45	450.53	0.00	450.53	137.32	2977.59	907.5
WIPP-22	CUL	3428.12	10-90	10:55	450.00	0.00	450.00	137.16	2978.12	907.7
WIPP-22	CUL	3428.12	11-90	10:59	449.93	0.00	449.93	137.14	2978.19	907.7
WIPP-22	CUL	3428.12	12-90	09:17	449.67	0.00	449.67	137.06	2978.45	907.8



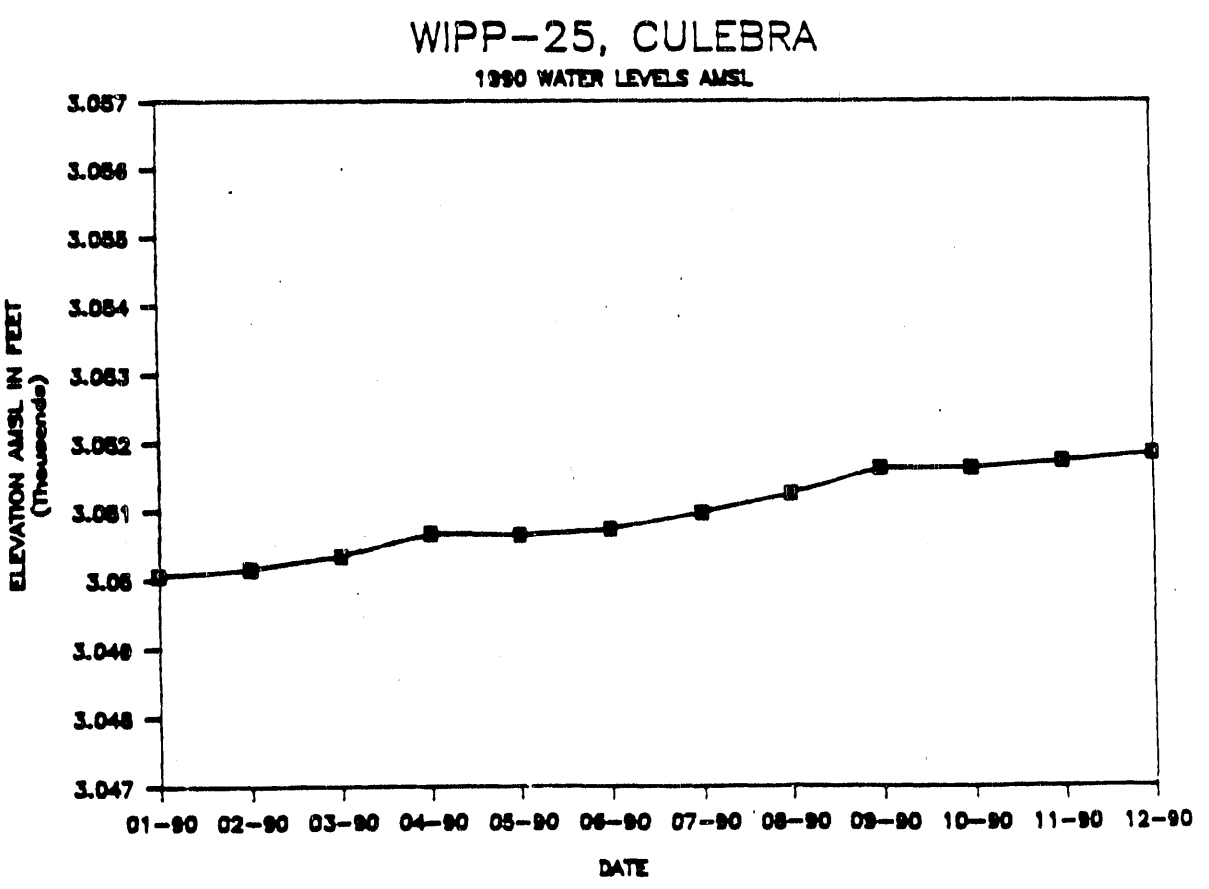
GROUND WATER-LEVELS
CALENDAR YEAR 1990
WIPP-25, MAGENTA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL
WIPP-25 (ANNULUS)	MAG	3214.39	01-90	13:15	162.94	0.00	162.94	49.66	3051.45	930.(
WIPP-25 (ANNULUS)	MAG	3214.39	02-90	11:13	162.79	0.00	162.79	49.62	3051.60	930.'
WIPP-25 (ANNULUS)	MAG	3214.39	03-90	12:10	162.65	0.00	162.65	49.58	3051.74	930.'
WIPP-25 (ANNULUS)	MAG	3214.39	04-90	09:55	162.51	0.00	162.51	49.53	3051.88	930.2
WIPP-25 (ANNULUS)	MAG	3214.39	05-90	10:06	162.32	0.00	162.32	49.48	3052.07	930.2
WIPP-25 (ANNULUS)	MAG	3214.39	06-90	09:14	162.18	0.00	162.18	49.43	3052.21	930.3
WIPP-25 (ANNULUS)	MAG	3214.39	07-90	12:55	162.08	0.00	162.08	49.40	3052.31	930.3
WIPP-25 (ANNULUS)	MAG	3214.39	08-90	13:20	161.97	0.00	161.97	49.37	3052.42	930.3
WIPP-25 (ANNULUS)	MAG	3214.39	09-90	17:48	161.80	0.00	161.80	49.32	3052.59	930.4
WIPP-25 (ANNULUS)	MAG	3214.39	10-90	07:06	161.61	0.00	161.61	49.26	3052.78	930.-
WIPP-25 (ANNULUS)	MAG	3214.39	11-90	16:50	161.50	0.00	161.50	49.23	3052.89	930.5
WIPP-25 (ANNULUS)	MAG	3214.39	12-90	16:05	161.43	0.00	161.43	49.20	3052.96	930..



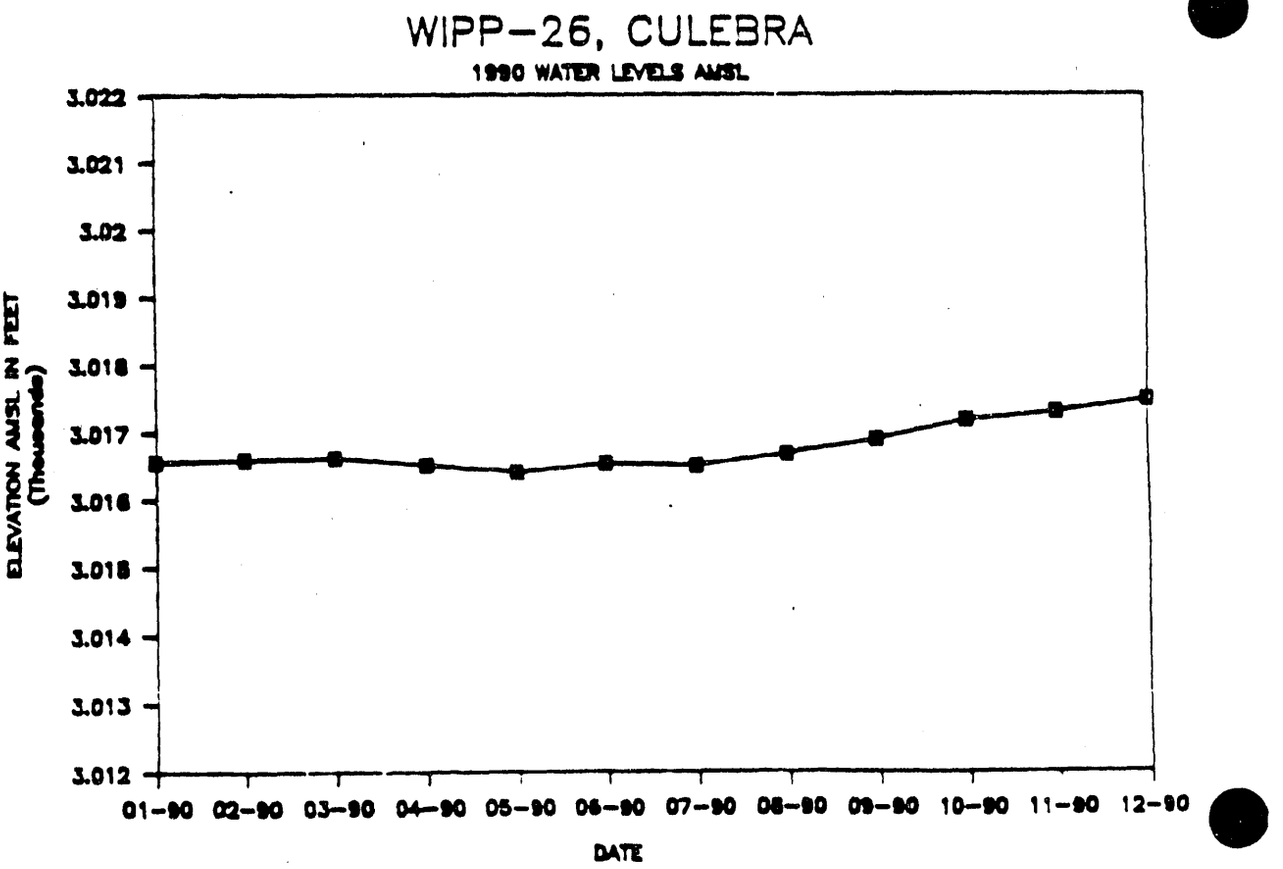
GROUND WATER-LEVELS
CALENDAR YEAR 1990
WIPP-25, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_M
WIPP-25 (PIP)	CUL	3214.39	01-90	13:10	164.75	0.42	164.33	50.09	3050.06	929.66
WIPP-25 (PIP)	CUL	3214.39	02-90	11:05	164.65	0.42	164.23	50.06	3050.16	929.69
WIPP-25 (PIP)	CUL	3214.39	03-90	12:05	164.46	0.42	164.04	50.00	3050.35	929.75
WIPP-25 (PIP)	CUL	3214.39	04-90	09:51	164.13	0.42	163.71	49.90	3050.68	929.85
WIPP-25 (PIP)	CUL	3214.39	05-90	10:03	164.15	0.42	163.73	49.90	3050.66	929.84
WIPP-25 (PIP)	CUL	3214.39	06-90	09:11	164.07	0.42	163.65	49.88	3050.74	929.87
WIPP-25 (PIP)	CUL	3214.39	07-90	12:50	163.83	0.42	163.41	49.81	3050.98	929.94
WIPP-25 (PIP)	CUL	3214.39	08-90	13:18	163.55	0.42	163.13	49.72	3051.26	930.02
WIPP-25 (PIP)	CUL	3214.39	09-90	17:45	163.18	0.42	162.76	49.61	3051.63	930.14
WIPP-25 (PIP)	CUL	3214.39	10-90	07:00	163.18	0.42	162.76	49.61	3051.63	930.14
WIPP-25 (PIP)	CUL	3214.39	11-90	16:45	163.08	0.42	162.66	49.58	3051.73	930.17
WIPP-25 (PIP)	CUL	3214.39	12-90	16:00	162.97	0.42	162.55	49.55	3051.84	930.20



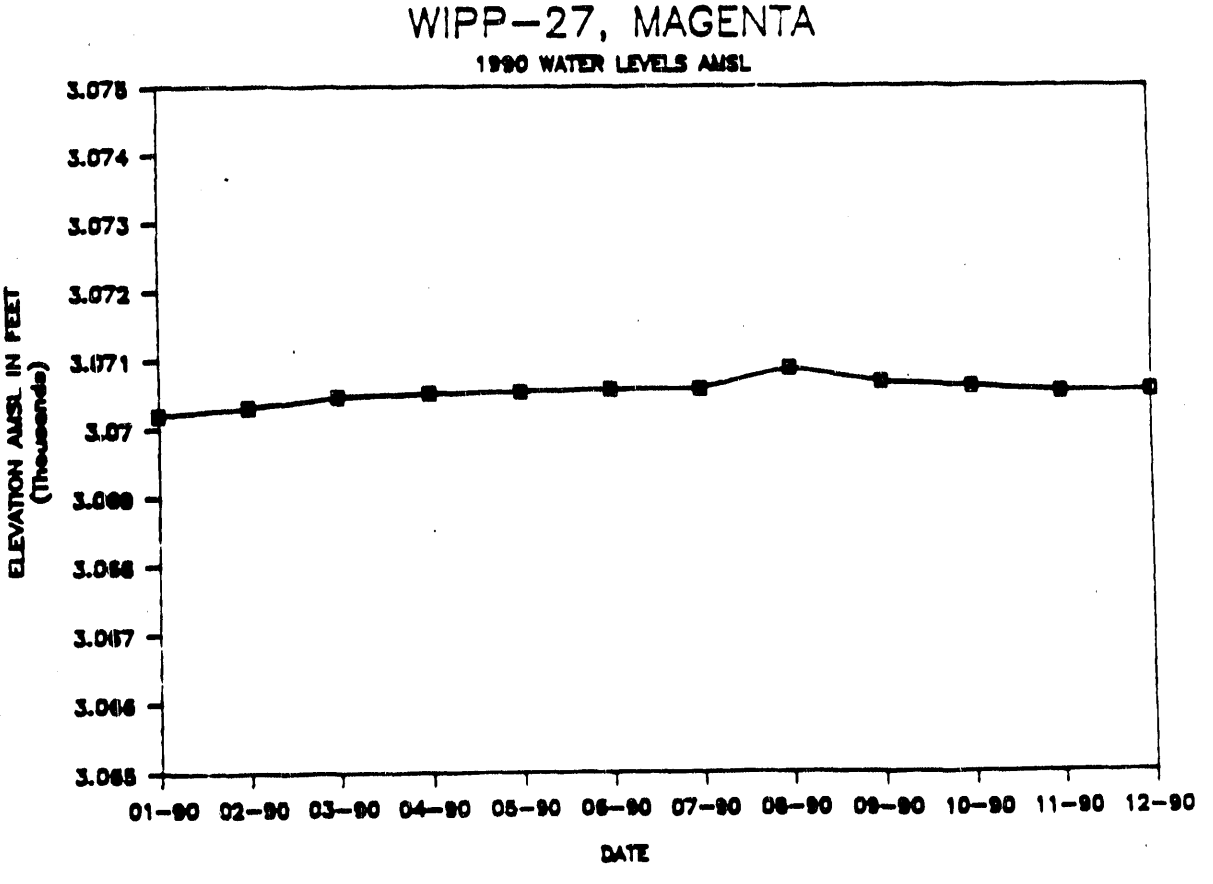
GROUND WATER-LEVELS
CALENDAR YEAR 1990
WIPP-26, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_
WIPP-26	CUL	3153.20	01-90	08:04	136.63	0.00	136.63	41.64	3016.57	91
WIPP-26	CUL	3153.20	02-90	15:15	136.60	0.00	136.60	41.64	3016.60	91
WIPP-26	CUL	3153.20	03-90	07:15	136.57	0.00	136.57	41.63	3016.63	91
WIPP-26	CUL	3153.20	04-90	06:48	136.68	0.00	136.68	41.66	3016.52	91
WIPP-26	CUL	3153.20	05-90	06:22	136.78	0.00	136.78	41.69	3016.42	91
WIPP-26	CUL	3153.20	06-90	14:32	136.65	0.00	136.65	41.65	3016.55	91
WIPP-26	CUL	3153.20	07-90	06:30	136.69	0.00	136.69	41.66	3016.51	9
WIPP-26	CUL	3153.20	08-90	06:40	136.51	0.00	136.51	41.61	3016.69	
WIPP-26	CUL	3153.20	09-90	11:05	136.30	0.00	136.30	41.54	3016.90	
WIPP-26	CUL	3153.20	10-90	07:34	136.02	0.00	136.02	41.46	3017.18	
WIPP-26	CUL	3153.20	11-90	07:36	135.90	0.00	135.90	41.42	3017.30	9
WIPP-26	CUL	3153.20	12-90	06:52	135.72	0.00	135.72	41.37	3017.48	919.



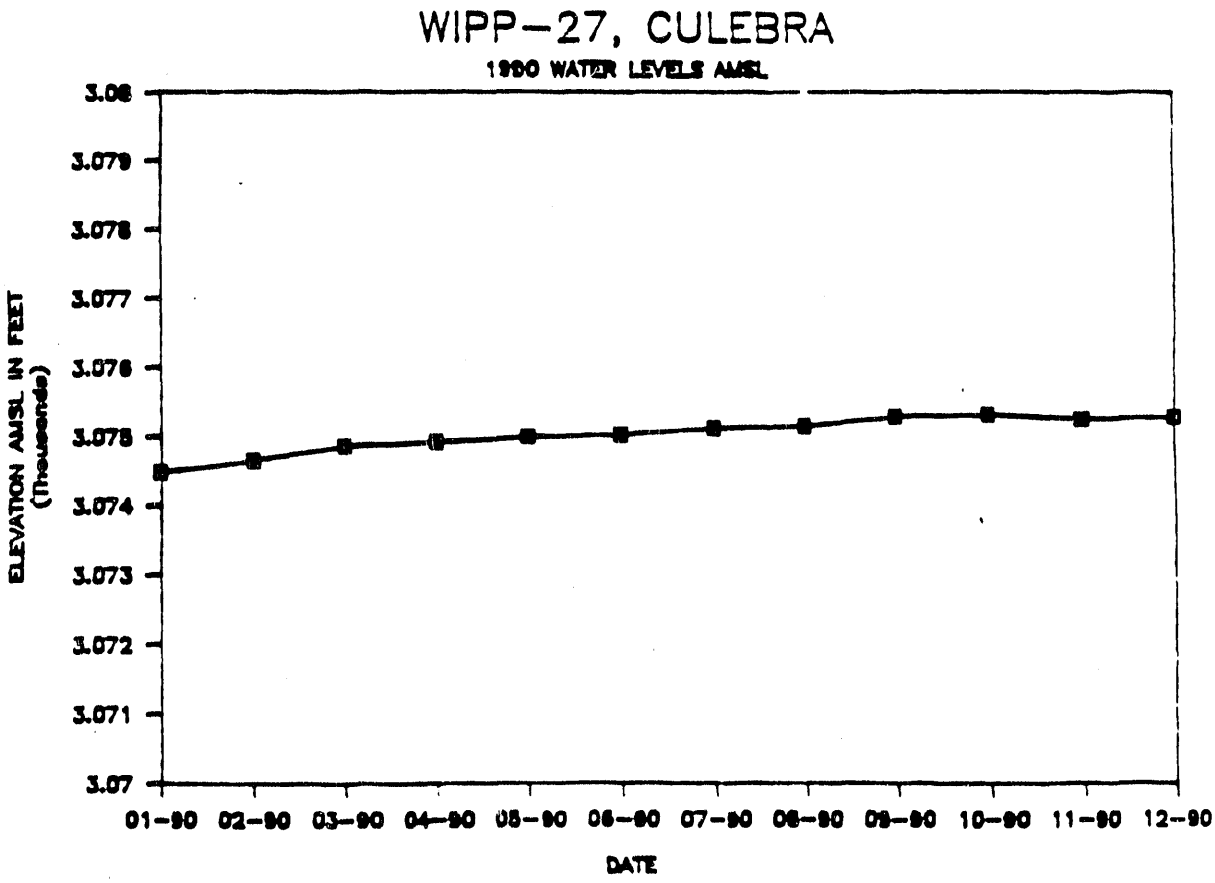
GROUND WATER-LEVELS
CALENDAR YEAR 1990
WIPP-27, MAGENTA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_
WIPP-27 (ANNULUS)	MAG	3178.98	01-90	07:50	108.78	0.00	108.78	33.16	3070.20	935.80
WIPP-27 (ANNULUS)	MAG	3178.98	02-90	07:26	108.66	0.00	108.66	33.12	3070.32	935.83
WIPP-27 (ANNULUS)	MAG	3178.98	03-90	06:40	108.51	0.00	108.51	33.07	3070.47	935.88
WIPP-27 (ANNULUS)	MAG	3178.98	04-90	06:26	108.46	0.00	108.46	33.06	3070.52	935.89
WIPP-27 (ANNULUS)	MAG	3178.98	05-90	05:55	108.43	0.00	108.43	33.05	3070.55	935.90
WIPP-27 (ANNULUS)	MAG	3178.98	06-90	06:16	108.40	0.00	108.40	33.04	3070.58	935.91
WIPP-27 (ANNULUS)	MAG	3178.98	07-90	12:05	108.40	0.00	108.40	33.04	3070.58	935.91
WIPP-27 (ANNULUS)	MAG	3178.98	08-90	06:13	108.09	0.00	108.09	32.95	3070.89	936.01
WIPP-27 (ANNULUS)	MAG	3178.98	09-90	06:36	108.31	0.00	108.31	33.01	3070.67	935.94
WIPP-27 (ANNULUS)	MAG	3178.98	10-90	06:55	108.38	0.00	108.38	33.03	3070.60	935.92
WIPP-27 (ANNULUS)	MAG	3178.98	11-90	06:54	108.45	0.00	108.45	33.06	3070.53	935.90
WIPP-27 (ANNULUS)	MAG	3178.98	12-90	06:40	108.44	0.00	108.44	33.05	3070.54	935.90



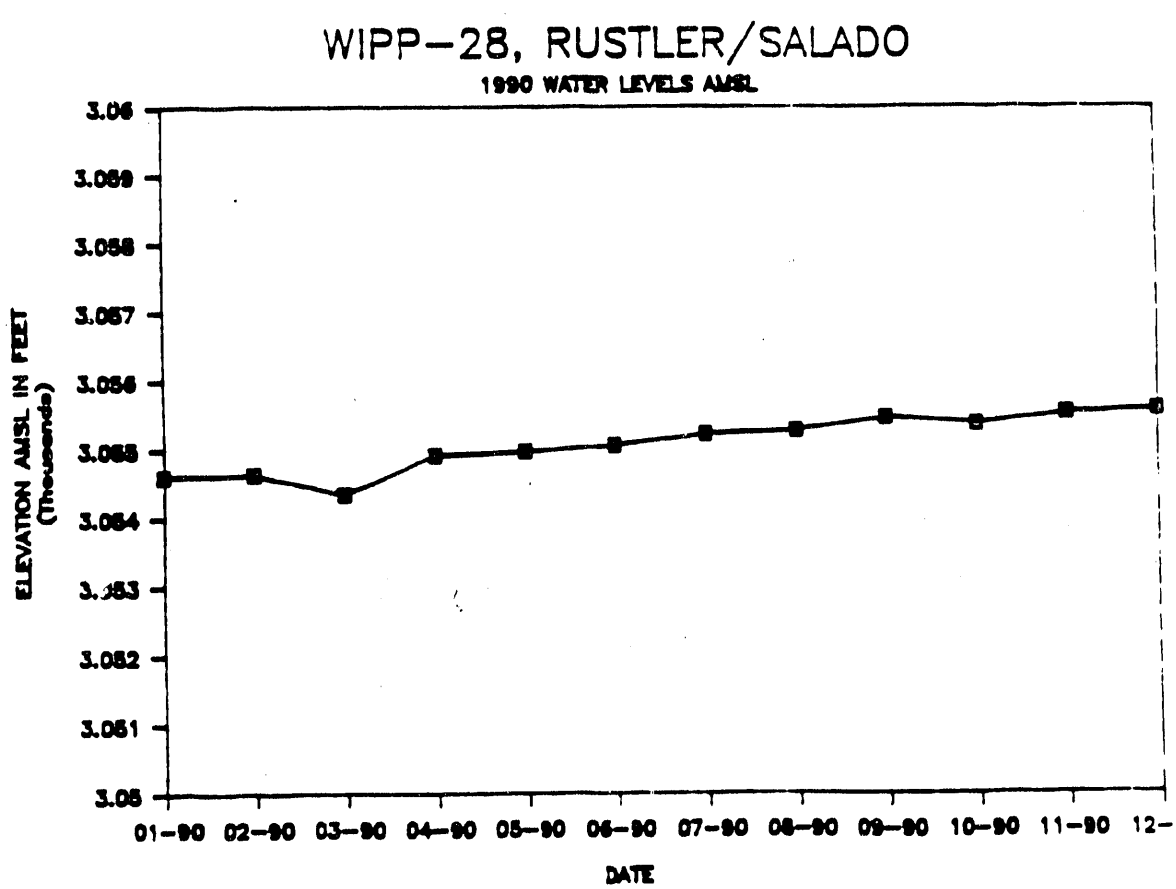
GROUND WATER-LEVELS
CALENDAR YEAR 1990
WIPP-27, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL
WIPP-27 (PIP)	CUL	3178.98	01-90	07:40	104.91	0.42	104.49	31.85	3074.49	937.1
WIPP-27 (PIP)	CUL	3178.98	02-90	07:16	104.74	0.42	104.32	31.80	3074.66	937.1
WIPP-27 (PIP)	CUL	3178.98	03-90	06:35	104.53	0.42	104.11	31.73	3074.87	937.22
WIPP-27 (PIP)	CUL	3178.98	04-90	06:20	104.47	0.42	104.05	31.71	3074.93	937.24
WIPP-27 (PIP)	CUL	3178.98	05-90	05:53	104.39	0.42	103.97	31.69	3075.01	937.2
WIPP-27 (PIP)	CUL	3178.98	06-90	06:00	104.36	0.42	103.94	31.68	3075.04	937.2
WIPP-27 (PIP)	CUL	3178.98	07-90	12:00	104.27	0.42	103.85	31.65	3075.13	937.30
WIPP-27 (PIP)	CUL	3178.98	08-90	06:10	104.24	0.42	103.82	31.64	3075.16	937.3
WIPP-27 (PIP)	CUL	3178.98	09-90	06:30	104.10	0.42	103.68	31.60	3075.30	937.3
WIPP-27 (PIP)	CUL	3178.98	10-90	06:50	104.08	0.42	103.66	31.60	3075.32	937.3
WIPP-27 (PIP)	CUL	3178.98	11-90	06:50	104.14	0.42	103.72	31.61	3075.26	937.34
WIPP-27 (PIP)	CUL	3178.98	12-90	06:35	104.11	0.42	103.69	31.60	3075.29	937.3



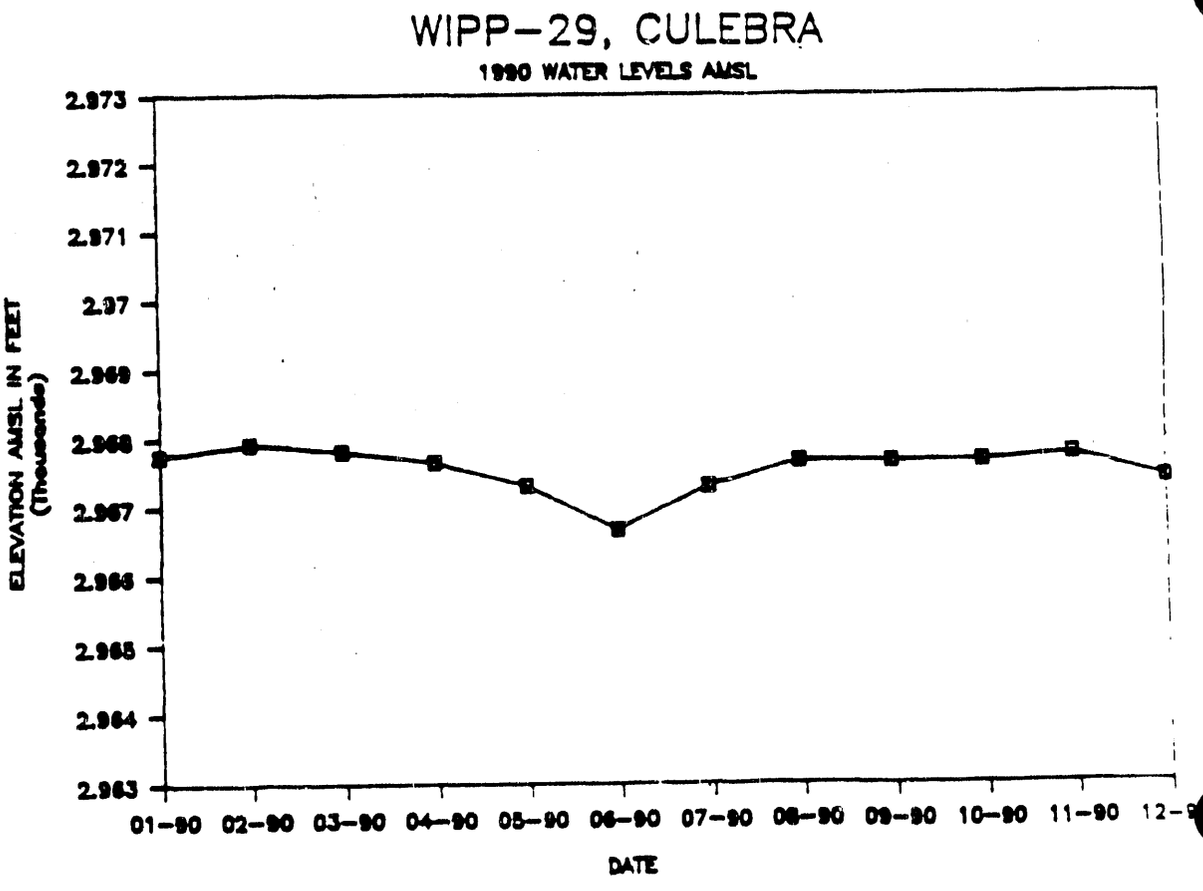
GROUND WATER-LEVELS
CALENDAR YEAR 1990
WIPP-28 RUSTLER/SALADO

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL_
WIPP-28 (PIP)	RUS/SAL	3349.21	01-90	08:57	295.02	0.42	294.60	89.79	3054.61	931.05
WIPP-28 (PIP)	RUS/SAL	3349.21	02-90	08:36	294.99	0.42	294.57	89.78	3054.64	931.05
WIPP-28 (PIP)	RUS/SAL	3349.21	03-90	07:35	295.28	0.42	294.86	89.87	3054.35	930.97
WIPP-28 (PIP)	RUS/SAL	3349.21	04-90	07:20	294.71	0.42	294.29	89.70	3054.92	931.14
WIPP-28 (PIP)	RUS/SAL	3349.21	05-90	06:42	294.65	0.42	294.23	89.68	3054.98	931.16
WIPP-28 (PIP)	RUS/SAL	3349.21	06-90	07:09	294.56	0.42	294.14	89.65	3055.07	931.19
WIPP-28 (PIP)	RUS/SAL	3349.21	07-90	11:10	294.40	0.42	293.98	89.61	3055.23	931.23
WIPP-28 (PIP)	RUS/SAL	3349.21	08-90	07:00	294.35	0.42	293.93	89.59	3055.28	931.25
WIPP-28 (PIP)	RUS/SAL	3349.21	09-90	07:45	294.17	0.42	293.75	89.54	3055.46	931.30
WIPP-28 (PIP)	RUS/SAL	3349.21	10-90	08:00	294.26	0.42	293.84	89.56	3055.37	931.28
WIPP-28 (PIP)	RUS/SAL	3349.21	11-90	08:20	294.10	0.42	293.68	89.51	3055.53	931.33
WIPP-28 (PIP)	RUS/SAL	3349.21	12-90	07:35	294.05	0.42	293.63	89.50	3055.58	931.34



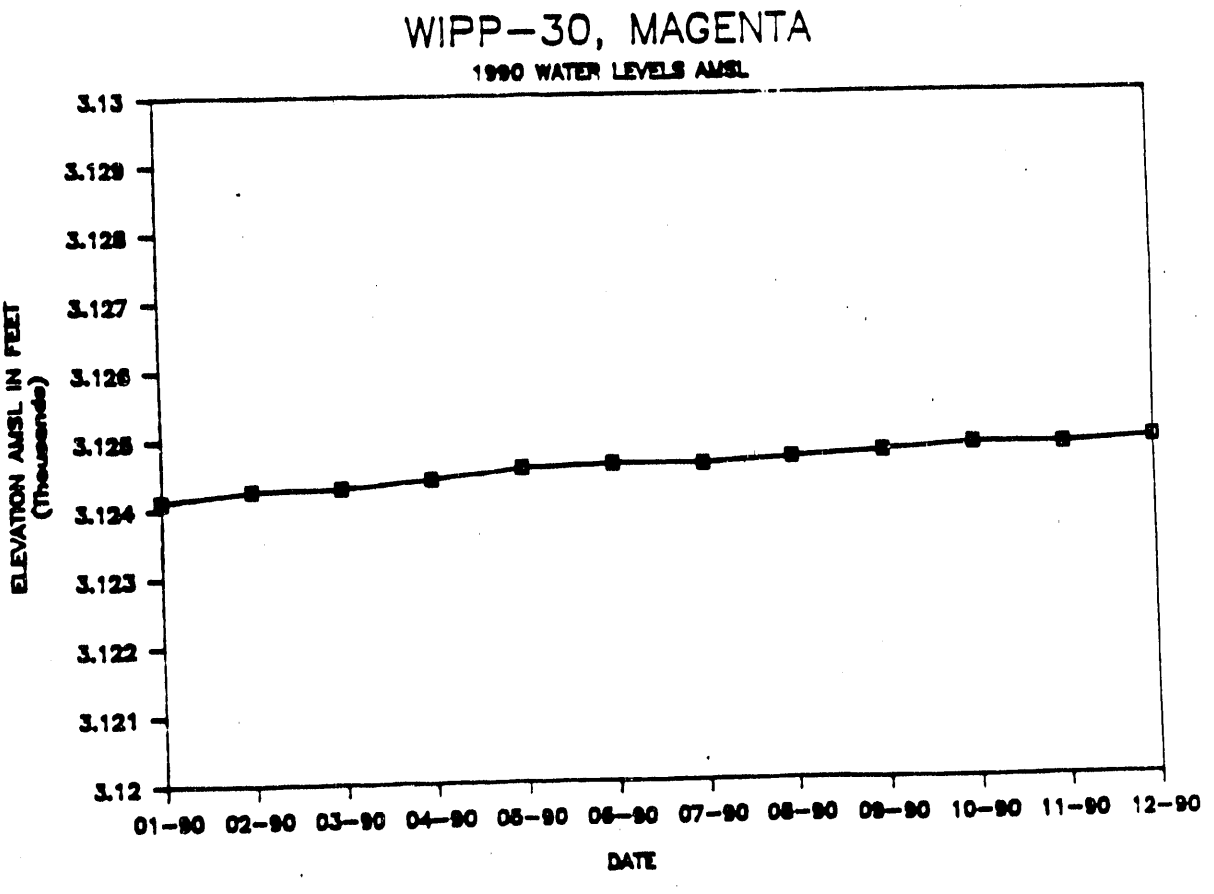
GROUND WATER-LEVELS
CALENDAR YEAR 1990
WIPP-29, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MSL
WIPP-29	CUL	2978.26	01-90	15:47	10.50	0.00	10.50	3.20	2967.76	904.
WIPP-29	CUL	2978.26	02-90	06:55	10.33	0.00	10.33	3.15	2967.93	904.
WIPP-29	CUL	2978.26	03-90	06:36	10.44	0.00	10.44	3.18	2967.82	904.3
WIPP-29	CUL	2978.26	04-90	06:03	10.60	0.00	10.60	3.23	2967.66	904.5
WIPP-29	CUL	2978.26	05-90	05:45	10.95	0.00	10.95	3.34	2967.31	904.
WIPP-29	CUL	2978.26	06-90	14:00	11.59	0.00	11.59	3.53	2966.67	904.
WIPP-29	CUL	2978.26	07-90	06:15	10.96	0.00	10.96	3.34	2967.30	904.
WIPP-29	CUL	2978.26	08-90	06:04	10.59	0.00	10.59	3.23	2967.67	90
WIPP-29	CUL	2978.26	09-90	10:17	10.60	0.00	10.60	3.23	2967.66	904.
WIPP-29	CUL	2978.26	10-90	06:33	10.60	0.00	10.60	3.23	2967.66	904.
WIPP-29	CUL	2978.26	11-90	06:45	10.50	0.00	10.50	3.20	2967.76	904.5
WIPP-29	CUL	2978.26	12-90	06:20	10.86	0.00	10.86	3.31	2967.40	904.



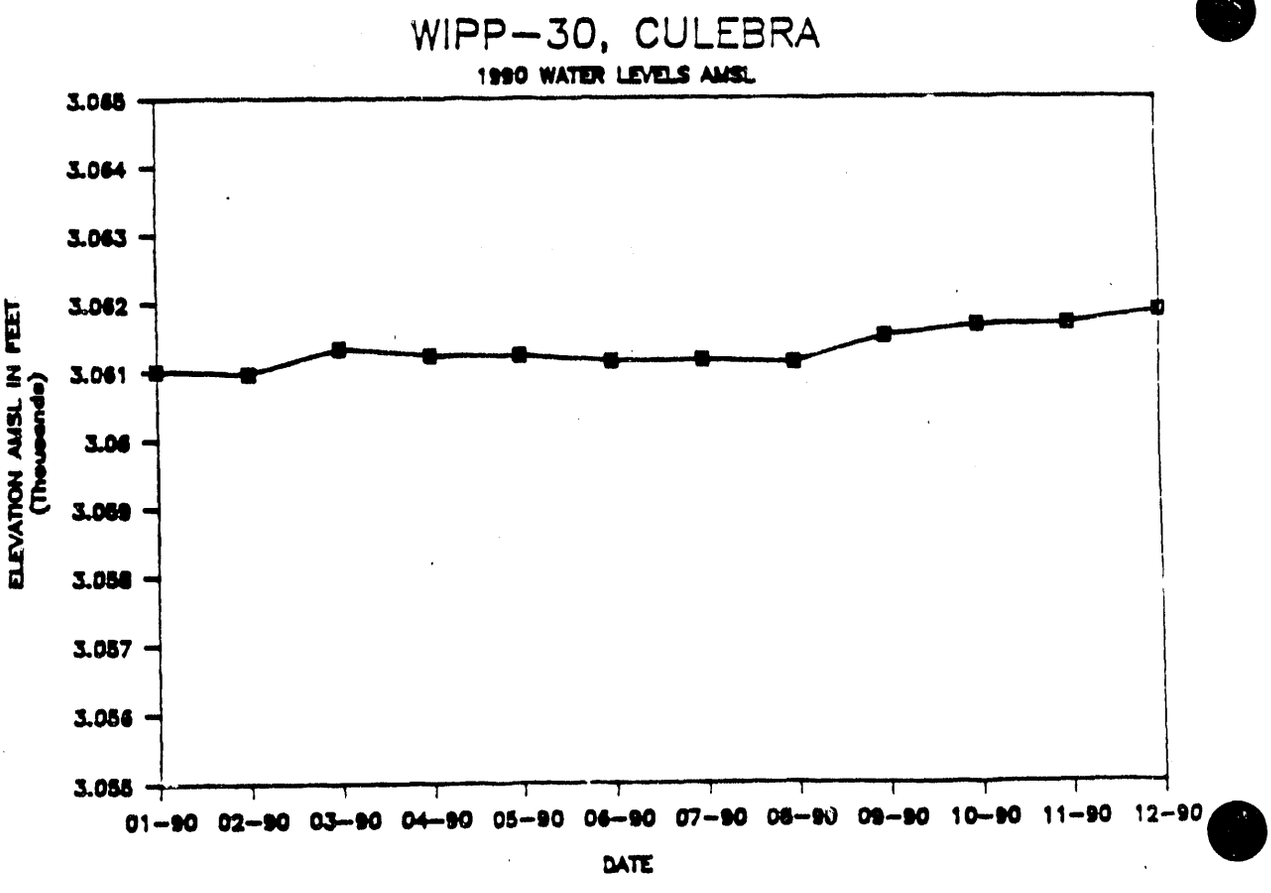
GROUND WATER-LEVELS
CALENDAR YEAR 1990
WIPP-30, MAGENTA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_MS.
WIPP-30 (ANNULUS)	MAG	3429.05	01-90	11:52	304.93	0.00	304.93	92.94	3124.12	952.3
WIPP-30 (ANNULUS)	MAG	3429.05	02-90	11:26	304.78	0.00	304.78	92.90	3124.27	952.3
WIPP-30 (ANNULUS)	MAG	3429.05	03-90	09:36	304.75	0.00	304.75	92.89	3124.30	952.3
WIPP-30 (ANNULUS)	MAG	3429.05	04-90	09:14	304.63	0.00	304.63	92.85	3124.42	952.3
WIPP-30 (ANNULUS)	MAG	3429.05	05-90	09:36	304.48	0.00	304.48	92.81	3124.57	952.3
WIPP-30 (ANNULUS)	MAG	3429.05	06-90	09:43	304.44	0.00	304.44	92.79	3124.61	952.3
WIPP-30 (ANNULUS)	MAG	3429.05	07-90	10:30	304.45	0.00	304.45	92.80	3124.60	952.3
WIPP-30 (ANNULUS)	MAG	3429.05	08-90	12:32	304.37	0.00	304.37	92.77	3124.68	952.4
WIPP-30 (ANNULUS)	MAG	3429.05	09-90	17:06	304.29	0.00	304.29	92.75	3124.76	952.4
WIPP-30 (ANNULUS)	MAG	3429.05	10-90	16:25	304.20	0.00	304.20	92.72	3124.85	952.4
WIPP-30 (ANNULUS)	MAG	3429.05	11-90	15:18	304.22	0.00	304.22	92.73	3124.83	952.4
WIPP-30 (ANNULUS)	MAG	3429.05	12-90	15:35	304.14	0.00	304.14	92.70	3124.91	952.4



GROUND WATER-LEVELS
CALENDAR YEAR 1990
WIPP-30, CULEBRA

WELL_NO	ZONE	TOC_AMSL	DATE	TIME	TP_FT_TOC	ADJ_FT	WL_FT	WL_METERS	WL_MSL_FT	WL_M
WIPP-30 (PIP)	CUL	3429.05	01-90	11:47	369.23	1.20	368.03	112.18	3061.02	933
WIPP-30 (PIP)	CUL	3429.05	02-90	10:20	369.27	1.20	368.07	112.19	3060.98	932
WIPP-30 (PIP)	CUL	3429.05	03-90	11:18	368.91	1.20	367.71	112.08	3061.34	933.
WIPP-30 (PIP)	CUL	3429.05	04-90	09:04	369.01	1.20	367.81	112.11	3061.24	933.
WIPP-30 (PIP)	CUL	3429.05	05-90	09:33	369.01	1.20	367.81	112.11	3061.24	933.
WIPP-30 (PIP)	CUL	3429.05	06-90	08:34	369.10	1.20	367.90	112.14	3061.15	933.
WIPP-30 (PIP)	CUL	3429.05	07-90	10:25	369.08	1.20	367.88	112.13	3061.17	93?
WIPP-30 (PIP)	CUL	3429.05	08-90	12:27	369.12	1.20	367.92	112.14	3061.13	933.
WIPP-30 (PIP)	CUL	3429.05	09-90	16:56	368.74	1.20	367.54	112.03	3061.51	933.
WIPP-30 (PIP)	CUL	3429.05	10-90	16:20	368.59	1.20	367.39	111.98	3061.66	93?
WIPP-30 (PIP)	CUL	3429.05	11-90	15:21	368.57	1.20	367.37	111.97	3061.68	
WIPP-30 (PIP)	CUL	3429.05	12-90	15:20	368.38	1.20	367.18	111.92	3061.87	93?



APPENDIX XI
HISTORICAL GROUNDWATER LEVEL DATA

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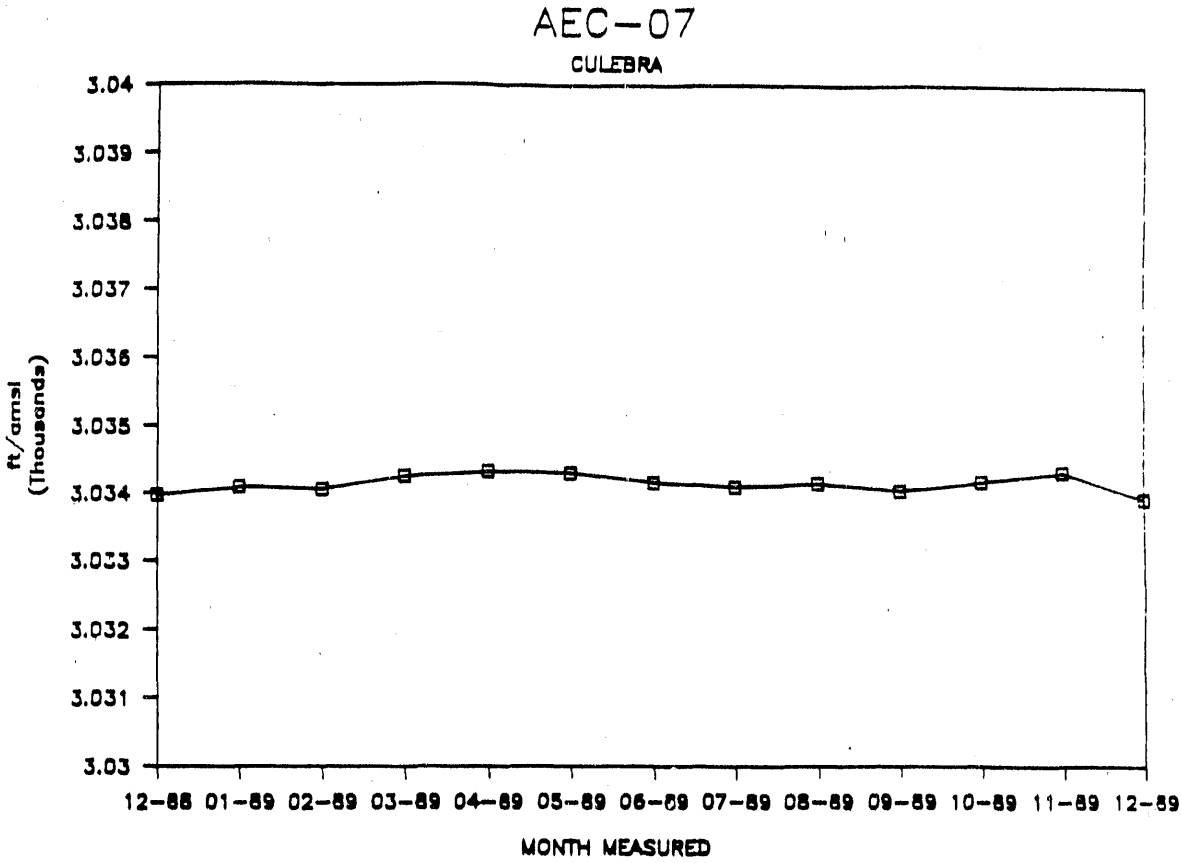
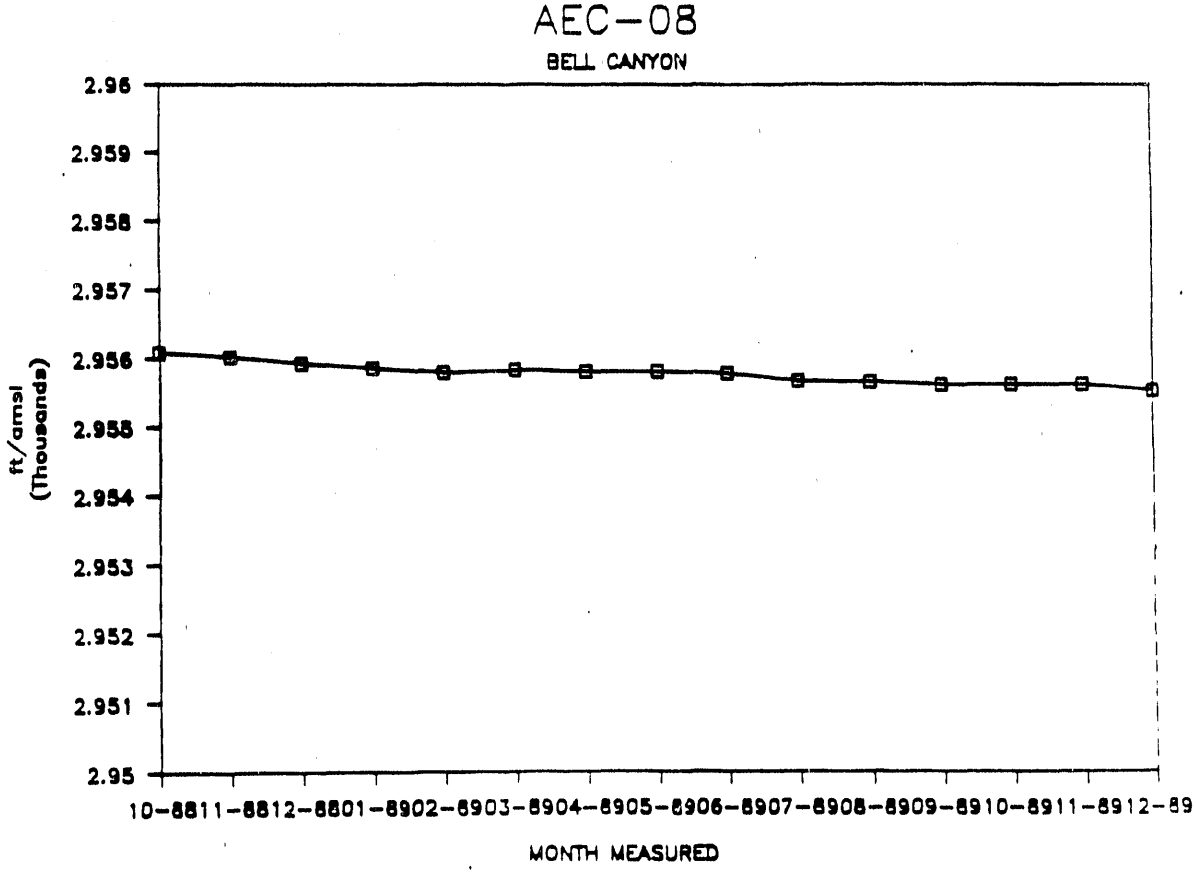
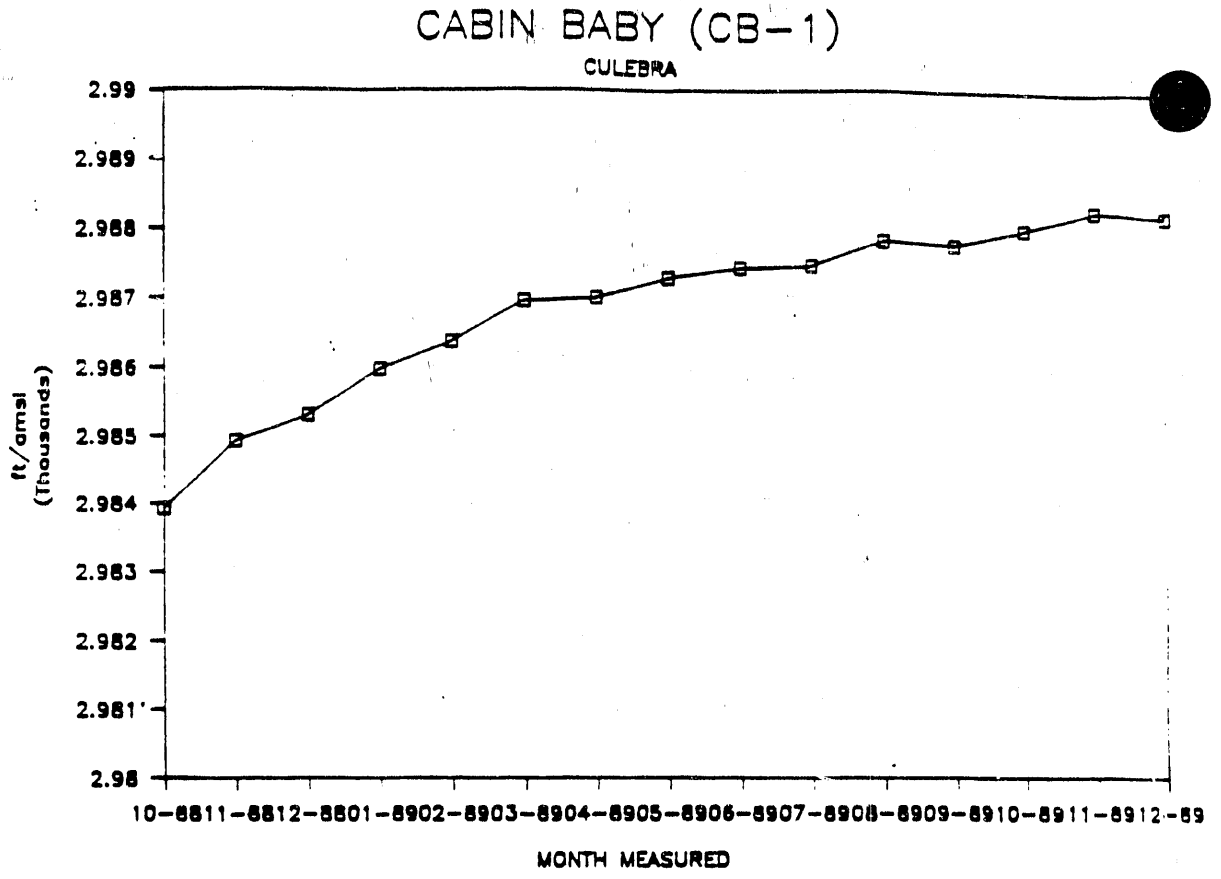
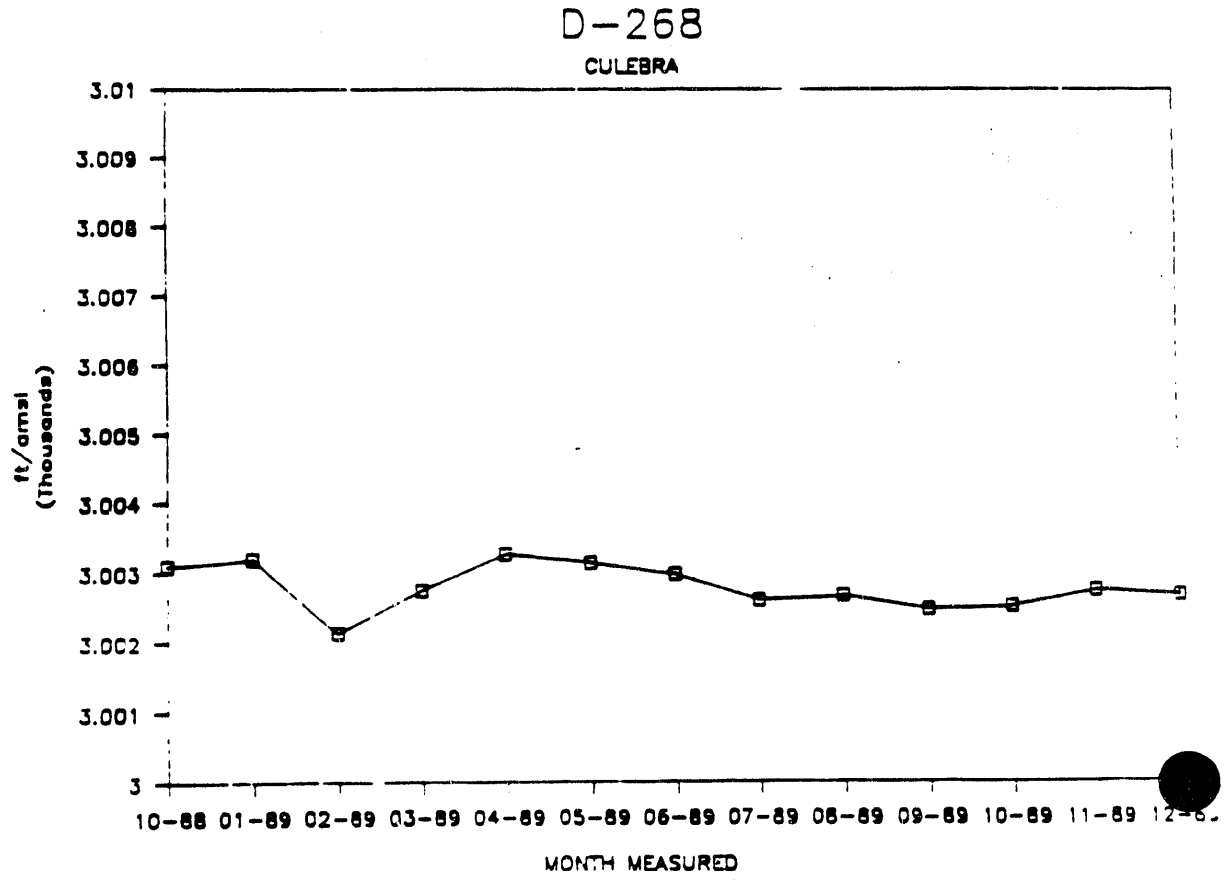
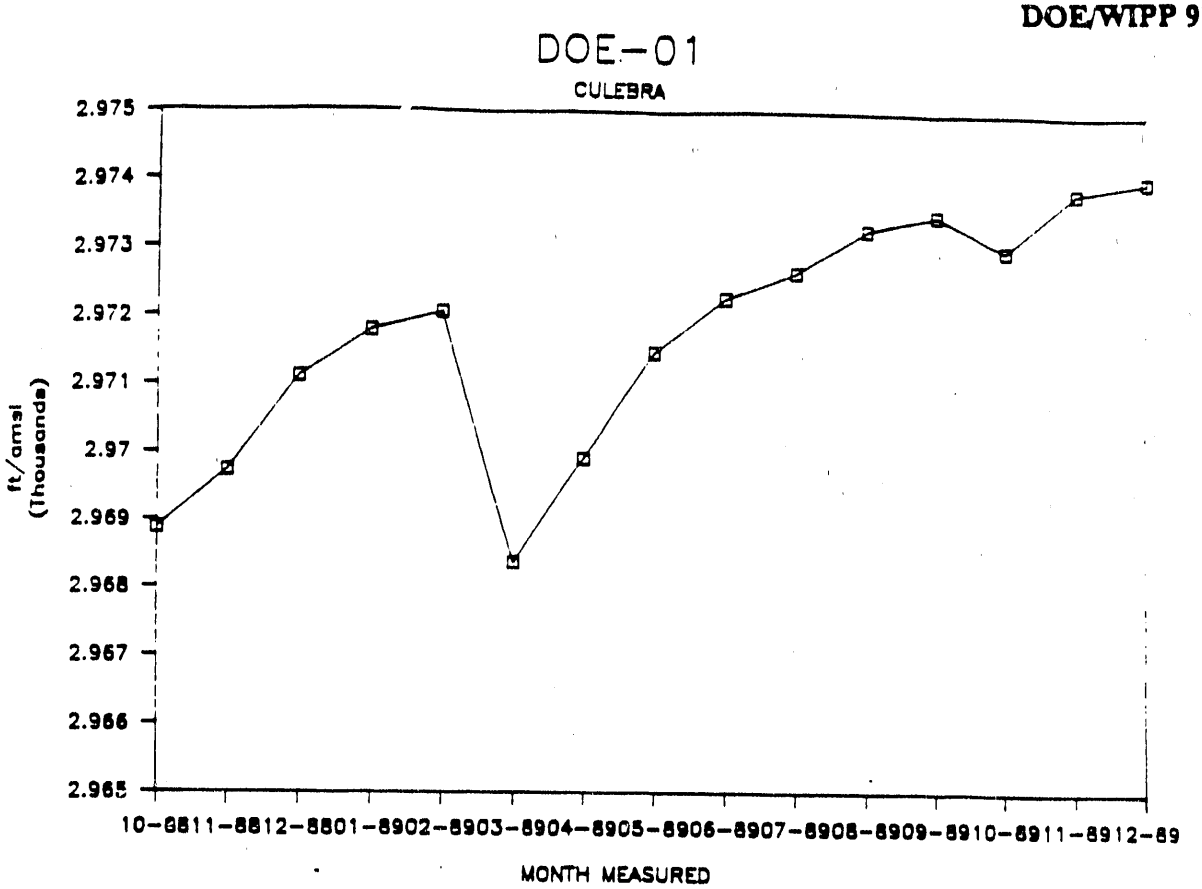
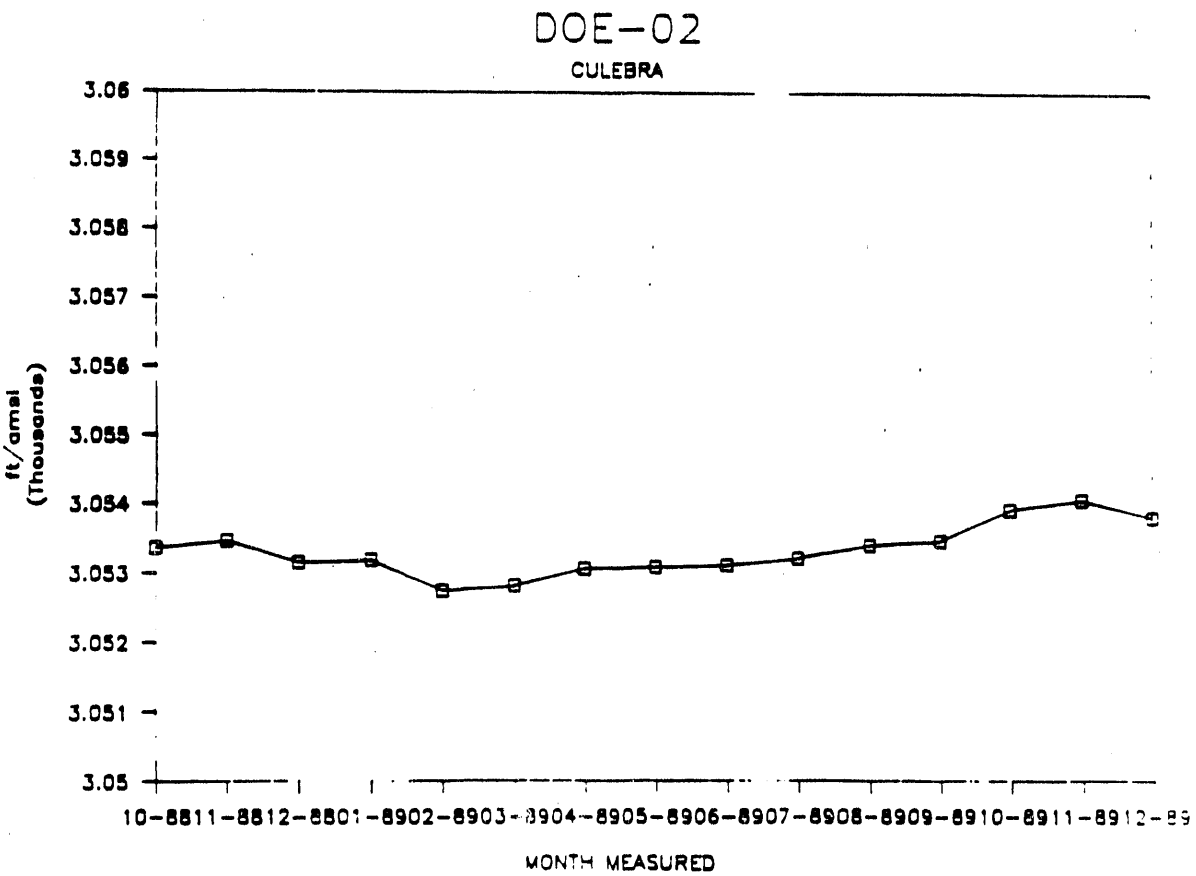

AEC-07
CULEBRA
3.04
3.039
3.038
3.037
3.036
3.035
3.034
3.033
3.032
3.031
3.03
ft/amsl (Thousands)
12-88 01-89 02-89 03-89 04-89 05-89 06-89 07-89 08-89 09-89 10-89 11-89 12-89
MONTH MEASURED

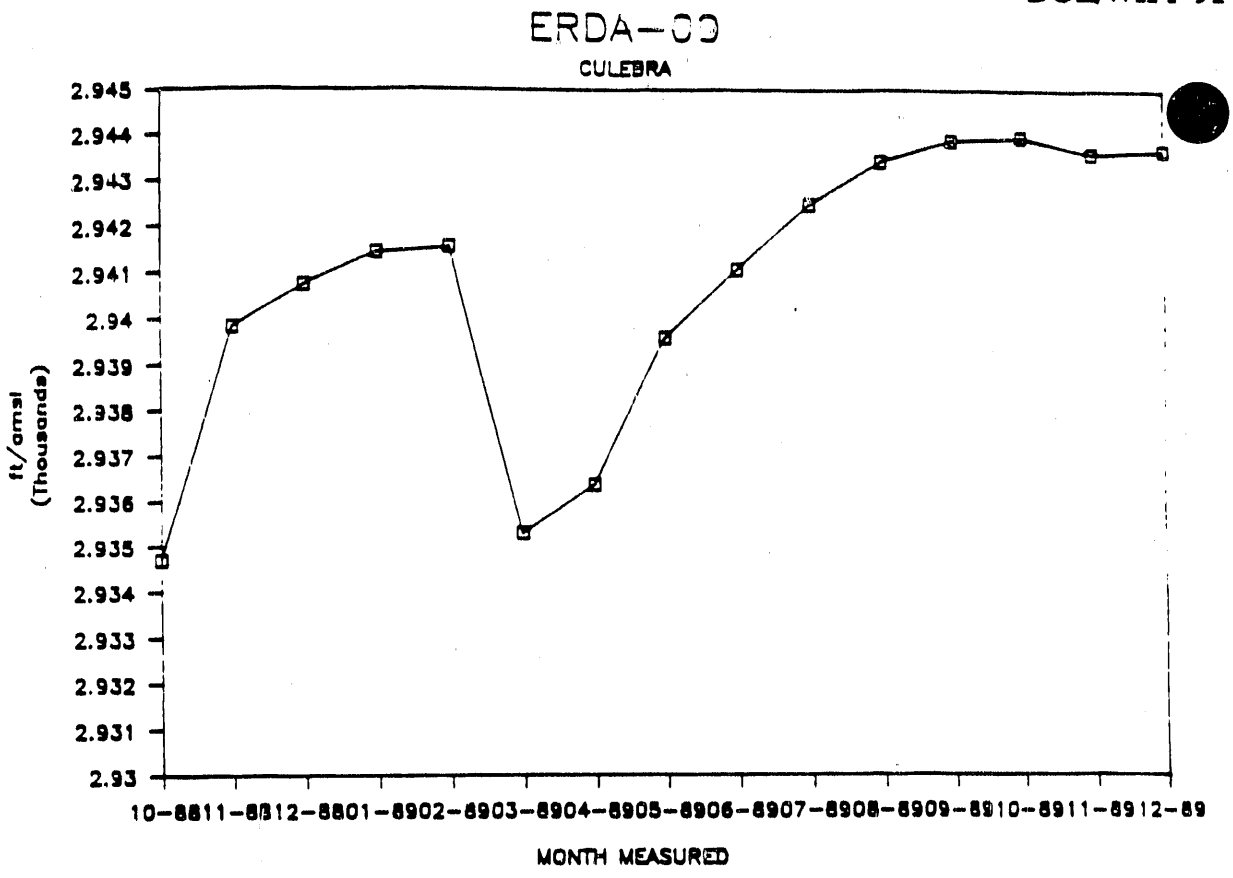

AEC-08
BELL CANYON
2.96
2.959
2.958
2.957
2.956
2.955
2.954
2.953
2.952
2.951
2.95
ft/amsl (Thousands)
10-8811-8812-8901-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

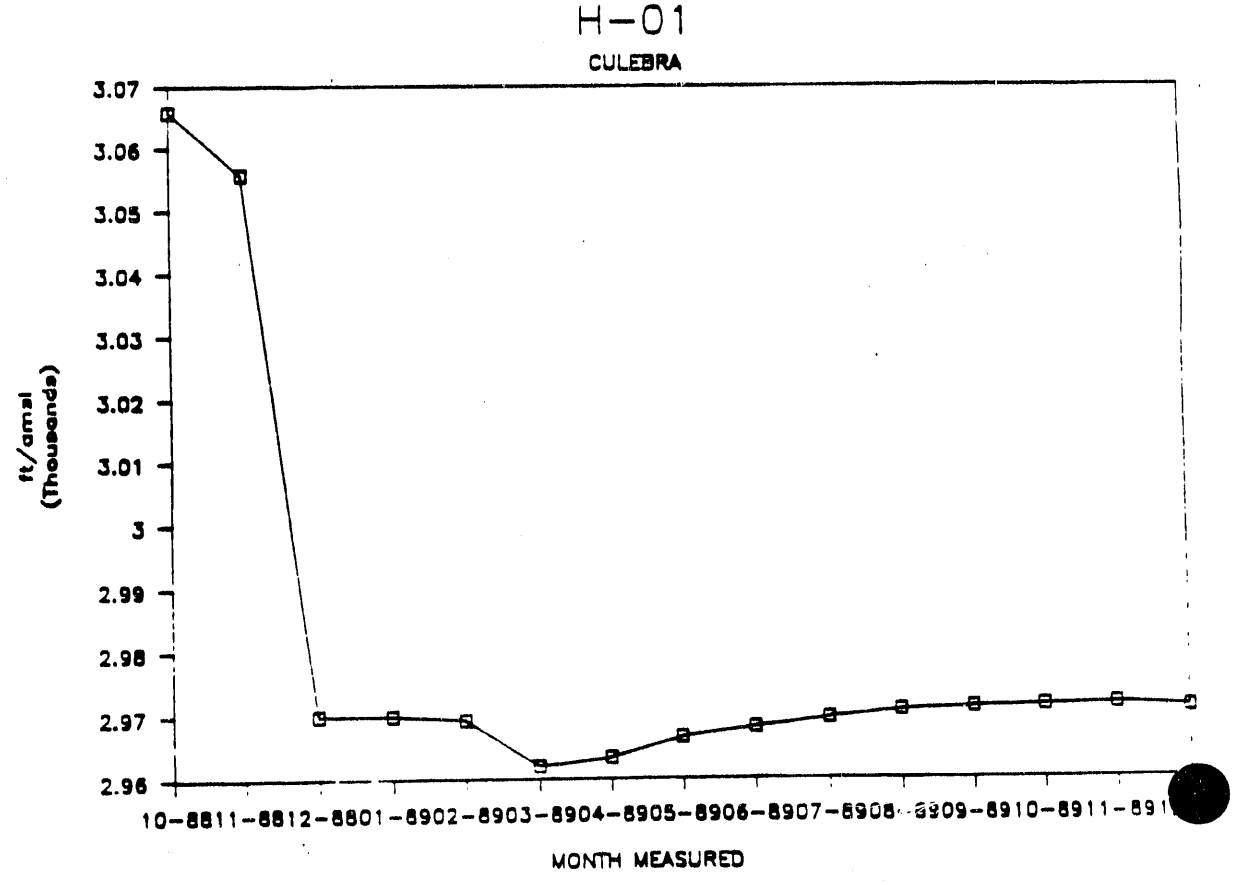

CABIN BABY (CB-1)
CULEBRA
2.99
2.989
2.988
2.987
2.986
2.985
2.984
2.983
2.982
2.981
2.98
ft/amsl (Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

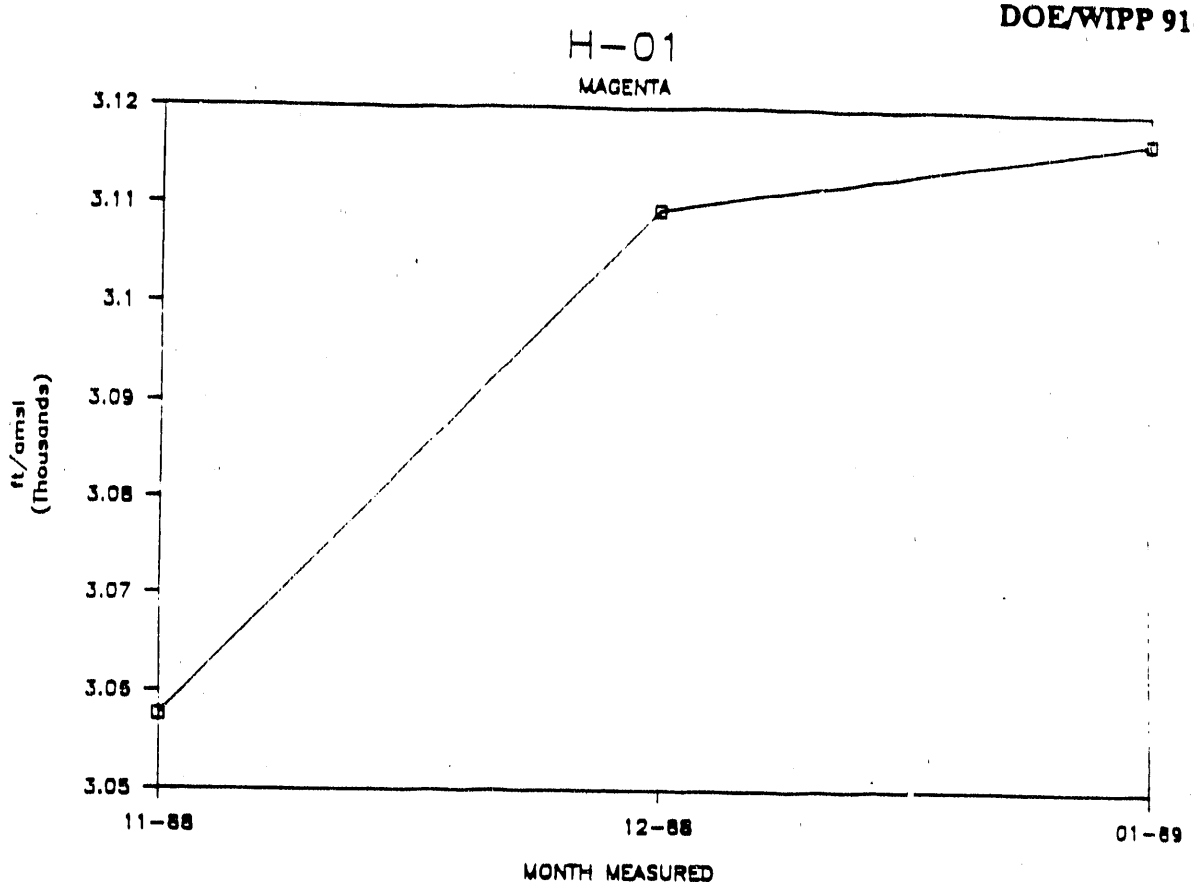

D-268
CULEBRA
3.01
3.009
3.008
3.007
3.006
3.005
3.004
3.003
3.002
3.001
3
ft/amsl (Thousands)
10-88 01-89 02-89 03-89 04-89 05-89 06-89 07-89 08-89 09-89 10-89 11-89
MONTH MEASURED

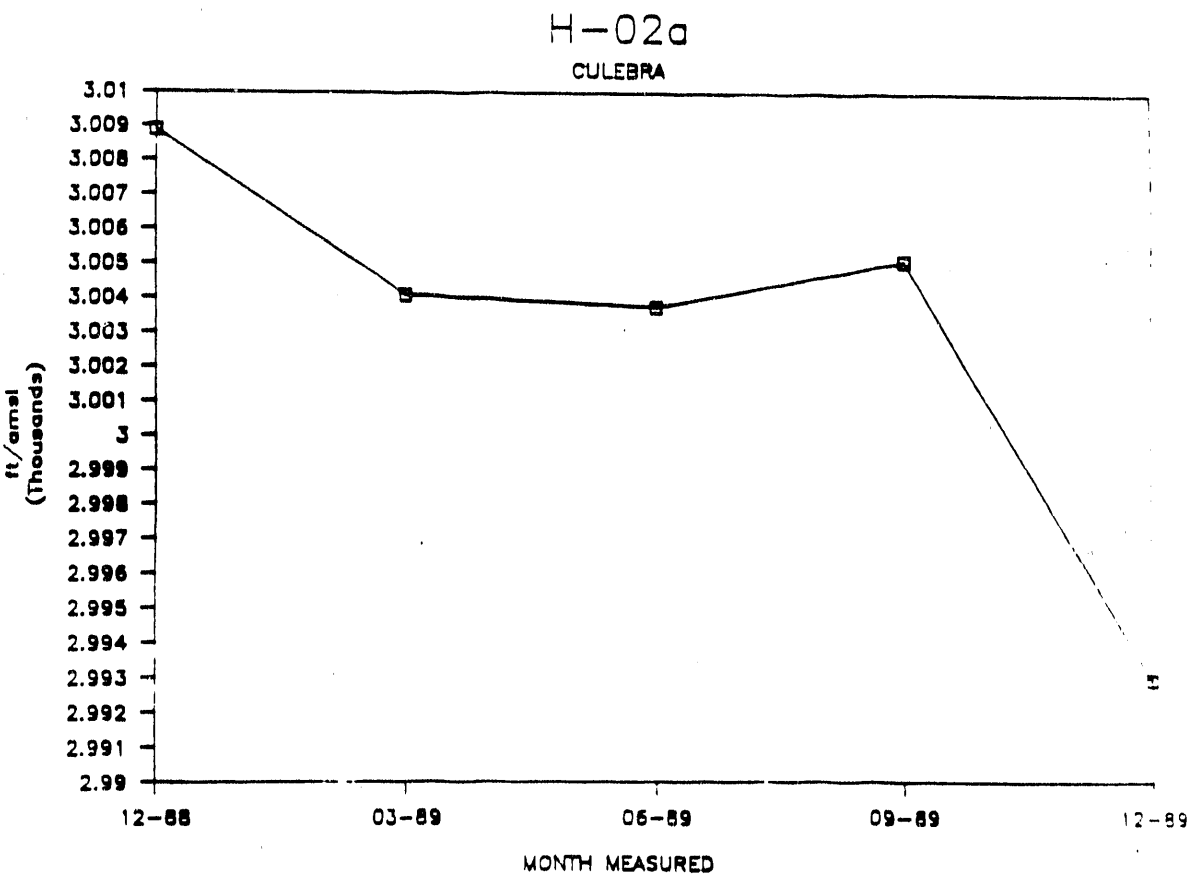

DOE-01
CULEBRA
2.975
2.974
2.973
2.972
2.971
2.97
2.969
2.968
2.967
2.966
2.965
ft/amsl (Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

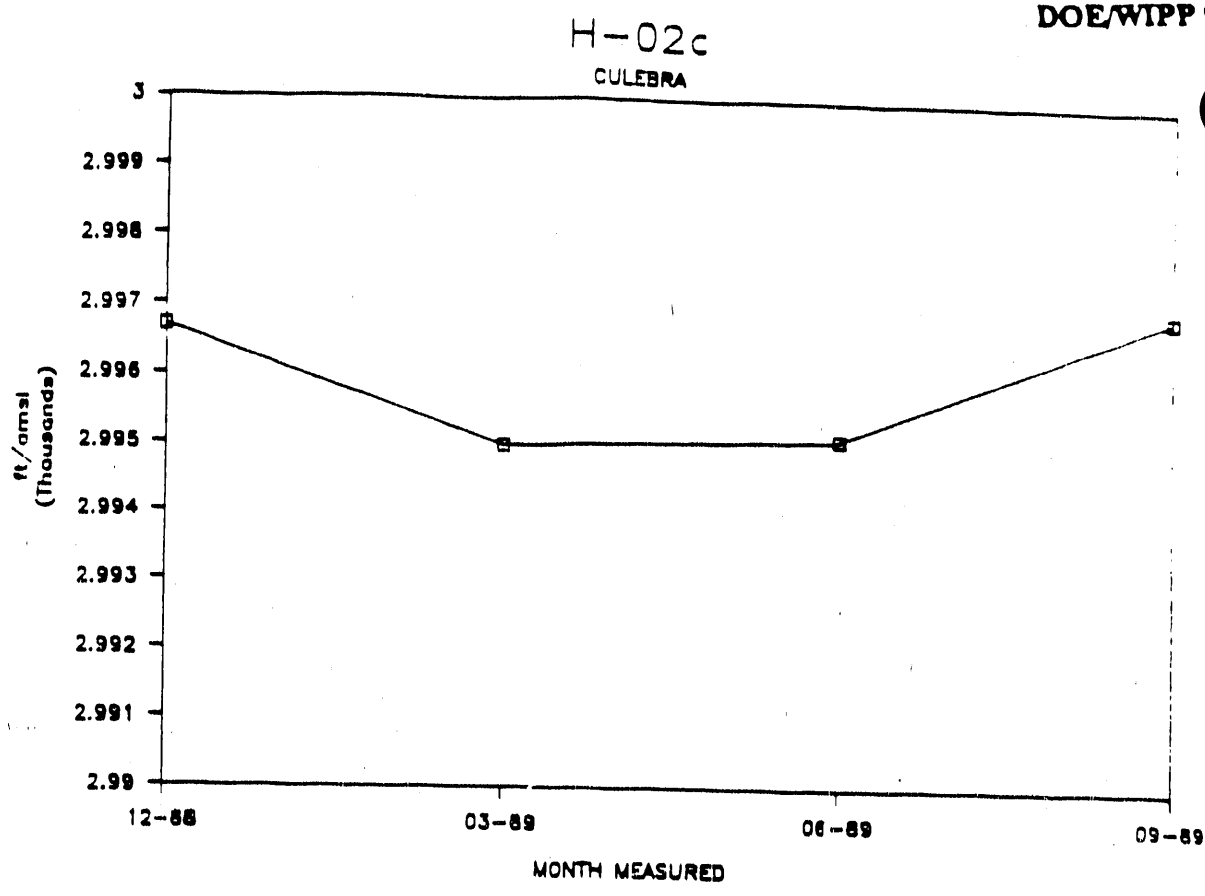

DOE-02
CULEBRA
3.06
3.059
3.058
3.057
3.056
3.055
3.054
3.053
3.052
3.051
3.05
ft/amsl (Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

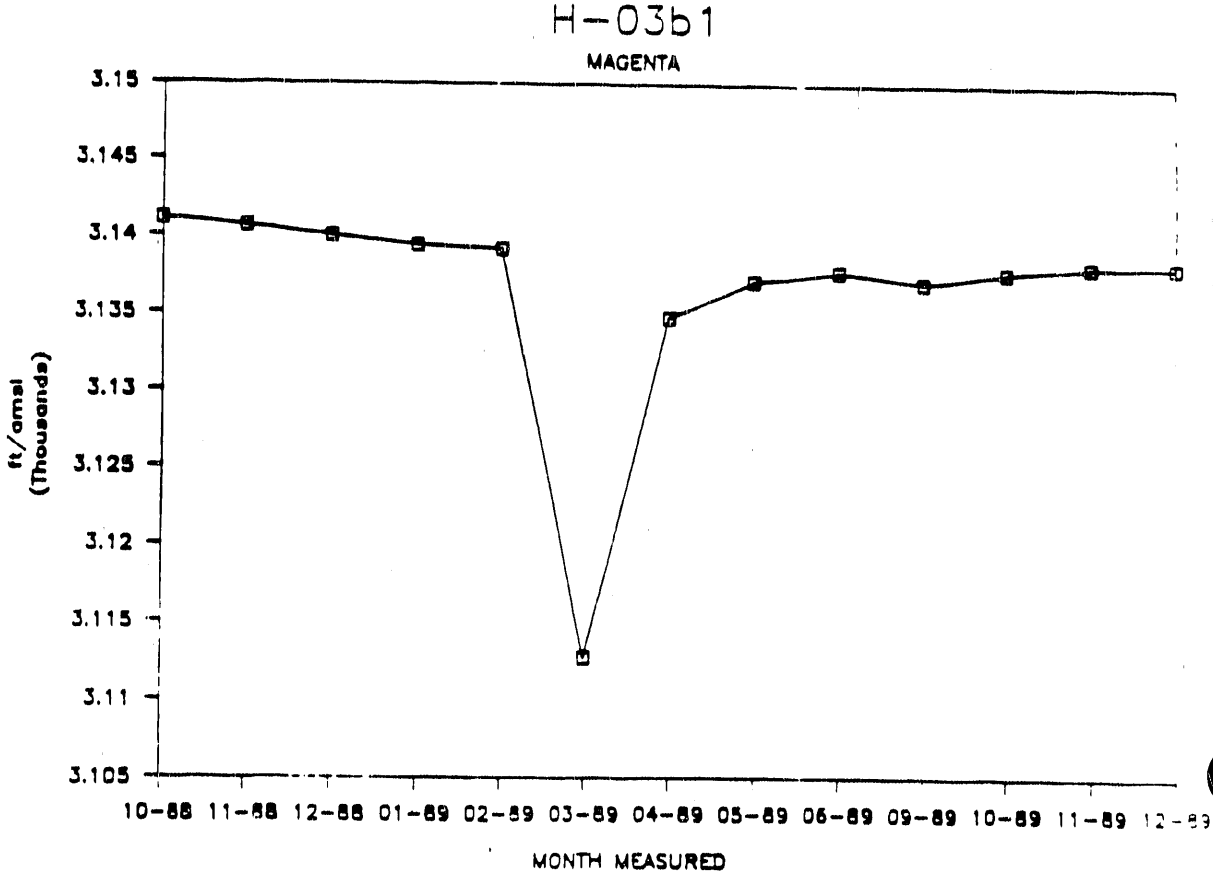

ERDA-09
CULEBRA
2.945
2.944
2.943
2.942
2.941
2.94
2.939
2.938
2.937
2.936
2.935
2.934
2.933
2.932
2.931
2.93
ft/amsl (Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

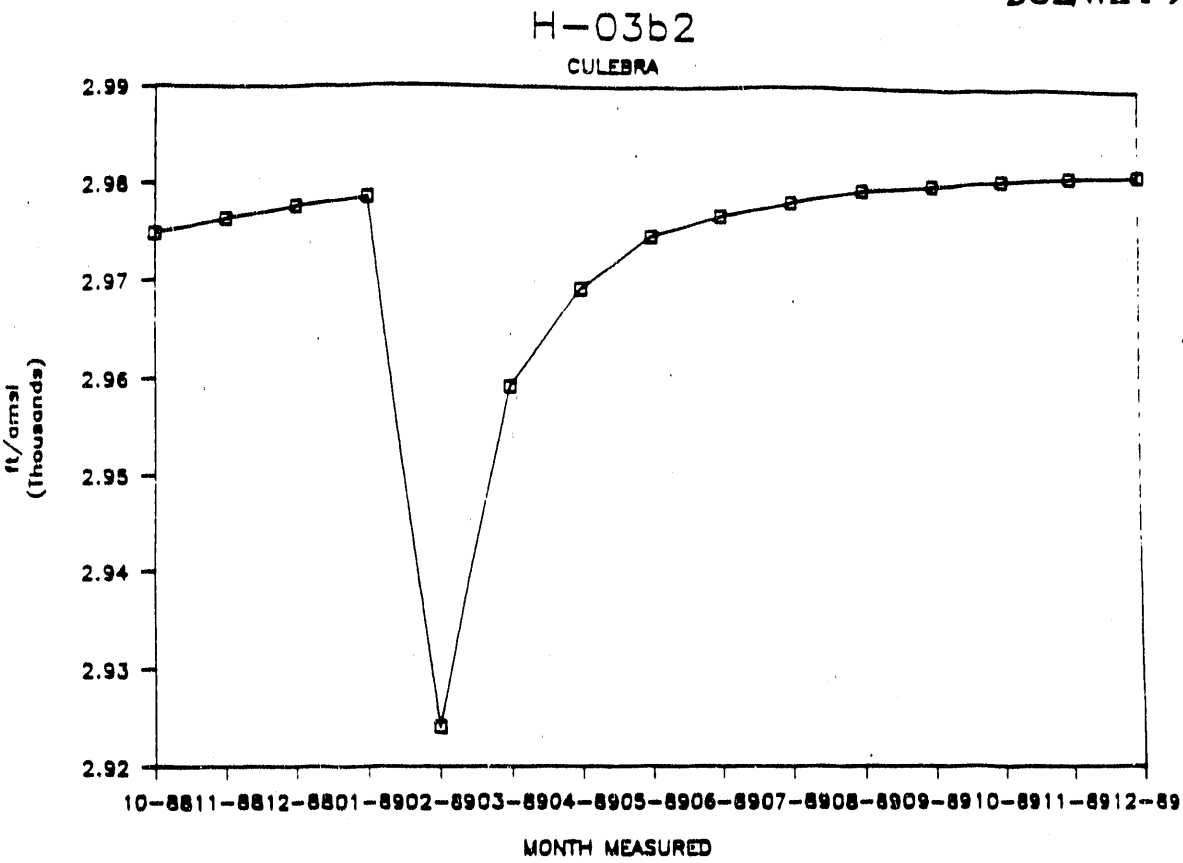

H-01
CULEBRA
3.07
3.06
3.05
3.04
3.03
3.02
3.01
3
2.99
2.98
2.97
2.96
ft/amsl (Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-891
MONTH MEASURED

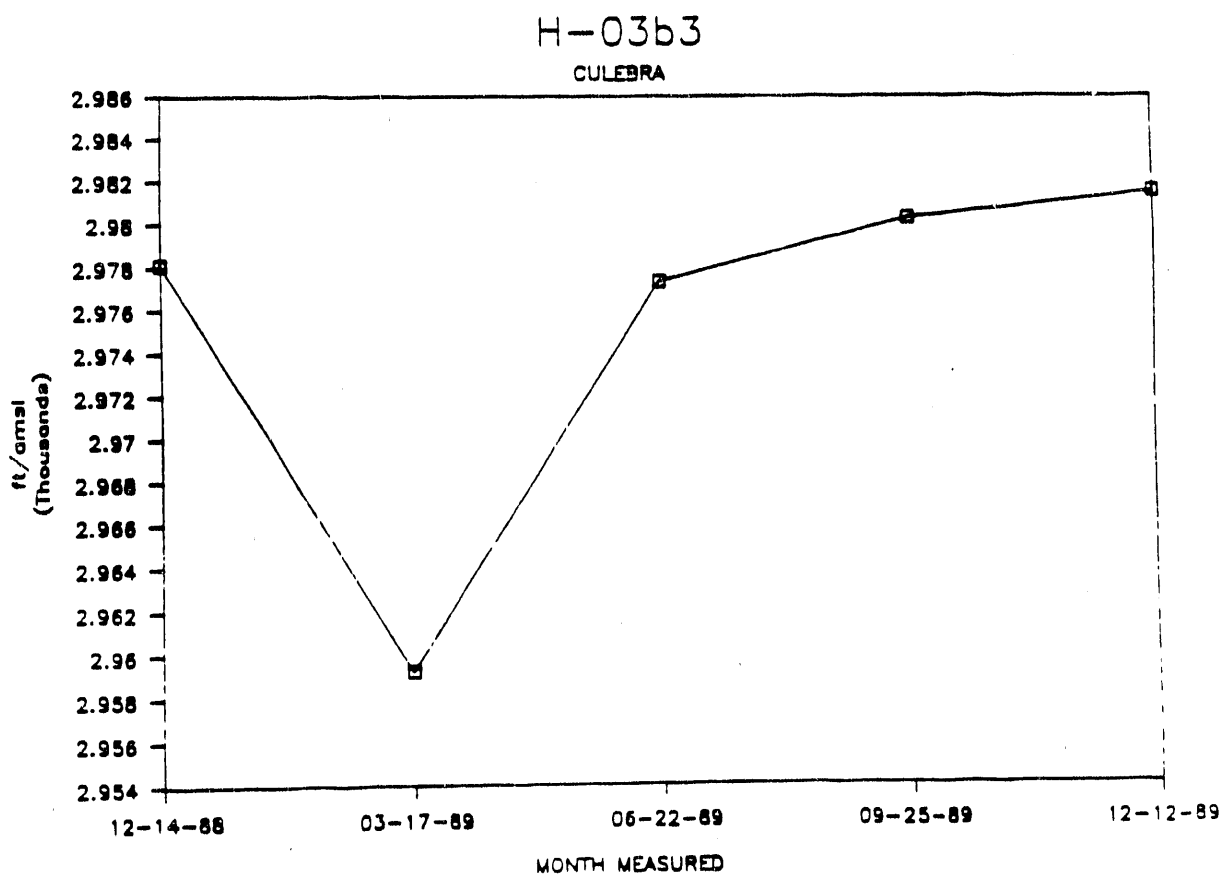

H-01
MAGENTA
3.12
3.11
3.1
3.09
3.08
3.07
3.06
3.05
ft/amsl
(Thousands)
11-88
12-88
01-89
MONTH MEASURED

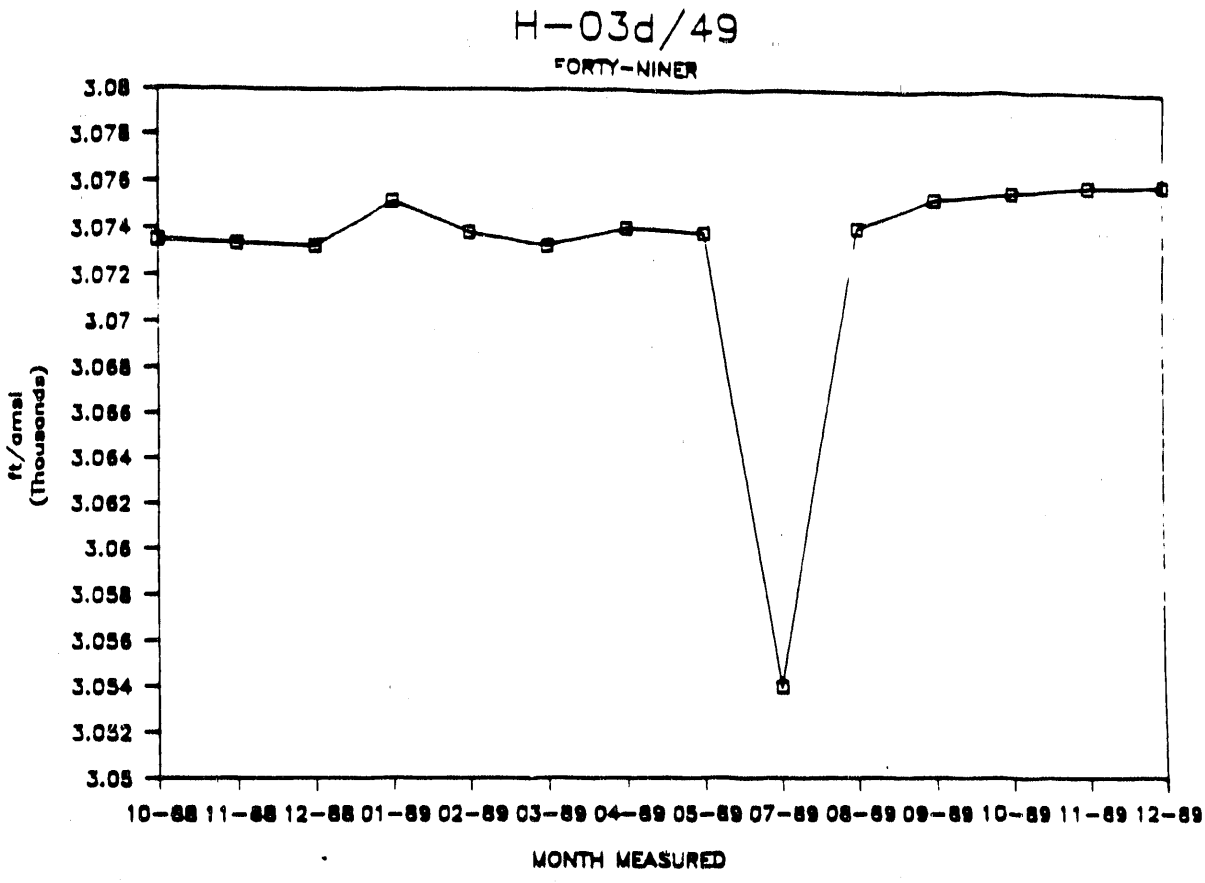

H-02a
CULEBRA
3.01
3.009
3.008
3.007
3.006
3.005
3.004
3.003
3.002
3.001
3
2.999
2.998
2.997
2.996
2.995
2.994
2.993
2.992
2.991
2.99
ft/amsl
(Thousands)
12-88
03-89
06-89
09-89
12-89
MONTH MEASURED

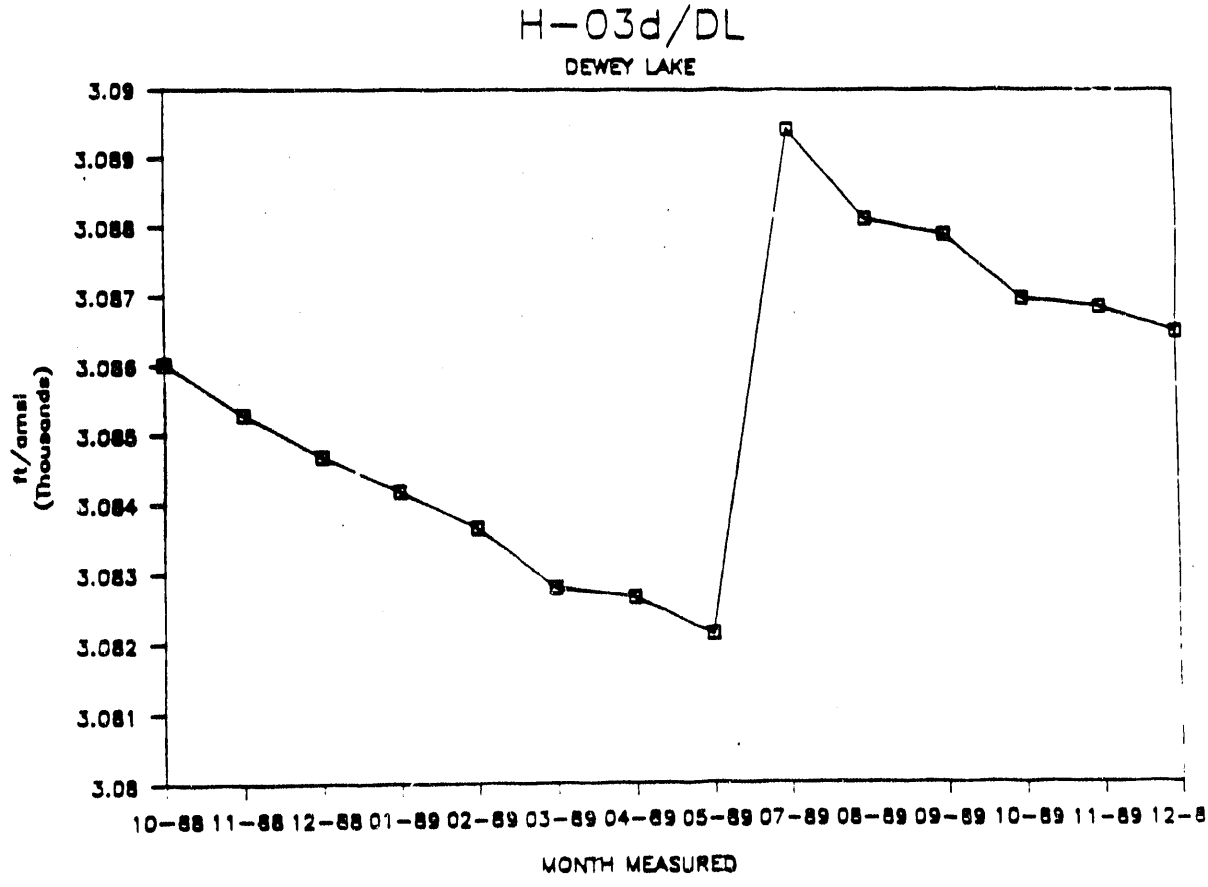

H-02c
CULEBRA
3
2.999
2.998
2.997
2.996
2.995
2.994
2.993
2.992
2.991
2.99
ft/amsl (Thousands)
12-88
03-89
06-89
09-89
MONTH MEASURED

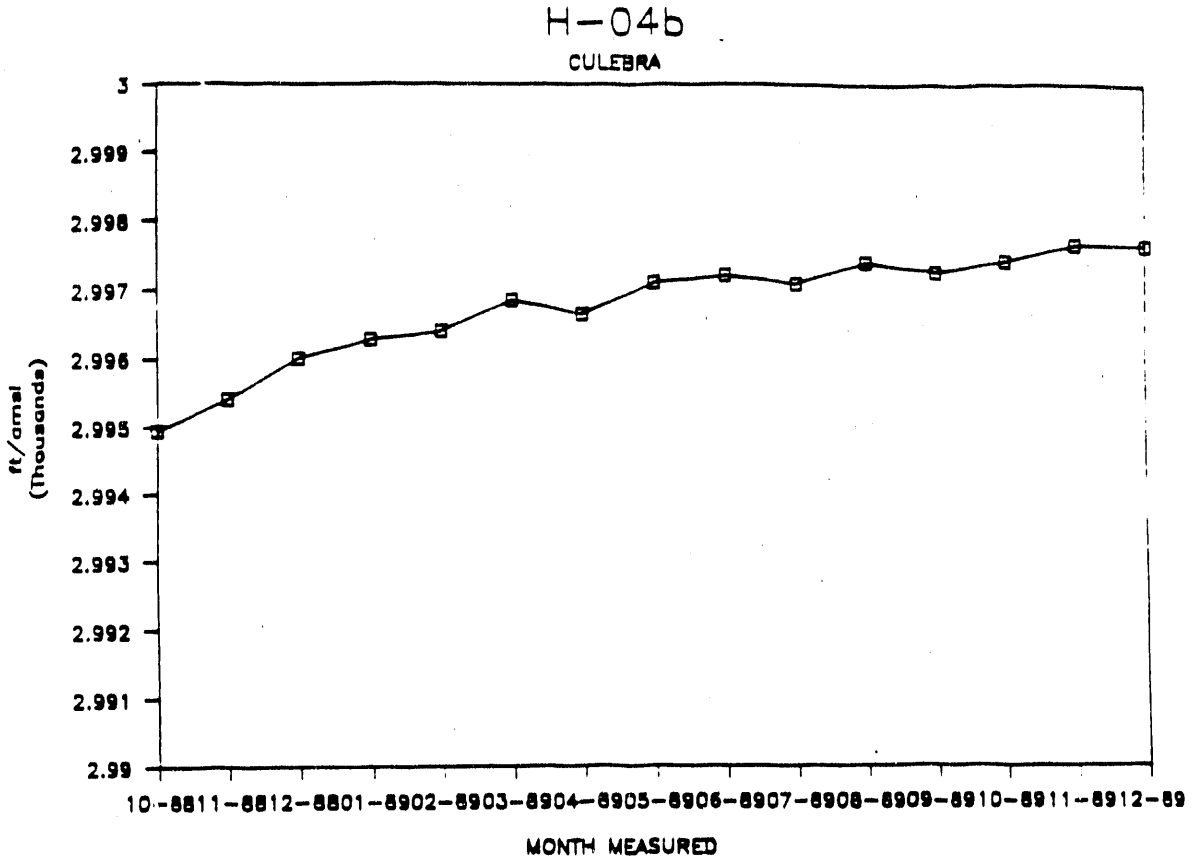

H-03b1
MAGENTA
3.15
3.145
3.14
3.135
3.13
3.125
3.12
3.115
3.11
3.105
ft/amsl (Thousands)
10-88 11-88 12-88 01-89 02-89 03-89 04-89 05-89 06-89 09-89 10-89 11-89 12-89
MONTH MEASURED

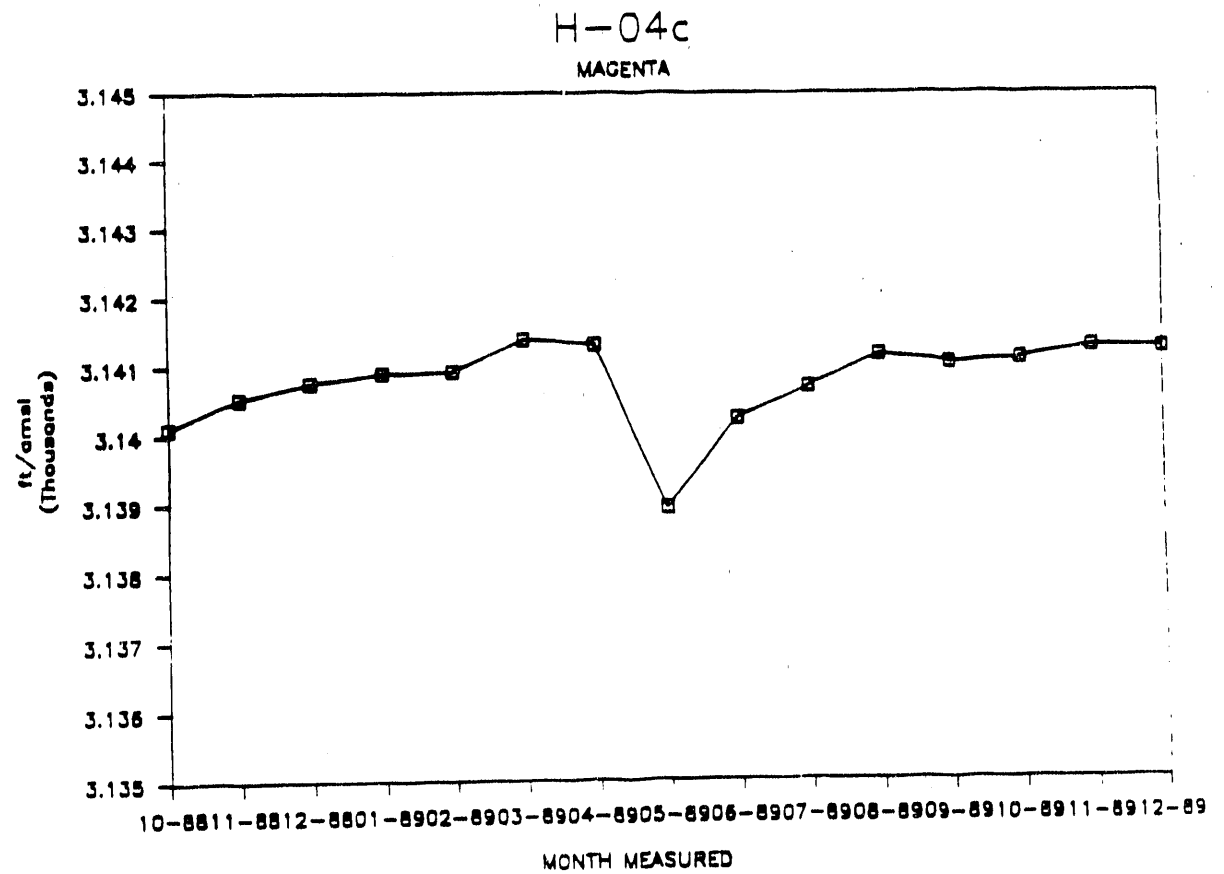

H-03b2
CULEBRA
2.99
2.98
2.97
2.96
2.95
2.94
2.93
2.92
ft/amsl
(Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

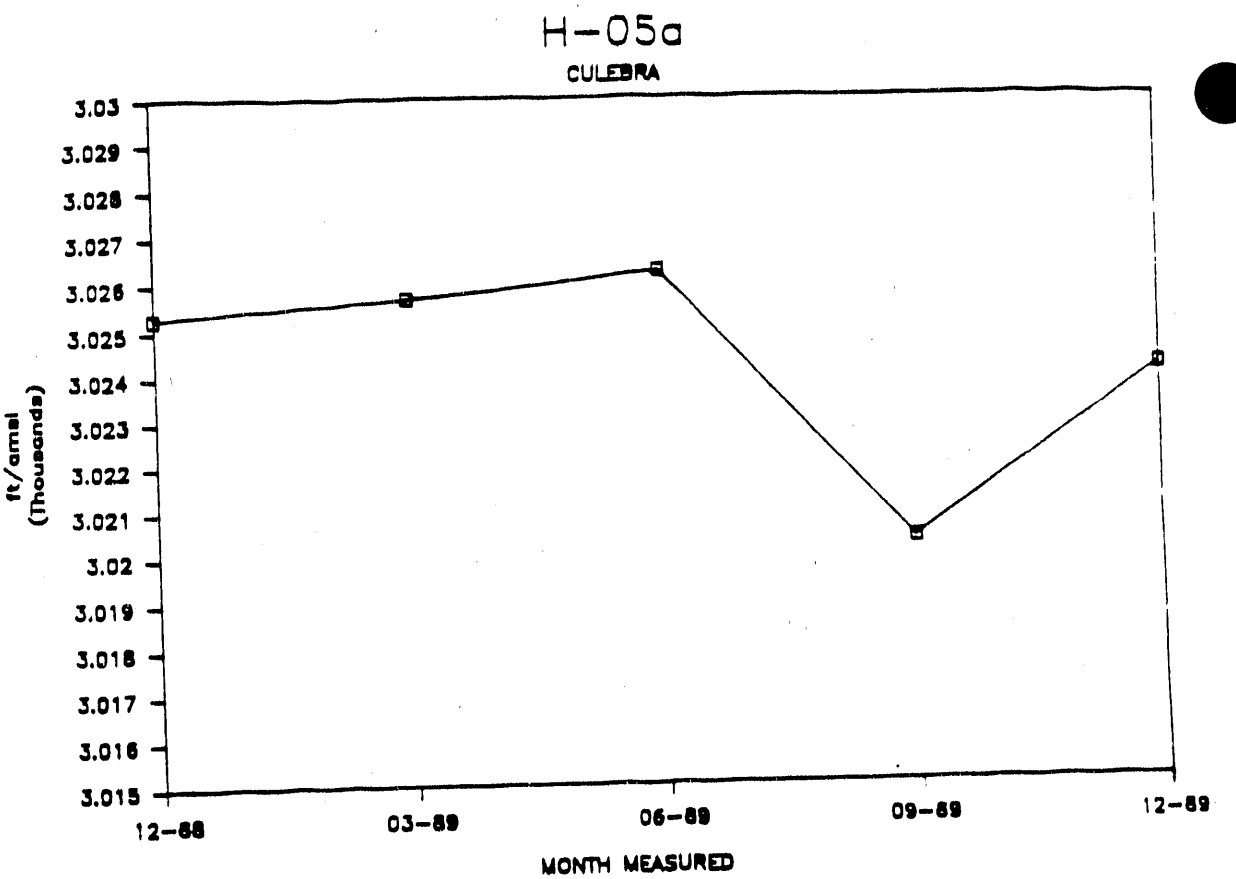

H-03b3
CULEBRA
2.986
2.984
2.982
2.98
2.978
2.976
2.974
2.972
2.97
2.968
2.966
2.964
2.962
2.96
2.958
2.956
2.954
ft/amsl
(Thousands)
12-14-88
03-17-89
06-22-89
09-25-89
12-12-89
MONTH MEASURED

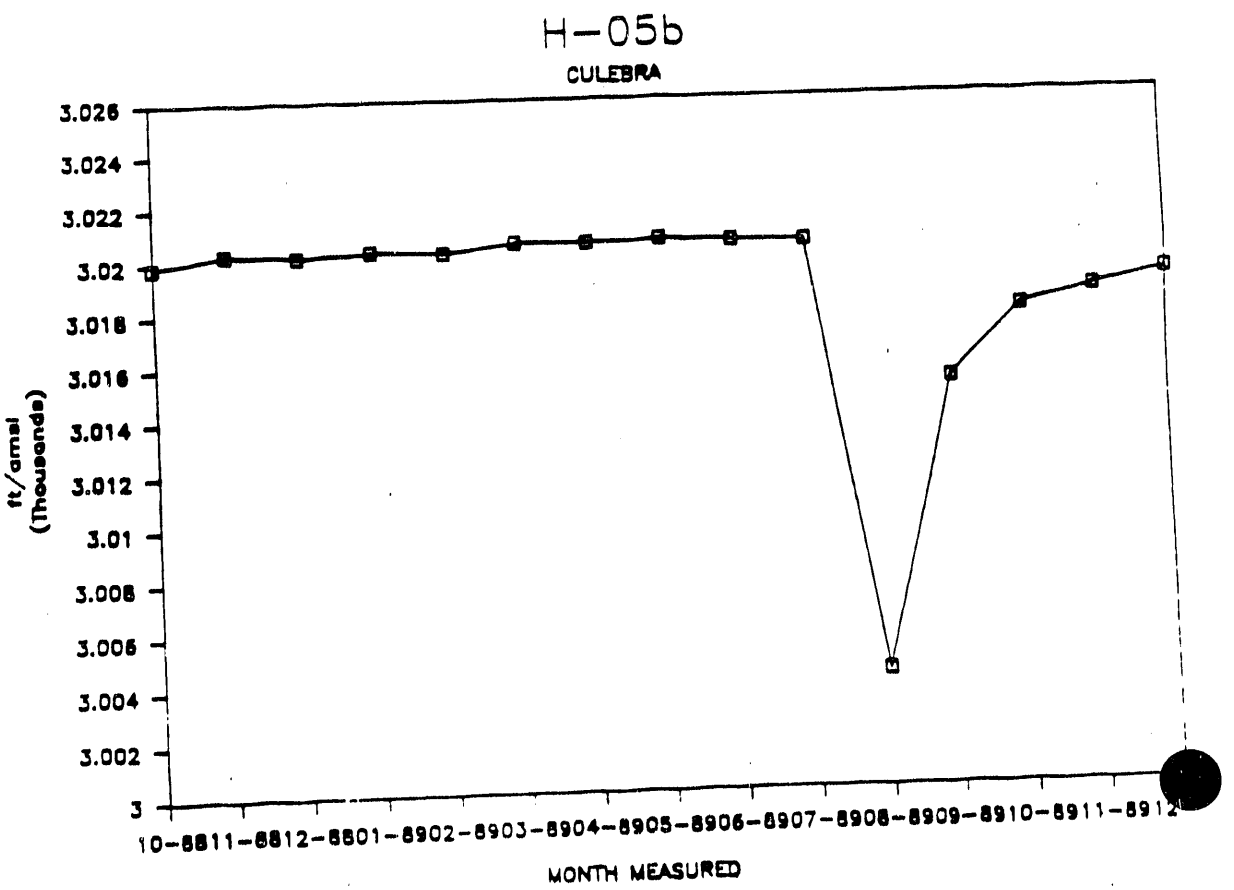

H-03d/49
FORTY-NINER
3.08
3.078
3.076
3.074
3.072
3.07
3.068
3.066
3.064
3.062
3.06
3.058
3.056
3.054
3.052
3.05
ft/amsl (Thousands)
10-88 11-88 12-88 01-89 02-89 03-89 04-89 05-89 07-89 08-89 09-89 10-89 11-89 12-89
MONTH MEASURED

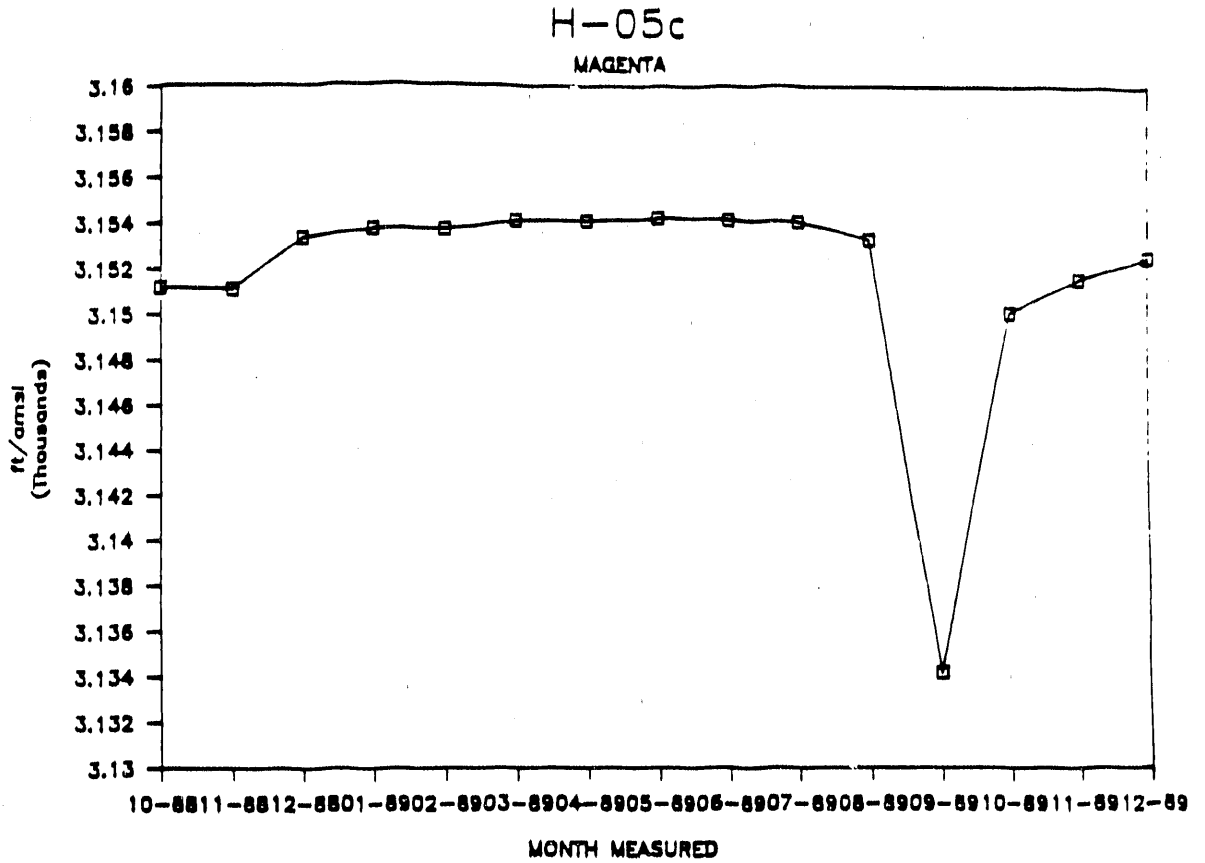

H-03d/DL
DEWEY LAKE
3.09
3.089
3.088
3.087
3.086
3.085
3.084
3.083
3.082
3.081
3.08
ft/amsl (Thousands)
10-88 11-88 12-88 01-89 02-89 03-89 04-89 05-89 07-89 08-89 09-89 10-89 11-89 12-89
MONTH MEASURED

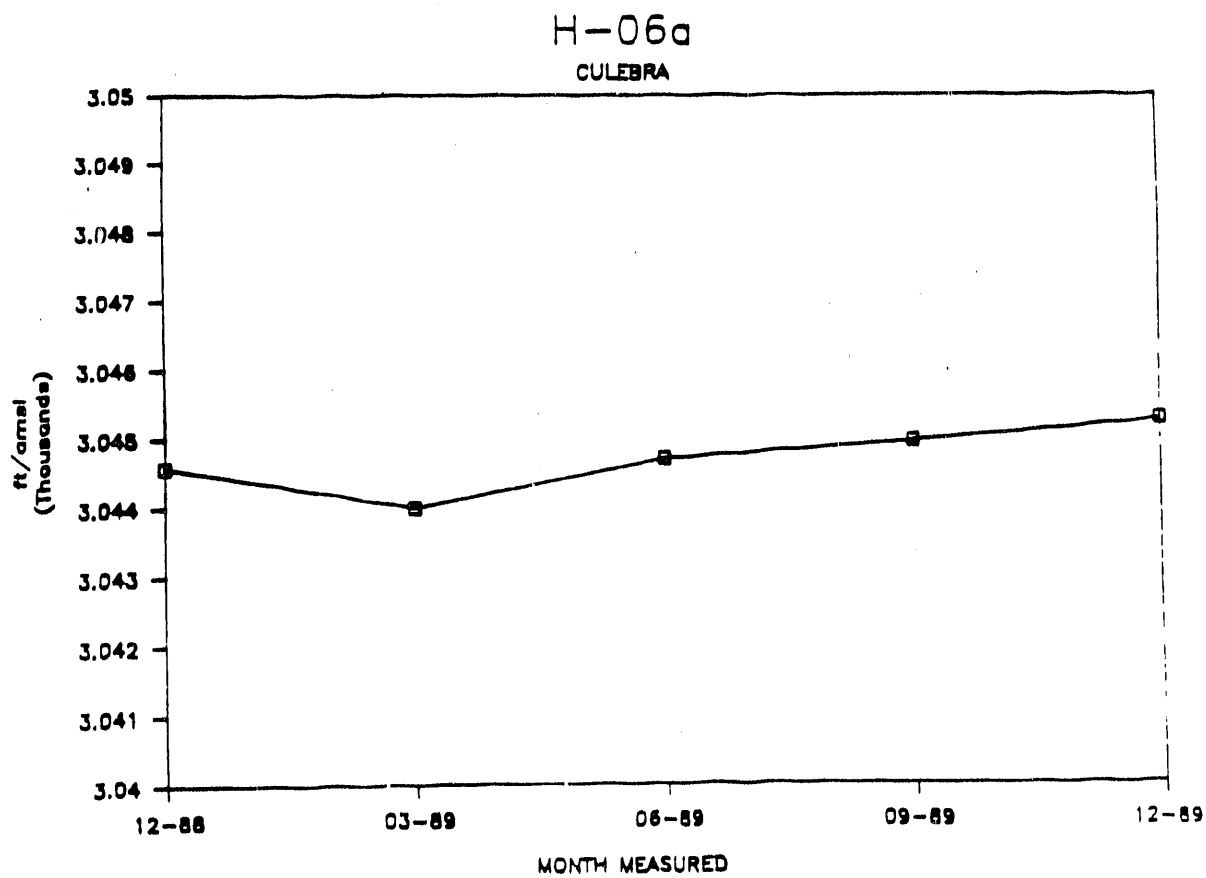

H-04b
CULEBRA
3
2.999
2.998
2.997
2.996
2.995
2.994
2.993
2.992
2.991
2.99
ft/amsl (Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

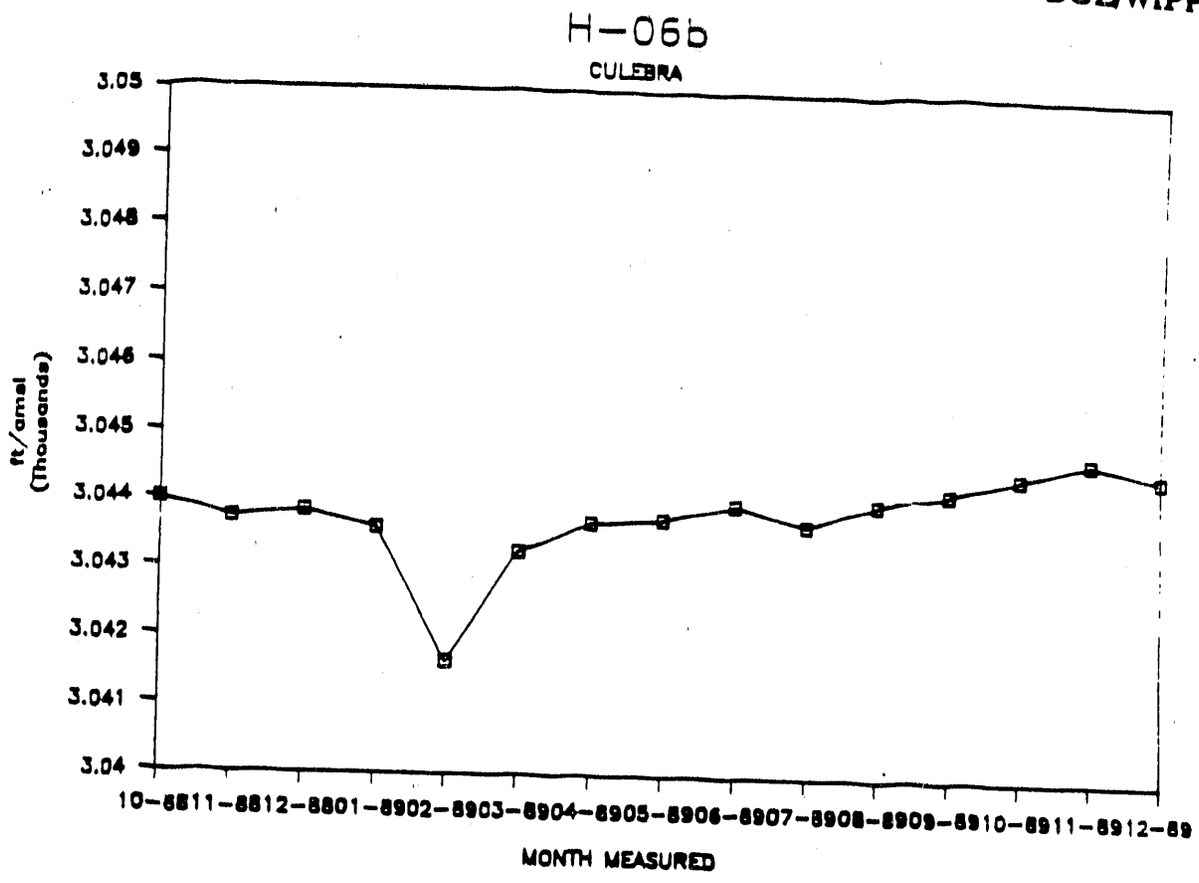

H-04c
MAGENTA
3.145
3.144
3.143
3.142
3.141
3.14
3.139
3.138
3.137
3.136
3.135
ft/amsl (Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

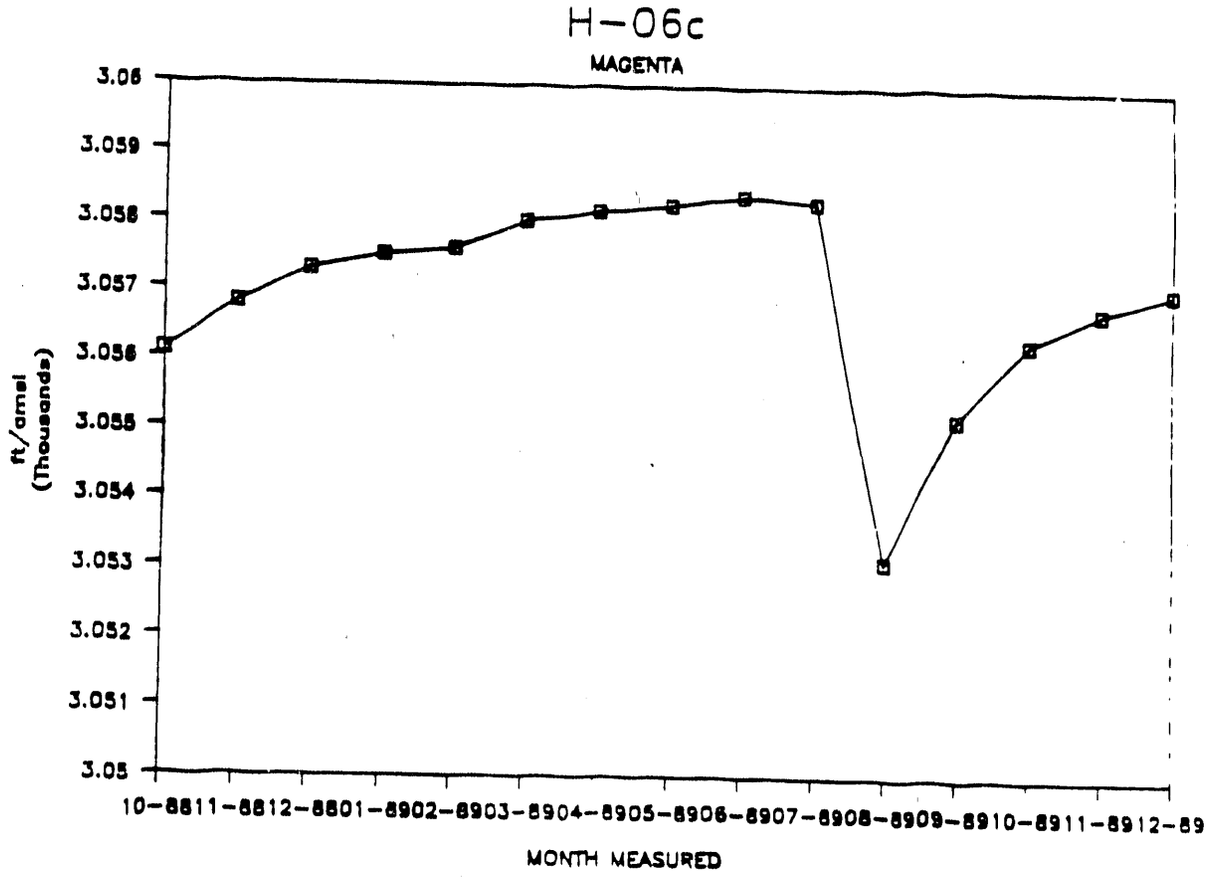

H-05a
CULEBRA
3.03
3.029
3.028
3.027
3.026
3.025
3.024
3.023
3.022
3.021
3.02
3.019
3.018
3.017
3.016
3.015
ft/amsl (Thousands)
12-88
03-89
06-89
09-89
12-89
MONTH MEASURED

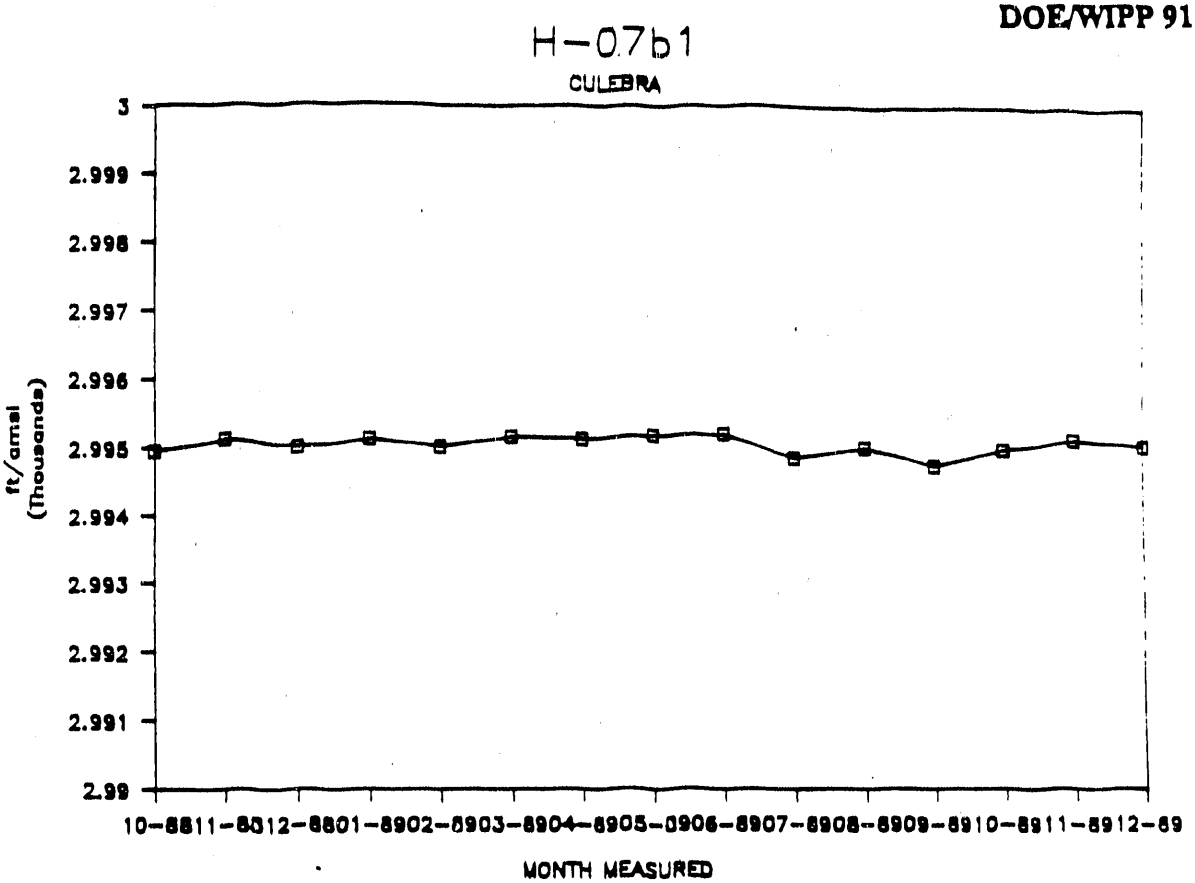

H-05b
CULEBRA
3.026
3.024
3.022
3.02
3.018
3.016
3.014
3.012
3.01
3.008
3.006
3.004
3.002
3
ft/amsl (Thousands)
10-8811-8812-8901-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912
MONTH MEASURED

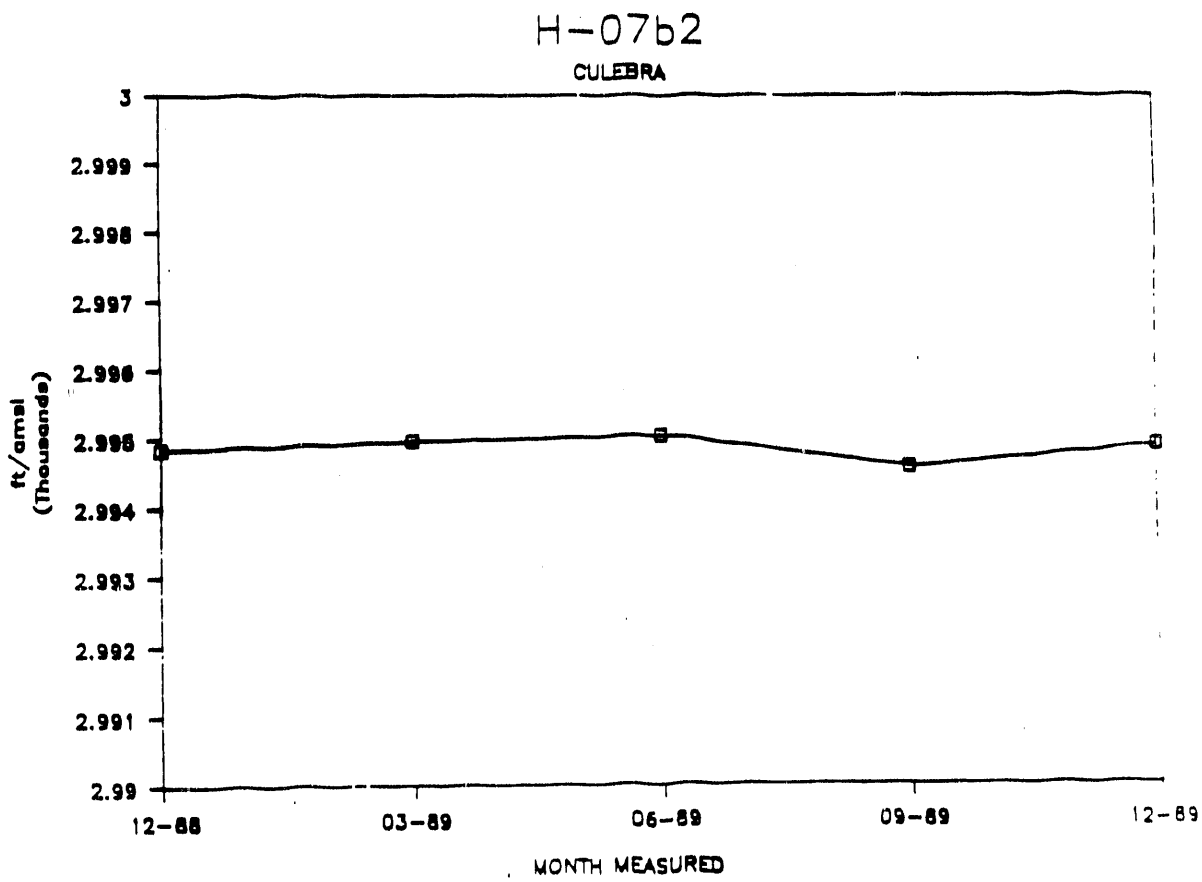

H-05c
MAGENTA
3.16
3.158
3.156
3.154
3.152
3.15
3.148
3.146
3.144
3.142
3.14
3.138
3.136
3.134
3.132
3.13
ft/amsl (Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

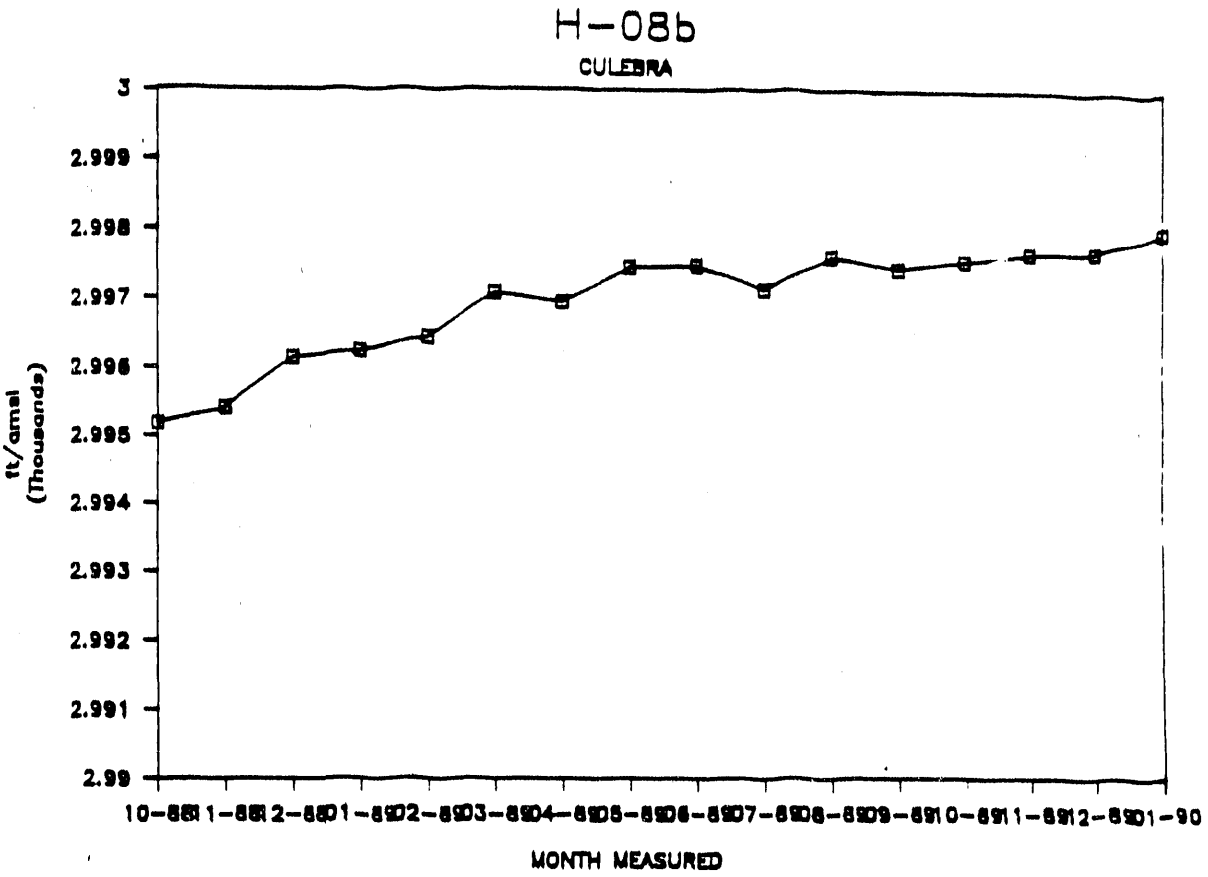

H-06a
CULEBRA
3.05
3.049
3.048
3.047
3.046
3.045
3.044
3.043
3.042
3.041
3.04
ft/amsl (Thousands)
12-88
03-89
06-89
09-89
12-89
MONTH MEASURED

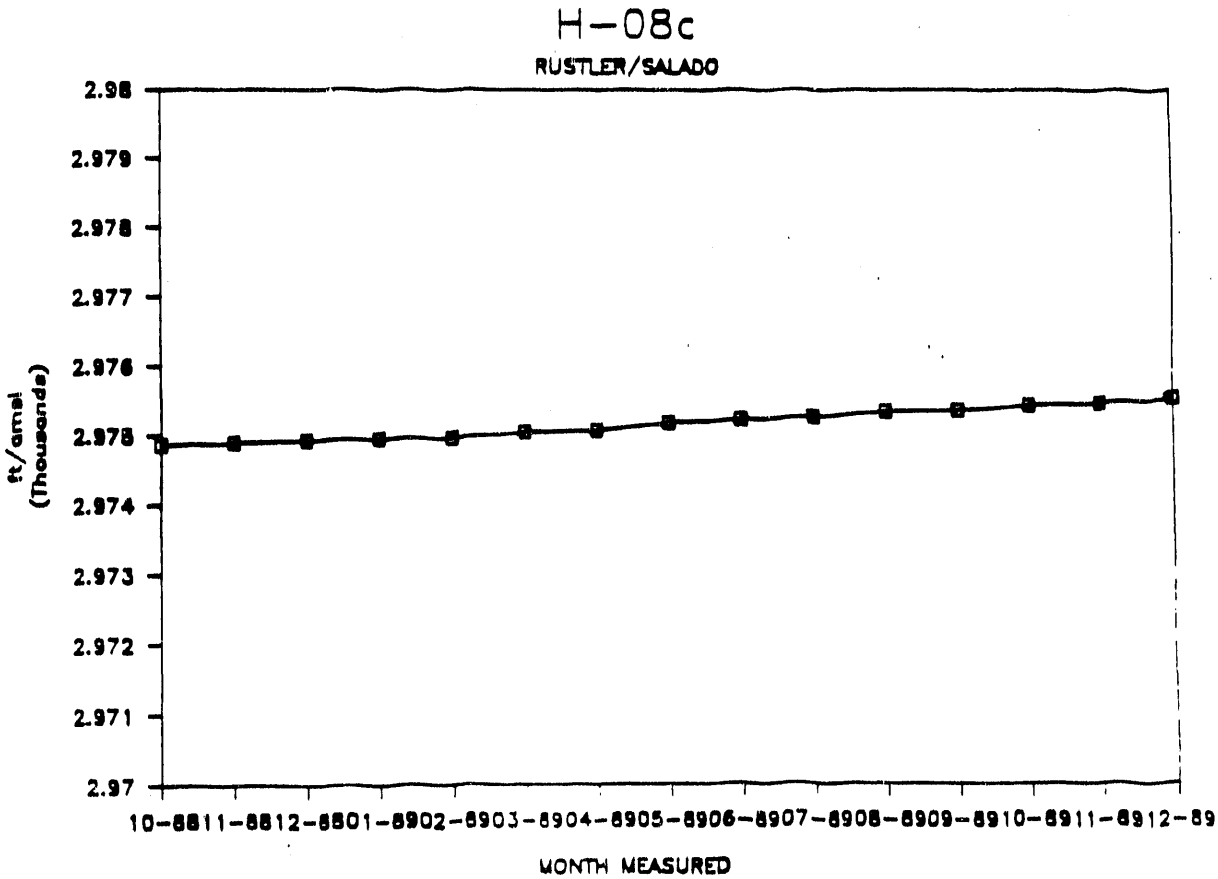

H-06b
CULEBRA
3.05
3.049
3.048
3.047
3.046
3.045
3.044
3.043
3.042
3.041
3.04
ft/amsl
(Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

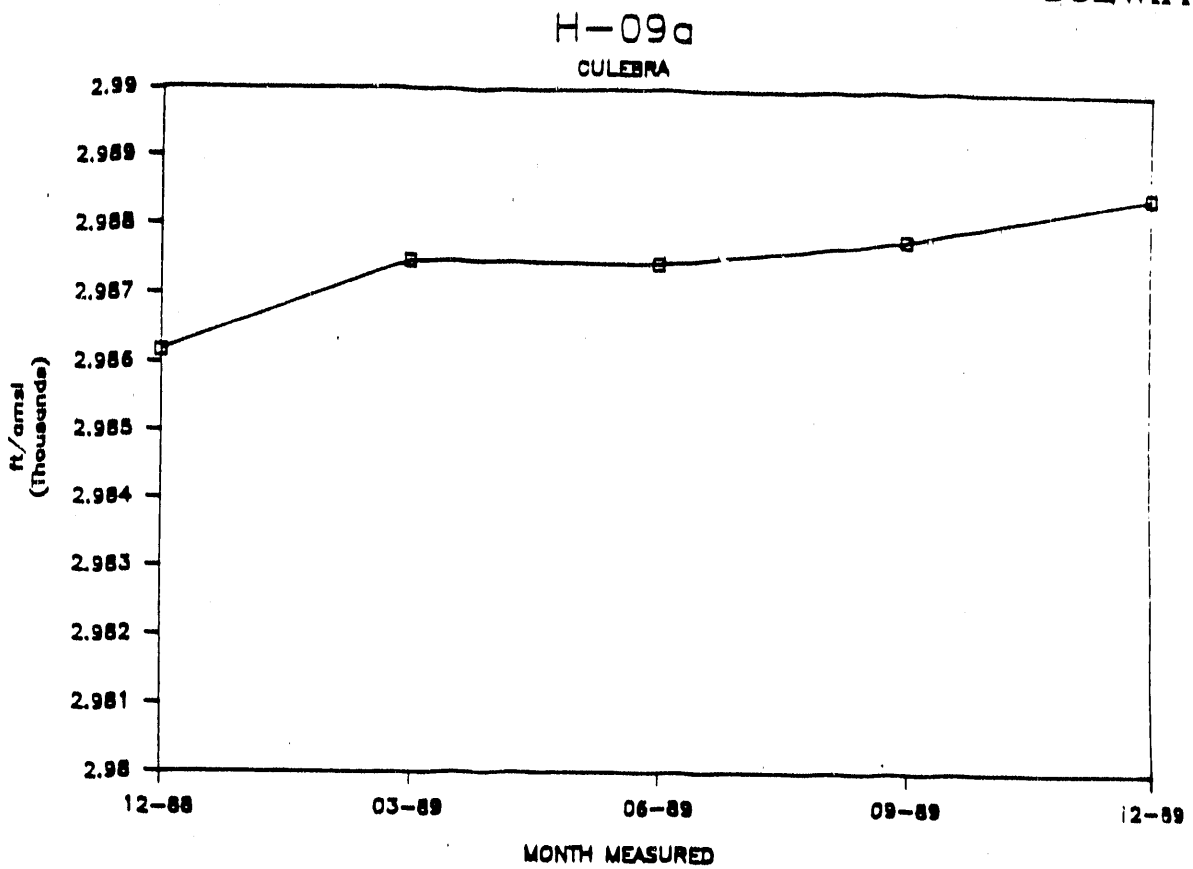

H-06c
MAGENTA
3.06
3.059
3.058
3.057
3.056
3.055
3.054
3.053
3.052
3.051
3.05
ft/amsl
(Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

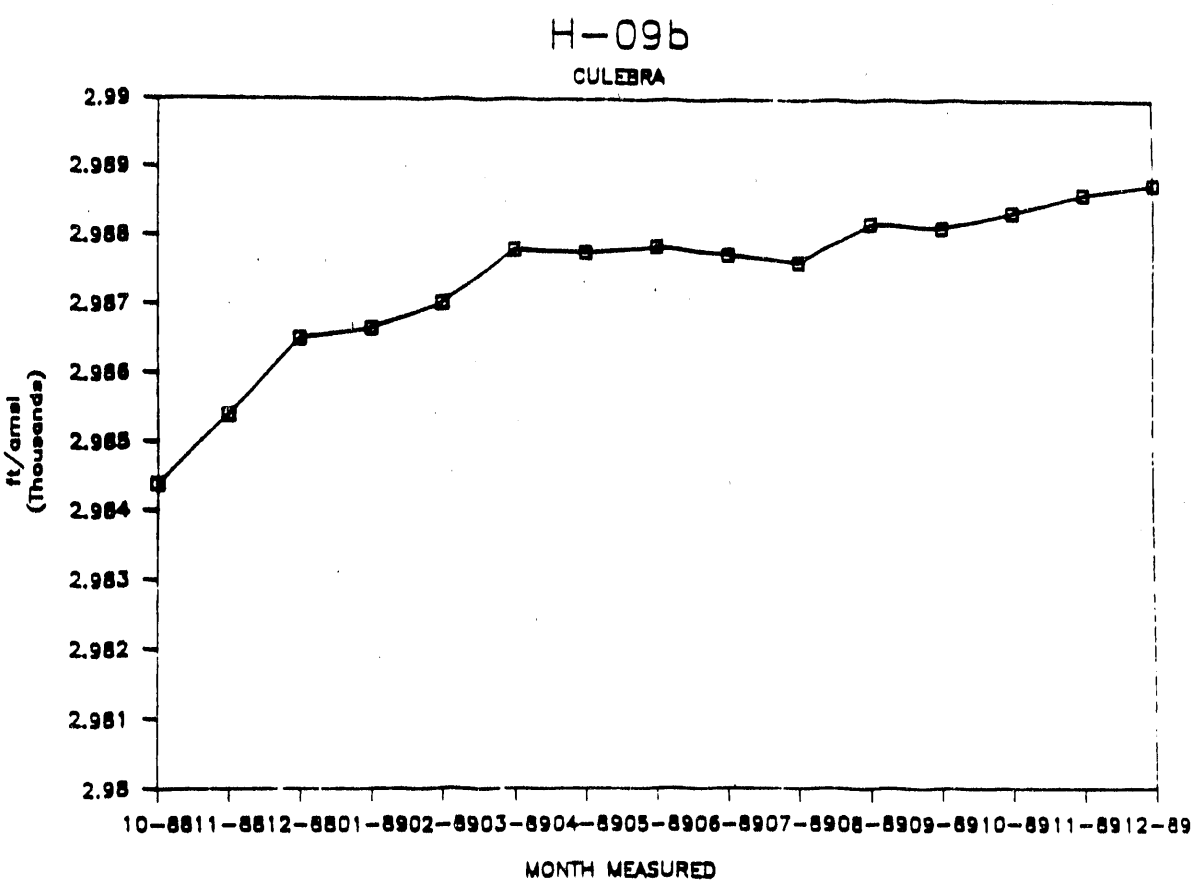

H-07b1
CULEBRA
3
2.999
2.998
2.997
2.996
2.995
2.994
2.993
2.992
2.991
2.99
ft/amsl (Thousands)
10-8811-8812-8901-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

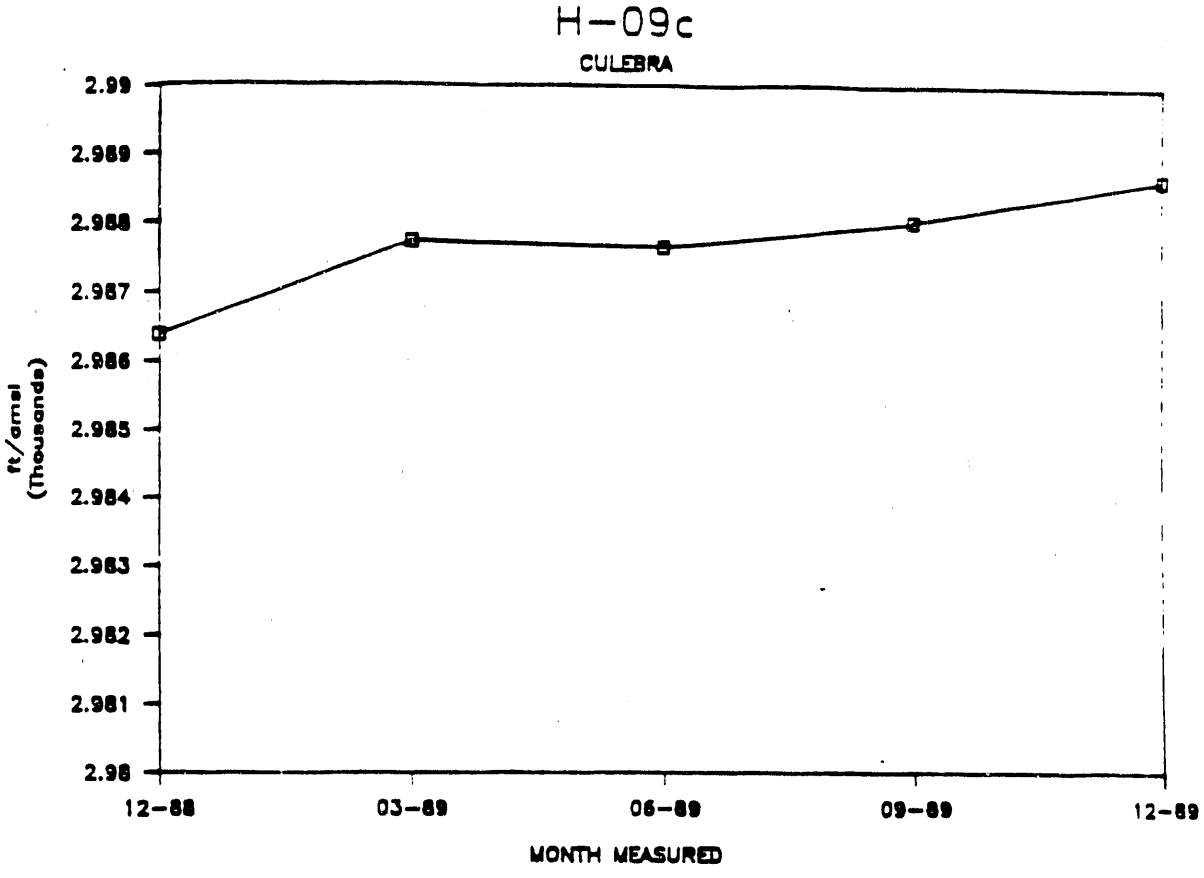

H-07b2
CULEBRA
3
2.999
2.998
2.997
2.996
2.995
2.994
2.993
2.992
2.991
2.99
ft/amsl (Thousands)
12-88
03-89
06-89
09-89
12-89
MONTH MEASURED

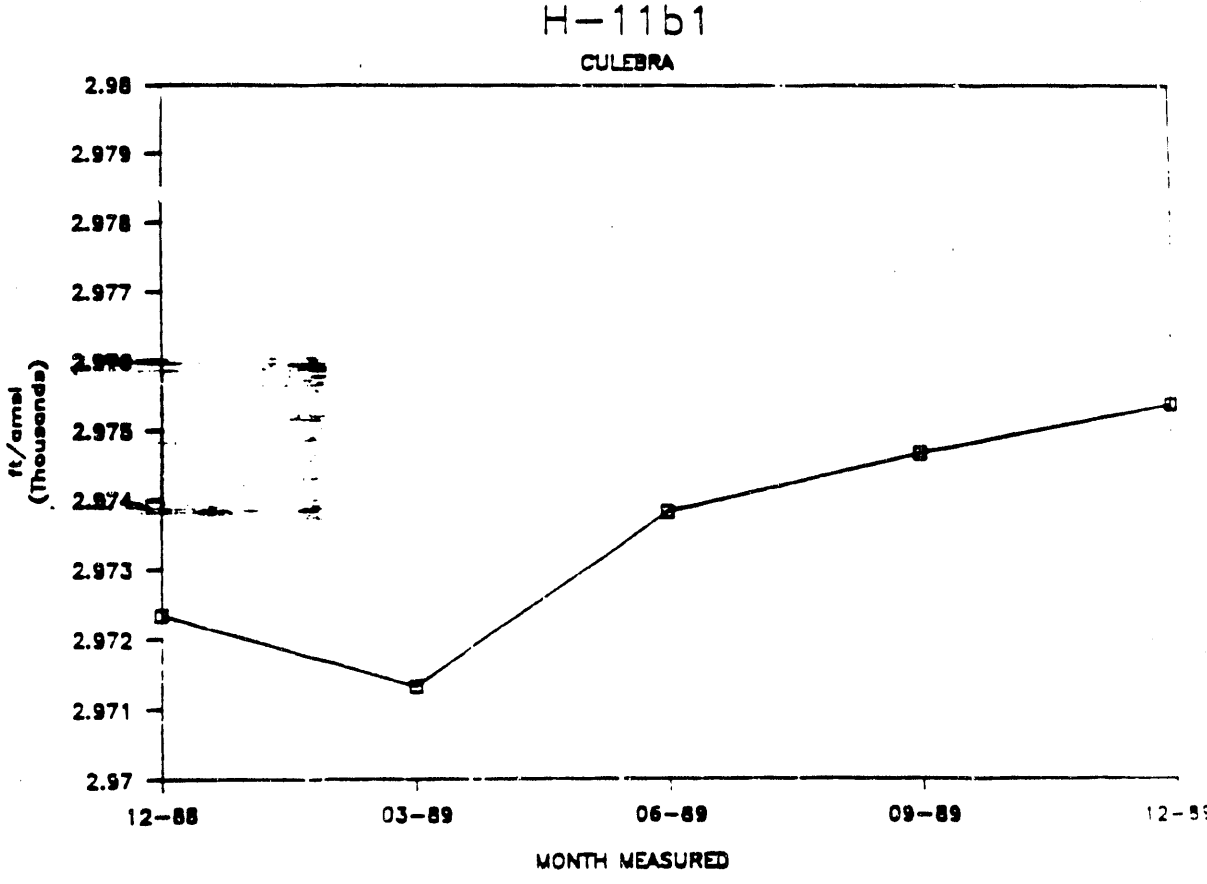

H-08b
CULEBRA
3
2.999
2.998
2.997
2.996
2.995
2.994
2.993
2.992
2.991
2.99
ft/amsl
(Thousands)
10-8811-8812-8901-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-8901-90
MONTH MEASURED

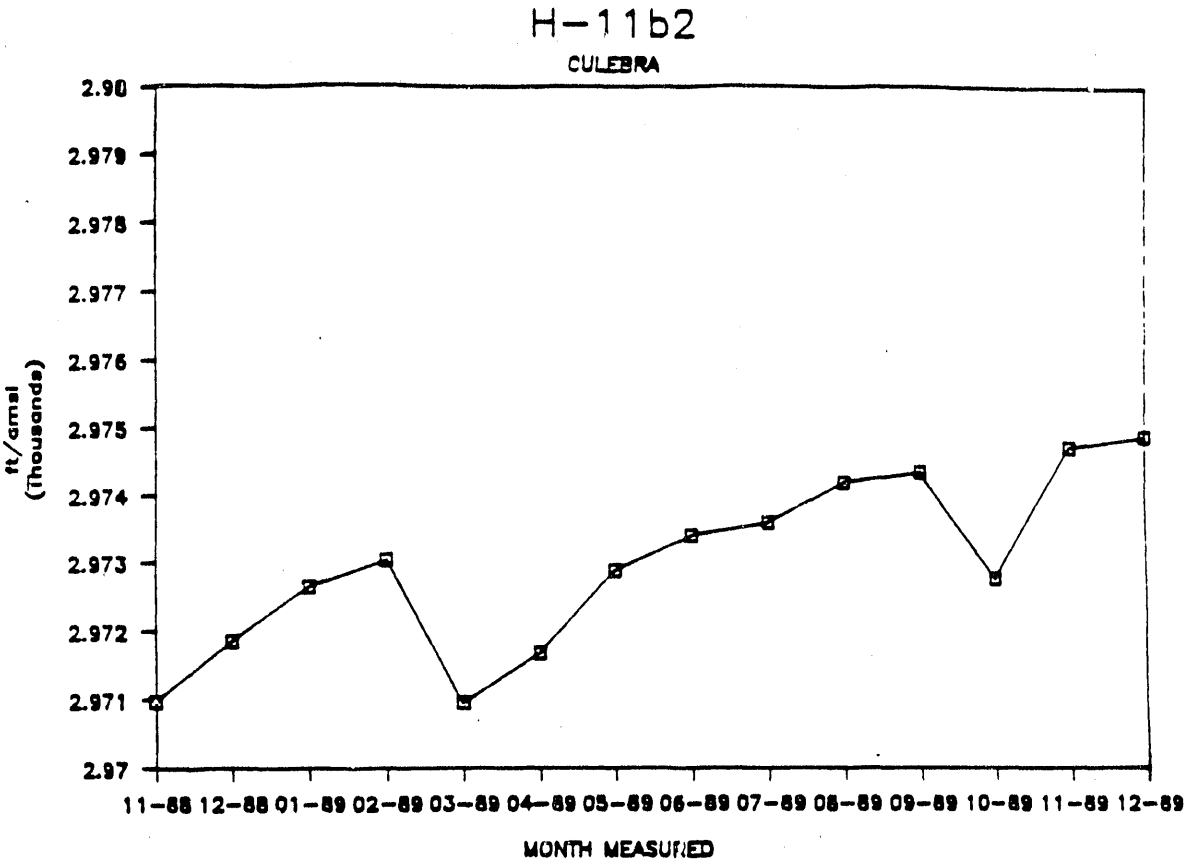

H-08c
RUSTLER/SALADO
2.98
2.979
2.978
2.977
2.976
2.975
2.974
2.973
2.972
2.971
2.97
ft/amsl
(Thousands)
10-8811-8812-8901-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

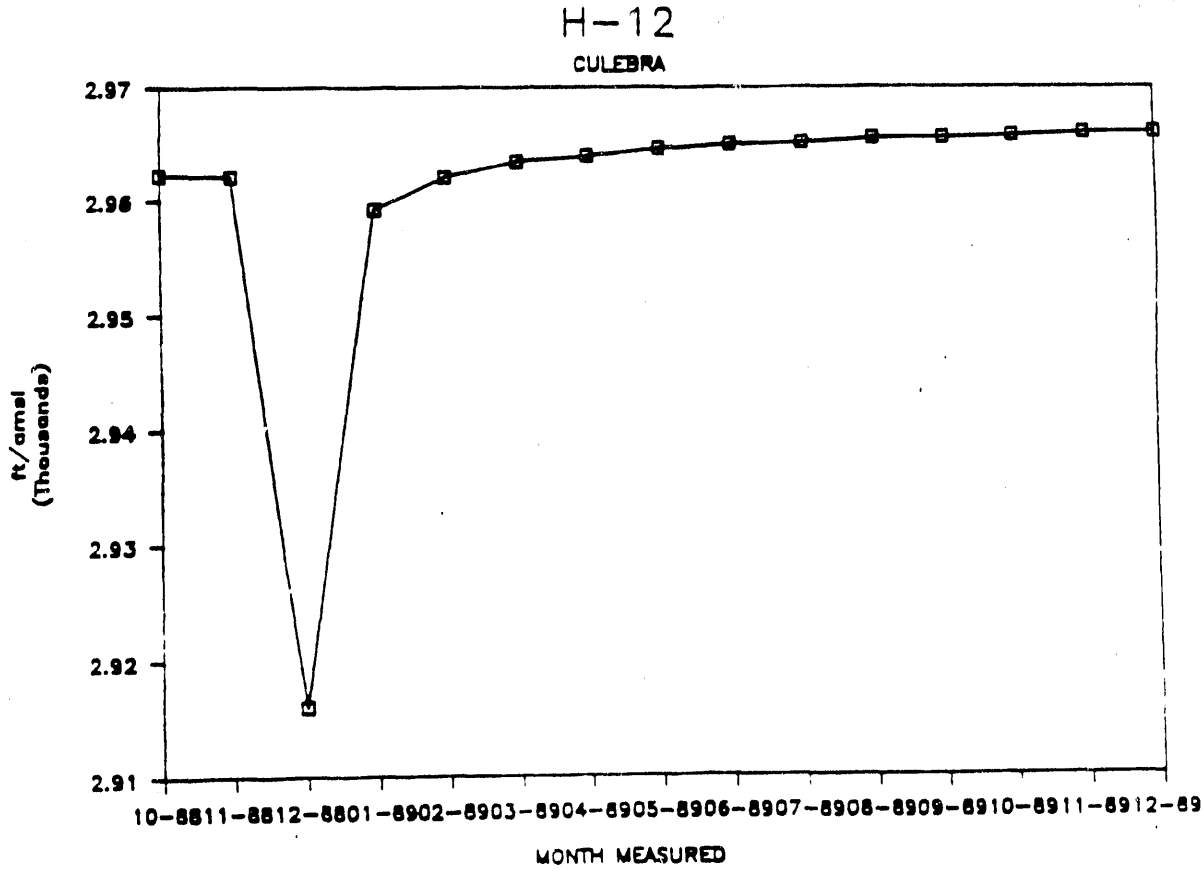

H-09a
CULEBRA
2.99
2.989
2.988
2.987
2.986
2.985
2.984
2.983
2.982
2.981
2.98
ft/amsl (Thousands)
12-88
03-89
06-89
09-89
12-89
MONTH MEASURED

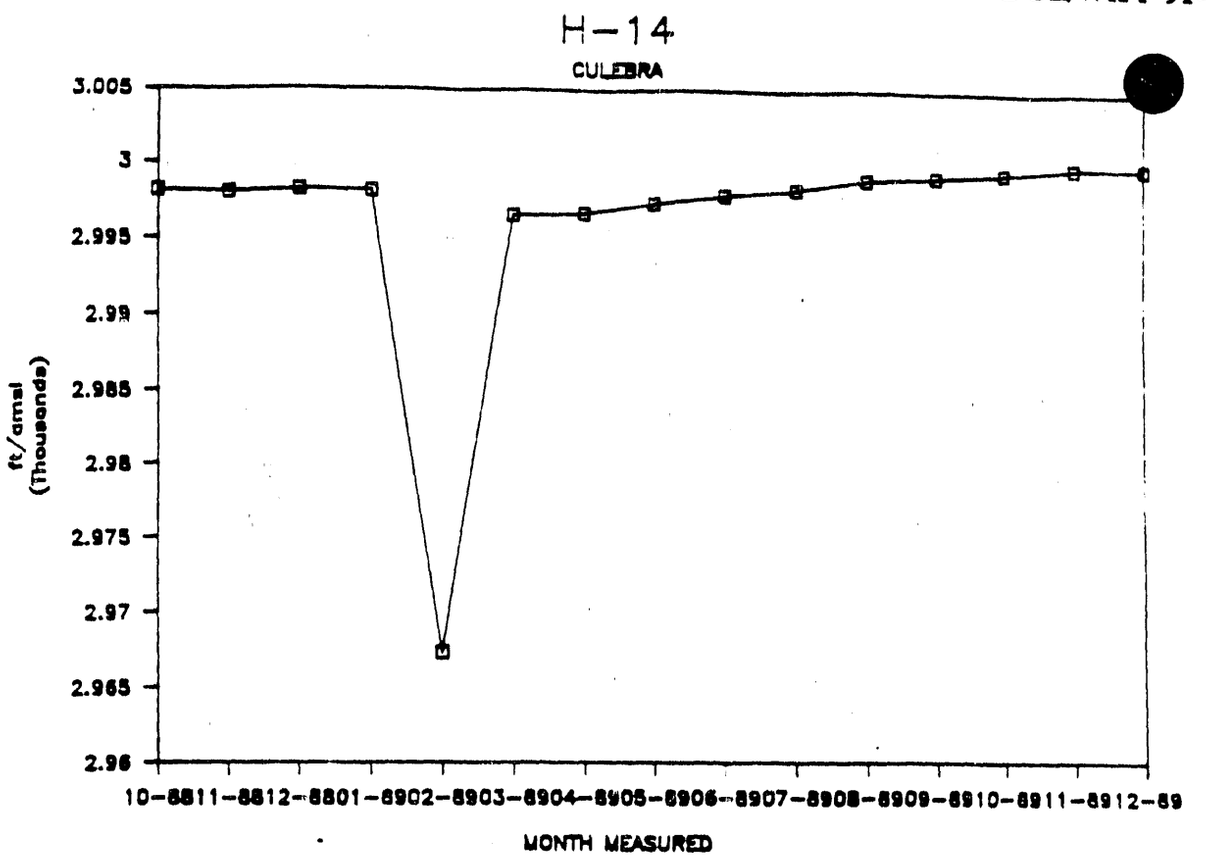

H-09b
CULEBRA
2.99
2.989
2.988
2.987
2.986
2.985
2.984
2.983
2.982
2.981
2.98
ft/amsl (Thousands)
10-8811-8812-8901-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

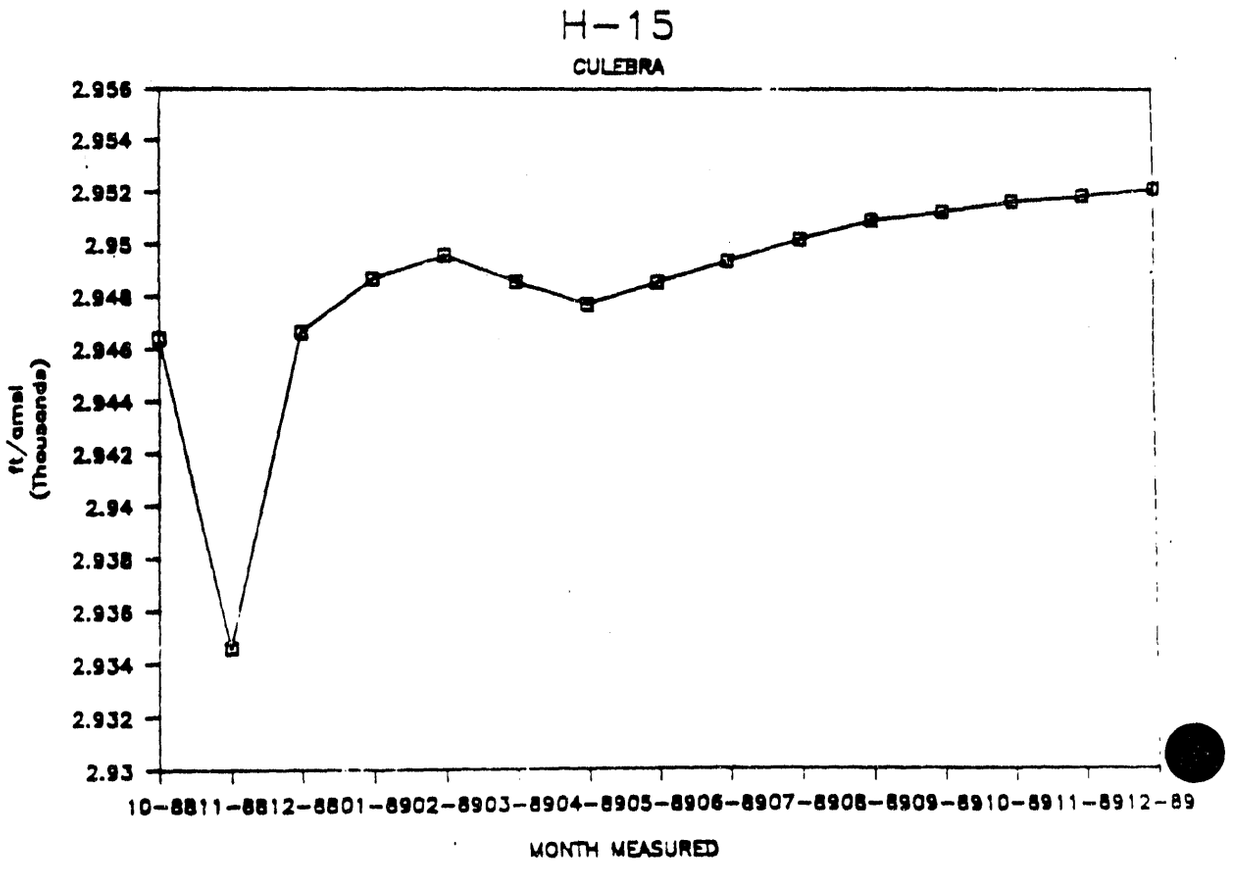

H-09c
CULEBRA
2.99
2.989
2.988
2.987
2.986
2.985
2.984
2.983
2.982
2.981
2.98
ft/amsl (Thousands)
12-88
03-89
06-89
09-89
12-89
MONTH MEASURED

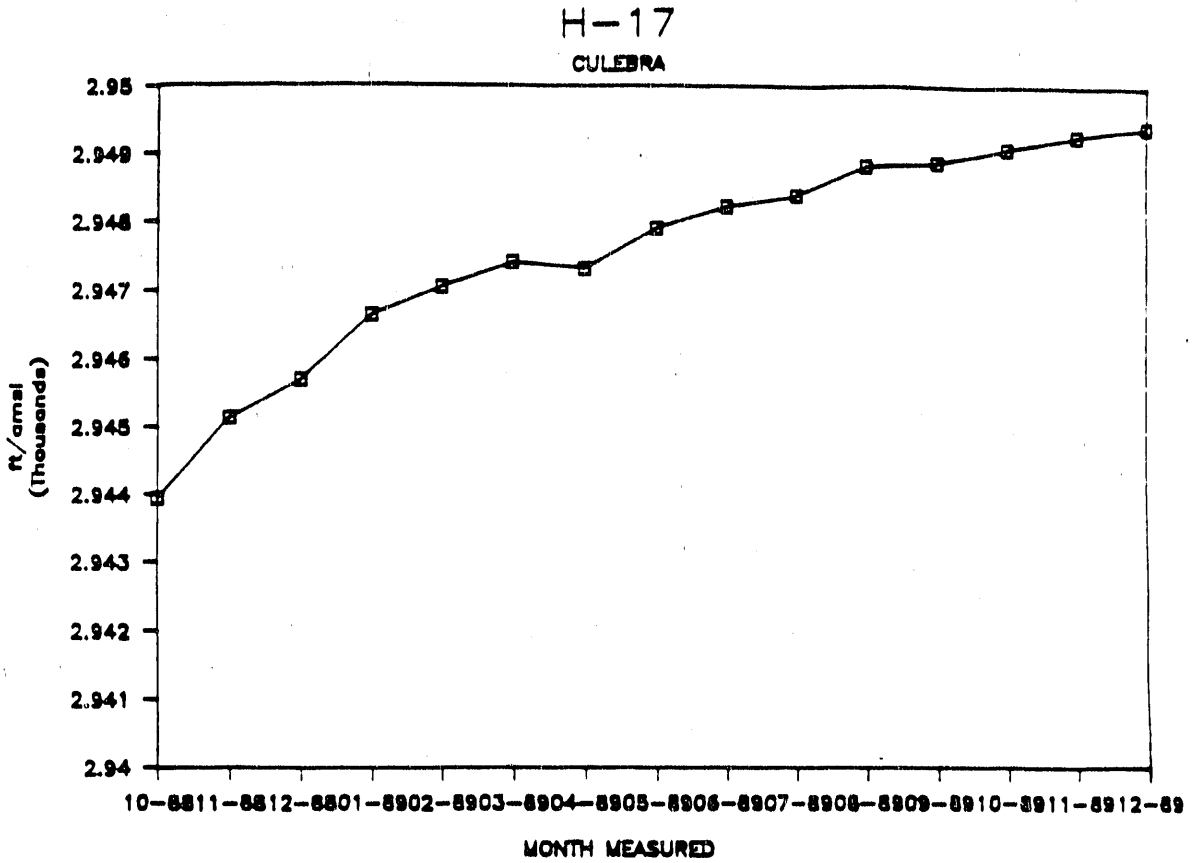

H-11b1
CULEBRA
2.98
2.979
2.978
2.977
2.976
2.975
2.974
2.973
2.972
2.971
2.97
ft/amsl (Thousands)
12-88
03-89
06-89
09-89
12-89
MONTH MEASURED

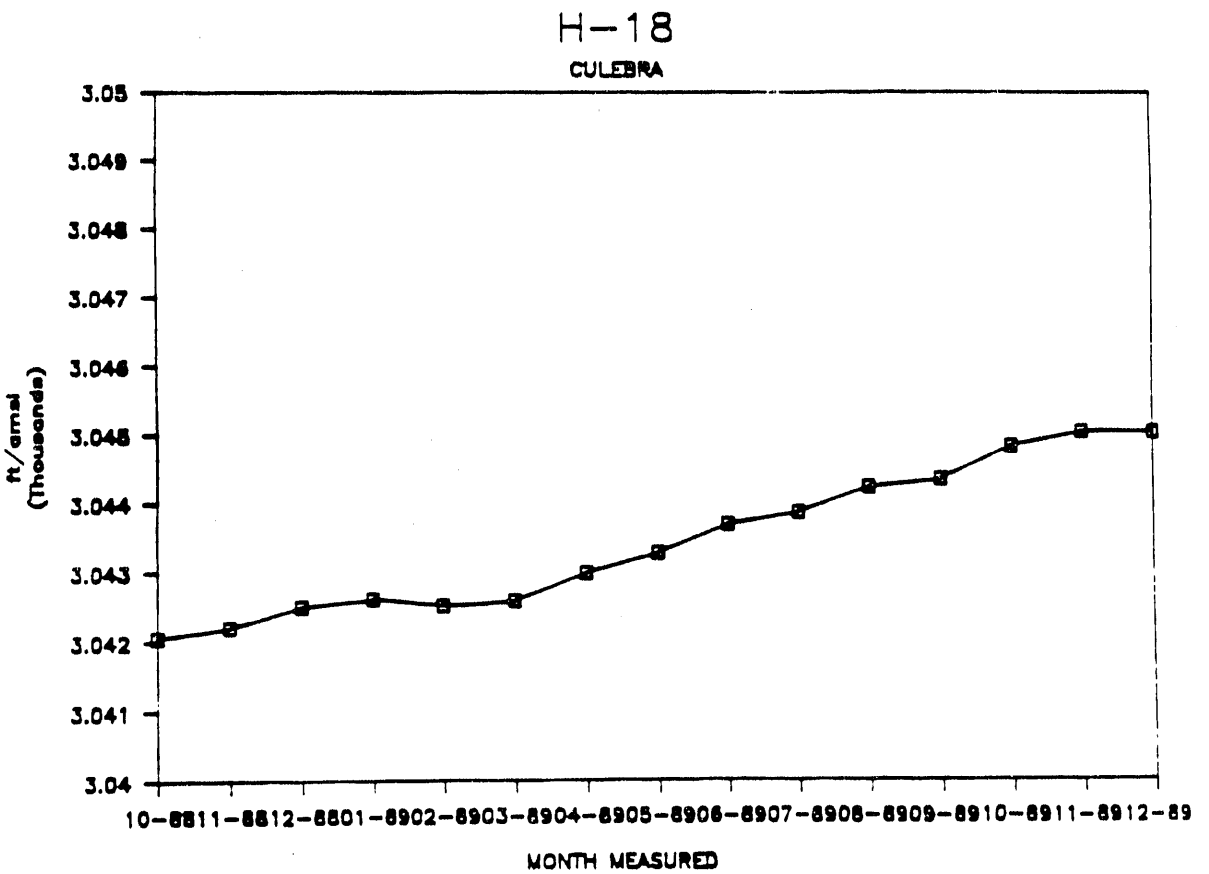

H-11b2
CULEBRA
2.98
2.979
2.978
2.977
2.976
2.975
2.974
2.973
2.972
2.971
2.97
ft/amsl (Thousands)
11-88 12-88 01-89 02-89 03-89 04-89 05-89 06-89 07-89 08-89 09-89 10-89 11-89 12-89
MONTH MEASURED

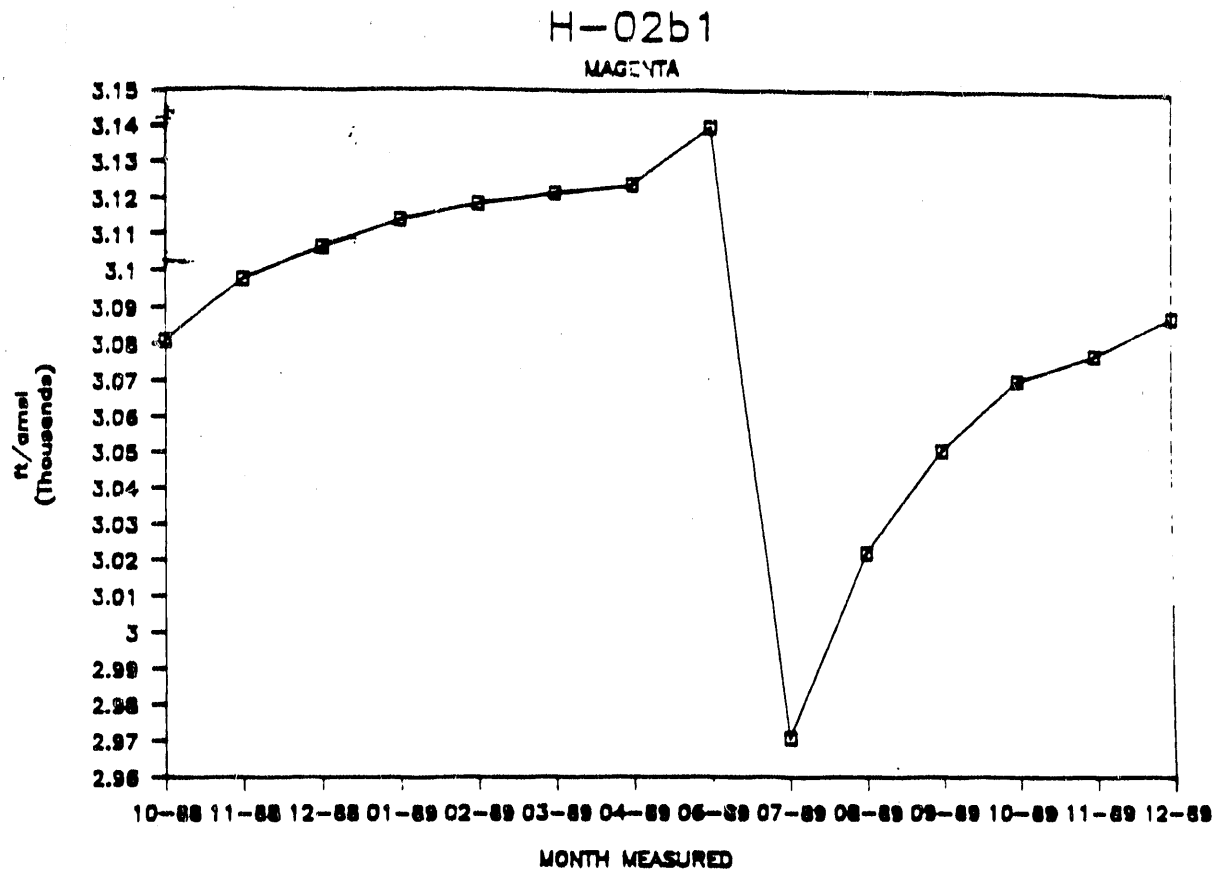

H-12
CULEBRA
2.97
2.96
2.95
2.94
2.93
2.92
2.91
ft/amsl (Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

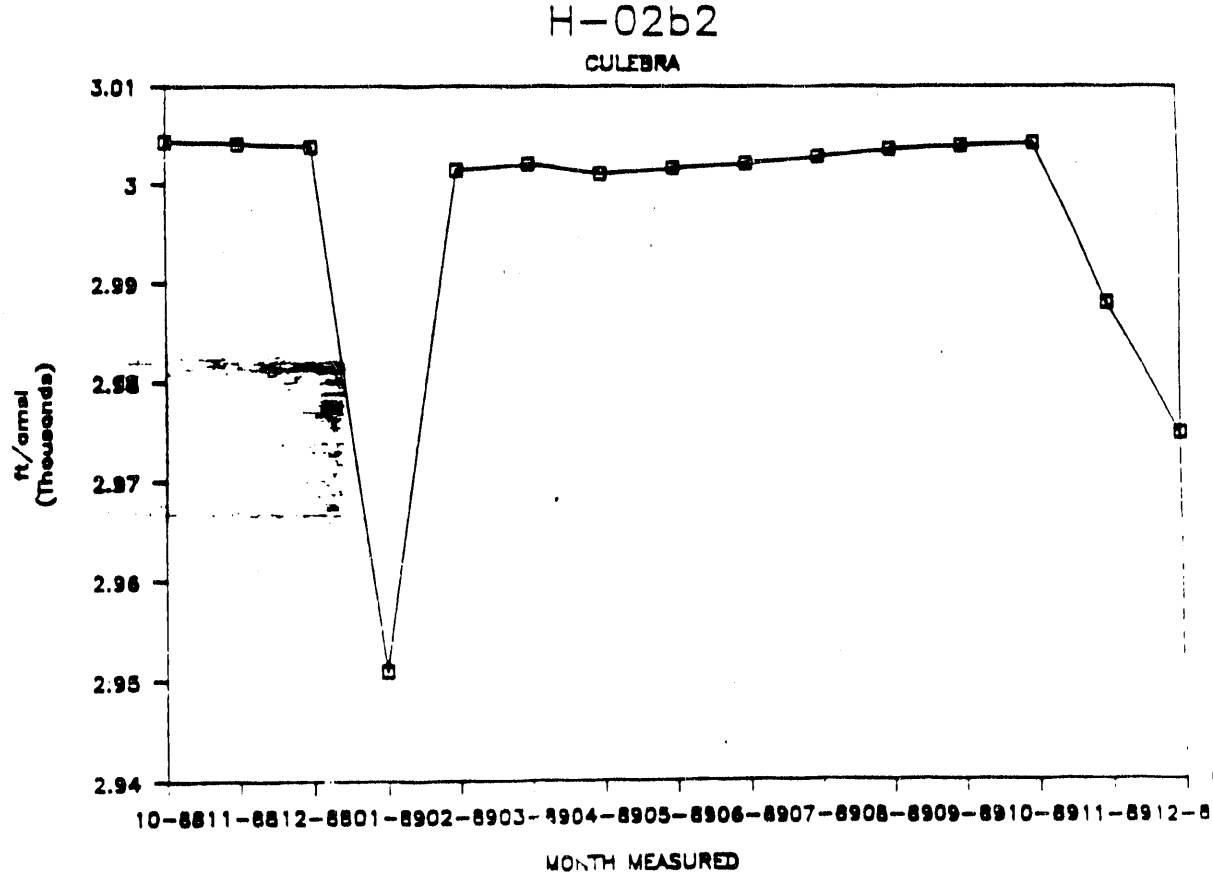

H-14
CULEBRA
3.005
3
2.995
2.99
2.985
2.98
2.975
2.97
2.965
2.96
ft/amsl (Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

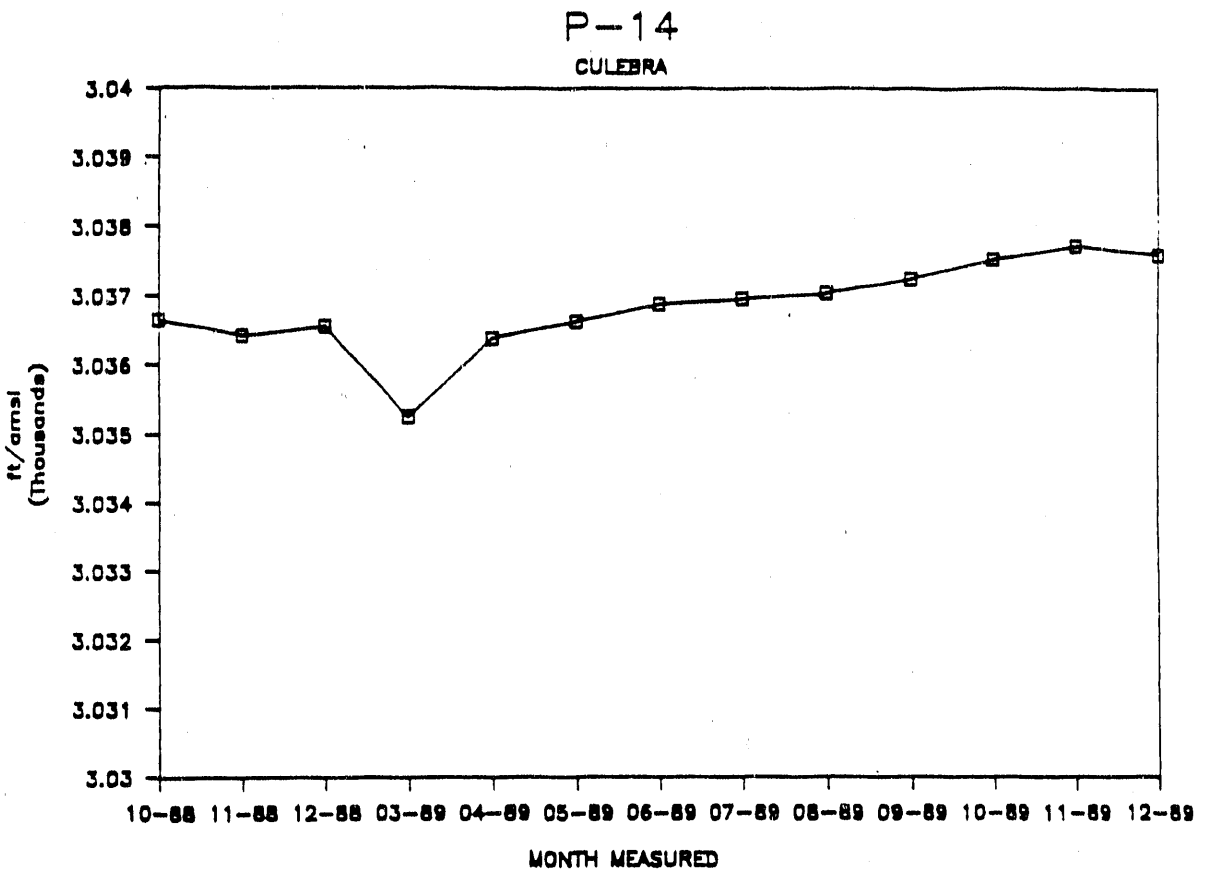

H-15
CULEBRA
2.956
2.954
2.952
2.95
2.948
2.946
2.944
2.942
2.94
2.938
2.936
2.934
2.932
2.93
ft/amsl (Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

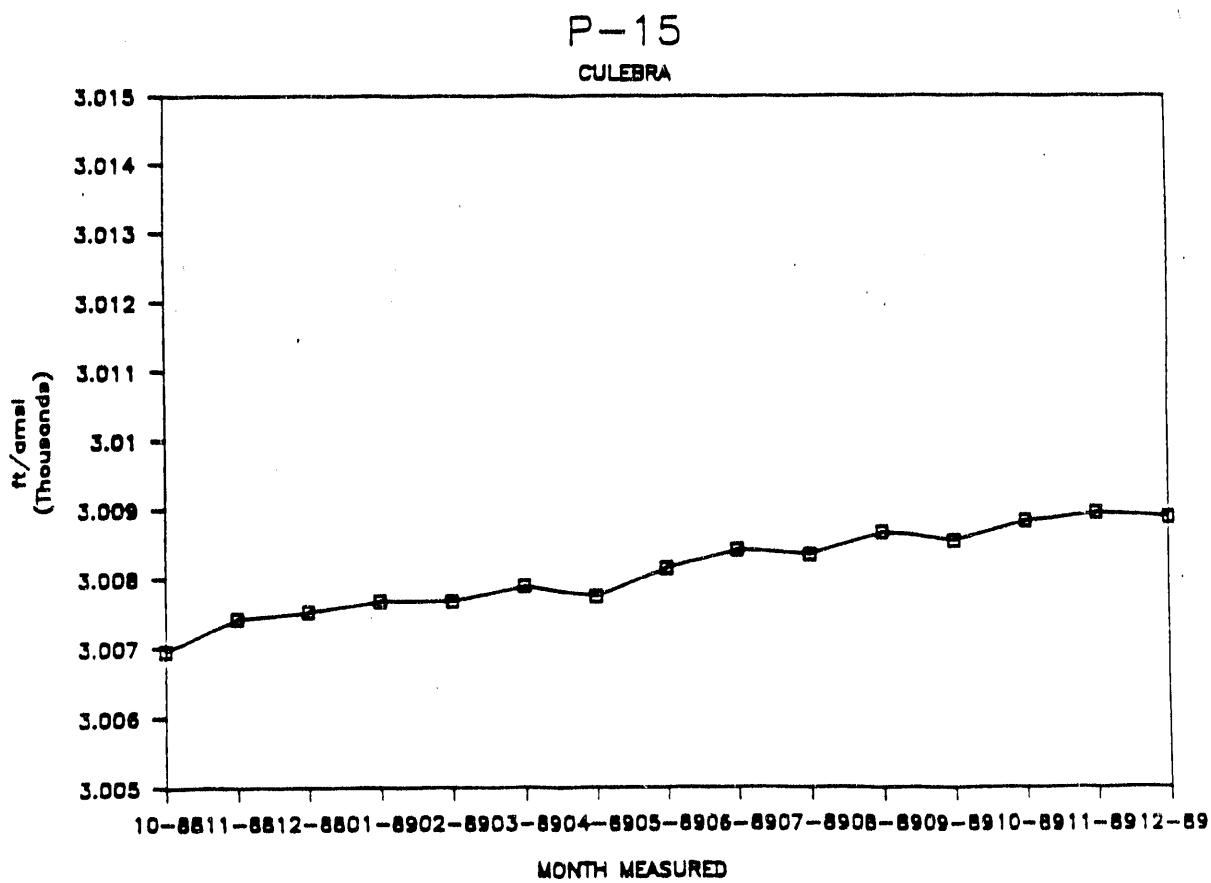

H-17
CULEBRA
2.95
2.949
2.948
2.947
2.946
2.945
2.944
2.943
2.942
2.941
2.94
ft/amsl (Thousands)
10-8811-8812-8901-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

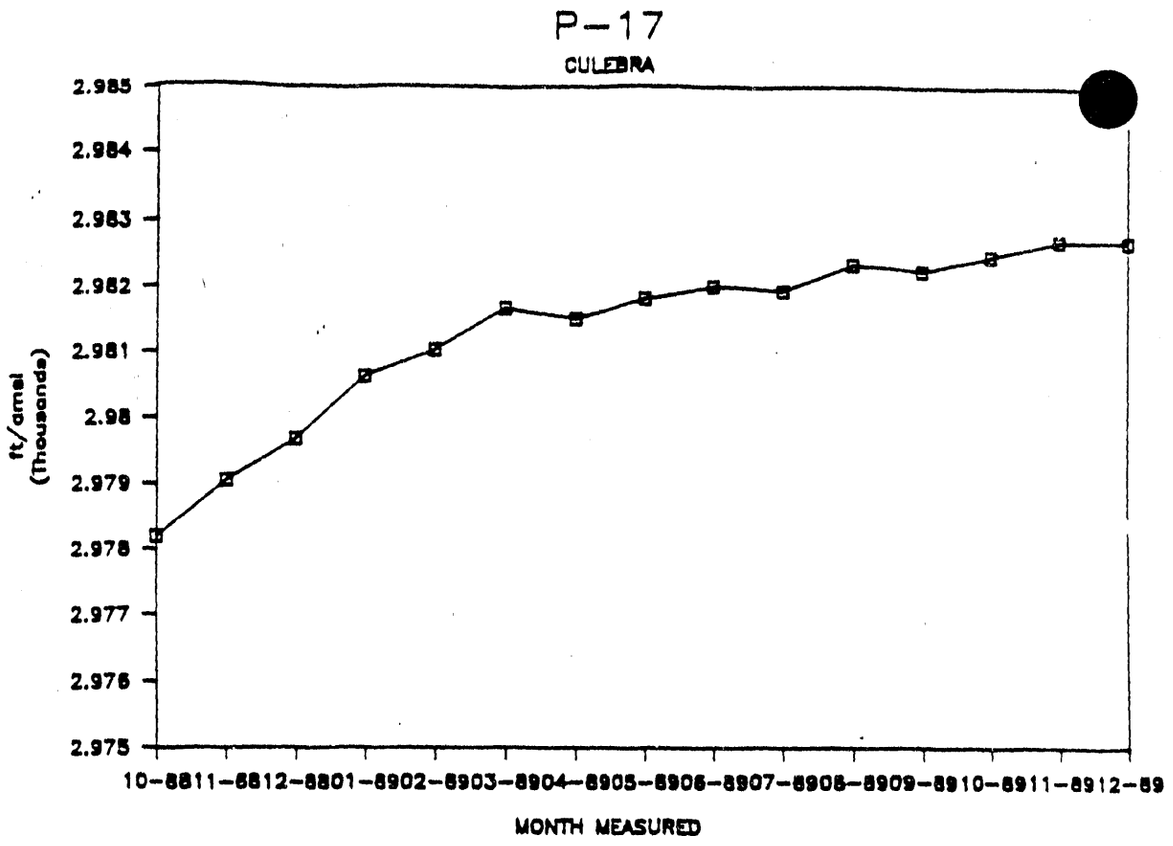

H-18
CULEBRA
3.05
3.049
3.048
3.047
3.046
3.045
3.044
3.043
3.042
3.041
3.04
ft/amsl (Thousands)
10-8811-8812-8901-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

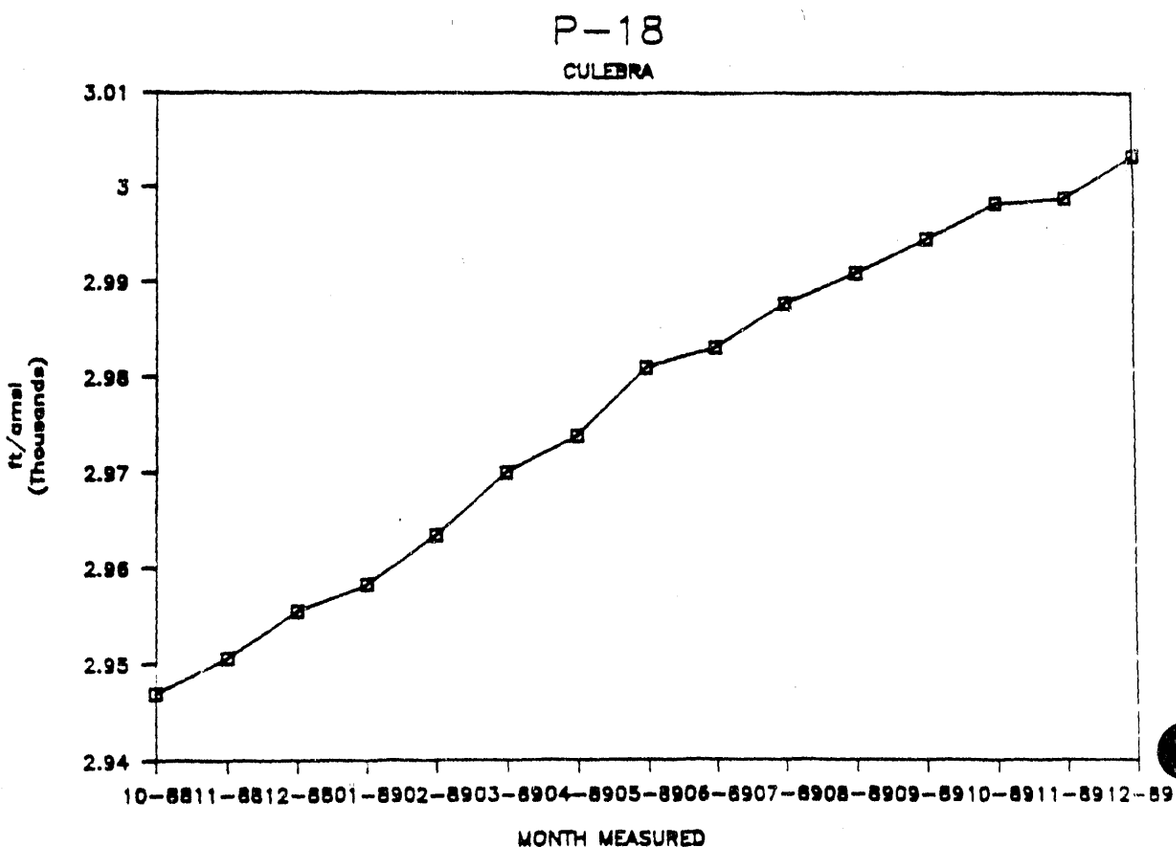

H-02b1
MAGENTA
ft/amsl (Thousands)
3.15
3.14
3.13
3.12
3.11
3.1
3.09
3.08
3.07
3.06
3.05
3.04
3.03
3.02
3.01
3
2.99
2.98
2.97
2.96
10-88 11-88 12-88 01-89 02-89 03-89 04-89 06-89 07-89 08-89 09-89 10-89 11-89 12-89
MONTH MEASURED

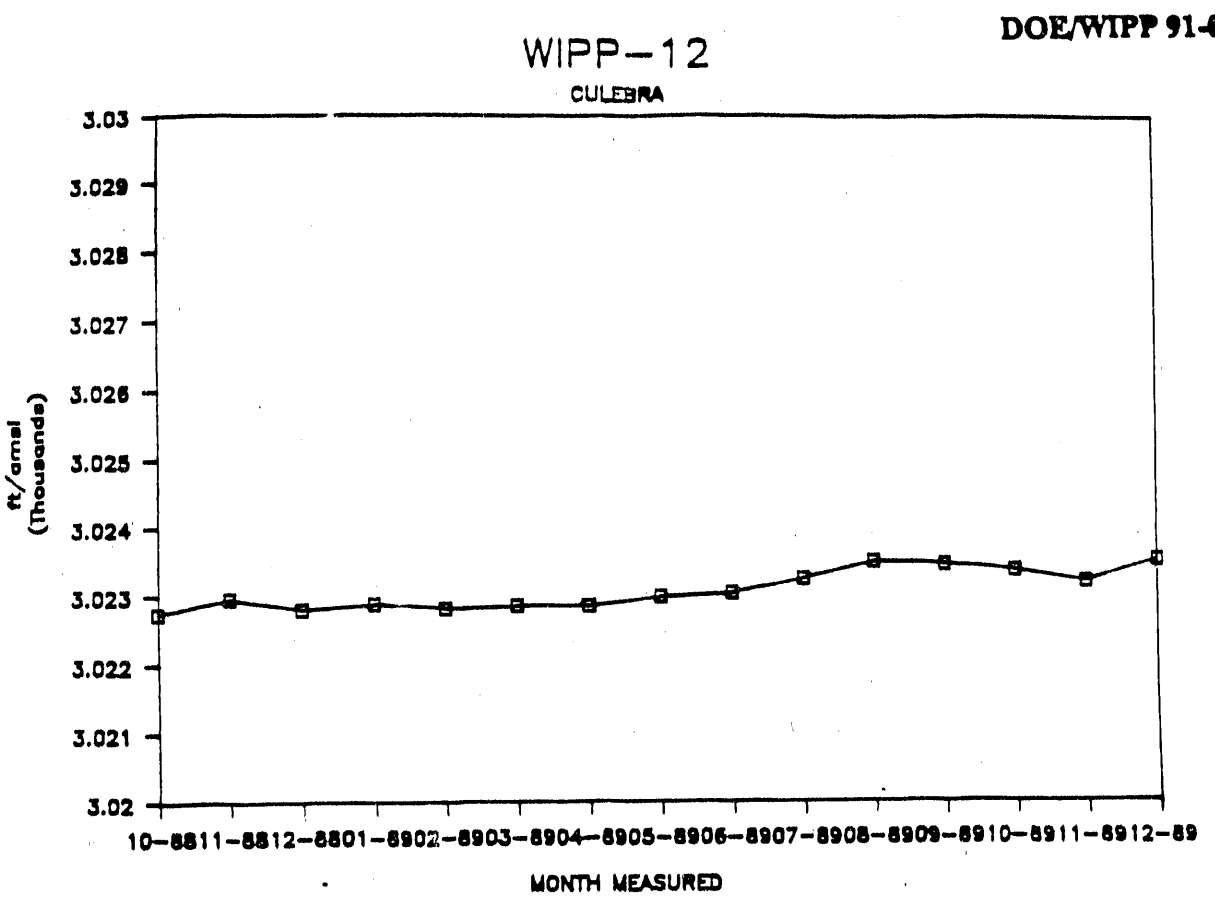

H-02b2
CULEBRA
ft/amsl (Thousands)
3.01
3
2.99
2.98
2.97
2.96
2.95
2.94
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

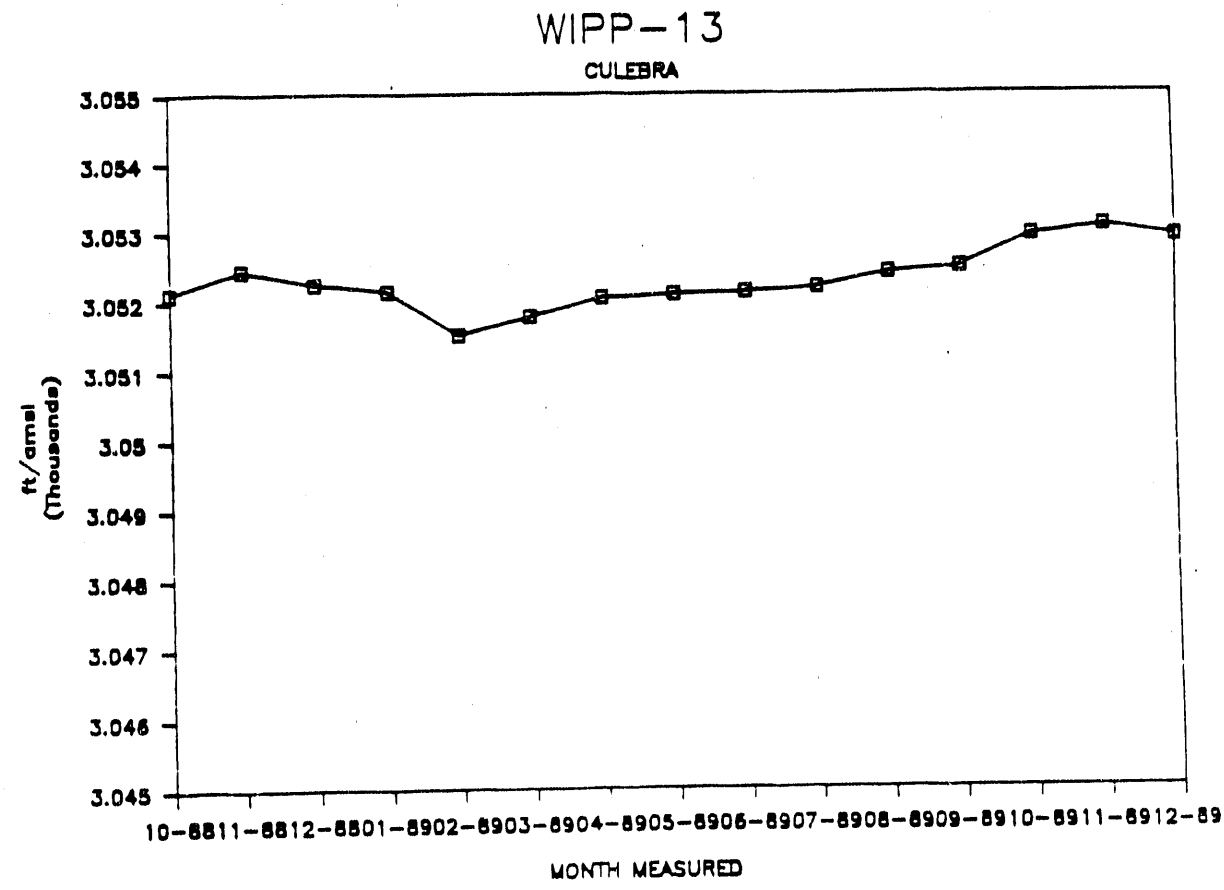

P-14
CULEBRA
3.04
3.039
3.038
3.037
3.036
3.035
3.034
3.033
3.032
3.031
3.03
ft/amsl (Thousands)
10-88 11-88 12-88 03-89 04-89 05-89 06-89 07-89 08-89 09-89 10-89 11-89 12-89
MONTH MEASURED

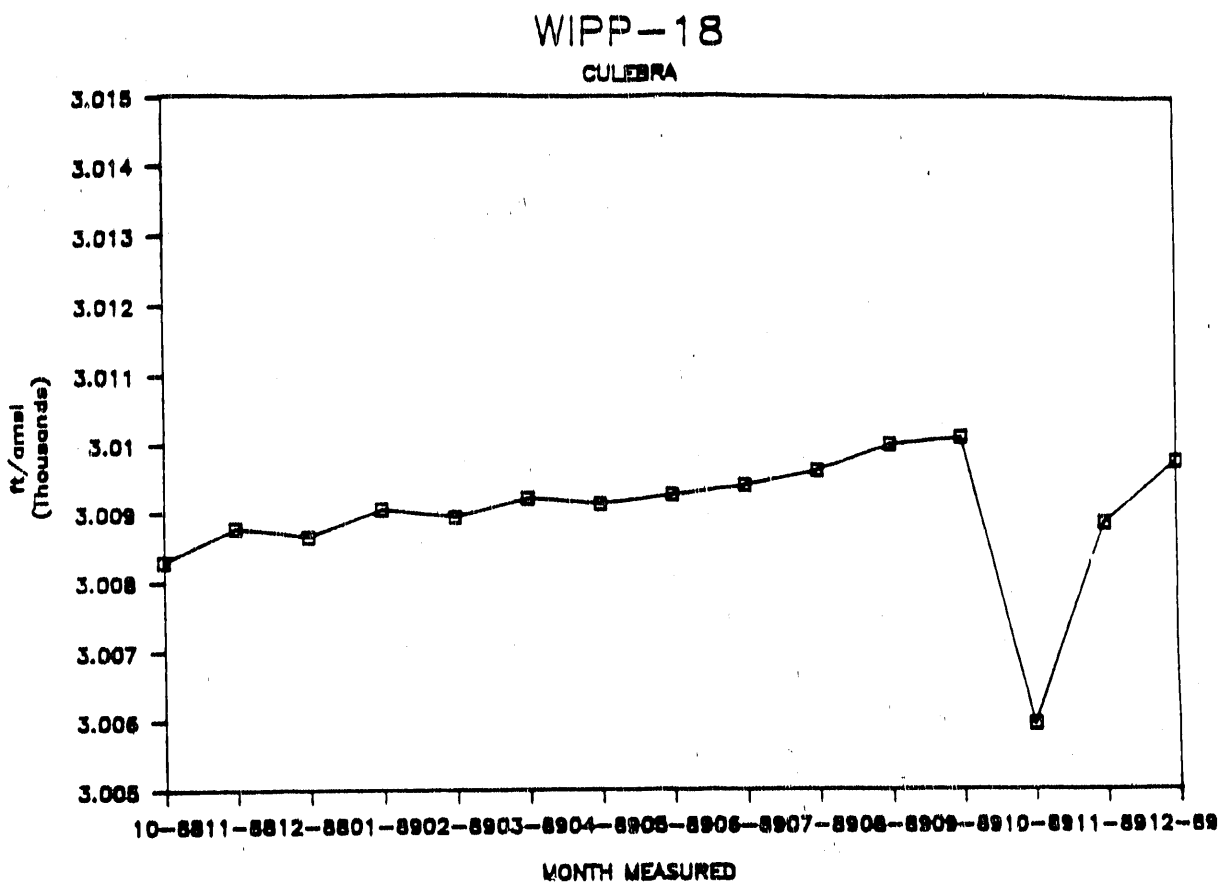

P-15
CULEBRA
3.015
3.014
3.013
3.012
3.011
3.01
3.009
3.008
3.007
3.006
3.005
ft/amsl (Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

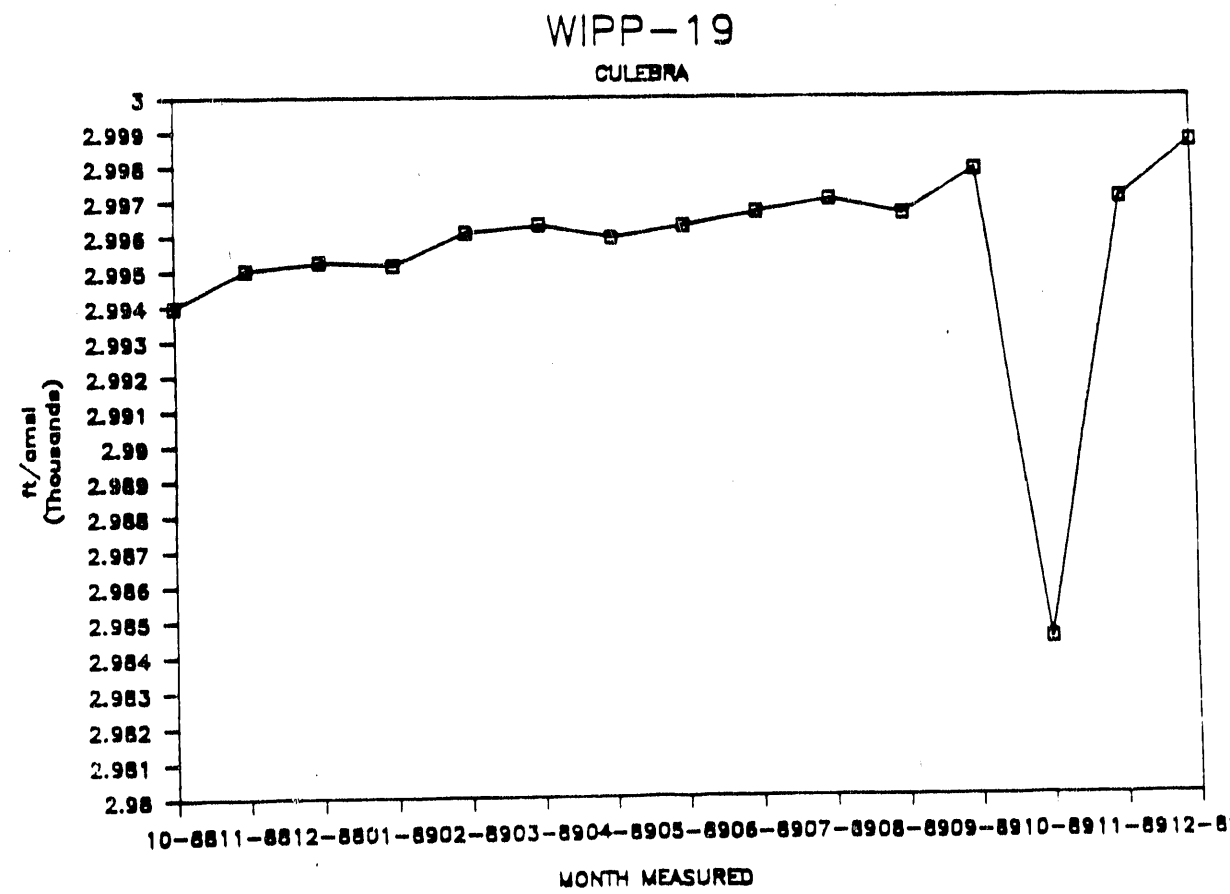

P-17
CULEBRA
2.985
2.984
2.983
2.982
2.981
2.98
2.979
2.978
2.977
2.976
2.975
ft/amsl
(Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

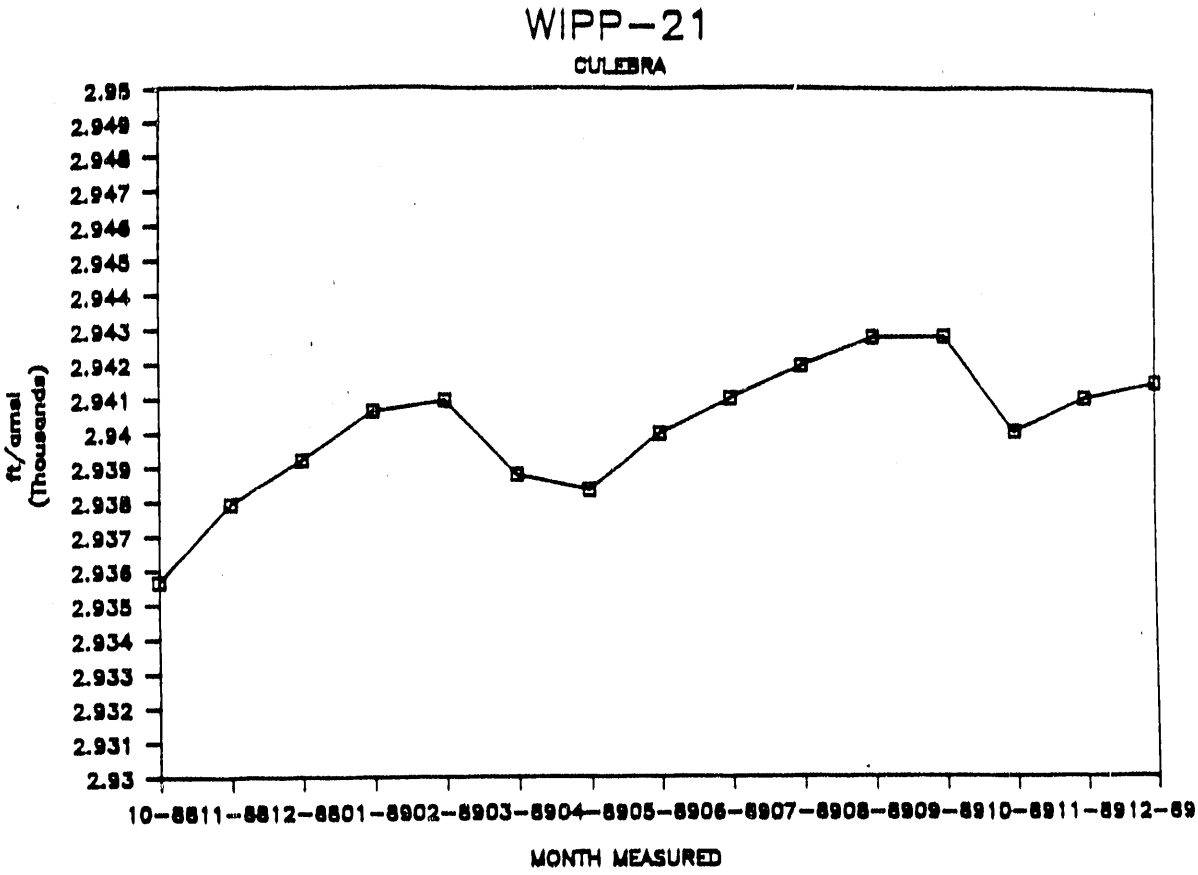

P-18
CULEBRA
3.01
3
2.99
2.98
2.97
2.96
2.95
2.94
ft/amsl
(Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED


WIPP-12
CULEBRA
3.03
3.029
3.028
3.027
3.026
3.025
3.024
3.023
3.022
3.021
3.02
ft/amsl (Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED


WIPP-13
CULEBRA
3.055
3.054
3.053
3.052
3.051
3.05
3.049
3.048
3.047
3.046
3.045
ft/amsl (Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED


WIPP-18
CULEBRA
3.015
3.014
3.013
3.012
3.011
3.01
3.009
3.008
3.007
3.006
3.005
ft/amsl
(Thousands)
10-8811-8812-8901-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED


WIPP-19
CULEBRA
3
2.999
2.998
2.997
2.996
2.995
2.994
2.993
2.992
2.991
2.99
2.989
2.988
2.987
2.986
2.985
2.984
2.983
2.982
2.981
2.98
ft/amsl
(Thousands)
10-8811-8812-8901-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED


WIPP-21
CULEBRA
ft/amsl (Thousands)
2.95
2.949
2.948
2.947
2.946
2.945
2.944
2.943
2.942
2.941
2.94
2.939
2.938
2.937
2.936
2.935
2.934
2.933
2.932
2.931
2.93
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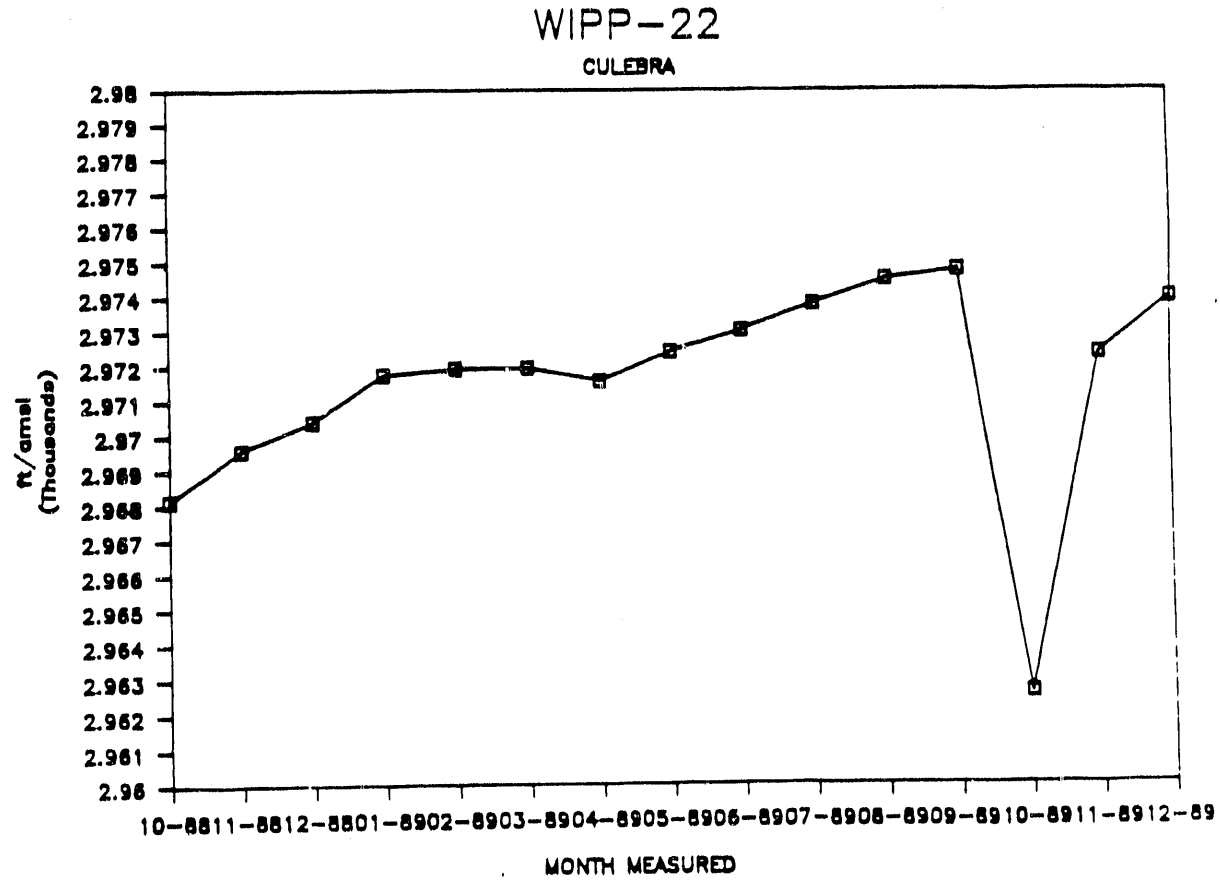
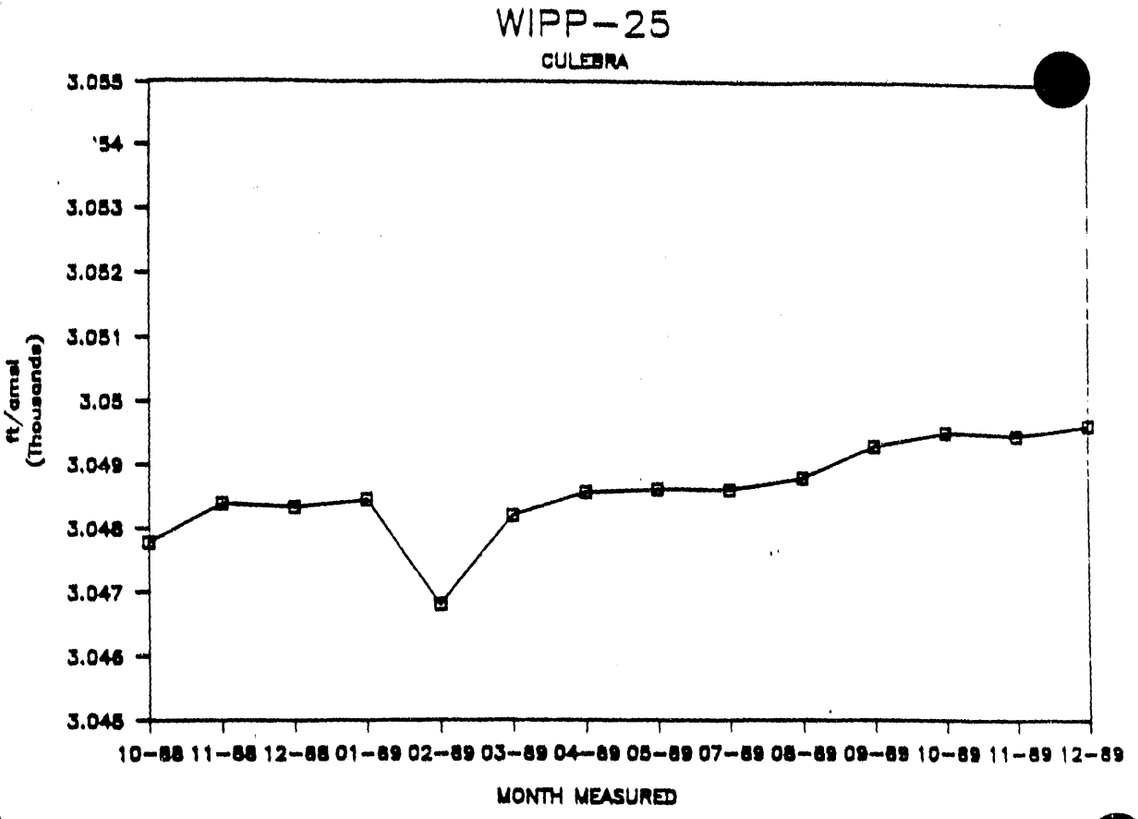
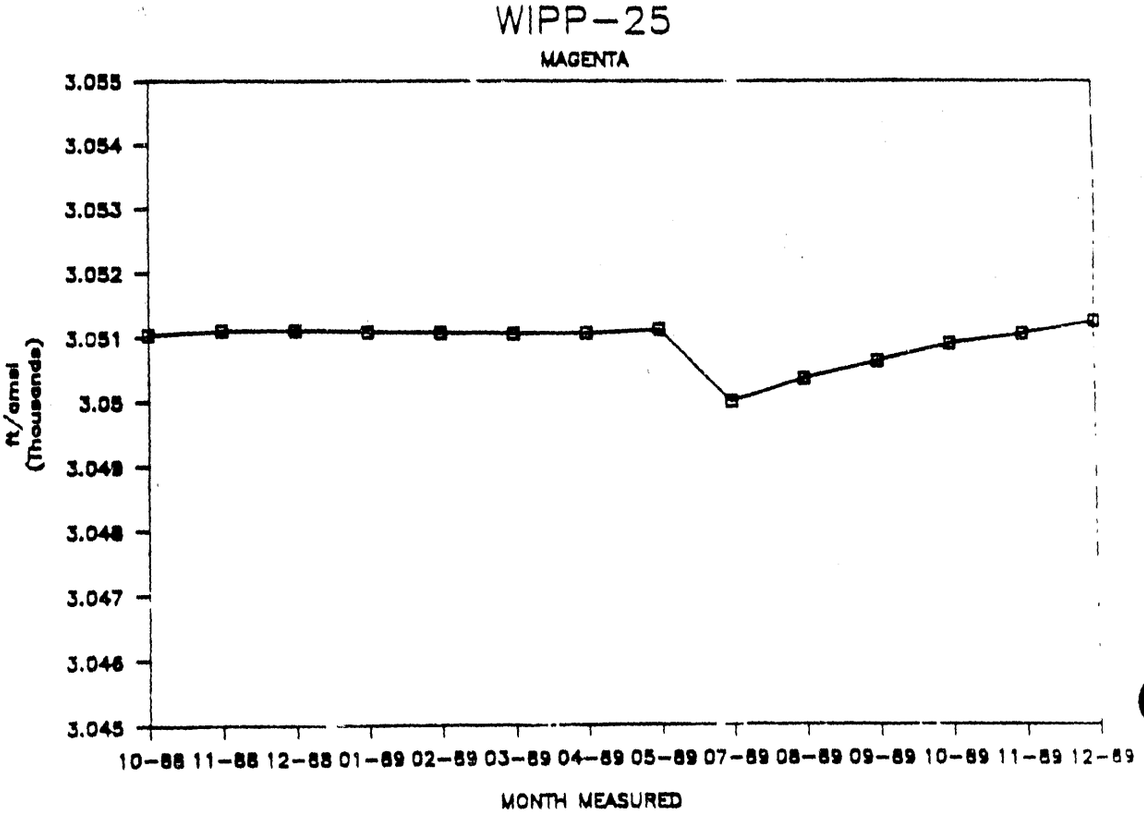
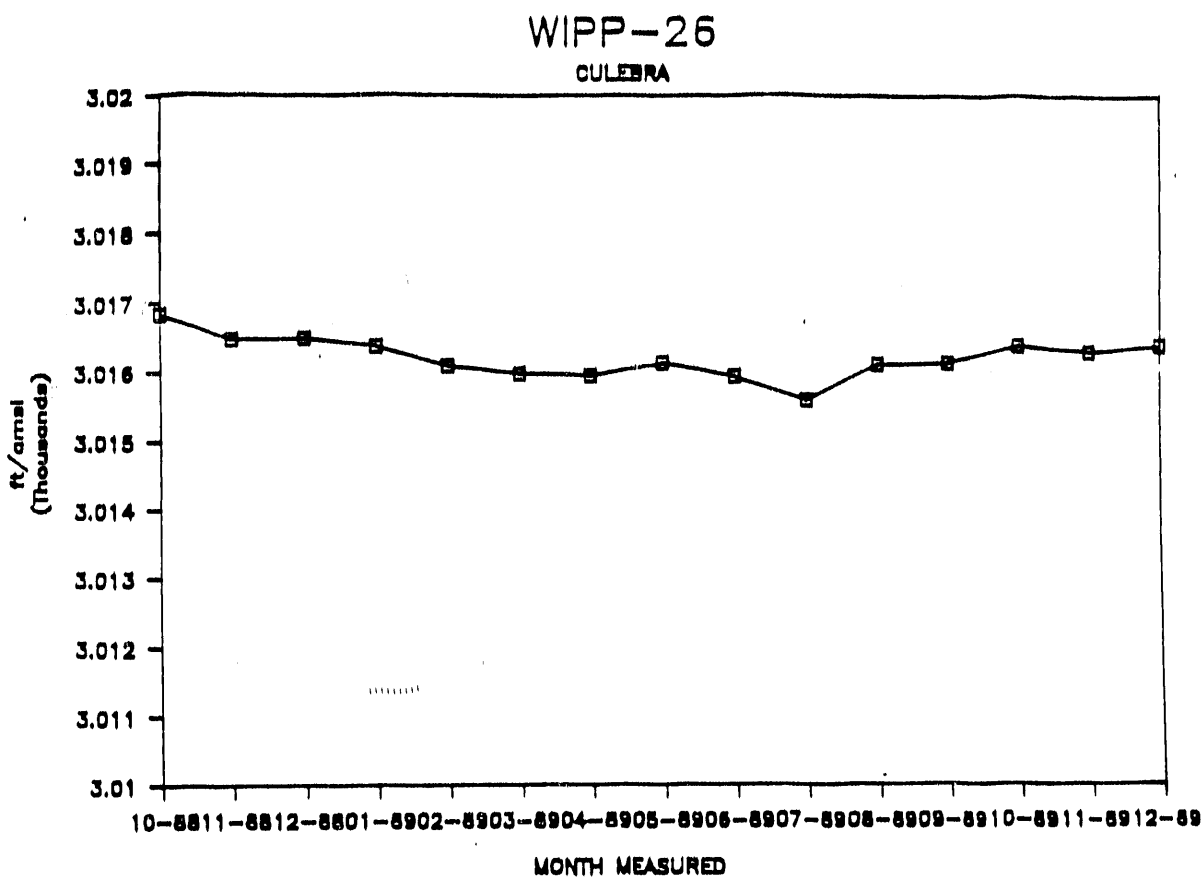
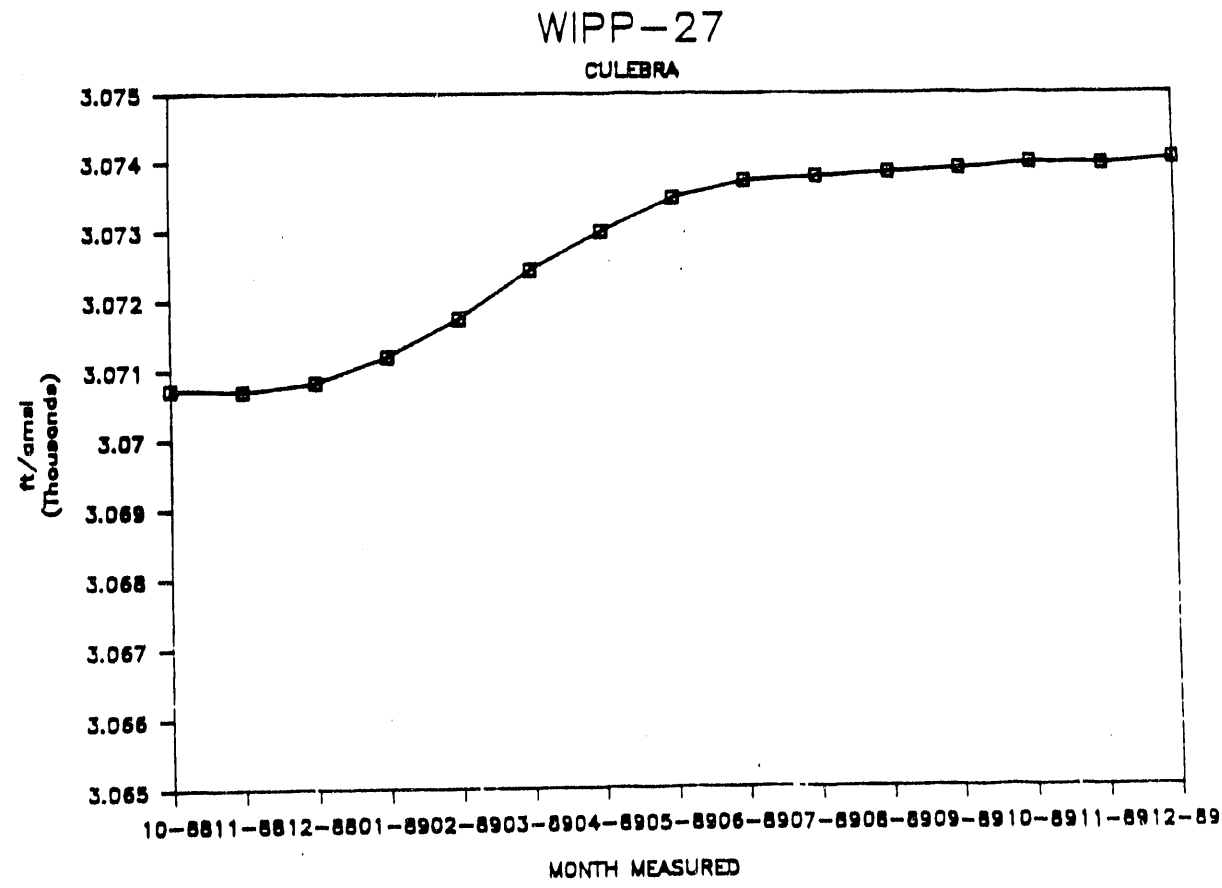
MONTH MEASURED

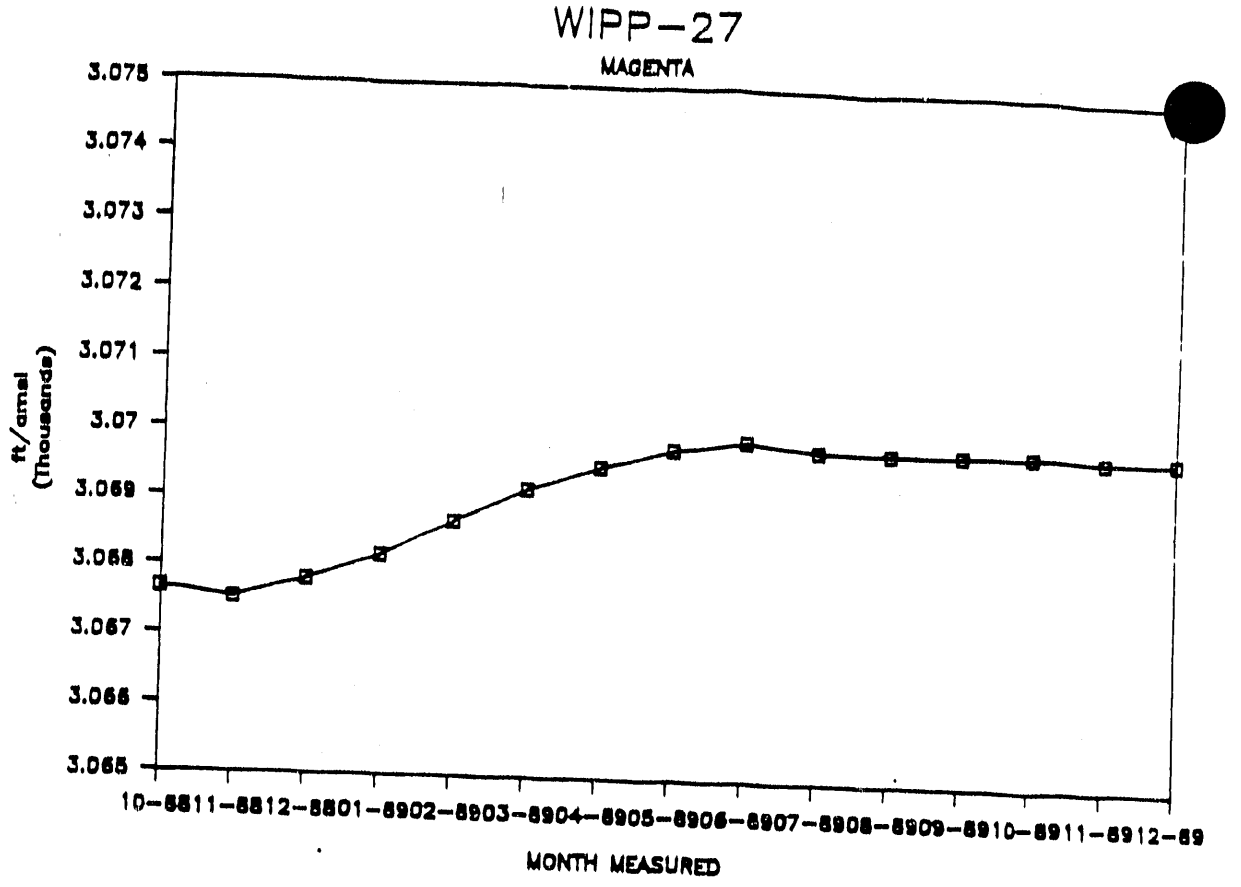

WIPP-22
CULEBRA
ft/amsl (Thousands)
2.98
2.979
2.978
2.977
2.976
2.975
2.974
2.973
2.972
2.971
2.97
2.969
2.968
2.967
2.966
2.965
2.964
2.963
2.962
2.961
2.96
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED


WIPP–25
CULEBRA
3.055
'54
3.053
3.052
3.051
3.05
3.049
3.048
3.047
3.046
3.045
ft/amsl (Thousands)
10–88 11–88 12–88 01–89 02–89 03–89 04–89 05–89 07–89 08–89 09–89 10–89 11–89 12–89
MONTH MEASURED


WIPP–25
MAGENTA
3.055
3.054
3.053
3.052
3.051
3.05
3.049
3.048
3.047
3.046
3.045
ft/amsl (Thousands)
10–88 11–88 12–88 01–89 02–89 03–89 04–89 05–89 07–89 08–89 09–89 10–89 11–89 12–89
MONTH MEASURED


WIPP-26
CULEBRA
3.02
3.019
3.018
3.017
3.016
3.015
3.014
3.013
3.012
3.011
3.01
ft/amsl (Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED


WIPP-27
CULEBRA
3.075
3.074
3.073
3.072
3.071
3.07
3.069
3.068
3.067
3.066
3.065
ft/amsl (Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED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MAGENTA
3.075
3.074
3.073
3.072
3.071
3.07
3.069
3.068
3.067
3.066
3.065
ft/amsl (Thousands)
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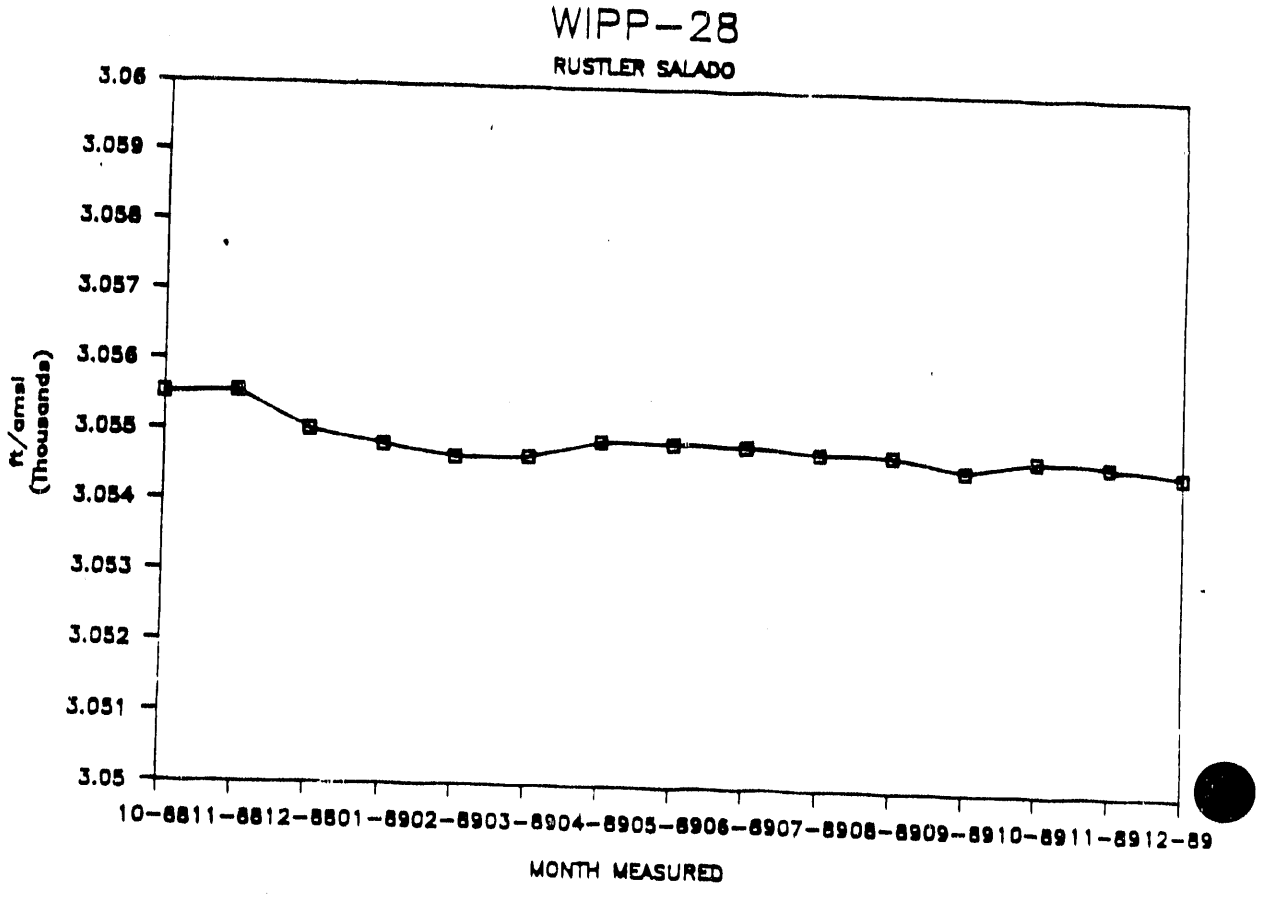
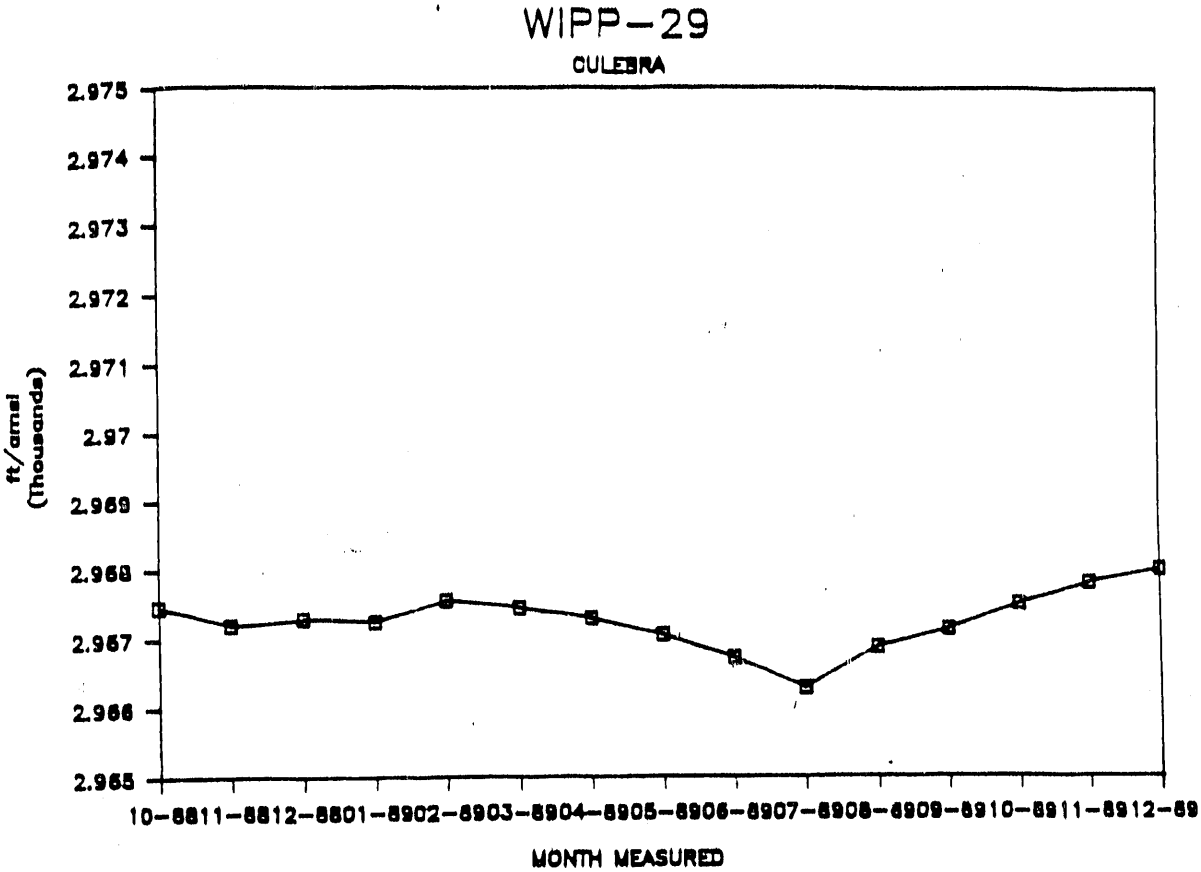
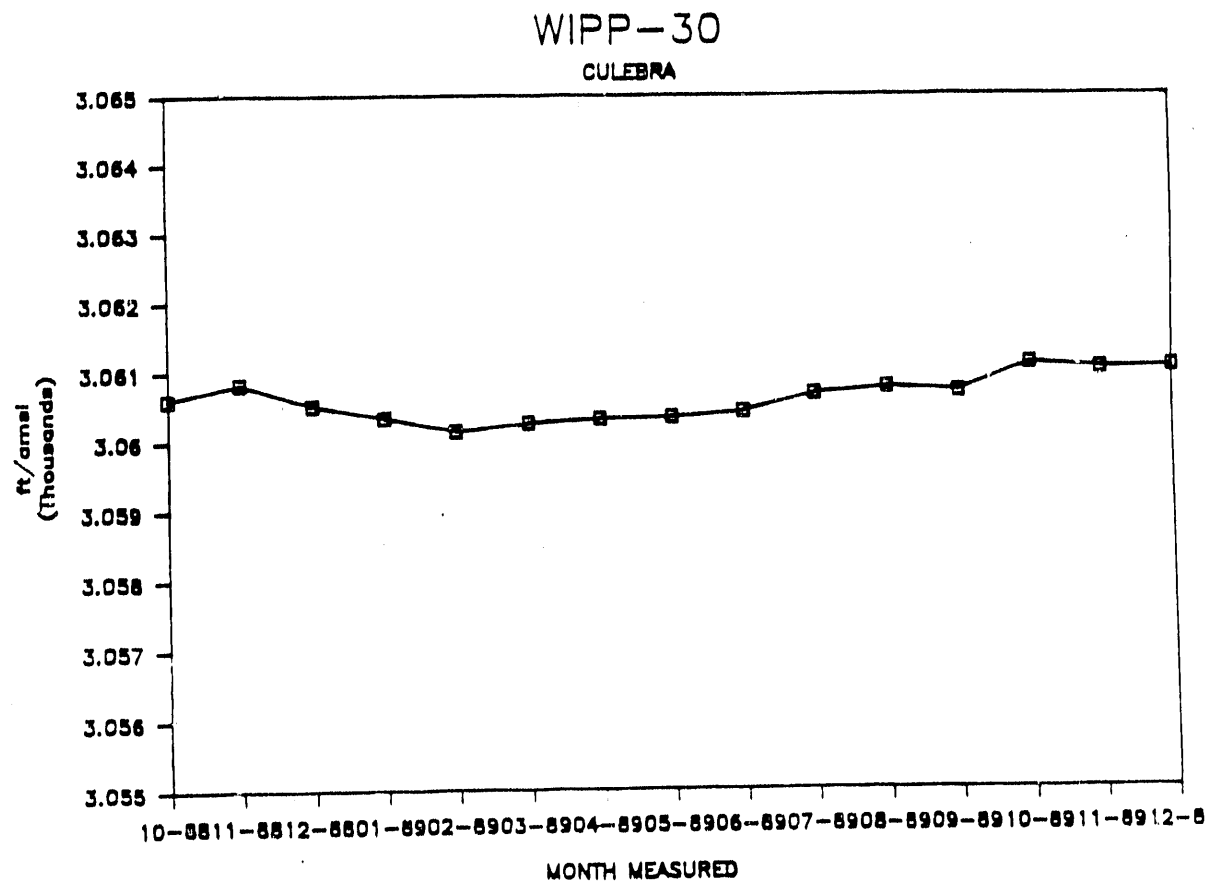
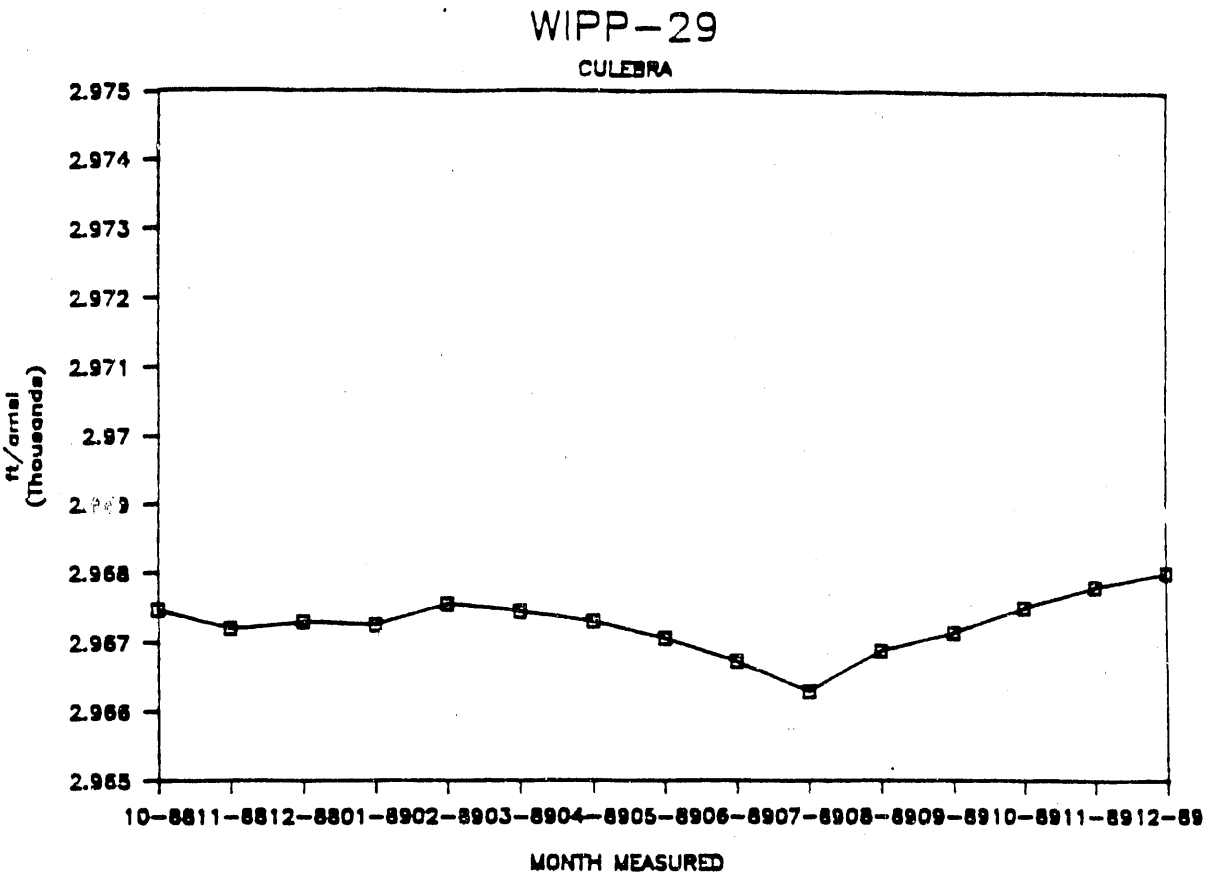
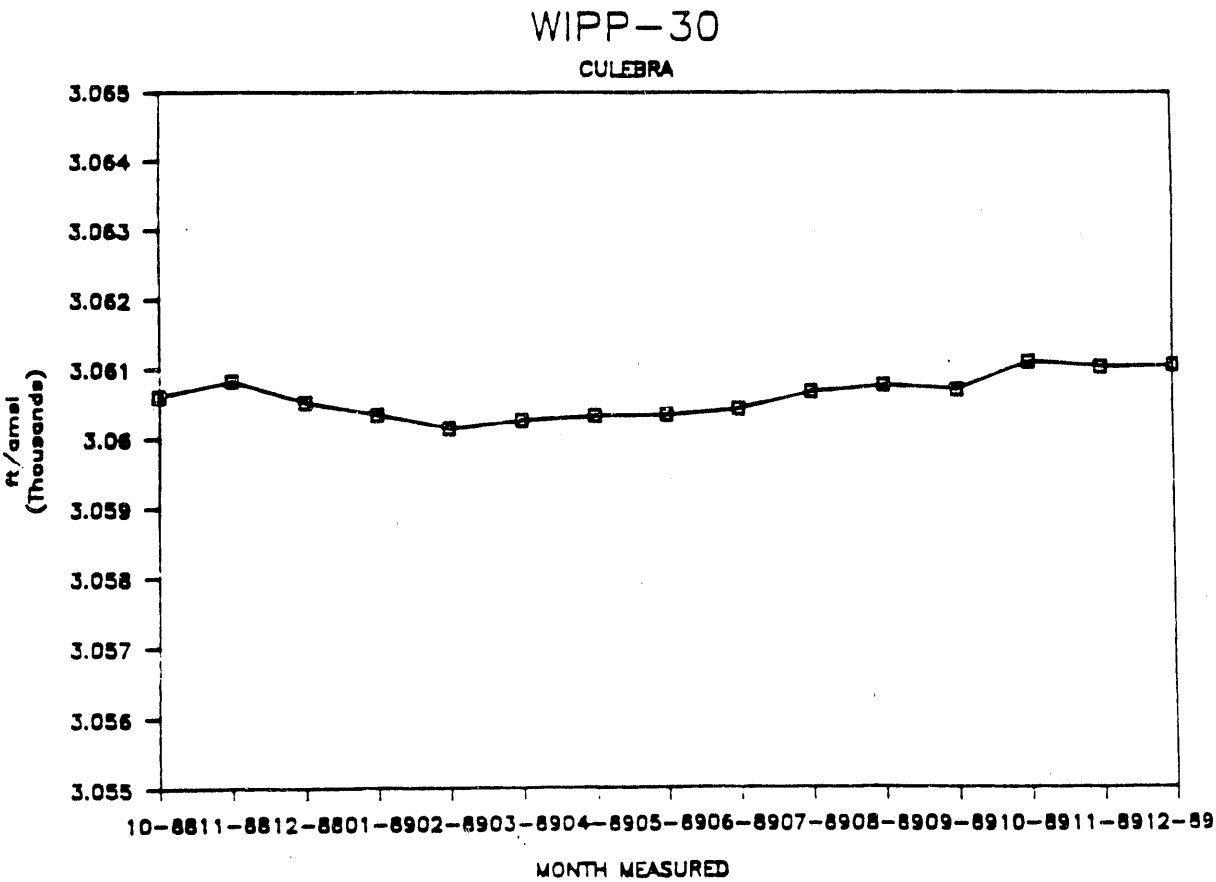
MONTH MEASURED


WIPP-28
RUSTLER SALADO
3.06
3.059
3.058
3.057
3.056
3.055
3.054
3.053
3.052
3.051
3.05
ft/amsl (Thousands)
10-8811-8812-8901-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED


WIPP-29
CULEBRA
2.975
2.974
2.973
2.972
2.971
2.97
2.969
2.968
2.967
2.966
2.965
ft/amsl (thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED


WIPP-30
CULEBRA
3.065
3.064
3.063
3.062
3.061
3.06
3.059
3.058
3.057
3.056
3.055
ft/amsl (thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED


WIPP-29
CULEBRA
2.975
2.974
2.973
2.972
2.971
2.97
2.968
2.967
2.966
2.965
ft/amsl (Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED


WIPP-30
CULEBRA
3.065
3.064
3.063
3.062
3.061
3.06
3.059
3.058
3.057
3.056
3.055
ft/amsl (Thousands)
10-8811-8812-8801-8902-8903-8904-8905-8906-8907-8908-8909-8910-8911-8912-89
MONTH MEASURED

FRACTIONS AND MULTIPLES OF UNITS

Multiple	Decimal Equivalent	Prefix	Symbol
10^{6}	1,000,000	mega-	M
10^{3}	1,000	kilo-	k
10^{2}	100	hecto-	h
10	10	deka-	da
10^{-1}	0.1	deci-	d
10^{-2}	0.01	centi-	c
10^{-3}	0.001	milli-	m
10^{-6}	0.000001	micro-	µ
10^{-9}	0.000000001	nano-	n
10^{-12}	0.000000000001	pico-	p
10^{-15}	0.000000000000001	femto-	f
10^{-18}	0.000000000000000001	atto-	a

CONVERSION TABLE

Multiply	By	To Obtain	Multiply	By	To Obtain
in.	2.54	cm	cm	0.394	in.
ft	0.305	m	m	3.28	ft
mi	1.61	km	km	0.621	mi
lb	0.4536	kg	kg	2.205	lb
liq qt - U.S.	0.946	L	L	1.057	liq qt - U.S.
ft^2	0.093	m^2	m^2	10.764	ft^2
mi^2	2.59	km^2	km^2	0.386	mi^2
ft^3	0.028	m^3	m^3	35.31	ft^3
mCi/mi^2	0.386	mCi/km^2 (nCi/m^2)	mCi/km^2	2.59	mCi/mi^2
d/m	0.450	pCi	pCi	2.22	d/m
nCi	1×10^{3}	pCi	pCi	1×10^{-3}	nCi
d/m/L	0.45×10^{-6}	µCi/cc	µCi/cc	2.22×10^{6}	d/m/L
$d/m/ft^2$	0.01256	mCi/mi^2	mCi/mi^2	79.6	$d/m/ft^2$
pCi/L (water)	10^{-6}	µCi/mL (water)	µCi/mL (water)	10^{6}	pCi/L (water)
pCi/m^3 (air)	10^{-12}	µCi/cc (air)	µCi/cc (air)	10^{12}	pCi/m^3 (air)
mCi/km^2	1	nCi/m^2	nCi/m^2	1	mCi/km^2

APPENDIX D5

ECOLOGICAL MONITORING PROGRAM AT THE WASTE ISOLATION PILOT PLANT

FROM PREVIOUSLY PUBLISHED NO-MIGRATION VARIANCE PETITION,
APPENDIX K, VOLUME VI

U.S. Department of Energy (DOE), 1990,
DOE/WIPP 89-003, Revision 1, Carlsbad, New Mexico

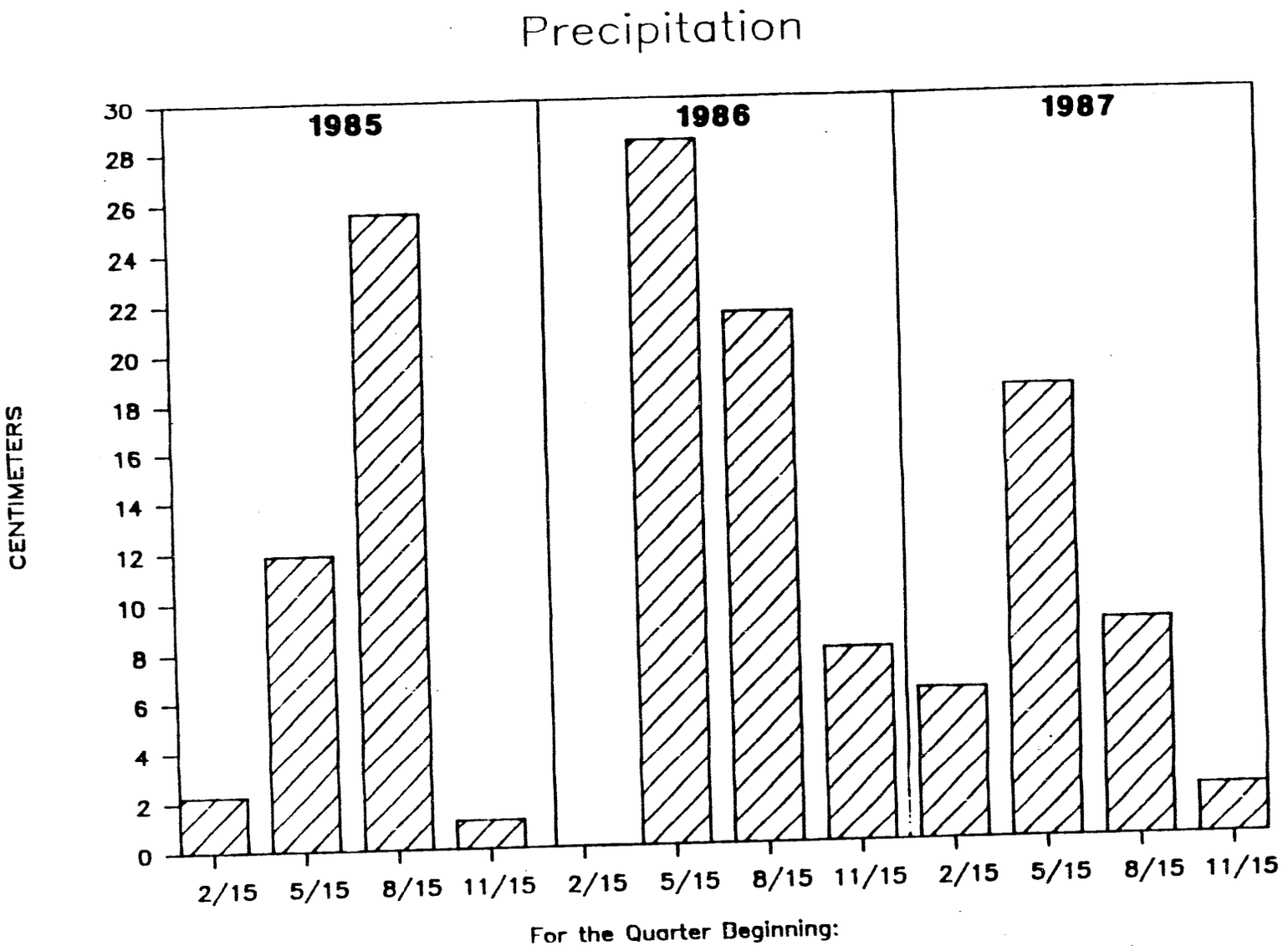


FIGURE 8.2 Precipitation during the three years of litter bag studies.

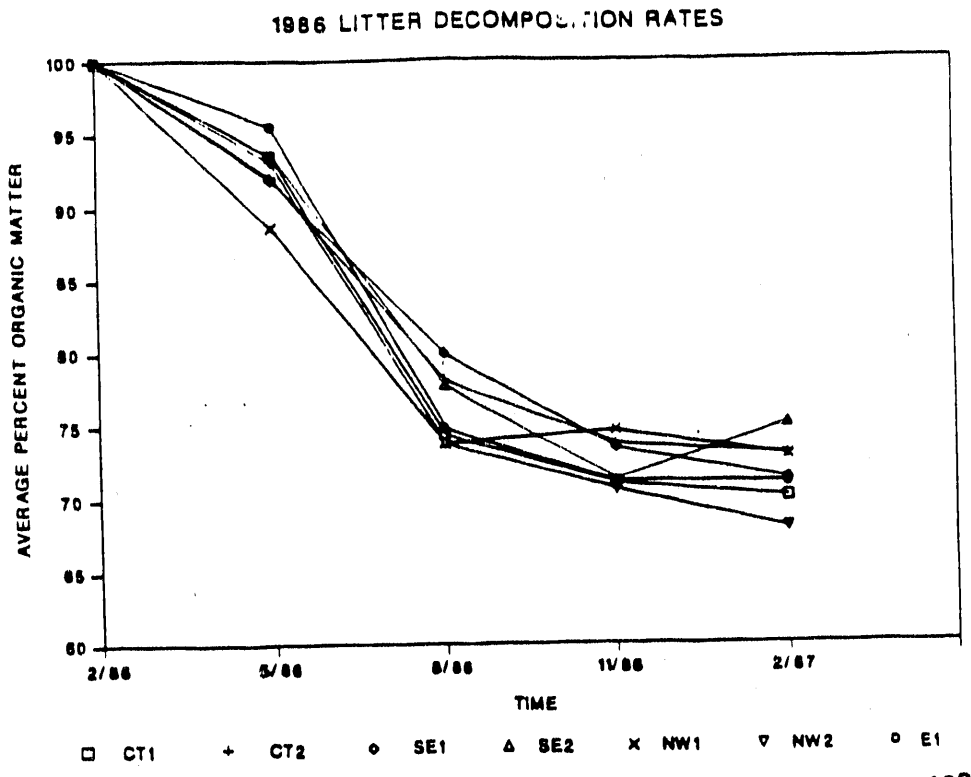


FIGURE 8.3 Average loss of organic matter from litter bags in 1986.

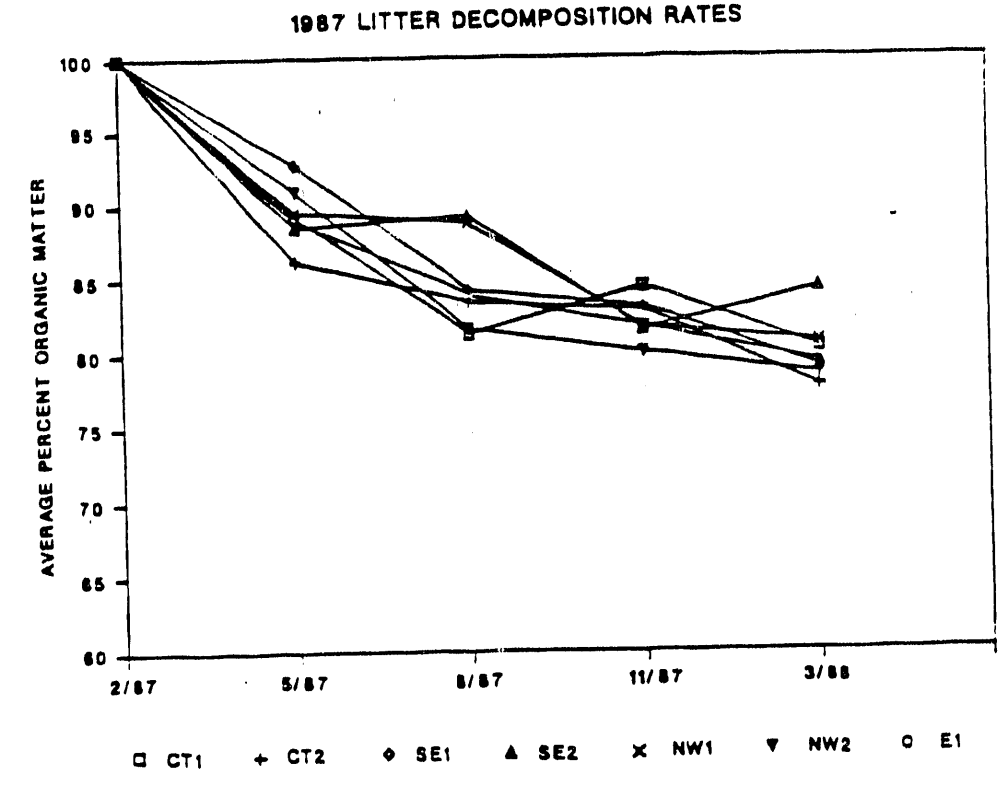


FIGURE 8.4 Average loss of organic matter from litter bags in 1987.

9.0 VEGETATION

Vegetation is monitored in permanent ecological monitoring plots to assess the impact of transported salt on plant life. Parameters being monitored in each plot are foliar cover of all species, density of annual species, species richness, and the structure of the vegetation community. Cover and density are measured at the beginning and end of the growing season. Spring readings of vegetation are taken when most spring-flowering plants are mature enough to identify, usually in June. Fall readings are taken when warm season plants (primarily the grasses) are blooming, usually in late August through October. Changes in community structure are documented by means of fixed-location comparative photographs. Species richness is determined at the end of the growing season; 1987 data also include spring measurements of species richness.

The methods used are described in detail in the first two EMP reports (Reith et al., 1985; Fischer, 1985) and follow widely accepted methodology (Cain and Castro, 1959). In 1985, some modifications were made to the program to increase the accuracy and reliability of vegetation measurements (Fischer et al., 1985). Measurements are facilitated by using a meter square sampling frame which is placed at 20 random locations in each monitoring plot (16 locations per plot were read in 1984). Foliar cover is estimated for all species as a visual estimate of canopy cover within the sampling frame. Density of annuals is calculated from direct counts of individuals. Vegetation in each plot is photographed from a central signpost to record community structure. Species richness for the first three years (1984-1986) was measured at the end of the growing season. In 1987, species richness was calculated for both spring and fall. Modifications in 1987 include:

- Species richness was supplemented by implementing phenology studies and establishing an herbarium to enhance species identification. Individuals too small to identify at the time of sampling were flagged and revisited at times when phenology was optimal for taxonomic characterization, thus reducing the number of unknown or unidentified species in the data base.

- Annual species were separated from perennial species for closer examination of the plant community structure.

- Control 2 plot was again relocated (see Chapter 1). Field examinations indicate that the area of the Control 2 locations from 1986 and 1987 has received heavier livestock use than other areas of WIPP and it may have received chemical treatment for brush control in times past. A 1971 graduate study at New Mexico State University recorded chemical treatment of mesquite in the grazing allotment in question (Leifeste, 1971). This history has made it difficult to establish a representative control in that area. In this chapter, Control 2 used in 1986 has been labeled C2W. The 1987 control is labeled C2S; W and S denote relative positions of west and south. The C2W was monitored spring and fall, 1987. The new C2S was monitored fall, 1987. Both data sets are presented here. An index of similarity between C2S and C2W is presented in Table 9.1. Similarity data for each species are included in Appendix 9-A.

Mesquite cover has been excluded from the calculations of total cover and shrub/half-shrub cover due to the high degree of variability in its measurement obtained by the quadrat method. Plants such as mesquite, which are large with respect to the size of the quadrat (one meter square) but few in number, will rarely be struck by the randomly-placed quadrat frames. When struck, the cover measurement in the frame is high, resulting in the reduction of precision of the measurement.

TABLE 9.1

INDEX OF SIMILARITY (C2S AND C2W COMPARED TO C1)

Similar to C1

	C2S	C2W
SHRUBS	77.78	95.24
PERENNIAL FORBS	80.00	85.71
ANNUAL FORBS	95.45	96.63
PERENNIAL GRASSES	78.16	64.10
ANNUAL GRASSES	25.00	26.67
TOTAL VEGETATION	89.81	90.23

Values derived from species richness (% frames including a particular species). Calculated from Motyka's Modified Sorensen's Index. Data in Appendix 9-A.

TABLE 9.2

PERCENT FOLIAR COVER (AVERAGE OF ALL PLOTS)

		Shrubs (no PRGL)	Perennial Forbs	Annual Forbs	Perennial Grass	Annual Grass
Spring	1985	19.65	0.37	0.47	1.54	----
Fall	1985	12.57	0.87	1.88	4.83	0.57
Spring	1986	17.39	1.03	0.80	3.19	----
Fall	1986	14.79	1.16	1.50	4.91	0.13
Spring	1987	27.70	0.83	0.83	4.74	0.11
Fall	1987	15.92	0.73	0.73	4.08	0.66

---- = no data

Within the current reporting period, vegetation parameters were measured three times; fall, 1986, and spring and fall, 1987, are presented. Plants are referred to by common name. An index of scientific names, common names and acronyms is presented in Appendix 9-B.

9.1 RESULTS AND DISCUSSION

Foliar Cover. Shrub foliar cover shows a decreasing trend over the growing season from spring to fall (Figure 9.1). This may be due to the cessation of growth early in the season followed by a gradual decline in leaf size through the season from herbivory. In 1985 and 1986, foliar cover increased over the growing season for perennial forb, annual forb, and perennial grass categories. This trend would be expected excluding outside factors, such as drought, heavy forage utilization, and mechanical or chemical treatment. However, the 1987 data show a decrease over the growing season for the latter three categories (Figure 9.2). The averages for all plots are presented in Table 9.2.

A change in species dominants from spring to fall may explain the data from 1987. Among the perennial forbs, leaf-flower and cotta were dominants in the C2W spring sampling but were replaced by plains flax and hog potato in the fall sampling. Groundsel and woolly dalea decreased sharply from spring to fall in C1 and NW2 (Table 9.3).

Annual forb cover also shows a change in species composition from spring to fall in 1987 (Table 9.4). Spotted horsemint, scorpionweed, and bluets were spring dominants but were absent from or greatly reduced in fall readings, being replaced by individuals with less foliar cover. Telegraph plant was the only annual to show an increase in foliar cover over the growing season.

Perennial grass cover decreased over the growing season in 1987 (Figure 9.3). This can be seen as a decrease in three-awn in the far-field (NW2 and SE2) and C2 plots (Figure 9.4). Three-awn represents an important forage grass in the WIPP area. Although it is not a preferred forage grass, its relative abundance makes it important to the WIPP range. The near-field plots (NW1, SE1, E1) are closed to grazing whereas the far-field and control plots are open range and support cattle. The difference in grass cover may be attributed to differential grazing pressure. Supplemental data showing utilization of the forage by cattle on each pasture would help explain the foliar cover data.

Data from 1985 and 1986 showed similar behavior between near-field, far-field and control plots. However, 1987 data showed an inverse relationship between the far-field and near-field/control plots (Table 9.5). Whereas foliar cover increased over the growing season in the control and near-field plots, it decreased in the far-field plots. One would expect the far-field and control plots to behave similarly. A strong inverse relationship was seen for perennial grasses and annual forbs. The same was seen to a lesser degree for perennial forbs. These data indicate that there are no adverse impacts from salt transport on vegetation taking place in those plots closest to the salt stockpiles. However, data on grazing impacts would clarify differences between the plots.

Percent foliar cover data for each species sampled are presented in Appendices 9-C, 9-D, 9-E, and 9-F for spring 1986, fall 1986, spring 1987 and fall 1987, respectively.

Density of Annuals. Three years of data (1985, 1986, 1987) show a large fluctuation in annual density with much reduced numbers in 1986 (Figure 9.5). Precipitation data for 1985 and 1987 reveal high spring rainfall which contributed to the emergence of significant numbers of annual plants. Precipitation data for 1986 show low spring rainfall (no measurable precipitation was recorded in March or April) which may have delayed germination or hindered emergence (Figure 9.6).

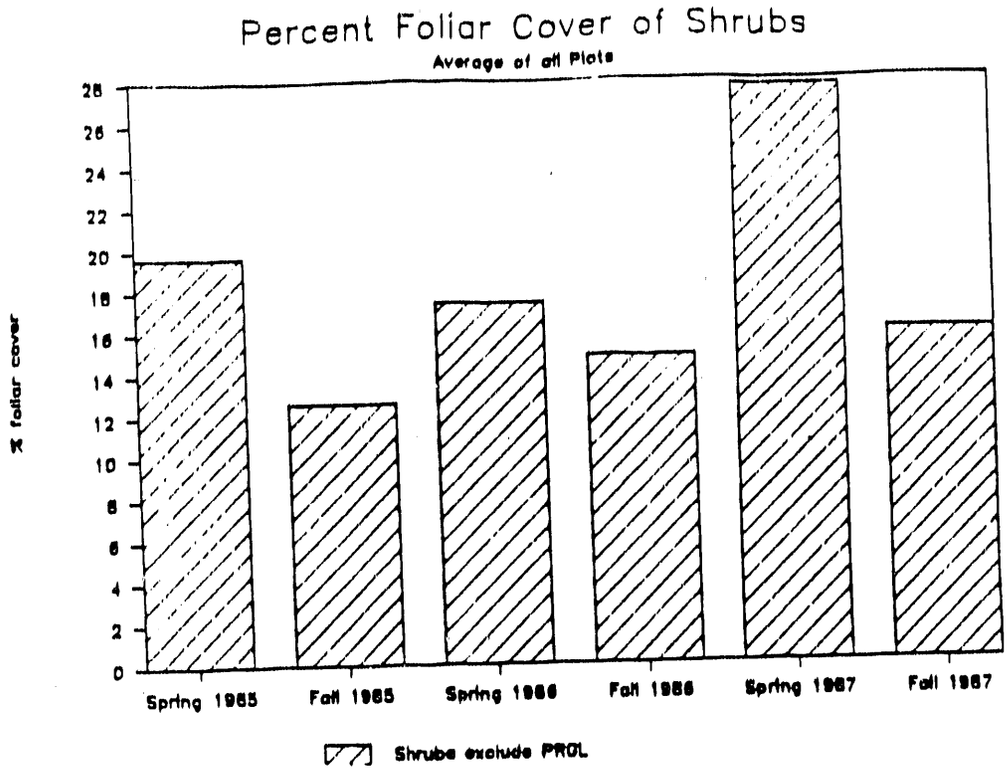


FIGURE 9.1 Percent foliar cover of shrubs averaged over all plots for three years of data.

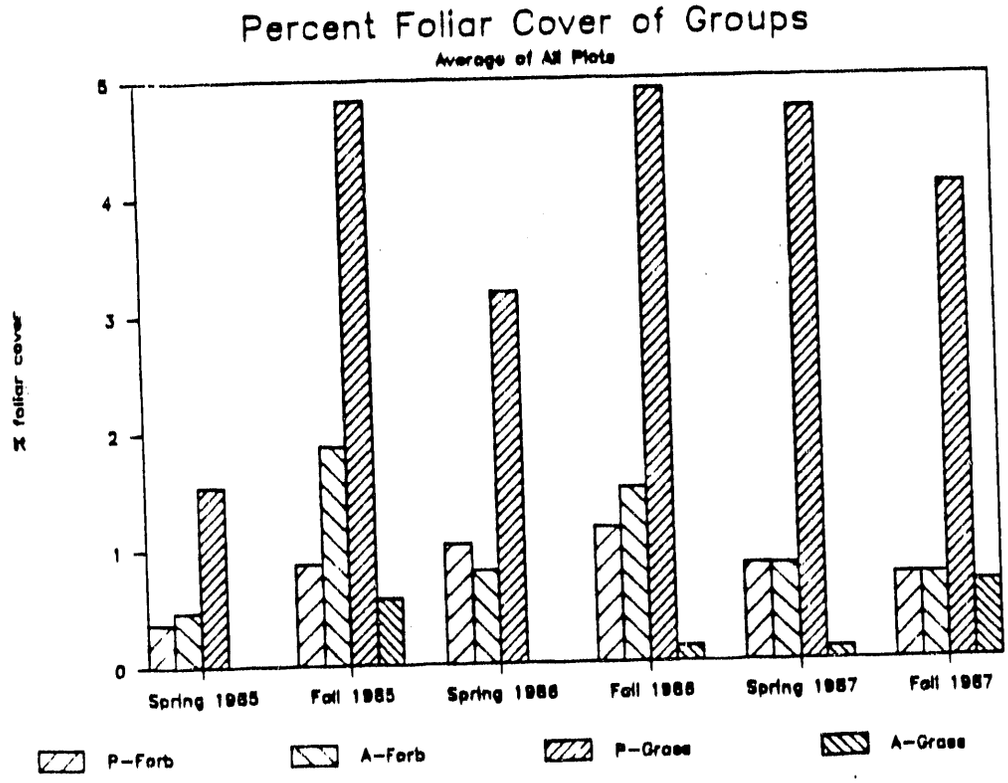


FIGURE 9.2 Percent foliar cover of perennial forb, annual forb, perennial grass, and annual grass groups averaged over all plots for three years of data.

TABLE 9.3

PERCENT FOLIAR COVER OF DOMINANT PERENNIAL FORBS, 1987

	Spring C1	Fall C1	Spring C2W	Fall C2W	Spring NW2	Fall NW2	Spring Av	Fall Av
Woolly dalea	0.50	0.20	0.00	0.80	0.50	0.05	0.19	0.23
Groundsel	0.25	0.03	0.05	0.26	0.50	0.03	0.29	0.23
Plains flax	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.07
Hog potato	0.00	0.03	0.00	0.30	0.05	0.00	0.04	0.05
Leaf-flower	0.00	0.02	0.20	0.03	0.00	0.02	0.13	0.05
Cotta	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.09

TABLE 9.4

PERCENT FOLIAR COVER OF ANNUAL FORBS, 1987
(AVERAGE OF ALL PLOTS)

Spring 1987		Fall 1987	
Telegraph plant	2.70	Telegraph plant	3.50
Spotted horsemint	0.83	Annual buckwheat	0.88
Scorpionweed	0.61	Lace spurge	0.13
Bluets	.55	Fetid marigold	0.10
Annual buckwheat	0.27	Prairie sunflower	0.06
White ragweed	0.08	Bluets	0.03
Primrose	0.07	Coulter's conyza	0.01
Spurge	0.07	Palafoxia	0.01
Sunflower	0.05	Spectaclepod	<.01
Spectaclepod	0.04	Arizona doze daisy	<.01
Palafoxia	0.04	Ridge-seed spurge	<.01
Fetid marigold	0.03	White ragweed	<.01
Western fleabane	0.02	Bindweed heliotrope	<.01
Fleabane	0.01	Cutleaf aster	<.01
Texas spreadwing	0.01	Sunflower	<.01

TABLE 9.5

COMPARISON OF PERCENT FOLIAR COVER

	Near-field	Far-field	Controls
	Perennial Forbs		
Spring 1985	0.35	0.52	0.24
Fall 1985	0.54	0.62	1.60
Spring 1986	1.72	0.48	0.56
Fall 1986	1.12	1.75	0.65
Spring 1987	0.95	0.76	0.73
Fall 1987	0.74	0.14	1.33
	Annual Forbs		
Spring 1985	0.15	0.29	0.96
Fall 1985	1.30	1.34	.32
Spring 1986	0.84	0.46	1.09
Fall 1986	2.34	0.75	1.00
Spring 1987	3.95	4.50	8.38
Fall 1987	2.94	5.76	6.45
	Perennial Grasses		
Spring 1985	0.74	1.63	2.25
Fall 1985	3.38	4.40	7.45
Spring 1986	3.11	2.53	3.99
Fall 1986	4.49	5.52	4.92
Spring 1987	3.78	6.94	3.98
Fall 1987	3.96	3.74	4.60

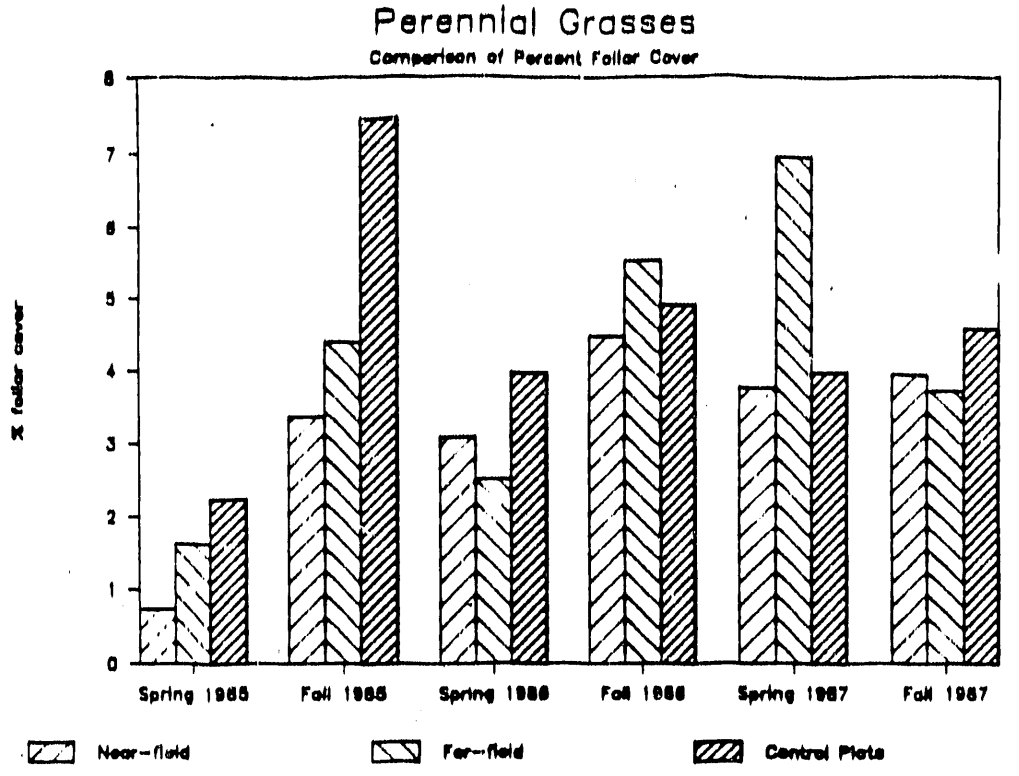


FIGURE 9.3 Comparison of perennial grass foliar cover between near-field, far-field, and control plots over three years.

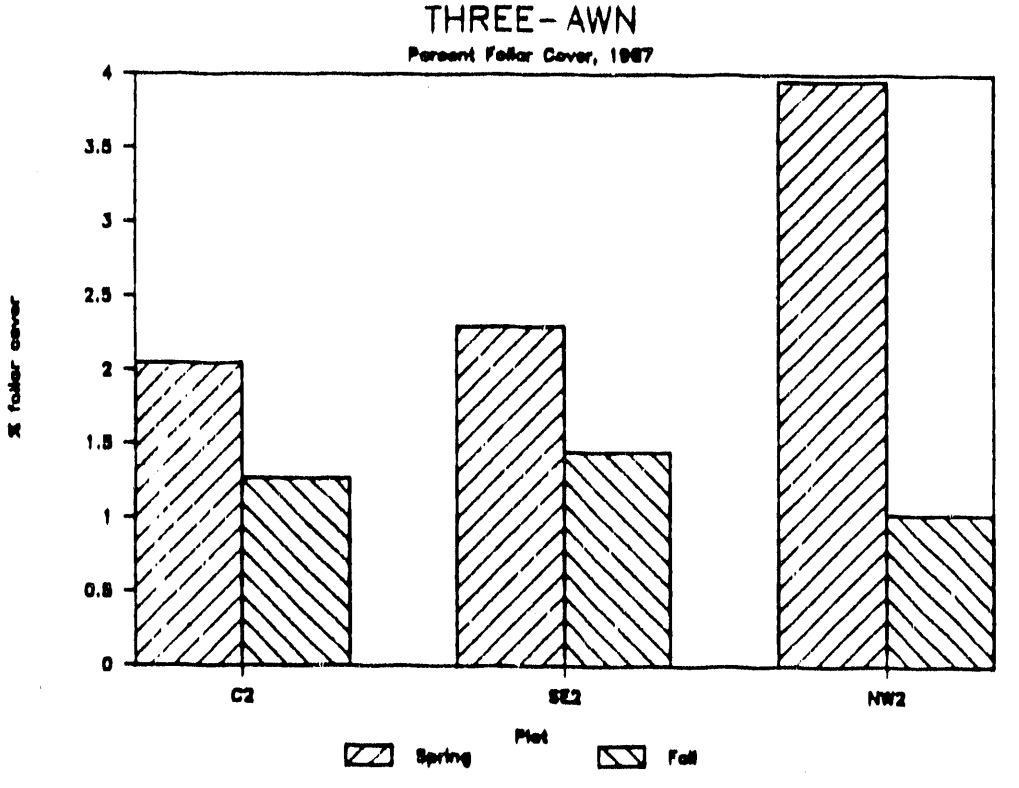


FIGURE 9.4 Comparison of three-awn foliar cover between spring and fall measurements at three plots.

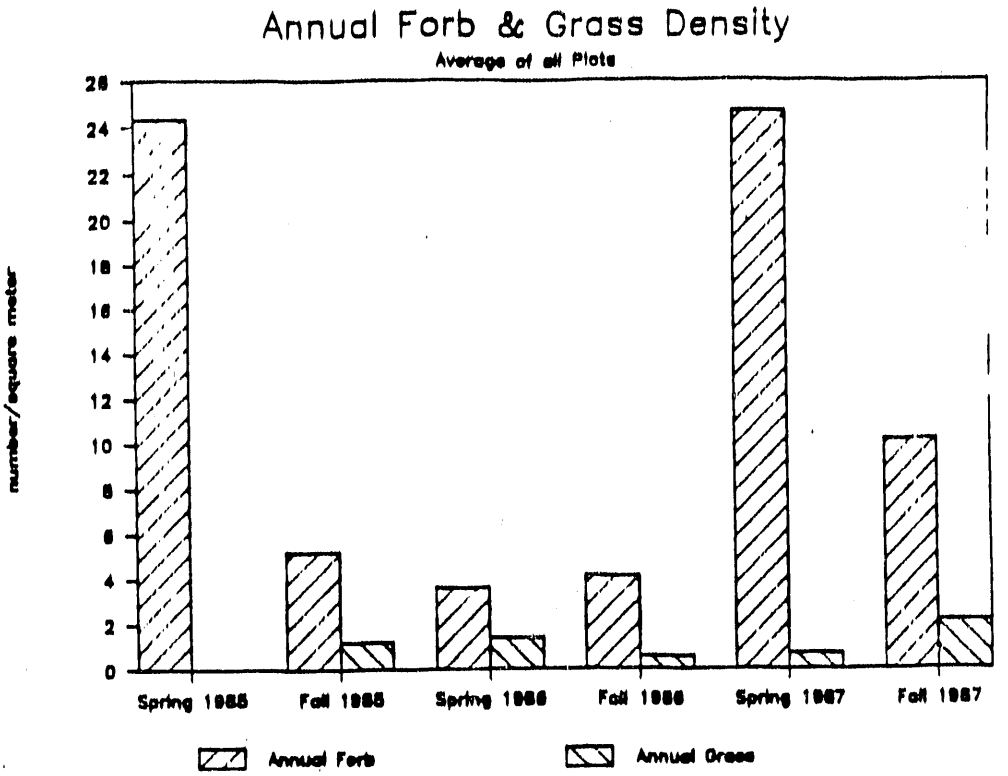


FIGURE 9.5 Densities of annuals over three years.

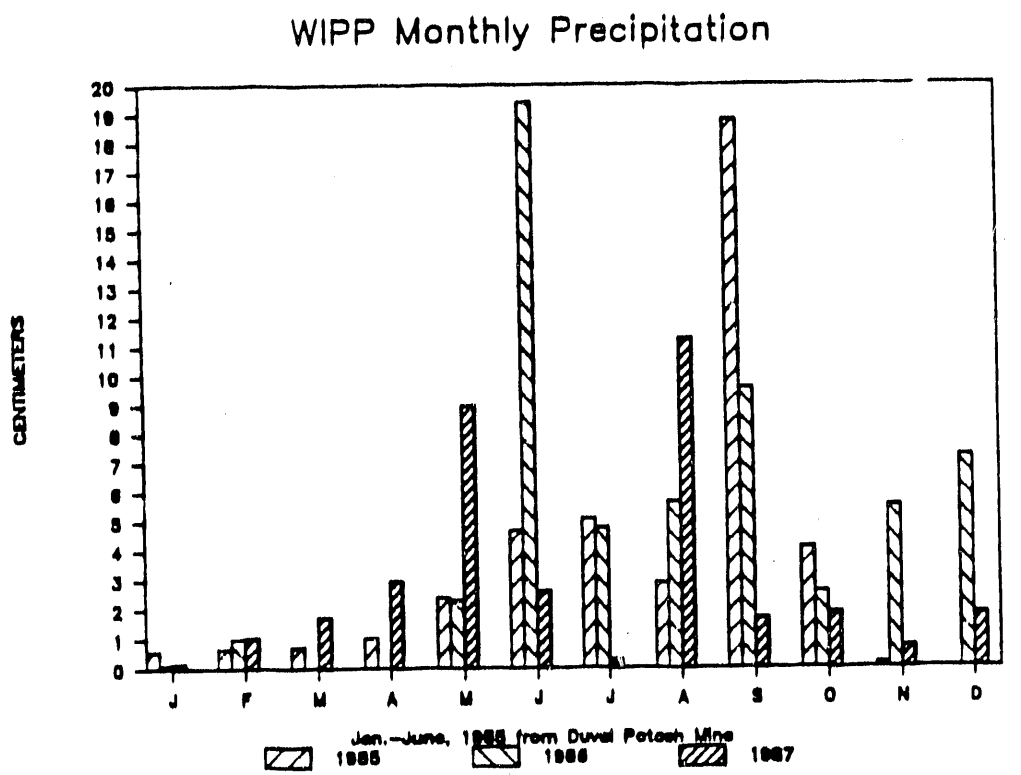


FIGURE 9.6 Precipitation at the WIPP site over three years.

EMP monitoring emphasizes emergence of the seedling plant from the ground rather than germination of the seed. Since the seed pool has been planted by nature, there is no easy way of recognizing its presence until seedling plants emerge from the soil. Emergence requires both germination and seedling survival to be recognized and during the process is subject to more hazards over time. Consequently, emergence percentages will be lower than germination percentages (McDonough, 1977).

Prior to collection of the 1987 data, it was hypothesized that the decline in annual density from spring to fall in 1985 may have been due to a mid-summer drought which caused a high degree of mortality among the annuals before seed-set had occurred (Fischer et al., 1987). A low seed crop from 1985 could produce low annual numbers in 1986. However, one might then expect to see reduced numbers in 1987, which was not the case. The data for all three years reveals a similar decrease in annual density from spring to fall. This three year picture seems to support the hypothesis that a low spring rainfall in 1986 rather than a poor seed crop from the previous year, caused low survival of annuals. The timing of precipitation relative to seedling emergence appears to be a critical factor. However, data on phenology of the annual species are needed to better understand this relationship.

Annual plants ensure their survival from generation to generation by producing a seed crop which is far greater than what is needed to replace their actual numbers. Seeds may remain dormant for years before favorable environmental factors occur which allow germination. Seed dormancy is a state of suspended animation which permits the survival of plants under unfavorable conditions (Cohn, 1987). The state of dormancy is attained during seed set with dehydration of the protoplast of the embryo and development of a protective coat around the seed (McDonough, 1977). A drought may enhance seed dormancy and contribute to a bumper crop when environmental factors are optimal for seed germination.

Precipitation is not the only factor limiting emergence, although it is well documented in the WIPP data. Among wild plants, a single adverse condition could wipe out the entire plant population if the seed source germinated simultaneously. However, seeds of wild species germinate intermittently over a course of time (McDonough, 1977). The amount and distribution of precipitation at WIPP may have an exaggerated impact on seedling emergence compared to other environs, because of the droughty nature of the soil. The soils are mostly sandy and have very low water-holding capacity (Soil Conservation Service, 1974).

Annual grass density decreased over the growing season in 1986 but increased over the growing season in 1987 (Table 9.6). This also may reflect the lack of rain during the summer of 1986 as compared to the summer of 1987. Data on annual plant densities are not adequate to define the underlying processes. Three years of data reveal similarities between 1985 and 1987 but do not allow prediction of trends or identify "normal" years from abnormal years, or wet years from dry years. The examination of annual plant densities could be enhanced significantly by knowledge of plant phenology. To accurately determine whether or not a lack of rainfall has affected the annual plant population before seed set has occurred, it is necessary to examine the development of the individual plants as they are affected throughout the growing season.

Densities of all annual species sampled over three years (1985, 1986, 1987) are presented in Appendix 9-G.

Species Richness. Species richness is a measure of the number of different species encountered in the whole sample throughout the sampling period. This was determined at the end of the growing season from the fall measurements for the first three years of the monitoring program (1984-1986). In 1987, the examination was extended to include spring sampling since some plants encountered in the spring samples go dormant before the fall samples are taken and, therefore, do not show up in the fall data.

In four years of data, fluctuations can be seen between seasons, but there is a general trend of increasing species richness (Figure 9.7). This is probably due to improvements in sampling methodology rather than abrupt changes in the environment. These include:

- Increased sample size from 16 to 20 frames in 1985
- Increased familiarity of personnel with the ecosystem
- Phenology and herbarium studies which were implemented in 1987 and which decreased the number of unidentified species in the data base.

The herbarium program yielded 37 vouchered specimens which had not been previously recorded in the WIPP literature. These plants were added to the list of flora produced by University of New Mexico during the WIPP Biology program of the 1970's. Additions to the floristic list may reflect the dynamics of the Chihuahuan desert ecosystem where some plants emerge or bloom only once in several years. The additions also underline the importance of an herbarium on site at WIPP to house voucher specimens as evidence in support of the field data.

It is interesting to note that the list of dominant annuals in 1985 and 1987 are similar, even though the 1986 survey shows a change in species composition. This may be due to the difference in rainfall in those years. Telegraph plant, annual buckwheat, bluets, spotted horsemint, and purple sandgrass were dominant in years of heavier rainfall. Lace spurge, fetid marigold, telegraph plant, and false buffalograss were dominants in 1986 when less rain fell. A similar pattern was noted between wet and dry years during the WIPP Biology program (Dowhower, 1981) (Table 9.7).

Similarity indices were calculated using Motyka's modification of the Sorensen's index (Mueller-Dombois and Ellenberg, 1974). Values for each species were derived for each monitoring plot by calculating the percentage of quadrat frames containing a particular species for each monitoring plot. Thus, species presence was given a numerical value based on frequency. Table 9.8 shows percent similarity between control and far-field, control and near-field, and near-field and far-field plots. Similarity indices for spring and fall, 1987, were calculated separately. Indices were calculated for each growth-form group (shrubs, perennial forbs, annual forbs, perennial grass, annual grasses) and for total plant community species richness. In spring, the far-field plots slightly surpass the near-field plots in similarity to the control plots. In fall, the far-field plots again slightly surpass the near-field plots in similarity to the controls. But over all, little difference can be seen between the near-field data and the far-field data.

However, spring annual grass and fall perennial forbs show significantly reduced values in the far-field data. At this time no explanation can be given. Spring and fall, 1987, percent presence values for each species are given in Appendices 9-H and 9-I.

Community Structure. Fixed station photography has been conducted at all seven monitoring plots. Four years of photographs exist to date. Both C2S and C2W were photographed in 1987. A series of eight photographs are taken from the central sign post in each plot, in a 360-degree spread. Each photo includes an identification label bearing plot number, direction from the signpost (N, NE, E, SE, S, SW, W, NW), and a color chart. The date the photo is taken is printed on the film.

Changes in vegetation community structure have been recorded by a number of authors using archived photographs from historical records. The old photos are retaken by approximating camera position relative to the landscape under study. The new photographs are then compared to the old photographs to study the landscape (Rogers, 1982; Turner and Karpiscak, 1980).

TABLE 9.6

COMPOSITION OF ANNUALS COMPARED BETWEEN YEARS (INDIVIDUALS PER SQUARE METER)

	Spring 1985	Fall 1985	Spring 1986	Fall 1986	Spring 1987	Fall 1987
Telegraph plant	11.06	3.62	0.28	0.08	13.51	7.96
Bluets	3.62				3.61	0.27
Spotted horsemint	3.54	0.15	0.23		1.97	
Lace spurge	3.08		0.32	0.44	0.92	0.39
Annual buckwheat	2.28	1.07	0.28	0.09	0.36	1.16
Fetid marigold			1.49	0.42	1.36	0.15
Prairie sunflower	0.41	0.06	0.17	0.29		0.13
Paladoxia		0.13				
Nightshade		0.07				
White ragweed				0.02		
Purple sandgrass		1.08		0.11	0.45	1.87
False buffalograss		0.04		0.18	0.22	0.26

Blank spaces indicate less than .01 individuals per square meter.

TABLE 9.7

COMPARISON OF DOMINANT ANNUALS BETWEEN WET AND DRY YEARS

High PPT	Low PPT
WIPP EMP DATA	
1985, 1987	1986
Annual buckwheat	False buffalograss
Bluets	Fetid marigold
Purple sandgrass	Lace spurge
Spotted horsemint	Telegraph Plant
Telegraph plant	
WIPP BICLOGY DATA	
1979	1978
Annual buckwheat	False buffalograss
Annual sunflower	Fetid marigold
Bluets	
Lace spurge	1980
Telegraph plant	
	Annual sunflower
	Lace spurge

WIPP Biology Data by S.L. Dowhower, 1971, Range Science Thesis, NMSU

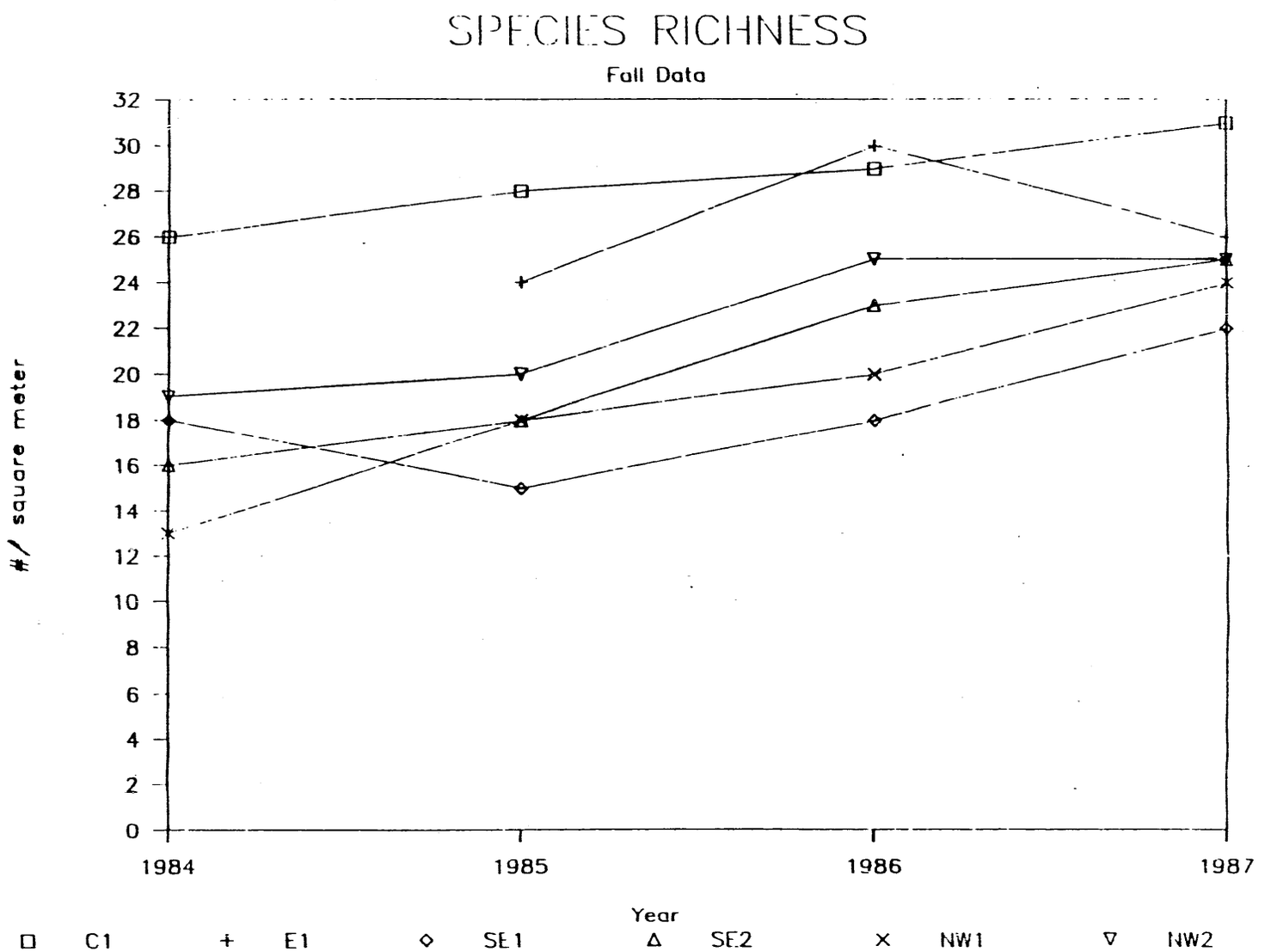


FIGURE 9.7 Species richness in the seven ecological monitoring plots over four years.

TABLE 9.8

SIMILARITY OF SPECIES RICHNESS
(NEAR-FIELD, FAR-FIELD, CONTROL PLOTS)

	% SIMILAR TO CONTROLS		% SIMILAR NEAR-
	NEAR-FIELD	FAR-FIELD	FIELD TO FAR-FIELD
SPRING 1987			
SHRUBS	95.33	99.56	94.87
PERENNIAL FORBS	88.89	90.91	97.96
ANNUAL FORBS	92.89	95.90	96.98
PERENNIAL GRASSES	97.40	82.15	84.89
ANNUAL GRASSES	77.65	46.81	65.00
TOTAL VEGETATION	93.18	94.62	98.68
FALL 1987			
SHRUBS	97.48	92.94	95.66
PERENNIAL FORBS	86.53	97.56	83.33
ANNUAL FORBS	90.18	92.12	98.04
PERENNIAL GRASSES	93.15	99.61	93.79
ANNUAL GRASSES	66.67	68.18	98.98
TOTAL VEGETATION	100.00	98.34	98.34

Controls = Avg. C1 and C2W
Near-field = Avg. E1, SE1, NW1
Far-field = Avg. NW2 and SE2
Values derived from species richness (% frames including a particular species).
Calculated from Motyka's Modified Sorensen's Index.
Data in Appendix 9-I.

Recording changes in the vegetation community from photographs has several advantages over other methods. Photographs record minute detail that is often overlooked. They record subtle features such as high water marks, soil cracks, flood-formed banks, and presence or absence of plants. More importantly, they provide an unbiased and complete visual record of existing conditions at the time of the photograph. When paired with old photos of the same area, a change over time can be discerned (Turner and Karpiscak, 1980).

A partial list of the subtle features which may be recorded in WIPP photography are: numbers of perennial grasses, height of shrubs, numbers of mesquite and other woody plants, size and position of sand trap blow outs, direction of sand dune movement, pedestalling of bunch grasses, and direction and impact of livestock trails. The features listed are all important to understanding the local ecosystem. Measuring all of these features would require enormous amounts of time and manpower. However, relative changes can be recorded by means of photographs which can be compared from year to year.

Changes recorded with photographs typically happen over long periods of time. However, the impact of salt on the environment may speed up the process of change. As explained by Stoddart et al. (1975), changes in a plant community are ususally changes in the vegetation and not of the soil. For example, if the factor of change is grazing by livestock and soil trampling is not a major effect, but over utilization of vegetation is, then changes in plant community structure will be measured earlier than indicators of soil deterioration. If trampling and severe overgrazing continues, the soil may deteriorate to such an extent that it will not produce a superior vegetation community even when the grazing has ceased.

9.2 EVALUATION OF SALT IMPACTS

In 1979 and 1980, salt impact experiments were conducted as part of the WIPP Biology Program. Salt was applied to the soil at a rate of 3,900 kilograms per hectare and 11,700 kilograms per hectare. The low rate reduced foliar cover of native vegetation 23-37 percent. The high rate reduced foliar cover 54-75 percent. It was noted that the effect of salt was to sharply reduce annual plant populations and to decrease perennial cover proportionally to the amount of salt applied (Dowhower, 1981). Dowhower concluded that the plants' response to salt was determined by a combination of plant-controlled and climate-controlled factors. He cited plant-controlled factors as: salt tolerance, rooting habit, importance of dormancy, and dependence upon reproduction by seed. He cited climate-controlled factors as: salt movement affected by rainfall and moisture available to the plant.

To date, EMP data show no measurable impact on the vegetation from salt stress. However, it has been shown in this report that supplemental data on forage utilization and plant phenology are needed to interpret the data more precisely.

As discussed in Chapter 7, WIPP precipitation for 1985, 1986 and 1987 show a dramatic impact on salt concentration levels in surface soil. The data support Dowhower's prediction that rainfall would be one of the most important factors affecting salt movement. Soil samples collected after heavy rains show much reduced levels of measured ions, these having been leached through the soil profile. Figure 9.8 shows elevated electrical conductivity in the near-field plots. Similar patterns were seen for sodium, magnesium, potassium, calcium, chloride, and pH (see Chapter 7). Although the near-field plots do show elevated levels of ions relative to the far-field and control plots, there is no apparent adverse impact on the near-field vegetation at this time. This observation is based solely on foliar cover and annual plant density data. As outlined by Dowhower (1981), rooting habit may be an important factor to examine.

The Berino soil is comprised of loose sands overlying an argillic horizon. Below the argillic horizon is a calcic (or caliche) layer which is an accumulation of leached ions from the upper profile cemented together. The loose sand has very low water-holding capacity and ions leach through the profile rapidly

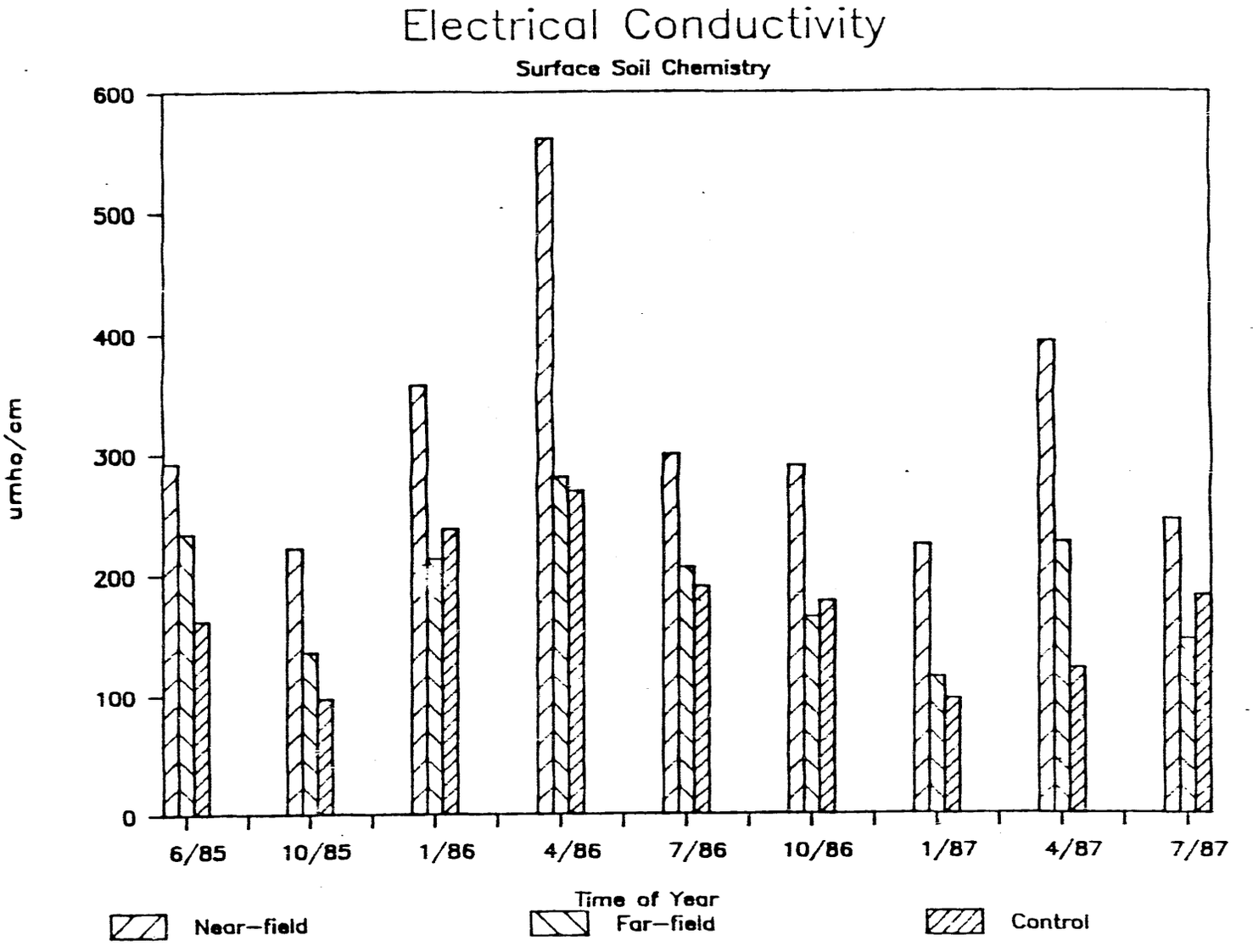


FIGURE 9.8 Electrical conductivity compared between near-field, far-field, and control plots from June 1985, to July 1987.

where they accumulate in a calcic layer. Here, permeability is slow and the calcic layer may act as a hard pan for salts to flow across. Under these conditions, rooting depth could play an important role in plant growth and survival. Plants with shallow roots would be able to tap less saline moisture from the sandy profile. Plants with roots extending to the calcic horizon would be in contact with concentrated salt flow.

Plants under salt stress may exhibit symptoms similar to drought stress such as rolling or shedding leaves (Dowhower, 1981). Reduction of growth may also occur under saline conditions due to a negative solute potential in the soil solution which causes the water potential to be negative and results in a decrease in water uptake by the plant (Goodin, 1977).

Observations on physiology of the plant species relative to salt stress play an important role in the monitoring program. Although monitoring at the permanent plots does not show any adverse impacts from salt stress within the monitoring plots, a small area next to one salt stock pile does show stress. It is believed that this is due to subsurface movement of salt and that plant rooting depth relative to the soil caliche layer is an important factor in this area. The area of impact is being examined and the results will be published in another report.

The monitoring data have shown the Los Medanos area to be a dynamic ecosystem which shows measurable changes in response to local precipitation patterns. However, salt and precipitation interact to show a complex vegetation pattern that is affected by more than total precipitation.

Salt in soil chemistry includes other ions besides sodium. In particular, calcium, magnesium, and potassium are ions of saline soil as well as plant macronutrients. An excess of sodium can cause deterioration of the soil structure. An excess of magnesium can be toxic to plant tissue and reduce the absorption of calcium and potassium. An excess of calcium can cause a nutritional imbalance unless accompanied by other cations such as sodium or potassium. In general, sodium is directly toxic to sodium-sensitive plants and can cause an imbalance of other ions needed for plant nutrition (Goodin, 1977).

As explained by Goodin, many plants are capable of cycling salts through the soil-plant system and are essential to the continued functioning of the ecosystem. Critical plant nutrients may occur as islands of fertility in arid regions which are cycled by a particular species. Displacement of a species component will probably result in the loss of a particular nutrient through leaching. Once it is gone, there is little chance that a new plant of the same or different species will be established to fill the niche (Goodin, 1977).

Salt impacts remain a concern, although no adverse impacts have been recorded to date. Four years of data begin to reveal patterns and fluctuations but are not enough to establish trends or make predictions. Outside factors such as difference in grazing pressure, difference in pasture management, and history of chemical treatment have been identified and should be examined to enable a better analysis of the salt impact data.

9.3 CONTINUING PROGRAM

Future monitoring will continue to include thorough plant inventory and species identification which evaluate each plant as a potential indicator species. Activities initiated in 1987 (study of plant phenology and development of an herbarium) will continue. Knowledge of plant phenology (especially among annual species) is needed to relate annual plant densities to critical precipitation data. Continued development of the herbarium is needed to include voucher specimens of each species in the plant community. Voucher specimens are documentation of field data.

Activities which should be considered in the future include establishment of photo plots to supplement the fixed place photography, monitoring of forage utilization and monitoring of plant physiology related to salt stress.

The study of paired photographs can be supplemented by a technique which combines a permanent quadrat and a photo plot. The photo plot provides a more detailed record of individual plants within a small area, such as the meter square frame. It is marked permanently so the exact piece of ground may be photographed from year to year. As suggested by Oosting (1956), permanent quadrats should be utilized whenever there is a chance that a site may be revisited. When photographed each year, the quadrat yields a unique record with certain advantages:

- It has increased accuracy because personal bias is eliminated
- It produces a visual, two-dimensional record
- It provides the possibility of enlarging negatives from different years which may be overlayed for direct comparison (Weaver, and Clements, 1938).

Forage utilization studies provide supplemental data on grazing impacts. Plant vigor should be investigated for each species at the same time since the purpose of the monitoring plots is to look for any change reflecting salt impacts. Where traditional utilization studies monitor only key forage species (those preferred by livestock), it will be necessary to account for each species. Confining observations to a few key species fails to give a true picture of range condition or trend (the progress a plant community is making toward improved or deteriorating species composition), because the undesirable species are ignored (Cook and Stubbendieck, 1986). A thorough inventory of forage utilization may reveal that impacts are related to grazing rather than salt stress.

Several grazing exclosures were established at WIPP over ten years ago. These exclosures can provide data on plant vigor relative to ungrazed forage and may increase the understanding of current range condition and trend.

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APPENDIX 2-A

TEMPERATURE DATA FOR WIPP AND VICINITY (°C)
OCTOBER THROUGH DECEMBER, 1986

OCTOBER 1986

	WIPP		W-AG		CARLSBAD		BRANTLY DAM		ARTESIA	
DAY	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	32	17	29	12	32	12	32	13	31	7
2	27	19	31	18	26	18	28	17	32	7
3	29	16	26	17	29	14	31	17	26	15
4	25	14	28	16	27	15	31	13	29	9
5	18	12	24	14	19	13	31	12	26	9
6	16	11	16	11	17	11	19	11	21	11
7	21	12	16	11	22	13	23	10	17	10
8	30	11	21	10	28	11	31	9	23	7
9	28	13	28	11	27	11	28	9	29	8
10	20	16	27	11	19	16	22	10	26	12
11	22	6	24	14	23	8	23	11	21	11
12	17	6	17	6	20	5	17	3	21	4
13	18	3			20	4	21	2	7	3
14	25	4	18	3	22	3	24	1	19	-1
15	24	7	22	5	23	3	23	1	22	-1
16	24	9	23	9	22	6	23	3	22	0
17	26	12	23	10	24	8	22	4	24	3
18	27	11	24	9	26	8	28	7	24	4
19	21	13	24	14	19	14	18	8	26	6
20	17	14	18	13	18	14	17	13	18	13
21	24	15	17	13	24	14	24	13	18	12
22	25	13	23	10	23	7	24	5	23	4
23	23	13	23	9	22	11	24	8	23	7
24	24	10	22	11	21	9	23	9	21	9
25	24	10	21	11	22	9	24	8	22	7
26	24	8	22	8	24	7	26	6	22	4
27	27	7	22	9	26	7	29	6	23	3
28	31	7	26	9	28	5	25	3	26	2
29	23	7	27	7	22	9	26	8	28	4
30	25	10	22	9	24	7	26	6	21	3
31	27	10	24	9	26	7	24	8	24	3

APPENDIX 2-A

TEMPERATURE DATA FOR WIPP AND VICINITY (°C)
OCTOBER THROUGH DECEMBER, 1986
(CONTINUED)

NOVEMBER 1986

	WIPP		W-AG		CARLSBAD		BRANTLY DAM		ARTESIA		HOBBS	
DAY	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	24	12	20	5	22	8	11	6	27	8	21	6
2	12	6	7	5	8	5	26	2	22	3	14	4
3	11	6	26	5	9	6	8	3	6	3	11	3
4	11	2	14	6	12	2	13	4	9	4	17	4
5	19	1	11	3	18	1	21	-1	12	-2	21	9
6	22	6	17	6	22	2	20	0	18	-1	21	8
7	18	8	21	7	18	4	17	1	21	2	22	10
8	20	5	18	9	19	6	21	3	18	-1	20	7
9	17	1	14	4	16	2	14	0	21	-3	21	6
10	17	0	14	4	16	2	17	0	15	-1	17	4
11	10	-1	16	-2	9	-1	12	-3	17	-3	12	-4
12	11	-3	8	-1	10	-2	14	-2	8	-3	10	0
13	-2	-4	9	-3	-2	-3	7	-2	9	-4	4	-7
14	14	-4	-2	-3	13	-3	-3	-7	-2	4	11	-2
15	17	5	14	8	19	3	12	-7	12	-4	17	1
16	21	7	19	9	22	8	18	-4	17	3	21	1
17	26	7	21	9	26	8	17	7	22	3	24	10
18	19	10	24	10	21	11	25	6	27	4	22	10
19	23	8	19	9	24	8	26	6	21	6	22	6
20	18	4	23	7	17	3	17	4	25	2	24	7
21	21	4	17	6	19	12	0	-2	17	-3	23	9
22	23	7	17	8	23	3	24	3	19	-2	23	5
23	10	-1	20	7	12	1	5	2	24	3	10	-1
24	12	-4	6	-1	11	-2	14	-6	6	-6	12	-2
25	18	-2	10	-2	19	-6	20	-8	12	-8	17	-1
26	10	0	17	-1	9	1	20	-4	17	-7	22	9
27	17	-4	13	-2	16	-4	20	-7	10	-8	21	6
28	20	-2	16	-2	21	-3	22	-7	16	-7	22	2
29	22	0	17	0	22	-3	20	-7	19	-7	20	0
30	19	6	21	-1	20	3	21	-7	22	-5	21	-1

APPENDIX 2-A

TEMPERATURE DATA FOR WIPP AND VICINITY (°C)
OCTOBER THROUGH DECEMBER, 1986
(CONTINUED)

DECEMBER 1986

DAY	WIPP		W-AG		CARLSBAD		ARTESIA		HOBBS	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	13	-3	13	-1	14	-2	19	-6	13	2
2	21	-1	20	2	20	-4	14	-7	19	2
3	16	2	15	1	14	-1	19	-5	13	-1
4	8	2	14	2	8	-2	16	-7	9	-1
5	12	6	10	1	11	6	7	-6	8	4
6	15	8	11	3	16	7	12	4	17	6
7	19	7	13	6	0	8	13	6	21	4
8	15	5	19	4	16	6	20	4	14	1
9	7	0	14	2	8	1	16	-1	10	1
10	1	-5	6	-2	2	-5	4	-3	1	-6
11	4	-6	-1	-5	4	-6	0	-9	1	-6
12	11	-5	4	-4	11	-7	5	-9	11	-4
13	12	-1	9	0	9	-4	11	-8	14	-3
14	17	2	9	2	15	1	11	-7	15	-2
15	20	-1	14	2	19	-3	14	-7	21	-3
16	10	5	19	6	9	3	21	-7	16	3
17	12	0	9	5	9	1	8	1	10	-1
18	6	0	9	3	6	-1	8	-1	5	0
19	15	-1	6	-1	12	-3	6	-4	14	-2
20	14	1	12	2	13	-2	13	-6	12	-1
21	6	3	6-	1	7	3	15	-5	5	-1
22	2	0	13	-1	3	1	6	-1	1	0
23	11	0	7	1	10	-1	3	-2	6	0
24	12	-1	8	1	12	-2	10	-3	8	0
25	11	0	10	-1	12	-1	11	-2	8	0
26	13	-2	11	0	11	-3	11	-7	10	-3
27	12	-1	11	3	11	-4	12	-7	10	-3
28	14	4	9	3	10	1	12	-7	11	1
29	14	0	9	0	13	-2	10	-5	12	-1
30	16	-4	13	-2	17	-4	13	-8	14	1
31	13	0	15	-2	13	-2	17	-9	14	-2

APPENDIX 2-B

TEMPERATURE DATA FOR WIPP AND VICINITY (°C)
JANUARY THROUGH DECEMBER, 1987

JANUARY 1987

	WIPP		W-AG		CARLSBAD		BRANTLY DAM		ARTESIA		HOBBS	
DAY	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	11	0	11	1	11	-4	10	-6	13	-9	18	-3
2	19	0	9	-1	20	-4	11	-7	11	-6	18	-3
3	13	-2	16	0	14	-1	13	-4	21	-5	11	1
4	20	0	11	1	20	-5	19	-3	14	-9	17	-1
5	20	4	17	2	18	-1	22	-2	18	-8	17	-2
6	18	3	18	3	17	3	17	-3	22	-7	17	2
7	12	2	17	2	10	0	10	-4	17	-7	13	1
8	10	4	11	3	10	0	10	-3	11	-6	6	2
9	11	-4	9	-2	11	-4	13	-7	10	-8	7	-3
10	12	-4	11	-2	12	-4	12	-9	12	-9	8	-4
11	15	-4	11	-2	15	-6	16	-11	13	-11	11	-6
12	21	-4	13	-3	19	-6	22	-10	16	-10	19	-3
13	19	0	18	-2	19	-4	21	-9	20	-8	18	1
14	22	0	17	-3	22	-3	-4	-6	20	-7	18	-1
15	6	-2	21	-2	5	-4	23	7	22	-6	14	-3
16	1	-4	4	-2	1	-3	-1	-7	7	-4	3	-4
17	-4	-14	-5	-13	-2	-12	-6	-9	1	-8	-6	-8
18	3	-15	2	-13	3	-11	4	-14	-5	-13	0	-12
19	11	-7	2	-6	8	-8	10	-11	6	-10	4	-9
20	1	-3	7	-4	1	-3	-2	-11	8	-10	4	-4
21	7	-4	2	-3	7	-8	7	-16	-1	-13	5	-5
22	10	-8	6	-6	10	-10	11	-14	6	-13	8	-7
23	12	-3	8	-3	10	-6	13	-12	11	-12	14	-5
24	15	-1	8	2	17	0	18	-7	14	-7	12	-1
25	19	-2	12	1	21	-5	24	-7	16	-7	17	0
26	22	1	17	4	21	0	23	-7	21	-7	21	3
27	27	0	20	3	25	-4	27	-8	21	-8	24	3
28	23	6	24	5	25	3	26	2	26	-7	24	3
29	24	7	21	7	24	6	22	2	26	-1	22	7
30	22	1	22	2	18	1	17	-3	23	-4	18	2
31	19	8	17	8	19	4	20	-2	18	-4	17	2

APPENDIX 2-B

TEMPERATURE DATA FOR WIPP AND VICINITY (°C)
JANUARY THROUGH DECEMBER, 1987*
(CONTINUED)

FEBRUARY 1987

	WIPP		W-AG		CARLSBAD		BRANTLY DAM		ARTESIA		HOBBS	
DAY	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	19	1	20	3	21	3	22	2	19	-3	18	2
2	25	1	19	3	25	1	27	-3	22	-4	22	3
3	24	0	24	3	24	1	26	-3	27	-4	22	2
4	23	4	23	4	22	4	24	-2	22	-2	21	6
5	21	4	21	4	10	-1	11	3	22	1	18	2
6	13	-4	9	-3	16	-2	17	-8	10	-7	12	-3
7	17	-4	12	-1	19	-4	22	-8	15	-9	16	-3
8	22	-2	17	3	22	-5	24	-9	20	-8	17	0
9	18	1	21	1	14	-1	24	-4	20	-8	14	-1
10	22	2	14	1	24	-2	24	-3	14	-4	24	2
11	26	2	23	4	26	1	29	-4	23	-2	26	4
12	25	3	24	6	23	5	26	-1	26	-2	23	6
13	25	3	23	6	24	3	26	0	24	1	22	7
14	24	7	24	11	22	8	19	0	24	1	20	8
15	16	4	20	7	17	3	21	6	21	5	17	6
16	15	2	16	3	8	1	6	0	16	-1	6	2
17	7	3	7	2	8	3	8	2	7	2	7	-1
18	9	-1	7	0	9	1	7	-1	8	1	7	-2
19	9	1	8	1	7	1	3	0	8	1	7	-1
20	5	1	5	1	3	1	1	-1	6	0	1	-1
21	3	-1	3	0	2	-3	1	-2	2	-1	2	-1
22	9	-5	1	-5	10	-4	12	-11	1	-9	8	-6
23	10	2	9	1	11	-3	10	-6	9	-9	9	-4
24	14	2	11	1	16	-4	14	-6	11	-6	12	3
25	13	6	14	3	12	6	11	-3	16	-4	11	3
26	14	5	13	8	16	4	13	7	13	6	15	7
27	14	3	14	3	12	3	12	-1	14	-1	12	2
28	14	-2	12	2	16	-1	17	-1	13	-2	12	-2

*All data taken from Climatological Data/New Mexico, February 1987.

APPENDIX 2-B

TEMPERATURE DATA FOR WIPP AND VICINITY (°C)
JANUARY THROUGH DECEMBER, 1987*
(CONTINUED)

MARCH 1987

DAY	WIPP		W-AG		CARLSBAD		BRANTLY DAM		ARTESIA		HOBBS	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	14	0	13	2	14	-3	17	-6	16	-6	16	-1
2	19	3	13	3	20	-2	22	1	14	-6	19	-1
3	19	3	19	4	20	2	23	4	21	-4	18	3
4	19	3	19	3	19	1	21	3	21	-2	18	2
5	22	3	18	4	23	-1	27	1	20	-4	22	3
6	23	3	22	3	25	0	27	-4	23	-3	24	3
7	24	6	22	6	21	2	22	-1	25	-2	18	2
8	24	6	19	6	23	2	26	-1	22	-2	20	4
9	21	3	21	4	17	3	18	4	24	-1	12	2
10	16	0	15	-1	5	2	7	1	16	1	11	-1
11	12	2	6	2	16	3	19	2	6	-1	13	1
12	22	1	13	2	22	0	23	0	16	[illegible]	20	1
13	22	1	21	4	22	2	23	-1	21	-2	21	8
14	24	7	20	4	26	2	28	3	22	3	18	7
15	25	4	24	8	26	6	27	9	27	1	20	6
16	24	7	24	9	14	5	17	11	25	5	12	2
17	13	3	13	3	17	3	15	2	13	-1	14	3
18	21	2	12	2	24	9	26	4	14	1	19	4
19	22	9	22	7	24	6	26	9	24	3	21	5
20	24	6	23	6	24	3	24	4	24	2	22	3
21	23	2	22	4	25	6	26	4	24	0	22	3
22	25	6	23	8	26	6	26	11	25	2	23	7
23	19	4	24	5	19	5	21	4	24	4	17	2
24	18	-2	21	1	16	-1	17	-1	21	-4	17	-2
25	16	3	15	2	9	2	11	-1	16	-2	13	1
26	11	0	9	2	13	2	16	3	11	2	8	0
27	21	3	12	4	22	0	22	0	11	-1	21	0
28	21	1	10	0	12	0	12	0	23	-1	19	-7
29	12	-6	6	-6	2	-5	2	-5	12	-7	1	-9
30	15	-9	-3	-8	12	-7	12	-7	0-11	10	-9	
31	20	-4	11	1	21	-2	21	-2	13	-7	20	-2

*All data taken from Climatological Data/New Mexico, March 1987.

APPENDIX 2-B

TEMPERATURE DATA FOR WIPP AND VICINITY (°C)
JANUARY THROUGH DECEMBER, 1987
(CONTINUED)

APRIL 1987

	WIPP		W-AG		CARLSBAD		BRANTLY DAM		ARTESIA		HOBBS	
DAY	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	25	2	21	2	27	-1	29	-3	22	-2	9	1
2	26	2	26	2	12	0	14	-7	27	1	16	-1
3	17	0	11	0	18	-3		-7	11	-7	16	-1
4	17	3	15	2	17	0			18	-2	15	0
5	14	5	11	3	14	6	18		17	2	12	0
6	11	3	12	4	12	4	14	2	12	4	12	7
7	14	-1	13	1	17	-1	17	-2	13	-3	13	1
8	17	-1	16	2	19	0	21	-2	16	-3	18	0
9	25	7	19	2	26	2	28	0	19	-3	25	0
10	25	7	26	7	27	7		1	26	0	26	0
11	29	7	24	8	31	6			26	2	27	6
12	29	12	27	16	26	12	31		31	3	23	11
13	24	2	23	4	20	3	21	4	27	0	21	3
14	18	2	19	3	23	1	24	1	19	-1	22	3
15	31	6	22	5	32	4	34	1	22	1	31	8
16	32	9	31	8	32	9	33	7	32	2	32	9
17	33	11	32	13	34	8		6	31	4	34	10
18	34	11	32	14	36	9			34	6	37	10
19	34	14	34	11	30	11	37		35	7	30	13
20	28	16	27	18	27	14	28	7	29	11	24	13
21	26	7	26	7	16	7	16	9	26	9	23	4
22	18	6	12	7	20	7	23	4	13	2	19	4
23	23	7	20	6	25	4	27	2	21	-1	26	5
24	24	11	25	10	23	8		2	27	2	26	6
25	22	9	26	9	23	8			23	6	26	7
26	25	11	24	11	25	8	28		24	7	27	9
27	26	11	21	11	26	9	24	6	25	7	27	9
28	25	11	25	10	23	7	24	7	26	6	27	9
29	26	11	23	11	27	7	21	-2	23	8	26	7
30	28	12	27	12	28	9	17	0	27	7	27	4

APPENDIX 2-B

TEMPERATURE DATA FOR WIPP AND VICINITY (°C)
JANUARY THROUGH DECEMBER, 1987
(CONTINUED)

MAY 1987

	WIPP		W-AG		CARLSBAD		BRANTLY DAM		ARTESIA		HOBBS	
DAY	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	29	11	29	12	29	11		7	28	8	27	5
2	27	15	28	16	28	15			31	9	26	3
3	24	9	25	12	26	11	31		28	10	26	6
4	26	6	22	7	26	7	31	7	24	5	28	4
5	29	7	25	8	27	9	29	7	24	6	28	6
6	23	13	27	11	23	13	24	8	26	8	27	5
7	25	8	22	9	24	11	27	10	22	9	28	6
8	28	10	23	9	27	8		7	24	6	28	7
9	28	11	24	12	28	7			26	6	29	4
10	31	14	26	13	31	8	32		27	7	28	6
11	30	14	28	13	30	9	31	6	31	8	28	8
12	31	13	30	13	31	11	32	10	31	9	29	8
13	32	16	31	16	31	16	32	10	30	11	31	7
14	31	18	30	17	32	16	34	13	31	12	32	7
15	29	14	30	15	30	16		13	31	14	29	15
16	33	15	29	15	31	14			28	13	31	14
17	35	14	33	13	34	12	34		29	9	33	12
18	29	19	31	18	29	14	31	11	32	12	30	17
19	24	16	28	16	25	15	26	16	29	16	29	16
20	29	13	23	13	29	14	31	14	25	12	27	11
21	28	13	29	13	30	13	31	11	29	9	29	14
22	28	17	29	16	27	14			29	12	30	13
23	22	14	27	13	21	13			27	14	27	11
24	26	14	21	14	24	14			22	12	26	13
25	30	17	28	16	29	13	31		26	11	30	14
26	31	19	28	18	31	18	32	11	30	13	30	18
27	31	16	31	16	30	13	32	13	31	10	28	17
28	28	15	30	14	29	13	31	13	30	11	29	12
29	31	11	29	14	30	9		14	28	6	29	12
30	26	17	28	16	27	16			29	11	27	16
31	28	13	26	13	27	15	30		29	13	27	11

APPENDIX 2-B

TEMPERATURE DATA FOR WIPP AND VICINITY (°C)
JANUARY THROUGH DECEMBER, 1987
(CONTINUED)

JUNE 1987

	WIPP		W-AG		CARLSBAD		BRANTLY DAM		ARTESIA		HOBBS	
DAY	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	32	14	25	14	33	14	36	13	28	14	32	14
2	33	18	33	18	35	13	38	13	34	11	33	16
3	27	17	33	17	27	15	27	12	35	15	27	12
4	26	13	27	12	26	13	28	13	26	14	31	10
5	27	13	26	12	25	13		11	26	12	31	16
6	27	15	24	16	26	15			25	13	31	15
7	30	17	26	16	29	17	31		27	16	32	16
8	23	16	29	17	22	16	23	14	29	16	27	16
9	30	17	23	17	27	17	28	15	22	17	29	17
10	32	19	27	18	29	16	31	16	27	16	31	18
11	31	16	31	17	32	14	32	14	29	13	31	17
12	35	17	31	17	33	17		14	31	16	33	17
13	35	17	32	18	33	17			32	15	34	17
14	37	18	32	19	34	17	36		34	16	36	17
15	36	19	33	19	35	17	37	16	34	16	34	17
16	39	21	35	21	36	19	38	19	36	18	36	18
17	40	20	36	19	37	17	39	15	36	14	34	18
18	38	20	38	19	36	16	37	16	37	14	36	18
19	40	20	36	19	37	17		13	36	15	36	18
20	38	17	36	18	38	13			37	12	36	18
21	35	19	36	20	34	18	38		37	17	32	17
22	37	16	32	16	34	18	41	13	34	14	34	17
23	41	19	35	20	39	14	39	13	35	12	38	19
24	37	21	39	21	37	20	38	21	39	16	36	20
25	35	21	37	21	34	32	34	22	38	19	36	17
26	26	16	35	17	27	18		19	34	18	27	16
27	31	18	34	16	29	18			26	17	32	18
28	32	18	29	19	32	18	33		31	17	31	18
29	38	19	29	17	34	16	36	16	31	14	33	18
30	32	17	34	18	30	18	32	16	36	15	34	16

APPENDIX 2-B

TEMPERATURE DATA FOR WIPP AND VICINITY (°C)
JANUARY THROUGH DECEMBER, 1987
(CONTINUED)

JULY 1987

	WIPP		W-AG		CARLSBAD		BRANTLY DAM		ARTESIA		HOBBS	
DAY	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	36	20	30	19	36	19	36	20	31	18	33	18
2	42	23	35	21	39	19	42	19	34	16	38	19
3	42	20	38	22	41	21	41	19	39	17	38	20
4	40	22	41	21	40	19			41	13	38	21
5	41	23	39	22	39	17	42		41	14	38	19
6	39	22	37	21	39	16	41	16	39	12	38	19
7	40	21	39	19	40	16	41	16	39	14	37	20
8	36	21	39	21	35	18	37	18	39	19	37	20
9	37	20	35	20	37	19	37	20	35	18	34	20
10	37	20	37	19	37	18	38	20	36	18	34	19
11	39	21	35	20	37	19			36	18	37	19
12	40	22	37	20	39	18	39		36	18	37	20
13	26	18	38	18	26	17	26	18	36	19	37	16
14	32	18	26	18	32	18	33	18	26	17	30	18
15	34	16	32	16	33	16	34	17	32	16	31	15
16	30	20	33	18	30	17	32	18	32	17	31	19
17	34	19	29	18	35	18		19	30	16	33	17
18	36	20	32	19	36	16			33	14	37	20
19	34	21	36	20	34	21	38		36	17	36	19
20	34	21	32	20	33	19	34	19	34	17	32	19
21	32	21	33	21	32	21	33	20	32	18	31	19
22	34	19	33	19	33	18	36	19	32	16	32	18
23	35	20	33	20	36	19	37	19	33	17	33	18
24	34	20	34	19	34	19		21	35	18	32	19
25	33	19	32	19	33	18			34	17	32	17
26	32	19	32	18	30	17	35		33	15	31	18
27	33	20	29	19	31	19	32	18	31	18	32	18
28	31	19	32	19	31	19	32	20	31	18	30	18
29	34	18	31	18	34	17	35	18	31	17	33	17
30	35	19	33	19	35	18	36	19	33	18	33	17
31	36	20	35	19	37	19			34	18	34	18

APPENDIX 2-B

TEMPERATURE DATA FOR WIPP AND VICINITY (°C)
JANUARY THROUGH DECEMBER, 1987
(CONTINUED)

AUGUST 1987

	WIPP		W-AG		CARLSBAD		BRANTLY DAM		ARTESIA		HOBBS	
DAY	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	38	21	34	19	38	19	41	21	36	18	37	18
2	37	22	37	21	37	21	38	22	38	19	36	19
3	39	22	36	21	38	20		22	37	19	36	19
4	38	22	36	21	37	21	38	20	37	19	36	21
5	36	20	36	21	36	21	36	21	36	19	36	21
6	39	22	34	22	38	22	38	22	36	18	36	21
7	38	22	36	22	38	21	40		37	19	36	21
8	41	22	36	22	39	21	42	23	37	21	37	19
9	33	20	38	18	33	21	34	21	38	20	33	19
10	36	20	38	18	33	20	35	20	32	18	33	20
11	33	21	31	19	34	21	35	21	30	19	32	21
12	35	20	33	18	35	20	33	17	31	17	33	19
13	36	19	34	20	33	21		21	33	18	33	19
14	37	20	36	20	37	19			32	17	36	19
15	38	22	37	22	37	21			36	18	36	18
16	37	20	35	20	38	22			36	16	36	23
17	40	19	36	21	38	19	39		36	16	37	21
18	40	23	37	20	38	18	38	20	37	16	34	23
19	37	21	33	19	36	22	37	19	38	16	36	20
20	37	22	34	19	37	19		21	36	17	35	20
21	36	22	35	21	35	19	38	22	36	17	34	19
22	36	21	34	21	34	20	37	22	35	18	33	18
23	27	20	34	21	24	18		19	34	19	21	14
24	31	18	25	18	28	19	29	20	24	17	30	17
25	29	19	29	18	31	18	32	19	29	18	30	17
26	27	17	29	18	27	17	29	18	31	17	28	19
27	30	15	27	16	28	16		16	28	14	28	15
28	24	17	28	16	24	17	29	17	28	13	25	16
29	30	17	24	16	28	16			24	14	28	14
30	30	18	26	17	30	16			28	14	29	21
31	28	13	27	14	29	13	32	12	30	11	-18	-18

APPENDIX 2-B

TEMPERATURE DATA FOR WIPP AND VICINITY (°C)
JANUARY THROUGH DECEMBER, 1987
(CONTINUED)

SEPTEMBER 1987

	WIPP		W-AG		CARLSBAD		BRANTLY DAM		ARTESIA		HOBBS	
DAY	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	28	14	28	16	29	14	30	11	29	12	28	14
2	29	13	29	16	31	14	30	14	29	11	30	15
3	31	17	30	17	32	13	32	15	31	11	31	14
4	31	18	31	18	31	17	32	18	31	12	31	18
5	30	19	28	16	31	19			29	16	30	18
6	31	15	30	16	32	15			30	13	28	16
7	31	16	30	15	33	15			31	13	31	17
8	31	16	29	14	30	18	32	11	27	13	25	15
9	29	17	29	17	31	16	31	16	29	14	30	14
10	29	17	29	18	31	16	31	16	29	14	29	16
11	28	13	31	14	29	13	32	12	31	9	28	12
12	32	17	27	14	33	16			28	11	29	17
13	31	18	34	17	36	15			32	11	33	17
14	31	17	34	17	22	17	37	12	36	12	22	14
15	27	14	20	16	30	16	24	17	20	11	27	14
16	30	12	28	14	34	13	31	12	29	10	31	14
17	31	14	32	16	31	13	34	13	32	10	31	16
18	28	16	29	17	19	14	31	16	30	11	29	14
19	26	12	17	12	27	12			19	9	24	10
20	29	16	23	13	30	12			28	10	28	11
21	29	13	27	14	27	14	30	11	29	10	26	13
22	27	14	27	13	26	13			27	10	25	13
23	26	11	27	13	28	9			27	7	27	12
24	27	12	27	13	32	9	29	8	28	6	30	12
25	30	13	31	15	31	12	31	12	31	6	29	14
26	30	13	26	12	32	13			31	9	29	13
27	32	16	26	12	34	12			30	10	31	14
28	32	13	30	14	29	17	33	11	33	10	26	13
29	27	16	26	15	26	13			28	13	25	14
30	29	11	25	11	28	9	30	8	25	8	27	12

APPENDIX 2-B

TEMPERATURE DATA FOR WIPP AND VICINITY (°C)
JANUARY THROUGH DECEMBER, 1987
(CONTINUED)

OCTOBER 1987

	WIPP		W-AG		CARLSBAD		BRANTLY DAM		ARTESIA		HOBBS	
DAY	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	29	11	27	11	29	9	29	13	28	7	26	11
2	31	10	28	12	32	9	29	7	29	6	24	11
3	28	7	28	11	26	8			31	6	23	6
4	28	8	26	9	30	8			26	4	27	9
5	35	9	27	12	34	7	31	7	30	4	28	10
6	26	8	32	12	26	8	33	8	31	5	23	8
7	30	12	26	11	30	8	26	6	26	4	27	9
8	34	14	29	11	34	8	31	8	29	5	30	10
9	32	13	33	12	29	9	34	9	29	6	24	12
10	28	12	27	12	28	11			28	7	21	10
11	23	7	24	7	22	8			27	7	19	4
12	28	8	20	9	28	8			23	4	26	8
13	31	13	28	9	32	12			27	4	28	11
14	30	14	31	13	29	12	33	8	32	9	27	11
15	27	14	29	14	28	13	29	13	28	11	24	12
16	27	11	26	12	27	11	30	9	27	7	22	11
17	16	8	24	8	18	9			26	6	17	6
18	25	12	16	8	27	11			20	6	26	10
19	27	9	24	10	26	9	27	7	25	5	21	17
20	19	8	27	8	16	9	26	6	26	5	20	4
21	20	9	17	8	21	12	17	9	17	3	18	6
22	26	11	20	10	27	9	21	9	21	3	23	7
23	20	12	24	11	19	12	22	11	26	9	24	11
24	27	12	24	11	27	9			19	6	26	10
25	29	12	27	11	30	11			27	6	28	10
26	29	13	28	11	28	12	31	8	31	7	23	10
27	27	13	27	13	26	8	22	7	27	5	25	9
28	28	9	27	8	27	8	27	7	27	4	26	7
29	30	11	27	11	29	10	27	7	27	6	30	7
30	31	14	28	13	31	10	27	9	29	7	29	18
31	25	15	27	13	23	12			30	9	27	13

APPENDIX 2-B

TEMPERATURE DATA FOR WIPP AND VICINITY (°C)
JANUARY THROUGH DECEMBER, 1987
(CONTINUED)

NOVEMBER 1987

	WIPP		W-AG		CARLSBAD		BRANTLY DAM		ARTESIA		HOBBS	
DAY	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	20	14	24	16	19	13	24	12	24	11	18	14
2	26	13	17	12	26	11	22	7	18	11	25	11
3	28	12	30	11	26	9	25	11	25	7	26	9
4	29	11	27	11	27	9	26	10	26	8	27	11
5	23	14	27	13	19	12	27	9	27	8	26	11
6	21	13	20	13	21	12			19	9	19	11
7	23	7	17	8	23	7			21	3	21	6
8	18	6	19	7	20	6			23	3	21	4
9	17	3	15	3	16	4			18	2	14	4
10	16	-3	15	0	13	-3	23	-3	16	-4	12	-3
11	18	-1	13	-1	18	-4	19	-3	15	-7	17	-2
12	20	2	18	3	19	1	18	1	18	-4	17	3
13	26	5	18	3	26	-3	19	-1	19	-4	23	0
14	25	7	21	8	25	4	26	-1	24	-3	22	3
15	22	3	20	8	17	4	17	7	25	7	14	6
16	20	-3	14	4	13	0		1	17	-2	11	-1
17	18	-1	11	3	19	-2	19	2	13	-4	18	-1
18	12	2	18	3	12	-2	19	1	20	-3	15	1
19	19	-4	12	-2	17	-7	18	-7	12	-9	13	-4
20	20	-3	16	-3	19	-7	20	-6	17	-9	18	-1
21	23	4	21	4	25	-1	24	-5	19	-8	20	0
22	24	3	21	3	24	1	24	1	24	-3	21	3
23	24	3	22	4	23	1	22	1	24	-3	23	2
24	22	6	21	1	22	5	22	3	21	-3	21	9
25	15	-2			15	-2	17	-3	21	-7	16	-2
26	5	1	15	1	6	-3		-2	16	-7	10	0
27	10	-5	2	-3	11	-3	10	-3	4	-8	9	-4
28	15	-4	7	-2	14	-7	13	-7	10	-11	11	-6
29	18	0	10	-4	15	-3	15	-12	16	-10	11	-3
30	14	-4	12		14	-5	14	-3	16	-7	12	-1

APPENDIX 2-B

TEMPERATURE DATA FOR WIPP AND VICINITY (°C)
JANUARY THROUGH DECEMBER, 1987
(CONTINUED)

DECEMBER 1987

	WIPP		W-AG		CARLSBAD		BRANTLY DAM		ARTESIA		HOBBS	
DAY	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1	18	-2	13	-3	18	-6	16	-7	14	-9	16	-4
2	23	-1	16	-1	23	-2	23	-1	18	-9	21	-4
3	26	5	22	4	25	2	22	2	26	-3	24	12
4	26	4	24	6	26	3	27	0	26	-3	24	4
5	26	8	22	13	26	11	26	3	25	2	24	8
6	22	5	19	8	23	6	24	3	24	-3	23	6
7	23	5	25	5	26	1		3	23	-3	24	4
8	21	6	24	7	21	3	22	3	25	-7	20	8
9	21	4	20	1	21	-3	22	-2	21	-6	20	1
10	22	4	21	3	25	-1	25	-1	21	-4	22	1
11	27	4	22	5	27	4	28	4	23	-2	26	8
12	9	5	24	9	12	0		2	28	-2	18	-3
13	-2	-3	10	3	4	-2		-3	12	-4	0	-5
14	-2	-13	3	-3	-2	-16	3	-16	3	-25	-3	-5
15	5	-15	-2	-16	-3	-20	-3	-14	-2	-23	0	-14
16	2	-11	-2	-13	-2	-17	-3	-16	-4	-19	3	-12
17	6	-5	0	-12	4	-10	1	-10	-3	-12	8	-4
18	4	-1	1	-4	3	-2	1	-9	2	-3	8	2
19	13	2	9	-4	13	-1		-2	3	-1	11	4
20	15	1	10	3	13	0	12	1	12	-4	14	1
21	17	10	16	-1	17	-3	13	-1	11	-5	6	3
22	18	-1	17	-1	17	0	17	-1	16	-3	10	2
23	24	7	23	1	24	-1	17	0	16	0	23	3
24	10	0	0	1	13	0	23	0	22	-3	21	-9
25	0	-6	-4	-4	0	-6	0	-7	4	-8	-1	-11
26	-3	-10	3	-8	-3	-10	-3	-12	-3		-6	-8
27	6	-10	3	-8	6	-12	4	-14	-3	2	-11	
28	12	-6	9	-6	9	-8	3	-12	4	-9	6	-7
29	9	-5	8	-4	8	-8	5	-13	10	-8	7	-6
30	21	1	21	-2	22	-2		-12	7	-5	13	-1
31	6	-4	-18	-3	8	-3		-11	19		10	-7

APPENDIX 2-C

MONTHLY PRECIPITATION FOR TWO YEARS AT WIPP

Monthly Precipitation (cm)
WIPP Site

	1986	1987
January	0.1	0.2
February	1.0	0.3
March	0.0	1.7
April	0.0	3.0
May	2.3	9.0
June	19.4	2.6
July	4.8	0.3
August	5.7	11.3
September	9.6	1.7
October	1.0	1.9
November	2.2	0.7
December	2.9	1.8

APPENDIX 6-A

CONTROL 1 - EMLEN BREEDING BIRD CENSUS DATA FOR FOUR TRANSECTS, 1987 (INDIVIDUALS PER TRANSECT)

NORTHERN BOBWHITE

	TRANSECT CT1 - - - OUT										TRANSECT CT1 - - - RETURN									
	DISTANCE INTERVAL										DISTANCE INTERVAL									
	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 12	0	0	0	2	1	0	0	0	3	0	0	0	0	0	0	1	2	0	2	0
JUNE 18	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	3	0	2	0
JUNE 30	0	0	0	0	0	0	1	1	1	0	0	0	0	0	4	0	3	0	0	0
DENSITY	0		11.4		5.74		7.17		7.17		0		0		25.8		22.9		5.74	

SCALED QUAIL

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 30	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		0		1.43		0		0		0		0		0		0	

COMMON NIGHTHAWK

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
DENSITY	0		0		0		0		0		0		0		0		1.43		0	

ASH-THROATED FLYCATCHER

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		0		0		0		0		0		0		0		0	

APPENDIX 6-A

CONTROL 1 - EMLEN BREEDING BIRD CENSUS DATA FOR FOUR TRANSECTS, 1987 (INDIVIDUALS PER TRANSECT) (CONTINUED)

	TRANSECT CT1 - - - OUT										TRANSECT CT1 - - - RETURN									
	DISTANCE INTERVAL										DISTANCE INTERVAL									
WESTERN KINGBIRD	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 30	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	5.74		5.74		0		0		0		0		0		0		0		0	
CACTUS WREN	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 12	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 30	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		2.87		2.87		0		0		0		0		0		0	
NORTHERN MOCKINGBIRD	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 12	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1	1	0
JUNE 18	0	0	0	1	0	0	1	0	1	0	0	0	0	1	0	0	1	1	0	1
JUNE 30	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0
DENSITY	0		5.74		2.87		10.0		1.43		0		5.74		2.87		12.9		2.15	
LOGGERHEAD SHRIKE	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 18	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 30	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		5.74		0		0		0		0		0		0		0	

APPENDIX 6-A

CONTROL 1 - EMLEN BREEDING BIRD CENSUS DATA FOR FOUR TRANSECTS, 1987
(INDIVIDUALS PER TRANSECT)
(CONTINUED)

PYRRHULOXIA

	TRANSECT CT1 - - - OUT										TRANSECT CT1 - - - RETURN									
	DISTANCE INTERVAL										DISTANCE INTERVAL									
	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 12	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	1	0	0
JUNE 18	0	2	0	1	0	0	2	0	0	0	0	0	0	0	2	0	1	0	0	0
JUNE 30	0	1	0	4	0	1	1	0	0	0	0	0	0	0	1	2	0	1	1	0
DENSITY	17.2		28.7		2.87		11.4		0		5.74		11.4		22.9		5.74		1.43	

BLACK-THROATED SPARROW

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 12	0	1	0	0	2	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
JUNE 18	0	0	0	0	2	0	1	0	0	0	0	1	0	0	2	1	0	0	0	0
JUNE 30	0	1	0	4	4	0	5	0	1	0	0	2	0	0	1	1	2	0	0	0
DENSITY	11.4		22.9		45.9		17.2		1.43		17.2		0		34.4		5.74		0	

EASTERN MEADOWLARK

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 12	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0
JUNE 18	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	0	1	0
JUNE 30	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0
DENSITY	0		0		0		5.74		2.87		0		0		0		8.61		4.30	

BROWN-HEADED COWBIRD

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 12	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 18	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		0		8.61		0		0		0		0		0		0	

APPENDIX 6-A

CONTROL 2 - EMLEN BREEDING BIRD CENSUS DATA FOR FOUR TRANSECTS, 1987 (INDIVIDUALS PER TRANSECT)

NORTHERN BOBWHITE

	TRANSECT CT2 - - - OUT										TRANSECT CT2 - - - RETURN									
	DISTANCE INTERVAL										DISTANCE INTERVAL									
	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 17	0	0	0	0	0	0	2	0	1	0	0	0	0	0	1	0	2	0	0	0
JUNE 28	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	3	0	2	0
JULY 7	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		0		11.4		4.30		0		0		5.74		14.3		2.87	

SCALED QUAIL

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JULY 7	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0
DENSITY	0		0		2.87		0		0		0		0		2.87		1.43		0	

MOURNING DOVE

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JULY 7	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		11.4		0		0		0		0		0		0		0		0	

POORWILL

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 28	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
JULY 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		0		0		0		5.74		0		0		0		0	

APPENDIX 6-A

CONTROL 2 - EMLEN BREEDING BIRD CENSUS DATA FOR FOUR TRANSECTS, 1987 (INDIVIDUALS PER TRANSECT) (CONTINUED)

COMMON NIGHTHAWK

	TRANSECT CT2 - - - OUT										TRANSECT CT2 - - - RETURN									
	DISTANCE INTERVAL										DISTANCE INTERVAL									
	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 17	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 28	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JULY 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	5.74		0		2.87		0		0		0		0		0		0		0	

ASH-THROATED FLYCATCHER

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 28	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
JULY 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		0		0		0		5.74		0		0		0		0	

WESTERN KINGBIRD

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JULY 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		0		0		0		0		0		0		0		0	

CACTUS WREN

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 17	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
JUNE 28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JULY 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
DENSITY	0		0		0		0		0		0		5.74		2.87		0		0	

APPENDIX 6-A

CONTROL 2 - EMLEN BREEDING BIRD CENSUS DATA FOR FOUR TRANSECTS, 1987
(INDIVIDUALS PER TRANSECT)
(CONTINUED)

NORTHERN MOCKINGBIRD

	TRANSECT CT2 - - - OUT										TRANSECT CT2 - - - RETURN									
	DISTANCE INTERVAL										DISTANCE INTERVAL									
	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 17	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	1	2	0	1	0
JUNE 28	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	3	1	1	0	0
JULY 7	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0
DENSITY	5.74	5.74	0	14.3	0		0	0	14.3	15.7	1.43									

LOGGERHEAD SHRIKE

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 17	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 28	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
JULY 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
DENSITY	0		0		2.87		0		0		0		5.74		0		1.43		0	

PYRRHULOXIA

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 17	0	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	2	0	0	0
JUNE 28	0	0	1	0	1	0	1	0	0	0	0	0	0	0	1	0	3	0	0	0
JULY 7	0	0	0	0	2	0	2	0	0	0	0	1	2	0	1	1	1	0	0	0
DENSITY	0		22.9		22.9		12.9		0		5.74		22.9		14.3		17.2		0	

BLACK-THROATED SPARROW

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 17	0	0	0	1	1	0	1	0	0	0	0	1	1	0	1	1	2	0	0	0
JUNE 28	0	1	1	2	3	0	0	0	0	0	0	0	0	1	4	0	1	0	0	0
JULY 7	0	1	1	0	3	0	1	0	0	0	0	2	3	0	2	0	1	0	0	0
DENSITY	11.4		40.1		40.1		5.74		0		17.2		51.6		43.0		11.4		0	

APPENDIX 6-A

CONTROL 2 - EMLEN BREEDING BIRD CENSUS DATA FOR FOUR TRANSECTS, 1987
(INDIVIDUALS PER TRANSECT)
(CONTINUED)

EASTERN MEADOWLARK

	TRANSECT CT2 - - - OUT										TRANSECT CT2 - - - RETURN									
	DISTANCE INTERVAL										DISTANCE INTERVAL									
	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 17	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
JUNE 28	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0
JULY 7	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0
DENSITY	0		0		0		8.61		1.43		0		0		0		5.74		2.87	

BROWN-HEADED COWBIRD

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 17	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 28	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0
JULY 7	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
DENSITY	0		0		5.74		1.43		0		0		0		8.61		4.30		0	

APPENDIX 6-A

NORTHWEST - EMLEN BREEDING BIRD CENSUS DATA FOR FOUR TRANSECTS, 1987 (INDIVIDUALS PER TRANSECT)

NORTHERN BOBWHITE

	TRANSECT NW - - - OUT										TRANSECT NW - - - RETURN									
	DISTANCE INTERVAL										DISTANCE INTERVAL									
	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 16	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0	3	0	1	0
JUNE 24	0	1	0	0	0	0	1	1	2	0	0	0	0	0	2	0	2	0	1	0
JULY 2	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0	1	0
DENSITY	5.74		0		0		7.17		7.17		0		0		17.2		17.2		4.30	

SCALED QUAIL

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 16	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JULY 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		0		2.87		0		0		0		0		0		0	

KILLDEER

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
JUNE 24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JULY 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		0		0		0		0		0		0		0		0.71	

MOURNING DOVE

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JULY 2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
DENSITY	0		0		0		0		0		0		11.4		0		0		0	

APPENDIX 6-A

NORTHWEST - EMLEN BREEDING BIRD CENSUS DATA FOR FOUR TRANSECTS, 1987
(INDIVIDUALS PER TRANSECT)
(CONTINUED)

ASH-THROATED FLYCATCHER

	TRANSECT NW - - - OUT										TRANSECT NW - - - RETURN									
	DISTANCE INTERVAL										DISTANCE INTERVAL									
	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 16	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0
JUNE 24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
JULY 2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		0		1.43		0		5.74		0		5.74		0		0	

WESTERN KINGBIRD

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 24	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
JULY 2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		11.4		1.43		0		0		11.4		14.3		0		0	

CACTUS WREN

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 16	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0	0
JUNE 24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JULY 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		0		0		0		0		5.74		8.61		1.43		0	

NORTHERN MOCKINGBIRD

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
JUNE 24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JULY 2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
DENSITY	0		0		0		1.43		0		0		0		0		1.43		0.71	

APPENDIX 6-A

NORTHWEST - EMLEN BREEDING BIRD CENSUS DATA FOR FOUR TRANSECTS, 1987
(INDIVIDUALS PER TRANSECT)
(CONTINUED)

LOGGERHEAD SHRIKE

	TRANSECT NW - - - OUT										TRANSECT NW - - - RETURN									
	DISTANCE INTERVAL										DISTANCE INTERVAL									
	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 16	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
JUNE 24	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
JULY 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		2.87		2.87		0		0		0		2.87		1.43		0	

PYRRHULOXIA

	TRANSECT NW - - - OUT										TRANSECT NW - - - RETURN									
	DISTANCE INTERVAL										DISTANCE INTERVAL									
	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 16	0	0	0	0	1	1	0	0	0	0	0	0	0	1	2	0	0	0	0	0
JUNE 24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0
JULY 2	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
DENSITY	0		5.74		17.2		0		0		0		5.74		11.4		8.61		1.43	

HOUSE FINCH

	TRANSECT NW - - - OUT										TRANSECT NW - - - RETURN									
	DISTANCE INTERVAL										DISTANCE INTERVAL									
	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 16	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JULY 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	5.74		0		0		0		0		0		0		0		0		0	

BLACK-THROATED SPARROW

	TRANSECT NW - - - OUT										TRANSECT NW - - - RETURN									
	DISTANCE INTERVAL										DISTANCE INTERVAL									
	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 16	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 24	0	0	1	0	1	0	0	2	0	0	0	0	0	1	1	0	0	0	0	0
JULY 2	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	5.74		28.7		14.3		2.87		0		0		5.74		5.74		0		0	

APPENDIX 6-A

NORTHWEST - EMLEN BREEDING BIRD CENSUS DATA FOR FOUR TRANSECTS, 1987
(INDIVIDUALS PER TRANSECT)
(CONTINUED)

	TRANSECT NW - - - OUT										TRANSECT NW - - - RETURN									
	DISTANCE INTERVAL										DISTANCE INTERVAL									
	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
EASTERN MEADOWLARK																				
JUNE 16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
JULY 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		0		0		0		0		0		0		0		1.43	
BROWN-HEADED COWBIRD																				
	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 18	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		5.74		0		0		0		0		0		2.87		0		0	

APPENDIX 6-A

SOUTHEAST - EMLEN BREEDING BIRD CENSUS DATA FOR FOUR TRANSECTS, 1987 (INDIVIDUALS PER TRANSECT)

NORTHERN BOBWHITE

	TRANSECT SE - - - OUT										TRANSECT SE - - - RETURN									
	DISTANCE INTERVAL										DISTANCE INTERVAL									
	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 2	0	0	0	0	0	0	1	0	4	0	0	0	0	0	0	0	2	0	2	0
JUNE 15	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
JULY 31	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	1	0	0
DENSITY	0		0		0		11.4		8.61		0		0		0		7.17		2.87	

MOURNING DOVE

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JULY 31	0	0	0	0	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		8.61		1.43		0		0		0		0		0		0	

COMMON NIGHTHAWK

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 15	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
JULY 31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		2.87		0		0		0		0		0		0		0	

ASH-THROATED FLYCATCHER

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 15	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
JULY 31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		5.74		0		0		0		5.74		0		0		0		0	

APPENDIX 6-A

SOUTHEAST - EMLEN BREEDING BIRD CENSUS DATA FOR FOUR TRANSECTS, 1987
(INDIVIDUALS PER TRANSECT)
(CONTINUED)

WESTERN KINGBIRD

	TRANSECT SE - - - OUT										TRANSECT SE - - - RETURN									
	DISTANCE INTERVAL										DISTANCE INTERVAL									
	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
JUNE 15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JULY 31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		0		0		0		0		0		0		1.43		0	

BARN SWALLOW

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 15	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JULY 31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	5.74		0		0		0		0		0		0		0		0		0	

CHIHUAHUAN RAVEN

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JULY 31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		0		1.43		0		0		0		0		0		0	

CACTUS WREN

	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 2	0	0	0	0	0	3	0	1	0	0	0	3	0	0	0	0	0	0	0	0
JUNE 15	0	0	0	1	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0
JULY 31	0	1	0	1	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0
DENSITY	5.74		11.4		11.4		1.43		0		28.7		11.4		2.87		0		0	

APPENDIX 6-A

SOUTHEAST - EMLEN BREEDING BIRD CENSUS DATA FOR FOUR TRANSECTS, 1987
(INDIVIDUALS PER TRANSECT)
(CONTINUED)

TRANSECT SE - - - OUT — DISTANCE INTERVAL

NORTHERN MOCKINGBIRD

	0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 2	0	0	0	0	1	3	0	0	0	0
JUNE 15	0	0	0	0	2	0	0	0	0	0
JULY 31	0	0	0	0	0	0	1	1	0	0
DENSITY	0		0		25.8		4.30		0	

LOGGERHEAD SHRIKE

	0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 2	0	0	0	0	0	0	0	0	0	0
JUNE 15	0	0	0	0	0	0	0	0	0	0
JULY 31	0	0	0	0	0	3	0	0	0	0
DENSITY	0		0		8.61		0		0	

PYRRHULOXIA

	0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 2	0	0	0	0	1	0	2	0	0	0
JUNE 15	0	0	0	0	1	1	1	0	0	0
JULY 31	1	0	1	0	2	0	0	0	0	0
DENSITY	11.4		11.4		25.8		8.61		0	

HOUSE FINCH

	0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 2	0	0	0	0	0	0	0	0	0	0
JUNE 15	0	0	0	0	0	0	0	0	0	0
JULY 31	0	0	0	1	0	0	0	0	0	0
DENSITY	0		5.74		0		0		0	

TRANSECT SE - - - RETURN — DISTANCE INTERVAL

NORTHERN MOCKINGBIRD

	0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 2	0	0	0	0	0	0	2	1	0	0
JUNE 15	0	1	0	0	0	0	1	0	0	0
JULY 31	0	0	0	0	0	2	0	1	0	0
DENSITY	5.74		0		5.74		11.4		0	

LOGGERHEAD SHRIKE

	0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 2	0	0	0	0	0	0	0	0	0	0
JUNE 15	0	0	0	0	0	0	0	0	0	0
JULY 31	0	1	0	0	0	1	0	0	0	0
DENSITY	5.74		0		2.87		0		0	

PYRRHULOXIA

	0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 2	0	0	0	0	0	0	1	0	0	0
JUNE 15	0	0	0	2	0	1	1	0	0	0
JULY 31	1	0	0	1	1	0	0	0	0	0
DENSITY	11.4		17.2		8.61		5.74		0	

HOUSE FINCH

	0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 2	0	1	0	0	0	0	0	0	0	0
JUNE 15	0	2	0	1	0	0	0	0	0	0
JULY 31	0	0	0	0	0	0	0	0	0	0
DENSITY	17.2		5.74		0		0		0	

APPENDIX 6-A

SOUTHEAST - EMLEN BREEDING BIRD CENSUS DATA FOR FOUR TRANSECTS, 1987
(INDIVIDUALS PER TRANSECT)
(CONTINUED)

	TRANSECT SE - - - OUT										TRANSECT SE - - - RETURN									
	DISTANCE INTERVAL										DISTANCE INTERVAL									
BLACK-THROATED SPARROW																				
	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 2	1	0	0	0	1	0	2	2	0	0	0	1	0	0	0	0	2	0	0	0
JUNE 15	0	3	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0
JULY 31	0	1	0	1	2	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0
DENSITY	34.4		5.74		17.2		12.9		0		5.74		22.9		20.0		5.74		0	
EASTERN MEADOWLARK																				
	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
JUNE 15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
JULY 31	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		0		2.87		0		0		0		0		0		0	
BROWN-HEADED COWBIRD																				
	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
JUNE 15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
JULY 31	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
DENSITY	0		5.74		0		0		0		0		5.74		2.87		4.30		0	
NORTHERN ORIOLE																				
	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 15	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
JULY 31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	5.74		5.74		0		0		0		0		0		0		1.43		0	

APPENDIX 6-A

SOUTHEAST - EMLEN BREEDING BIRD CENSUS DATA FOR FOUR TRANSECTS, 1987
(INDIVIDUALS PER TRANSECT)
(CONTINUED)

	TRANSECT SE - - - OUT										TRANSECT SE - - - RETURN									
	DISTANCE INTERVAL										DISTANCE INTERVAL									
UNKNOWN	0-50		50-100		100-200		200-400		400-800		0-50		50-100		100-200		200-400		400-800	
	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C	S	O/C
JUNE 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JUNE 15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JULY 31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENSITY	0		0		0		0		0		0		0		2.87		1.43		0	

S = Singing Males; O/C = Observed or Calling birds
Densities in birds per 40 hectares
Distance intervals in feet

APPENDIX 6-B

SMALL MAMMAL TRAPPING DATA AND DENSITY ESTIMATIONS FOR 1985, 1986, AND 1987 (ANIMALS PER TRAP GRID)

ORD'S KANGAROO RAT (DIPODOMYS ORDII)

CONTROL-1 1985

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 24	8	6	3	48.0
JULY 25	8	3	3	24.0
JULY 26	8	4	2	32.0
		SUMS	8.0	104.0
			EST. DENSITY	13.0

CONTROL-2 1985

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
AUG. 14	2	4	0	8.0
AUG. 15	2	2	0	4.0
AUG. 16	2	2	0	4.0
		SUMS	0.0	16.0
			EST. DENSITY	(6.0)

SOUTHEAST-2 1985

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 24	13	6	2	78.0
JULY 25	13	8	3	104.0
JULY 26	13	13	5	169.0
		SUMS	10.0	351.0
			EST. DENSITY 35.1	

NORTHWEST-2 1985

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
AUG. 14	10	6	3	60.0
AUG. 15	10	8	4	80.0
AUG. 16	10	1	0	10.0
		SUMS	7.0	150.0
			EST. DENSITY	21.4

APPENDIX 6-B

SMALL MAMMAL TRAPPING DATA AND DENSITY ESTIMATIONS FOR 1985, 1986, AND 1987 (ANIMALS PER TRAP GRID) (CONTINUED)

PLAINS POCKET MOUSE (Perognathus flavescens)

CONTROL-1 1985

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 24	9	3	0	27.0
JULY 25	9	4	0	36.0
JULY 26	9	4	1	36.0
		SUMS	1.0	99.0
			EST. DENSITY	99.0

CONTROL-2 1985

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
AUG. 14	2	1	1	2.0
AUG. 15	2	0	0	0.0
AUG. 16	2	1	1	2.0
		SUMS	2.0	4.0
			EST. DENSITY	2.0

SOUTHEAST-2 1985

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 24	4	1	0	4.0
JULY 25	4	1	0	4.0
JULY 26	4	2	0	8.0
		SUMS	0.0	16.0
			EST. DENSITY	(6.0)

NORTHWEST-2 1985

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
AUG. 14	5	9	3	45.0
AUG. 15	5	5	0	25.0
AUG. 16	5	6	1	30.0
		SUMS	4.0	100.0
			EST. DENSITY	25.0

APPENDIX 6-B

SMALL MAMMAL TRAPPING DATA AND DENSITY ESTIMATIONS FOR 1985, 1986, AND 1987 (ANIMALS PER TRAP GRID) (CONTINUED)

NORTHERN GRASSHOPPER MOUSE (Onychomys leucogaster)

CONTROL-1 1985 TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 24	2	3	1	6.0
JULY 25	2	1	0	2.0
JULY 26	2	3	2	6.0
		SUMS	3.0	14.0
			EST. DENSITY	4.7

CONTROL-2 1985 TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
AUG. 14	3	0	0	0.0
AUG. 15	3	1	0	3.0
AUG. 16	3	1	0	3.0
		SUMS	0.0	6.0
			EST. DENSITY	(4.0)

SOUTHEAST-2 1985 TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 24	11	5	1	55.0
JULY 25	11	2	0	22.0
JULY 26	11	6	1	66.0
		SUMS	2.0	143.0
			EST. DENSITY	71.5

NORTHWEST-2 1985 TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
AUG. 14	2	1	0	2.0
AUG. 15	2	1	0	2.0
AUG. 16	2	1	0	2.0
		SUMS	0.0	6.0
			EST. DENSITY	(3.0)

APPENDIX 6-B

SMALL MAMMAL TRAPPING DATA AND DENSITY ESTIMATIONS FOR 1985, 1986, AND 1987 (ANIMALS PER TRAP GRID) (CONTINUED)

SOUTHERN PLAINS WOODRAT (Neotoma micropus)

CONTROL-1 1985 TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 24	0	0	0	0.0
JULY 25	0	0	0	0.0
JULY 26	0	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(0.0)

CONTROL-2 1985 TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
AUG. 14	1	0	0	0.0
AUG. 15	1	0	0	0.0
AUG. 16	1	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(1.0)

SOUTHEAST-2 1985 TRAP NIGgHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 24	1	0	0	0.0
JULY 25	1	0	0	0.0
JULY 26	1	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(1.0)

NORTHWEST-2 1985 TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
AUG. 14	0	0	0	0.0
AUG. 15	0	0	0	0.0
AUG. 16	0	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(0.0)

APPENDIX 6-B

SMALL MAMMAL TRAPPING DATA AND DENSITY ESTIMATIONS FOR 1985, 1986, AND 1987 (ANIMALS PER TRAP GRID) (CONTINUED)

HISPID COTTONRAT (Sigmodon hispidus)

CONTROL-1 1985 TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 24	1	0	0	0.0
JULY 25	1	0	0	0.0
JULY 26	1	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(1.0)

APPENDIX 6-B

SMALL MAMMAL TRAPPING DATA AND DENSITY ESTIMATIONS FOR 1985, 1986, AND 1987 (ANIMALS PER TRAP GRID) (CONTINUED)

ORD'S KANGAROO RAT (Dipodomys ordii)

CONTROL-1 1986 TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 29	6	1	1	6.0
JULY 30	6	3	1	18.0
JULY 31	6	0	0	0.0
		SUMS	2.0	24.0
			EST. DENSITY	12.0

CONTROL-2 1986 TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
AUG. 27	4	3	1	12.0
AUG. 28	4	1	1	4.0
AUG. 29	4	0	0	0.0
		SUMS	2.0	16.0
			EST. DENSITY	8.0

SOUTHEAST-2 1986 TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 29	7	3	3	21.0
JULY 30	7	3	2	21.0
JULY 31	7	4	1	28.0
		SUMS	6.0	70.0
			EST. DENSITY	11.7

NORTHWEST-2 1986 TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
AUG. 27	2	2	0	4.0
AUG. 28	3	0	0	0.0
AUG. 29	3	2	2	6.0
		SUMS	2.0	10.0
			EST. DENSITY	5.0

APPENDIX 6-B

SMALL MAMMAL TRAPPING DATA AND DENSITY ESTIMATIONS FOR 1985, 1986, AND 1987 (ANIMALS PER TRAP GRID) (CONTINUED)

PLAINS POCKET MOUSE (Perognathus flavescens)

CONTROL-1 1986

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 29	1	0	0	0.0
JULY 30	1	0	0	0.0
JULY 31	1	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(1.0)

CONTROL-2 1986

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
AUG. 27	0	0	0	0.0
AUG. 28	0	0	0	0.0
AUG. 29	0	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(0.0)

SOUTHEAST-2 1986

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 29	1	0	0	0.0
JULY 30	1	0	0	0.0
JULY 31	1	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(1.0)

NORTHWEST-2 1986

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
AUG. 27	0	0	0	0.0
AUG. 28	0	0	0	0.0
AUG. 29	0	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(0.0)

APPENDIX 6-B

SMALL MAMMAL TRAPPING DATA AND DENSITY ESTIMATIONS FOR 1985, 1986, AND 1987 (ANIMALS PER TRAP GRID) (CONTINUED)

NORTHERN GRASSHOPPER MOUSE (Onychomys leucogaster)

CONTROL-1 1986

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 29	0	0	0	0.0
JULY 30	0	0	0	0.0
JULY 31	0	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(0.0)

CONTROL-2 1986

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
AUG. 27	1	2	0	2.0
AUG. 28	1	4	1	4.0
AUG. 29	4	4	2	16.0
		SUMS	3.0	22.0
			EST. DENSITY	7.3

SOUTHEAST-2 1986

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 29	0	0	0	0.0
JULY 30	0	1	0	0.0
JULY 31	0	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(1.0)

NORTHWEST-2 1986

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
AUG. 27	0	1	0	0.0
AUG. 28	0	2	0	0.0
AUG. 29	0	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(2.0)

APPENDIX 6-B

SMALL MAMMAL TRAPPING DATA AND DENSITY ESTIMATIONS FOR 1985, 1986, AND 1987 (ANIMALS PER TRAP GRID) (CONTINUED)

SOUTHERN PLAINS WOODRAT (Neotoma micropus)

CONTROL-1 1986

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 29	0	0	0	0.0
JULY 30	0	0	0	0.0
JULY 31	0	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(0.0)

CONTROL-2 1986

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
AUG. 27	3	0	0	0.0
AUG. 28	3	0	0	0.0
AUG. 29	3	1	0	3.0
		SUMS	0.0	3.0
			EST. DENSITY	(4.0)

SOUTHEAST-2 1986

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 29	1	0	0	0.0
JULY 30	1	0	0	0.0
JULY 31	1	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(1.0)

NORTHWEST-2 1986

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
AUG. 27	0	0	0	0.0
AUG. 28	0	0	0	0.0
AUG. 29	0	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(0.0)

APPENDIX 6-B

SMALL MAMMAL TRAPPING DATA AND DENSITY ESTIMATIONS FOR 1985, 1986, AND 1987 (ANIMALS PER TRAP GRID) (CONTINUED)

ORD'S KANGAROO RAT (Dipodomys ordii)

CONTROL-1 1987

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
SEPT. 1	7	6	5	42.0
SEPT. 2	8	8	6	64.0
SEPT. 3	10	6	5	60.0
		SUMS	16.0	166.0
			EST. DENSITY	10.4

CONTROL-2 1987

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 21	1	1	1	1.0
JULY 22	1	1	0	1.0
JULY 23	2	2	1	4.0
		SUMS	2.0	6.0
			EST. DENSITY	3.0

SOUTHEAST-2 1987

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
SEPT. 1	1	6	1	6.0
SEPT. 2	6	9	4	54.0
SEPT. 3	10	2	2	20.0
		SUMS	7.0	80.0
			EST. DENSITY	11.4

NORTHWEST-2 1987

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 21	3	1	1	3.0
JULY 22	3	8	2	24.0
JULY 23	9	4	3	36.0
		SUMS	6.0	63.0
			EST. DENSITY	10.5

APPENDIX 6-B

SMALL MAMMAL TRAPPING DATA AND DENSITY ESTIMATIONS FOR 1985, 1986, AND 1987 (ANIMALS PER TRAP GRID) (CONTINUED)

PLAINS POCKET MOUSE (Perognathus flavescens)

CONTROL-1 1987

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
SEPT. 1	3	4	1	12.0
SEPT. 2	5	6	2	30.0
SEPT. 3	7	6	3	42.0
		SUMS	6.0	84.0
			EST. DENSITY	14.0

CONTROL-2 1987

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 21	1	1	0	1.0
JULY 22	1	2	1	2.0
JULY 23	2	3	2	6.0
		SUMS	3.0	9.0
			EST. DENSITY	3.0

SOUTHEAST-2 1987

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
SEPT. 1	1	0	0	0.0
SEPT. 2	1	0	0	0.0
SEPT. 3	1	2	0	2.0
		SUMS	0.0	2.0
			EST. DENSITY	(3.0)

NORTHWEST-2 1987

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 21	2	0	0	0.0
JULY 22	2	1	1	2.0
JULY 23	2	1	0	2.0
		SUMS	1.0	4.0
			EST. DENSITY	4.0

APPENDIX 6-B

SMALL MAMMAL TRAPPING DATA AND DENSITY ESTIMATIONS FOR 1985, 1986, AND 1987 (ANIMALS PER TRAP GRID) (CONTINUED)

NORTHERN GRASSHOPPER MOUSE (Onychomys leucogaster)

CONTROL-1 1987

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
SEPT. 1	0	0	0	0.0
SEPT. 2	0	0	0	0.0
SEPT. 3	0	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(0.0)

CONTROL-2 1987

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 21	0	1	0	0.0
JULY 22	1	2	0	2.0
JULY 23	3	1	1	3.0
		SUMS	1.0	5.0
			EST. DENSITY	5.0

SOUTHEAST-2 1987

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
SEPT. 1	1	2	0	2.0
SEPT. 2	3	1	1	3.0
SEPT. 3	3	0	0	0.0
		SUMS	1.0	5.0
			EST. DENSITY	5.0

NORTHWEST-2 1987

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 21	0	0	0	0.0
JULY 22	0	1	0	0.0
JULY 23	1	1	0	1.0
		SUMS	0.0	1.0
			EST. DENSITY	(2.0)

APPENDIX 6-B

SMALL MAMMAL TRAPPING DATA AND DENSITY ESTIMATIONS FOR 1985, 1986, AND 1987 (ANIMALS PER TRAP GRID) (CONTINUED)

SOUTHERN PLAINS WOODRAT (Neotoma micropus)

CONTROL-1 1987 TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
SEPT. 1	0	0	0	0.0
SEPT. 2	0	0	0	0.0
SEPT. 3	0	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(0.0)

CONTROL-2 1987 TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 21	4	2	1	8.0
JULY 22	5	1	1	5.0
JULY 23	5	1	1	5.0
		SUMS	3.0	18.0
			EST. DENSITY	6.0

SOUTHEAST-2 1987 TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
SEPT. 1	1	0	0	0.0
SEPT. 2	1	0	0	0.0
SEPT. 3	1	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(1.0)

NORTHWEST-2 1987 TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 21	0	0	0	0.0
JULY 22	0	0	0	0.0
JULY 23	0	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(0.0)

APPENDIX 6-B

SMALL MAMMAL TRAPPING DATA AND DENSITY ESTIMATIONS FOR 1985, 1986, AND 1987 (ANIMALS PER TRAP GRID) (CONTINUED)

WHITE-FOOTED AND DEER MOUSE (Peromyscus sp.)

CONTROL-1 1987

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
SEPT. 1	0	0	0	0.0
SEPT. 2	0	0	0	0.0
SEPT. 3	0	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(0.0)

CONTROL-2 1987

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 21	0	0	0	0.0
JULY 22	0	0	0	0.0
JULY 23	0	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(0.0)

SOUTHEAST-2 1987

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
SEPT. 1	1	0	0	0.0
SEPT. 2	1	1	0	1.0
SEPT. 3	2	1	0	2.0
		SUMS	0.0	3.0
			EST. DENSITY	(3.0)

NORTHWEST-2 1987

TRAP NIGHT	TAGGED	CAPTURED	RECAPTURED	TAG x CAP
JULY 21	0	0	0	0.0
JULY 22	0	0	0	0.0
JULY 23	0	0	0	0.0
		SUMS	0.0	0.0
			EST. DENSITY	(0.0)

APPENDIX 7-A

SURFACE SOIL CHEMISTRY DATA FOR SEVEN ECOLOGICAL MONITORING PLOTS, THIRD AND FOURTH QUARTERS, 1986

Third Quarter 1986

	CT1	CT2	SE1	SE2	NW1	NW2	E1
Cl	6.0	9.0	5.0	5.0	5.0	6.0	5.0
mg/kg	7.0	5.0	5.0	5.0	7.0	33.0	5.0
	10.0	5.0	6.0	5.0	5.0	7.0	8.0
	5.0	8.0	6.0	17.0	5.0	6.0	5.0
	5.0	6.0	5.0	5.0	13.0	5.0	9.0
	5.0	5.0	9.0	5.0	6.0	6.0	6.0
Mean	6.3	6.3	6.0	7.0	6.8	10.5	6.3
pH	5.9	6.1	6.7	6.5	7.2	7.0	7.2
	5.9	5.9	6.2	6.2	6.5	6.6	8.0
	5.7	6.0	6.4	6.5	7.2	6.5	6.9
	6.0	5.7	6.6	6.6	6.9	6.5	6.5
	6.0	5.9	6.7	6.3	6.9	6.8	6.6
	5.8	6.0	6.6	6.4	6.9	6.5	6.7
Mean	5.9	5.9	6.5	6.4	6.9	6.7	7.0
EC	293	347	202	87	383	141	293
umho/cm	243	136	223	95	255	130	290
	198	99	228	260	172	127	332
	169	118	202	247	298	122	539
	142	132	345	149	316	217	207
	135	133	236	278	351	125	363
Mean	197	161	239	186	296	144	337
Ca	32.0	39.0	24.0	11.0	62.0	20.0	47.0
mg/l	27.0	14.0	26.0	10.0	47.0	18.0	46.0
	19.0	10.0	29.0	33.0	24.0	16.0	51.0
	17.0	12.0	23.0	27.0	47.0	16.0	78.0
	15.0	12.0	49.0	15.0	46.0	32.0	33.0
	10.0	14.0	29.0	24.0	54.0	17.0	52.0
Mean	20.0	16.8	30.0	20.0	46.7	19.8	51.2
mg	5.6	6.3	2.7	1.7	3.4	2.2	3.7
mg/l	4.7	2.6	2.9	1.5	3.5	2.0	2.8
	3.7	1.9	3.8	4.7	2.2	2.0	3.5
	3.7	1.9	2.7	3.3	3.4	1.9	6.0
	2.2	2.1	4.3	2.7	3.0	3.7	2.6
	1.9	2.5	3.0	3.3	4.4	2.2	3.4
Mean	3.6	2.9	3.2	2.9	3.3	2.3	3.7

APPENDIX 7-A

SURFACE SOIL CHEMISTRY DATA FOR SEVEN ECOLOGICAL MONITORING PLOTS, THIRD AND FOURTH QUARTERS, 1986 (CONTINUED)

Third Quarter 1986

	CT1	CT2	SE1	SE2	NW1	NW2	E1
K	7.7	9.0	3.0	3.3	4.7	4.4	3.6
mg/l	8.7	3.0	3.3	2.5	11.0	3.3	4.8
	5.2	3.0	2.8	4.3	4.9	4.4	4.0
	4.2	4.1	3.6	12.0	4.5	4.2	7.8
	4.4	2.7	4.0	4.0	3.9	4.8	2 8
	2.9	2.9	3.3	4.4	5.0	3.8	5.2
Mean	5.5	4.1	3.3	5.1	5.7	4.2	4.7
Na	1.7	1.6	2.2	1.4	2.2	1.7	1.5
mg/l	2.1	1.4	2.6	1.6	2.2	2.1	1.8
	2.2	1.4	2.5	1.6	2.0	2.9	2.7
	1.9	1.7	2.0	2.0	2.0	1.3	2.2
	1.3	3.4	4.9	3.6	9.9	1.4	2.0
	8.2	1.7	1.6	35.0	2.6	1.4	1.8
Mean	2.9	1.9	2.6	7.5	3.5	1.8	2.0

Fourth Quarter 1986

	CT1	CT2	SE1	SE2	NW1	NW2	E1
Cl	6.0	6.0	13.0	26.0	16.0	10.0	38.0
mg/kg	8.0	6.0	16.0	14.0	6.0	12.0	7.0
	7.0	8.0	15.5	15.0	12.0	8.0	6.0
	6.0	7.0	21.0	11.0	11.0	36.0	6.0
	7.0	7.0	21.0	16.0	12.0	10.0	23.0
	6.0	6.0	17.0	14.0	16.0	12.0	6.0
Mean	6.7	6.7	17.3	16.0	12.2	14.7	14.3
pH	5.5	6.4	6.2	5.8	7.7	6.4	6.7
	5.6	6.0	6.5	5.9	7.6	6.1	7.1
	6.0	5.6	6.5	6.0	7.3	6.2	6.7
	6.3	5.7	6.5	6.1	7.3	6.1	6.5
	6.2	5.7	6.4	6.2	7.3	6.4	6.8
	6.6	5.5	6.9	7.0	7.2	6.3	6.8
Mean	6.0	5.8	6.5	6.2	7.4	6.3	6.8

APPENDIX 7-A

SURFACE SOIL CHEMISTRY DATA FOR SEVEN ECOLOGICAL MONITORING PLOTS, THIRD AND FOURTH QUARTERS, 1986
(CONTINUED)

Fourth Quarter 1986

	CT1	CT2	SE1	SE2	NW1	NW2	E1
EC	121	47	118	84	347	111	232
umho/cm	115	111	241	78	257	87	265
	118	76	173	79	203	83	290
	127	83	149	110	303	83	316
	84	104	169	84	185	101	260
	102	74	81	386	226	106	221
Mean	111	83	155	137	254	95	264
Ca	5.1	2.6	9.6	6.0	44.0	9.2	32.0
mg/l	4.8	11.0	28.0	5.4	26.0	5.0	38.0
	5.2	3.1	14.0	3.8	23.0	5.2	44.0
	8.3	5.7	12.0	8.6	30.0	5.6	30.0
	4.8	6.9	12.0	4.4	17.0	7.2	40.0
	7.8	3.7	5.2	39.0	19.0	7.0	21.0
Mean	6.0	5.5	13.5	11.2	26.5	6.5	34.2
mg	2.2	0.9	1.8	1.8	12.0	1.6	4.4
mg/l	1.8	2.3	3.9	1.0	3.0	1.2	3.6
	1.6	1.1	2.1	1.0	2.7	1.8	4.2
	5.9	2.1	2.3	1.6	4.7	1.4	3.8
	2.2	2.5	2.2	1.0	2.3	1.6	3.2
	2.4	0.3	1.0	3.9	3.3	1.0	2.4
Mean	2.7	1.5	2.2	1.7	4.7	1.4	3.6
K	5.3	2.3	4.0	5.1	18.0	4.5	9.9
mg/l	4.6	8.1	7.5	2.7	4.2	4.1	10.0
	1.1	2.7	3.9	2.9	4.3	5.4	8.8
	2.7	6.0	3.8	4.9	19.0	3.4	4.1
	6.2	4.8	3.3	4.6	3.6	4.4	6.7
	5.7	2.2	3.4	25.0	4.7	7.0	5.5
Mean	4.3	4.4	4.3	7.5	9.0	4.8	7.5
Na	12.0	1.5	3.3	2.6	4.3	2.2	6.1
mg/l	10.0	1.7	14.0	2.0	2.8	1.8	3.2
	13.0	1.9	4.3	2.0	3.0	1.8	2.3
	7.4	2.1	2.9	2.0	4.1	1.6	24.0
	2.7	3.9	8.7	1.8	4.3	1.8	3.2
	3.1	2.3	1.6	7.1	2.9	2.4	2.2
Mean	8.0	2.2	5.8	2.9	3.6	1.9	6.8

APPENDIX 7-B

SURFACE SOIL CHEMISTRY DATA FOR SEVEN ECOLOGICAL MONITORING PLOTS, 1987

First Quarter 1987

	CT1	CT2	SE1	SE2	NW1	NW2	E1
Cl	26	28	10	16	5	25	5
mg/kg	21	21	7	8	22	15	11
	28	16	5	10	12	20	14
	12	20	5	11	5	21	5
	26	12	7	5	22	25	5
	30	5	10	5	27	12	8
Mean	24	17	7	9	16	20	8
pH	6.2	5.4	7.0	6.1	7.4	6.4	6.7
	6.4	5.3	6.8	6.3	7.3	6.4	6.5
	6.3	5.8	6.9	6.7	7.2	6.5	6.5
	6.3	5.5	6.9	6.4	7.0	6.3	6.6
	6.2	5.7	7.0	6.3	7.2	5.9	6.7
	5.8	5.8	6.6	6.2	7.2	6.4	7.0
Mean	6.2	5.6	6.9	6.3	7.2	6.3	6.7
EC	91	135	394	141	445	257	302
umho/cm	135	130	594	194	407	259	123
	117	120	423	164	405	254	355
	162	113	541	491	408	248	358
	200	103	404	123	445	222	339
	84	83	377	132	492	227	271
Mean	132	114	456	208	434	245	291
Ca	4.0	11.0	43.0	16.0	50.0	14.0	45.0
mg/l	12.0	11.3	72.0	22.0	46.0	14.0	9.8
	7.8	9.0	40.0	15.0	41.0	14.0	52.0
	16.0	7.6	60.0	46.0	42.0	16.0	50.0
	20.0	8.4	33.0	12.0	45.0	12.0	37.0
	7.8	6.2	28.0	12.0	47.0	9.2	38.0
Mean	11.3	8.9	46.0	20.5	45.2	13.2	38.6
mg	0.8	1.8	3.7	2.2	4.3	1.8	3.0
mg/l	2.0	2.2	6.7	3.0	3.1	2.2	1.5
	1.5	1.8	4.1	2.2	3.2	1.8	4.7
	2.8	1.6	5.1	5.5	3.8	1.8	3.3
	3.4	1.6	3.7	1.8	3.8	1.7	3.2
	1.8	1.2	3.4	2.1	4.1	1.2	2.6
Mean	2.1	1.7	4.5	2.8	3.7	1.8	3.1

APPENDIX 7-B

SURFACE SOIL CHEMISTRY DATA FOR SEVEN ECOLOGICAL MONITORING PLOTS, 1987 (CONTINUED)

First Quarter 1987

	CT1	CT2	SE1	SE2	NW1	NW2	E1
K	4.3	3.9	5.7	4.8	8.9	4.8	13.0
mg/l	8.0	6.0	11.0	8.9	7.4	7.2	3.8
	5.1	4.5	7.6	7.5	8.8	5.9	6.4
	7.5	3.0	9.4	6.9	13.0	4.8	8.0
	6.6	4.5	9.7	4.8	11.0	4.1	3.7
	3.5	3.5	6.5	6.3	13.0	5.8	5.6
Mean	5.8	4.2	8.3	6.5	10.4	5.4	6.8
Na	5.9	5.7	7.8	3.2	6.9	4.5	5.0
mg/l	5.7	3.9	11.0	3.4	10.0	3.7	4.8
	5.5	5.7	6.2	6.2	13.0	4.5	6.6
	4.1	4.5	7.4	90.0	8.7	3.9	8.2
	5.7	4.1	4.5	3.3	10.0	3.9	11.0
	5.5	3.7	4.6	6.0	13.0	7.3	7.6
Mean	5.4	4.6	6.9	18.7	10.3	4.6	7.2

Second Quarter 1987

	CT1	CT2	SE1	SE2	NW1	NW2	E1
Cl	33	28	25	30	25	28	28
mg/kg	28	30	33	28	25	30	27
	28	25	28	30	28	24	28
	25	28	27	30	28	27	25
	29	27	28	28	33	30	28
	23	23	29	40	29	28	28
Mean	28	27	28	31	28	28	27
pH	5.8	7.0	7.4	6.1	7.8	6.8	7.1
	5.9	6.7	7.7	6.2	8.0	6.6	6.9
	6.2	6.8	7.6	5.9	7.8	6.8	7.0
	5.5	6.7	7.4	6.5	8.0	6.7	7.0
	6.2	6.9	6.7	6.8	7.8	6.8	6.9
	6.1	6.8	7.5	7.0	7.6	6.4	6.8
Mean	6.0	6.8	7.4	6.4	7.8	6.7	7.0
EC	314	206	210	136	256	135	314
umho/cm	184	129	233	132	289	121	200
	185	109	280	113	264	97	216
	160	161	226	188	260	214	312
	277	196	141	128	244	129	301
	150	129	193	243	260	126	228

APPENDIX 7-B

SURFACE SOIL CHEMISTRY DATA FOR SEVEN ECOLOGICAL MONITORING PLOTS, 1987 (CONTINUED)

Second Quarter 1987

	CT1	CT2	SE1	SE2	NW1	NW2	E1
Mean	212	155	214	157	262	137	262
Ca	29	21	29	15	35	18	51
mg/l	17	12	34	17	41	16	30
	16	11	42	14	33	12	33
	16	16	28	24	39	26	48
	25	23	18	16	33	17	44
	13	13	26	26	39	15	32
Mean	19	16	30	19	37	17	40
mg	5.3	3.3	3.2	2.6	2.6	2.4	3.3
mg/l	3.0	2.2	2.8	2.5	3.3	2.2	2.5
	3.1	1.8	4.7	2.3	2.9	1.6	2.4
	2.6	2.7	3.6	3.4	3.5	3.6	4.6
	4.4	3.7	2.1	2.5	2.8	2.2	3.6
	2.6	2.3	2.9	4.1	3.4	2.0	2.8
Mean	3.5	2.7	3.2	2.9	3.1	2.3	3.2
K	13.0	9.0	6.5	5.7	4.9	5.1	6.4
mg/l	9.6	5.8	5.0	5.1	8.6	5.8	4.7
	7.9	2.5	7.2	4.4	6.9	3.4	5.0
	6.7	3.8	7.5	14.0	7.7	7.8	6.9
	14.0	8.5	3.4	6.0	7.8	6.3	11.0
	5.4	2.5	4.6	13.0	7.9	4.5	4.4
Mean	9.4	5.4	5.7	8.0	7.3	5.5	6.4
Na	12.0	1.8	2.2	2.2	5.9	2.3	2.4
mg/l	3.2	1.7	3.1	2.8	3.9	1.9	1.6
	2.1	1.2	3.2	1.7	2.8	2.2	1.3
	2.4	1.7	2.5	3.6	2.1	2.2	2.5
	2.2	1.7	2.7	1.5	4.5	2.0	1.3
	1.9	1.5	2.6	13.0	2.9	1.3	1.9
Mean	4.0	1.6	2.7	4.1	3.7	2.0	1.8

APPENDIX 7-B

SURFACE SOIL CHEMISTRY DATA FOR SEVEN ECOLOGICAL MONITORING PLOTS, 1987 (CONTINUED)

Third Quarter 1987

	CT1	CT2	SE1	SE2	NW1	NW2	E1
Cl	5.0	8.0	8.0	16.0	1.0	12.5	2.0
mg/kg	8.0	8.0	13.0	2.0	12.0	14.0	2.0
	9.0	5.0	12.0	7.0	13.0	12.5	2.0
	9.0	2.0	7.0	5.0	11.0	7.0	12.0
	11.0	5.0	7.0	5.5	7.0	10.5	7.0
	8.0	2.0	8.0	9.0	14.0	9.5	14.0
Mean	8.3	5.0	9.2	7.4	9.7	11.0	6.5
pH	6.5	6.5	7.2	6.4	7.5	6.8	7.5
	6.5	6.5	6.9	6.5	7.6	6.5	7.6
	6.6	6.3	6.8	6.2	7.6	6.7	7.1
	6.4	6.5	7.0	6.5	7.4	6.7	7.1
	6.3	6.5	6.7	6.2	7.4	6.6	7.5
	6.4	6.4	6.7	6.8	7.5	6.7	7.4
Mean	6.5	6.5	6.9	6.4	7.5	6.7	7.4
EC	115	151	266	622	272	165	231
umho/cm	298	175	181	104	310	180	197
	187	130	153	192	235	218	243
	255	119	189	109	224	185	239
	246	95	147	131	179	140	304
	133	119	171	159	268	139	652
Mean	206	132	185	220	248	171	311
Ca	13.0	19.0	45.0	35.0	41.0	21.0	39.0
mg/l	35.0	24.0	28.0	12.0	51.0	24.0	34.0
	21.0	13.0	22.0	24.0	37.0	32.0	39.0
	23.0	14.0	29.0	13.0	35.0	23.0	35.0
	33.0	12.0	19.0	15.0	28.0	17.0	52.0
	16.0	13.0	23.0	20.0	47.0	19.0	70.0
Mean	23.5	15.8	27.7	19.8	39.8	22.7	44.8
mg	2.1	2.6	4.2	8.1	3.3	2.9	3.1
mg/l	7.4	3.5	2.3	1.6	3.8	3.0	2.3
	4.7	2.6	2.5	3.4	2.6	4.1	3.6
	5.9	1.9	3.1	1.9	3.4	3.2	3.7
	7.7	2.2	2.3	2.0	2.3	2.4	3.9
	2.5	2.2	2.7	2.6	3.6	2.3	9.7
Mean	5.1	2.5	3.0	3.3	3.2	3.0	4.4

APPENDIX 7-B

SURFACE SOIL CHEMISTRY DATA FOR SEVEN ECOLOGICAL MONITORING PLOTS, 1987 (CONTINUED)

Third Quarter 1987

	CT1	CT2	SE1	SE2	NW1	NW2	E1
K	5.5	4.9	9.9	6.3	11.0	8.6	4.5
mg/l	8.2	6.4	8.4	4.2	8.8	11.0	4.4
	6.6	3.5	5.6	17.0	10.0	11.5	11.0
	6.4	3.0	5.7	4.0	8.1	8.2	7.4
	8.0	3.6	4.6	6.2	5.2	5.0	10.0
	7.0	3.4	6.1	6.9	9.8	4.5	15.0
Mean	7.0	4.1	6.7	7.4	8.8	8.1	8.7
Na	2.7	1.6	2.4	78.0	4.8	1.6	1.5
mg/l	6.5	1.4	1.7	1.2	5.4	1.9	1.4
	6.9	2.4	1.7	1.1	2.1	2.0	1.9
	12.0	2.2	3.2	1.1	2.7	2.5	3.9
	23.0	1.0	1.8	1.5	2.3	1.9	6.0
	1.7	1.5	2.2	2.0	2.2	2.0	55.0
Mean	8.8	1.7	2.2	14.2	3.3	2.0	11.6

Fourth Quarter 1987

	CT1	CT2	SE1	SE2	NW1	NW2	E1
Cl	9.3	8.0	74.0	12.0	17.0	74.0	16.0
mg/kg	9.0	10.0	67.0	63.0	19.0	73.0	12.0
	5.0	12.5	70.0	72.0	12.0	10.5	21.0
	9.0	14.0	71.0	74.0	14.0	70.0	16.0
	16.0	8.5	71.5	74.0	14.0	70.0	16.0
	8.5	9.0	71.0	73.0	19.0	14.0	10.0
Mean	9.5	10.3	70.8	61.3	15.8	51.9	15.2
pH	5.8	6.4	6.3	6.5	7.3	6.3	5.8
	6.0	6.2	7.3	6.5	7.5	6.3	6.3
	6.3	6.2	7.3	6.6	7.6	6.4	6.6
	6.4	6.4	7.2	6.4	7.4	6.3	6.9
	6.3	6.4	6.9	6.2	7.7	6.1	7.2
	6.3	6.4	6.7	6.3	6.2	6.2	7.1
Mean	6.2	6.3	7.0	6.4	7.3	6.3	6.7

APPENDIX 7-B

SURFACE SOIL CHEMISTRY DATA FOR SEVEN ECOLOGICAL MONITORING PLOTS, 1987 (CONTINUED)

Fourth Quarter 1987

	CT1	CT2	SE1	SE2	NW1	NW2	E1
EC	99	80	260	131	338	147	288
umho/cm	159	100	253	155	295	160	327
	163	117	276	183	345	121	278
	134	101	220	133	374	167	252
	129	93	195	182	386	112	229
	162	77	190	110	313	148	284
Mean	141	95	232	149	342	143	276
Ca	11.0	9.0	40.0	17.0	53.0	17.0	48.0
mg/l	19.0	12.0	39.0	21.0	46.0	19.0	59.0
	18.0	16.0	40.0	25.0	52.0	14.5	40.0
	17.0	13.0	29.0	15.5	55.0	22.0	40.0
	16.0	11.0	30.0	26.0	58.0	13.0	36.5
	19.0	9.7	28.0	14.0	51.0	19.0	45.0
Mean	16.7	11.8	34.3	19.8	52.5	17.4	44.8
mg	2.1	1.5	5.1	2.9	4.4	2.3	4.1
mg/l	2.8	1.7	4.1	3.0	3.2	2.5	4.2
	3.2	2.2	5.1	4.1	4.0	2.0	4.5
	2.4	1.9	3.3	2.4	3.4	2.6	3.8
	2.5	1.9	3.6	3.8	4.5	2.0	3.3
	3.6	1.5	2.9	2.2	3.6	2.7	4.4
Mean	2.8	1.8	4.0	3.1	3.9	2.4	4.1
K	4.8	4.1	17.0	7.3	14.0	12.0	13.0
mg/l	12.0	6.3	10.9	9.2	11.0	12.0	12.0
	14.0	6.4	21.0	16.0	12.0	3.8	21.0
	9.4	5.1	12.0	4.8	9.3	11.0	8.8
	11.0	4.2	12.0	11.0	17.0	6.4	5.1
	15.0	4.1	4.9	4.5	10.0	9.4	18.0
Mean	11.0	5.0	13.0	8.8	12.2	9.1	13.0
Na	2.8	1.7	2.7	1.3	10.0	3.0	4.3
mg/l	4.1	1.7	4.6	1.7	10.0	3.4	5.3
	1.5	1.9	3.1	1.8	15.0	2.8	4.8
	2.8	1.8	5.1	4.2	18.0	3.5	5.1
	2.3	1.6	2.1	1.8	16.0	1.9	5.5
	2.0	1.8	5.4	1.7	8.6	3.4	5.3
Mean	2.6	1.8	3.8	2.1	12.9	3.0	5.1

APPENDIX 9-A

SIMILARITY BETWEEN C2S AND C2W
(MOTYKA MODIFIED SORENSEN'S INDEX)

ACRONYM	C1	C2S	C2W	MIN1	MI:
SHRUBS					
ARFI	0.30		0.15		0.15
CALYL					
CASE					
CHRYS					
CRDI	0.40				
GUMI			0.10		
OPUNT					
PRGL	0.05	0.10	0.05	0.05	0.05
QUHA	0.75	0.80	0.85	0.75	0.75
YUCA	0.15	0.15	0.35	0.15	0.15
SUBT	1.65	1.05	1.5	1.05	1.5
PERENNIAL FORBS					
CYUN	0.05				
DALA	0.05	0.15	0.10	0.05	0.05
HASP	0.05				
HOJA	0.05		0.05		0.05
LIAR			0.05		
LIMU					
MENTZ	0.05				
MELE	0.05				
OXGL	0.05		0.05		0.05
PHPO	0.15	0.15	0.05	0.15	0.05
PSTA					
SEDO	0.10	0.10	0.15	0.1	0.1
THME					
SUBT	0.60	0.40	0.45	0.40	0.45
ANNUAL FORBS					
AMARA					
APAR	0.05				
COCO					
DIWI			0.05		
ERAN	0.65	0.50	0.35	0.5	0.35
ERBE					
EUGL					
EUMI	0.05	0.15	0.75	0.05	0.05
HEHU	0.25				
HEPE	0.15	0.45	0.15	0.15	0.15
HEPS	0.90	0.80	0.45	0.8	0.45
HYFL	0.10				

APPENDIX 9-A

SIMILARITY BETWEEN C2S AND C2W
(MOTYKA MODIFIED SORENSEN'S INDEX)
(CONTINUED)

ACRONYM	C1	C2S	C2W	MIN1	MIN2
ANNUAL FORBS (continued)					
MOVE			0.05		
MOPU		0.15			
PASP	0.10				
PEAN	0.05	0.05	0.35	0.05	0.05
SUBT	2.30	2.10	2.15	2.10	2.15
PERENNIAL GRASSES					
ANSC					
ARIST		0.05	0.20		
ARLO		0.05	0.20		
ARPU	0.70	0.55	0.10	0.55	0.1
BOER	0.05				
BRCI	0.10				
CEIN	0.60	0.15	0.20	0.15	0.2
ERIN					
ERSE					
LECO	0.70	0.40	0.05	0.4	0.05
PASES	0.45	0.05	0.05	0.05	0.05
PAVI					
SEMA		0.05			
SPCO		0.05	0.05		
SPCR	0.05	0.35	0.40	0.05	0.05
SUBT	2.65	1.70	1.25	1.70	1.25
ANNUAL GRASSES					
MUSQ		0.05	0.10		
TRPU4	0.10	0.65	0.55	0.1	0.1
SUBT	0.10	0.70	0.65	0.10	0.10
TOTAL	7.30	5.95	6.00	5.95	6.00

MIN1 = smaller value between C1 and C2S.
MIN2 = smaller value between C1 and C2W.
Values = % frames including a particular species.
ISmo = 2mw x 100; mw = MIN, ma = first value, mb = second value ma + mb i.e., ISmo Total Vegetation
C2S = (2(5.95)/7.3 + 5.95)100 = 89.81%

APPENDIX 9-B

INDEX OF PLANT SPECIES

ACRONYM	SCIENTIFIC NAME	COMMON NAME	FAMILY NAME
SHRUBS/HALF-SHRUBS			
ARFI	Artemisia filifolia	Sand sage	Asteraceae
ATCA	Atriplex canescens	Four-wing saltbush	Chenopodiaceae
CALYL	Calylophus sp.	Primrose	Onagraceae
CAHA	C. hartwegii	Hartweg primrose	Onagraceae
CASE	C. serrulatus	Halfleaf sundrops	Onagraceae
CHRYS	Chrysothamnus sp.	Rabbitbrush	Asteraceae
CHPU	C. pulchellus	Southwest rabbitbrush	Asteraceae
CRDI	Croton dioecus	Croton	Euphorbiaceae
GUMI	Gutierrezia microcephala	Snakeweed	Asteraceae
OPUNT	Opuntia sp.	Prickly pear	Cactaceae
OPPH	O. phaecantha	Prickly pear	Cactaceae
PRGL	Prosopis glandulosa	Honey mesquite	Fabaceae
QUHA	Quercus havardii	Shinnery oak	Fagaceae
SASA	Sapindus saponaria	Soapberry	Sapindaceae
YUCA	Yucca campestris	Yucca	Liliaceae
PERENNIAL FORBS			
ASCLE	Asclepias sp.	Milkweed	Asclepiadaceae
ASTRA	Astragalus sp.	Locoweed	Fabaceae
ASWO	A. wootonii	Wooton's locoweed	Fabaceae
BAMU	Baileya multiradiata	Desert marigold	Asteraceae
CAREX	Carex sp.	Sedge	Cyperaceae
COER	Commelina erecta	Whitemouth dayflower	Commelinaceae
CUFO	Cucurbita foetidissima	Buffalogourd	Cucurbitaceae
CYUN	Cyperus uniflora	Flatsedge	Cyperaceae
DALA	Dalea lanata	Woolly dalea	Fabaceae
EVPI	Evolvulus pilosus	Morning glory	Convolvulaceae
EVSE	E. sericeous	Silver morning glory	Convolvulaceae
GAILL	Gaillardia sp.	Blanketflower	Asteraceae
GAPU	G. pulchella	Firewheel	Asteraceae
GAURA	Gaura sp.	Gaura	Onagraceae
HASP	Haplopappus spinulosus	Spiny yellow aster	Asteraceae
HECU	Heliotropium currassavicum	Salt heliotrope	Boraginaceae
HOFFM	Hoffmanseggia sp.	Hog potato	Fabaceae
HOJA	H. jamesii	Hog potato	Fabaceae
KRLA	Krameria lanceolata	Lanceleaf ratany	Krameriaceae
LEFE	Lesquerella fendleri	Fendler bladderpod	Brassicaceae
LIAR	Linum aristatum	Plains flax	Linaceae
LIMU	Lithospermum multiflorum	Gromwell	Asteraceae
MAWI	Mauryanda wislizenii	Snapdragon vine	Scrophulariaceae
MENTZ	Mentzelia sp.	Stickleaf	Loasaceae
MEST	M. strictissima	Prairie stickleaf	Loasaceae
MELE	Melempodium leucanthum	Plains blackfoot	Asteraceae
OXYBA	Oxybaphus sp.	Smooth oxybaphus	Nyctaginaceae

APPENDIX 9-B

INDEX OF PLANT SPECIES
(CONTINUED)

ACRONYM	SCIENTIFIC NAME	COMMON NAME	FAMILY NAME
OXGL	O. glaber	Smooth oxybaphus	Nyctaginaceae
PEAM	Penstemon ambiguus	Plains beardtongue	Scrophulariaceae
PEFE	P. fendleri	Fendler beardtongue	Scrophulariaceae
PHPO	Phyllanthus polygonoides	Leaf-flower	Euphorbiaceae
PSTA	Psilostrophe tagetina	Paper daisy	Asteraceae
SCOC	Schranckia occidentalis	Sensitive briar	Fabaceae
SENEC	Senecio sp.	Groundsel	Asteraceae
SEDO	S. douglasii	Longlobed groundsel	Asteraceae
SOLAN	Solanum sp.	Nightshade	Solanaceae
SOEL	S. eleagnifolium	Elegant nightshade	Solanaceae
THME	Thelesperma megapotamicum	Cotta	Asteraceae
TROC	Tradescantia occidentalis	Spiderwort	Commelinaceae
VERBE	Verbena sp.	Vervain	Verbenaceae
VEBR	V. bracteata	Prostrate vervain	Verbenaceae
VILU	Vicia ludoviciana	Milkvetch	Fabaceae
ANNUAL FORBS			
ABFR	Abronia fragrans	Snowball sandverbena	Nyctaginaceae
AMARA	Amaranthus sp.	Pigweed	Amaranthaceae
APAR	Aphanostephus arizonicus	Arizona doze daisy	Asteraceae
CHENO	Chenopodium sp.	Goosefoot	Chenopodiaceae
COCO	Conyza coulteri	Coulter's conyza	Asteraceae
CORIS	Corispermum sp.	Bugseed	Chenopodiaceae
CRTE	Croton texensis	Texas croton	Euphorbiaceae
DIWI	Dithyrea wislizenii	Spectaclepod	Brassicaceae
ERAN	Eriogonum annuum	Annual buckwheat	Polygonaceae
ERIGE	Erigeron sp.	Fleabane	Asteraceae
ERBE	E. bellidiastrum	Western fleabane	Asteraceae
EUPHO	Euphorbia sp.	Spurge	Euphorbiaceae
EUGL	E. glyptosperma	Ridge-seed spurge	Euphorbiaceae
EUMI	E. missurica	Lace spurge	Euphorbiaceae
EUTE	Eurytaenia texana	Texas spreadwing	Apiaceae
HEHU	Hedyotis houstonia	Bluets	Rubiaceae
HELIA	Helianthus sp.	Sunflower	Asteraceae
HEPE	H. petiolaris	Prairie sunflower	Asteraceae
HECO	Heliotropium convolvulaceum	Bindweed heliotrope	Boraginaceae
HEPS	Heterotheca psammophila	Telegraph plant	Asteraceae
HYFL	Hymenopappus flavescens	White ragweed	Asteraceae
IPPR	Ipomopsis pringlei	Trumpets	Polemoniaceae
LARE	Lappula redowskii	Whitebristle stickseed	Boraginaceae
LITE	Linaria texana	Texas toadflax	Scrophulariaceae
MOVE	Mollugo verticillata	Indian chickweed	Aizoaceae
MOPU	Monarda punctata	Spotted horsemint	Lamiaceae
MATA	Machaeranthera tanacetifolia	Cutleaf aster	Asteraceae
NAHI	Nama hispidum	Curled nama	Hydrophyllaceae
OENOT	Oenothera sp.	Evening primrose	Onagraceae

APPENDIX 9-B

INDEX OF PLANT SPECIES
(CONTINUED)

ACRONYM	SCIENTIFIC NAME	COMMON NAME	FAMILY NAME
ORMU	Orobanche multiflora	Broomrape	Orobanchaceae
PASP	Palafoxia sphacelata	Palafoxia	Asteraceae
PEAN	Pectis angustifolia	Fetid marigold	Asteraceae
PHIN	Phacelia integrifolia	Small-lobed scorpionweed	Hydrophyllaceae
SAKA	Salsola kali	Russian thistle	Chenopodiaceae
SORO	Solanum rostratum	Spiny nightshade	Solanaceae
PERENNIAL GRASSES (Poaceae)			
ANSC	Andropogon scoparius	Little bluestem	
ARIST	Aristida sp.	Three-awn	
ARLO	A. longiseta	Red three-awn	
ARPU	A. purpurea	Purple three-awn	
ARWR	A. wrightii	Wright's three-awn	
BOER	Bouteloua eriopoda	Black grama	
BOGR	B. gracilis	Blue grama	
BOHI	B. hirsuta	Hairy grama	
BRCI	Brachiaria ciliatissima	Sandhill grass	
CEIN	Cenchrus insertus	Sandbur	
ERAGR	Eragrostis sp.	Lovegrass	
ERLE	E. lehmanniana	Lehmann's lovegrass	
ERIN	E. intermedia	Intermediate lovegrass	
ERSE	E. secundiflora	Mexican lovegrass	
ERSE2	E. sessilispica	Sessil lovegrass	
LECO	Leptoloma cognatum	Fall witchgrass	
MUHLE	Muhlenbergia sp.	Muhly	
MUPO	M. porteri	Bush muhly	
PASPA	Paspalum sp.	Paspalum	
PASES	P. setaceum var.stramineum	Knotgrass	
PAVI	Panicum virgatum	Switchgrass	
SEMA	Setaria macrostachya syn. S. leucopila	Plains bristlegrass	
SPCO	Sporobolus contractus	Spike dropseed	
SPCR	S. cryptandrus	Sand dropseed	
SPGI	S. giganteus	Giant dropseed	
SPFL	S. flexuosus	Mesa dropseed	
ANNUAL GRASSES (Poaceae)			
MUSQ	Munroa squarrosa	False buffalograss	
TRPU4	Triplasis purpurea	Purple sandgrass	

APPENDIX 9-C

PERCENT FOLIAR COVER: SPRING, 1986

	PLOT #	C1	C2W	SE1	SE2	NW1	NW2	E1	AVERAGE
	TOTAL (Excludes PRGL)	19.83	25.22	22.30	22.08	27.69	17.65	22.17	22.42
SHRUBS/HALF-SHRUBS									
SHINNERY OAK	QUHA	6.77	14.01	17.39	13.00	14.35	11.76	10.02	12.47
SAND SAGE	ARFI	3.68	4.30	2.59	4.16	4.08	0.46	2.25	3.07
YUCCA	YUCA	0.44	1.79	0.55	0.40		2.23	2.24	1.09
CROTON	CROTO	1.87						0.20	0.30
GROUNDSEL	SENEC	0.06	0.08	0.04	0.31	0.62	0.50	0.30	0.27
CALYLOPHUS	CALYL		0.68			0.23			0.13
SNAKEWEED	GUMI	0.09						0.31	0.06
MESQUITE	PRGL	3.78		2.56	0.81		1.44	2.63	1.60
SUBTOTAL (Mesquite excluded)	12.91	20.86	20.57	17.87	19.28	14.95	15.32	17.39	
NON-GRASS HERBACEOUS PLANTS									
DUNEWEED	PHPO	0.41	0.23	0.69	0.26	2.04	0.32	0.88	0.69
RUSSIAN THISTLE	SADA				0.30			0.04	
WOOLY DALEA	DALA	0.08			0.04	0.32	0.09	0.86	0.20
PRAIRIE SUNFLOWER	HEPE	0.51	0.19			0.15	0.13	0.14	
LACE SPURGE	EUMI	0.22	0.03	0.02	0.14	0.14	0.05	0.19	0.11
FETID-MARIGOLD	PEAN	0.03				0.08	0.68	0.11	
WILD-BUCKWHEAT	ERAN	0.14	0.05	0.03	0.01	0.23	0.04	0.20	0.10
TELEGRAPH PLANT	HEPS	0.43	0.07	0.01	0.06	0.03	0.03		0.09
HORSEMINT	MOPU	0.09	0.07	0.08	0.05	0.01	0.13	0.16	0.08
FORB SDLG		0.16		0.04	0.20	0.01		0.03	0.06
BLUETS		0.16			0.16			0.08	0.06
HOFFMANSEGIA	HOFFM				0.04			0.12	0.02
SPECTACLE-POD	DIWI					0.16		0.02	
NIGHTSHADE	SOLAN	0.05		0.08					0.02
4-0'CLOCK	OENOT	0.06						0.06	0.02
PALAFOXIA	PASP	0.10					0.01		0.02
HAPLOPAPPUS	HASP	0.09							0.01
PLAINS BLACKFOOT	MELE	0.05						0.03	0.01
UNKNOWN		0.03				0.03			0.01
WHITE RAGWEED	HYFL	0.01							0.01
CAREX	CYPER			0.03					<.01
ASTRAGALUS	ASTRA	0.01							<.01
COTTA	THME	0.01							<.01
SUBTOTAL		2.67	0.64	0.98	0.96	3.27	0.90	3.42	1.83

APPENDIX 9-C

PERCENT FOLIAR COVER: SPRING, 1986
(CONTINUED)

	PLOT #	C1	C2W	SE1	SE2	NW1	NW2	E1	AVERAGE
GRASSES									
THREE-AWN	ARIST	2.11	0.40	0.21	1.42	0.27	0.55	1.13	0.87
SANDBUR	CEIN	0.25	1.34	0.13	0.31	1.46	0.38	0.94	0.69
FALL WITCHGRASS		0.07	0.00	0.09	0.15	1.21	0.39	0.00	0.27
GIANT DROPSEED	SPGI	0.37	0.71	0.06	0.09	0.62	0.36	0.47	0.38
SDLG		0.45	0.21	0.08	0.13	0.37	0.12	0.41	0.25
SWITCHGRASS		0.45	0.63	0.03	0.24	1.21		0.48	0 43
LITTLE BLUESTEM	ANSC	0.04	0.43						0.07
KNOTGRASS	PASPA	0.07		0.09	0.15				0.04
PLAINS BRISTLEGRASS	SEMA	0.09							0.01
LOVEGRASS	ERAGR	0.03		0.06					0.01
SAND DROPSEED	SPCR	0.03							<.01
MUHLY	MUHLE	0.29			0.76				
SUBTOTAL		4.25	3.72	0.75	3.25	5.14	1.80	3.43	3.19

APPENDIX 9-D

PERCENT FOLIAR COVER: FALL, 1986

	PLOT #	C1	C2W	SE1	SE2	NW1	NW2	E1	AVERAGE
	TOTAL (Excludes PRGL)	24.37	19.77	20.12	18.08	22.65	25.13	27.33	22.49
SHRUBS/HALF-SHRUBS									
Shinnery oak	QUHA	8.29	12.71	7.18	5.84	10.10	8.00	10.61	8.96
Sand sage	ARFI	0.81	0.07	7.14	4.50	3.35	4.85	3.53	3.46
Yucca	YUCA	0.05	2.66	0.00	0.25	0.00	2.90	3.17	1.29
Croton	CRDI	2.66	0.00	0.07	0.00	0.00	0.00	0.82	0.51
Snakeweed	GUMI	2.53	0.91	0.00	0.00	0.00	0.00	0.03	0.49
Prickly pear	OPPH	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.04
Primrose	CALYL	0.00	0.00	0.00	0.00	0.00	0.28	0.00	0.04
Hartweg's primrose	CAHA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
SUBTOTAL		14.33	16.34	14.39	10.90	13.44	16.03	18.15	14.79
Honey mesquite	PRGL	0.00	0.00	0.00	1.13	1.13	0.00	1.29	0.51
PERENNIAL FORBS									
Groundsel	SEDO	0.08	0.00	0.13	1.91	0.95	0.84	0.78	0.67
Phyllanthus	PHPO	0.12	0.13	0.78	0.28	0.00	0.28	0.34	0.27
Woolly dalea	DALA	0.30	0.45	0.00	0.04	0.13	0.04	0.08	0.15
Plains blackfoot	MELE	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Gaura	GAURA	0.00	0.00	0.00	0.00	0.07	0.06	0.00	0.02
Spiny yellow aster	HASP	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Carex	CAREX	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.01
Hog potato	HOFFM	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.01
Blanket flower	GAILL	0.00	0.00	0.00	0.00	0.00	0.00	0.03	<.01
Nightshade	SOLAN	0.03	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Oxybaphus	OXYBA	0.00	0.00	0.03	0.00	0.00	0.00	0.00	<.01
Cotta	THME	0.00	0.00	0.00	0.00	0.00	0.00	0.01	<.01
Loco	ASTRA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Unknown	UNK	0.00	0.00	0.00	0.00	0.00	0.00	0.01	<.01
Seedling	SEDLG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
SUBTOTAL		0.72	0.58	0.93	2.27	1.15	1.22	1.28	1.16
ANNUAL FORBS									
Fetid marigold	PEAN	0.00	0.01	1.73	0.27	0.00	0.33	1.70	0.58
Telegraph plant	HEPS	0.81	0.05	0.33	0.12	0.83	0.16	0.11	0.34
Lace spurge	EUMI	0.23	0.00	0.21	0.24	0.52	0.01	0.24	0.21
Prairie sunflower	HEPE	0.47	0.00	0.05	0.00	0.62	0.00	0.00	0.16
Annual buckwheat	ERAN	0.06	0.00	0.07	0.05	0.00	0.04	0.19	0.06
White ragweed	HYFL	0.06	0.00	0.00	0.00	0.00	0.13	0.04	0.03
Euphorbia	EUPHO	0.03	0.00	0.00	0.03	0.00	0.00	0.04	0.01

APPENDIX 9-D

PERCENT FOLIAR COVER: FALL, 1986
(CONTINUED)

	PLOT #	C1	C2W	SE1	SE2	NW1	NW2	E1	AVERAGE
ANNUAL FORBS (CONTINUED)									
Bluets	HEHU	0.00	0.00	0.00	0.06	0.00	0.00	0.01	0.01
Palafoxia	PASP	0.03	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Russian thistle	SAKA	0.00	0.00	0.00	0.00	0.03	0.00	0.00	<.01
Spectacle pod	DIWI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Spotted horsemint	MOPU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Unknown	UNK	0.00	0.04	0.00	0.00	0.02	0.03	0.03	0.02
Seedling	SEDLG	0.22	0.01	0.19	0.02	0.05	0.00	0.04	0.08
SUBTOTAL		1.90	0.11	2.57	0.82	2.06	0.69	2.39	1.50
PERENNIAL GRASSES									
Sandbur	CEIN	1.24	1.12	0.34	1.70	4.99	1.87	0.94	1.74
Three-awn	ARIST	2.23	1.30	1.47	1.19	0.23	2.61	3.00	1.72
Sandhill grass	BRCI	2.19	0.20	0.34	0.76	0.00	1.38	0.32	0.74
Sand dropseed	SPCR	0.19	0.00	0.03	0.10	0.18	0.10	0.31	0.13
Fall witchgrass	LECO	0.00	0.00	0.00	0.00	0.33	0.30	0.16	0.11
Little bluestem	ANSC	0.03	0.00	0.00	0.00	0.00	0.64	0.00	0.10
Giant dropseed	SPGI	0.00	0.11	0.00	0.13	0.24	0.18	0.00	0.09
Muhly	MUHLE	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.08
Lovegrass	ERAGR	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Hairy grama	BOHI	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Paspalum	PASPA	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Plains bristlegrass	SEMA	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Mesa dropseed	SPFL	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.01
Spike dropseed	SPCO	0.00	0.00	0.00	0.03	0.00	0.00	0.00	<.01
Black grama	BOER	0.01	0.00	0.00	0.00	0.00	0.01	0.00	<.01
Switchgrass	PAVI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Unknown	UNK	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Seedling	SEDLG	0.00	0.02	0.06	0.00	0.00	0.02	0.05	0.02
SUBTOTAL		7.09	2.75	2.23	3.94	5.96	7.10	5.29	4.91
ANNUAL GRASSES									
Purple sandgrass	TRPU4	0.08	0.00	0.00	0.16	0.05	0.10	0.08	0.07
False buffalograss	MUSQ	0.27	0.00	0.00	0.00	0.00	0.00	0.15	0.06
SUBTOTAL		0.35	0.00	0.00	0.16	0.05	0.10	0.23	0.13

APPENDIX 9-E

PERCENT FOLIAR COVER: SPRING, 1987

	PLOT #	C1	C2W	E1	SE1	SE2	NW1	NW2	AVERAGE
	TOTAL (Excludes PRGL)	47.80	30.50	38.60	36.85	36.60	34.76	42.65	38.25
SHRUBS/HALF-SHRUBS									
Shinnery oak	QUHA	26.30	16.85	19.40	25.40	19.45	14.68	20.10	20.31
Sand sage	ARFI	4.15	1.45	2.85	6.35	5.70	8.75	5.60	4.98
Yucca	YUCA	0.35	1.35	5.65	0.90	0.70	0.20	2.90	1.72
Snakeweed	GUMI	0.05	0.35	2.60	0.00	0.00	0.00	0.00	0.43
Croton	CRDI	1.15	0.00	0.10	0.00	0.00	0.00	0.00	0.18
Primrose	CALYL	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.05
Halfleaf sundrops	CASE	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.03
Prickly pear	OPPH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Hartweg primrose	CAHA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Rabbitbrush	CHRYS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Prickly pear	OPUNT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Soapberry	SASA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Four-wing saltbush	ATCA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
SUBTOTAL		32.00	20.00	30.60	32.65	25.85	23.98	28.80	27.70
Honey mesquite	PRGL	0.00	19.95	5.45	0.15	0.00	0.30	1.30	3.88
PERENNIAL FORBS									
Groundsel	SEDO	0.25	0.05	0.50	0.20	0.15	0.35	0.50	0.29
Woolly dalea	DALA	0.50	0.00	0.05	0.05	0.10	0.10	0.50	0.19
Phyllanthus	PHPO	0.00	0.20	0.05	0.00	0.00	0.64	0.00	0.13
Cotta	THME	0.00	0.00	0.50	0.00	0.00	0.00	0.15	0.09
Milkweed	ASCLEP	0.25	0.05	0.10	0.05	0.00	0.00	0.00	0.06
Hog potato	HOJA	0.00	0.00	0.00	0.20	0.00	0.00	0.05	0.04
Plains blackfoot	MELE	0.15	0.00	0.05	0.00	0.00	0.00	0.00	0.03
Sedge	CAREX	0.00	0.00	0.00	0.00	0.05	0.05	0.00	0.01
Groundsel	SENEC	0.00	0.00	0.00	0.00	0.00	0.00	0.03	<.01
Plains flax	LIAR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Oxybaphus	OXYBA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Silver morning glory	EVSE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Unknown	UNK	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Seedling	SEDLG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
SUBTOTAL		1.15	0.30	1.25	0.45	0.30	1.14	1.23	0.83

APPENDIX 9-E

PERCENT FOLIAR COVER: SPRING, 1987
(CONTINUED)

	PLOT #	C1	C2W	E1	SE1	SE2	NW1	NW2	AVERAGE
ANNUAL FORBS									
Telegraph plant	HEPS	4.05	2.10	1.25	1.95	3.25	3.43	2.85	2.70
Spotted horsemint	MOPU	1.95	0.70	1.10	0.70	0.75	0.20	0.43	0.83
Scorpionweed	PHIN	0.00	4.25	0.00	0.00	0.00	0.00	0.00	0.61
Bluets	HEHU	1.70	0.00	0.80	0.55	0.50	0.15	0.13	0.55
Annual buckwheat	ERAN	0.40	0.20	0.40	0.40	0.25	0.03	0.23	0.27
White ragweed	HYFL	0.30	0.00	0.00	0.25	0.00	0.00	0.00	0.08
Evening primrose	OENOT	0.10	0.30	0.00	0.00	0.10	0.00	0.00	0.07
Spurge	EUPHO	0.05	0.00	0.05	0.05	0.10	0.15	0.08	0.07
Sunflower	HELIA	0.00	0.00	0.00	0.05	0.00	0.18	0.13	0.05
Spectaclepod	DIWI	0.15	0.00	0.10	0.00	0.05	0.00	0.00	0.04
Palafoxia	PASP	0.10	0.05	0.00	0.00	0.00	0.02	0.13	0.04
Fetid marigold	PEAN	0.00	0.15	0.05	0.00	0.00	0.00	0.00	0.03
Western fleabane	ERBE	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Fleabane	ERIGE	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.01
Texas spreadwing	EUTE	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Unknown	UNK	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Seedling	SEDLG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
SUBTOTAL		9.00	7.75	3.75	3.95	5.05	4.14	3.95	5.37
PERENNIAL GRASSES									
Three-awn	ARIST	3.05	2.05	1.80	0.85	2.30	0.05	3.95	2.01
Sandbur	CEIN	0.60	0.00	0.20	1.70	0.85	2.55	2.03	1.13
Fall witchgrass	LECO	1.05	0.05	0.25	0.55	1.90	1.40	1.00	0.89
Knotgrass	PASES	0.00	0.00	0.00	0.00	0.20	1.05	0.35	0.23
Spike dropseed	SPCO	0.10	0.15	0.00	0.00	0.00	0.20	0.85	0.19
Sand dropseed	SPCR	0.10	0.05	0.30	0.05	0.05	0.05	0.40	0.14
Switchgrass	PAVI	0.45	0.00	0.00	0.00	0.00	0.05	0.00	0.07
Blue grama	BOGR	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Hairy grama	BOHI	0.05	0.00	0.00	0.05	0.00	0.00	0.00	0.01
Black grama	BOER	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.01
Red three-awn	ARLO	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Mexican lovegrass	ERSE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Lovegrass	ERAGR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Plains bristlegrass	SEMA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Muhly	MUHLE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Sandhill grass	BRCI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Unknown	UNK	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.03
Seedling	SEDLG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
SUBTOTAL		5.65	2.30	2.80	3.20	5.30	5.35	8.58	4.74

APPENDIX 9-E

PERCENT FOLIAR COVER: SPRING, 1987
(CONTINUED)

	PLOT #	C1	C2W	E1	SE1	SE2	NW1	NW2	AVERAGE
ANNUAL GRASSES									
Purple sandgrass	TRPU4	0.00	0.15	0.05	0.10	0.10	0.15	0.08	0.09
False buffalograss	MUSQ	0.00	0.00	0.15	0.00	0.00	0.00	0.03	0.03
SUBTOTAL		0.00	0.15	0.20	0.10	0.10	0.15	0.10	0.11

Other species encountered as trace amounts less than .01 percent foliar cover.

PERENNIAL FORBS	ANNUAL FORBS	PERENNIAL GRASSES
Astragalus sp.	Abronia fragans	Andropogon scoparius
A. wootonii	Aphanostephus arizonicus	Aristida purpurea
Baileya multiradiata	Croton texensis	Eragrostis lehmanniana
Commelina erecta	Euphorbia glyptosperma	Leptoloma cognatum
Cucurbita foetidissima	E. missurica	Paspalum sp.
Cyperus uniflorus	Heliotropium convolvulaceum	Sporobolus giganteus
Evolvulus pilosus	Helianthus petiolaris	
Gaillardia sp.	Ipomopsis pringlei	
G. pulchella	Linaria texana	
Gaura sp.	Machaeranthera tanacetifolia	
Haplopappus spinulosus	Mollugo verticillata	
Heliotropium currassavicum	Nama hispidum	
Kraemeria lanceolata	Orobanche multiflora	
Lepidium fendleri	Salsola kali	
Lithospermum multiflorum	Solanum rostratum	
Oxybaphus glaber		
Penstemon ambiguus		
Penstemon fendleri		
Schranckia occidentalis		
Solanum sp.		
S. eleagnifolium		
Tradescantia occidentalis		
Verbena sp.		
V. bracteata		
Vicia ludoviciana		

APPENDIX 9-F

PERCENT FOLIAR COVER: FALL, 1987

	PLOT #	C1	C2W	E1	SE1	SE2	NW1	NW2	AVERAGE
	TOTAL (Excludes PRGL)	31.76	29.03	27.66	16.41	29.31	27.33	21.53	26.14
SHRUBS/HALF-SHRUBS									
Shinnery oak	QUHA	8.69	15.50	11.86	9.25	12.44	13.89	11.46	11.87
Sand sage	ARFI	2.29	0.60	2.10	3.35	4.37	2.11	2.22	2.43
Yucca	YUCA	2.37	2.92	1.19	0.00	0.91	0.20	1.23	1.26
Snakeweed	GUMI	0.00	0.50	2.52	0.00	0.00	0.00	0.00	0.43
Croton	CRDI	1.57	0.00	0.31	0.00	0.25	0.00	0.00	0.30
Halfleaf sundrops	CASE	0.00	0.00	0.00	0.00	0.00	0.08	0.04	0.02
Primrose	CALYL	0.00	0.00	0.00	0.00	0.00	0.01	0.00	<.01
Prickly pear	OPPH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Hartweg's primrose	CAHA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Rabbitbrush	CHRYS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Pricklypear	OPUNT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Soapberry	SASA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Four-wing saltbush	ATCA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
SUBTOTAL		14.91	19.51	17.97	12.60	17.97	16.29	12.25	15.92
Honey mesquite	PRGL	1.06	0.50	0.57	8.75	6.95	0.00	0.00	2.55
PERENNIAL FORBS									
Woolly dalea	DALA	0.20	0.80	0.51	0.01	0.00	0.05	0.05	0.23
Groundsel	SEDO	0.03	0.26	0.40	0.31	0.06	0.54	0.03	0.23
Plains flax	LIAR	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.07
Hog potato	HOJA	0.03	0.30	0.01	0.02	0.00	0.00	0.00	0.05
Phyllanthus	PHPO	0.02	0.03	0.01	0.07	0.09	0.08	0.02	0.05
Spiny yellow aster	HASP	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Plains blackfoot	MELE	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Oxybaphus	OXGL	0.01	0.10	0.00	0.00	0.00	0.03	0.00	0.02
Paper daisy	PSTA	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.02
PERENNIAL FORBS									
Flatsedge	CYUN	0.01	0.00	0.00	0.00	0.00	0.03	0.03	0.01
Snapdragon vine	MAWI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Oxybaphus	OXYBA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Unknown	UNK	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Seedling	SEDLG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
SUBTOTAL		0.69	1.97	0.93	0.55	0.15	0.74	0.13	0.73

APPENDIX 9-F

PERCENT FOLIAR COVER: FALL, 1987
(CONTINUED)

	PLOT #	C1	C2W	E1	SE1	SE2	NW1	NW2	AVERAGE
	TOTAL (Excludes PRGL)	31.76	29.03	27.66	16.41	29.31	27.33	21.53	26.14
ANNUAL FORBS									
Telegraph plant	HEPS	7.05	1.87	2.71	0.90	5.09	2.92	4.00	3.50
Annual buckwheat	ERAN	1.66	0.85	0.86	0.28	1.60	0.40	0.53	0.88
Lace spurge	EUMI	0.01	0.70	0.01	0.06	0.06	0.07	0.03	0.13
Fetid marigold	PEAN	0.15	0.24	0.33	0.02	0.00	0.00	0.00	0.10
Prairie sunflower	HEPE	0.04	0.13	0.00	0.00	0.00	0.12	0.12	0.06
Bluets	HEHU	0.05	0.00	0.06	0.03	0.07	0.00	0.00	0.03
Coulter's conyza	COCO	0.00	0.00	0.01	0.06	0.00	0.00	0.00	0.01
Palafoxia	PASP	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Spectacle pod	DIWI	0.00	0.03	0.00	0.00	0.00	0.00	0.00	<.01
Arizona doze daisy	APAR	0.03	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Ridge-seed spurge	EUGL	0.00	0.00	0.00	0.00	0.03	0.00	0.00	<.01
White ragweed	HYFL	0.02	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Bindweed heliotrope	HECO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Cutleaf aster	MATA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Sunflower	HELIA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Unknown	UNK	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.01
Seedling	SEDLG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
SUBTOTAL		9.04	3.86	3.97	1.34	6.84	3.51	4.68	4.75
PERENNIAL GRASSES									
Fall witchgrass	LECO	2.13	0.01	1.87	0.08	1.29	1.53	2.57	1.35
Purple three-awn	ARPU	3.22	0.69	1.09	0.84	1.39	0.00	0.41	1.09
Sandbur	CEIN	0.61	0.30	0.61	0.36	0.06	2.25	0.67	0.69
Red three-awn	ARLO	0.00	0.50	0.77	0.00	0.00	0.49	0.62	0.34
Spike dropseed	SPCO	0.00	0.03	0.03	0.00	0.03	1.05	0.25	0.20
Knotgrass	PASES	0.15	0.43	0.02	0.01	0.05	0.28	0.18	0.16
Sand dropseed	SPCR	0.00	0.09	0.31	0.14	0.20	0.02	0.10	0.12
Little bluestem	ANSC	0.72	0.00	0.00	0.05	0.03	0.00	0.00	0.11
Plains lovegrass	ERIN	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.04
Three-awn	ARIST	0.00	0.08	0.01	0.07	0.06	0.00	0.00	0.03
Sandhill grass	BRCI	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Mexican lovegrass	ERSE	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.01
Black grama	BOER	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Switchgrass	PAVI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Plains bristlegrass	SEMA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Muhly	MUHLE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
Unknown	UNK	0.00	0.03	0.00	0.00	0.00	0.00	0.00	<.01
Seedling	SEDLG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	<.01
SUBTOTAL		7.06	2.14	4.71	1.54	3.48	5.62	4.01	4.08

APPENDIX 9-F

PERCENT FOLIAR COVER: FALL, 1987
(CONTINUED)

	PLOT #	C1	C2W	E1	SE1	SE2	NW1	NW2	AVERAGE
	TOTAL (Excludes PRGL)	31.76	29.03	27.66	16.41	29.31	27.33	21.53	26.14
ANNUAL GRASSES									
Purple sandgrass	TRPU4	0.06	1.52	0.09	0.27	0.85	1.15	0.48	0.63
False buffalograss	MUSQ	0.00	0.00	0.00	0.11	0.03	0.03	0.00	0.02
SUBTOTAL		0.06	1.56	0.09	0.38	0.88	1.18	0.48	0.66

Other species encountered as trace amounts less than .01 percent foliar cover.

PERENNIAL FORBS	ANNUAL FORBS	PERENNIAL GRASSES
Asclepias sp.	Abronia fragrans	Bouteloua gracilis
Astragalus sp.	Amaranthus sp.	B. hirsuta
A. wootonii	Croton texensis	Eragrostis sp.
Baileya multiradiata	Erigeron bellidiastrum	E. lehmanniana
Carex sp.	Euphorbia sp.	E. sessilispica
Commelina erecta	Eurytaenia texana	Paspalum sp.
Cucurbita foetidissima	Ipomopsis pringlei	Sporobolus giganteus
Evolvulus pilosus	Linaria texana	
E. sericeous	Monarda punctata	
Gaillardia sp.	Nama hispidum	
G. pulchella	Oenothera sp.	
Gaura sp.	Orobanche multiflora	
Heliotropium currassavicum	Phacelia integrifolia	
Kraemeria lanceolata	Salsola kali	
Lepidium fendleri	Solanum rostratum	
Lithospermum multiflorum		
Mentzelia sp.		
Penstemon ambiguus		
P. fendleri		
Schranckia occidentalis		
Solanum sp.		
S. eleagnifolium		
Thelesperma megapotamicum		
Tradescantia occidentalis		
Verbena sp.		
Verbena bracteata		
Vicia ludoviciana		

APPENDIX 9-G

DENSITY OF ANNUAL PLANTS FOR 1985, 1986 AND 1987 (PLANTS PER M^2)

	S85	F85	S86	F86	S87	F87
ANNUAL FORBS						
ABFR						
AMARA						
APAR					0.01	0.01
CHENO	0.02					
COCO						0.02
CORIS	0.01					
CRTE						
DIWI		0.01	0.04		0.06	0.01
ERAN	2.28	1.07	0.28	0.09	1.36	1.16
ERBE					0.03	
ERIGE	0.02				0.15	
EUPHO	3.08				0.01	0.92
EUGL						0.01
EUMI		0.15	0.32	0.44	0.06	0.39
EUTE					0.01	
HECO						
HEHU	3.62		0.15	0.01	3.61	0.27
HELIA					0.20	
HEPE	0.41	0.06	0.17	0.08		0.13
HEPS	11.06	3.62	0.28	0.29	13.51	7.96
HYFL		0.04	0.03	0.02	0.09	0.02
IPPR						
LARE	0.01					
LITE					0.04	
MATA						
MOPU	3.54		0.23		1.97	
MOVE					0.04	0.01
NAHI						
OENOT	0.09		0.01		0.20	
ORMU					0.01	
PASP		0.13	0.06		0.50	0.02
PEAN		0.01	1.49	0.42	1.36	0.15
PHIN	0.06				0.51	
SAKA	0.01		0.03	0.01	0.01	
SOLAN		0.07				
SOEL					0.01	
SORO						
UNK	0.16	0.04	0.11	0.01		
SEDLG	0.00		0.41	2.75		0.03
SUBTOTAL	24.36	5.20	3.59	4.13	24.66	10.17
ANNUAL GRASSES						
MUSQ		0.04		0.18	0.22	0.26
TRPU4		1.08		0.11	0.45	1.87
UNK		0.08				
SEDLG			1.38	0.26		
SUBTOTAL		1.20	1.38	0.55	0.67	2.13
TOTAL		6.40	4.97	4.68	25.33	12.30

APPENDIX 9-H

SPRING 1987, PERCENT SPECIES RICHNESS SIMILARITY (MOTYKA MODIFIED SORENSEN'S INDEX)

ACRONYM	CONTROLS	NEAR-FIELD	FAR-FIELD	MIN1	MIN2	MIN3	SIM1	SIM2	SIM3
ARFI	0.30	0.65	0.55	0.30	0.30	0.55	63.16	70.59	91.67
CALYL		0.05	0.03			0.03			66.67
CAHA				0.03					
CASE				0.03					
CHRYS									
CRDI	0.18	0.03		0.03			32.00		
GUMI	0.10	0.10		0.10			100.00		
OPUNT									
PRGL	0.20	0.08	0.03	0.08	0.03	0.03	58.82	22.22	46.15
QUHA	0.83	0.82	0.90	0.82	0.83	0.82	99.49	95.65	95.15
YUCA	0.10	0.13	0.13	0.10	0.10	0.13	85.71	88.89	96.77
SUBTOTAL	1.70	1.87	1.68	1.70	1.68	1.68	95.33	99.56	94.87
PERENNIAL FORBS									
ASCLE	0.13	0.07	0.03	0.07	0.03	0.03	69.57	33.33	54.55
COER		0.02							
CYUN		0.03	0.03			0.03			85.71
DALA	0.15	0.07	0.18	0.07	0.15	0.07	61.54	92.31	55.17
HASP	0.03								
HOJA		0.05	0.03	0.00		0.03			66.67
LIMU			0.03						
MELE	0.03	0.02		0.02			80.00		
PHPO	0.38	0.55	0.43	0.38	0.38	0.43	81.08	93.75	87.18
SENEC			0.03						
SEDO	0.23	0.43	0.45	0.23	0.23	0.43	68.35	66.67	98.11
SOEL	0.05								
THME	0.03	0.02	0.03	0.02	0.03	0.02	80.00	100.00	80.00
SUBTOTAL	1.00	1.25	1.20	1.00	1.00	1.20	88.89	90.91	97.96
ANNUAL FORBS									
APAR	0.03								
DIWI	0.08	0.05	0.05	0.05	0.05	0.05	80.00	80.00	100.00
ERAN	0.73	0.50	0.43	0.50	0.43	0.43	81.63	73.91	91.89
ERIGE		0.15	0.13	0.00		0.13			90.91
ERBE	0.05								
EUPHO	0.28	0.50	0.65	0.28	0.28	0.50	70.97	59.46	86.96
EUMI	0.03	0.03		0.03			85.71		
EUTE	0.03								
HEHU	0.50	0.53	0.65	0.50	0.50	0.53	96.77	86.96	90.14
HELIA		0.10	0.05			0.05			66.67
HEPS	0.80	0.75	0.88	0.75	0.80	0.75	96.77	95.52	92.31
HYFL	0.15	0.07	0.03	0.07	0.03	0.03	61.54	28.57	54.55
LITE	0.05	0.03		0.03			80.00		
MOVE	0.03								
MOPU	0.48	0.40	0.53	0.40	0.48	0.40	91.43	95.00	86.49

APPENDIX 9-H

SPRING, 1987, PERCENT SPECIES RICHNESS SIMILARITY (MOTYKA MODIFIED SORENSEN'S INDEX) (CONTINUED)

ACRONYM	CONTROLS	NEAR-FIELD	FAR-FIELD	MIN1	MIN2	MIN3	SIM1	SIM2	SIM3
ANNUAL FORBS (continued)									
OENOT	0.33	0.03	0.15	0.03	0.15	0.03	18.60	63.16	36.36
ORMU				0.03					
PASP	0.30	0.17	0.25	0.17	0.25	0.17	71.43	90.91	80.00
PEAN	0.08	0.22		0.08			51.43		
PHIN	0.23	0.02		0.02			13.79		
SAKA		0.03							
SUBTOTAL	4.13	3.58	3.80	3.58	3.80	3.58	92.89	95.90	96.98
PERENNIAL GRASSES									
ARIST	0.55	0.38	0.70	0.38	0.55	0.38	82.14	88.00	70.77
ARWR	0.05								
BOER		0.02							
BOGR	0.03								
POHI	0.03	0.03		0.03			85.71		
SEIN	0.13	0.33	0.40	0.13	0.13	0.33	54.55	47.62	90.9
LECO	0.20	0.27	0.53	0.20	0.20	0.27	85.71	55.17	67.37
MUHLE	0.03								
PASES		0.08	0.05			0.05			75.00
PAVI	0.13	0.03		0.03			42.11		
SPCO	0.13	0.12	0.20	0.12	0.13	0.12	96.55	76.92	73.68
SPCR	0.28	0.32	0.33	0.28	0.28	0.32	92.96	91.67	98.70
UNK		0.03							
SUBTOTAL	1.53	1.62	2.20	1.53	1.53	1.62	97.40	82.15	84.89
ANNUAL GRASSES									
MUSQ	0.03	0.18	0.23	0.03	0.03	0.18	24.00	20.00	89.80
TRPU4	0.25	0.25	0.68	0.25	0.25	0.25	100.00	54.05	54.05
SUBTOTAL	0.28	0.43	0.90	0.28	0.28	0.43	77.65	46.81	65.00
TOTAL ALL VEGETATION	3.30	3.78	3.68	3.30	3.30	3.68	93.18	94.62	98.68

APPENDIX 9-I

FALL, 1987, PERCENT SPECIES RICHNESS SIMILARITY (MOTYKA MODIFIED SORENSEN'S INDEX)

ACRONYM	CONTROLS	NEAR-FIELD	FAR-FIELD	MIN1	MIN2	MIN3	SIM1	SIM2	SIM3
SHRUBS									
ARFI	0.23	0.55	0.58	0.23	0.23	0.55	58.06	56.25	97.78
CALYL		0.05							
CASE	0.03	0.05			0.03				80.00
CHRYS									
CRDI	0.20	0.03	0.03	0.03	0.03	0.03	28.57	22.22	85.71
GUMI	0.05	0.07		0.05			85.71		
OPUNT									
PRGL	0.05	0.07	0.10	0.05	0.05	0.07	85.71	66.67	80.00
QUHA	0.80	0.82	0.88	0.80	0.80	0.82	98.97	95.52	96.55
YUCA	0.25	0.05	0.20	0.05	0.20	0.05	33.33	88.89	40.00
SUBTOTAL	1.58	1.67	1.83	1.58	1.58	1.67	97.48	92.94	95.66
PERENNIAL FORBS									
CYUN	0.03	0.03	0.03	0.03	0.03	0.03	85.71	100.00	85.71
DALA	0.08	0.07	0.05	0.07	0.05	0.05	94.12	80.00	85.71
HASP	0.03								
HOJA	0.05	0.03		0.03			80.00		
LIAR	0.03								
LIMU									
MENTZ	0.03								
MELE	0.03								
OXGL	0.05	0.02		0.02			50.00		
PHPO	0.10	0.25	0.35	0.10	0.10	0.25	57.14	44.44	83.33
PSTA		0.02							
SEDO	0.13	0.28	0.08	0.13	0.08	0.08	61.22	75.00	41.86
THME									
SUBTOTAL	0.53	0.70	0.50	0.53	0.50	0.50	86.53	97.56	83.33
ANNUAL FORBS									
AMARA									
APAR	0.03								
COCO	0.05								
DIWI	0.03								
ERAN	0.50	0.45	0.55	0.45	0.50	0.45	94.74	95.24	90.00
ERBE									
EUGL			0.03						
EUMI	0.40	0.23	0.15	0.23	0.15	0.15	73.68	54.55	78.26
HEHU	0.13	0.08	0.10	0.08	0.10	0.08	80.00	88.89	90.91
HEPE	0.15	0.05	0.15	0.05	0.15	0.05	50.00	100.00	50.00
HEPS	0.68	0.85	0.85	0.68	0.68	0.85	88.52	88.52	100.00
HYFL	0.05	0.02		0.02			50.00		
MOVE	0.03								
MOPU									
PASP	0.05		0.03		0.03			66.67	
PEAN	0.20	0.10	0.05	0.10	0.05	0.05	66.67	40.00	66.67
SUBTOTAL	2.23	1.83	1.90	1.83	1.90	1.83	90.18	92.12	98.04

APPENDIX 9-I

FalL, 1987, PERCENT SPECIES RICHNESS SIMILARITY (MOTYKA MODIFIED SORENSEN'S INDEX) (CONTINUED)

ACRONYM	CONTROLS	NEAR-FIELD	FAR-FIELD	MIN1	MIN2	MIN3	SIM1	SIM2	SIM3
PERENNIAL GRASSES									
ANSC			0.03						
ARIST	0.10	0.23	0.05	0.10	0.05	0.05	60.00	66.67	35.29
ARLO	0.10	0.30	0.20	0.10	0.10	0.20	50.00	66.67	80.00
ARPU	0.40	0.13	0.33	0.13	0.33	0.13	50.00	89.66	58.18
BOER	0.03								
BRCI	0.05								
CEIN	0.40	0.30	0.35	0.30	0.35	0.30	85.71	93.33	92.31
ERIN			0.03						
ERSE			0.08						
LECO	0.38	0.27	0.40	0.27	0.38	0.27	83.12	96.77	80.00
PASES	0.25	0.13	0.08	0.13	0.08	0.08	69.57	46.15	72.00
PAVI									
SEMA									
SPCO	0.03	0.10	0.18	0.03	0.03	0.10	40.00	25.00	72.73
SPCR	0.23	0.23	0.23	0.23	0.23	0.23	98.18	100.00	98.18
SUBTOTAL	1.95	1.70	1.93	1.70	1.93	1.70	93.15	99.61	93.79
MUSQ	0.05	0.27	0.15	0.05	0.05	0.15	31.58	50.00	72.00
TRPU4	0.33	0.48	0.58	0.33	0.33	0.48	80.41	72.22	91.34
SUBTOTAL	0.38	0.75	0.73	0.38	0.38	0.73	66.67	68.18	98.98
TOTAL ALL VEGETATION	6.65	6.65	6.88	6.65	6.65	6.65	100.00	98.34	98.34

Controls = Avg. C1 and C2w.
Near-field = Avg. E1, NW1, SE1.
Far-field = Avg. NW2, SE2.
Values = % frames including a particular species.
MIN1 = smaller value between controls and near-field.
MIN2 = smaller value between controls and far-field.
MIN3 = smaller value between near-field and far-field.
SIM1 = % similarity of near-field plots to control plots.
SIM2 = % similarity of far-field plots to control plots.
SIM3 = % similarity of near-field plots to far-field plots.
ISmo = 2mw x 100 ; mw = MIN, ma = first value, mb = second value; ma + mb (i.e., ISmo Total Vegetation Far-field and Control = (2(6.65)/(6.65+6.88))100 = 98.34%.

TABLE 8.4

LITTER DECOMPOSITION RATES FOR 1987
% ORGANIC MATTER LOSS

3 Month

	CT1	CT2	SE1	SE2	NW1	NW2	E1
	5.8	12.1	3.7	17.4	13.2	9.0	7.9
	16.4	14.2	9.0	10.0	9.0	11.1	12.1
	10.0	14.8	9.0	6.8	9.0	6.8	13.2
Mean	10.7	13.7	7.2	11.4	10.4	9.0	11.1
Std dev	4.4	1.2	2.5	4.4	2.0	1.8	2.3

6 Month

	CT1	CT2	SE1	SE2	NW1	NW2	E1
	19.4	18.4	16.8	5.9	10.1	19.1	17.7
	16.3	16.3	16.3	14.4	10.7	16.8	15.8
	20.2	14.8	13.8	11.6	12.6	18.9	14.9
Mean	18.6	16.5	15.6	10.6	11.1	18.3	16.1
Std dev	1.7	1.5	1.3	3.5	1.1	1.0	1.2

9 Month

	CT1	CT2	SE1	SE2	NW1	NW2	E1
	18.5	21.0	15.6	18.9	20.0	15.8	17.0
	14.8	6.3	19.1	16.2	18.1	22.4	16.3
	13.2	24.1	16.1	20.1	16.4	21.6	21.3
Mean	15.5	17.1	16.9	18.4	18.2	19.9	18.2
Std dev	2.2	7.8	1.5	1.6	1.5	2.9	2.2

12 Month

	CT1	CT2	SE1	SE2	NW1	NW2	E1
	16.0	15.9	22.0	13.9	20.4	21.1	20.3
	23.3	30.7	22.8	15.8	17.9	18.9	19.2
		20.3	18.1	17.5	19.6	24.4	22.6
Mean	19.7	22.3	21.0	15.7	19.3	21.5	20.7
Std dev	3.6	6.2	2.1	1.5	1.0	2.3	1.4

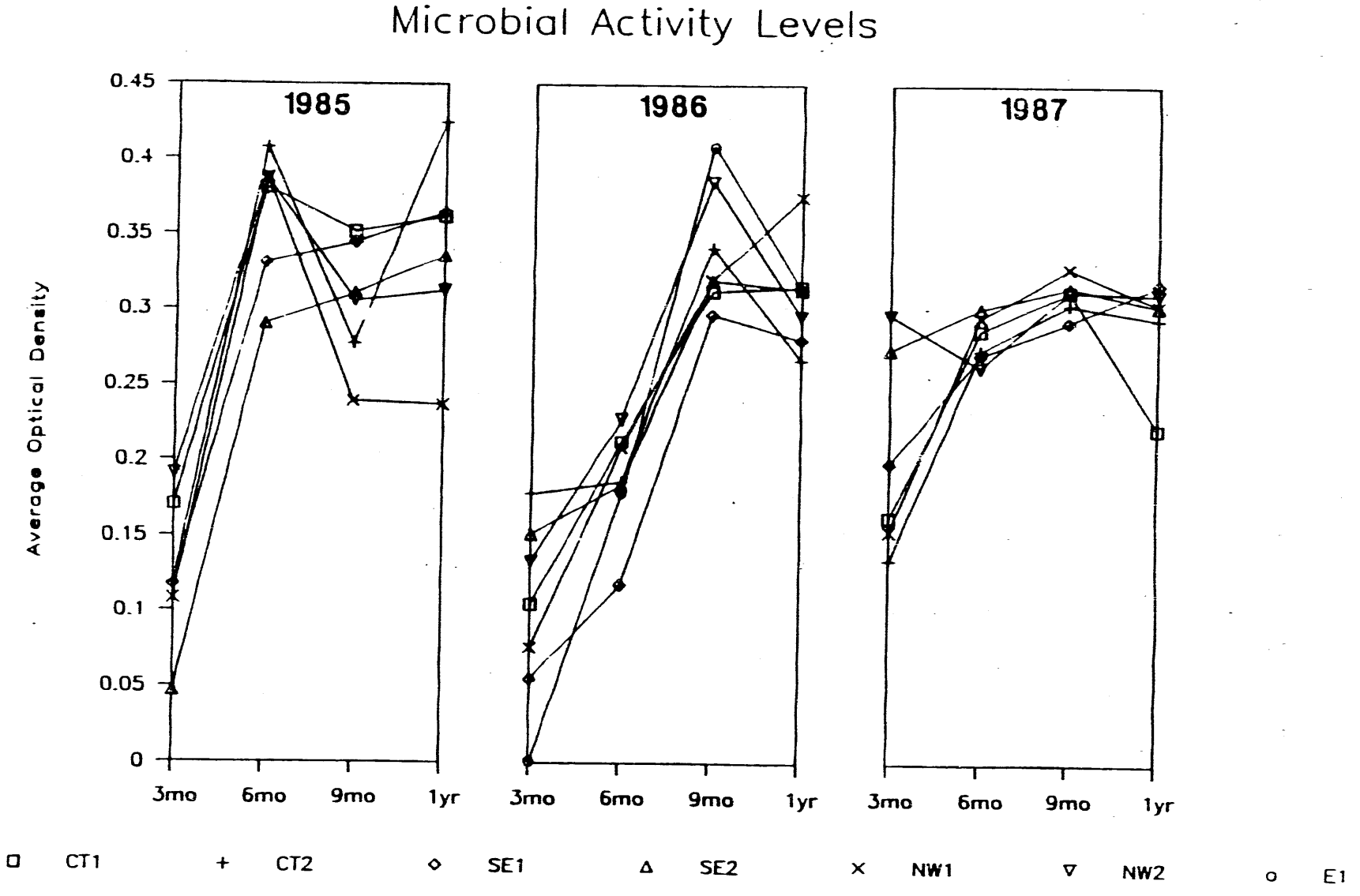


FIGURE 8.1 Plot average microbial activity levels measured in surface litter collected over one-year. Levels at all plots were statistically equivalent to control plots.

Cumulative average microbial activity levels are plotted in Figure 8.1. Activity levels are low during the first three months of the study period each year when moisture is often limited (Figure 8.2). Values are generally highest in the third or fourth sampling periods of the year. Extreme temperatures do not seem to inhibit microbial activity in the litter. Near-field plots do not show any consistent effect of salt input, even though increased salt levels have been observed in those plots (see Chapter 7). The only repeating patterns in microbial activity levels between plots appear to be those related to moisture and chemical changes in substrate which are due to chemical decomposition.

Litter Decomposition. Litter decomposition data from 1986 and 1987 are presented in Tables 8.3 and 8.4, respectively. Figures 8.3 and 8.4 illustrate results of the two studies. For the 1986 samples, decomposition values in the near-field and far-field plots do not vary from the control plots. Decomposition during the second sampling period of 1987 is lower in SE2 than in either of the control plots. There is no apparent reason for this difference.

Litter decomposition rates vary somewhat from year to year and are probably influenced by the amount and distribution of precipitation at the site. However, at least some organic matter is lost from the samples during the first three months of the study even when no measurable precipitation has been recorded. Moisture in the form of fog is generally available at the site during this period. The amount of litter in each sample bag (initial weight of ten grams) can absorb and retain moisture from the atmosphere, allowing the continued activity of the decomposer community. During the driest quarter of the year, loss of organic matter during later parts of the annual cycle may reflect more directly the effects of precipitation levels (Figure 8.2).

8.3 CONTINUING PROGRAM

The microbial community will continue to be monitored in the coming year. Study of microbial activity in the tebuthiuron plot has been discontinued. A baseline for this location has been obtained from which areas similarly treated in the future may be evaluated.

TABLE 8.3

LITTER DECOMPOSITION RATES FOR 1986
% ORGANIC MATTER LOSS

3 Month

	CT1	CT2	SE1	SE2	NW1	NW2	E1
	8.2	7.6	15.7	5.0	7.8	5.4	3.0
	6.4	11.8	3.7	6.6	18.5	8.7	5.9
	4.8	4.2	4.8	7.4	8.0	6.7	4.4
Mean	6.5	7.9	8.1	6.3	11.4	6.9	4.4
Std dev	1.4	3.1	5.4	1.0	5.0	1.4	1.2

6 Month

	CT1	CT2	SE1	SE2	NW1	NW2	E1
	25.1	23.0	21.2	24.8	28.2	27.7	25.5
	23.6	24.1	20.4	23.9	24.4	22.8	24.4
	28.0	18.5	18.6	17.9	26.1	28.1	25.6
Mean	25.6	21.9	20.1	22.2	26.2	26.2	25.2
Std dev	1.8	2.4	1.1	3.1	1.6	2.4	0.5

9 Month

	CT1	CT2	SE1	SE2	NW1	NW2	E1
	28.2	26.2	33.1	37.9	30.8	27.4	26.3
	28.0	34.4	24.9	23.0	26.2	28.1	20.7
	30.9	18.2	21.8	25.1	19.3	32.7	24.6
							23.1
Mean	29.0	26.3	26.6	28.7	25.4	29.4	29.0
Std dev	1.4	6.6	4.8	6.6	4.7	2.3	2.3

12 Month

	CT1	CT2	SE1	SE2	NW1	NW2	E1
	27.2	28.0	25.7	24.1	27.1	34.3	33.3
	31.1	27.6	29.6	23.9	NS	32.6	32.2
	31.3	25.5	30.8	26.8	NS	29.1	NS
Mean	29.9	27.0	28.7	24.9	27.1	32.0	29.1
Std dev	1.9	1.1	2.2	1.3	0.0	2.2	0.6

NS = No Sample

TABLE 8.2

MICROBIAL ACTIVITY LEVELS FOR 1987 (AVERAGE OPTICAL DENSITY)

3 Month

Sample	CT1	CT2	SE1	SE2	NW1	NW2	E1
	0.150	0.069	0.323	0.319	0.178	0.186	0.281
A	0.245	0.101	0.183	0.249	0.131	0.271	0.163
	0.152	0.123	0.210	0.459	0.109	0.248	0.155
	0.022	0.170	0.148	0.255	0.132	0.291	0.153
B	0.122	0.284	0.209	0.293	0.163	0.341	0.155
	0.156	0.216	0.115	0.248	0.139	0.349	0.171
	0.223	0.049	0.193	0.220	0.132	0.283	0.376
C	0.101	0.132	0.129	0.127	0.245	0.354	0.343
	0.298	0.073	0.278	0.300	0.161	0.353	0.304
Mean	0.163	0.135	0.199	0.274	0.154	0.297	0.233
Std dev	0.027	0.026	0.023	0.030	0.013	0.019	0.031

6 Month

Sample	CT1	CT2	SE1	SE2	NW1	NW2	E1
	0.162	0.395	0.323	0.368	0.306	0.238	0.242
D	0.211	0.311	0.272	0.349	0.321	0.257	0.174
	0.234	0.304	0.234	0.295	0.343	0.275	0.150
	0.318	0.160	0.271	0.315	0.358	0.203	0.313
E	0.342	0.143	0.304	0.260	0.246	0.271	0.348
	0.349	0.133	0.206	0.345	0.342	0.210	0.297
	0.336	0.266	0.239	0.321	0.142	0.274	0.239
F	0.312	0.198	0.256	0.258	0.294	0.315	0.203
	0.315	0.317	0.336	0.209	0.316	0.327	0.225
Mean	0.287	0.247	0.271	0.302	0.296	0.263	0.243
Std dev	0.022	0.031	0.014	0.017	0.022	0.014	0.022

TABLE 8.2

MICROBIAL ACTIVITY LEVELS FOR 1987 (AVERAGE OPTICAL DENSITY) (CONTINUED)

9 Month

Sample	CT1	CT2	SE1	SE2	NW1	NW2	E1
	0.329	0.284	0.314	0.301	0.226	0.265	0.290
H	0.290	0.314	0.325	0.349	0.288	0.316	0.302
	0.318	0.291	0.298	0.295	0.287	0.276	0.328
	0.339	0.323	0.325	0.305	0.353	0.312	0.389
I	0.268	0.356	0.361	0.331	0.347	0.346	0.338
	0.335	0.334	0.337	0.358	0.398	0.321	0.384
	0.297	0.248	0.242	0.341	0.310	0.333	0.332
J	0.251	0.270	0.207	0.252	0.373	0.326	0.334
	0.396	0.324	0.231	0.319	0.378	0.335	0.351
Mean	0.314	0.305	0.293	0.317	0.329	0.314	0.339
Std dev	0.014	0.011	0.018	0.011	0.018	0.009	0.011

12 Month

Sample	CT1	CT2	SE1	SE2	NW1	NW2	E1
	0.284	0.249	0.305	NS	0.310	0.332	0.347
K	0.260	0.273	0.349	NS	0.315	0.290	0.276
	0.269	0.254	0.284	NS	0.318	0.338	0.324
	0.119	0.282	0.367	0.299	0.305	0.257	0.309
L	0.186	0.297	0.341	0.285	0.291	0.350	0.324
	0.219	0.299	0.388	0.273	0.312	0.338	0.268
	NS	0.328	0.282	0.331	0.251	0.278	0.301
M	NS	0.351	0.280	0.324	0.245	0.295	0.349
	NS	0.325	0.272	0.309	0.394	0.327	0.323
Mean	0.223	0.295	0.319	0.304	0.305	0.312	0.313
Std dev	0.025	0.012	0.014	0.009	0.014	0.011	0.009

NS = No sample

TABLE 8.1

MICROBIAL ACTIVITY LEVELS FOR 1986 (AVERAGE OPTICAL DENSITY)

3 Month

Sample	CT1	CT2	SE1	SE2	NW1	NW2	E1
	0.144	0.191	0.024	0.163	0.113	0.028	0.005
A	0.115	0.186	0.028	0.043	0.080	0.132	0.081
	0.113	0.161	0.069	0.166	0.017	0.163	0.087
	0.065	0.243	0.072	0.237	0.045	0.220	0.066
B	0.197	0.111	0.046	0.207	0.140	0.046	0.115
	0.154	0.119	0.019	0.294	0.164	0.098	0.042
	0.025	0.255	0.004	0.074	0.076	0.217	0.000
C	0.062	0.130	0.076	0.121	0.024	0.129	0.032
	0.073	0.211	0.154	0.064	0.025	0.169	0.043
Mean	0.105	0.179	0.055	0.152	0.076	0.134	0.052
Std dev	0.045	0.044	0.038	0.071	0.045	0.057	0.032

6 Month

Sample	CT1	CT2	SE1	SE2	NW1	NW2	E1
	0.235	0.190	0.156	0.208	0.199	0.228	0.269
D	0.228	0.207	0.105	0.163	0.256	0.167	0.273
	0.234	0.153	0.134	0.194	0.291	0.192	0.295
	0.211	0.202	0.150	0.253	0.180	0.207	0.109
E	0.251	0.227	0.173	0.217	0.120	0.227	0.128
	0.197	0.211	0.198	0.217	0.050	0.254	0.079
	0.204	0.169	0.057	0.149	0.256	0.278	0.145
F	0.183	0.159	0.058	0.144	0.247	0.211	0.150
	0.172	0.169	0.029	0.120	0.278	0.286	0.192
Mean	0.213	0.187	0.118	0.185	0.209	0.228	0.182
Std dev	0.022	0.021	0.049	0.036	0.068	0.033	0.067

TABLE 8.1

MICROBIAL ACTIVITY LEVELS FOR 1986 (AVERAGE OPTICAL DENSITY)
(CONTINUED)

9 Month

Sample	CT1	CT2	SE1	SE2	NW1	NW2	E1
	0.345	0.276	0.268	0.385	0.293	0.429	0.426
G	0.358	0.244	0.231	0.363	0.392	0.474	0.443
	0.345	0.228	0.299	0.391	0.340	0.419	0.436
	0.314	0.361	0.236	0.300	0.341	0.314	0.262
H	0.311	0.353	0.291	0.327	0.361	0.349	0.365
	0.331	0.415	0.306	0.378	0.346	0.322	0.326
	0.294	0.300	0.342	0.283	0.203	0.413	0.558
I	0.299	0.460	0.350	0.249	0.344	0.386	0.443
	0.216	0.437	0.352	0.201	0.261	0.372	0.494
Mean	0.313	0.342	0.297	0.320	0.320	0.386	0.410
Std dev	0.042	0.085	0.046	0.067	0.058	0.053	0.077

12 Month

Sample	CT1	CT2	SE1	SE2	NW1	NW2	E1
	0.346	0.315	0.208	0.357	NS	0.303	0.344
J	0.291	0.315	0.198	0.257	NS	0.364	0.284
	0.297	0.363	0.215	0.356	NS	0.346	0.307
	0.289	0.155	0.301	0.286	0.265	0.295	NS
K	0.296	0.259	0.343	0.276	0.563	0.258	NS
	0.326	0.209	0.333	0.343	0.300	0.249	NS
	0.338	0.231	0.349	0.216	NS	0.274	0.337
L	0.283	0.284	0.264	0.357	NS	0.297	0.315
	0.380	0.274	0.309	0.345	NS	0.280	0.303
Mean	0.316	0.267	0.280	0.314	0.376	0.296	0.315
Std dev	0.033	0.063	0.060	0.047	0.163	0.038	0.022

NS = No Sample

Magnesium, Potassium and Sodium. These cations generally vary with calcium, though not to the same extent. Magnesium and potassium are present at low concentrations in the soil and have not shown any sign of accumulating at the surface (Figures 7.16 and 7.17). Sodium concentrations (Figure 7.15) are relatively high during some quarters in NW1, which is adjacent to the active saltpile and the parking lot, and is surrounded by a caliche berm. Sodium has not accumulated in the surface soil of any of the plots.

Chloride. Chloride (Figure 7.19), a major component of the Salado salt formation, is monitored as an indicator of the deposition of materials from the saltpile onto the soil surface. As with sodium, analytical results indicate periods of deposition following by leaching of the surface soils. There has not been any long-term accumulation of chloride in the soil.

7.4 CONTINUING PROGRAM

Surface soils will continue to be sampled on a quarterly schedule since this provides a direct measure of changes in soil quality which could impact ecosystem processes. Salt will be stockpiled on the surface throughout the operating life of the facility and will therefore be available to impact the area. However, results to date indicate that salt deposition is limited and, during periods of average or above average rainfall, salts are easily flushed from the surface soil.

8.0 SOIL MICROBIOTA

As described in previous annual reports, the soil microbial sampling subprogram is designed to monitor an important portion of the biological community which can be affected by changes in chemical properties at the soil surface. The normal cycle of microbial activity will be influenced by climatic factors as well as the physical and chemical condition of the substrate. Microbial activity levels and decomposition rates in the control plots are compared to those in the near-field and far-field plots to detect any effect of salt deposition on these biologic processes.

8.1 METHODS

A litter sample is composed of two nylon mesh bags wired together, each containing ten grams of oven-dried oak (Quercus havardii) leaves which are collected soon after leaf fall. In February, twelve sample bags of litter are randomly distributed and secured (under oak) in each of seven ecological monitoring plots. Three samples are then collected from each plot quarterly. The preparation and placement of litter samples has been described in previous reports (Fischer et al., 1985; Reith et al., 1985). The following parameters are measured for each litter sample collected: 1) the level of microbial activity, and 2) the rate of organic matter loss via decomposition.

Microbial activity levels are measured indirectly using the fluorescein diacetate hydrolysis (FDA) assay method described by Schnurer and Rosswall (1982). The enzymes measured by the assay are produced in small amounts by dormant organisms and spores relative to the amount produced by active individuals. Therefore, the optical density of a sample, which is a measure of the amount of breakdown product produced by the microbial community in the sample, is proportional to total microbial activity, or respiration, in the sample. Activity levels measured at a given time are affected by the immediate chemical and physical conditions in the environment, i.e., moisture, temperature, and nutrient availability.

The rate at which plant litter is broken down by microorganisms is another indirect measure of a biotic soil process. The amount of organic matter lost from the litter over time is determined using the ashing techniques described by Santos et al. (1984). Decomposition rates reflect, to a greater degree than activity levels, the long-term impacts of the physical and chemical environment.

Methods of sample preparation, collection, and analysis are the same as those described in previous reports (Fischer et al., 1987; Fischer et al., 1985; Reith et al., 1985). Laboratory analysis of microbial activity levels follows the method described by Schnurer and Rosswall (1982). Decomposition rates are calculated using the method described in Santos et al. (1984).

Results of the FDA assay are analyzed using a one-way analysis of variance (ANOVA). The grams of organic matter remaining in each sample are calculated from the percentage decomposition and are transformed prior to analysis by one-way anova. When the analysis of variance indicates that statistically-significant differences exist between plot means, a SNK test is performed to identify homogenous groups.

8.2 RESULTS AND DISCUSSION

Microbial Activity Levels. Results of the FDA hydrolysis assay are given in Tables 8.1 (1986) and 8.2 (1987). During the 1986 study, activity levels in SE1 were significantly lower than for the control plots in the six-month sample set. All other average activity levels measured during the year did not differ significantly from one or the other of the control plots. During the 1987 study period, none of the near-field or far-field plot averages differed significantly from one or the other of the control plots.

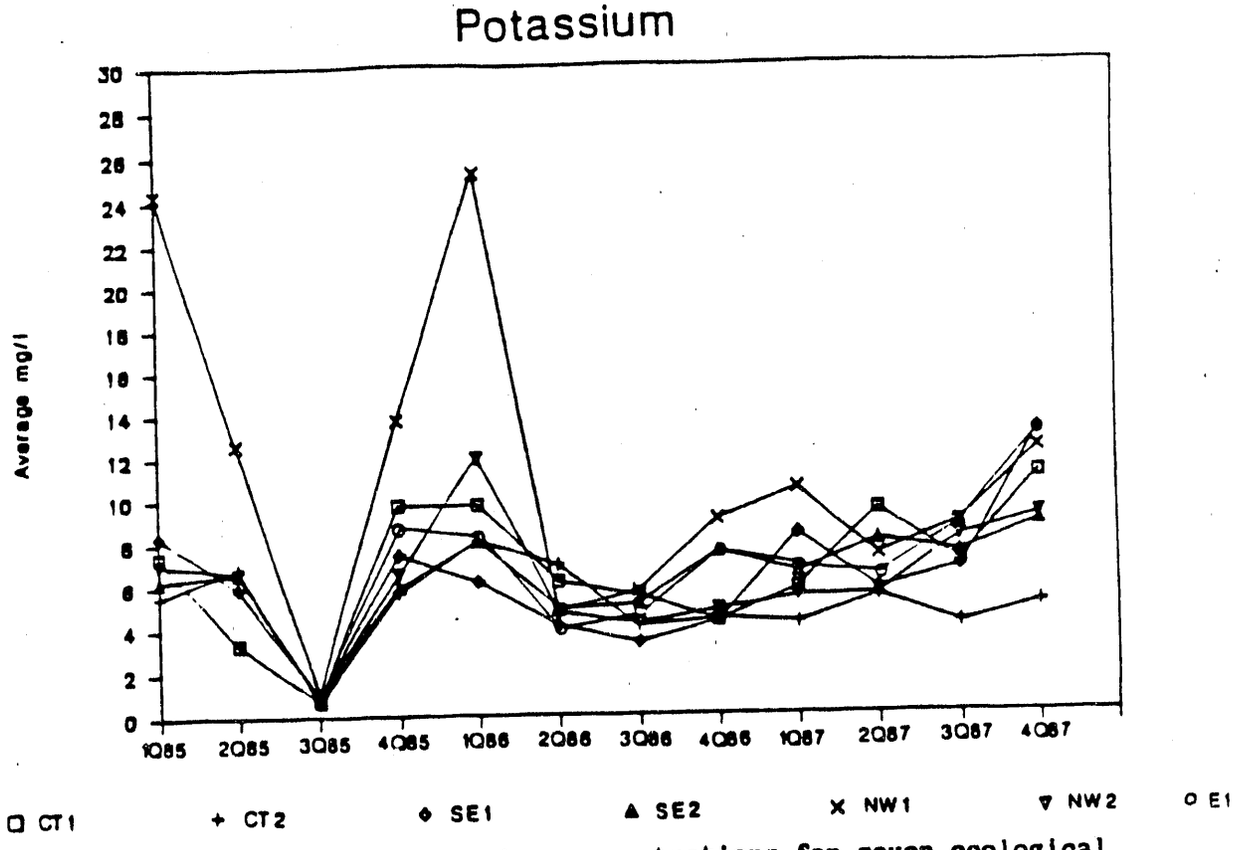


FIGURE 7.17 Cumulative potassium concentrations for seven ecological monitoring plots over a three-year period.

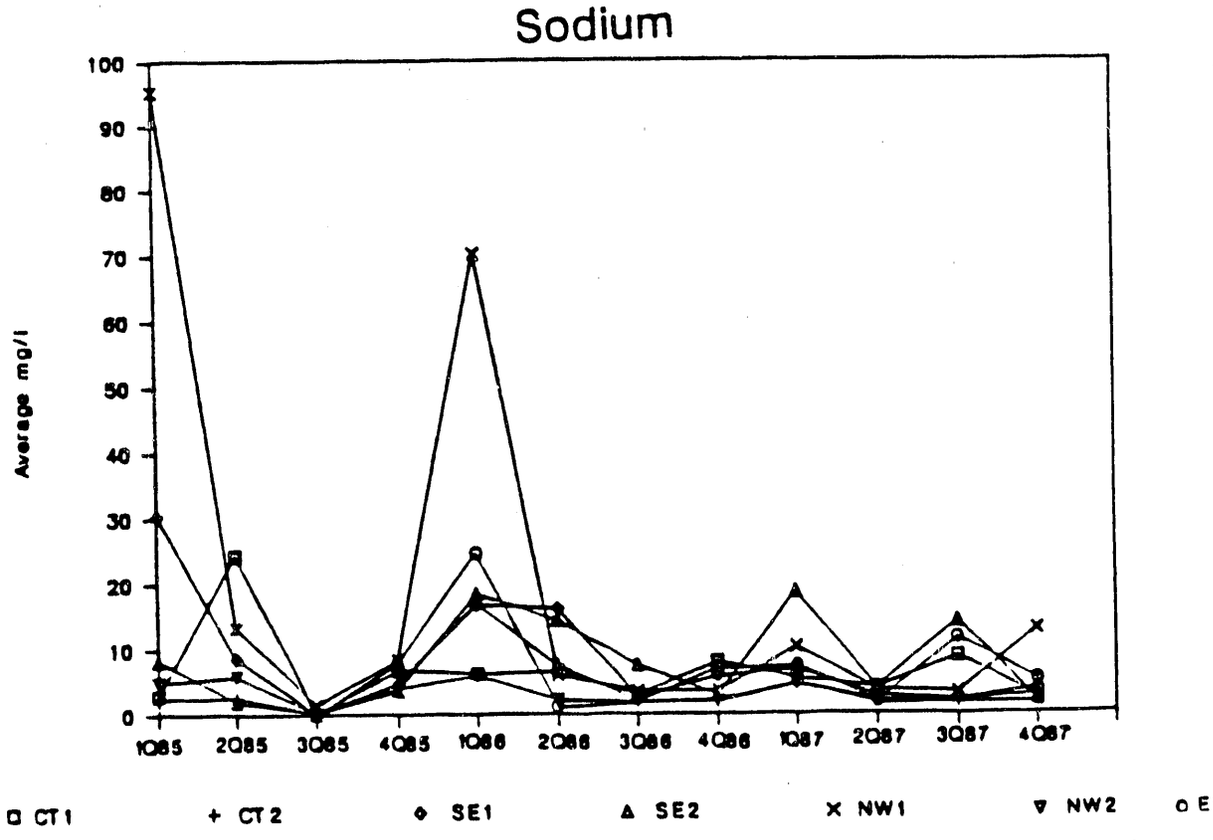


FIGURE 7.18 Cumulative sodium concentrations for seven ecological monitoring plots over a three-year period.

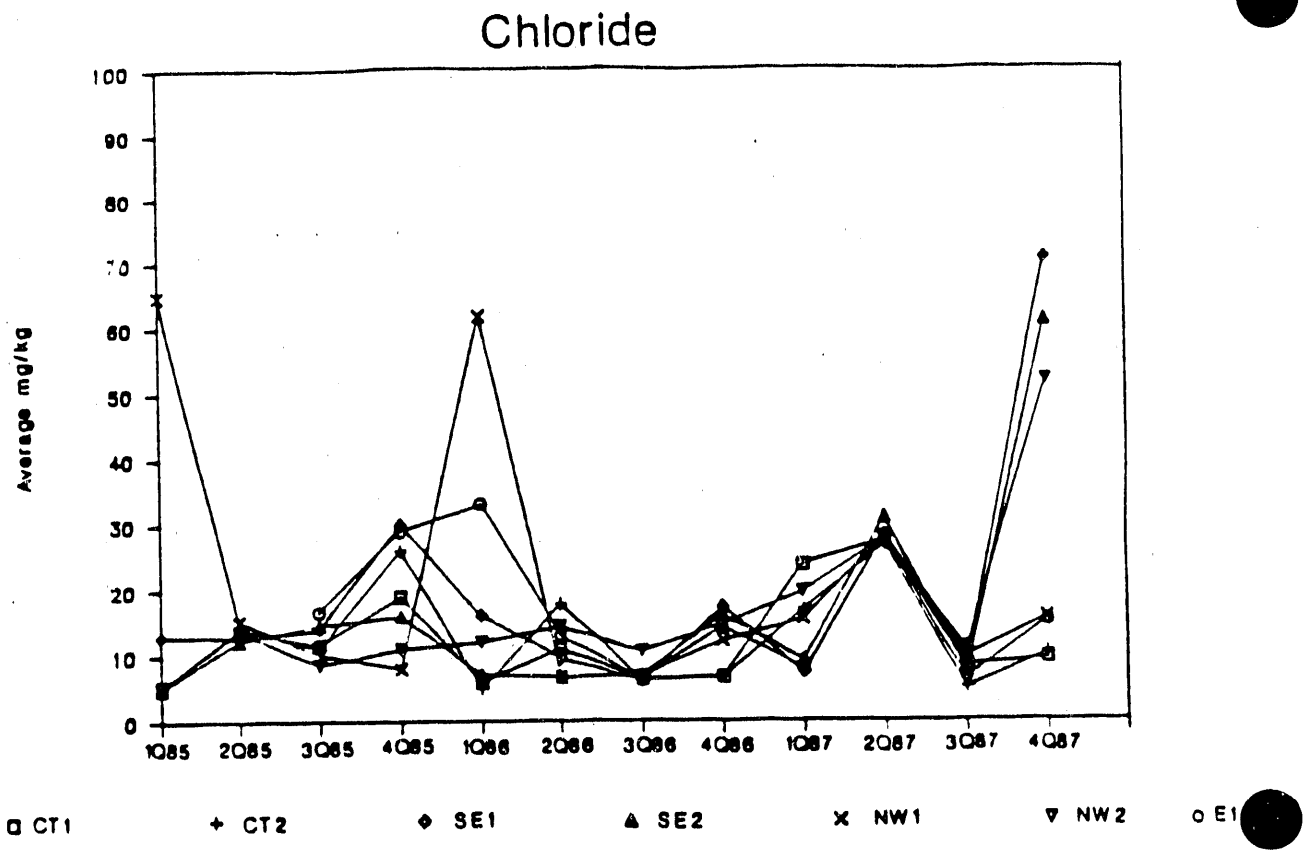


FIGURE 7.19 Cumulative chloride concentrations for seven ecological monitoring plots over a three-year period.

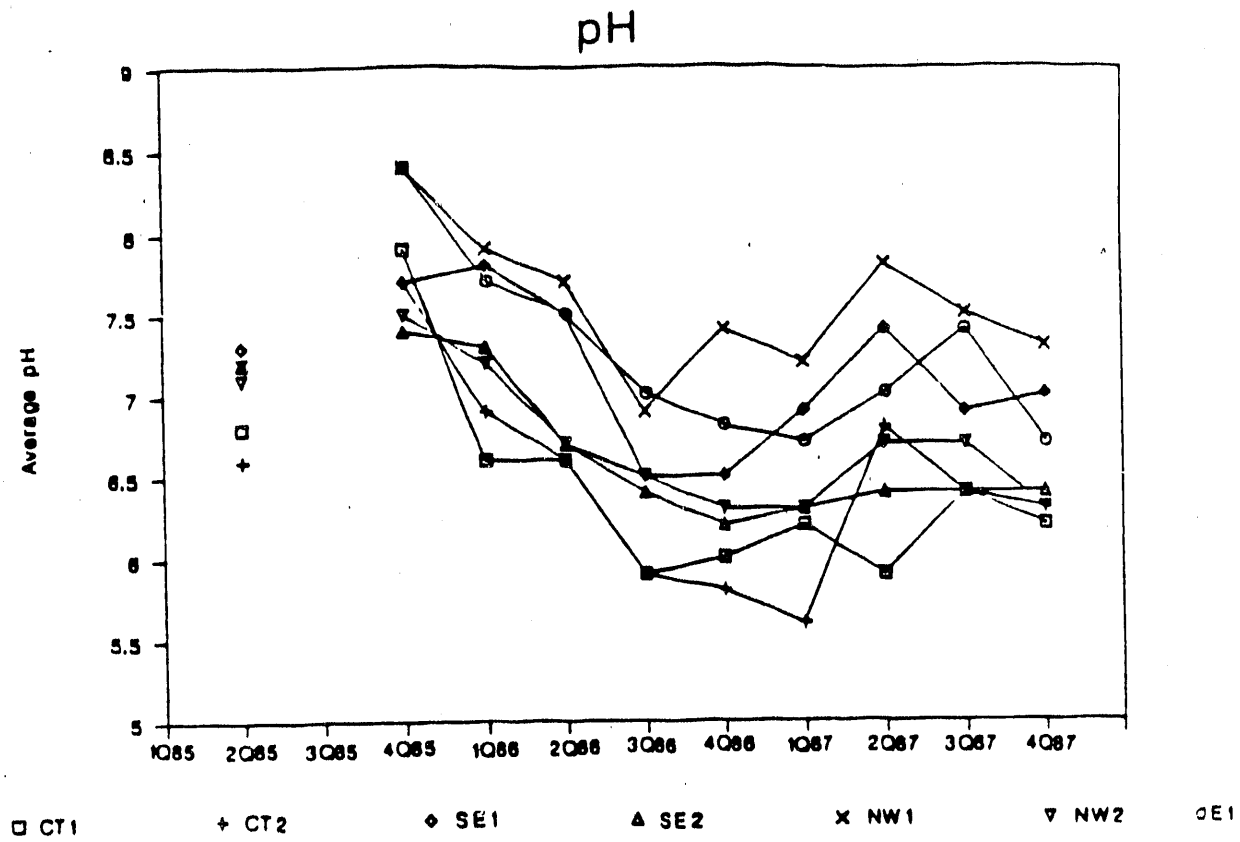


FIGURE 7.13 Cumulative pH levels for seven ecological monitoring plots over a three-year period.

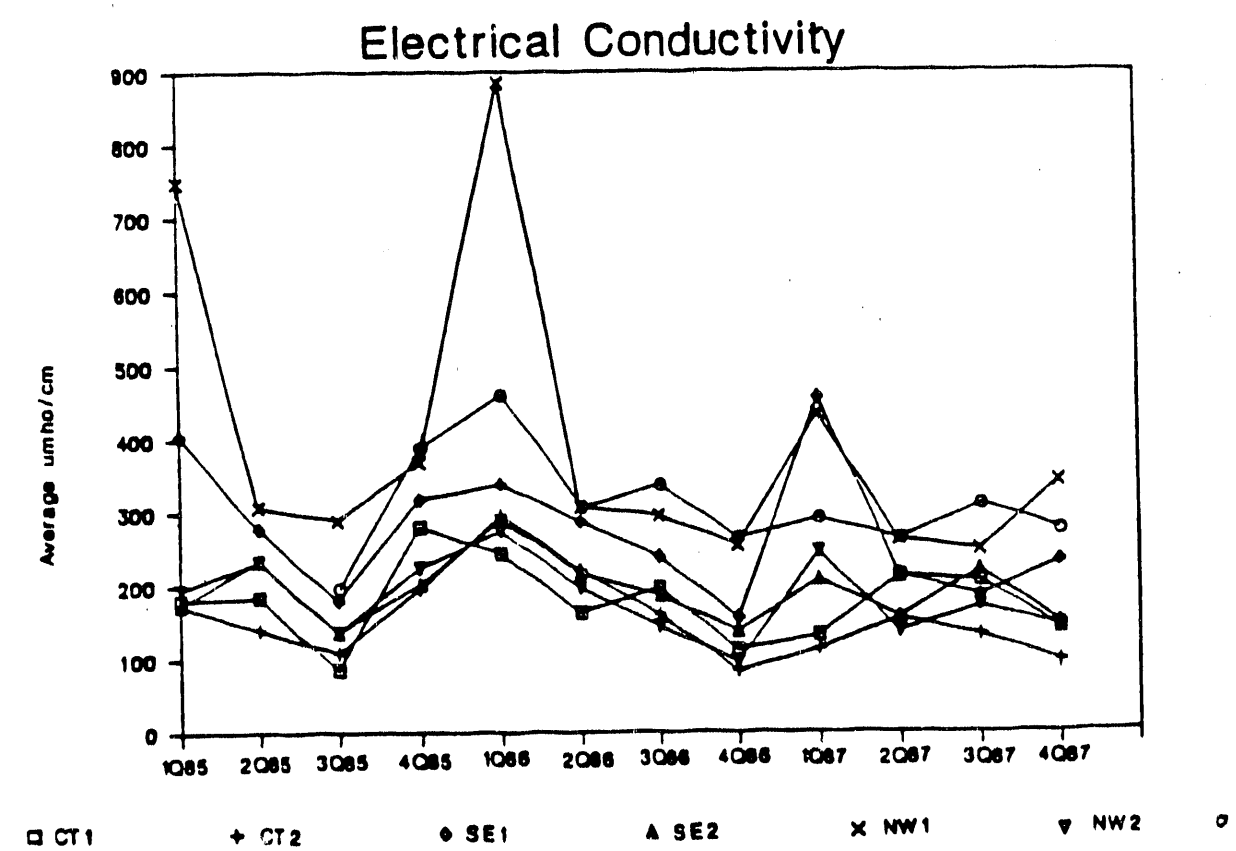


FIGURE 7.14 Cumulative electrical conductivity levels for seven ecological monitoring plots over a three-year period.

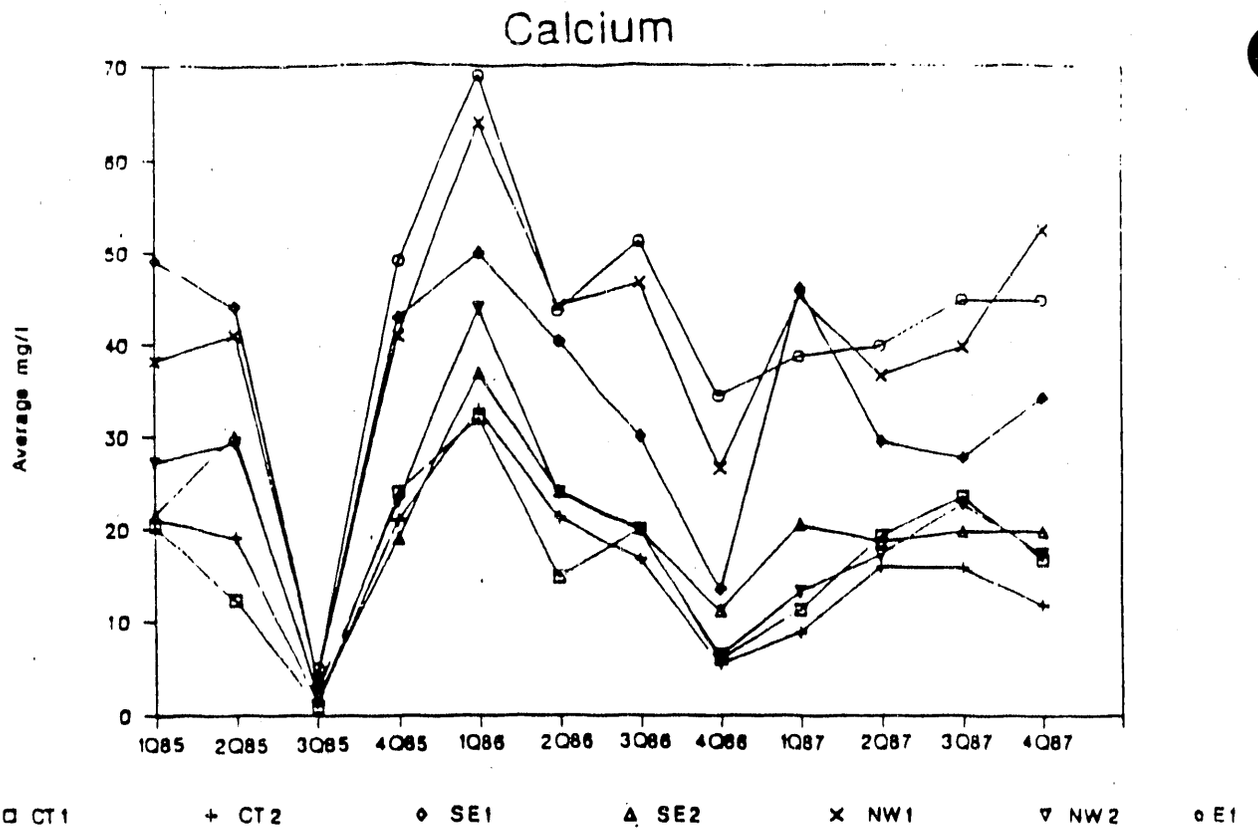


FIGURE 7.15 Cumulative calcium concentrations for seven ecological monitoring plots over a three-year period.

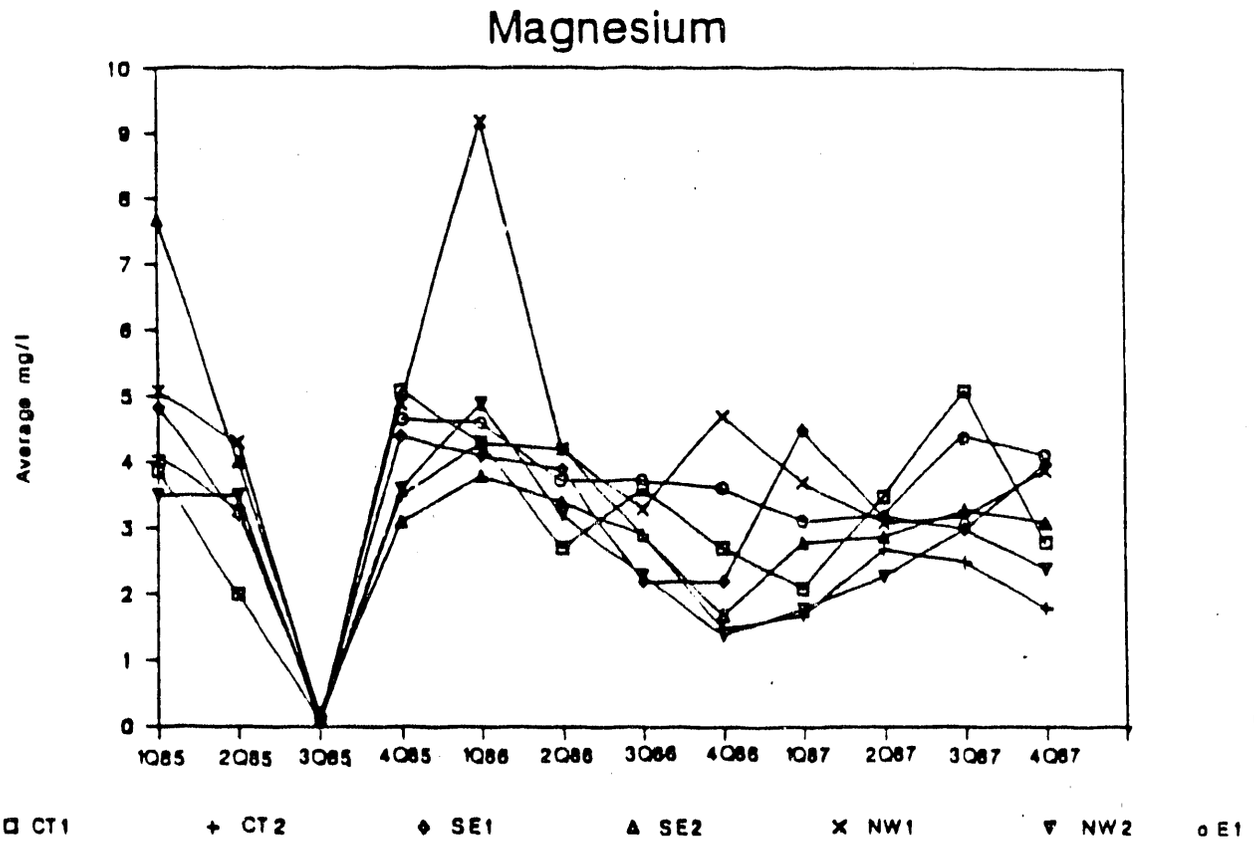


FIGURE 7.16 Cumulative magnesium concentrations for seven ecological monitoring plots over a tnree-year period.

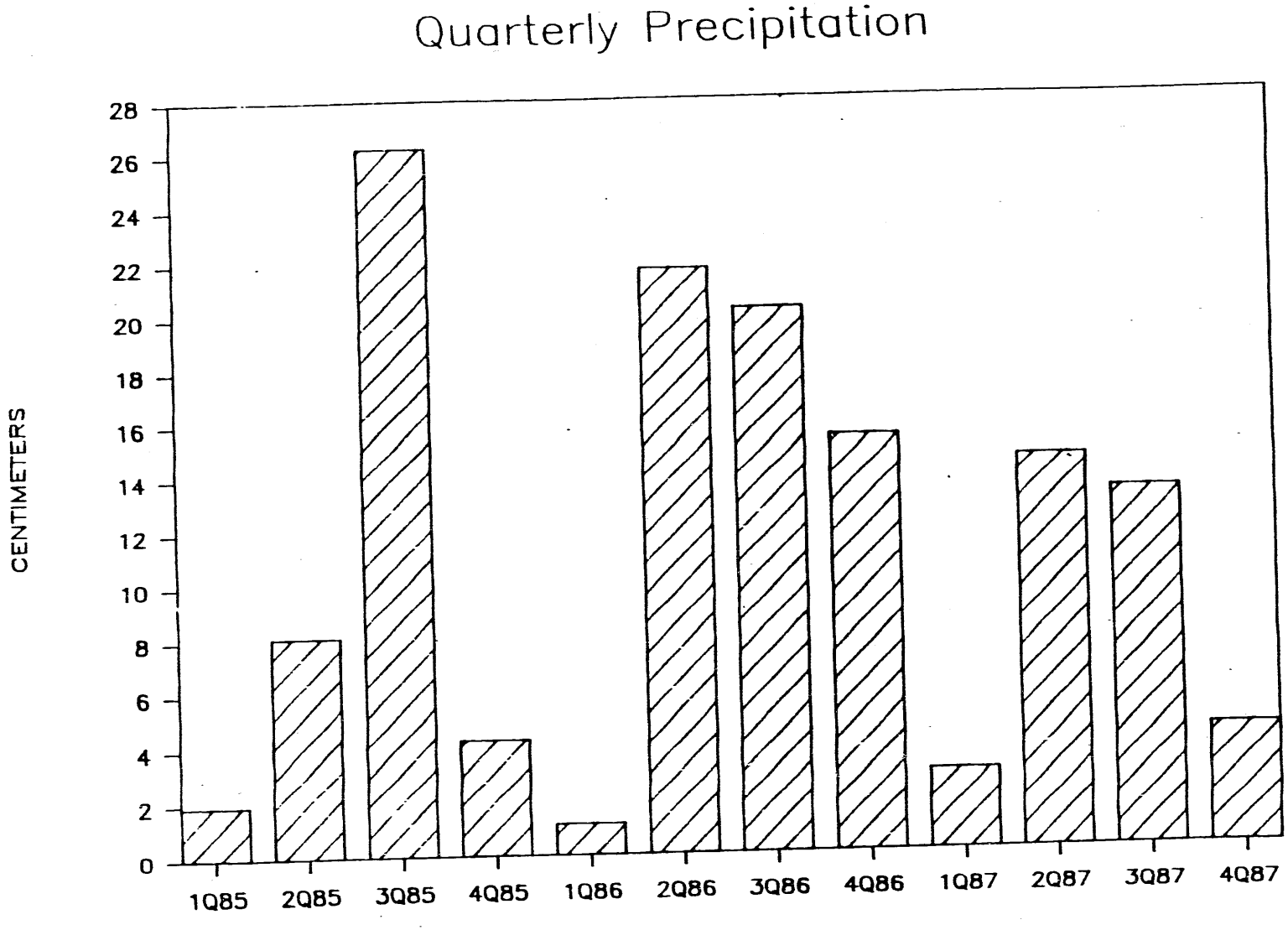


FIGURE 7.12 Quarterly precipitation at WIPP over a three-year period.

First Quarter, 1987. Average sodium and conductivity values are relatively high during this quarter. Sodium is highest in SE2 but differences between plot averages are not statistically significant. Conductivity values are highest in SE1 and NW1 but remain well below one millimho/centimeter. Calcium, magnesium, and potassium concentrations follow the typical pattern; that is, ion concentrations in the near-field plots are higher than those in far-field plots, which in turn are higher than concentrations in the control plots. Average pH values are again slightly higher than in the previous quarter, but follow the same pattern between plots as in the previous quarter.

Second Quarter, 1987. Average conductivity and calcium concentrations continue to be elevated in near-field plots. Calcium values do not differ statistically from one or the other control values. Average pH values are slightly higher than in the previous quarter and follow the same pattern between plots as in the previous quarter.

Third Quarter, 1987. For calcium and pH, near-field plots show significantly higher values than the control plots. Soil pH values are close to neutral in all plots and calcium concentrations remain relatively low.

Fourth Quarter, 1987. Chloride concentrations are elevated in the SE plots and in NW1, for which there is no apparent explanation as none of the other parameters reveal that pattern of distribution. Calcium, magnesium, sodium, and electrical conductivity are all significantly higher in the near-field plots than in the control plots. Again, actual cation concentrations are not much higher than during the previous quarter, even though precipitation during the quarter was less than five centimeters.

7.3 CUMULATIVE DATA SUMMARY

No clear, long-term patterns have emerged for the measured soil parameters which are discussed separately below. Cumulative data for each parameter are plotted in Figures 7.13 through 7.19.

pH. Average pH values peaked during the Fourth Quarter, 1985 (Figure 7.13), falling approximately two pH units in each plot between then and the Fourth Quarter, 1986. A possible explanation of pH shift in the plots is as follows: leaf fall and litter decomposition result in the release of organic acids to the soil, forcing the soil pH below neutral. The deposition of cations such as calcium and magnesium in the near and far-field plots replaces hydrogen ions on soil particles and tends to push the soil pH up above neutral. This parameter varies a great deal over time, but pH values measured in each plot at any sampling period are very similar, and the relationship between plots does not appear to change. The cycle of variation, if there is a cycle, is not an annual one and does not seem to shift with litter fall or decomposition. Although the "normal" pattern of variation in pH is not clear, it is clear that measurable significant differences exist between plots at various distances from site activities.

Electrical Conductivity. Conductivity values are highest in near-field plots between periods of intense rainfall which flush the surface soils. (Figure 7.14). Conductivity values do not remain high and there has been, as yet, no long-term impact of surface deposition of salt and caliche. During one or a sequence of dry years, however, conductivity values would be expected to rise over several quarters in the near-field plots, reflecting a continued accumulation of salts on the soil surface.

Calcium. Calcium concentrations illustrate most clearly the dominant pattern observed in the surface soil chemistry (Figure 7.15). With few exceptions, calcium levels are low in the control plots, intermediate in the far-field plots (SE2, NW2) and high in the near-field plots (SE1, NW1, E1). Calcium is leached from the surface soils during rainy periods.

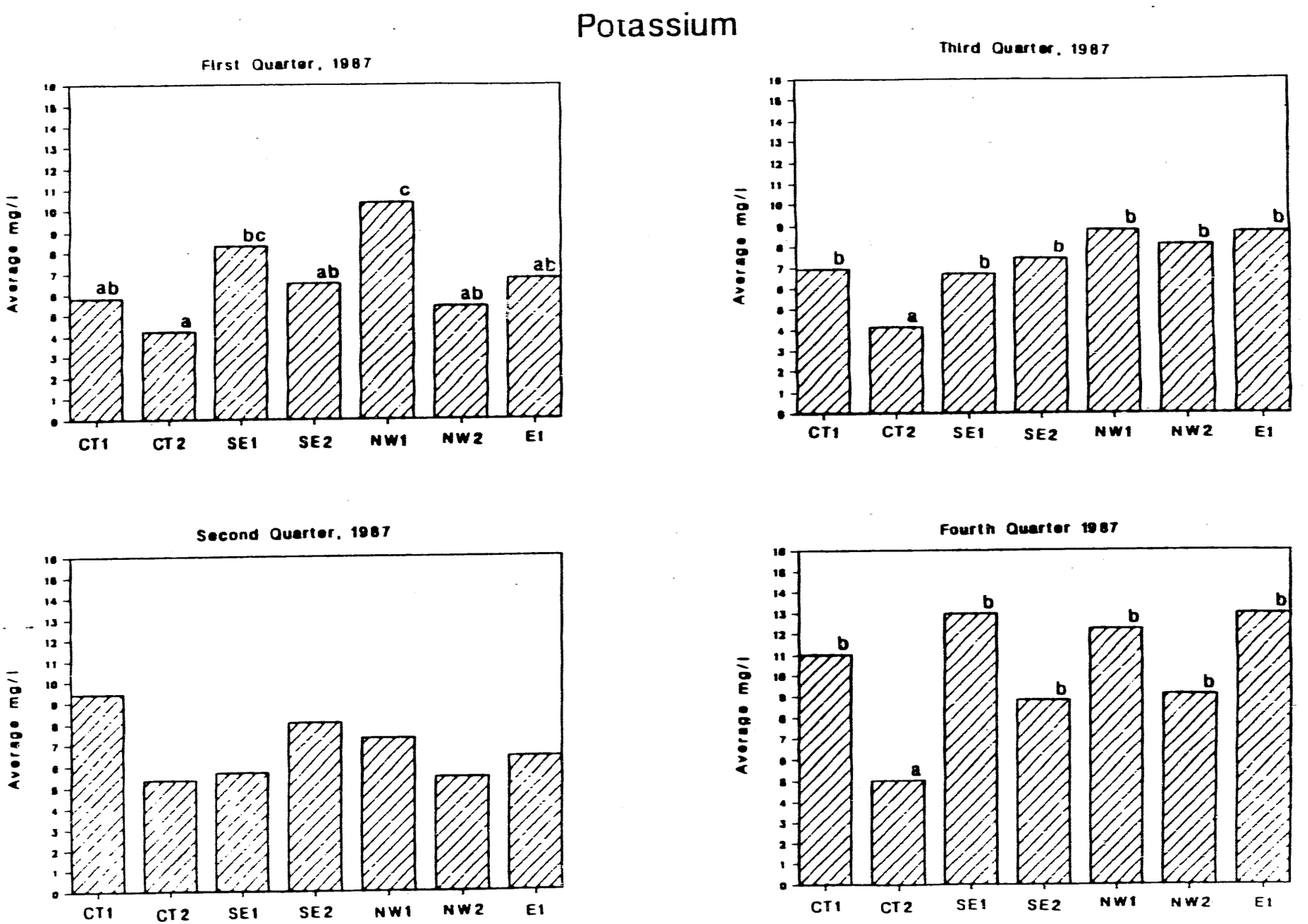


FIGURE 7.10 Potassium concentrations for seven ecological monitoring plots for 1987.

Sodium

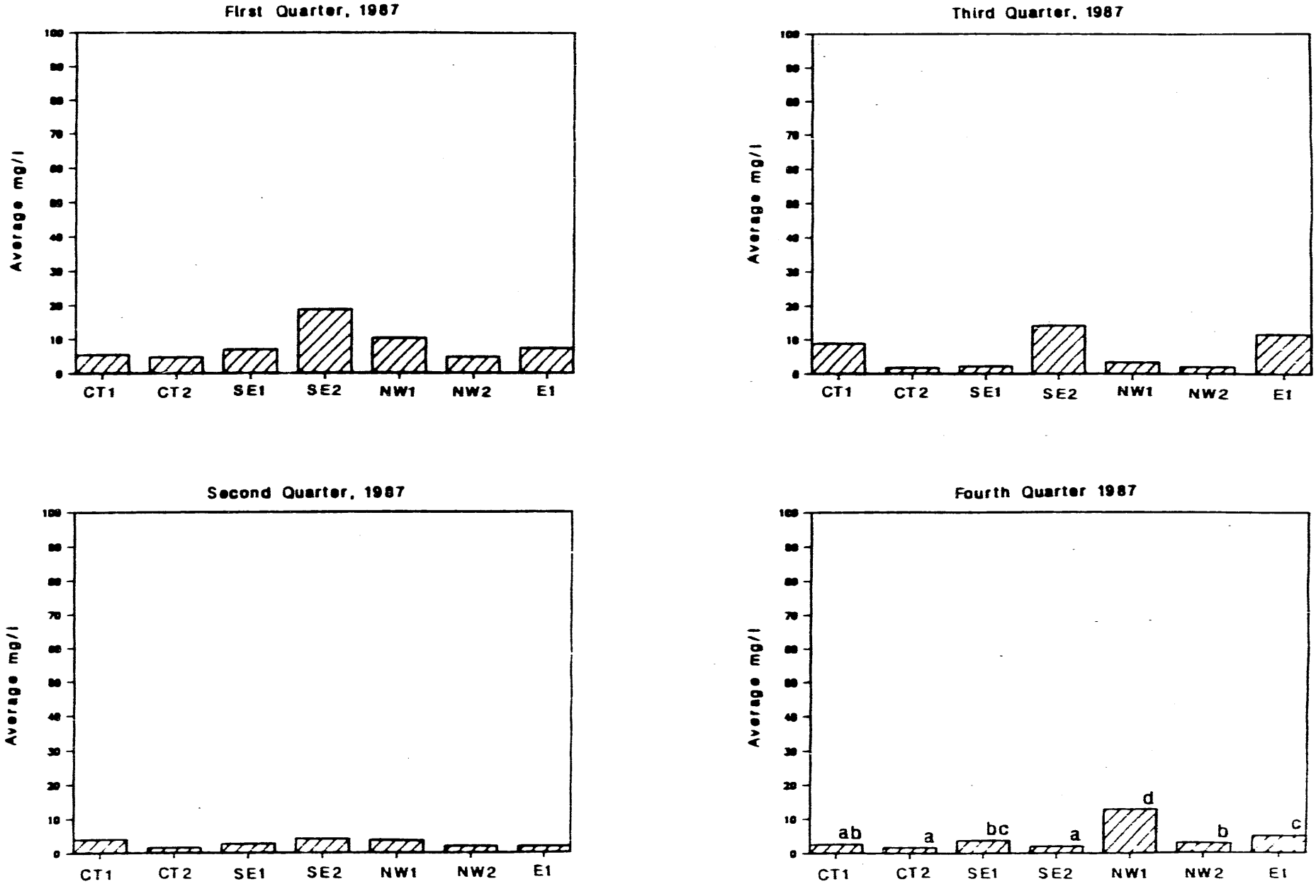


FIGURE 7.11 Sodium concentrations for several ecological monitoring plots for 1987.

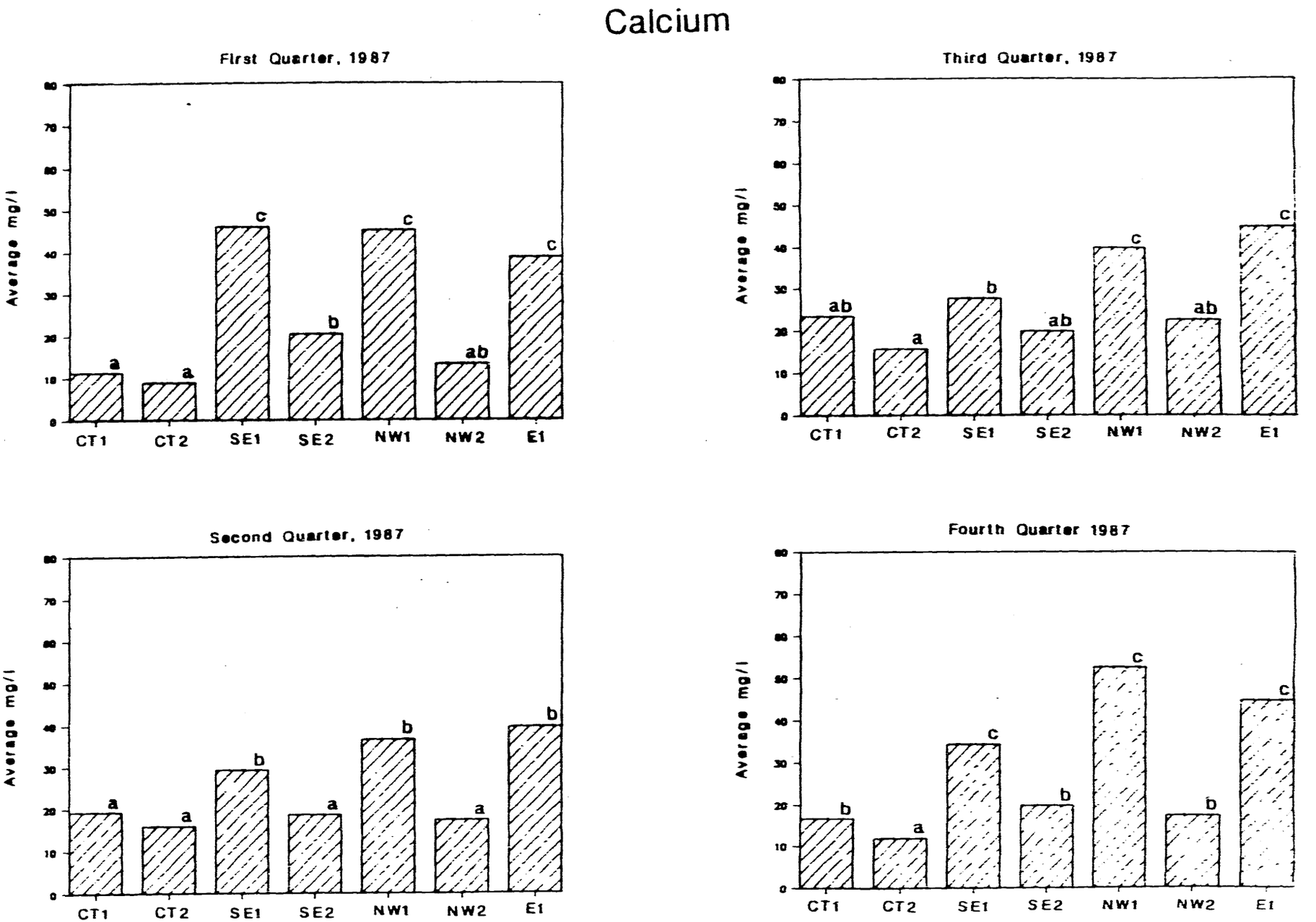


FIGURE 7.8 Calcium concentrations for seven ecological monitoring plots for 1987.

Magnesium

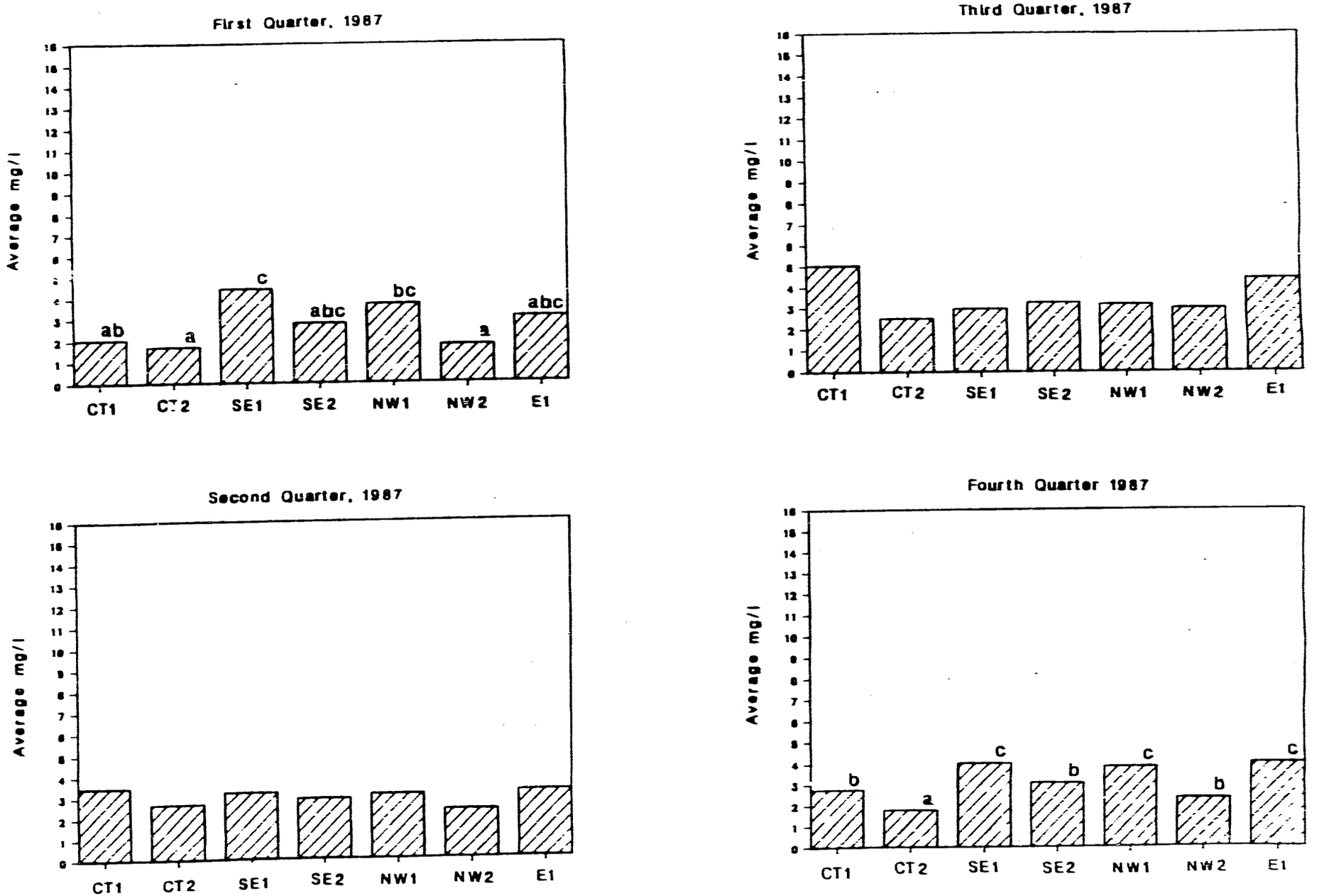


FIGURE 7.9 Magnesium concentrations for seve[illegible]cological monitoring plots for 1987.

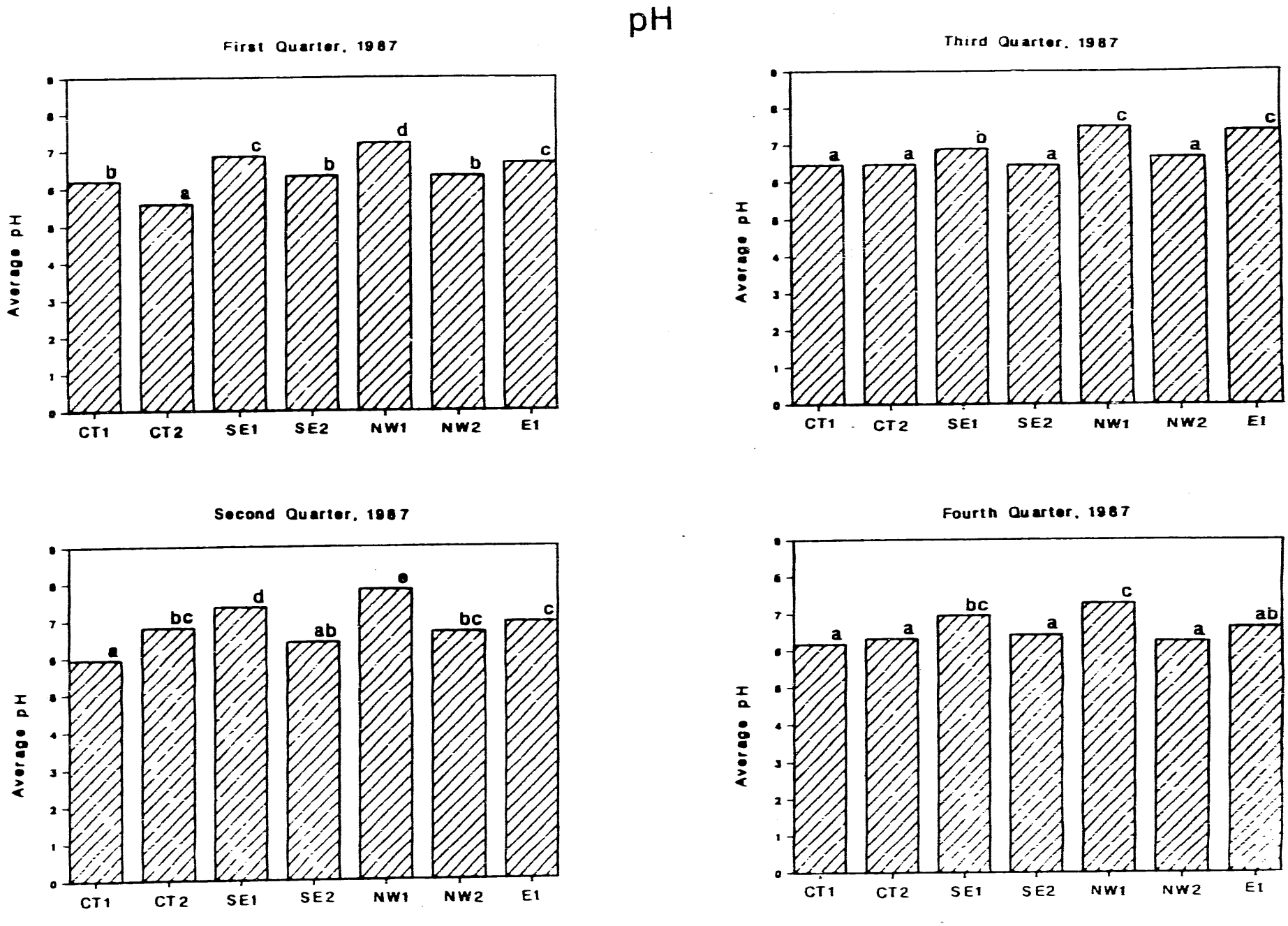


FIGURE 7.6 Levels of pH for seven ecological monitoring plots in 1987.

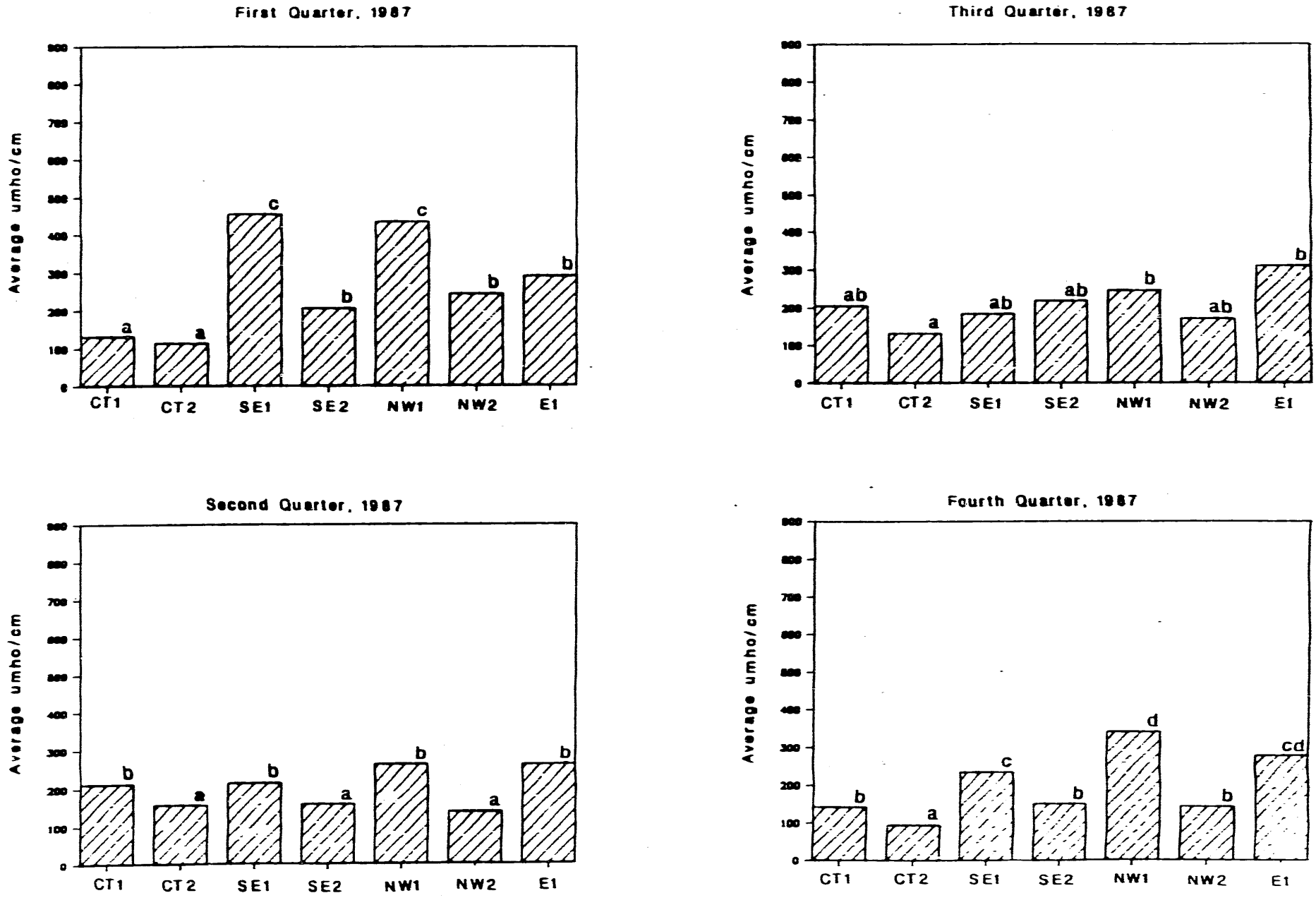


FIGURE 7.7 Electrical conductivity levels for seven ecological monitoring plots in 1987.

Sodium

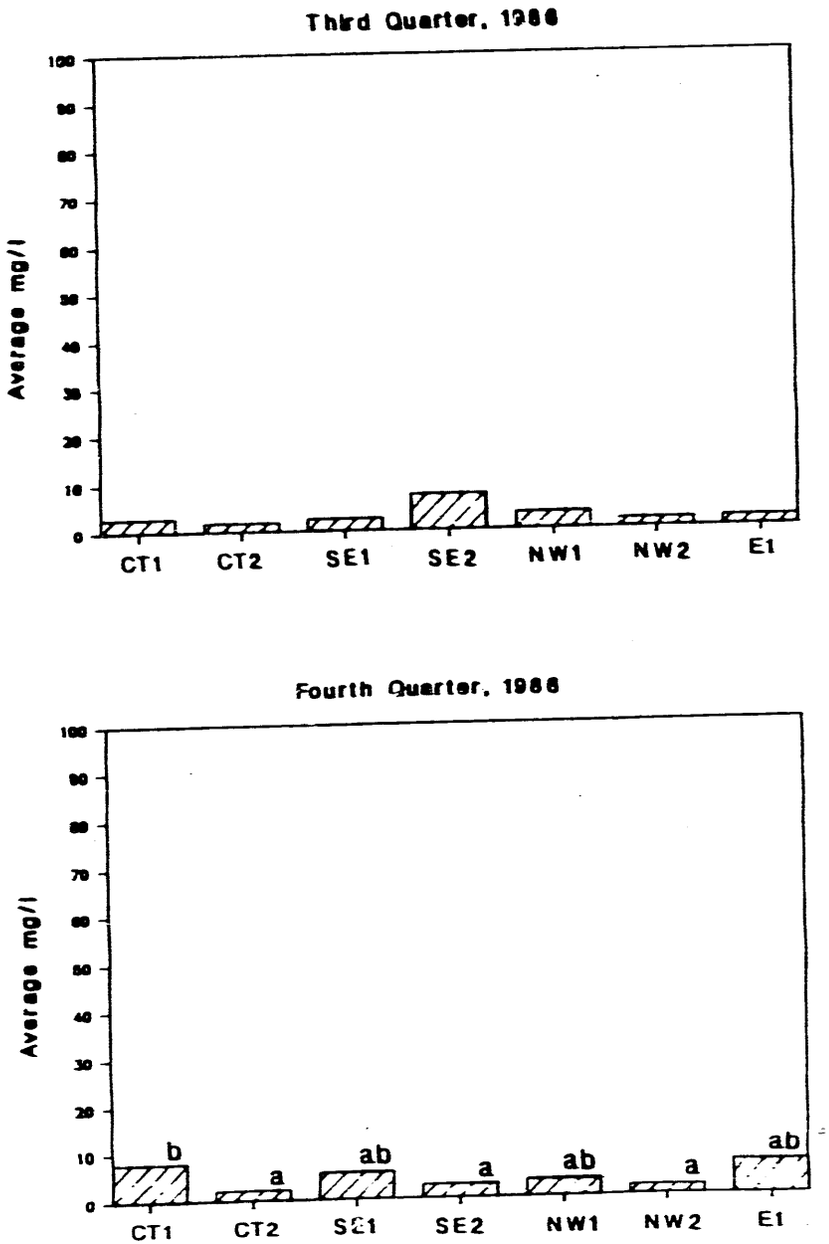


FIGURE 7.4 Sodium concentrations for seven ecological monitoring plots in 1986.

Chloride

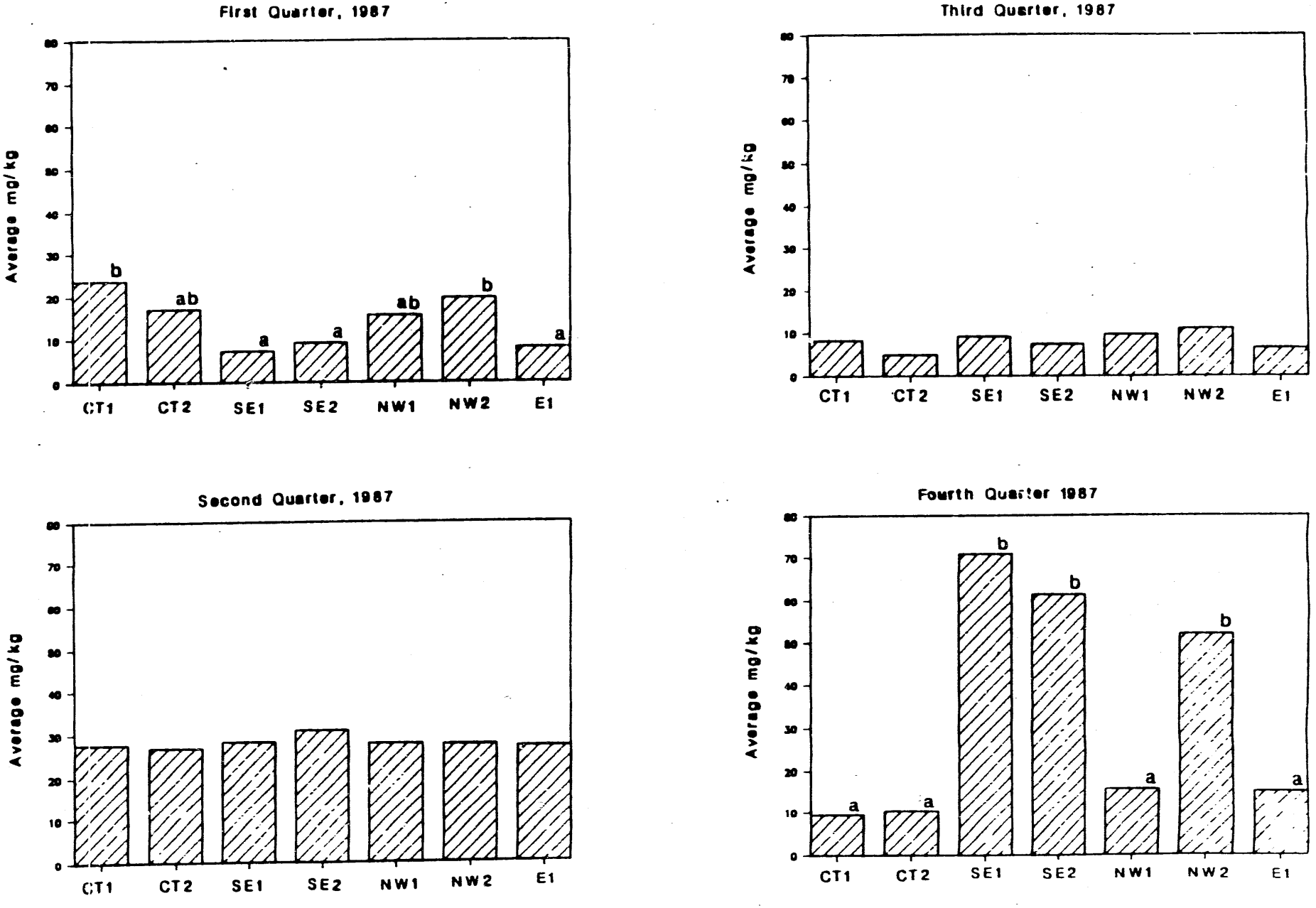
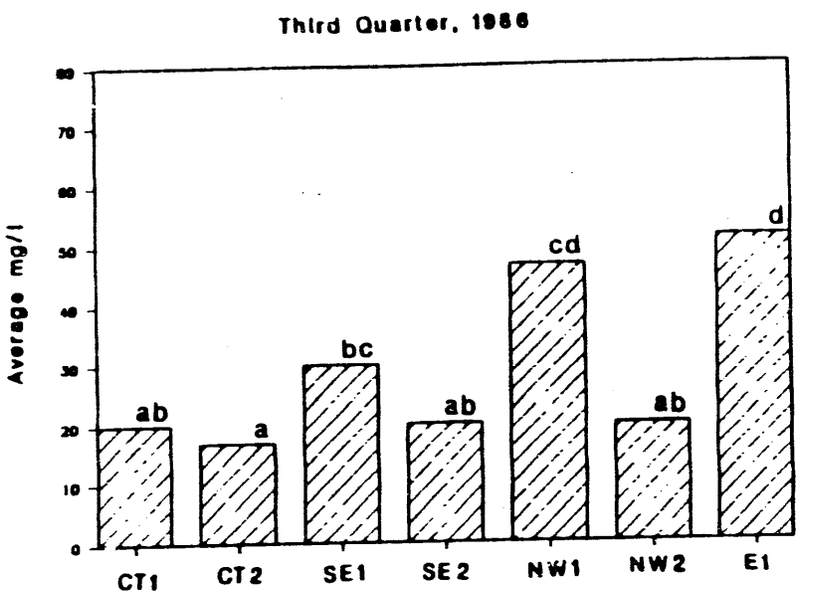
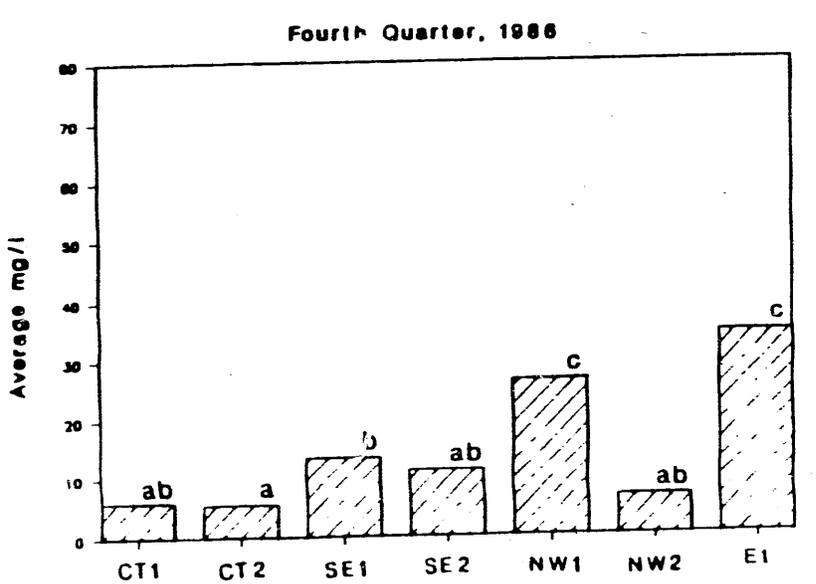


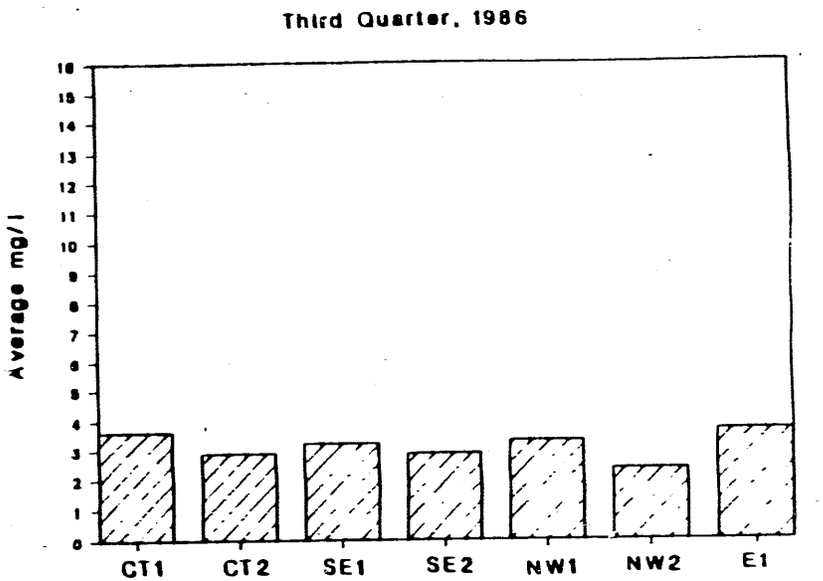
FIGURE 7.5 Chloride concentrations for seven ecological monitoring plots in 1987.

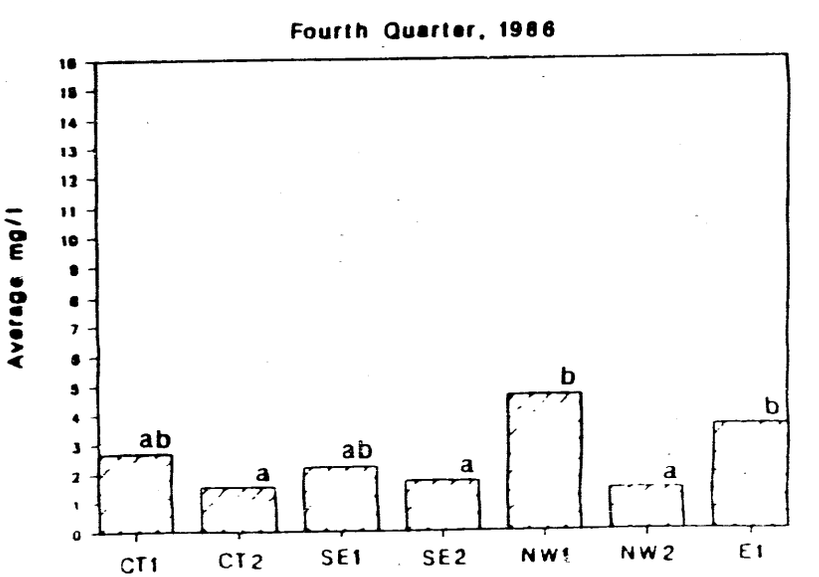
Calcium





Magnesium





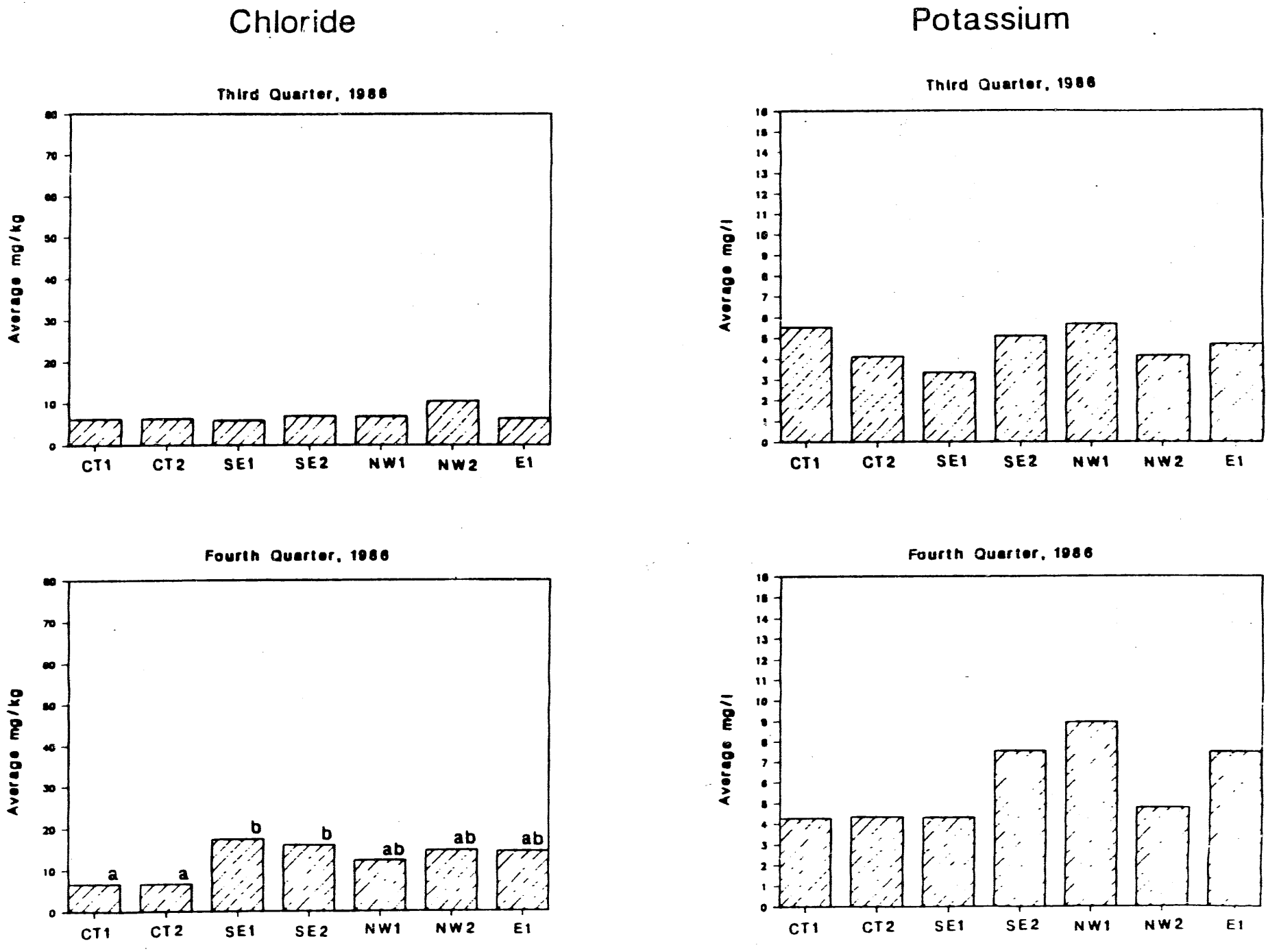


FIGURE 7.3 Chloride and potassium concentrations for seven ecological monitoring plots in 1986.

7.0 SOIL

The soil monitoring subprogram, which has been fully described in previous reports, provides a direct measure of ion concentrations at the soil surface and at two depths (30-45 centimeters and 60-75 centimeters) in the soil profile. The deposition of windblown salts from the salt storage piles or from traffic on caliche-paved roadways on-site could have long-term effects on the stability of the surrounding ecosystem.

Surface soils are collected quarterly from the seven ecological monitoring plots and are analyzed for several soil parameters which may be indicative of the impacts under study. The following patterns are of interest in determining potential cause and effect relationships in the soil ecosystem:

- Consistent increases in concentrations of specific ions over time
- Seasonal variation in soil parameters which are consistent in all plots
- Identification of patterns which may indicate interactions among components of the soil ecosystem or of the total ecosystem.

Data collected in the third and fourth quarters of 1986 and in the first, second, third, and fourth quarters of 1987 are discussed in this report. Plot averages for each parameter measured quarterly are illustrated in Figures 7.1 through 7.11. The data are included in Appendices 7-A and 7-B. Data collected since the first quarter of 1985 are discussed in the Cumulative Data section. Subsurface samples are collected annually and the results are reported biennially.

7.1 METHODS

The methods of sample collection and laboratory analysis have been described in previous reports (Reith et al., 1985; Fischer et al., 1985). Samples are analyzed for pH, electrical conductivity, chloride, calcium, magnesium, potassium and sodium.

Analytical results are evaluated statistically using a one-way analysis of variance (ANOVA) procedure. All data except pH values are lognormally transformed prior to analysis to allow the use of parametric statistics. When the analysis of variance indicates that a parameter varies significantly among plots ($p<0.05$), a Student-Newman-Keuls (SNK) test is calculated to identify homogenous groups.

7.2 RESULTS AND DISCUSSION

For the six sampling periods included in this report, soil ion concentrations remain low. Fifteen to twenty centimeters of rainfall was measured during each of the last three quarters of 1986 and during the second and third quarter of 1987 (Figure 7.12). The amount and intensity of precipitation at the site determines whether accumulated surface salts are flushed through the soil profile or remain at the soil surface. Analytical results for quarterly samples are illustrated in Figures 7.1 through 7.11.

Third Quarter, 1986. Electrical conductivity and calcium values are elevated in near-field plots over those measured in far-field or control plots. This is a pattern which is typical of the surface soils. Average pH values are less than neutral (pH of 7) in all plots, but pH values are significantly lower in control and far-field plots than in near-field plots.

Fourth Quarter, 1986. Average pH values rose slightly over the last quarter, but follow the same pattern between plots as in the previous quarter. Electrical conductivity, calcium and magnesium are elevated in the near-field plots. Sodium and chloride concentrations vary significantly between plots during this period. Sodium values are highest in CT1 and E1, chloride concentrations are highest in the southeast plots.

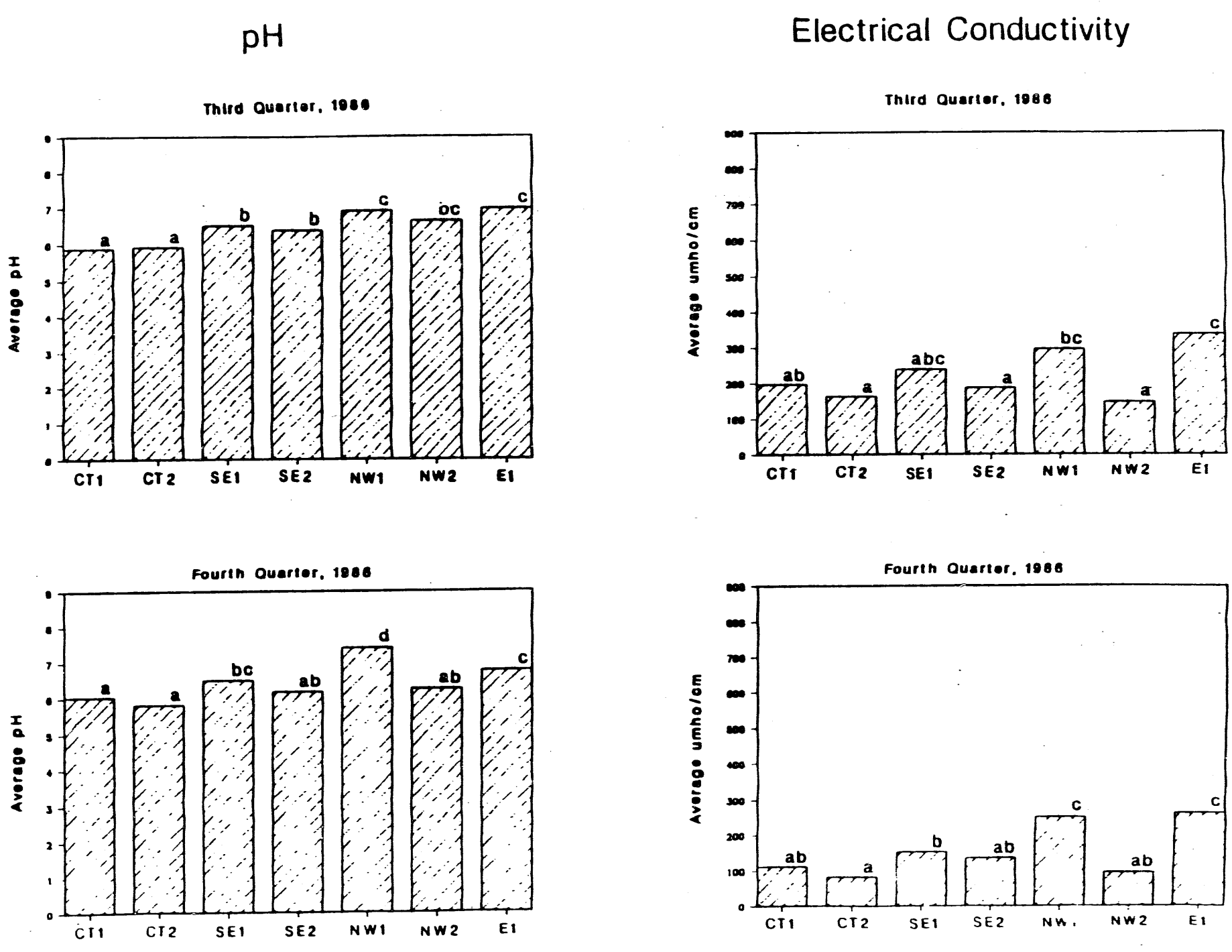


FIGURE 7.1 Electrical conductivity and [illegible] level[illegible]r seven ecological monit[illegible] plots in 1986.

TABLE 6.3

SUMMARY OF SMALL MAMMAL DENSITIES OVER THREE YEARS
(DENSITIES IN INDIVIDUALS PER GRID)
(CONTINUED)

SOUTHERN PLAINS WOODRAT (Neotoma micropus)

PLOT	1985	1986	1987	3-YR AVG
CT-1	0	0	0	0
CT-2	1	4	6	4
NW-2	0	0	0	0
SE-2	1	1	1	1
CTRL PLOTS	1	2	3	2
WIPP PLOTS	1	1	1	1
ALL PLOTS	1	1	2	1

WHITE-FOOTED AND DEER MOUSE (Peromyscus sp.)

PLOT	1985	1986	1987	3-YR AVG
CT-1	0	0	0	0
CT-2	0	0	0	0
NW-2	0	0	0	0
SE-2	0	0	3	1
CTRL PLOTS	0	0	0	0
WIPP PLOTS	0	0	2	1
ALL PLOTS	0	0	1	0

HISPID COTTON RAT (Sigmodon hispidus)

PLOT	1985	1986	1987	3-YR AVG
CT-1	1	0	0	0
CT-2	0	0	0	0
NW-2	0	0	0	0
SE-2	0	0	0	0
CTRL PLOTS	1	0	0	0
WIPP PLOTS	0	0	0	0
ALL PLOTS	0	0	0	0

6.2 CONTINUING PROGRAM

Breeding birds and small nocturnal mammals will continue to be surveyed in 1988 at the locations described in this chapter. After this sampling period, the data will be carefully examined and recommendations will be made for the continued monitoring of these species based on the operational needs of WIPP.

The statistical treatment of mark-and-recapture data is still a rapidly developing field, particularly in light of applications of Bayesian and bootstrap methods. These methods are currently being evaluated for their accuracy and applicability to the existing EMP data base. If a newer method of analysis is found which improves upon the accuracy of the current method, and if this method can be applied to the existing data, it will be adopted and the data base reevaluated.

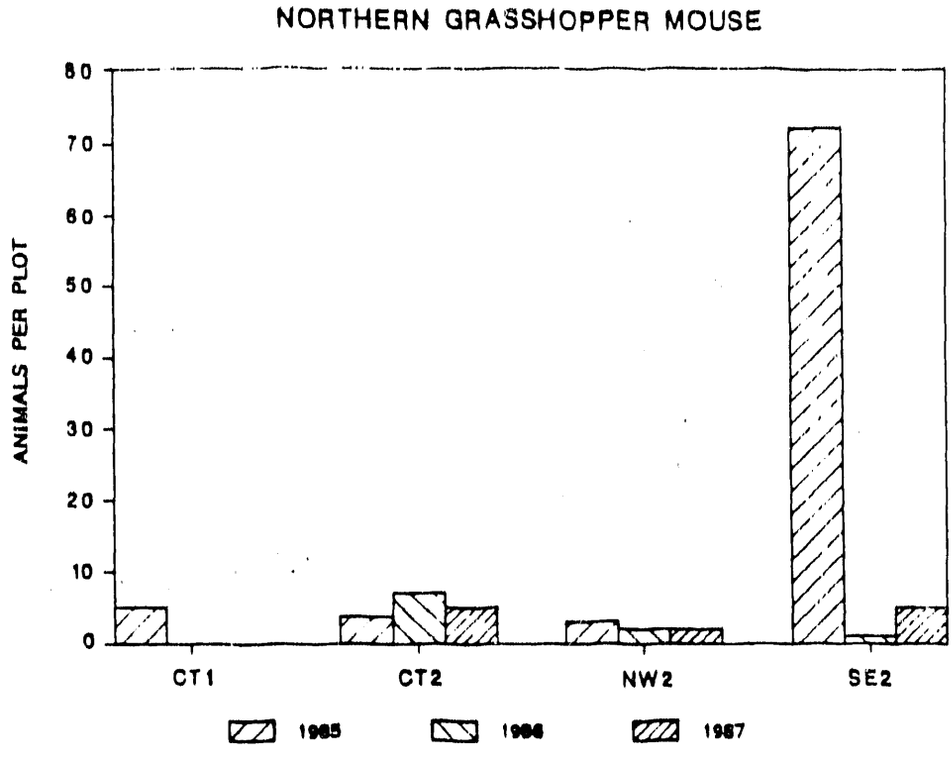


FIGURE 6.7 Population densities for northern grasshopper mice.

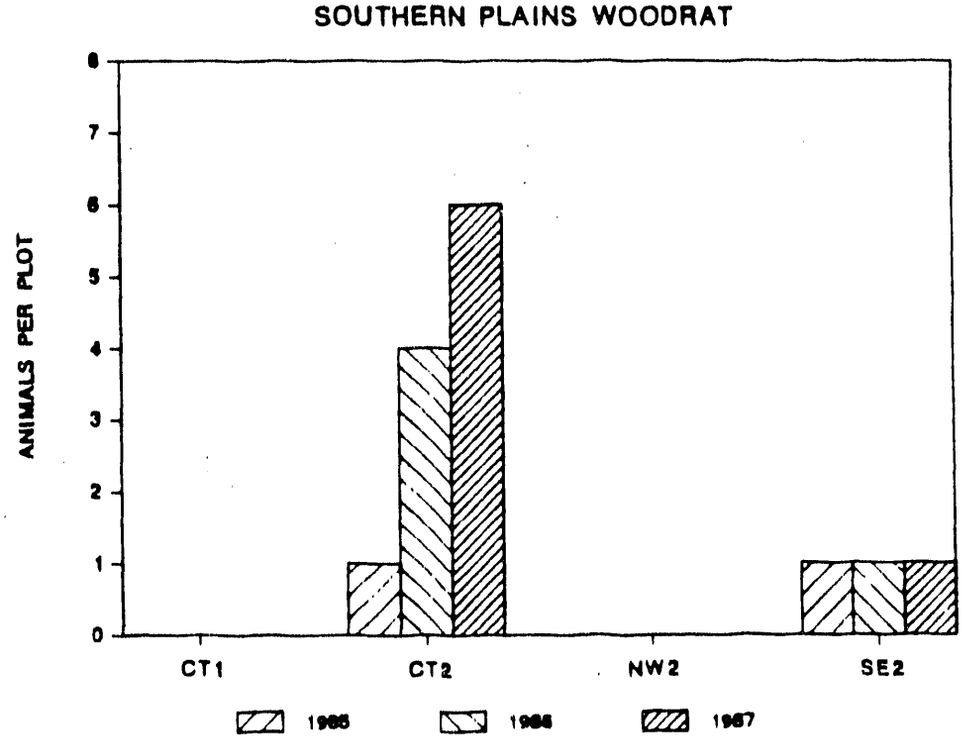


FIGURE 6.8 Population densities for southern plains woodrats.

TABLE 6.3

SUMMARY OF SMALL MAMMAL DENSITIES OVER THREE YEARS (DENSITIES IN INDIVIDUALS PER GRID)

ORD'S KANGAROO RAT (Dipodomys ordii)

PLOT	1985	1986	1987	3-YR AVG
CT-1	13	12	10	12
CT-2	6	8	3	6
NW-2	21	5	10	12
SE-2	35	12	11	19
CTRL PLOTS	10	10	7	9
WIPP PLOTS	28	9	11	16
ALL PLOTS	19	9	9	12

PLAINS POCKET MOUSE (Perognathus flavescens)(1)

PLOT	1985	1986	1987	3-YR AVG
CT-1	99	1	14	38
CT-2	2	0	3	2
NW-2	25	0	4	10
SE-2	6	1	3	3
CTRL PLOTS	51	1	9	20
WIPP PLOTS	16	1	4	7
ALL PLOTS	33	1	6	13

(1)Misidentified as silky pocket mouse (Perognathus flavus) in 1985 and 1986.

NORTHERN GRASSHOPPER MOUSE (Onychomys leucogaster)

PLOT	1985	1986	1987	3-YR AVG
CT-1	5	0	0	2
CT-2	4	7	5	5
NW-2	3	2	2	2
SE-2	72	1	5	26
CTRL PLOTS	4	4	3	3
WIPP PLOTS	38	2	4	14
ALL PLOTS	21	3	3	9

TABLE 5.1

SUMMARY OF SURFACE WATER AND SEDIMENT ANALYSIS - OCTOBER 22-23, 1986

	SURFACE WATER				SEDIMENT			
PARAMETERS	HILL TANK	RED TANK	INDIAN TANK	LAGUNA GRANDE DE LA SAL	HILL TANK	RED TANK	INDIAN TANK	LAGUNA GRANDE DE LA SAL
FIELD								
Temperature (°C)	19	16	17	28	—	—	—	—
pH 7.0	8.2	7.4	7.8	—	—	—	—	
Conductivity (umhos/cm)	140	230	250	30,000	—	—	—	—
GENERAL CHEMISTRY[1]								
Bicarbonate	95	150	120	260	1000	620	760	340
Carbonate	0	0	0	0	0	0	0	0
Chloride	3.1	5.0	2.5	25,000	83	21	11	79,000
Phosphate (total)	0.32	0.38	0.52	0.05	4	2	4	<1
Total Dissolved Solids (Filterable)	110	180	100	320,000	—	—	—	—
Total Suspended Solids (Nonfilterable)	47	110	120	850	—	—	—	—
Moisture Content (%)	—	—	—	—	35.9	30.0	32.3	24.2
Sulfate	4	4	3	18,000	11	40	19	33,000
Total Organic Carbon (TOC)	6	5	8	40	—	—	—	—
Total Organic Halogen (TOX)	0.09	0.13	0.10	12	—	—	—	—
METALS[1]								
Aluminum	0.1	0.2	0.2	<10	16,000	3,500	23,000	670
Arsenic	<0.005	<0.005	<0.005	<0.005	11	2.8	19	2.7
Barium	0.10	0.15	0.12	<0.5	300	98	210	120
Calcium	21	36	25	790	(4)	(4)	(4)	(4)
Cesium	<0.1	<0.1	<0.1	<0.1	18	<10	18	18
Chromium	0.01	0.02	0.01	2.3	14	5.2	24	3.2
Lithium	<0.01	<0.01	<0.01	1.7	17	5.0	37	13
Magnesium	4.7	3.2	5.6	10,000	(4)	(4)	(4)	(4)
Potassium	6	12	5.7	29,000	(4)	(4)	(4)	(4)
Selenium	<0.005	<0.005	<0.005	0.047	<0.5	<0.5	<0.5	<0.5
Sodium	1.4	2.4	0.1	93,000	(4)	(4)	(4)	(4)
Strontium	0.07	0.09	0.03	3.6	57	30	12	2,000

TABLE 5.1

SUMMARY OF SURFACE WATER AND SEDIMENT ANALYSIS - OCTOBER 22-23, 1986
(CONTINUED)

	SURFACE WATER				SEDIMENT			
PARAMETERS	HILL TANK	RED TANK	INDIAN TANK	LAGUNA GRANDE DE LA SAL	HILL TANK	RED TANK	INDIAN TANK	LAGUNA GRANDE DE LA SAL
ORGANICS(2)(3)								
Volatile Organics								
Acetone	<10	96	<10	14(5)	<100	<100	1,000	<100
1,2-Dicloroethane	<5.0	26	<5.0	<5.0	<50	<50	<50	<50
Methylene Chloride	<10	<10	<10	16(5)	<100	<100	120	<100
Toluene	<5.0	15	<5.0	<5.0	61	67	<50	<50
Semi-Volatile Organics								
Bis(2-ethylhexyl)phthalate	22	<10	<10	<10	<330	<330	<330	<330
N-Nitrosodiphenylamine (Diphenylamine)	<10	<10	<10	<10	<330	<330	1,000	<330
Pesticides/PCBs		ND	ND	ND	ND	ND	ND	ND

1) All units, unless indicated otherwise, are in mg/l or parts per million (ppm) for surface water and mg/kg or ppm for sediments.
2) All units, unless indicated otherwise, are in ug/l or parts per billion (ppb) for surface water and ug/kg or ppb for sediments.
3) Only those organic compounds which were at or above the detection limits are included in this table.
4) No data available due to incorrect laboratory procedure.
5) Concentration obtained from the northern sampling location of Laguna Grande de la Sal.
– = Not Tested.

where:

N is the population estimate
I is the number of trap nights
T_j is the number of tagged animals in the population on the jth night
C_j is the number of captures made on the jth night
R_j is the number of recaptures made on the jth night.

Since this formula often gives slightly different estimates of population size than the previous method, the 1985 and 1986 data were recalculated using this formula. The three years' data are presented in Appendix 6-B. A summary of these data are presented in Table 6.3. In the cases where no recaptures were made, the sum of the number of marked animals and captures was used as the estimate.

In 1985, Ord's kangaroo rats (Figure 6.5) exhibited population densities in the WIPP grids which were two to three times those of CT1 and well above any of the three CT2 grids. The density of this species in SE2 has since declined to a level near that of CT1. In NW2, however, this species declined sharply in 1986, but apparently recovered to the levels of the other grids in 1987.

Plains pocket mice (misidentified in 1985 and 1986 as silky pocket mice, Perognathus flavus) were very abundant in CT1 and NW2 in 1985, but nearly disappeared from all grids in 1986 (Figure 6.6). The 1987 data indicate that this species is increasing again in all grids, with a notably rapid increase in CT1.

Northern grasshopper mice were extremely abundant in SE2 during the 1985 survey period and were common in other grids (Figure 6.7). As with the Plains pocket mouse, this species exhibited a dramatic decline in the 1986 data, disappearing completely in CT1. In 1987, this species showed a prominent recovery in SE2, but not in the other grids.

Southern plains woodrats have yet to be recorded in CT1 and NW2 (Figure 6.8). The trap record for this species has been very consistent in SE2. This species may be relatively abundant in the new CT2 grid. Also of interest in the 1987 trap record is the capture of three white-footed mice in SE2.

The overall effects of the WIPP facility and its construction are, to date, difficult to assess. Although differences in the WIPP and control grids have been detected in these data, none can yet be identified as being indicative of possible long-term environmental degradation. Of interest in these data are the broad, year-to-year fluctuations in some populations which were also observed in the WIPP Biology Program (Paul Polechla, personal communication). With such naturally dynamic populations, the effects of the WIPP facility may not be immediately detectable in the structure of the mammal community, but may be inferred by the community's ability to recover from a natural "crash." Differential recovery rates in WIPP and control grids will be watched for in the future.

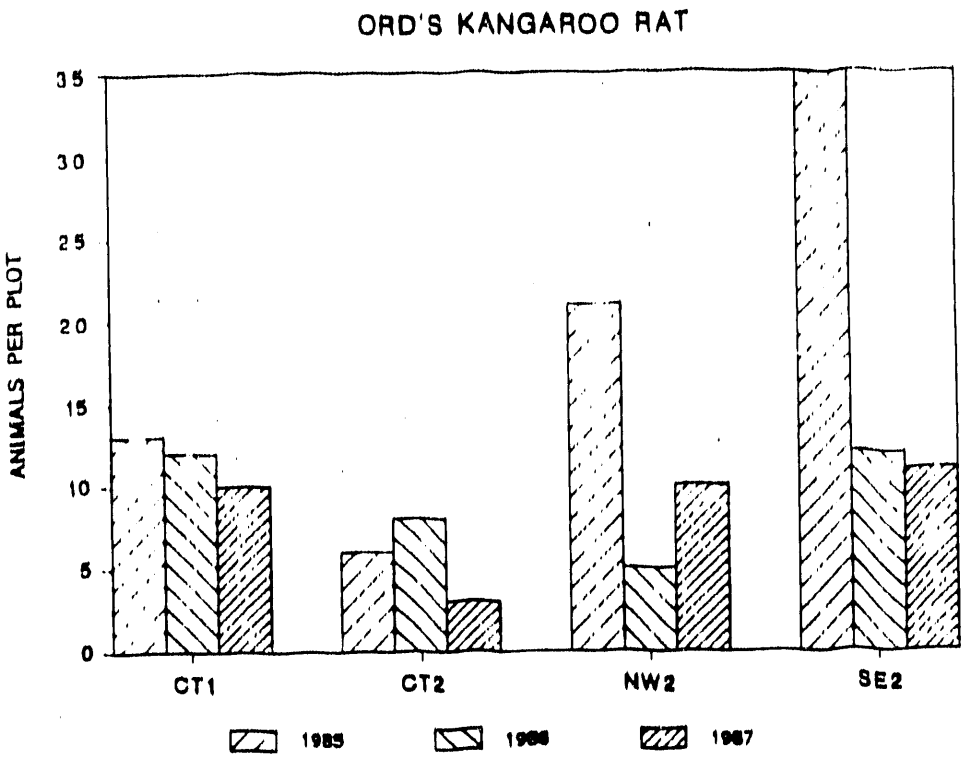


FIGURE 6.5 Population densities for Ord's kangaroo rats.

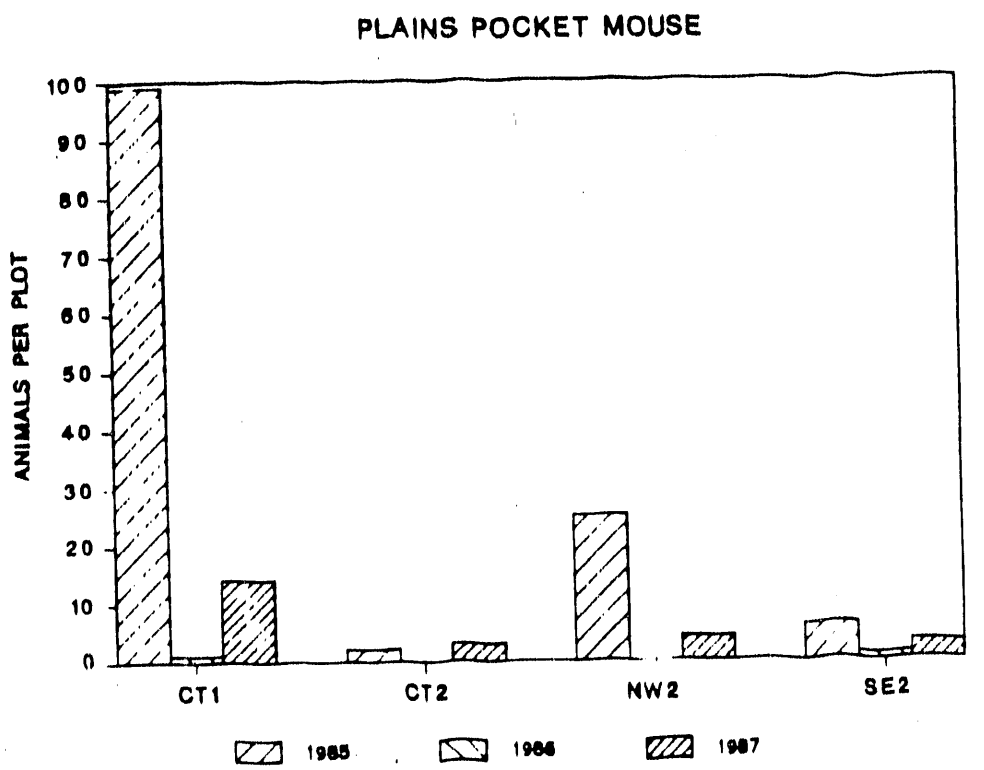


FIGURE 6.6 Population densities for plains pocket mice.

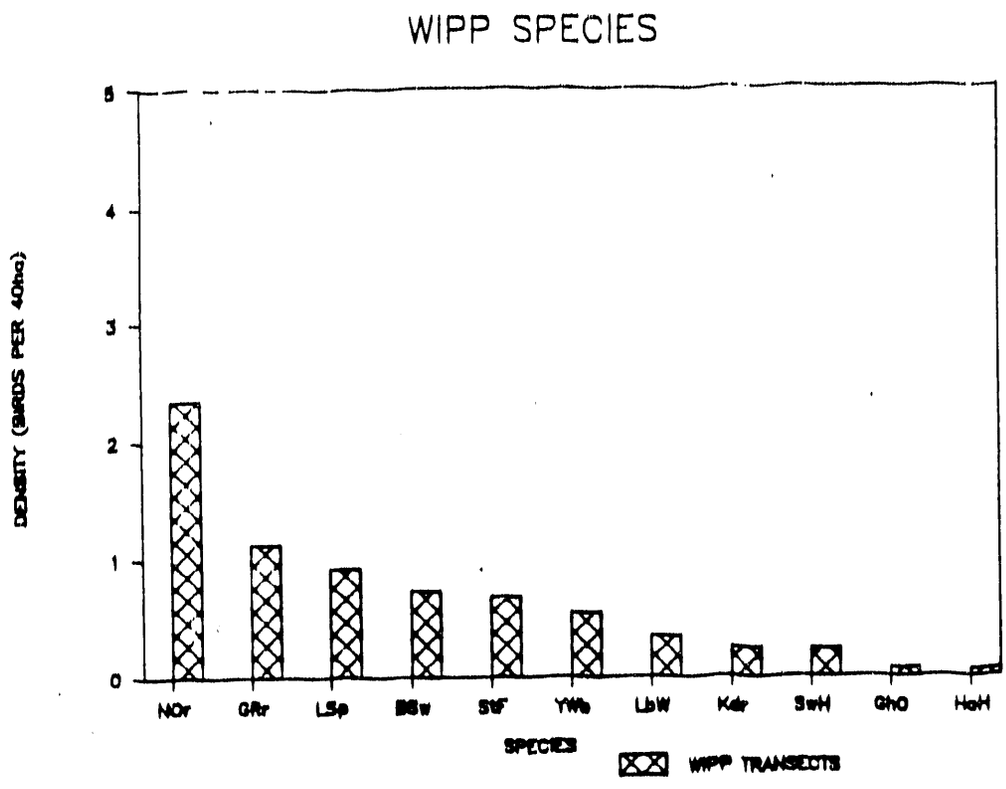


FIGURE 6.4 Densities of breeding bird (WIPP species) on the WIPP transects (see Table 6.1 for species abbreviations).

TABLE 6.2

PROPORTIONAL SIMILARITY INDICES FOR EMLEN TRANSECT DATA COMPARING CONTROL AND WIPP TRANSECTS OVER FOUR YEARS

YEAR	PROPORTIONAL SIMILARITY
1984	0.34
1985	0.65
1986	0.61
1987	0.72
SIMILARITY BETWEEN FOUR-YEAR AVERAGES	0.72

Small Mammal Surveys. Densities of small nocturnal mammals were measured for the third consecutive year in 1987 using the mark-and-recapture technique described in Fischer et al. (1985). As in the previous years, four trap grids were sampled (Figure 6.1), two immediately adjacent to the WIPP facility (NW2 and SE2) which act as indicators of facility-related impacts, and two control grids (CT1 and CT2). which are located outside of the expected area of impact.

Three of the four grids were the same as used in 1985 and 1986. The fourth, CT2. was relocated approximately 300 meters south of the 1986 location (see Chapter 1). Since the CT2 grid has been relocated each year, comparisons between years for this location cannot be made.

As in previous years, the grids were trapped in pairs, one WIPP and one control. Each pair was trapped in two sessions of three trap nights, the first to mark animals and the second to record recaptures. Full-moon nights were avoided. The NW2 and CT2 grids were trapped between July 8 and 23. The SE2 and CT1 grids were initially trapped between August 4 and August 7; however, due to poor trap success during this marking session, a second marking session was performed on August 18 and 19, before the recapture session occurred between September 1 and 3.

In the 1987 program, a step was taken to alleviate the past problem of low numbers of marked animals of some species after the first trap session. This year, new captures were marked in both trap sessions. The results of this modification were good, as indicated by the record for Ord's kangaroo rats in SE2 where only one animal had been marked during the first session, but ten had been marked by the end of the second and the proportion of recaptures reached 100 percent.

This modification in marking methodology necessitated a modification of the method for calculating the density estimate. Both the previous and the modified methodologies conform to the repeated mark/recapture method described by Tanner (1978). A standard formula for estimating density from this method, first published by Schnabel (1938), is:

$$N = \frac{T_1C_1 + T_2C_2 + \ldots + T_iC_i}{R_1 + R_2 + \ldots + R_i}$$

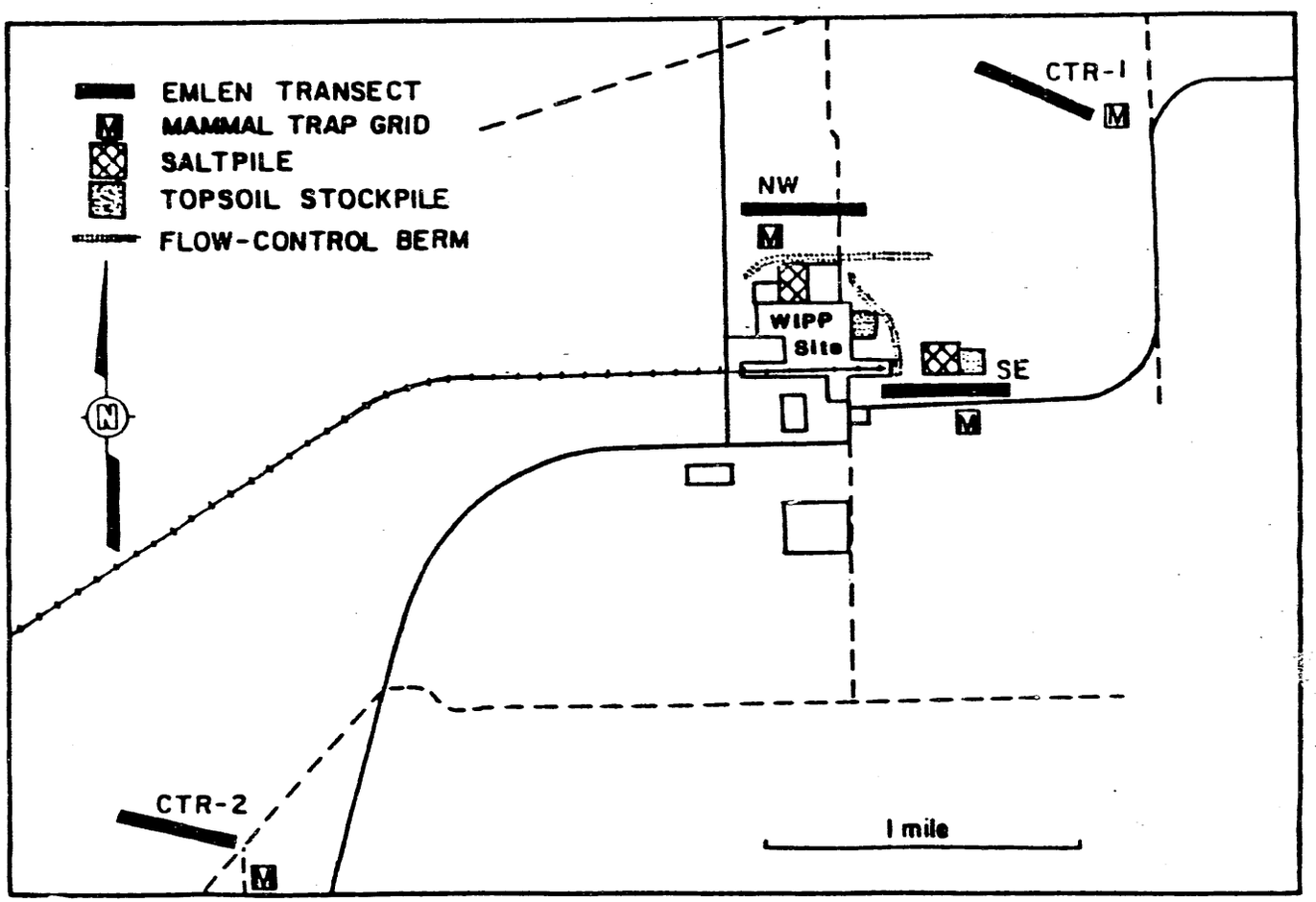


FIGURE 6.1 Locations of Emlen transects and mammal trap grids.

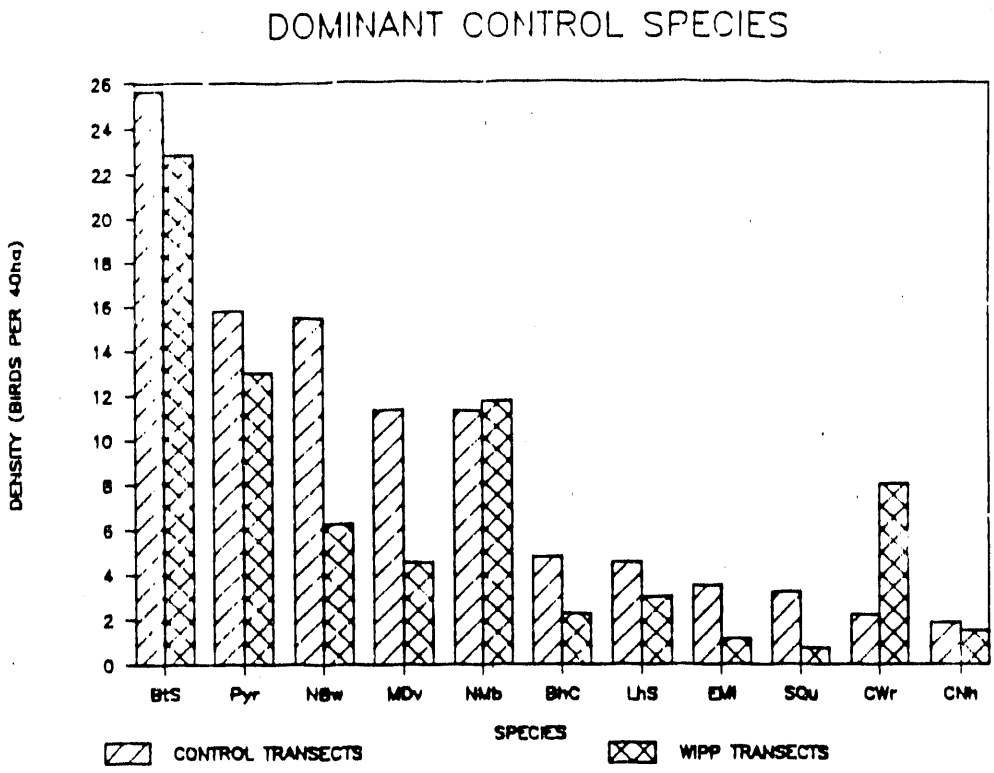


FIGURE 6.2 Comparison of breeding bird densities (dominant control species) between Control and WIPP transects (see Table 6.1 for species abbreviations).

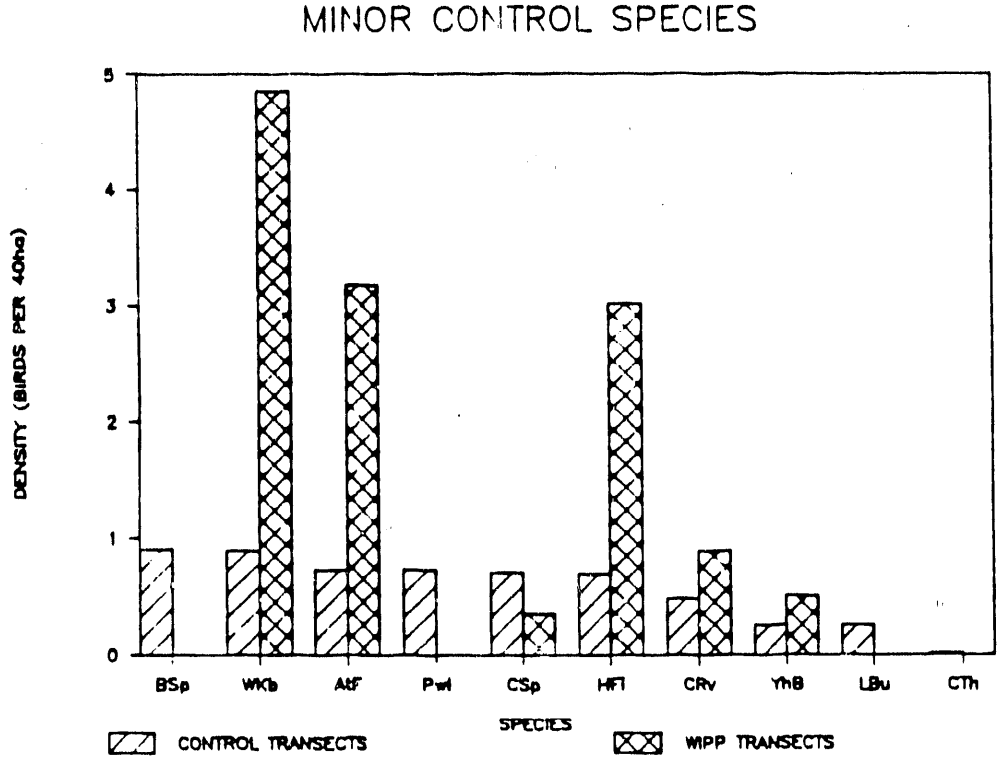


FIGURE 6.3 Comparison of breeding bird densities (minor control species) between Control and WIPP transects (see Table 6.1 for species abbreviations).

TABLE 6.1

SUMMARY OF BREEDING BIRD DENSITIES (INDIVIDUALS PER 40 HECTARES) IN FOUR EMLEN TRANSACTS OVER FOUR YEARS OF SAMPLING (NAME ABBREVIATION IN PARENTHESES)

	CONTROL TRANSECTS					WIPP TRANSECTS				
SPECIES	1984	1985	1986	1987	ALL YRS.	1984	1985	1986	1987	ALL YRS.
Dominant Control Species:										
Black-throated Sparrow (BtS)	7.3	24.9	21.5	48.8	25.6	29.1	19.0	11.8	31.6	22.9
Pyrrhuloxia (Pyr)	4.1	17.3	16.1	25.8	15.8	5.5	8.7	16.5	21.5	13.0
Northern Bobwhite (NBw)	29.5	3.6	8.7	20.1	15.5	0.5	2.1	8.1	14.4	6.3
Mourning Dove (MDv)	6.8	23.6	9.4	5.7	11.4	4.1	3.5	0.6	10.0	4.5
Northern Mockingbird (NMb)	0.5	15.4	15.1	14.4	11.3	4.6	16.0	12.9	13.6	11.8
Brown-headed Cowbird (BhC)	0.9	3.7	5.9	8.6	4.8		2.7	0.6	5.7	2.2
Loggerhead Shrike (LhS)	3.2		9.4	5.7	4.6	1.8	1.9	2.5	5.7	3.0
Eastern Meadowlark (EMl)	0.9	0.1	4.4	8.6	3.5	0.5	0.1	1.7	2.2	1.1
Scaled Quail (SQu)	0.5	7.1	3.0	2.2	3.2		1.2	0.2	1.4	0.7
Cactus Wren (CWr)	0.9	1.6	2.0	4.3	2.2	3.2	2.4	7.9	18.7	8.0
Common Nighthawk	0.5		3.3	3.6	1.8	2.7	1.8		1.4	1.5
Minor Control Species:										
Brewer's Sparrow (BSp)		0.9	2.7		0.9					
Western Kingbird (WKb)		0.7		2.9	0.9	2.3	5.8	3.5	7.9	4.9
Ash-throated Flycatcher (AtF)				2.9	0.7	2.7		4.3	5.7	3.2
Poorwill (Pwl)				2.9	0.7					
Cassin's Sparrow (CSp)	0.5	0.2	2.2		0.7	0.9	0.5			0.4
House Finch (HFi)		2.0	0.8		0.7			0.6	11.5	3.0
Chihuahuan Raven (CRv)	1.4		0.6		0.5	1.8	1.1		0.7	0.9
Yellow-headed Blackbird (YhB)		1.0			0.3		2.0		0.5	
Lark Bunting (LBu)		1.0			0.3					
Crissal Thrasher (CTh)		0.1			0.0					
WIPP Species:										
Northern Oriole (NOr)						0.9	0.5	5.1	2.9	2.3
Greater Roadrunner (GRr)						1.8		2.7		1.1
Lark Sparrow (LSp)						3.7				0.9
Barn Swallow (BSw)									2.9	0.7
Scissor-Tailed Flycatcher (StF)						2.7				0.7
Yellow Warbler (YWb)								2.2		0.5
Ladder-backed Woodpecker (LbW)						1.4				0.3
Killdeer (Kdr)								0.6	0.4	0.2
Great-horned Owl (GhO)							0.3			0.1
Harris' Hawk (HaH)								0.2		0.1
NUMBER OF SPECIES	13	16	15	14	21	18	18	19	18	28
TOTAL DENSITY (per 40 Ha)	56.7	102.9	104.6	156.5	105.2	69.8	69.5	82.3	158.2	94.9

Eleven species have thus far been recorded only in the WIPP transects. Figure 6.4 shows the average densities of these species over the four years of survey. The occurrence of the great-horned owl, Swainson's hawk, and Harris' hawk on this list must be considered a chance result, since they are well documented throughout the area (Bednarz and Hayden, 1988).

The total density of breeding birds in 1987 was significantly higher than the previous three years and has been increasing over this period in both the control and WIPP transects. In the control transects, relatively high densities were recorded in 1987 for pyrrhuloxias, black-throated sparrows, eastern meadowlarks, and brown-headed cowbirds. In the WIPP transects, high densities were recorded for northern bobwhites, mourning doves, cactus wrens, pyrrhuloxias, house finches, and black-throated sparrows.

Although more species have been recorded in the WIPP transects (19 as opposed to 14 in the controls), the total densities are approximately equivalent in both transect types. Similarly, for the four year averages, the number of species is greater in the WIPP transects (29 as opposed 21), but the total density is slightly less, probably reflecting habitat loss near the facility.

Proportional similarity indices (Pielou, 1977) were calculated for comparisons between the control and WIPP transects for each of the four years and for the four-year averages (Table 6.2). In general, the similarity between the control and WIPP transects has increased over the period of record from 0.34 in 1984 to 0.72 in 1987 (the index ranges from zero, complete dissimilarity, to one, identical communities). For the four-year averages, the index of similarity between the control and WIPP transects is relatively high (0.72), indicating WIPP has had a minor effect on bird populations in the Los Medanos Area.

The results of the breeding bird surveys thus far indicate that the construction of the WIPP facility has affected the avifauna in the area around the site, although not in a way which can be judged detrimental nor even unexpected. Some species are less dense in the area of the facility, probably the result of lost habitat, while others have apparently benefited from activities at the site, and increased in numbers. The 1987 data has shown a greater similarity between the control and WIPP transects than in any of the previous years, possibly indicating a recovery of the avifauna near the facility as the surface construction activities decrease and the birds become more acclimated to the activities and disturbances.

Concentrations of metals in the tank sediments were generally several orders of magnitude greater than metal concentrations in the water. The common occurrence of caliche in the area is the primary source for the high calcium concentrations in the tank sediments. Several metals, including calcium and barium, are present in greater concentrations in the sediment of Laguna Grande de la Sal - Laguna Tres than in its water. Other metals from Laguna Grande de la Sal - Laguna Tres, though, do not show large differences between their water and sediment concentrations. These include magnesium, potassium, sodium, and selenium.

Extensive organic testing was conducted on the water sediment samples collected during October, 1986, and November, 1987. The testing consisted of analyses for volatile organic compounds (VOCs), semi-volatile organics, and pesticide/PCB compounds. A limited analytical program composed primarily of VOC analysis was conducted during the June, 1987, sampling effort. The data from the sampling programs (shown in Tables 5.1, 5.2, and 5.3) does not indicate any clear pattern of organic contamination. Only a few contaminants were detected during each sampling program with no consistency shown between the contaminants and the sampling events. Acetone was the most common organic, and its presence in these samples is questionable. Therefore, based on the analytical results it appears that organic contamination is not a current concern at the nonradiological monitoring locations.

5.3 CONTINUING PROGRAM

Sampling and analysis of ground water from 26 wells in the WIPP area will continue in the Water Quality Sampling Program to monitor for WIPP-related impacts to ground water quality. Monitoring of surface water bodies will continue in 1988; however, with the completion of surface construction activities and the beginning of the operational phase of the project, the number of locations and frequency of sampling will be reduced.

TABLE 5.4

SURFACE WATER AND SEDIMENT ANALYTICAL DATA COMPARISONS FOR GENERAL CHEMISTRY OCTOBER 1986, JUNE 1987, AND NOVEMBER 1987

DATE OF SAMPLING	SURFACE WATER[1]				SEDIMENT[2]			
	HILL TANK	RED TANK	INDIAN TANK	LAGUNA GRANDE	HILL TANK	RED TANK	INDIAN TANK	LAGUNA GRANDE
				BICARBONATE				
Oct. 1986	95	150	120	280	1,000	620	760	340
Jun. 1987	130	180	93	270	980	610	620	290
Nov. 1987	160	180	130	380	1,100	790	570	180
				CHLORIDE				
Oct. 1986	3.1	5.0	2.5	25,000	83	21	11	79,000
Jun. 1987	6.0	5.0	3.2	190,000	74	33	83	45,000
Nov. 1987	5	8.1	23	192,000	21	12	22	154,000
				TOTAL ORGANIC CARBON				
Oct. 1986	6	5	8	12	—	—	—	—
Jun. 1987	7	7	11	46	14,000	3,000	7,000	3,900
Nov. 1987	8	16	14	19	26,000	9,600	5,600	1,400
				SULFATE				
Oct. 1986	4	4	3	18,000	11	40	19	33,000
Jun. 1987	12	6	7	15,000	70	73	110	32,000
Nov. 1987	3	9	1	21,500	<10	<10	<10	34,300
			TOTAL SUSPENDED SOLIDS				MOISTURE CONTENT (%)	
Oct. 1986	47	110	120	850	35.9	30.0	32.3	24.2
Jun. 1987	53	150	150	850	45.5	23.2	29.4	28.8
Nov. 1987	22	65	160	1,600	30.2	29.9	30.1	26.9
			TOTAL DISSOLVED SOLIDS					
Oct. 1986	110	180	100	320,000	NA	NA	NA	NA
Jun. 1987	220	220	150	350,000	NA	NA	NA	NA
Nov. 1987	140	240	210	349,000	NA	NA	NA	

[1] In mg/l or parts per million.
[2] In mg/kg or parts per million.

— = Not tested.
NA = Not applicable.

TABLE 5.5

SURFACE WATER AND SEDIMENT ANALYTICAL DATA COMPARISONS FOR METALS
OCTOBER 1986, JUNE 1987, AND NOVEMBER 1987

DATE OF SAMPLING	SURFACE WATER[1]				SEDIMENT[2]			
	HILL TANK	RED TANK	INDIAN TANK	LAGUNA GRANDE	HILL TANK	RED TANK	INDIAN TANK	LAGUNA GRANDE
				ARSENIC				
Oct. 1986	<0.005	<0.005	<0.005	<0.005	11	2.8	19	2.7
Jun. 1987	<0.005	<0.005	0.005	<0.010	8.2	3.9	8.2	4.2
Nov. 1987	<0.005	0.006	0.005	<0.036	1.6	1.2	1.1	1.4
				CALCIUM				
Oct. 1986	21	36	25	790	(3)	(3)	(3)	(3)
Jun. 1987	33	36	18	930	62,000	29,000	36,000	200,000
Nov. 1987	34	32	32	270	58,800	45,000	20,600	95,000
				MAGNESIUM				
Oct. 1986	4.7	3.2	5.6	10,000	(3)	(3)	(3)	(3)
Jun. 1987	4.5	4.4	4.1	9,800	14,000	4,300	31,000	9,600
Nov. 1987	5.9	8.2	7.7	12,500	13,000	5,600	18,400	5,700
				POTASSIUM				
Oct. 1986	8	12	5.7	29,000	(3)	(3)	(3)	(3)
Jun. 1987	13	11	9.4	28,000	4,500	1,200	2,200	8,300
Nov. 1987	17	20	9.2	37,500	6,400	3,400	[illegible]	24,600
				SODIUM				
Oct. 1986	1.4	2.4	0.1	93,000	(3)	(3)	(3)	(3)
Jun. 1987	2.0	3.7	0.03	100,000	200	62	100	32,000
Nov. 1987	2.4	8.7	1.2	101,000	69	85	60	214,000
				STRONTIUM				
Oct. 1986	0.07	0.09	0.03	3.6	57	30	12	2,000
Jun. 1987	0.09	0.07	0.02	41	110	29	40	850
Nov. 1987	0.10	0.13	0.04	17	140	82	32	1,400

(1) In mg/l or parts per million.
(2) In mg/kg or parts per million.
(3) No data available due to incorrect laboratory procedures.

TABLE 5.2

SUMMARY OF SURFACE WATER AND SEDIMENT ANALYSIS - JUNE 23-25, 1987

	SURFACE WATER						SEDIMENT					
PARAMETERS	HILL TANK	RED TANK	RED TANK DUPLICATE[1]	INDIAN TANK	LAGUNA GRANDE DE LA SAL	BLANK[2]	HILL TANK	RED TANK	RED TANK DUPLICATE[1]	INDIAN TANK	LAGUNA GRANDE DE LA SAL	BLANK[2]
FIELD												
Temperature (°C)	27	27	27	29	27	—	—	—	—	—	—	—
pH 8.2	8.4	8.4	9.6	7.7	—	—	—	—	—	—	—	
Conductivity (umhos/cm)	210	260	260	53	—	—	—	—	—	—	—	—
GENERAL CHEMISTRY[3]												
Bicarbonate	130	180	150	93	270	1.0	960	610	600	620	290	2.0
Carbonate	0	0	3	0	0	0	0	0	0	12	0	0
Chloride	6.0	5.0	5.0	3.2	190,000	3.9	74	33	44	83	45,000	2.2
Nitrate	<0.1	<0.1	<0.1	0.3	2.0	<0.1	<1	<1	<1	2	3	<0.1
Phosphate (total)	0.51	0.42	0.38	0.61	0.02	0.02	<1	<1	<1	<1	<1	<0.01
Total Dissolved Solids	220	220	220	150	350,000	19	—	—	—	—	—	IS[6]
Total Suspended Solids	53	150	61	150	850	23	—	—	—	—	—	IS
Moisture Content %	—	—	—	—	—	—	45.5	23.2	22.8	29.4	28.8	—
Sulfate	12	6	8	7	15,000	<1	70	73	67	110	32,000	15
Total Organic Carbon	7	7	7	11	46	63	14,000	3,000	2,800	7,000	3,900	60
METALS[3]												
Arsenic	<0.005	<0.005	<0.005	<0.005	0.010	<0.005	8.2	3.9	2.6	8.2	4.2	<0.005
Calcium	33	36	37	18	930	0.2	62,000	29,000	32,000	36,000	200,000	0.1
Magnesium	4.5	4.4	4.5	4.1	9,800	<0.1	14,000	4,300	4,100	31,000	9,600	<0.1
Potassium	13	11	11	9.4	28,000	0.05	4,500	1,200	1,200	2,200	8,300	<0.01
Sodium	2.0	3.7	4.3	0.03	100,000	0.4	200	62	53	100	32,000	0.2
Strontium	0.09	0.07	0.07	0.02	41	0.02	110	29	33	40	850	<0.01
ORGANICS[4][5]												
Volatile Organics							—	—	—	ND	—	—
Acetone[6]	<10	<10	<10	26	89	24						
Semi-Volatile Organics	—	—	—	—	—	—	—	—	—	ND	—	—

(1)Designated "Coyote Tank."
(2)Designated "Coyote Well."
(3)All units, unless indicated otherwise, are in mg/l or parts per million [ppm] for surface water and mg/kg or ppm for sediments.
(4)All units, unless indicated otherwise, are in ug/l or parts per billion [ppm] for surface water and ug/kg or ppb for sediments.
(5)For the organics, only those compounds with concentrations at or above the detection limits are included in this table.
(6)The indicated compound is a common laboratory contaminant. Results should be considered suspect
— = Not Tested.
IS = Insufficient Sample.
ND = Not detected.

TABLE 5.3

SUMMARY OF SURFACE WATER AND SEDIMENT ANALYSES - NOVEMBER 10-12, 1987

	SURFACE WATER						SEDIMENT					
PARAMETERS	HILL TANK	HILL TANK DUPLICATE	RED TANK	INDIAN LAGUNA GRANDE TANK	DE LA SAL	BLANK	HILL TANK	HILL TANK DUPLICATE	RED TANK	INDIAN LAGUNA GRANDE TANK	DE LA SAL	BLANK
ELD												
Temperature °C	14	14	11	13	11*	23	—	—	—	—	—	—
pH	7.8	8.0	8.4	7.0	7.0*	6.5	—	—	—	—	—	—
Conductivity umhos/cm	230	230	260	200	>10,000*	1.6	—	—	—	—	—	—
NERAL CHEMISTRY[3]												
Bicarbonate	160	160	180	130	380	2.5	1,100	1,100	790	570	180	3.7
Carbonate	0	1	0	13	0	0	0	0	0	0	0	0
Chloride	5	4.9	8.1	23	192,000	<0.2	25	21	12	22	154,000	<0.2
Phosphate (total)	0.10	0.10	0.34	0.77	0.06	0.02	410	550	150	210	2.6	0.01
Total Dissolved Solids	140	140	240	210	349,000	<10	—	—	—	—	—	<10
Total Suspended Solids	22	24	65	160	1,600	<4	—	—	—	—	—	<4
Moisture Content	—	—	—	—	—	—	30.4	30.2	29.9	30.1	26.9	—
Sulfate	3	3	9	1	21,500	<1	<10	<10	<10	<10	34,300	<1
Total Organic Carbon	8	8	16	14	19	2	24,000	26,000	9,600	5,600	1,400	10
Total Organic Halogen	<0.05	<0.05	<0.05	<0.05	11	<0.05	<0.05	<0.05	<0.05	3.0	11	—
TALS[3]												
Arsenic	<0.005	<0.005	0.006	<0.005	0.036	<0.005	1.6	1.6	1.2	1.1	1.4	<0.005
Barium	0.19	0.19	0.23	0.16	<0.5	<0.005	360	360	190	98	61	<0.005
Calcium	34	34	32	32	270	0.06	63,200	58,800	45,000	20,500	95,000	0.08
Cesium	0.16	0.02	0.07	0.10	1.2	<0.01	90	13	4.5	4.3	15	0.05
Chromium	<0.01	<0.01	<0.01	<0.01	2.2	<0.01	20	19	12	15	<10	<0.01
Lithium	<0.01	<0.01	<0.01	<0.01	2.3	<0.01	23	22	12	24	6.1	<0.01
Magnesium	5.9	5.9	8.2	7.7	12,500	<0.05	13,200	13,000	5,600	18,400	5,700	0.31
Potassium	17	17	20	9.2	37,500	<0.4	6,600	6,400	3,400	2,600	24,600	1.0
Selenium	<0.005	<0.005	<0.005	<0.005	3.1	<0.005	<0.7	<0.7	<0.7	<0.7	0.8	<0.005
Sodium	2.4	2.3	8.7	1.2	101,000	<0.4	81	69	85	60	214,000	1.2
Strontium	0.10	0.10	0.13	0.04	17	<0.01	160	140	82	32	1,400	<0.01
Zinc	<0.01	<0.01	<0.01	<0.01	<1	<0.01	81	77	36	29	12	<0.01
GANICS[4][5]												
Volatile Organics												
Acetone	<10	<10	<10	<10	92[6]	<10	<100	<100	<100	<100	<100	<10
1,1-Dichloroethylene	<5.0	<5.0	<5.0	<5.0	5.0	ND	<50	<50	<50	<50	<50	5.0
Semi-Volatile Organics	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pesticides/PCBs	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Designated "Coyote Tank."
Designated "Coyote Well."
All units, unless indicated otherwise, are in mg/l or parts per million (ppm) for surface water and mg/kg or ppm for sediments.
All units, unless indicated otherwise, are in ug/l or parts per billion (ppb) for surface water and ug/kg or ppb for sediments.

[5] Only those organic compounds which were at or above the detection limits are included in this table.
[6] Common laboratory contaminant; results should be considered suspect.
*Average of three subsamples.
— = Indicates "Not Tested".
ND = Not detected.

5.0 WATER QUALITY

The water quality subprogram of the Ecological Monitoring Program monitors both surface water bodies and water-bearing geologic strata for chemical impacts to water quality which may be the result of WIPP construction activities. These data may also be useful in the interpretation of data from other environmental monitoring programs, such as the Radiological Baseline Program.

5.1 GROUND WATER

Ground-water sampling and analysis are performed as part of the WIPP Water Quality Sampling Program (WQSP). During 1987, 24 of the 26 WQSP wells and eight privately-owned wells were sampled. Among the parameters being monitored at these wells are general chemistry, trace metals, and EPA priority organic pollutants. These data are presented in Randall et al. (1988). No indication of WIPP-related impacts on ground-water quality has been discerned from these results. Of the organic pollutants, acetone, methylene chloride, and species of phthalate have been found (sporadically) to be above the level of detection in 17 samples. These are common laboratory contaminants and this is the probable source of these elevated values.

5.2 SURFACE WATER AND SEDIMENT

Water and sediment samples have been collected from four selected surface water bodies near the WIPP site as part of the Ecological Monitoring Program. These sampling locations are: Hill Tank, Red Tank, Indian Tank and Laguna Grande de la Sal - Laguna Tres (Figure 5.1). The rationale for selecting these locations for sampling, and the methods used in collecting the samples are presented in the Guidance Manual, Surface Water and Sediment Sampling for the Environmental Monitoring Programs (Prill and Buckle, 1987). Sampling at these locations occurred on three occasions: October 22 and 23, 1986; June 23 through 25, 1987; and November 10 through 12, 1987.

Duplicate samples were collected at the Red Tank location during the June sampling round. This sample was designated as Coyote Tank. For the November sampling round, Hill Tank had duplicate samples designated as Coyote Tank. One blank sample was prepared for each round and designated Coyote Well. Selected data pertaining to these sampling efforts are provided in Tables 5.1, 5.2, and 5.3, respectively. For purposes of comparison, analytical data concerning several parameters obtained from each sampling event are included in Table 5.4 (General Chemistry) and 5.5 (Metals).

In comparing the general water chemistry of the three tanks, a common characteristic is evident; that is, most parameters exhibited similar concentrations between each sampling event as well as between each tank. Due to its saline nature, the water sample collected from Laguna Grande de la Sal - Laguna Tres contained much higher concentrations of chloride, sulfate, total dissolved solids (TDS), total suspended solids (TSS), and bromide (not shown in the tables). Overall, the sediment characteristics (based on general chemistry parameters) were roughly similar to those found in the water quality of the sampling locations. One exception was total organic carbon (TOC), which occurred in much higher concentrations in the sediment than in the water.

The water and sediment collected during the October, 1986, and November, 1987, sampling events were analyzed for 30 metals; an abbreviated metals testing program was conducted on the samples obtained during the June, 1987, sampling. As with the general chemistry results, the concentrations of metals were consistent between the waters of the three tanks, with no unusual concentrations noted. Metals concentrations in Laguna Grande de la Sal - Laguna Tres were typically greater than concentrations found in the tanks. This is particularly evident for magnesium, potassium, sodium, selenium, and strontium.

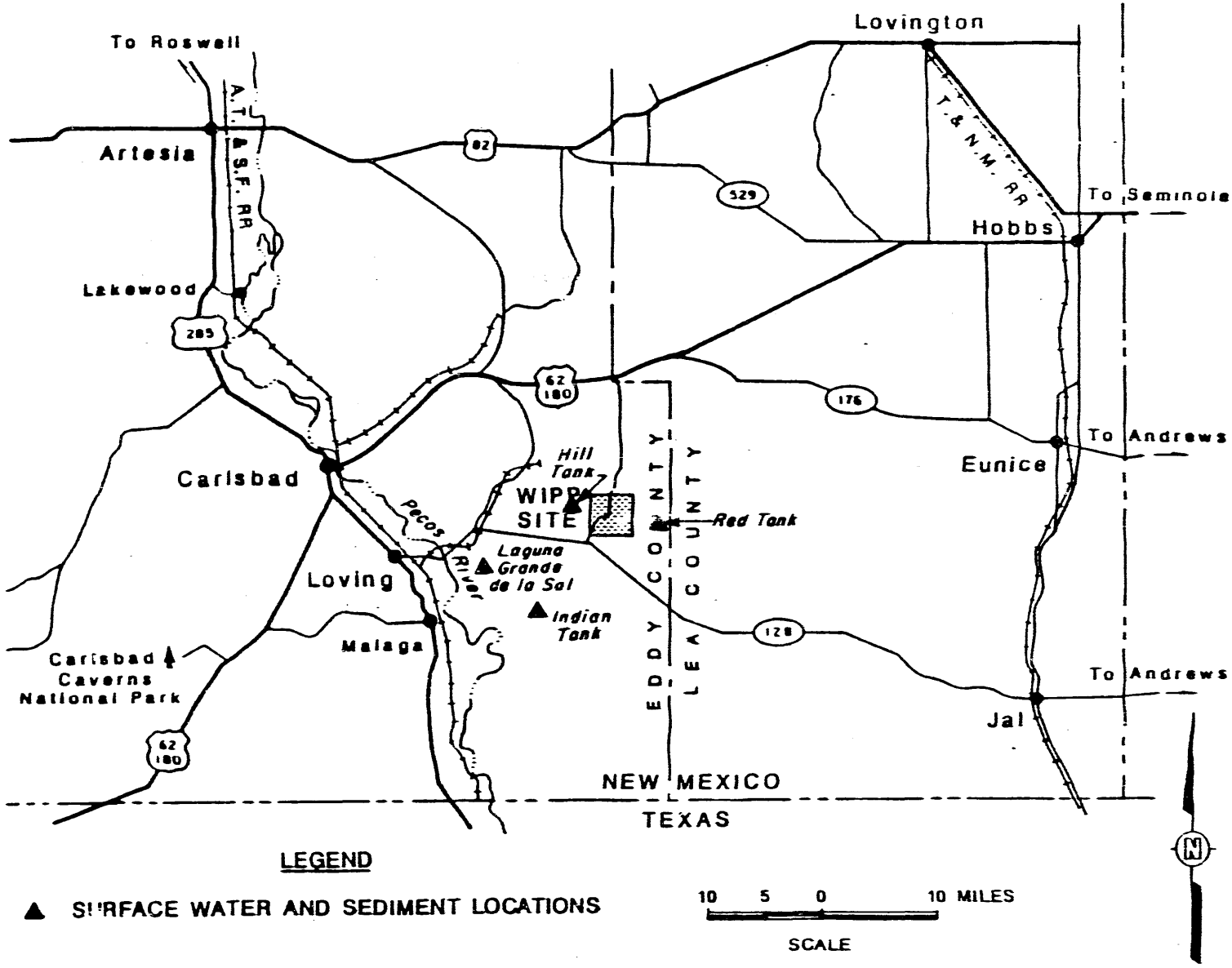


FIGURE 5.1 Surface water and sediment sampling locations.

TABLE 4.2

ATMOSPHERIC MONITORING STATION POLLUTANT GAS CONCENTRATIONS (PPM) FOR 1987 (CONTINUED)

DECEMBER 1987

	SO_2		CO		O_3		H_2S		NO		NO_2		NO_X*	
Day	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max
1	.004	.006	LLD	.05	LLD	LLD	LLD	LLD	LLD	.013	.002	.004	LLD	.016
2	.005	.006	.15	.38	LLD	LLD	LLD	LLD	LLD	.011	LLD	LLD	.003	.014
3	.005	.008	.30	1.08	LLD	LLD	LLD	LLD	.002	.010	.002	.002	.004	.013
4	.006	.009	.25	.50	LLD	LLD	LLD	.004	.004	.012	LLD	.002	.006	.024
5	.006	.009	.20	.23	LLD	LLD	LLD	LLD	.005	.017	LLD	LLD	.006	.020
6	.005	.007	LLD	.15	LLD	LLD	LLD	LLD	LLD	.010	LLD	LLD	LLD	.012
7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9	.009	.62	.23	1.05	.02	.02	LLD	.048	.010	.079	.009	.028	.026	.093
10	.006	.005	.20	.58	.021	.018	.002	.005	.012	.004	.003	.019	.019	.022
11	LLD	LLD	.22	.74	.016	.020	LLD	LLD	LLD	.004	.007	.016	.010	.017
12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
13	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14	LLD	.007	.85	1.44	.020	.024	LLD	.002	.005	.016	LLD	LLD	.007	.017
15	.003	.007	.83	1.29	.023	.027	LLD	.002	.004	.010	.002	.005	.008	.010
16	.003	.007	.47	1.08	.023	.029	LLD	.005	.005	.009	.004	.012	.010	.014
17	LLD	.003	LLD	.32	.020	.030	.003	.009	.007	.022	.005	.015	.012	.022
18	LLD	LLD	LLD	LLD	.015	.019	LLD	LLD	LLD	.002	.010	.012	.011	.013
19	LLD	LLD	LLD	LLD	.016	.024	LLD	LLD	.002	.005	.008	.016	.009	.021
20	LLD	LLD	LLD	LLD	.013	.020	LLD	LLD	.005	.038	.010	.040	.014	.077
21	LLD	LLD	LLD	LLD	.015	.023	LLD	LLD	.003	.025	.008	.031	.010	.056
22	LLD	LLD	LLD	.14	.018	.024	LLD	LLD	.003	.005	.004	.012	.007	.014
23	LLD	.018	LLD	.26	.010	.019	LLD	.054	.021	.221	.006	.030	.028	.244
24	LLD	LLD	LLD	LLD	.008	.012	LLD	LLD	.010	.024	LLD	LLD	.010	.024
25	LLD	LLD	.38	.56	.012	.015	.003	.004	LLD	LLD	LLD	LLD	LLD	LLD
26	LLD	LLD	.51	.66	.014	.017	.004	.005	LLD	LLD	LLD	LLD	LLD	LLD
27	LLD	.004	.44	.87	.012	.017	.003	.008	LLD	.004	LLD	LLD	LLD	.004
28	LLD	LLD	.28	.81	.009	.013	LLD	.004	LLD	.015	LLD	LLD	LLD	.016
29	LLD	LLD	.19	.52	.008	.014	.002	.006	.004	.019	LLD	LLD	.004	.019
30	LLD	LLD	.11	.31	.009	.018	LLD	.004	.008	.021	LLD	LLD	.008	.021
31	LLD	LLD	LLD	.29	.010	.016	LLD	LLD	.010	.021	LLD	LLD	.010	.021

LLD = Lower Limit of Detection
ND = No Data
*Figures for the 24-hour average of NO_X contain an approximate bias of .003 ppm due to inclusion at calibration.

TABLE 4.3

TOTAL SUSPENDED PARTICULATES (MG/M3) FOR WIPP FAR-FIELD AIR SAMPLER

1986 4th Quarter		1987 1st Quarter		1987 2nd Quarter		1987 3rd Quarter		1987 4th Quarter	
Week of:	TSP	Week of:	TSP	Week of:	TSP	Week of:	TSP	Week of:	TSP
10/1	*ND	12/31	0.0165	4/1	0.0830	7/1	0.0326	9/30	0.0266
10/8	0.0199	01/7	0.0107	4/8	0.0163	7/8	0.0350	10/7	0.0543
10/15	0.0112	1/14	0.0084	4/15	0.0201	7/15	0.0348	10/14	0.0126
10/22	0.0151	1/21	0.0117	4/22	0.0188	7/22	0.0284	10/21	0.0142
10/29	0.0130	1/28	0.0204	4/29	0.0148	7/29	0.0868	10/28	0.0214
11/5	0.0145	2/4	0.0112	5/6	0.0170	8/5	0.0245	11/4	0.0149
11/12	0.0089	2/11	0.0172	5/13	0.0177	8/12	0.0121	11/11	0.0192
11/19	0.0113	2/18	0.0134	5/20	0.0198	8/19	0.0152	11/18	0.0207
11/26	0.0168	2/25	0.0096	5/27	*ND	8/26	0.0100	11/24	0.0175
12/3	0.0149	3/4	0.0217	6/3	0.0374	9/2	0.0128	12/2	0.0244
12/10	0.0084	3/11	0.0366	6/10	0.0203	9/9	0.0123	12/9	0.0273
12/17	0.0044	3/18	0.0203	6/17	0.0246	9/16	0.0136	12/16	0.0121
12/24	0.0074	3/25	0.0097	6/24	0.0193	9/23	0.0136	12/22	0.0110

*ND = No Data

TABLE 4.2

ATMOSPHERIC MONITORING STATION POLLUTANT GAS CONCENTRATIONS (PPM) FOR 1987
(CONTINUED)

OCTOBER 1987

	SO_2		CO		O_3		H_2S		NO		NO_2		NO_X*	
Day	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max
1	LLD	LLD	LLD	LLD	LLD	LLD	.009	.001	LLD	LLD	.002	.003	LLD	LLD
2	LLD	LLD	LLD	.03	LLD	LLD	.008	.012	LLD	LLD	.002	.002	LLD	LLD
3	LLD	LLD	LLD	LLD	LLD	LLD	.006	.009	LLD	LLD	.002	.002	LLD	LLD
4	LLD	LLD	LLD	LLD	LLD	LLD	.007	.009	LLD	LLD	.002	.002	LLD	LLD
5	LLD	LLD	LLD	LLD	LLD	LLD	.007	.011	LLD	LLD	.002	.002	LLD	LLD
6	LLD	LLD	LLD	LLD	LLD	LLD	.006	.008	LLD	LLD	.002	.002	LLD	LLD
7	LLD	LLD	LLD	LLD	LLD	LLD	.007	.009	LLD	LLD	.002	.003	LLD	LLD
8	LLD	LLD	LLD	.40	LLD	LLD	.004	.008	LLD	LLD	.002	.003	LLD	LLD
9	LLD	LLD	.40	.45	LLD	LLD	LLD	.002	LLD	LLD	.002	.003	LLD	LLD
10	LLD	LLD	.35	.50	LLD	LLD	LLD	.002	LLD	LLD	.002	.003	LLD	LLD
11	LLD	LLD	.15	.35	LLD	LLD	LLD	.002	LLD	LLD	.002	.002	LLD	LLD
12	LLD	LLD	.28	.43	LLD	LLD	LLD	.002	LLD	LLD	.002	.003	LLD	LLD
13	LLD	LLD	.45	1.03	LLD	LLD	LLD	LLD	LLD	LLD	.002	.002	LLD	LLD
14	LLD	LLD	.43	.58	LLD	LLD	LLD	.003	LLD	LLD	.002	.002	LLD	LLD
15	LLD	LLD	.03	.35	LLD	LLD	LLD	.002	LLD	LLD	.002	.003	LLD	LLD
16	LLD	LLD	LLD	LLD	LLD	LLD	LLD	.003	LLD	LLD	.002	.002	LLD	LLD
17	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	.002	.002	LLD	LLD
18	LLD	LLD	LLD	LLD	LLD	LLD	LLD	.003	LLD	LLD	.002	.002	LLD	LLD
19	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	.002	.003	LLD	LLD
20	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	.002	.003	LLD	LLD
21	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	.002	.003	LLD	LLD
22	LLD	LLD	LLD	.08	LLD	LLD	LLD	LLD	LLD	LLD	.002	.002	LLD	LLD
23	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	.002	.002	LLD	LLD
24	LLD	.002	LLD	.03	LLD	LLD	LLD	.002	LLD	LLD	.002	.002	LLD	LLD
25	LLD	.003	LLD	LLD	LLD	LLD	LLD	.002	LLD	LLD	.002	.002	LLD	LLD
26	LLD	.003	LLD	LLD	LLD	LLD	LLD	.001	LLD	LLD	.002	.002	LLD	LLD
27	LLD	.002	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	.002	.002	LLD	LLD
28	LLD	.002	LLD	.13	LLD	LLD	LLD	LLD	LLD	LLD	.003	.003	LLD	LLD
29	LLD	.004	LLD	.35	LLD	LLD	LLD	LLD	LLD	LLD	.002	.003	LLD	LLD
30	.002	.004	.10	.28	LLD	LLD	LLD	LLD	LLD	LLD	.002	.003	LLD	LLD
31	.002	.003	.08	.43	LLD	LLD	LLD	LLD	LLD	LLD	.002	.002	LLD	LLD

LLD = Lower Limit of Detection
ND = No Data
*Figures for the 24-hour average of NO_X contain an approximate bias of .003 ppm due to inclusion at calibration.

TABLE 4.2

ATMOSPHERIC MONITORING STATION POLLUTANT GAS CONCENTRATIONS (PPM) FOR 1987 (CONTINUED)

NOVEMBER 1987

	SO_2		CO		O_3		H_2S		NO		NO_2		NO_X*	
Day	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max
1	.002	.003	LLD	1.38	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD
2	.003	.005	.23	1.68	LLD	LLD	LLD	LLD	LLD	LLD	.002	.002	LLD	LLD
3	.003	.006	LLD	.43	LLD	LLD	LLD	.004	LLD	LLD	.002	.003	LLD	LLD
4	.004	.007	LLD	.18	LLD	LLD	LLD	.004	LLD	LLD	LLD	.003	LLD	LLD
5	.004	.005	.35	2.90	LLD	LLD	LLD	LLD	LLD	LLD	LLD	.003	LLD	LLD
6	.002	.003	.20	1.43	LLD	LLD	LLD	LLD	LLD	LLD	.004	.005	LLD	LLD
7	.002	.003	LLD	.25	LLD	LLD	LLD	LLD	LLD	LLD	.003	LLD	LLD	LLD
8	LLD	.003	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	.002	.002	LLD	LLD
9	LLD	.002	LLD	.25	LLD	LLD	LLD	LLD	LLD	LLD	.002	.002	LLD	LLD
10	.002	.004	LLD	.33	LLD	LLD	LLD	.004	LLD	LLD	LLD	.003	LLD	LLD
11	.002	.003	LLD	.48	LLD	LLD	LLD	LLD	LLD	LLD	.002	.003	LLD	LLD
12	.002	.003	LLD	LLD	LLD	LLD	LLD	.002	LLD	LLD	.002	.002	LLD	LLD
13	.003	.006	LLD	.08	LLD	LLD	LLD	LLD	LLD	LLD	.003	.003	LLD	LLD
14	.005	.013	LLD	.30	LLD	LLD	LLD	LLD	LLD	LLD	.002	.003	LLD	LLD
15	LLD	.004	LLD	.55	LLD	LLD	LLD	LLD	LLD	LLD	.002	.002	LLD	LLD
16	LLD	.002	.40	2.08	LLD	LLD	LLD	LLD	LLD	LLD	.002	.003	LLD	LLD
17	.002	.004	.40	.88	LLD	LLD	LLD	LLD	.006	.045	LLD	.003	.008	.016
18	.002	.002	.23	.33	LLD	LLD	LLD	LLD	.007	.016	LLD	.002	.008	.019
19	.003	.005	.43	.68	LLD	LLD	LLD	LLD	LLD	.010	LLD	.004	LLD	.012
20	.004	.005	.43	.75	LLD	LLD	LLD	LLD	LLD	LLD	.002	.006	LLD	LLD
21	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
22	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
23	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
24	.003	.006	LLD	LLD	LLD	LLD	LLD	LLD	.008	.013	LLD	LLD	.010	.016
25	.003	.004	LLD	.43	LLD	LLD	LLD	LLD	.005	.007	LLD	LLD	.006	.008
26	.003	.004	.40	.58	LLD	LLD	LLD	LLD	LLD	.005	LLD	LLD	LLD	.007
27	.005	.008	.55	.88	LLD	LLD	LLD	LLD	LLD	.012	LLD	.002	LLD	.014
28	.004	.006	.45	.63	LLD	LLD	LLD	LLD	LLD	.007	LLD	.002	LLD	.008
29	.004	.005	.38	.45	LLD	LLD	LLD	LLD	.002	.010	LLD	.002	LLD	.013
30	.004	.005	LLD	.65	LLD	LLD	LLD	.005	LLD	.007	LLD	.005	LLD	.008

LLD = Lower Limit of Detection
ND = No Data
*Figures for the 24-hour average of NO_X contain an approximate bias of .003 ppm due to inclusion at calibration.

TABLE 4.2

ATMOSPHERIC MONITORING STATION POLLUTANT GAS CONCENTRATIONS (PPM) FOR 1987 (CONTINUED)

JULY 1987

	SO_2		CO		O_3		H_2S		NO		NO_2		NO_X*	
Day	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max
1	.010	.011	LLD	.40	LLD	LLD	.006	.017	.018	.037	.007	.012	.029	.052
2	.011	.012	LLD	LLD	LLD	LLD	.008	.019	.008	.019	.004	.005	.014	.028
3	.011	.012	LLD	LLD	LLD	LLD	.007	.020	.003	.004	.004	.005	.007	.008
4	.011	.012	LLD	LLD	LLD	LLD	.005	.020	.009	.014	.005	.007	.015	.023
5	.011	.012	LLD	LLD	LLD	LLD	.005	.020	.012	.018	.005	.008	.019	.027
6	.011	.012	LLD	LLD	LLD	LLD	.004	.020	.011	.018	.005	.009	.018	.027
7	.012	.013	LLD	.65	LLD	LLD	.004	.019	.010	.016	.005	.007	.017	.024
8	.012	.012	LLD	.10	LLD	LLD	.003	.014	.016	.024	.006	.008	.026	.034
9	.012	.012	LLD	.10	LLD	LLD	.004	.013	.019	.026	.008	.011	.030	.038
10	.012	.012	LLD	.10	LLD	LLD	.006	.018	.017	.022	.008	.012	.028	.032
11	.012	.012	.03	.10	LLD	LLD	.006	.017	.016	.021	.007	.010	.026	.031
12	.012	.012	.05	.13	LLD	LLD	LLD	.002	.016	.023	.007	.010	.025	.034
13	.012	.014	.08	.40	LLD	LLD	LLD	.006	.018	.025	.007	.008	.027	.038
14	.005	.012	.20	.33	LLD	LLD	LLD	LLD	.020	.029	.008	.011	.032	.044
15	LLD	LLD	.10	.63	LLD	LLD	LLD	LLD	.012	.032	.008	.016	.022	.044
16	LLD	LLD	.15	.40	LLD	LLD	LLD	LLD	.009	.032	.007	.020	.017	.058
17	LLD	LLD	.15	.38	LLD	LLD	LLD	LLD	.017	.082	.011	.024	.035	.113
18	LLD	LLD	.13	.20	LLD	LLD	LLD	LLD	.005	.020	.005	.007	.010	.030
19	LLD	LLD	.15	.20	LLD	LLD	LLD	LLD	.012	.029	.006	.007	.020	.041
20	LLD	LLD	.18	.38	LLD	LLD	LLD	LLD	.013	.024	.006	.008	.021	.035
21	LLD	LLD	.20	.30	LLD	LLD	LLD	LLD	.013	.019	.007	.008	.022	.029
22	LLD	LLD	.15	.28	LLD	LLD	LLD	LLD	.013	.021	.007	.009	.022	.033
23	LLD	LLD	.25	.35	LLD	LLD	LLD	LLD	.014	.029	.007	.010	.023	.041
24	LLD	LLD	.33	.43	LLD	LLD	LLD	LLD	.015	.030	.007	.009	.024	.041
25	LLD	LLD	.30	.38	LLD	LLD	LLD	LLD	.015	.024	.007	.008	.024	.035
26	LLD	LLD	.43	.55	LLD	LLD	LLD	LLD	.015	.022	.007	.010	.025	.033
27	LLD	LLD	.45	.53	LLD	LLD	LLD	LLD	.016	.028	.007	.011	.026	.039
28	LLD	LLD	.45	.53	LLD	LLD	LLD	LLD	.013	.022	.006	.010	.022	.033
29	LLD	LLD	.25	.58	LLD	LLD	LLD	.003	.025	.041	.005	.010	.036	.093
30	.002	.002	LLD	.03	LLD	LLD	LLD	.009	.025	.054	LLD	LLD	.031	.066
31	.002	.003	LLD	.03	LLD	LLD	.002	.014	.017	.037	LLD	LLD	.022	.044

LLD = Lower Limit of Detection
ND = No Data
*Figures for the 24-hour average of NO_X contain an approximate bias of .003 ppm due to inclusion at calibration.

TABLE 4.2

ATMOSPHERIC MONITORING STATION POLLUTANT GAS CONCENTRATIONS (PPM) FOR 1987 (CONTINUED)

AUGUST 1987

	SO_2		CO		O_3		H_2S		NO		NO_2		NO_X*	
Day	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max
1	.002	.003	LLD	.03	.31	.76	.004	.019	.014	.027	LLD	LLD	.017	.038
2	.002	.003	LLD	LLD	.67	1.0	.002	.011	.013	.026	LLD	LLD	.017	.030
3	.002	.003	LLD	.08	.43	1.0	.004	.014	.014	.024	LLD	LLD	.018	.029
4	LLD	.002	.03	.15	LLD	.07	LLD	.008	.016	.027	LLD	LLD	.020	.032
5	LLD	.007	LLD	.10	LLD	LLD	LLD	.011	.015	.024	LLD	LLD	.019	.028
6	.003	.008	.03	.10	LLD	LLD	LLD	.011	.014	.022	LLD	LLD	.018	.027
7	.007	.016	LLD	.08	LLD	LLD	LLD	.011	.015	.022	LLD	LLD	.019	.027
8	.011	.018	LLD	.08	LLD	LLD	LLD	.012	.013	.014	LLD	LLD	.016	.034
9	.008	.012	.13	1.07	LLD	LLD	LLD	.003	.021	.032	LLD	LLD	.026	.038
10	.006	.010	.08	.20	LLD	LLD	LLD	LLD	.023	.035	LLD	LLD	.029	.042
11	.004	.007	.18	.28	LLD	LLD	LLD	LLD	.025	.034	LLD	LLD	.031	.038
12	.006	.008	.20	.40	LLD	LLD	LLD	.014	.024	.035	LLD	LLD	.029	.041
13	.009	.010	.05	.30	LLD	LLD	LLD	LLD	.022	.037	LLD	LLD	.028	.044
14	.002	.006	LLD	LLD	LLD	LLD	LLD	.005	.023	.037	LLD	LLD	.029	.044
15	.002	.008	LLD	LLD	LLD	LLD	LLD	.008	.024	.036	LLD	LLD	.029	.042
16	.002	.006	LLD	LLD	LLD	LLD	LLD	.005	.023	.037	LLD	LLD	.029	.045
17	.003	.010	LLD	LLD	LLD	LLD	LLD	.012	.019	.027	LLD	LLD	.023	.032
18	.003	.010	LLD	LLD	LLD	LLD	LLD	.011	.023	.031	LLD	LLD	.028	.049
19	.002	.007	LLD	LLD	LLD	LLD	LLD	.003	.025	.035	LLD	LLD	.031	.041
20	.002	.006	LLD	LLD	LLD	LLD	LLD	.004	.002	.030	LLD	LLD	.027	.036
21	.002	.005	LLD	LLD	LLD	LLD	LLD	.002	.021	.027	LLD	LLD	.026	.033
22	LLD	.005	LLD	LLD	LLD	LLD	LLD	LLD	.023	.031	LLD	LLD	.028	.037
23	LLD	.002	LLD	LLD	LLD	LLD	LLD	LLD	.034	.047	LLD	LLD	.041	.057
24	LLD	.004	LLD	.03	LLD	LLD	LLD	.002	.027	.037	LLD	LLD	.033	.044
25	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
26	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
27	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
28	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
29	LLD	.004	LLD	LLD	LLD	LLD	LLD	LLD	.030	.040	LLD	LLD	.034	.055
30	LLD	.006	1.03	1.25	LLD	LLD	LLD	LLD	.039	.042	LLD	LLD	.046	.079
31	LLD	LLD	.35	.85	LLD	LLD	LLD	.098	.032	.048	.005	.010	.025	.058

LLD = Lower Limit of Detection
ND = No Data
*Figures for the 24-hour average of NO_X contain an approximate bias of .003 ppm due to inclusion at calibration.

TABLE 4.2

ATMOSPHERIC MONITORING STATION POLLUTANT GAS CONCENTRATIONS (PPM) FOR 1987 (CONTINUED)

MAY 1987

	SO_2		CO		O_3		H_2S		NO		NO_2		NO_X*	
Day	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max
1	.201	.202	LLD	LLD	LLD	LLD	.009	.016	.009	.016	.005	.006	.015	.019
2	.200	.201	LLD	LLD	LLD	LLD	.008	.011	.007	.009	.004	.005	.011	.015
3	.201	.203	LLD	LLD	LLD	LLD	.006	.011	.009	.015	.004	.005	.015	.022
4	.201	.204	LLD	.28	LLD	LLD	.008	.014	.009	.015	.004	.006	.014	.024
5	.202	.206	LLD	.33	LLD	LLD	.010	.019	.011	.021	.004	.008	.013	.030
6	.202	.203	LLD	.25	LLD	LLD	.008	.013	.013	.024	.006	.007	.021	.035
7	.202	.203	LLD	.20	LLD	LLD	.008	.012	.013	.017	.007	.011	.021	.029
8	.154	.203	LLD	.40	LLD	LLD	.012	.029	.031	.095	.021	.056	.051	.118
9	.064	.065	LLD	LLD	LLD	LLD	.011	.018	.021	.404	.044	.050	.068	.098
10	.064	.065	LLD	LLD	LLD	LLD	.013	.022	.011	.016	.031	.035	.040	.051
11	.028	.065	LLD	LLD	LLD	LLD	.014	.023	.011	.021	.023	.024	.027	.048
12	.002	.003	LLD	LLD	LLD	LLD	.015	.025	.013	.030	.017	.020	.031	.050
13	.002	.002	LLD	LLD	LLD	LLD	.014	.021	.010	.016	.013	.014	.023	.028
14	.002	.008	LLD	LLD	LLD	LLD	.013	.025	.015	.031	.013	.018	.031	.052
15	.112	.252	LLD	LLD	LLD	LLD	.012	.027	.017	.030	.010	.012	.032	.047
16	.252	.258	LLD	LLD	LLD	LLD	.014	.028	.014	.017	.009	.010	.028	.028
17	.252	.257	LLD	LLD	LLD	LLD	.014	.028	.016	.026	.009	.011	.029	.041
18	.251	.252	LLD	LLD	LLD	LLD	.011	.017	ND	ND	.008	.025	.035	.093
19	.250	.253	LLD	.23	LLD	LLD	.009	.012	.030	.045	.010	.016	.045	.068
20	.150	.253	LLD	LLD	LLD	LLD	.005	.017	.016	.022	.010	.012	.036	.036
21	.008	.013	LLD	.48	LLD	LLD	.010	.028	.009	.024	.009	.012	.019	.038
22	.007	.011	LLD	.15	LLD	LLD	.012	.019	.023	.043	.010	.012	.039	.061
23	.006	.008	LLD	LLD	LLD	LLD	.009	.014	.012	.018	.008	.019	.021	.031
24	.006	.007	LLD	LLD	LLD	LLD	.010	.016	.017	.026	.009	.010	.029	.042
25	.007	.010	LLD	LLD	LLD	LLD	.014	.027	.023	.029	.010	.012	.037	.043
26	.010	.019	LLD	LLD	LLD	LLD	.013	.018	.022	.032	.010	.011	.035	.046
27	.008	.011	LLD	.45	LLD	LLD	.013	.018	.010	.020	.008	.012	.018	.031
28	.007	.011	LLD	LLD	LLD	LLD	.011	.016	.012	.022	.007	.009	.019	.036
29	.006	.007	LLD	LLD	LLD	LLD	.014	.024	.010	.017	.008	.015	.021	.035
30	.005	.006	LLD	LLD	LLD	LLD	.012	.020	.016	.023	.007	.008	.026	.035
31	.005	.008	LLD	LLD	LLD	LLD	.013	.023	.016	.022	.007	.009	.027	.035

LLD = Lower Limit of Detection
ND = No Data
*Figures for the 24-hour average of NO_X contain an approximate bias of .003 ppm due to inclusion at calibration.

TABLE 4.2

ATMOSPHERIC MONITORING STATION POLLUTANT GAS CONCENTRATIONS (PPM) FOR 1987 (CONTINUED)

June 1987

	SO_2		CO		O_3		H_2S		NO		NO_2		NO_X*	
Day	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max
1	.005	.006	LLD	LLD	LLD	LLD	.016	.025	.018	.022	.008	.010	.029	.036
2	.005	.006	LLD	LLD	LLD	LLD	.018	.033	.018	.021	.008	.014	.029	.038
3	.006	.006	LLD	LLD	LLD	LLD	.008	.017	.012	.027	.006	.010	.020	.042
4	.006	.009	LLD	LLD	LLD	LLD	LLD	.003	.005	.011	.006	.008	.012	.024
5	.006	.007	LLD	LLD	LLD	LLD	LLD	.005	.005	.010	.008	.011	.013	.019
6	.006	.006	LLD	LLD	LLD	LLD	LLD	.005	.004	.005	.006	.008	.010	.013
7	.006	.007	LLD	.08	LLD	LLD	LLD	.009	.004	.005	.005	.006	.009	.011
8	.007	.007	LLD	.40	LLD	LLD	LLD	LLD	.005	.006	.005	.009	.010	.011
9	.007	.007	.33	.78	LLD	LLD	LLD	.009	.005	.007	.005	.007	.011	.014
10	.007	.008	.50	.73	LLD	LLD	.004	.012	.006	.007	.005	.007	.011	.015
11	.007	.008	.53	.90	LLD	LLD	.004	.016	.005	.006	.005	.010	.010	.016
12	.008	.009	.23	.80	LLD	LLD	.007	.019	.007	.010	.006	.009	.014	.018
13	.009	.011	LLD	LLD	LLD	LLD	.008	.023	.007	.012	.006	.007	.015	.019
14	.009	.010	LLD	.15	LLD	LLD	.006	.018	.006	.010	.005	.008	.013	.018
15	.009	.010	.05	.25	LLD	LLD	.005	.017	.005	.009	.005	.009	.011	.016
16	.009	.010	.08	.25	LLD	LLD	.006	.018	.004	.005	.005	.009	.009	.015
17	.009	.010	.05	.15	LLD	LLD	.008	.022	.004	.005	.005	.007	.009	.013
18	.009	.010	.13	.25	LLD	LLD	.007	.016	.003	.005	.005	.006	.009	.011
19	.010	.010	.20	.40	LLD	LLD	.007	.018	.004	.009	.005	.013	.009	.017
20	.010	.010	.18	.28	LLD	LLD	.007	.021	.002	.004	.004	.006	.007	.009
21	.010	.010	LLD	.23	LLD	LLD	.005	.017	.004	.009	.004	.005	.009	.015
22	.010	.010	LLD	LLD	LLD	LLD	.005	.015	.002	.003	.004	.005	.006	.007
23	.010	.011	LLD	LLD	LLD	LLD	.008	.022	.007	.017	.004	.005	.012	.025
24	.010	.011	LLD	LLD	LLD	LLD	.006	.018	.012	.031	.005	.006	.019	.041
25	.010	.010	LLD	LLD	LLD	LLD	.006	.019	.010	.036	.005	.006	.016	.049
26	.010	.014	LLD	LLD	LLD	LLD	LLD	.004	.008	.015	.004	.008	.013	.023
27	.010	.010	LLD	LLD	LLD	LLD	.004	.013	.010	.026	.006	.007	.017	.037
28	.010	.010	LLD	LLD	LLD	LLD	.003	.010	.010	.019	.004	.008	.015	.030
29	.010	.011	LLD	.98	LLD	LLD	.006	.015	.010	.021	.005	.012	.017	.029
30	.010	.011	.33	.43	LLD	LLD	.004	.012	.012	.028	.005	.007	.019	.039

LLD = Lower Limit of Detection
ND = No Data
*Figures for the 24-hour average of NO_X contain an approximate bias of .003 ppm due to inclusion at calibration.

TABLE 4.2

ATMOSPHERIC MONITORING STATION POLLUTANT GAS CONCENTRATIONS (PPM) FOR 1987
(CONTINUED)

APRIL 1987

	SO_2		CO		O_3		H_2S		NO		NO_2		NOX*	
Day	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max
1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
13	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16	.003	.009	ND	ND	LLD	LLD	.003	.009	.005	.014	.003	.006	.009	.023
17	.008	.011	ND	ND	LLD	LLD	.004	.015	.013	.022	.007	.012	.022	.038
18	.008	.010	ND	ND	LLD	LLD	.005	.020	.012	.021	.006	.008	.019	.031
19	.008	.009	ND	ND	LLD	LLD	.002	.007	.012	.018	.005	.007	.019	.028
20	.009	.014	ND	ND	LLD	LLD	.002	.006	.014	.026	.006	.009	.022	.040
21	.013	.015	ND	ND	LLD	LLD	LLD	LLD	.021	.036	.006	.007	.031	.050
22	.013	.014	LLD	.28	LLD	LLD	.002	.007	.010	.013	.006	.010	.018	.022
23	.013	.014	.63	1.73	LLD	LLD	.006	.017	.012	.017	.006	.008	.020	.026
24	.013	.014	.80	1.58	LLD	LLD	.008	.012	.011	.014	.006	.008	.019	.022
25	.014	.014	LLD	LLD	LLD	LLD	.007	.013	.011	.017	.006	.007	.019	.025
26	.014	.014	LLD	.25	LLD	LLD	.009	.014	.009	.012	.006	.008	.017	.022
27	.014	.014	LLD	.30	LLD	LLD	.010	.016	.009	.011	.006	.008	.017	.021
28	.014	.014	LLD	.18	LLD	LLD	.008	.013	.009	.012	.005	.007	.016	.021
29	.107	.201	LLD	LLD	LLD	LLD	.009	.018	.009	.012	.006	.012	.016	.021
30	.200	.201	LLD	.23	LLD	LLD	.010	.020	.011	.015	.005	.006	.018	.024

LLD = Lower Limit of Detection
ND = No Data
*Figures for the 24-hour average of NO_X contain an approximate bias of .003 ppm due to inclusion at calibration.

TABLE 4.2

ATMOSPHERIC MONITORING STATION POLLUTANT GAS CONCENTRATIONS (PPM) FOR 1987
JANUARY 1987

	SO_2		CO		O_3		H_2S		NO		NO_2		NO_X*	
Day	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max
1	ND	ND	LLD	LLD	LLD	LLD	LLD	.005	.008	.011	LLD	.005	.013	.015
2	ND	ND	LLD	.65	LLD	LLD	LLD	.005	.006	.008	.002	.005	.012	.013
3	ND	ND	.65	.87	LLD	LLD	LLD	LLD	.012	.009	.003	.007	.013	.014
4	ND	ND	.75	1.05	LLD	LLD	LLD	LLD	.005	.007	.002	.005	.011	.012
5	ND	ND	.70	.97	LLD	LLD	LLD	LLD	.007	.009	.003	.007	.013	.014
6	ND	ND	.12	.90	LLD	LLD	LLD	LLD	.007	.008	.005	.018	.017	.029
7	ND	ND	LLD	LLD	LLD	LLD	LLD	.002	.008	.012	.007	.015	.019	.027
8	ND	ND	LLD	.50	LLD	LLD	LLD	LLD	.010	.014	.004	.011	.018	.021
9	ND	ND	.20	.70	LLD	LLD	LLD	LLD	.008	.011	.022	.006	.013	.014
10	ND	ND	.22	.62	LLD	LLD	LLD	LLD	.006	.010	.001	.008	.011	.015
11	ND	ND	.37	.80	LLD	LLD	LLD	.003	.006	.010	LLD	.004	.010	.012
12	ND	ND	.27	.82	LLD	LLD	LLD	.004	.007	.010	.003	.015	.013	.024
13	ND	ND	LLD	.20	LLD	LLD	.002	.004	.009	.015	.022	.011	.015	.019
14	ND	ND	.10	.47	LLD	LLD	.003	.005	.008	.011	LLD	LLD	.012	.016
15	ND	ND	.20	.65	LLD	LLD	.004	.008	.008	.013	LLD	LLD	.012	.015
16	ND	ND	.30	.50	LLD	LLD	.004	.008	.008	.010	LLD	LLD	.013	.012
17	ND	ND	.50	.70	LLD	LLD	.009	.011	.006	.008	LLD	LLD	.009	.010
18	ND	ND	.32	.82	LLD	LLD	.009	.014	.007	.015	LLD	LLD	.011	.019
19	ND	ND	.07	.52	LLD	LLD	.007	.009	.009	.014	LLD	.007	.014	.019
20	ND	ND	.17	.42	LLD	LLD	.008	.012	.007	.010	LLD	LLD	.011	.012
21	ND	ND	LLD	.65	LLD	LLD	.005	.008	.006	.007	LLD	.005	.010	.0
22	ND	ND	.47	.87	LLD	LLD	.005	.009	.007	.015	LLD	.004	.011	.0
23	ND	ND	.35	.52	LLD	LLD	.003	.005	.008	.015	.002	.012	.014	.019
24	ND	ND	.12	.20	LLD	LLD	.002	.003	.008	.012	LLD	.004	.012	.015
25	ND	ND	.20	.42	LLD	LLD	.003	.005	.009	.019	LLD	LLD	.013	.023
26	ND	ND	.25	.47	LLD	LLD	.004	.006	.010	.017	LLD	LLD	.014	.020
27	ND	ND	.27	.52	LLD	LLD	.004	.008	.009	.011	LLD	LLD	.013	.014
28	ND	ND	.45	.97	LLD	LLD	.004	.006	.008	.014	LLD	LLD	.012	.017
29	ND	ND	.12	.52	LLD	LLD	.004	.011	.013	.027	.002	.010	.020	.041
30	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
31	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

LLD = Lower Limit of Detection
ND = No Data
*Figures for the 24-hour average of NO_X contain an approximate bias of .003 ppm due to inclusion at calibration.

TABLE 4.1

ATMOSPHERIC MONITORING STATION
POLLUTANT GAS CONCENTRATIONS (PPM) FOR THE FOURTH QUARTER, 1986
(CONTINUED)

DECEMBER 1986

	SO_2		CO		O_3		H_2S		NO		NO_2		NO_X*	
Day	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max
1	ND	ND	.27	.77	LLD	LLD	LLD	.005	.003	.005	.005	.009	.011	.010
2	ND	ND	.25	.82	LLD	LLD	LLD	.004	.003	.005	.006	.016	.013	.022
3	ND	ND	.20	.40	LLD	LLD	.003	006	.003	.005	.010	.011	.016	.016
4	ND	ND	.25	.55	LLD	LLD	.003	.007	.004	.007	.009	.010	.016	.017
5	ND	ND	.10	.42	LLD	LLD	LLD	LLD	.006	.008	.008	.013	.018	.021
6	ND	ND	.05	.12	LLD	LLD	LLD	LLD	.008	.010	.005	.005	.017	.016
7	ND	ND	LLD	.05	LLD	LLD	LLD	.003	.008	.009	.005	.008	.017	.018
8	ND	ND	LLD	.17	LLD	LLD	LLD	LLD	.008	.011	.006	.010	.017	.023
9	ND	ND	.15	.55	LLD	LLD	LLD	.003	.005	.007	.007	.014	.014	.022
10	ND	ND	.77	1.10	LLD	LLD	.004	.006	.006	.010	LLD	LLD	.009	.012
11	ND	ND	.47	1.32	LLD	LLD	.002	.006	.004	.008	.003	.011	.010	.015
12	ND	ND	.40	.87	LLD	LLD	LLD	.004	.005	.010	.004	.011	.013	.015
13	LLD	LLD	.25	.55	LLD	LLD	.002	.005	.004	.006	.008	.014	.015	.018
14	LLD	LLD	.20	.45	LLD	LLD	LLD	.003	.005	.007	.006	.007	.014	.013
15	ND	ND	.10	.45	LLD	LLD	.002	.004	.007	.013	.005	.010	.015	.016
16	ND	ND	LLD	.15	LLD	LLD	LLD	.002	.008	.011	.008	.011	.020	.023
17	ND	ND	LLD	LLD	LLD	LLD	.002	.003	.007	.010	.008	.010	.019	.021
18	ND	ND	LLD	LLD	LLD	LLD	LLD	.004	.005	.009	.005	.009	.013	.018
19	ND	ND	LLD	LLD	LLD	LLD	LLD	.005	.007	.009	.003	.007	.014	.018
20	ND	ND	LLD	LLD	LLD	LLD	LLD	LLD	.007	.010	.009	.016	.020	.028
21	ND	ND	LLD	LLD	LLD	LLD	LLD	LLD	.008	.009	.007	.009	.018	.021
22	ND	ND	LLD	LLD	LLD	LLD	LLD	LLD	.006	.012	.003	.007	.013	.015
23	ND	ND	LLD	LLD	LLD	LLD	LLD	LLD	.007	.017	.005	.014	.017	.030
24	ND	ND	LLD	LLD	LLD	LLD	LLD	LLD	.006	.008	.006	.007	.015	.022
25	ND	ND	LLD	LLD	LLD	LLD	LLD	LLD	.006	.008	.003	.006	.013	.013
26	ND	ND	LLD	LLD	LLD	LLD	LLD	LLD	.008	.014	.003	.008	.015	.017
27	ND	ND	LLD	LLD	LLD	LLD	LLD	.005	.010	.022	.004	.011	.017	.027
28	ND	ND	LLD	LLD	LLD	LLD	LLD	.002	.009	.014	.004	.012	.017	.019
29	ND	ND	LLD	LLD	LLD	LLD	LLD	.005	.009	.014	.002	.007	.016	.017
30	ND	ND	LLD	LLD	LLD	LLD	LLD	.005	.008	.014	.004	.013	.016	.023
31	ND	ND	LLD	LLD	LLD	LLD	LLD	LLD	.008	.010	.003	.005	.014	.017

LLD = Lower Limit of Detection; ND = No Data

*Figures for the 24-hour average of NO_X contain an approximate bias of .003 ppm due to inclusion at calibration.

TABLE 4.1

ATMOSPHERIC MONITORING STATION POLLUTANT GAS CONCENTRATIONS (PPM) FOR THE FOURTH QUARTER, 1986
(CONTINUED)

NOVEMBER 1986

	SO_2		CO		O_3		H_2S		NO		NO_2		NO_X*	
Day	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max
1	ND	ND	.05	.25	LLD	LLD	.002	.003	.008	.009	.006	.009	.017	.020
2	ND	ND	.05	.10	LLD	LLD	.002	.003	.004	.007	.005	.007	.012	.014
3	ND	ND	.17	.95	LLD	LLD	.002	.003	.005	.007	.006	.008	.014	.017
4	ND	ND	.05	.27	LLD	LLD	.001	.002	.005	.006	.005	.011	.013	.017
5	ND	ND	.25	.57	LLD	LLD	.003	006	.003	.005	.007	.011	.013	.014
6	ND	ND	LLD	.12	LLD	LLD	LLD	.003	.006	.010	.006	.010	.016	.020
7	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	.007	.011	.005	.005	.015	.017
8	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	.005	.006	.004	.004	.012	.011
9	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	.005	.007	.005	.006	.012	.014
10	LLD	LLD	.02	.37	LLD	LLD	LLD	LLD	.005	.006	.006	.007	.015	.015
11	LLD	LLD	.12	.55	LLD	LLD	LLD	LLD	.003	.007	.005	.006	.011	.014
12	LLD	LLD	.20	.67	LLD	LLD	LLD	.005	.003	.005	.005	.007	.010	.012
13	LLD	LLD	.15	.75	LLD	LLD	.006	.007	LLD	LLD	.005	.006	.007	.006
14	LLD	LLD	LLD	.10	LLD	LLD	.003	.007	.005	.011	.006	.006	.013	.020
15	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	.007	.011	.005	.005	.016	.018
16	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	.009	.012	.005	.015	.018	.028
17	LLD	LLD	LLD	LLD	LLD	LLD	LLD	.002	.010	.011	.006	.009	.020	.021
18	LLD	LLD	LLD	LLD	LLD	LLD	LLD	LLD	.012	.014	.006	.007	.022	.023
19	LLD	LLD	LLD	LLD	LLD	LLD	LLD	.002	.011	.013	.006	.008	.021	[illegible]
20	LLD	LLD	LLD	.95	LLD	LLD	LLD	.004	.008	.012	.006	.010	.017	[illegible]
21	ND	ND	.25	.65	LLD	LLD	.003	.004	.004	.005	.008	.018	.015	[illegible]
22	ND	ND	LLD	LLD	LLD	LLD	.002	.003	.005	.006	.005	.006	.012	.012
23	ND	ND	.12	.42	LLD	LLD	LLD	.003	.002	.005	.004	.006	.009	.012
24	ND	ND	.35	.97	LLD	LLD	.003	.006	.003	.006	.004	.005	.009	.011
25	ND	ND	.27	.80	LLD	LLD	.002	.006	.003	.006	.004	.007	.010	.012
26	ND	ND	.17	.42	LLD	LLD	LLD	.003	.002	.004	.005	.005	.009	.010
27	ND	ND	.25	.70	LLD	LLD	.002	.006	.003	.005	.004	.008	.010	.010
28	ND	ND	.17	.52	LLD	LLD	.002	.004	.003	.004	.006	.011	.010	.009
29	ND	ND	.12	.47	LLD	LLD	.002	.004	.003	.004	.004	.005	.010	.010
30	ND	ND	LLD	.65	LLD	LLD	LLD	LLD	.004	.005	.004	.005	.011	.009

LLD = Lower Limit of Detection; ND = No Data

*Figures for the 24-hour average of NO_X contain an approximate bias of .003 ppm due to inclusion at calibration.

TABLE 4.1

ATMOSPHERIC MONITORING STATION
POLLUTANT GAS CONCENTRATIONS (PPM) FOR THE FOURTH QUARTER, 1986

OCTOBER 1986

	SO_2		CO		O_3		H_2S		NO		NO_2		NO_X*	
Day	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max
1	LLD	LLD	.12	.30	LLD	LLD	.011	.012	.025	.040	.006	.009	.038	.056
2	LLD	LLD	.15	.20	LLD	LLD	.012	.014	.030	.041	.004	.005	.043	.054
3	LLD	LLD	.12	.25	LLD	LLD	.011	.012	.021	.034	.005	.007	.032	.045
4	LLD	LLD	.12	.17	LLD	LLD	.007	.008	.009	.013	.005	.007	.018	.023
5	LLD	LLD	.17	.20	LLD	LLD	.008	.009	.016	.023	.006	.008	.026	.032
6	LLD	LLD	.22	.30	LLD	LLD	.007	.008	.009	.012	.005	.007	.018	.019
7	LLD	LLD	.27	.30	LLD	LLD	.008	.009	.012	.013	.005	.006	.021	.021
8	LLD	LLD	.35	.00	LLD	LLD	.009	.011	.011	.015	.005	.008	.020	.023
9	LLD	LLD	.32	.40	LLD	LLD	.009	.010	.015	.028	.006	.008	.025	.038
10	LLD	LLD	.37	.42	LLD	LLD	.009	.010	.024	.027	.005	.007	.035	.037
11	LLD	LLD	.27	.37	LLD	LLD	.008	.009	.012	.024	.004	.005	.020	.032
12	LLD	LLD	.17	.25	LLD	LLD	.005	.005	.001	.002	.004	.005	.007	.005
13	LLD	LLD	LLD	.30	LLD	LLD	.006	.007	.003	.004	.006	.008	.011	.010
14	LLD	LLD	LLD	LLD	LLD	LLD	.006	.009	.002	.003	.006	.009	.011	.012
15	LLD	LLD	LLD	LLD	LLD	LLD	.006	.008	.002	.004	.006	.010	.011	.014
16	LLD	LLD	LLD	LLD	LLD	LLD	.006	.007	.002	.004	.008	.018	.013	.023
17	LLD	LLD	LLD	LLD	LLD	LLD	.007	.010	.005	.007	.006	.009	.014	.015
18	LLD	LLD	LLD	LLD	LLD	LLD	.007	.010	.007	.009	.006	.007	.016	.017
19	LLD	LLD	LLD	LLD	LLD	LLD	.005	.006	.007	.009	.004	.004	.015	.014
20	LLD	LLD	LLD	LLD	LLD	LLD	.005	.006	.009	.015	.006	.007	.018	.022
21	LLD	LLD	LLD	LLD	LLD	LLD	.007	.009	.017	.022	.005	.007	.028	.031
22	LLD	LLD	LLD	LLD	LLD	LLD	.007	.008	.013	.016	.006	.014	.023	.033
23	LLD	LLD	LLD	LLD	LLD	LLD	.007	.009	.013	.016	.006	.009	.023	.025
24	LLD	LLD	LLD	LLD	LLD	LLD	.007	.012	.009	.010	.006	.007	.018	.018
25	LLD	LLD	LLD	LLD	LLD	LLD	.006	.008	.008	.016	.006	.008	.018	.024
26	LLD	LLD	.17	.35	LLD	LLD	.006	.009	.005	.007	.006	.008	.014	.015
27	LLD	LLD	.02	.37	LLD	LLD	.006	.009	.004	.005	.008	.018	.014	.024
28	LLD	LLD	.15	.67	LLD	LLD	.006	.009	.003	.004	.007	.011	.016	.015
29	LLD	LLD	.35	.57	LLD	LLD	.006	.008	.004	.005	.007	.010	.014	.016
30	LLD	LLD	.22.	.40	LLD	LLD	.006	.008	.005	.007	.008	.013	.016	.020
31	LLD	LLD	.05	.10	LLD	LLD	.004	.007	.006	.008	.006	.008	.015	.017

LLD = Lower Limit of Detection; ND = No Data

*Figures for the 24-hour average of NO_X contain an approximate bias of .003 ppm due to inclusion at calibration.

4.0 AIR QUALITY

This chapter describes air quality monitoring at WIPP. Seven classes of atmospheric gases are being monitored continually at the site: carbon monoxide (CO), hydrogen sulfide (H_2S), ozone (O_3), oxides of nitrogen (NO, NO_2, NO_x), and sulfur dioxide (SO_2). All are EPA-regulated pollutants. Another parameter being measured in conjunction with the atmospheric gases are the total suspended particulates (TSP). These are quantified at the Far Field sampling site, located one kilometer northwest (downwind) of the exhaust shaft.

4.1 AIR QUALITY MONITORING INSTRUMENTATION

The Atmospheric Monitoring Station (AMS), manufactured by Thermo Electron, Inc., is located in the northwest (downwind) corner of WIPP Zone I. This system operates continually and reports pollutant gas concentrations as parts per million (ppm). The AMS is composed of seven analyzers, two data logging devices, and three bottles of calibration gases (NBS traceable). Detailed descriptions of these instruments and their respective modes of operation are given in the Ecological Monitoring Program Annual Report for 1986 (Fischer, 1987).

At 6:00 a.m. each day, the AMS system performs an automatic calibration verification cycle, or "span check." Each analyzer, in specific sequence, takes in a measured amount of calibration gas and resets its output scale according to this concentration. After the span check cycle, the instrument performs a "zero check." This is identical to the span check except that the ambient air being tested has been passed through scrubbers to remove the compounds which the analyzer measures. This procedure sets the zero reading of the instrument.

Each analyzer in the AMS continually monitors the ambient air. At the beginning of each hour, the Sum-X datalogger records a summary of the prior hour's recorded data averaged over a specified interval for that hour. Also recorded at this time is the hourly average of the data collected. At the end of each day, a daily summary is recorded, which is a list of the past 24 hourly averages. The daily average, which is an average of the hourly averages, is then recorded.

4.2 RESULTS AND DISCUSSION

Operation of the AMS system began on August 27, 1986. Tables 4.1 and 4.2 list daily averages and maximum concentrations of pollutant gases from October 1 through December 31, 1986, and January 1 through December 31, 1987, respectively. No data was available for February, March, April 1 through 15, and September of 1987. LLD indicates that the concentration of gas was less than the analyzer's limit of detection. For each gas, the maximum hourly concentration is recorded for that day. The mean is the average of all hourly averages for the day. Between April 29, 1987, and May 20, 1987, the SO_2 levels exceeded the New Mexico air quality standards for 24-hour averages. No known source from WIPP has been determined to be responsible for the elevated levels. Natural gas, or other extractive activities in the vicinity of WIPP, may be the cause.

Another air quality parameter, total suspended particulates (TSP), is measured in conjunction with the aerosol sampling program of the Regulatory and Environmental Surveillance Program. These data are presented in Table 4.3. The TSP values are all below the New Mexico air quality standard values.

4.3 CONTINUING PROGRAM

The gases discussed in this chapter will be monitored at WIPP on a continual basis by the instruments in the AMS.

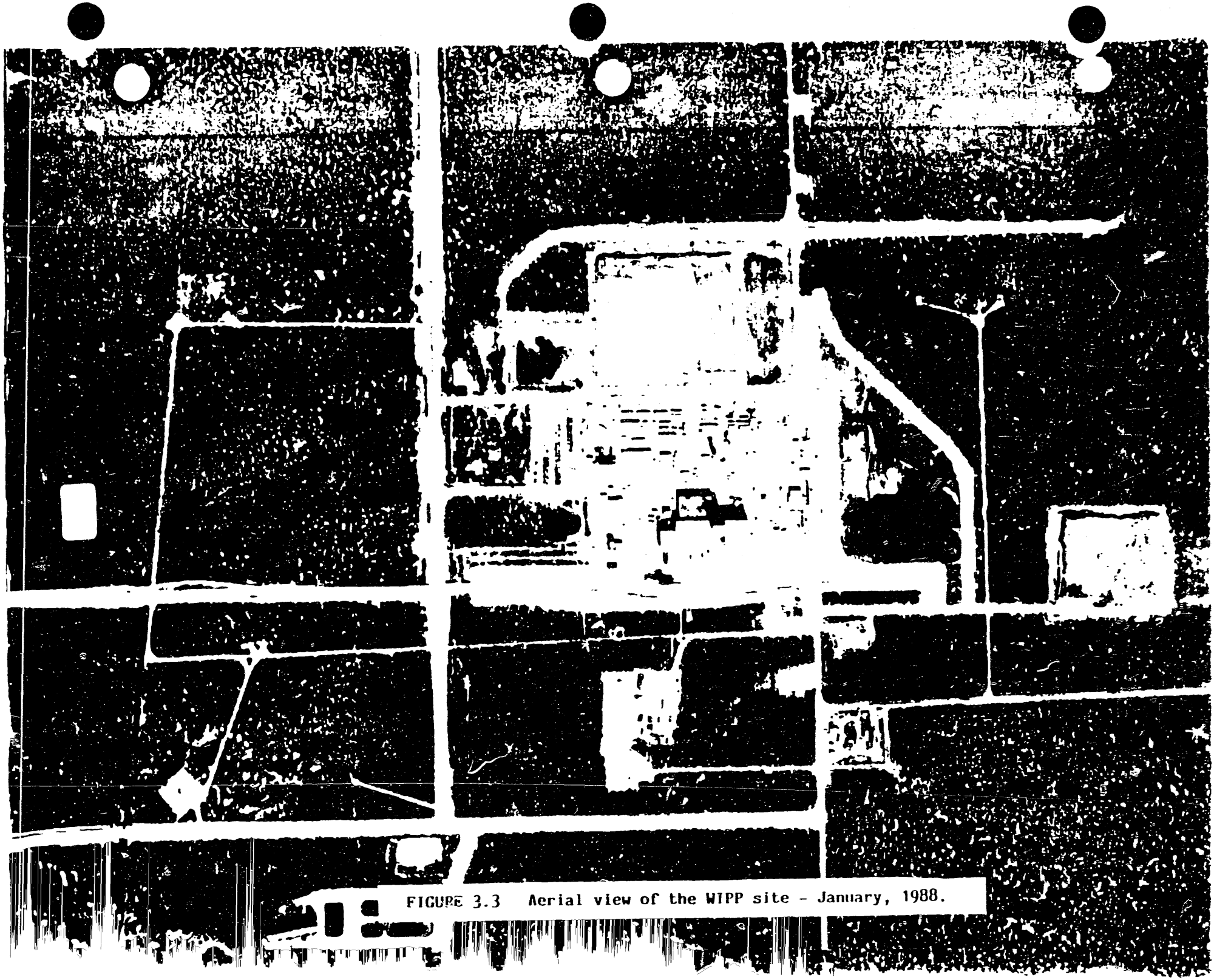


FIGURE 3.3 Aerial view of the WIPP site - January, 1988.

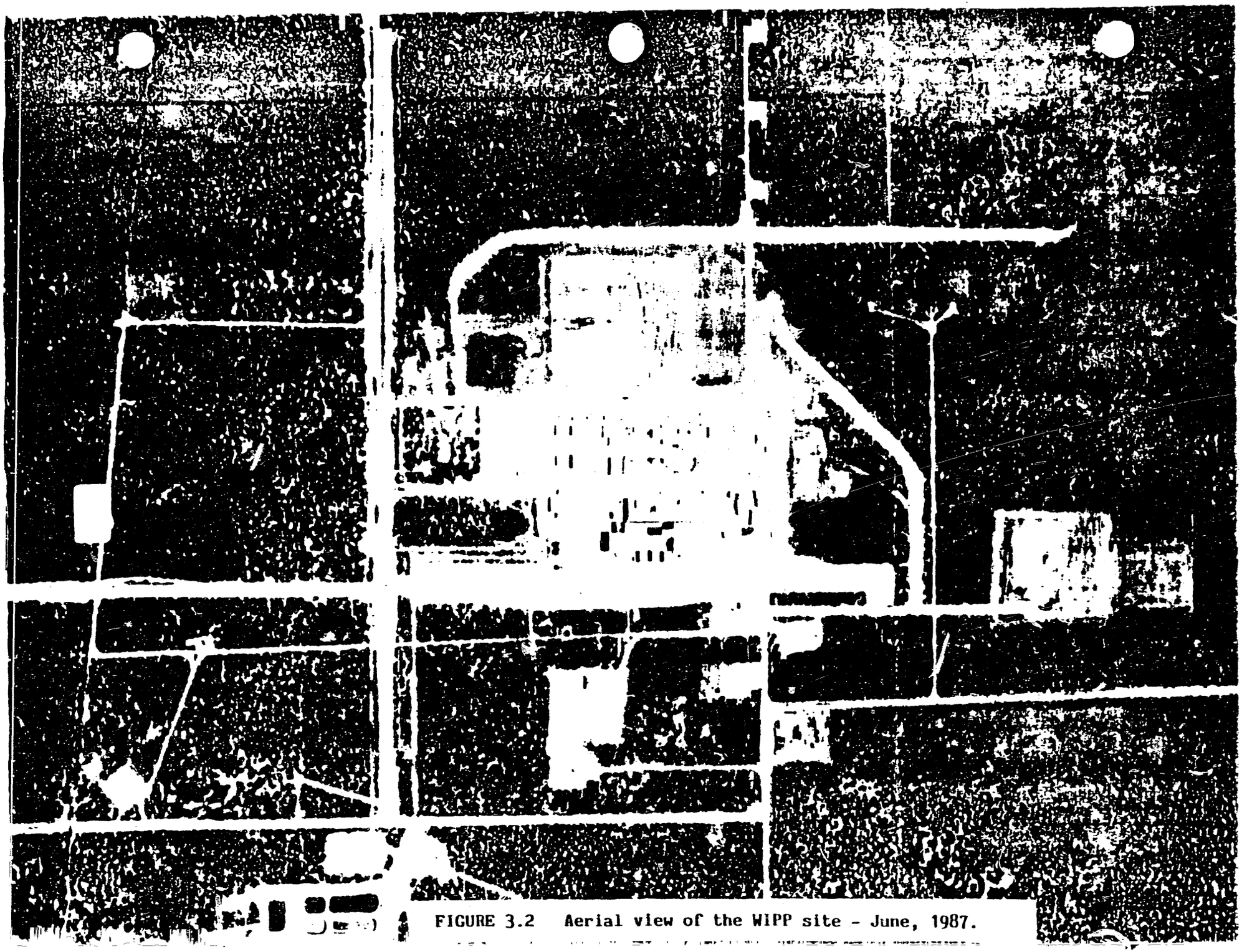


FIGURE 3.2 Aerial view of the WIPP site - June, 1987.

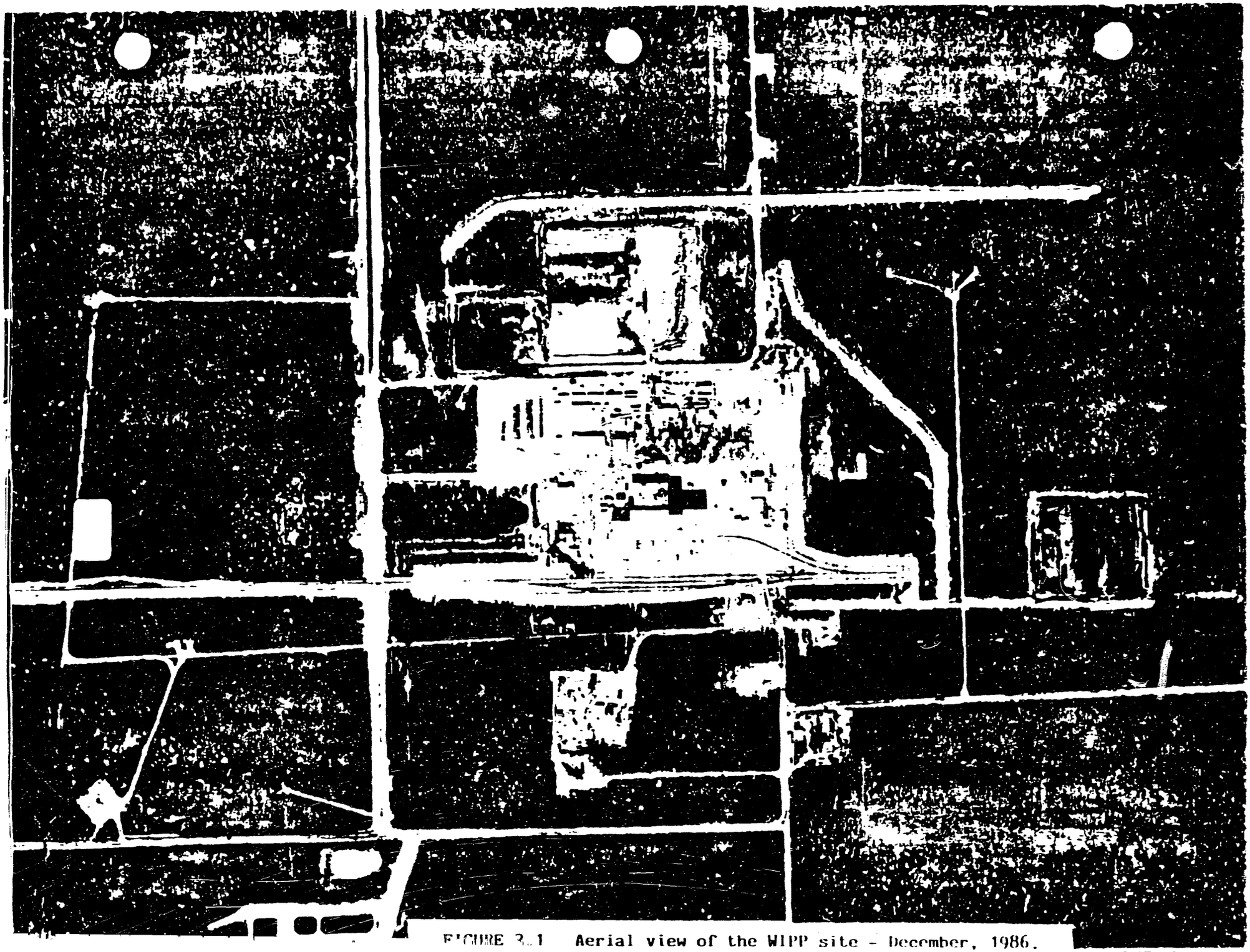


FIGURE 3.1 Aerial view of the WIPP site - December, 1986.

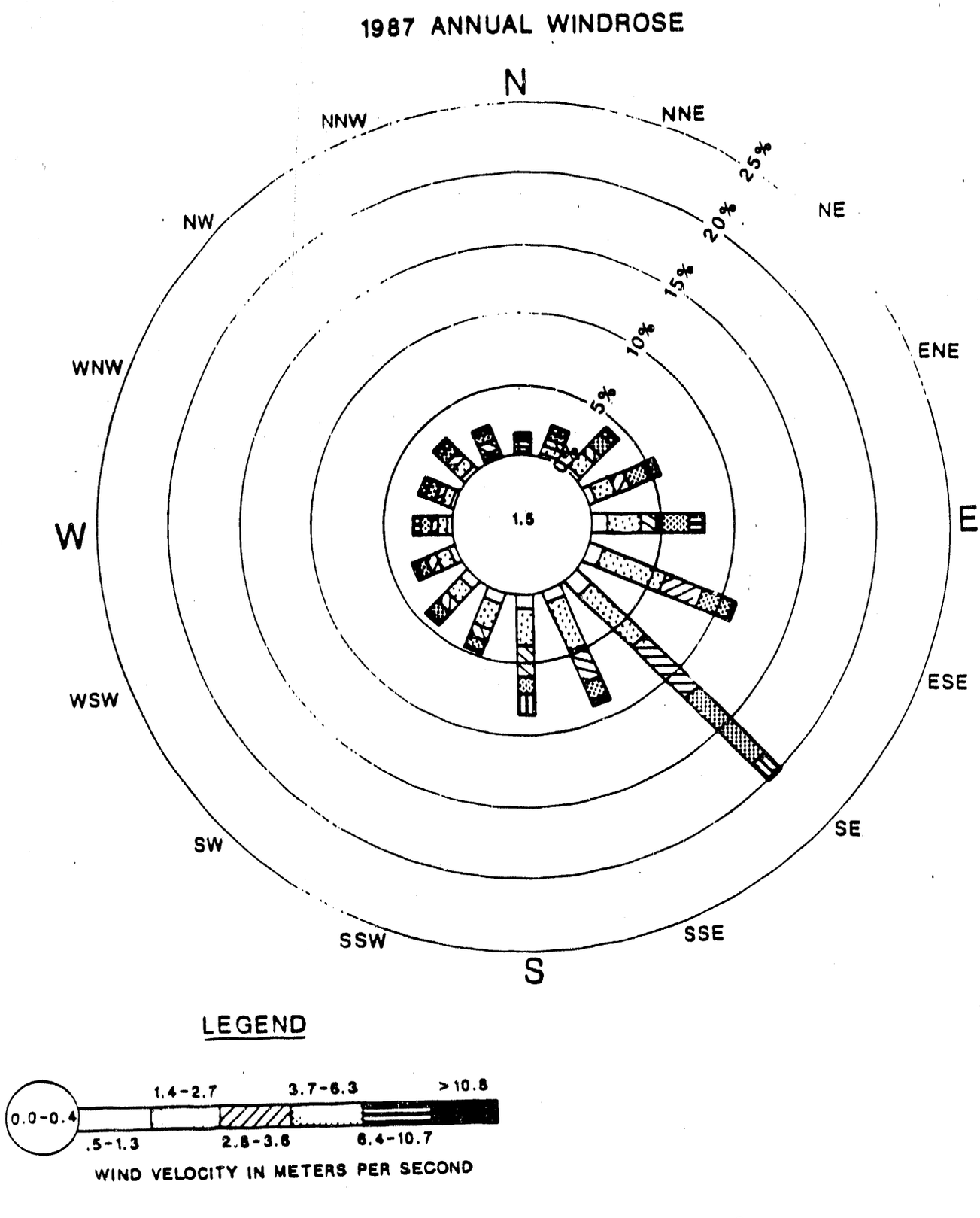


FIGURE 2.9 Annual windrose for 1987.

3.0 ENVIRONMENTAL PHOTOGRAPHY

The purpose of the environmental photography subprogram is to establish a long-term photographic record of environmental conditions around the WIPP site. In particular, this program documents the land use patterns and quantity of land disturbed at the WIPP site. The program includes the production of a photographic record which can be used to evaluate the effects of construction or operations on the environment.

3.1 METHODS

Aerial photographs of the WIPP site have been taken semiannually, in June and November or December, since 1982. These photographs are archived for future reference and for use by the Regulatory and Environmental Programs Section.

3.2 RESULTS AND DISCUSSION

Aerial photographs document surface construction and development activities to date. Figures 3.1, 3.2, and 3.3 are black and white reproductions of aerial photographs taken in December, 1986; June, 1987; and January, 1988; respectively. Poor weather conditions delayed the photo run scheduled for December, 1987. Color prints (36"x36") are on file at the WIPP site with the Regulatory and Environmental Programs Section.

These photos show no significant new surface disturbance since the previous report. At that time, the total disturbed area was approximately 66 hectares, 12 hectares less than the area of disturbance projected in the Final Environmental Impact Statement (DOE, 1980).

3.3 CONTINUING PROGRAM

Future rounds of aerial photography will follow the flight lines described in Reith et al. (1985). Should aerial information be required for more remote locations, the photo coverage may be expanded or modified on some future missions.

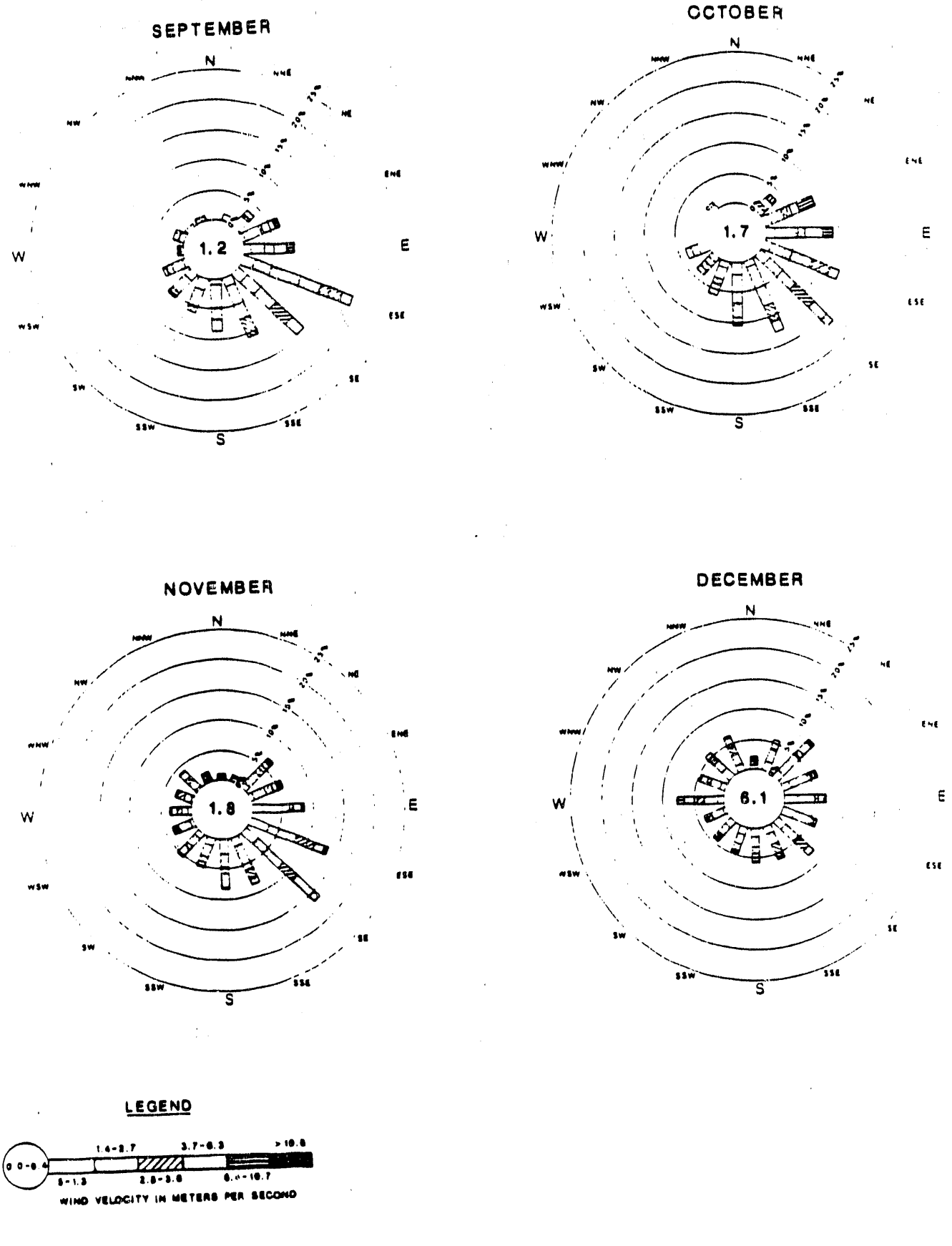


FIGURE 2.8 Windroses for September through December, 1987.

eight kilometers southwest of the WIPP site. The weather instruments monitored during the time of this sighting, but showed no change. Although prevailing winds are from the SSE, SE, and ESE, winds were recorded from all directions during the winter months.

Figure 2.9 shows the annual windrose for 1987. Winds greater than 8.5 meters per second were recorded from all 16 directions. Most of the time, wind speeds fall in the 1.4 through 2.7 meters-per-second category.

2.3 CONTINUING PROGRAM

Weather parameters will continue to be measured and reported in future EMP reports. Barometric pressure and humidity sensors have been installed and these data will be included in future reports.

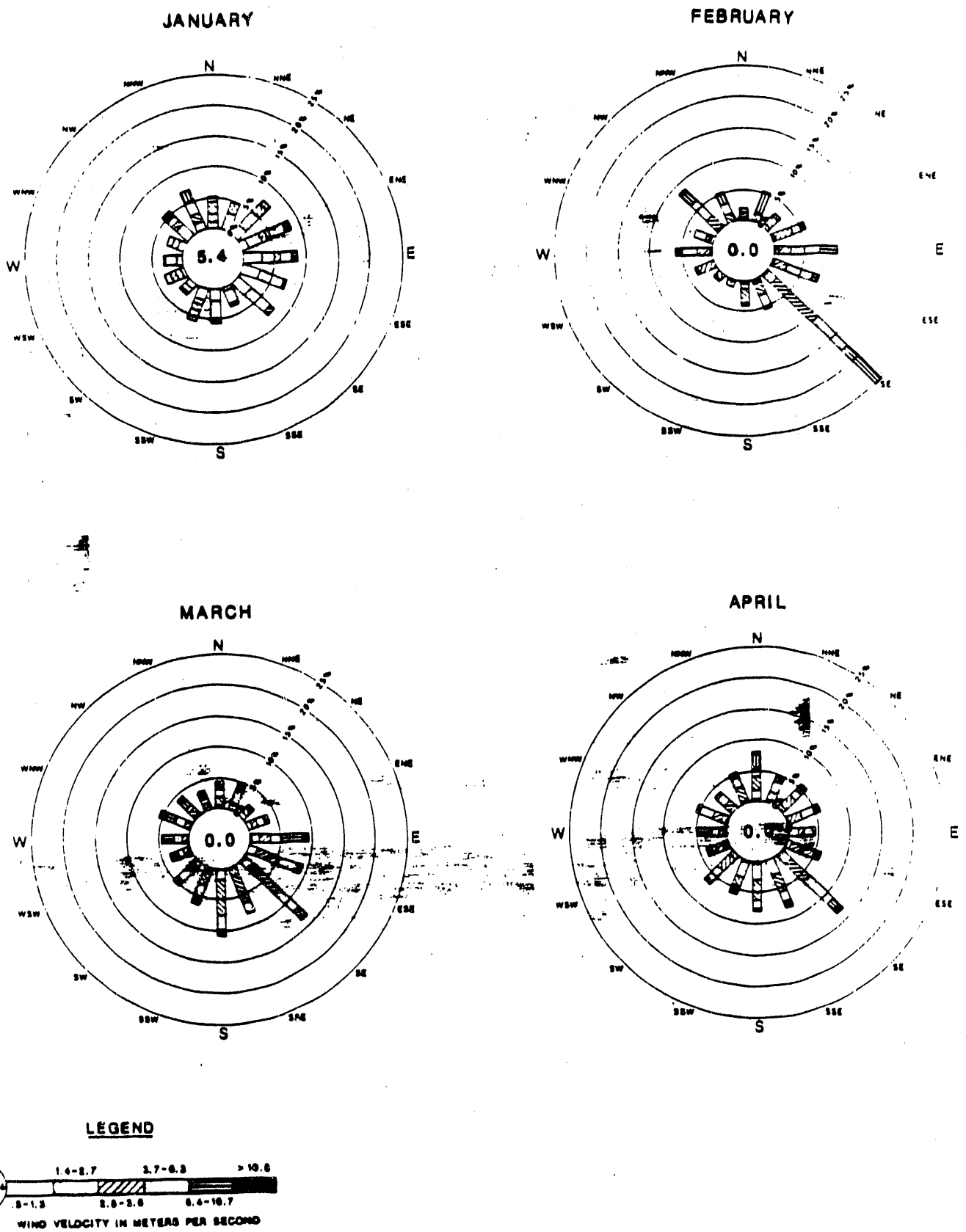


FIGURE 2.6 Windroses for January through April, 1987.

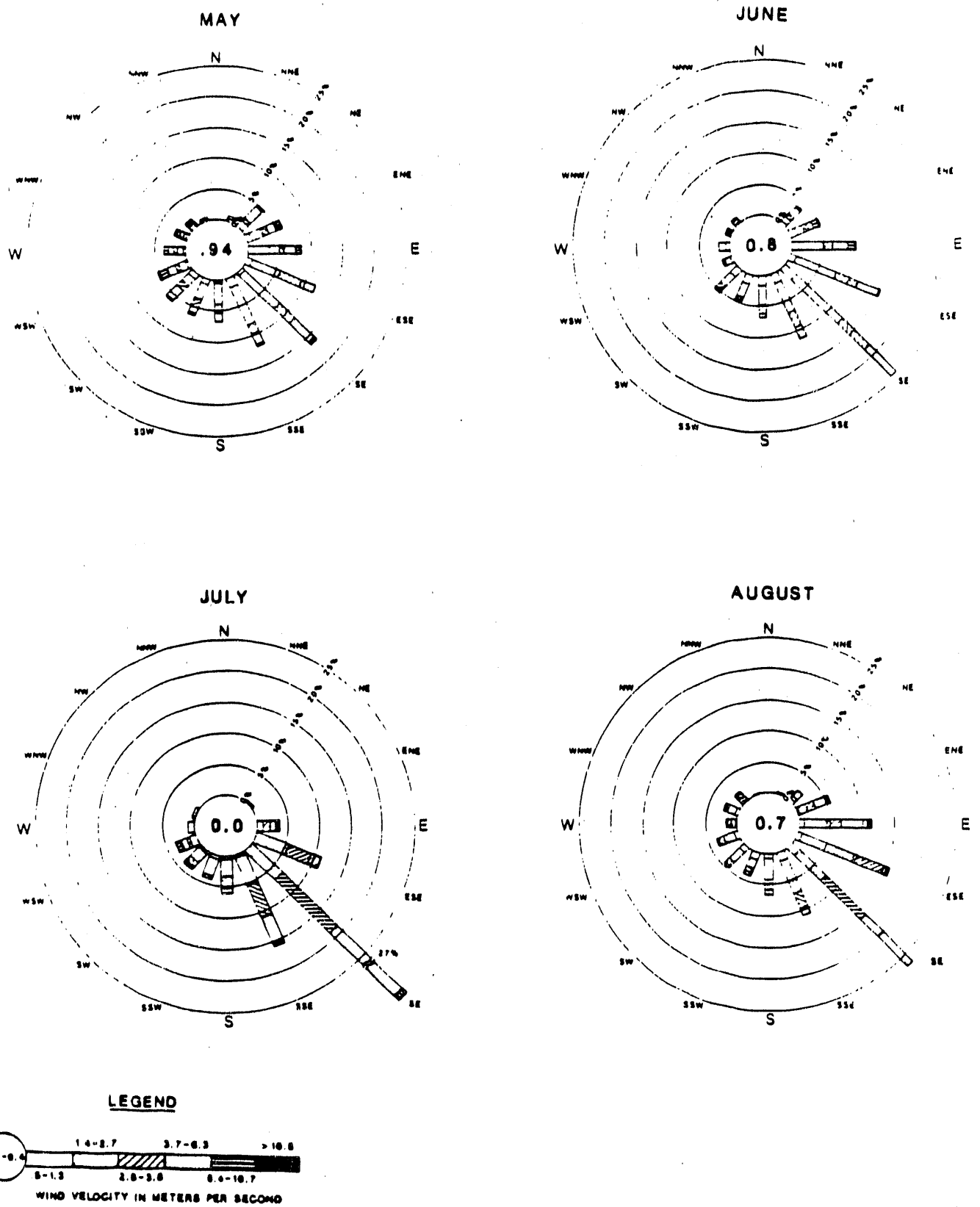


FIGURE 2.7 Windroses for May through August, 1987.

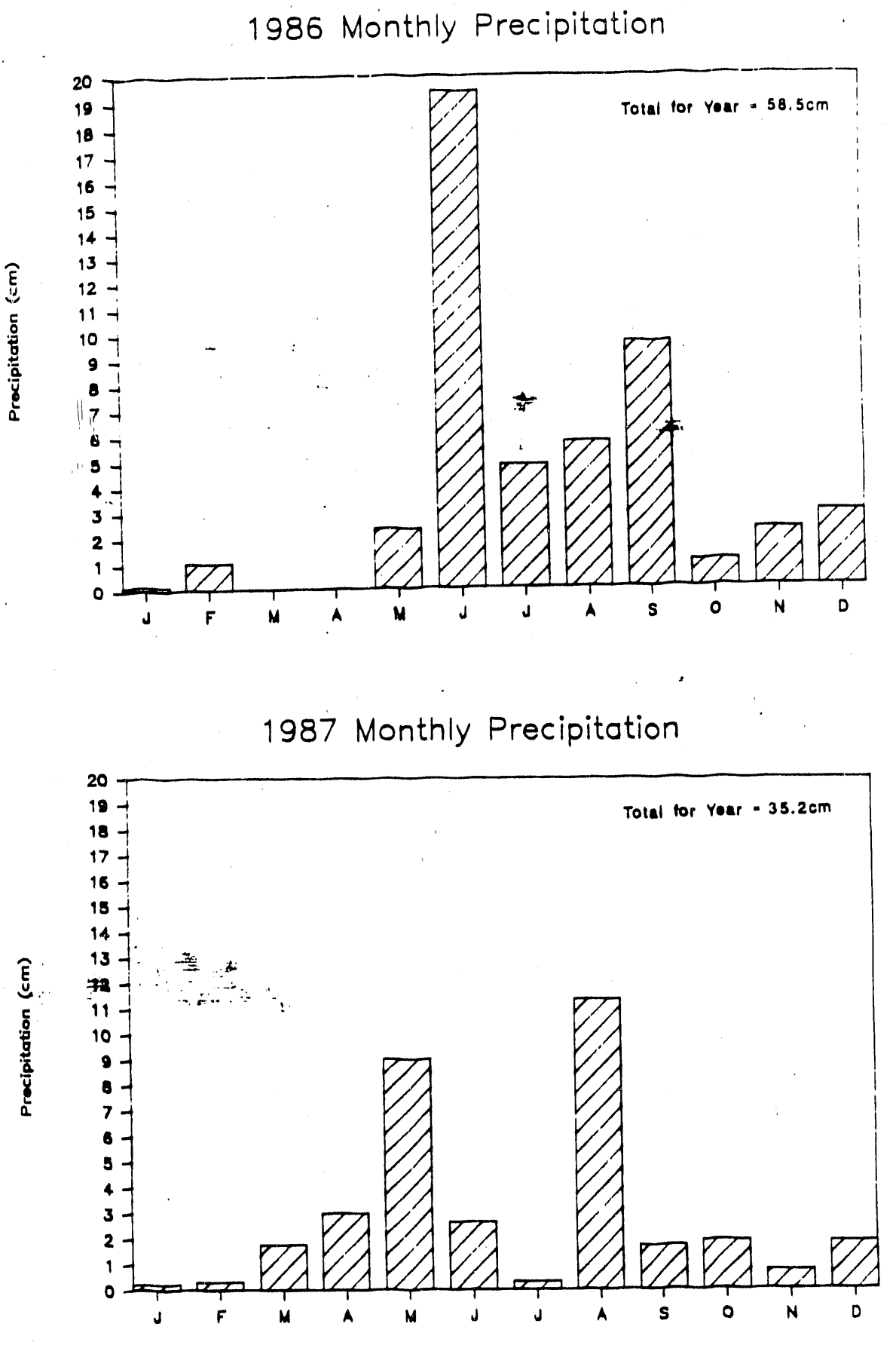


FIGURE 2.4 Precipitation for 1986 (Top) and 1987 (Bottom).

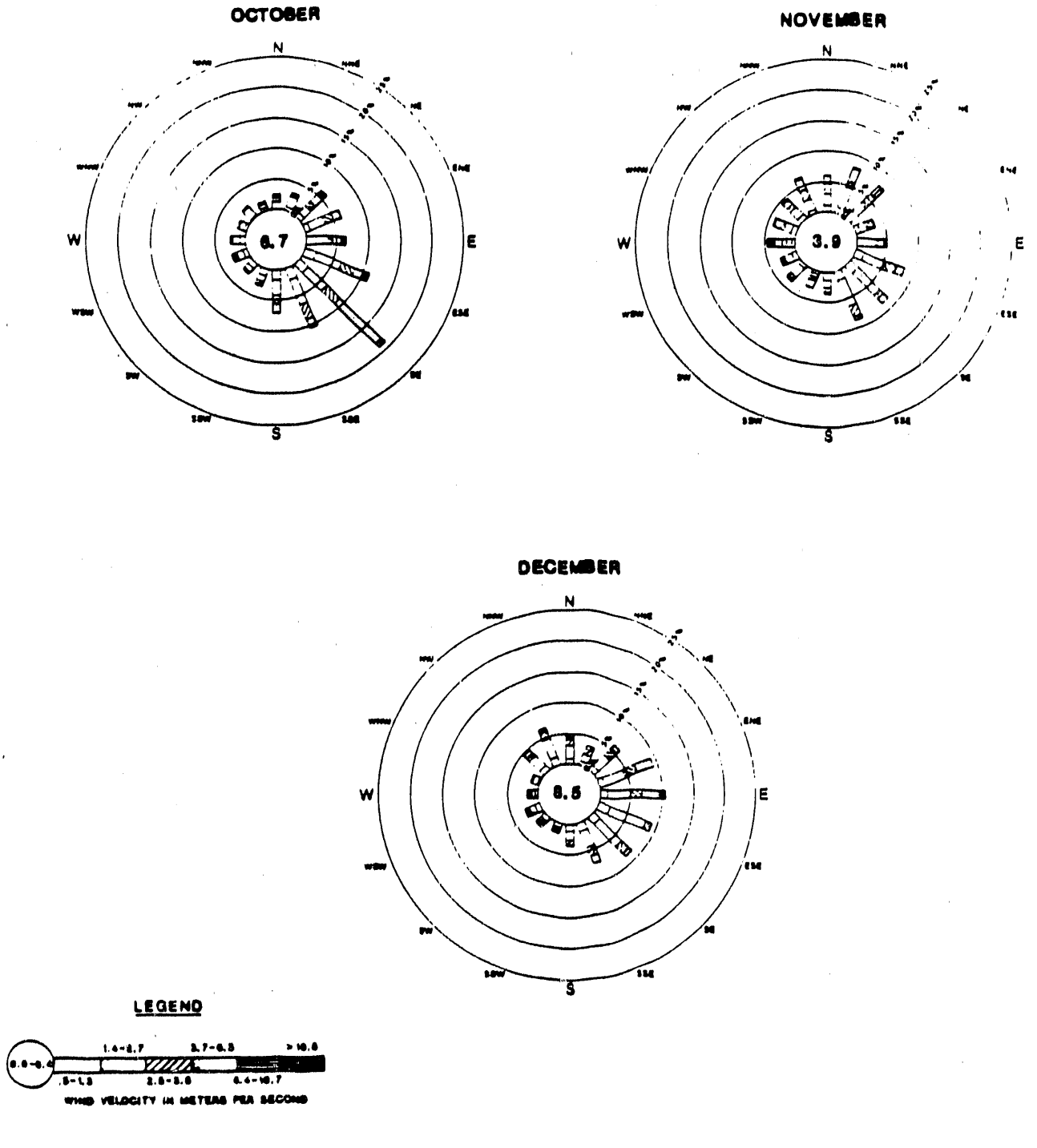


FIGURE 2.5 Windroses for October through December, 1986.

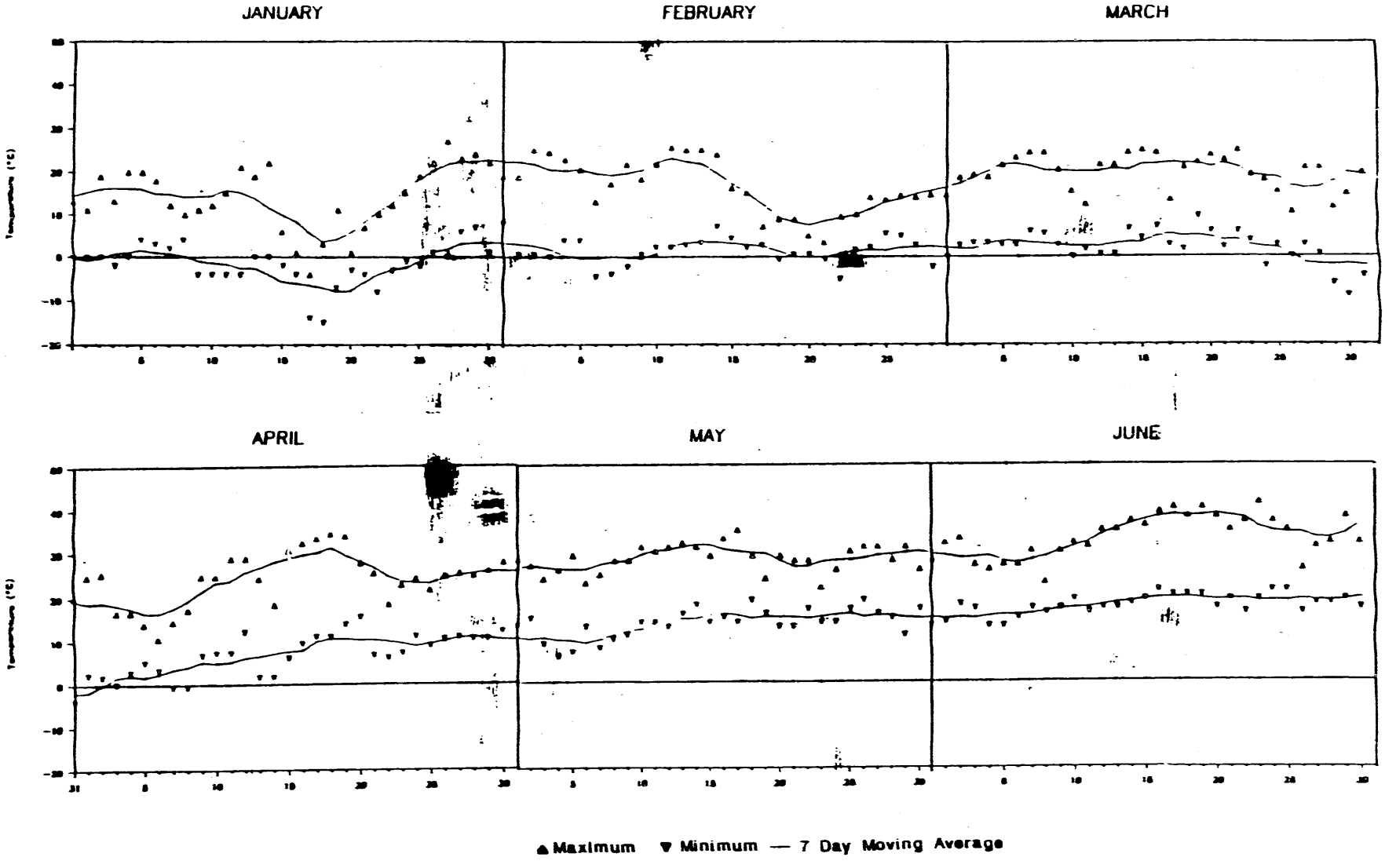


FIGURE 2.2 Daily maximum/minimum temperatures at the WIPP site, January through June, 1987.

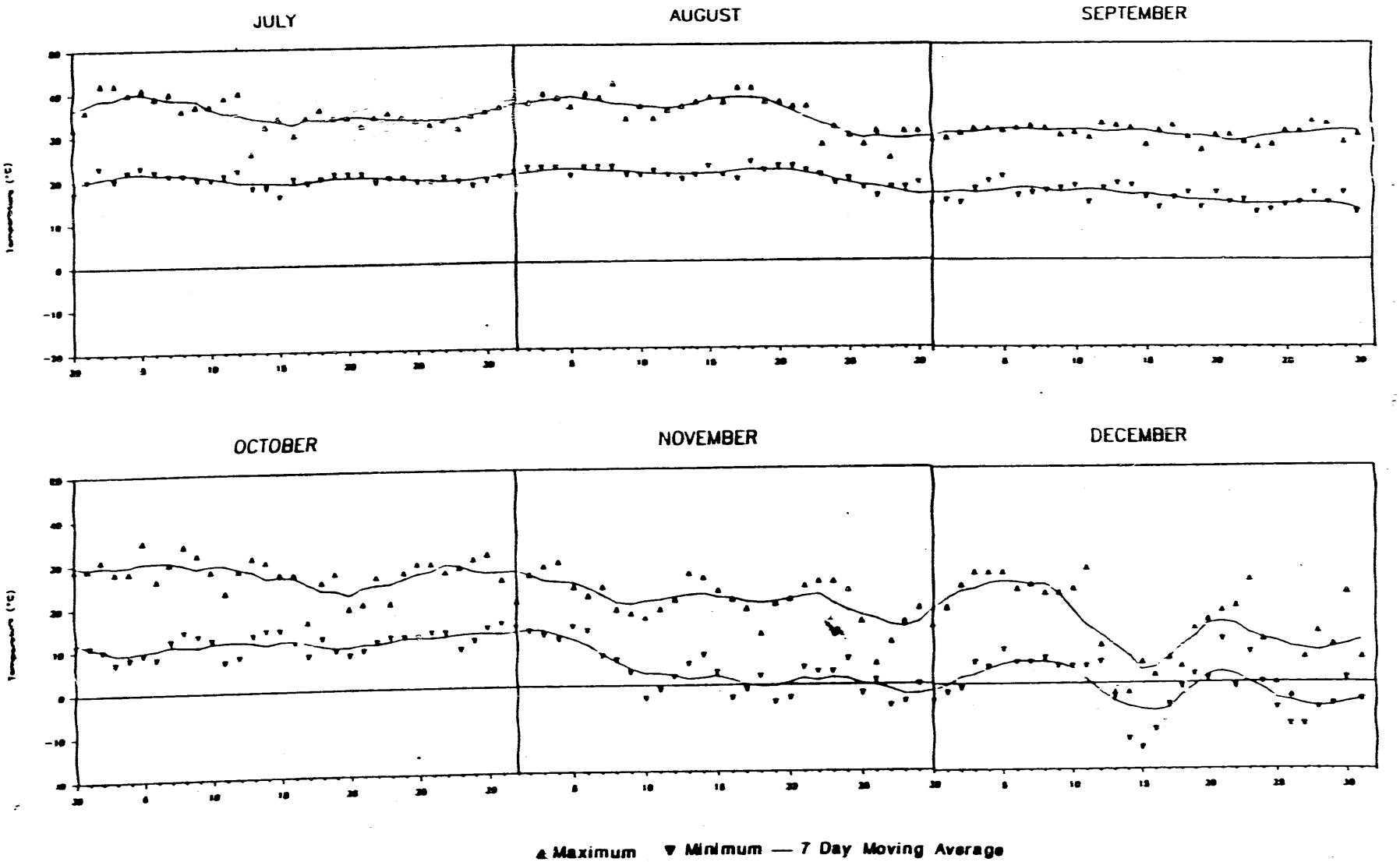


FIGURE 2.3 Daily maximum/minimum temperatures at the WIPP site, July through December, 1987.

2.0 METEOROLOGY

As previously described (Fischer et al., 1987), the Ecological Monitoring Program has measured weather parameters at the WIPP Site since September, 1984. The purpose is to provide a continuous record of meteorological data to support the Radiological and Nonradiological Environmental Surveillance programs and other monitoring programs at WIPP. Wind speed, wind direction, and ambient temperature are being recorded continuously. Humidity and barometric pressure sensors were added to the system in August, 1986. Rainfall is measured daily. Maximum and minimum temperature data is compiled from five additional locations in southeastern New Mexico. Meteorological data are summarized for October through December, 1986 (Appendix 2-A), and January through December, 1987 (Appendix 2-B).

2.1 METEOROLOGICAL MONITORING INSTRUMENTATION

Currently, the weather monitoring instruments are located approximately 20 meters northwest of the core storage building within the Zone I Boundary (Figure 1.2). The wind data are collected from instruments elevated ten meters above the ground, while temperature and rainfall are measured approximately two meters above the ground.

On September 1, 1986, the WIPP Site was designated as an official National Oceanic Atmospheric Administration (NOAA) record station. Since that date the precipitation data have been taken from the rain gauge provided by NOAA.

2.2 RESULTS AND DISCUSSION

This section summarizes the weather data for the fourth quarter of 1986 and for 1987.

Daily Maximum/Minimum Temperatures at WIPP. Daily minimum and maximum temperatures are graphed in Figure 2.1 (1986) and Figures 2.2 and 2.3 (1987). In the last quarter of 1986, a low maximum temperature of 1°C was recorded on December 11, along with the low minimum temperature of -6°C. Temperature fluctuation is greatest in the winter and early spring, reflecting the periodic movement of cold air masses through the WIPP area. Drops of ten degrees or more in daily maximums are not uncommon during this time.

Figures 2.2 and 2.3 illustrate the maximum and minimum temperatures for 1987. The last freezing day (-1°C) of the year occurred on April 7, and the first freezing day (-3°C) occurred on November 10. The maximum temperature exceeded 38°C 24 days out of the year. The minimum temperature fell below 0°C.

Precipitation. Precipitation data (Figure 2.4) are provided for 1986 and 1987. A total of 58.5 centimeters of precipitation fell in 1986. The highest monthly precipitation (19.4 centimeters of precipitation) fell in June. Total precipitation for 1987 was 35.2 centimeters. The highest monthly precipitation (11.3 centimeters) fell in August. Rainfall for the southeastern plains averages 30.5 centimeters (Ken Kunkle, State Meteorologists, personal communication). Rainfall in 1986 was well above the average, while the amount of rain falling in 1987 was close to the average (Appendix 2-C).

Snowfall. Snowfall is a rare occurrence in southeastern New Mexico. Approximately 0.83 centimeters of snow fell on December 13 and 14, 1987, with a trace falling on December 25.

Wind Direction and Wind Speed. Hourly average wind data from the Sum-X data logger (see Chapter 4 for a description of the Sum-X logging system) are compiled into monthly windroses illustrated in Figures 2.5 through 2.8. Wind speeds rarely fell below 1.3 meters per second, the lowest measurable speed during the 15 months of record. On two occasions (April 11 and 12, 1987) windgusts over 20 meters per second were recorded from the northeast. On May 15, 1987, a funnel cloud was sighted approximately

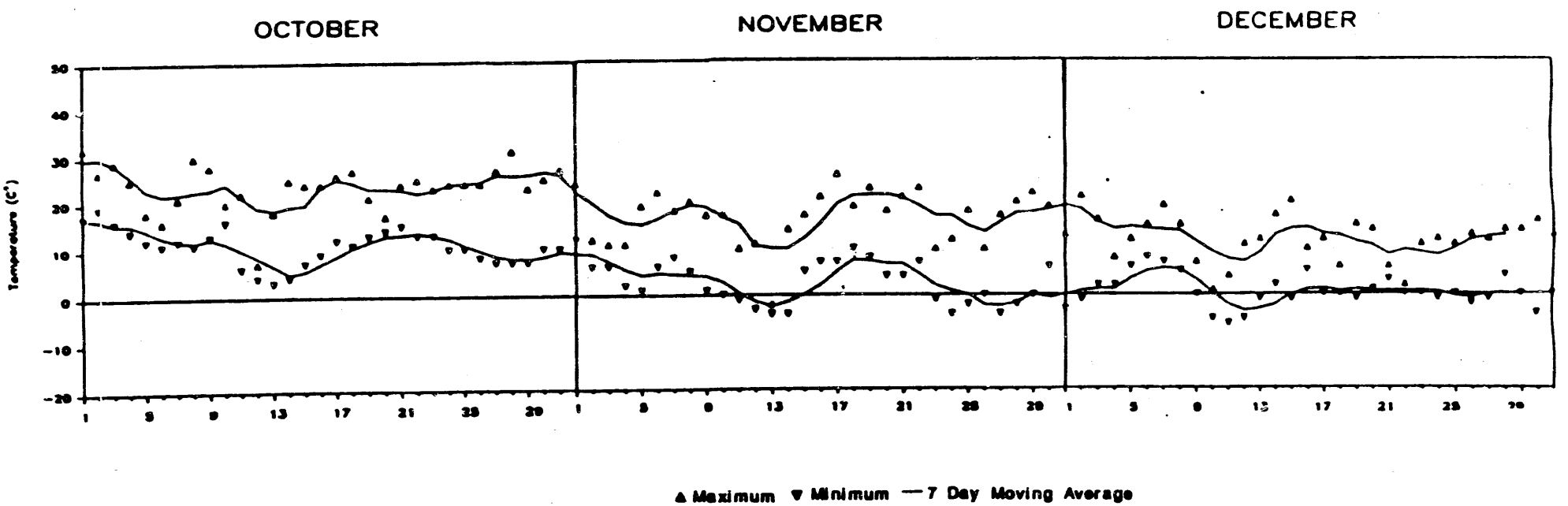


FIGURE 2.1 Daily maximum/minimum temperatures at the WIPP site, October through December, 1986.

monitoring includes five subprograms, surface disturbance monitoring through the analysis of aerial photographs, air quality monitoring, water quality monitoring, wildlife population monitoring, and meteorological monitoring.

The second part comprises those data which are being collected specifically to address the question of whether salt is being transported away from the surface storage piles and if so, what impacts it is having in the surrounding ecosystem. Data collection activities for these studies are focused on seven permanent Ecological Monitoring Plots, located at various distances and directions from saltpiles, including five in potentially affected areas (see Figure 1.2) and two control plots situated outside of the area of probable impact. The salt impact studies include three subprograms: soil chemistry, soil microbial activity, and vegetation. The results of the environmental monitoring activities and discussions of significant findings are presented in this report.

One change in this study design which occurred during the current reporting period is the relocation of the Control 2 site approximately 300 meters to the south southeast in order to bring the plot completely within the WIPP Site Boundary. A quantitative comparison of vegetation between this new location and the old, as well as between the new location and the other plots, was performed on the 1987 fall vegetation survey data and the results of these comparisons are presented in Chapter 9.

Unless otherwise noted, all methods used in data collection are those described in the first Ecological Monitoring Program semiannual report (Reith et al., 1985) and incorporating the modifications described in subsequent reports (Fischer, 1985; Fischer, 1987).

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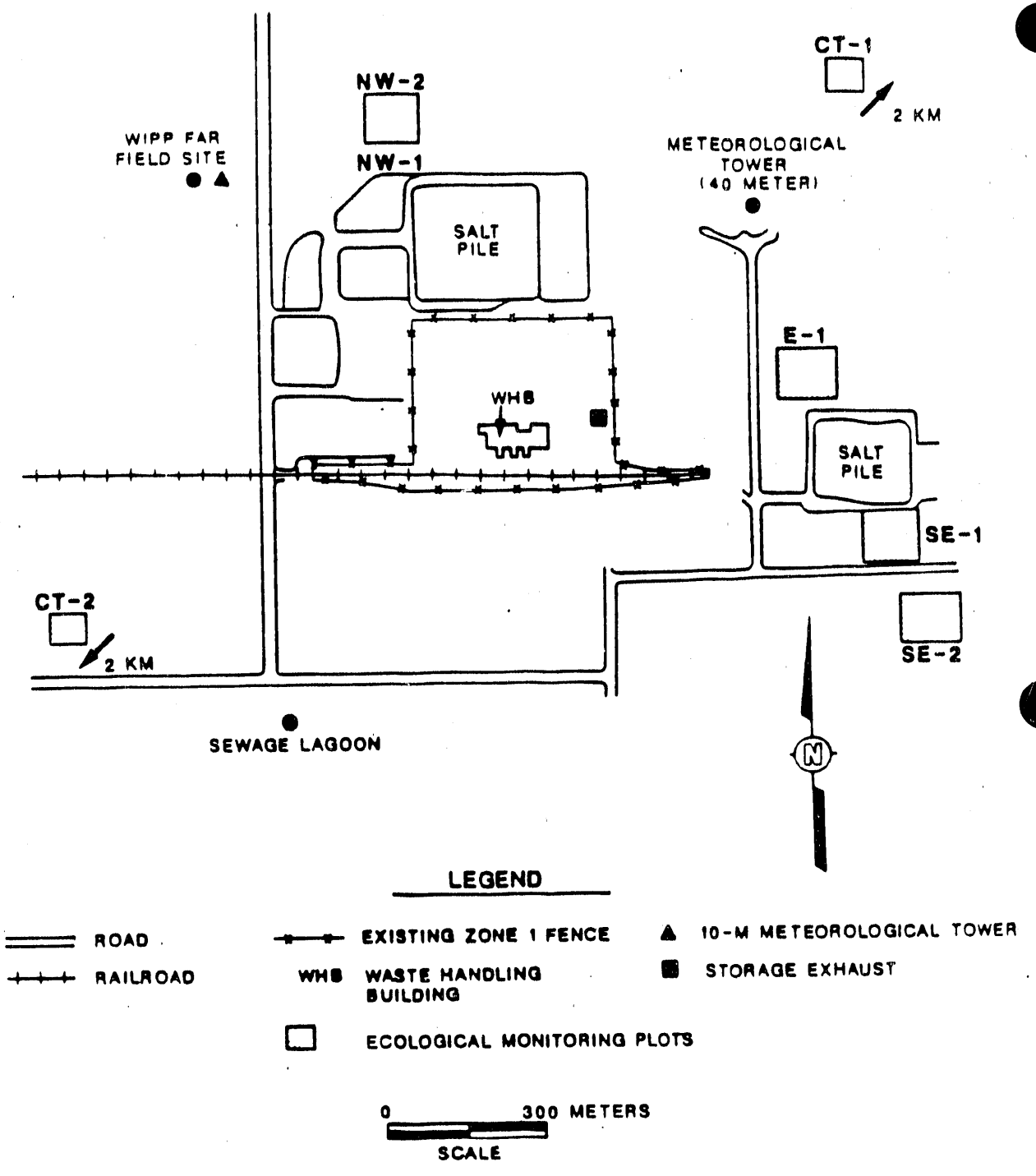

FIGURE 1.2 OVERVIEW OF SURFACE FACILITIES

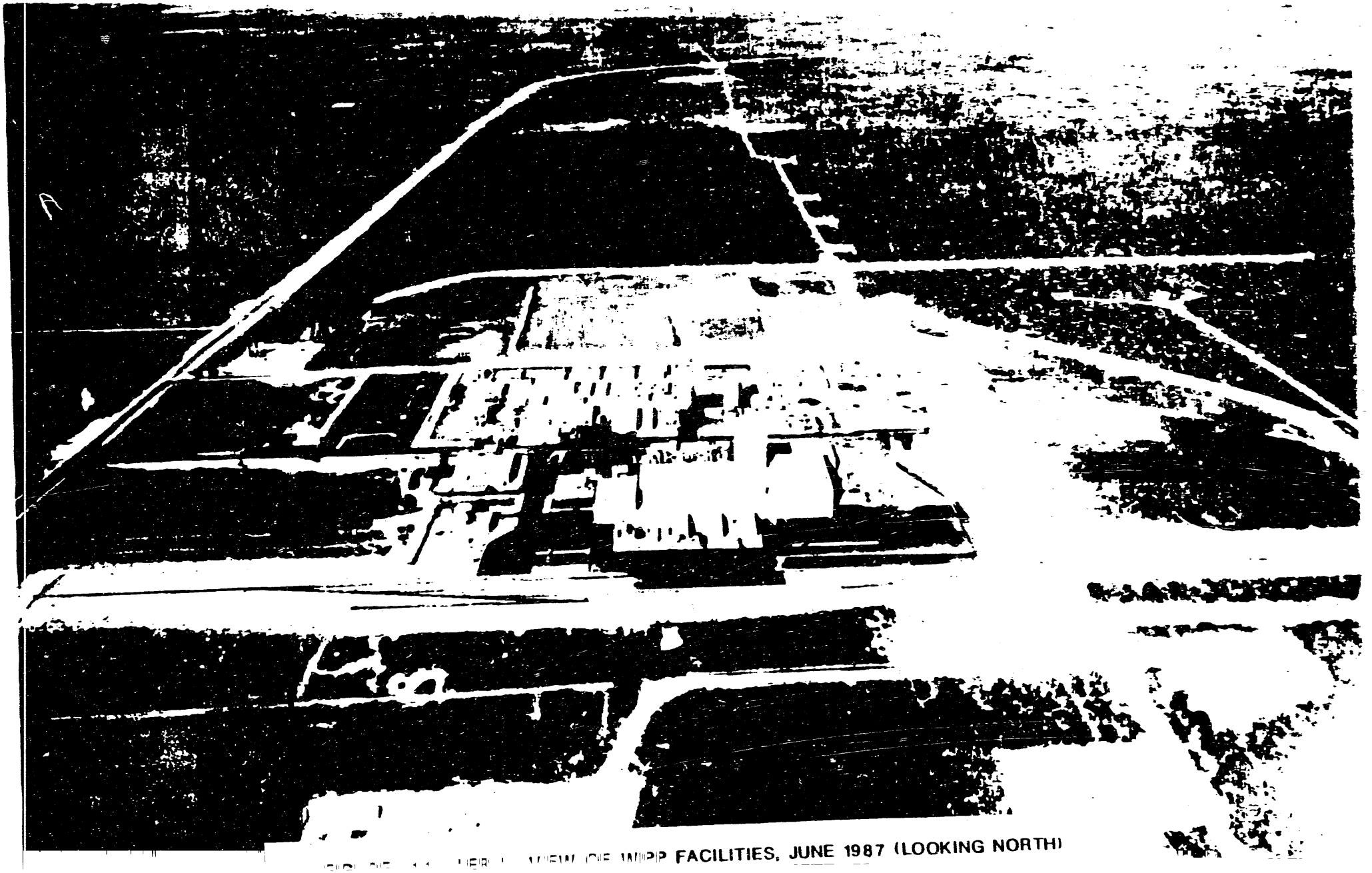

FIGURE 1.1 AERIAL VIEW OF WIPP FACILITIES, JUNE 1987 (LOOKING NORTH)

1.0 INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is a research and development facility operated by the U.S. Department of Energy (DOE) to demonstrate the safe disposal of transuranic (TRU) radioactive wastes derived from the defense activities of the United States. Containerized TRU wastes will be transported to the plant and emplaced in bedded salt of the Salado Formation, 655 meters below ground surface. Details of the project and its mission are presented in the WIPP Final Environmental Impact Statement (FEIS) (DOE, 1980) and the WIPP Safety Analysis Report (SAR) (DOE, 1988).

1.1 GENERAL SITE DESCRIPTION

WIPP is located approximately 40 kilometers east-southeast of Carlsbad, New Mexico, on a flat, sandy plain known as Los Medanos ("the dunes"). The surface facilities, currently under construction (Figure 1.1), will cover approximately 80 hectares and consist of a variety of buildings (including a large waste handling building, warehouses, offices, maintenance shops, and other support buildings), shaft headframes, roads, a lighted parking area, and a sewage stabilization facility. Paved, two-lane roads provide access to the site from three directions (north, south, and east) and a railroad spur enters the site from the west.

In addition to these surface facilities, two locations are being used for the stockpiling of topsoil and two locations have been designated for the stockpiling of mined materials, or "muck", consisting principally of salt (NaCl). Flow-control structures (e.g., berms and channels) have been constructed to prevent these materials from being transported off site by surface runoff. A holding pond collects water from the active saltpile north of the site. Runoff from the older, "SPDV" saltpile east of the site is retained in a surrounding moat. An overview of the surface facilities is shown in Figure 1.2.

1.2 ECOLOGICAL MONITORING PROGRAM AT WIPP

The Ecological Monitoring Program (EMP) is conducted by the Regulatory and Environmental Programs Section (formerly Radiological and Environmental Programs Section) of the Safety, Security and Environmental Protection Biology Program (1975-1982), which combined scientific and technical expertise from six universities to develop an extensive baseline of information describing the major components of the Los Medanos Ecosystem prior to the initiation of WIPP construction activities (see Reith et al., 1985, for a summary of this program). The principal functions of the EMP are:

- To detect and quantify the impacts of construction and operational activities at the WIPP on the surrounding ecosystem
- To continue the development of the ecological database for the Los Medanos Area initiated by the WIPP Biology Program
- To investigate unusual and unexpected elements in the ecological and radiological databases
- To provide environmental data which are important to the mission of the WIPP project, but which have not or will not be acquired by other programs.

This report presents and discusses data collected between October 1, 1986, and December 31, 1987, as part of the EMP. The data are divided into two main types: general environmental monitoring (Part A) and salt impact studies (Part B). The first includes those data which are being collected as a general assessment of the impacts of WIPP construction activities on the surrounding environment and those data which are being collected in support of other WIPP programs. The general environmental

EXECUTIVE SUMMARY

This document reports data collected as part of the Ecological Monitoring Program (EMP) at the Waste Isolation Pilot Plant near Carlsbad, New Mexico, for Calendar Year 1987. Also included are data from the last quarter (October through December) of 1986.

This report divides data collection activities into two parts. Part A covers general environmental monitoring which includes meteorology, aerial photography, air quality monitoring, water quality monitoring, and wildlife population surveillance. Part B focuses on the special studies being performed to evaluate the impacts of salt dispersal from the site on the surrounding ecosystem. The fourth year of salt impact monitoring was completed in 1987. These studies involve the monitoring of soil chemistry, soil microbiota, and vegetation in permanent study plots.

None of the findings indicate that the WIPP project is adversely impacting environmental quality at the site. As in 1986, breeding bird censuses completed this year indicate changes in the local bird fauna associated with the WIPP site. The decline in small mammal populations noted in the 1986 census is still evident in the 1987 data; however, populations are showing signs of recovery. There is no indication that this decline is related to WIPP activities. Rather, the evidence indicates that natural population fluctuations may be common in this ecosystem.

The salt impact studies continue to reveal some short-range transport of salt dust from the saltpiles. This material accumulates at or near the soil surface during the dry seasons in areas near the saltpiles, but is flushed deeper into the soil during the rainy season. Microbial activity does not appear to be affected by this salt importation. Vegetation coverage and density data from 1987 also do not show any detrimental effect associated with aerial dispersal of salt.

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DOE/WIPP-87-008

ECOLOGICAL MONITORING PROGRAM AT THE WASTE ISOLATION PILOT PLANT ANNUAL REPORT FOR CALENDAR YEAR 1987

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ECOLOGICAL MONITORING PROGRAM AT THE WASTE ISOLATION PILOT PLANT

The Ecological Monitoring Program (EMP) at the Waste Isolation Pilot Plant (DOE/WIPP-88-008, CY1987) focuses on nonradiological baseline studies during the preoperational phase at WIPP. EMP sampling activities focus on the plant and animal communities immediately surrounding the site and on the ecological parameters most likely to be affected by construction and operational activities. (Subsequent results of the EMP are published in the Annual Site Environmental Report, Appendix J.)

APPENDIX D6

SITE CHARACTERIZATION

FROM PREVIOUSLY PUBLISHED NO-MIGRATION VARIANCE PETITION,
SECTION 4.0, VOLUME I

U.S. Department of Energy (DOE), 1990,
DOE/WIPP 89-003, Revision 1, Carlsbad, New Mexico

4.0 SITE CHARACTERIZATION

This chapter presents a description of the natural environmental setting at the WIPP facility. Site climatology, air quality, geology, hydrology, and ecology are described in sufficient detail to demonstrate that there will be no migration of hazardous waste from the WIPP facility repository to the environment for as long as the waste remains hazardous. Data collected during preoperational environmental programs are included in the following sections; these characterize background air, soil, and water quality at the site.

The WIPP facility is 40 kilometers (26 miles) east-southeast of Carlsbad in an area known as Los Medanos (the dunes), a relatively flat, sparsely inhabited plateau with little water and limited land uses. Most of the land is owned by the federal government or the State of New Mexico and is used for grazing. Other land uses in the general area include potash mining and oil-and-gas exploration and/or development.

4.1 CLIMATE

The regional and local climate is semiarid with generally warm temperatures. The average annual precipitation is about 30 centimeters (12 inches), of which half is received during summer thunderstorms. Daytime summer temperatures consistently exceed 32°C (90°F) and occasionally rise above 38°C (100°F). Winter temperatures often rise as high as 21°C (70°F) during the afternoon. Nighttime lows during winter average near -5°C (23°F), occasionally dipping below -10°C (14°F). Prevailing winds are from the southeast; however, strong winds are frequent, especially in spring, and can blow from any direction creating potentially violent windstorms which carry large volumes of dust and sand. Figure 4-1 summarizes wind data collected at the site during 1987. Detailed compilations of climatic data, presently collected near the northwest corner of the Zone I boundary (see Figure 2-3), appear in the Ecological Monitoring Program Annual Reports (Fischer et al., 1985; Fischer, 1987, 1988). Additional climatic information appears in the Final Environmental Impact Statement (FEIS) (DOE, 1980) and WIPP Draft Final Safety Analysis Report (FSAR) (DOE, 1988a, Revised 1990).

4.2 AIR QUALITY

Five classes of atmospheric gases are monitored continually at the site: carbon monoxide, hydrogen sulfide, ozone, oxides of nitrogen, and sulfur dioxide at a sampling site located 1 kilometer (0.6 mile) northwest (downwind) of the exhaust shaft. All are EPA-regulated pollutants. In addition, total suspended particulates are measured. Air quality data from the WIPP monitoring station are reported in the Ecological Monitoring Program Annual Report for 1987 (Fischer, 1988) and the Annual Site Environmental Report for 1988 (Flynn, 1989). These data show periodic increases in three of the monitored gases (sulfur dioxide, hydrogen sulfide, and ozone) which exceed the New Mexico air quality standards. Sulfur dioxide exceeded the state standard from April 29 through May 20, 1987. This was an isolated incident and no source of this gas was identified at the WIPP facility (Fischer, 1988). Hydrogen sulfide and ozone regularly exceeded the state standard during the spring and summer months of 1988 (Flynn, 1989) and 1989 (preliminary data). These data are being analyzed against concurrent wind direction data to determine the direction of the source. Preliminary results indicate that this is a regional effect and not the result of gas effluents from the WIPP facility.

4.3 GEOLOGY OF THE WIPP SITE

The WIPP facility is constructed in the bedded salt deposits of the Salado Formation, the second of three evaporite-bearing formations in the Delaware Basin (Figure 4-2). The WIPP facility is designed as a geologic repository and, because it relies principally on geologic barriers to isolate waste, a thorough understanding of the nature of those geologic barriers is necessary. Since 1975, numerous geologic studies have been conducted to determine the suitability of the WIPP facility for long-term waste

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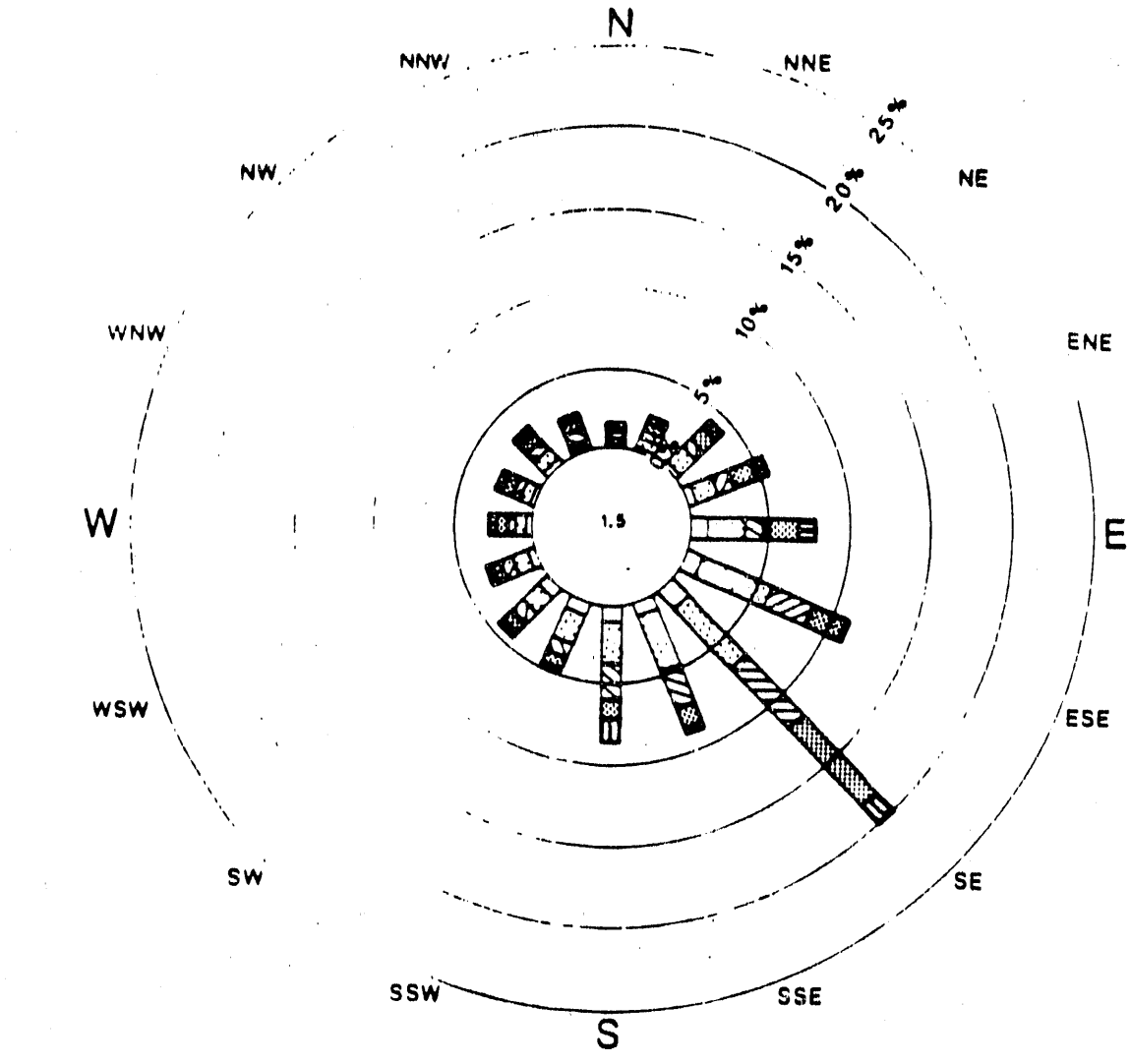

FIGURE 4-1 1987 ANNUAL WINDROSE

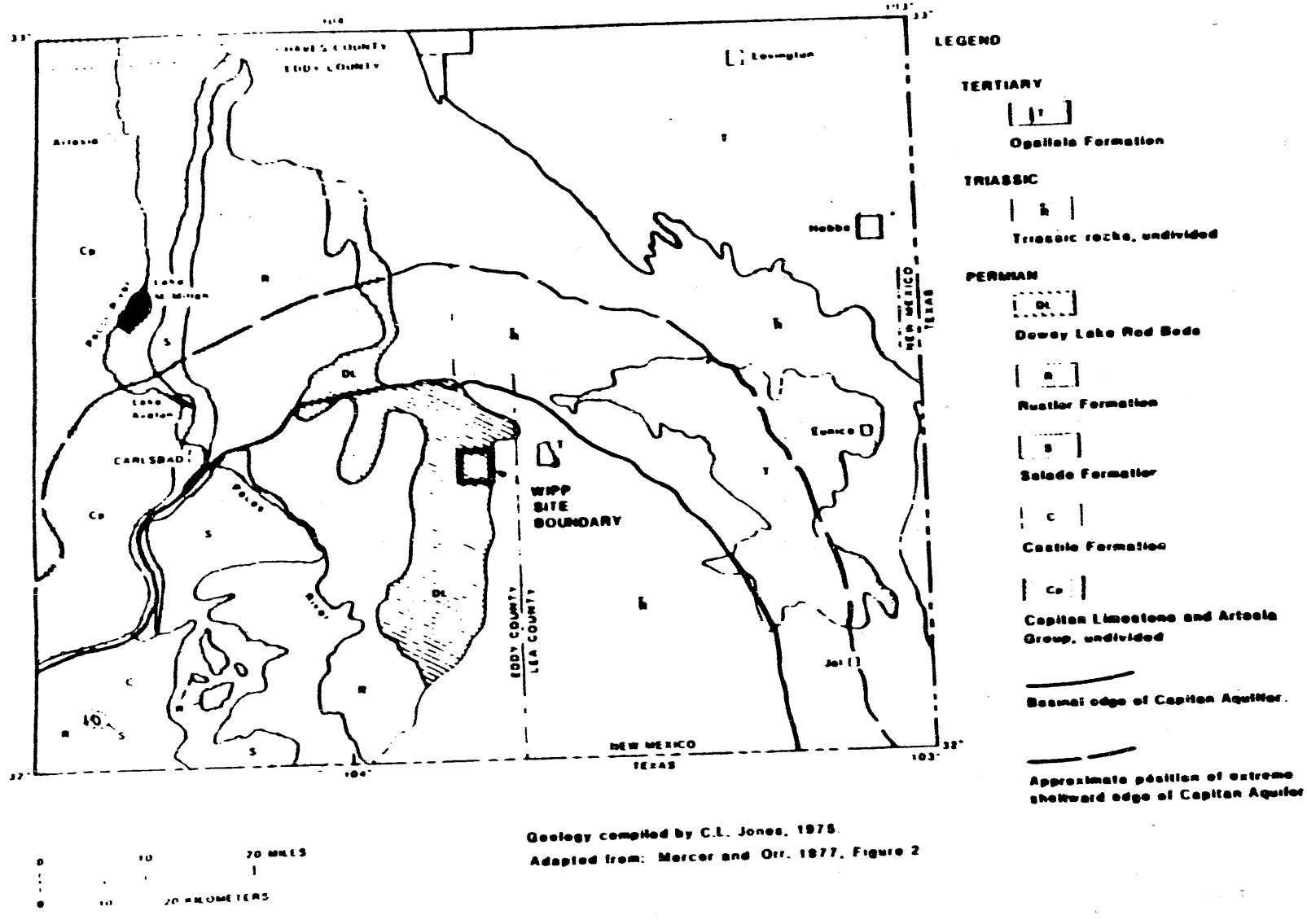

FIGURE 4-2 GEOLOGIC MAP OF LOS MEDAÑOS AREA AND VICINITY

isolation. The site selection process is described in Section 2.5. The geologic history of the region and the site area provides a reasonable basis for prediction of future geologic influences upon repository performance. An exhaustive summary of the site and regional geology is included in Appendix L. Portions of that literature review are included in Sections 4.3 through 4.5.

The salt deposits of the Delaware Basin were selected for the WIPP facility partly because the area is very tectonically stable. The WIPP facility is located in the northern part of the Delaware Basin, a structural depression filled with more than 7,300 meters (24,000 feet) of Phanerozoic sedimentary rocks (Hills, 1984). It is part of the larger Permian Basin and is located at the southwestern extent of the central stable region of North America (North American Craton). With the exception of a broad tilting of the basin during the Jurassic period and regional uplift during the Late Tertiary period, the Delaware Basin has been tectonically inactive since the close of the Paleozoic era (Powers et al., 1978). The sedimentary rocks within the basin dip gently to the east and only locally show slight deformation. The bedded salt deposits of the Salado Formation at the WIPP facility do not show any evidence of tectonic activity or structural deformation (Figure 4-3).

The salt of the Salado Formation was selected to host the WIPP facility repository because of its hydrologic and mechanical characteristics, bedded nature, and lateral continuity. The average permeability of the salt is low, typically 0.05 microdarcy or 4.2×10^{-13} meters per second (1.2×10^{-7} feet per day), and no hydrologic gradient exists across the formation which could cause the movement of ground water and subsequent dissolution of the salt. Mechanically, the salt behaves in a plastic fashion at lithostatic pressures and readily recrystallizes, or anneals, at repository depth. Bedded salt deposits, like the Salado, are typically of great areal extent, an additional factor facilitating waste isolation in the context of a repository. The Salado salt is approximately 610 meters (2,000 feet) thick and underlies an area of approximately 95,000 square kilometers (36,680 square miles) (Jones, 1972). The Salado is underlain and overlain by sequences of relatively impermeable evaporite deposits which further act to confine and hydrologically isolate the WIPP facility repository.

The basement rock in the region consists of Precambrian metasedimentary and igneous strata (Hills, 1984). The Precambrian basement is overlain by a thick sequence of Phanerozoic sedimentary rocks, consisting primarily of carbonates and evaporites with a small quantity of interbedded clastic rocks. The lower and mid-Paleozoic sediments were deposited on a slowly subsiding continental shelf, and consist predominantly of carbonates with minor sand, shale, and chert. The upper Paleozoic section was deposited in a rapidly developing basin and shelf environment. Reefs grew around the margins of the Delaware Basin and reached a peak in the mid to late Permian (Figure 4-3). Their growth eventually restricted the circulation of water in the basin and led to the accumulation of a thick section of late Permian evaporites, including the Salado Formation. The rocks of Mesozoic and Cenozoic age are relatively thin deposits mostly consisting of terrestrial sandstones, siltstones, mudrocks, and conglomerate, all of which are overlain by caliche and windblown sand. Thick sequences of Mesozoic and Cenozoic rocks did not accumulate, as the region was emergent and subject to erosion or nondeposition for most of the Mesozoic and Cenozoic Eras.

The geology, stratigraphy, structure, and geomorphology of the area are thoroughly reviewed in Appendix L, and are summarized in the following sections.

4.3.1 Geomorphology

The terrain of much of southeastern New Mexico is characterized by a gentle southwesterly slope and hummocky surface marked by karst features, caliche, and sand dunes. The major permanent drainage of the area is the Pecos River, located 23 kilometers (14 miles) west of the site, which is in the Pecos Valley section of the southern Great Plains physiographic province (Fenneman, 1931). The Pecos River

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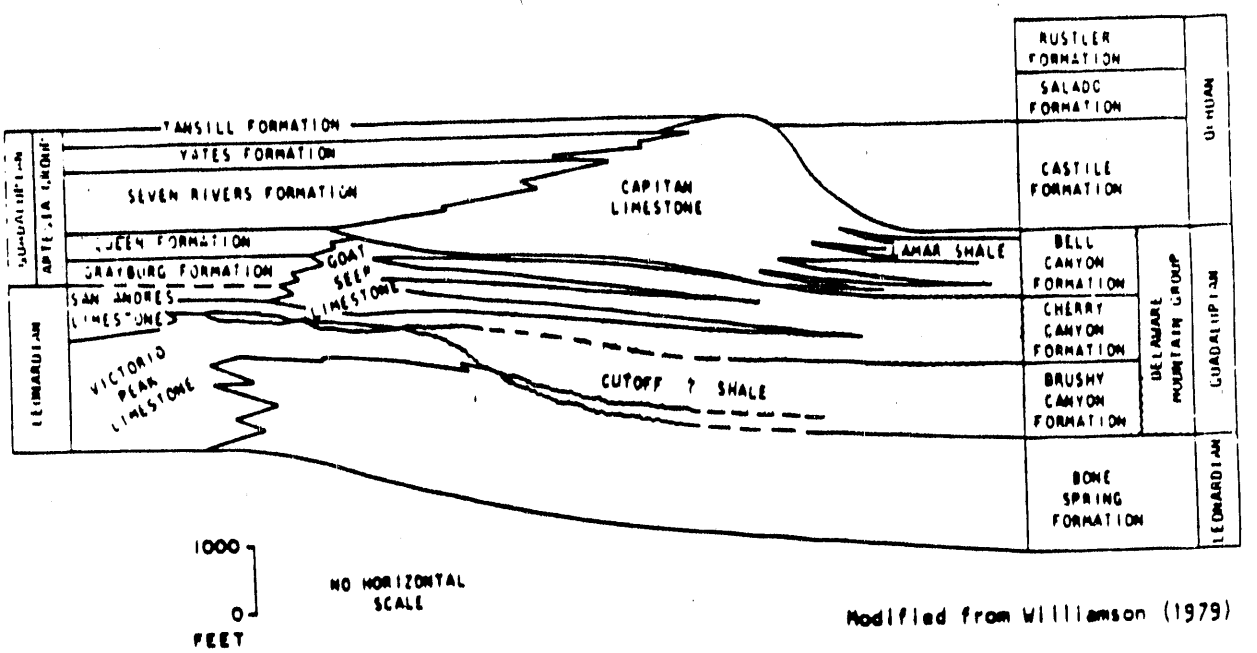

FIGURE 4-3 GENERALIZED STRATIGRAPHIC SECTION SHOWING THE RELATIONSHIPS OF THE GUADALUPIAN REEF COMPLEX TO THOSE OF THE DELAWARE MOUNTAIN GROUP, SOUTHEASTERN NEW MEXICO

Valley is the dominant feature in the Pecos Valley section. The Pecos River is the only major perennial stream in the Eddy and Lea Counties area of southeastern New Mexico. It receives almost all the surface drainage in this region and a large part of the subsurface drainage. Most of the ground surface east of the Pecos River Valley lies in the Llano Estacado, a poorly drained eastward-sloping surface covered by gravel, wind-blown sand, and caliche that has developed since early Pleistocene time. Locally, the surface has a karst terrain containing superficial sinkholes, dolines, and solution-subsidence troughs, formed from both surface erosion and subsurface dissolution.

East of the Pecos River to longitude 104°W lies an extensive, gently sloping pediment surface known as the Mescalero Plain. Although termed a "plain," the area includes many low mesas, bluffs, and wide draws. Locally, the surface has been dissected by intermittent streams, but in general, the area is poorly drained and contains numerous playa pans and smaller sinks (Brokaw et al., 1972; Kelley, 1971). The deposits of the Mescalero Plain are generally covered by the calcareous, cemented remnant of an extensive soil profile known as the Mescalero Caliche, which forms a resistant caprock averaging three to ten feet thick. Caliche may be locally absent due to erosion or nondeposition. Because of the generally uniform cover of the erosion-resistant caliche, the irregular surfaces probably result from subsurface solutioning and subsequent subsidence of the underlying sediments after the caliche caprock formed.

Eolian sand covers much of the Mescalero Plain in southeastern New Mexico. Except at the WIPP site and other areas where the sand is stabilized by vegetation, the sand is continually blown about to form transverse dune ridges and barchan dune areas separated by broad flats.

The land surface in southeastern New Mexico locally exhibits a karst topography characterized by geomorphic features such as sinkholes, linear depressions (solution-subsidence troughs), domes (including one known "breccia pipe"), "castiles," and collapsed outliers (Anderson, 1978). These features resulted from the dissolution of salts and other soluble materials of the upper Permian Ochoan series, particularly in the Rustler and the Upper Salado Formations. The water which caused dissolution contacted the soluble materials either by surface exposure following erosional removal of the protective mantle of younger sediments, such as the caliche, or, at depth, by downward percolation or contact via fracture systems between the Ochoan rocks and underlying regional aquifers exposed along basin margins by the regional Cenozoic uplift, tilting, and erosion. These solution processes were then followed by collapse of the insoluble strata into the voids created by the dissolution (Bachman, 1974).

Some of the major collapse features in the area, such as Nash Draw, Clayton Basin, and Crow Flats, exhibit evidence of several intervals of dissolution and subsidence activity. Dissolution has apparently progressed from west to east and from south to north across the Delaware Basin.

Near-Site Geomorphology

The WIPP facility surface structures are located on a thick section of the stable Mescalaro Caliche, within the vegetated sand dunes of the Los Medanos area. The facility lies near a caliche- and sand-covered drainage divide separating two major and actively developing solution-erosion features: Nash Draw to the west and San Simon Swale to the east (Figure 4-4).

The nearest major geomorphic feature is Nash Draw. Nash Draw, approximately eight kilometers (five miles) northwest of the WIPP facility, is an undrained physiographic depression which probably developed as a result of regional and differential dissolution of the anhydrite, gypsum, and halite beds of the Rustler and upper Salado Formations. According to Vine (1963), dissolution on top of the massive salt in the Salado Formation has produced a uniform lowering of the land surface in Nash Draw. Its surficial structural features were produced and greatly modified by differential dissolution of the more

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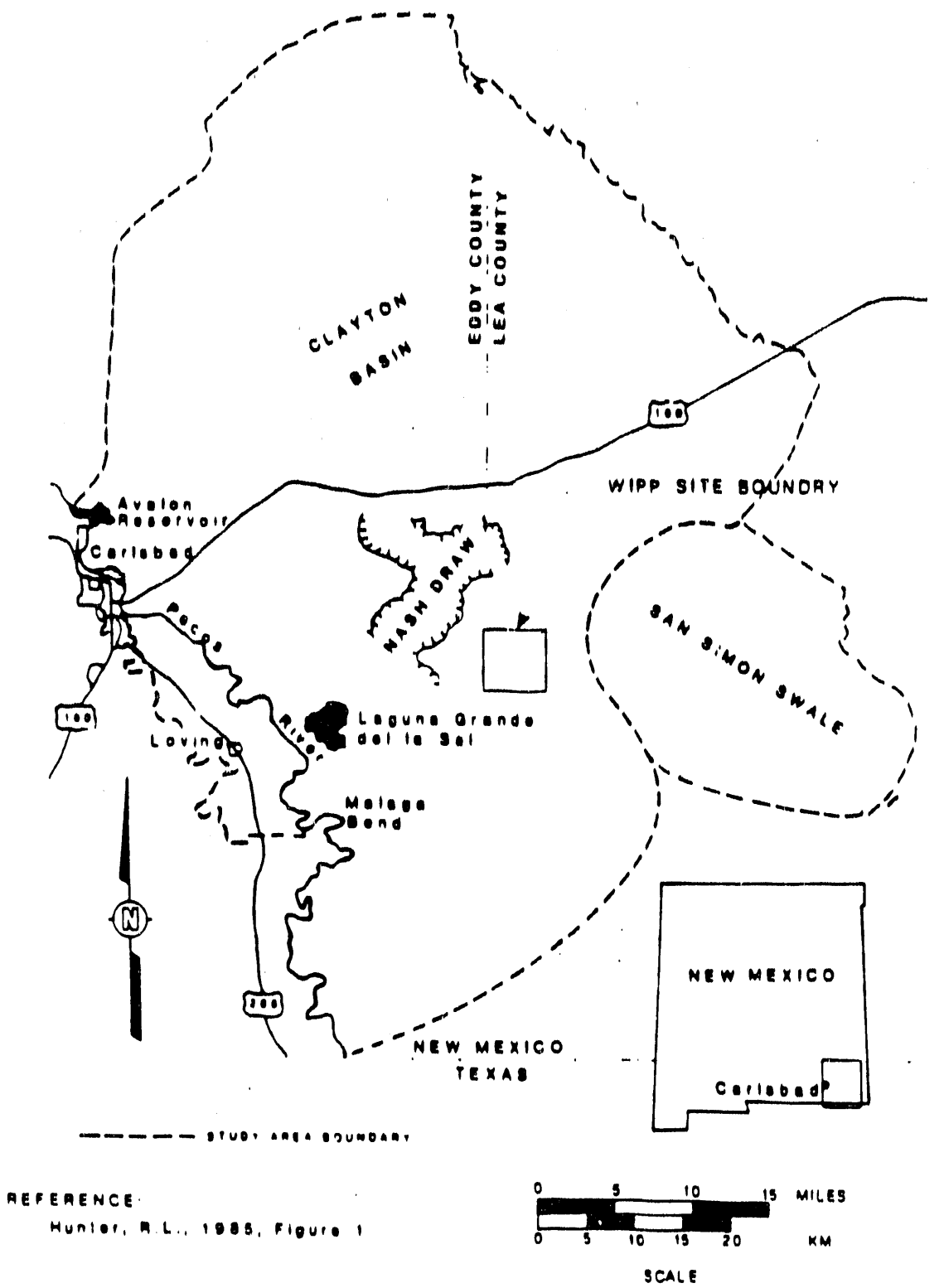

FIGURE 4-4 GENERALIZED PHYSIOGRAPHIC SETTING OF THE WIPP FACILITY SHOWING THE AREA OF THE WIPP WATER BALANCE STUDY

soluble portions of the Rustler Formation. While the bedrock in the northern part of the draw is covered by eolian sand, caliche, and alluvium, the central and southern portions contain exposures of the Rustler that are highly deformed as a result of large-scale collapse following solution of the Rustler and Salado Formations. This dissolution activity also produced numerous individual sinkholes in Nash Draw, which vary in configuration from circular features a few tens of meters (tens or hundreds of feet) across to irregular or arcuate features more than two kilometers (one mile) across. Many of the larger depressions in the area of the draw, including the basin at its southwestern extent, probably formed through the coalescing of several smaller solution depressions or sinks. Places where several depressions tend to align may also indicate the location of subterranean cavernous water courses (Vine, 1963).

San Simon Swale is another major karst-related feature near the WIPP facility. San Simon Swale is one of a series of large deep-dissolution depressions filled with Cenozoic sediments lying above the inner margin of the Capitan Reef along the eastern side of the Delaware Basin (Anderson, 1978). Situated approximately 32 kilometers (20 miles) east of the facility, the San Simon Swale forms a southeasterly-trending depression approximately 40 kilometers (25 miles) long and 3 to 10 kilometers (2 to 6 miles) in width. Much of the surface of the swale is covered by eolian sand, which masks the relief.

Of particular interest within the swale is a compound collapse feature named the San Simon Sink, which occupies an area approximately three kilometers (two miles) long and two kilometers (one mile) wide at the southeastern end of the swale (Bachman et al., 1973). The sink formed as a secondary collapse structure, probably during the Pleistocene. Numerous ring fractures around the sink indicate a long history of successive collapse events since its initial formation. The most recent of these events is reported to have occurred in the 1930s (Nicholson and Clebsch, 1961). It is therefore assumed that salt dissolution in the underlying formation is continuing here and that the brine produced by dissolution is moving in a southeasterly direction toward Texas (Bachman et al., 1973). Bachman (1974) reports that more than 150 meters (500 feet) of Cenozoic sediments have thus far been deposited in San Simon Sink. Nicholson and Clebsch (1961) estimate that alluvium deposition in the sink occurs at a rate of approximately 30 centimeters (1 foot) in five years.

Some of the geomorphic depressions near the WIPP facility were formed by processes other than the previously described mechanisms of dissolution and collapse. The most conspicuous of these near the WIPP site are the Williams Sink, Laguna Gatuna, and Laguna Plata, all of which are approximately 24 kilometers (15 miles) north of the WIPP facility. These features, termed blowouts, formed through the removal of loose sand deposits by wind erosion. Their floors are mantled with clay and saline deposits, and during the rainy season the blowouts may retain water. Many blowouts are surrounded by eolian sand and dune fields commonly develop along the northeastern and eastern leeward margins of these depressions (Bachman, 1974). (A discussion of the potential impacts of dissolution on the WIPP facility is provided in Section 6.1.2.)

Impact of Geomorphologic Processes on Repository Integrity

The integrity of the WIPP site is not jeopardized by any geomorphic processes.
The resistant Mescalero caliche covers most of the land surface around the site and indicates that no significant surface erosion has occurred since its formation in mid-Pleistocene time. The major areas of surface relief in the area were caused by subsidence resulting from subsurface dissolution. The two major subsidence features of significance to the site are Nash Draw and San Simon Swale, previously described. The surface in Nash Draw has been lowered by dissolution at least 30 meters (100 feet), and in places as much as 55 meters (180 feet), within the past half million years. San Simon Swale, a product of both surface erosion and solution-subsidence, lies at its lowest point some 55 to 60 meters (180 to 200 feet) below the surrounding land surface (Claiborne and Gera, 1974) and may have undergone a total subsidence of 230 meters (750 feet). Wind erosion of areas not covered by caliche

has produced other depressions in the area with a resultant deposition of windblown material in the area of the WIPP facility. However, these features are generally of minor dimensions and local in extent (Claiborne and Gera, 1974). Although there have been and may continue to be dissolution and subsidence events in the WIPP vicinity, these events are limited in extent to the upper levels of the Rustler Formation and do not affect the integrity of the Salado Formation near repository depth. No significant erosion has occurred in the area since mid-Pleistocene time.

4.3.2 Geologic History

New Mexico offers a complete record of geologic history from the Precambrian period to the Recent. The mountain complexity of New Mexico results from two periods of folding and considerable volcanic activity. Much of the state was covered by a shallow sea during the Pennsylvanian period. Resulting sedimentary rocks range up to 2,440 meters (8,000 feet) thick. The southern part of the state also has thin layers of shale and sandstone from the Permian period. Deposits of salt, gypsum, and potash from the Permian period are also found. The following is a discussion of the geologic history of the area of the WIPP facility and the region in which it is located.

Pre-Pennsylvanian Period

Prior to the Late Mississippian, Paleozoic depositional patterns in the Delaware Basin reflect migrations of epeiric seas over the region and the structural development of the Tobosa Basin, the predecessor to the Permian Basin. From the Late Cambrian/Early Ordovician until the Late Mississippian, a nearly continuous record of sedimentation is preserved as the region was, for the most part, tectonically stable during that time. Carbonates deposited under shallow shelf conditions dominate the rock record.

During and immediately following the Late Mississippian, the Delaware Basin began to develop structurally by vertical movement along preexisting structural trends (Hills, 1984). A thick sequence of basinal shales was deposited in the Delaware Basin during the Late Mississippian.

Pennsylvanian Period

The tectonic processes that were initiated during the Mississippian continued into the Early Pennsylvanian, and clastic materials derived from the Pedernal uplift in central New Mexico, the exposed Central Basin Platform, mountains in the Ouachita-Marathon area, and the Matador Arch filled the growing Delaware Basin (Hills, 1984; Powers et al., 1978).

During the Middle to Late Pennsylvanian, tectonic activity increased in the region (Ross, 1986), with concurrent development of broad carbonate shelves along the margins of the Delaware Basin (Hills, 1984). Carbonate bank development began in Atoka time and persisted through the Late Pennsylvanian and much of Permian time (Mazzullo, 1981). For the most part, clastic input from the north was trapped behind the carbonate banks, thus starving the Delaware Basin of sediment (Adams et al., 1951).

By early Permian (mid-Wolfcampian) time, tectonic activity had ceased (Ross, 1986), and the entire region subsided, deepening the Delaware Basin and establishing the major features of the Permian Basin.

Permian Period

In the early Permian, the last stages of the Marathon orogeny thrust geosynclinal rocks northward, providing a source of fine clastic material which filled much of the southern and central portion of the Delaware Basin (Hills, 1984; Ross, 1986). Limestones, including the Abo Reef, were deposited on the shelfal areas and, during periods of quiescence, as thin units within the basin (Hills, 1972, 1984). The

development of carbonate reefs severely restricted basinal circulation (Hills, 1984). Regional tectonic stability marked the remainder of the Permian, although local structural events continued to modify the basin (Powers et al., 1978) (Figures 4-5 and 4-6).

The restriction of marine circulation continued into Leonardian time, and the sea regressed to the southwest (Hills, 1972). This led to the development of large reefs and carbonate banks (Figure 4-3). Evaporites were deposited in highly saline shallow lagoons in the back reef (Hills, 1972). Sandstones continued to be deposited in the central part of the basin and were interbedded with carbonate wedges thinning toward the center of the basin.

A general eastward tilting of the Delaware Basin began near the end of Leonardian time and subsidence continued through Guadalupian time (Hills, 1984). About 900 to 1,200 meters (3,000 to 4,000 feet) of Guadalupian sands and silts were poured into the Delaware Basin; large carbonate reefs developed through later Guadalupian time (Hills, 1984).

As circulation became widely restricted due to the upward growth of the reefs and continued subsidence, the basin again became sediment-starved (Oriel et al., 1967; Hayes, 1964; Hills, 1984). Reef and bank growth continued around the basin margins and, by late Guadalupian time, had closed the Hovey Channel (Ross, 1986). The salinity of the fluids within the basin increased, dramatically halting reef growth.

The Delaware Basin was very restricted by the beginning of Ochoan time and evaporative conditions prevailed. Topographically, the Delaware Basin was fairly deep. Up to 440 meters (1,600 feet) of Castile evaporites, consisting of carbonate and anhydrite with interbeds of halite, were deposited on the Guadalupian sediments.

Following the deposition of the Castile, which is restricted to the Delaware Basin, the basin desiccated to an areally extensive salt-pan/saline mudflat. Surface topography was essentially nonexistent and the laterally continuous desiccating-upward cycles of carbonate-sulfate-halite were deposited (Jones, 1972; Lowenstein, 1982, 1987). Locally, more than 700 meters (2,300 feet) of the Salado evaporites, mostly halite, were deposited in the basin. Salado deposition extended over the margins of the then-buried Capitan Reef.

Deposition of the Rustler Formation was marked by a major freshening of the basin. Clastic sediments were introduced into a deeper, somewhat less saline lagoonal-type environment which later desiccated to a saline mudflat/salt pan. Rapid transgressions followed by desiccation-deposited carbonates, sulfates, and halite rocks in the Rustler Formation.

Near the end of the Permian, nearly 200 meters (650 feet) of the Dewey Lake Redbeds (siltstones and sandstones) were deposited over Rustler evaporites in mudflat and fluvial depositional settings.

Post-Permian Period

Following the deposition of the Dewey Lake Redbeds (Figure 4-3), most of southeastern New Mexico and west Texas were subject to erosion. The uplift and/or tilting that caused erosion was minor as the unconformity between the Late Triassic Dockum Group and the Late Permian Dewey Lake Redbeds is minimal. By the Late Triassic, southeastern New Mexico was reduced to a broad peneplain (Kelley, 1971). A northwesterly draining flood plain basin formed in the Late Triassic and was not contained by the Delaware Basin (Hills, 1963; Brokaw et al., 1972; McGowen et al., 1983). Source areas to the south provided detrital material for the Santa Rosa and Chinle Formations (McGowen et al., 1983).

The Jurassic was a period of uplift and erosion of Triassic and possibly Permian rocks in the western part of the Delaware Basin. Southeastern New Mexico was a source area for Jurassic rocks in central and northern New Mexico (Powers et al., 1978).

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SYSTEM	SERIES	GROUP	FORMATION	MEMBER
RECENT	RECENT		SURFICIAL DEPOSITS	
QUATERNARY	PLEISTOCENE		MESCALEROCALICHE	
			GATUNA	
TERTIARY	PLIOCENE		OGALLALA	
TRIASSIC		DOCKUM	UNDIVIDED	
PERMIAN	OCHOAN		DEWEY LAKE RED BEDS	
			RUSTLER	Forty-niner
				Magenta
				Tamarisk
				Culebra
				Unnamed
			SALADO	Upper
				McNutt
				Lower
			CASTILE	
	GUADALUPIAN	DELAWARE MOUNTAIN	BELL CANYON	
			CHERRY CANYON	
			BRUSHY CANYON	

Geologic Column Representative of WIPP Facility Area

Reference:
(After Powers et al., 1978 and Cooper and Glanzman, 1971)

FIGURE 4-5 GEOLOGIC COLUMN REPRESENTATIVE OF WIPP FACILITY AREA

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SYSTEM	SERIES	GROUP	FORMATION	MEMBER OR ZONE
PERMIAN	OCHOAN		CASTILE	
	GUADALUPIAN	DELAWARE MOUNTAIN GROUP	BELL CANYON	LAMAR SHALE MEMBER TRAP MEMBER RAMSEY SANDSTONE MEMBER FORD SHALE MEMBER OLDS SANDSTONE MEMBER HAYS SANDSTONE MEMBER (INFORMAL UNITS)
			CHERRY CANYON	
			BRUSHY CANYON	
	LEONARDIAN		BONE SPRING LIMESTONE	

Modified from Grauten (1965)

FIGURE 4-6 STRATIGRAPHIC RELATIONSHIPS OF THE DELAWARE MOUNTAIN GROUP, TEXAS AND NEW MEXICO

By Cretaceous time, earlier erosion had exposed Precambrian- through Permian-age rocks in the region. From approximately the Middle Cretaceous, southeastern New Mexico was covered by shallow shelfal seas (Hills, 1984). Thin deposits of limestone and coarse sandstone and conglomerate were deposited. In the Delaware Basin, the Cretaceous rocks were removed by later erosion, save isolated slump blocks of limestone and shale associated with karst features (Bachman, 1974). Late in the Cretaceous or early in the Tertiary, the Guadalupe Mountains were uplifted and tilted to the northeast. Mild tectonism affected the Northwestern Shelf (Kelley, 1971).

Additional regional uplifting and tilting in the late Tertiary in southeastern New Mexico and west Texas resulted in the uplift of the Delaware, Guadalupe, and Sacramento Mountains. Eastward-flowing streams drained the recently elevated highlands, forming coalescing alluvial systems. These systems eventually produced an extensive blanket of sand and gravel called the Ogallala Formation. The Ogallala represents the first preserved sedimentary record since the Cretaceous (Bachman, 1974). Ogallala deposition ended in the Pliocene with the advent of additional regional uplift and warping (Powers et al., 1978). The surface became stabilized, and soil forming processes began that resulted in the formation of the extensive caliche caprock (Bachman, 1980).

Another period of uplift of the Guadalupe Mountains (Figure 4-7) occurred in the late Pliocene and early Pleistocene. Subsequent erosion and coalescence of subsided areas removed Ogallala sediments (Nicholson and Clebsch, 1961; Mercer and Orr, 1979). During the early to middle Pleistocene, Nash Draw, the Clayton Basin, and San Simon Swale underwent subsidence (Bachman, 1974).

The middle Pleistocene was relatively humid, and the conditions were right for dissolution of older formations and the deposition of the Gatuna Formation fluvial reworking and redeposition of older sediments. The late Pleistocene, following deposition of the Gatuna Formation, was characterized by a much more arid environment. The arid conditions coupled with a tectonic and an erosionally stable surface permitted the formation of the Mescalero Caliche. During the late Pleistocene to Holocene, eolian reworking of detrital materials formed the extensive dune fields which now blanket large portions of southeastern New Mexico.

4.3.3 Ochoan Stratigraphy

The Ochoan series in the Delaware Basin consists of four formations, three of which consist primarily of evaporites (Figures 4-5 and 4-6). They are, in ascending order, the Castile, Salado, and Rustler Formations, and the Dewey Lake Redbeds. The Dewey Lake Redbeds do not contain evaporites and probably form a protective cover that retards the dissolution and removal of soluble salts in the lower evaporite units (Jones, 1954). Among the lower evaporite units, the Castile and Rustler contain more anhydrite and carbonate than the Salado. In the area of the WIPP facility, these anhydrites have formed protective barriers that have retarded the upward or downward movement of meteoric water into the salt-rich Salado Formation. The Ochoan sequence conformably overlies the Bell Canyon Formation and unconformably underlies the Triassic Santa Rosa Sandstone.

Castile Formation

The Castile Formation consists of thick units of laminated anhydrite/carbonate and halite. It provides a hydrologic barrier below the Salado Formation and prevents both the downward movement of water from the WIPP facility into and the upward movement of water from the underlying Bell Canyon Formation. The Castile Formation consists of thick units of sulfate (mainly anhydrite) or thinly laminated anhydrite and carbonate. Near the center of the basin, thick units of relatively pure halite are interbedded and interfingered with the sulfate units. The halite thins or is absent in the western part of the basin. The thickness of beds within the Castile are consistent over considerable distances, interrupted only by intraformational deformation or by dissolution. Extensive outcrops of the Castile are present in the western part of the Delaware Basin. The Castile has localized structural deformation (Anderson and

Powers, 1978; Borns et al., 1983). Borns and Shaffer (1985) examined deformation in the Castile near the WIPP facility and concluded that the structures were caused by salt flowage. The basal contact of the Castile with the underlying Bell Canyon Formation of the Delaware Mountain Group is transitional (Cys, 1978). The upper contact with the Salado is gradational and interfingering (Bachman, 1984; Jones, 1954). The Castile Formation is considered an example of a deep-water evaporite basin; the characteristics attendant with such deposits are discussed more fully by Schmalz (1969), Dean et al., (1975), and Kendall (1984).

Salado Formation

The Salado Formation is the host unit for the WIPP facility repository. Section 2.0 provides a discussion of the criteria that were used to determine its suitability as a repository for transuranic waste. The formation is roughly 610 meters (2,000 feet) thick in the area of the repository and underlies an area greater than 95,000 square kilometers (36,380 square miles). Unlike the Castile, the Salado is not confined to the Delaware Basin. Salado deposition north and east of the WIPP facility passed well beyond the Capitan reef and occurred on the Northwestern Shelf and the Central Basin Platform. The Salado has been erosionally removed from the west and south sides of the Delaware Basin leaving a horseshoe-shaped rim of brecciated insoluble material.

The Salado salt consists of halite with minor amounts of anhydrite, polyhalite, and other potassium-bearing minerals. The formation is subdivided into three informal stratigraphic units. Each contains similar amounts of halite, anhydrite, and polyhalite (Jones, 1972), and is distinguished by its content of other potassium- and magnesium-bearing minerals. The upper and lower units generally lack these minerals, while the middle (McNutt potash zone) contains a relative abundance of potassium- and magnesium-bearing minerals. Potassium-bearing minerals are mined from the middle member of the Salado in Lea and Eddy Counties.

Rustler Formation

The Rustler Formation is the youngest of three Ochoan evaporite-bearing formations in the Delaware Basin. It is of significance to the WIPP facility because it contains several water-bearing zones (Figure 4-5). The Rustler Formation in this area is characterized by a variable lithology consisting of interbedded sulfates, carbonates, clastics, and halite. Vine (1963) divided the Rustler into five units: (1) at the base, an unnamed unit of clayey siltstone and very fine-grained sandstone with thin interbeds of anhydrite and halite in its upper part; (2) the Culebra Dolomite Member, a unit of thin-bedded, solution-pitted, finely crystalline dolomite; (3) the Tamarisk Member, anhydrite with a single thick interbed of claystone; (4) the Magenta Dolomite Member, a unit of thinly cross-laminated, fine-grained dolomite; and (5) the Forty-Niner Member, anhydrite with a single thin interbed of siltstone. The anhydrite beds may be partially altered to gypsum in places where dissolution has occurred. The dolomite units are not only hydrologically important, but are distinctive in the subsurface as marker beds throughout the Delaware Basin (Adams, 1944). The Rustler varies in thickness from a few meters (tens of feet), where exposed and subjected to solution and erosion, to nearly 170 meters (560 feet) in the northeastern part of the Delaware Basin (Holt and Powers, 1988). The western margin of the Rustler has been removed by erosion. The Rustler crops out along the Pecos River Valley, within Nash Draw, and in an arcuate pattern near the southwestern edge of the Delaware Basin. It has been extensively altered by near-surface ground water in Nash Draw. The upper contact of the Rustler with the Dewey Lake Redbeds is conformable.

Dewey Lake Redbeds

The Dewey Lake Redbeds are the uppermost of the four Ochoan formations and represent the close of the Paleozoic in the Delaware Basin. The Dewey Lake unit ranges in thickness from 105 to 165 meters (345 to 541 feet) across the WIPP facility. It is important because it acts as a barrier and prevents

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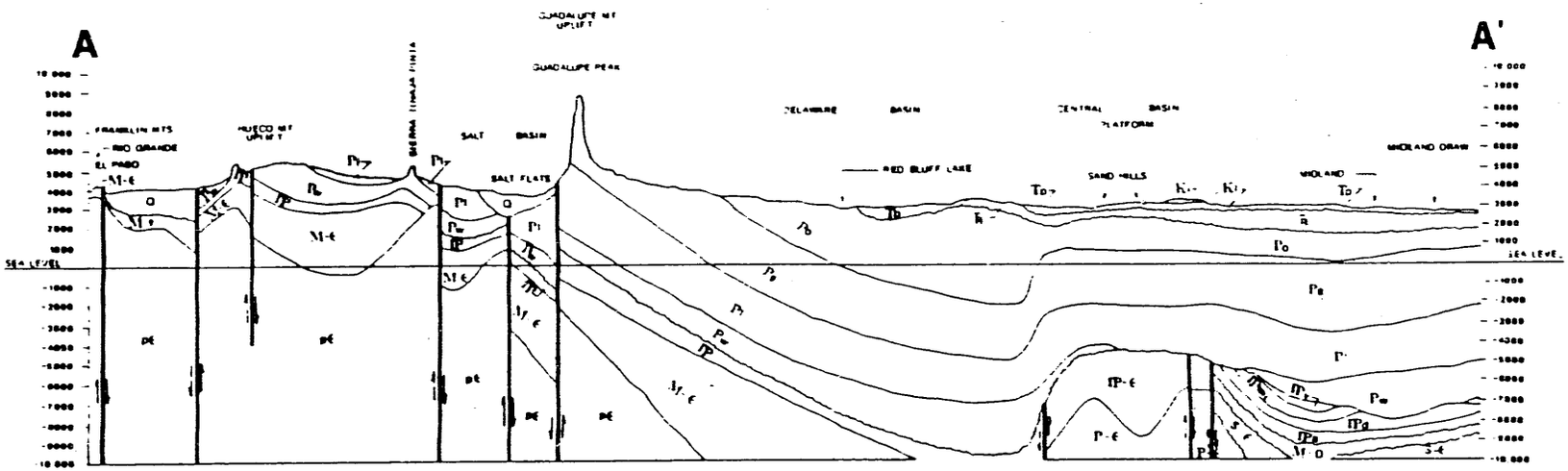
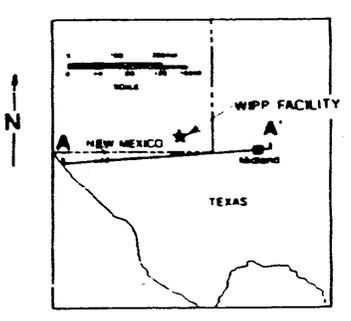


NOTE

Q	Quaternary	P_{mo}	Pennsylvanian (Missourian)
Tb	Tertiary (Pliocene - Oligocene)	P_{de}	Pennsylvanian (Desmoinesian)
Kl	Lower Cretaceous	P_{at}	Pennsylvanian (Atokan)
Tr	Triassic (Santa Rosa)	P	Pennsylvanian
Po	Permian (Ochoan)	M-D	Devonian - Mississippian
Pg	Permian (Guadalupian)	P-€	Cambrian - Pennsylvanian
Pl	Permian (Leonardian)	M-€	Cambrian - Mississippian
P_w	Permian (Wolfcampian)	S-€	Cambrian - Silurian
P_v	Pennsylvanian (Virgilian)	pC	Precambrian
			Unconformity
			Fault

REFERENCE

American Association of Petroleum Geologists, 1973



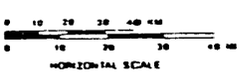


FIGURE 4-7 EAST-WEST CROSS-SECTION NEW MEXICO-TEXAS BORDER

downward percolation of ground water into the evaporite section overlying the WIPP facility repository. The Dewey Lake conformably overlies the Rustler Formation on a large scale (with local minor erosional relief) and unconformably underlies Late Triassic (Dockum Group) and younger rocks. The Dewey Lake thins to the northwest as the result of pre-Late Triassic erosion. The Dewey Lake consists almost entirely of mudstone, claystone, siltstone, and interbedded sandstone. With the exception of the upper portion, the Dewey Lake is characterized by gypsum-filled fractures. These fractures are nearly all horizontal and are the result of unloading (Holt and Powers, 1988), and indicate that no fresh ground water has moved through the Dewey Lake since they were formed.

Post-Permian Deposits

Across the WIPP facility area, the only Triassic unit present is the Santa Rosa Sandstone, part of the Dockum Group. The Santa Rosa Sandstone is present to the east, having been removed by erosion in the west. At the WIPP facility, the Santa Rosa is 6 meters (20 feet) thick (Holt and Powers, 1986a). It consists of sandstone and conglomerate with interbeds of siltstone and mudstone. In the WIPP facility area, it is often unconformably overlain by the Pleistocene Gatuna Formation.

Tertiary and Quarternary deposits around the WIPP facility include the Ogallala Formation of Miocene age; the Gatuna Formation of Pleistocene age; and sands, playa deposits, caliche, and alluvium of Holocene age. The units cover most of the region and lie unconformably on older rocks.

In southeastern New Mexico, the Ogallala Formation is a well-sorted, windblown sand with minor, poorly-sorted stream deposits and carbonate pans that are usually capped by a rather resistant layer of well-indurated caliche. The Ogallala is not present around the WIPP facility, but erosional remnants of Ogallala are found locally within the Gatuna Formation.

The Gatuna Formation is a Pleistocene fluvial deposit consisting of sandstone, siltstone, and conglomerate with the conglomeratic beds containing pebbles of quartz and quartzite reworked from Triassic conglomerates (Bachman, 1976). At the WIPP facility, the Gatuna is 5 meters (17 feet) thick and is overlain by the Mescalero Caliche (Holt and Powers, 1986a).

The Mescalero Caliche is an informal stratigraphic unit which derives its name from the Mescalero Plain. It began to form about 510,000 years ago as a pedogenic caliche on an aggrading eolian surface (Bachman, 1985). Calcium carbonate, leached from overlying eolian sands, was deposited along a soil horizon. Where the caliche is well developed, all available porosity at the top of the zone of carbonate accumulation is plugged with calcium carbonate. The caliche caps the geomorphic surface and lies with angular unconformity on the underlying Gatuna and older formations; its lower part commonly engulfs large masses of older bedrock. At the WIPP facility, the Mescalero Caliche is roughly three meters (ten feet) thick with a well-defined upper surface and a very diffuse lower contact (Holt and Powers, 1986a). In general, the overall degree of induration and the carbonate content both decrease downward. The upper part of the Mescalero (the caprock) displays a well-developed laminar texture which developed after all permeability in the downward direction was plugged.

Hummocky surficial deposits of dune and sand cover most of the site. Although the sand may occur as dune ridges, most of it is found on the flats and is generally stabilized by vegetation. At the WIPP facility, 2.4 meters (8 feet) of unconsolidated sand occurs (Holt and Powers, 1986a).

There are no through-flowing streams in the immediate area of the WIPP facility; therefore, there are no recent stream deposits of any magnitude. Surficial deposits are composed of locally-derived materials deposited by sheet wash.

4.3.4 Structural and Tectonic Setting

The WIPP facility lies among the vegetated dunes of the Los Medanos area, some 42 kilometers (26 miles) east of Carlsbad, and is located in the northern part of the Delaware Basin between Nash Draw and San Simon Swale. The Delaware Basin of southeastern New Mexico and west Texas is a major subdivision of the Permian Basin. It is bounded on the west by the Diablo Platform, on the east by the Central Basin Platform, and on the north by the Northwestern Shelf. The areal extent of the basin is greater than 33,650 square kilometers (13,000 square miles), and it is filled with as much as 7,500 meters (24,600 feet) of Phanerozoic sedimentary rocks (Hills, 1984). The Capitan Reef almost completely surrounds the Delaware Basin. It is considered among the latest deposits immediately preceding deposition of the Ochoan evaporites. The WIPP facility area has been examined in detail for any potential structural or tectonic features that might affect the integrity of the facility. Such features include: folds and flexures, faults, deformation of the Salado salt, and salt dissolution.

Folds and Flexures

The northern Delaware Basin contains open, undulatory, flexure-like structures in the Paleozoic section. At the WIPP facility, these folds do not propagate upward into the Salado Formation. Some thickening of the lower Salado occurs 3.2 kilometers (2 miles) north of the WIPP facility over gravity-driven salt flowage structures in the Castile Formation (Borns and Shaffer, 1985). Castile salt flowage structures occur elsewhere within the Delaware Basin, but do not affect the integrity of the WIPP facility (Anderson and Powers, 1978).

Faults

No surface faults have been mapped within eight kilometers (five miles) of the center of the WIPP facility. Faults with surface expression are plainly related to collapse features. Bachman's (1976) mapping east of the WIPP facility shows no surface faults. The nearest faults mapped by Vine (1963) involve Rustler offsets in Nash Draw approximately 14.5 kilometers (9 miles) southwest of the facility. Surface mapping and structural interpretations from boreholes do not indicate any anomalous structure in the vicinity of the WIPP facility caused by differential subsidence of underlying strata.

Deep seated, high-angle normal or reverse faults are present throughout the Delaware Basin. They offset strata from the Precambrian through the Pennsylvanian and portions of the lower Permian. Movement along these faults ceased before the mid-Permian (Hills, 1984). The Bell Lake Fault, located in Lea County, is the closest such structure to the WIPP facility, with approximately 152 meters (500 feet) of displacement in the Precambrian. There are no known Quarternary faults of tectonic origin in the facility area. The only faulting in the WIPP facility area since the Permian is related to the differential subsidence due to dissolution and collapse of soluble materials in and near karst features. The nearest recent faulting attributable to tectonic activity is along the western margin of the Guadalupe Mountains.

Castile Brine Reservoirs

Artesian brine reservoirs have been encountered in the Castile. They are high-pressure, low-volume reservoirs with no external communication. They are associated with thickened salt sections and salt-cored anticlines in the Castile. A thickened salt section and salt-cored anticline was drilled in WIPP 11 (see Appendix L) without encountering fluids. These reservoirs appear to occur under structural highs in the Salado Formation. No such structural features are recognizable within the limits of the WIPP facility repository on any of the Salado horizons contoured. In fact, the facility appears to be in a slight structural saddle.

Salt Deformation in the Salado Formation

Thick salt is known to deform plastically and to behave as a viscous medium over extended periods of time. This behavior is promoted by high overburden pressures and increased temperatures. Under favorable conditions, even slight tilting of the beds or lateral differences in lithostatic pressure are sufficient to initiate long-term viscous flow of salt. Plastic deformation and buckling associated with salt migration or flow has apparently not occurred in the Salado in the geologic past to the extent that it has in the lower levels of the underlying Castile Formation. Thickened salt sections and salt-cored anticlines developed in the Castile as a response to loading (e.g., the DOE 2 and WIPP 11 structures). Locally, the lower Salado thickens over structural lows created by Castile deformation, but across the WIPP facility area deformation of this kind has not occurred.

Salt Dissolution

No dissolution of soluble materials from the Ochoan section has occurred at the WIPP facility proper. Some post-depositional dissolution of halite has affected the Rustler in the WIPP facility area, but this is a local phenomena and is relatively minor with approximately 3 to 9 meters (10 to 30 feet) of thickness reduction due to dissolution (Holt and Powers, 1988). This minor amount of dissolution has not resulted in differential subsidence in the site area. Across the site area, dissolution has not affected the Salado. Within Nash Draw and near its margins, however, dissolution of Salado salt has occurred and is currently active resulting in widespread collapse structures (Bachman, 1987; Holt and Powers, 1988).

Structure in the WIPP Facility Area

Structure contour maps on various units within the Salado and Rustler Formations show a clear eastward tilting of these units across the WIPP facility area, with no structural anomalies (Holt and Powers, 1988; Powers et al., 1978). The top of Dewey Lake Redbeds is the first horizon that does not reveal the eastward gradient of the Delaware Basin, which affects all lower horizons. The Dewey Lake surface across the area is undulatory, possibly reflecting original undulations in the unconformable Dewey Lake-Santa Rosa contact. Isopachs of the Dewey Lake Redbeds disclose that the west-trending slope of the Dewey Lake surface is the result of the Late Tertiary erosion associated with the development of Nash Draw (Brokaw et al., 1972).

Seismology

Seismic studies have been conducted to build a body of information from which to predict the ground motions to which the repository may be subjected in both the near and distant future. Near-term concerns relate to design requirements for surface and underground structures which have been built to withstand levels of ground motion greater than any expected during the operational phase. Long-term concerns pertain to the potential for relative motions (faulting) within the repository and the resulting impact on the integrity of the salt beds and/or shaft seals. In this discussion, all intensities are based on the modified Mercalli intensity scale (Wood and Neuman, 1931). Most of the magnitudes were determined by the New Mexico Institute of Mining and Technology, or are described in the Geological Characterization Report (Powers et al., 1978) and in the FSAR (DOE, 1988a, Revised 1990).

The earthquake record in southern New Mexico dates back to 1923, but seismic instruments have only been in place in the state since 1961. Sanford and Toppozada (1974) examined available records to determine the seismic history of the region within 290 kilometers (180 miles) of the facility. The results of that review for the period before 1961 are given in Appendix L. With the exception of the weak shock in 1926 at Hope, New Mexico, and the shocks in 1936 and 1949 felt at Carlsbad, all shocks recorded before 1961 occurred to the west and southwest of the facility and more than 160 kilometers (100 miles) away. Since 1961, comprehensive instrument coverage has allowed the identification of moderately strong

earthquakes in the region. Shocks that occurred within 290 kilometers (180 miles) of the facility since 1961 also are listed in Appendix L. The distribution of data may be biased by the fact that seismic stations are more numerous north and west of the facility and have been in operation for longer periods. Except for the activity southeast of the facility, the distribution of epicenters since 1961 differs little from the distribution of shocks recorded before that time. There are two clusters of activity, one associated with the Rio Grande Rift on the Texas-Chihuahua border and another associated with the Central Basin platform in Texas near the southeastern corner of New Mexico. This latter activity was not reported before 1964.

The strongest earthquake on record within 290 kilometers (180 miles) of the facility occurred at Valentine, Texas, on August 16, 1931. Coffman and von Hake (1973) estimate its magnitude as 6.4 (modified Mercalli intensity of VIII). This earthquake occurred 209 kilometers (130 miles) southwest of the WIPP facility and its intensity at the facility is estimated to have been V, believed to be the highest intensity felt at the facility in this century.

Any seismic activity around the facility is of great interest. From April 1974 to October 1978, 420 events identified as local or regional earthquakes [within approximately 340 kilometers (210 miles)] were recorded by a station 6.4 kilometers (4 miles) from the center of the facility. For 150 of those events, the epicenters were identified and magnitudes determined. Nine tentative epicenter locations were identified. From January 1962 through September 1986, 448 events were instrumentally recorded within 290 kilometers (180 miles) of the repository. These seismic patterns resemble those of preinstrumental data. Three events (July 26, 1972; November 28, 1974; and January 19, 1978) have been recorded by instrument within 56 kilometers (35 miles) of the WIPP facility. The event (magnitude 2.3) closest to the repository occurred on January 19, 1978, approximately 16 kilometers (10 miles) northeast of the station nearest the WIPP site. It does not appear to have been related to any human activity. Seismic activity increases away from the WIPP facility.

An estimate has been made of the largest seismic motions possible at the WIPP facility with an estimate of their probability, starting with an analysis of the recurrence rates of earthquakes in nearby active areas. The historical data have been supplemented with field geologic data. Cornell's (1968) method was used to estimate seismic risk at the facility (Powers et al., 1978) utilizing three source regions suggested by Algermission and Perkins (1976). The analysis also used Sanford's recurrence relationships (Sanford et al., 1976, 1978; DOE, 1988a, Revised 1990). The depth of earthquakes in the site source zone was assumed to be five kilometers (three miles). The Cornell method expresses seismic risk as the probability per year that a specific acceleration will be reached or exceeded. Specific assumptions, input parameters, and assessment of risks are detailed in Appendix L. This analysis indicates that the possibility of faulting at the facility of a magnitude that could significantly affect the integrity of the repository is extremely low.

4.3.5 Summary of WIPP Facility Region Geology and Conclusions

The geologic structure of the Los Medanos area is relatively simple and the rocks are, for the most part, only slightly deformed. Nevertheless, the rocks have been tilted, warped, eroded, and subroded (i.e., subjected to subsurface solution), and discrete structural features can be recognized. These include structural features of regional extent related to Permian sedimentation and intraformational folds of limited extent related to "down-the-dip" movement of salt under the influence of gravity and weight of overburden.

On the basis of available geological information, the salt deposits of the Los Medanos area constitute a suitable geologic medium for use as a radioactive waste repository. The deposits have thick seams of rock salt at moderate depths, and have escaped almost completely the effects of long periods of erosion. The deposits are structurally deformed only slightly and are located in an area with a long history of tectonic stability. Tectonic faulting and warping of rocks in the vicinity seem to be restricted to

Pennsylvanian and older strata and to have predated Permian evaporite deposition; certain minor faulting within the thick Permian section appears to have occurred contemporaneously with sedimentation. Deformation related to salt flow has occurred primarily in the Castile Formation beneath the Salado Formation and may have modified the regional easterly gradient at the repository level. Artesian brine reservoirs in the area are associated with thickened salt sections and salt-cored anticlines in the Castile Formation, but no such structural features are recognizable within the limits of the WIPP facility on any of the Salado horizons contoured. The site appears to be in a slight structural saddle, a condition considered favorable for site selection. Dissolution of bedded salt in the site area has been restricted to horizons within the Rustler Formation, but there is no evidence that the dissolution produced significant structural irregularities in the overlying strata.

4.4 GROUND WATER HYDROLOGY

The WIPP facility lies in the Northern Delaware basin, where the only major sources of potable ground water is the Capitan Limestone Aquifer. The Delaware basin is bounded by this limestone reef of Permian age, which is one of the eight rock units important to the hydrology of the WIPP facility. The others are, in ascending order, the Delaware Mountain Group (comprised of the Brushy Canyon, Cherry Canyon and Bell Canyon Formations), the Castile Formation, the Salado Formation, the Culebra and Magenta Members of the Rustler Formation, the Dewey Lake Redbeds, and the Triassic Dockum Group (Santa Rosa Sandstone and the Chinle Formation) (Figure 4-5). Of these eight rock units, the Castile and Salado Formations are defined as aquicludes; the rest contain water-bearing units of low yield and nonpotable water.

Appendix L presents a detailed description of both local and regional groundwater hydrology. This section describes those features of most interest in demonstrating the repository's capabilities with regard to permanent waste isolation.

4.4.1 Bell Canyon Formation

The formations that comprise the Delaware Mountain Group are the basin equivalents of the Capitan Reef and form the floor beneath the Delaware basin evaporite sequence. The Bell Canyon Formation is the uppermost rock unit within the group and consists of approximately 290 to 460 meters (950 to 1,500 feet) of interbedded sandstone, shales and siltstones, and represents the first water-bearing unit underlying the WIPP facility.

The uppermost sandstone of the Bell Canyon Formation, known as the Ramsey Sandstone Member (Figure 4-5), exhibits a primary porosity that is intergranular and ranges from 20 to 28 percent. This unit's permeability ranges from 14 to 90 millidarcies (Berg, 1979) and contains unsaturated brine under sufficient "freshwater" head to reach the overlying Rustler Formation. These sandstones, however, are surrounded by very low permeability siltstones and shaley siltstones, and the formation itself is confined by the thick anhydrites of the Castile Formation above it. Recent studies (Lappin, 1988) suggest that the Bell Canyon below the WIPP facility does not contain any major channel sandstone units.

Water found in the permeable upper sandstones of the Bell Canyon is saline, with sodium and chloride as the predominant ions. Total dissolved solids in water sampled from the upper part of the Bell Canyon at the WIPP facility ranged from 180,000 to 270,000 milligrams per liter.

4.4.2 Castile Formation

The Castile Formation overlies the Bell Canyon (Figure 4-5) and consists of thick anhydrite beds with thin interbeds of halite. At the WIPP facility, the Castile averages 457 meters (1,500 feet) thick and represents a major regional ground water confining layer. Throughout most of the Delaware Basin, the Castile evaporites act as a barrier or confining layer for water moving up from the upper part of the Bell Canyon Formation.

Little hydraulic data are available for the Castile Formation. In the halite zones, the presence of water is restricted because the halite does not readily maintain primary porosity, solution channels, or open fractures. The same characteristics are inherent in the anhydrite, with the exception that fractures may remain open for longer periods than in the halite. Hydration of anhydrite, which occurs in the presence of slightly saline water, usually is accompanied by a 64 percent expansion in volume.

Drill stem tests were conducted in the Castile Formation during installation of several test holes. The permeabilities of the anhydrites and salt interbeds were negligible and in many cases were too low to be measured. However, a conservative estimate for a hydraulic conductivity of tested sections would be 3.5×10^{-14} meters per second (1×10^{-6} feet per day) or less (Lambert and Mercer, 1977).

Because the Castile Formation overlies the Bell Canyon Formation, it has been suggested that any potential movement of fluids upward from the Bell Canyon through the Castile evaporites could create a flow path for deep dissolution of the overlying Salado salts, leading to the development of dissolution features referred to as "breccia pipes" (Anderson, 1978). For this flow path to form, an extensive fracture system would have to develop through the anhydrite of the Castile. Detailed studies of the logs and cores from drilling in the vicinity of the WIPP facility have failed to identify such a fracture system or any other evidence that would indicate water has moved vertically through the evaporite sequence. No dissolution feature has been identified to extend to the depths associated with the Castile Formation.

Isolated pockets of brine and associated hydrogen sulfide have been discovered in the region around the WIPP facility during past oil exploration and more recent site characterization. These pressurized brines are present in a fractured anhydrite bed in the Castile Formation. The brines are associated with anticline structures and exist in isolated pockets. Geochemical studies have shown that the Castile brines are chemically and isotopically distinct from fluids in formations underlying and overlying the Castile, supporting the isolated nature of this formation.

4.4.3 Salado Formation

The Salado Formation laps extensively over the back reef of the Capitan Limestone (Figure 4-3), acts hydrologically as a confining bed, and does not contain any circulating ground water. The Salado Formation consists of about 610 meters (2,000 feet) of bedded halite with seams of anhydrite, clay, and polyhalite. The WIPP facility underground structures are located near the center of this formation.

The porosity of the Salado halite is very low and interconnected pores are virtually nonexistent. The salt does not readily maintain open fractures or solution channels because of the high plasticity of the material at the depths of interest. As a result, the hydraulic conductivity of the halite beds is extremely low (generally less than 1 microdarcy) (Mercer, 1983).

The average permeability of the waste repository horizon is less than 0.3 microdarcy, with a corresponding transmissivity of less than 6.5×10^{-11} square meters per second (6×10^{-5} square feet per day) and a hydraulic conductivity of less than 2×10^{-12} meters per second (6×10^{-7} feet per day) Interbedded seams of laterally continuous anhydrite, clay, and polyhalite should not provide substantial conduits for fluids as their permeabilities are also quite low. Field permeability tests have been conducted on a 30 meter (100 foot) thick salt layer centered at the 690 meter (2,264 foot) depth at the WIPP facility. This interval contained numerous clay seams and yielded permeabilities between 12 and 21 microdarcies.

Circulating waters do not exist in the Salado Formation, which acts as a major confining unit in the Delaware Basin. Fluids within the Salado occur mainly as fluid inclusions within halite crystals and as fluid between crystal boundaries in the massive salt formation. Migration of brine is promoted by

temperature and pressure gradients, such as those existing in the WIPP facility repository. The permeability of the Salado Formation is often too low to measure, but where measurable, is an average of 0.3 microdarcy.

Brine Seepage in the WIPP Facility Excavations

The Permian salt beds of the WIPP facility are considered to be "dry" in that inflow of brine is virtually nonexistent. Measurements of brine encountered in the underground workings, however, indicate that small amounts of brine can and do accumulate in the underground environment. The brine migrates into the repository in response to pressure gradients created by the excavation of the repository. Moisture content studies were initiated in 1982 as soon as the underground drifts began to be excavated. Brine seepages are manifested by salt efflorescences, moist areas, and fluid accumulations in drill holes (Deal and Case, 1987; Deal et al., 1987).

Measurement of the amount of moisture present in the rocks exposed in the excavations have been made (Deal et al., 1987) and show correlation between moisture content and stratigraphy. The investigations concentrated on determining the "easily moved" moisture available, and therefore, measurements of the amount of moisture driven off at 95°C (203°F) were made. The loss ranged from 0.03 to 2.53 percent by weight. Samples from clay-rich stratigraphic horizons were more moist than those from clear halite horizons. The average sample contained approximately 0.5 percent moisture by weight. Measurements were also made of the amount of moisture driven off at 150°C (302°F), and the results indicate that only 0 to 20 percent additional moisture was driven off at that temperature. This is probably an indication that water was being driven off as a result of the dehydration of clay minerals present.

Very small volumes of brine have been observed to "weep" from surfaces in the WIPP facility underground excavations. The moisture readily evaporates into the air circulated through the workings for ventilation. As a result, the weep locations are typically marked by thin salt crusts that build up over periods of months.

Small amounts of brine have been observed to accumulate in drillholes made from the repository excavations (Deal and Case, 1987). The drillholes are typically 15 meters (50 feet) or less in length and 15 centimeters (5.9 inches) or less in diameter. Measured occurrences have inflow rates that range from less than the rate at which surface moisture is evaporated into the repository atmosphere to approximately 0.5 liter per day (0.13 gallon per day). Individual occurrences vary greatly and some drillholes separated by less than a meter have seepage rates that contrast dramatically, making the discussion of "averages" or "typical occurrences" difficult or misleading. The typical range of seepage rates is from 0.01 to 0.2 liter per day (0.002 to 0.05 gallon per day) and decreases with time.

Brine samples have been chemically analyzed. They are high ionic-strength, saturated, magnesium-rich sodium chloride brines that have a specific gravity in excess of 1.2 grams per cubic centimeter.

The concern has been raised that brine might prevent complete consolidation of the WIPP facility openings by filling pore spaces, resulting in a volume approximately the shape of the excavations that is somewhat more porous and permeable than the surrounding, undisturbed salt. Sandia National Laboratories has modeled the brine seepage (Nowak et al., 1988) and has calculated that the expected brine accumulation in a disposal room will be in the range of 4 to 43 cubic meters (141 to 1,518 cubic feet) in 100 years. The maximum expected accumulation, 43 cubic meters (1,518 cubic feet), is 1.2 percent of the initial room volume, which is within the range of the amount of easily moved brine present in the salt that was removed by mining the room.

WIPP facility disposal rooms, filled with waste and backfilled, are expected to be virtually completely reconsolidated due to host rock creep in about 100 years, preventing further accumulation of brine. Calculations show that water-absorbing, tailored backfill materials can readily absorb the maximum expected brine accumulations in WIPP facility disposal rooms while maintaining adequate mechanical strength. Although modeling and brine observations continue at the WIPP facility, it does not appear that the small amounts of brine that seep into the excavations pose any significant, technical problem to the safe disposal of waste at the facility.

The Zone of Influence in the Salado Formation

The underground boundary of the repository is defined as the subsurface projection of the surface boundary and extends upward to the top of the Salado Formation and beneath the repository the same distance. However, within this boundary is a "zone of influence," the radial extent of which is marked by a change in rock behavior from brittle to plastic. The creation of this zone is a consequence of excavation, which de-stresses the rock around the opening, resulting in an area that is fractured. When fracturing occurs, the permeability of the rock increases. If there is brine present, it will flow toward the mined surface of the repository. Measurements of the WIPP facility rocks have shown an average brine content of approximately 0.5 percent (Deal and Case, 1987; Deal et al., 1987).

There are two mechanisms operating within the zone of influence that drive the brine toward the facility. First, there is a pressure gradient. The zone of increased permeability currently extends approximately 14 meters (46 feet) into the salt away from the mined openings (Case and Kelsall, 1987). Beyond the influenced zone, the pressure is lithostatic, approximately 15×10^6 pascals. At the mined surface, the pressure is atmospheric. The extreme difference in pressures drives the brine from the high pressure area toward the repository.

The second mechanism is the degassing of the brine. The brine contains small amounts of dissolved nitrogen gas. Gas solubility increases as pressure increases. When the pressure on the brine is relieved around the opening, the gas evolves, expands, and drives the brine out of the salt, much as carbonation carries soda out of a glass. As long as the brine is flowing toward the facility, there is no mechanism for moving hazardous waste away from the facility.

The region outside the zone of influence does not exhibit increased permeability. In this area, the salt behaves plastically and flows (creeps) toward the facility horizon in response to the deviatoric stress (i.e., stress which is not equal in all directions) at a rate that will remove 95 percent of the void space in the backfill, rooms, and waste within about 100 years (Lappin, 1988). At that point, the stress will begin to build up in the disturbed zone, the waste, and the backfill. Once the void space is mostly removed and this reloading has begun, the WIPP facility salt, in the presence of a small amount of brine (0.5 to 3 percent), will reconsolidate to its intrinsic permeability (on the order of 10^{-7} darcies) within a very short time. (The experimental data show a one-year reconsolidation period at a pressure of 1×10^6 pascal; the lithostatic pressure at the WIPP facility will be considerably higher.) After reconsolidation to 95 percent of the original density, the permeability will be in the sub-microdarcy range, the point at which salt forms an effective barrier to fluid flow (Holcomb and Shields, 1987). When the brine has stopped flowing because of the lack of permeability and the salt has reconsolidated itself, the waste will be sealed in the salt.

4.4.4 Rustler/Salado Contact Residuum

At the contact of the Rustler and Salado Formations is a layer of thinly bedded clay and brecciated gypsum containing brine. This layer ranges in thickness from 3 to 18 meters (10 to 60 feet) and averages 7 meters (24 feet).

Transmissivities determined during testing of this layer at the WIPP facility range from 3.2×10^{-11} to 5.4×10^{-8} square meters per second (3×10^{-5} to 5×10^{-2} square feet per day). Ground water flow in this layer is southwest across the region toward Nash Draw. A zone of greater permeability is associated with the residuum in Nash Draw, where flow is primarily through fractures and the intergranular spaces of the clay and gypsum. In contrast, brine underlying the WIPP facility east of Nash Draw occurs in a zone of minute permeability along the contact between the Salado and the overlying Rustler Formation, and is essentially bedding plane flow. Water in this unit, considered a sodium-chloride brine, contains the largest concentrations of total dissolved solids in the WIPP facility area, ranging from 80,000 to 480,000 milligrams per liter.

4.4.5 Culebra Dolomite Member of the Rustler Formation

The Culebra Dolomite member is the first continuous water-bearing zone above the Salado Formation (waste repository horizon) and is the most transmissive hydrologic unit in the WIPP facility area. The Culebra ranges from 7.6 to 9.1 meters (25 to 30 feet) in thickness. At the WIPP facility, the Culebra is a vuggy, finely crystalline dolomite that is present below the thick anhydrite of the Tamarisk Member. Water in the dolomite usually is present in fractures and is confined by overlying gypsum or anhydrite and underlying clay and anhydrite beds. Hydrologic studies of the WIPP facility area indicate that there is considerable variability in gradient and flow direction in the Culebra Dolomite (Figure 4-8). The hydraulic gradient in the immediate WIPP facility vicinity is approximately 3.8 meters per kilometer (20 feet per mile) while the gradient south and southwest of the site is much flatter, on the order of 1 to less than 0.2 meter per kilometer (5 to less than 1 foot per mile). Across the area, there is a general south-southwest flow direction. The area south of the WIPP facility, with its flatter gradient, has a somewhat more southeasterly flow direction.

Hydraulic properties of the Culebra Dolomite Member determined by testing vary considerably from place to place and appear to be related to the size and number of fractures and openings. Transmissivities calculated for the Culebra in Nash Draw, a highly fractured area caused by dissolution, range from 1.9×10^{-5} to 1.3×10^{-3} square meters per day (18 to 1,250 square feet per day).
Transmissivities calculated from test holes at the WIPP facility range from 7.5×10^{-8} to 8×10^{-5} square meters per second (7×10^{-2} to 74 square feet per day). Analysis of tracer tests in the Culebra Dolomite at the WIPP facility indicates a fracture porosity of 1.9×10^{-3}.

Use of water from the Culebra Dolomite is quite limited because of the variability of yields and the marginal water quality. The dissolved solids in these waters range in concentration from 3,200 to 420,000 milligrams per liter (Figure 4-9). The dissolved mineral constituents in the water from the Culebra Dolomite consist primarily of sulfate, chloride, calcium, magnesium, sodium, and potassium. This water is classified as being slightly saline to briny. The Culebra water is not used at the WIPP facility; however, 19 to 24 kilometers (12 to 15 miles) south of the facility, the water quality is acceptable for stock watering.

4.4.6 Magenta Dolomite Member of the Rustler Formation

The Magenta Dolomite, found throughout the WIPP facility area, is a persistent and distinctive clastic carbonate bed with thin layers of anhydrite. The Magenta is the uppermost water-producing zone in the Rustler Formation and ranges in thickness from 6 to 9 meters (20 to 30 feet). Stratigraphically, it occurs between the thick anhydrite confining beds of the Tamarisk and Forty-Niner members. Water, when present, usually occurs in the thin silt beds or silty dolomite but also has been found along bedding planes and in fractures.

The potentiometric surface, based on freshwater equivalent heads, suggests some variability in permeability across the WIPP facility (Figure 4-10). The gradient is estimated to be 3 to 4 meters per kilometer (16 to 20 feet per mile) on the eastern side and steepening to about 6 meters per kilometer (32

301001 89 14 02 A46

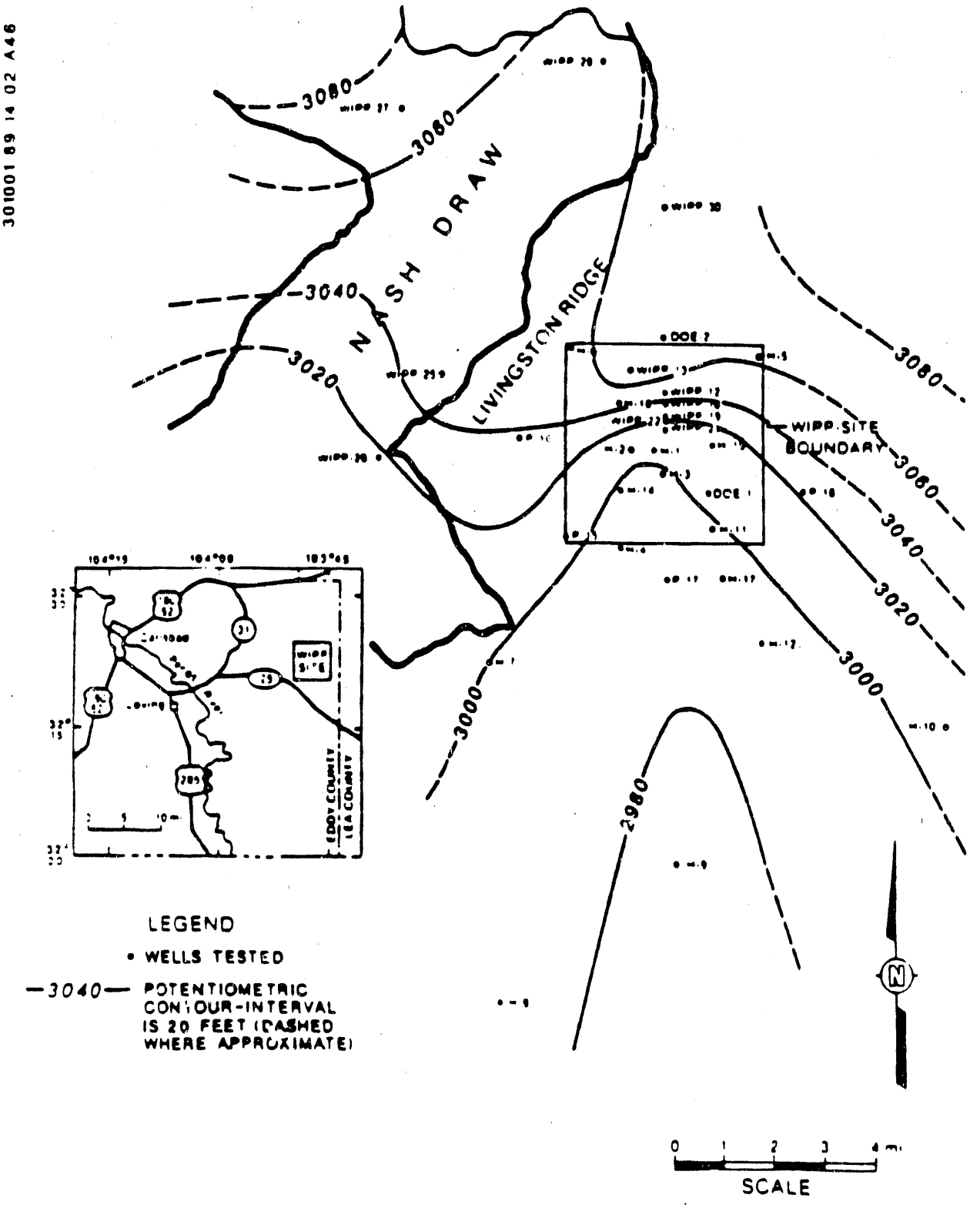


FIGURE 4-8 CULEBRA FRESHWATER HEAD POTENTIOMETRIC SURFACE

301001 69 14 02 A 47

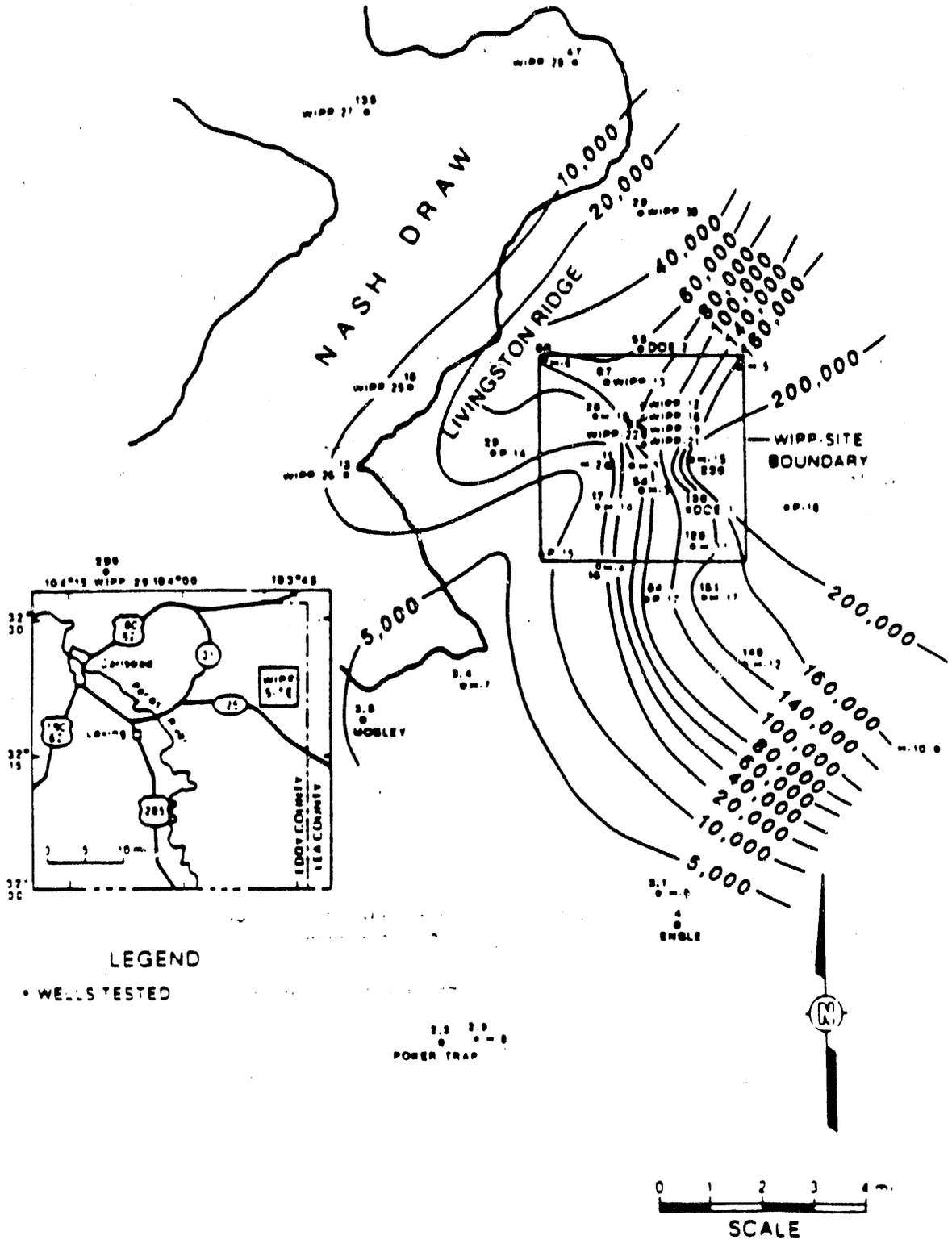
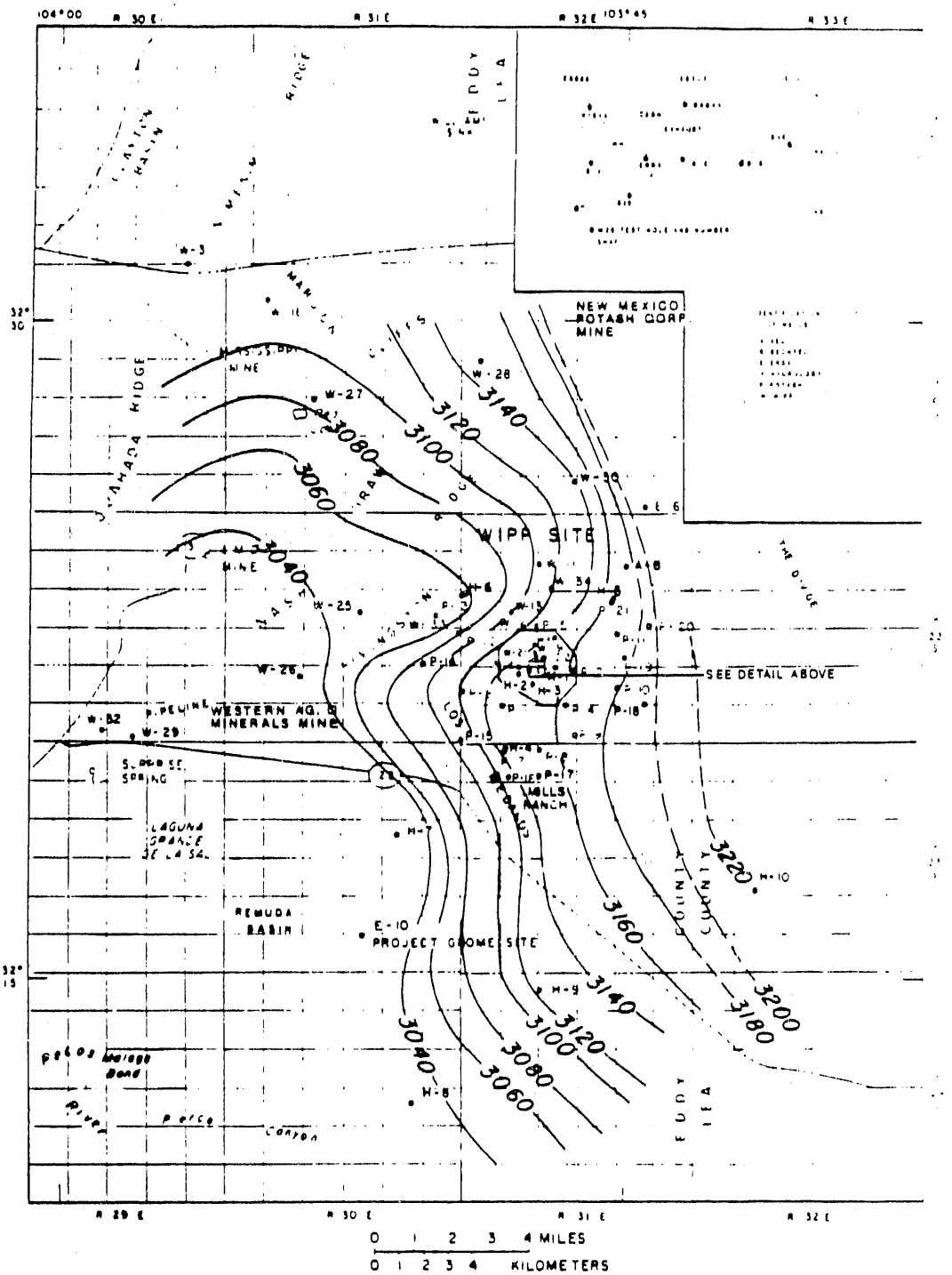


FIGURE 4-9 TOTAL DISSOLVED SOLIDS DISTRIBUTION IN THE CULEBRA DOLOMITE



NOTE

POTENTIOMETRIC CONTOUR SHOWS ALTITUDE AT WHICH WATER HAVING A DENSITY OF 1.0 GRAM PER CUBIC CENTIMETER WOULD HAVE STOOD IN A TIGHTLY CASED WELL CASHED WHERE APPROXIMATELY LOCATED. CONTOUR INTERVAL 20 FEET. DATUM IS SEA LEVEL

MODIFIED FROM

LEGEND

TEST HOLE AND NUMBER W-28

FIGURE 4-10 EQUIVALENT POTENTIOMETRIC SURFACE OF THE MAGENTA DOLOMITE WATER-BEARING UNIT IN THE RUSTLER FORMATION

feet per mile) along the western side near the boundary of Nash Draw. Water draining to the west may flow into lower units through the fractures associated with Nash Draw dissolution activity.

Recharge to the Magenta Dolomite takes place outside of the area. The most likely area is to the north in Bear Grass Draw and possibly in Clayton Basin (Figure 4-4). Discharge of water from the Magenta Dolomite in Nash Draw ultimately is to the brecciated area in the Rustler Formation near Malaga Bend and then possibly into the Pecos River.

The water in the Magenta Dolomite is classified as saline to briny. As is characteristic of other hydrologic units in the Rustler Formation, the dissolved mineral constituents on the Magenta consist largely of sulfates and chlorides of calcium, potassium, magnesium, and sodium. The water of the Magenta Dolomite is not used anywhere in the WIPP facility area.

4.4.7 Summary and Conclusions

The Salado Formation overlies a thick evaporite deposit (Castile Formation) which acts as an effective confining layer to deeper water-bearing sandstones (Bell Canyon Formation) preventing their upward movement. The Salado Formation itself has only an extremely small amount of interstitial water which does not naturally flow. The Rustler/Salado Contact contains water saturated with halite and could not dissolve halite in the Salado. The Culebra and Magenta Dolomites of the Rustler Formation are confined water-bearing units. Hydraulic tests have not indicated any detectable leakage between the two water-bearing units or between the water-bearing zones and the confining units. The head gradient from the Rustler/Salado Contact through the Rustler is upward so that if there were vertical ground water flow in the Rustler, it would be upward. Horizontal ground water flow in the Culebra Dolomite is generally to the south along a decreasing gradient at a very slow rate.

4.5 SURFACE WATER HYDROLOGY

Appendix L provides a detailed discussion of regional and site-specific surface water hydrology. These discussions include precipitation patterns, drainage patterns, evaporation, flooding, and estimations of probable maximum flood (PMF) flow. The following sections summarize those discussions.

4.5.1 Precipitation

The WIPP facility is located in the Chihuahuan Desert with an arid to semiarid climate. The mean annual precipitation in the region is about 12 inches, and the mean annual runoff is 0.2 to 0.5 centimeter (0.1 to 0.2 inch). The maximum recorded 24-hour precipitation at Carlsbad was 13 centimeters (5.12 inches) in August 1916. The 6-hour, 100-year precipitation event for the site is 9.1 centimeters (3.6 inches) and is most likely to occur during the summer. The maximum daily snowfall at Carlsbad was 33 centimeters (13 inches) in December 1987.

4.5.2 Evaporation

The potential evaporation in the vicinity of the WIPP facility is much greater than the average annual precipitation of 30 centimeters (12 inches). More than 90 percent of the mean annual precipitation at the site is estimated to be lost by evapotranspiration. The annual shallow lake evaporation rate for southeastern New Mexico is estimated at 2 meters (80 inches).

A nearly continuous caliche horizon underlies the surficial soil at the WIPP facility at a depth of a few centimeters to over 4.5 meters (15 feet). This caliche horizon forms by the precipitation of calcium carbonate at the limits of soil moisture penetration and forms an extremely impervious barrier. Almost all of the infiltrating water that reaches this horizon is retained above it and is typically lost by evapotranspiration.

4.5.3 Flooding and Probable Maximum Flood

Although large floods have occurred on the Pecos River, the WIPP facility is at an elevation over 150 meters (500 feet) above the river bed and over 122 meters (400 feet) above the floodplain. Probable maximum flood calculations, discussed in Appendix L, predict maximum flood levels on the Pecos near the WIPP facility to be near the levels of the modern floodplain.

4.5.4 Regional Drainage

The WIPP facility lies within the Los Medanos area in the drainage basin of the Pecos River (Figure 4-11). The Pecos is about 23 kilometers (14 miles) west of the WIPP facility at its closest point and has a drainage area of about 49,000 square kilometers (19,000 square miles). Flow in the Pecos River is regulated by several dams used for storage, irrigation, and power production (Figure 4-11).

At the WIPP facility no natural drainage features exist. A few small unnamed drainage channels constitute all the tributaries joining the Pecos River from the east within 80 kilometers (50 miles) north or south of the site. About 6.5 kilometers (4 miles) west of the WIPP site, there is a topographical depression know as Nash Draw which contains an ephemeral drainage system. This carries water only during very wet years and joins the Pecos River about 1.6 kilometers (1 mile) upstream of Malaga, New Mexico.

There are no major surface water bodies located within 16 kilometers (10 miles) of the WIPP facility. Beyond 16 kilometers (10 miles), several water bodies lie to the north and south of the site. The largest of these, Laguna Grande de la Sal, located south of the site, is several square kilometers in area and is a catchment basin for limited surface drainage and artesian saline springs.

Scattered throughout the area near the WIPP facility are livestock watering impoundments known as tanks. These tanks are essentially bermed areas designed to capture and contain surface water runoff.

4.5.5 Site Drainage

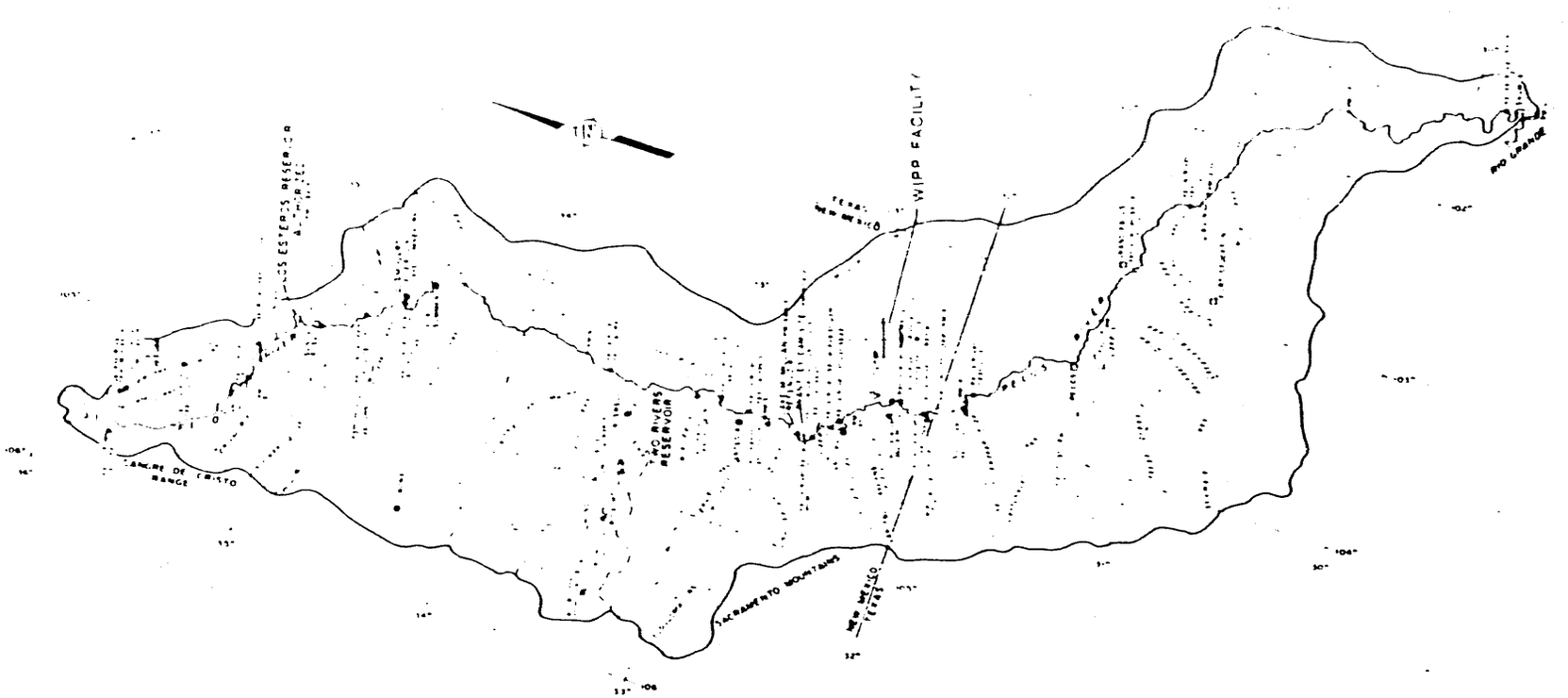
The drainage patterns at the WIPP facility are such that normal surface runoff from areas north, south, and west of the surface facilities drains westward into Nash Draw without affecting the site structures. Surface runoff during intense precipitation events could potentially pass through the site from the east; however, storm water runoff is diverted away from the surface facilities by a system of berms and ditches (Figure 4-12). The WIPP facility drainage system is designed so that storm runoff due to the probable maximum precipitation event would not flood the WIPP facility.

4.5.6 Summary and Conclusions

The WIPP facility is in an area of low precipitation and high evaporation. Storm runoff is directed away from the surface facilities to further reduce the potential of water ponding. The WIPP facility is approximately 23 kilometers (14 miles) from the Pecos River. The general ground elevation of the WIPP facility is over 150 meters (500 feet) above the riverbed and over 122 meters (400 feet) above the floodplain and probable maximum flood. The WIPP facility can be categorized as a "dry site" with no potential for flooding from the Pecos River. There are no outstanding surface water drainages near the facility and there are no major surface water bodies located within 16 kilometers (10 miles) of the facility.

4.6 SOILS

Regionally, soils in southeastern New Mexico developed from Quaternary and Permian parent material. The parent material from the Quaternary system is represented by alluvial deposits of major streams, dune sand which is the soil type in the immediate area of the facility, and other surface deposits. These



LEGEND

- INTERMITTENT STREAMS
- PERENNIAL STREAMS
- WATERSHED BOUNDARY
- SUB WATERSHED BOUNDARY
- STREAM GAGING STATION (ACTIVE)
- STREAM GAGING STATION (INACTIVE)
- MUNICIPALITY
- RESERVOIR AREA
- PRECIPITATION STATIONS
- RIVER MILE

SCALE IN MILES

Reference:

Flood Control, Brantley Dam and Reservoir Pecos River, New Mexico, U.S. Army Engineer District, Albuquerque, New Mexico (July 1964)

FIGURE 4-11 DRAINAGE PATTERN AND GAGING STATIONS, PECOS RIVER BASIN

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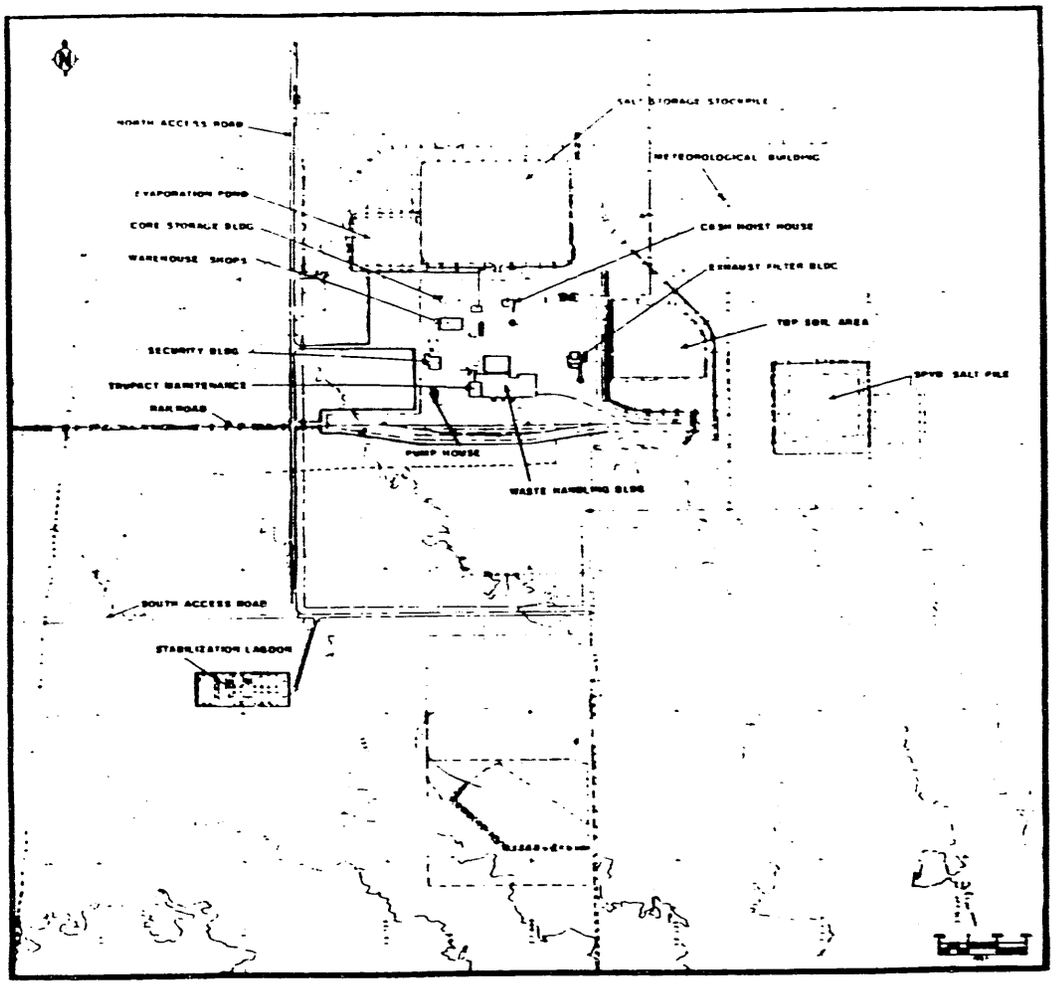

FIGURE 4-12 WIPP FACILITY DRAINAGE

are mostly loamy and sandy sediments containing some coarse fragments. Parent material from the Permian system is represented by limestone, dolomite, and gypsum bedrock.

There are three soil associations within eight kilometers (five miles) of the facility. Of these, only the Kermit-Berino association occurs at the facility in Control Zones I and II. Generally, a hard caliche layer occurs at 2 to 4 meters (7 to 13 feet) below the surface. The Berino series, which covers about 50 percent of the area, consists of deep, noncalcareous, yellow-red to red sandy soils that developed in wind-worked material of mixed origin. These soils occur as gently sloping (0 to 3 percent slopes), undulating to hummocky areas and are the most extensive of the deep, sandy soils in the Eddy County area. Berino soils are subject to continuing wind and water erosion. If the vegetative cover is seriously depleted, the water-erosion potential is slight, but the wind-erosion potential is very high. These soils are particularly sensitive to wind erosion in the spring when rainfall is low and winds tend to be strongest.

The Kermit series is made up of deep, lightly-colored, noncalcareous, excessively drained loose sands, typically yellowish-red fine sand. The surface is undulating to billowy (0 to 3 percent slope) and consists primarily of stabilized sand dunes. Kermit soils are slightly to moderately eroded. Permeability is very high, and the potential for wind erosion is very high in denuded areas.

Soils at the facility have been collected and characterized during the preoperational period by two monitoring programs, the Radiological Baseline Program (RBP) and the Ecological Monitoring Program (EMP). The purpose of the RBP program is to characterize background radiation levels at the site to establish a norm against which operational monitoring results may be compared. Analytical results are reported in the Annual Site Monitoring Reports for the Waste Isolation Pilot Plant (Reith et al., 1986; Banz et al, 1987; and Flynn, 1988), in accordance with DOE requirements. Radionuclide concentrations in RBP soil samples analyzed to date fall within expected ranges and do not indicate any unexpected environmental activity.

The EMP is designed to measure the impacts of WIPP facility activities on the surrounding ecosystem, and has focused primarily on the dispersal of salt from surface storage piles and the impact of that salt on soil process and vegetation. Analytical results are reported in the annual Ecological Monitoring Program Reports (Reith et al., 1985, 1986; Fischer, 1987, 1988). EMP results have been incorporated into the Annual Site Monitoring Reports starting in CY 1988.

There is some variation in EMP soil parameters throughout the year as windblown particulates from the storage pile as well as from crushed caliche used to pave the site are deposited on the soil surface in the immediate vicinity. To date, studies indicate that only limited dispersal of salt from the surface storage piles is occurring. Concentrations of water-soluble ions (sodium, chloride, potassium, magnesium, and calcium) in the surface soil are seasonally elevated within 200 meters (660 feet) of the salt piles; however, summer rains flush these ions from the soil surface.

4.7 BIOLOGICAL COMMUNITY STRUCTURE

In general, the biota of Los Medanos represents a transition between the northern Chihuahuan Desert and the southern Great Plains, and is dominated by Quercus havardii (Shinnery oak), Artemisia filifolia (Sand sage), Prosopis glandulosa (Honey mesquite), and perennial grasses. Soils are sandy and form stabilized coppice dunes interspersed with swales. Extensive root systems of the dominant species provide stability to the erodible dune soil.

Vegetation in the EMP monitoring plots is surveyed in the spring and fall to detect impacts of salt transport and the resultant changes in soil chemistry on extant vascular plants. This subprogram monitors foliar cover for all species, density of annual species, species richness and the structure of the

vegetation community in the plots. To date, the data indicate that the impacts of WIPP facility construction and salt storage on the vegetation in the surrounding ecosystem are minimal (Fischer, 1988).

Additional parameters monitored for the EMP include the populations of breeding birds, activity levels of microbial populations on plant litter, and populations of small nocturnal mammals. The results of the breeding bird surveys thus far indicate that the construction of the WIPP facility has affected the avifauna in the area around the facility, although not in a way which can be judged detrimental or even unexpected. Some species are less dense in the area of the facility, probably as a result of lost habitat, while others, apparently benefiting from activities at the facility, have increased in numbers. The 1987 data showed a greater similarity between the control and WIPP facility transects than in any of the previous years, possibly indicating a recovery of the avifauna near the facility as the surface construction activities decrease and the birds are more acclimated to the activities and disturbances.

This area of southeastern New Mexico is unusual in that it supports a large population of raptors (birds-of-prey), particularly Harris Hawks, which reproduce more successfully here than in other parts of their range. A DOE-supported project was initiated in March 1985 to study the population dynamics, behavior, and strategies for management of raptors in the area around the WIPP facility (Bednarz and Hayden, 1988). Threatened and endangered species consultation with the U.S. Fish and Wildlife Service and the New Mexico Department of Game and Fish was performed in 1979 as part of the WIPP Final Environmental Impact Statement (DOE, 1980) and was renewed in 1989. The conclusion of this consultation is that no State or Federally listed threatened or endangered species nor critical habitat is projected to be impacted by the construction and operation of WIPP.

To date, microbial populations fluctuate to some extent with available moisture, but do not appear to be impacted by the effects of any WIPP facility-related activity. The overall effects of the WIPP facility and its construction on small nocturnal mammal populations are difficult to assess due to large-scale natural fluctuations in these populations. Although differences in the impacted and control monitoring grids have been detected, none can yet be identified as being indicative of possible long-term environmental degradation. Mammal species counted during EMP trapping sessions include the Ord's kangaroo rat (Dipodomys ordii), the Plains pocket mouse (Perognathus flavescens), and the northern grasshopper mouse (Onychomys leucogaster). With such naturally dynamic populations, the effects of the WIPP facility may not be immediately detectable in the structure of the mammal community, but may be inferred by the community's ability to recover from a natural "crash."

4.8 LONG-TERM ENVIRONMENTAL CHANGES

The potential impacts of WIPP facility construction activities on the surrounding ecosystem are illustrated in Figure 4-13. A disturbance of community structure over an area of 0.9 square kilometers (224 acres) is considered to be the only long-term impact that will affect the environment in the area (DOE, 1980). Additionally, intrusion by humans will be prevented because access to mineral reserves will be restricted. Other potential impacts to the site could result from the potential release scenarios described in Section 5. In lieu of any such occurrences, however, there are expected to be no long-term releases of radioactive or hazardous materials from the repository to the surrounding environments.

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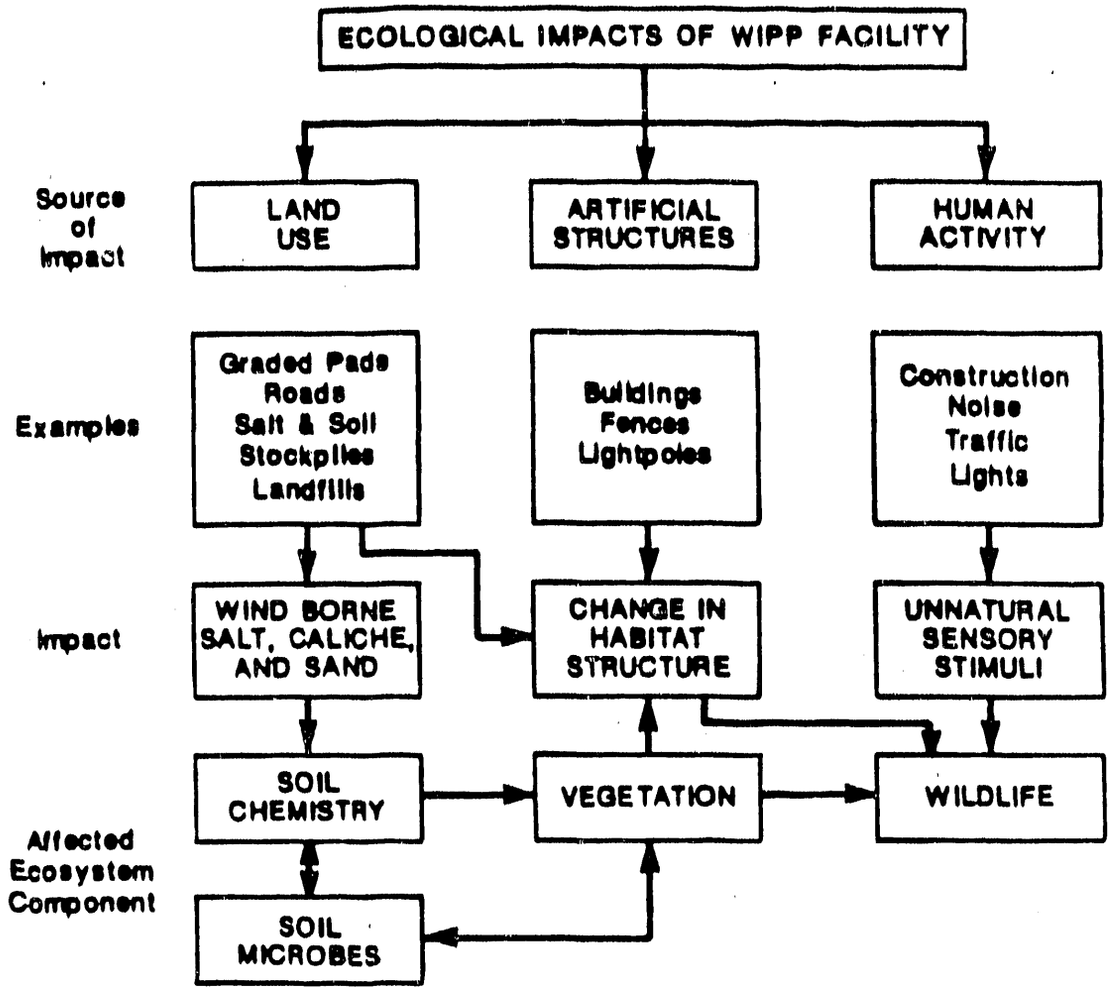

FIGURE 4-13 ECOLOGICAL IMPACTS OF WIPP FACILITY

APPENDIX D7

REGIONAL AND SITE GEOLOGY AND HYDROLOGY

FROM PREVIOUSLY PUBLISHED NO-MIGRATION VARIANCE PETITION,
APPENDIX L, VOLUME VI

U.S. Department of Energy (DOE), 1990,
DOE/WIPP 89-003, Revision 1, Carlsbad, New Mexico

APPENDIX L

SITE AND REGIONAL GEOLOGY AND HYDROLOGY

The Site and Regional Geology and Hydrology data provide an extensive summary of the geology, stratigraphy, structure, and geomorphology of the area in and around the WIPP facility. The geologic history of the region and the site area provides a reasonable basis for predicting future geologic influences upon repository performance.

1.0 REGIONAL AND SITE GEOLOGY

The region surrounding the WIPP site has been under study for many years. Before WIPP was proposed, the region was studied intensively by the U.S. Geological Survey because of its potash and oil and gas resources. In the WIPP context, two exploratory holes were drilled northeast of the present site in 1974, and intensive geologic studies started in 1975. The results of these studies are given in numerous reports cited later in this chapter.

The geologic studies at and around the WIPP site have been aimed at collecting detailed geologic information for use in evaluating the site's suitability as a radioactive waste repository. This section summarizes the large amount of geologic information currently available. A major source of information is the WIPP Geological Characterization Report (Powers et al., 1978), which should be consulted for more detailed discussion and for references to primary sources. The WIPP Safety Analysis Report (DOE, 1988, Revised 1990) is another important source of site-specific information.

Characterizing the site's geology began with surveys of literature and existing data and has continued with the collection of new data. On-going studies employ many standard petroleum and mineral industry techniques. Special emphasis has been placed on correlating data obtained by geophysical techniques and borehole drilling. The geophysical techniques most widely used have been seismic reflection and resistivity. By June 1980, new seismic reflection data for about 152 line-miles had been obtained, and more than 9,000 resistivity measurements had been made and analyzed. Twenty-one boreholes had been drilled to evaluate potash resources. Sixteen boreholes had been drilled primarily for stratigraphic information on or near the site and to study salt dissolution. Three of these holes, located outside the site's boundaries, acquired geologic data on the deeper strata. Eighteen locations were drilled for the purpose of collecting hydrologic data, and numerous additional drill holes have been completed as monitor wells.

Geologic studies continue in order to permit a better quantification of the rates of geologic processes in and near the site and to develop a more thorough understanding of the geologic phenomena of interest. More detailed descriptions of the geologic, hydrologic, and geophysical methods of investigation are given in the Geological Characterization Report (Powers et al., 1978) and other documents referenced in this report.

The basement rock in the WIPP Site region consists of Precambrian metasedimentary and igneous strata. This basement is overlain by a late Cambrian through Cenozoic sedimentary sequence consisting primarily of carbonates and evaporites with a small quantity of redbeds and terrestrial clastics. The lower and mid-Paleozoic sediments were deposited on a slowly subsiding continental shelf. They consist predominantly of carbonates with minor sand, shale, and chert. The upper Paleozoic section was deposited in a rapidly developing basin and shelf environment. The Delaware Basin, in which the WIPP Site is located, was one of the basins to form at this time. Reefs eventually grew around the margins of the Delaware Basin and reached a peak in the mid to late Permian. Their growth eventually restricted the water circulation in the basin and led to the accumulation of a thick section of upper Permian evaporites. The Mesozoic and Cenozoic sections consist of redbeds and scattered patches of limestone, sandstone, and conglomerate, all of which are overlain by caliche and windblown sand. These meager deposits are the result of the periodic and long-term emergent conditions which existed in this area throughout the Mesozoic and Cenozoic Eras.

Structurally, the WIPP site is situated at the southwestern extent of the central stable region of North America (Figure 1). It lies within a fairly undeformed area, north and west of the Ouachita Tectonic Belt in Texas and Mexico, which is characterized by broad arches, basins, platforms, and shelves. The immediate structural setting of the site is the northern Delaware Basin (Figure 2). Structural development of this basin began in the Pennsylvanian and ceased in the late Permian when it was filled with

evaporites and covered by younger sediments. Since that time, it has undergone only broad regional tilting. The geology, stratigraphy, structure, and local geomorphology of the WIPP Site area are discussed in detail in the following sections.

1.1 GEOMORPHOLOGY

The terrain of much of southeastern New Mexico is characterized by a gentle southwesterly slope and hummocky surface marked by karst features, caliche, and sand dunes. The major permanent drainage of the area is the Pecos River, located 14 miles east of the site.

1.1.1 Regional Physiography and Geomorphology

The WIPP Site is in the Pecos Valley section of the southern Great Plains physiographic province, a broad highland belt sloping gently eastward from the Rocky Mountains and the Basin and Range province to the Central Lowlands province (Figure 1). The Pecos Valley section itself is dominated by the Pecos River Valley, a long north-south trough 5 to 30 miles wide and as much as 1,000 feet deep in the north. The valley has an uneven rock- and alluvium-covered floor with widespread solution-subsidence features, the result of dissolution in the underlying Upper Permian rocks. The terrain varies from plains and lowlands to rugged canyonlands, including such erosional features as scarps, cuestas, terraces, and mesas. The surface slopes gently eastward, reflecting the dip of the underlying rock strata. Elevations range from more than 6,000 feet in the northwest to about 2,000 feet in the south (Powers et al., 1978).

The Pecos Valley section is bordered on the east by the Llano Estacado, a virtually uneroded plain. The Llano Estacado is part of the High Plains section of the Great Plains physiographic province. Few and minor topographic features are present in the High Plains section, formed when more than 500 feet of Tertiary silts, gravels, and sands were laid down in alluvial fans by streams draining the Rocky Mountains. In many areas, the nearly flat surface is cemented by a hard caliche layer.

To the west of the Pecos Valley section are the Sacramento and the Guadalupe Mountains, part of the Sacramento section of the Basin and Range province. The Capitan escarpment along the southeastern side of the Guadalupe Mountains marks the boundary between the Basin and Range and the Great Plains provinces. The Sacramento section has large basinal areas and a series of intervening mountain ranges.

The main geomorphic features bearing on the region are the Pecos River drainage system, the Mescalero plain, a karst terrain, and wind-erosion "blow-outs." The Pecos River system has evolved from the south, cutting headward through the sediments of the Ogallala Formation and becoming entrenched sometime after the middle Pleistocene. It receives almost all the surface and subsurface drainage of the region; most of its tributaries are intermittent because of the semiarid climate. Most of the ground surface east of the Pecos River Valley lies in the Llano Estacado, a poorly drained eastward-sloping surface covered by gravels, wind-blown sand, and caliche that has developed since early to middle Pleistocene time. The surface locally is represented by the Mescalero Plain and has a karst terrain containing superficial sinkholes, dolines, and solution-subsidence troughs, from both surface erosion and subsurface dissolution. The site lies near a caliche- and sand-covered drainage divide separating two major and actively developing solution-erosion features: Nash Draw to the west and San Simon Swale to the east (Figure 2).

1.1.2 Major Geomorphic Features of the WIPP Site Region

The geomorphic development of the major land forms which constitute the near-site setting are discussed in this section. These features include the Pecos River drainage system, the Mescalero Plain and associated deposits (Mescalero Caliche), karst topography, and blowouts. In general, these geomorphic features are located within the Pecos Valley physiographic section.

Pecos River Drainage System

The Pecos River, 20 miles west of the site, is the only major perennial stream in the Eddy and Lea Counties area of southeastern New Mexico. It receives almost all of the surface drainage in this region and a large part of the subsurface drainage. The Pecos River originates in the southern Rocky Mountains of north-central New Mexico and flows south and southeastward to join the Rio Grande in west Texas (Kottlowski et al., 1965). The dimensions of the contemporary river valley are described in Section 1.1.1.

According to King (1948), the Pecos River apparently had its origin to the south, in the Edwards Plateau, as a short tributary of the Rio Grande River. As the river worked its way northward, eroding the Ogallala sediments in the process, it captured the westward-flowing streams of the present upper Pecos River Valley, thereby reversing their drainage direction. This stream piracy was facilitated by the underlying, poorly resistant Permian rocks (Thornbury, 1965).

Bachman (1973, 1974) has expressed the opinion, in accordance with Lee (1925) and Morgan (1942), that the present course of the Pecos River was formed, at least in part, through the coalescence of trains of solution sinks (see Karst Topography below for discussion of solution sink development). Bachman cites as evidence for this theory many places along the course of the river in southeast New Mexico where the river follows broad meanders, although the floodplain as a whole is unusually narrow or nonexistent, as well as locations adjacent to the Pecos where intermittent tributaries follow semicircular collapse valleys. Bachman concludes that the river became entrenched in its present position by a combination of this solution-subsidence, headward cutting, and piracy.

The age of entrenchment of the Pecos River is somewhat uncertain. Thornbury (1965) has stated that the age of the piracy which constituted part of the entrenchment process is rather definitely dated as post-Pliocene and is assumed to have taken place in the early Pleistocene. Bachman (1974) has stated that it is not possible to date the entrenchment of the ancestral Pecos River in southern New Mexico precisely. Bachman (1976) has observed that the Pecos entrenched itself near its present channel along the toes of pediments east of the Sacramento Mountains sometime after the middle Pleistocene, which would place the establishment of the present course at a later date. Since entrenchment, the river has carved a valley in which a variety of subsidence features have developed through dissolution processes which are probably still active in the valley today.

Mescalero Plain

East of the Pecos River to about longitude 104°W lies an extensive, gently sloping pediment surface known as the Mescalero Plain (Thornbury, 1965) which extends from the vicinity of Fort Sumner in northern New Mexico to south of the Mexico-Texas border (Bachman, 1974). The surface of the plain rises eastward from about 150 feet above the Pecos River to as much as 400 feet above the river at the base of the Llano Estacado (Bachman, 1973; Kelley, 1971). The average elevations range from about 3,800 to 4,100 feet above sea level in northwestern Lea County near Mescalero Ridge to about 3,100 feet in southeastern Eddy County, south of Big Sinks (Bachman, 1973).

Although termed a "plain," the area includes many low mesas, bluffs and wide draws. Locally, the surface has been dissected by intermittent streams, but in general, the area is poorly drained and contains numerous playa pans and smaller sinks (Brokaw et al., 1972; Kelley, 1971). The surface of the plain is covered widely with gravels and sands, often cemented with the Mescalero caliche. As much as five to ten feet, and locally more, of these materials are exposed along the edges of the long irregular mesas of the area (Kelley, 1971).

The Mescalero Plain probably formed during a period of tectonic stability after deposition of the Gatuna Formation in the Early to Middle Pleistocene and has been modified both during and after its formation by solution-subsidence features, discussed below (Bachman, 1976). The widely distributed gravel deposits have probably been derived from erosion of the Ogallala Formation in the Llano Estacado, to the east (Kelley, 1971). The development and distribution of caliche and sand dune deposits, both of which overlie extensive portions of the pre-caliche Mescalero Plain surface in the southeast New Mexico, are discussed separately in the following paragraphs.

Mescalero Caliche

The deposits of the Mescalero Plain are generally covered by the calcareous, cemented remnant of an extensive soil profile known as the Mescalero caliche. The caliche forms a resistant caprock which averages three to five feet thick and is generally less than ten feet thick. It is locally absent over the solution depressions of the plain, and in areas of collapse may be nearly vertical. Caliche may also be locally absent due to erosion or nondeposition. It consists of a basal earthy to firm, nodular calcareous deposit and an upper well-cemented laminar caprock (Bachman, 1976). In places, the caliche has weathered to a ledge that overhangs less resistant deposits. Because of the generally uniform covering by the erosion-resistant caliche, it is probable that irregular surfaces, such as missing sections and vertically oriented blocks of caliche, result from subsurface solutioning and subsidence of the underlying sediments, primarily after the caliche caprock formed.

Although the genesis of the Mescalero caliche is uncertain, it is thought to be a process dependent upon climatic conditions involving certain ranges of both temperature and rainfall in which carbonate movement is produced within the soil profile, resulting in the reworking and cementing of the soil constituents into a cohesive, calcareous mass. This caliche formed during a period of stable, semiarid climatic conditions which have been tentatively correlated with the Yarmouthian interglacial stage of the middle Pleistocene (Bachman, 1974, 1976).

Eolian Sand

Eolian sand covers much of the Mescalero Plain in southeastern New Mexico and is known locally as the Mescalero sand (Vine, 1963). This sand generally forms two distinct types of deposits: sheetlike stretches of surficial sand which vary in thickness from about 5 to 15 feet (Bachman, 1973; Vine, 1963), and dunes having a maximum thickness of about 60 feet (Hendrickson and Jones, 1952).

The eolian sand deposits of the Mescalero Plain have probably been derived from a widespread source of fine-grained sediments. Bachman (1974) suggests that most of this sand originated from the Ogallala Formation, although local sources, such as blowouts, have also been a source of some dune materials. There is little evidence to indicate that much sand has been derived from the Pecos River (Bachman, 1973, 1974, 1976).

Except where the sand is stabilized by vegetation, it is continually blown about to form transverse dune ridges and barchan dune areas separated by broad barren flats. The orientation of the dune ridges is not uniform throughout the area, with the long dimension of the ridges apparently reflecting the direction of the strongest prevailing winds at the time of their formation (Vine, 1963).

At least two periods of eolian sand emplacement have occurred since the formation of the Mescalero Plain in Pleistocene time and are evidenced in some places by two distinct layers of sand. The lower deposit consists of a semiconsolidated, somewhat clayey sand, as much as 1.5 feet thick, overlain by as much as 20 to 25 feet of loose surficial sand forming the contemporary sheet and dune formations (Bachman, 1976).

Blowouts

Some of the basins which are present in southeastern New Mexico have been formed by processes other than the previously described mechanisms of dissolution and collapse. The most conspicuous of these basins in the area of the proposed WIPP site are Williams Sink, Laguna Gatuna, and Laguna Plata, all of which are situated approximately 15 miles to the north of the site.

These features, termed blowouts, have formed through the removal of loose sand deposits by wind erosion. During the rainy season, many of the blowouts are partially filled with water. Their floors are mantled with clay and saline deposits, and many are surrounded by eolian sand. Dune fields commonly develop along the northeastern and eastern leeward margins of these depressions (Bachman, 1974).

Karst Topography

The land surface in southeastern New Mexico locally exhibits a karst topography, characterized by geomorphic features such as sinkholes, linear depressions [called solution-subsidence troughs by Olive (1957)], domes (including one known "breccia pipe"), "castiles," and collapsed outliers (Anderson, 1978). Many of these features show up on LANDSAT imagery as ponds and other water-filled depressions concentrated particularly near Roswell and also between the Pecos River and Mescalero Ridge. These features have resulted from the dissolution of salts and other soluble materials within the upper Permian Ochoan Series, particularly in the Rustler and the Upper Salado Formations. The water required for the dissolution process has come into contact with the soluble materials either by surface exposure, following erosional removal of the protective mantle of younger sediments such as the Ogallala Formation and caliche or, at depth, by means of the downward percolation of local surface water or by contact by means of fracture systems between the Ochoan rocks and underlying regional aquifers, which have been exposed along basin margins by the Cenozoic regional uplift, tilting and erosion. These solution processes have been followed by collapse of the insoluble strata into the voids left behind by the dissolution (Bachman, 1974).

Development of karst features may have occurred in southeastern New Mexico as early as Triassic or Jurassic time, when the area was above sea level and probably undergoing extensive erosion which exposed the soluble materials. Bachman (1976) surmised that some dissolution of Permian salts and gypsum probably took place in the western part of the Delaware Basin during Jurassic time, before resubmergence in the Cretaceous. Extensive regional erosion also took place during the early Tertiary, presumably with accompanying renewed dissolution activity, although no sedimentary records of that period are preserved today. The earliest and most widespread basis for relative dating of solution-collapse features in the area is the Mescalero caliche, of Middle Pleistocene time. If, as is generally believed, the caliche was derived from a soil profile, it could not have formed on the irregular and, in places, very steep slopes of today. Additionally, the fracturing and slumping of the Mescalero caliche along the widely occurring depressions of the area indicate collapse after Mescalero time. Some of the major collapse features here, such as Nash Draw, Clayton Basin and Crow Flats, exhibit evidence of several intervals of dissolution and subsidence activity. For example, Crow Flats, a large feature 15 miles east of Artesia, contains evidence for at least three such episodes, ranging in time from after Triassic and before Pleistocene Gatuna deposition, during or after Gatuna time and after Mescalero time (Bachman, 1976). Notwithstanding this evidence of long-term dissolution history, Anderson (1978) believes that many of the deep-seated dissolution features formed during the most recent and most extensive period of salt removal following the Cenozoic erosion and exposure of the evaporites. Much of this activity is suggested to have occurred during the past few million years; dissolution has apparently progressed from west to east and from south to north across the Delaware Basin.

Solution - Subsidence Features

Several types of solution and subsidence features have been observed in the vicinity of the WIPP site. The following discuss describes the features and their causes.

Sinkholes - Sinkholes form a category of features represented by thin or missing sections of halite in the Castile Formation and often result in surficial depressions. Many of the sinkholes present in the northern Delaware Basin are developed as deep-seated features originating in the Castile Formation. The sinks are often expressed as thin or missing sections of the major halite beds of the Castile Formation and, to a lesser extent, of smaller salt beds above these units, and resulting structural depression of the overlying stratigraphic units. At least 100 deep-seated sinks are estimated to exist presently in the New Mexico portion of the basin. Around the margin of the basin, a number of these deep-seated sinks appear to be associated with anticlinal structures in the salt; in the mid-basin area, these sinks occur as both isolated features and in association with salt anticlines (Anderson, 1978). In addition to these deep-seated features, there are many sinks present in the area which are associated with active near-surface dissolution such as those along the Pecos River and in Nash Draw (Anderson, 1978).

Compound sinkholes, resulting from coalescing collapse sinks, are common along the Pecos River valley south of Roswell. Many of these sinks have collapsed within historic time (Bachman, 1974). As discussed above, Bachman (1974) suggests that the course of the Pecos River southward from Carlsbad to near the New Mexico-Texas border lies within a major belt of such collapse sinks. Bachman describes similar developments along the east side of the Pecos River southeast of Carlsbad, where a linear scarp is believed to have formed as the result of a collapse structure which is now occupied by the river.

Dolines - Dolines are very common features in southeastern New Mexico, forming on limestone bedrock and caliche surfaces. Dolines are defined as relatively shallow solution sinks that develop on the surface beneath the soil mantle without physically disturbing the underlying rocks or being underlain by subsurface solution cavities (Bachman, 1974).

Solution-Subsidence Troughs - Narrow, linear, generally northeast-trending depressions in southeastern New Mexico that vary in width from a few hundred feet to a mile and, in length, from one-half mile to ten miles have been termed solution-subsidence troughs by Olive (1957), who proposes that these troughs result from the subsidence of near-surface material which fills voids dissolved by water flowing in underground channels. According to Thornbury (1965), these troughs are particularly common west of the Pecos River in areas underlain by the Castile Formation and extend eastward, parallel to the regional dip, as a result of dissolution along eastward-trending joint systems that parallel the regional dip. These are distinguished from sinkholes mainly by their larger size and linear shape.

Bachman and Johnson (1973) also describe linear features occurring in areas generally underlain by the Ogallala Formation, to the north and northeast of the site, and suggest that at least some of these depressions may be the result of alternate leaching and wind deflation (Judson, 1950; Price, 1958). These features appear on LANDSAT imagery as alternating linear strips of vegetation and white to gray soil, trending northwest-southeast. They are most prominent north of the City of Hobbs and San Simon Sink and at scattered locations on the Mescalero Plain. The leaching may have been produced by the chemical action of plant growth on the caliche surface between longitudinal sand dunes where small amounts of ground water were able to collect during periods of eolian quiescence; later periods of eolian activity removed these leached sediments from between the dunes. The swales left behind by this leaching activity mark the location of former longitudinal dune fields which have been displaced or removed by continued eolian activity. The effect of these linear features has been to provide depressions in which surface runoff collects and serves as sources of ground water recharge. Solutioning and erosion along these lineaments may also have opened conduits to the subsurface and contributed to a more rapid dissolution of the underlying soluble rocks (Bachman and Johnson, 1973).

Breccia Pipes and Domes - Various domal structures, having diameters from several hundred to several thousand feet, occur in southeastern New Mexico, particularly along and east of the Pecos River, and are associated with areas of relatively recent surface salt dissolution (Anderson, 1978). Although they have been termed "breccia pipes," these features have no relationship whatsoever to volcanic activity. Many of the domes have been breached by erosion to reveal brecciated cores of stratigraphically displaced Gatuna, Rustler, and Triassic beds. These features are also characterized by doming-related deformation of rocks as young as the Mescalero caliche (Vine, 1960).

Anderson (1978) hypothesized that breccia pipes originate from the dissolution of salt at depth by waters circulating along intersecting joint sets in adjacent brittle rocks. Subsequent collapse of insolubles into the cavity forms a rubble breccia chimney, which sometimes penetrates to the ground surface. The depth to which breccia pipes may extend is not known. The only known breccia pipe in the vicinity of the WIPP site is known to reach as deep as the McNutt member of the Salado Formation, as evidenced by underground exposure, in the Mississippi Chemical Company potash mine (Griswald, 1977). This breccia pipe is observed to be well-cemented by fine-grained material with no perceptible open space and with no evidence of removal of soluble material from the evaporites adjacent to the feature in the mine. This particular feature is expressed at the surface by a dome with a collapsed center. The doming of this brecciated core took place at a later time. Vine (1960) suggests three possible mechanisms for this later deformation: the erosion of the rock surrounding the core of the sink; the upward flow of salt into the sink; an increase in volume of rock as anhydrite is altered to gypsum in the brecciated core. Anderson (1978) believes that the doming has been produced by regional near-surface dissolution removing the salt from around the pipes and producing a sagging of the beds around the pipes. As a result of the doming process, the rock strata surrounding the dome at the surface generally dip away from the breccia pipe core (Vine, 1960). Underground, in the Mississippi Chemical mine, beds adjacent to the breccia pipe dip toward the breccia pipe at about 10-20°.

The age of the breccia pipe formation in this area has not been determined. Mescalero caliche, of Middle Pleistocene age, is present on the flanks of breccia pipes and lying at steeper angles than those at which the caliche probably originally formed. This may indicate that the breccia pipes are younger than the mid-Pleistocene. It is also possible, however, that the breccia pipes predate the caliche and that later subsurface removal of salt by dissolution produced greater amounts of downdrop away from the more resistant breccia pipes, resulting in the slopes present today.

Despite the fact that known breccia pipes are generally expressed topographically as domes, it has been surmised that others may have no surficial expression and remain undetected. Geophysical techniques have been used to explore for pipes. Electrical resistivity surveys have shown that the breccia core of the known pipe has a much lower resistivity than the surrounding undisturbed strata (Elliot, 1976). Continuity of seismic reflections is lost when similar geomorphic features are crossed by survey lines (Griswold, 1977).

Collapsed Outliers and "Castiles" - Outliers of the Rustler Formation, separated from the main outcrop area through erosional processes, as described by Anderson (1978), are circular to elongate or irregular shaped features consisting mostly of the Culebra Dolomite member of the Rustler Formation. They occur where the salt has been completely dissolved from the underlying Salado Formation and the Culebra has collapsed into the underlying strata.

Limestone buttes, called castiles, occur west and south of the collapsed outliers, primarily in Texas, in the lower part of the Castile Formation outcrop area. These features consist of biogenic calcite which has replaced the gypsum or anhydrite of the Castile Formation. Some exhibit collapse structures with brecciated cores. These buttes are similar in size and distribution to the collapsed outliers but do not consist of the Culebra Dolomite as described above (Anderson, 1978).

1.1.3 Prominent Near-Site Features

Geomorphic features which have formed in the area of the WIPP site as a result of sinkhole formation and related solution-subsidence mechanisms include Nash Draw and San Simon Swale (see Figure 2 for their location and topographic configurations). These features and their specific development are discussed separately below.

Nash Draw

Approximately five miles northwest of the proposed WIPP site is a prominent geomorphic feature, known as Nash Draw, which Vine (1960) describes as a sinuous depression about four miles wide and 18 miles long (Figure 2). Its surface structural expression is similar to that of a breached anticline plunging gently northward, with the older Rustler Formation exposed in its center and the younger Dewey Lake redbeds and Santa Rosa Sandstone exposed along its flanks. However, well records in the area indicate that the bedrock underlying the draw exhibits a gentle monoclinal configuration. Accordingly, Nash Draw has been identified as an undrained physiographic depression, which has probably developed as a result of regional and differential dissolution of the anhydrite, gypsum, and halite beds of the Rustler and upper Salado Formations (Vine, 1963).

According to Vine (1963), dissolution on top of the massive salt in the Salado Formation has produced a rather uniform lowering of the land surface in Nash Draw, but its surficial structural features have been produced and greatly modified by differential solution of the more soluble portions of the Rustler Formation. While the bedrock in the northern part of Nash Draw is generally covered by eolian sand, caliche and alluvium, the central and southern portions of the draw contain exposures of Rustler that have been highly deformed primarily as a result of large-scale collapse following solution of the Rustler and Salado Formations. This dissolution activity has also produced numerous individual, small-scale local sinkholes in Nash Draw, which vary in configuration from circular features a few tens or hundreds of feet across to irregular or arcuate features up to more than a mile across. Many of the larger depressions in the area of Nash Draw, including the basin at its southwestern extent which contains a Salt Lake, have probably formed through the coalescing of several smaller solution depressions or sinks. Some such places, where several depressions tend to align, may also indicate the location of subterranean cavernous water courses (Vine, 1963).

The age of the earliest solution activity that produced Nash Draw is uncertain. It is thought that some of the deep-seated solution in the Delaware Basin area had occurred by the middle part of the Mesozoic, but that a substantial amount of this process has taken place since the Late Tertiary regional tilting of this area. Within Nash Draw, the formation of a large number of the individual solution features has resulted in the deformation of rock units as young as the Pleistocene Mescalero caliche, which indicates that Quaternary dissolution of the Salado and Rustler Formations is of primary importance in the geomorphic history of Nash Draw. Assuming that this disturbed caliche originally lay at an elevation corresponding to that of the adjacent Mescalero Plain, then at least 100 to 150 feet of local warping and depression has occurred in Nash Draw within relatively recent time (Vine, 1963). Bachman (1974) estimates that at one place in Nash Draw, a surface lowering of approximately 180 feet, almost wholly the result of solutioning and subsidence, has occurred in the past 600,000 years.

San Simon Swale

San Simon Swale is one of a series of large deep dissolution depressions filled with Cenozoic sediments, lying above the inner margin of the Capitan Reef (Figure 2) along the eastern side of the Delaware Basin (Anderson, 1978). Situated approximately 20 miles east of the proposed WIPP site, San Simon Swale forms a southeasterly-trending depression approximately 25 miles long and from two to six miles in width. Much of the surface of the swale is presently covered by eolian sand, which masks the relief. Of

particular interest within San Simon Swale is a compound collapse feature called San Simon Sink, which occupies an area about two miles long and one mile wide at the southeastern end of the swale (Bachman and Johnson, 1973).

San Simon Swale originated from a combination of surface stream erosion and solution-subsidence (Bachman and Johnson, 1973). During the Pleistocene, a major tributary of the Pecos River is thought to have flowed southeastward through what is now San Simon Swale to join the Pecos River in western Texas. The initial course of this tributary was determined as it eroded headward through the caliche caprock of the Ogallala Formation (Bachman and Johnson, 1973). The dissolution and subsequent removal of underlying soluble beds resulted in the formation of numerous collapsed structures, some of which coalesced to form, at least in part, the San Simon Swale (Bachman and Johnson, 1973). The swale has been lowered at least 180 to 200 feet below its original surface, in view of lake deposits in the sink encountered during preliminary WIPP site characterization studies (Claiborne and Geva, 1974). Past drilling operations reveal a thickness of more than 600 feet of post-Ogallala sediments underlying the present floor of the swale.

Located within San Simon Swale, the San Simon Sink formed as a secondary collapse structure, probably during the Pleistocene. Numerous ring fractures around the sink indicate that it has had a long history of successive collapse events since its initial formation (Bachman and Johnson, 1973). The most recent of these events is reported to have occurred in the 1930's (Nicholson and Clebsch, 1961). It is therefore assumed that salt dissolution in the underlying formation is continuing here and that the resulting brine is being carried in a southeasterly direction toward Texas (Bachman and Johnson, 1973).

On the basis of written communication from C. L. Jones of the U.S. Geological Survey, Bachman (1973) reports that more than 500 feet of Cenozoic sediments have thus far been deposited in San Simon Sink. Nicholson and Clebsch (1961) estimates that alluvium deposition in the sink occurs at a rate of about one foot in five years. Preliminary analysis of a core (identified as WIPP 15) acquired from San Simon Sink shows about 545 feet of fill on top of Triassic sediments (Anderson, 1978). Dates of the fill have not yet been obtained.

1.1.4 Future Geomorphic Developments to the WIPP Site

This section briefly describes the degree to which the major surface and subsurface processes discussed in the previous section have affected the land surface in the vicinity of the site and considers the extent to which these activities may be predictive of future geomorphic modifications in this area.

The resistant Mescalero caliche covers most of the land surface in the vicinity of the site and underlies the site itself. Where present, the caliche provides an indication that no significant erosion of the surface in these areas has occurred since the formation of the caliche in mid-Pleistocene time.

The major areas of relief which have developed since the mid-Pleistocene have probably resulted, to a large extent, from subsurface dissolution and subsidence. The two major features of significance to the site, originating from these processes, are Nash Draw and San Simon Swale, described in the previous section. In Nash Draw the surface has been lowered at least 100 feet by dissolution, and locally as much as 180 feet, within approximately the past half million years. Bachman (1974) also cited one location within the draw where the lowering of the ground surface appears to have exceeded the rate of salt removal, indicating a surface erosion of about 400 feet in addition to solution activities. San Simon Swale, a product of surface erosion as well as solution-subsidence, lies at its lowest point approximately 180 to 200 feet below the surrounding land surface (Claiborne and Gera, 1974) and may have undergone a total subsidence of about 750 feet.

Wind erosion has produced other depressions (blowouts) in the area, with a resultant build-up of material in the same vicinity. These features are generally of only minor dimensions and are local in extent (Claiborne and Gera, 1974). They are located 15 miles north of the WIPP site and some contain lakes as discussed previously.

These observations should not be considered as constants for rates of erosion which would hold true for the future. However, they do indicate the pattern of continuing geomorphic development of the area. Variations in climatic conditions give rise to variations in rates of denudation and also in rates of subsurface dissolution. The nature of the ground surface is also of major importance in terms of its vulnerability to erosional processes.

The site is located west of and near a drainage divide (Figure 2) between Nash Draw and San Simon Swale, where it appears that very little dissolution or surface erosion has occurred since Early Pleistocene time, as evidenced by the relatively undisturbed nature of the Mescalero caliche, which also serves as a protective layer for the underlying soluble rock units. Contouring studies indicate that this area has served as a drainage divide at least since mid-Pleistocene time (Bachman, 1976). Although minimal erosion occurs here under the present semiarid climatic conditions, under more humid conditions which may develop in the future, an accelerated erosion of the caliche is reasonable. With increased rainfall, it is also expected that Nash Draw and San Simon Swale will be exposed to more erosive stress because most of the runoff will probably flow out of the immediate area along these depressions.

To summarize, no significant erosion has occurred at the WIPP site since mid-Pleistocene time. Most of the current land surface features have been caused by past dissolution and subsidence during that geologic time period.

1.2 REGIONAL STRATIGRAPHY AND LITHOLOGY

The stratigraphic sequence of southeastern New Mexico and west Texas is dominated by the sediments of the late Paleozoic Permian Basin. A metasedimentary-igneous Precambrian basement is overlain by a maximum of about 20,000 feet of Paleozoic carbonates, evaporites, and clastics which are, in turn, mantled by relatively thin, primarily terrestrial Mesozoic and Cenozoic clastics, caliche, and eolian deposits. Figure 3 is a geologic map of the region. The major rock units underlying the area are discussed below, from oldest to youngest. Figures 4 and 5 are north-south and east-west crosssections, respectively, demonstrating the relative thickness and relationships of these units.

1.2.1 Precambrian Rocks

Precambrian outcrops composed of siltstone, shale, quartz sandstone (intruded by diabase sills) (Kelley, 1971; Pray, 1954; Bachman, 1960), and gneiss are present west of the Delaware Basin. Further east in the basin, the Precambrian dips beneath the thick sedimentary section to depths of up to 20,000 feet below sea level. It then rises rapidly on the Central Basin Platform to between 4,000 and 5,000 feet below sea level (Figure 5).

Slightly foliated and sheared granitic rock underlies most of south-central New Mexico, including the vicinity of the site and nearby parts of Texas (Flawn, 1954). Radiometric dates for these granites range from between 1,250 and 1,400 million years in the north to 1,090 million years in the south. Diabase and slightly metamorphosed clastics are also present in the northwest and southwest parts of the Delaware and Permian Basins. Rhyolitic materials predominantly undeformed, overlie much of the older Precambrian of the region. These rhyolites are intruded by gabbros and basalts in Texas and in the vicinity north of the WIPP site. [Muehlberger et al. (1967) describe the regional classification of these terrains.]

1.2.2 Paleozoic Rocks

The Paleozoic stratigraphic column in this region includes Cambrian, Ordovician, Silurian-Devonian, Mississippian, Pennsylvanian, and Permian rocks. Paleozoic strata rocks consist of several thousand feet of lower through middle Paleozoic carbonates and clastics overlain by up to about 18,000 feet of upper Paleozoic clastics, carbonates, and evaporites. This area contains the most massive and complete section of Permian evaporites in North America. The formation nomenclature and correlation within this section follows the 1983 AAPG correlation chart series.

1.2.3 Cambrian System

The Bliss Sandstone is exposed only to the west of the Delaware Basin in the Sacramento, San Andres, and Franklin Mountains. It consists mainly of fine to coarse, well-sorted quartz sandstone. Thin beds of clastic dolomite form approximately one-fourth of the beds, while siltstone and shale occur only in minor quantities. Many beds are cross-laminated and others contain burrows approximately 0.1 to 0.2 inches in diameter. Some layers of the formation weather to a dark reddish-brown because they contain the iron-rich mineral glauconite.

The sands of the Bliss Formation were deposited in the beach or nearshore environments of the sea which slowly transgressed over the Precambrian continental margin. The formation is therefore time transgressive and ranges in age from late Cambrian (to the west of the Delaware Basin) to early Ordovician (to the east). Under the WIPP Site area, the Bliss is probably of early Ordovician age.

1.2.4 Ordovician System

The Ordovician System is composed almost entirely of shallow water carbonates. These carbonates comprise the El Paso Group (known as the Ellenberger Group in Texas), the Simpson Group, and the Montoya Group. The El Paso Group (King, 1948; Cloud and Barns, 1948) varies in thickness from 400 to 1,600 feet and is composed predominantly of light olive gray, finely crystalline dolomite. Dolomitic quartz sandstone and chert nodules are present in the lower portions of the group.

A withdrawal of the sea in the mid-Ordovician ended carbonate deposition of the El Paso Group. The subsequent transgression of the sea, a little later in the Ordovician, led to the deposition of the carbonates, shales, and sands of the Simpson Group. Because there is no evidence of a nearshore facies within these sediments, Galley (1958) suggests that the group once extended east of the Permian Basin (possibly into Oklahoma and Kansas) and that subsequent erosion reduced its areal extent to the Permian Basin region.

The carbonates of the upper Ordovician Montoya Group were deposited above the Simpson. This group ranges in thickness from 280 to 440 feet in southwest New Mexico. It is composed predominantly of dolomite and cherty dolomite, except for a thin interval of dolomitic quartz sandstone or sandy dolomite near its base. The top of the unit is marked by a distinctive zone of cherty dolomite.

1.2.5 Silurian - Devonian Systems

The Silurian, Devonian, and Mississippian strata of the Delaware Basin were deposited in the broad subsiding region of the Tobosa Basin (Figure 6). The Silurian of the Delaware Basin and Central Basin Platform is represented by the Fusselman Dolomite of middle and possible early Silurian age, and the Wristen Formation of upper Silurian age (Hays, 1975; Pray, 1958). The Silurian of the Carlsbad and Northern Shelf regions is represented by a carbonate unit known as the "Silurian Limestone."

Lower to Middle Devonian strata in the Delaware Basin and on the Central Basin Platform are called the Thirty-one Formation (Hills and Kottlowski, 1983). This unit is composed primarily of chert, siliceous micrite, and light-colored calcarenite. Along the Sacramento Mountain escarpment to the west, the upper middle-Devonian unit is the Onate Formation. This formation consists of dark gray, finely crystalline dolomite interbedded with silt, sand, and shale.

The sea withdrew from the region in the late Devonian period. The subsequent transgression deposited a shale known in the Basin and on the Central Basin Platform as the Woodford Shale and in the Sacramento and Franklin Mountains as the Percha Shale and Canutillo Formation (McGlasson, 1968). This unit, which is less than 200 feet thick in the Delaware Basin, consists of black, fissile, bituminous, spore-bearing shale. It contains interbedded chert layers to the south and west and becomes arenaceous to the north.

1.2.6 Mississippian System

The Woodford Shale, in the Delaware Basin and on the Northern Shelf, is overlain unconformably by the argillaceous gray limestones of the Rancheria Formation (Pray, 1954), which is turn is overlain by the fine-grained clastics of the Helms Formation. The Mississippian system on the Central Basin Platform also includes a lower carbonate unit (the Mississippian Limestone) and an upper clastic unit (the Barnett Shale) (Hills and Kottlowski, 1983) in the Western Palo Duro Basin. To the northeast, the Mississippian system is composed entirely of carbonates (Osage Limestone, Meramec Limestone, and Chester Limestone).

1.2.7 Pennsylvanian System

The stresses generated by the collision of North and South America began to affect the west Texas-New Mexico region in the Pennsylvanian. The Central Basin Platform and Matador Arch were uplifted while the Delaware and Midland Basins were depressed. This rapidly differentiating basin and shelf structural configuration make the correlation of Pennsylvanian rock units extremely difficult.

The northern Delaware Basin was the site of clastic deposition in the early Pennsylvanian (Morrowan Epoch). These argillaceous carbonates, sands, and shales comprise the Morrow Group. Clastic deposition continued into the beginning of the Atokan Epoch; however, as this epoch progressed, carbonates became more abundant (Bachman, 1975). The mid-Pennsylvanian Des Moines Series is composed predominantly of carbonates. Deposition during this time was very much influenced by the developing basin and shelf environments. The shelves were the sites of shallow carbonate deposition while the deeper basins received dark brown, fine-grained cherty carbonates (Meyer, 1966). These basinal sediments, known as the Strawn Group, are noted for containing numerous stratigraphic oil and gas traps. The Missourian rocks of early late-Pennsylvanian age, generally present only in the deeper portions of the Permian Basin, consist of clastics as well as carbonates. The uppermost Pennsylvanian section, the Virgilian Series, differs from the earlier series in that reefs began to grow around the northern margin of the Delaware Basin. The reefs, which would continue to grow in the Wolfcampian (lowermost Permian Series), restricted water circulation and initiated the precipitation of the evaporites found in the Virgilian Series (Meyer, 1966, 1968).

1.2.8 Permian System

The Permian System contains the most significant and the thickest geologic units found in the WIPP Site area. The Delaware Basin became a distinct structure by the late Pennsylvanian Period to early Permian Period, approximately 280 million years ago. Approximately 250 million years ago, the reef now represented by the Capitan Limestone began to grow around the margins of the developing basin (Figures 2 and 7), and the sandstones, shales, and carbonates now making up the Delaware Mountain Group (DMG) were deposited within the basin. Most of the Capitan Limestone is relatively massive. Some portions of the unit are hydrologically active and support local karst hydrology, including the formation of large cavities such as Carlsbad Caverns.

The DMG, which is limited to the Basin, contains three major subdivisions and is overlain by Permian evaporite sediments including the Castile Formation, Salado Formation, and the Rustler Formation. The evaporite sediment sequence is overlain by the Dewey Lake Formation, which is the youngest Permian formation existing in the WIPP Site area. Each of the Permian geologic units present in the WIPP Site area is discussed in detail in the following sections.

Delaware Mountain Group

The Delaware Mountain Group is part of the Guadalupian Series deposited during the Permian age and mainly is composed of fine-grained clastic rocks with a few thin limestone and shale beds. The group is divided, in ascending order, into the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations. The Delaware Mountain Group is underlain by the Bone Spring Formation of Leonardian age, which consists of basinal siltstone, chert, and dark limestone. The Ochoan Series overlies the Delaware Mountain Group and principally consists of evaporites with increasing quantities of red mudstone and siltstone in the younger rocks. The following table lists the formations and their respective thickness from the Richardson and Bass, No. 1 Regan H. Legg well (T. 22 S., R. 30 E., sec. 27) and the Clayton W. Williams, Jr., Badger Unit Federal well (T. 22 S., R. 31 E., sec. 15) near the WIPP site (Figures 7 and 8).

	LEGG WELL	BADGER UNIT WELL
Bell Canyon Formation	1,415 feet	961 feet
Cherry Canyon Formation	1,050 feet	1,047 feet
Brushy Canyon Formation	1,605 feet	1,936 feet

Detailed descriptions of these formations can be found in publications by King (1948), Newell et al., (1953), Hayes (1964), and Sullivan (1979). The Bell Canyon Formation is the closest water-bearing rock unit underlying the WIPP facility. For this reason, the stratigraphy and hydrologic characteristics of this formation are described in detail in this report.

Both the Brushy Canyon and Cherry Canyon Formations are composed mostly of siltstone or shales and thin, fine-grained sandstone with a few thin limestone beds. Conglomerate and coarser-grained sandstone are found only in the Brushy Canyon Formation (Harms, 1974). These units interfinger with their reef-facies equivalents, the Goat Seep Limestone and San Andres Limestone (Figure 7).

Bell Canyon Formation - Stratigraphic relationships of the Bell Canyon Formation are of importance when studying the hydrology of the Delaware Mountain Group (Watson, 1979). The Capitan Limestone is the reef facies equivalent to the Bell Canyon and interfingers with the Bell Canyon along the basin margin (Figure 7). The upper part of the Bell Canyon Formation was studied using cores from three test holes drilled near the WIPP site: ERDA-10, AEC-7, and AEC-8. The stratigraphic subdivisions used in the WIPP study are shown in Figure 8 and are those informal members described by Grauten (1965).

Olds and Hays Sandstone Members - The Hays sandstone member is separated from the overlying Olds sandstone (informal units) in most places by a shaly bed (Grauten, 1965). The Olds and Hays sandstone members have laminated and clean sandstones facies, and they both produce some hydrocarbons in the Delaware Basin.

Ford Shale Member - The Ford shale member (informal unit) overlies the Olds sandstone member in the Delaware Basin. It consists of two 2-foot-thick beds of black shale separated by a six-foot-thick laminated siltstone, forming one of the most important marker-beds used in exploration for hydrocarbons in the Bell Canyon Formation (Grauten, 1965).

Ramsey Sandstone Member - The Ramsey sandstone member (informal unit) overlies the Ford member throughout the study area. As described by Grauten (1965), the Ramsey sandstone member has two main facies: a laminated, shaly siltstone, interlaminated with black shale; and a clean, very fine-grained sandstone with crossbeds of laminated, limy, shaly siltstone or very fine-grained sandstone with interlaminae of black shale. This stratigraphic sequence is common in many of the units in the lower parts of the Delaware Mountain Group. An important characteristic of the Ramsey Sandstone Member is that, in most instances, the clean sandstones grade laterally into laminated siltstone with negligible permeability, thus creating stratigraphic traps where hydrocarbons and other fluids may accumulate. The Ramsey is the main oil- and gas-producing unit of the Bell Canyon Formation.

Trap Member - The Trap member (informal unit) overlies the Ramsey sandstone member and consists of an interlaminated shaly siltstone and shale sequence, the laminae of siltstone and shale being very thin (Grauten, 1965). This member has been referred to as the upper laminated Ramsey (Watson, 1979), and is very thin, averaging only five to ten feet thick.

Lamar Shale Member - The uppermost member of the Bell Canyon Formation is the Lamar Shale Member (informal unit), commonly referred to as the "Lamar lime." It is composed of a very dark, silty shale; in some places beds of hard, black, very shaly limestone are present. Throughout the Delaware Basin, the thickness of the Lamar Shale Member is 25 to 30 feet.

Guadalupian Reef Complex

The Guadalupian reef complex, specifically the Capitan aquifer as defined by Hiss (1980), is a lithosome that includes the Capitan and Goat Seep Limestones and most or all of the Carlsbad facies of Meissner (1972). It also includes shelf-margin carbonate banks or stratigraphic reefs in the upper part of the San Andres Limestone where these cannot readily be distinguished from the Goat Seep Limestone and Carlsbad facies. Generally, the units discussed are of Permian Guadalupian age and comprise a reef complex that was deposited along the margin of the Delaware Basin in a continuous, narrow, arcuate belt (Figure 7).

The units are composed mostly of limestones, dolomites, reef breccias (Capitan Limestone), and massive dolomites and limestones (Goat Seep Limestone). The complex includes facies transitions composed of shelf-edge dolomites and thin interbedded sandstones (Carlsbad facies of Meissner, 1972), along with chert and dolomite (San Andres Limestone). Terrigenous clastics are notably absent in this sequence of rocks (Meissner, 1972). A more detailed description of lithologic relationships in the "reef complex" described above can be found in Hiss (1976), Meissner (1972), Motts (1968), Newell et al. (1953), and Silver and Todd (1969).

Ochoan Series

The Ochoan rocks studied at the WIPP site are composed of extensive evaporite deposits that filled the Delaware Basin and extended across the Guadalupian reef zone during Permian time. The Ochoan Series is represented, in ascending order, by the Castile, Salado, and Rustler Formations, and the Dewey Lake Redbeds. The Ochoan Series is entirely of marine origin, but it has two dissimilar parts: a thick lower section of evaporites, and a thin upper section of Redbeds (Jones et al., 1973). The lower section, containing extensive deposits of halite and anhydrite, includes the Castile, Salado, and Rustler Formations, whereas the upper section is composed of the Dewey Lake Redbeds. The Dewey Lake is composed entirely of red sandstone, siltstone, and some shale. The sequence probably forms a protective cover that has retarded the dissolution and removal of the soluble salts in the lower evaporite units (Jones, 1954). Among the lower evaporite units, the Castile and Rustler Formations contain more anhydrite and carbonate than the Salado Formation. In the area of the WIPP site, these anhydrites have

formed protective barriers that have retarded the upward or downward movement of meteoric water into the salt-rich Salado Formation. The Ochoan Series conformably overlies the Guadalupian Bell Canyon Formation and unconformably overlain by the Triassic Santa Rosa Sandstone.

The WIPP geotechnical studies have generated intense interest in the Ochoan Series, not only because the halite of the Salado Formation is the location of the WIPP facility, but also because the evaporites could be barriers to fluid migration should the facility be breached. Discussions of detailed stratigraphy of the area are found in numerous documents (Vine, 1963; Hayes, 1964; Gard, 1968; Jones, 1954, 1973, 1978; Powers, Lambert, Shaffer, Hills, and Weart, 1978; and Bachman, 1973, 1974, 1980, 1981); therefore, stratigraphic discussions in this paper will be limited to those deposits that may affect the hydrologic system at the WIPP site.

Castile Formation - The Castile Formation, the basal unit in the Ochoan evaporite sequence, consists principally of anhydrite, calcite-banded anhydrite, and halite with some limestone and sandstone. As originally defined by Richardson (1904), it included all the evaporites between the Delaware Mountain Group and the Rustler Formation; however, present useage follows that of Lang (1935), who divided the Castile Formation of Richardson into two formations: the anhydrite-rich Castile below, and the halite-rich Salado above. Extensive outcrops of the Castile Formation are present in the western part of the Delaware Basin. The formation, where it is exposed, is devoid of halite, and the anhydrite primarily has been altered to gypsum by weathering.

The contact between the Castile Formation and the overlying Salado Formation is conformable and gradational but, nonetheless, generally is defined as the horizon at which the dominant anhydrite below changes to halite above (Jones, 1973).

Salado Formation - The Salado Formation is the principal salt formation being investigated at WIPP because the facility is being built in a selected salt horizon of this unit. The formation has been differentiated from the Castile by Lang (1935) and consists principally of halite in thick seams interbedded with anhydrite, polyhalite, and glauberite. The upper contact of the Salado is the distinct conformable contact between halite and the gray siltstone and sandstone of the lower part of the Rustler Formation. Parts of the Salado Formation (McNutt potash zone) in eastern Eddy and western Lea Counties are mined for potash minerals (Jones, 1978).

Jones (1975) describes three divisions within the Salado Formation near the WIPP site: the lower member (1,040 to 1,154 feet thick), the McNutt potash zone (357 to 375 feet thick), and the upper member (468 to 504 feet thick). The lower member consists largely of clayey halite interbedded with thin seams of anhydrite and polyhalite, as well as some thin-bedded siltstones and sandstones. The lithology of the McNutt potash zone, while similar to the clayey halite of the lower member, includes sylvite and langbeinite, which are both economically important potash salts. The upper member is composed of clayey halite interbedded with minor anhydrite and polyhalite. A layer of residuum that lies immediately on top of the Salado Formation in certain areas is considered to be residue from evaporite dissolution and is considered in this report to be part of the lower part of the Rustler Formation.

Throughout the Salado Formation, the principal lithologic types are repeated in a rhythmic depositional cycle that consists in ascending order of a clastic, a sulfate, a halite, and a mixed halite-clastic stratum (Jones, 1954). Jones (1973) interprets these rock sequences to represent a fundamental sedimentation unit or evaporite cyclothem.

Rustler Formation - The Rustler Formation, named by Richardson (1904), is the youngest unit in the Ochoan evaporite sequence. The Rustler is a key marker bed of the upper Permian in Texas and New Mexico. Hydrologically, this unit is one of the most extensively investigated units at the WIPP site because it contains the most productive water-bearing units in the study area.

In the vicinity of the WIPP site, Vine (1963) has described a five-fold division of the Rustler (Figure 9). The division includes: (1) at the base, an unnamed unit of clayey siltstone and very fine-grained sandstone with thin interbeds of anhydrite and halite in its upper part; (2) the Culebra Dolomite Member, a unit of thin-bedded, solution-pitted, finely crystalline dolomite; (3) the Tamarisk Member, anhydrite with a single think interbed of unconsolidated clayey silt (residuum from a thick seam of halite and associated polyhalite and halitic siltstone); (4) the Magenta Dolomite Member, a unit of thinly cross-laminated, fine-grained dolomite; and (5) the Forty-Niner Member, anhydrite with a single thin interbed of unconsolidated clayey silt (residuum from a much thicker seam of clayey and silty halite). The anhydrite beds may be partially altered to gypsum in places where dissolution has occurred. The dolomite units are not only hydrologically important, but are distinctive marker beds throughout the Delaware Basin (Adams, 1944).

The upper contact of the Rustler Formation is represented by a distinct lithologic change, going from anhydrite to siltstone, sandstone, or shale. The discordance and hiatus between the Rustler and overlying Dewey Lake Redbeds probably are not very great.

Dewey Lake Redbeds - The Dewey Lake Redbeds overlie the Rustler Formation in the WIPP area. This sequence was named by Page and Adams (1940) for a sequence of rocks composed of siltstone and claystone with thin lenticular beds of sandstone. As observed in many of the cores from the test holes drilled at the WIPP site, almost all of the siltstone and claystone are intruded by horizontal and crisscrossing veins of selenite. The Dewey Lake is thin bedded and contains numerous greenish-gray spots. Many of the bedding surfaces contain mud cracks and ripple marks. The Dewey Lake Redbeds range in thickness from 345 to 541 feet across the WIPP site. An erosional unconformity marks the contact between the Dewey Lake Redbeds and the overlying Santa Rosa Sandstone of Late Triassic age.

1.2.9 Upper Triassic Rocks

Santa Rosa Sandstone

Triassic rocks of the WIPP area, part of the Dockum Group, include the Santa Rosa Sandstone of Darton (1922). The Santa Rosa is present only in the eastern half of the WIPP site (Figure 10), having been removed by erosion in the west. At the WIPP site, the Santa Rosa sandstone consists of medium- to coarse-grained, micaceous sandstone and conglomerate with interbeds of siltstone and mudstone.

The Santa Rosa Sandstone in most of the area is truncated by a nodular to laminar limestone of middle Pleistocene age, informally called the Mescalero caliche by Bachman (1974). In the area east of the WIPP site, the Santa Rosa may be overlain by the Triassic Chinle Formation or a Chinle equivalent.

Chinle Formation

The uppermost unit present in the Triassic Dockum Group is the Chinle Formation, or an equivalent, which, although not present at the WIPP site, was penetrated in the H-10 test hole drilled 4 miles southeast of the WIPP site (Figure 11). The Chinle Formation at the H-10 test hole was described as a dominantly shaly mudstone interspersed with greenish-gray mudstone and lenses of sandstone and conglomerate. Anderson (1981) discusses the presence of as much as 230 feet of Triassic Chinle Formation in test well WIPP-15, located in San Simon Swale ten miles east of the WIPP site. According to Nicholson and Clebsch (1961), there are many lithologic similarities between the Chinle and Santa Rosa, which they believe cannot be separated. In fact, Bachman (1980) believes that there is little justification to even extend these formation names into southeastern New Mexico and that the sequence should be simply referred to as Triassic or Dockum Group undivided. Although problems in nomenclature exist concerning the Triassic Chinle Formation, this report retains the formation names and uses them, at least in the vicinity of the WIPP site.

1.2.10 Tertiary and Quaternary Rocks

Tertiary and Quaternary deposits in the vicinity of the WIPP site include the Ogallala Formation of Miocene age, the Gatuna Formation of Pleistocene age, and sands, playa deposits, caliche, and alluvium of Holocene age. These units cover the surface of nearly the whole region and lie unconformably on older rocks.

Ogallala Formation

The Ogallala Formation of Miocene age is the oldest record of Cenozoic depositional history and climate preserved in southeastern New Mexico (Bachman, 1980). Although the Ogallala is well exposed several miles to the east along Mescalero Ridge, Hat Mesa, Gramma Ridge, and the Divide (Figure 2), Bachman (1980) indicated that the Ogallala Formation could not be recognized west of San Simon Swale towards the WIPP site except for a few thin outliers near the Divide.

In southeastern New Mexico, the Ogallala Formation generally is described as a well-sorted, windblown sand with minor poorly sorted stream deposits; and carbonate pans that are usually capped by a rather resistant layer of well-indurated caliche. Bachman (1980) reports that even though the upper surface is relatively smooth, the irregular surface on which it was deposited has resulted in irregular thicknesses for the Ogallala.

Gatuna Formation

The Gatuna Formation is the oldest known Quaternary formation in the study area and probably the thickest though the least extensive. The Gatuna was named by Robinson and Lang (1938) and occurs as discontinuous bolson-type deposits in channels and depressions, possibly related to solution within the Salado and Rustler Formations. Bachman (1976) describes a reference section of the Gatuna Formation in the vicinity of Gatuna Canyon that consists of sandstone, siltstone, and conglomerate, with the conglomeratic beds containing pebbles of quartz and quartzite reworked from Triassic conglomerates.

Mescalero Caliche

The Mescalero caliche, an informal stratigraphic unit named for the Mescalero Plain, occurs east of the Pecos River and west of the High Plains (Bachman, 1976). The caliche is a well-lithified alluvial deposit of chalky, finely-crystalline limestone. The caliche caps the geomorphic surface and lies with angular unconformity on the underlying Gatuna Formation and older formations; its lower part commonly engulfs large masses of older bedrock.

Alluvium and Other Surficial Deposits

There are no through-flowing streams in the immediate area of the WIPP site; therefore, there are no recent stream deposits of any magnitude. Surficial deposits are composed mostly of locally derived materials deposited by sheet wash. In some parts of the area, such as Nash Draw, the surficial deposits include gypsum and dolomite fragments derived from the Rustler Formation as well as caliche fragments from the Mescalero caliche. There are small intermittent streams and collapse features that, although they may be discontinuous, do contain alluvial sand and silt that is locally conglomeratic.

Hummocky surficial deposits of dune and sand cover almost the entire WIPP site. The sand, locally known as the Mescalero sand (Vine, 1963), is fine- to medium-grained, with the grains predominantly angular to subrounded. Although the sand may occur as dune ridges, most of it is present on the flats and is generally stabilized by mesquite and other vegetation.

The most extensive deposits of true alluvium in the vicinity of the WIPP site are present along the west side of the Pecos River north of Malaga Bend. Isolated patches of alluvium are present to the south of Malaga Bend, but these are not very extensive.

Alluvium east of the Pecos River is localized and present in depressions, as in Clayton Basin and Nash Draw. The thickest alluvial deposits, however, were found in San Simon Swale 10 miles east of the WIPP site, where drilling at WIPP-15 penetrated about 547 feet of fill (Sandia National Laboratories and the University of New Mexico, 1981).

Maley and Huffington (1953) and Cooper (1962b) have described several structural features in the study area as thick accumulations of alluvium that fill deep solution depressions. Nicholson and Clebsch (1961) describe similar collapse structures in southern Lea County. These studies show that alluvial deposits underlie an area of 150 square miles east of the Pecos River in Eddy County, New Mexico, and extend southward into western Texas (Figure 12). Maley and Huffington (1953) indicate more than 1,400 feet of fill at the center of this area near the New Mexico-Texas state line, but Cooper's (1962b) investigations show that, at least in New Mexico, the thickness probably does not exceed 1,000 feet. Lithologic descriptions from logs of several holes drilled into the fill indicate the materials to be sands separated by somewhat thicker interbeds of silt and clay.

Other surficial material in the area of the WIPP site includes the fill associated with playas. This material generally consists of alluvium and eolian sands reworked by lake waters but may also contain reworked gypsum as well as precipitated gypsum and chlorides, as is present at Laguna Grande de la Sal. Some playas may contain perennial lakes, such as Laguna Grande de la Sal; others may be dry most of the year.

1.2.11 Conclusions

The stratigraphy and lithology of the WIPP site and surrounding area have been extensively studied. The physical properties of these formations have been measured and presented in numerous reports.

1.3 REGIONAL STRUCTURAL AND TECTONIC SETTING

The single dominating tectonic feature in the region around the WIPP site is the Delaware Basin, the locus of unusually thick and rapid sedimentation in late Paleozoic. Beneath the site, for example, about 15,000 feet of Pennsylvanian and Permian clastics, limey clastics, and evaporites accumulated. The basin was marginal to an orogenic belt located farther southwest (the Diablo Platform), which was tectonically active in Late Pennsylvanian and Permian time. The basin evolved by downwarp of Pre-Cambrian basement terrain of the Texas foreland, a granitic craton. South of the New Mexico border in Texas, the Delaware Basin in Late Pennsylvanian time was trough-like and received much of its sediment from a bordering mobile orogenic belt (Marathon system), in the manner of a molasse trough or exogeosyncline. In New Mexico, however, the northern part of the Delaware Basin received sediment from intracratonic highs located both to the west (Huapache flexure) and to the east (Central Basin Platform). The Delaware Basin assumed more the character of an intracratonic basin in which subsidence was accomplished mainly by downwarping of the craton without major marginal faulting and without subsequent folding or compressive tectonic deformation, although buried normal faults of fairly large displacement are known at the margins of the Central Basin Platform. The Central Basin Platform, located approximately along the New Mexico-Texas border east of the site, may be viewed as a medial, arched horst, now deeply buried by later sedimentary deposits which separated and partly isolated the Delaware Basin from its eastern counterpart, the Midland Basin, during Late Pennsylvanian and Early Permian time; later in Permian time these basins constituted part of the broad Permian Basin (Bachman and Johnson, 1973).

In the Delaware Basin toward the close of Permian time, as much as 4,000 feet of evaporite beds, dominantly rock salt, accumulated, during which time differential subsidence ceased and stable cratonic conditions returned to the area. Later, Triassic Redbeds mantled the region. In mid- to late-Tertiary time, rifting and tensional faulting occurred in the Basin and Range region of New Mexico as far east as the Sacramento and Delaware Mountain anticlinal structures west of the Delaware Basin itself. The basin was, however, tilted gently one or more times between Late Triassic and Pliocene time, producing a general net eastward tilt of about two degrees. The Late Permian Ochoan rocks and the Triassic rocks exposed in the basin today do not reflect basin-wide warping; the major structural feature of these deposits is merely the regional eastward slope produced after Triassic time (Bachman and Johnson, 1973). The most significant structural features of the region surrounding the Delaware Basin are discussed in detail in the following sections.

1.3.1 Northwestern Shelf

North and northwest of the Delaware Basin is an area underlain by shelf limestone and Late Permian age reefs and evaporites. This "northwestern shelf" (Figure 13) may have originated in the early Paleozoic (Oriel et al., 1967) when it formed the margin of the early Tobosa Basin (Figure 6). The abundance of pre-Permian shelf limestone and reefs indicate that it definitely was well developed before the Permian. During the late Permian, the Northwestern Shelf was a low-lying, lagoonal tidal flat area. Decreased circulation in this back reef area frequently led to the precipitation of gypsum and other evaporites.

Except for the Guadalupe Mountains, which are located in the southwestern portion of the shelf, deformation has been minor. Structural features consist primarily of early Tertiary and older folds, arches, flexures, and several linear shears or monoclinal features. Many of the fold systems lie parallel to or near the reef front escarpment. Some of these folds reflect deep basement faulting, while others are superimposed over older flexures or are thought to result from sedimentary compaction (Foster, 1974). Many of the folds, particularly those in the southwestern part of the shelf, were formed in the early to mid-Permian, possibly as a result of the Marathon Orogeny. Rejuvenation of some of these features, such as the Bone Spring Flexure, occurred prior to the late Permian and influenced the emplacement of the Guadalupian reefs. Some minor folding and shearing to the north may have continued during the Laramide Orogeny and into the Tertiary.

An area of prominent fault-like structure (on the shelf) lies north of the Delaware Basin and consists of a zone of straight northeast trending shears: the Border Hills, Six-Mile Hill, and Y-O Buckles shown in Figure 13. Movement along these shears may have been initiated in the Pennsylvanian period or earlier (Kelley, 1971; Brokaw et al., 1972). Another area of faulting, which may have been active throughout the Mississippian to early Permian, underlies the northern Guadalupe Mountains (Hayes, 1964). The most recent faulting of the Northwestern Shelf was the last Tertiary to Quaternary faulting associated with Basin and Range tectonism. Since that time the shelf has represented a broad area of tectonic stability.

1.3.2 Pedernal Uplift and Matador Arch

Two ancient structures to the north, the Matador Arch and the Pedernal Uplift (Figure 13), influenced the depositional and structural history of the northern Delaware Basin. The Matador Arch (uplifted in the early Pennsylvanian) was a narrow east-west trending Paleozoic highland which separated the Delaware and Midland Basins from the basins in the Texas Panhandle (Figure 13). It is approximately 300 miles long and underlain by Pre-Cambrian granites. The Pedernal Uplift, located north of the Sacramento Mountains, was an ancient highland representing the southern portion of the Ancestral Rocky Mountains. It was probably a broad uplift in some places and a fault-bounded block in others. From the early Pennsylvanian until the Permian (Pray, 1961; Thompson, 1942), it was connected to the Diablo Platform. Clastics from the uplift were deposited on the shelf and in the Delaware basin. The structural development of the Pedernal ended with the slight uplift and northward tilting which occurred during the late Jurassic and early Cretaceous.

1.3.3 Central Basin Platform

The Central Basin Platform is a broad feature which at one time formed a topographic high separating the Delaware and Midland Basins. It is approximately 200 miles long, and extends in a north-northwest trend from southwest Texas to southeast New Mexico (Bachman, 1973). The platform has a complex horst configuration formed by a number of fault blocks with vertical separations of up to several thousand feet. In the structurally high parts of the platform, centering around the Cities of Hobbs and Eunice (Foster, 1974), the Pre-Cambrian surface is from 4,000 to 7,000 feet below sea level (Foster and Stipp, 1961), while the adjacent low, extending from Monument through Jal, stands at 6,500 to 11,500 feet below sea level. The Central Basin Platform is separated from the Delaware Basin on the west by a complex fault system across which the maximum structural relief is remarkably uniform at about 9,000 feet (Foster, 1974).

The Central Basin Platform had a more intense deformational history than the adjacent basins or shelves (Brokaw et al., 1972). Its tectonic development may have begun in the Pre-Cambrian and it appears to have been a structural high during the early Ordovician and the late Devonian. It was generally stable until the latest Mississippian or early Pennsylvanian. At that time the area was deformed into an emergent north-northwest trending fold belt, with faults trending toward the northeast and northwest (Hills, 1976). Submergence and deposition followed, however, during the late Pennsylvanian and early Permian. Renewed uplift produced large north-northwest trending faults. By the late Permian, erosion had significantly reduced the elevation of the platform, and it was once again submerged beneath a shallow sea.

The Central Basin Platform appears to have been structurally stable since the Permian. Hills (1976) suggests that some minor early Tertiary activity along the western margin of the platform may have helped to tilt the Delaware Basin eastward; however, no tectonic displacement has been found in rocks younger than the late Permian and no surficial fault scarps have been observed (Sanford et al., 1978). Recent low-magnitude seismic activity has been recorded within the Central Basin Platform, but it is postulated to have nontectonic origins (Sanford et al., 1978).

1.3.4 Diablo Platform

The Diablo Platform is a northwest trending horst, located to the southwest of the Delaware Basin (Figure 13). It extends from the Cornudas Mountains southeastward to the Quachita Tectonic Belt. The platform has an average elevation of 3,660 feet and is bounded on the east, west, and south by grabens. At its northeastern extent (its closest approach to the site), the platform is bordered by the Salt Basin and the Guadalupe Mountains (Brokaw et al., 1972).

The Diablo Platform underwent its primary deformation, consisting of uplift, folding, and faulting, in the early Permian (Stevens et al., 1967). Post-Permian faulting however has occurred along the northeastern margin of the platform and late Cenozoic Basin and Range activity has produced regional uplift as well as buckling and block faulting, primarily along northwest trending faults (Stevens et al., 1967). Contemporary arching of the Diablo Platform-Salt Basin area has been suggested by leveling surveys and may represent some form of pre-seismic deformation or intracrustal magmatic activity, possibly indicative of continuing Basin and Range tectonism in this area (Brown et al., 1978).

1.3.5 Guadalupe Mountains

The Guadalupe Mountains (and their southern extension, the Delaware Mountains) trend northwestward from the Diablo Platform, along the western portion of the Delaware Basin and onto the Northwestern Shelf (approximately 110 miles). The southern margin of the Guadalupe Mountains is coincident with the Reef Escarpment while the northeastern margin is coincident with the Huapache Monocline (Flexure). The uplift is therefore triangular in shape and thins from 11 miles in the south to about 3 miles in the north (Figure 13).

Both the Guadalupe and the Delaware Mountains were formed in the late Pliocene and early Pleistocene when a large fault block was uplifted and tilted toward the east. The late Cenozoic fault scarp, composed of en echelon normal faults with displacements ranging from 2,000 to 4,000 feet, forms the steep western slope of the range. The broad eastern flank dips gently toward the east. Offset alluvial fans and scarps along the western escarpment suggest that the structural uplift of the Guadalupe Mountains may be continuing today. All of the principal structural elements within the mountains are described in detail by King (1948), Boyd (1958), and Hayes (1964).

Although the Basin and Range forces of the late Pliocene and Pleistocene were primarily responsible for the formation of the Guadalupe Mountains, there were earlier uplifts in the region. In the Pennsylvanian and early Permian, movement occurred on a northwest trending fault zone which existed along the east side of the Guadalupe Mountains. This fault zone may have defined the eastern boundary of a southeastern extension of the Pedernal land mass, or one of a chain of smaller positive elements (Hayes, 1964). The broad southeast-dipping Bone Spring Flexure was formed in the late Leonardian and early Guadalupian periods (late early to early middle Permian) and later rejuvenated in the mid-Guadalupian. Minor Guadalupian flexing may also have taken place along the older northwest trending Huapache faults, producing the Huapache Monocline.

1.3.6 Sacramento Mountains

The Sacramento Mountains, which are located west of the Northwestern Shelf (Figure 13), constitute a north-south trending uplift approximately 45 miles long. Their overall structure, like that of the Guadalupe Mountains, is of a gently tilted fault block. Most of the structures within the range exhibit a northerly trend, and greater uplift along a central crest has produced a slight doming effect. The eastern flank consists of relatively undeformed strata with easterly dips of 100 to 140 feet/mile, while the western side is bounded by normal faults with several thousand feet of displacement (Stipp, 1960).

The range developed through at least three periods of tectonic activity, beginning probably in the late Pennsylvanian or earliest Permian. During this period, the strata were folded and faulted, creating many of the internal structures of the range. During the Mesozoic or early Cenozoic, strong folding, faulting, and intrusive igneous activity occurred. The final development of the range began with late Cenozoic Basin and Range faulting, uplift and tilting. This uplift appears to be continuing (Pray, 1959).

1.3.7 Folds and Flexures

The northern Delaware Basin contains open, undulatory, flexure-like structures in the Paleozoic section. Many of these structures formed during the rapid basinal downwarping which occurred in the early to mid-Permian. Others formed in the early late Permian (Guadalupian) during the deposition of the Bone Spring Formation and the Delaware Mountain Group.

Also thought to be responsible for many of the anticlinal structures within the basin is the movement or dissolution of halite (Jones, 1973; Anderson and Powers, 1978). Borns et al. (1983) attributed anticlinal and domal features to the flow of salt within the lower units of the Castile Formation. This salt flow produces large variations in the thickness of the lower halite beds and creates a series of anticlinal and synclinal structures in the overlying strata. The details of these evaporite-related structures are discussed in Section 1.3.8.1.

North of the Capitan reef front, in the basinal regions which existed prior to reef progradation and subsequent conversion to back reef, are the Carlsbad Folds (Figure 13). These are a 6-to-9-mile-wide belt of sharply flexured, symmetrical folds, with an average wavelength of 1.5 miles (Motts, 1972) and an average arc bringing it within approximately 15 miles of Carlsbad and 10 miles of the site. These folds,

which are partially-expressed in the present topography, contain biothermal shelf domes, suggesting that this region may have been topographically positive during Capitan deposition. The major fold development occurred during the Laramide Orogeny (late Cretaceous) (Brokaw et al., 1972; Hays, 1964). Other folds in this same region include the Waterhole Anticlinorium and numerous Cenozoic folds which parallel the reef.

The largest folds in the Northwestern Shelf region are the Artesia-Vacuum Trend and the Huapache Flexure (Figure 13), both of which reflect older structures. The Artesia-Vacuum Trend, an eastward plunging anticline of early Permian age, is 75 miles long and located approximately 35 miles north of the Capitan Reef front (Stipp, 1960). It was formed as a result of the differential compaction over the Abo reef (early Permian) (Brokaw et al., 1972). The Huapache Flexure is a long, northwest-trending monocline, generally less than two miles wide, involving rocks as young as late Guadalupian. The flexure extends from the western Delaware Basin, across the reef escarpment and onto the Northwestern Shelf (Figure 13), terminating at the northern extent of the Guadalupe Mountains. It dips between 5 degrees and 15 degrees to the east and has a structural relief on the Pre-Cambrian of between 300 feet (in the north) and 1,000 feet (in the south) (Kelley, 1971). The flexure may overlie a series of thrust faults which offset rocks from the Wolfcampian (lower Permian) down through the Pre-Cambrian basement.

Drill data obtained from the Huapache Flexure suggests that it might be a drape feature which formed when deposition occurred across the thrust fault burying it by the Leonardian. However, Hayes (1964), believes that the Huapache Monocline resulted from late Permian to post-Permian flexing along the older thrust zone. The precise time of this renewed flexing is difficult to pinpoint; however, it may be concluded that if minor flexing had occurred, it could have taken place up until the Guadalupian (late Permian). Other folds in this vicinity of the Delaware Basin-Northwestern Shelf are described as early Tertiary to Guadalupian or older; therefore, it is reasonable to place the age of the Huapache Flexure somewhere in this time frame.

1.3.8 Faults

General topics considered in this section include the nature and history of faulting activity (major faults of the region are shown in Figure 14 and the occurrence of and potential for future surface faulting. The capacity of these faults for generating ground motion at the site is discussed in the section on site seismicity.

Delaware Basin Faults

Deep seated, high-angle normal or reverse faults are present throughout the Delaware Basin. They offset strata from the Pre-Cambrian through the Pennsylvanian and also portions of lower Wolfcampian. Some of these faults originated during the widespread block faulting (Adams, 1965) which occurred as a result of the rapid Pennsylvanian to early Permian subsidence of the basin. The presence of continuous post-Wolfcampian strata (across these faults) indicates that movement ceased before the mid-Permian.

The closest such structure to the WIPP site is the Bell Lake Fault, located in Lea County, 15 to 20 miles east of the site (Figure 15). Haigler and Cunningham (1972) and Haigler (1962) describe the Bell Lake Fault as being about 15 miles long and displacing strata from the Pre-Cambrian up through the Pennsylvanian. This displacement, approximately 500 feet in the Pre-Cambrian, is also reflected in the Wolfcampian (lower Permian) as a north-south trending structural high. Closure is also indicated on the Bone Springs Formation; however, it is not known whether this represents Leonardian movement on the Bell Lake Fault or the effects of compaction (Foster, 1974).

The Barrera and Carlsbad Faults (Kelley, 1971) are located along the reef escarpment 20 miles and 10 miles southwest of Carlsbad, respectively. Kelley (1971) suggests that these faults have late Tertiary with possible Quaternary movement; however, many geologists who have investigated the area are not

convinced that the features exist. In a study specifically addressed to the investigation of these two faults, Hayes and Bachman (1979) conclude that the faults are nonexistent and that Kelley's conclusions were based on misinterpretation of exposures of fan gravel, jointing and shrub alignment.

There are no known Quaternary faults of tectonic origin in the site area. Bachman (1973) conducted a detailed investigation of the surface features within the site area and concluded that no recent faulting had taken place. The only differential movements subsequent to late Permian evaporite deposition were produced by the local settling which resulted from the dissolution of these evaporites.

Faults Bounding the Delaware Basin

The only large-scale fault structure near the western perimeter of the Delaware Basin is a probable thrust fault system that underlies the Permian to Cenozoic Huapache Flexure. This flexure, shown in Figure 13, extends from the northern Guadalupe Mountains southeastward to just beyond the Texas-New Mexico border. The fault system thought to underlie this feature dips steeply and offsets strata from the Pre-Cambrian through the early Permian. Displacement in this fault system appears to be between 4,000 and 6,000 feet (Hays, 1964).

Northwest-trending high-angle normal or reverse faults form the boundary between the Delaware Basin and the Central Basin Platform. Hills (1976) described one of the faults along the southern boundary of these two features and named it the West Platform Fault. Foster (1974) cites a displacement of about 2,000 feet for this fault system, while Haigler (1962) believes that the displacement is nearly equivalent to that in the Huapache structure (5,400 feet) on the west side of the Delaware Basin.

In addition to vertical movement, the Platform-Delaware Basin bounding faults may also have undergone considerable right lateral movement (Hills, 1976). The amount, however, is difficult to determine. The stress that gave rise to this movement may have resulted from the early mid-Wolfcampian thrusting of the Quachita Belt to the south (Hills, 1976).

Hills (1976) has also speculated that movement on the West Platform Fault has continued through the Cenozoic and into the Holocene. His evidence for fault movement however is very indirect, and he also reports "nowhere in the Permian basin do the faults and sharp folds at the lower Paleozoic rocks continue into the Permian rocks above the middle Wolfcamp." This geologic evidence suggests that fault movement has not occurred since the early Permian, and therefore does not support his hypothesis of Cenozoic movement.

Central Basin Platform Faults

Faults within the central Basin Platform are similar in type to those bordering the platform. High-angle faults, with vertical displacements more than 1,000 feet, border each of the horst-like blocks which together compose the platform. Foster (1974) indicates that "the fault system separating the highs of Hobbs and Eunice from the Monument-Jal low has a displacement of about 1,000 feet in the north to possibly 4,000 feet west of Eunice" and "the fault bounding the west side of the Monument-Jal low extends about 50 miles southward into Texas, with an inferred displacement of 1,500 feet at the north to over 6,000 feet west of Jal." Horizontal movement is also evident on some of these faults (Hills, 1976).

Two groups of faults are present on the platform: an early late-Mississippian to late middle-Pennsylvanian system, and an early Permian system. The older group of faults consists of two sets: one strikes N55-80 degrees east and has indications of right lateral movement, while the other strikes N50-65 degrees west and has indications of left lateral movement. The early Permian fault system strikes just slightly west of north and includes the West Platform Fault described by Hills (1976). These platform faults, like the basin-bounding faults, exhibit no post-early Permian displacement, and seismic activity recently recorded on the central Basin Platform does not correlate with the subsurface traces of the faults.

Northwestern Shelf Faults

The most prominent region of faulting on the Northwestern shelf is a zone of straight, northeast-trending features which extend from the area north of the Guadalupe Mountains to approximately 25 miles northeast of the City of Roswell (Figure 13). The major structures of this group, such as the Y-O, Six Mile Hill, and Border Hills Buckles, are exposed for 25 to 80 miles along strike and are spaced 8 to 20 miles apart. The nature of deformation may change markedly over a short distance along strike, and includes such features as folding, faulting along strike, and overthrusting. Evidence suggests that movement along these zones was initiated in the Carboniferous or earlier and may have been primarily right lateral (Kelley, 1971). These features, like many other structures on the Northwestern Shelf, have been inactive since at least the Tertiary.

Faulting West of the Delaware Basin

The Sacramento Mountain area was the site of faulting throughout the Pennsylvanian and early Wolfcampian (early Permian). Other faulting, accompanied by igneous activity (Motts, 1972), occurred during the Mesozoic or early Cenozoic. Late Cenozoic Basin and Range faulting produced the uplift and tilting which gave the range its present configuration. The dominant late Cenozoic movement occurred on the large, steeply dipping normal fault zone along the western margin of the Sacramento Range.

Recent fault scarps, which offset a Quaternary geomorphic surface, suggest that the uplift along this zone is still in progress (Pray, 1959). Displacement on this Quaternary surface of as much as 100 feet indicate that major seismic events have occurred within the past 500,000 years. Offset has also been observed in the San Andres Range, which borders the Tularosa Basin to the west (Sanford and Toppozada, 1974).

The Guadalupe Mountains region also underwent late Paleozoic faulting. The largest of these faults is thought to lie beneath the Huapache Monocline. The major faulting in the Guadalupe-Delaware Mountain uplift, however, consists of a complex system of nearly en echelon north-to-northwest trending normal faults of late Cenozoic age which form the west-bounding fault scarp (Kelley, 1971). King (1948) dates most of the major faults of the Guadalupe Mountains as late Pliocene or early Pleistocene. He points out, however, that the dissection of early Pleistocene deposits (indicative of a lowered base level) might be indirect evidence for a renewed period of faulting in the late Pleistocene.

While King found no evidence of movement later than late Pleistocene in either the Delaware or Guadalupe Mountains other evidence exists, however, which suggests that the uplift of the Guadalupe and Delaware Mountains may be continuing at a reduced rate. Leveling surveys from the Diablo Plateau to Carlsbad have revealed uplift within the Diablo Plateau relative to Carlsbad. Kelley (1971) reports a small scarp in the alluvial fans along the northern end of the Guadalupe fault scarp (T20S, R17E), and recent field investigations in the Salt Basin have identified more than 100 Quaternary-age, normal, down-to-basin faults, with individual or aggregate displacements of as much as 20 feet. The scarps, which have a predominant north-to-northwest orientation due to pre-existing zones of weakness (Goetz, 1977), are short and widely scattered along the eastern side of the graben, but are more continuous along the western side. This suggests that the western border of the graben is actively subsiding. The orientation of the scarps, the proximity of recurring seismic activity, and the youthfulness of offset surfaces all suggest that these scarps have a tectonic origin and are maintained by intermittent activity. In some places movement has occurred within the past 1,000 years and is probably continuing. Releveling measurements of the Diablo Plateau-Salt Basin region indicate relative uplift of the Plateau of 8 $\pm$1 inches between 1934 and 1977 (Reilinger et al., 1983). The maximum uplift occurred approximately eight miles west of the boundary between the Diablo Plateau and Salt Basin. These data indicate that the Basin and Range system of southeastern New Mexico and west Texas is a region of ongoing structural development.

1.3.9 Tectonic and Structural Setting of the WIPP Site

At the WIPP site, stresses associated with the origin and development of the Permian Delaware Basin have deformed the pre-existing rocks or contemporaneous sediments in different ways. Specifically, these stresses included the nontectonic downward pressure imposed by the weight of rapidly deposited sediment, in addition to the tectonic stress arising from within the earth's crust and transmitted through the basement rocks to the sedimentary pile. The tectonic stress would have been most effectively imposed upon those rocks of the sedimentary pile that had already undergone lithification and were therefore mechanically coupled with the basement rocks. Stress imposed by sedimentary loading would have been most effectively absorbed by subjacent materials that were the least lithified, the most compressible, and capable of adjusting to differential sediment loads. Each mechanism would have produced different kinds of structures and caused different types of faulting in the rocks beneath the basin.

The presence of thick salt beds profoundly affects the type of deformation which occurs in the salt itself and which is imposed upon rocks and sediment lying above the salt, because thick salt is known to deform plastically and to behave as a viscous medium over extended periods of time (Powers et al., 1978). This behavior is promoted by high overburden pressures and increased temperatures. Under favorable conditions, even slight tilting of the beds or lateral differences in lithostatic pressure are sufficient to initiate long-term viscous flow of salt. Salt deformation is therefore quite different in mechanism and manifestation than the deformation of the enclosing rock materials. As a result, deformational features exhibited by rocks and sediments lying above thick salt would normally be expected to have little or no mechanical relationship to structures in rocks occurring beneath the salt, because the intervening salt effectively decouples the two rock masses. Rocks overlying salt would be expected to display local structures that are generated by mass flow of salt. In addition, because shallow salt is susceptible to dissolution by ground water unsaturated in sodium-chloride, sediments above shallow salt where active solutioning had occurred could be expected to exhibit karst and collapse features, or to have internal irregularity and chaotic structure brought about by uneven subsidence or upward sloping following removal of significant thicknesses of salt in the subsurface. It should be emphasized, however, that at the WIPP site, evaporite dissolution has been restricted to salt beds of the Rustler Formation. No evidence has been obtained to date to indicate that this relatively small amount of dissolution of Rustler salt has resulted in significant differential subsidence in the site area. In contrast, the potential for subsidence structures to occur has been realized in areas such as Nash Draw, where partial dissolution of Salado evaporite beds has taken place (Powers et al., 1978).

It is concluded on the basis of the preceding discussion that the origin and development of possible structural features in the rocks which occur in the immediate site area is spatially related to the position of these rocks in the geologic column relative to the position of thick bedded salt in the Castile and Salado Formations. Accordingly, the following description of geologic structure at the WIPP site is organized into separate discussions of deep structure (i.e., structure in rocks underlying Ochoan salt), salt deformation, and shallow structure.

1.3.9.1 Deep Structures

Subregional Structure of Pre-Evaporite Rocks

A number of structure contour maps covering an area within about a 25-mile radius of the WIPP site have been prepared, generally from well-log data. Foster (1974) provides seven such subregional maps from top of Pre-Cambrian to top of the Bell Canyon Formation (base of the Castile Formation). Sipes et al. (1976) show somewhat more structural detail on top of Devonian, Pennsylvanian, and Permian strata (their exhibits 11, 10, 9, and 8), the first two of which incorporate seismic reflection profile interpretations.

Netherland, Sewell and Assoc. (1974) present generalized structure contour maps on 11 horizons, from the Ellenburger to top of the Bell Canyon Formation (their Figures G-6 through G-16).

Structure contour maps express a homoclinal regional dip toward the southeast to east on all pre-Ochoan Paleozoic strata, reflecting the presence of the Delaware Basin downwarp. Structural gradients on all pre-Permian horizons are similar in magnitude and direction, decreasing from about 150 feet per mile southeasterly in the lower Paleozoic to about 100 feet per mile at the top of the Pennsylvanian. The nearest fault large enough to be indicated by subsurface well control is a north-trending fault shown by Foster (1974) about 15 to 20 miles east and southeast of the WIPP site, and referred to as the "Bell Lake Fault." It has a length of about 15 miles and a displacement of about 500 feet. Located west of the central axis of the Delaware Basin, it nevertheless appears to be structurally related by orientation and displacement (thrown up to the east) to the west-bounding fault of the Central Basin Platform farther east, as is shown on the regional structure contour map of Haigler and Cunningham (1972). The fault is not indicated to offset Permian strata (Foster, 1974), but contours of Wolfcamp and Bone Springs strata in the lower part of the Permian section are deflected in the area of the fault. Permian structure contour maps indicate a difference in gradient and direction of horizons compared to earlier strata. This indicates significant tectonic activity in the basin in Late Pennsylvanian and Early Permian time, which was the major period of structural adjustment in the Delaware Basin (Foster, 1974). Permian strata beneath the Ochoan Series slope east-southeast at about 50 feet per mile (Foster, 1974), markedly less that pre-Permian strata.

In the immediate site area seismic reflection data were utilized as an adjunct to well control in preparing more detailed structure contour interpretations of the Paleozoic rocks. In general, the analysis of deep structures reveals the existence of minor faulting and secondary warping (swells and saddles) in Paleozoic strata below the evaporite beds. This analysis indicated a pattern of generally north-northeast-trending faults, oriented roughly parallel to regional strike and typically thrown up to the east. Small, subdued dome-like features and complementary saddles spaced several miles apart and with crest-to-trough amplitude of several hundred feet are superimposed on the regional gradient and appear to persist in position through both horizons. In the Silurian, for example, several small arches of up to 300 feet of relief are aligned to an east-southeast or west-northwest anticlinal trend passing just north of the WIPP site exclusion area (Powers, et al., 1978). In the Borrow, a similar east-west trend defined by more subdued structural gradients and highs of lower amplitude is about the same location. This trend is identified as the "Cabin Lake" trend by Netherland, Sewell and Associates (1974). On both horizons a domal feature is evident beyond the southwest edge of the site. This feature, which Netherland, Sewell and Associates (1974) indicate is at the east edge of the "Los Medanos" trend, is presumably responsible for the gas production of the Los Medanos field, the nearest hydrocarbon field to the WIPP site. Between these two anticlinal trends, a northwest-trending saddle is defined, located beneath the southwestern edge of the site.

These north-northeast-trending features, interpreted as faults based on seismic reflection records, are of greater intensity in the Devonian, being traceable over distances exceeding ten miles and having displacements of up to 400 feet (Figure 16). Faulting of the Morrow (Figure 17), some 2,500 feet higher stratigraphically, is roughly correlative with the deeper displacements, but seems to dissipate into discontinuous segments of generally smaller displacement.

Small-scale structures interpreted on the top of the Delaware Mountain Group, roughly 9,500 feet above the Morrow Formation horizon, show little or no correlation with deeper features (refer to Figures 16 and 17). The north-northeast-trending faulting is no longer apparent. Warping in the Delaware Mountain Group appears to be much more subdued than in the Morrow Formation; structure contours lack closure around irregularities, and trends in the Delaware Mountain Group appear to be unrelated to Morrow Formation and deeper trends.

The contrasting structural characteristics between the Delaware Mountain Group and pre-Permian horizons suggest different origins. All strata, including below the Pennsylvanian, have been deformed in continuity, with intensity of deformation increasing with depth. Tectonic deformation apparently occurred in Late Pennsylvanian or Early Permian time and established the local structural elements of all pre-Permian rocks. The "rootless" character of at least some of the small normal faulting in the lower Permian suggests that these are shallow-seated features. Considering the unusually rapid rate of accumulation of material in Permian time (about 13,000 feet), it seems reasonable to presume a predisposition for the occurrence of contemporaneous sedimentary deformation brought about by such factors as gravity creep, compaction during diagenesis, differential sedimentary loading and rates of dewatering, and differential subsidence. Such deformation has been documented along "growth faults" in the Gulf Coast Basin (Murray, 1961; Bishop, 1973). Contemporaneous faults of this type may have been initiated during deposition of thick pre-Ochoan clastic s[Auences. Conceivably, further movement might have been promoted by mass movement of salt subsequent to evaporite deposition, which shifted overburden loads over possibly still compressible sedimentary material.

Figures 16 and 17 show southwest-northeast and northwest-southeast cross sections, respectively, across the WIPP site area, adapted from Griswold (1977). The overwhelming thickness of Permian pre-evaporite strata relative to earlier deposition is graphically displayed. Faults arising in the basement offset Pennsylvanian strata, but do not propagate through the lowest Permian series, the Wolfcampian. The regional dip of the Delaware Basin is most evident in Figure 17.

Salt Deformation

For the purpose of this discussion, detailed description of deformational features within the salt beneath the WIPP site and in the northern part of the Delaware Basin is restricted to consideration of structure displayed by the Castile and Salado Formations even though the Rustler Formation is normally considered part of the evaporite sequence. At the site and in the vicinity of the site, the Rustler Formation has been leached of much of its salt, with the result that most of its structure is surficial in origin and is included under the heading "Shallow Structures" later in this section.

Of previous studies available in the literature on the northern part of the Delaware Basin, the papers by Brokaw et al. (1972), Anderson et al. (1972), Jones (1973), Anderson (1978), Snyder and Gard (1982), Lambert (1983), Bachman (1985), Bachman (1987), Borns (1987), and Borns (1987) are most relevant to salt deformation and dissolution in the area of the WIPP site.

Subregional Structure of Evaporite Beds. Throughout the northern Delaware Basin, the general uniformity in direction and amount of the gentle southeastward homoclinal dip is practically the only structural feature that is common to all levels of the evaporite section (Jones, 1973). Superimposed on this homocline is a rather complex system of flow features variably developed relative to both areal location and stratigraphic position. These features are attributable to large-scale migration of salt.

A feature that is of subregional significance, and that appears to have a fundamental role in the development of salt deformation, is the Capitan Reef front. It formed a steep, submarine prominence or wall 1,000 to 1,500 feet high, isolating the deep water of the early Castile brine sea from the rest of the Permian inland sea. Figure 10 of Jones (1973), a structure contour map on the base of the Castile Formation, graphically depicts the structural relationship of reef and basin in the WIPP site area. Immediately basinward of these buried reef masses, which are located eight miles north of the WIPP site, is a northwest-southeast-trending structural trough paralleling the base of the reef and descending in elevation, or plunging, southeastward. The most intense deformation in the evaporite sequence seems to be spatially related to this trough. Not only is a trough expressed within the salt layers, but the top of

the clastic Delaware Mountain Group (Bell Canyon Formation) is also depressed. Subregional geologic sections constructed by Jones across Nash Draw and Livingston Ridge (Brokaw et al., 1972; Jones, 1973) illustrate the general configuration of reef, trough, and deformation within the evaporite sequence in the site area. Jones' (1973) assessment of these particular features is pertinent:

> At intermediate and other levels in the [evaporite] section, the structure is generally more uneven than at the base of the Castile Formation, and minor folds are somewhat more prominent. Salt and anhydrite in the middle member of the Castile are crumpled in sharp intraformational folds that appear to die out northwestward up the dip and to become more pronounced southeastward down the dip. Spatially the intraformational folding of the salt and anhydrite appears to be confined to a single long northwestwardly trending belt, about three to four miles wide, that more or less coincides in trend and extent with the prominent southeastwardly plunging trough at the base of the Castile. The folding has resulted in some buckling and downwarping of rocks in the Salado Formation, and it has uplifted the Salado and other rocks as young as the Chinle Formation in a fairly broad arch that trends northwestward across the area. The exact age of the deformation is unknown; it can be dated only very broadly as post-Late Triassic to pre-Pliocene. Specific considerations concerning minimum thickness of overburden required to initiate salt movement suggest that the deformation may have occurred during or shortly after the period of regional tilting that followed the deposition of Cretaceous rocks. The deformation almost certainly had to occur before any great thickness of Cretaceous rocks was removed by erosion.

Subsequent studies by Anderson (1978), Anderson and Powers (1978), Borns et al. (1983), Lambert (1983), and Borns (1987), have supplied much new detail on the character of the salt deformation recognized by Jones. Apparently the only part of the Castile Formation that has not been involved in significant plastic flow deformation is the lower or basal anhydrite. On the other hand, the lowest thick Castile salt member has undergone several-fold increases in thickness in some areas. Anderson (1978) presents a basin-wide isopach map of the lower Castile Halite unit which shows an increase of thickness from a normal value of about 300 to 350 feet, as occurs in the area of the WIPP site, to a value of 1,200 feet at the ERDA-6 location 5 miles north-northeast of the site. The isopach lines at this location define an elongated, sharply thickened bulge of the Halite unit, the long axis of which is about 12 miles long and is oriented parallel to, and on the basin side of, the buried Capitan reef front. Anderson's isopach map also shows numerous similar, slightly smaller elongate bulges, their long axes all about 3-1/2 times the length of their shorter ones, contained within a belt about five miles wide paralleling the basin side of the reef front. Because the anhydrite unit underlying this deformed salt is not significantly deformed and does not itself rest on deformed rocks (Jones, 1973), the tops of these large salt mounds or bulges define what may be termed salt anticlines. These are not anticlines in the usual sense of the term because the top and base of the unit have totally dissimilar profiles; piercement associated with the term salt anticline is not generally present. This belt of salt anticlines, then, is the northwestward-trending belt of intraformational salt deformation recognized by Jones as occurring within the Castile Formation and affecting strata above the Castile Formation.

Structural detail within the large salt anticline located about five miles northeast of the center of the WIPP site has been provided by cores recovered from the ERDA-6 hole drilled near the center of the anticline. Stratigraphic interpretation made by Anderson and Powers (1978) from study of the core indicates that the middle anhydrite bed which overlies the salt has indeed been pushed up by the rising salt, but has

apparently acted as a semirigid confining blanket that was stretched upward like a flexible sheath; whether the anhydrite bed everywhere remained intact or was in places fully ruptured and detached by extension is not known. What is displayed in the core is that most of the anhydrite, which actually consists of finely interlaminated calcite and anhydrite, was stretched by extensional microfracturing of the calcite laminae and in-filling of the fractures by mobilized calcium sulfate, which presumably was derived by diffusion or creep from adjacent anhydrite laminate. The process seems closely analogous to boudinage in metamorphic rocks, and could be viewed as a microboudinage structure brought about by the properties of finely laminated calcite and anhydrite when subjected to high shear stress under sufficient confining pressure.

Anderson and Powers (1978) find that in the Castile, Halite-I salt (lower salt), together with stretched Anhydrite II or middle anhydrite, have in their upward migration pushed aside both the overlying upper salt (Halite II) and upper anhydrite (Anhydrite III) beds in the manner of an intrusion, because the stratigraphy in the ERDA-6 hole passes directly from Infra-Cowden salt (lower Salado salt) to Anhydrite II. The authors show that the overlying Salado Formation beds, though not breached by the intrusion, are arched over it. It is therefore evident that the arching effect in beds of the Salado Formation and younger rocks referred to by Jones (1973) along the belt of deformation is, in at least some cases, due to the presence beneath these anticlines of a salt core which arose from the lower part of the Castile Formation and partly intruded the overlying rocks.

In addition to revealing the cores of many of the salt anticlines in the northwest-southeast belt of deformation described above, the subregional Halite-I isopach map (Anderson, 1978) shows numerous, sharply defined localized depressions at locations where the Halite-I salt is entirely missing from the section. In the central part of the basin, these "deep-seated sinks," as Anderson calls them, do not have obvious surface expression, and are not clearly related to shallower dissolution features--such as collapsed and uncollapsed domes, dissolution fronts, castiles, and collapsed outliers--which have been documented elsewhere in the Delaware Basin region. Many of these isopachous depressions, some of which are defined by a single data point, may possibly by attributed to "deep dissolution" processes (Anderson, 1978), presumably acting from near, or perhaps below, the base of the salt section.

These structural depressions north of the WIPP site have been further investigated. Hole DOE-2 was drilled in the spring of 1985 largely to investigate the structure of these depressions. Borns (1987) reports that the characteristics of the depressions were manifest in thicker halite units in the Castile and Salado Formations. At hole DOE-2, and in nearby deep boreholes, complex structures in the Castile Formation were found where, in some cases, Castile halite was thinned to less than three meters thick, with recumbent structures and thickening of the anhydrite units by folding. The results of Borns' investigation indicate that dissolution was not the dominant process in the Castile. The favored hypothesis for the Castile structures associated with these local depressions is salt flow in response to gravity inversion of the anhydrite and halite units of the Castile.

Unlike the belt of salt anticlines having cores of Halite I, the distribution of the localized pockets of missing, or greatly reduced thickness of Halite I and higher Castile or Infra-Cowden halite that Anderson classifies as "deep sinks" is not confined to a belt above or adjacent to the Capitan reef, but includes mid-basin areas as well, as illustrated by Figure 16 of Anderson (1978). The nearest of these deep mid-basin features to the WIPP site, as disclosed by the various halite isopach maps of Anderson (1978), occurs about five miles southeast of the site at the Eddy-Lea County line.

It is not yet clear whether any of these deeply buried mid-basin "sinks" identified by Anderson have a hydrologic origin subsequent to diagenesis and salt deformation. If they do, they may well be related to other collapse features in the Delaware Basin region as simply one manifestation of the same general

process being seen at different levels of exhumation by erosion (Anderson, 1978). The concept that these diverse solution structures are being exhumed by present-day erosion suggests that the conditions of their formation in the geologic past may not be present today in kind or to the same degree.

The nature of the deformation in the middle and upper part of the salt sequence above the Halite-I zone is recorded by the subregional halite isopach and structure contour maps of Anderson (1978) and Brokaw et al. (1972). The salt isopachs of Anderson (1978, Figures 4 through 10) clearly show that no other salt member of the evaporite sequence has experienced local flow deformation as severe as the Halite-I zone, nor are the "deep sinks" apparently as prevalent in the middle and upper part as they are near the base of the Castile Formation. The Halite-II member of the Castile Formation mirrors the same thickness trends exhibited by the Halite-I bed, but in a much muted manner. The infra-Cowden salt is the highest salt of the Castile-Salado sequence to exhibit marked thickening along the trend of the buried Capitan reef; it is also the lowest, or first, major salt bed to overtop and extend beyond the confines of the reef margin in this part of the basin. Even though no appreciable thickening of Salado salt above the infra-Cowden is apparent over the Capitan reef margin (Anderson, 1978), structure contours at the base of the Salado Formation (the top of the Castile Formation) (Jones, 1973), and on the 124-marker bed within the McNutt potash zone (Anderson, 1978), document that the Salado is indeed arched along the basinward edge of the reef and confirm that the salt deformation which occurs at depth around this margin had imposed an anticlinal structure on overlying strata, much as Jones (1973) described (also compare Brokaw et al., 1972, with Jones, 1973).

The evidence presented in this section regarding the subsurface structure of Castile and Salado halite beds and the spatial relationship of deformation structures with the bounding Capitan reef margin suggests that viscous flow of salt was initiated by post-depositional regional tilting and that the Capitan reef acted as a dam or abutment obstructing the eastward subsurface viscous flow of the lower part of the salt section which impinged against it. The salt piled up slightly, as a rug might when gently pushed against a wall, until lithostatic equilibrium was attained with the superjacent rock mass.

That larger, more dramatic salt plumes were not formed in the Delaware Basin, as they are known to occur in the Gulf Coast basin, for example, may be attributed to several factors. Two of these factors are the gentleness of the regional tilt and perhaps a relatively shallow depth of burial of salt. This would have resulted in lower lithostatic pressures and relatively higher viscosity of salt, and hence greater resistance to migration. Evidence from structures nearer the site (e.g., in holes WIPP 11 and DOE-2) indicates that the Redbeds overlying the Salado are not always involved in the structure. This implies that some of the structures may be Permian in age.

No conclusive evidence establishing the exact time of regional tilting of the Delaware Basin has yet been found, except that it occurred after Chinle deposition (late Triassic time) and before Ogallala time (uppermost Miocene). King (1948) has proposed that regional tilting took place in early- to mid-Tertiary, concomitant with known Basin and Range faulting that occurred in the region west of the Delaware Basin, with relative upthrow of the Guadalupe and Delaware Mountains.

Northeast of the site, Long (1977a) shows a domal feature in section 36, T. 31 S., R. 22 E of about 500 feet of structural relief. ERDA-6, which was drilled in section 35 just west of the crest of this feature, encountered a geopressured (artesian) brine reservoir in the Castile Formation. Studies of the ERDA-6 core establish that the doming in this area is due to a salt anticline with a core of mobilized Halite-I salt (Anderson and Powers, 1978; refer to Figure 16). This dome is located within the belt of salt deformation flanking the Capitan Reef where such occurrences are to be expected. Artesian brine flow was also encountered by the Belco No. 1 Hudson-Federal over a similar domal feature southwest of the site in the Los Medanos gas field area (Section 1, T. 23 S., R. 30 E), although no salt-cored anticline of the type encountered at ERDA-6 was thought to occur there.

A previous seismic investigation (Long, 1977b) also defined an area of poor data quality to the north of the site. From the ERDA-6 anomaly westward into Range 30 E and southward into section 17 at the north edge of the site, the quality and continuity of data as viewed on the seismic records deteriorate. This suggests the possibility of increased structural disturbance in this area, presumably caused (if real) by some form of salt deformation. Deterioration of the seismic record can also be brought about by anomalous or irregular transmission characteristics of the overlying medium. For example, near-surface structural disturbance, such as might be caused by dissolution in the Rustler Formation, or the presence of an anomalously rigid near-surface layer, such as caliche, could change the quality of the seismic record (Dobrin et al., 1954). A salt anticline at the northwest corner of Section 9, T22S, R31E, was suspected on the basis of seismic reflection data; drilling (WIPP 11) confirmed the structure was present in the Castile. WIPP 11 did not show any brine or gas, though drilled to the lower anhydrite of the Castile Formation. This confirms that anticlinal structures within the evaporites are not always associated with brine and gas. The apparent non-involvement of the overlying Dewey Lake Redbeds in the structure may be interpreted, as noted in the previous section, as indicating a Permian age for this structure. As discussed previously, two anticlines, or domal structures, are present, one centered near the ERDA-6 locality and the other at the Los Medanos gas field. At both structures, and only at these structures in the study area, exploratory drilling encountered artesian brine reservoirs in the Castile Formation. No such structures are indicated by the 125 marker bed contours to be present within the site exclusion area.

Preliminary interpretation of seismic reflection data (Long, 1977b) near the top of the Salado Formation indicate the possibility of faulting, with a possible displacement of 100 to 250 feet, less than one mile north of ERDA 9. Consequently, four holes (WIPP 18, 19, 21, 22) were drilled bracketing the possible location of the faulting (see Figure 19) to validate the interpretation. The resulting borehole data show no apparent faulting in this region.

A preliminary assessment of the WIPP site relative to structural features presently indicated in the Salado and Castile salt formations enclosing the selected waste storage level can now be stated. Structure contour maps of various horizons in the Salado Formation indicate a uniform easterly regional structural gradient of about 80 to 100 feet per mile across the limits of the proposed storage facility, with little indication of the presence of any significant structural anomalies. Plastic deformation and buckling associated with salt migration or flow has apparently not occurred in the Salado Formation in the geologic past to the extent that it has in the lower levels of the underlying Castile Formation. Areas in the region in which artesian brine reservoirs have been encountered are associated with thickened salt sections and salt-cored anticlines in the Castile Formation. However, as previously mentioned, a thickened salt section and salt cored anticline was drilled in WIPP 11 (Sec. 9, T. 22 S. R. 31 E) without encountering fluids. Further, the occurrence of these reservoirs appears to correlate with consistent structural highs, delimited by structure contours of successive horizons in the overlying Salado Formation. No such structural features are recognizable within the limits of the WIPP storage facility on any of the Salado horizons contoured; in fact, the site appears to be in a slight structural saddle.

1.3.9.2 Shallow Structures

As discussed previously, in the Los Medanos area a distinction may conveniently be made between structural features exhibited by rocks occurring above the Salado Formation and structural features of all other strata. The distinction may be made because rocks above the Salado Formation at the WIPP site have at one time or another in the geologic past been subject to weathering processes, and hence might display secondary structures related to surficial dissolution and subsidence that would not have been imposed upon deeper strata. Accordingly, shallow structures at the WIPP site have a potential for

greater irregularity and complexity than those which occur at depth. "Shallow structure" is here defined to include the Rustler Formation which extends to a depth of about 850 feet beneath the center of the site. Figures 20 through 24 are structure contour maps of Rustler and higher strata, constructed from the data obtained from wireline geophysical logging of WIPP exploratory holes, holes drilled at the WIPP site to assess potash reserve potential, and holes drilled for hydrogeologic investigations.

Structure contours on top of the Culebra Dolomite member of the Rustler Formation are shown on Figure 20. The Culebra is the most productive water-bearing unit in the Rustler Formation. The closely spaced contours in the southwestern quadrant of the map define a slope of about 80 feet per mile eastward. The wider spacing of contours in the eastern half of the map is anomalous with respect to regional structure and marks the increasing amount of halite present progressively eastward in the Rustler below the Culebra member. A similar configuration is evident on top of the Rustler (Figure 21); again the regional gradient appears in the southwestern quadrant, while an anomalously gentle eastward gradient, in some places even reversed, signifies thickening due to an increasing content of salt present in the formation. Virtually the same pattern is observed with respect to the structure contours of the Magenta Dolomite Member (Griswold, 1977). Isopachs of the Rustler Formation (Figure 25) show the gradient and amount of eastward thickening. A broad, shallow depression with 30 to 40 feet of closure near hole P-11 appears near the northeast corner of the site on both the Magenta and the top of Rustler Formation levels, but not on the Culebra. Possibly it represents an area of greater dissolution in the upper part of the Rustler Formation, since Rustler Formation isopachs show the Rustler Formation is not thickening eastward at this particular location (Figure 25).

The area in Figures 20 and 21 where the regional gradient is reflected by the Rustler Formation structure contours, identifies the area where the Rustler Formation has perhaps been leached of most of its salt, and hence presumably where maximum settlement of overlying rocks has occurred, assuming, of course, that no dissolution took place prior to deposition of overlying Dewey Lake strata. Jones (1973) supplies a subregional structure contour map of the Dewey Lake-Rustler contact and recognizes that the unevenness it shows is due to the added complexities of subsidence (Jones, 1973).

Proceeding higher in the section, the top of Dewey Lake Redbeds (Figure 22) is the first horizon that does not reveal the eastward gradient of the Delaware Basin that all lower horizons show. The Dewey Lake surface across the site area is undulatory, possibly reflecting to some extent original undulations in the unconformable Dewey Lake-Santa Rosa contact mentioned by Jones (1973). A broad depression near hole P-11 with about 50 feet of closure is in the same location as a similar depression on the underlying Rustler Formation surface (Figure 21). Subregional structure contours of Jones (1973) indicate considerable irregularity of the Dewey Lake surface as is also suggested by Figure 22, but overall the surface slopes northeastward. Isopachs of the Dewey Lake Redbeds (Figure 26) disclose that the west-trending slope of the Dewey Lake surface at the west edge of Figure 22 is the result of the Late Tertiary erosion which is associated with the development of Nash Draw and which completely truncates Dewey Lake in Nash Draw itself (Brokaw et al., 1972). Continuation of this erosion surface to the east across higher strata is quite obvious in Figure 23, contoured on the surface of the Santa Rosa Sandstone. Structure contours of the Gatuna surface (below the Mescalero caliche) (Figure 24) show virtually the same configuration as does the Santa Rosa surface on the east and the Dewey Lake surface on the west, indicating that the thin Gatuna veneer was deposited over these surfaces after erosion occurred.

No surface faults have been mapped within five miles of the center of the WIPP site; faults that are mapped at the surface are distant and are plainly related to collapse features. Bachman's (1976) mapping east of the WIPP site shows no surface faults. The nearest faults mapped by Vine (1963) involve offsets of the Rustler Formation in Nash Draw about nine miles southwest of the site in

section 18, T. 23 S., R. 30 E. Although Vine recognized these faults as being produced by karst processes, involving areas of circular or semicircular rock deformation up to a few thousand feet in diameter, he was unsure how to account for the fact that some were positive topographic features or domes (Vine, 1960; 1963). Anderson (1978) believes that they may be the eroded remnants of former caverns in salt whose roofs had collapsed; the collapsed debris then remained as the upper part of the surrounding salt was partially dissolved and carried away.

Livingston Ridge, four miles northwest of the site, marks the edge of Nash Draw. Bachman (1974) mapped occurrences of caliche in the region around the WIPP site. He noted the structural relationship of the caliche to depressions such as Nash Draw (refer to structure contour map of the Mescalero caliche in Bachman, 1976). He concluded that,

> Major solution and collapse preceded and followed the accumulation of the Mescalero caliche in Nash Draw . . . (Bachman, 1976). The Mescalero caliche probably formed on an undulatory stable surface. . . . Along Livingston, Quehada, and Nimenim Rodges . . . the caliche dips abruptly into the adjacent depressions. The crowding of contours, the presence of fractures, the uniform thickness of the caliche along these ridges indicate that Nash Draw and Clayton Basin were subjected to collapse after the formation of the Mescalero caliche. On the other hand . . . the uniform spacing of the contours in the area of the Divide between Livingston and Antelope Ridges suggest that this surface . . . approaches its original slope.

Thus, surface mapping structural interpretations have found no evidence of any anomalous structure in the vicinity of the WIPP site east of Nash Draw that might be indicative of significant differential subsidence of underlying strata. Such surface features and structural relationships that are exposed in the area reveal no indication of any surface faulting at the WIPP site.

In summary, surface and shallow surface structure in the vicinity of the WIPP site has presumably been modified to some extent by loss from dissolution of 100 to 200 feet of salt thought to be originally present in the Rustler Formation. The resulting subsidence and settlement would not be expected to have progressed in a perfectly constant and uniform manner over an area of several square miles. On the other hand, there is no indication of the presence of the types of chaotic structure encountered in the Rustler in Nash Draw, as described by Jones (1973) and by Vine (1963). In the Nash Draw area, the widespread collapse structures observed are due to extensive dissolution in the Salado Formation rather than in the Rustler alone. Further, the successive erosional stripping of Santa Rosa, Dewey Lake, and Rustler strata westward into Nash Draw, coupled with the general eastward regional dip of the evaporite strata, indicates that the amount of overburden above the Rustler and Salado Formations actually was much less in Nash Draw than it presently is east of Nash Draw. Thus the potential for significant differential subsidence to have occurred beneath the WIPP site seems to have been minimized by the restriction of salt dissolution to beds within the Rustler and by the relatively high overburden pressure which would have tended to provide more uniform settlement as salt was being removed. Stratigraphic data from potash holes drilled in the WIPP site area indicate no major irregularities in horizons above the Salado.

1.3.10 Summary and Conclusions of WIPP Site Geology

The structure of the Los Medanos area is basically simple and the rocks are, for the most part, only slightly deformed. Nevertheless, the rocks have been tilted, warped, eroded, and subroded (i.e., subjected to subsurface solution), and discrete structural features can be recognized. These include: structural features of regional extent related to Permian sedimentation; intraformational folds of limited

extent related to "down-the-dip" movement of salt under the influence of gravity and weight of overburden; and subsidence folds related to warping and settling of rocks to conform with the general shape [Ad topography of the surface of salt in areas of subrosion.

On the basis of available geological information, the salt deposits of the WIPP site area seem in many ways to constitute a suitable receptacle for use in a pilot-plant repository for radioactive wastes. The deposits have thick seams of rock salt at moderate depths and are almost completely undamaged from subrosion. The deposits are only slightly structurally deformed, and they are located in an area that has had a long history of tectonic stability.

The geologic information collected to date indicates that tectonic faulting and warping of rocks in the site vicinity seems to be restricted to Pennsylvanian and older rocks and to have predated Permian evaporite deposition; certain minor faulting within the thick Permian section appears to have occurred contemporaneously with sedimentation. Deformation related to salt flow has occurred primarily in the Castile Formation beneath the Salado Formation, and has perhaps increased the regional easterly gradient to 80 to 100 feet per mile to some extent at the level of the storage horizon. Areas in the vicinity of the site in which artesian brine reservoirs have been encountered are associated with thickened salt sections and salt-cored anticlines in the Castile, but no such structural features are recognizable within the limits of the WIPP storage facility on any of the Salado horizons contoured. The site, if anything, appears to be in a slight structural saddle. Dissolution of bedded salt at the site has been restricted to horizons within the Rustler Formation; there is no evidence that the resulting settlement produced any significant structural irregularities or collapse features in the overlying strata within the area of the WIPP site.

1.3.11 Seismology

The purpose of the seismic studies has been to build a basis from which to predict the ground motions that the WIPP repository might be subjected to in both the near and distant future. The concern about seismic effects in the near future, during the operational period, pertains mainly to the design requirements for surface and underground structures to withstand levels of ground motion much greater than those expected during this period. The concern about effects occurring over the long term, after the repository has been decommissioned and sealed, pertains more to relative motions (faulting) within the repository and possible effects on the integrity of the salt beds and/or shaft seals.

In this discussion, all intensities are based on the modified Mercalli intensity scale (Wood and Neuman, 1931). Most of the magnitudes were determined by the New Mexico Institute of Mining and Technology or described in the Geological Characterization Report (Powers et al., 1978) and in the FSAR (Final Safety Analysis Report) (DOE, 1988, Revised 1990).

Seismic History

Seismic history is discussed both before and after the time when seismograph data for the region became available.

The earthquake record in southern New Mexico dates back only to 1923, and seismic instruments have been in place in the state only since 1961. Sanford and Toppozada (1974) have examined various records to determine the seismic history of the area within 180 miles of the site. The results for the period before 1961 area given in Table 1. With the exception of the weak shock in 1926 at Hope, New Mexico, and the shocks in 1936 and 1949 felt at Carlsbad, all known shocks before 1961 occurred to the west and southwest of the site and more than 100 miles away. Since 1961, instrument coverage has become comprehensive enough to locate most of the moderately strong earthquakes in the region. Shocks that occurred within 180 miles of the site since 1961 are listed in Table 2 and are shown in Figure 28. The distribution of data in Table 1 may be biased by the fact that seismic stations were more numerous and were in operation for longer periods north and west of the site.

Except for the activity southeast of the site, the distribution of epicenters since 1961 differs little from that of shocks before that time. There are two clusters, one associated with the Rio Grande Rift on the Texas-Chihuahua border and another associated with the Central Basin platform in Texas near the southeastern corner of New Mexico. This latter activity was not reported before 1964. It is not clear from the record whether earthquakes were occurring in the Central Basin platform before 1964, although local historical societies and newspapers tend to confirm their absence before that time.

A station operated for 10 months at Fort Stockton, Texas indicated many small shocks from the Central Basin platform. Activity was observed at the time the station opened on June 21, 1964. Shurbet (1969) suggested that this activity was related to the injection of water underground for oil recovery. The suggestion has merit in that the Central Basin platform is an old structure (Early Permian), with no surface indication of having been rejuvenated, and also because enormous quantities of water have been injected. In one of the oil fields, the Ward-Estes North operated by Gulf Oil Corporation, the cumulative total of water injected up to 1970 was over 1 billion barrels. Accounting for 42 percent of the water injected in Ward and Winkler Counties, Texas, the quantity is three times the total injected in all the oil fields of southeastern New Mexico in the same period. The known hydrocarbon resources nearest the site are two gas wells approximately three miles to the southwest of the center of the site. Water injection has not been used in the region around the site to stimulate gas production. The nearest oil fields in the Delaware Basin, where secondary recovery might be attempted, are seven miles from the site. Water-injection operations would be prohibited within the WIPP site during the period of administrative control. After the closing of the repository, seismicity induced by water injection would not produce enough ground displacement to jeopardize the repository.

The strongest earthquake on record within 180 miles of the site was the Valentine, Texas, earthquake of August 16, 1931 (event 4 in Table 1). Coffman and von Hake (1973) estimate it to have been of magnitude 6.4 (modified Mercalli intensity of VIII). The Valentine earthquake was 130 miles southwest of the site. Its modified Mercalli intensity at the site is estimated to have been V; this is believed to be the highest intensity felt at the site in this century.

In 1887, a major earthquake occurred in northeast Sonora, Mexico. Although about 335 miles west-southwest of the site, it is indicative of the size of earthquakes possible in the eastern portion of the Basin and Range province west of the province containing the site. Sanford and Toppozada (1974) estimate its magnitude to have been 7.8 and Coffman and von Hake (1973) list it as VIII-IX in modified Mercalli intensity. It was felt over an area of 0.5 million square miles (as far as Santa Fe to the north and Mexico City to the south); fault displacements near the epicenter were as large as 26 feet (Aguilera, 1920).

Recent Seismic Activity

Any seismic activity at or near the site is of great interest. From April, 1974, to October, 1978, 420 events identifiable as local and regional earthquakes (within about 210 miles) were recorded by a station (CLN) 4 miles from the center of the site. For 150 of those events, the epicenters were identified and magnitudes determined (Table 2). Nine tentative locations were also determined. From January, 1962, through September, 1986, 448 events were instrumentally recorded that occurred within 180 miles of the WIPP facility. These seismic patterns are similar to those of the preinstrumental data.

Three events (July 26, 1972; November 28, 1974; and January 19, 1978) have been instrumentally recorded within 35 miles of the WIPP site. The nearest event to the WIPP site occurred on January 19, 1978, about ten miles northeast of station CLN. Its magnitude was 2.3, and the event does not appear to have been related to human activity.

The other two nearby events (July 26, 1972, and November 28, 1974) had magnitudes of 2.8 and 3.6, respectively, and both were about 25 miles to the northwest. At both times, rockfalls and ground cracking were reported at an active potash mine. To determine whether collapse at this mine was responsible for both events, an analysis was made of whether the two epicenters coincided. They were about six miles apart, and thus the two events could not both have been caused by the mine. Moreover, the earthquake had too much energy to have been caused by the rockfall. In the absence of additional seismic data on these events, seismic risk at the site has been estimated on the assumption that both were natural (Caravella and Sanford, 1977).

Seismic Risk

One desires not only an estimate of the largest seismic motions possible at a site, but also an estimate of their probability. Such an estimate has been made for the WIPP site, starting with an analysis of the recurrence rates of earthquakes in nearby active areas. While maps of the position and intensity of recorded earthquakes are useful in evaluating the probability of an earthquake at a given site, to increase their usefulness the historical data have been supplemented with field geologic data.

Several researchers have divided the United States into zones of earthquake risk. The standard estimate is that of Algermissen (1969). According to this estimate, the site is located in seismic risk zone 1, where only minor damage to structures is to be expected, corresponding to a modified Mercalli intensity of V to VI. Earlier, Richter (1959) had placed the region within a seismic zone where the probably maximum intensity would be VIII. Sanford and Toppozada (1974) considered the site to be either on the boundary of zones 2 and 3 or within zone 2, depending on whether earthquakes in the Central Basin platform are found to be natural or induced by human activity.

Instrumental studies have shown the Central Basin platform, a structural feature less than 30 miles east of the site, adjacent to the Delaware Basin, to have been active since at least mid-1964, and much more active than would be expected from its stable tectonic setting. Primarily for this reason, a seismographic station array was established in Kermit, Texas, in late 1975. This station was in operation from 1975 through 1979. During the period from November 1975 to July 1977, 407 local events were detected and 135 located with array data.

Data show the Central Basin platform to be the most active seismic area within 180 miles of the site in the number of events, but not in magnitude of events. The data imply that seismic activity is equally likely to occur anywhere along the Central Basin platform, without any clear relationship to small-scale structural details such as pre-Permian buried faults. Attempts have been made to relate this seismicity to the injection of water for the recovery of oil. Such a relationship has not been unequivocally established, but the lack of evidence for tectonic origin suggests this correlation.

Sanford et al. (1978), and again reported in the FSAR (DOE, 1988, Revised 1990), calculated the apparent recurrence rates for earthquakes on the Central Basin platform. The distribution of minor shocks implied a recurrence rate of every 10,000 years for earthquakes of the size of the 1887 Sonoran event. There is no evidence that such earthquakes have occurred in the Central Basin platform area. Fault scarps 25 miles long would be expected from shallow quakes such as these, with displacements of perhaps 10 feet. They are not found. To explain this discrepancy, three possible explanations have been advanced:

- Crustal movement has only recently resumed on the Central Basin Platform;
- The structure of the Central Basin platform imposes a limit on the possible magnitude of earthquakes; and
- The minor shocks observed were caused by human activity.

The first explanation may not be absolutely discarded. However, it is extremely unlikely that a structure such as the Central Basin platform, which has exhibited no tectonic movement for about 200 million years, should be tectonically reactivated so recently that no surface manifestations are observed. The calculated recurrence rates previously discussed indicate a large event every 10,000 years; no surficial evidence has been found to confirm such events. The first explanation is not reasonable given the information now available. The third explanation, which seems best supported by the evidence, means that the seismic activity in the Central Basin platform is not natural and should not be used for assessing tectonic stability over the long term. The second explanation is used in the analysis conducted for the WIPP site and briefly presented here. It is more conservative in that it assumes natural causes (which is probably not the case), but with an upper limit to the magnitude of an earthquake on the Central Basin platform. This assumption would be consistent with natural earthquakes in a region where the geology does not indicate large recent events.

The method of Cornell (1968) was used to estimate seismic risk at the site (Powers et al., 1978). Three source regions suggested by Algermissen and Perkins (1976) were used: the Rio Grande Rift, the Central Basin platform, and the remainder of the area within 180 miles of the WIPP site (site source zone). The analysis used Sanford's recurrence relationships (Sanford et al., 1976; 1978). On the basis of the earthquake of 1887, an upper limit of 7.5 was set on the magnitude of earthquakes in the Rio Grande Rift. The fact that this magnitude is less than Sanford and Toppozada's (1974) estimate of 7 to 8 does not affect the conclusions of the analysis. On the basis of the largest earthquake observed so far (magnitude 3.2), and considering the uncertainties in causative mechanisms, the upper magnitude limit for the Central Basin platform was set at 5 and 6 in separate calculations. The largest earthquake so far observed in the remaining region (the site source zone) was of magnitude 3.6; from this, and from the absence of any indication of Holocene local faulting, the upper magnitude limit for the site region was set at 4.5 and 5 in separate calculations. The depth of earthquakes in the site source zone was assumed to be 3 miles.

The Cornell method expresses seismic risk as the probability per year that a specific acceleration will be reached or exceeded. The probabilities calculated for the WIPP site are shown in Figure 29. Figure 29 also shows the separate contributions to these totals from each of the three source regions with each of the assumed upper magnitude limits. The contributions of the Rio Grande Rift source zone to the total seismic risk at the site is small at all acceleration levels. Curves A and B and curves C and D indicate the total combined acceleration for the various combinations of upper magnitude limits indicated above.

From Figure 29 the accelerations that would be experienced at the site from earthquakes in the three source zones separately are as follows for two levels of probability:

SOURCE ZONE	UPPER LIMIT MAGNITUDE	ACCELERATION G FOR PROBABILITY (PER YEAR) 10^{-5}	10^{-6}
Rio Grande Rift	7.5	0.14	0.09
Central Basin Platform	6.0	0.17	0.15
Central Basin Platform	5.0	0.17	0.07
Site Source Zone	5.0	>0.3	0.23
Site Source Zone	4.5	0.21	0.17

The total seismic risk is controlled by earthquake probabilities in one of these source zones, depending on the acceleration level considered. The relationships are shown below.

UPPER LIMIT MAGNITUDE			CONTROLLING ZONE	
RIO GRANDE RIFT	CENTRAL BASIN PLATFORM (CBP)	SITE SOURCE ZONE (SSZ)	HIGH ACCELERATION	LOW ACCELERATION
7.5	5	4.5	SSZ	SSZ
7.5	6	4.5	SSZ	CBP
7.5	5	5.0	SSZ	SSZ
7.5	6	5.0	SSZ	CBP

This assumption about the seismic properties of the area around and beneath the WIPP site (site source zone) is important in estimating seismic accelerations at the WIPP site and the potential for faulting through the repository after its closure. The possibility of faulting at the site of a magnitude that could significantly affect its integrity is extremely low.

1.3.12 Man-Induced Subsidence Features

In the Carlsbad mining district (BLM, 1975), there has been subsidence during and after underground mining. Areas where subsidence effects have occurred (14 square miles) or are expected (40 square miles) are shown in Figure 27. These areas are north, northwest, and west of the site at distances from 3.5 to 26 miles. The maximum subsidence observed is about two-thirds of the height of the ore zone mined. Current ore zones are four to eight feet thick; maximum subsidences are two feet eight inches to five feet four inches.

1.3.13 Summary and Conclusions of WIPP Site Seismology

The WIPP site is in an area of low seismic risk. The seismic history of the area has been well documented. The possibility of faulting at the site of a magnitude that could significantly affect its integrity is extremely low.

2.0 HYDROLOGY

Ground water and surface water data have been collected in the WIPP site area since 1975 as part of a study to evaluate the feasibility of storing defense-generated nuclear waste in the halite deposits of the Salado Formation. Full-scale site-characterization studies at the site began in 1976 and are still going on today. Hydrologic site characterization studies at the site since 1983 have been aimed at refining and updating the overall conceptual model of the hydrologic and geologic behavior of the WIPP site and providing data adequate for use in WIPP performance assessment. Much fundamental geologic and hydrologic information was available for the general area prior to the beginning of WIPP-related site-characterization studies. This information was the result of potash exploration, mining, oil and gas exploration, and site-assessment activities related to the GNOME project.

In 1976, the site-characterization studies began with the drilling of hole ERDA-9 near the center of the present WIPP site. The final series of hydrologic site-characterization studies, such as a recently conducted, long-term, regional-scale interference pumping test and local-scale conservative tracer test of the Culebra Dolomite Member of the Rustler Formation, should be completed and reported by December 1988. However, understanding the hydrologic and geologic behavior of the WIPP facility (and the site) will continue to develop after that time.

Data collected from these investigations have and will continue to support a full evaluation of the facility performance against criteria developed by the U.S. Environmental Protection Agency (40 CFR 191) in their present or revised form. The structural, geologic, hydrologic, and waste-isolating behavior of the WIPP facility, including far-field paths of nuclide release to the accessible environment, will be monitored throughout the WIPP operational period.

2.1 GROUND WATER HYDROLOGY

The WIPP facility is located in the Pecos Valley section of the Great Plains physiographic province in the north-central part of the Delaware Basin about 25 miles east-southeast of Carlsbad, New Mexico (Figure 2). The WIPP underground storage area is at a depth of about 2,150 feet, which is near the middle of the 1,750- to 2,000-foot thick Permian Salado Formation (Figure 30). The stratigraphy and structural geology of the region and the site are described in Sections 1.2 and 1.3 respectively.

The characterization and evaluation of the subsurface hydrology in the region has consisted of the following principal tasks or items:

- Compilation and evaluation of available pre-WIPP data and literature, mainly from potash, oil and gas, Pecos River, and GNOME investigations.
- Drilling and logging of about 80 exploration holes as part of the "Site Characterization," "Stipulated Agreement," and "Site Validation" programs; about 52 of these holes were the subject of hydrologic testing.
- Extensive field testing programs comprised of drill stem tests, flow tests, pump tests, packer tests, etc.
- Laboratory testing of physical and chemical properties of selected rock units.
- Laboratory testing of fluid samples.
- Monitoring of water levels and water pressure in wells and piezometers and monitoring surface discharge at gaging stations.

- Performing hydrologic and geotechnical observations and measurements during excavation of the WIPP facility (three shafts, approximately 25,000 feet of drifts, and our design validation test rooms) and during construction of the WIPP facility.

- Numerical modeling of the hydrologic systems, including assessment of various hypothetical accident/breach scenarios.

Ground water within the Delaware Basin varies from fresh to saline. Water-bearing zones that consistently produce potable water exist west of the Pecos River north of the City of Malaga in the alluvium and east of the WIPP site in the Triassic Dockum Group and Tertiary Ogallala Formation (Figure 9). In the vicinity of the WIPP site, there are limited occurrences of potable water and several water-bearing zones able to produce poor-quality water. Discussions of regional ground-water conditions are included in Hendrickson and Jones (1952) and Nicholson and Clebsch (1961). Detailed discussions of ground water conditions in the vicinity of the WIPP site are given by Mercer (1983).

The characterization/evaluation program identified the following regional and WIPP site specific hydrologic systems/units in descending stratigraphic order (Figures 30 and 34):

- Fresh-water aquifers in alluvial deposits along streams, primarily the Pecos River; regional.

- Perched bodies of fresh water in near-surface Quaternary and Tertiary deposits, such as the Gatuna Formation; regional and site-specific.

- Two fresh to saline water-bearing units, the Magenta and Culebra Dolomite Members of the Permian Rustler Formation; regional and site-specific.

- A saline water-bearing unit along the contact between the Rustler and Salado Formations; regional and site-specific.

- Pressurized brine reservoirs in fractured anhydrite units of the Castile Formation; regional and site-specific.

- Brine and gas occurrences in potash mines north and east of the site, primarily in the McNutt Potash Zone 800 feet above the facility horizon; regional.

- Brine and gas occurrences in the Salado Formation evaporites at the facility horizon; site-specific.

- A major aquifer in the Guadalupian reef complex (Capitan Reef, in particular) forming a long arcuate belt around most of the margin of the Delaware Basin; regional.

- Shelf aquifers of the "backreef" zone of the basin; regional.

- Saline water-bearing zone(s) in the fine-grained sandstones of the Bell Canyon Formation of the Delaware Mountain Group; regional and site-specific.

To the west of the Pecos River, many of the rock units of the basin crop out (Figure 3). In these areas, the soluble salts have been leached from the Ochoan evaporites. The remaining, fairly permeable strata provide a conduit for percolation of precipitation into the subsurface and for movement of relatively fresh water to the east. The only large quantities of potable ground water in these units are found west of and along the Pecos River.

The near-surface aquifers east of the Pecos River are limited in extent, and the water present usually contains more than 3,000 milligrams per liter TDS. These shallow aquifers are recharged from precipitation on outcrop areas or from overlying formations. The direction of migration of the ground water is not uniform, but is generally to the south or southwest, eventually reaching the Pecos River.

Yield to wells from Rustler Formation water-bearing zones present above the Salado Formation typically ranges from less than 1 gallon per minute to over 80 gallons per minute. The water in these zones ranges from less than 100 milligrams per liter TDS to greater than 220,000 milligrams per liter TDS and occurs under both unconfined and confined conditions.

The Salado Formation has extremely low permeability and small amounts of isolated fluids (discussed in Section 2.1.6). Due to this fact, the Salado Formation functions as a regional aquitard.

The underlying Castile Formation also acts as an aquitard despite the occasional presence of brine reservoirs encountered within fractured anhydrite beds of the formation. Since the reservoirs are not connected to other fluid-containing units in the basin, their presence does not diminish the aquitard properties of the Castile Formation.

Water-bearing zones stratigraphically below the evaporite sequence (Bell Canyon Formation, in particular) are widespread and contain large quantities of saline to brine fluids under confined conditions. These fluids move very slowly towards the northeast and eventually discharge into the partially depleted Capitan aquifer.

Little development of ground water has occurred in the WIPP site area. The waste storage horizon within the Salado Formation is hydrologically isolated by thick, confining beds of the Salado, Rustler, and Dewey Lake Formations overlying it and by the beds of the Salado and Castile Formations underlying it. Any significant circulation of fluids, particularly in a vertical direction, within the Salado is precluded by the self-healing, nearly impermeable character of the evaporite beds. Dissolution of the Salado beds, based on the geologic evidence, will progress at such slow rates that the formation is expected to maintain its nearly impermeable character for at least one million years.

The Natural Resources Study (Braush et al., 1982) indicates that the WIPP site area could contain several potential productive horizons (pay zones) of hydrocarbons within the rocks that underlie the evaporite deposits. However, only the Morrow Formation of Pennsylvanian age, which is a consistent natural gas producer over much of the area surrounding the WIPP site, is worthy of exploration risk at the present time. Some ancillary gas production may also be possible from the overlying Pennsylvanian Atoka Formation. The crude oil resources in the WIPP site area are not considered reasonably extractable at the present time.

2.1.1 Evaluation of Hydrologic Systems

At the WIPP site and its vicinity, fluid-bearing horizons from the surface through the Bell Canyon Formation have been investigated. Additionally, the geologic observations and documentation of the conditions encountered in the four shafts and other underground openings provided additional data on penetrated fluid-bearing zones, i.e., on the two dolomite members of the Rustler Formation, the Rustler/Salado contact, and the Salado Formation, in particular.

In the immediate vicinity of the WIPP site, ground water above the Salado Formation is commonly of such poor quality that it is not usable for most purposes. Ground water of marginal quality, available in rare near-surface perched aquifers in the Dewey Lake Redbeds and Dockum Group, is used for watering livestock and is considered a valuable resource.

Exploratory holes were drilled with air through the Gatuna Formation, Dockum Group, Dewey Lake Redbeds, and Rustler Formation. Saturated zones are readily detected with this drilling method. The Gatuna Formation and Dockum Group (Figure 30) occur within 50 feet of the surface, but little or no water is present. The Dockum Group is found only in discontinuous thin lenses beneath the eastern half of the site and is not present to the west. Small zones of moisture were reported in three holes in the Dewey Lake Redbeds and one hole in the Dockum Group. Otherwise, no moisture was encountered until the Magenta Dolomite Member was reached. Observation wells constructed in the Dewey Lake Redbeds and Dockum Group are dry, confirming the absence of large saturated zones and aquifers above the Magenta Dolomite. Occasional bodies of perched water have limited extent and yield.

Hydrologic exploration at the site has identified and tested five fluid-bearing zones. These include the Magenta and Culebra Dolomite Members of the Rustler Formation and Rustler/Salado contact zone, each of which may be a potential avenue for radionuclide transport.

The fourth zone tested was the Castile Formation, the hydraulic conductivity of which is generally very low in the site vicinity, as determined by drill-stem tests in exploratory drill-holes AEC-7, AEC-8 and ERDA-10. In some cases, deformation of the Castile beds has occurred, resulting in anticlinal structures with local fracturing of anhydrite beds as described in the previous section on structural geology. In some of these areas, brine reservoirs have been encountered that have substantially higher hydraulic conductivities than those determined for intact anhydrite. However, interbedded halite units are not fractured and exhibit low permeabilities typical of halite.

The fifth zone tested was the sands of the underlying Bell Canyon Formation which contains a confined fluid-bearing zone of unsaturated brine under sufficient head to reach the Salado Formation. Additional hydrologic testing and investigations have been conducted in the WIPP underground openings to address localized weeps of small quantities of brine and gas. Section 2.1.6 contains more detailed discussion of these phenomena and the permeability and hydrologic characteristics of the Salado Formation (repository host formation).

The permeability of the fluid-bearing zones above the Salado Formation and within the WIPP site boundaries is highly variable. The range of transmissivities and storage coefficients is discussed with regard to each water-bearing unit in the following sections. Modeling studies have shown large areas of the Culebra Dolomite Member have transmissivity values as great as 2×10^{-4} square meters per second. Static heads in all of the fluid-bearing zones are generally more than 200 feet below land surface, except the initial heads of the isolated, artesian brine reservoirs encountered in the Castile Formation.

2.1.2 Hydrologic Testing and Evaluation Methodology

The geologic and geophysical exploration conducted at and the near the WIPP site, as well as geologic mapping and related investigations of the underground openings, provide a detailed understanding of the stratigraphy, structure, rock properties, and other features of the subsurface geology. In coordination with the geologic characterization, a program of hydrologic testing and monitoring was established. The primary objective of this program was to identify individual hydrogeologic units/systems and their potential effects with regard to the WIPP facility. To fulfill this objective, investigations were conducted to determine the characteristics of the fluid-bearing zones, such as equivalent potentiometric surfaces, formation transmissivity, and the chemical and physical properties of the formation and wellbore fluids. These data were used to develop mathematical fluid and solute-transport models of the hydrologic systems and provided input into breach consequence calculations.

An inventory was made of existing water wells in the vicinity of the WIPP site prior to the development of site-specific test wells (Table 3). During the early testing history of the WIPP Project (from about 1977 to 1981), the U.S. Geological Survey and Sandia National Laboratories conducted hydrologic tests in 39 exploratory drill holes within the site boundary and in the WIPP vicinity. Additionally, unsaturated zones were tested in shallow, site-specific holes to determine the potential permeability of the shallow units. From 1981 through 1988, Sandia National Laboratories and the Management and Operating Contractor re-completed existing wells and established new testing sites comprised of either single or multiwell pads. Pressure-transient hydraulic tests, chemical analyses, and non-sorbing tracer tests were conducted in wells installed prior to 1981 and in the newly completed or installed wells. Figure 11 shows the location of selected wells used for hydrologic testing in the vicinity of the WIPP site.

Hydrologic testing was also conducted during shaft and repository construction. During the site validation phase, the effects of shaft construction on the local water-bearing units were assessed, detailed geologic and hydrogeologic mapping was conducted in the shaft after construction, hydrologic observations were performed during underground mapping and reconnaissance/ inspection trips, and facility horizon brine and gas occurrences were evaluated.

Multiple-well interference tests were conducted at a number of three-well hydropads completed in the Culebra Dolomite Member of the Rustler Formation. This testing program consisted of pressure transient and non-sorbing tracer tests to determine the principal transmissivities, porosity, storativity, and dispersivity of the Culebra Dolomite Member. Test methods employed during these interference tests are discussed in Gonzalez (1983), Ward and Walter (1983), Walter (1983), Hydro Geo Chem, Inc. (1986), Kelly and Pickens (1986), and Beauheim (1986). A discussion of the results of hydraulic testing activities are given in the following sections for each individual hydrogeologic unit.

Fluid samples have been collected from several different water-bearing units by bailing, swabbing, or pumping; these fluid samples were obtained both during initial drilling and installation of the test wells and during dedicated sampling programs mainly the Water Quality Sampling Program (WQSP). To maximize the probability that the fluid samples obtained were representative of the zone being tested, analyses of key chemical indicator parameters have been performed in the field on a periodic basis during fluid removal until stabilization of these parameters occurred. Results, plans, and discussions from these testing programs are given in Mercer and Orr (1979), Mercer (1983), Lambert and Robinson (1983), Mercer and Orr (1977), Colton and Morse (1985), Uhland and Randall (1986), Uhland et al. (1987), and Randall et al. (1988).

Boreholes in which hydrologic testing has been performed were completed as observation wells and are used to monitor the hydrostatic heads in fluid-bearing zones. Several of the test holes were completed as multiple observation wells and are used to monitor fluid levels of two separate zones by means of packers and an inner tubing string. In some wells, a third zone was perforated and tested and a bridge plug was later set above it; consequently, the zone is not now available for periodic monitoring. Other wells were completed to monitor one zone in an open hole rather than through perforations in the casing. In addition to zones found to yield fluid to wells, selected shallow test holes were completed as observation wells to allow detection of perched or transitory saturated conditions that could develop. Shallow zones monitored include near-surface alluvium, the Gatuna Formation, the Dockum Group, and the Dewey Lake Redbeds. Some observation or test wells have been temporarily or permanently plugged.

Periodic monitoring of fluid levels in the wells began after the initial series of hydrologic tests in each well were completed. Because of the low yields of some of the tested fluid-bearing zones, considerable time is required after water removal for the fluid level in some wells to stabilize. The rate of recovery would be

slowed if the interconnection between the well and the water-bearing zones was impaired by the well's construction, such as by having insufficient perforations. Most fluid levels have stabilized, however, and provide an accurate determination of the potentiometric levels of the monitored zones as well as data to establish potentiometric gradients.

During the site validation phase the effects of shaft construction on local aquifer hydrology were assessed by:

- Ground-water inflow tests in the ventilation shaft (diameter of six feet).
- Drawdown analysis of the Culebra aquifer in the unlined ventilation shaft using piezometer data from the exploratory shaft and nearby monitor wells at pads H-01, H-02, and H-03.
- Chemical analyses of inflow samples collected in the ventilation and intake shafts.

The zones of interest were the two principal water-bearing zones in the Rustler Formation, the Magenta and Culebra Dolomites, and the Rustler/Salado contact.

Two methods were used for the inflow tests:

- Measuring the change in water level in the shaft sump during three separate tests intervals, and
- Installing a water collection ring to determine the inflow from the Rustler Formation dolomite members.

After enlarging the SPDV ventilation shaft to the approximately 20-foot diameter waste handling shaft, hydrologic observations were included as part of the detailed geologic mapping. Hydrologic observations were also performed during underground mapping and reconnaissance/inspection trips.

During the excavation of the Site and Preliminary Design Validation (SPDV) underground drifts, several occurrences of minor gas emissions were noticed in vertical core holes drilled into the roof and floor of the drifts. A subsequent test program consisted of:

- Inventory of boreholes and determination of their suitability for gas testing.
- Gas testing in existing accessible holes penetrating Anhydrite beds "A" and "B," and Marker Bed 138:
  - Determination of gas-producing zones using straddle packers,
  - Measurements of gas flow rates, and
  - Collection of gas samples.
- Testing of an available drill rig underground for its suitability for gas testing, which included drilling a new hole to the bottom of Marker Bed 139, measurement of gas flow and collection of gas and brine samples.

Later tests included drilling four one-inch diameter holes into the roof of the drifts with rapid shut-ins (after gas was encountered), enabling initial flow rate and pressure build-up measurements to be made. These boreholes penetrated Anhydrites "A" and "B."

During the SPDV phase, samples of the facility horizon halite were also subjected to laboratory testing to determine:

- The fluid content of releaseable water/brine in the form of fluid inclusions or as hydrated minerals; and
- Permeability.

Hydrologic data presented and/or referenced in Section 2.0 have been collected or calculated by a number of individuals in different organizations over a period of many years using various values/units for similar phenomena, such as hydraulic conductivity versus permeability versus transmissivity or milligrams per liter versus parts per million, etc. These values are presented as they have been used in the individual references because their unification could lead to inaccuracies and/or interpretative errors.

The following discussion describes the hydrologic and hydrochemical characteristics of each of the water-bearing units found to be significant to the performance of the WIPP site. The individual discussions include the distribution of hydrologic parameters, water quality, and their relationships to the WIPP site and other hydrogeological units. The term "aquifer" is not used in its formal sense in this report. Formal usage defines an aquifer as a geologic formation or group of formations or a part of a formation that is capable of yielding economic quantities of water to a pumped well or to springs. The use of the term aquifer in reference to most water-bearing units at and adjacent to the WIPP site would be misleading. More appropriately the zones associated with the WIPP site will be referred to as "hydrologic units" or preferably as "water bearing units" in this report.

2.1.3 Hydrology of the Delaware Mountain Group

The lithology of the Delaware Mountain Group has been described previously in detail. It is predominantly a fine-grained, silty sandstone with interbeds of black shale and black limestone. The basinal deposits are composed, in ascending order, of the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations. The Delaware Mountain Group crops out in the southern Guadalupe Mountains and in the Delaware Mountains in Texas. The maximum thickness of the Delaware Mountain Group is in the central part of the Delaware Basin, where it exceeds 4,000 feet. The Delaware Mountain Group either pinches out or interfingers with the several stages of reef facies on the basin edge.

Geohydrologic Characteristics

Data for a regional analysis of the hydrologic characteristics of water-bearing units within the Delaware Mountain Group are sparse due to the depth, the salinity of the water, and the overall lack of permeability of these rocks. Studies (Grauten, 1965; Sullivan, 1979) of the Delaware Mountain Group concluded that the Lamar shale at the top of the Bell Canyon Formation plus the several thousand feet of dense anhydrite and salt of the overlying Castile Formation would probably form effective confining beds over the Bell Canyon Formation. These confining beds, if they were not fractured, would restrict water from migrating upward from the Bell Canyon Formation to dissolve the salt of the Salado Formation and would also restrict movement of fluids downward from the proposed facility horizon to the Bell Canyon Formation. Since these studies, interpretations of the potential for upward movement of fluids from the Bell Canyon into the overlying evaporites (Anderson, 1978, 1981) have created a need for a re-evaluation of the hydrologic system of the Delaware Mountain Group.

This discussion is restricted to the upper part of the Bell Canyon Formation because it is the closest water-bearing zone below the evaporites and contains the most porous sandstones of the Delaware Mountain Group. The hydrologic system of the Delaware Mountain Group probably is confined to the upper 600 feet of the Bell Canyon Formation.

Based on drill stem tests conducted in the Bell Canyon Formation and from data from previous studies, it became apparent that earlier studies (Hiss, 1976; Mercer and Orr, 1977) indicating that the Delaware Mountain Group is a uniform hydrologic unit were in error. Numerous studies of oil reservoirs indicate that the sandstones of the upper part of the Bell Canyon are present as narrow, sinuous channels that grade laterally into less permeable shales and siltstones. These channel sandstones may be covered with siltstone and locally are poorly connected hydrologic units. Though studies of geophysical logs may indicate that an individual sandstone body is continuous, each major sandstone body is composed of many individual sandstone beds that are either separated by siltstone or have different degrees of cementation (Williamson, 1979). Grauten (1965) describes the apparently continuous sands of the Ramsey sandstone actually to be composed of three or more separate sublenses of porous sandstone separated by relatively impermeable siltstone beds, each sublens to be virtually separated hydraulically from the others. The entire system is confined by overlying beds with negligible permeability; in the case of the sandstones of the Ramsey member, the overlying Trap and Lamar shale members form a very effective seal (Grauten, 1965). As a result, vertical permeability within these sandstone units is very small, as indicated by data from a drill-stem test in test well AEC-8 where two sandstone units, separated by a siltstone unit 16 feet thick were individually tested (Mercer and Orr, 1979). The water levels for the upper and lower sandstones stabilized at 553 and 568 feet below land surface. Extensive evaluation of drill-stem tests in other wells throughout the basin indicated that potentiometric (or head) differences of this magnitude are common between adjacent sandstone hydrologic units. These differences indicate that confining beds between the sandstones are so poorly connected that they cause hydraulic-head differences of 15 feet in sandstone lenses only 16 feet apart.

The hydraulic properties of the upper part of the Bell Canyon Formation have been compiled from several sources, including drill-stem tests at the WIPP site (Table 4) and selected oil-field production data. The following discussion provides the average values for hydraulic properties published in the Delaware Mountain Group Symposium (Sullivan, 1979) for reservoirs at which oil, gas, and water are present and includes the values for the hydraulic properties for the permeability barriers of siltstone and shale.

The primary porosity of the upper Bell Canyon Formation sandstones (generally the Ramsey) is intergranular and generally ranges from 20 to 28 percent. The permeabilities of these Ramsey sandstones range from 14 to 90 millidarcies (Berg, 1979), although permeability may be greater locally. The siltstones and shaly siltstones forming the permeability barriers generally have porosities ranging from 10 to 20 percent, with a permeability usually less than 0.1 millidarcy. A good example of this type of stratigraphy is shown in the cross section across the El Mar oil field in Loving County, Texas (Figure 31).

Recent studies suggest that the Bell Canyon Formation at the WIPP site does not contain any major channel sandstone units (Figure 32). This decreases the probability that the Bell Canyon can serve as a source of fluids for dissolution of overlying evaporites at the WIPP.

To evaluate the water-bearing units in the upper Bell Canyon Formation in the vicinity of the WIPP site, three test holes (AEC-7, AEC-8, and ERDA-10) were drilled into the upper part of the Bell Canyon Formation and were hydraulically tested. Several sand stringers that were identified from the geophysical logs and cores were permeable enough to test and were found to contain brine. These zones included an upper and lower sand in test hole AEC-8 (probably pre-Ramsey), a series of sandstones in test hole ERDA-10 (Ramsey and pre-Ramsey), and sandstone in test hole AEC-7 (Ramsey). Although test holes AEC-8 and ERDA-10 are only about 14 miles apart, and the sandstones tested are about the same depth below the top of the Bell Canyon, they may not be in good hydraulic connection because they appear to be channel sandstones. Test hole AEC-7 penetrated similar sandstones at a shallower depth.

The tests were conducted using standard and modified drill-stem-test procedures (Mercer and Orr, 1979), which primarily test the horizontal hydraulic conductivity. From analyses of the hydraulic data (Table 4), the hydraulic conductivities of the sandstones were 4.0×10^{-2} foot per day for the zone tested in AEC-7, 2.0×10^{-2} and 7.0×10^{-3} foot per day for the two zones tested in AEC-8, and 5×10^{-2} foot per day for the zone tested in ERDA-10. The Lamar shale also was tested in the three holes to evaluate the effectiveness of the zone as a confining bed which would restrict upward movement of fluids, assuming the unit is not fractured. These tests of the Lamar shale yielded values of hydraulic conductivity of 2.0×10^{-6} foot per day in test hole AEC-8, and 4.0×10^{-4} foot per day in test hole ERDA-10. In AEC-7, the Lamar shale was evaluated to determine its effectiveness as a confining bed, but it had such negligible permeability it could not be tested. These hydraulic-conductivity values for the upper sandstone units of the Bell Canyon Formation were within the range of permeability values reported by various oil companies for the sandstones and shales of the Delaware Mountain Group throughout the basin. These tests also indicated that the head in the upper portion of the Bell Canyon is less than the heads in the Rustler Formation. Therefore, if an interconnection were formed between the two units, the potential would be for downward movement if, in fact, these zones were interconnected.

Ground Water Movement

Several studies have produced potentiometric-surface maps for the Delaware Group; however, because most of the pressure-head information comes from the upper part of the Bell Canyon, these maps probably are most representative of that zone. The common procedure during oil exploration is to run a drill-stem test on a zone that (from geophysical logs) appears to have the greatest porosity along with some associated permeability. Because of the lack of lateral continuity in many of the sandstones tested in the upper part of the Bell Canyon Formation, less reliable data are available than would be expected from the number of wells shown on an oil and gas map.

Hiss (1976) and McNeal (1965) have constructed potentiometric maps for the upper part of the Bell Canyon Formation, and the maps generally are similar even though Hiss's map covers only the northern part of the Delaware Basin. Both of these maps were constructed after adjusting hydraulic head data to a freshwater equivalent to account for variations in brine density. In the WIPP characterization study, available oil-field drill-stem tests, production tests, and water analyses were coupled with data collected from the deep test holes AEC-7, AEC-8, and ERDA-10 near the WIPP site to construct a potentiometric map. The base map developed by Hiss (1976) was used, and new information was corrected for density as described by Hiss and incorporated in a new map. The new contour map duplicated Hiss's map with very little modification (Figure 33).

The potentiometric gradient of the upper part of the Bell Canyon is nearly parallel with the regional structural trend. Water apparently enters the unit in the western part of the basin, perhaps in the Delaware and Guadalupe Mountains, and moves northeastward across the basin at a hydraulic gradient ranging from 25 to 40 feet per mile. The rate of water movement in the sandstone is probably very slow because it is assumed to be restricted by negligible hydraulic conductivity of the intervening siltstones. Although the Capitan aquifer of Hiss (1976) abuts and overlies the Delaware Mountain Group along the basin margins, the lithologic and hydrologic characteristics of the Capitan aquifer and Delaware Mountain Group (in particular the upper part of the Bell Canyon Formation) are quite different (Hiss, 1980). The hydraulic conductivity of the Delaware Mountain Group is several orders of magnitude less than that of the Capitan aquifer; this fact, coupled with differences in quality of water, would indicate that only a relatively small quantity of water in the Delaware Mountain Group, if any, would move into the Capitan aquifer. Data from tests of the upper part of the Bell Canyon Formation in test holes AEC-7, AEC-8, and ERDA-10 fit with the regional trend. Fluid density and permeability variations and discontinuity of the upper sandstone units in the Bell Canyon Formation preclude detailed site-specific analyses by means of the potentiometric map.

Hydrochemistry

Generally, the waters in the upper part of the Bell Canyon Formation are brines in which sodium and chloride are the predominant ions (Table 5). The "clean" sandstones near the outcrop of the Ramsey sandstone of the Bell Canyon Formation, west of the WIPP site near the Guadalupe Mountains, appear to be saturated with relatively fresh water (Grauten, 1965). As the water moves across the Delaware Basin, however, the salinity of the water increases; total dissolved solids concentrations of more than 300,000 milligrams per liter occur in the structural trough of the basin (McNeal, 1965). Concentrations of dissolved solids in brines sampled during the testing of the upper part of the Bell Canyon Formation at the WIPP site ranged from 180,000 milligrams per liter in test hole AEC-8 to 270,000 milligrams per liter in test hole ERDA-10. The abundance of calcium, magnesium, sodium, and potassium cations, the presence of chloride and sulfate as the major anions, and the measured low hydraulic conductivity support the concept of extensive brine-rock interaction as the water moves slowly northeastward across the basin. Detailed informtion on the composition of the water from the Bell Canyon in test holes AEC-7, AEC-8, ERDA-10 and DOE-2 can be found in Mercer (1983), and Uhland and Randall (1986).

2.1.4 Hydrology of the Guadalupian Reef Complex

In general, the position and dimensions of the Guadalupian reef complex, which contains the Capitan Limestone Aquifer as defined by Hiss (1976, 1980) and as used in this report, closely agree with the location of the Capitan and Goat Seep Limestones and carbonate banks of the Carlsbad facies of Meissner (1972) (Figure 2). It also includes shelf margin carbonates and the upper part of the San Andres Limestone. Although the Capitan aquifer is one of the most productive aquifers in southeastern New Mexico, it is present in the subsurface, at the closest, approximately ten miles north of the WIPP facility. Here, the Capitan aquifer is generally composed of a relatively "clean" carbonate with low insoluble residue, especially near the forereef edge.

Geohydrologic Characteristics

This discussion is concerned with the section of the Capitan aquifer that parallels the northern and eastern margins of the Delaware Basin in an arcuate strip that extends from the Guadalupe Mountains southwest of Carlsbad to the Glass Mountains near Fort Stockton, Texas. The width of the Capitan aquifer in this strip ranges from 10 to more than 14 miles (Hiss, 1976). In the subsurface, the forereef edge is relatively abrupt and abuts against the sediments of the basin. Approximately 1,200 feet of vertical relief along the forereef edge was detected in two oil test holes drilled a few hundred feet apart (horizontal distance) in sections 5 and 9, T. 22 S., R. 33 E. in Lea County (Hiss, 1976). The backreef edge of the Capitan aquifer is much more irregular. The thickness of the unit is quite variable, with a maximum thickness of nearly 2,400 feet present about 13 miles northeast of Carlsbad. Hiss (1976) reported that a thickness of more than 1,500 feet has been observed in 49 percent of the wells that penetrate the Capitan aquifer in New Mexico. He also discussed the presence of submarine canyons that eroded into the reef in Eddy and Lea Counties, New Mexico, which decrease the overall thickness of the aquifer by one-half or more. These features all have a bearing on the occurrence and movement of water in the reef complex.

The hydraulic conductivity of the Capitan aquifer along the eastern margin of the Delaware Basin in Texas and New Mexico has been calculated and found to range from 1 to 25 feet per day (Hiss, 1976); average values for the aquifer in southern Lea County and east of the Pecos River valley at Carlsbad are about 5 feet per day. Although no values of hydraulic conductivity are available for the Capitan aquifer

west of Carlsbad, Motts (1968) indicates that yields of developed wells are from 1,000 to 4,000 gallons per minute. He also indicates from his studies that the occurrence and movement of water in the Capitan aquifer is controlled primarily by lithofacies changes. Permeabilities are greatest in coarser grained rather than finer-grained detrital carbonates and in calcareous rather than dolomitic rocks. This association also is borne out in the work of Hiss (1976).

Ground Water Movement

Water in the Capitan aquifer is under water-table conditions southwest of the Pecos River at Carlsbad, but to the north and east, where the aquifer is entirely in the subsurface, artesian conditions prevail. Hiss (1976) indicates that water entering the Capitan aquifer system in the Guadalupe Mountains moves eastward toward Carlsbad where most of the water discharges into the Pecos at Carlsbad Springs. He concludes that a deep, incised submarine canyon near the Eddy-Lea County line forms a hydraulic restriction that constrains the eastward movement of water from the vicinity of the Pecos River. Apparently, there is little movement of water between the Pecos River and this restriction (Figure 34). East of this restriction, however, the regional potentiometric surface, represented by the hydraulic head in the aquifer, has been changed significantly in response to withdrawal of both ground water and petroleum, especially during the last 50 years (Hiss, 1980).

In summary, the Capitan aquifer system is unique hydrologically in that it forms a long narrow arcuate belt composed of very permeable rocks. Rocks with little permeability adjoining and underlying the Capitan aquifer control the movement of water. Lateral movement into the basin is prevented by the nearly impermeable anhydrites of the Castile Formation, while downward movement is controlled by the higher hydraulic head in the relativity impermeable Delaware Mountain Group. The shelf-aquifer system (Hiss, 1976) to the west and east of the Pecos River is interconnected with the Capitan aquifer, but the relatively lower permeability of the shelf-aquifers (one to two orders of magnitude less than that of the Capitan) restricts hydraulic connection.

Hydrochemistry

There is an extensive discussion of the chemical composition of ground water associated with the Capitan aquifer in Hiss (1976). In general, the water with the lowest chloride-ion concentrations is present in the Capitan aquifer throughout the region where the rocks have the greatest permeability; conversely, the water with the highest concentrations is present in rocks with the least permeability. The slightly saline water found in the Capitan aquifer and backreef rocks in southeastern New Mexico and western Texas probably is a result of selective displacement of the original brines by fresh water moving from the Glass and Guadalupe Mountain into formations with the regionally greatest transmissivity (Hiss, 1976). Moderately saline waters are found in the Capitan aquifer in eastern Eddy County, especially in the area of the apparent hydraulic restriction near Eddy-Lea County Line.

2.1.5 Hydrology of the Castile Formation

The Castile Formation, consisting of thick anhydrite beds with thin interbeds of salt, lies between the Delaware Mountain Group and the overlying Salado Formation and represents a major regional confining layer. Its distribution is almost completely limited to the Delaware Basin (Oriel et al., 1967), the only evaporite unit so restricted. Generally, the Castile Formation averages between 1,500 and 1,850 feet in thickness except in west-central Ward County, Texas, southeast of the WIPP site where it reaches a maximum thickness of more than 2,100 feet (Adams, 1944). Based on data from the test holes drilled during site-characterization investigations at the WIPP site, the Castile is 1,518 feet thick in test hole AEC-7, 1,377 feet thick in test hole AEC-8, and 1,492 feet thick in test hole ERDA-10.

Extensive outcrops of the Castile Formation are present in the western part of the Delaware Basin, in south-central Eddy County, New Mexico, and southward into Texas. The upper anhydrite beds have been altered to gypsum in the area of the outcrop and contain solution features.

Geohydrologic Characteristics

Very little hydraulic data are available from the Castile Formation. In the halite zones, the presence of water is restricted because the halite does not readily maintain primary porosity, solution channels, or open fractures. The same characteristics are inherent in the anhydrite, with the exception that if developed, fractures may remain open temporarily. Anhydrite hydrates to gypsum in the presence of slightly saline water. Hydration usually is accompanied by a 64 percent expansion in volume, which possibly could seal the fractures and prevent further water migration.

Drill-stem tests were conducted in the Castile Formation during drilling of test holes AEC-7, AEC-8, and ERDA-10 (Lambert and Mercer, 1977). The permeabilities of the anhydrites and salt interbeds were negligible and in most tests could not be determined with conventional testing methods. However, based on the sensitivity of the test equipment, a conservative estimate for a hydraulic conductivity of the sections tested would be equal to or less than $1x10^{-8}$ foot per day.

In most of the basin, the Castile Formation evaporites act as a barrier or confining layer for water moving "through" or "in" the upper part of the Bell Canyon Formation of the Delaware Mountain Group. It has been suggested that movement of fluids upward from the Bell Canyon Formation through the Castile evaporites could develop a flow path for deep dissolution of the overlying Salado Formation salts and subsequently develop dissolution features referred to as "breccia pipes" (Anderson, 1978, 1981) (Section 1.1). Anderson also suggested that the upward-moving water would, as the concentration of dissolved salts increased, begin to move back downward due to a density differential. This concentrated brine, it is postulated, would move back down through the fracture system in the Castile Formation to discharge into the Bell Canyon Formation.

For this density-flow mechanism to work, an extensive fracture system would have to develop through the anhydrites of the Castile. Detailed studies of logs and cores from drill holes in the vicinity of the WIPP site have failed to identify such a fracture system or any other evidence that would indicate water has moved vertically through the evaporite sequence. In fact, no dissolution feature that has been identified within the basin has been shown to extend as deep as the Castile Formation.

The hypothesis also requires that the upper part of the Bell Canyon Formation would be capable of transmitting these saturated brines away from the density-flow systems. The minimal permeability of sands in the Bell Canyon Formation probably would preclude removal of the volume of salt-bearing brines suggested by the hypothesis.

Appreciable quantities of water have been reported (Mercer, 1983) in the Castile Formation along the western side of the Delaware Basin, but only in weathered zones near the outcrop. Anhydrites in these areas have been altered to gypsum, forming solution channels and cavities. These cavities are filled with silt and broken blocks of gypsum and act as reservoirs for ground water. This ground water is used locally for stock watering, but usually has large concentrations of dissolved solids.

Isolated pockets of brine and associated hydrogen sulfide have been penetrated by test holes of various oil companies and during site-characterization investigations at the WIPP site (Section 1.3.9). These occurrences have been discussed in several reports resulting from these investigations (Griswold, 1980; Register, 1981; Lappin, 1988). In general, these pressurized brines are present in a fractured anhydrite bed in the Castile Formation. The brines, in all known instances, are associated with structural features, as determined by seismic methods, and appear isolated and not part of interconnected hydrologic system as determined by testing. Geochemical studies by Lambert (1978) show the Castile brine present in ERDA-6 test hole to be chemically and isotopically distinct from indigenous fluids in rocks above and below the Castile Formation.

The known distribution of these Castile brine occurrences as of 1983 is shown in Figure 35. Castile brines have been encountered largely in hydrocarbon-exploration drill-holes both north and northeast of the WIPP site (i.e., between the WIPP site and the margin of the basin). However, brine has also been encountered southwest of the WIPP site at the Belco well. During site characterization, Castile brines have been encountered in hole WIPP-12, approximately 1.6 kilometers north of the site center, and in ERDA-6, approximately 8 kilometers northeast of the site center.

Brine volumes in the two WIPP testing occurrences have been estimated on the basis of flow tests and drill-stem testing, but remain somewhat uncertain. Estimated brine volumes ranges between 9.5×10^3 and 10^5 barrels for the ERDA-6 well, and between 5×10^6 and 17×10^6 barrels for WIPP-12 (Popielak et al., 1983; Neill et al., 1983).

A geophysical survey using electromagnetic methods was made directly over the WIPP waste-emplacement panels in 1986 (Earth Technology, 1987) to determine the presence or absence of Castile brines beneath the facility. The results of this survey indicate that there may be localized and isolated brine occurrences beneath the furthest northern and northeastern parts of the waste emplacement panels, occurring within the Castile Anhydrite III unit (upper anhydrite).

Extensive geologic, hydrologic, and geochemical studies have been performed on the reservoirs intersected by boreholes ERDA-6 and WIPP-12. These studies showed that the brine is located in fractures in the Castile anhydrites (Anhydrite III at WIPP-12 and probably in Anhydrite II at ERDA-6) likely formed during the creation of the anticlinal structures (see Section 1.3.9). Also, hydrologic and geochemical data indicate that the reservoirs at ERDA-6 and WIPP-12 are not interconnected and are not connected to water-bearing units in the area. Geochemical data support the hypothesis that the brines represent trapped, concentrated Permian seawater that is currently saturated with sodium chloride in equilibrium with the reservoir host rock (Popielak et al., 1983). Other hypotheses have been proposed for the origin of the brine. These include water from the Capitan or other basin aquifers trapped in the past and fluid from dehydration of gypsum in the Castile (Powers et al., 1978).

In summary, the brine reservoirs are thought to represent stagnant, isolated pockets of fluid that cannot naturally become connected to the WIPP storage rooms by any credible processes. Of the approximately 100 boreholes drilled into or through the Castile in this area, 13 intersected pressurized brine reservoirs. Eleven of these 13 occurrences are located north and east of the WIPP site center (WIPP-12 is approximately one mile north) and are associated with known intraformational anticlinal structures in the Castile Formation (Section 1.3.9). The Belco occurrence, located southwest of the WIPP site, is also thought to be related to an anticline, though the structure is not as pronounced as those to the north and east. The H&W Danford occurrence is located west of the WIPP site, where structural contours are not well defined. All known brine encounters in the Castile Formation flowed to the surface with initial rates estimated between about 700 and 20,000 barrels per day. Initial downhole pressures were estimated to range from 1,460 to 2,519 psi (Popielak et al., 1983).

The regional breccias described in Section 1.1 comprise a dissolution feature that would require the development of an extensive hydrologic system in the Castile Formation. These breccias, Anderson (1978) postulated, are present in the subsurface at stratigraphic horizons corresponding to major halite beds; the proposed source of the water required for halite dissolution is the Capitan reef system. As discussed by Bachman (1980), a well-developed flow system would be required over an extended period

of time for such extensive lateral dissolution to take place. During careful examination of geophysical logs, Bachman could not find a hydraulic system in the Castile Formation; in fact, he indicates that the halite beds have never been in close proximity with the Capitan reef system. Bachman proposes instead that the halites were deposited in individual and discrete sub-basins within the large Delaware Basin. The dissolution breccia zones described by Anderson would correspond to areas outside these sub-basins where halite was not deposited. To complete the circulation system, Anderson's (1981) theory relies on fracture communication through the evaporites into the Bell Canyon Formation to drain off the brine; as discussed earlier, evidence for this flow mechanism is lacking.

Ground Water Movement

No regional flow system is present within the Castile Formation. Brine occurrence in the Castile Formation appear to occur in isolated pockets. Within the outcrop areas to the west, some localized flow systems have developed in places where anhydrites have been hydrated to gypsum and localized recharge can occur through solution channels and cavities.

2.1.6 Salado Formation Hydrogeology

The Salado Formation represents a regional aquitard due to the hydraulic properties of the bedded halite which forms most of the unit. During geologic mapping activities in the WIPP Exhaust Shaft, the Salado Formation did not yield any observable fluid inflow. The porosity of the Salado halite is very low, and interconnected pores are virtually nonexistent. The salt does not readily maintain open fractures or solution channels due to the high plasticity of the material at the depths of interest. As a result, the hydraulic conductivity of the halite beds is extremely low (Mercer, 1983).

Because halite is quite soluble, it would readily dissolve if the beds were to come in contact with circulating solutions unsaturated with respect to sodium chloride. West of the site where the Salado Formation rises to the surface, progressively less halite is present. This condition is a result of leaching by percolating ground water.

Dissolution of the salt has left behind a residuum of halitic clay, gypsum, and sand. Along the Pecos River in the Carlsbad area to the west, this residuum forms dense redbeds. This low permeability residue retards ground water infiltration and subsequent salt removal (Hendrickson and Jones, 1952).

The average gas permeability of rock salt samples from the site at lithostatic confining pressures (i.e., the underground storage horizon) is less that 0.05 microdarcy (about 1.2×10^{-7} feet per day). Interbedded seams or marker beds of anhydrite, clay, polyhalite, and others, which are laterally continuous throughout the Salado Formation, should not provide substantial conduits for fluids because their permeabilities are also quite low. Typical permeabilities for these type clay assemblages generally range from 10^{-6} to 10^{-3} darcy at atmospheric pressure (Fetter, 1980). Under lithostatic compression at depth, permeability would generally be less. Other seams occur as thin (a few hundredths of an inch to about a tenth of an inch) discontinuous stringers dispersed within the argillaceous halite zones. Field permeability tests have been conducted on a 100-foot thick salt layer centered at the 2,264-foot depth in well AEC-7 (Sandia, 1979). This interval contained numerous clay seams and yielded permeabilities between 12 and 21 microdarcies, demonstrating the minimal effect of the clay seams on permeability.

Very small angular cavities, containing both brine and gas, exist within and between the grains of halite. The cavities in the core samples inspected constituted an average of 0.61 percent of the rock sample volume. Analyses of 26 rock samples, taken from the facility horizon during the SPDV Program, indicate a brine and other volatile content averaging about 0.59 percent by weight. Less common are much larger cavities in which halite-saturated brine and nitrogenous gas may be confined. Brine occurrences

in the McNutt potash zone (a zone in the Salado Formation stratigraphically located about 800 feet above the WIPP facility horizon) have been encountered in three potash mines during mining operations. Estimated brine volumes in two of the three mines are 190,000 gallons in Lundberg Industries Mine (17 miles from the WIPP site), and 2,500 gallons in New Mexico Potash Corporation Mine (ten miles from the WIPP site). The brine occurrences lo not appear to be interconnected and seem to be in isolated porous zones. Geochemical evidence tends to preclude interconnection of these brine occurrences or connection with water-bearing zones in the area (Popielak et al., 1983).

Detailed hydrologic investigations (Deal and Case, 1987) performed in the underground openings were directed to attaining a better understanding of minor fluid/moisture and gas occurrences and their movement within the Salado Formation in and around the facility horizon. These efforts addressed local weeping of small quantities of brine and/or gas (mostly nitrogen with traces of methane, carbon dioxide, and ethane) directly from freshly excavated halite and from layers of impurities. These types of liquid/gas movement are typically associated with the redistribution of stress induced by the excavation activities. Therefore, the fluid migration observed in the underground excavations should decrease with time and with increased distance from the openings as the pressure gradient approaches the low undisturbed value. Pressurized gas, consisting of mostly nitrogen with some amounts of methane, has been encountered during drilling and mining activities resulting in small gas releases. The gas appears to be associated primarily with clay seams, although it may occur in fractures and pores in evaporites.

Preliminary observations from the WIPP brine sampling and evaluation program show that brine inflow usually occurs as "weeps" on the exposed surfaces and occasionally as small inflows into drill holes. These brine inflows are small, usually less than a few hundredths of a liter per day or less. There was found to be considerable variations in brine inflow between locations even when the locations are only a few feet apart (Deal and Case, 1987).

Experiments are being conducted as part of the near field effects/waste package performance tests to study brine migration due to thermal gradients. For this mechanism, thermal gradients were established using heaters placed within the salt. Because of the temperature dependence of halite solubility, movement occurs towards the higher temperature. Results from the Brine Migration Study (Nowak, 1986) showed that combined inflow rates under both a thermal and pressure gradient were higher for higher borehole wall temperatures. Inflow rates at the WIPP were in the range of 65 to 75 grams per day from Room B, an experimental heated test room, at 115° to 125°C wall temperatures.

The gas testing in selected drifts of the WIPP facility has produced the following observations:

- The emission of gas appears to be associated with clay layers at the base of the anhydrite strata, such as Marker Bed 138, Anhydrites "A" and "B," and Marker Bed 139.

- The flow from the vertical boreholes (penetrating the above mentioned beds) is very low, erratic, often pulsating, and rapidly decreasing. Maximum flow rates greater than 12 liters per minute, subsequently diminishing to a few milliliters per minute within four days, and shut-in pressures of up to 120 psi were recorded. The flow rates decreased to one-half of the initial rate in less than an hour. There is a definite relationship between gas rates and stress relief from underground excavations and possibly the atmospheric pressure.

- The samples of emitting gases were composed mainly of nitrogen (78 to 94 percent). Some oxygen (5 to 21 percent) was observed; however, this was probably due to air contamination of the samples as a consequence of the low flow rates of gas. Minor amounts of methane

(0.02 to 6.6 percent), carbon dioxide (less than 0.6 percent), and ethane (less than 0.1 percent, with one exception of 0.9 percent) were also detected.

- The highest flow rates appear to be from the base of Anhydrite "B," which is the anhydrite layer closest to the roof of the underground workings.

Gas releases from halite exposed during the excavation of the WIPP repository have occasionally been noted. These releases occurred during mining and the drilling of probe holes. In some instances, the gas occurred in association with porous zones and fractures in the salt, not obviously related to clay seams. The releases were the result of excavation-induced stress redistributions, involved small and unmeasured volumes of gas, and were audible for only short periods of time. They appear to fall within the range of the better-documented releases reported above as part of the gas testing program.

Hydrologic testing at the DOE-2, AEC-7, ERDA-9, and Cabin Baby wells was performed within the Salado Formation (Table 6) to determine if high pressure zones were present and to obtain information on the hydrologic properties of the Salado Formation. A pulse-withdrawal test at DOE-2 was completed on an interval which includes the Marker Beds 138 and 139 and the facility horizon at a depth of 2,195 to 2,309 feet below the ground surface (BGS). The maximum permeability obtained was less than 0.3 microdarcy, with a corresponding transmissivity of less than $6x10^{-5}$ square feet per day and a hydraulic conductivity of less than $6x10^{-7}$ square feet/day. The entire Salado Formation interval, between 1,040 and 3,095 feet BGS, was also tested with a pulse-withdrawal test and an additional pulse-injection test, but had an apparent permeability too low to measure.

Hydrologic testing of the Salado Formation at DOE-2 produced the following conclusions:

- There are no high pressure zones within the Salado Formation at DOE-2.

- The Salado Formation interval from Marker Bed 138 to Marker Bed 139, which includes the WIPP facility horizon, has an average permeability of less than 0.3 microdarcy.

In summary, the Salado Formation does not have any active circulation of water and is a major confining unit of extremely low permeability in the Delaware Basin. Fluids within the Salado Formation occur mainly as fluid inclusions within halite crystals and as fluid between crystal boundaries in the massive salt formation. Migration of brine is promoted by temperature and pressure gradients, such as those existing in the WIPP underground facility. The permeability of the Salado Formation halite and anhydrite/clay beds is often too low to measure, but where high enough to measure is generally less than 1.0 microdarcy (Mercer, 1983).

2.1.7 Hydrology of the Rustler Formation

The Rustler Formation in the WIPP site area has been divided into five members (Vine, 1963) that are, in ascending order, an unnamed lower member, the Culebra Dolomite Member, an anhydrite called the Tamarisk Member that is partly altered to gypsum, the Magenta Dolomite Member, and an upper anhydrite called the Forty-Niner Member (Figure 9). The Tamarisk and Forty-Niner Members also contain halite in areas where dissolution has not been active. The Culebra and Magenta Dolomite Members at the WIPP site are the most significant units from a hydrologic standpoint and consequently are the most extensively studied.

The Culebra Dolomite Member consists of 25 to 30 feet of microcrystalline dolomite. It characteristically contains many small spherical cavities that range from 2 to 20 millimeters in diameter and may be partly filled with secondary gypsum and calcite. Although many cavities are open, they do not appear to be interconnected except along fractures. Vine (1963) considers these cavities to be either a primary or a diagenetic phenomenon and not related to weathering in outcrops or secondary dissolution in the subsurface. In the subsurface, the Culebra is bounded above by anhydrites, which may contain gypsum as thick rinds along the contact with the dolomite. These gypsum rinds probably were formed by the movement of water through the dolomite. Underlying the Culebra, there is either a clayey halite or a clayey residue, depending on whether the halite has undergone dissolution. Dissolution and removal of this halite bed is directly associated with subsidence, fracturing, and the occurrence of permeable zones in the Culebra. In outcrop, the dolomite also may be locally brecciated or deformed by dissolution collapse.

The Magenta Dolomite Member ranges in thickness from 20 to 30 feet and is characterized by alternating wavy laminae of silty dolomite and anhydrite (altered in places to gypsum). The dolomite is detrital in origin and is bounded above and below by anhydrite, which may be altered to gypsum along the contact with the dolomite (Vine, 1963).

A layer of residuum underlies the Rustler Formation in Nash Draw and geologically is probably part of the Salado Formation, but for hydrologic purposes it is considered part of the Rustler Formation. It is a unit composed of clay with crudely interlayered seams of brecciated gypsum and fine-grained sandstone (Jones, 1973). The clay is considered to be the result of dissolution of clayey halite and other evaporites in the upper part of the Salado. The clay, gypsum, and sandstone comprise a distinctive sequence referred to as the Rustler-Salado residuum. Because it is formed by dissolution, the residuum is quite variable in thickness, especially in Nash Draw. The unit thins eastward, grading into and intertonguing with halite from which it originated. The residuum thickens westward and crops out locally along the Pecos River.

Exposure of the Rustler Formation along the Pecos River and in Nash Draw are locally deformed creating an irregular outcrop pattern. This deformation is caused by collapse of the harder, less soluble beds following differential dissolution within the anhydrite, gypsum, and halite of the Rustler Formation and the upper part of the Salado Formation. Generally, the dolomite members are not as susceptible to dissolution as the evaporites; consequently, the dolomites are present throughout most of the area. The dolomites commonly are slumped and form draped features in outcrops along the Nash Draw, while in other areas they may be broken into discontinuous blocks.

In some areas of Nash Draw, dissolution and erosion have been so extensive that the Magenta and Culebra Dolomite Members are virtually in contact, whereas in a normal stratigraphic sequence they would be separated by as much as 150 feet of halite beds and anhydrite. Other evidence of dissolution in the Rustler Formation can be found throughout Nash Draw, as indicated by the development of sinkholes and other types of karst topography. Bachman (1985) presents a detailed discussion of these types of near-surface dissolution features. Nash Draw is separated by a low topographic divide from Clayton Basin to the north (Figure 43). A similar type of genesis, that of dissolution collapse accompanied by erosion, also is postulated for Clayton Basin.

There has been extensive dissolution of the Rustler Formation in the Malaga Bend area causing the development of karst mounds (Bachman, 1980). As described by Bachman, these mounds and other similar features appear to be controlled more by surficial dissolution in the Rustler Formation than deep-seated geologic processes.

Eastward from the Pecos River, especially east of Nash Draw where the Rustler Formation occurs in the subsurface and is protected by the Dewey Lake Redbeds and younger rocks, structures are less chaotic

and the Rustler Formation attains a more regular character. In fact, detailed stratigraphy, lithology, and estimates of thickness are obtainable only from drill holes. The structure of the rocks indicates a relatively simple homoclinical dip to the east.

The Rustler Formation ranges in thickness from 300 feet in test hole P-14 at the western edge of the WIPP site, to more than 460 feet in P-18 near the southeastern edge of the site. The increase of 160 feet in thickness between P-14 and P-18 may provide an approximate measure of the increase in halite content of the Rustler Formation from west to east between the test holes. The thickness of the Rustler Formation is 330 feet in the northeast part of the study area near test hole AEC-7. Jones (1973) believes the difference in formation thickness between the southeast and northeast corners of the area may be depositional in origin because the formation is more thickly bedded in the southeast near test hole P-18. The theory for depositional variation in thickness is enhanced because evaluation of cores from test holes in these areas show no evidence of the dissolution residues common in other areas where the Rustler Formation is thinner. The varying thicknesses shown by an isopach of the Rustler Formation (Figure 25) represent both changes resulting from proposed dissolution as well as those resulting from the depositional history. This becomes important when describing the hydrologic system because the areas of dissolution have an important bearing on the hydraulic properties of the Rustler Formation and associated rocks.

The hydrologic units of the Rustler Formation have been among the most extensively studied rocks at the WIPP site for two reasons: (1) they are the most productive; and (2) they directly overlie the Salado Formation and could provide a potential avenue for halite dissolution and, consequently, a means for transporting radionuclides from the proposed repository. Based on many previous studies, the most areally extensive water-bearing units at the WIPP site have been identified as the Culebra Dolomite Member, the Magenta Dolomite Member, and the Rustler-Salado contact residuum. Locally, water also may be found in some of the altered anhydrite units and at places in residue zones where halite has been leached. These occurrences usually are limited to Nash Draw and appear to be discontinuous.

The hydrologic flow system in Nash Draw is very complex and probably is controlled by geologic factors that caused development of the feature itself. Bachman (1980) proposes the process of "solution-and-fill," which was discussed by Lee (1925) as the process responsible for the development of Nash Draw. Bachman describes the process whereby near-surface dissolution occurs as surface and ground water penetrates soluble rocks through joint systems and fractures. The fractures are widened, developing cavities that either collapse (forming sinks) or subside (causing disruption of the more resistant beds). Collapse and subsidence commonly have been observed in Nash Draw. Arroyos actually disappear along fractures into caves in the gypsum.

Hydrology of the Rustler-Salado Contact Residuum

Brine in the Rustler-Salado contact residuum, immediately above the top of the salt in the vicinity of Nash Draw, was first described by Robinson and Lang (1938) and referred to as the "brine aquifer." They suggested that the structural conditions that caused the development of Nash Draw also might control the occurrence of the brine; thus, the "brine aquifer" boundary may coincide with the topographic surface expression of Nash Draw. Their studies show the brine to be concentrated along a strip two to eight miles wide and about 26 miles long (Figure 36). Data from the test holes they drilled indicate that the residuum (containing the brine) ranges in thickness from 10 to 60 feet and averages about 24 feet. Hydraulic properties determined by Hale, Hughes, and Cox (1954) were computed primarily for the area between Malaga Bend on the Pecos River and Laguna Grande de la Sal. They calculated a value of transmissivity of 8,000 square feet per day and estimated by potentiometric gradient to be 1.4 feet per mile. In this area, the "Rustler-Salado residuum" apparently is part of a continuous hydrologic system as evidenced by the coincident fluctuation of water levels in the test holes (as far away as Laguna Grande de la Sal) with pumping rates in irrigation wells along the Pecos River (Hale, Hughes, and Cox, 1954).

Robinson and Lang (1938) also made a study of Laguna Grande de la Sal and the area between it and Malaga Bend to determine if brine in the lake was a source of recharge to the system. They determined, at the time of their study, that the sources of the water in the lake were precipitation and surface drainage, ground-water inflow from units above the Rustler-Salado contact and effluent from the U.S. Borax and Chemical Company plant. Since that time, the plant has been closed; however, there still may be some inflow from mining activities that take place farther north in Nash Draw. Robinson and Lang concluded that the lake and underlying Rustler-Salado residuum were not connected. Factors supporting this conclusion were: (1) test holes drilled into the hydrologic units under the lake contained water with a different chemical composition and a much smaller chloride concentration; and (2) water levels in the fill indicated movement toward the lake and not away from it (in fact, the hydraulic heads were above the lake level in most test holes). Theis and Sayre (1942) supported this conclusion in finding water levels in the lake to be high in winter and low in summer, whereas the hydraulic head in the Rustler-Salado contact residuum were high in the irrigation season and low between seasons.

Discharge of ground water into Laguna Grande de la Sal, and probably into the fill, is by the flow of springs and seeps, particularly along the northern end of the lake. The largest of these springs was identified by Robinson and Lang (1938) and called Surprise Spring (SW... NE... SW... sec. 4, T. 23 S., R. 29 E.), which was reported to discharge 115 to 125 gallons per minute. More recent WIPP studies indicate that the spring and accompanying seeps now discharge over such a broad area that accurate measurements of flow cannot be made. The increase in the areal extent of the discharge area indicates an increase in discharge, probably resulting from the effects of effluent added by mining activities since Robinson and Lang's studies. The discharge of the spring probably comes from the cavernous gypsum of the Tamarisk Member of the Rustler Formation even though alternative sources, the Culebra Dolomite Member or the Rustler-Salado contact residuum, have been proposed. Data from more recent WIPP investigations indicate that the water chemistry and hydraulic-head information identify the source of the water to be something other than Culebra or the residuum. Analyses of water samples from the Culebra Dolomite Member and Rustler-Salado contact residuum in test hole WIPP-29 (Figure 11) near Surprise Spring indicate an increase in both sodium and chloride concentrations compared to Surprise Spring. However, there is two and one-half times more calcium in the water discharging from Surprise Spring. Additionally, hydraulic-head data from a potash test hole drilled for AMOCO in Laguna Grande de la Sal (T. 23 S., R. 29 E., sec. 4) show the Culebra to have a hydraulic head about 21 feet above the lake level, indicating a confined system although there may be some minor upward leakage. The Culebra was confined under about 40 feet of gypsum mud and flowed at a rate of approximately 20 gallons per minute when first penetrated during drilling activities. This evidence indicates that neither the water present in the Culebra Dolomite Member nor in the Rustler-Salado residuum are in good hydraulic connection with the brine from the spring that flows into Laguna Grande de la Sal. The most likely source of the brine is the Tamarisk Member.

In the northern one-half of Nash Draw, the approximate outline of the "brine aquifer" (Rustler-Salado contact residuum) as described by Robinson and Lang (1938) (Figure 36) has been supported by drilling associated with the WIPP hydrogeologic studies (Mercer, 1983). These studies also indicate that the main differences in areal extent occur along the eastern side where the boundary is very irregular and, in places (test holes P-14 and H-07), extends farther east than previously indicated by Robinson and Lang.

Other differences from the earlier studies include the variability in thickness of residuum present in test holes WIPP-25 through WIPP-29. These holes indicate thicknesses ranging from 11 feet in WIPP-25 to 108 in WIPP-29 in Nash Draw compared to eight feet in test hole P-14 east of Nash Draw. The specific

geohydrologic mechanism that has caused dissolution to be greater in one area than in another is not apparent, although a general increase in chloride concentration in water from the north to the south may indicate the effects of movement down the natural hydraulic gradient in Nash Draw.

The historical data concerning hydraulic properties collected from the Rustler-Salado contact residuum are concentrated in the area from north of Laguna Grade de la Sal south to Malaga Bend. The data collected for the WIPP regional and site-specific hydrologic studies generally are from north of Laguna Grande de la Sal and east of Nash Draw, including the immediate WIPP site area.

A potentiometric surface map for the hydrologic unit of the Rustler-Salado contact residuum (Figure 37) is based on data from both the Rustler-Salado contact residuum of Nash Draw and the brine at the contact of the Rustler and Salado Formations east of Nash Draw in the WIPP site area. The mapped head data are adjusted for the effects of variations in water chemistry which create density differences. As discussed under methods of investigation, the static heads represented by water levels in the wells were adjusted to a common density of 1.00 gram per cubic centimeter (freshwater equivalent). Equivalent freshwater head is defined as the elevation of the water level in a well that is filled with freshwater to a level which will balance the fluid pressure in the aquifer (Lusczynski, 1961; DeWiest, 1965). The contours of this map represent the approximate values of static head and show the variation in gradients between Nash Draw and the area of the WIPP site. The average hydraulic gradient in Nash Draw is about ten feet per mile; in contrast, at the WIPP site the average gradient is 39 feet per mile. This difference reflects the changes in transmissivity, which are as much as five orders of magnitude greater in Nash Draw. The transmissivity determined from aquifer tests in test holes completed in the Rustler-Salado contact residuum of Nash Draw ranges from $2x10^{-4}$ square feet per day at WIPP-27 to 8 square feet per day at WIPP-29. This is in contrast to the WIPP site proper, where transmissivities range from $3x10^{-5}$ square feet per day at test holes P-18 and H-05c to $5x10^{-2}$ square feet per day at test hole P-14.

The potentiometric surface map of the hydrologic unit of the Rustler-Salado contact residuum indicates that there are two areas of considerably different permeability (Figure 37). The zone of greater permeability is associated with the residuum (brine aquifer) of Nash Draw, where flow is primarily through associated fractures and the intergranular spaces of the clay and gypsum. In contrast, brine underlying the WIPP site east of Nash Draw occurs in a zone of very low permeability along the contact between the Salado Formation and the overlying Rustler Formation (bedding-plane flow).

As stated earlier, potentiometric surface maps can be useful in showing the areal variations in hydraulic gradient from which a general trend in movement can be inferred. Inspection of the potentiometric surface map for the hydrologic unit of the Rustler-Salado contact residuum indicates that the apparent ground-water flow is southwest across the WIPP site toward Nash Draw and then south-southwest down Nash Draw toward Malaga Bend (Figure 37).

Although caution should be used in making interpretations of the hydraulic-head distribution in the WIPP site for the hydrologic unit of the Rustler-Salado contact residuum, the inferred flow direction probably is valid (Mercer, 1983). Static-head interpretations of the Rustler-Salado contact residuum within the area of the WIPP site are complicated by variations in water chemistry and its effects on density, and by the great length of time required during testing to establish static conditions in test holes because of the very low permeabilities.

Calculations of the rate of movement of water in the Rustler-Salado contact residuum are complicated by the variations in permeabilities as well as in the hydraulic gradient. The rate of movement calculated by Hale and Clebsch (1958) was 0.2 foot per day for the residuum (brine aquifer) south of Laguna Grande

de la Sal. Assuming, as they did, an average effective porosity of 0.2, an average hydraulic conductivity of 0.15 foot per day, and a hydraulic gradient of ten feet per mile, the flow rate for the area from Maroon Cliffs to Laguna Grade de la Sal would be 0.002 foot per day, assuming that the residuum behaves as a uniform porous medium. Although the hydraulic characteristics of the Rustler-Salado contact residuum are variable, this rate probably is a conservative value. The rate of movement in the Rustler-Salado contact residuum at the WIPP site has not been determined because the hydraulic properties are extremely variable and because of the lack of a valid value for the effective porosity. Water-quality data, in particular the large concentrations of magnesium and potassium, indicate an extremely slow rate of movement with long periods of rock-water contact (Mercer, 1983).

The area of recharge suggested by Lang (1938) is in the area of Bear Grass Draw (T. 18 S., R. 30 E.), some 30 miles north of Malaga Bend. He suggests that water percolating into the ground may pass into the truncated lower part of the Rustler Formation and then migrate south and east into Nash Draw, gradually dissolving salt in the Salado Formation. Data from WIPP regional studies indicate that there is a hydraulic gradient from the north and that the Bear Grass Draw area may be a recharge area. There also is a possibility of some recharge occurring in Clayton Basin and Nash Draw.

Hale et al., (1954) believed the Rustler-Salado contact residuum discharges to the alluvium near Malaga Bend on the Pecos River. Because the confining beds in this area probably are fractured due to dissolution and collapse of the evaporites, the brine (under artesian head) moves up through these fractures into the overlying alluvium and then discharges into the Pecos River. Theis and Sayre (1942) estimated that the discharge rate was about 200 gallons per minute and that, in the Malaga Bend area, about 342 tons of sodium chloride per day were discharged to the river, presumably all coming from the Rustler-Salado contact residuum.

Although the potentiometric surface map for the Rustler-Salado contact (Figure 37) indicates a potentiometric high to the east of the WIPP site, there are insufficient data to determine its origin. The possibility exists that there could be leakage from the overlying Culebra in this area; however, to accomplish this leakage, the water would have to move through 80 feet of clay and silt and a 25-foot-thick anhydrite bed. Drilling at the WIPP site has not revealed any fractured anhydrite that could increase the vertical permeability allowing water to move into the Rustler-Salado contact residuum, nor is there any indication that the water has altered the anhydrite to gypsum. Additionally, the hydraulic-head differences between the two hydrologic units, about 90 feet in test hole H-02c, coupled with the water-quality difference, would tend to indicate the zones are isolated and confined systems. The apparent potentiometric high at test hole H-05 could be due to the conversion of the dense brine to equivalent freshwater head.

Evidence for very slow ground-water movement is found in the water quality, especially in the magnesium concentrations. Large magnesium concentrations appear to be indicative of an environment in which ground-water flow is extremely slow and there has been extensive interaction between the water and its host rock. Large concentrations of magnesium, ranging from 21,000 milligrams per liter in water from test hole H-06 to 82,000 milligrams per liter in water from test hole H-05, were present in most of the test wells in the eastern part of the WIPP site (Mercer, 1983). Aquifer tests at these test holes were characterized by very low transmissivities. To the west, approaching the more developed part of the flow system of the Rustler-Salado contact residuum in Nash Draw, the magnesium concentrations decreased by one to two orders of magnitude. Magnesium concentrations of 1,200 milligrams per liter in water from test hole P-14 and 350 milligrams per liter in water from test hole P-15 may indicate the eastern boundary of the more developed Rustler-Salado flow system. Magnesium concentrations are as small as 430 milligrams per liter in water from test hole H-08; other values range from 910 milligrams per liter in water from test hole H-07 to 3,200 milligrams per liter in water from test hole WIPP-25 (Mercer, 1983).

Water in the Rustler-Salado contact residuum contains the largest concentrations of dissolved solids in the WIPP area, ranging from 79,800 milligrams per liter in test hole H-07 to 480,000 milligrams per liter in test hole H-01. These waters are classified as brines. The general chemical composition of the brine collected from the Rustler-Salado contact residuum and the major dissolved cations and anions are discussed in a following section on WIPP site water quality.

The dissolved-mineral constituents in the brine largely consist of sulfates and chlorides of calcium, magnesium, sodium, and potassium; the major constituents are sodium and chloride. Concentrations of the other major ions vary according to the spatial location of the sample and probably are directly related to the interaction of the brine and the host rocks and reflect residence time within the rocks. Residence time of the brine depends upon the transmissivity of the rock. For example, the presence of large concentrations of potassium and magnesium in water is correlated with minimal permeability and a relatively undeveloped flow system (Mercer, 1983).

Hydrology of Culebra Dolomite Member of the Rustler Formation

The Culebra Dolomite Member of the Rustler Formation has received the majority of attention during WIPP site-characterization studies. This is because it is the first continuous water-bearing unit above the Salado Formation (waste facility horizon), and it is the most transmissive hydrologic unit in the WIPP site area. The majority of water quality sampling and hydrologic testing since 1983 has been conducted in the Culebra Dolomite Member. The hydrologic characteristics of the Culebra Dolomite Member and the results of testing and sampling are discussed in detail below.

The Culebra Dolomite Member of the Rustler Formation ranges from 25 to 30 feet in thickness and is the most persistent and productive hydrologic unit in the area (Mercer, 1983). In the WIPP site area, the Culebra is a vuggy, finely crystalline dolomite that is present below the thick anhydrite of the Tamarisk Member, which in Nash Draw is mostly altered to gypsum. Water in the dolomite usually is present in fractures and is confined by the overlying gypsum or anhydrite and the underlying clay and anhydrite beds. The water may be under water-table conditions in the area south of Laguna Grande de la Sal where the Culebra Dolomite Member has been subjected to dissolution activity that has caused the confining beds to be extremely fractured and altered.

Hydraulic properties of the Culebra Dolomite Member determined by testing vary considerably from place to place and appear to be related to the size and number of fractures and openings. As previously mentioned, these fractures and openings may be related to the degree of evaporite dissolution occurring either in the Rustler or the upper part of the underlying Salado Formation. The potentiometric surface map, representing equivalent freshwater heads, is shown in Figure 38. This potentiometric surface map was constructed from actual measured Culebra hydrostatic pressures collected during the Pressure-Density Survey Program (Crawley, 1988).

As discussed previously, freshwater heads for units other than the Culebra have been calculated for observation wells at the WIPP site using measured water levels and estimated well-bore fluid densities. The freshwater heads determined for the Culebra are derived from actual measured formation fluid pressures and are given in Table 3-7.

The contours on Figure 38 indicate that there is considerable variability in gradient and flow direction within the WIPP site area. This variability may be the result of lateral variations in Culebra permeability and differences in fracture orientation as discussed in Mercer (1983). The hydraulic gradient in the immediate WIPP site vicinity is approximately 20 feet per mile while the gradient south and southwest of the site is much flatter. The gradient between wells H-07b and H-09b is less than five feet per mile, while the gradient from H-07b to H-08b is less than one foot per mile (Crawley, 1988).

Mercer (1983) reports a potentiometric high associated with the area near test hole H-05b, which he attributed to the effects of the conversion of brine density to freshwater head. The results of the equivalent freshwater head analysis in the more recent investigations also indicate that the area of the H-05 well site is a potentiometric high for the Culebra hydrologic unit and it extends to and includes the areas associated with wells DOE-2 and WIPP-13. The potentiometric surface south of the WIPP site has a very flat gradient with the contours indicating an apparent potentiometric low in the region surrounding the H-09 well site. Examination of the contours in the southern study area (between wells H-07, H-08, and H-09) indicates that there may be a local divide or a change in the general ground-water flow direction. This represents a change from the basic south-southwest flow direction to a somewhat more southeasterly direction. This change in flow direction may be the result of local directional differences in hydraulic conductivity or perhaps some localized recharge to the Culebra Dolomite Member near the eastern side of Nash Draw, in the vicinity of the H-07 well site. The broad area south of WIPP, where gradients appear to be extremely flat, may represent the transition from an area of fractured dolomite to that of a fractured and disrupted unit created by the extensive dissolution in the Nash Draw area.

The hydraulic properties of the Culebra Dolomite Member, as determined by testing in cased and open holes, vary considerably depending on its structural character (Table 8). Mercer (1983) and Mercer and Orr (1979) provide detailed test results and analyses for a number of wells completed in the Culebra and other water-bearing zones prior to 1983. Beauheim (1987) presents hydraulic test analyses for both single well and multi-well tests at the DOE-2 and H-03 hydropads, and for single-well tests at DOE-1, H-04, H-08, H-14, H-15, WIPP-18, WIPP-19, WIPP-21, WIPP-22, ERDA-9, P-17, Cabin Baby, and Engle. Additional hydraulic testing has been completed at H-02, H-05, H-06, H-07, H-09, H-11, H-12, and WIPP-13. Testing has shown that the Culebra is a fractured, heterogeneous system with varying local anisotropy.

Transmissivities calculated for the Culebra Dolomite Member in Nash Draw range from 18 square feet per day to 1,250 square feet per day (Mercer, 1983). Laboratory tests of two samples of the Culebra taken from the Project GNOME Shaft indicate total porosites of 13.7 percent and 14.4 percent, and effective porosities of 7.8 percent and 11.1 percent. Transmissivities calculated for the Culebra Dolomite for wells within the WIPP Site Boundary range from 7×10^{-2} to approximately 69 square feet per day. Tests in three three-well arrays indicate the heterogeneous nature of the Culebra Dolomite Member. It was found that the ratio of major to minor transmissivity components ranges from 2.1 to 2.7.

Tracer tests have been conducted at hydropads H-02, H-03, H-04, H-06, and H-11. The types of tracer tests conducted include: convergent-flow, with pumping of one well and addition of tracer(s) to one or more wells at the same hydropad; and injection-withdrawal, where one well is pumped and the water injected with the tracer(s) into a second well. The tracers used for these tests were organics and were assumed to be conservative (i.e., were not sorbed by the rock framework).

The tracer test conducted at the H-02 hydropad has been analyzed using a porous-medium conceptualization where the model predictions generally are in poor agreement with field measurements. A tracer test analyzed at the H-03 hydropad utilized a double-porosity conceptualization and assumed longitudinal dispersivities from 5 to 10 percent of the flow path, a fracture porosity of 1.9×10^{-3}, and effective matrix block sizes of 0.25 to 2.1 meters. Analysis of the H-04 tracer tests did not provide reliable quantitative estimates of physical solute-transport parameters for the Culebra. The analysis of the H-11 tracer test has not been completed at this time.

From the observations and measurements in the Ventilation Shaft (later reamed out and now called the Waste Handling Shaft) it was determined that most of the observed inflow of about 0.5 to 0.6 gallons per minute (gpm) to the shaft was from the Culebra. The analyzed drawn down of the fluid levels in the

Rustler water-bearing zones resulting from shaft construction corresponded well with the measurements in observation wells H-01, H-02, and H-03. A long-term effect of less than ten feet of drawdown at a distance of about 4,200 feet from the shaft was observed.

Transmissivity values calculated from tests in two test holes in the WIPP site area are much larger than the average; these test holes are H-06b, with a transmissivity of 73 square feet per day; and P-14, with a transmissivity of 140 square feet per day. Both of these test holes are on the western side of the WIPP site along Nash Draw. Geologic data from cores from these test holes indicate that the large transmissivity values may be related to localized dissolution in the Rustler Formation or upper part of the Salado Formation. Although not expressed topographically at the surface, an eastward subsurface extension of the geologic processes that formed Nash Draw may be the cause of the larger transmissivity (Mercer, 1983). Approximately eight feet of residuum was penetrated at the base of the Rustler in test hole P-14 and about two feet of residuum was penetrated in test hole H-06b. The transmissivity of the Rustler-Salado contact residuum in these test holes also is the largest in the WIPP site area. A similar occurrence was found south of the WIPP site in test hole H-08b where the transmissivity was calculated to be 16 square feet per day and in test hole H-09B where the value was 231 square feet per day. Because of these large values of transmissivity, it is possible, as in the case of test holes H-06b and P-14, that the geologic processes active in Nash Draw also may be occurring here.

When the distribution of halite beds in the Rustler Formation (Figure 37) is compared to the distribution of transmissivity across the WIPP site, it appears that absence of the halite in the lower part of the Rustler Formation may be related to the permeability changes in the Culebra Dolomite Member. As these halite beds below the Culebra are dissolved, subsidence occurs, creating fractures in the dolomite that open up and allow movement of water. No fractures were noted in the overlying anhydrite in cores from most of the WIPP site test holes; thus, the Culebra is assumed to be effectively isolated from overlying water-producing zones east of the site. However, west of the site, fracturing may create some interconnection. It is generally accepted that the extensive dissolution in the Rustler Formation in Nash Draw is responsible for the permeability increases in the Culebra in that area.

During construction of the four shafts (Waste Handling, Construction and Salt Handling, Air Intake, and Exhaust), a record of leakage or drainage and corresponding pressure changes has been compiled. Leakage and drainage into the shafts is reported only for the Culebra Dolomite Member. Attempts have been made to incorporate this information into a transient flow model for the WIPP site area and preliminary interpretations of this effort are provided in Haug et al. (1987), and more recently in La Venue et al. (1988).

The best estimate of undisturbed freshwater head (pre-shaft construction) has been calculated using most of the tested wells and those data are given in Table 9 (La Venue et al., 1988). This information was used to prepare the equivalent potentiometric surface map in Figure 39. Additional water level data for the Culebra Dolomite Member can be found in Winstanley and Carrasco (1986), Saulnier et al. (1987), Mercer (1983), and Crawley (1988).

Flow directions may be estimated from the contours on the map. However, the flow path of water moving in rock such as the Culebra Dolomite Member is affected by fractures, variable density, and heterogeneity; consequently, the regional direction of flow may have little or no relationship to the localized flow paths that may be visualized using Figure 39. In Nash Draw, the Culebra hydrologic unit is so extensively fractured that a local flow system may exist which has little relationship to the regional flow in the Culebra. Based on this premise and on inspection of the equivalent potentiometric surface map, the flow trend in Nash Draw generally is southward toward Malaga Bend. Local flow paths in the area of the WIPP site indicate flow to the west, southwest, and southeast. If steady-state flow conditions exist, the recharge area for the Culebra Dolomite Member appears to be to the north and northeast of Nash Draw.

The conclusions drawn from the most recent hydrogeologic studies of the Culebra Dolomite Member and all of the Rustler Formation indicate that steady-state flow conditions do not exist today (Lappin, 1988). Fluid flow and geochemistry within the Culebra Dolomite and shallower units are in continuing transient response to the marked decrease or cessation of local recharge at approximately the end of the last pluvial period. Both bulk chemistry and isotopic relations within Culebra fluids are inconsistent with modern flow directions if steady-state confined flow is assumed. Because of the relative head potentials within the Rustler Formation at and near the WIPP site, there must be a small amount of vertical fluid flow between its members, even though the permeabilities of Rustler members other than the Culebra Dolomite Member are quite low. Where measured successfully, the modern head potentials within the Rustler Formation prevent fluid flow from the surface downward into the Rustler carbonates (Beauheim, 1987). These modern day conditions do not proibit either the present movement of fluids from the underlying Salado Formation upwards into the Rustler Formation or the past downward movement of Dewey Lake waters into the Rustler Formation during or even after the cessation of local recharge at the end of the last pluvial period. They do, however, suggest that recharge from the surface to the Rustler Formation is not now occurring at the WIPP site. The results of the stable-isotope, radiocarbon, and uranium-disequilibrium studies also are consistent with the interpretation that there is no measurable modern recharge to the Culebra Dolomite Member from the surface at and near the WIPP site (Lambert and Harvey, 1987). The transient hydrologic response of the Rustler Formation to the end of the last pluvial period has involved at least some change in flow directions in the Culebra Dolomite Member. Although the modern flow is largely north-south, the results of uranium-disequilibrium studies suggest that flow was more easterly during a previous recharge period.

The dissolved mineral constituents in the water from the Culebra consist primarily of sulfate, chloride, calcium, magnesium, sodium, and potassium. The filterable residue dried at 105°C in waters associated with the Culebra Dolomite range in concentration from 3,100 milligrams per liter at well H-08b to 420,000 milligrams per liter at well P-18. The water is classified as being sightly saline to brine. A listing of undisturbed formation water densities has been compiled (Table 10) and contoured (Figure 40) (Crawley, 1988). A more detailed discussion of Culebra water chemistry is given in a following section of this report.

Use of water from the Culebra Dolomite is quite limited because of the variability of yields and the marginal water quality. Where the water quality is acceptable, water from the Culebra Dolomite Member is used for stock watering, but rarely for domestic purposes.

The mineralization of water in the Culebra increases from west to east across the WIPP site area. The sum of potassium and magnesium also increases. An arbitrarily chosen line of equal concentration representing 100 milliequivalents per liter of potassium plus magnesium approximates not only a dividing line between active and restricted circulation systems, but also approximately coincides with a line to the east of which halite is present in the Rustler Formation below the Culebra and to the west of which halite beds have been removed by dissolution (Mercer, 1983). As previously mentioned, the removal of these halite beds may have contributed to an increase in the transmissivity of the dolomite. Although not as obvious in the Culebra as at the Rustler-Salado contact residuum, this line divides the area into zones where transmissivities generally are greater than one square foot per day to the west and generally less than one square foot per day to the east. Even though this division is arbitrary, it does relate the water chemistry to the existing ground-water flow system (Mercer, 1983).

Based on water-quality data from the Culebra Dolomite Member and other units, hydraulic head differences, and analyses of cores taken from the hydrologic test holes in the WIPP site area, probably no effective vertical connection exists between the Culebra Dolomite Member and overlying hydrologic units. In test hole H-03 near the site center, the stabilized hydraulic head in the Culebra is 155 feet lower

than that in the overlying Magenta Dolomite Member. In the northwest part of the WIPP site at test hole H-06, the hydraulic heads in the Culebra and Magenta are nearly the same; however, differences in the sodium and chloride concentrations in the water from the two units at test holes H-06a and H-06b indicate that vertical flow probably is very small (Mercer, 1983). The dissolved-sodium concentration in water from the Culebra was 18,000 milligrams per liter compared to 1,100 milligrams per liter in the Magenta; the chloride concentration was 28,000 milligrams per liter in the Culebra and 1,200 milligrams per liter in the Magenta.

In test hole WIPP-25 in the northeast part of Nash Draw, the static-head difference between the Culebra and Magenta is four feet; the sodium concentration was 5,100 milligrams per liter in the Culebra and 3,100 milligrams per liter in the Magenta, whereas the chloride concentration was 8,300 milligrams per liter in the Culebra Dolomite Member and 5,600 milligrams per liter in the Magenta Dolomite Member These minimal hydraulic head differences and similar sodium and chloride concentrations, along with similar values of transmissivity (Culebra, 270 square feet per day, and Magenta, 375 square feet per day), suggest localized vertical interconnection in the north end of Nash Draw (Mercer, 1983).

From test hole WIPP-29 south to Malaga Bend, places probably exist where the Rustler-Salado contact residuum and Culebra Dolomite Member may be hydraulically interconnected; however, data are insufficient in this area to verify this possibility.

The Culebra was unsaturated in test hole ERDA-6 to the northeast of the site. Similar information has been reported for the area along Quahada Ridge west of Nash Draw. These data may identify permeability boundaries in the Culebra Dolomite Member to the west and northeast.

Hydrology of Magenta Dolomite Member of the Rustler Formation

The Magenta Dolomite Member of the Rustler Formation is a persistent and distinctive clastic carbonate bed with thin laminae of anhydrite. The Magenta ranges in thickness from 20 to 30 feet and is present throughout most of the study area. The Magenta is the uppermost water-producing horizon in the Rustler Formation. Stratigraphically, it occurs between the thick anhydrite confining beds of the Tamarisk and Forty-Niner Members (Figure 9). Water, when present, usually occurs in the thin silt beds or silty dolomite but also has been found along bedding planes between rock units and in fractures. The Magenta, where it has been tested, was always under confined conditions except where it was extensively fractured and altered. In test holes H-07a, WIPP-26, and WIPP-28, the dolomite was virtually unsaturated and was extensively fractured; the underlying anhydrite was fractured and in places altered to gypsum. The water formerly present in the Magenta in this area probably drained through the fractures into the underlying units.

The structure of the Magenta Dolomite Member, particularly in Nash Draw, is related to the presence or absence of evaporite dissolution. The Magenta in the northern and central parts of Nash Draw and along the eastern boundary is present in the subsurface as a relatively continuous bed. Along the western side of Nash Draw below Quahada Ridge, outcrops of the Magenta are present. To the east of Nash Draw, in the vicinity of and including the WIPP site, the Magenta Dolomite Member generally dips gently to the east. Although relatively continuous, outcrops show effects of weathering and are quite fractured, but are not saturated. A reasonable conclusion is that the dissolution responsible for the formation of Nash Draw fractured the Magenta and brecciated the underlying anhydrite, allowing water to drain into underlying units. In the vicinity of test hole WIPP-29 and south to Malaga Bend, most of the Magenta has been stripped away by erosion. There are isolated blocks scattered throughout this area; the Magenta is present along the sides of karst sinks and in other collapsed features as breccia. The breccia mounds

shown on Bachman's (1980) maps, particularly in T. 22 S., R. 29 E., sections 33 and 34, are excellent examples of this type of occurrence. These same features were described by Vine (1963) as domal structures.

An isolated occurrence of spring remnants was found along Livingston Ridge (Bachman, 1981). These spring deposits are represented by a northeast-trending alignment of gypsite mounds (east half of section 15, T. 22 S., R. 30 E.). The spring deposits are believed by Bachman to have resulted from the evaporation of sulfate-bearing water, discharging into Nash Draw, that had drained from the surface through fractures in the Rustler Formation east of Nash Draw, particularly in the vicinity of test hole WIPP-33.

Although some flow along Livingston Ridge may be in fractures in the Magenta, the core samples and hydraulic tests at the WIPP site indicate the flow in the Magenta Dolomite Member probably is more within the silt beds and the silty dolomite, with some minor flow along bedding planes. Fracture flow probably is more predominant in Nash Draw.

The potentiometric surface map (Figure 41), representing freshwater equivalent heads (Mercer, 1983), indicates a flow system with some variability in permeability across the WIPP site. The contours show the gradient across this area to be 16 to 20 feet per mile on the eastern side and steepening to about 32 feet per mile along the western side near the boundary of Nash Draw. This steepening of gradient may reflect the drainage of ground water from the Magenta into lower units through the fractures associated with Nash Draw dissolution activity or may only reflect a decrease in permeability. The gradient in Nash Draw of about 13 feet per mile indicates a more uniform permeability than at the WIPP site. The Magenta, as an identifiable continuous bed, is not present below the central part of Nash Draw because erosion has removed all strata down to the Tamarisk Member of the Rustler (Mercer, 1983).

Values of transmissivity for the Magenta Dolomite Member are included in Table 11. In Nash Draw, these values range from 53 square feet per day in test hole WIPP-27 to 375 square feet per day in test hole WIPP-25; the large values probably are the result of increased permeability in fractured rock (Mercer, 1983). The transmissivity calculated for test hole WIPP-25 is the largest value recorded in the region for the Magenta Dolomite Member; this test probably was affected by vertical leakage along fractures that connect with the underlying Culebra Dolomite Member. The Magenta is unsaturated in test hole WIPP-26 as a consequence of fracturing caused by dissolution in lower beds. These fractures drained water from the unit; however, core analyses have indicated that these fractures were later filled with gypsum. Evaluation of the core from test hole WIPP-28 indicated that bedding-plane partings and fractures were filled with gypsum, which has significantly decreased the permeability there. The Magenta also was unsaturated in test hole H-07a at the margin of Nash Draw south of the WIPP site. The ground water at test hole H-07a also probably drained from the Magenta into lower units, the subsequent alteration of the rocks considerably decreasing the vertical permeability. The core showed that this dolomite has been altered extensively to a partly cemented dolomite mud with the thin anhydrite beds that have been altered to gypsum. Like the other cores, secondary filling of gypsum sealed the fractures.

Hydraulic tests for the Magenta in the WIPP site area east of Nash Draw have been conducted in seven test holes; transmissivity values from these tests ranged from 4×10^{-3} square feet per day in test hole WIPP-30 to 3×10^{-1} square feet per day in test hole H-03a (Table 11). Hydraulic tests from the regional test holes south of the site showed that the transmissivity ranged from 6×10^{-3} square feet per day in test hole H-08a to 1.0 square foot per day in test hole H-09a (Table 11).

The contours on the potentiometric surface map for the Magenta Dolomite Member (Figure 41) indicate that water moves westward across the WIPP site towards Nash Draw, where it probably flows through fractures into lower units. In the northeast end of Nash Draw, the water flow generally is to the southwest, probably moving down through fractures into lower units in the central part of the draw.

The static heads and water-quality analyses indicate isolation of the Magenta hydrologic unit from other units in the area east of Nash Draw and east and south of test site H-06. The hydraulic head differences between the Magenta and Culebra in this area range from 115 feet at test site H-02 to 155 feet at test site H-03. In Nash Draw, static-head differences between the Magenta and the Culebra vary from eight feet in test hole WIPP-27 and four feet in test hole WIPP-25; a head difference of 72 feet in test hole WIPP-28 probably is anomalous for Nash Draw. It is expected that some hydraulic connection does exist between zones in all the other Nash Draw test holes. The water quality in the Culebra and Magenta hydrologic units in test holes WIPP-25 and WIPP-27 is very similar, indicating the possibility of hydraulic connection between these units.

If modern day recharge to the Magenta is occurring, it probably takes place outside of the WIPP area. The most likely area is to the north of the vicinity of Bear Grass Draw and possibly in Clayton Basin. An inspection of the contours on the potentiometric surface map indicates the possibility of recharge to the east of the WIPP site. This apparent recharge is believed to be the effect of either the corrections made for variable water quality (and its density effect on the static-head calculations) or the locally steep gradients that result from decreased permeability to the east.

Discharge of water from the Magenta Dolomite in Nash Draw probably takes place in one of two ways, either by moving into lower units such as the Culebra or into cavernous zones in the Forty-Niner Member, which has been altered by dissolution. The ultimate area of discharge is into the brecciated area in the Rustler Formation near Malaga Bend and then perhaps into the Pecos River.

The dissolved solids in water associated with the Magenta Dolomite Member of the Rustler Formation range in concentration from 5,460 milligrams per liter in test hole H-09a to 270,000 per liter in test hole H-10a. The water is classified as being saline to briny. As is characteristic of the other hydrologic units in the Rustler Formation, the dissolved-mineral constituents in the Magenta Dolomite Member consist largely of sulfates and chlorides of calcium, potassium, magnesium, and sodium; the major constituents by percentage are sodium and chloride (Randell et al., 1988). The water quality characteristics of the Magenta are discussed in more detail in the section on water quality.

The relationship between the magnesium and potassium concentrations and the hydraulic properties of the hydrologic unit of the Magenta Dolomite Member is not as well defined as in other units, but does exist. The mineralization of the water and the combined concentration of magnesium and potassium in the Magenta Dolomite Member increase from the northwest to the southeast. The unusually large degree of mineralization in the water at test hole WIPP-27 may be caused by a relatively well-developed hydraulic connection between the Magenta Dolomite Member and other rock units that contain highly mineralized water (Mercer, 1983).

2.1.8 Hydrology of the Dewey Lake Redbeds

The Dewey Lake Redbeds comprise the youngest rocks in the Ochoan sequence at the WIPP site and mark an abrupt change in the depositional environment. This change was from predominantly evaporitic deposits in the Rustler Formation to a deltaic sequence of alternating thin, even beds of siltstone and mudstone with lenticular interbeds of fine-grained sandstone. Nearly all the siltstone and mudstone are veined with selenite gypsum in the cores. The Dewey Lake dips gently eastward, increasing in thickness from 350 feet in test hole P-14 to 541 feet in test hole P-18 (Figure 10). The Dewey Lake Redbeds are separated from the overlying Triassic Santa Rosa Sandstone by an erosional unconformity east of test

hole ERDA-9; west to Livingston Ridge (along Nash Draw), the Dewey Lake is overlain by the Gatuna Formation and other Cenozoic deposits. The thickness of the formation decreases to the west where it was thinned by post-Permian erosion. The Dewey Lake in Nash Draw has been almost completely removed, and is present locally only in sinks and other collapse features. The Dewey Lake crops out in low bluffs along the north and east sides of Nash Draw. Because of its characteristically minimal permeability, it does not contain significant quantities of ground water.

Geohydrologic Characteristics

Drilling during area geohydrologic evaluation did not identify a continuous zone of saturation within the Dewey Lake Redbeds; however, localized permeable zones were detected. In the geologic test holes, the presence of these zones was indicated by minor losses of circulation during drilling. Detailed data collected during air-drilling of the hydrologic test holes (Mercer and Orr, 1979) identified minor zones of saturation, particularly in several of the thin lenticular sands in the upper part of the Dewey Lake at test holes H-01, H-02, and H-03. Geologic data from the wells at the WIPP site indicate the lenticular sands pinch out laterally. Where water is present, it probably is perched or semiperched and its occurrence is very localized, probably depending to a great extent on locally favorable conditions for recharge.

In most instances, the only indication of ground water was the presence of moist cuttings. In test hole H-02c, an attempt was made to test the moist sands present at a depth of 185 feet. After monitoring the zone for five hours, very little water had entered the hole and the test was stopped (Mercer and Orr, 1979).

Four intervals of Dewey Lake Redbeds were hydraulically tested in site foundation holes (holes B-8, B-38, B-52, and B-53) (Figure 42). The two intervals at B-52 and B-53, selected because fractures were observed in the core, indicated hydraulic conductives of 0.7 and 0.5 foot per day, respectively. All other foundation borings that encountered the formation indicated the Dewey Lake was unfractured. Testing in B-38 indicated a conductivity of less that 0.003 foot per day.

Although no saturated condition was encountered in the foundation exploration holes, ten observation wells were installed in these shallow holes. They provided a monitoring system to determine whether transient saturated zones might develop. Observation well B-54, the deepest of this group, is open to a zone of permeable but unsaturated material that was encountered in hole drilling in the Dewey Lake Redbeds.

The water levels in the observation wells were measured on a regular monthly basis during an approximate 18-month period. In all wells, the water levels were below the lowermost perforations in the monitor tubing, indicating that the water encountered was from well flushing after installation, as was confirmed by bailing observation wells B-4 and B-13. The apparent fluctuation of water levels is within the limits of precision of the measurement methods.

The Dewey Lake has not normally been found to yield water to wells; however, two wells used for domestic and stock purposes at the James Ranch, three to four miles south of the WIPP site, could possibly be completed in one of these lenticular sands. These wells in T. 23 S., R.31 E., sections 6 and 7, range in depth from 94 to 212 feet (Cooper and Glanzman, 1971). These wells have either saline water or small yields; geologic data indicate they are completed in the upper part of the Dewey Lake. Just east of this area there is an extensive, thick, active area of sand dunes, which could be a recharge area for these water-bearing units. A few other wells in the area, generally to the east and southeast, are known to produce water from the Dewey Lake.

Ground Water Movement

Recharge of sand units in the Dewey Lake could result from localized conditions, as in the James Ranch area, or could occur by downward percolation of water through fractures or along bedding planes in the

mudstone and siltstone. Discharge towards deeper zones through existing fractures or through dissolution of the gypsum veinlets is minor. The Dewey Lake is a protective cover that retards dissolution of evaporites in the Rustler Formation. Generally, in the WIPP-site area the Dewey Lake acts as an unsaturated confining layer. If the ground water penetrated to the top of the Rustler Formation in the WIPP site, then the upper anhydrite should be altered to gypsum. Cores and geophysical logs do not indicate that this alteration is present except where the Dewey Lake is thin or absent. Ground water movement within the Dewey Lake is restricted as evidenced by the perched character of the water in these lenticular sands.

Several private ranch wells believed to be completed in the Dewey Lake have been sampled as part of the Water Quality Sampling Program. The results of this sampling activity is given in the section on water quality.

2.1.9 Hydrology of the Dockum Group/Santa Rosa Sandstone

The Santa Rosa Sandstone (now referred to as the Dockum Group) is present only in the eastern one-half of the WIPP site and overlies the Dewey Lake Redbeds (Figure 10). The Santa Rosa Sandstone crops out at the north end and along the east side of Nash Draw. The Santa Rosa Sandstone consists of a fine- to coarse-grained sandstone with interbeds of siltstone and mudstone; it ranges in thickness from a featheredge west of test hole ERDA-9 to 176 feet in test hole H-10. To the west of test hole ERDA-9, the Santa Rosa has been removed by erosion. Throughout most of the area, the Santa Rosa is covered by surficial Cenozoic deposits; however, in test hole H-10, the sandstone is overlaid by 392 feet of unsaturated Triassic Dockum Group sediments.

Geohydrologic Characteristics

Although the Santa Rosa Sandstone is reported to be a principal aquifer in southwestern Lea County (Nicholson and Clebsch, 1961) water was present only in the lower part of the formation in test hole H-05 where about two feet of saturation was found. Air drilling was used to identify the presence of water. An attempt was made to test the zone, and the yield was estimated at about 0.1 gpm. The water was under water-table conditions and was present in a sandstone immediately overlying the Dewey Lake Redbeds. In test hole H-10, the Santa Rosa Sandstone was monitored during air-drilling and no indication of water was found. Several wells east of the WIPP site have been reported to obtain water from the Santa Rosa Sandstone, but yields are reported to be small. According to geophysical logs, a well in T. 22 S., R. 31 E., section 15, just west of test hole H-05, was completed in the lower part of the Santa Rosa Sandstone; however, well yields were reported to be very small.

Ground Water Movement

The Santa Rosa probably is recharged by precipitation in the area where it is overlain by permeable Cenozoic deposits, especially in the eastern part of the WIPP site. The water moves downward until it is impeded by the relatively impermeable Dewey Lake Redbeds and then probably moves down the structural dip to the east. Where the Santa Rosa Sandstone lies beneath the younger Dockum Group units, water that is found in the Santa Rosa Sandstone probably is under confined conditions. Small quantities of water probably discharge locally into the Dewey Lake through fractures and along bedding planes. Nicholson and Clebsch (1961) believe that, further to the east, ground-water movement in the Santa Rosa Sandstone is controlled by the collapse features of San Simon Swale, and that the pressure gradients are toward the swale.

Samples for chemical analysis have been collected from a few wells believed to be completed in the Santa Rosa Sandstone east of the WIPP site. The results of this sampling activity is given in the section on water quality.

2.1.10 Hydrology of Tertiary and Quaternary Rocks

Of the Tertiary and Quaternary rocks in the vicinity of the WIPP site, the Gatuna Formation of Pleistocene age and the playa deposits and alluvium of Holocene age are the only units that contain water. The volume of water in these sediments is quite small.

The Ogallala Formation of Miocene age is an aquifer north and east of the area; however, along the divide near the WIPP site, it occurs in isolated outliers no more than 60 feet thick. These outliers generally are unsaturated.

The Mescalero caliche of Holocene age is a well-lithified calcium carbonate and functions more as a barrier to downward movement of water than as a ground-water reservoir. The Mescalero caliche covers most of the WIPP site area although it is not present in Nash Draw.

Gatuna Formation

The Gatuna Formation is present as discontinuous bolson-type deposits. In the WIPP site area, the Gatuna Formation is represented by several tens of feet of poorly-sorted silt, clay, and sandstone that may grade downward into conglomeratic sandstone containing clasts of siltstone and sandstone (Jones, 1978). Of the post-Tertiary rocks in the study area, the Gatuna Formation is absent in some test holes and more than 100 feet thick in others (143 feet in test hole H-08, for example). Where it does occur at the WIPP site, it is generally no thicker than 46 feet. In most areas, the Gatuna Formation is overlain by the Mescalero caliche.

Because of its erratic distribution, there is no known continuous saturated zone within the Gatuna Formation. Although Cooper and Glanzman (1971) have reported that there were some limited occurrences of water in the Gatuna Formation in the Project Gnome area, no water was found during the drilling at the WIPP site. If water were present locally, it probably would be perched in sandstone lenses overlying the less permeable Dewey Lake Redbeds.

During building-foundation tests in the central part of the WIPP site, 30 exploration holes were drilled to test the hydraulic conductivity of the Gatuna Formation. Packer permeability tests in these holes were conducted using injected water; these tests indicated that the hydraulic conductivity generally ranged from less than 3×10^{-3} to 1.9 feet per day; one value of 5.1 feet per day was noted (Register, 1981). No indication of water was found in any of these holes, and no wells in the WIPP site region are known to be completed in the Gatuna Formation.

Water movement in the Gatuna Formation apparently is restricted by the discontinuous "perched" zones and the sporadic occurrence of the unit. Recharge to the Gatuna Formation probably is by local downward percolation of precipitation, especially in areas where rain water is ponded on the surface. This recharge probably is hindered by the caliche cover in the WIPP site area. Most water in the Gatuna Formation probably is transpired by phreatophytes, although some water may percolate downward into lower zones, particularly in the eastern part of the study area where the Gatuna overlies the Triassic Santa Rosa Sandstone.

Surficial Deposits and Alluvium

In the main part of the study area there are no through-flowing streams; the surficial deposits are composed of locally derived material deposited by sheet wash or by discontinuous arroyos. These surficial deposits are present almost everywhere in the region and usually are only a veneer over the underlying bedrock. Exceptions exist where deposits are concentrated in depressions created by dissolution of underlying rocks.

The only stream-deposited alluvium in areas near the WIPP site is along the Pecos River, mostly along the west side of the river north of Malaga Bend. This alluvium is composed of sand, gravel, silt, and clay and is as much as 200 feet thick. One of the most notable features of the alluvium is its large variation in thickness, which probably is caused by the alluvium filling the depressions created by dissolution of underlying rocks (Hale, Hughes, and Cox, 1954). South of Malaga Bend, the alluvium is present in isolated patches, which may be as much as 150 feet thick but generally average about 50 to 75 feet thick. The alluvium associated with the Pecos River, especially north of Malaga Bend, is a productive aquifer. Transmissivities in the alluvium vary considerably, but calculations made by Bjorklund and Motts (1959) average 13,600 square feet per day; the hydraulic conductivity probably averages 116 feet per day. The average hydraulic conductivity, however, could be misleading; lime-cemented conglomerates in the alluvium may greatly increase the value because of solution channels. Detailed data for the alluvium can be found in studies by Hale, Hughes, and Cox (1954) and Bjorklund and Motts (1959). South of Malaga Bend, the alluvium is less extensive and more variable in thickness, so average hydraulic properties are more difficult to determine. Recharge to the alluvium is from several sources. Near Carlsbad, water moves from the Guadalupian reef complex to alluvium. In the south near Malaga Bend, adjacent Permian geologic units, such as the Rustler Formation, recharge the alluvium. Infiltration from precipitation and from streams, canals, and applied irrigation water are also sources of recharge to the alluvium. Water moving through the alluvium generally flows toward the Pecos River and then southwestward toward the Red Bluff Reservoir. Because the thick accumulations of alluvium have been derived, to a great extent, from evaporites and fine-grained clastic rocks, the permeability of the alluvium is probably minimal, resulting in fairly low flow velocities (Hale and Clebsch, 1958). However, localized zones of greater permeability may be present, especially where semiconsolidated alluvium is fractured. North of Malaga Bend, wells drilled into the alluvium vary in yield, but the yields are large enough to be used for irrigation. Generally, the chemical composition of the water in the alluvium near Malaga Bend is affected by brine inflow from the Permian rocks to the east, downward percolation of relatively fresh water from irrigation, and local dissolution of evaporites. This mixing has caused variability in the overall quality of the water, with dissolved constituents dominated by sodium and chloride. Hale, Hughes, and Cox (1954) reported that the chloride concentration in the water in the alluvium increases with depth and a saturated brine is present in the lower part of the fill. The overall ionic composition of the water is similar to the ground water from the other hydrologic units, predominantly consisting of chlorides and sulfates of calcium, magnesium, sodium, and potassium.

Playas within the study area are reported to contain alluvium and eolian sands that have been reworked by shallow lake waters (Vine, 1963). Playa deposits consist of silt, sand, and gypsum; the thickest deposits exceed 55 feet at Laguna Grande de la Sal (Robinson and Lang, 1938). The gypsum and other materials deposited in the other playas in Nash Draw are similar to those at Laguna Grande de la Sal, but the deposits are not as thick. The ground water in the playa deposits usually is localized and water movement is restricted. The water table in the area around the playas slopes inward toward the playas, indicating water in the fill is moving into the playa and been discharged by evaporation. The source of the water is partly from recharge from precipitation and partly from ground-water inflow from springs (Robinson and Lang, 1938). The playa deposits are known to contain water, but the water generally has such large salt concentrations that it is unusable. Robinson and Lang (1938) reported the water associated with the Laguna Grande de la Sal playa was under a slight artesian head.

Windblown sands are common throughout most of the area east of Nash Draw. The sands are only a few feet thick except where they have been concentrated by wind into dunes. The greatest concentration of dunes is located east of the James Ranch (located southeast of the WIPP site) where they may have a localized effect on the hydrology. Where present, water associated with the surficial deposits and windblown sand probably is perched or semiperched; consequently, the occurrence of water is spotty

and greatly dependent on local conditions. Recharge takes place in areas of surface ponding and moves downward through fractures and joints into permeable zones. In several trenches dug through sand dunes at the WIPP site, the sand was found to be unsaturated and no perched water was found. The high evapotranspiration rate in the area and the relatively impermeable underlying beds (caliche and siltstone) probably preclude large volumes of water moving downward. No wells in the WIPP site area are known to produce water from the surficial deposits or from the windblown sands; however, where these deposits are thickest, they may contain localized perched zones of ground water. The sand dunes east of James Ranch are very permeable; however, evapotranspiration probably removes most of the water.

The occurrence of water in the Tertiary and Quaternary rocks in the WIPP area generally is quite variable and is restricted to the area south of the WIPP site. The quality of ground water characteristically ranges from fresh to saline, although in isolated areas near playas it may be quite briny.

2.1.11 Ground Water Use

Ground water is used in the region for irrigation, municipal supplies, rural domestic supplies, livestock watering, a few industrial purposes, and for secondary oil recovery (usually referred to as "oil field flooding"). The Capitan aquifer, located north of the WIPP site, is the largest source, but supplies are also taken from the Dockum Group and the Rustler Formation. A recent study has been completed on the local water usage and the water balance for an area of approximately 2,000 mile^2 around the WIPP site (Figure 43). An extensive discussion of the modeling requirements for such a study is included in that report. Recent ground-water use data cited here are taken from a recently published report by the New Mexico State Engineer's office on water use in 1985 (Wilson, 1986).

Regional Ground Water Use

Demand for water throughout the region increased steadily since the 1950s and this trend had been expected to continue into the 1980s. Production from the Capitan aquifer alone increased from about 80,000 acre-feet in 1950 to about 700,000 acre-feet in 1970 (Hiss, 1975). The increase has been fairly linear over the 20-year period. Most of the increased demand has been for oil field flooding which began in the early 1950s. The largest amount of pumping for this purpose is in Ward and Winkler Counties, Texas, and is primarily extracted from the Capitan aquifer. The other major source is the San Andres Limestone. According to Hiss (1975), the cumulative total of water produced from these aquifers for the period 1920-1969, in thousands of acres feet, is as follows:

USE	EDDY COUNTY	LEA COUNTY	WEST TEXAS	TOTAL
Industrial	65.4	--	--	65.4
Irrigation	151.0	--	223.7	374.7
Municipal	162.0	--	--	162.0
Secondary Recovery	0.6	2.8	293.0	296.4
TOTAL	379.0	2.8	516.7	898.5

According to the New Mexico State Engineer's office, ground-water use in Eddy and Lea Counties declined between 1980 and 1985. High rainfall, low crop prices and the government Payment-in-Kind (PIK) program lowered ground-water use in 1985. The fall in oil and gas prices affected ground-water use in Eddy and Lea Counties because oil refineries and gas processing plants in the area have cut back on production activities or shut down operations completely. Table 12 illustrates the change in use of surface and ground water in the state between 1980 and 1985.

Table 13, modified from the State Engineer's Report (Wilson, 1986), lists water use, by user category, for Eddy and Lea Counties. Seventy-eight percent of the ground water withdrawn in Eddy County went for irrigation, while in Lea County, 67 percent of ground water used was for irrigation.

The occurrence of large quantities of potable ground water is restricted to west of the Pecos River, and most of it is extracted from the Capitan aquifer. Municipal water supplies for the communities of Carlsbad and White's City are obtained from wells completed in the Capitan aquifer. Water pumped from the Capitan aquifer is used to irrigate about 2,300 acres of farmland in the Pecos River valley, the immediate vicinity of Carlsbad.

In addition to the above uses, water pumped from the Capitan aquifer at Carlsbad is transported by pipeline to a potash refining plant about 18 miles east of Carlsbad. About 3,740 acre-feet of water per year was used to refine potash ore during the period of 1965-1969. Approximately 31,962 acre-feet of ground water was pumped in Eddy and Lea counties in 1985 to support industries extracting and processing minerals and fossil fuels. This includes any of the following activities: mine dewatering, oil and gas well drilling, secondary oil recovery, oil refineries and gas processing plants.

Local Ground Water Use East of the Pecos River

East of the Pecos River in southeastern New Mexico, small amounts of ground water are used for rural domestic supplies, watering livestock, gasoline plants, and gas stripping. The Artesia Group, the Dockum Group and the Rustler Formation are the principal hydrologic units pumped for these purposes. In the area of Nash Draw, relatively large quantities of ground water have been taken from the Rustler Formation for use in potash refining.

The future development of ground water at the WIPP site is limited by the paucity of good quality water and the low permeability of the formations present. As discussed previously, in the WIPP site vicinity, the geologic units above the Salado Formation are either unsaturated (Dewey Lake Formation) or contain very poor quality water (Rustler Formation). In the surrounding area, there are a few wells used for livestock watering purposes or for human consumption at ranches east and south of the WIPP site. These wells are shown in Figure 44. The majority of these wells have been sampled for water chemistry analysis by the WIPP Water Quality Sampling Program. The results of these analyses are discussed in the section on Water Quality.

2.1.12 Ground Water Quality

The water-bearing units at the WIPP site have been sampled for water quality since 1976. As part of the early hydrogeologic site-characterization studies, Mercer (1983) reported the results of ground-water sample analyses from the Rustler-Salado contact residuum, the Culebra Dolomite and the Magenta Dolomite of the Rustler Formation, the Upper Bell Canyon, and the Santa Rosa Sandstone.

Beginning in 1985, a formal ground-water quality sampling and monitoring program became operational. This program is called the Water Quality Sampling Program (Colton and Morse, 1985). In this program, a large number of monitoring wells have been sampled repeatedly and the samples analyzed for an extensive list of inorganic, organic and radiologic parameters. The program was enlarged in 1986 to include several area private wells.

The WIPP site monitoring wells now access water from the Culebra and Magenta Dolomite Members of the Rustler Formation. Earlier, one of these wells (DOE-2) was completed in the Hays Sandstone Member of the Bell Canyon Formation. The area private wells are completed in the Dewey Lake Redbeds, the Triassic Dockum Group (Santa Rosa Sandstone) and far to the south, in the Culebra Dolomite Member of the Rustler Formation.

Ground Water Quality of the Culebra Dolomite Member

The water quality of the Culebra Dolomite Member is highly variable, ranging from a calcium sulfate type water having less than 10,000 milligrams per liter total dissolved solids to a sodium chloride brine having over 230,000 milligrams per liter total dissolved solids (Figure 45). The chemical compositions of sampled Culebra ground water is given in Table 14. A complete listing of the analytical results of Culebra ground-water samples can be found in Randell, Crawley, and Lyon (1988), Uhland et al. (1987), and Uhland and Randell (1986).

Ground water chemical analyses of samples from the Culebra Dolomite were evaluated in order to establish if any apparent trends in water quality existed or if any chemical groupings could be defined within the study area. When attempting to classify or categorize ground-water analyses from numerous wells spread over a large area or an entire hydrologic basin, the use of plotting techniques, such as the trilinear diagram, is often very revealing. The use of the trilinear diagram to assess groups of water analyses may help to identify if a particular water or sample falls within a closely defined population, represents a simple mixture of waters for which other analyses are available, or whether ground-water quantity is affected by solution or precipitation of particular mineral species.

Ground-water anaylses from 26 individual wells completed in the Culebra Dolomite were evaluated based on their chemical composition. This evaluation indicated that four hydrochemical type areas can be defined. These type areas and their relationship to the WIPP site are shown in Figure 51. These type areas were defined based on their major solute distributions, total dissolved solids (TDS) content, potassium to sodium concentration ratios, and other solute relationships. Type Area 1 includes wells H-07b1, H-08b, H-09b, Engle Well, the Poker Trap Well, and the Mobley Ranch Well. The water from this zone is a relatively dilute $CaSO_4$ type with less than 5,000 milligrams per liter TDS. Type Area 2, containing a very saline NaCl brine, is found in the eastern portion of the study area and includes wells H-05b, H-11b3, H12, H-15, H-17 and DOE-1. This type area water contains between 120,000 and 230,000 milligrams per liter TDS. Type Area 3 represents water with a somewhat variable composition and TDS concentration. Area 3 includes wells P-14, H-14, H-06b, H-04b, P-17, H-3b3, H-18, WIPP-19, WIPP-13, WIPP-30, H-02a, WIPP-25, WIPP-26, and DOE-2. This area has ground water which has a TDS concentration ranging from 13,000 up to 85,000 milligrams per liter. Type Area 4 includes wells WIPP-27 and WIPP-29; both wells exhibit anomalous concentrations of several chemical parameters and appear to be contaminated by local potash refining operations. Each of these four type areas are discussed in more detail below.

- Type Area 1

  Type Area 1 is characterized by Culebra ground waters with a relatively low Total Dissolved Solids content when compared with the Culebra ground waters over the majority of the project area. TDS ranges from 2,200 milligrams per liter at the Poker Trap Well up to a high of 4,000 milligrams per liter at the Engle Well (Figure 45). Type Area 1 exhibits very low chloride concentrations (24 to 45 milligrams per liter) which are not typical or representative of Culebra ground water found across the WIPP site area. In general, the water of this type area is a $CaSO_4$ type, having sulfate concentrations ranging from 1,400 up to 2,000 milligrams per liter. Calcium concentrations range from 420 to 690 milligrams per liter and generally increase from west to east across Type Area 1. Sodium concentrations range from a low of 43 milligrams per liter at the Poker Trap Well to a high of 200 milligrams per liter at the Engle Well and at H-07b1.

Type Area 1 is located south and southwest of the WIPP site along the eastern edge of Nash Draw (Figure 51). The northern boundary is located between wells P-14 and H-7b1. The eastern boundary is

somewhat difficult to define and is represented by a northwest to southeast line from just west of the H-02 well pad to just east of the H-09 well pad. The western extent of Type Area 1 is undefined due to the unavailability of hydrogeologic and geochemical data from the southern part of Nash Draw. Generally, Type Area 1 is a north-south running, linear-shaped region, widening toward the south.

- Type Area 2

  Type Area 2 is characterized by Culebra ground waters having sodium and chloride as the dominant ions, and having very high TDS concentrations (Figure 45), ranging from 120,000 milligrams per liter at well H-11B3 to as high as 230,000 milligrams per liter at well H-15. Generally, TDS concentration increases toward well H-15, which is approximately centered within Type Area 2. Sodium concentrations are typically in excess of 80 percent of the total cation population as is chloride for the total anion population. Sulfate concentrations range from 6,500 milligrams per liter at well DOE-1 to a maximum of 8,200 milligrams per liter at well H-12. Calcium plus magnesium concentrations are fairly high, although comprising less than 20 percent of the cation population, and range from 2,450 milligrams per liter at well H-11b3 up to 4,000 milligrams per liter at well H-15. Sodium concentrations range from 44,000 milligrams per liter at well H-11b3 to a maximum of 79,000 milligrams per liter as determined at well H-15.

Type Area 2 comprises the eastern one-third of the WIPP site area, bounded on the west by a line running generally north to south between well pads H-05 and DOE-2 (on the north side), DOE-1 and H-03 (near the center), and H-17 and P-17 (on the southern edge). Type Area 2 appears to extend to the east, but this cannot be defined because very little reliable Culebra ground-water chemistry data are available for the area east of the WIPP site (Figure 51).

- Type Area 3

  Type Area 3 represents a large area which generally separates Type Areas 1 and 2, and extends to the north and west into Nash Draw (Figure 51). Many of the wells included in Type Area 3 actually have similar compositions to Type Area 2 ground water. However, even though many wells included in Type 3 are basically NaCl types of waters, they exhibit significantly lower TDS concentrations. It appears that much of the Type Area 3 Culebra ground water represents a distinct mixing of the more saline NaCl brine of Type Area 2 with the much fresher $CaSO_4$ water of Type Area 1. Type Area 3 water is variable in TDS concentration and in the overall percentages of the major cations and anions making up its composition.

TDS concentration ranges from a low of just 11,000 milligrams per liter at well H-02a up to a maximum of 85,000 milligrams per liter at well WIPP-19 as shown in Figure 45. Chloride concentrations range from 4,800 milligrams per liter at well H-02a, located just west of the WIPP site, to a maximum of 47,000 milligrams per liter at well P-17. Sulfate concentrations range from 1,600 milligrams per liter at well P-14 to 6,400 milligrams per liter at well H-04b. The concentrations of the divalent cations, calcium and magnesium range from 830 milligrams per liter at the H-02A well site to 4,330 milligrams per liter at well P-14. Sodium ranges from 2,600 milligrams per liter to 29,000 milligrams per liter at wells H-02a and P-17, respectively.

- Type Area 4

  Type Area 4 is located in the western half of Nash Draw (Figure 51). This area contains only two wells, WIPP-27 and WIPP-29. Culebra ground water in the areas of these wells has some characteristics which differ from the waters found in both Type Areas 2 and 3. The TDS concentrations are much greater than those found in Type Area 3 (135,000 milligrams per liter at well WIPP-27 and 290,000 milligrams per liter at well WIPP-29). The potassium/sodium ratios are considerably higher than for waters of either Type Area 2 or 3 (0.21 at WIPP-27 and 0.22 at WIPP-29). The higher potassium concentrations, and thus potassium/sodium ratios at both WIPP-27 and WIPP-29 and the anomolously high magnesium/calcium ratio at well WIPP-29, indicate that the Culebra ground water surrounding and probably between these wells has been contaminated by potash mining and refining operations in Nash Draw. The ground-water chemistry of the Culebra Dolomite Member in the western and northwestern sections of Nash Draw is not representative of the natural undisturbed conditions.

Ground water from the Culebra Dolomite Member is not used in the WIPP site area except in the far southwestern part of the area shown in Figure 44, near the wells H-08 and H-09. Near these wells private windmills use brackish Culebra ground water for livestock watering purposes. Generally the water quality in the Culebra deteriorates from west to east across the site, with increasing chloride and TDS concentrations.

The analyses for trace metals of Culebra ground-water samples showed some anomalous concentrations for several parameters (Randell et al., 1988). It is difficult to assess if the reported concentrations of such trace metals as lead (1.1 milligrams per liter at well P-17), antimony (1.5 milligrams per liter at P-17), cesium (5.0 milligrams per liter at well H-17), chromium (10 milligrams per liter at H-17), tin (0.60 milligrams per liter at well H-11b3) and antimony (0.9 milligrams per liter at H-11b3) for example, are actually natural-occurring concentrations of the trace metals. In general, it is believed that many of these reported trace metals are a product of the deterioration and corrosion of the steel well casings used in monitoring well construction. Because of the very high TDS concentrations in many of the WQSP wells at the WIPP site, reported concentrations for many trace elements may be much higher than actual concentrations due to analytical enhancement or interferences. Alternative methods are now being evaluated, as part of a WIPP water quality sampling verification program, to ascertain if current analytical methods are appropriate for ground waters (brines) of the type occurring in the WIPP site area.

With few exceptions, the results of analyses for organic compounds in Culebra ground waters have shown no detectable concentration in the majority of samples analyzed. From well to well and from sampling episode to episode, there have been a few exceptions. In the majority of cases where analysis have reported detectable concentrations of organics, previous analyses for the same well have failed to detect any of the compounds. The compounds usually detected are acetone and phthalates. These are frequently found as laboratory contaminants due to their abundance in the typical laboratory environment (i.e., solvents, adhesives, etc.).

Ground Water Quality of the Magenta Dolomite

The Magenta Dolomite Member of the Rustler Formation has not been sampled with the same density as that of the Culebra Dolomite Member, due to the fewer number of wells completed in the Magenta and the fact that much more emphasis has been placed on characterizing the Culebra ground water in past investigations. Ground-water quality data from four Magenta wells including H-03b1, H-04c, H-05c, and H-06c were evaluated in the same manner as previously described for the Culebra ground water.

In general, the chemistry of the Magenta grounds waters is variable (Table 14). Ground-water types range from a predominantly sodium-chloride type at well H-04c to a calcium-magnesium-sodium sulfate

type at well H-06c. Review of the Magenta Water quality data indicates that there is no clear trend or definitive groupings of water chemistry within the Magenta. Chloride is the dominant anion in samples from just south of the WIPP site at wells H-03b1 and H-04c where the chloride concentrations represent 68 and 61 percent of the anion populations, respectively. North of the WIPP site, sulfate becomes the dominant anion at wells H-05c and H-06c comprising 66 and 82 percent of the anion population, respectively.

The cations of these four samples are also variable. Sodium concentrations range from a high of 82 percent of the cations in well H-04c to a low of 42 percent of well H-06c. Calcium and magnesium (combined) range from 57 percent at well H-06c to as little as 18 percent at well H-04c. Generally, calcium and magnesium comprise a larger portion of the cation population moving from south to north across the central WIPP site area. This is the result of decreasing sodium and TDS concentrations toward the north, not an increase in the concentration of the divalent cations. The concentrations of the major cations and anions for the four Magenta wells are shown in Table 14.

Well H-04c appears to be anomolously high in TDS concentrations as shown in Table 14 (23,500 milligrams per liter), and in sodium (7,100 milligrams per liter). The TDS concentrations for the other three wells shown in Table 14 are in the range from 4,800 to 8,100 milligrams per liter and sodium concentrations from 650 to 1,500 milligrams per liter. Well H-04c may indicate a general overall increase in TDS concentrations toward the south and southwest, away from the WIPP site, and perhaps a change to a more predominantly sodium-chloride type water in the Magenta in that area.

The overall water quality of the Magenta in the WIPP site vicinity is better than that of the Culebra, because the TDS, chloride, sulfate, and sodium concentrations are all generally much lower. However, the water in the Magenta is considered brackish to slightly saline and is not used anywhere in the WIPP site area.

Ground Water Quality of Dockum Group and Dewey Lake Formation

The water quality sampling activities at the WIPP site have recently included the sampling of several private wells in the vicinity of the WIPP site (Figure 44). The formations sampled include the Dewey Lake Redbeds and the Triassic Dockum Group. As shown in Figure 44, these private wells are all south and east of the WIPP site. The general quality of the ground water produced from both the Dewey Lake Redbeds and the Dockum Group is fairly good and is suitable for use as livestock water and, in some cases, for human consumption.

The ground water chemistry of the Dewey Lake is basically a calcium-magnesium-sulfate type with a TDS concentrations ranging from 670 to 3,400 milligrams per liter. Chloride concentrations range from 50 to 470 milligrams per liter. Sulfate and bicarbonate concentrations range from 190 to 1,600 milligrams per liter and 79 to 270 milligrams per liter, respectively. Calcium plus magnesium concentrations range from 100 to 570 milligrams per liter and sodium ranged from 110 to 240 milligrams per liter. There is no general trend to the distribution of dissolved chemical species in the Dewey Lake Redbeds as the formation is not saturated over most of the area, and the Dewey Lake Redbeds wells sampled here represent isolated occurrences, each having a somewhat different chemical composition.

The analyses of the Dewey Lake Redbeds samples included trace metals and a number of organic parameters. The results of these minor component analyses (Randell, Crawley, and Lyon, 1988) indicate that none of the organic parameters analyzed for were present in samples from the Dewey Lake Redbeds. In some cases, inorganic trace metals such as copper, zinc, and lead were reported in the detectable range. It seems unlikely that natural ground water in this type of formation would have significant concentrations of trace metals. The source of the metals listed above is probably the well pumping assembly and metal pipe associated with the wells discharge and routing systems, which consisted of galvanized steel, copper, and/or lead piping.

The water quality of the Dockum Group (Santa Rosa Sandstone), as based on the analyses from two wells, is generally good. The TDS concentrations ranged from 340 to 780 milligrams per liter. The Dockum Group water is basically a sodium-bicarbonate to sodium-sulfate type water. Chloride concentrations ranged from only 24 to 45 milligrams per liter, and sulfate ranged from 40 to 330 milligrams per liter. The sum of the divalent cations calcium and magnesium are low ranging from 53 to 90 milligrams per liter. Sodium ranges from 45 to 190 milligrams per liter. The two wells reported to be completed in the Dockum Group are the Clifton well and the Commanche well, both located approximately ten or more mile east of the WIPP site. Trace metal analyses were conducted on the samples from these two wells and the only parameter reported in any significant concentration was zinc. The source of zinc in these samples is believed to be from the galvanized steel discharge pipe assembly present at the well sites. The analysis of these samples for several organic parameters showed no detectable concentrations.

2.2 SURFACE WATER HYDROLOGY

The WIPP site lies within the Los Medanos area in the drainage basin of the Pecos River (Figure 46). The following sections describe regional and local surface water hydrology.

2.2.1 Hydrologic Description

The headwaters of the Pecos River are located northeast of Santa Fe, New Mexico; from there, the river flows south through eastern New Mexico and western Texas until it discharges into the Rio Grande. The Pecos River has an overall length of approximately 500 miles, a maximum basin width of 130 miles, and a total discharge area of roughly 44,500 square miles. Of these, 25,500 square miles are classified as noncontributing (DOE, 1988, Revised 1990). Climatic characteristics of the basin vary from sub-humid in the mountains to semi-arid at the lower elevations.

The Pecos River is about 14 miles west of the WIPP site at its closest point (river mile 430 above the confluence with the Rio Grande), and has a drainage area of about 19,000 square miles. The slope of the Pecos riverbed in this area is approximately 4.0 feet per mile (U.S. Army, 1964).

East of the river, near the WIPP site no outstanding natural drainage features exist. A few small, unnamed drainage channels constitute all the tributaries joining the Pecos from the east within 50 miles north or south of the site. From the west, the principal tributaries joining the Pecos north of Carlsbad are Rio Penasco with a drainage area (D.A.) of 1,060 square miles at river mile 496 (rounded to the nearest mile), the Rocky Arroyo (64 square miles D.A.) at river mile 475, and the Dark Canyon (451 square miles D.A.) at river mile 459. Other smaller tributaries flowing from the west are the Little Walt Canyon, Willow Draw, Spencer Draw, and the North Seven, Middle Seven, and South Seven Rivers. Most of these tributaries originate in the Guadalupe Mountains (USACE, 1978). Downstream from Carlsbad, the Black River (436 square miles D.A.) joins the Pecos from the west at a point about 16 miles southwest of the site at river mile 438. The Delaware River (689 square miles D.A.) joins the Pecos River from the west at river mile 406 and a number of other small creeks and draws join at various points between Carlsbad and Malaga.

In the reach between Carlsbad and Malaga (where the river is closest to the WIPP site), the bed of the Pecos is made up of sand and gravel. The overbanks adjacent to the main channel consist of sandy soil dominated by mesquite and salt cedar. In general, the right (west) bank has a steeper slope than the left (east bank) and, at a few places, the banks are made up of bare rock. During major floods, river water spreads over a flood plain.

The Pecos River flow above Malaga (river mile 432) is regulated by storage in several dams, including Santa Rosa Lake (Los Esteros Dam, river mile 757), Lake Sumner (Alamogordo Dam, river mile 702), Lake McMillan (river mile 484), Lake Avalon (river mile 467) and several other smaller dams that divert water for irrigation and power production. In addition, the Brantley Dam (river mile 479) has been

completed and began impounding water during 1988. The dam at Lake McMillan will then be breached following the commencement of operations at Brantley Dam. The locations of dams on the Pecos River and its tributaries are shown in Figure 46.

Numerous stream-gaging stations are located on the Pecos River and several of its tributaries. These gaging stations are shown in Figure 46. Information pertaining to several gaging stations, including average, maximum, and minimum recorded discharges, is contained in Table 15.

The stream-gaging station at Malaga, New Mexico, on the Pecos River, is the nearest station to the WIPP site. The maximum and minimum recorded flows at this station during the period 1938 to 1985 were 120,000 cubic feet per second (August 23, 1966) and 3.7 cubic feet per second (October 20, 1976), respectively (USGS, 1986).

There are no major surface-water bodies located within ten miles of the WIPP site. Beyond ten miles, several water bodies lie to the north including Laguna Gatuna, Laguna Tonto, Laguna Plata, and Laguna Toston. These lakes are situated at or above elevation 3,460 feet (mean sea level (MSL)). As the floor elevation of the WIPP surface facilities is about 3,400 feet MSL, surface runoff from the WIPP site would not flow north toward any of these lakes.

About four miles west of the site, there is a topographical depression known as Nash Draw which contains an ephemeral drainage system. This drainage carries water only during very wet years and joins the Pecos River about a mile upstream from Malaga. At its nearest point to the WIPP site, Nash Draw is about five miles wide. The general bed elevation of Nash Draw in the vicinity of the site is 3,150 feet MSL, which is approximately 250 feet below the grade elevations of the WIPP surface facilities. Red Lake, located in Nash Draw about seven miles northwest of the site, is at 3,160 feet MSL.

Several brine lakes are located in southeastern Nash Draw. The largest of these, Laguna Grande de la Sal, is several square miles in area and is a downslope catchment basin for limited surface drainage and artesian saline water-bearing formations (Robinson and Lang, 1938). Emptying into its northern end is a large saline spring, Surprise Spring, and the much smaller, less saline Pupfish Spring. Only the northern third of the lake is perennial.

The amount of water in the southern portion of the lake depends strongly on the amount of precipitation (Hunter, 1985). The remaining brine lakes, including Laguna Tres, Laguna Quatro, Laguna Dos, Lindsey Lake, and Tamarisk Flat, lie northeast of Laguna Grande de la Sal. These lakes were formed between 1942 and 1979, apparently as a result of potash refining and oil brine disposal in Nash Draw. These water bodies are located at elevations of approximately 3,000 feet MSL.

Scattered throughout the area near the WIPP site are livestock-watering impoundments (tanks). These tanks are essentially bermed areas designed to capture and contain surface water runoff. Some of these include Hill Tank, Indian Tank, Red Tank, and Noye Tank.

There are no known domestic surface water users on the Pecos River downstream from Carlsbad. Most of the surface water is used for irrigation while less than one percent of the total water withdrawn is used for industrial purposes. The actual amount of water diverted by any user differs from year to year. Approximate quantities of surface water diverted from the Pecos River in the years 1978 to 1985 from the reach between Carlsbad and the New Mexico-Texas border are listed in Table 16.

Water quality in the Pecos River Basin near the WIPP site is strongly influenced by both human and natural factors. Human impacts on the Pecos River include irrigation water returned to the river and wastewater treatment plant discharges. In addition, waste water from the potash and oil industries has been discharged into surface sediments, spoil piles and ponds contaminating the shallow brackish

aquifers and recharging existing water bodies in Nash Draw. The land surface slope and shallow aquifer gradient around Nash Draw are toward the Pecos River (DOE, 1980). Natural effects on water quality are inflows of ground waters that have dissolved salts in the aquifers and water contact with the river banks and bottom causing dissolution of salts and other constituents.

The water quality of the Pecos River between Carlsbad and Red Bluff exhibits increasing concentrations of several dissolved constituents in a downstream direction. Selected water-quality parameter concentrations per station are presented in Table 17. Especially noteworthy are the increases in sodium and chloride concentrations. Theories explaining these increases include contributions from ground-water inputs, irrigation return water, and dissolution of ions from river sediments.

2.2.2 Local Precipitation Patterns

The WIPP site is located in the Chihuahuan Desert with an arid to semi-arid climate. Precipitation in this area varies between localities and years, but averages approximately 12 inches per year.

At the WIPP site, precipitation amounts have been recorded during the periods of May 1976 to February 1980, and June 1985 to February 1987. These data are noted in Table 18 which indicates that four complete years of precipitation data have been obtained at the site. 1977 appeared to be a slightly dry year (9.3 inches), 1979 was a "normal" year (11.8 inches), and 1978 and 1986, very wet years (19.4 and 23.0 inches, respectively).

The probable maximum precipitation (PMP) quantities during "all season" and "winter" for different durations within a ten square mile drainage area in the vicinity of the WIPP site are listed in Table 19. The corresponding intensities are shown in Figure 47. The PMP determinations have been used to design the drainage systems and roof loads for the surface facilities at the WIPP site (discussed in Sections 2.2.3 and 2.2.4, respectively).

2.2.3 Site Drainage Patterns

In the proximity of WIPP, subsurface geologic formations are covered with smoothly rounded hills of dune sand. Surface drainage patterns in the area are not well defined, and rain that collects in pools between the sand dunes is lost through infiltration into the sand and evapotranspiration. Vegetation generally consists of mesquite, shinnery oak, and other plants commonly found in the northern Chihuahuan Desert and southern Great Plains.

The general ground slope at the site is about 50 feet per mile downward from the east toward the west. The average ground slope from north to south is downward about 15 feet per mile. A topographic and surface-water divide (Antelope Ridge) exists about ten miles east of the site. The WIPP is not expected to alter appreciably the existing drainage pattern of the area around the site.

The local drainage pattern is such that normal surface runoff from contributing areas north, south, and west of the surface facilities drains westward into Nash Draw without affecting the site structures. However, surface runoff generated by intense precipitation over local catchments, especially immediately east of the surface facilities, could potentially pass through the site. Storm-water runoff from areas around the surface facilities, including that from the east, are diverted away from the facilities by a system of peripheral interceptor diversions. As shown in Figure 48, this site drainage system is designed so that storm runoff due to a PMP event on the contributing drainage areas does not flood the plant. In addition, the grade elevations of most roads, railroad tracks, and surface facilities are designed so that storm water will drain away under the most severe conditions. For example, the floors of the Waste Handling Building and other surface facilities are 0.5 foot above the grade elevation.

2.2.4 Evaporation

The maximum, average, and minimum mean monthly temperatures at Carlsbad (26 miles from the site) over a period of 30 years (1951 to 1980) are discussed in the section of the No Migration Exemption Petition on climate (4.1). Generally, June, July, and August are the warmest months (average temperature for this period is 81.2°F), and December and January are the coldest (average temperature for this period is 43.8°F). The record high temperature recorded at Carlsbad was 112°F (June, 1902) and the record low was -18°F (January, 1962). Wind speeds are usually moderate with the prevailing wind from the south. The maximum recorded wind at Roswell was a gust of 75 miles per hour. The average relative humidities at 5:30 a.m., 11:30 a.m., 5:30 p.m., and 11:30 p.m. at Roswell are 65, 36, 30, and 52 percent respectively.

The potential evaporation in the vicinity of the site is much greater than the average annual precipitation of about 12 inches. More than 90 percent of the mean annual precipitation at the site is estimated to be lost by evapotranspiration (Hunter, 1985). National Oceanographic and Atmospheric Administration (NOAA) records show the average annual Class A pan evaporation rate at Lake Avalon to be 116 inches, with an average of 76 inches lost between May and October. The annual shallow lake evaporation for southeastern New Mexico is estimated to be 80 inches. The maximum evaporation rate occurs typically in June while the minimum is typically in December or January.

In the site area, the natural soil material is comprised of loamy sand of depths of as much as 15 feet. A nearly continuous caliche soil horizon (the Mescalero caliche) that varies from zero up to ten feet in thickness underlies the surficial soil at the site from a depth of a few inches to over 15 feet. The Mescalero caliche horizon forms by the precipitation of calcium carbonate at the limits of soil-moisture penetration and forms an extremely impervious barrier. Thus, little, if any, soil moisture infiltrates beyond this horizon (Siemers et al., 1978). Preliminary investigations indicate that natural breaches of this horizon amount to only a very small percentage of the area underlain by it. Even under conditions of a rare, locally intense precipitation event which might cause deeper-than-average infiltration, the caliche horizon is an additional obstruction to infiltrating and recharging the underlying beds. Where the caliche horizon is close to the surface, a mat of plant roots forms on top of it. Almost all the infiltrating water that reaches this layer is retained above it and is typically lost by evapotranspiration.

The above discussion indicates that precipitation losses due to evaporation in the basin are high; therefore, the runoff coefficients are low. The mean annual runoff in the region is only 0.1 to 0.2 inch (Hunter, 1985).

2.2.5 Flooding

Flood History

Floods on the Pecos River can be generated by: (1) frontal storms which produce large runoff volumes and high flood peaks; (2) thunderstorms (convective storms) which produce small runoff volumes but very high peaks; and (3) snowmelt in the mountainous portion of the drainage area which produces large runoff volumes but relatively low peaks.

Between the confluence of the Rio Hondo with the Pecos River (river mile 566) and McMillan reservoir (river mile (484), the channel capacity of the Pecos River, without any overbank flooding, is about 8,500 cubic feet per second. In the reach between McMillan reservoir and the confluence of Dark Canyon near Carlsbad (river mile 459), the channel capacity is estimated to be 50,000 cubic feet per second. From

the confluence of Dark Canyon to Red Bluff reservoir (river mile 411), the channel capacity is approximately 20,000 cubic feet per second (U.S. Army District, 1964).

Large floods are reported to have occurred on the Pecos River in 1893, 1904, 1905, 1915, 1916, 1919, 1936, 1941, and 1966 (USGS, 1986). No data are available for the 1893 event. The earliest flood for which discharge information is available occurred on October 2, 1904, following the failure of Avalon Dam. This flood was caused by a storm that lasted five days and covered the upper catchments of the Pecos River, Rio Hondo, Rio Felix, and Rio Penasco. The runoff generated by that storm caused floods throughout the Pecos River basin, and during the flood, the peak flow at Avalon gaging station (river mile 466) probably exceeded 90,000 cubic feet per second. The corresponding river stage is not available. The river stage at Red bluff during this flood (river mile 411) is reported to have reached 28 feet (gage datum = 2,895.64 feet MSL). The corresponding discharge was 40,400 cubic feet per second.

Another major flood on the Pecos River is reported to have occurred on May 30, 1936, when the peak flow at Artesia (river mile 504) and Lake Arthur (river mile 522) was 51,500 cubic feet per second. The corresponding stage at Lake Arthur was 21.77 feet (gage datum = 3,327.07 feet). The area in the vicinity of Carlsbad was flooded again on May 22, 1941, when the peak flow at Dam Site 3 (river mile 474) reached 60,000 cubic feet per second with regulation by Alamogordo (Lake Sumner), McMillan, and Avalon reservoirs. This flood resulted from intense rainfall over the drainage area of the Pecos River upstream of Red Bluff reservoir. It produced a stage of 35.1 feet at Malaga.

The highest flood on record (through 1988) on the Pecos River occurred on August 23, 1966, when the discharge and stage at Malaga were 120,000 cubic feet per second and 42.1 feet, respectively, with regulation by the Alamogordo, McMillan, and Avalon reservoirs. Three cross sections of the Pecos River near Malaga are shown in Figure 50. The water-surface elevations of the historic flood of August 23, 1966, are marked on these cross sections, which were used by the USGS to estimate the peak flow of 120,000 cubic feet per second that passed down the Pecos River on August 23, 1966.

Probable Maximum Flood (PMF) Flow

The peak flow of the Pecos River during a PMF near the WIPP site was estimated using the conservative approach suggested in Appendix B of the NRC Regulatory Guide 1.59 (NRC, 1977). The WIPP site lies just west of the 103rd meridian. The regional isolines of PMF peaks shown on the maps of Appendix B of the NRC Regulatory Guide extend sightly west of the 103rd meridian; however, they are recommended to be used for areas east of the 103rd meridian. In view of the proximity of the WIPP site to the 103rd meridian, it is considered reasonable to use the extrapolated portions of these isolines. This gives a PMF peak flow for the Pecos River of 1,350,000 cubic feet per second near the WIPP site for a drainage area of 19,000 square miles.

In Table B-1 of Appendix B to Regulatory Guide 1.59, the estimated PMF flow of the Pecos River at the Los Esteros Dam (2,430 square miles D.A.) is shown as 352,000 cubic feet per second. The same table indicates the PMF flow at Alamogordo Dam (4,390 square miles D.A.) to be 277,000 cubic feet per second. Both values are less than 60 percent of the values estimated from the extrapolated portions of the isoline maps from Appendix B. It is, therefore, concluded that the 1,350,000 cubic feet per second value obtained from the extrapolated portion of the isoline maps for a drainage area of 19,000 square miles is conservatively large.

The rating curve of the Pecos River at USGS gaging station 084Q6500 near Malaga, New Mexico, is shown in Figure 49. Since this rating curve does not extend beyond a discharge of 25,000 cubic feet per second, its extrapolation to the PMF peak flow of 1,350,000 cubic feet per second is not appropriate. Therefore, the water-surface elevation corresponding to the PMF peak flow was estimated by the slope area method using representative cross sections of the Pecos River applicable to the reach near Malaga.

To compute the conveyances of the cross sections shown in Figure 50, the USGS divided each of these cross sections into four subsections. The values of Manning's n used for each subsection are shown in Table 20. Based on a comparison of the photographs of the Pecos riverbed with those available in the literature (Chow, 1959) for known values of n, the USGS values of Table 20 are considered reasonable.

The average water-surface slope of the Pecos River at Carlsbad during the flood of August 23, 1966, was 0.00095. The average water-surface slope, based on high-water marks near Malaga recorded by the USGS for the same flood, is 0.00123. The energy slopes used by the USGS for its estimates of the flood discharge of August 23, 1966, for two consecutive reaches of 752 feet and 645 feet with beginning and ending cross-sections shown in Figure 50, are 0.00113 and 0.00161 respectively. In view of these values, it is assumed that the average energy slope during the PMF on the Pecos River would be about 0.001, i.e., 5.28 feet per mile. For the three cross sections of the Pecos River near Malaga (Figure 50), weighted average values of Manning's n are computed using the equation:

$$n = \frac{AR^{2/3}}{\sum_{i=1}^{M} \frac{A_i R_i^{2/3}}{n_i}}$$

where:

- A = total cross sectional area, in square feet
- R = hydraulic radius of cross-section, in feet
- M = number of subsections in which a cross-section is divided,
- A_i = Area of the ith subsection square feet,
- n_i = Manning's roughness coefficient applicable to the ith subsection, and
- R_i = hydraulic radius of ith subsection, in feet.

Using the average of the weighted roughness coefficients computed previously (Table 20) and an average energy slope of 0.001, the water-surface elevation corresponding to the PMF peak flow of 1,350,000 cubic feet per second near the WIPP site is estimated to be 2,980 feet MSL, or 420 feet below the surface facility at WIPP.

2.2.6 Summary and Conclusions of Surface Water Hydrology

As noted earlier, the WIPP site is approximately 14 miles from the Pecos River. The general ground elevation in the vicinity of the surface facilities (approximately 3,400 feet MSL) is about 500 feet above the riverbed and over 400 feet above the flood plain. As discussed in previous sections, a probable maximum flood (PMF) or floods induced by potential dam failures on the Pecos River or its tributaries cannot raise the water level 500 feet to endanger the WIPP site. Therefore, as far as the potential for flooding from the Pecos River is concerned, the WIPP site is categorized as a "dry site."

In the past, the Pecos River has maintained a reasonably stable course in the vicinity of the WIPP site and does not exhibit any marked tendencies to shift several miles east or west. This stability is demonstrated by the narrow width of alluvial deposits along the river's flood plain as discussed in Section 1.2.10. Therefore, because the horizontal and vertical separations between the site and the river are both large, any change in the river course accompanied by bank erosion during unprecedented future floods could not affect facilities at the site.

The nearest watercourse to the WIPP site is Nash Draw, an irregular depression about four miles from the site. Its bed (approximately 3,150 feet MSL closest to the site) is about 250 feet below the site grade. In view of the large horizontal and vertical separation between Nash Draw and the WIPP site surface facilities, it is inconceivable that the PMF of Nash Draw could affect the WIPP surface facilities.

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APPENDIX D8

GENERAL GEOLOGY

FROM PREVIOUSLY PUBLISHED NO-MIGRATION VARIANCE PETITION,
ADDENDUM, SECTION 7.0, VOLUME VII

U.S. Department of Energy (DOE), 1990,
DOE/WIPP 89-003, Revision 1, Carlsbad, New Mexico

7.0 GENERAL GEOLOGY

EPA representatives have raised questions concerning the geology of the WIPP site. Topics discussed at the early-April EPA/DOE meeting include: WIPP shaft and drift mapping activities; Salado Formation geology; gravity-driven structures in the Castile; Salado Formation penetrations; and the expected impact of Marker Bed 138 upon repository performance. A summary of this section is provided in the following paragraphs.

Section 7.1 describes the mapping of all four shafts and a little more than half of the 6.2 miles of underground drifts at WIPP that have been done to characterize the geology of the facility host rock. In addition, 126 vertical (both up and down) core holes (Table 7.1-1) have been drilled and logged in the underground at WIPP to confirm the stratigraphic and structural continuity of the host rock away from the openings.

Section 7.2 provides a detailed description of the Salado Formation geology, including discussion of the stratigraphy within the formation. It explains that while there is considerable vertical variability in the Salado due to cyclical episodes of sedimentation and evaporation, the formation exhibits extreme lateral continuity across the entire Delaware Basin.

Section 7.3 provides a historical perspective on the understanding of the structurally deformed "disturbed zone" (DZ) which underlies the WIPP site in the Castile Formation. It concludes that of the five processes that may have caused the Castile disturbed zone, the leading hypothesis is gravity foundering due to the difference in density between halite and anhydrite. Finally, evidence indicates that pressurized brine and gas occurrences are confined to anhydrite layers within the Castile, and the time required for development of "disturbed zone" structures (700,000 years) is well beyond the period of regulatory concern.

Section 7.4 details the 36 boreholes which penetrate the Salado Formation within the 16 square-mile boundary of the WIPP site. Six of the wells penetrate through the Salado; two have been plugged and four are currently used for hydrologic testing and sampling. Thirty boreholes were completed near the top of the Salado for hydrologic exploration, stratigraphic characterization, geotechnical foundation analysis, or potash assessment. Twenty of these holes have been plugged and abandoned; the remaining ten are used for hydrological testing and sampling.

Marker Bed 138, a 0.2 meter thick Salado Formation anhydrite layer located approximately 11 meters above the facility horizon, is described in Section 7.5. Although fracturing occurs in the rock surrounding the opening, the enhanced porosity of this zone decreases with distance from the opening. It is not expected that Marker Bed 138 will provide a pathway for migration of brine or gas away from the facility; confirmation of the limited disturbance of the marker bed is provided by data from geomechanical instrumentation.

7.1 SHAFT AND DRIFT MAPPING

Extensive work has been done to characterize the stratigraphic section at the WIPP facility. The generalized stratigraphic column has been developed from information obtained from 126 core holes and the mapping of three shafts from ground level to the facility horizon. Mapping of the fourth shaft is underway. A total of 5 anhydrite layers, 12 clay layers, and 6 argillaceous units are present in the facility horizon (Figure 7.1-1).

Core Logging

A total of 126 vertical core holes have been drilled and logged in the underground drifts, in the test rooms, and the first storage panel, excluding those drilled as part of Sandia National Laboratories' in situ tests. Core holes were usually drilled in pairs, one hole drilled vertically into the roof and one drilled into

the floor. At each location, core was obtained to a nominal depth of 50 feet. Table 7.1-1 presents location and geologic data from the 126 core holes.

The objectives of the vertical core hole program are described in Supporting Document 3 of the "Results of Site Validation Experiments" (DOE, 1983a). The vertical core hole program was conducted to:

1. Confirm thickness, lateral extent, mineralogy and stratigraphic continuity of the host rock beyond the limits of excavation;

2. Confirm the continuity of structure and the absence of any unusual features within the immediate zone of influence of the excavations; and

3. Obtain stratigraphic information in order to determine extensometer depths.

The core holes were rotary drilled with compressed air or saturated brine to remove the cuttings. The core was logged underground as it was removed from the core barrel or soon after drilling was completed. The following items were recorded for each log:

1. Hole number and date drilled;

2. Location and collar elevation of drill hole and direction of drilling (up or down);

3. Diameter of hole;

4. Beginning and completion dates of drilling;

5. Type of drill and drilling method;

6. Who logged the hole and date logged;

7. Length and number of run;

8. Amount and percentage of recovery;

9. Lithologic description, colors noted by reference to the GSA color chart, seams and any other relevant information;

10. Graphic lithologic profile; and

11. Miscellaneous pertinent information related to core conditions and observations made during drilling.

Lithologic Drift and Shaft Mapping

Detailed geologic mapping of the shafts and the underground drifts and rooms have been completed and continues to be done as new openings are mined. The objectives of the geologic mapping are to:

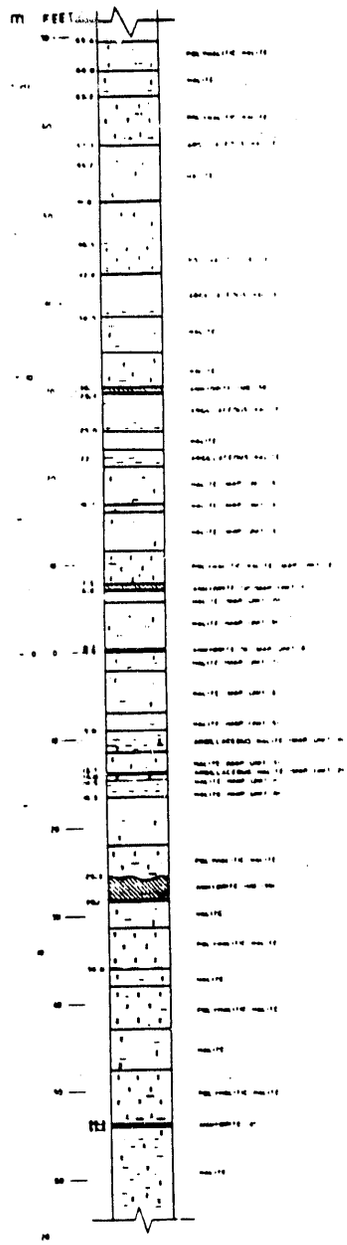
1. Confirm the lateral continuity of facility strata;

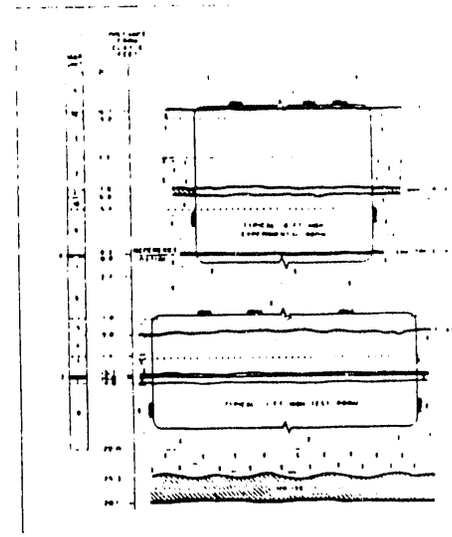
2. Confirm the absence of disqualifying fractures and faults;

3. Confirm the suitability of the facility horizon stratigraphy, lithology, and structure;

4. Evaluate interbeds which could have possible unacceptable influence on the horizon rock; and

5. Establish a baseline record of the geologic conditions.





EXPLANATION

ROCK TYPE

ACCESSORY CONSTITUENT

LITHOLOGIC CONTACTS

NOTES:

1. DISTANCES ARE MEASURED FROM THE BASE OF ANHYDRITE 'A' BED AT LEVEL OF AND ARE AVERAGED FROM REPRESENTATIVE CORE HOLE LOGS, SHAFT AND TEST ROOM MAPPING. ACTUAL DISTANCES AND UNIT THICKNESSES MAY VARY LOCALLY FROM THOSE SHOWN.

2. DESCRIPTIONS OF UNITS ARE BASED ON CORE HOLE DATA, SHAFT MAPPING, AND VISUAL INSPECTION OF EXPOSURES IN UNDERGROUND DRIFTS AND ROOMS.

3. PERCENTAGES OF ARGILLACEOUS MATERIAL AND POLYHALITE ARE BASED ON VISUAL ESTIMATES FROM EXAMINATION OF UNDIL CORE AND EXPOSURES IN THE UNDERGROUND EXCAVATIONS. GAMMA RAY LOGS (API UNITS) WERE MEASUREMENTS OF RADIOACTIVITY FROM SELECTED CORE HOLES USED AS A POINT OF REFERENCE.

FIGURE 7.1-1
GENERALIZED STRATIGRAPHIC COLUMN

3010011 89 04 06 81

TABLE 7.1-1

CORE HOLE DATA

CORE HOLE NO.	DIRECTION	COLLAR ELEVATION (FT-MSL)	APPROXIMATE STATION (FT)	FACILITY COORDINATES (FT)	DEPTH/ PENETRATION (FT)	INSTRUMENT DESIGNATION
MB-139-1	Down	1264.1	N79, W6	N9766, E6888	10.0	None
MB-139-2	Down	1251.2	S410, E150	N9277, E7044	15.7	None
MB-139-3	Down	1260.5	S101, E157	N9586, E7051	16.0	None
MB-139-4	Down	1258.7	S99, W17	N9588, E6877	16.2	None
DO-45	Up	1285.5	N254, E147	N9941.0, E7041.3	52.4	GE-230
DO-46	Down	1276.5	N254, E147	N9941.0, E7041.3	51.5	None
DO-52	Up	1280.4	N146, W4	N9832.5, E6890.5	51.6	GE-226
DO-53	Down	1266.6	N146, W4	N9832.5, E6890.5	49.2	None
DO-201	Up	1262.2	S406, W19	N9280.6, E6874.9	51.7	None
DO-202	Down	1248.6	S406, W19	N9280.6, E6874.9	51.4	None
DH-207	Up	1259.8	S697, E155	N8989.7, E7049.1	53.0	GE-246
DH-208	Down	1251.6	S698. E150	N8988.8, E7044.0	49.2	None
DH-211	Up	1270.5	S1320, E163	N8366.5, E7057.1	50.0	None
DH-212	Down	1261.7	S1320, E163	N8366.5, E7057.1	52.1	None
DH-215	Up	1272.0	S1960, E153	N7727.2, E7046.9	52.0	GE-247
DH-216	Down	1262.6	S1960, E153	N7727.2, E7046.9	54.2	GE-248
DH-219	Up	1266.3	S2422, E162	N7264.9, E7056.6	51.0	None
DH-219A	Up	1266.1	S2418, E162	N7268.5, E7056.2	11.3	None
DH-220	Down	1257.4	S2421, E162	N7265.5, E7055.9	51.8	None
DH-223	Up	1255.1	S3079, E154	N6007.2, E7048.5	52.6	GE-249
DH-224	Down	1246.6	S3079, E154	N6607.5, E7048.5	52.5	None
DH-227	Up	1247.0	S3656, E147	N6030.7, E7041.2	51.7	None
DH-228	Down	1237.8	S3656, E147	N6030.7, E7041.2	50.4	None
DO-56	UP	1296.8	N621, E0	N10311.8, E6892.3	52.1	GE-234
DO-57	Down	1288.1	N621, E0	N10311.8, E6892.4	52.1	None
DO-63	Up	1310.6	N1110, E0	N10796.0, E6891.9	52.8	GE-243
DO-64	Down	1301.5	N1110, E0	N10796.0, E6891.6	52.8	GE-221
DO-67	Down	1296.8	N1265, W231.5	N10952.1, E6662.9	51.7	GE-220
DO-69	Up	1310.1	N1265, W231.5	N10952, E6662.9	51.4	GE-218
DO-77	Down	1294.6	N1270, W364.5	N10962.5, E6529.6	53.4	GE-216
DO-79	Up	1307.7	N1270, W364.5	N10962.6, E6529.5	51.8	GE-214
DO-88	Up	1305.9	N1265, W497.5	N10952.8, E6396.5	52.7	GE-212
DO-90	Down	1292.1	N1265, W497.5	N10952.8, E6396.5	53.6	GE-210
DO-91	Down	1292.1	N1275, W630.5	N10961.5, E6263.9	51.8	GE 209
DO-93	Up	1304.9	N1275, W630.5	N10961.1, E6263.9	52.0	GE-207
DO-203	Up	1298.2	N624, E140	N10308.6, E7041.7	52.0	GE-235
DO-204	Down	1290.5	N640, E140	N10308.5, E7041.5	51.6	None
DO-205	Up	1316.5	N1410, E0	N11095, E6892	50.7	None

NOTE: For corresponding geologic drill logs of the above core holes, see TME 3177 (DOE, 1983a).

TABLE 7.1-1

CORE HOLE DATA
(CONTINUED)

CORE HOLE NO.	DIRECTION	COLLAR ELEVATION (FT-MSL)	APPROXIMATE STATION (FT)	FACILITY COORDINATES (FT)	DEPTH/ PENETRATION (FT)	INSTRUMENT DESIGNATION
DO-206	Down	1308.0	N1410, E0	N11095, E6892	50.6	None
DO-229	Up	1259.8	S401, E153	N9287, E7049	50.6	None

NOTE: For corresponding geologic drill logs of the above core holes, see WIPP-DOE-163 (DOE, 1983b).

DH-01	Up	1318.2	N1424, E439.5	N11110.9, E7335.5	50.8	None
DH-02*	Down	-	N1424, E440	N11110.9, E7336.06	50.2	None
DH-02A	Down	-	N1424, E435	-	49.2	None
DH-02B	Down	1206.3	N1424, E442	N11110.9, E7331.29	53.0	None
DH-03	Up	1318.1	N1112, E444	N10799.2, E7335.4	48.8	None
DH-03A	Up	1317.4	N1112, E450.5	N10779.2, E7341.92	49.9	None
DH-04	Down	1309.6	N1112.4, E444	N10799.2, E7335.4	45.8	None
DH-04A*	Down	-	N1113, E446	-	11.2	None
DH-04B	Down	1309.7	N1112, E450.5	N10799.70, E7341.85	51.4	None
DH-05	Up	1329.9	N1463, E972	N11149.6, E7865.0	51.0	None
DH-06	Down	1317.9	N1463, E972	N11149.7, E7864.9	49.75	None
DH-07	Up	1326.7	N1112, E976.5	N10799.3, E7870.8	49.8	None
DH-08	Down	1318.8	N1112, E976.5	N10799.4, E7870.9	38.3	None
DH-8A*	Down		N1112, E975	-	50.7	None
DH-08B	Down	1318.0	N1112, E979.5	N10799.47, E7866.66	51.4	None
DH-09	Up	1324.5	N1432, E1332.5	N11108.71, E8227.11	51.1	None
DH-10	Down	1312.1	N1432, E1332.5	N11108.70, E8227.09	52.0	None
DH-11	Up	1320.5	N1112, E1332.5	N10799.8, E8227.3	50.9	None
DH-12	Down	1311.1	N1112, E1332.5	N10799.4, E8227.2	51.3	None
DH-15	Up	1308.9	N1104, E1688.5	N10793.26, E8589.96	51.0	None
DH-16	Down	1300.3	N1104, E1688	N10792.89, E8589.39	51.0	None
DH-17	Up	1316.5	N1427, E178	N11114.2, E7071.8	52.0	None
DH-18	Down	1305.1	N1429, E181	N11114.2, E7071.8	50.8	None
DH-19	Up	1314.7	N1107, E206.5	N10794.2, E7101.7	51.6	None
DH-20	Down	1306.2	N1109, E206	N10794.2, E7101.7	51.1	None
DH-21	Up	1331.0	N1421, E786	N11109.1, E7680.9	50.4	None
DH-22	Down	1318.8	N1421.5, E785.5	N11109.2, E7680.9	51.0	None
DH-23	Up	1328.0	N1112, E781	N10799.2, E7679.9	51.0	None
DH-24	Down	1319.5	N1112, E781	N10799.2, E7679.8	49.4	None
DH-24A	Down	1319.5	N1112, E780	N10799.08, E7678.59	50.4	None
OH-9	Up	1310	N1433, W231.5	N11125.6, E6662.9	15.4	None
OH-11	Up	1308	N1433, W364.5	N11125.6, E6529.6	19.7	None
OH-13	Down	1298	N1433, W231.5	N11125.6, E6662.9	9.5	None
OH-14	Down	1296	N1433, W364.5	N11125.6, E6529.6	9.7	None

*Survey data are not available.

NOTE: For corresponding geologic drill logs of the above core holes, see WIPP-DOE-200 (DOE, 1984a).

TABLE 7.1-1

CORE HOLE DATA
(CONTINUED)

CORE HOLE NO.	DIRECTION	COLLAR ELEVATION (FT-MSL)	APPROXIMATE STATION (FT)	FACILITY COORDINATES (FT)	DEPTH/ PENETRATION (FT)	INSTRUMENT DESIGNATION
DH-13	Up	1311.4	N1424, E1690	N11112, E8585	13.8	None
DH-13A	Up	1311.5	N1424.5, E1691	N11112, E8586	49.0	None
DH-13B	Up	1311.4	N1425, E1695	N11112.6, E8590.1	21.0	None
DH-14	Down	1299.5	N1425, E1695	N11112.6, E8590.1	49.1	None
DH-25	Up	1318.8	N1422, E1510	N11109.7, E8403.8	51.8	None
DH-26	Down	1307.2	N1427, E1510	N11114.3, E8403.8	53.0	None

NOTE: For corresponding geologic drill logs of the above core holes, see WIPP-DOE-200 (DOE, 1984a).

DH-27	Up	1300.8	N1107, W682	N10793.7, E6218.4	50.5	None
DH-28	Down	1289.9	N1107, W682	N10793.8, E6218.3	50.5	None
DH-29	Up	1298.3	N1099, W982	N10785.4, E5932.4	50.4	None
DH-29A	Up	1298.1	N1099, W987	N10786.1, E5927.3	35.0	None
DH-30	Down	1289.2	N1099, W982	N10785.5, E5932.2	50.1	None
DH-31	Up	1298.5	N1099, W1282	N10784.9, E5632.3	50.5	None
DH-31A	Up	1298.5	N1099, W1280	N10784.8, E5630.5	49.2	None
DH-31B	Up	1298.5	N1099, W1261	N10786.7, E5652.2	4.9	None
DH-32	Down	1289.6	N1099, W1282	N10784.9, E5632.2	50.0	None
DH-32A	Down	1289.5	N1099, W1261	N10786.7, E5652.2	5.5	None
DH-33	Up	1298.6	N1099, W1582	N10786.0, E5331.1	50.5	None
DH-33A	Up	1297.4	N1099, W1570	N10786.8, E5342.0	4.1	None
DH-34	Down	1289.4	N1099, W1582	N10786.5, E5331.7	51.5	None
DH-34A	Down	1289.2	N1099, W1570	N10786.8, E5341.9	3.6	None
DH-301	Up	1276.9	N150, W170	N9830.5, E6724.5	50.75	None
DH-302	Down	1264.9	N150, W170	N9830.9, E6724.5	50.6	None
DH-303	Up	1267.2	S400, W170	N9282.3, E6726.1	51.4	None
DH-304	Down	1254.3	S400, W170	N9282.5, E6726.1	50.5	None
DH-306	Down	1244.1	S400, E140	N9287.3, E7049.9	52.0	None
DH-306A	Down	1244.0	S400, E125	N9287.9, E7034.6	8.5	None
DH-307	Up	1262.6	S400, E300	N9286.7, E7194.2	52.0	GE-263
DH-309	Up	1259.8	S700, E220	N8987.1, E7123.0	52.3	GE-265
DH-311	Up	1264.4	S1000, E300	N8686.3, E7194.9	52.0	GE-264
DH-313	Up	1270.6	S1300, E300	N8385.9, E7190.6	19.6	None
DH-313A	Up	1270.9	S1300, E299	N8386.6, E7189.5	50.2	None
DH-314	Down	1258.3	S1300, E300	N8386.5, E7189.5	50.75	None
DH-315	Up	1272.1	S1300, W170	N8387.3, E6725.5	50.3	None
DH-316	Down	1259.9	S1300, W170	N8387.2, E6725.3	50.1	None
DH-317	Up	1271.3	S1600, W33	N8077.4, E6875.9	50.1	None
DH-317A	Up	1271.2	S1600, W30	N8077.5, E6879.5	5.0	None
DH-317B	Up	1271.2	S1597, W30	N8080.3, E6881.6	51.0	None
DH-318	Down	1258.5	S1600, W30	N8077.3, E6876.1	50.0	None
DH-319	Up	1260.0	S700, E300	N8988.1, E7191.6	51.05	None
DH-321	Up	1261.4	S400, E0	N9792.0, E6891.8	52.0	GE-268

NOTE: For corresponding geologic drill logs of the above core holes, see WIPP-DOE-202 (DOE, 1984b).

TABLE 7.1-1

CORE HOLE DATA
(CONTINUED)

CORE HOLE NO.	DIRECTION	COLLAR ELEVATION (FT-MSL)	APPROXIMATE STATION (FT)	FACILITY COORDINATES (FT)	DEPTH/ PENETRATION (FT)	INSTRUMENT DESIGNATION
DH-35	Up	1292.4	N1102, W1882	N10789.4, E5032.2	52.0	None
DH-36	Down	1284.6	N1102, W1882	N17089.4, E5032.2	51.5	None
DH-37	Up	1297.4	N1101, W2182	N10788.9, E4732.0	51.5	None
DH-38	Down	1287.0	N1101, W2182	N10788.8, E4731.9	47.5	None
DH-39	Up	1296.0	N1101, W2482	N10789.2, E4430.2	50.7	None
DH-40	Down	1286.1	N1101, W2482	N10789.2, E4431.0	51.0	None
DH-41	Up	1295.8	N1101, W2782	N17089.0, E4132.6	49.9	None
DH-42	Down	1285.9	N1101, W2782	N10789.0, E4132.4	51.2	None
DH-42A	Down	1285.7	N1101, W2789	N10789.2, E4125.5	40.5	None
DH-323	Up	1261.2	S400, E55	N9291.7, E6952.5	52.5	GE-267

NOTE: For corresponding geologic drill logs of the above core holes, see WIPP-DOE-213 (DOE, 1985).

DHP-401	Up	1268.0	S1950, E1320	N8737.2, E8214.9	49.3	None
DHP-402A	Down	1255.8	S1950, E1320	N8737.2, E8214.9	49.9	None

NOTE: For corresponding geologic drill logs of the above core holes, see DOE/WIPP 87-017 (DOE, 1987).

Approximately 6.2 miles of drift have been excavated at the facility horizon. Of this total, 3.3 miles have been geologically mapped; however, the base of a marked bed, the orange marker band, has been either mapped or surveyed in all of the drifts to check the continuity of the lithology and the structure throughout the facility horizon. The attached table (Table 7.1-2) presents a list of the drifts and rooms which have been mapped to date.

Geologic mapping has been conducted in three of the shafts at WIPP. A fourth shaft, the Air Intake Shaft, is currently being mapped. A continuous lithologic record of the shafts has been compiled from the ground surface to the shaft sumps below the facility level.

Geologic shaft and drift mapping was performed in accordance with all applicable WIPP procedures and/or program plans. The area to be mapped was cleaned to remove dust or debris that interfered with visual observation of the rock surface. The walls were cleaned with brushes, water spray bottles, or other appropriate methods. A vertical and horizontal datum was established from a known survey benchmark. For drift mapping, an elevation datum was established on the wall and a grid was laid out at ten foot intervals. In the shafts, the elevation datum was established from the shaft collar and the horizontal datum was laid out as a 360° grid. The geologic features were mapped in detail and recorded on standardized, preprinted log sheets by sketching to scale all the visible traces formed by geologic features exposed at the excavation surface and by describing the lithology of the rock. Figure 7.1-2 shows a typical log sheet completed for geologic mapping of an underground drift.

7.2 GEOLOGY OF THE SALADO FORMATION

This section describes the geology of the Salado Formation around the WIPP site and in the adjacent region of the Delaware Basin. To provide adequate background for the reader, general information about the Salado and its importance are first considered. Some of the concerns and problems associated with the Salado are better understood if the stratigraphy and historical context of the Salado are presented. The Salado varies considerably vertically due to depositional cycles, while the setting of the formation in a very large, flat depositional basin resulted in great lateral continuity of individual beds. These cycles and the lateral continuity will be described in greater detail so the reader can appreciate both qualities of vertical variability and lateral continuity. The Salado is sometimes unconciously thought of as a giant bed of pure halite; this document should help the readers to understand that the Salado is much more heterogeneous, consisting of halite, sulfate minerals, potassium-rich beds, and mudstone to fine sandstone. These rocks vary vertically because they were deposited from an environment which varied through time. If we understand the lithologic changes that are due to deposition, we can then highlight the profound changes that have occurred in some areas due to dissolution of Salado rocks and collapse of overlying materials. More recent studies (Holt and Powers, 1988) have clarified the relationship between depositional and dissolution processes for the Rustler Formation, and, as a consequence, the effects of dissolution in general can be more properly considered. Basic information about the Salado will be presented here; dissolution has been considered in another section (Section 3.3).

This document summarizes information from a variety of sources. Primary sources of information and interpretation will be cited as appropriate. Recent analysis (Holt et al., 1989) in support of the Rustler geohydrology study is extensively used or modified in this document. Regional information comes mainly from Holt et al. (1989), Lowenstein (1982, 1988), and Jones et al. (1973). For the WIPP site, much of the information comes from shaft mapping (Holt and Powers, 1984, 1986) and underground mapping (see Sections 1.6 and 7.1).

Background Information

The Permian Salado Formation was deposited over a large area of the Permian Basin in New Mexico and west Texas (Figure 7.2-1). Lowenstein (1988) considers the Salado a saline giant because of its areal extent. Over much of the area, Salado strata are readily traceable. Marker beds, consisting of sulfate minerals (anhydrite, gypsum, and polyhalite), are continuous over large areas; the U.S. Geological Survey (Jones et al., 1960) numbered and described the more prominent of these marker beds. The Salado displays features that have been interpreted to have formed in shallow water in a desiccating basin (Gard, 1968; Jones, 1972; Lowenstein, 1982, 1988). The middle part of the Salado is well known as the major domestic source of potash for fertilizers in the U.S. Within the Delaware Basin, the Salado overlies the Permian Castile Formation (Figure 7.2-2), also an evaporite deposit, and underlies the Rustler Formation, a mixed clastic and evaporite unit (Holt and Powers, 1984, 1986, 1988) also assigned to the Permian System. The Permian age is based on fossils found within the Rustler Formation in Texas (Donegan and DeFord, 1950; Walter, 1953). Fossils have also been discovered from the basal Rustler at the WIPP site (Holt and Powers, 1984, 1986, 1988; Lowenstein, 1988), but they have not been studied. Radiometric ages of different minerals in the Salado are variable. Clays tend to be considerably older than Permian. Rb-Sr dates of clays usually range from 330 million years before present (m.y.b.p.) to more than 400 m.y.b.p. (Brookins and Lambert, 1987), probably because the clay minerals were at least partially inherited from older rocks. Potassium minerals, such as polyhalite, yield ages younger than Permian (about 210 m.y.b.p.) (Brookins et al., 1980; Register and Brookins, 1980).

The total Salado section in the eastern part of the Delaware Basin (Figure 7.2-1) consists of about 600 meters (2,000 feet) of evaporites. The dominant mineral is halite, estimated at 85-90 percent in the thickest areas (Jones et al., 1973), but marker beds are mainly sulfate minerals. The Salado is about the same thickness at the WIPP site in the northern Delaware Basin. The Salado can be considerably thinner (300 meters; 1,000 feet) northwest of the WIPP site, near the potash mines.

Over the western part of the Delaware Basin, however, the Salado consists of yellowish-brown, poorly consolidated argillaceous and silty sediment and blocks of gypsum that are commonly bright reddish-brown. The gypsum blocks are often attributed informally to incongruent solution of polyhalite beds, as most polyhalite beds are orange to reddish-brown from disseminated iron oxide. The blocks also are often considered to be from one or another of the major marker beds of the Salado. These outcrops are thin, and they have been studied little because they are usually considered a residue from nearly complete dissolution of the Salado.

Between these extremes, the Salado may vary due to deposition, dissolution (including synsedimentary dissolution), or some combination of the two. Holt and Powers (1988), following Bachman (1974), demonstrated that in the Nash Draw area dissolution removed as much as 55 meters (180 feet) of upper Salado, causing collapse upward that has affected the overlying units, including the Culebra Dolomite Member of the Rustler Formation. The hydrologic character of the Culebra has been altered by this process in the Nash Draw area (Holt et al., 1988, 1989; see Sections 3.0 and 4.0 for details).

From the general vicinity of the Pecos River eastward, the subsurface Salado thickens toward an area near the eastern margin of the Delaware Basin. Additional sulfate marker beds can be distinguished in the upper Salado in the eastern Delaware Basin. In this area, the depositional record is considered to be more nearly complete, and the depositional history has been inferred from these areas.

7.2.1 Salado Stratigraphy

As discussed below, the Salado has a quite different history as a named unit from the adjacent evaporite formations. The unit stratigraphy is based wholly upon subsurface information, as a rock dominated by

TABLE 7.1-2

DRIFT AND SHAFT MAPPING RECORD

DRIFT MAPPING

DRIFT	FROM	TO	DATES MAPPED
E0	N150	S50	11/17/82
W30	S150	S400	11/17/82
N140	E0	E140	11/18/82
W30	S50	S150	11/22/82
S90	E0	E140	11/22/82
E0	N150	N400	12/10/82-12/13/82
S400	W30	E140	12/10/82-12/13/82
E140	S400	S3664	12/14/82-02/11/83
E140	S380	N240	12/17/82-01/06/83
E0	N400	N1420	02/14/83-03/11/83
N1420	E140	W627	03/09/83-03/11/83
Room D	N1100	N1420	07/11/84-07/13/84
Room B	N1100	N1420	08/17/84-08/18/84
Room A2	N1100	N1420	11/25/84
Room A3	N1100	N1420	12/03/84-12/05/84
Room A1	N1100	N1420	12/19/84
Room H Access			01/09/85-01/10/85
Room H Pillar			03/20/85
Room H Rib			03/21/85
N1420	E154	E1702	12/10/84-12/19/84
N1100	W668	W2840	04/26/85-05/10/85
S1950	E530	E1335	08/13/86-11/04/86
E520	S1620	S1930	09/08/86-09/10/86
S1600	E310	E510	09/15/86
S1950	E310	E510	09/25/86
E660	S1620	S1930	03/10/87-03/11/87
E790	S1620	S1930	04/15/87-04/16/87
E920	S1620	S1930	05/23/88-05/24/88
E1050	S1620	S1930	05/25/88-05/26/88
E1190	S1620	S1930	06/13/88
E1320	S1620	S1930	06/13/88
S1600	E520	E1335	08/10/88-08/11/88

SHAFT MAPPING

SHAFT	DATES MAPPED
Salt Handling	3/82-5/82
Waste Handling	12/09/83-06/05/84
Exhaust	07/16/84-01/18/85

REFERENCES

DOE, 1983a
DOE, 1985
DOE, 1987
DOE, 1989d

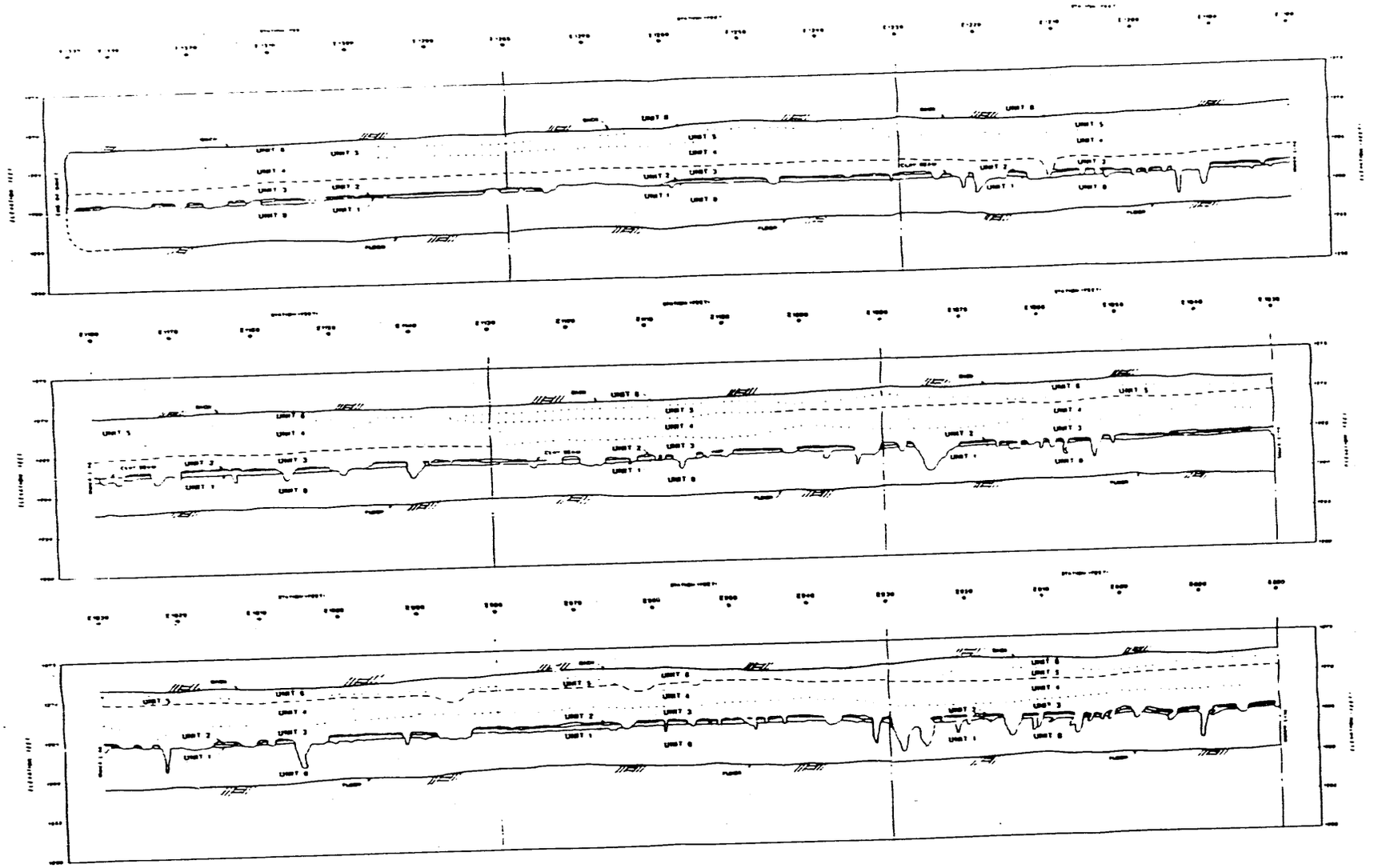


FIGURE 7.1-2 TYPICAL DRIFT GEOLOGIC MAP
S1950 DRIFT - VIEW SOUTH

301001 89 04 06 A47

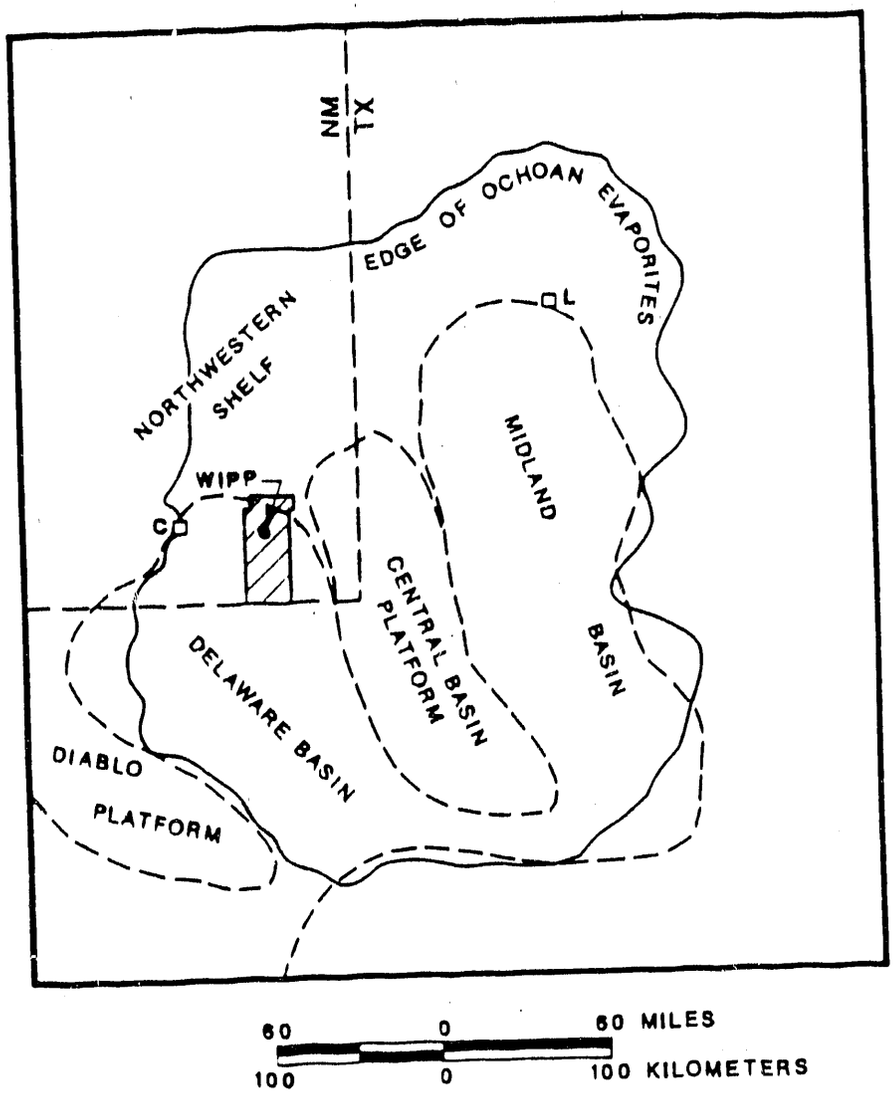


FIGURE 7.2-1 EXTENT OF OCHOAN EVAPORITES

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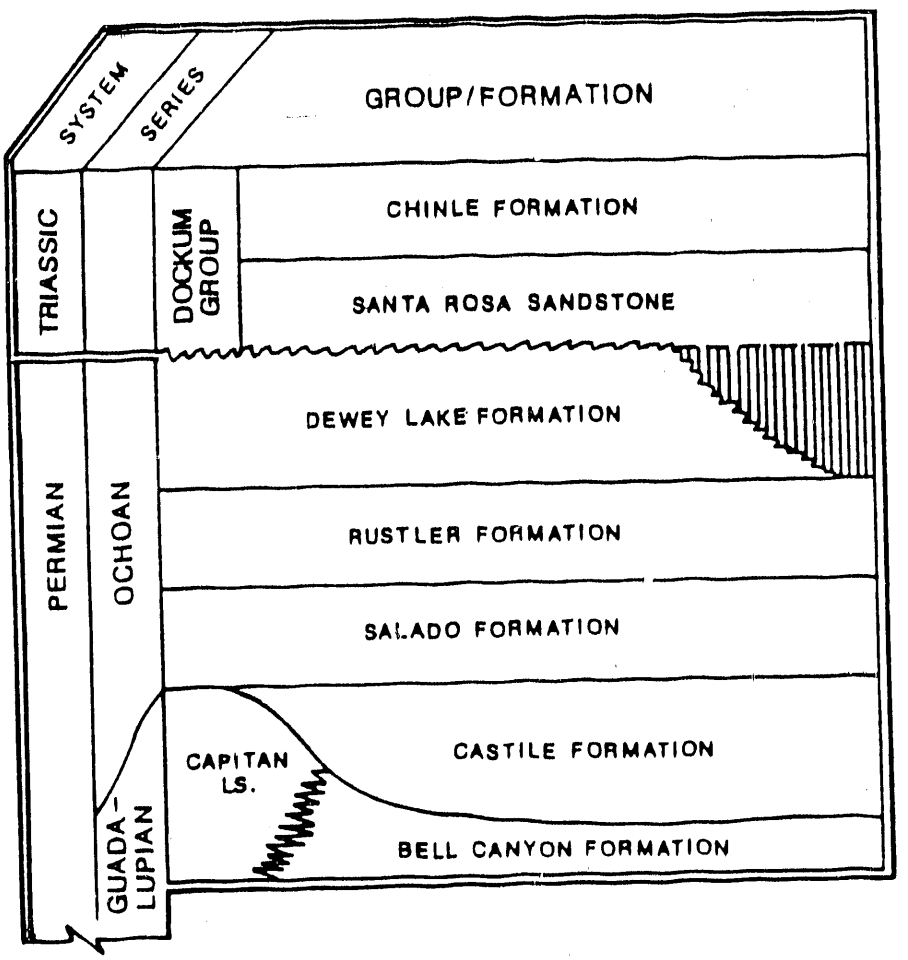


FIGURE 7.2-2 GENERAL STRATIGRAPHIC COLUMN NORTHERN DELAWARE BASIN

halite will not crop out well even in a semiarid region such as the Carlsbad area. Until drilling began in the Delaware Basin, the rocks which make up the Salado were not even known to exist. Surface terminology was applied first, and the Salado Formation later had to be stratigraphically differentiated from the Castile Formation. Virtually all subsequent stratigraphic and sedimentologic data are derived from the subsurface, either in mines or from cores and/or geophysical logs.

Several members or beds within the Salado have been formally or informally proposed and are used with varying frequency (Figure 7.2-3). Kroniein (1939) named the McNutt potash zone after the 76 meter (250 feet) thick interval with soluble potash salts first demonstrated in the Snowden-McSweeny V. N. McNutt No. 5 corehole. The Cowden Anhydrite Member was included in the lower Salado by Lang (1942); the Cowden was designated by Giesey and Fulk (1941) in a well in the North Cowden field in Ector County, Texas. In the northern Delaware Basin, a zone of halite below the Cowden has informally been called the Infra-Cowden. Within this salt unit, Lang (1942) designated the La Huerta Siltstone Member for a five-foot thick red silt that Lang felt is common over the Capitan reef area. In the northern Delaware Basin, a widespread unit was named the Vaca Triste Sandstone Member (Adams, 1944) for Vaca Triste Draw. The type section was designated between 474 and 477 meters (1,555 and 1,565 feet) depth in the Continental King no. 1 well (sec 26, T.25S., R.32E.) in Lea County, New Mexico. Adams (1944) reports 5 meters (15 feet) of anhydrite immediately underlying the Vaca Triste. However, interpretation of geophysical logs from that area suggest a prominent siltstone bed at about the same depth as the Vaca Triste, but there is no indication of an anhydrite or sulfate unit beneath it (Figure 7.2-4; Holt et al., 1989). The log signature provided here coincides with later placement of the Vaca Triste in other areas (e.g. Jones et al., 1960).

Jones et al. (1960) provide general geophysical log responses and a corresponding lithologic log for the Salado in the potash resource area in the northern Delaware Basin and on the northwestern shelf. Jones et al. (1960) clarified and established informal marker bed and ore zone terminology (Figure 7.2-3) that is used here and more generally as the standard. In addition, Jones et al. (1960) comment on the variability of marker bed thickness and lithology on the shelf north of the Capitan reef and in the northern Delaware Basin area.

7.2.2 Vertical Variability

The vertical succession of beds in the Salado Formation has struck many investigators as being cyclical. From the original drilling program for potash exploration, Schaller and Henderson (1932) described a vertical succession of clay - anhydrite - polyhalite - halite with minor polyhalite - halite. From further work by the U.S. Geological Survey, Jones (1954, 1972) and Jones and Madsen (1968) interpreted "cyclical sedimentation units" with a sequence of clay - magnesite - anhydrite, polyhalite or glauberite - halite - argillaceous halite followed at the top by mudstone interpreted as a solution residue on a corrosion surface. Unpublished studies (Powers et al., 1984) of the lithologic data contained in Jones (1978) indicated statistically significant relationships between certain lithologies, though the degree of ordering among the lithologies may still be very low (Powers, 1984).

More recently, Lowenstein (1988) interpreted two types of depositional cycles within the McNutt potash zone of the Salado (Figure 7.2-5). Lowenstein (1988) proposes that type I cycles originated from massive influx of marine water and that type II cycles recorded continental conditions of a salt pan - saline mudflat complex. Type I cycles consist of basal mudstone - sulfate (anhydrite or polyhalite) - halite - muddy halite, in succession. Various sedimentary structures and textures within these rocks suggest that the cycle I sediments were deposited subaqueously in a basin that was progressively shallowing due to evaporation. Muddy halite that caps an ideal type I cycle was deposited from a salt pan - mudflat basin. Type II cycles consist of repetitions of halite overlain by muddy halite, recording water level and

salinity changes due to meteoric influx during the desiccated salt pan - mudflat environment. There is no indication of significant subaqueous environments for type II cycles. Type II cycles are thicker in total than type I, indicating that the salt pan - saline mudflat environment dominated the McNutt potash zone. From the work of Jones et al. (1960) there may be as many as 46 type I cycles in the entire Salado, corresponding to named or numbered sulfate marker beds. The upper Salado, including the McNutt potash zone, contains many type II cycles, though the lower third of the Salado has few muddy halites (e.g. Powers et al., 1978) that would indicate type II cycles. Unpublished data (Powers et al., 1984) analyzing the core descriptions of the upper Salado in Jones (1978) show that the upper Salado averages at least 120 changes in lithology over an average thickness of about 200 meters (700 feet). The average lithology is about 1 meter (4 feet) thick through this interval. The Salado varies considerably in lithology through the formation. The lower Salado is less variable than the upper and middle parts of the Salado. The facility horizon is located in the upper part of the lower Salado, displaying a corresponding variability. Mapping within shafts and of cores taken from the underground (see Section 7.1) continues to verify the vertical sequence of lithologies within and around the facility horizon (e.g., Holt and Powers, 1984, 1986).

7.2.3 Lateral Continuity

The system of marker beds (MB) designated within the Salado (Jones et al., 1960) attests to the lateral continuity of units within the Salado Formation. The great lateral continuity may be even more impressive than the indications of cyclicity. The marker beds system is used throughout the basin without significant debate over identification of individual sulfate units. Closely spaced potash drillholes and geophysical logs through numerous boreholes for oil and gas exploration permit high confidence in the continuity of individual beds over hundreds to thousands of square miles. Holt et al. (1989) examined geophysical logs from 82 holes for hydrocarbon exploration within a single township (36 square miles) and found excellent correspondence of marker beds within closely spaced holes (as many as 17 in 1 square mile). These logs correlate well with examples provided in Jones et al. (1960) for the region.

Powers et al. (1988) and Holt et al. (1989) also examined geophysical log signatures of Salado lithologies other than sulfatic marker beds. The principal objectives were to establish the degree of continuity of other parts of the lithologic sequence and to examine the regional extent of some units for evidence of lateral lithology changes. Lateral changes in lithology due to lateral differences in paleoenvironments were not obvious from that study, though in one ore zone, Jones and Madsen (1968) identified lateral changes in clay content that should be considered a facies change. The geophysical log study does demonstrate the very considerable lateral continuity to some non-sulfate beds within the Salado. The Vaca Triste Sandstone Member has been identified for many years (Adams, 1944), and its lateral extent and continuity is further verified (Jones et al., 1960; Powers et al., 1988; Holt et al., 1989). The Vaca Triste is continuous over an area similar to that of the sulfatic marker beds. In addition, much thinner siliciclastic beds, dominated by clay minerals, are also traceable continuously over large areas within the basin (Powers et al., 1988; Holt et al., 1989). By inference, the halite and dominantly halite beds between these sulfatic and clay beds are laterally very continuous as well.

Mapping within the excavations for the WIPP (see Section 7.1) demonstrates the overall lateral continuity of mapping units. Clastic units, such as mapping unit 4, have been followed throughout the excavations (DOE, 1989d). Such units correspond to some of the clay-rich units that have been traced through miles on geophysical logs, as described above. As part of the depositional process, however, these beds can be disrupted very locally, down to hand specimen or even microscopic scale. Powers and Hassinger (1985) interpreted clear, channel-like pods of halite within argillaceous halite units (Figure 7.2-6) as the result of syndepositional dissolution of the halite, probably by an influx of less saline water. Hundreds of

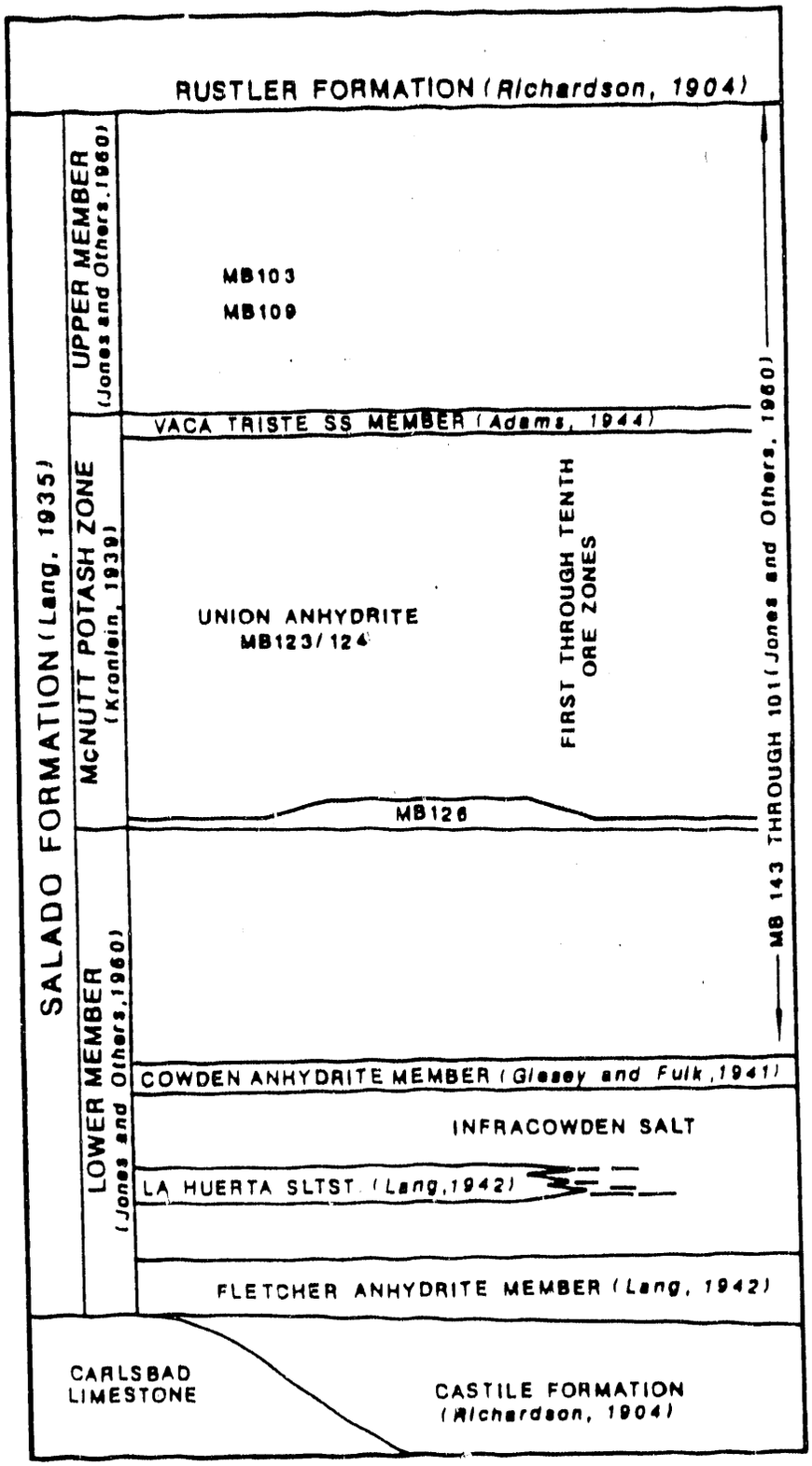


FIGURE 7.2-3 SALADO STRATIGRAPHY

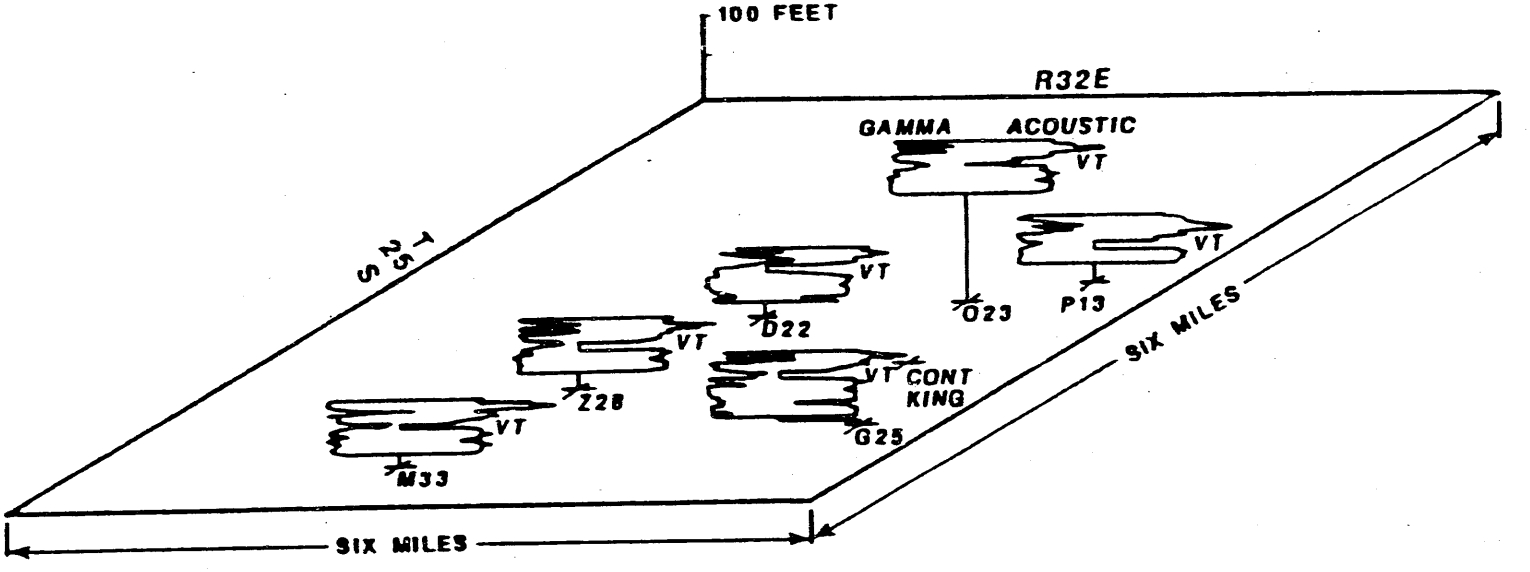
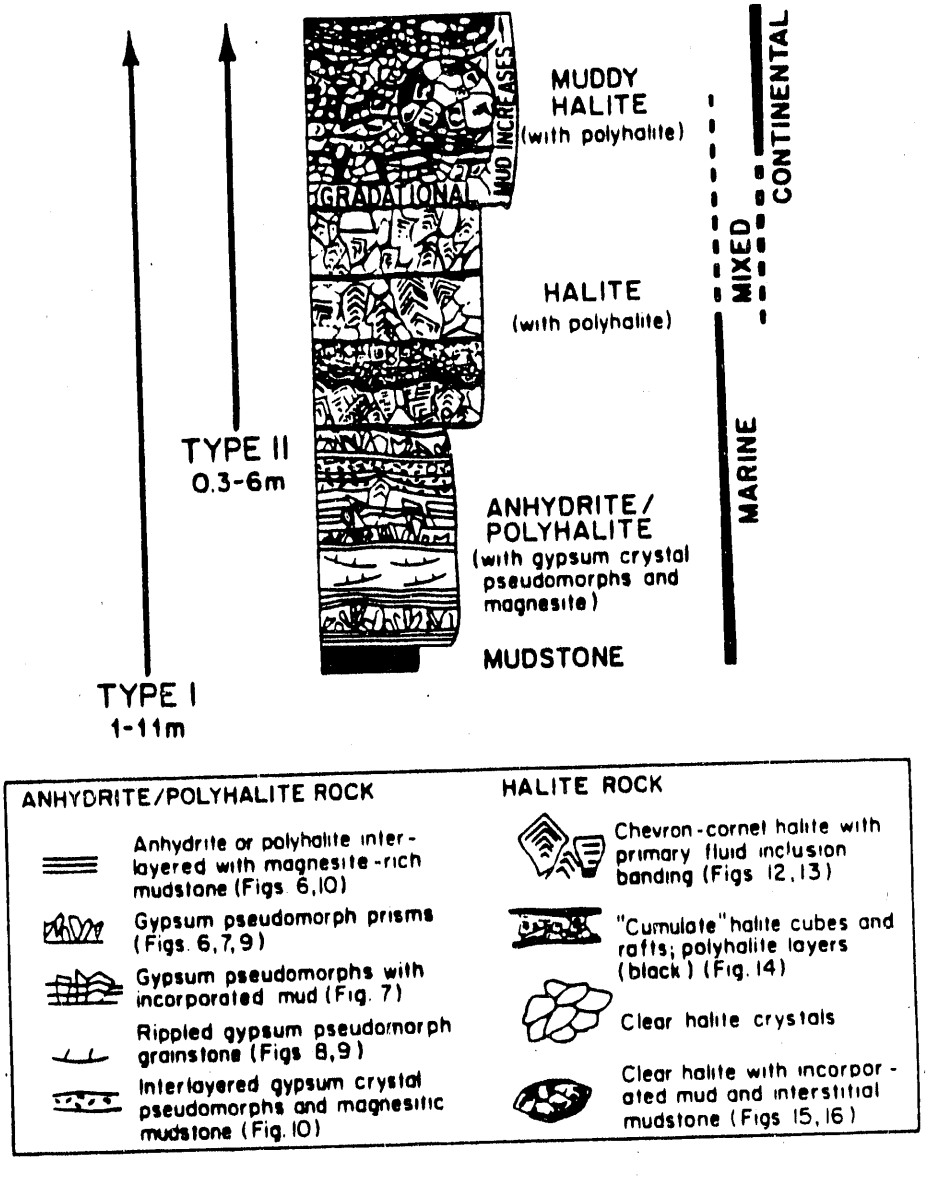


FIGURE 7.2-4 VACA TRISTE LOG SIGNATURES NEAR CONTINENTAL KING WELL, PADUCA FIELD
(SEE FIGURE 7.2-8 FOR LOCATIONS)

3011 9 04 06 A51



(Source: Lowenstein, 1988)

FIGURE 7.2-5 TYPES OF DEPOSITIONAL CYCLES WITHIN THE McNUTT POTASH ZONE

89 04 06 A52

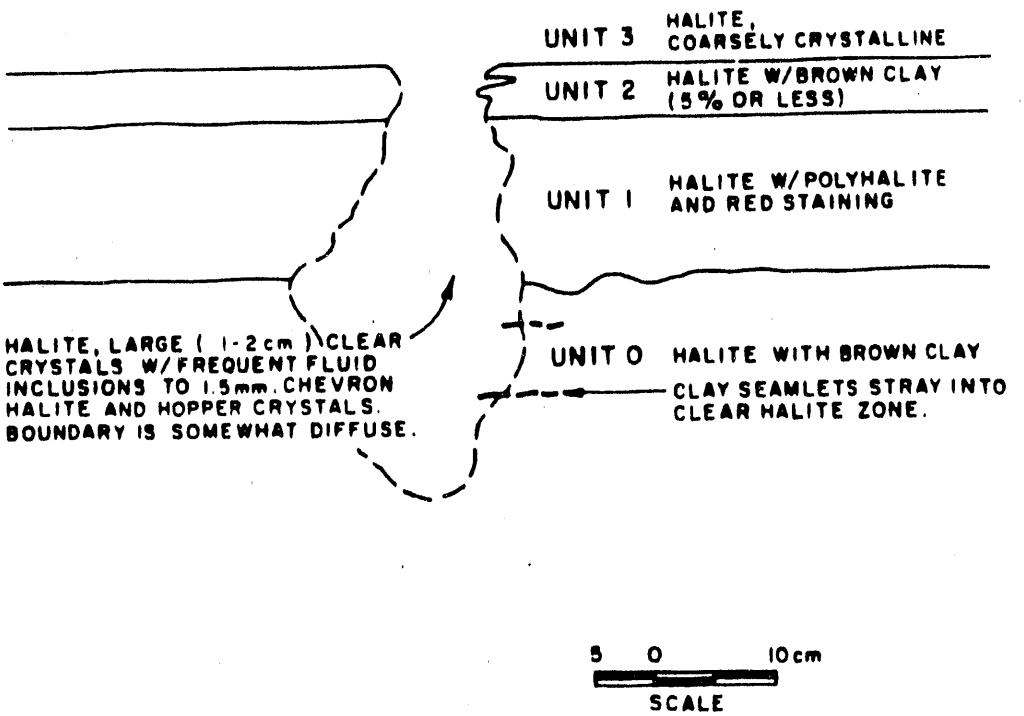


FIGURE 7.2-6 DIAGRAM OF SYNSEDIMENTARY DISSOLUTION OF SALADO AT WIPP REPOSITORY HORIZON (From Powers and Hassinger, 1985)

these features have now been mapped underground (Figure 7.2-7), and they illustrate how widespread the process was. Near the end of either type I or type II cycles (Lowenstein, 1988), fresher water can flow over a desiccated or nearly desiccated surface and can easily dissolve such pits. Hovorka (1987) reports similar microkarst features from the halitic units of the Palo Duro (Texas) Basin. At the scale of a hand specimen, argillaceous or muddy halite appears disrupted. The clastic sediment is not arranged in well-formed beds or laminae at that scale. The clastic-halite rock fabric has been disrupted by the repeated process of halite solution and recrystallization (haloturbation: Smith, 1971) at the surface (Holt and Powers, 1988).

In summary, beds display great lateral continuity within the evaporite sequence in the underground, in cores, and in the region. At hand specimen scale, however, the fabrics are disrupted by depositional processes which include syndepositional dissolution.

7.2.4 Regional Salado Geology

In the sections on vertical variability and lateral continuity, the background was established for examining some of the regional Salado geology. Because the depositional environment varied with time, the vertical sequence of lithology varies. The chemical constraints on evaporating brine resulted in broad repetition of lithologies, and the set of marker beds was formed. Marker beds have lateral continuity and can be used stratigraphically to correlate and establish zones of interest that are bounded. Holt et al. (1989) examined several intervals within the Salado in the northern Delaware Basin to establish thickness variations (isopachs) of the intervals and to compare these to changes in the orientation of these units or marker beds bounding them (structure contour maps). Related earlier work by Adams (1970), Anderson (1978b), Borns et al., (1983), and Borns and Shaffer (1985) and various site characterization reports (e.g., Powers et al., 1978) include similar isopach maps, but few are as comprehensive for the Salado and none are directed toward a particular problem that needs to be addressed - the possible effects of dissolution on the upper Salado Formation (see Section 3.0). A few maps have been modified from Holt et al. (1989) to illustrate the kinds of information developed and their utility.

Broad Patterns

A series of isopach maps are presented to illustrate the broader patterns of upper Salado thickness. A map showing the well control for these isopach maps is presented in Figure 7.2-8. An isopach map from the base of Marker Bed (MB)124 to the base of the Vaca Triste Sandstone Member shows the middle of the Salado quite well. An isopach map from the top of the Vaca Triste to the top of the Salado provides the broad patterns of thinning that are of interest for the Rustler geohydrology. The isopach map of the lower unit, in comparison, shows a larger region less affected by dissolution and indicates depositional variations in thickness as a pattern for the Salado. Maps of specific interbeds have also been constructed to provide additional detail in support of these broader patterns.

The isopach of MB124 to base of Vaca Triste (MB124-VT) (Figure 7.2-9) shows that the thickness of this interval in the site area ranges about 76-91 meters (250-300 feet) thick. This interval thickens generally to the southeast at a rate of about about 3 meters/10 kilometers (10 feet/township). In this part of the depocenter, in the area of T.24-26S., R.32-33E., the MB124-VT interval is generally over 90 meters (300 feet) thick. The northeast corner of the map area, over and behind the Capitan reef margin, is slightly thinner (<75 meters; <250 feet). Small areas in the southwest part of the map area, in the vicinity of Big Sinks and Phantom Banks, are significantly thinner than either the depocenter or site areas. This same area is more seriously disrupted in higher units, as described in following sections. Within the map area, the best defined and sharpest thinning of the MB124-VT interval occurs in the southwest corner of T.25S., R.32E., at the southwest end of the Paduca oil field. This thinning trend will be observed in stratigraphically higher intervals, and its trend and width will be much better defined.

The interval from the top of the Vaca Triste to the top of the Salado (VT-Sal) (Figure 7.2-10) indicates that, in the site vicinity, the VT-Sal ranges over about 135-160 meters (450-520 feet) thick. The interval may be starting to thin about 10 m/km (50 ft/miles) off the northwest corner of the site, but the data are relatively few. In general, the VT-Sal interval thickens to the southeast of the site toward a probable depocenter in the area of T.24-26S., R.33E. As in the MB124-VT interval, the rate of thickening is of the order of 3 m/10 km (10 feet/township). In this probable depocenter, the interval is commonly greater than 168 meters (550 feet). As in the MB124-VT interval, this interval also is thinner in the northeastern part of the map area, over and behind the Capitan reef margin. In the southwest part of the map, in the Phantom Banks and Big Sinks areas, the VT-Sal interval is usually <90 meters (<300 feet) thick, though there are a few exceptions. A zone of relatively sharp thinning of this interval trends northwest-southeast from the Paduca oil field area (T.25S., R.32E.) through the Remuda Basin area southwest of the WIPP site. The interval thins through this zone at an apparent rate of about 10 m/km (50 ft/mile), and is quite different from the rate of thinning/thickening from the site area towards the apparent depocenter.

Subintervals of MB124-VT Interval

Holt et al. (1989) illustrated two subintervals (combined MB123-124 and tops of MB123 to base Union) and found great similarity. As an example, the MB123-Union is presented here (Figure 7.2-11). Much of the central map area ranges from 15-18 meters (50-60 feet) thick. The WIPP site area and an area east-northeast of the site are thicker (18-21+ m; 60-70+ ft). A small area near the southeastern side of the map area also exceeds 18 meters (60 feet) thickness. A thinner area (<12 meters; <40 feet) dominates the south central margin of map area, and it appears more reliable than, though similar to, the thinning in that area of MB123-124.

Subintervals of VT-Sal Interval

Several subintervals of the VT-Sal interval reveal additional detail about the trends that were previously discussed. Two subintervals (top of VT to MB109 and MB103 to top of Sal) show the trends outlined by Holt et al. (1989) for this interval.

The isopach from top of VT to base of MB109 (VT-MB109) (Figure 7.2-12) demonstrates a thickness of about 49-55 meters (160-180 feet) in the WIPP site area. There is a slight increase in thickness immediately south of the site and generally in the southeastern part of the map (55+ meters generally to - 61+ meters very locally; 180+ - 200+ feet). North and northeast of the site, the VT-MB109 interval thins slightly across the reef margin. The isopach data are not very systematic in the southwestern part of the map area. Overall, there is no well defined southeast-northwest thinning trend as observed in the the VT-Sal interval (Figure 7.2-10).

An isopach map (Figure 7.2-13) of the interval from the base of MB103 to top of Salado (MB103-Sal) shows thicknesses of about 56-61 meters (175-200 feet) in the site vicinity. A few data points indicate that the interval is thinning immediately west and northwest of the site. As in previous interbed intervals, MB103-Sal thickens from the site vicinity to the southeast (T.24S., R32-33E.; T.25S., R33E.), where MB103-Sal exceeds 61 meters (200 ft). The southwestern end of the map area reveals a much thinner interval, as does part of the southeastern boundary. There is also slight thinning from the site to the north and northeast across the Capitan reef margin. The zone of rapid thinning trends northwest to southeast, paralleling the similar zone in MB109-103 interval, but it is displaced further northeast. As in other intervals represented by isopach maps, the thinning occurs at about 9.5 m/km (50 ft/mile).

Structure Contour Map of Top of Salado

The top of the Salado is configured like most of the underlying and overlying strata in the eastern part of the Delaware Basin (Holt and Powers, 1988; Holt, 1988) (Figure 7.2-14). The eastern part of the basin is

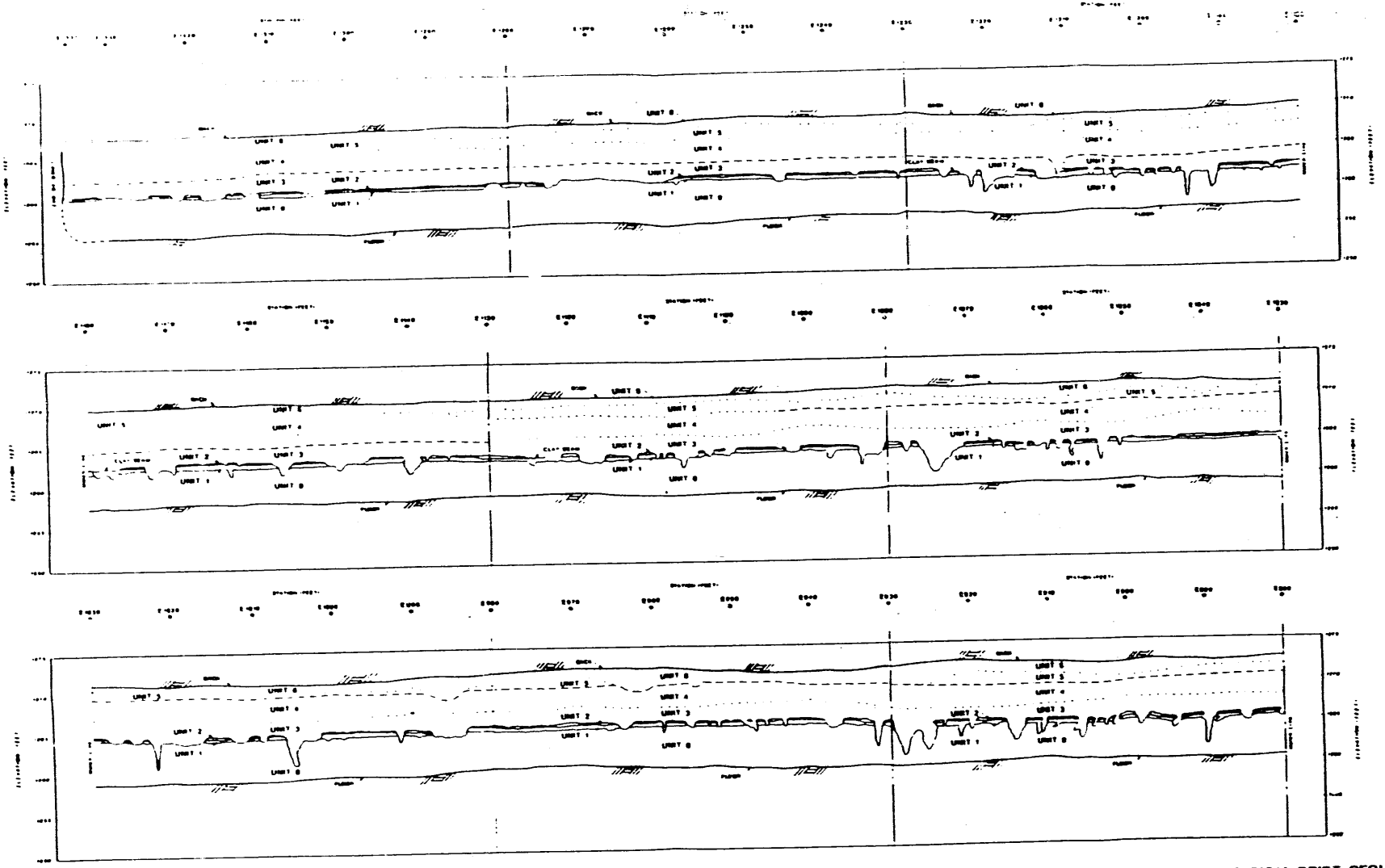


FIGURE 7.2-7 TYPICAL DRIFT GEOLOGIC MAP
S1950 DRIFT - VIEW SOUTH

relatively smoothly downwarped, and it accommodated the thickest Salado. To the west, however, the Delaware Basin has been uplifted and the Salado was exposed, dissolved, and eroded. Throughout much of the western Delaware Basin, this tilting superimposed a rather uniform structure dipping to the east about 20 meters/kilometer (100 ft/mile). The central part of the structure contour map of top of the Salado shows this dip; contours are generally oriented north-south and are rather evenly spaced.

In the western part of the map area, contours become more irregular and are more closely spaced along a northwest-southeast trend that passes just southwest of the WIPP site. This zone corresponds to a zone where the isopachs of the MB103-Sal interval become compressed and show a sharp decrease in the thickness of the subinterval. These phenomena are interrelated and are discussed in Section 3.0 (Dissolution). The isopach and structure contour maps both also illustrate how data become more difficult to obtain and interpret in this western part of the map area where the Salado is nearer or at the surface and has been modified by dissolution. Logs and cores are scarce in these areas. Structure contours of underlying units have been presented in Borns and Shaffer (1985) and Anderson (1978) for the region. Holt and Powers (1988) presented and interpreted structure contour maps of several beds in the overlying Rustler Formation.

Discussion

Isopach maps are traditionally valued because variations in the thickness of an individual unit can reveal information about the tectono-sedimentary regime during deposition of the unit and about events such as tilting, folding, or erosion before the overlying beds are deposited. The value of such maps is diminished when soluble evaporites are included in isopach units because the thickness may be greatly reduced by dissolution long after overlying units are deposited. Thus, we interpret the thickness of various units in the upper Salado with great care. Structure contours can also be altered by these same processes. The maps included in this report still appear to contain information about some depositional trends.

Most of the mapped intervals are thickest in the east to southeast part of the map area. The same halitic intervals are also slightly thinner over and behind the Capitan reef margin to the north. The thickest area is interpreted as a depocenter because it is thickest, it is located in about the same position as the Rustler depocenter (Holt and Powers, 1988), and because these same upper Salado units in the WIPP site area are slightly thinner but show no evidence of recent or continuing dissolution (Holt and Powers, 1984, 1986, 1988).

Compared to halitic units of the Rustler, the upper Salado depocenter appears to be somewhat broader and flatter. In the northern and northeastern part of the map area, thinner upper Salado intervals seem to show some effects of the boundary of the Capitan reef. A significant area of the Rustler depocenter over the reef is east of the mapped Salado data in this study, however, so the data to compare Capitan effects are not completely comparable.

Upper Salado intervals show a relatively narrow (generally about 1.5-5 km; 1-3 mi) zone where the interval thins dramatically compared to the broader depocenter. The width and rate of thinning compare reasonably well to a similar zone of the Tamarisk Member of the Rustler Formation (Holt and Powers, 1988). The major difference is that cores of the Rustler are available and show evidence of a large facies tract of synsedimentary dissolution without collapse of overlying units. Cores from Nash Draw, where this zone of thinning upper Salado occurs, show fracturing and collapse of overlying sediments, demonstrating post-Rustler dissolution. This margin of the upper Salado appears to be dominated by dissolution; the rest of the margin southeast of the WIPP site is assumed to be similar, though cores are not available to confirm this assumption.

The upper Salado dissolution margin from the WIPP site to the southeast trends subparallel to the strike line of the Culebra (Holt and Powers, 1988). If this margin of upper Salado salt is attacked further by dissolution, the Culebra transmissivities should be disturbed (increased) along strike to slightly downdip to the south-southeast of the site (see Section 4.0). This could provide a considerably different and longer path for fluid transport than is usually assumed, as in the Final Environmental Impact Statement (FEIS) (DOE, 1980).

The third major observation and discussion point is that the Salado logs are often not interpretable in the west and southwest section of the map area. Where an individual geophysical log is interpretable, it is generally difficult to interpret the resultant isopachs. This western and southwestern section is disturbed, at least, by dissolution, including karst; erosion before, during, and after deposition of the Quaternary Gatuna Formation has also affected the Salado and Rustler in this area.

7.2.5 Cross-Section Data

Holt et al. (1989) constructed geophysical log cross-sections to demonstrate relationships among the various marker beds of the upper Salado and to display information that may indicate the presence/absence of significant facies changes. One of these cross-sections is presented as sonic logs (Figure 7.2-15) with a corresponding cross-section with natural gamma signatures for the same boreholes (Figure 7.2-16). The Vaca Triste has been chosen as an arbitrary baseline. The upper Salado is emphasized, as the most significant changes occur above MB109.

Lateral facies changes are recognized when a distinguishable and interpretable lithologic change occurs laterally within a rock unit. In the upper Salado, some facies changes do occur. It is clear that potassium distribution is not uniform within the Salado. Adams (1970), for example, showed the general distribution of mineralization in different ore zones, though he did not characterize these as facies changes. Holt et al. (1989) illustrated the lateral change in potassium distribution in sulfate marker beds based on geophysical logs. The cross-section from Holt et al. (1989) shows mainly that units are laterally continuous and that facies changes are difficult to document within the Salado. There is little to indicate that the larger lateral thickness changes in the Salado are due to depositional processes rather than dissolution. This contrasts with conclusions drawn by Holt and Powers (1988) about the significant lateral changes in Rustler thicknesses and textures that are due mainly to depositional processes, including significant syndepositional dissolution. Because modern erosion and solution are also attacking the exposed and near-surface Salado, and because cores of this interval in critical areas are not available, it is not possible to demonstrate that depositional thinning occurred similar to the Rustler. As positive evidence of dissolution does exist, rapid thinning of the upper Salado is for now attributed to dissolution.

7.2.6 Summary

The Salado Formation varies lithologically due to changes in the depositional environment over time. The beds display a kind of cyclicity that shows repeated freshening of the basin followed by evaporation, concentration of salts, and, quite frequently, complete desiccation. Siliciclastics and sulfate beds generally show marked freshening and transport of sediment into the basin. Desiccated surfaces or very shallow water levels may also be marked by increased siliciclastic (mud) content. Because the Salado basin was very flat and extensive, individual beds were deposited continuously over very large areas and can now be traced in cores and geophysical logs. Mapping at the facility horizon of the WIPP also demonstrates this kind of vertical variability and lateral continuity, though very small areas may be disrupted by synsedimentary dissolution and surficial exposure.

The thicker intervals that have been used to produce isopach maps also show lateral continuity, as the thicknesses over much of the area become slightly thicker toward a general depocenter in the eastern

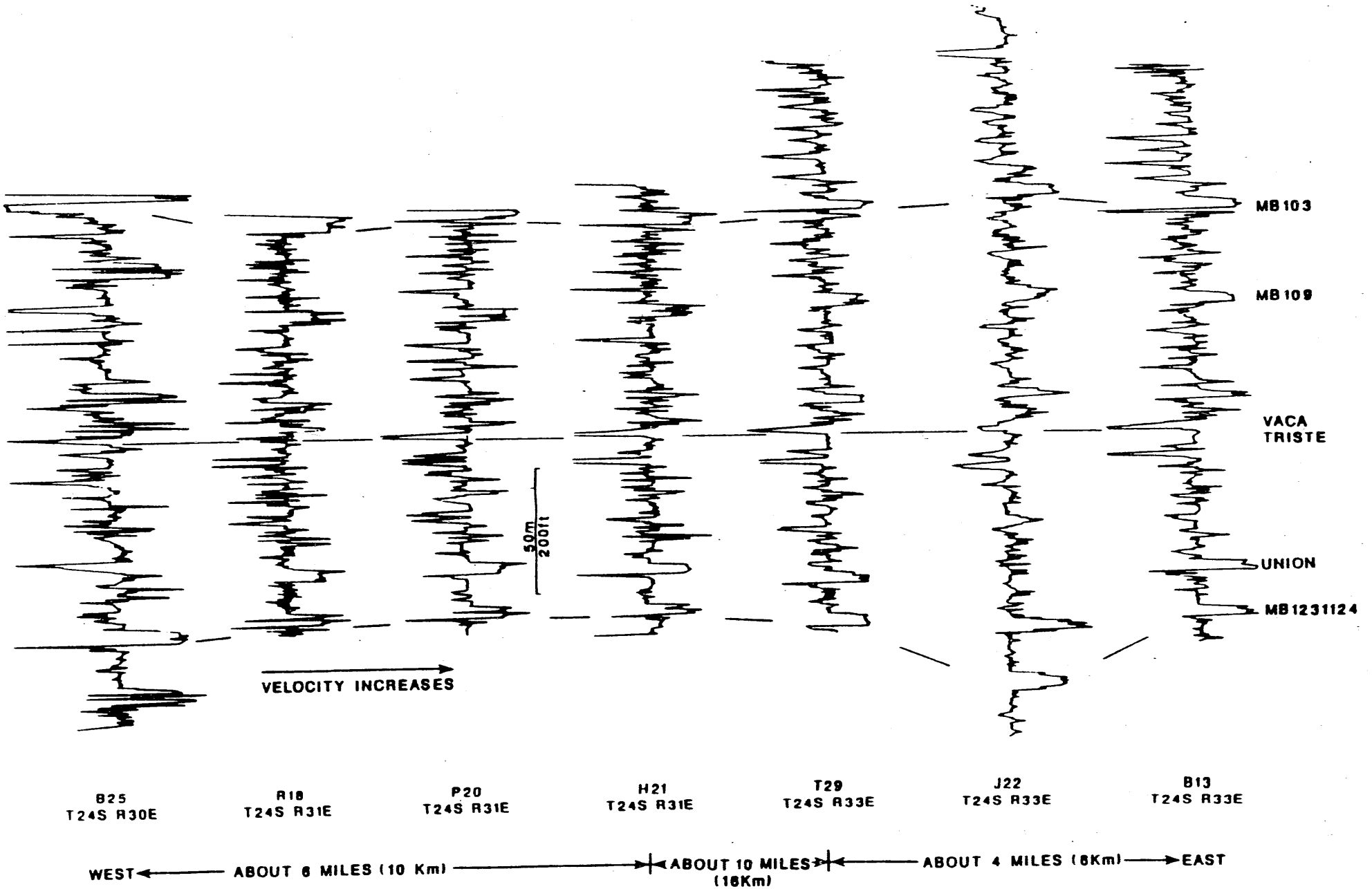


FIGURE 7.2-15 ACOUSTIC LOGS (T24S)

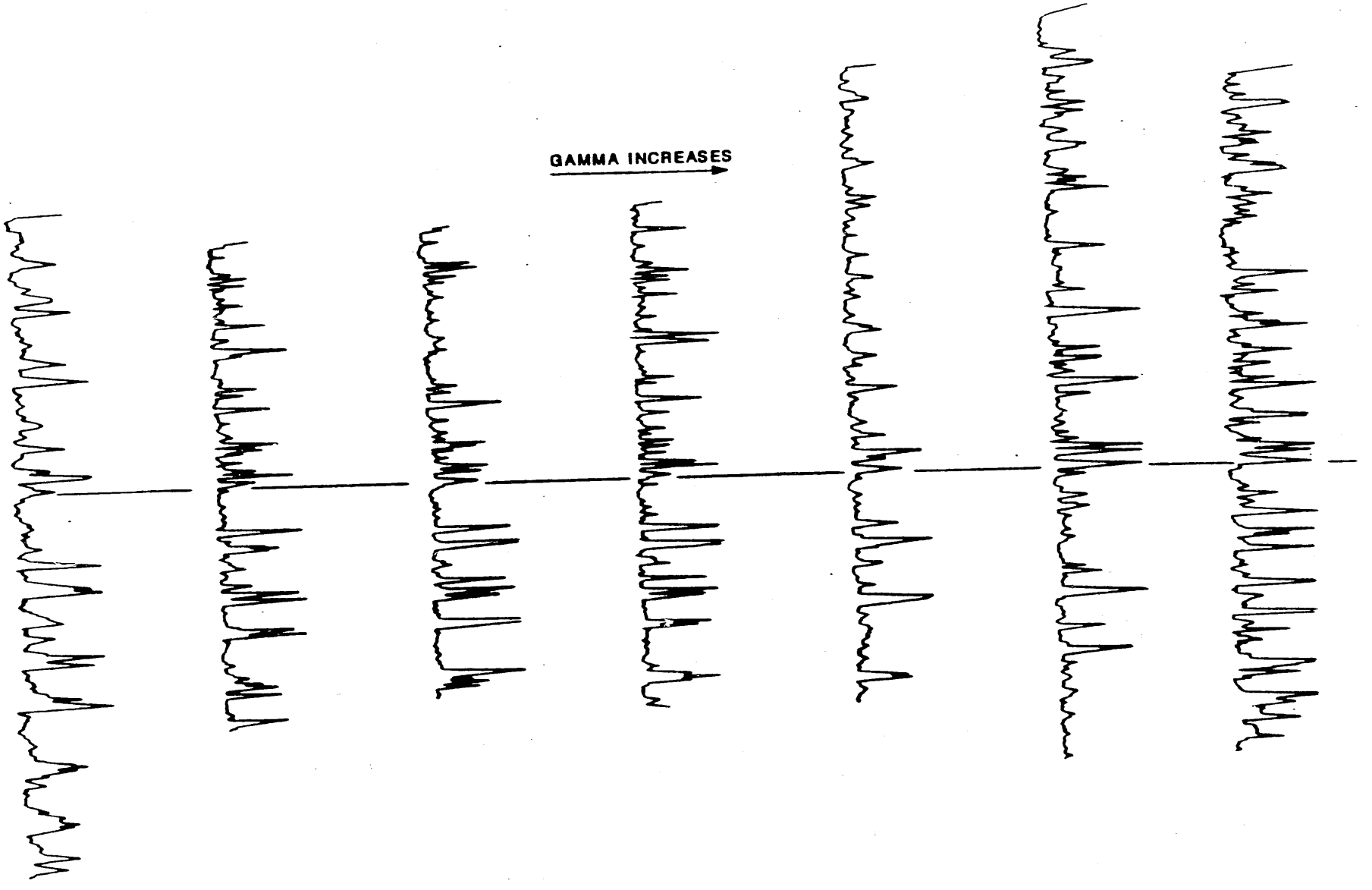


FIGURE 7.2-16 NATURAL GAMMA (T24S)

and southeastern parts of these maps. In contrast, the western edges of these maps also show much more abrupt thinning of the units. The Rustler Formation displays similar margins in several halite-bearing members. The Rustler halite margins are interpreted now (Holt and Powers, 1988) as principally due to synsedimentary dissolution of halite from a halite pan margin on the basis of rock textures and sedimentary features observed in shafts and cores. The Salado margin may be due to the same process, but in the near absence of any cores to check textures in that area, the margin is more probably considered to be due to more recent dissolution. Holt and Powers (1988) directly observed fracturing of upper Salado and Rustler rocks due to solution and collapse of the upper Salado as well. The Salado margins present today appear to be dominated by dissolution rather than depositional processes.

The Salado also lacks easily defined lateral facies changes that could explain the abrupt thinning of the Salado.

7.3 GRAVITY-DRIVEN STRUCTURE IN THE CASTILE

This document describes the structural features in the Castile Formation that are commonly attributed to gravity-driven deformation. In order to properly present this subject, the data will first be presented in a general historical overview, permitting the reader to understand the sequence of investigations. The known extent of deformation in the Castile, how these structures are likely to develop in the future, how well they can be predicted, and the potential impact of these structures on the WIPP will also be discussed. Apart from the general geological impact, the performance of the WIPP as it might be affected by such structures is not specifically assessed here.

7.3.1 Background Information

Parts of the Castile Formation have been known for a number of years to be deformed. Cross-sections of the basin geology through its margins have shown some evidence of deformation. Jones et al. (1973) provided a map of the isopachs of part of the Castile which clearly show much thicker portions in some of the areas along the northwestern to northern Delaware Basin, just inside the margin of the Capitan reef. Very little information had been collated concerning deformation within the Delaware Basin until studies were initiated of the Delaware Basin as a possible site for radioactive waste disposal. Jones et al. (1973) is probably the clearest early presentation of this information, though the dissertation by Snider (1966) and the paper by Anderson et al. (1972) also reflect thicker sections in some Castile units adjacent to the reef.

In 1975, Sandia National Laboratories (SNL) drilled a third borehole, called ERDA-6, at a site (Figure 7.3-1) that had been partially investigated by Oak Ridge National Laboratories (ORNL) during 1974. Two boreholes (AEC-7 and AEC-8) had been drilled in 1974 by ORNL before Sandia was assigned to carry out the task of investigating this site for radioactive waste disposal under programs that preceded WIPP. Formation boundaries and marker beds in ERDA-6 were structurally high compared to AEC-7 and 8, and the degree of deformation increased downward. At about 826-meter (2,711-foot) depth, ERDA-6 began to produce pressurized brine and gas. The hole was eventually tested extensively to determine the nature and origin of the brine (see Section 4.4). Beds within the Castile were displaced structurally upward, apparently by hundreds of feet (Jones, 1981; Anderson and Powers, 1978), and some of the lower units may have actually pierced upper units (Anderson and Powers, 1978). Because of the desire for structurally uncomplicated units to simplify mining for a repository, the site under investigation at ERDA-6 was abandoned in 1975, and in 1975-76 the current site was initially selected and investigations were begun (Powers et al., 1978). As part of the selection criteria, a zone about 10 kilometers (6 miles) wide inside the Capitan reef was avoided because it included known deformed Castile and Salado (Griswold, 1977). This is the first instance in which the site investigations were directly influenced by discovery of deformation in the Castile and lower Salado.

The present site for the WIPP was selected and initially investigated in 1976 to determine if the desired characteristics for the preliminary site selection were present (Griswold, 1977; Powers et al., 1978). As the general criteria appeared to be met during this phase, the site and surrounding areas were characterized much more extensively and intensively beginning in 1977. Extensive new seismic reflection data were collected in 1977 and 1978 that began to reveal the deformed Castile north of the center of the site (Figure 7.3-2). Because the principal effect was that the good quality Castile reflectors from the area south of the site center were "disturbed", the area to the north was dubbed the "disturbed zone". It also became known as "the area of anomalous seismic reflectors" or "zone of anomalous seismic reflection data." The boundary of the "disturbed zone" (DZ) was variously described as being from about 0.8 to 1.6 kilometers (0.5 to 1 mile) north of the center of the site, depending on the criteria to define the DZ. Powers et al. (1978) generally defined the DZ beginning about 1.6 kilometers (1 mile) north of the site center, where the seismic reflector character was poor to uninterpretable or "anomalous" (Borns et al., 1983). About 0.8 kilometer (0.5 mile) north of the site center, it appeared that beds within the Castile Formation began to steepen in gradient, dipping to the south from a higher area to the north. The Environmental Evaluation Group (EEG) summarized various map limits to the DZ, including the area where the Castile dip begins to steepen (Neill et al., 1983). Borns et al. (1983) included two separate areas south of the site as part of the DZ based on seismic character.

The first new drillhole within the area encompassed by the DZ was WIPP-11, and it was located about 5 kilometers (3 miles) north of the center of the WIPP site (Figure 7.3-1). Long and Associates (1977) examined proprietary petroleum company data in 1976, and they identified anomalous areas around the WIPP site, including the structural anomaly at the WIPP-11 location. Seismic reflection data acquired in 1977 indicated possible salt flowage within the Castile and a structure that could be similar to that at ERDA-6 (Sandia National Laboratories and U.S. Geological Survey, 1979). WIPP-11 was drilled early in 1978, demonstrating the extensive deformation within the Castile and extending upward into the Salado. WIPP-11 did not encounter any brine or gas flows.

Seismic reflection data acquired in 1977 not only showed a zone of steepened dip of the Castile north of the site center, it also showed a possible fault offsetting parts of the Salado and Rustler Formations. A series of five boreholes were planned to provide detailed information on the structure of the Rustler/Salado contact. Four boreholes (WIPP 18, 19, 21, and 22) were required to demonstrate that there was no detectable offset on that contact in the area interpreted from 1977 seismic reflection data (Figure 7.3-1). Later epochs (1978 and 1979) of seismic data in the same area, along with the drilling, continued to show generally poor resolution or uninterpretable data in the area of the DZ. These studies generally showed that the acoustic velocity of the upper section changes laterally, complicating further the interpretation of the deeper Castile structure. Through the WIPP 18-22 drilling program, the upper Salado and Rustler were determined to be fundamentally undisturbed over the southern margin of the disturbed zone where the Castile appears to dip to the south (Sandia National Laboratories and U.S. Geological Survey, 1979).

The upper part of the Castile about 1.6 kilometers (1 mile) north of the WIPP site center was interpreted to range from about 100 meters to as much as 120 meters (250 to 400 feet) (Sandia National Laboratories and D'Appolonia Consulting Engineers, 1982c) above the elevation of the top of Castile at about the center of the WIPP site. WIPP-12 was located approximately 1.6 kilometers (1 mile) north of the site center to test the amount the Castile was elevated (Figures 7.3-1, 7.3-2). It was drilled late in 1978 to the top of the Castile and detected approximately 50 meters (160 feet) of structural elevation compared to ERDA-9 and the center of the site (Sandia National Laboratories and D'Appolonia Consulting Engineers, 1982c). The amount of disturbance of the Salado was not considered to be an impediment to underground development, though the underground storage facility was later reoriented

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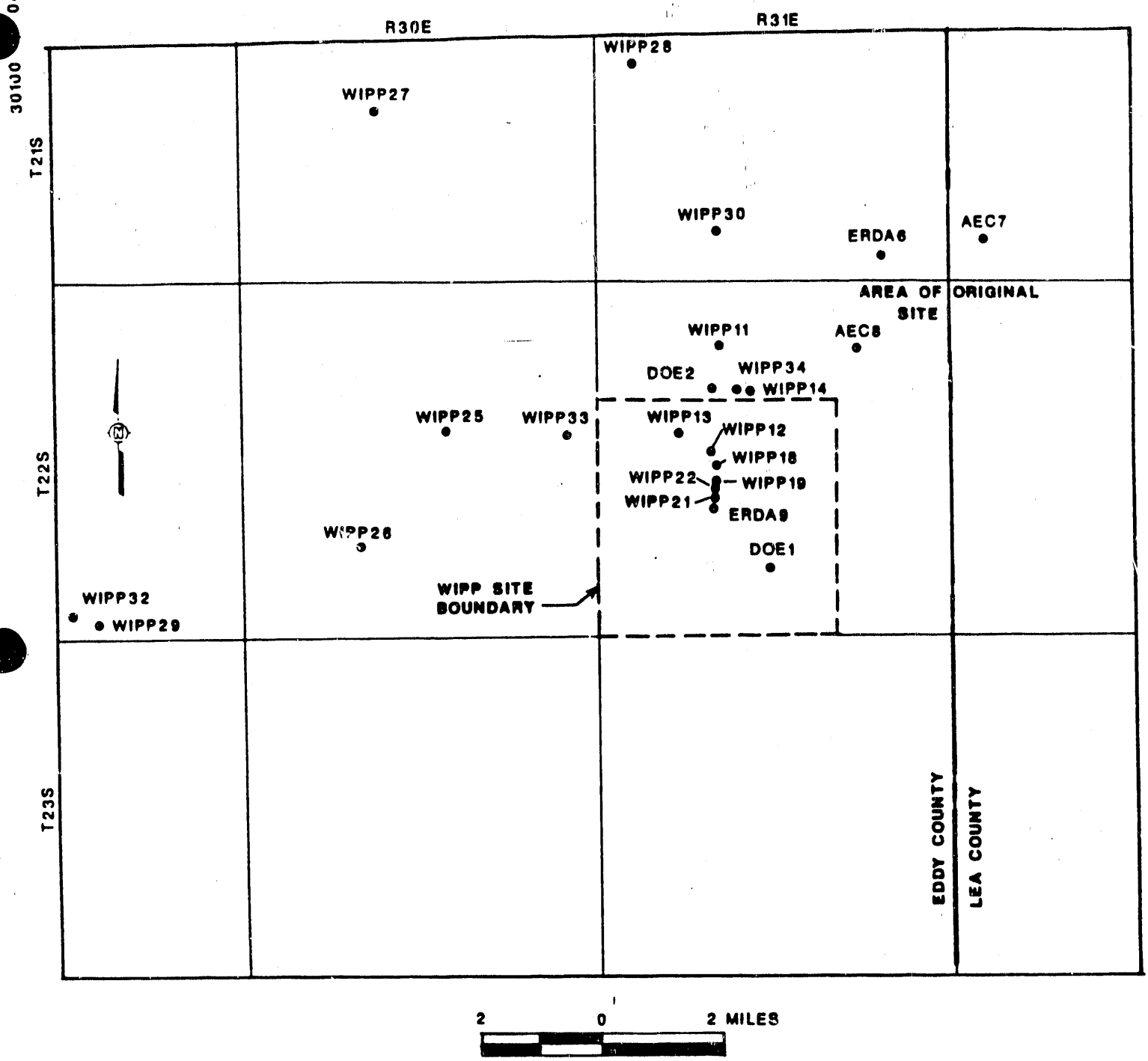

FIGURE 7.3-1 LOCATION OF MAIN STRATIGRAPHIC DRILLHOLES

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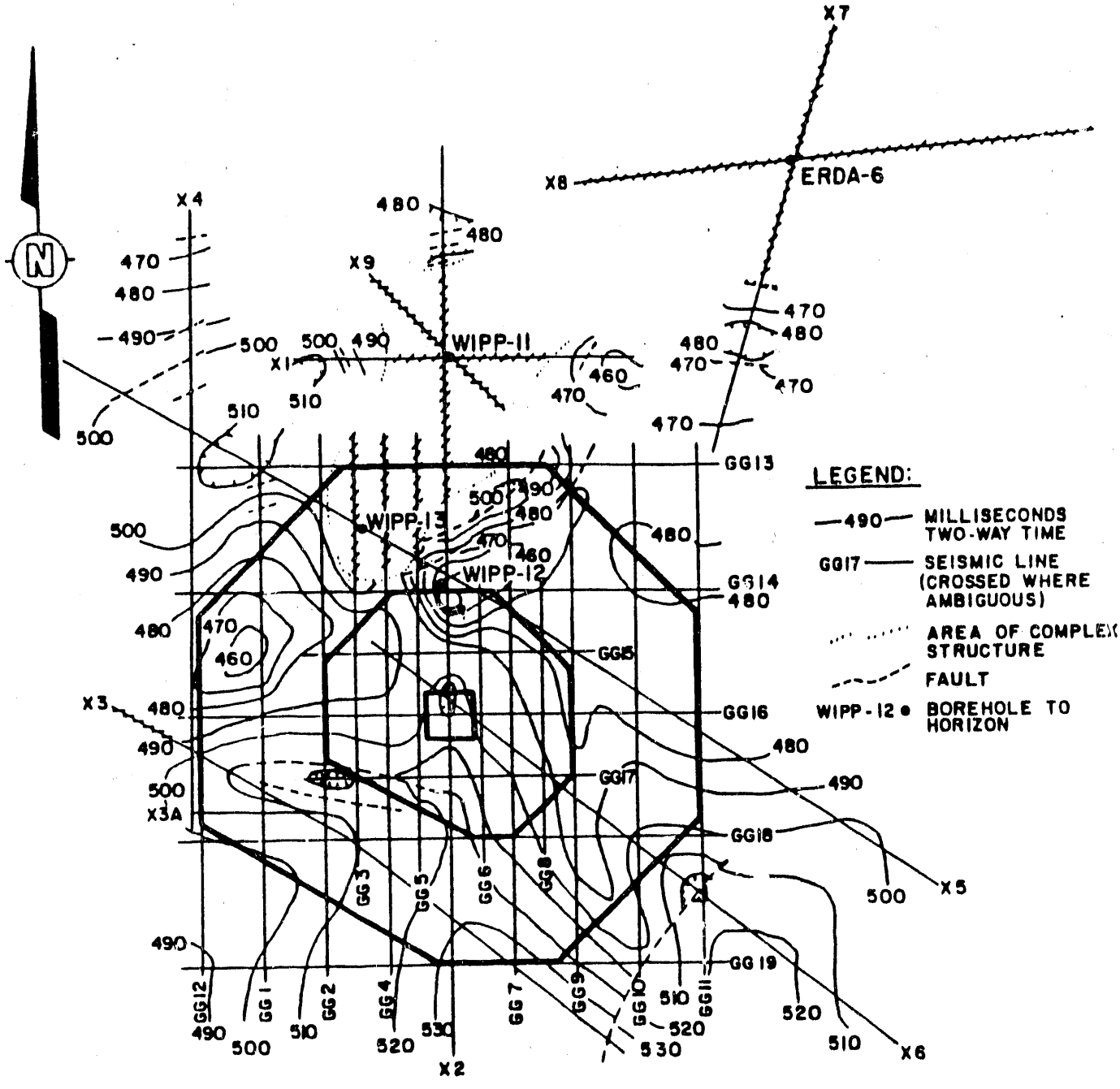

NOTES:

1. CONTOUR INTERVAL 10 MILLISECONDS; DATUM 3350 FEET ABOVE SEA LEVEL.
2. CONTOUR INTERVAL IN FEET WOULD BE APPROXIMATELY 75 FEET BASED ON AN AVERAGE SEISMIC VELOCITY OF 7620 FT./SEC. AVERAGED OVER THE ENTIRE STRATIGRAPHIC INTERVAL FROM GROUND SURFACE TO THE MIDDLE OF THE CASTILE FORMATION.

Source: Popielak et al., 1985

FIGURE 7.3-2 SEISMIC TIME STRUCTURE MIDDLE CASTILE FORMATION

from this northern area to an area south of the site center (see Section 1.1). From drilling WIPP-12 and the WIPP 18-22 series, the southern margin of the DZ was considered to be much more gentle in structure, while the seismic character and WIPP-11 indicated much more severe deformation of the Castile further to the north.

Two additional phases of seismic reflection data were acquired in 1978 and 1979. These data mainly concerned the immediate site area [about ten square kilometers (four square miles)] and the southern edge of the DZ. They indicated much the same problems and margins associated with the DZ from the 1977 data. The latest seismic data (1979) were principally acquired to facilitate construction and Site and Preliminary Design Validation (SPDV) activities. As the project moved into SPDV activities, the DZ was little investigated directly during the period from about late 1979 until mid-1981.

A microgravity survey of the site area was conducted to determine if the structure within the DZ could be partially resolved by that method (Barrows et al., 1983; Barrows and Fett, 1985). The large differences in density of halite and anhydrite might cause detectable differences in the gravity field locally if the units were displaced and/or thickened relative to the surrounding areas. The microgravity survey covered an area of "normal" stratigraphy from south of the WIPP site center to the area of WIPP-11 (Figure 7.3-3). As interpreted (Barrows et al., 1983), the microgravity does not resolve the larger scale deformation within the Castile Formation. Based on the interpretation of probable shallow disturbance of the gravity field, WIPP-14 and WIPP-34 were drilled about 3 kilometers (two2 miles) north and about 0.8 kilometer (0.5 mile) east of the site center (Figure 7.3-1). These boreholes encountered normal stratigraphy within the Rustler and upper Salado (Sandia National Laboratories and D'Appolonia Consulting Engineers, 1982c; Sandia National Laboratories and U.S. Geological Survey, 1981) with some slight structural depression made apparent mainly by the deformation northeast of this area around ERDA-6 (Holt and Powers, 1988). Barrows et al. (1983) attributed the gravity anomaly around WIPP-14 to decreased density within parts of the Rustler Formation, mainly from the difference in density due to anhydrite versus gypsum in WIPP-14. The overall difference in mass was attributed to karst processes by Barrows et al. (1983) rather than to deformation of any of the units associated with the DZ.

During the mapping of the first shaft drilled at the WIPP site (the Construction and Salt Handling shaft), MB 139 was observed to have a few inches of relief on the basal contact and 0.6 to 0.9 meters (2 to 3 feet) of relief on the upper surface. Jarolimek et al. (1983) interpreted the internal structure on these high points of MB 139 as showing a radial structure due apparently to gypsum growth textures and subsequent crushing, indicating a fundamentally depositional origin to the relief rather than any structural disturbance related to the DZ. Borns (1985) conducted an investigation of additional cores and holes drilled through MB 139, as there was concern on the part of the EEG that the apparent structure was related to the DZ. Borns (1985) also concluded that the relief was not due to structural deformation, but instead was due mainly to erosional processes which carved part of the relief found on the top of the MB. From either point of view, the difference in relief on the upper and basal contacts of MB 139, in such a thin unit, were convincing evidence that a form of tectonic deformation was not involved.

In late 1981, WIPP-12 was deepened to test for the possible presence of brine and/or pressurized gas within the structure in the Castile Formation (D'Appolonia Consulting Engineers, Inc., 1982). The probability of producing brine/gas from WIPP-12 was considered reasonably low at the time because most known pressurized brine/gas was associated with much more deformed units than the Castile at WIPP-12. Fractured anhydrite in the upper Castile did begin to yield pressurized brine and gas when intercepted late in 1981, and WIPP-12 and ERDA-6 were further tested (see Section 4.4). Later geophysical work (The Earth Technology Corporation, 1987) suggests that the brine may underlie part of the WIPP facility, beyond the area usually included in the DZ. Though the DOE and EEG agreed that neither brine nor structure constituted a threat to the health and safety, the proposed underground

facilities were reoriented south of the site center, avoiding longer haulage and the slight structure encountered at the facility horizon (see Section 1.1). As a consequence of the deepening and testing of WIPP-12, the link between structure and pressurized brine and gas was strengthened (see also Section 4.4).

The last direct investigation of the DZ was a by-product of another investigation. DOE-2 was drilled approximately 2 miles north of the center of the WIPP site to investigate the origin of a modest depression on MB 124 (Griswold, 1977; Powers et al., 1978) that was detected in a corehole drilled by a potash company. DOE-2 was was principally a test of the hypothesis that the depression was caused by ductile flow of halite in response to deep dissolution of halite by water from the Bell Canyon Formation (Mercer et al., 1987). Halite layers in the lower Salado were thicker than usual, indicating that part of the sequence had not been dissolved, and the Castile was very deformed. The Castile stratigraphy was not normal; the second halite was apparently squeezed out of the area during deformation. The stratigraphy in DOE-2 is apparently the result of processes which caused the DZ, and is not the result of any dissolution (Borns, 1987; Mercer et al., 1987).

The preceding paragraphs describe most of the direct investigations of the disturbed zone and place them in their historical context. In the next few sections, more of the specific features of the DZ will be described, interpreted, and discussed to indicate the significance of the structures and processes of formation for the WIPP.

7.3.2 Specific Features of the Disturbed Zone

The first specific feature of the DZ is its boundary. In Section 7.3.1, the different concepts of the boundary depended on ideas of where the Castile began to change and steepen dip (about one half mile north of the site center, or where the various epochs of seismic data became unreliable to uninterpretable. Borns et al. (1983) present one diagram (Figure 7.3-2) of the seismic time structure for the top of the Castile Formation which illustrates the variously defined boundaries as well as any diagram. The principal part of the disturbed zone is defined by a lobate area (Figure 7.3-2) shown as an "area of complex structure" where the seismic data are considered "ambiguous". The structurally deformed area clearly includes an area about halfway between boreholes WIPP-12 and ERDA-9, as well as a larger area to the northeast. The two-way travel time contoured on the map is a function of depth; as the reflector is nearer the surface, the travel time to the reflector and back to the surface decreases. Thus, the areas enclosed with contours of smaller values should be structurally higher. [The top of Castile in WIPP-12 was 50 meters (160 feet) higher than it is in ERDA-9.] The map was not directly converted to depth because the seismic reflection and borehole geophysical logging programs demonstrate clearly that there are also lateral velocity variations within the upper part of the rock section, especially within the Rustler and Dewey Lake Formations. These velocity variations cannot be extracted from the travel times adequately to permit converting the travel time to depth. Nonetheless, the map demonstrates the general best information about the extent of the DZ. The central and southern part of the WIPP site area displays relatively uniform seismic travel time structure and nothing within the geological data contradicts that information to date.

The broad forms of the structures within the DZ are commonly generally anticlinal and synclinal (Borns, 1987), though they are not necessarily regular shapes. The best known shape for part of the DZ is between WIPP-12 and ERDA-9, where seismic information and several drillholes constrain part of the stratigraphy. There the structure tends to be a gently dipping limb of an anticlinal structure. Most of the remaining shapes attributed to the Castile within the DZ or related areas are based more on one drillhole or a few drillholes that somewhat constrain the structure. WIPP-11, WIPP-13, DOE-1, and ERDA-6 are all examples. A generalized cross-section of the structure at ERDA-6 (Anderson and Powers, 1978) shows a piercement structure and a regular shape; the piercement is based on stratigraphic inferences,

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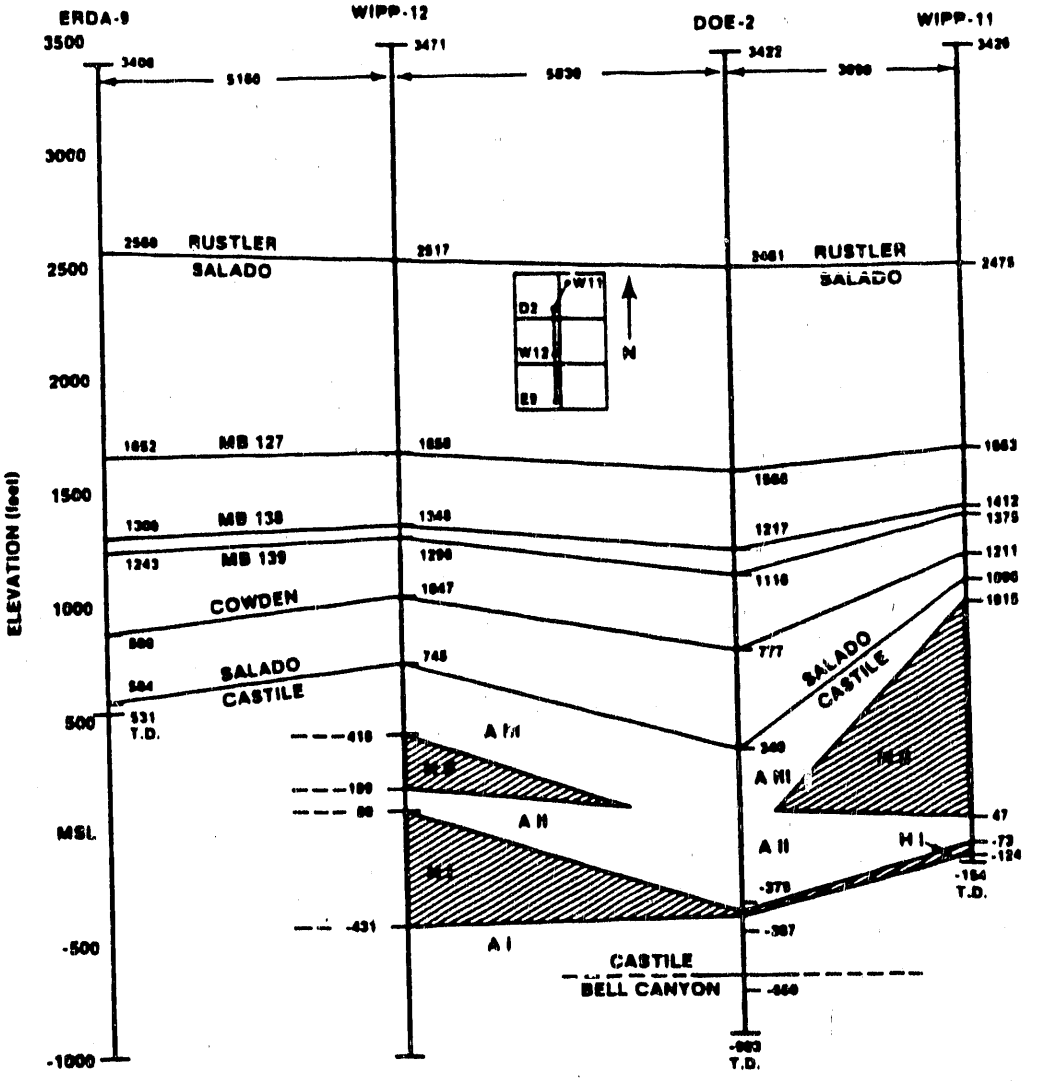


(Source: Borns, 1987)

FIGURE 7.3-3 FENCE DIAGRAM USING DOE-2 AND ADJACENT HOLES

but the shape is fundamentally uncontrolled by closely spaced data. WIPP-11 and WIPP-12 are both believed to penetrate anticlinal forms, though the structure is only partially known from drilling and seismic reflection data. DOE-2 is believed to lie in a synclinal structure, and contacts on various units show a nested series of depressions in the upper Salado (Borns, 1987). There are too few drillholes into the Castile to reconstruct the detailed shapes of Castile structures. The seismic data are not well enough constrained to calculate depths to reflectors, and most reflectors are too "disturbed" to interpret in this area. The specific shapes of individual structures are unlikely to be defined in the near future.

Anderson and Powers (1978) contoured several structures within the Delaware Basin, including structures at Poker Lake at least grossly similar to ERDA-6. Borns and Shaffer (1985) reexamined the information from Poker Lake and concluded that the actual shape is poorly constrained. Outside of the area on the north side of the current WIPP site, the information available is too sparse to define the individual shapes of structural features on borehole data.

It is important to note that, to date, none of the structures is demonstrably associated with comparable structure on the underlying Delaware Mountain Group. Snyder (in Borns et al., 1983) does show an upthrown block (horst) through WIPP-11 on the top of the Bell Canyon Formation that is based on his projection of the thickness of the lower Castile; WIPP-11 did not penetrate the complete Castile section. Other areas, such as the Poker Lake structures, may display some relief on the top of the Delaware Mountain Group, but Borns and Shaffer (1985) do not attribute the relief to faulting. They believe the relief existed before and during deposition of the overlying Castile units. The underlying units to the Castile Formation are, for the most part, uninvolved in the structures displayed by the Castile.

Structure contour and isopach maps of the Salado and Rustler over areas of complicated Castile structure also show that the overlying units are successively less involved in the structure (e.g., Section 7.2; Borns and Shaffer, 1985; Borns et al., 1983; Holt and Powers, 1988). Lower units that are thicker and deformed are overlain by units that are thinner and less structurally involved in the deformation. Under normal geological circumstances, e.g., dealing with a rock sequence of carbonates or siliciclastics, the deformation would be considered to be completed by the time of deposition of the lowermost undeformed rock unit. Here, within a much more plastic set of rocks, the same geological reasoning is of less value, as the rocks may compensate laterally for late deformation effects and produce the same results as we see here.

Borns (1983, 1987; Borns et al., 1983) has extensively examined the macroscopic to microscopic features from cores taken within the structurally deformed areas. These studies follow earlier, broader studies of macroscopic features from the "state line outcrop" (Kirkland and Anderson, 1970) and ERDA-6 (Anderson and Powers, 1978). Kirkland and Anderson (1970) reported that small scale folding within the Castile outcrops is oriented consistently along the general north-south strike of beds in the Delaware Basin. From this they concluded that the deformation was related to tilt of the basin, generally believed to be Cenozoic in age (e.g., Anderson, 1978b; King, 1948; Borns et al., 1983) though authors differ in opinions of when this took place by tens of millions of years. Anderson and Powers (1978) used this apparent relationship to estimate that folding at ERDA-6 took place after the tilt of the basin. Jones (1981) estimated that deformation took place before the Ogallala Formation was deposited because that unit is undeformed at the location of ERDA-6. Bachman (1980) and Madsen and Raup (1988) are among investigators who interpret angular relationships between various formations of the Ochoan Series, beginning with the Castile-Salado contact. These relationships require tilting of the existing beds to the east, as the angular unconformities are always placed on the west side of the basin. Tilting of the basin may well have occurred through much of the time when the Ochoan Series was being deposited,

as Holt and Powers (1988) present evidence that the depocenter for the Rustler Formation was displaced eastward from the Castile and Salado patterns and overlies part of the Capitan reef on the northeast side of the Delaware Basin. The Delaware Basin appears to have tilted at various times from the late Permian to at least the Cenozoic, and the conditions for deformation may well have existed since the late Permian. Direct evidence of the time of deformation has been difficult to obtain, and tilting of the basin, as a condition for the deformation, appears to have occurred at times beginning in the late Permian. Jones (1981) argues that the structure at ERDA-6 must be in part younger than Triassic because Triassic rocks are also deformed over the deformed evaporites. He further believes that the structure must be older than late Cenozoic because the Ogallala Formation over part of the structure is undeformed and erosionally truncates the upper part of the Triassic rocks. This may be the most conclusive age relationship demonstrated for any of these related structures. Conventional relationships with beds overlying deformed evaporites, such as that cited by Jones (1981) for the Ogallala, are suspect if the deformation ends or dies out vertically within the evaporites because of the potential for compensating deformation in evaporites (e.g., Borns, 1983).

Borns (1983, 1987) reexamined the "state line outcrop" as well as the cores from various boreholes, and he concluded that the styles of deformation present in these cores indicate a very complicated history, including episodes of deformation that are probably synsedimentary. The folding may, for example, display disharmonic or opposing styles that would not normally be attributed to a single episode of strain in a pervasive stress field. If the deformation all occurred in response to a single event such as the tilting of the Delaware Basin, the folds and other strain indicators should all have a common orientation. Isoclinal folding may be very early while asymmetric folding is often penetrative, indicating later time of origin. Fractures in more brittle units such as the Castile anhydrites are often very high angle to vertical and are considered one of the late deformation features in cores. These fractures in the larger anticlinal structures of the DZ are apparently the proximate source of pressurized brines and gases. Borns (1985, 1987) recognized that tilting of the basin, among other possible sources of stress, may have occurred at several different times and is not limited to a single Cenozoic event.

7.3.3 Hypotheses of Formation or Deformation in Castile

Several hypotheses have been advanced for the formation of the Castile structures in the DZ and other parts of the Delaware Basin (Borns et al., 1983). The five principal processes hypothesized as causes of the DZ are gravity foundering, dissolution, gravity sliding, gypsum dehydration, and depositional processes (Borns et al., 1983). Each of these hypotheses will be briefly summarized, though gravity foundering due to density differences between halite and anhydrite is considered the leading hypothesis (Borns, 1987).

Gravity foundering is based on the fact that anhydrite (about 2.9 gm/cc) is much more dense than halite (about 2.15 gm/cc). When anhydrite beds overlie halite, there is considerable potential for the anhydrite to sink and the halite to rise. This potential exists throughout much of the Delaware Basin in the Castile. Mathematical and centrifuge models of similar systems confirm the potential for such deformation and even suggest that the rate of deformation is about 0.05 centimeter/year (0.02 inch/year) (Borns et al., 1983). At such a rate, the DZ could be inferred to develop over about 700,000 yrs (Borns et al., 1983). The principal difficulty with this hypothesis is that there are large areas of the Delaware Basin which remain undeformed, though the stratigraphy is similar to that within the DZ. The potential for gravity foundering exists over most of the basin, but only a small part actually manifests such deformation. A special condition, localized higher water content or an anomalous distribution of water, is hypothesized to

explain why deformation is localized despite the pervasive density inversion (Borns et al., 1983). Pressurized brine and gas associated with some of these structures is at least consistent with this explanation (see also Section 4.4).

Halite could potentially be removed from the evaporite section by dissolution and change the form of the evaporites. The density structure could be changed by removing salt near the surface, causing collapse and fill with sediment that is more dense than the removed salt (Anderson and Powers, 1978). Borns et al. (1983) reviewed some of the evidence that evaporites were deformed near surficial sinks and concluded that there was certainly some association but that the pattern of deformation did not match the shallow dissolution. If salt is dissolved from the lower Salado or Castile, then overlying beds should deform in response to the removal of mass. DOE-2 was drilled to test that hypothesis. Recrystallized halite has been offered as evidence of the passage of fluids, but there appears to be no unique relationship between recrystallized halite and deformation. In addition, certain halite sections appear much overthickened, which is clearly not directly due to halite removal. These features indicate generally that the halite can be squeezed and will "move" laterally. The fact that the Rustler shows no discernible overall structural lowering over the DZ (Holt and Powers, 1988) suggests that dissolution of the lower Salado or Castile is not the origin of the deformation. The one area in which the Rustler is structurally affected is around ERDA-6, and there it is warped upward as noted by Jones (1981). Borns et al. (1983) do not believe that the Bell Canyon has been a source for brines in the Castile because of the chemistry (Lambert, 1978, 1983) and the small volume.

Gravity sliding in the Delaware Basin could be driven by two physical situations: the general eastward dip and the dip off the Capitan reef and forereef into the basin. In contrast to the gravity foundering mechanism, where movement is dominantly vertical, gravity would result in sliding blocks moving mainly laterally as well as downslope in this mechanism. Some of the deformation is adjacent to the reef (Jones et al., 1973), lending some substance to the hypothesis that the reef-forereef slope and facies changes could cause such sliding. Some deformation is in somewhat isolated portions of the basin (e.g. Poker Lake; Anderson and Powers, 1978; Borns and Shaffer, 1985), and these structures were originally interpreted to align along the strike of the basin (Anderson and Powers, 1978). Borns and Shaffer (1985) conclude that the data do not uniquely support that interpretation, and these structures may or may not support the concept of gravity sliding within the basin. Borns et al. (1983) also concluded that the timing of the various structures is an important factor in evaluating this hypothesis. As discussed above, neither the age of the various structures nor the timing of the basin tilt are well constrained. If tilting of the basin is an important event in forming these structures, the various macro to microstructures should probably be consistently related. As in gravity foundering, much of the basin area has not reacted to what appears to be widespread similar stresses. Special circumstances, such as an anomalous distribution of water, may be necessary to overcome a threshold for deformation to occur.

In general, as temperature and pressure increase, gypsum dehydrates to form anhydrite and release free water. Borns et al. (1983) discuss the effects this process has in experiments in weakening the anhydrite. Borns et al. (1983) suggest, however, that a major difficulty with this hypothesis is that there should remain relicts of the original gypsum within the sedimentary column and these are not observed. Borns et al. (1983) suggest that mostly anhydrite was deposited in the Castile, and, as a consequence, the dehydration hypothesis has little observable support. More recently, pseudomorphs after gypsum have been recorded in every major anhydrite of the Castile (Harwood and Kendall, 1988, pers. comm.; Hovorka, 1988, pers. comm.; Powers, unpublished data; Sandia National Laboratories and D'Appolonia Consulting Engineers, 1982a). Gypsum certainly has been present in the Castile, though anhydrite cannot be dismissed as possibly an important primary mineral. Delicate forms of original gypsum crystals are sometimes preserved and pseudomorphed by anhydrite or halite. Each requires volume for volume

replacement, probably through dissolution and crystallizing the replacement mineral. There are no observed fluid escape paths, and the gypsum may have been replaced very early in the sedimentary history. The additional major drawback of this hypothesis is that the process should be prevasive, while the deformation is localized. Special pleading for an additional factor is necessary in this process as in some other hypotheses.

Depositional or syndepositional processes have been invoked for some of the deformation in the Castile Formation. Borns et al. (1983) list four main mechanisms that have been suggested: penecontemporaneous folding, resedimentation, slump blocks off reef margins, and sedimentation on inclined surfaces. Penecontemporaneous folding requires consolidation of the units over relatively short times. Borns et al. (1983) also cite the lack of observed features that indicate the rocks were reexposed. Evaporite units in the Mediterranean contain resedimented material: turbidites, slumping and mudflows with other clastic sediment. Borns et al. (1983) report that "the units of the WIPP area show little chaotic or clastic structures". They also apply the same argument of Kirkland and Anderson (1970) that the deformed units would have to be consolidated by the time of resedimentation.

In a more recent study of cores from the western part of the Delaware Basin, Robinson and Powers (1987) report a lobate unit of resedimented Castile anhydrite clasts overlying both the lower anhydrite and halite of the Castile and underlying the second anhydrite. The apparently unconformable contact with both anhydrite I and halite I lies across the extension of the Huapache monocline which appears to have been still active during the time part of the Castile was deposited. Polyclasts within some beds of this unit demonstrate that the original anhydrite was partially consolidated and that a unit of clasts was also at least partially consolidated to provide the polyclasts. These units were consolidated early - between the time halite I was deposited and anhydrite II began to be deposited.

In the rest of the basin, there is no apparent interval between the end of halite and beginning of the anhydrite deposition. The relationship clearly indicates that the western margin was an area of sulfate clast formation, deposition, and lithification over a very short interval of geologic time. Hovorka (1988, pers. comm.) indicates that similar clastic deposits occur in cores from nearer the eastern margin of the Delaware Basin. Snider (1966) proposed much earlier that sedimentation caused anomalous thickness of Castile units near the basin margin, and Billo (1986) presented a similar conclusion. Neither reported any textural evidence to support their conclusions.

Clearly, Castile rock has been resedimented, but in the area where textural data are available, only modest deformation appears to be present (Robinson and Powers, 1987). At this time, there is little to suggest that such sedimentation resulted in the deformation in the DZ. There is also no direct evidence from the WIPP area that suggests slump blocks off the reef margin moved into the area, causing deformation. The high inferred slopes of some of these structures argues strongly against sedimentation on inclined surfaces (Borns et al., 1983).

The concept that deformation was syndepositional or penecontemporaneous with deposition appears to mainly be driven by the fact that deformation decreases upward through successive units. Normal geologic reasoning would support penecontemporaneous deformation, but does not take into account the rather plastic behavior of halite, allowing flow from over high areas to move halite into low areas. Overlying units, such as the Rustler, are made of much less plastic material and do not respond as the Salado does. The deformation just appears to be compensated in overlying units through deposition.

Overall, both gravity-driven mechanisms require some special additional conditions restricting deformation to small areas though most of the basin appears to be equally susceptible. Dissolution permits a more localized effect, but there does not appear to be an overall loss of mass in these areas

and the chemistry of the fluids and hydrology of the units do not readily support the concept. Most of the syndepositional processes have no evidence to support them in the area of the DZ. The most favored hypothesis at the moment is gravity foundering, with a yet undetected anomalous distribution of fluid lowering the viscosity of halite locally to permit deformation.

7.3.4 Timing of Deformation

Most of the arguments about timing of deformation have already been discussed. Standard geologic arguments about relative timing, based on involvement of the overlying units, is unlikely to hold for the evaporite units. Jones (1981) notes that uplifted and arched Triassic rocks near the ERDA-6 borehole are truncated by the flat-lying, undeformed Pliocene Ogallala Formation. He interpreted this as an indication that salt movement was complete before deposition of the Ogallala. However, he does not explain either how the Triassic structure relates to the deeper DZ or how it is distinguished from near-surface dissolution effects (Borns et al., 1983). Castile rocks may have been deformed during any time period from Permian to the present. More to the point, for some hypotheses, the general conditions thought necessary to deform the Castile and Salado are still present, and mechanisms such as gravity foundering are potentially active (Borns et al., 1983).

An additional piece of data is relevant. Brines from ERDA-6 and WIPP-12 were analyzed, and the brines were calculated to last have moved after about 800,000 years ago (Lambert and Carter, 1984; Barr et al., 1979). One set of reasonable assumptions about brine chemistry and interactions with the rock leads to calculated residence times of about 25,000 to 50,000 years for these brines. This may relate to the last time deformation was active on this structure, though it is not uniquely an indicator of deformation. The interaction between rock and water may have been strictly hydrologically driven, and may not require deformation at that time.

The second point of interest is that some modelling calculations indicate, as stated above, that the kinds of structures observed in the DZ may require periods on the order of 700,000 years to form. There is no indication when the structures formed by this calculation, but it is relevant to timing and assessing how these structures might affect the WIPP.

7.3.5 Importance to the WIPP

The structures interpreted from core retrieved from WIPP-12 and ERDA-6 serve as possible analogs to effects of deformation on the WIPP. The DOE and EEG have analyzed the effects of brine and structure at WIPP-12 and the southern portion of the site and concluded the geologic conditions represent no threat to health and safety (see Section 1.1). In addition, both boreholes encountered brine only within the anhydrite units, and that is the experience of all other encounters of these larger brine inflows (see Section 4.4; Popielak et al., 1983). Anhydrite supports the fractures that provide porosity for the brine, and the anhydrite/halite units form an effective seal, as the pressurized brines and gas did not escape upward. The principal concern for isolation would be that the deformation, and its associated phenomena such as pressurized brine and gas, could cause breaching of the repository and provide or make a pathway for the escape of the waste constituents. The period of time expected for development of the structure (700,000 years) is well beyond periods of regulatory concern. In addition, the evidence of the pressurized brine and gas occurrences is that they are confined to these Castile anhydrite layers and do not breach the lower Salado to reach the stratigraphic level of the repository. There is nothing at present to indicate that these features will form in the time period of concern or that they can directly cause a breach of the repository.

7.4 SALADO PENETRATIONS

Within the 16 square-mile WIPP Site Boundary, 36 boreholes have been identified as penetrating into the Salado Formation (Figure 7.4-1; Table 7.4-1). Thirty of these boreholes terminate near the top of the

Salado, the remaining six boreholes were completed through the Salado to deeper formations. These boreholes have either been plugged and abandoned or recompleted for use as hydrologic monitoring wells.

The six wells that penetrate through the Salado are two exploration wells and four drilled in support of WIPP. Two hydrocarbon exploration wells, Clayton Williams #1 Badger Unit and Michael Grace #1 Cotton Baby, were drilled within the WIPP Site Boundary. The location of these wells is shown on Figure 7.4-1, and the construction information is provided in Table 7.4-1. These wells did not produce economical quantities of hydrocarbons and were plugged and abandoned in accordance with the State of New Mexico plugging criteria. The four additional deep boreholes, WIPP-12, WIPP-13, DOE-1 and ERDA-9, were drilled as stratigraphic holes for geologic site characterization (Figure 7.4-1; Table 7.4-1). These four boreholes have been recompleted and are currently used for hydrologic testing and sampling.

Most of the thirty boreholes completed near the top of the Salado Formation were drilled in support of WIPP. Seven of the boreholes (designated with an "H" prefix on Figure 7.4-1) were drilled to just below the Rustler/Salado Formation contact and were completed as hydrologic exploration wells. These wells were completed with the section within the Salado Formation either left as an open hole or, in some cases, a cement plug was installed to prevent mixing of ground water between the Rustler and Salado formations. Five boreholes were drilled within the boundary to characterize the site stratigraphy. Four of these boreholes (WIPP-18, WIPP-19, WIPP-21, and WIPP-22) were subsequently recompleted for hydrological testing and sampling purposes and are currently in use. The remaining stratigraphic borehole, B-25, was drilled as part of the geotechnical foundation analysis program. This borehole was plugged as described in Table 7.4-1. Industry potash and WIPP potash assessment boreholes (designated as "D", "I", or "P", respectively, on Figure 7.4-1) were drilled within the site boundary. These boreholes were plugged with cement and abandoned, except for borehole P-15. This borehole was plugged as described on Table 7.4-1 and recompleted as a hydrologic test well.

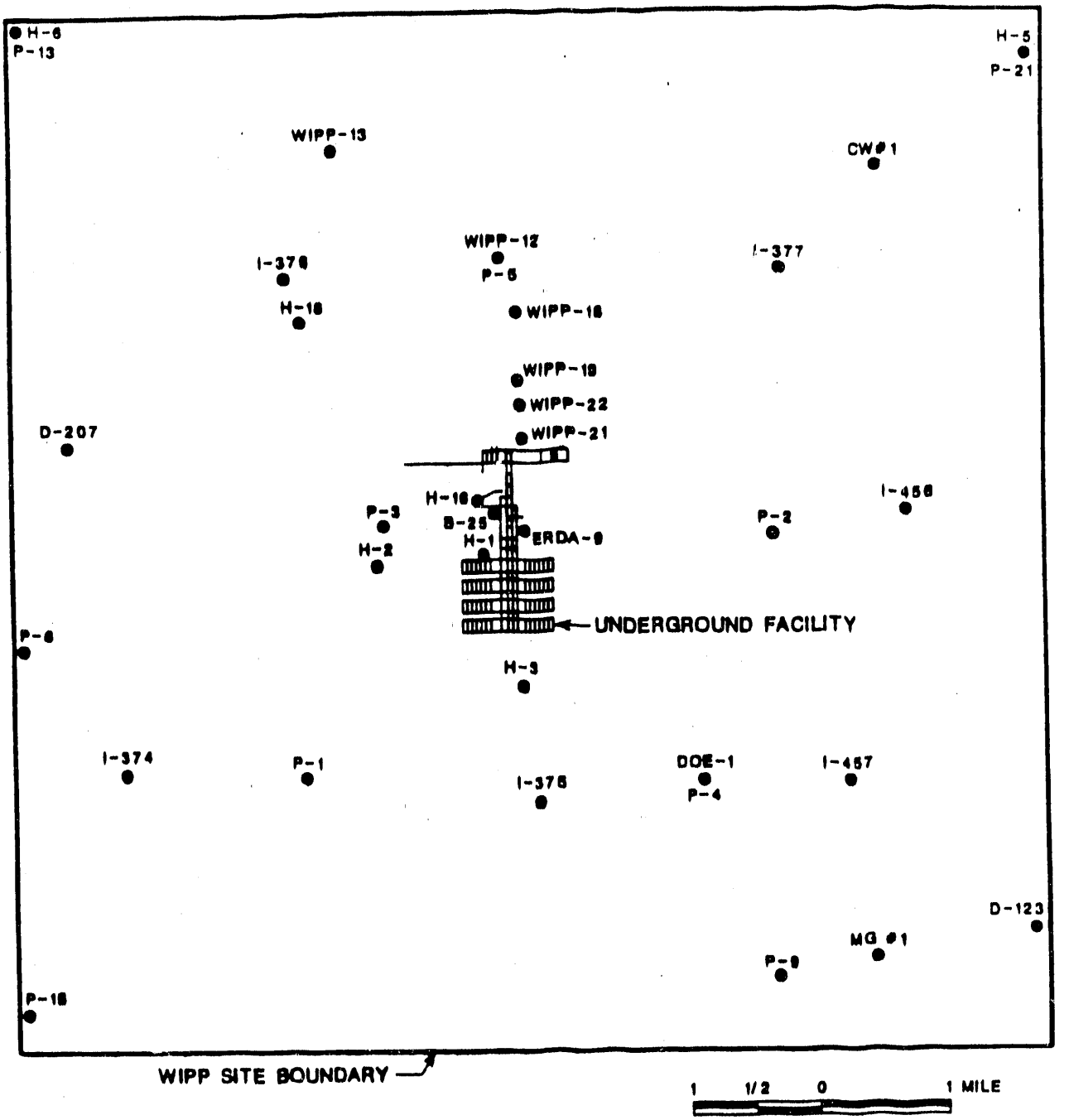
7.5 MARKER BED 138

Marker Bed 138 is an anhydrite layer within the Salado Formation that is located above the facility horizon in the WIPP underground. Two other laterally continuous anhydrite beds are also present. The location of anhydrite layers within the immediate strata sequence around the facility location is shown in Figure 7.5-1.

The actual position of Marker Bed 138 relative to the excavations in different parts of the underground is provided in the Design Validation Final Report (DOE, 1986b). In the proposed storage area, it is approximately 11 meters (36 feet) above the roofs of rooms. It consists of a light to medium grey, microcrystalline, partly laminated anhydrite which contains scattered halite growths. It typically is 0.2 meter (0.7 foot) thick. Clay seam 'K', which is about 1.3 centimeters (0.5 inches) thick, is present at the base of the marker bed.

The two additional anhydrite beds present in the roof at WIPP are closer to excavations than is Marker Bed 138. They are not continuous throughout the basin and therefore, are not identified as marker beds, but they are continuous across the WIPP site. For identification, they have been designated as Anhydrite "A" and Anhydrite "B".

Anhydrite "A" lies approximately 5 meters (16 feet) above the roof in the storage areas but is exposed in the Sandia experimental area north of the storage panels. It is about 0.2 meter (0.7 foot) thick and consists of a light to medium grey, light brown, and sometimes light moderate reddish orange, microcrystalline, partly laminated anhydrite. Halite growths occur within it, and a clear, coarsely



EXPLANATION

B = BOREHOLE DRILLED FOR GEOTECHNICAL FOUNDATION ANALYSIS PROGRAM
D = BOREHOLES FOR POTASH EXPLORATION TO SUPPORT ASSESSMENT OF POTASH RESERVES AT THE WIPP SITE
H = BOREHOLES COMPLETED AS WELLS AT THE RUSTLER/SALADO CONTACT
I = BOREHOLES DRILLED FOR POTASH EXPLORATION BY POTASH INDUSTRY
P = BOREHOLES DRILLED FOR POTASH EXPLORATION TO SUPPORT AN ASSESSMENT OF POTASH RESERVES AT THE WIPP SITE
ALL OTHER BOREHOLES WERE DRILLED TO SUPPORT CHARACTERIZATION OF THE WIPP SITE

FIGURE 7.4-1 SALADO DRILLHOLE LOCATIONS WITHIN WIPP SITE BOUNDARY

TABLE 7.4-1

INFORMATION FOR BOREHOLES WITHIN *16 SQUARE MILE WIPP BOUNDARY*

BOREHOLE NO.	LOCATION T/R/SEC.	COMPLETION DATE	TOTAL DEPTH (FT)	PURPOSE	COMMENTS
B-25	22S/31E/20	2/13/79	902	Stratigraphy	Plugged and abandoned; cement plug from 902' to 461', sand from 461' to 5', cement plug from 5' to surface
CW#1	22S/31E/15	9/13/73	15,22S	Hydrocarbon Explor.	Plugged and abandoned, 9/17/73
Cotton Baby	22S/31E/34	6/16/75	6,700	Hydrocarbon Explor.	Plugged and abandoned, 12/22/75
DOE-1	22S/31E/28	7/28/82	4,057	Statigraphy	Converted to hydrologic monitoring
D-123	22S/31E/34	--	1,880	Potash Exploration	Plugged and abandoned
D-207	22S/31E/19	--	1,613	Potash Exploration	Plugged and abandoned
ERDA-9	22S/31E/20	6/26/76	2,875	Geo. Exploration	Converted to hydrologic monitoring
H-1	22S/31E/29	6/10/76	856	Hydro. Exploration	7" O.D. casing to 848', cement plug to 831'
H-2c	22S/31E/29	2/5/77	795	Hydro. Exploration	6-5/8" O.D. casing to 742', open hole to T.D
H-3b1	22S/31E/29	8/12/76	902	Hydro. Exploration	6-5/8" O.D. casing to 891', cement plug to 864'
H-5c	22S/31E/15	6/3/78	1,076	Hydro. Exploration	5-1/2" O.D. casing to 1,024', open hole to T.D
H-6c	22S/31E/18	6/26/78	741	Hydro. Exploration	5-1/2" O.D. casing to 699', open hole to T.D
H-16	22S/31E/20	8/-/87	851	Hydro. Exploration	7" O.D. casing to 469', open hole to T.D
H-18	22S/31E/20	10/-/87	831	Hydro. Exploration	7" O.D. casing to 673', Cement plug to 766'
I-374	22S/31E/30	--	1,538	Potash Exploration	Plugged and abandoned
I-375	22S/31E/33	--	1,746	Potash Exploration	Plugged and abandoned

TABLE 7.4-1

INFORMATION FOR BOREHOLES WITHIN 16 SQUARE MILE WIPP BOUNDARY
(CONTINUED)

BOREHOLE NO.	LOCATION T/R/SEC.	COMPLETION DATE	TOTAL DEPTH (FT)	PURPOSE	COMMENTS
I-376	22S/31E/20	--	1,702	Potash Exploration	Plugged and abandoned
I-377	22S/31E/22	--	1,876	Potash Exploration	Plugged and abandoned
I-456	22S/31E/27	--	1,975	Potash Exploration	Plugged and abandoned
I-457	22S/31E/27	--	1,885	Potash Exploration	Plugged and abandoned
P-1	22S/31E/29	9/2/76	1,591	Potash Exploration	Plugged and abandoned; 4-1/2" O.D. casing from 591' to 974', plugged with cement
P-2	22S/31E/28	9/2/76	1,895	Potash Exploration	Plugged and abandoned; Recoved all casing, plugged with cement
P-3	22S/31E/20	9/7/76	1,676	Potash Exploration	Plugged and abandoned; 4-1/2" O.D. casing from 490' to 826', plugged with cement
P-4	22S/31E/28	9/4/76	1,857	Potash Exploration	Plugged and abandoned; Recovered all casing, plugged with cement
P-5	22S/31E/17	9/21/76	1,830	Potash Exploration	Plugged and abandoned; 4-1/2" O.D. casing from 435' to 1,003', plugged with cement
P-6	22S/31E/30	9/16/76	1,573	Potash Exploration	Plugged and abandoned; Recovered all casing, plugged with cement
P-9	22S/31E/33	9/25/76	1,796	Potash Exploration	Plugged and abandoned; Recovered all casing, plugged with cement
P-13	22S/31E/18	9/23/76	1,576	Potash Exploration	Plugged and abandoned; Recovered all casing, plugged with cement
P-15	22S/31E/18	10/15/76	1,465	Potash Exploration	Converted to hydrologic monitoring, cement plug from 1465 to 620 feet

TABLE 7.4-1

INFORMATION FOR BOREHOLES WITHIN 16 SQUARE MILE WIPP BOUNDARY
(CONTINUED)

BOREHOLE NO.	LOCATION T/R/SEC.	COMPLETION DATE	TOTAL DEPTH (FT)	PURPOSE	COMMENTS
P-21	22S/31E/15	10/26/76	1,915	Potash Exploration	Plugged and abandoned; Recovered all casing, plugged with cement
WIPP-12	22S/31E/17	12/7/78	3,928	Geo. Exploration	9-5/8" O.D. casing to 1,001'; cement plug to 2,784'; converted to hydrologic monitoring
WIPP-13	22S/31E/17	8/6/78	3,856	Geo. Exploration	9-5/8" O.D. casing to 1,023'; open hole to T.D., converted to hydrologic monitoring
WIPP-18	22S/31E/20	4/3/78	1,060	Stratigraphy	5-1/2" O.D. casing to 1,050'; cement plug to 1,050'; converted to hydrologic monitoring
WIPP-19	22S/31E/20	5/8/78	1,040	Stratigraphy	5-1/2" O.D. casing to 1,035'; cement plug to 1,035'; converted to hydrologic monitoring
WIPP-21	22S/31E/20	5/27/78	1,045	Stratigraphy	5-1/2" O.D. casing to 1,014'; cement plug to 1,014'; converted to hydrologic monitoring
WIPP-22	22S/31E/20	5/24/78	1,452	Stratigraphy	5-1/2" O.D. casing to 950'; cement plug to 941'; converted to hydrologic monitoring

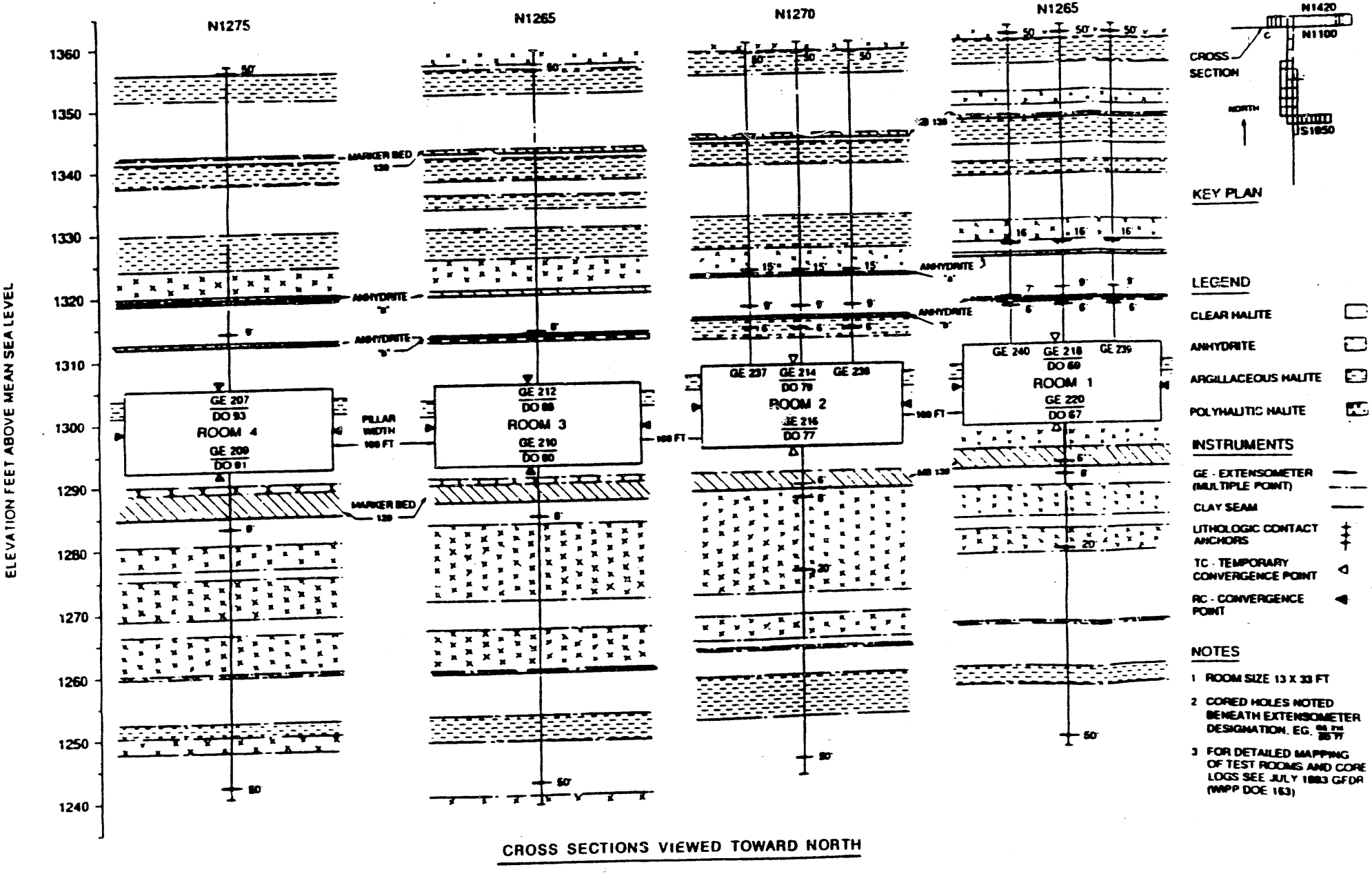


FIGURE 7.5-1 GEOLOGIC CROSS SECTIONS IN TEST ROOMS

crystalline halite layer up to 5 centimeters (2 inches) wide is found within exposures in the experimental areas. A thin grey clay seam identified as clay seam 'H' lies at the base of Anhydrite "A".

Anhydrite "B" lies approximately 2 meters (7 feet) above the storage areas, and again is exposed in the experimental area. It is about 0.2 meters (0.7) feet thick and consists of a light to medium grey, microcrystalline anhydrite. Halite growths occur within it. A thin grey clay seam identified as clay seam 'G' lies at the base of Anhydrite "B". Anhydrite "A" and Anhydrite "B" both have characteristics that are similar to Marker Bed 138. Evaluations of repository performance with respect to brine and gas migration in the roof of excavations must consider these anhydrite layers as well as Marker Bed 138.

7.5.1 Development of Disturbed Rock Zone

The disturbed rock zone is the zone of rock that is disturbed by excavation of openings. In general, the disturbed rock zone is characterized by an increase in rock porosity that decreases with distance from the opening. At the WIPP, the disturbed zone contains discrete fractures that develop with time. These are found down to Marker Bed 139 in the floor and up to the Anhydrite "B" in the roof. To date, there is no evidence of open fractures developing beyond these stratigraphic units surrounding openings within the storage horizon. The fracturing has been characterized from observations made in the SPDV Test Rooms. These test rooms, some of the oldest excavations at the WIPP, are located at the same horizon.

Marker Bed 139 lies approximately 1.7 meters (5.5 feet) below floor level in the test rooms. It is approximately 1.2 to 1.5 meters (4 to 5 feet) thick. Marker Bed 139 has been significantly disturbed by the excavation of these openings. This was first observed as fracturing of floor strata down to Marker Bed 139, about 2-1/2 years following excavation of the test rooms. Fractures in some locations in the test rooms are now more than 15 centimeters (6 inches) wide. Discussion of the fracturing that developed in the floor associated with Marker Bed 139 and the salt above it is provided in the Design Validation Final Report (DOE, 1986b).

About 4 years after excavation, fracturing developed in the roof of the test rooms. The roof fractures can be summarized as follows:

1. Sub-horizontal fractures develop within the first 46 centimeters (18 inches) of the roof. The fractures are generally closed and show little evidence of displacement. They may be associated with lithologic changes.

2. Low-angled fracturing develops from the corners of the rooms. These fractures may be filled with sheared material.

3. Bed separation develops at the Anhydrite "B"/salt interface.

7.5.2 Impact of Anhydrite Layers on Brine and Gas Migration

Marker Bed 138 is not expected to impact repository performance with respect to brine and gas migration through the roof strata in the same manner that Marker Bed 139 may affect performance via migration beneath the floor. Marker Bed 138 is about 11 meters (36 feet) away from the storage rooms, whereas Marker Bed 139 is only about 1.5 meters (5 feet) beneath the excavations. Since disturbance of the rock is a function of distance from excavation, Marker Bed 139 will be more disturbed than Marker Bed 138.

The limited disturbance of Marker Bed 138 is confirmed by the field data from geomechanical instrumentation which has monitored performance up to 15 meters (50 feet) from the excavations both in the roof and floor. Extensometers, which measure vertical rock movements in the roof, have indicated small rock deformations occurring at the Marker Bed 138 level, but offer no evidence for open separations occurring at the Marker Bed 138/salt interface. Inclinometers, which measure lateral rock

movements in roof and floor boreholes, do show lateral strata shifts at Marker Bed 138. These shifts probably indicate that shear is occurring at the interface due to the markedly different mechanical properties of the salt, anhydrite, and clay. The discontinuities produced by these shifts remain tight and therefore are not likely to provide pathways for brine or gas migration. The distance from the excavations, the impermeability of the intervening salt, and the lack of pathways connecting Marker Bed 138 and the excavations are reasons to believe that this geologic unit will not have an impact on performance with respect to brine and gas migration.

Anhydrite "A" is not expected to impact gas or brine migration for the same reasons that Marker Bed 138 will not. However, Anhydrite "B" is much closer to the excavations and has been disturbed. In the SPDV test rooms, bed separation of several inches has been observed at the Anhydrite "B" layer within boreholes and has been measured by extensometers. Inclinometers have also shown significant offset in strata at the Anhydrite "B"/salt interface. In addition, fracturing that extends toward and possibly as far as the Anhydrite "B" layer has been observed in the roof of test rooms. The fracturing could provide direct open pathways connecting the bed separation with the room. The pathways will be similar to pathways in the floor connecting that of Marker Bed 139 with the rooms. Therefore, it is expected that the performance of Anhydrite "B" will be similar to that of Marker Bed 139 with respect to brine and gas migration.

Pathways for brine and gas migration in the floor and in the roof are limited to zones directly above and below excavations. In the pillars, the anhydrite beds will remain closed due to the compressive loading and it is not expected that migration will occur through pillars. At the panel entrance, seals will be installed to isolate each panel. These will prevent migration out of a panel not only through the excavation, but also through any disturbed zone about the excavations. Although seal design is not final, the removal of material from roof and floor may be required in seal areas up to Anhydrite "B" and down to Marker Bed 139 to eliminate any open fractures that may have developed with time.

Following decommissioning of the repository, the salt will creep close to and heal fractures. This will probably not occur until room closure is complete and compressive stresses build up in the disturbed zone.

7.6 QA/QC FOR GEOLOGICAL INFORMATION

The information cited in this section generally falls into three categories. These are Agency reports, reports by WIPP project participants, and other reports. This latter category includes reports by academia, reports by private interests, and reports published in referenced literature.

Quality Assurance/Quality Control (QA/QC) information varies with each type of report and is a direct function of the purpose for which the report was prepared. Generally, agency reports from government agencies such as the U.S. Geological Survey follow internal QA/QC procedures to provide reasonable assurance that the information disseminated is accurate since, in many cases, it may be used for investment (resource or construction) purposes. On the other extreme, reports prepared by academia or by private parties may have little if any independent QA/QC associated with them since their purpose may be one of "proof of principle" regarding the interpretation of geological information. In this case, the process of peer review and comment in the open literature and/or in technical meetings provides some degree of QA/QC.

The majority of the information used in selecting and verifying the adequacy of the WIPP site was gathered by project participants under contract to the DOE. In these instances, extensive QA/QC was applied to field work, the process of analyzing the data, and the reporting. For the reports cited in this

section, the three participants that have played the largest roles are Sandia National Laboratories, Westinghouse Electric Corporation, and International Technology Corporation (and its predecessor, D'Appolonia Consulting Engineers).

Sandia National Laboratories conducts geologic and hydrologic activities in accordance with their "WIPP Quality Assurance Program Plan" (WIPP QAPP, Rev. N, 10/5/89). This QA program meets the requirements of NQA-1, DOE 5700.6B, DOE AL 5700.6B, Chapter 11 of the WIPP Final Safety Analysis Report, WPO Management Directives, Sandia National Laboratories Quality Plan, and Sandia National Laboratories Organization 6000 QA Policy. Records documenting the QA/QC activity applied to past and ongoing geotechnical activities by Sandia are maintained at the WIPP site (for the most recent activities) and in the Sandia Library in Albuquerque.

A comprehensive Westinghouse Quality Assurance Program has been developed at the WIPP site related to the geologic and hydrologic activities. The Westinghouse commitment to quality is stated in the Final Safety Analysis Report and is documented in the Westinghouse Quality Program Manual, WP 13-1. The Westinghouse program embraces the QA standards of ANSI/ASME NQA-1 and DOE 5700.6B. Records and other documents related to the Westinghouse QA/QC program for geological, hydrological, and environmental work are available at the WIPP site.

The engineering activities performed by International Technology Corporation (IT) in support of the WIPP Project are controlled by a written Quality Assurance Program. This program, established in 1973, operates in compliance with ANSI/ASME NQA-1 and current EPA guidance (e.g., QAMS 005-80). Records relative to IT's QA/QC activity are maintained at their corporate office in Albuquerque.

List of References for Appendix D8

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APPENDIX D9

DISSOLUTION FEATURES

FROM PREVIOUSLY PUBLISHED NO-MIGRATION VARIANCE PETITION,
ADDENDUM, SECTION 3.0, VOLUME VII

U.S. Department of Energy (DOE), 1990,
DOE/WIPP 89-003, Revision 1, Carlsbad, New Mexico

3.0 DISSOLUTION FEATURES

This section provides a detailed discussion of dissolution processes, features, and rates. It includes a review of the published literature to relate features observed in southeastern New Mexico to features and processes observed elsewhere. The following paragraphs summarize this section and can serve as a guide for readers wishing to find more information about a specific topic regarding dissolution.

Section 3.1 reviews the literature with respect to factors controlling dissolution (Section 3.1.1), dissolution features in southeastern New Mexico (Section 3.1.2), karst formation (Section 3.1.3.1), solution breccia formation (Section 3.1.3.2), other breccia formation mechanisms (Section 3.1.3.3), Delaware Basin features (Section 3.1.4), and Rustler Formation dissolution features (Section 3.1.5). The conclusion of this section, with respect to dissolution around the WIPP site, is that dissolution is not considered a significant threat to the performance of the WIPP site. This conclusion relates to both dissolution of the Rustler Formation, which overlies the repository host formation, the Salado, and the Castile Formation, which underlies the Salado Formation.

The presence of brecciated material in Rustler Formation has been the most widely accepted evidence of dissolution after deposition. Recent evaluations of the brecciated materials in cores, shafts, and geophysical logs suggest that the Rustler has undergone little post-depositional dissolution. This evidence limits the volume of halite assumed to have been dissolved and hence decreases estimates of dissolution rate.

Potential for dissolution upward into both the Castile and Salado Formations from the underlying Bell Canyon Formation is also evaluated. The high salinity of the Bell Canyon fluid and the volume of fluid present are not likely to cause dissolution of the Castile Formation. Similar to the Rustler Formation, post-depositional dissolution is now interpreted to be less, based on physical features in the Castile Formation. These features suggest that halite was not deposited as widely or was destroyed during deposition of clastic units. The result of this interpretation is to decrease the previously estimated rates of dissolution.

Section 3.2 describes the dissolution features present in Nash Draw. These include sinkholes, caves, domes, and pipes in and on the Rustler Formation. It is concluded that the features in Nash Draw are the result of dissolution of the upper part of the Salado Formation and collapse of the overlying units. A dissolution front moving from Nash Draw eastward to the WIPP site has been hypothesized. Estimates of the rate of dissolution front advance vary from 0.1 to 0.15 meters/1000 years (0.33 to 0.5 feet/1000 years). At that rate, the dissolution front of the upper Salado would reach the northwestern corner of the WIPP site in 10.5 to 16 million years. This rate is based on the assumption that the halite was originally deposited in constant thicknesses across the area, recent studies demonstrate that this assumption is not true, therefore this rate is an extremely high upper bound on the rate of dissolution. Some investigators have suggested that the dissolution front has already impinged on the northwestern corner of the WIPP site. However, the estimated maximum amount of dissolved material from the Rustler-Salado contact is about 3 meters (10 feet).

Deep seated dissolution features are discussed in Section 3.3. These feature include karst mounds and domes. Four of these are located in the northern edge of Nash Draw. Three of these have been shown to have formed as a result of processes exclusively related to the Capitan Reef aquifer, which underlies them. This type of dissolution could not occur at the WIPP site because the Capitan Reef aquifer is 11 kilometers (7 miles) away from the boundary of the WIPP site. The fourth dome is interpreted to be a structural feature, unrelated to dissolution.

Section 3.4 describes other dissolution features in southeastern New Mexico. These are the Big Sinks, located within the Balmorhea-Loving Trough, and San Simon Swale. Both of these features are the result of collapse following dissolution, but neither of them appear to have potential to create any significant effects on the WIPP.

Section 3.5 examines that impact of climatic change on dissolution patterns and rates. It concludes that increase in rainfall is the only factor in predicted climate change that could increase the removal of soluble parts of the surficial and near-surface evaporites. There is no specific information on the absolute amounts by which rainfall may have changed in the Pleistocene, however, rainfall amounts and patterns are expected to be similar in scope to those that occurred during the Pleistocene. Since dissolution at the WIPP site during the Pleistocene had a negligible effect, it is expected that a return to wetter climatic conditions would have the same, negligible effect.

The occurrence of brine pockets in Salado Formation is described in Section 3.6. They occur in relatively small (< 1 cubic meter, <100 gallons), isolated pockets along bedding planes. These are described in greater detail in Section 4.0.

3.1 REVIEW OF DISSOLUTION

This section is a review of literature of both the general phenomenon of evaporite dissolution and specific features and hypotheses of dissolution in southeastern New Mexico. The objective of this section is to summarize current knowledge of evaporite dissolution. Because the literature has been reviewed in Holt and Powers (1988) and in part in Holt et al. (1989), text from these sources will be used extensively or modified as appropriate. Specific features in the area of the WIPP site will be discussed in later sections; some readers may wish to review only that portion. In this first part of the section, a broad range of ideas will be presented, and concepts such as deep-seated dissolution will be reviewed. A general analysis of more speculative aspects, such as the effects that might be expected from climatic change, is presented.

In general, dissolution is not considered a significant threat to isolation of waste at the WIPP site. Several estimates of the rates of dissolution (e.g., Bachman et al., 1973; Jones et al., 1973) would indicate periods of millions of years before the Salado at the WIPP site would be affected. Anderson (1978) and Anderson and Kirkland (1980) proposed that solution from the Delaware Mountain Group upward through the Castile and Salado Formations could jeopardize the site because specific locations would not be predictable. An analysis of this proposed mechanism by Wood et al. (1982) indicates small potential for dissolution of the Castile and Salado by fluid from the Delaware Mountain Group. Lambert (1983) concurred because the chemistry of the water in the Delaware Mountain Group, as well as the volume of fluid, are inconsistent with dissolution of the Castile. Units below the Castile have high salinities and little present potential for dissolution.

Above the Salado evaporites and within the Rustler Formation, dissolution has occurred, but its extent within the Rustler Formation has been greatly overestimated. This is because most units whose configuration was formerly attributed to dissolution are now interpreted to be due to depositional processes (Holt and Powers, 1988). The relatively low estimates of dissolution rates by Jones et al. (1973) are based on removal of halite from rocks now interpreted to be where halite was not preserved during deposition.

3.1.1 Introduction

From the time bedded salt was initially recommended (NAS, 1957) as the preferred rock type for the disposal of radioactive waste, part of the concern in selecting specific sites has been the role of dissolution. Thick sections of evaporites, including halite, in basins around the world clearly attest to the

fact that dissolution has not had a significant impact. No halite section could long remain in the presence of circulating fresh, or even moderately saline, fluid in any quantity. Nevertheless, some basins that have evaporite rocks, such as the Delaware Basin, include areas in which outcrops and/or beds at depth contain no halite or appear to have greatly reduced sections of halite compared to other parts of the basin. These areas are frequently interpreted, with or without additional criteria, as the result of the dissolution of halite or other soluble evaporites from the section. The Delaware Basin continues to be examined for evidence of dissolution and the processes, rates, and ages of such dissolution. The discussion and search for evidence continues partly because opinions have varied as to the effects such dissolution might have on the long-term isolation of radioactive waste in the Waste Isolation Pilot Plant (WIPP).

Evaporites are generally considered to dissolve when the factors of source, solution, pathway, and sink are present (Johnson, 1981). That is, a soluble material needs to be present, a fluid capable of dissolving the soluble rocks exists, a pathway for movement is provided, and a sink is available to permit continuing drainage from the area of solution. Lambert (1983) used slightly different terminology for these factors, using five terms (trigger, path, continuity, source, and sink) to be more explicit about initiating events (trigger), lateral or vertical extent of soluble rock (continuity), and the nature of the fluid (source). In a recent study of the Rustler Formation, Holt and Powers (1988) recognized that more fundamental questions, however, overrode the discussion of these factors:

- What is the real extent of dissolution in the Rustler Formation?
- What is the timing of dissolution in the Rustler Formation?
- What are the criteria can be used to distinguish between depositional variation, modern or continuing dissolution, and ancient dissolution?

Most previous investigators conservatively estimated the extent and effects of dissolution, assuming the maximum possible halite removal. In a different approach, Holt and Powers (1988) examined the evidence about deposition of halite and interpreted large areas of Rustler Formation rocks to have had halite removed before the overlying sediments were deposited. This evidence changes the previous assumptions made about the extent, timing, and nature of the dissolution products.

The features generally attributed to dissolution in southeastern New Mexico are observable at the various scales:

- Mapable at scales from 1:100,000 to 1:250,000
- On borehole geophysical logs
- In hand specimen without magnification
- Microscopic examination of minerals and rock fragments.

At all scales, the same factors are critical. The difference in scale is due to the relative volume of material dissolved and whether the solutes were transported out of the system (at whatever scale of observation). For example, a large relative volume may be removed at a microscopic scale without necessarily affecting operations or isolation of waste on the scale of a repository. Although these microscopic diagenetic alterations to the sediment are important in interpreting the geologic history, the major focus of this discussion of dissolution phenomena and processes is on scales that are nearer repository size.

3.1.2 Dissolution in Southeastern New Mexico

This section is a summary of the study of dissolution in the Delaware Basin, and it indicates the range of studies that bear on the problem. Recent detailed studies of the rocks and their settings are weighted heavily in the discussion over some of the earlier work which concentrated almost exclusively on the variation in thickness of units. The features of several zones previously attributed exclusively to

dissolution are reinterpreted as depositional phenomena, albeit with synsedimentary dissolution for some areas. The extent of dissolution is more realistically estimated if both depositional patterns and dissolution features are considered. More importantly, it is necessary to use descriptive, non-genetic terminology to describe the sedimentary features present in the rocks. The descriptive terminology should always be applicable, even though genetic interpretations of those features may change as our understanding of evaporite synsedimentary processes grows. This section will emphasize studies with this perspective over some of the earlier work.

Early workers include Lee (1925), who discussed solution and fill related to the Pecos River valley and gypsum terrains. Maley and Huffington (1953) described stratigraphic relationships of evaporite beds near and under the Pecos River valley, and they ascribed thinned beds and the observable stratigraphic relationships to dissolution. Olive (1957) described surficial troughs on a surface of Castle gypsum in the Yeso Hills/Gypsum Plain area; he concluded that subsidence had occurred as a result of dissolution of gypsum. More recently, Anderson and several co-workers (Anderson, 1978, 1981, 1982; Anderson et al., 1972, 1978) discussed data and interpreted dissolution of the Castile and Salado Formations. These authors generally concluded that about 50 percent of the halite in the Delaware Basin has been dissolved and that a major part dissolved in the late Tertiary. Bachman (1974, 1976, 1980, 1981, 1984, 1985) extends the period of possible dissolution, mainly for the Rustler and Salado Formations, back to Triassic, and possibly Permian, time. Robinson and Powers (1987) examined alleged dissolution residues from the lower Castile Formation in the western Delaware Basin and concluded that these rocks are resedimented clasts of the Castile. This hypothesis would limit both the depositional extent of lower Castile halite and the extent of dissolution in this unit. Lambert (1983) extensively reviewed the data and hypotheses concerning the existence, processes, and rates of dissolution for evaporites of the northern Delaware Basin and has modified dissolution hypotheses previously presented by Anderson (1978). Holt and Powers (1984, 1986b, 1988) concluded that the Rustler was less extensively dissolved than had previously been interpreted, based on the hypothesis that some zones that have been interpreted as dissolution residues are depositional features in the Rustler Formation at the WIPP site. Sares and Wells (1987) present some of the details of dissolution associated with development of karst in evaporites of the Gypsum Plains.

In addition to the data and hypotheses concerning the evaporite rocks of southeastern New Mexico, the literature has also been examined for related discussions. Some of the opposing viewpoints and some of the assumptions and/or background information and implications for southeastern New Mexico will be stated as they may not always be explicit or familiar to some readers. Some details are not reviewed here, as that has frequently been done (e.g., Anderson, 1978, 1981, 1982; Anderson et al., 1972, 1978; Anderson and Kirkland, 1980; Bachman, 1974, 1976, 1980, 1981, 1984; Bachman et al., 1977; Lambert, 1983; Powers et al., 1978), emphasizing the suitability of the northern Delaware Basin or the WIPP site for the disposal of radioactive waste. Several authors (e.g., Anderson, 1982; Bachman, 1984; Lambert, 1983) have reviewed various hypotheses to account for some of the features in southeastern New Mexico.

This review begins with the features and characteristics from a number of studies in the literature and summarizes the evidence and processes hypothesized to account for them. There are processes which occur at or near the surface (karst) and processes that are hypothesized to occur at some depth within the sedimentary rocks ("deep" dissolution or stratabound dissolution resulting in solution breccias). In addition, there are features attributed to "early" and "late" stages. Early may mean synsedimentary (e.g., Powers and Hassinger, 1985), or it may mean that the dissolution is geologically old and there is no evidence of dissolution since that time. Late usually means that dissolution has occurred during the Quaternary or may be active. Neither of these terms has necessarily been used consistently with depth of process, so that near-surface ("shallow") and deep are also used as modifiers to describe the relative position of the sediments when dissolution took place.

3.1.3 Dissolution Literature Review

Within the following sections, dissolution features or processes are grouped according to the location of the solution process: (a) karst, if the dissolution occurred at or near the surface, or (b) solution breccia beds, if dissolution occurred at sufficient depth (undefined) to result in brecciation of the units.

3.1.3.1 Karst

This discussion of karst is extracted from the extensive summary in Holt and Powers (1988). The literature on near-surface dissolution or karst is very extensive for carbonates. Excellent reviews of karst and their hydrologic systems have been provided by Herak and Stringfield (1972), Boeglie (1980), Sweeting (1972), Jennings (1971), and in Dilamarter and Csallany, eds. (1977).

Evaporite rocks dissolving at and near the surface by karst processes are not commonly described in the literature, partly because sulfates and halite, especially, are more soluble and do not crop out well. Among the reports of research on karst in evaporites in the southeastern New Mexico area are those by Sares and Wells (1987); Bachman et al. (1973); and Bachman (1974, 1976, 1980, 1981, 1984, 1985, 1987a, 1987b). The processes by which karst is formed in evaporites are different from carbonate karst, because the dissolution and corrosion of evaporites are dominantly physical processes in contrast to the chemical activity where meteoric water combines with carbon dioxide to form acid which dissolves carbonate (Bachman, 1985; Pfeiffer and Hahn, 1972). Though the processes by which karst is formed might be differentiated, most of the resulting landforms and near surface features are described by the same terminology.

Two evaporite karst features, karst mounds and karst domes from southeastern New Mexico, have been named and described by Bachman (1980). Karst mounds are slightly elevated topographic features consisting of brecciated material attributed to solution-collapse and subsequent erosion of less resistant surrounding rocks. Karst domes are also slightly elevated topographic features, apparently domal in structure, and attributed to solution of surrounding evaporites at shallow depths and subsidence of these areas to leave the domal features. Some karst domes may be resistant to shallow solution due to a collapsed core from earlier dissolution. Breccia pipes, breccia chimneys, and transformational breccias are extreme examples of this, from deep-seated earlier dissolution and collapse that have been reported from southeastern New Mexico (e.g., Elliot, 1976; Anderson, 1978; Bachman, 1987a, 1987b) and elsewhere (e.g., Landes, 1945; Bowles and Braddock, 1963; Wenrich, 1985).

Sares and Wells (1987) report their work on the karst of the Gypsum Plain of southeastern New Mexico. Among the features formed are dolines, collapse sinkholes, caves, and erosional surfaces, while the drainage system has been significantly affected by karst processes. From the same general area, Olive (1957) examined large linear valleys which he termed solution-subsidence troughs. Bachman (1974, 1976, 1980) also reports dolines and collapse features in the Pecos River valley, some of which are attributable to evaporite karst. Nash Draw is considered by Bachman (1974) to be due to solution, erosion, and subsidence from evaporite karst processes.

Modern or active karst terrains are mainly investigated for their hydrological patterns and may exhibit few important features by which to interpret ancient karst systems from the breccias and related rocks, including residues, that are the preserved record. Several studies of interpreted ancient karst in carbonates are important summaries. Units from two separate areas, the Madison Limestone or Group of Wyoming and Montana and the Mississippi Valley-type (MVT) lead-zinc deposits of Missouri and surrounding areas, reveal important features that are partially attributed to surficial and near-surface processes.

Roberts (1966) describes both paleokarst features and solution breccia beds from the Madison Group of south-central Montana. The paleokarst and solution breccia beds have some features in common: unstratified deposits, mainly carbonate fragments with some chert in a matrix that weathers reddish or yellowish gray, and mostly angular to subangular fragments. The clay mineralogy is different, mainly kaolinite in karst deposits and illite in solution breccias. Roberts (1966) reports that karst is not stratigraphically controlled, exhibiting poorly defined upper and lower surfaces, cavities that widen upward, and more matrix. He also inferred that the karst developed in the late Mississippian, prior to the deposition of the Amsden Formation of late Mississippian (Chesterian) to Pennsylvanian age. He separated the karst in process and time from the solution breccia beds.

Sando (1974) examined the Madison Limestone of north-central Wyoming, and he attributed several features to paleokarst. Enlarged joints, filled by red clastics, are fractures enlarged by meteoric water percolating down from the surface. Large cavities, with angular blocks of carbonate and clastic fill, occur at the top of the Madison and extend as much as 30 meters (90 feet) below the surface of the Madison. Sando (1974) interprets these cavities as sinkholes. Caves are also common in this part of the Madison. Sando (1974) differentiates pre-Amsden caves, filled with red clastics, from open cavities which may be Tertiary or Holocene in age. The older caves lack flowstones and dripstones, and are interpreted to have occurred below the vadose zone during the time of exposure in the late Mississippian. Breccia zones that are stratigraphically limited and have a clastic matrix were also reported by Sando (1974). He interprets these forms as another phase of the same process that formed caves, sinkholes, and enlarged joints during the Mississippian. In this respect, Sando (1974) differs from the interpretation by Roberts (1966) of breccia beds caused by solution at depth (see below).

The Carrara Formation and overlying Bonanza King Limestone in southern Nevada display angular breccia blocks, varying in size, that are grossly stratiform. Gillett (1983) proposes this breccia unit as a "healed" early Tertiary age cave and rejects the hypothesis of collapse due to evaporite dissolution. Gillett follows Middleton (1961), Roberts (1966), and Vaughn (1978) (see below) in expecting a planar basal contact and strongly stratiform body to form from evaporite dissolution. No direct evidence of evaporites was found and Gillett (1983) cites work by Palmer and Halley (1979) suggesting open-shelf, unrestricted marine environments.

Bretz (1950) describes features called circle deposits from Missouri. He attributes these to collapsed caves. Bretz also reports filled caves which "are so obviously solution caves that there never have been other interpretations of their origin".

3.1.3.2 Solution Breccia Beds

Several features, including solution breccia beds or rough equivalents and transformational breccias or breccia pipes, have been described by a variety of authors, most of whom have attributed the phenomena to dissolution of a bed, especially evaporite rock, at some depth under saturated (phreatic) conditions. The descriptions of these features yield some comparisons with the apparently karst-related phenomena. The Madison Group and MVT deposits are important areas displaying these features.

Landes et al. (1945) describe the Mackinac Breccia, a brecciated equivalent to several Silurian to Devonian age formations of northern southern Michigan. Landes divides the breccia into three types: megabreccia, intra-formational breccia, and trans-formational breccia. Megabreccia consists of very large inclined blocks with random orientations. Stages of brecciation range from "let-down" to severely shattered and disturbed. Intra-formational breccia occurs in layers surrounded by non-brecciated rock. Landes always associates intra-formational breccias with megabreccias. Stages range from extensive

fissuring to complete brecciation. Trans-formational breccias cut through several stratigraphic units, occurring as vertical bodies to several hundred feet in width. Landes estimates the vertical thickness to be as much as 500 meters (1,500 feet). Fragments are nearly all very angular. Some trans-formational breccias are well-indurated, forming prominent stacks or other features due to higher resistance to recent erosion than the surrounding rocks. More commonly, these breccias are porous and non-indurated to partially indurated and do not stand out as an erosion-resistant rock.

Landes et al. (1945) conclude that brecciation occurred before the overlying Devonian Dundee Limestone was deposited. Landes interprets the Mackinac Breccia to have formed from collapse of overlying units when salt was dissolved from the Salina Group as the Salina was exposed during early Devonian around the margin of the basin. Brines created by the solution may be the source of the central basin salts of the lower Devonian Detroit River Formation. The surface was eroded and smoothed, and the Dundee Limestone was deposited unconformably over the Mackinac Breccia and related formations. Recent erosion has re-exposed these breccias.

The Mississippian Boone Formation of the area around the Kansas-Oklahoma border near Missouri is a dominantly carbonate unit that hosts lead and zinc deposits and displays solution/subsidence features (McKnight and Fischer, 1970). Slump pipes are brecciated, irregularly cylindrical masses 30 to 100 meters (100 to 300 feet) in diameter with a vertical displacement of several tens of feet along bounding vertical faults. Slump breccias are chert nodules to fragments of rock in a clay residuum in the Boone Formation. Later Mississippian units overlying the Boone have slump breccias with large limestone blocks and angular fragments in a residual material. McKnight and Fischer (1970) infer that these slump breccias are basal parts of slump pipes.

Ohle (1985) reviewed breccia types and probable breccia-producing processes for a variety of districts in North America hosting MVT Pb-Zn and related deposits. The breccia bodies are considered by Ohle (1985) to comprise two broad types: strata-bound (or mantos) and breccia columns or chimneys (or breccia bodies transecting strata boundaries). With some exceptions, the breccias are attributed principally to gravity-induced collapse associated with solution. Most of the solution and collapse is ascribed to passage of hot fluids related to ore deposition, though some has been considered true karst. The breccias may consist of very large to very small, angular clasts that tend to be equidimensional rather than slab-like blocks associated with cave fillings. Ohle (1985) considers chemical brecciation (Sawkins, 1969; Ohle, 1985) or tectonic forces may have produced smaller breccia fragments within these MVT deposits.

Ohle (1985) also briefly mentions breccias of minor extent probably caused by sedimentary processes or syndepositional slides. Snyder and Odell (1958), as reviewed below, consider some of the breccia bodies to be syndepositional slides.

Rogers and Davis (1977) reviewed the geology of the Buick mine, a Pb-Zn mine along the Viburnum Trend of southeast Missouri formed in carbonate breccias. They consider the setting consistent with a carbonate-evaporite margin, and they believe the evaporites dissolved, causing collapse and brecciation. Beales and Hardy (1977) have summarized the indirect evidence for evaporites in the Viburnum Trend of southeastern Missouri. They conclude that tiny gypsum crystals, including swallowtail twins, in impervious breccias directly indicate the former, more general presence of evaporites. The problem of "occult" evaporites was also discussed by Schreiber and Schreiber (1977) in a study of Mediterranean Messinian evaporites and modern solar salt works.

Middleton (1961) also describes breccias within the Mission Canyon Formation of the Madison Group in Montana. He reports that the fragments are variable in size (microscopic to 3 meters; 10 feet) and very angular to slightly rounded on edges. Limestone is the common lithology, but clasts are sometimes polymictic. Breccias of former breccias indicate multiple episodes. Fragments of different strata may be

mixed, though a crude stratigraphy may be preserved. Middleton (1961) states that "the lower boundary of almost every breccia is well defined," though the breccias do not have the same extent upward. He describes well the upward transitions:

> "A gradual transition may take place upwards from a breccia consisting of mixed, rotated fragments into one in which there is demonstrably little movement of the fragments and the rock has been brecciated in place."

Middleton suggests that brecciation occurred before the Amsden Formation was deposited, but he is careful to point out he did not have evidence to support or refute this hypothesis. Finally, as the overlying units are not extensively brecciated, Middleton (1961) believes that "a thick breccia usually indicates an original zone of thin interbeds or interlaminations of limestone and anhydrite".

Roberts (1966) also found that solution breccia beds in the Mission Canyon Formation have a sharp, well-defined, and laterally continuous lower boundary. He reported, as did Middleton (1961) and Severson (1952), a vertical progression of breccia fabrics from small heterogenous unsorted fragments upward to slightly fractured and displaced roof rocks. Some wells in the area show anhydrite that is considered stratigraphically in the same position as the solution-breccias. Roberts (1966) considers this solution at depth to have occurred during or after the Laramide orogeny.

Evaporites from the Williston Basin and surrounding areas are interpreted by Parker (1967) to have been partially dissolved. Beds overlying the evaporites are thickened by additional sedimentation to compensate for the salt removal and indicate the time of removal. Parker (1967) interprets these changes of thickness and lateral loss of halite mainly on the basis of geophysical logs. Also from North Dakota (Fryberg field), salt was removed from Permian rocks resulting in complete compensation by the end of the Jurassic (Swift Formation), though elsewhere in the area, Parker (1967) cites Anderson and Kirkland (1966) to indicate that collapse may affect Jurassic and Cretaceous rocks. In the Outlook field in Montana, Parker (1967) shows that solution of the Lower Devonian Prairie Formation is completely compensated by sedimentation during the late Devonian.

Stanton (1966) reviewed features and processes related to dissolution of the Upper Devonian Leduc Formation from the South Sturgeon Lake field, Alberta, and concluded that the features were indistinguishable from the Mission Canyon solution breccias and the Mackinac Breccia. Stanton (1966) reports successive stages of primary evaporite, breccia composed of evaporite matrix with floating dolomite clasts, and evaporite-free breccia. Clasts may be fractured, brecciated and displaced. Stanton lists four features he considers important:

1. Angular, unsorted, unbedded clasts; broken fragments displaced within breccia,
2. Clasts often float in anhydrite matrix,
3. Complete sequence: breccia with clasts floating in anhydrite --> breccia with more closely packed clasts and anhydrite matrix --> breccia without anhydrite,
4. Fractures are rare beneath breccia; breccia grades upward into highly fractured rock.

Stanton (1966) considered four processes in the development of the Leduc breccias:

a. Solution brecciation causing settling of evapo[illegible]s, plastic deformation, concentration of fine clasts up against clast surfaces,

b. Change in volume as gypsum --> anhydrite; lower strength from water in the rock,

c. Simultaneous clasts and evaporite "deposition"; no bedding or rounding,

d. Selective replacement of carbonate by anhydrite to explain anhydrite matrix.

Of these mechanisms, Stanton (1966) considers solution brecciation to account for all features observed. He also concludes that the solution brecciation is probably common at very shallow depths and that "gradual subsidence, brecciation, small-scale solution precipitation, and evaporite flowage occur simultaneously with the evaporite solution."

Gorrell and Alderman (1968) review evidence that the Devonian Prairie Formation of the Elk Point Group evaporites in Saskatchewan was dissolved beginning as early as late Devonian. Salt springs in the area are considered evidence that salt solution is continuing. Local collapse features in the Elk Point Group (DeMille et al., 1964; Christensen, 1971; Gendzwill and Hajnal, 1971) are similar to breccia pipes reported for southeastern New Mexico (Snyder and Gard, 1982; Bachman, 1987a; Davies, 1983). Compensating thicknesses of overlying units may be used to infer ages of solution and, in some circumstances, differentiate solution from tectonic or depositional features. Gorrell and Alderman (1968) distinguish depositional from dissolution edges on the basis of the configuration of the underlying units versus dip on the salt units (Figure 3.1-1). Sharp changes in halite with reversal of dip are associated with dissolution. The underlying units change little. Consistent dip directions and changes in dip of underlying units are associated with depositional changes.

Gustavson et al. (1980) recognize salt dissolution in the Palo Duro Basin, Texas, based on: (1) high solute loads, especially chlorides, in streams; (2) salt sequences that abruptly disappear between relatively closely spaced wells, as well as abrupt thinning of stratigraphic sequences away from salt units; (3) zones with abrupt salt thinning that also truncate facies tracts; (4) cores that show poorly consolidated to unconsolidated red-brown mud overlying salt beds; and (5) folds, collapse chimneys, breccia blankets, and sinkholes on Permian outcrops.

A playa, Lake McConnell, overlies an area where about 50 meters (165 feet) of salt appears to have been removed. Gustavson et al. (1980) question if the relationships are clear in indicating cause and effect between lake and salt dissolution. Other playas do not show any evidence of salt dissolution in underlying formations. Modern collapse in Hall County is attributed to salt dissolution.

Collapse chimneys in different areas of the Texas panhandle range in probable age from late Cretaceous to as late as Quaternary. Boundaries are nearly vertical with slickensides. Bedding may be vertical, and breccias may be cemented or uncemented. The breccia chimneys are located over areas identified as actively being dissolved or of possible paleodissolution of salt (Gustavson et al., 1980).

Dissolution is considered also to have caused fracturing of Permian mudstones and filling of fractures with gypsum. Goldstein and Collins (1984) describe in some detail the fault and fracture sets in outcrops of Permian formations overlying areas believed to have undergone or be subject to salt dissolution.

Gustavson (1986) has re-examined evidence of salt deposition and dissolution in the vicinity of the Canadian River valley to test the hypothesis that the river developed in response to solution and collapse. As evidence of dissolution of evaporites, Gustavson et al. (1980) cite the following:

a. "Abrupt" lateral loss of subjacent salt associated with "structural collapse" of overlying units (emphasis added);

b. Brecciated zones, fractures with slickensides, extension fractures filled with gypsum, insoluble residues of soft mudstone, anhydrite, or dolomite overlying salt;

c. Folds, breccia-filled chimneys, and systems of gypsum-filled fractures in Permian outcrops along the Canadian River Valley;

d. Sodium chloride brines in some wells above salt; and

e. High chloride in the Canadian River.

Gustavson concludes there "is strong evidence that Permian salts formerly extended farther to the north, northeast, and northwest beneath the valley of the Canadian River." Gustavson (1986) concludes also that a few salt units show lateral facies changes, generally without change in thickness or structural complications. He infers that dissolution may be as early as Miocene.

Residues or breccias are reported by Smith (1972) as textural evidence of more extensive or "mature" near surface dissolution of the Upper Magnesian Limestone of England. Beds of the Upper Magnesian Limestone have variously collapsed or foundered as a consequence of dissolution of the underlying anhydrite beds. The original anhydrite is estimated at 30 to 60 meters (100 to 200 feet) thick based on the insoluble content of the equivalent anhydrite. The degree of brecciation is highly variable, and clasts may vary from angular to subangular. Smith (1972) attributes the brecciation to "a number of rapid collapses separated by a long period of relative stability." In addition, broader scale foundering of strata is interpreted by Smith (1972) to be the result of gentle and slow sagging, and the process is considered to cause only slight brecciation. Along with this gentle foundering, the Upper Magnesian Limestone in the area displays "a gentle warping (not found in beds underlying the evaporites) into innumerable domes and basins of up to 10 metres (sic) amplitude and 25 to 200 metres (sic) diameter."

3.1.3.3 Other Breccia Sources

The Bonneterre Dolomite of Late Cambrian age is a Pb-Zn ore-bearing unit in southeast Missouri interpreted by Snyder and Odell (1958) to include breccias of approximately syndepositional origin. The breccias lie laterally adjacent to carbonate bars or banks and possible reef deposits. Snyder and Odell (1958) report that fragments are angular and there is little evidence of abrasion. The breccias are interbedded with undisturbed beds. Snyder and Odell (1958) believe the breccia bodies moved and formed during early diagenesis and lithification. A bed on the margin of a carbonate was subjected to increased slope by greater compaction of the basin facies. A glide plane forms in more indurated units as the unconsolidated material near the surface-water interface higher on the slop begins to move. More lithified beds are brecciated, and drag folds and thrust faults are created by the slumping mass. The glide planes and different brecciation styles within the breccia masses have been used by Snyder and Odell (1958) to separate breccia masses into distinct events. An individual mass, encountered in a core, for example, would reveal angular fragments within a matrix. It is possible the undisturbed units would also be properly interpreted. But the interpretation reached by Snyder and Odell (1958) would not have been reached without the extensive three-dimensional data available within the Pb-Zn mines.

3.1.4 Delaware Basin Features

Anderson et al. (1972), in a now classic paper on the laminated Castile Formation of the Delaware Basin, discussed the relationships between beds of anhydrite breccia and laterally equivalent halite units. Earlier, Anderson and Kirkland (1966) and Kirkland and Anderson (1970) reported that short, selected

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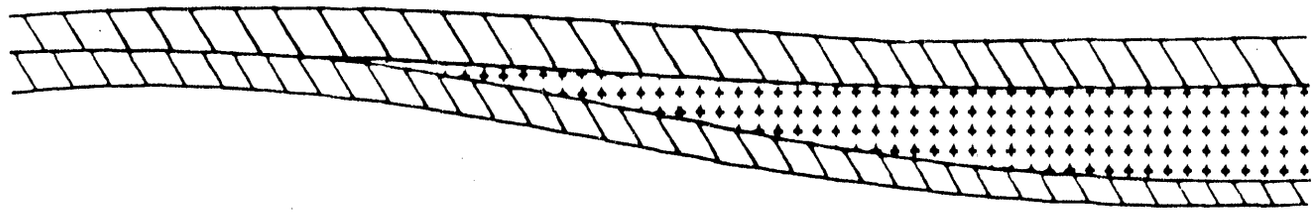
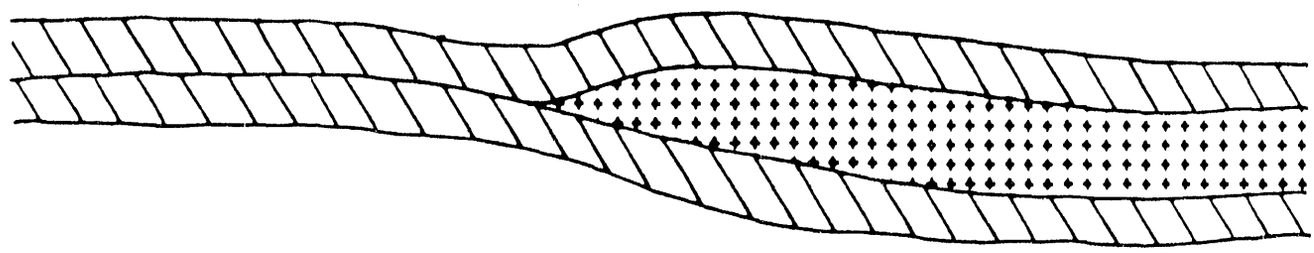


CONSISTENT DIPS, GRADUAL? THINNING: DEPOSITIONAL MARGIN



REVERSAL OF DIPS, MORE ABRUPT THINNING: DISSOLUTION MARGIN

Source: Holt and Powers, 1988

FIGURE 3.1-1 GENERAL BASIN MARGIN RELATIONSHIP: DEPOSITIONAL vs DISSOLUTION

thin intervals of laminated couplets from a few cores across the basin showed high correlation coefficients (r = 0.99). They concluded that there is a near one-to-one correspondence of laminae couplets across the basin, as well as of larger units, nodular zones, and other features, and that lateral facies changes did not occur. Around the western margin of the basin, Anderson et al. (1972) reported breccia beds in positions stratigraphically equivalent to halite units in the central part of the basin. Anderson et al. (1972) recorded some details of the arrangements of breccias in these beds:

> "Beds of laminated anhydrite as thin as one foot thick within halite beds more than 50 ft (15.2 m) thick are also present as unbrecciated layers within correlative breccia units, involve approximately the same number of laminae, and maintain their identity and remain undisturbed within overlying and underlying breccia beds despite the removal of salt. The presence of thin anhydrite beds within halite members can also be inferred from sonic logs, and these beds can be correlated with breccia zones in the University of New Mexico-Phillips no. 1 core...."
>
> "The breccia generally consists of rectangular-shaped, subangular fragments of single laminae or groups of laminae embedded in a matrix of anhydrite... The fragments, generally less than one cm in length, occur in various orientations, but most occur with stratification, if visible, and long dimension near the horizontal. Many of the fragments appear to have been only slightly displaced."
>
> "In some of the blanket breccia beds it is difficult to correlate the upper contact because of solution collapse that resulted in a collapse-type breccia...consisting of larger, more angular fragments than the blanket solution breccia, and with little matrix. Good examples of collapse-type breccia have been observed at the top of the Halite II Member (sic) and in the upper part of the Anhydrite IV Member (sic) above blanket solution breccia."

Along the eastern margin of the Delaware Basin, Anderson et al. (1972) report the relationships within halite of the Union-University "37" core:

> "The Winkler County core, however, revealed that thin anhydrite beds of only a few decimeters thick within more massive halite units maintained their position and character after halite solution. This fact (sic), and the observation that single anhydrite laminae, once separated by several centimeters of halite, were sometimes little disturbed upon solution, showed that the withdrawal of halite was a very gentle process."

Anderson et al. (1972) consider dissolution most likely to have taken place after Salado time. Both in Anderson et al. (1972) and Anderson et al. (1978), geophysical logs were used in conjunction with core to conclude that dissolution caused thick halite to thin laterally breccia beds. It was concluded that each of the halite units is represented by a breccia bed.

Anderson et al. (1978) used genetic rather than descriptive terms to recognize two different types of breccias within the breccia beds: dissolution breccias and collapse breccias. Within "dissolution" breccias, Anderson et al. (1978) describe textures similar to those described above, having fragments oriented generally parallel to bedding in units above and below. In addition, they also report that some fragments "are quite small (less than 0.5 cm), rounded, and suspended in random orientations within a matrix that comprises more than half the volume of material." The matrix is an impure anhydrite. Anderson et al. (1978) report that the "dissolution" breccias may be as much as a few tens of feet (several meters) thick and "are approximately proportional to the thicknesses of correlative salt beds."

These authors estimate that the ratios of breccia to salt thickness is about .03 to .05 within the examples available to them. "Collapse" breccias are angular fragments of anhydrite often overlying the "dissolution" breccias. "The angular fragments are fitted together in a tight interlocking pattern with little or no fine-grained anhydrite matrix. The fragments range in size from a few millimeters to blocks of more than 30 cm, with a definite tendency for fragments of similar size to be found together." These authors describe this type of breccia as forming "at apparently random positions in overlying anhydrite beds" as a consequence of dissolution chambers collapsing resulting in "a diminishing chain reaction above."

In addition to the features of the breccia beds, Anderson et al. (1972, 1978) consider that solution and subsidence/collapse caused, or is related to, the Big Sinks dissolution area, troughs with Gatuna age sediments at the surface (Maley and Huffington, 1953), and breccia pipes, castiles (Kirkland and Evans, 1976; Anderson and Kirkland, 1980) and other collapse structures (Vine, 1960, 1963; Bachman, 1987a, 1987b).

Anderson et al. (1978), as well as Anderson (1978), attribute dissolution around the margins of the basin to probable effects of contact with the Capitan reef. Anderson et al. (1978) are somewhat vague about the general process of dissolution, referring to an advancing front in the subsurface, probably preceded by caverns and tunnels at the leading edge developing an uneven front. They also attribute part of the dissolution to breccia pipes and other collapse structures. Anderson (1978) and Anderson and Kirkland (1980) described more specific roles for intrusion of water from the underlying Delaware Mountain Group through fractures, resulting in collapse structures or breccia pipes. Anderson et al. (1978) suggest some blocks and fragments may have moved laterally into voids between separated horizontal laminae of anhydrite, and that fluids or slurries may have helped move brecciated rock.

More recently, Robinson and Powers (1987) report a fan-shaped "breccia" unit in the Castile near the western margin of the Delaware Basin as a gravity-driven clastic deposit. Multiple cores from a relatively small area reveal bedding in clast units, graded clasts, clasts in an anhydrite matrix or cement, and intermittent normal laminated beds similar to those described by Anderson et al. (1972). Robinson and Powers (1987) interpret this unit as a Permian-age gravity-driven clastic unit, not as a dissolution breccia. The clastic unit is in the stratigraphic position of halite I and the equivalent "dissolution" breccias interpreted by Anderson et al. (1978). These interpretations are in conflict, though they are not mutually exclusive.

In many publications (e.g., Jones et al., 1973), the Rustler and upper Salado have been described as having undergone dissolution, resulting in complicated surficial features. However, specific features of the breccia beds or residues have not generally been presented until recently (Holt and Powers, 1988). Basic data reports for WIPP boreholes variously describe material attributed to "dissolution residue". Lambert (1983) relates several features to dissolution or hydration in the vicinity of Nash Draw; he indicates that geophysical log signatures in the area of Nash Draw may be guides to units that have been partially dissolved.

Core from the Permian in Culberson County, Texas, is described by Eager (1983) as exhibiting breccia within parts of the Rustler and Salado Formations, but no details are given of the nature of the breccia or extent. Natural gamma ray and neutron logs accompanying the lithologic log do not indicate any signatures diagnostic of the breccia, and Eager (1983) did not report any difficulties in reconstructing the stratigraphic sequence within the cores.

3.1.5 Dissolution Features In The Rustler Formation In The Vicinity Of The WIPP

Several authors (e.g., Bachman, 1984) have reviewed surficial features, especially in Nash Draw, indicating dissolution within the Rustler or upper Salado Formations in the vicinity of the WIPP site. Within some reports of the geology of WIPP boreholes (e.g. Jones, 1981), various lithologies and/or features have been reported as dissolution residues, breccias, caves or voids, or cave fillings. Each of those reports of features or inferences regarding dissolution will not be reviewed. Holt and Powers (1988) re-examined and redescribed the core from the Rustler from each WIPP borehole and reported many features of sedimentological significance. Within this section are reported features from the WIPP boreholes that are interpreted as due to dissolution. Holt and Powers (1984, 1986a, 1987, 1988) noted that they did not observe features within shafts and many cores that they interpreted as dissolution.

3.1.5.1 Brecciation

The most conclusive and pervasive evidence of dissolution having affected a lithified Rustler is the presence of brecciated, mixed lithologies. Holt and Powers (1988) observed such breccias in the following boreholes:

> WIPP-13, WIPP-25, WIPP-26, WIPP-27, WIPP-28, WIPP-29, WIPP-30, WIPP-32, WIPP-33, H-11.

The extent of brecciation varies from borehole to borehole, but in each case is known to include more than a small or or isolated zone within the borehole. These breccias are similar to those described previously from the Mission Canyon, for example, in that clasts are generally quite angular, though they may vary in size. These breccias in some cores display the upward decreasing extent of brecciation also described from the Mission Canyon (e.g. Middleton, 1961) and other evaporite solution zones. As the various boreholes were differentially affected by dissolution of the upper Salado. A conspicuous exception is apparent in WIPP-13, where the brecciation noted through the Tamarisk Member is not necessarily related to removal of upper Salado halite. The upper Tamarisk anhydrite (A3) is extended considerably in thickness over the normal thickness of this unit. Changes in dip and fracturing/brecciation noted in this unit account for this thickness change, and it is only marginally altered by gypsification.

Adjacent boreholes WIPP-29 and WIPP-32 show two important effects related to dissolution. Within the lower unnamed member, WIPP-32, in particular, displays brecciated smeared clast textures in zones that laterally have halite (Holt and Powers, 1988). Much of the lower unnamed member in this borehole is brecciated, but breccia is superimposed on the smeared clast texture. This reveals that the halite in the lower member was dissolved essentially syndepositionally, while the brecciated texture is post-lithification. The brecciated texture is clearly consistent with late removal of salt from the Salado which affected much of the overlying units (the upper portions of the Rustler have been removed by erosion). The textures in WIPP-29 are similar, but seem much reduced. Though this may partially be due to locally varying processes of dissolution, Holt and Powers (1988) attributed most of the variation to the difference in core diameter between the two boreholes. It was easier to detect and interpret the textures in the larger WIPP-32 core.

The amount of brecciation appears to be about 1 to 2 times the amount of halite dissolved (Holt and Powers, 1988). For each 0.3 meter (1 foot) of Salado halite removed, 0.3 to 0.6 meter (1 to 2 feet) of the overlying Rustler was brecciated. Lower limits on this apparent relationship are not known. For example, Parker (1967) provides data on the thickness of removed salt, but the logs do not reveal the extent of brecciation and the removal may have been early enough not to have caused breccias.

There exists within one WIPP shaft, and possibly within some core material, rare and isolated slightly brecciated areas. These areas, as in the Culebra in the exhaust shaft (Holt and Powers, 1986a), have throughgoing stratification underlying and overlying the brecciated area. There is no justification for interpreting these as evidence of broader dissolution, although in the case of the Culebra, extremely local solution of carbonate may have caused such a feature (Holt and Powers, 1988).

As described by McKnight and Fischer (1970), incompetent beds between stronger units can be brecciated by tectonic events. They described plucking of blocks from an overlying chert by a less competent carbonate. Within the Rustler, it is quite possible that some breccia, local in extent could be attributed to this mechanism as the contrast in competence is large for several beds. As McKnight and Fischer (1970) point out, the movement on adjacent beds may be very little to produce these features. From shaft mapping, slickensides and minor deformation may be consistent with a small amount of lateral movement taken up by incompetent beds. Though it seems likely that some breccia (or deformation) may be formed in such a manner, none has been uniquely attributed to the process (Holt and Powers, 1988). It may only be possible to do so where the affected units are exposed along drifts, as in the Mississippi Valley-type lead-zinc deposits examined by McKnight and Fischer (1970).

3.1.5.2 Caves and Cave Fillings

The only known cavernous porosity encountered in drilling the Rustler near the site was in WIPP-33 (Sandia National Laboratories and U.S. Geological Survey, 1980). There, drilling, logs and downhole television scanning demonstrated fluid-filled (at the time of drilling) cavernous porosity within the Magenta of undetermined lateral dimensions. Bachman (1980) attributes this porosity to dissolution along the margin of Nash Draw. It is clear that cavernous porosity also is prominent within Nash Draw as part of karst-forming processes (Bachman, 1980, 1985).

Ferrall and Gibbons (1980) attribute the laminated claystones found above the Culebra in WIPP-19 to filling of cavernous porosity. This claystone, observed closely in the WIPP shafts, is considered to be partially algal in origin and is believed to be ubiquitous (Holt and Powers, 1988). The lack of a lower Tamarisk anhydrite clearly led Ferrall and Gibbons (1980) to consider that dissolution had destroyed that bed, and that a bedded claystone must therefore have formed in cavernous porosity during this dissolution event. Holt and Powers (1988) demonstrated the depositional origin of the claystone, which is present even below the lower Tamarisk anhydrite. The anhydrite at WIPP-19 was eroded syndepositionally and the eroded area was filled with smeared intraclasts. Cave fillings found elsewhere sometimes exhibit bedded clastics, but the more common characteristic attributed to cave fillings is the piled to floating slablike collapse blocks piled one on another or floating in a matrix. More importantly, on a broader scale, caves and cave fillings are likely to show an upper contact that is well defined and an irregular lower boundary. None of the features described in Holt and Powers (1988) appear likely to be a cave filling.

3.1.5.3 Fractures

Much of the Rustler and the overlying Dewey Lake is extensively fractured, with many of the fractures filled with fibrous gypsum. These fractures are dissimilar to fracturing associated with solution collapse (e.g., Middleton, 1961). Solution collapse breccias vertically decrease clast separation to give way to a series of fractures, hairline fractures and cracks, and then undisturbed beds. Within WIPP cores and shafts, fractures are commonly, but not exclusively, horizontal. They occur in intervals that are not continuous, and the intervals persist through the Dewey Lake. There is no general relationship of WIPP fracturing to dissolution at the site area, though specific areas of Rustler and/or Salado dissolution near the site (see also Section 4) have apparently generated additional fracturing in the Culebra Dolomite Member of the Rustler.

Snyder (1985) interprets the Rustler in sharp contrast to Holt and Powers (1988). Snyder (1985) interprets the thickness differences in halite-bearing members of the Rustler as due to loss of halite by post-Permian dissolution. Snyder (1985) interprets increased thickness of sulfates as the consequence of the volume increase when anhydrite is converted to gypsum. Later discussions of the dissolution front at the WIPP site will highlight this contrasting interpretation.

3.1.6 Discussion of Literature Review

The literature reveals several common points and areas. Various authors clearly differentiate between those solution events that occur from the surface downward, either at or near the surface, and those events which took place after some amount of burial and which begin at the soluble bed. These concepts have been paralleled by the discussion of dissolution in southeastern New Mexico, where a dichotomy has been constructed between "deep dissolution" and near-surface (generally related to karst processes) dissolution. It is not possible to assign specific depths to these phenomena, for the various authors appear to have different, sometimes unspecified, criteria for deep and near-surface. However, the two end members of a probable general continuum can be differentiated as follows:

> Surficial to near-surface processes show clear and relatively direct connection to meteoric water sources from the surface downward, with soluble material dissolving as meteoric water passes through.
>
> "Deep dissolution" shows an indirect connection to meteoric water with dissolution initially generally confined stratigraphically and not immediately affecting the superjacent rocks except by brittle deformation as a consequence mass loss from the affected bed.

These two kinds of processes, in the reviewed literature, result in grossly different features as they are preserved in the geological record. Near-surface, karst-related processes will result in a sequence of brecciated material with sharp boundaries at the upper surface (Figure 3.1-2a) as deposition covers karst and ends the process. The lower extent of dissolution may be controlled at a water table or at some chemical boundary, but, unless the dissolution proceeds to a very mature stage, the lower boundary is likely to be poorly defined and irregular. By dissolving a bed buried to some depth, a lower boundary will usually be much sharper, defined by an insoluble or much less soluble underlying rock. The breccia is likely to be more continuous laterally, and brecciation will propagate upward to a variable distance (Figure 3.1-2b) in response to the removal of soluble rock. The upward boundary will generally, in this process, be more diffuse and undefinable, unless so much material is removed that fracturing propagates uniformly to the surface. It should still be expected, however, that the brecciation, as described well by Middleton (1961) and others, will decrease upward as the fractures become hairline cracks to microcracks and may disappear.

The time of dissolution can be well-defined in some cases. It is clear that there are rocks in which dissolution has occurred, but in which the process has long ceased to operate. Landes et al. (1945) and Parker (1967) provide two differing kinds of evidence of dissolution episodes from the geologic past. The criteria by which these authors decided the issue are that deposits overlying a surface that had been brecciated were unaffected and that compensation in the form of deposition had taken place by a particular point in geologic time. Present day geomorphic and sedimentologic adjustments may not easily be interpreted to determine if dissolution is contributing to the adjustment or not. It may be in a developmental stage or have been completed without a unique stage being assignable. Gustavson (1986) and other authors describing the Palo Duro Basin have compiled criteria they believe indicate continuing dissolution. Among these criteria, local subsidence and water carrying a large chloride content are the clearest, most easily accepted evidence of continuing dissolution.

A particular problem, not commonly addressed yet, is assessing the effects and extent of early or synsedimentary dissolution. Among the papers surveyed, few consider early or synsedimentary dissolution of evaporites. Of these, Powers and Hassinger (1985) relate synsedimentary dissolution in one horizon from the Salado as exposed in workings at the WIPP site. Hovorka (1983a, 1983b, 1983c, 1987) provides evidence of synsedimentary dissolution of halite to produce disturbed textures within parts of the San Andres Formation of the Palo Duro Basin. Holt and Powers (1988) relate textural features and bedding in cores and shafts to synsedimentary removal of halite from rather large tracts of Rustler facies. This directly conflicts with implied and stated opinions that these dissolution residues are much more recent. Of the papers known to consider dissolution of these most soluble of rocks, only these present significant evidence of synsedimentary dissolution (other papers consider mainly microscopic evidence of very minor removal; e.g., Schreiber and Schreiber, 1977). Lowenstein (1988) proposes that early diagenesis cements and plugs halite units before the sediment is buried deeper than several meters (a few tens of feet). Known early dissolution features are observationally related to the sedimentation surface, consistent with the proposal by Lowenstein (1988).

The extent of dissolution has been assessed largely by extrapolation from areas with evaporites to areas without evaporites or with a decreased section. Parker (1967) presents an early example based nearly exclusively on geophysical log interpretations. This approach, supplemented by some core information, was also used by Anderson et al. (1972, 1978) and by other authors attempting to understand the extent and nature of dissolution in the Delaware Basin. This practice is usually justified on the basis that underlying and overlying units are laterally extensive from areas with salt to areas without salt; it is believed that lateral facies changes within salt beds did not occur over short distances either. Gustavson (1986), Anderson et al. (1972, 1978), and Parker (1967) clearly follow this line of reasoning. Anderson et al. (1972) utilized the correlation of limited sequences of anhydrite/carbonate couplets within the Castile to bolster their belief that sulfatic and chloride beds extended virtually from side to side of the Delaware Basin. This provides a conservative, upper limit to the extent of salt dissolution within the basin. It is also clear, however, that within salt pan environments (Lowenstein and Hardie, 1985) lateral facies changes may occur over rather short distances, enhanced by the depositional changes that bring clastics to the margins and remove soluble materials. In addition, as water evaporates from basins, the brine is restricted to well-defined areas, again resulting in lateral facies changes over short distances. Within the Rustler Formation (Holt and Powers, 1988), and in the San Andres (Hovorka, 1983b, 1987), significant changes in environments and/or relative sea level may occur rapidly, covering an area with a carbonate from much higher and fresher water. These units may extend laterally far beyond the extent of a previous saline pan, and they should not be considered direct evidence of the extent of the most saline facies (Holt and Powers, 1988). As in some previous types of evidence, the extent of evaporites will have to be evaluated basin by basin and case by case.

The rate at which evaporites dissolve is not easy to evaluate. The criteria and examples provided by Parker (1967) may be as clear as any. In the Williston Basin, sedimentary units which adjust to dissolution have lower and upper bounds well defined in geologic time. The adjustment within parts of the Fryberg field of North Dakota clearly took place during the latest Jurassic, bounded by the deposition of the Swift Formation. Approximately 30 meters (100 feet) of compensating sediments were deposited within a few million years. Within the Delaware Basin, different authors have attributed dissolution to widely varying lengths of time as far back as Permian. Significant amounts of evaporites have been considered dissolved even as early as the time of the end of Castile deposition (Anderson et al., 1972; Bachman, 1974, 1976, 1980; Jones et al., 1973). In contrast, Anderson (1978, 1982) and Anderson and Kirkland (1980) attribute most dissolution to Cenozoic or later Cenozoic time. The specific information and basis for estimating rates of dissolution at Nash Draw and near the WIPP site will be covered in later sections (3.2, 3.3, 3.4).

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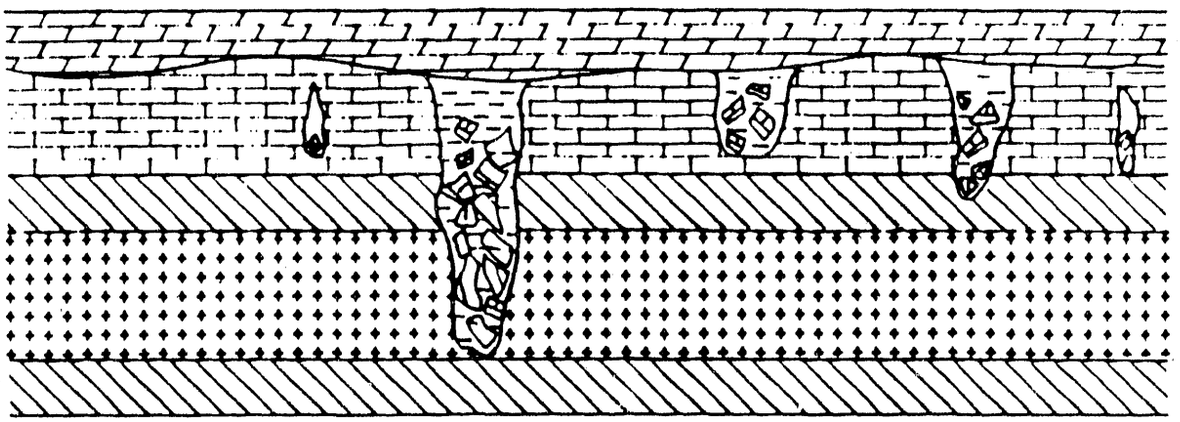
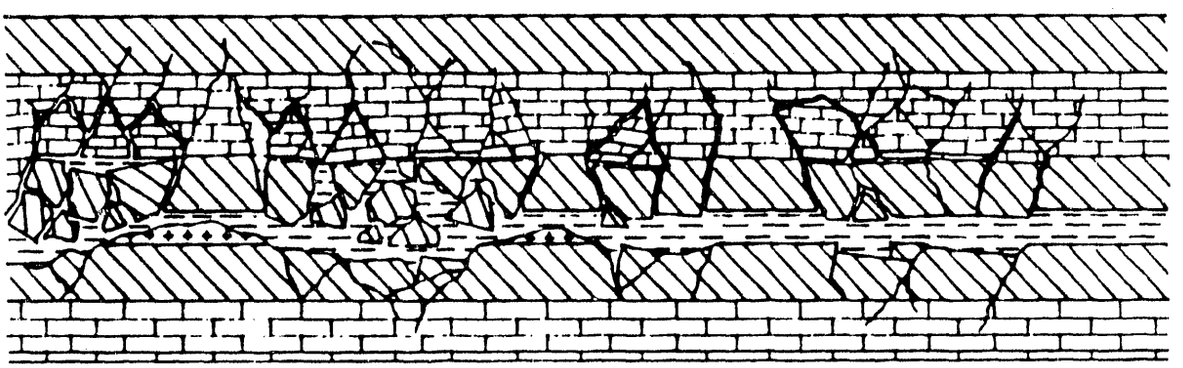
a. KARST

UPPER HORIZON CONTROLLED, BRECCIATION MAY INCREASE UPWARD, MIXING OF STRATA IN CLASTS, TRUNCATED UPPER SURFACE BOUNDING AGE



b. SOLUTION

LOWER HORIZON-CONTROLLED, BRECCIATION DECREASES UPWARD, STRATIGRAPHIC RELATIONS INTACT, POST-DEPOSITIONAL, POST-LITHIFICATION SOLUTION ("LATE")



(NOT TO SCALE)

NOTE: SYMBOLS DO NOT REPRESENT SPECIFIC LITHOLOGY

Source: Holt and Powers, 1988

FIGURE 3.1-2 GENERAL MID-STAGE FEATURES PRESERVED FOR KARST AND SOLUTION AT DEPTH

The forms which the dissolution residues take are often considered rate-dependent. Evaporite solution and subsidence/collapse create breccia and brecciation. However, several authors (e.g., Anderson et al., 1972) interpret dissolution to occur so gradually under some circumstances that thin, laminated anhydrite beds within halite beds may be undisturbed while large volumes and percentages of halite are removed. At the same time breccias are formed around the undisturbed thin anhydrite beds. This hypothesis seems internally inconsistent; even if it does occur, it will take place very gradually, it would be very slow even in relation to the lifetime of a repository.

It is appropriate to comment on the scale of events and processes that may be said to involve the dissolution of rock materials. Within the sedimentary sequence, several types of processes, sometimes given various names, may involve small or large amounts of dissolved rocks with transport distances of solutes ranging from microns to kilometers. Pressure solution from grain-grain contact and the creation or destruction of porosity is near one end of this scale. Hardly any sedimentary rock is free from the minute effects of diagenesis, including for some the effects of weathering immediately following deposition. These well-known, if imperfectly understood, phenomena are not reviewed here, though their effects are seen in the Rustler (Holt and Powers, 1988) and the Salado.

There is an important distinction in timing for the processes normally attributed to dissolution. In published studies of dissolution of the Rustler and other evaporites in the Delaware Basin, dissolution is a term used for processes occurring long after the deposition of the affected units. The term is used in the same sense here. The Rustler, however, displays very early, synsedimentary solution of evaporites, occurring before burial and lithification. In that sense, deposition includes the early removal of evaporites from some of the same units interpreted by others as dissolution residues where salt was removed long after burial and lithification. Synsedimentary dissolution is distinguished from late-stage dissolution in this section by calling it early or synsedimentary dissolution. Such synsedimentary features and processes clearly are associated with the sedimentary history of the units, differentiating them as well because they may be eliminated from the calculations of the consequences of dissolution affecting the WIPP at some future time.

The general features that are most widely accepted as evidence of later dissolution at depth are angular breccias that have propagated upward but with diminishing strain. These have lower bounds that locally are well defined. Early synsedimentary dissolution or dissolution before subsequent burial reveals an upper boundary that is stratiform. These relationships have been applied to the physical features apparent in cores, shafts, and geophysical logs from the Rustler Formation in the most recent interpretation to suggest that the Rustler has undergone little post-depositional dissolution. Additional features in the Castile Formation also suggest that halite was not deposited as widely as originally thought or was destroyed during deposition of sulfate clastic units. These studies are more limiting on the overall volume of halite previously considered to be dissolved from these formation, and they provide more margin over the already conservative estimates of rates of dissolution. The Salado has not been similarly studied, and the limits to halite are taken as principally due to dissolution in the absence of positive information indicating otherwise.

3.2 NASH DRAW FEATURES

Bachman (e.g., 1980, 1981, 1984, 1985, 1987b) has worked extensively in Nash Draw and its vicinity (Figure 3.2-1). He has described the solution-related features and interpreted the likely effects at the WIPP site. Other reports on aspects of Nash Draw geology include Vine (1963), Jones et al. (1973), Snyder (1985), and Holt and Powers, (1988). Lambert (1983) reviewed dissolution processes in general

for the Delaware Basin and included some analysis of the Nash Draw features and mode of origin. These are the principal sources about dissolution-related features, though many other reports include related data.

Nash Draw is mainly underlain by various units of the Rustler formation. Around the edges of Nash Draw, the Dewey Lake and the Gatuna Formations form most of Livingston and Quahada Ridges. The solution features in Nash Draw are developed mainly in and on the Rustler, but the underlying upper Salado has also been partially dissolved, with collapse features propagating upward to disrupt the Rustler.

The main surficial solution features in Nash Draw are sinkholes and caves (Bachman, 1985). These are developed in sulfate beds of the Tamarisk and Forty-niner Members of the Rustler Formation and some are clearly active. Depressions and closed contours on topographic maps may mark former sinkholes. Bachman (1980, 1985) reports surficial gypsite along the eastern side of Nash Draw that he interprets as spring deposits. Bachman (1980) relates the gypsite to a surficial sink, about 1.5 mi east of Livingston Ridge, that was drilled (WIPP-33). WIPP-33 shows cavernous porosity in the upper Rustler. Bachman (1980) proposes that sulfate was dissolved in the upper Rustler, was transported to springs just west of Livingston Ridge, and then was deposited on the surface. Around the edges of Nash Draw, where younger rocks are exposed, dipping and brecciated beds show that collapse is more recent and has affected these areas during or since the Pleistocene.

In Nash Draw, there are also karst domes (see Bachman, 1980 and the review in Section 3.1.3.1). WIPP-29 was drilled to investigate a karst dome, revealing that the upper Salado was partially dissolved and the Rustler brecciated as a consequence. At the north end of Nash Draw, two breccia pipes (domal structures at the surface with a cylindrical core that has collapsed to the depth of the Capitan reef) occur (Snyder and Gard, 1982), but they are only partially related to the processes that formed Nash Draw (see Section 3.3). The upper Salado has also been significantly dissolved to create Nash Draw. Bachman (1980) believes Nash Draw developed by solution and erosion, following the process described by Lee (1925). The process of dissolving the upper Salado (and Rustler) from the upper part downward as well as laterally has also been called "subrosion" (e.g. Jones et al., 1973). The upper part of the Salado is generally believed to be dissolving from the top downward as some form of dissolution wedge or "dissolution front" migrates laterally from Nash Draw to the east toward or perhaps over part of the WIPP site. The Nash Draw area has been extensively drilled for potash exploration, and U.S. Geological Survey geologists have drawn upon this restricted data base for much of their interpretation of the processes (Jones et al. 1973; Snyder, 1985). These data in Nash Draw and along the Livingston Ridge area have also been interpreted to suggest rates of dissolution and rates of advance of the "dissolution front" toward or over the WIPP site.

There are some separate lines of evidence that have been used to construct estimates of the rate of dissolution in and around Nash Draw. Jones et al. (1973) discuss geological reasoning about rates, while Bachman et al. (1973) include calculations of rates based on solutes delivered to the Pecos River from this area. Lines of evidence come both from the surface and subsurface, and the assumptions that affect these estimates are not always explicit. To estimate the amount of dissolution that has occurred, the original volume of rock must be estimated. It is seldom stated, but invariably implicitly assumed, that the strata of the Salado (and also the Rustler) were deposited continuously and with little or no change in thickness across the northern Delaware Basin. If an interval is 30 meters (100 feet) thick in the thicker parts of the formation in the eastern part of the basin, then it is assumed to have been 30 meters (100 feet) thick in the Nash Draw area. This may be a reasonable assumption for the upper Salado (see Section 7.2), though direct textural data have not been developed to examine alternatives. The Rustler Formation has been re-examined (Holt and Powers, 1988), and significant lateral changes in thickness of

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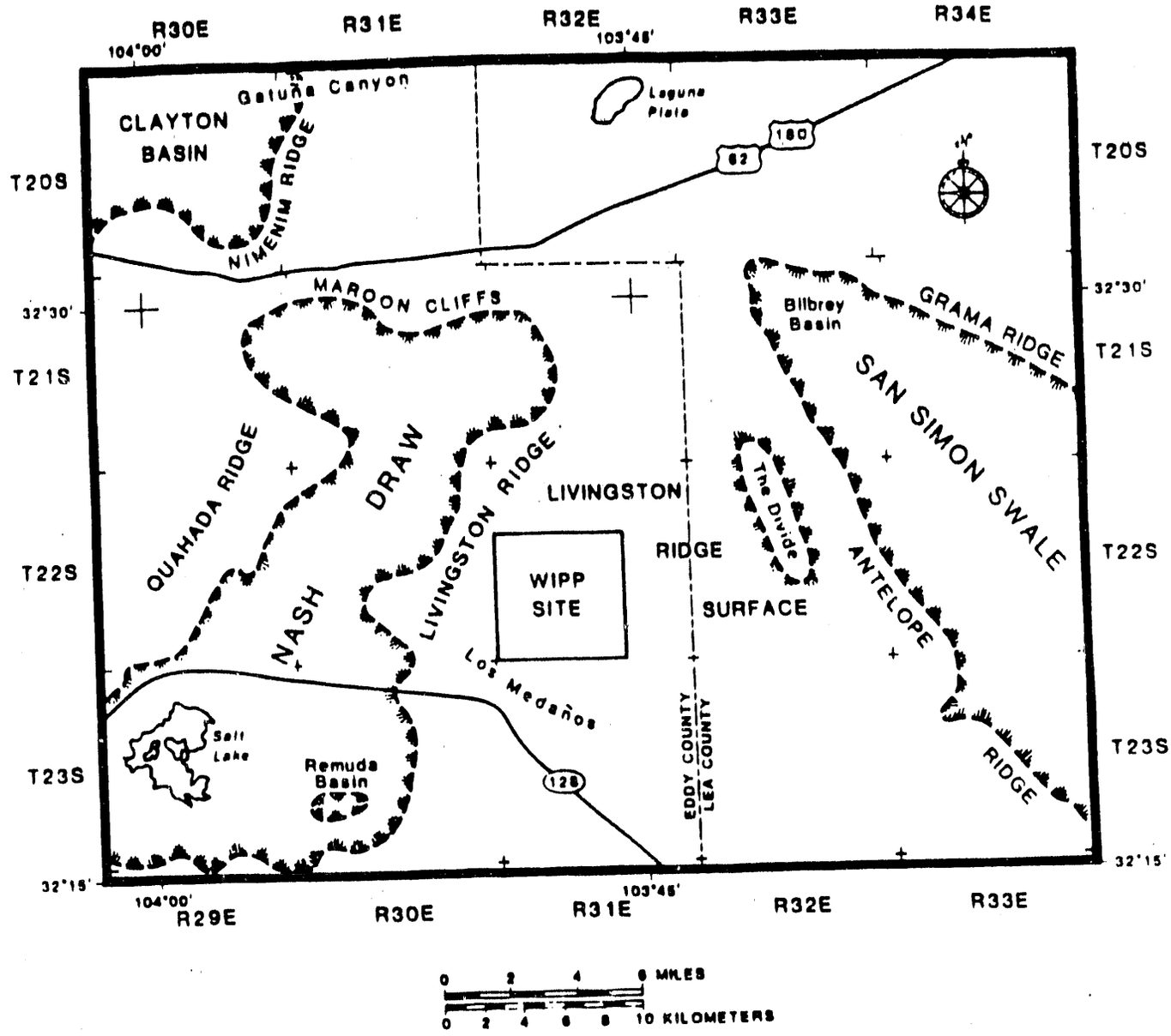

Source: Bachman, 1985

FIGURE 3.2-1 INDEX MAP OF NASH DRAW AND OTHER MAJOR FEATURES NEAR THE WIPP SITE

several members is interpreted to be due to deposition and synsedimentary dissolution rather than more recent dissolution. Evidence from mapping in shafts and textures in cores were important in this interpretation. Other recent interpretations of the Rustler (e.g. Snyder, 1985) depend almost exclusively on thickness differences and changes in lithology based on geophysical log interpretations. Dissolution will be estimated to occur at a conservatively large rate if units are assumed to have no original lateral change in thickness or mineralogy. No investigator to date has assumed that the thickness of any unit was greater in the Nash Draw to WIPP site area than in thicker parts of the Delaware Basin. The rates may be unrealistic, however, and Holt et al. (1989)(see also Section 7.2) reexamined upper Salado data to try to place more realistic limits on the depositional thicknesses of certain intervals of the upper Salado.

Bachman et al. (1973) estimated that salt was removed from the upper Salado at a rate of about 0.1 meter/1,000 years (0.5 foot/1,000 years). This estimate was provided by Swenson (in Bachman et al. 1973) by calculating the salt discharge into the Pecos River and attributing it to dissolution over an area including Nash Draw. Bachman et al. (1973) also calculated a lateral rate of advance of the "dissolution front" based on the assumption that the Salado Formation extended west to the Capitan reef at the end of the Ogallala. Bachman (1980) considers this to be a conservative overestimate of the rate, as he points out the evidence for earlier opportunities and episodes of dissolution from Permian through Ogallala deposition. Bachman (1974) found that the upper Salado near the center of Nash Draw was about 100 meters (330 feet) thinner than the same section at Livingston Ridge. The ground surface in Nash Draw at this location is only about 55 meters (180 feet) below the projected surface between Livingston and Quahada Ridges (Figure 3.2-2). Bachman attributed the 55 meter (180 foot) difference to dissolution since the Mescalero caliche began to form, at that time estimated to be about 600,000 years ago. By this means, Bachman (1974) obtained the estimated average vertical dissolution rate of 0.1 meter/1000 years (.33 foot/1000 years). Bachman (1974, 1980) has pointed out that the rocks have apparently been subject to dissolution many times in their history, providing additional times for dissolution of the remaining 46 meters (150 feet) missing in the section. Jones et al. (1973) provided an estimate of the time required to dissolve to the MB128-133 interval over an area which includes the WIPP site (Figure 3.2-3). The reasoning behind the estimates is not explicit, but it appears to be a combination of lateral and vertical rates provided in Bachman et al. (1973) and Bachman (1974). The time for the "subrosion edge" to reach an area is according to the lateral rate, and the time to dissolve the thickness of salt is given by the vertical rate of dissolution. Jones et al. (1973) translate the rates and distances into the period of time required to reach and dissolve to that depth. They provided these estimates to help site selection and exploration programs for the project which preceded the WIPP.

Some investigators suggest that the dissolution front has already impinged on portions of the WIPP site. Beauheim (1987) presented a map (Figure 3.2-4) which combines data and interpretations of the areas where halite is absent in the Rustler members and the apparent edge of attack by dissolution on the Salado. The Salado interpretation is based partly on restricted data from potash drilling held in files by the U.S. Geological Survey, and cannot be directly reviewed here. A slightly different interpretation of the upper Salado has been presented in Section 7.2, and the data are open for inspection.

The point at which the Salado begins to abnormally thin is in the vicinity of the northwest corner of the WIPP site. An isopach map of the interval between MB103 and the top of Salado (Figure 7.2-13) shows that the Salado is generally thinning from a depocenter southeast of the site to thicknesses of about 55 to 58 meters (180-190 feet) at the WIPP site. In the northwest corner, some values are about 52 meters (170 feet). Slightly to the west of the site boundary, thicknesses decrease sharply to values less than 46 meters (150 feet) thick. These abrupt changes in thickness are around Livingston Ridge and the edge of

Nash Draw. Some cores of the Rustler reveal brecciated textures, indicating halite was apparently removed after these rocks lithified. The rocks are interpreted to be at least partly dissolved from the upper Salado, in contrast to the interpretation of the margin of halite in the Rustler by Holt and Powers (1988) but consistent with the interpretation by Snyder (1985).

The data available for the northwest corner of the WIPP site are equivocal. If dissolution has removed some upper Salado halite from this area, the thickness removed appears to be no more than about 3 meters (10 feet).

These are the antecedents to the present discussion about dissolution at Nash Draw and in the vicinity of the WIPP site. The principal changes over the intervening time have been the modest increase in the number of boreholes available to assess the thickness of the upper Salado and Rustler Formations and the Rustler study which concluded that much of the Rustler did not retain salt through deposition. Thus the estimates of dissolution, which are already considered conservative overestimates, are apparently even more conservative overestimates. All of these estimates are orders of magnitude beyond the period of regulatory concern.

The main alternative viewpoint has been provided by Anderson (1978, 1981, 1982), as reviewed extensively in the introduction (Section 3.1) and also by Lambert (1983). Anderson (1978, 1981, 1982) proposed that about 50 percent of the halite in the combined evaporite section has been dissolved since late Cenozoic. Anderson (1978) recognized difficulties in projecting rates of dissolution, as differing climatic conditions may increase or decrease the short-term (geologically) rates. The implicit assumption in these calculations is that the Castile, Salado, and Rustler Formations were deposited uniformly across the basin and survived until late Cenozoic. Both of these assumptions appear wrong for at least the Castile and Rustler (e.g Bachman, 1980; Robinson and Powers, 1987; Holt and Powers, 1988), and the estimates again are conservative. Lambert (1983) extensively reviewed Anderson's (1978) proposals and concluded that the main mechanism hypothesized to remove salt was not sufficient for the scale of solution proposed.

3.3 DEEP-SEATED DISSOLUTION

The concepts of "deep" dissolution were reviewed in the introduction (Section 3.1). Within the Delaware Basin, "deep" dissolution usually means dissolution caused by water from the Bell Canyon Formation, underlying the Castile, or dissolution which may be taking place well within the body of evaporites from fluids which migrated downdip through the evaporite section. Anderson (1978) and Anderson and Kirkland (1980) and Davies (1983) proposed that water from the Bell Canyon could migrate through fractures in the lower Castile to dissolve halite in the evaporite section. This process would mainly produce localized dissolution with thinning evaporites and local depressions. Brecciated chimney-like topographic features, often called "castiles," were considered examples of this process, as were a number of features Bachman (1980) later described as karst mounds and karst domes (see Section 3.1) produced by near-surface dissolution. In the northern Delaware Basin, the only known examples of deep-seated dissolution are the breccia pipes described originally by Vine (1960, 1963) and more recently by Snyder and Gard (1982). Four domal structures at the north end of Nash Draw were extensively investigated during early stages of the WIPP studies because there was concern these types of structures might occur at or near the site and permit radionuclides to escape the site. Two of the domal structures were drilled and tested. Snyder and Gard (1982) conclude that the structures are generally cylindrical and propagated upward through the evaporite section after collapse of solution cavities in the underlying rocks which include the Capitan reef. The surface expression is domal because later dissolution in the Rustler or upper Salado lowered the topography around the more structurally resistant breccia in the pipe (Bachman, 1980, 1987a). No similar structure has been found elsewhere in the northern Delaware Basin. The last drillhole to investigate a structure proposed as an example of

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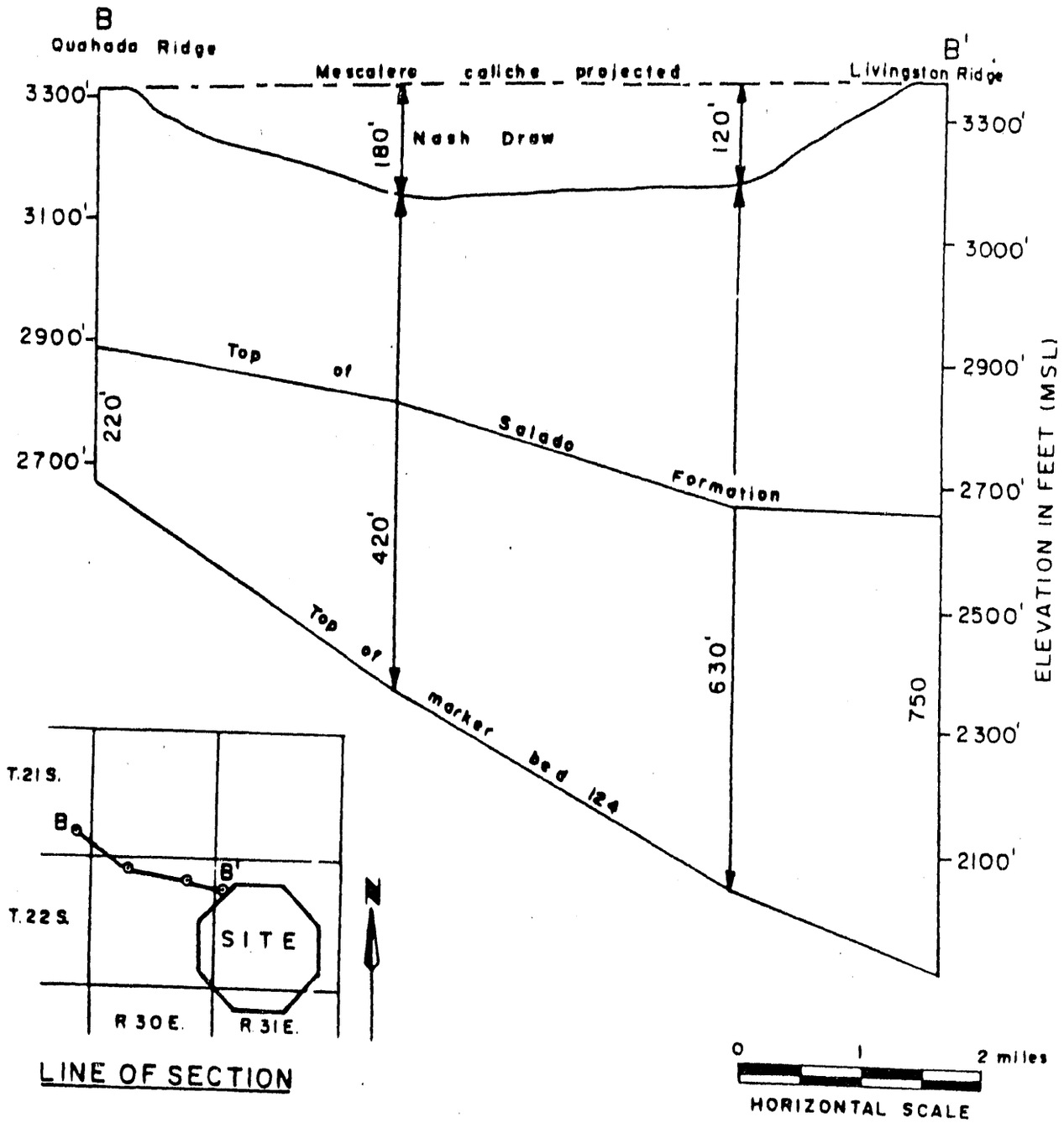

Source: Bachman, 1974

FIGURE 3.2-2 RELATIONSHIP OF NASH DRAW TO DISSOLUTION IN SALADO FORMATION

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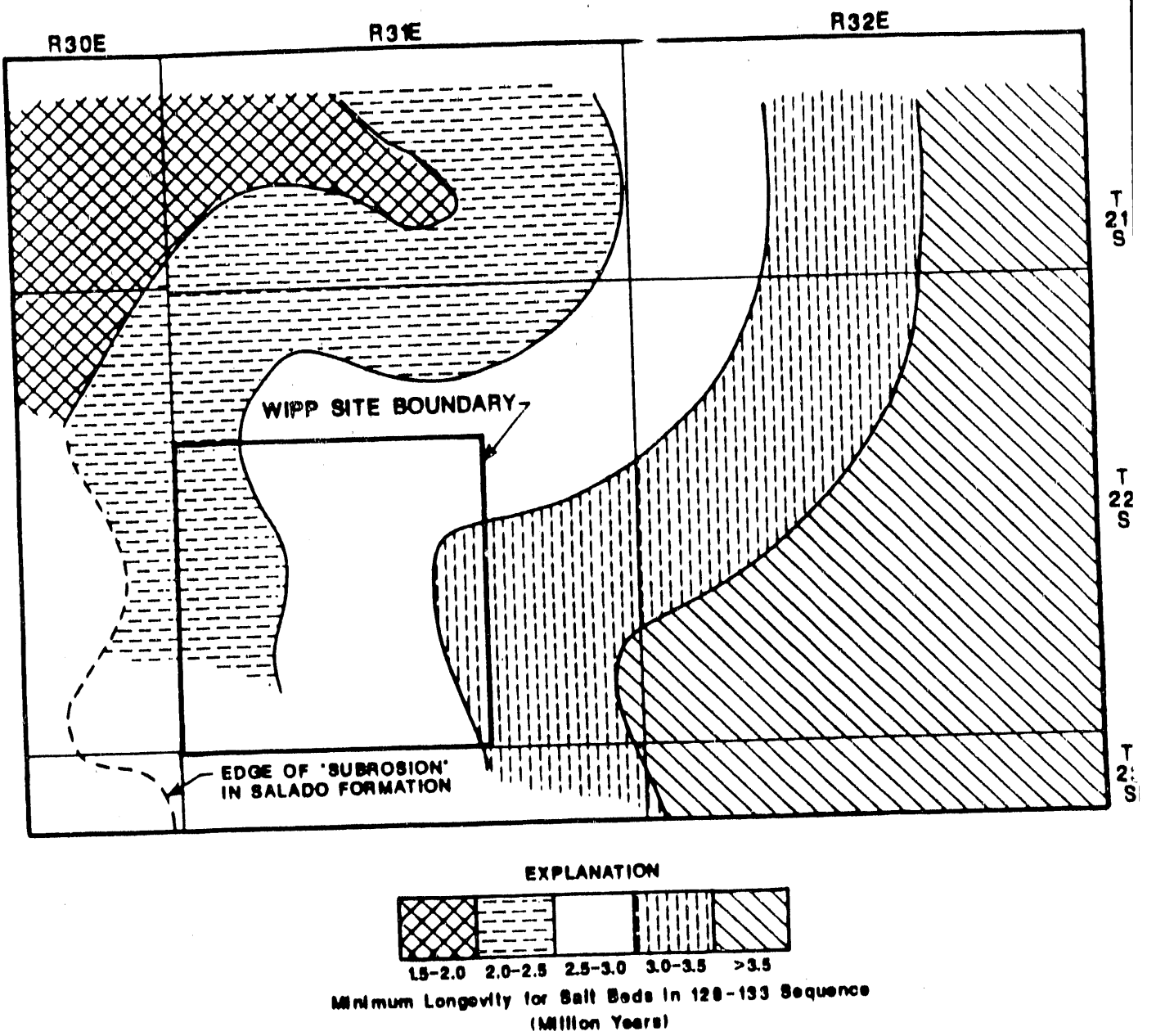

Source: Jones et al, 1973

FIGURE 3.2-3 MINIMUM LONGEVITY FOR SALT BEDS IN MB126-133 SEQUENCE

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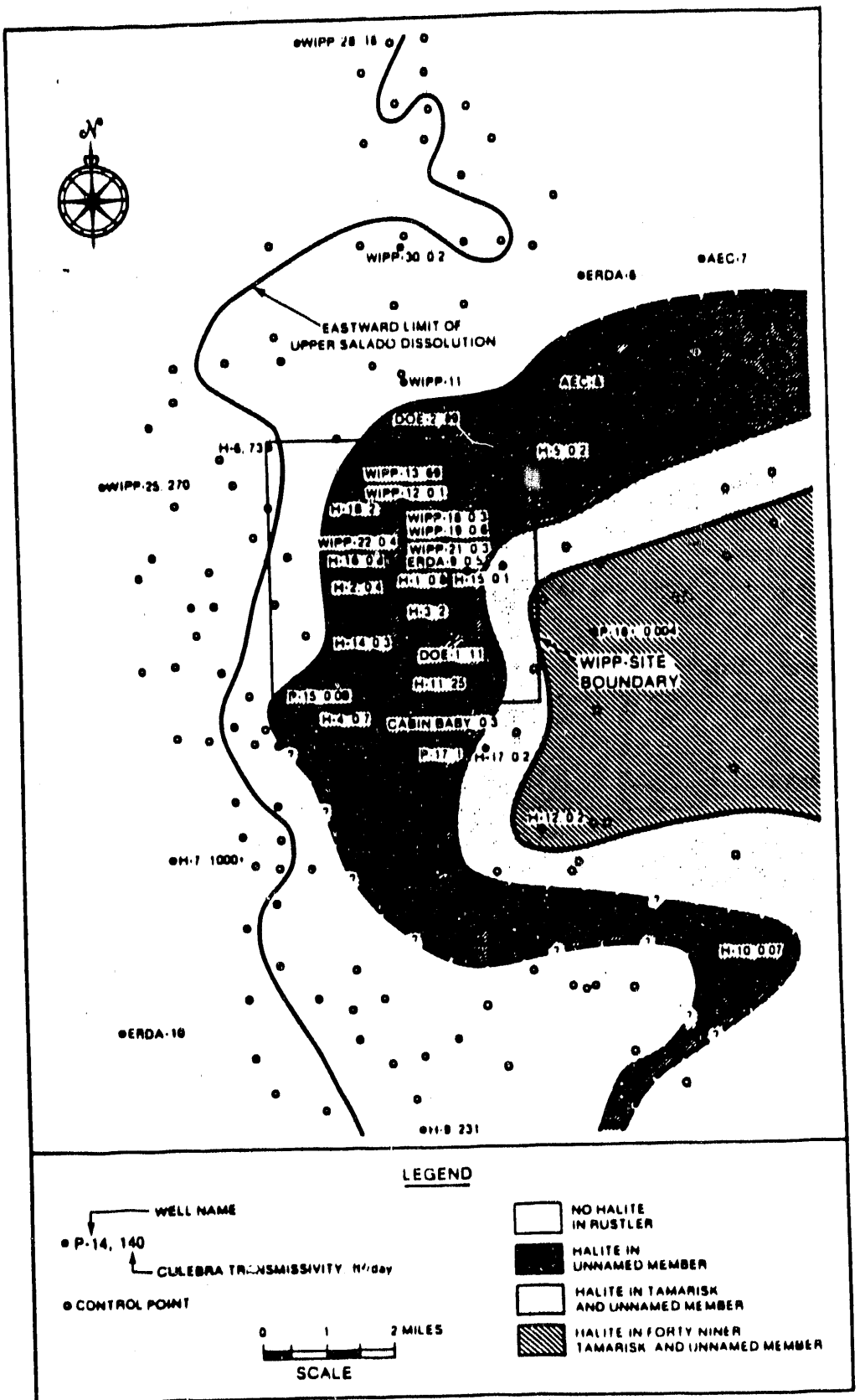

Source: Beauheim, 1987

FIGURE 3.2-4 DISTRIBUTION OF RUSTLER HALITE AND CULEBRA TRANSMISSIVITY AROUND THE WIPP SITE

deep dissolution (Davies, 1983) was DOE-2 (Figure 3.3-1). The structural depression on Salado marker beds was underlain by thicker Salado units and the Castile is missing a bed of halite at that location. Borns (1987) and Mercer (1987) attribute the configuration to structural deformation (see Section 7.3), not dissolution.

Deep dissolution is probably effective in the southern part of the Delaware Basin. In Culberson County, Texas, Smith (1978) hypothesizes that hydrocarbons, at least, from the Bell Canyon migrated upward into the Castile Formation and were utilized by bacteria to produce native sulfur deposits. Faults in the area are believed to be the pathway. Water or brine could also move through such a system.

At this time, there no real evidence to suggest that deep-seated dissolution from the Bell Canyon is likely to occur under the WIPP site. A further factor is that the brines in the formation have little potential for dissolving further halite (see also Lambert, 1983). There are some suggested fault patterns in the Bell Canyon in the vicinity of the WIPP site (Borns et al., 1983), but not one has been demonstrated to exist or to be related to loss of salt in the section. Brine density flows were hypothesized to drive deep dissolution (Anderson, 1978; Anderson and Kirkland, 1980), but this mechanism appears inadequate to dissolve the volume of salt allegedly removed (Wood et al., 1982; Lambert, 1983).

3.4 LOCAL AND REGIONAL FEATURES

Some of the local to regional features have already been discussed in other sections. Nash Draw and the Rustler-Salado dissolution front was discussed in Section 3.2. Breccia pipes, as examples of deep-seated dissolution, were described briefly in Section 3.3. The principal remaining known dissolution features are the Big Sinks area about 32 kilometers (20 miles) south of the WIPP site and San Simon Swale and Sink about 32 kilometers (20 miles) east of the WIPP site (Figure 3.2-1). Many other individual features have been proposed as evidence of dissolution, but most are very localized and have been treated in different documents (e.g. Lambert, 1983; Borns et al., 1983; Holt and Powers, 1988; Lappin, 1988).

Big Sinks is interpreted as a karst area (Bachman, 1985). The area has been little investigated. Holt et al. (1989) suggest that the upper Salado is being attacked along a zone through the Big Sinks area. Collapse associated with solution may be providing the permeability to create karst features. Big Sinks are mainly of interest in how they relate to this hypothesis.

San Simon Swale and San Simon Sink have been suggested as subsidence features related to dissolution (Anderson, 1978) and as a breccia pipe (Bachman, 1980). The low point in the Sink was drilled (Sandia National Laboratories and University of New Mexico, 1979), and the underlying rocks appear partially collapsed. San Simon Sink area may still be active, as there is historic evidence of faulting and subsidence. San Simon Sink and Swale are of general interest in interpreting the geologic history of the area, but they do not appear to have any significant direct effects on the WIPP during any period of regulatory concern.

Lambert (1983) and Bachman (1984) review information on the Balmorhea-Loving Trough (Figure 3.4-1) located south of the WIPP site and trending north-south across the state line with Texas. Bing Sinks partially overlies this trough. More than 300 meters (1,000 feet) of sediments of uncertain age fill this trough. Maley and Huffington (1953) attributed the thickness of fill to solution of the underlying halite. The fill in this trough represents a possible future path for groundwater migration if the Rustler flowpath is altered more toward the south and southeast from the site due to solution of the upper Salado salt (Holt et al., 1989).

3.5 IMPACT OF CLIMATE CHANGE IN DISSOLUTION

Over the period of regulatory concern, there is only one part of climatic change that would appear to have any chance of affecting waste isolation: increased rainfall. Other climatic changes, such as a change in temperature, or even a return to glaciation, would have no effects during this period. The rocks are relatively thermally massive, and the geothermal gradient overwhelming, to produce effects below a few tens of meters from surface temperature changes. Glaciation is unlikely to reach these latitudes and elevations, as there is no evidence whatsoever of glaciation in the WIPP site area during the Pleistocene. A drier climate than presently exists would increase eolian activity, but there is no potential for wind erosion to remove a significant amount of the cover over the repository. Along with increased rainfall, some additional changes in rainfall chemistry might occur that would increase or decrease the rate of dissolution.

It is most reasonable to expect that the climatic changes which occurred during the Pleistocene encompass the expectable ranges of rainfall that might occur during the next 10,000 years. This is approximately the period since the Wisconsinan pluvial, and rainfall has probably generally decreased in southeastern New Mexico during that time. The geologic record for the Pleistocene and Recent in southeastern New Mexico is modest, and it does not always yield details that can be interpreted in terms of rainfall. Of the geologic record over that time, some bounds on the probable ranges of rainfall can be suggested on the basis of the sedimentologic record of the Gatuna Formation and the preserved Mescalero caliche.

The Gatuna Formation was described and interpreted by Bachman (1980) to help reconstruct the geologic history of the Pecos valley. Holt et al. (1989) have extensively described the Gatuna from Gatuna Canyon area to Pierce Canyon. The Gatuna was principally deposited from fluvial environments, but there are also debris flow deposits and gypsum deposits that can both be indicators of semi-arid to arid climates. To counter these environmental indicators, channels are often filled with conglomerates that include clasts apparently transported about 160 kilometers (100 miles), which is the distance of the nearest known source. These deposits certainly indicate relatively high velocity flows in the channels, but are not uniquely indicators of very wet climates. Thus, the record from the Gatuna Formation is mixed and not very diagnostic of any particular climatic conditions. Gypsum growth textures indicate that the soil profiles were not generally flushed with meteoric water. Carbonate soil horizons are lacking, but these can also be due to limited exposure at the surface. The lack of well-developed soil profiles in general is consistent with short exposure times, as these deposits were very clearly exposed to weathering processes.

The best indicator of the climatic conditions is the Mescalero caliche. In general, these carbonate soil profiles develop in warm semiarid climatic conditions. If there is too little rain, carbonate is not mobilized in the vadose zone and reprecipitated to form the structures of a caliche. If there is too much rain, the carbonate will begin to dissolve, and it will be totally destroyed if climatic conditions become wet over too long a period of time. Between these extremes, caliche may be partially dissolved and be relithified during briefer wet climatic conditions. The Mescalero caliche has been partially brecciated and recemented, recording at least one interlude of wetter climatic conditions.

The limits to rainfall that form and preserve caliche are not very precise. Under modern conditions, caliche appear to be stable within the range of about 10 to 66 centimeters (4 to 26 inches) of rainfall per year. Less rainfall may permit eolian activity to destroy it and more rainfall will dissolve it. The Mescalero would appear to attest to initial conditions within that range, a limited period of greater rainfall, and a consequent period, lasting to the present, of rainfall within the stability range of caliche. As the Mescalero caliche is reported to be about 500,000 years old on the basis of uranium disequilibrium techniques (Bachman, 1980), these would appear to be the general conditions during the latter part of the Pleistocene.

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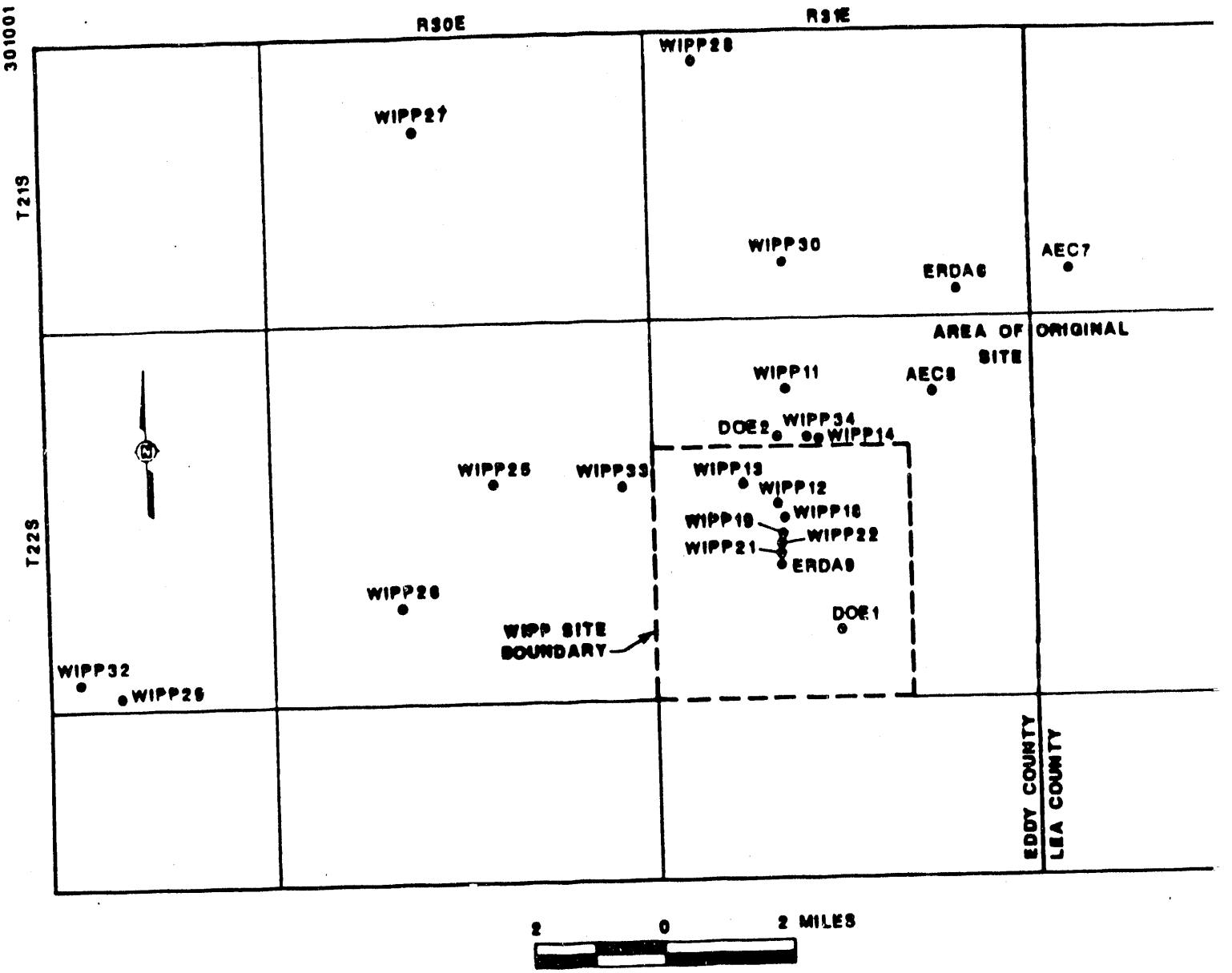

FIGURE 3.3-1 LOCATION OF MAIN STRATIGRAPHIC DRILLHOLES

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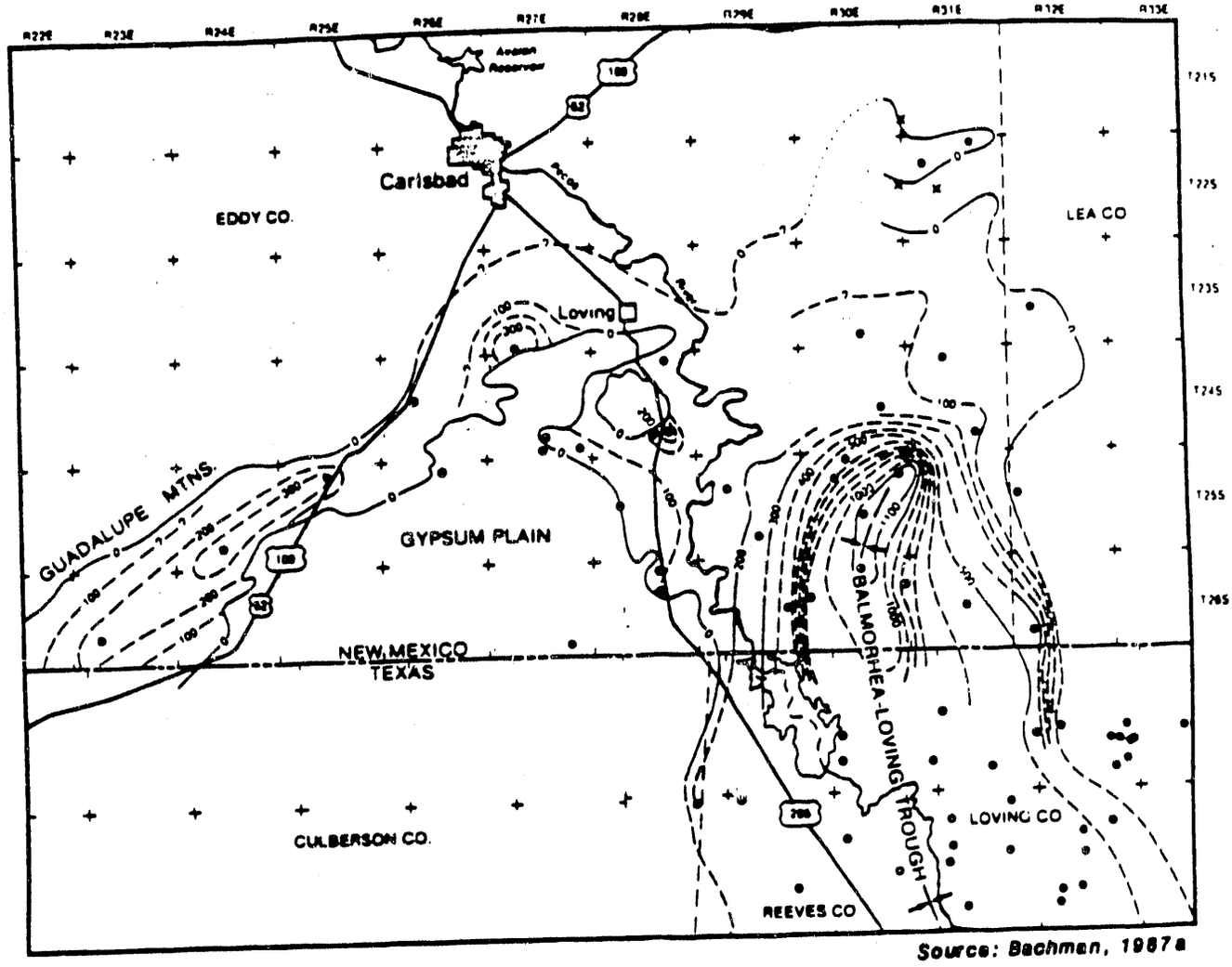

FIGURE 3.4-1 ISOPACH MAP OF CENOZOIC FILL IN BALMORHEA-LOVING TROUGH AND ADJACENT MINOR DEPOSITION BASIN

The Berino soil overlies much of the Mescalero caliche in the site area. In addition, stabilized dunes with clay-rich lower zones are present. Caliche has locally been dissolved, usually surrounding present or former root zones of plants such as the creosote bush where conditions are more acidic. These deposits and features are generally consistent with the idea that the climate has not become much wetter than the caliche stability range for a significant period of time since the Berino soil began to form on top of the caliche.

During the Wisconsinan, the local area was apparently wet enough that San Simon Sink had a standing body of water. Above the present floor of the sink, calcareous sediments include a microflora and microfauna that are aquatic (Sandia National Laboratories and University of New Mexico, 1979). These sediments are greater than 20,000 years old by radiocarbon dating. These deposits probably indicate wetter conditions that presently occur, but there is also the possibility that subsurface drainage has increased, causing the sink to remain dry or very temporarily flooded.

Geochemical studies of the groundwater and rocks around the WIPP site have not yielded direct information about the amount of rainfall during the Pleistocene and Recent climates. One piece of information is consistent with increased Wisconsinan rainfall, but does not uniquely indicate it. Lambert (1987) reports that the interpretable radiocarbon ages on fluids from the Rustler and Dewey Lake indicate that some of the fluids were isolated from atmospheric radiocarbon at least 12,000 to 16,000 years ago. Lambert (1987) concludes that the clustered ages may represent some type of recharge event. This period of time is, in general, considered to be wetter in North America, and the data are consistent with increased precipitation.

Bachman (1980, 1985) has interpreted gypsite deposits in Nash Draw as representing spring deposits in a karst terrain. He also suggests that these deposits are not being added to by spring activity, and that the system existed during a wetter climate than currently exists in the area. A somewhat contradictory date of about 25,000 years has been placed on these deposits on the basis of uranium disequilibrium of the gypsite (Bachman, 1980). Bones within the gypsite yield a much older date from uranium disequilibrium, and the differences have not been reconciled.

Van Devender (1980) studied packrat middens northwest of Carlsbad and found a juniper-oak community represented about 10,000 years ago where desert scrub communities now exist. The change in flora indicates a wetter climate at that time than is now present.

Since the time the Mescalero caliche began to form about 500,000 years ago, there would appear to be at least two wetter periods. The first wetter period interrupted caliche formation somewhat, but did not totally destroy it. During somewhat drier period later, the caliche was recemented. In addition, there appears to be clear evidence from the pack rat middens of a wetter climate about 10,000 years ago. That wetter period might be extended back to about 20,000 to 25,000 years if the gypsite and San Simon Sink represent wetter climate. There are no data in the interval. These are also consistent with the apparent recharge episode indicated by the cluster of radiocarbon dates (Lambert, 1987). More than 300,000 years are not known to be directly represented in the rock record between the gypsite and San Simon Sink and the much older Berino soil.

Inferences on the basis of lack of evidence are always exceedingly weak. The interval between the gypsite and the Berino soil must not be represented by climatic extremes, as the general North American climatic regime during this period is moderately well known. Excessive rainfall would most likely have destroyed the Berino and Mescalero or produced a very deep soil profile. The climate probably tended more toward the arid range because the soil profile does not seem to have been active during this interval or the uranium disequilibrium would indicate more recent ages. In addition, the soil profile is not

very deep, and this is consistent with more arid conditions and little infiltration. Infiltration did not generally penetrate the Mescalero caliche, or it should represent ages similar to the Ber[illegible]o. Overall, climatic conditions at the WIPP area do not appear to have greatly exceeded the stability of the caliche for long periods of time as it has not been deeply buried enough to escape that attack.

Certainly an increase in rainfall and recharge will increase the removal of soluble parts of the surficial and near-surface evaporites. There is no specific information on the absolute amounts by which rainfall may have changed over the last 10,000 years or longer. The dilemma is most easily resolved by examining the general evidence for rates of dissolution. As a consequence, the time period incorporates climatic changes of the type and magnitude that could reasonably be expected during the next 10,000 years. Extrapolating these dissolution effects indicates the WIPP site will not be significantly affected during such a period of time. The amount of dissolution that has occurred over several hundred thousand years can be compressed into the next 10,000 years without threat to the WIPP. Though it is not possible to predict the actual climatic changes nor the amount of recharge and dissolution, the bounds of dissolution that can be expected are very acceptable.

The flow characteristics of the Culebra and other units overlying soluble units may, however, be affected by dissolution.

3.6 BRINE POCKETS IN THE SALADO FORMATION

Griswold (1977) and Mercer (1987) have reported and summarized the available information about gas and the few discrete brine "pockets" in the Salado of the northern Delaware Basin. In studies for the WIPP, brine usually occurs in relatively small amounts along bedding discontinuities and sulfate units such as MB 139. The largest known brine "pocket" encountered in the Salado in a potash mine exceeded about 375 m^3 (100,000 gallons) of brine. The average brine "pocket" is reported by Griswold (1977) to be from about 0.04 to 0.4 cubic meters (10 to 100 gallons). No brine pockets of this size have been encountered while mining underground at the WIPP. Griswold (1977) thought that the brine pockets are more concentrated in the McNutt potash zone and are less likely to be encountered in the zones selected for the facility horizon. It is not clear that brine "pockets" encountered in the Salado Formation have any relationship to deformation as is suggested for pressurized brines in the Castile Formation.

Additional information about Salado hydrology and testing, as well as the pressurized brines in the Castile Formation can be found in Section 4.0.

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APPENDIX D10

GROUND WATER HYDROLOGY

FROM PREVIOUSLY PUBLISHED NO-MIGRATION VARIANCE PETITION,
ADDENDUM, SECTION 4.0, VOLUME VII

U.S. Department of Energy (DOE), 1990,
DOE/WIPP 89-003, Revision 1, Carlsbad, New Mexico

4.0 GROUND WATER HYDROLOGY

This section provides additional detail and clarification of the hydrogeology in the vicinity of the WIPP. The WIPP site is located in the northern part of the Delaware Basin, which is filled with approximately 73,000 meters (24,000 feet) of Phanerozoic sedimentary rocks (Hills, 1984). At the WIPP site, the upper 12,000 meters (4,000 feet) of sedimentary rocks contain evaporites (Powers, et al., 1978) (Figure 4.0-1). The nearest major aquifer is the Capitan Reef, which is located about 16 kilometers (10 miles) from WIPP site (Figure 4.0-2). The water-bearing zones within the rocks which underlie, host, and overlie the WIPP repository have low permeabilities and storativities, are generally confined, have high salinities, and long ground water residence times. As part of WIPP site characterization activities, each of the major water-bearing zones has been characterized. Several ongoing studies continue to supplement data and refine the understanding of the hydrogeologic system.

The following paragraphs provide a summary of the information presented in this section.

Section 4.1 describes the Bell Canyon Formation, which is the first water-bearing unit below the evaporite sequence in which the WIPP is located. The hydrology of the Bell Canyon Formation is considered important in the performance of the WIPP for two reasons: (1) it is potentially a source of water that could cause dissolution of the salt in the overlying evaporite sequence, and (2) it could be a source of water in performance assessment scenario of human intrusion where a borehole penetrates the repository and the Bell Canyon.

With respect to the dissolution issue, it is concluded that the mechanisms by which dissolution could occur are not active at the WIPP site. Dissolution is discussed in greater detail in Section 3.0. With respect to the borehole penetration scenario, it is concluded that a downward flow would be established as water in an uncased borehole became denser due to saturation with salt from the Salado and Castile formations. In this case, water from the Bell Canyon would not provide a continuous supply of water to the surface.

The Bell Canyon Formation consists of five informal members. The distribution of hydrologic properties within the Bell Canyon has been attributed to the distribution of sandstone, which were deposited in channel environments. The channel sandstones have relatively high porosity (20-28 percent) and high permeability (14-90 millidarcies). The intervening siltstone and limestone units have lower porosity (10-20 percent) and lower permeability (0.1 millidarcy). No Bell Canyon channel sandstones have been identified under the WIPP site.

Section 4.2 describes the Castile Formation, which is made up of layers of anhydrite/carbonate and halite. No regional hydraulic gradient exists within the Castile and the transmissivity is too low to measure. There are isolated pressurized brine reservoirs within the Castile Formation. The brine reservoirs occur exclusively over localized folded and fractured sections of the Castile Formation. A portion of a brine reservoir may underlie the northern portion of the WIPP site, as described in Section 1.1.

The hydrology of the Salado Formation is described in Section 4.3. Like the Castile Formation, the Salado Formation consists of layers of anhydrite, halite, and clay (Section 7.2 has a detailed description of Salado Formation geology). No regional hydraulic gradient exists within the Salado Formation. However, a local hydraulic gradient does exist adjacent to the underground portion of the WIPP facility. Excavation of the facility set up a distinct gradient, the result of which is the occurrence of brine seeps in the facility. The permeability of the Salado Formation to liquid is 0.01 to 25 microdarcies and to gas is 0.001 to 0.01 microdarcies. There have been occurrences of pressurized gas in boreholes and in the

facility excavation. These occurrences are probably the result of gas exsolving out of brine in excavated areas.

Two marker beds bound the repository horizon. MB 139 is below the repository and has transmissivity on the order of 10^{-6} square meters/second. MB 138 is above the repository horizon; although no hydrologic testing has been conducted, due to its location it is not expected to affect repository performance. Both marker beds are described in greater detail in Section 7.5.

The Rustler Formation is the first water-bearing unit above the Salado Formation; it is described in Section 4.4. It consists of five members, two of which (the Culebra Dolomite and the Magenta Dolomite) are producing aquifers. A detailed description of each member including further classification of the stratigraphy and hydrostratigraphy is provided in Subsections 4.4.1 through 4.4.5.

In the area surrounding the WIPP site, the distribution of hydrologic properties of each member of the Rustler Formation appears to follow the same general pattern -- flow towards the west to southwest and increase in transmissivity from east to west. This is interpreted to be the effect of unloading and dissolution, both of which tend to increase the fracturing of the rock. East and across most of the WIPP site, unloading is the primary cause of fracturing. As overburden decreases to the west, the fracturing increases. Within zones at the northern and southern margins of the WIPP site, dissolution of the Rustler increases the degree of fracturing. West and south of the WIPP site, in Nash Draw, shallow dissolution of the Salado Formation has caused more extensive fracturing of the Rustler Formation; hence the pattern of increasing transmissivity from east to west.

The Culebra Dolomite Member has a slightly different flow pattern, toward the south, and a conceptual hydrogeological model is presented in Section 4.4.2.4 to explain the Culebra hydrologic, geochemical, and geologic data. This model concludes that the hydrologic conditions within the Culebra are a relic of the Pleistocene hydrologic system.

The lowest member of the Rustler Formation is the Unnamed Lower Member. Estimates of transmissivity of this member are 10^{-3} to 10^{-5} square feet/day in the east and increases toward the west up to 5 square feet/day in Nash Draw. Overlying the Unnamed Lower member is the Culebra Dolomite. Transmissivities of the Culebra vary over six orders of magnitude from 0.004 square feet/day in the east to 10^{3} square feet per day to the west in Nash Draw. Estimates of ground water travel time for undisturbed Culebra flow from above the waste emplacement panels to the southern WIPP site boundary range from 5,100 to 13,000 years.

The Tamarisk Member overlies the Culebra. It consists of mudstone and anhydrite, and the transmissivity is too low to measure in most locations. Hydrologic testing in one borehole yielded an estimate of $< 10^{-5}$ square feet/day. The Magenta Dolomite overlies the Tamarisk Member. Flow in this unit is west to southwest and transmissivities increase from east (< 0.1 square feet/day) to west (375 square feet per day). The uppermost member of the Rustler Formation is the Forty Niner. It consists of anhydrite/gypsum interlayered with siltstone/mudstone/claystone. Flow is to the southwest to west and transmissivities have been estimated at 10^{-2} to 10^{-3} square feet/day and may be higher toward the west, in Nash Draw.

Sections 4.5 and 4.6 describe the formations overlying the Rustler Formation. These are the Dewey Lake Red Beds and the Santa Rosa Formation; neither of these formations are considered important to the performance of the WIPP. At the WIPP site, the Dewey Lake is moist and south of the site several stock wells extract water from the Dewey Lake. The Santa Rosa Formation is recharged by precipitation along the eastern margin of the WIPP site, and probably discharges downward into the Dewey Lake Red Beds.

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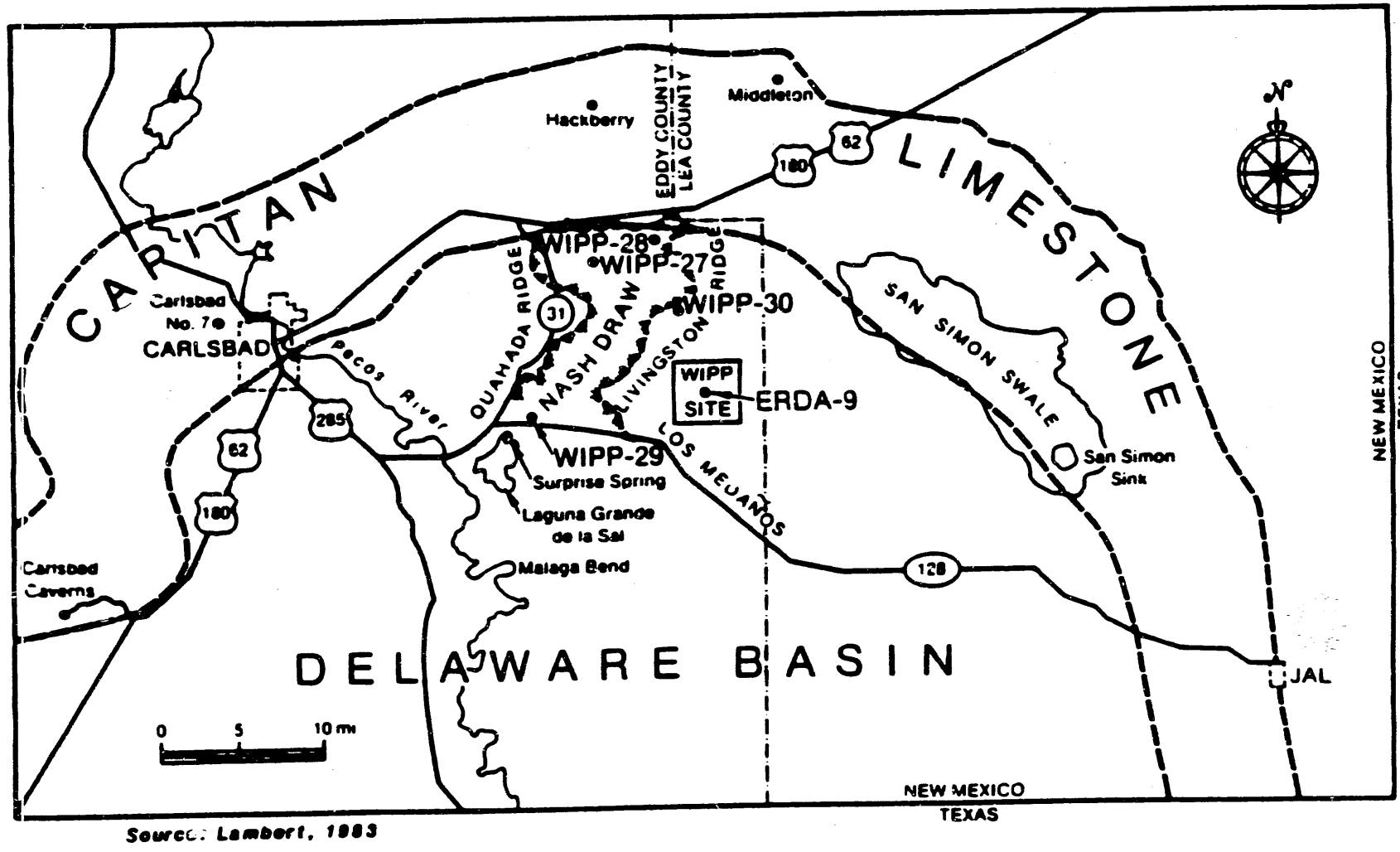
SYSTEM	SERIES	GROUP	FORMATION	MEMBER
RECENT	RECENT		SURFICIAL DEPOSITS	
QUATER-NARY	PLEISTO-CENE		MESCALERO CALICHE	
			GATUNA	
TRIASSIC		DOCKUM	SANTA ROSA	
PERMIAN	OCHOAN		DEWEY LAKE RED BEDS	
			RUSTLER	Forty-niner
				Magenta Dolomite
				Tamarisk
				Culebra Dolomite
				unnamed
			SALADO	
			CASTILE	
	GUADALUPIAN	DELAWARE MOUNTAIN	BELL CANYON	
			CHERRY CANYON	
			BRUSHY CANYON	

Source: Beauheim 1987b

FIGURE 4.0-1 GENERALIZED STRATIGRAPHIC COLUMN OF THE DELAWARE MOUNTAIN GROUP AND YOUNGER SEDIMENTARY ROCKS AT AND NEAR THE WIPP SITE.



Source: Lambert, 1983

FIGURE 4.0-2 SETTING OF THE WIPP SITE RELATIVE TO THE NORTHERN DELAWARE BASIN.

4.1 BELL CANYON FORMATION

The Bell Canyon Formation is the uppermost formation in the Delaware Mountain Group (Figure 4.0-1). The Bell Canyon is subdivided into five informal members: the Hays sandstone, Olds sandstone, Ford shale, Ramsey sandstone, and Lamar limestone (Figure 4.1-1). Individual lenticular sandstone units are separated laterally by stratigraphically equivalent siltstones and shales. The Bell Canyon is considered important to the WIPP site characterization for two reasons. First, the Bell Canyon has been suggested by some authors (e.g., Anderson, 1978a, 1981; Davies, 1983a) to be a source for fluids causing local or point source dissolution within the evaporites of the overlying Castile Formation. Second, in evaluating human intrusion scenarios, the fluid flow directions within the Bell Canyon and the vertical flow relationships between the Bell Canyon and overlying units are important. For repository breach scenarios, the Bell Canyon is important as it is the first regionally continuous water-bearing zone below the WIPP repository horizon (Lappin, 1988).

4.1.1 General Hydrology

The most significant hydrologic units within the Bell Canyon are the channel sandstones. Their porosity is intergranular and ranges from 20 to 28 percent, while their permeabilities range from 14 to 90 millidarcies (Berg, 1979). The siltstones and shaley siltstones have porosities ranging from 10 to 20 percent and permeabilities less than 0.1 millidarcy (Mercer, 1983). Tests conducted during WIPP site characterization activities showed the hydraulic conductivities of Bell Canyon sandstones, siltstones, and shales to range from 2×10^{-7} to 7×10^{-12} meters/second (m/s) (Mercer, 1983). Mercer (1983) reports these values to be consistent with the range of permeability values reported for the Bell Canyon by various oil companies.

Within the Bell Canyon, the shallowest significant hydrologic unit is the Ramsey sandstone, a channel sand deposit. It is overlain by the Lamar limestone, which acts as a confining layer. The Ramsey consists of laterally and vertically interlayered sandstones, siltstones, and shales deposited as deep-basin channels and related deposits (Lappin, 1988). The most porous and permeable lithologies are the channel sandstone units which trend roughly northeast/southwest through the basin (Figure 4.1-2).

The Hays Sandstone is the most permeable and transmissive unit within the Bell Canyon near the WIPP site based on hydrologic testing in two other WIPP wells (Cabin Baby-1 and DOE-2) (Beauheim et al., 1983; Beauheim, 1986). The Hays sandstone is the deepest of the five informal members of the Bell Canyon. Bell Canyon permeabilities were reported by Beauheim et al. (1983) to be 1.7 to 6×10^{-4} millidarcies at Cabin Baby-1 and by Beauheim (1986) to be 2.4 to 8.4×10^{-2} millidarcies at DOE-2. Transmissivity values for Cabin Baby-1 and DOE-2 ranged from 6.0×10^{-7} to 5.7×10^{-11} m^2/s (Beauheim et al., 1983; Beauheim, 1986). Wood et al. (1982) estimate that the transmissivities in the Bell Canyon sandstones range from 1.0×10^{-6} to 2.8×10^{-6} m^2/s with a maximum value of 1.7×10^{-5} m^2/s. This range is roughly an order of magnitude greater than the transmissivity in the Hays sandstone at Cabin Baby-1 and DOE-2 and more than two orders of magnitude greater than the transmissivities of the Olds and Ramsey members in the same boreholes. This comparison suggests that Cabin Baby-1 and DOE-2 do not intersect channel sandstones in the Ramsey member.

A narrow channel sandstone 20 to 40 feet thick occurs in the Ramsey member along the eastern margin of the WIPP site area (Davies, 1983a; Figure 4.1-2). As no channel sandstones are in this interval based on testing at Cabin Baby-1, which is along the projected trend of the channel, the channel is not continuous toward the southwest. Although this does not preclude the occurrence of a Ramsey channel sandstone across the WIPP site area, it indicates that any channel sandstone that is present is probably narrow, similar to the channel sandstone along the eastern part of the WIPP site (Figure 4.1-2).

Mercer (1983) updated the equivalent freshwater potentiometric surface map of Hiss (1976) to include data from WIPP boreholes (Figure 4.1-3). The potentiometric contours generally follow the regional structural trend. Flow direction, interpreted from the potentiometric contour lines, is a general northeastern flow across the WIPP site area (Figure 4.1-3). Recharge to the Bell Canyon occurs along the western margin of the Delaware Basin. The salinity of ground water within the Bell Canyon increases from fresh to very saline (300,000 mg/l TDS) from the recharge area to the structural trough of the basin (Grauten, 1965; McNeal, 1965), indicating abundant rock-water interaction. The hydraulic conductivity of the Bell Canyon is several orders of magnitude less than the Capitan aquifer; therefore, little discharge from the Bell Canyon into the Capitan aquifer is unlikely along the northeastern part of the basin (Mercer, 1983).

4.1.2 Dissolution Potential

Some authors (e.g., Anderson, 1978a; Davies, 1983a) have suggested that the Bell Canyon is capable of providing undersaturated ground water for local or point-source dissolution within the overlying Castile evaporites. The mechanism proposed involves: 1)recharge of halite-unsaturated fluids to the Bell Canyon from the Capitan limestone; 2) an upward hydraulic gradient causing movement of the fluids into the halite of the Castile Formation, presumably along fractures; 3) halite dissolution within the Castile; 4) subsidence and disruption of the Castile and overlying Salado Formations; 5) gravity-driven downward flow of halite saturated fluids back into the Bell Canyon along fractures; and 6) removal of the brines through the Bell Canyon. This mechanism relies on a density-driven convective ground water system.

Wood et al. (1982) examined the potential for Bell Canyon fluids to dissolve Castile evaporites and the impact of this process on the WIPP repository. On the basis of numerical modeling, Wood et al. (1982) concluded that density-driven convective processes may only be significant adjacent to the Capitan Reef aquifer and that the general salt removal potential by diffusion would advance a dissolution front by 0.3 centimeter (0.1 inch) in 10,000 years. An order of magnitude increase in flow rate would increase the dissolution potential to 0.4 centimeter (0.1 inch) in 10,000 years (Wood et al., 1982). In a worst case scenario, Wood et al. (1982) calculated that the theoretical maximum cavity radius would be 7 meters (23 feet) over a fracture and 1 meter (3 feet) above a circular porous zone in a period of 10,000 years. In addition, Lambert (1983) concluded that the Bell Canyon has no modern hydraulic connection with a source of halite-unsaturated fluids or any effective path for the brines to discharge from the Delaware Basin. Lambert (1983) interprets long residence times for the fluids and concludes that the fluid composition reflects extensive rock-water interaction, evolving isotopically and geochemically away from compositions representative of meteoric recharge.

The potential for vertical flow from the Bell Canyon upward into fluid-bearing zones in the Rustler is important in evaluating a human intrusion scenario, via borehole. At the time the Final Environmental Impact Statement (FEIS) was released (DOE, 1980), minimal hydrologic characterization of the Bell Canyon had been performed for the WIPP project. The early data indicated that the flow between the Rustler and Bell Canyon would be upward if the two were ever connected, based on conversion of measured potentiometric levels to equivalent fresh water levels. Mercer (1983) concluded, on the basis of additional testing, that flow between the two units would be downward. A more recent evaluation of the Bell Canyon by Beauheim (1986) showed that the hydraulic head relationship at DOE-2 is conducive to upward vertical flow from the Bell Canyon to the Culebra in a cased borehole. In an uncased borehole, the Bell Canyon fluids, which are undersaturated with respect to halite, would encounter and dissolve halite from the Salado Formation, thus increasing the fluid density. When this process is considered, the increase in fluid density would tend to lower the Bell Canyon hydraulic head, resulting in downward flow from the Culebra into the Bell Canyon (Lappin, 1988).

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SYSTEM	SERIES	FORMATION	MEMBER
PERMIAN	OCHOAN	CASTILE	
	GUADALUPIAN	BELL CANYON	Lamar
			Ramsey
			Ford
			Olds
			Hays
		CHERRY CANYON	

FIGURE 4.1-1 BELL CANYON STRATIGRAPHY

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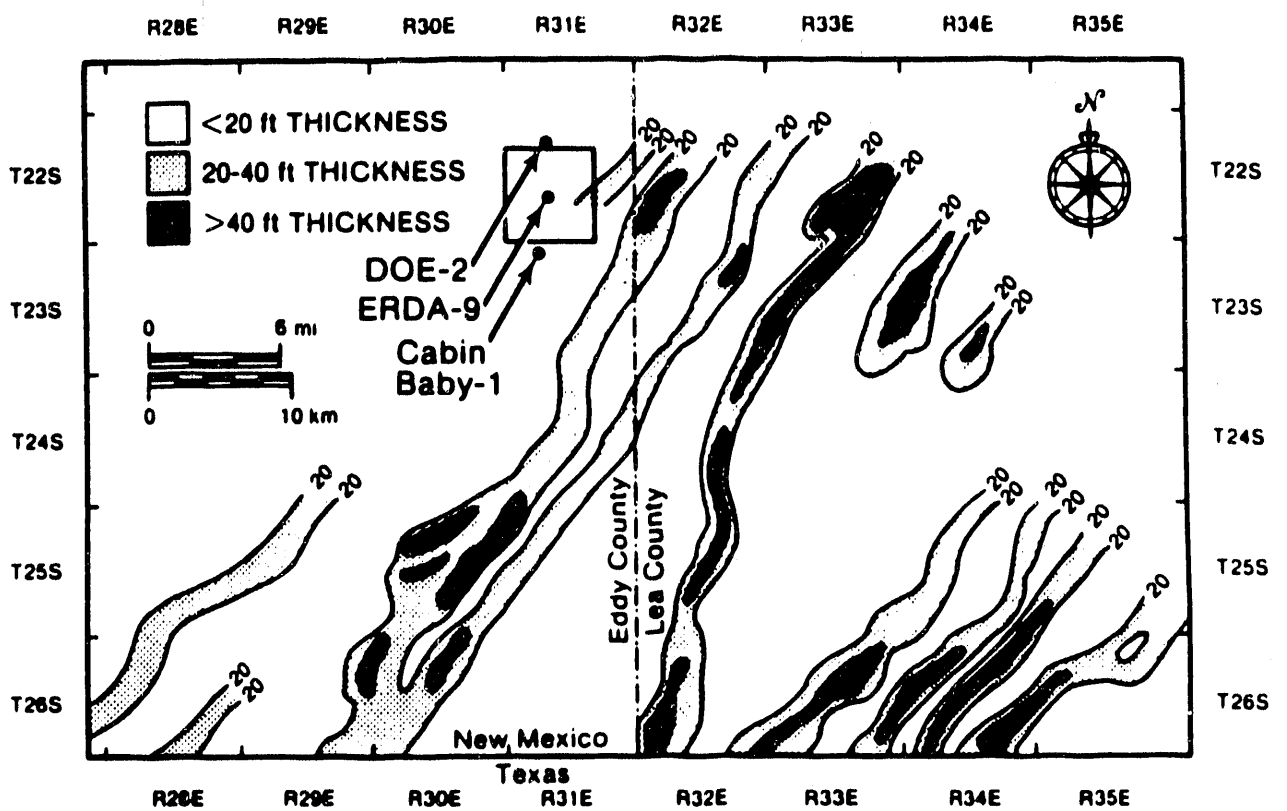

Source: Lappin, 1988

FIGURE 4.1-2 LATERAL DISTRIBUTION AND THICKNESSES OF CHANNEL SANDS IN THE INFORMAL RAMSEY MEMBER OF THE BELL CANYON FORMATION IN THE NORTHERN DELAWARE BASIN.

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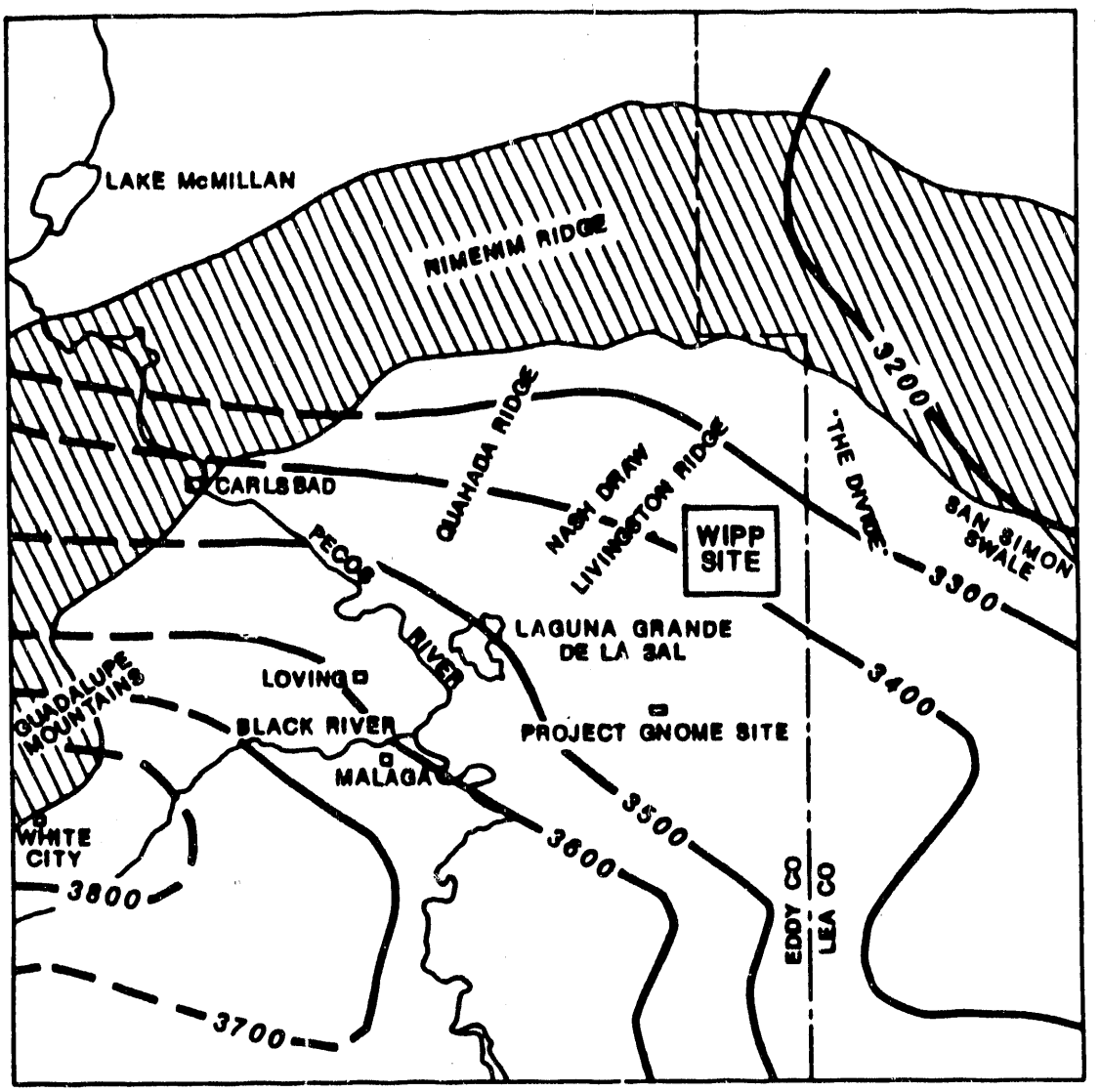

Contour interval is 100 feet.

10 5 0 10 MILES

10 5 0 10 KILOMETERS

SCALE

EXPLANATION

GUADALUPIAN REEF COMPLEX

Source: Mercer, 1983

FIGURE 4.1-3 CONTOUR MAP OF THE ESTIMATED FRESHWATER HEAD ELEVATION FOR THE HYDROLOGIC UNIT IN THE UPPER PART OF THE BELL CANYON FORMATION

4.2 CASTILE FORMATION

The Castile Formation directly underlies the Salado Formation (Figure 4.0-1). It is an aquitard that forms a hydrologic barrier between the Bell Canyon Formation and the Salado Formation.

4.2.1 General Hydrology

The Castile Formation consists of thick units of laminated anhydrite/carbonate and halite. The thickness of the Castile near the WIPP site is approximately 400 meters (1,200 feet) (Lappin, 1988). In the vicinity of the WIPP site, it is subdivided into five informal members: anhydrite I, halite I, anhydrite II, halite II, and anhydrite III (Figure 4.2-1). The Castile has low permeabilities and usually only minute quantities of in situ fluid, characteristic of evaporites. Regional hydraulic gradients do not exist within the Castile across the Delaware Basin (Lappin, 1988), although localized zones of brine and gas under high pressure have been encountered by several drillholes intersecting structural features (fractured areas) within the Castile. The hydraulic properties of undisturbed Castile anhydrite and halite have not been determined because the transmissivity is too low to measure with current test methods. Hydraulic properties have been estimated from fractured anhydrite brine reservoirs during testing of WIPP site characterization boreholes, ERDA-6 and WIPP-12 (Popielak et al., 1983).

Hydraulic connection and circulation of ground water undersaturated with respect to halite yield dissolution and subsequent structural collapse within evaporites (Holt and Powers, 1988). These conditions occur along the western and southern margins of the Delaware Basin, where the Castile outcrops or is very close to the surface. However, the Castile does not show evidence of regional deep-seated dissolution and collapse in the central and northern parts of the Delaware Basin; therefore, unsaturated ground water does not circulate in the Castile.

Deep-seated point source dissolution of Castile evaporites has been proposed by several authors including Anderson (1978, 1981) and Davies (1983). The proposed mechanism (previously discussed in Section 4.1.2) relies upon the presence of a hydraulic gradient/density-driven convection cell between Bell Canyon ground water undersaturated with respect to halite and Castile evaporites (Lappin, 1988). Wood et al. (1982) and Lambert (1983), however, demonstrated that the Bell Canyon hydrologic system does not support such a mechanism. Additionally, no open fractures from the Castile to the Bell Canyon have been observed in core.

4.2.2 Castile Brine Occurrences

Pressurized brine and gas occur in Castile anhydrite that is fractured and associated with deformed zones. Anderson and Powers (1978) report on deformation of parts of the Castile from several areas within the Delaware Basin buried no more than about 1,200 meters (4,000 feet) deep at present (Figure 4.2-2). Borns et al. (1983) and Borns and Shaffer (1985) examined deformation in the Castile near the WIPP site and in larger areas of the basin. Borns and Shaffer (1985) concluded that the Castile structures near the WIPP site and those described by Anderson and Powers (1978) were due to gravity-driven salt flowage/deformation.

Isolated zones of pressurized brine have been encountered in the Castile at several hydrocarbon exploration and two WIPP (ERDA-6 and WIPP-12) drillholes (Lappin, 1988). The brine is pressurized and capable of discharging at the surface under artesian conditions (Popielak et al., 1983).

As part of WIPP site characterization activities, two brine reservoirs, at ERDA-6 and WIPP-12, were studied by Popielak et al. (1983). They concluded that the fluids originated from ancient seawater with no fluid contributions from present meteoric waters, based upon analysis of major and minor element concentrations in the brines. The gas and brine chemistries are distinctly different for each reservoir, indicating an isolated and distinctly separate origin for each reservoir with no regional interconnection.

The brines are saturated, or nearly so, with respect to halite and have little or no halite dissolution potential. The reservoirs occur in fractured anhydrites. Structural deformation, specifically the creation of salt-anticlines, fractured the brittle anhydrite and created reservoirs for brine (Figure 4.2-3). Most of the brine is stored in low-permeability microfractures with only about 5 percent of the total brine in large open fractures. The volumes of the ERDA-6 and WIPP-12 brine reservoirs are estimated to be 75,000 and 2,000,000 cubic meters (630,000 and 17,000,000 barrels), respectively. Hydraulic gradients within the reservoirs are higher than other regional ground water systems, and have been maintained for at least a million years.

Lambert and Carter (1984) provide a different interpretation of the origin of the fluids on the basis of uranium-disequilibrium methods. They concluded that the brines were not derived from Permian seawater, but were instead the result of the isolation of waters transmitted to the Castile from the adjacent Capitan Reef through an intermittent or episodic hydrologic connection. Lambert and Carter (1984) conclude that the isolation times for the Castile brines at ERDA-6 and WIPP-12 are 360,000 and 880,000 years.

Recent geophysical studies relying on time domain electromagnetic (TDEM) methods suggest that a portion of the WIPP-12 brine reservoir may underlie the northern and northeastern most waste emplacement panels (Figure 4.2-4; Earth Technology, 1987).

4.3 SALADO FORMATION

The Salado Formation is informally divided into three members: an unnamed upper member, a middle member, locally designated the McNutt potash zone, and an unnamed lower member (Figure 4.3-1). The middle and upper Salado are also subdivided on a much finer scale based on laterally consistent beds of halite, anhydrite, and polyhalite with varying amounts of other potassium-bearing minerals. About 85-90 percent of the Salado is halite (Jones et al., 1973). Beds of anhydrite and polyhalite alternate with thicker beds of halite throughout the Salado Formation. Unlike the Castile, the Salado is not confined to the Delaware Basin and extends well beyond the Capitan reef onto the Northwestern Shelf and the Central Basin Platform. The Salado has been erosionally removed and dissolved by circulating ground waters along the west and south sides of the Delaware Basin, leaving a horseshoe-shaped rim of brecciated insoluble material.

4.3.1 General Hydrology

Due to the hydraulic properties of the salt and interbedded sulfates, the Salado is considered a regional aquitard and within most of the Delaware Basin, the Salado acts as a regional barrier to fluid flow (Lappin, 1988). Regional hydraulic gradients within Salado halites and interbeds have never been established. Unlike the Castile Formation, pressurized brine flows of significant size have never been encountered during the hydrologic testing of the Salado (Lappin, 1988), although a slow build-up of pressure has been observed during the hydrologic testing of some boreholes (Mercer, 1987). Mercer (1987) reports a maximum pressure of 3.3 MPa at WIPP-12 and suggests that the pressures are supported by a very small volume of brine.

Permeabilities of the Salado range from 0.01 to 25 microdarcies, estimated from hydrologic test data, although they may be lower because the permeability estimates are constrained by the current test methods. The most reliable hydrologic data for the Salado results in a permeability value of 0.3 microdarcies, based on tests done at DOE-2. In addition to test method limitations, Salado hydrologic test data collected from the surface may not represent that of intact halite, as each of the zones tested contains one or more interbeds and hole "aging" may artificially increase permeability (Mercer, 1987).

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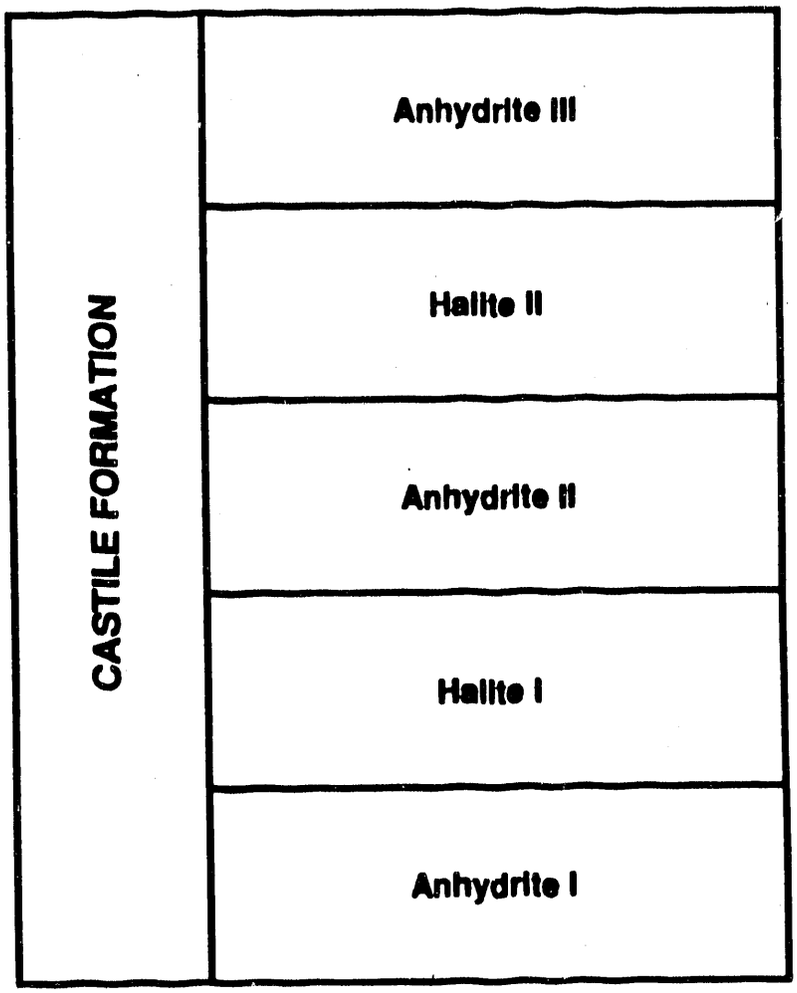


FIGURE 4.2-1 CASTILE STRATIGRAPHY NEAR THE WIPP SITE

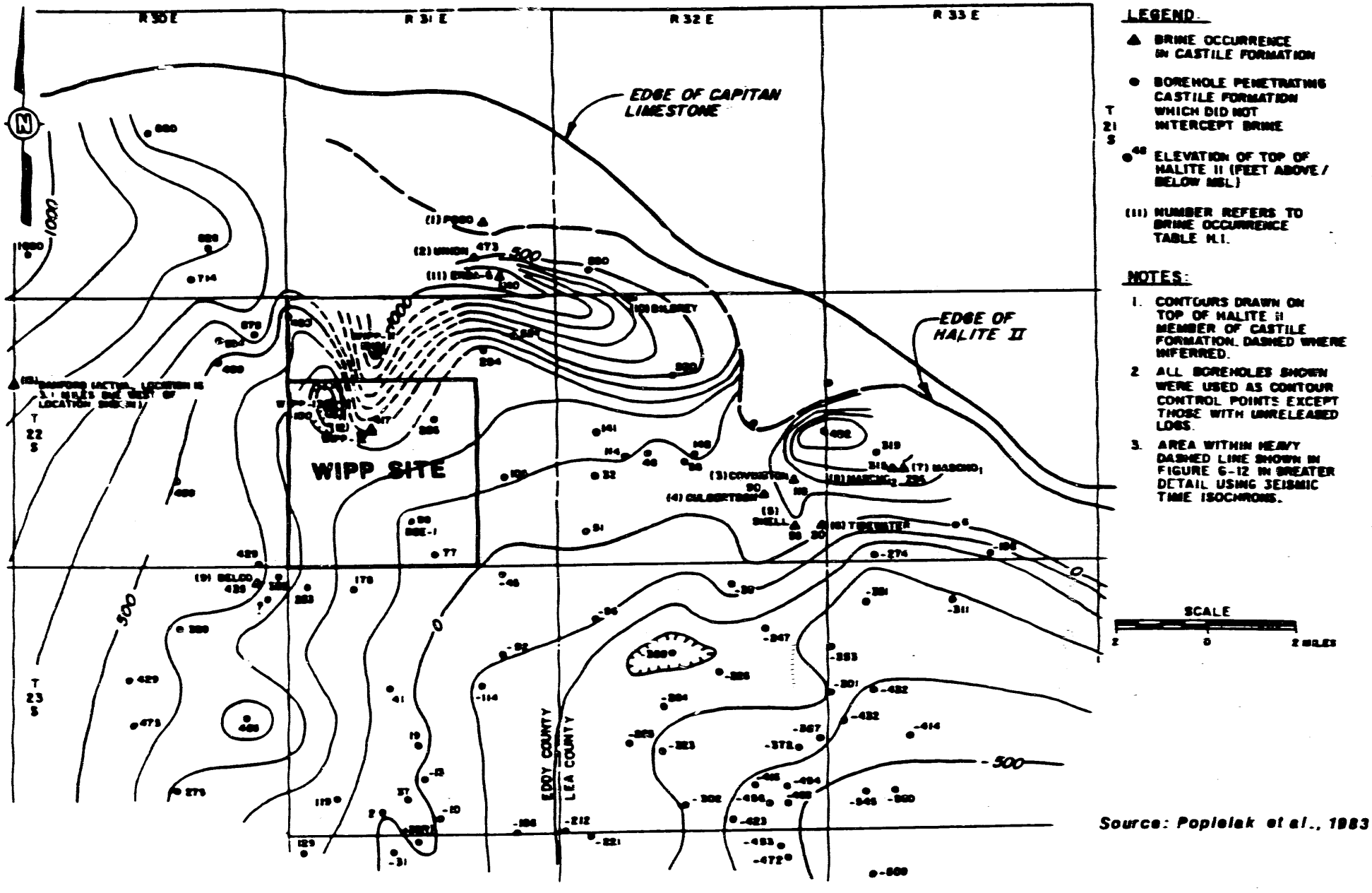
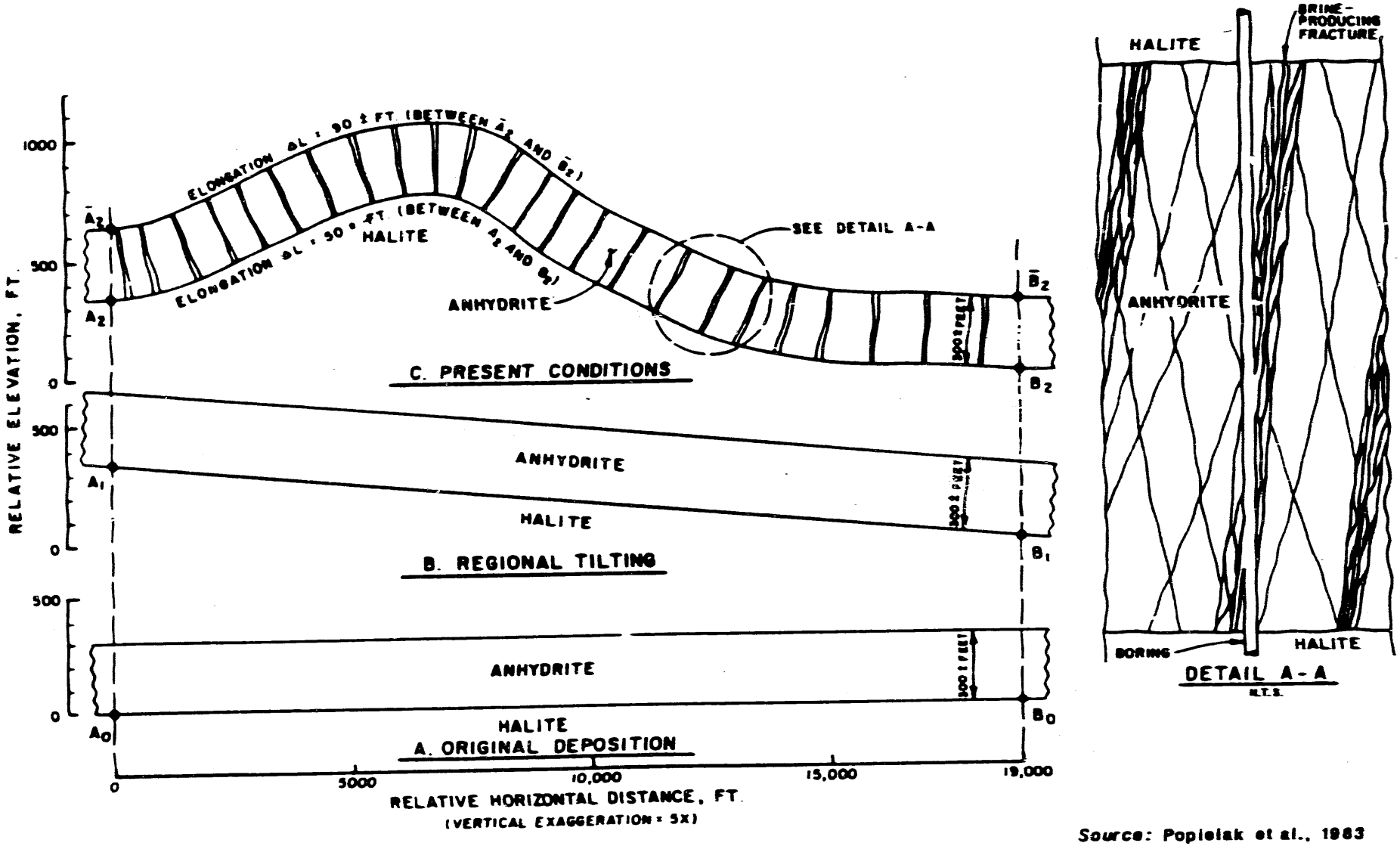
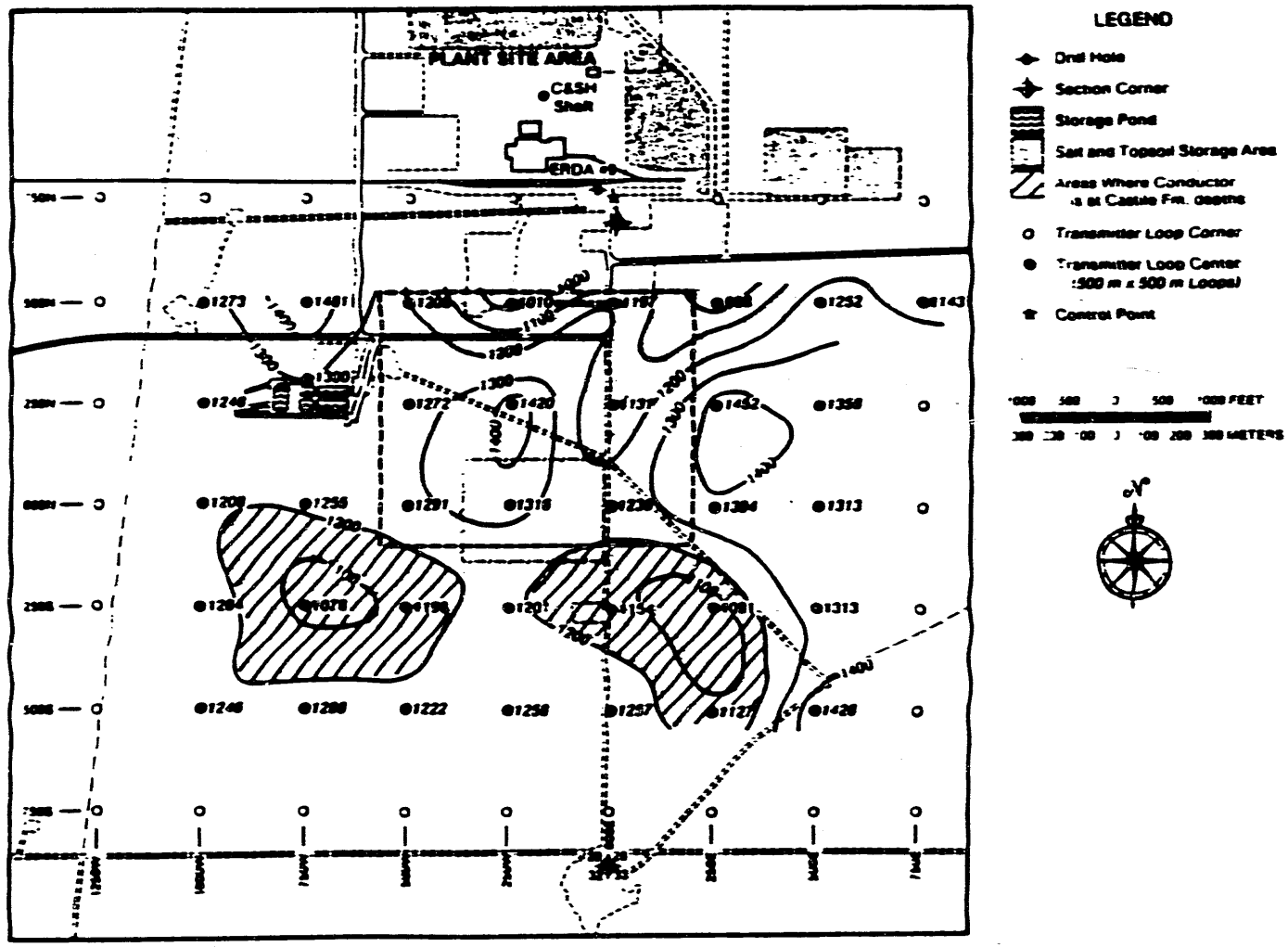


FIGURE 4.2-2 STRUCTURE CONTOUR MAP ON THE TOP HALITE II IN THE CASTILE SHOWING BRINE OCCURRENCES



Source: Popielak et al., 1983

FIGURE 4.2-3 SCHEMATIC OF BRINE RESERVOIR FORMATION



(from The Earth Technology Corp., 1988)

FIGURE 4.2-4 CONTOUR MAP OF DEPTH TO CONDUCTOR - FINAL INTERPRETATION RESULTS

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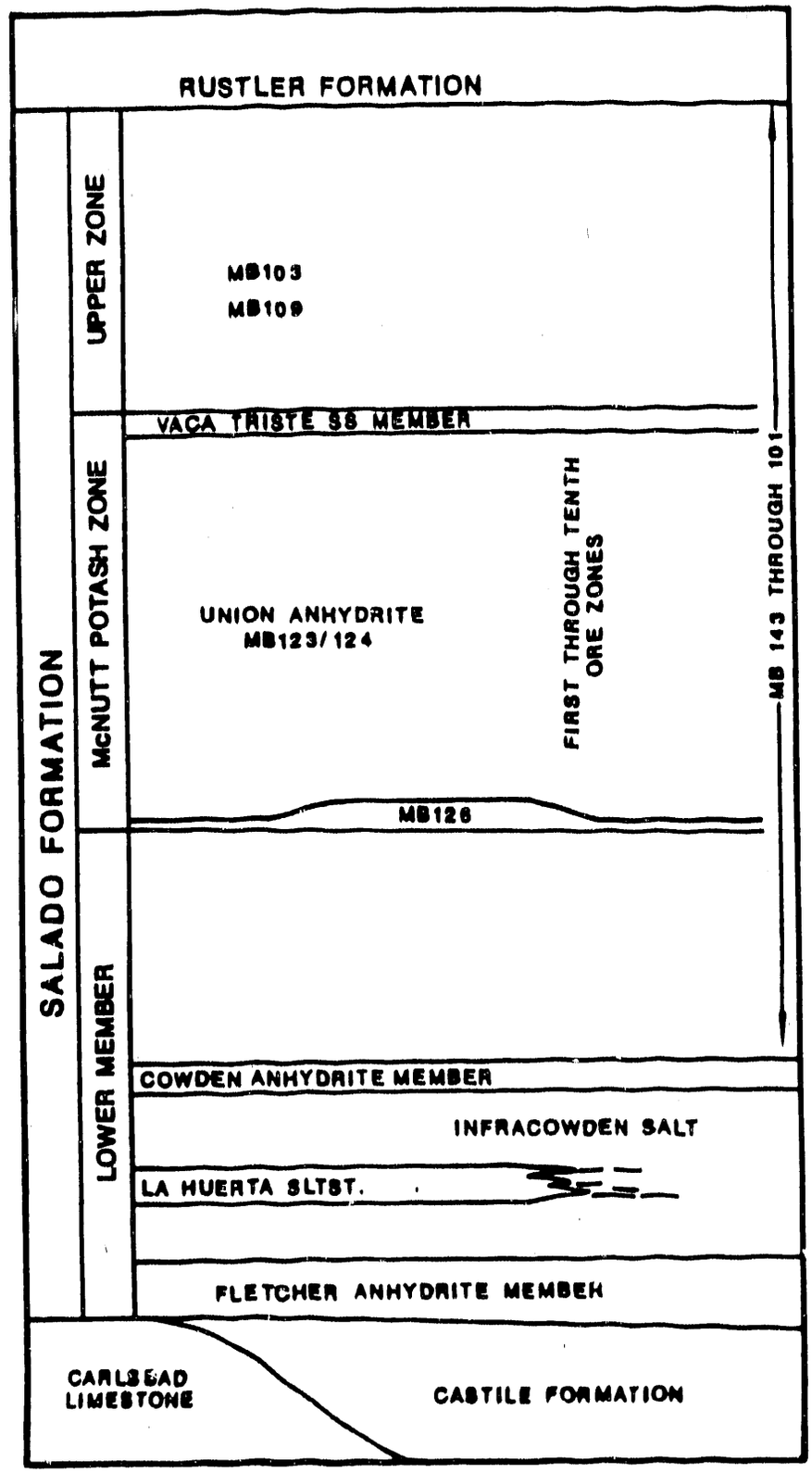

FIGURE 4.3-1 SALADO STRATIGRAPHY

Pressurized gas has been encountered within the Salado in surface boreholes, local mines, and WIPP excavations (Lappin, 1988). Mercer (1987) reports a large gas flow at AEC-8, a surface drillhole, of 6 x 10^5 cubic meters (2 x 10^7 cubic feet) with no apparent depletion of the gas reservoir. This inflow occurred roughly one year after original drilling. Pressurized gas has been encountered in several of the potash mines in the Delaware Basin and also in WIPP excavations. The origin of this gas has not been firmly established. Deal and Case (1987) report the occurrence of gas exsolving from Salado Brines collected in the WIPP underground. Pressurized gas has only been encountered in disturbed Salado (e.g., surface boreholes and underground excavations); the gas occurrences may be attributable to exsolution of gases dissolved into Salado brines during fluid pressure relief around disturbances such as boreholes and excavations.

Where halite unsaturated ground waters have actively circulated through the Salado, dissolution and collapse have resulted (Holt et al., 1989). On the basis of geophysical logs, Holt et al. (1989) evaluated the extent of Salado dissolution in the vicinity of the WIPP site (Figure 4.3-2). Although Salado dissolution is currently active in Nash Draw and areas adjacent to the Pecos River, most of the dissolution of Salado materials east of the Pecos River developed during the Cenozoic in response to hydraulic gradients associated with the Ancestral Pecos River (Holt et al., 1989). As no water-bearing zones within the Salado display a regional gradient, stratabound dissolution is not a viable dissolution mechanism for the Salado (Holt et al., 1989). Salado dissolution is in response to hydraulic gradients controlled by surface ground water regimes, not regional confined ground water systems (Holt et al., 1989).

4.3.1 Near-Facility Hydrology

The Salado Formation around the WIPP excavations is hydrologically active in response to pressure gradients generated by excavation. Brine inflow into the underground drifts and shafts has been well documented (e.g., Deal and Case, 1987; Holt and Powers, 1986, 1989). Brine has been observed accumulating in boreholes, as weeps on the surfaces of excavations, and weeping from anhydrite and polyhalite interbeds in the air intake shaft (Deal and Case, 1987; Holt and Powers, 1989). In most boreholes, fluid inflow rates vary from a few hundredths to a few tenths of a liter per day (Deal and Case, 1987). Brine inflow into boreholes usually is minimal following the initial drilling, increases to a maximum, and then slowly decreases with time (Deal and Case, 1987). Downholes generally accumulate more brine (Deal and Case, 1987). Stratigraphic variations in brine inflow have been reported by Deal and Case (1987).

Bredehoeft (1988) suggested that the Salado should be considered a saturated media. Stratigraphic and lateral variability within the salt is high and currently precludes any direct interpretation of the degree of saturation in the Salado. If free-phase gas is present in the far-field, the Salado cannot be considered a truly saturated media (Lappin, 1988).

Initial permeability testing shows that far-field [beyond 2 meters (6 feet)] permeabilities are very low, less than one microdarcy, on the basis of gas permeability testing (Stormont et al., 1987). Peterson et al. (1987) reported the results of shut-in, long-term brine flow tests in halite 8 meters (24 feet) from the excavation and in MB 139. 9 meters (27 feet) from the excavation. Assuming complete saturation, the far-field permeabilities of the halite and MB 139 are 0.001 and 0.01 microdarcy, respectively (Peterson et al., 1987). The apparent steady-state pore-pressures were 8.3 MPa for the halite and 10.8 MPa for MB 139 (Peterson et al., 1987). Where Salado brine pressures can be measured, calculated heads indicate potential for flow upward into the Rustler (Lappin, 1988). Stratigraphic effects and the influence of effective fracturing on permeability in the far-field have not been addressed (Lappin, 1988).

Generally, permeability increases around the facility within 2 meters (6 feet) due to fracturing and possibly matrix dilation (Lappin, 1988a). Fractures develop parallel to the excavation, while low angle fractures form in the corners of the rooms (DOE, 1988a, Revised 1990). Some high angle fractures

develop in MB 139 (DOE, 1988a, Revised 1990). The fracture development process is time and excavation geometry dependent (Lappin, 1988).

The brines which inflow into the WIPP facility are not derived from fluid inclusions, but instead are grain-boundary fluids with residence times of at least several million years (Stein and Krumhansl, 1986). Geophysical measurements suggest a far-field brine content of halite to be around two weight percent and a near-field brine content of approximately one weight percent (Pfeifer, 1987; Hudson, 1987).

4.3.2 Marker Bed 139

MB 139 consists of varying amounts of polyhalite, anhydrite, and halite. It is a regionally persistent unit within the Salado. In the vicinity of the WIPP facility, it is roughly 1 meter (3 feet) thick and lies 1 meter (3 feet) below the facility horizon. Investigation of MB 139 was prompted by the concern that the undulatory surface of the marker bed developed in response to some late-stage stress which might affect the integrity of the WIPP facility (Lappin, 1988). Studies conducted by Jarolimek et al. (1983) and Borns (1985) conclude that the undulations had a depositional origin.

Borns (1985) observed subhorizontal fractures partially to wholly filled with halite in MB 139 (Figure 4.3-3). Borns (1985) suggested that these fractures formed in response to unloading or, less likely, structural deformation in the Castile Formation. These pre-existing fractures provide planes of weakness which reactivate in response to near-field stresses generated by the WIPP excavation. Separations along these fractures in the floors of WIPP rooms and drifts may be quite large (several centimeters). Hydrologic testing of MB 139 in one area of the WIPP facility suggested that separate fracture systems exist within the marker bed and yielded transmissivity values of 1.0×10^{-6} to 2.2×10^{-6} m^2/s (Crawley, 1989). Further hydrologic testing is planned.

4.4 RUSTLER FORMATION

The Rustler Formation is the uppermost of three Ochoan evaporite-bearing formations in the Delaware Basin. The Rustler has been the subject of extensive characterization activities since 1972 as it contains the most transmissive hydrologic units overlying the WIPP facility horizon (as summarized in Powers et al., 1978; Lappin, 1988). The Rustler has a variable lithology consisting of interbedded sulfates, carbonates, clastics, and halite. The Rustler Formation is subdivided into four formal members and one informal member (Figure 4.4-1; Vine, 1963). Within the Rustler, five hydrologic units have been identified: the unnamed lower-member/Salado contact area, the Culebra Dolomite Member, the Tamarisk Member claystone (M-3 of Holt and Powers, 1988), the Magenta Dolomite Member, and the Forty-Niner Member claystone (M-4 of Holt and Powers, 1988) (Figure 4.4-1). Of the five hydrologic units, the Culebra is the most transmissive and regionally important unit and has been the focus of Rustler hydrologic studies.

The Rustler varies in thickness from tens of feet, where exposed and subjected to solution and erosion, to nearly 170 meters (560 feet), in the northeastern part of the Delaware Basin (Figure 4.4-2) (Holt and Powers, 1988). The western margin of the Rustler has been removed by erosion. The Rustler crops out along the Pecos River Valley, within Nash Draw, and in an arcuate pattern near the southwestern edge of the Delaware Basin. Where the Rustler outcrops or is in the shallow subsurface, it has been extensively altered by near-surface ground water systems and karst processes (Holt et al., 1989). Karst processes do not affect the Rustler across the WIPP site area, although evidence of Rustler karst is abundant in Nash Draw and along its margins (Bachman, 1987b; Holt et al., 1989). Rustler karst processes related to Nash Draw occurs as far east as WIPP-33 (Bachman, 1987b).

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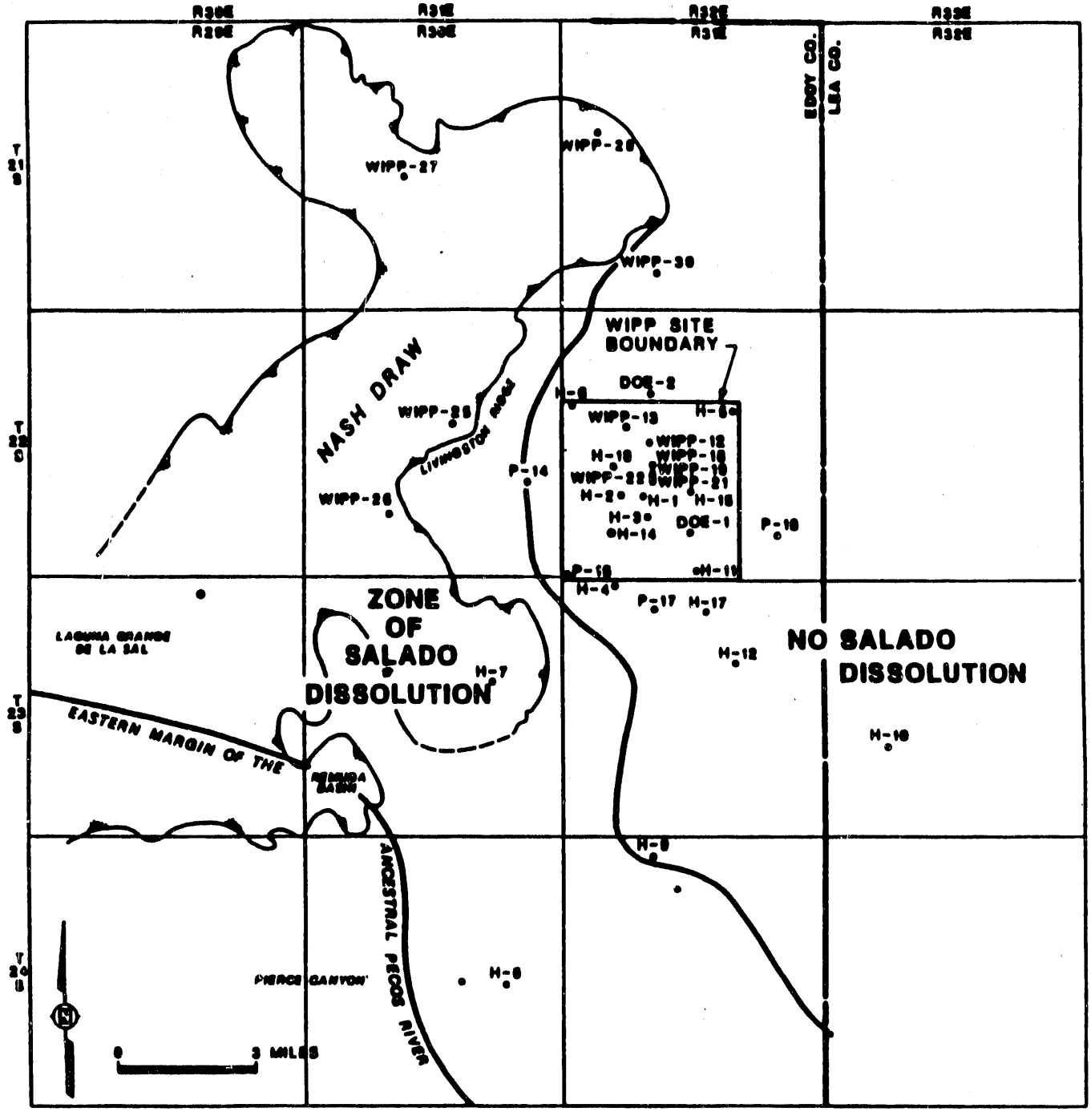
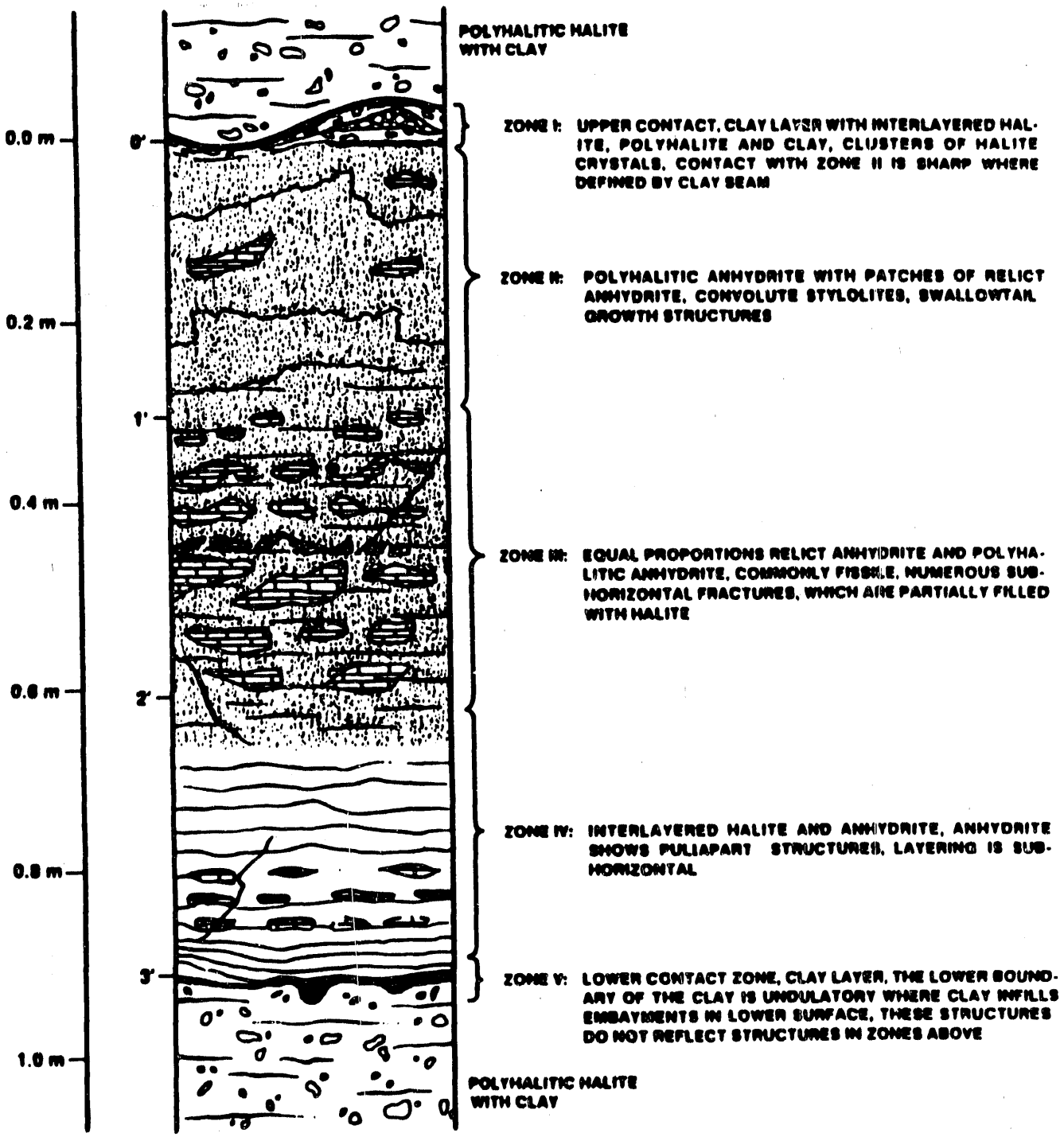


Source: Holt et al., 1989

FIGURE 4.3-2 EXTENT OF SALADO DISSOLUTION

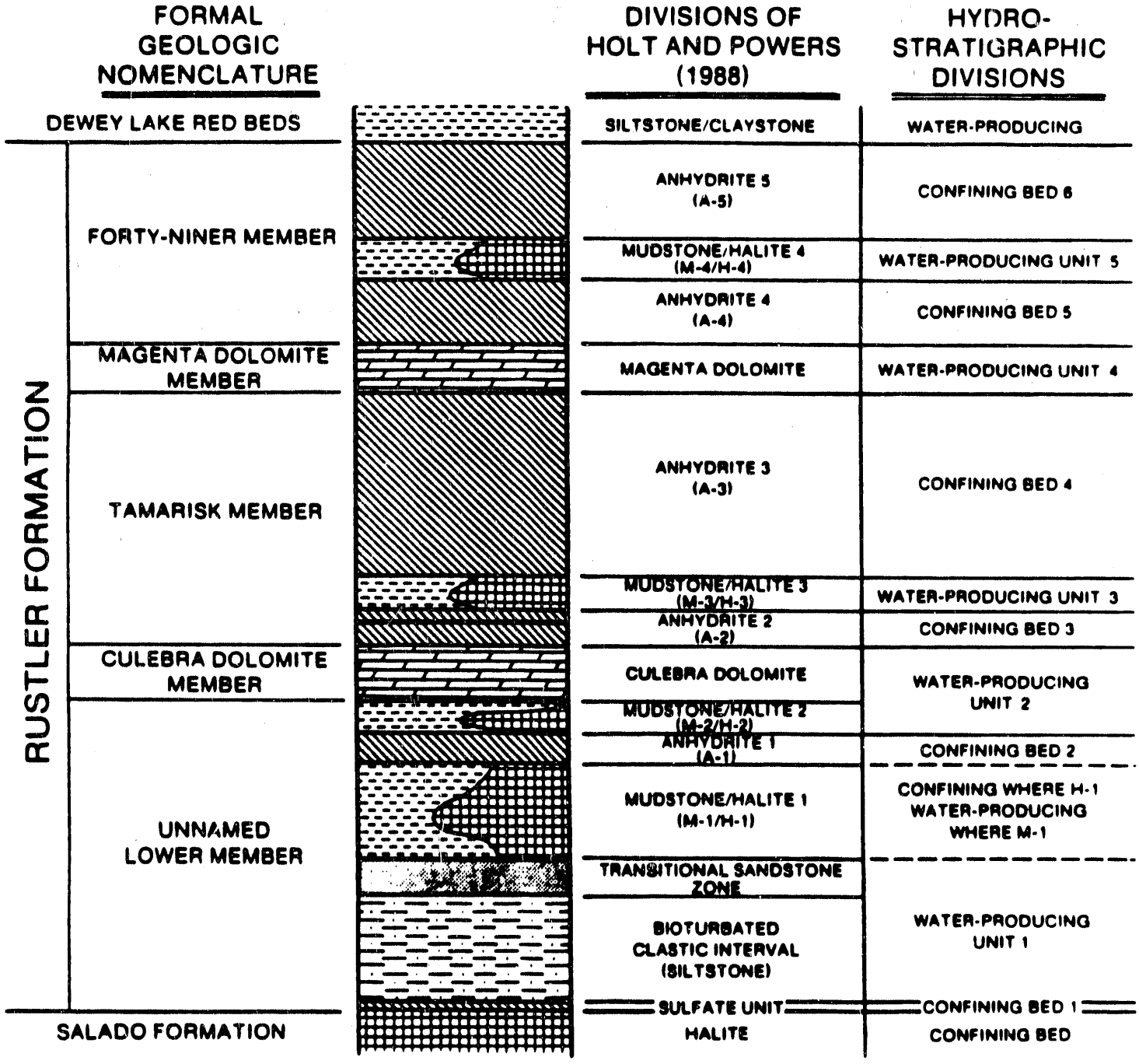
30100; 89 04 06 A26



Source: Borns, 1985

FIGURE 4.3-3 THE FIVE ZONES OF MB139, SHOWN IN AN IDEALIZED CORE SECTION

301001 89 04 06 A27



Source: Holt et al., 1988

FIGURE 4.4-1 LITHOSTRATIGRAPHY/HYDROSTRATIGRAPHY OF THE RUSTLER FORMATION

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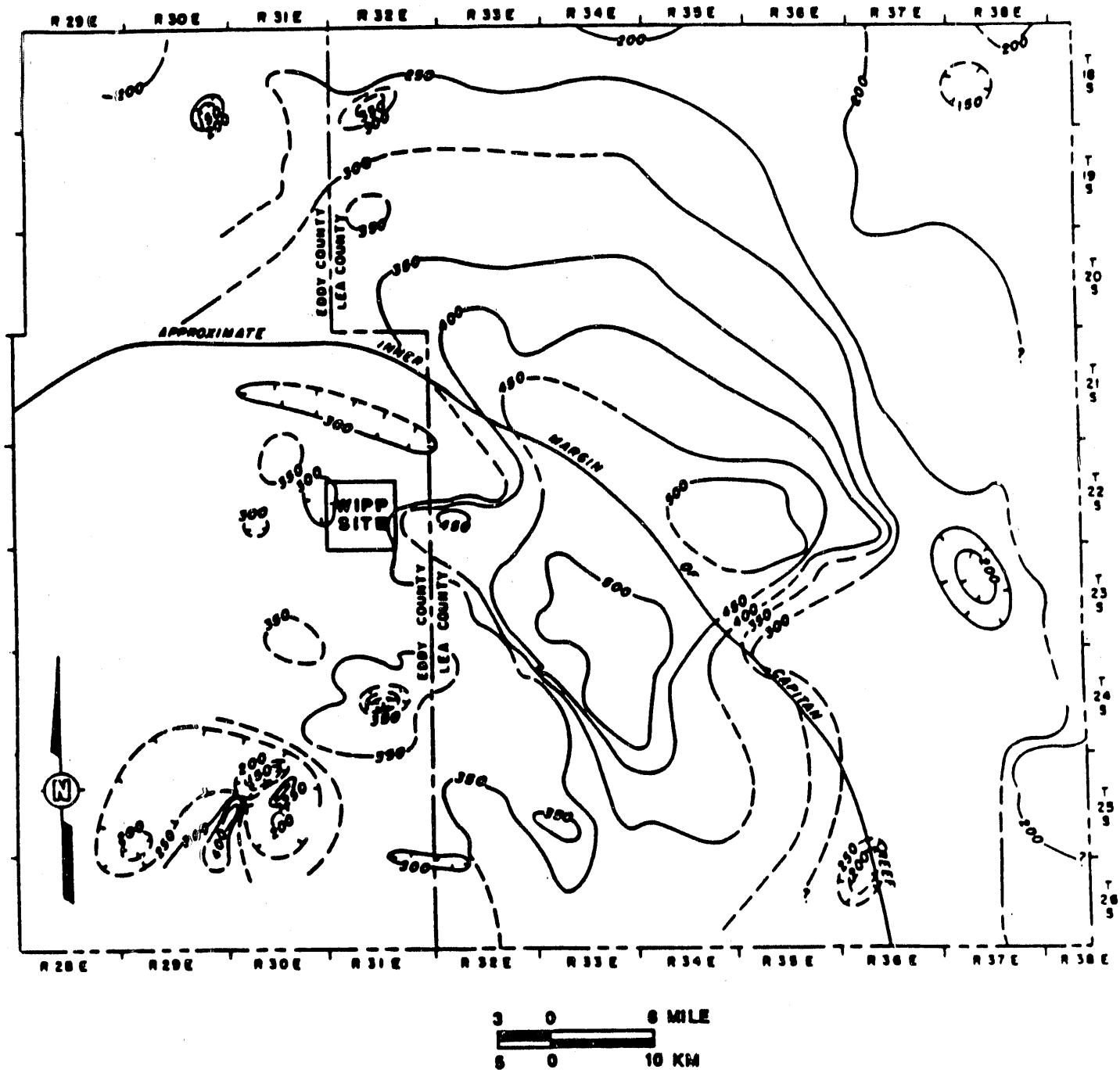

CONTOUR INTERVAL 5 FEET
(ABOUT 1.5 METERS)

Source: Holt and Powers, 1988

FIGURE 4.4-2 ISOPACH OF THE RUSTLER FORMATION

4.4.1 Unnamed Lower Member Hydrology

The unnamed lower member of the Rustler consists of interbedded siltstone, sandstone, halite, and anhydrite. Holt and Powers (1988) subdivided the unnamed lower member into several lithostratigraphic units (Figure 4.4-1). In ascending order, they are: a sulfate unit, bioturbated clastic interval, transitional sandstone, mudstone/halite 1 (M-1/H-1), anhydrite 1, and mudstone/halite 2 (M-2/H-2). Holt et al. (1989) recognize two confining beds and two water-producing units within the unnamed lower member.

The sulfate unit at the base of the Rustler is depositionally more related to the Salado Formation than the Rustler Formation and is underlain by halite and halite-bearing clastic rocks (Holt and Powers, 1988). It has been included within the Rustler, as it is a regionally persistent stratigraphic marker (Holt and Powers, 1988). Holt et al. (1989) considered this the lowermost confining bed within the Rustler, although this hydrologic role is mostly due to the presence of low permeability halite in the Salado. Where dissolution has affected the upper Salado, this stratigraphic unit is hydrologically compromised and the lower confining bed for water-bearing unit 1 is the top of intact Salado halite (Holt et al., 1989).

Water-producing unit 1 (WPU-1) of Holt et al. (1989) consists of the bioturbated clastic interval, the transitional sandstone, and includes the M-1/H-1 interval when halite is not present. WPU-1 is confined by confining bed 2. The bioturbated clastic interval is the principal water-bearing zone within WPU-1. It consists of bioturbated and interbedded siltstone and sandstone (Holt et al., 1989). The clastic material within this zone is argillaceous and cemented with halite (Holt and Powers, 1988; Holt et al., 1989). The transitional sandstone is also cemented with halite and locally sulfate (Holt and Powers, 1988). The M-1/H-1 interval contains bedded and argillaceous halite with some halitic clastic rocks. Porosity and permeability in undisrupted sections of these units is caused by dissolution of halite cements, which creates secondary intergranular pore space (Holt et al., 1989). Dissolution of halite from the upper part of the Salado causes structural collapse of and upward sloping through overlying units (Holt et al., 1989). Fracture porosity around displaced blocks of collapsed material is developed and the thickness of the water-bearing zone is increased to include the interval hydraulically connected by fractures (Holt et al., 1989). Once collapse occurs, the evaporite cements within the collapsed blocks are more readily accessible to undersaturated circulating ground water (Holt et al., 1989). Hydrologic testing of WPU-1, where collapse has followed the dissolution of Salado halite, is difficult at best as the borehole may only effectively intersect a few fractures and the permeability between collapse blocks may be limited by clay skins developed on the margins of blocks during the collapse process (Holt et al., 1989).

Holt et al. (1989) summarize the transmissivity values for WPU-1 contained in Mercer (1983) and Beauheim (1987a). Holt et al. (1989) suggest that the transmissivity values from those locations where Salado dissolution and collapse of overlying strata has occurred may not be representative of the entire WPU-1 interval thickness at the tested locations. These data are presented in Figure 4.4-3 and generally show a transmissivity increase in the direction of Nash Draw.

Few measurements have been made of the stabilized water level or fluid pressure of WPU-1. Stabilized water-levels and minimum water-level elevations are presented in Figure 4.4-4. Although freshwater head calculations are somewhat limited due to the quality of specific gravity measurements, estimated freshwater head values are probably accurate to within 3 meters (10 feet) (Holt et al., 1989). The freshwater heads in those wells completed within the collapse material associated with Salado dissolution do not appear to be significantly different than the hydraulic heads in wells completed in intact Rustler siltstone, indicating probable good lateral hydraulic connection (Holt et al., 1989). The heads are consistent with Mercer's (1983) interpretation that flow through the low-transmissivity sections of WPU-1 is generally westerly or southwesterly across the WIPP site towards the sink represented by the high

transmissivities in Nash Draw, while the flow within Nash Draw is generally southwesterly towards Malaga Bend on the Pecos River.

Holt et al. (1989) divided WPU-1 into three distinct hydrogeologic zones (Figure 4.4-5). The first zone is characterized by low permeabilities, no Salado dissolution, and intergranular porosity and permeability. The hydraulic properties of WPU-1 in zone 1 are related to the dissolution of halite cements, and permeability generally decreases toward the east across the WIPP site area. Within Zone 2, WPU-1 is characterized by permeabilities higher than Zone 1, Salado dissolution with varying amounts of collapse, and intergranular porosity coupled with fracture porosity proportional to the amount of collapse. Partial confining conditions exist within zone 2, and the zone is not actively tied to the surface ground water regime as varying amounts of overburden isolates WPU-1. Zone 3 is actively recharged by the surface ground water system and is confined to portions of Nash Draw. Limited overburden is present and the zone may locally be partly confined. Dissolution and collapse are extensive, and evaporite cements within collapse blocks are mostly dissolved. It is expected that the hydraulic properties of WPU-1 have great lateral and vertical variability due to the complex nature of collapse and brecciation. Part of zone 2 and all of zone 3 can be considered within Lang (1938) brine aquifer. Modern flow within zones 1 and 2 is generally west toward the transmissivity sink in Nash Draw, while flow in zone 3 is southwest along the axis of Nash Draw toward Malaga Bend (Holt et al., 1989).

Confining bed 2 consists of the transitional sandstone, where no dissolution of evaporite cements has occurred; the M-1/H-1 interval, where halite is present as cements and interbeds; and anhydrite 1 (Holt et al., 1989). This confining unit is most effective across the WIPP site area where no dissolution has affected the Salado (Figure 4.3-2; Holt et al., 1989). Anhydrite 1 contains halite across much of the WIPP area and displays some fractures (Holt and Powers, 1988). Within Nash Draw and other areas of extensive dissolution of Salado evaporites, the halite within A-1 and additional fracturing due to collapse may cause A-1 to be hydraulically breached, allowing vertical leakage to occur between water-producing units 1 and 2.

Mudstone/halite 2 (M-2/H-2) is considered to be part of water-producing unit 2, which also includes the Culebra Dolomite Member, across the WIPP site area (Holt et al., 1989). East of the WIPP site, M-2/H-2 contains halite and is considered to be part of confining bed 2 (Holt et al., 1989). M-2/H-2 consists of interbedded sulfatic mudstone and siltstone across and west of the WIPP area (Holt and Powers, 1988). It is probably in direct hydraulic communication with the Culebra and acts as a source of leakage to the Culebra during hydrologic tests where the hydraulic head of the Culebra is lowered (Holt et al., 1989). Further discussion of this unit is included in Section 4.4.2.1, Culebra Hydrology.

4.4.2 Culebra Dolomite Member

The Culebra Dolomite Member of the Rustler Formation is the most transmissive hydrologic unit overlying the WIPP facility horizon. It is considered to be the most important ground water transport pathway for radionuclides that may escape from the WIPP repository to the accessible environment. In the vicinity of the WIPP, the Culebra is finely crystalline, locally argillaceous and arenaceous, vuggy dolomite roughly 8 meters (25 feet) thick (Holt and Powers, 1988). It is the lowermost of two regionally persistent dolomite units within the Rustler. The Culebra has been the subject of extensive hydrologic testing which is summarized by Mercer (1983) and Lappin (1988). Various geochemical studies of Culebra ground water have been performed (e.g., Siegel et al., 1989; Holt et al., 1989), and the Culebra geology has been extensively characterized (e.g., Holt and Powers, 1988; Holt et al., 1989).

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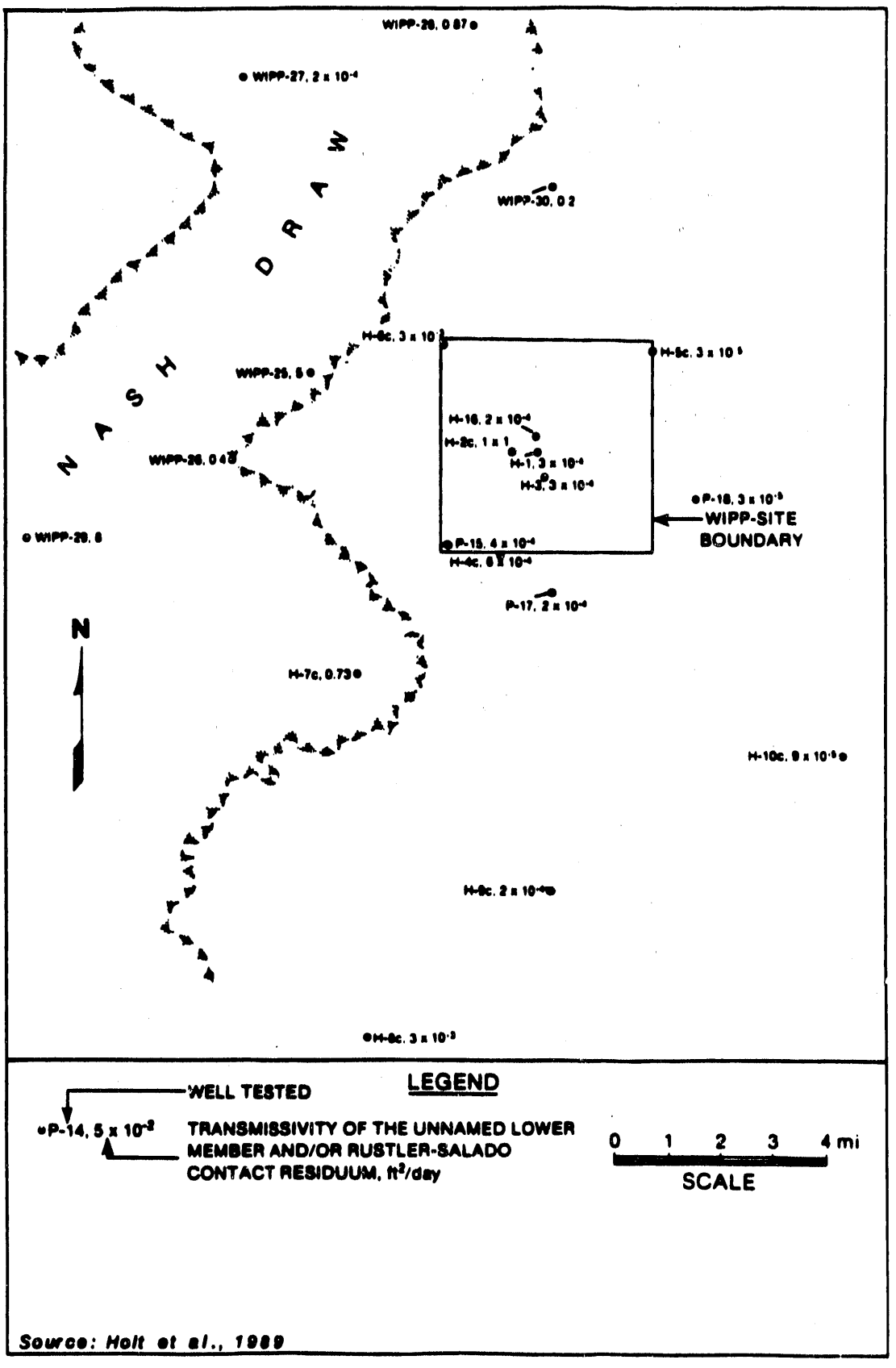

FIGURE 4.4-3 TRANSMISSIVITY OF THE UNNAMED LOWER MEMBER AND/OR RUSTLER-SALADO CONTACT RESIDUUM

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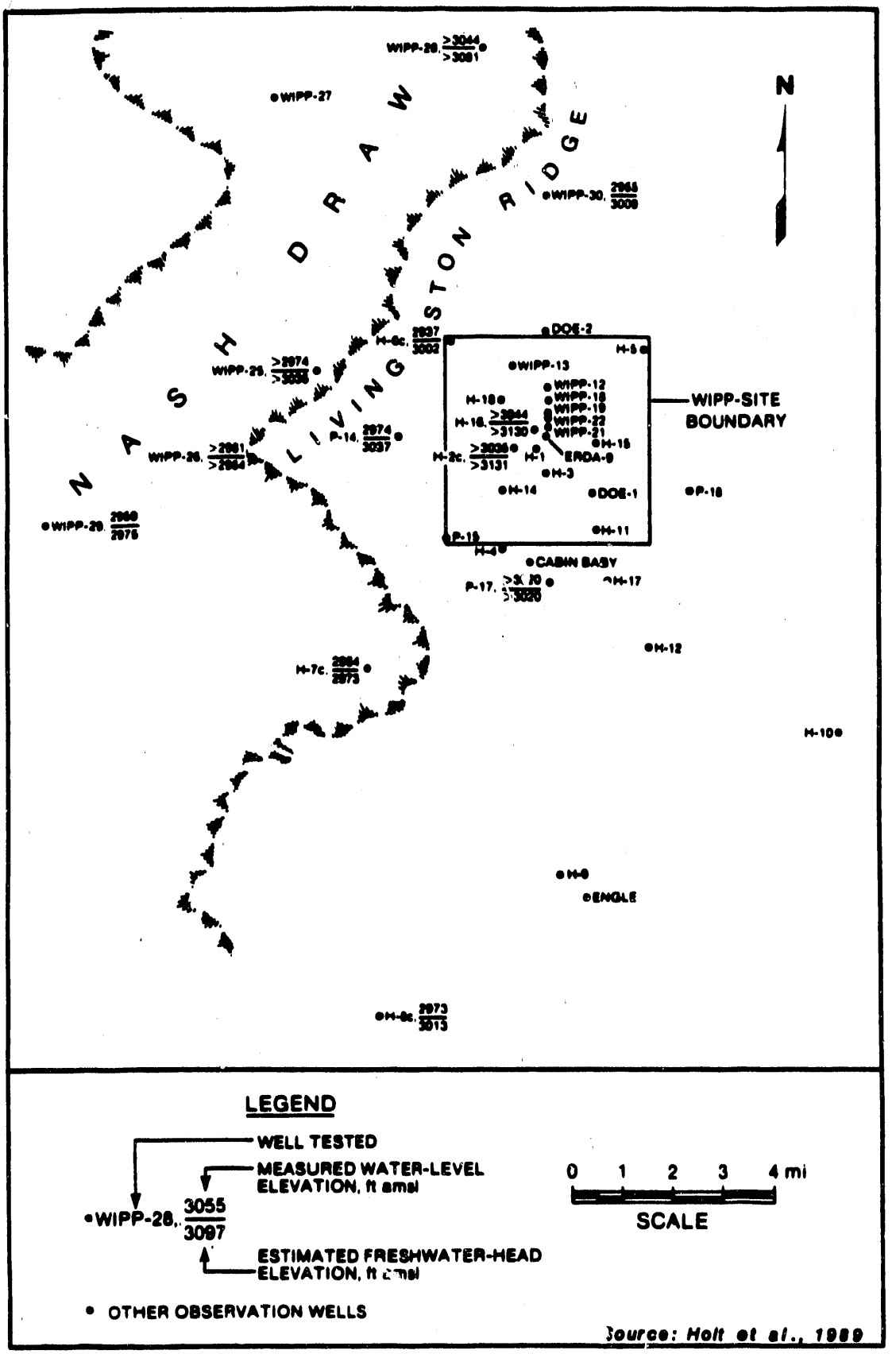

FIGURE 4.4-4 MEASURED WATER LEVEL AND ESTIMATED FRESHWATER HEAD ELEVATION OF UNNAMED LOWER MEMBER AND/OR RUSTLER/SALADO CONTACT

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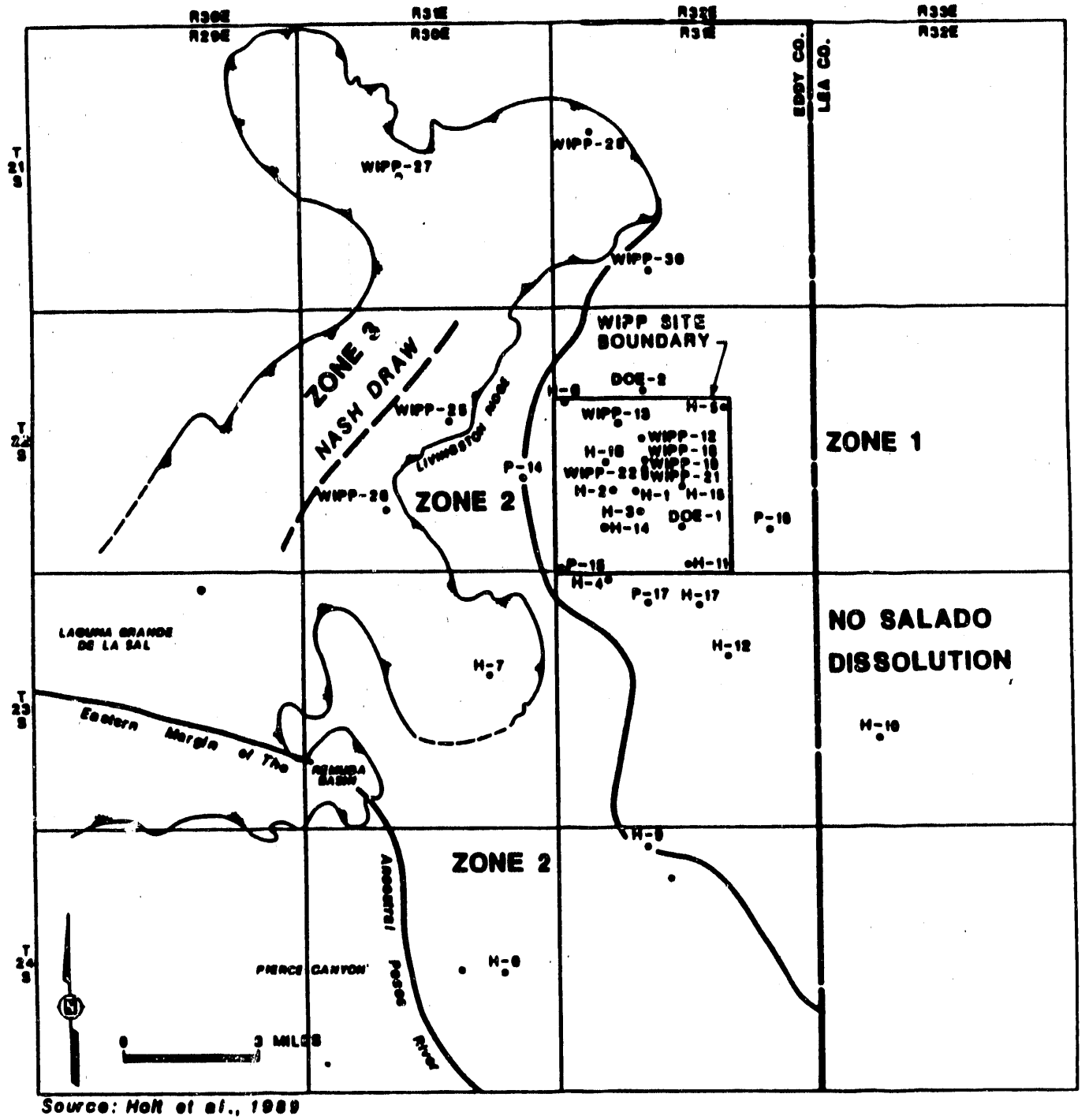

FIGURE 4.4-5 EXTENT OF HYDROGEOLOGIC ZONES WITHIN WATER-PRODUCING UNIT 1 (WPU1) OF THE RUSTLER FORMATION

4.4.2.1 Culebra Hydrology

The Culebra and M-2/H-2 (the uppermost mudstone/halite bearing unit within the unnamed lower member) collectively make up Water-Producing Unit 2 (WPU-2) of Holt et al. (1989), although M-2/H-2 does serve to confine the Culebra (Figure 4.4-1). The Culebra is the most hydraulically significant portion of WPU-2. M-2/H-2 provides some leakage into the Culebra during pumping tests (Beauheim, 1987a) and is therefore considered part of WPU-2 (Holt et al., 1989). WPU-2 is confined by anhydrites in the unnamed lower member and the Tamarisk Member, A-2 and A-3 of Holt et al. (1989). Within Nash Draw and adjacent to Nash Draw, evaporite dissolution may have decreased the effectiveness of the anhydrites as confining beds.

In most WIPP wells completed to the Culebra, water levels in 60 wells at 41 drilling-pad locations currently or once were completed to the Culebra have been measured on a regular basis since the wells were constructed (Holt et al., 1989). Culebra water levels at and around the WIPP site have been affected, however, by continuous drainage into one or more WIPP shafts since the construction of the exploratory shaft (now the construction and salt handling shaft) in late 1981, as well as by numerous pumping tests and water-quality sampling exercises conducted since 1980 (Lappin, 1988).

LaVenue et al. (1988) performed a thorough review of Culebra water-level data, borehole-fluid density data and WIPP-related hydraulic stresses, and derived estimates of the undisturbed freshwater heads at 31 wells. These estimates are shown contoured on Figure 4.4-6. Flow directions presented by Crawley (1988) and in Lappin (1988) indicate a general southerly flow direction across the WIPP site area (Figure 4.4-6). Davies (1989) and Crawley (1988) suggest that flow directions south of the WIPP site may have a larger easterly, down-dip component than is predicted considering only freshwater heads.

The transmissivity of the Culebra across the WIPP region varies by six orders of magnitude (Figure 4.4-7). These variations have been attributed to varying degrees of fracturing within the Culebra. In the vicinity of the WIPP, the Culebra has been tested in 41 locations, including the combined testing of the WIPP project and Project Gnome (Holt et al., 1989). The highest transmissivity value reported for the Culebra is 1.25×10^3 ft^2/day at WIPP-26 within Nash Draw. The lowest value reported is $\leq$0.004 ft^2/day at P-18. Where Culebra transmissivities are less than 1 ft^2/day, the Culebra behaves as single-porosity medium during pumping and slug tests (Holt et al., 1989). Where transmissivities are between 1 and at least 100 ft^2/day, the Culebra behaves as a double-porosity medium, with a matrix and fracture porosity set (Holt et al., 1989). Where the Culebra transmissivity exceeds 100 ft^2/day, double-porosity behavior is less apparent (Holt et al., 1989). LaVenue et al. (1988) calculated Culebra transmissivities across the WIPP site area based upon steady-state calibration against an estimate of the pre-shaft distribution of fresh-water equivalent heads. A contour map of these transmissivities is presented in Figure 4.4-7. Aside from the apparent increase of transmissivity toward Nash Draw, several other relationships are important. Transmissivities are relatively high in a wide region south of the WIPP site and east of Nash Draw. A high transmissivity "finger" penetrates the southern border of the WIPP site. Finally, a zone of higher transmissivity occurs north of, but does not penetrate, the WIPP site area.

4.4.2.2 Culebra Ground Water Chemistry

The geochemical condition of Culebra ground waters across the WIPP site region is extremely variable. The total dissolved solids (TDS) within the Culebra ground water increases from less than 5,000 mg/l southwest of the WIPP site to greater than 200,000 mg/l northeast of the WIPP site (Figure 4.4-8) (Holt et al., 1989; Siegel et al., 1989).

Culebra water has been typed by Siegel et al. (1989) and Holt et al. (1989) on the basis of major element concentration (Figure 4.4-9). On the basis of different sample sets and slightly different criteria, both Siegel et al. (1989) and Holt et al. (1989) report four coinciding "type areas" of Culebra water (Figure 4.4-

4.4-9). The easternmost type area of Siegel et al. (1989) and Holt et al. (1989) (Zone A and Type Area 1, respectively) is characterized by highly saline NaCl-rich brines rich in Mg and Ca. Culebra water from Zone B of Siegel et al. (1989) and Type Area 2 of Holt et al. (1989) is relatively fresh, with calcium and sulfate as the dominate solutes. NaCl dominated water of variable compositions occupy Zone C and Type Area 3, with the salinity of this water increasing to the east (Siegel et al., 1989; Holt et al., 1989). Holt et al. (1989) suggest that mixing of the highly saline NaCl brines in Type Area 2 with the sulfate-rich water in Type Area 1 may have generated the Type Area 3 water. Located in the western half of Nash Draw, anomalously high salinities and potassium contents characterize Zone D and Type Area 4 ground water (Siegel et al., 1989; Holt et al., 1989). The water in Zone D and Type Area 4 are dominated by effluent from potash refining operations (Siegel et al., 1989; Holt et al., 1989).

Ramey (1985) noted that modern flow directions within the Culebra do not appear consistent with the modern salinity distribution. When compared with fluid flow directions, the distribution of TDS within the Culebra generally decreases in the direction of flow, which is not a typical steady-state TDS/ground water flow relationship. Isotopic evidence (Lambert and Harvey, 1987), as well as modern Culebra transmissivity and head distribution, preclude modern vertical recharge to the Culebra (Lappin, 1988), so modern vertical recharge to the Culebra cannot account for the modern flow/salinity distribution relationship. One possible mechanism consistent with the modern flow direction/salinity distribution involves paleofluid flow to the northeast during past recharge followed by modern system draining and discharge to the south (Lambert and Harvey, 1987; Holt et al., 1989). This relationship is consistent with Lambert and Harvey's (1987) interpretation of a transient, rather than steady-state, hydrologic setting for the WIPP area with no active recharge to the Culebra.

Saturation indices for several evaporite minerals in Culebra ground water were calculated by Holt et al. (1989), using the mineral equilibrium computer code EQ3NR (Wolery, 1983) with a Pitzer equation to calculate activity coefficients for water with an ionic strength greater than 1.0 molal. The saturation index of a particular mineral equals zero at saturation, while positive or negative values indicate that the ground water is above saturation or below saturation, respectively. The saturation indices for gypsum within Culebra ground water are contoured in Figure 4.4-10 (Holt et al., 1989). All of the water is undersaturated with respect to gypsum, although the degree of undersaturation varies (Holt et al., 1989). Those values between ± 0.1 can be considered saturated (Holt et al., 1989). The contour map of gypsum saturation indices in Figure 4.4-10 shows that the Culebra waters are progressively more undersaturated with respect to gypsum from east to west, and a zone of less saturated waters penetrates the WIPP area from the south. The overall trend is similar to the transmissivity distribution in the Culebra, with the degree of undersaturation increasing with transmissivity (Holt et al., 1989).

4.4.2.3 Culebra Hydrogeology

The Culebra consists of argillaceous and arenaceous dolomite and roughly 8 meters (25 feet) thick across the WIPP site area (Holt and Powers, 1988). The majority of the permeability within the Culebra is along fractures, and transmissivity appears to be related to degree of fracturing (Holt et al., 1989), although open and sulfate-filled vugs and fractures are locally abundant (Holt and Powers, 1988). Although present throughout the Culebra section, the large vugs are principally concentrated in the lower portion of the Culebra (Holt and Powers, 1989). Holt et al. (1989) evaluated the hydrogeology of the Culebra and examined the Culebra for depositional and post-depositional controls on its hydrologic character. The following is a summary of their efforts.

The Culebra was deposited in a really extensive carbonate-rich lagoonal environment following a rapid marine transgression over a salt pan/saline mudflat environment (Holt and Powers, 1988). As the water-depth was stable over most of the WIPP area, the Culebra was uniformly deposited with slight increases

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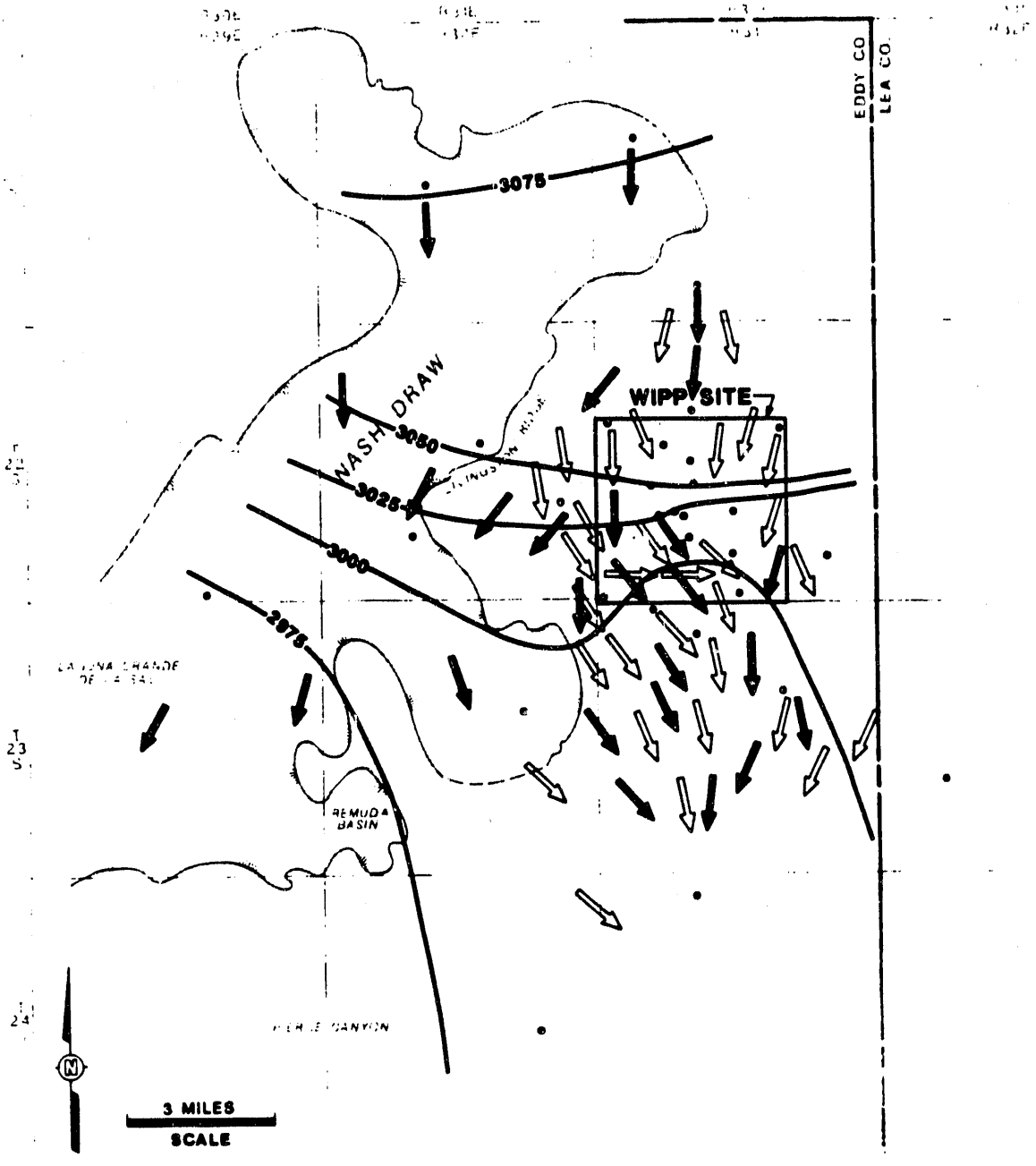

EXPLANATION

3000 — FRESHWATER-HEAD ELEVATION CONTOUR, CONTOUR INTERVAL = 25 FEET FROM LA VENUE, ET AL., 1988

• WELLS TESTED

GENERAL DIRECTION OF GROUND-WATER FLOW
⇨ FROM CRAWLEY, 1988
➡ FROM LAPPIN, 1988

FIGURE 4.4-6 ESTIMATED CULEBRA FRESHWATER HEADS AND FLOW DIRECTIONS

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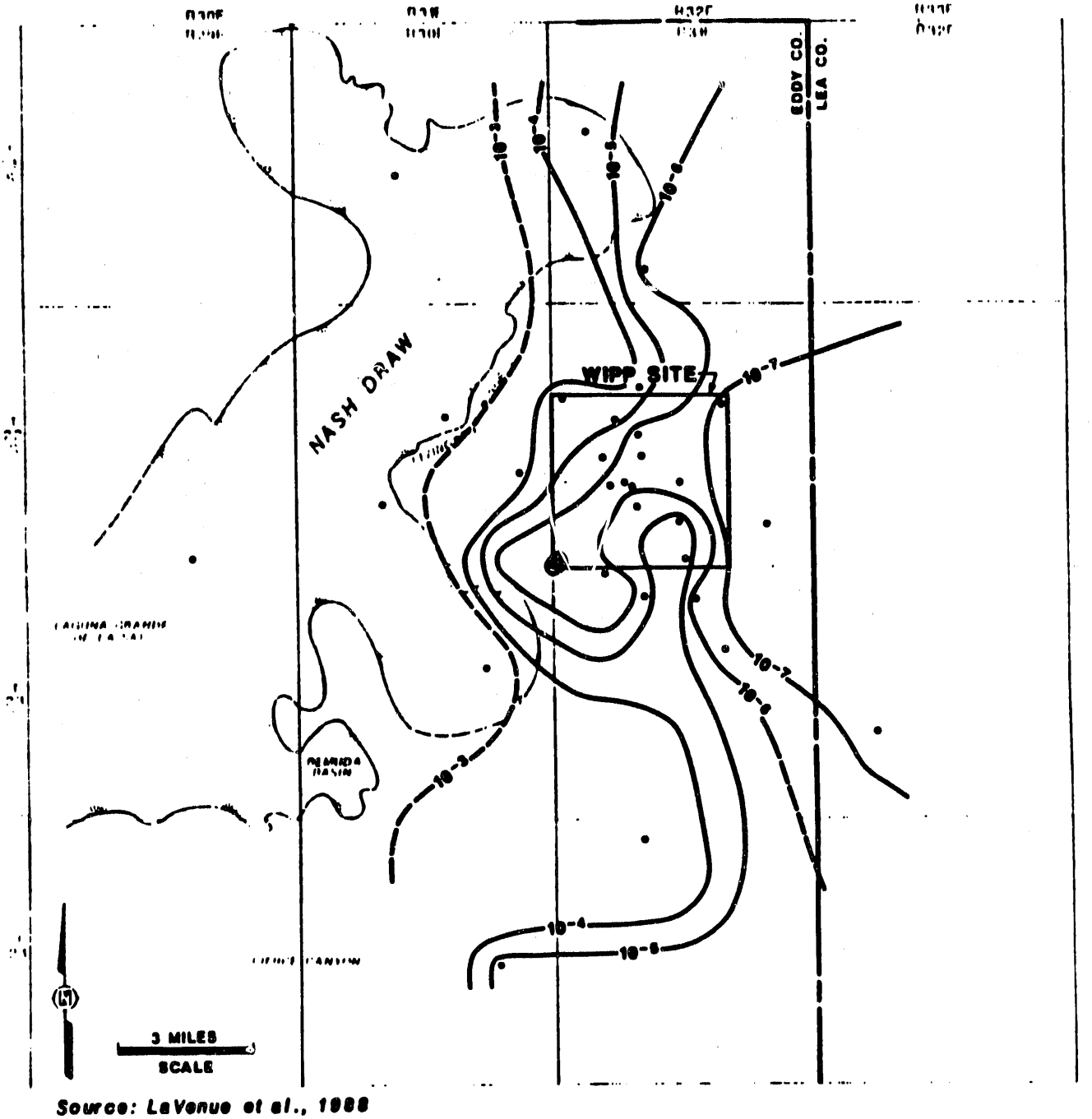


Source: LaVenue et al., 1988

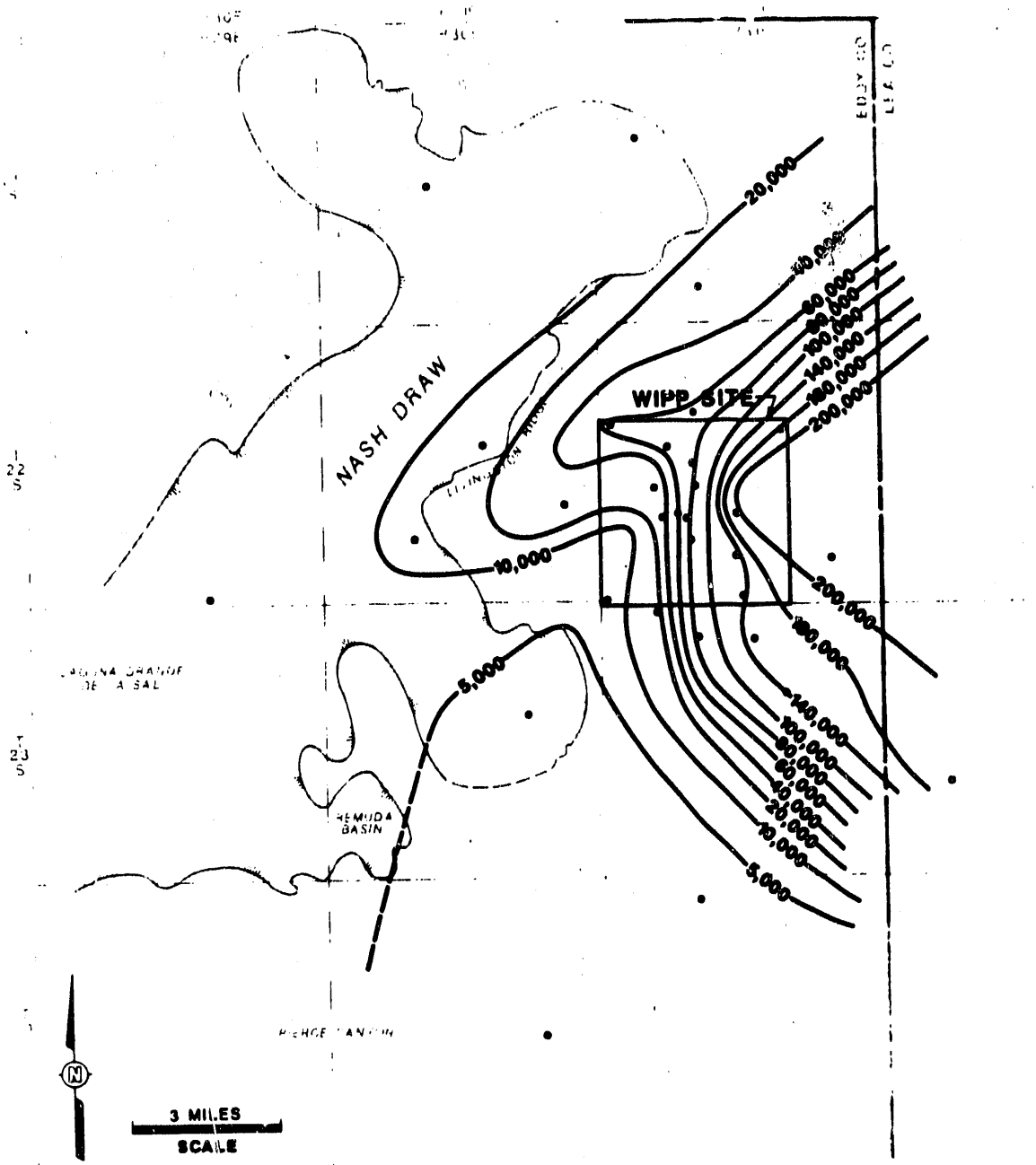
EXPLANATION

• WELLS TESTED

—10⁻⁶— TRANSMISSIVITY CONTOUR, m^2/s

FIGURE 4.4-7 CALCULATED CULEBRA TRANSMISSIVITIES

30100: 89 04 06 A34



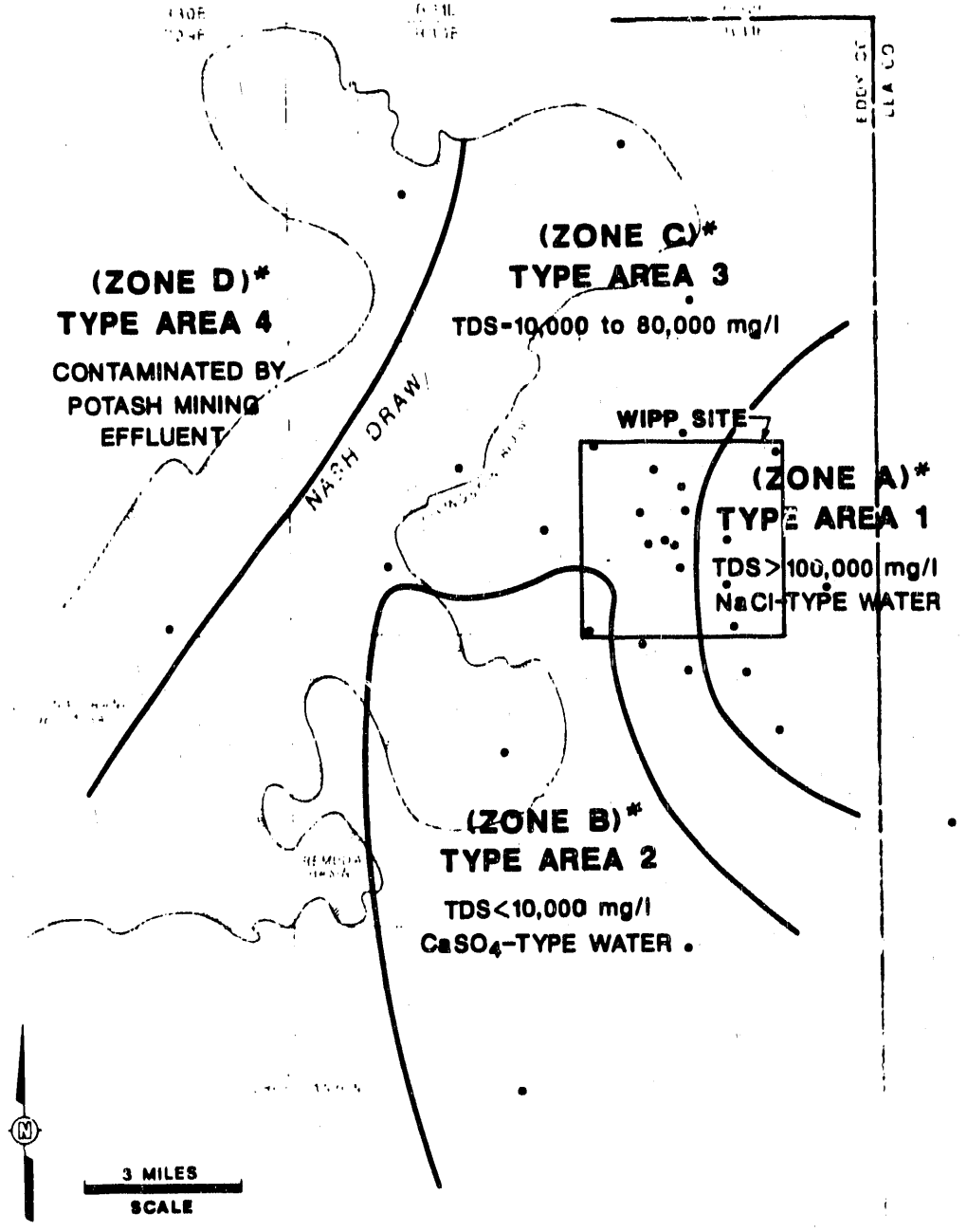
Source: Holt et al., 1989

EXPLANATION

• WELLS TESTED

—10,000— EQUAL CONCENTRATION CONTOUR LINE, mg/l

FIGURE 4.4-8 DISTRIBUTION OF TOTAL DISSOLVED SOLIDS (TDS) IN THE CULEBRA GROUND WATER



Note: Zones from Seigel et al., 1989

Sources: Holt et al, 1989
Siegel et al., 1989

EXPLANATION

• WELLS TESTED

FIGURE 4.4-9 CULEBRA HYDROCHEMICAL TYPE AREAS

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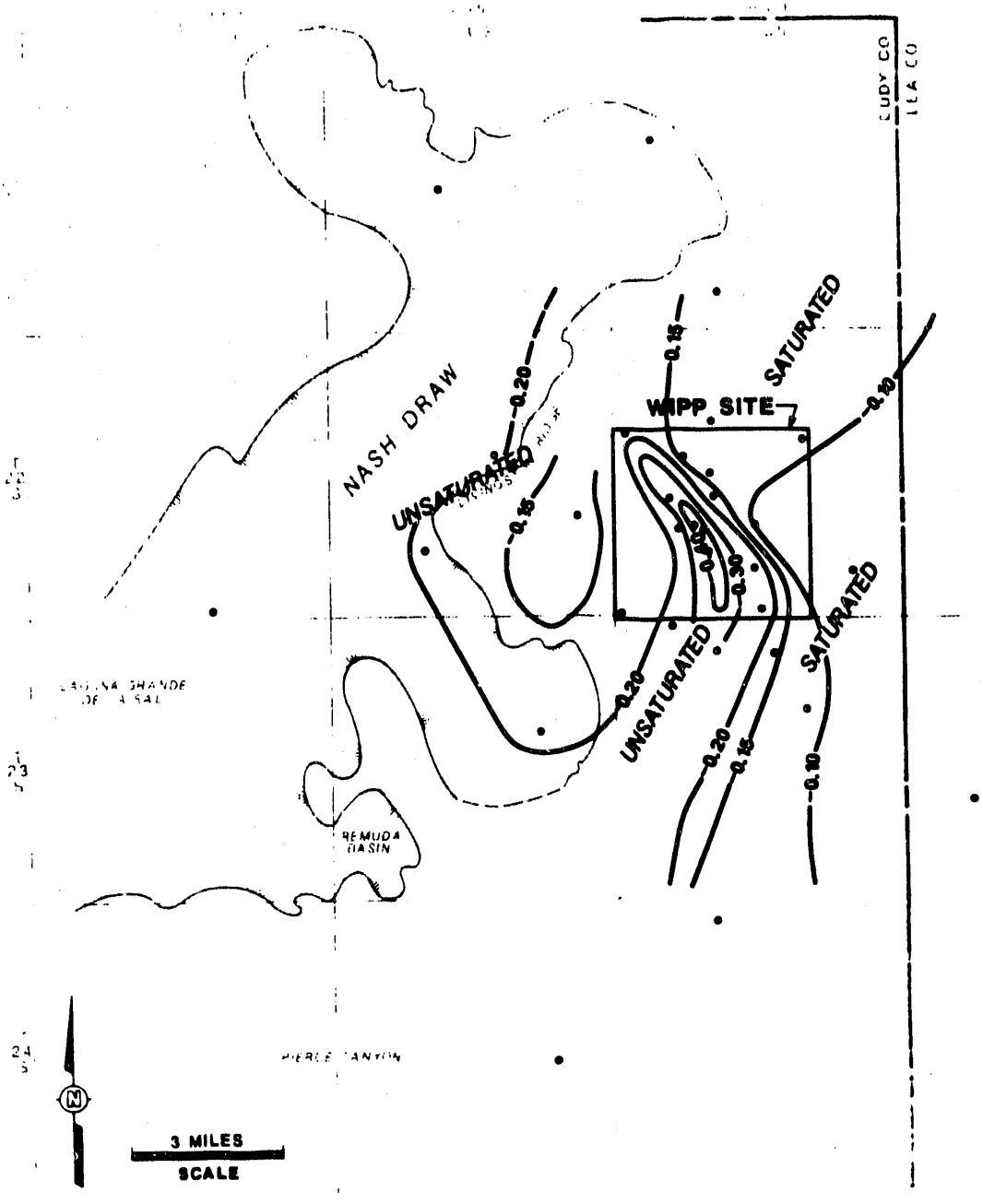

Source: Holt et al., 1989

EXPLANATION

• WELLS TESTED

FIGURE 4.4-10 CONTOUR MAP OF GYPSUM SATURATION INDICES OF CULEBRA WATERS

in thickness in those areas where dissolution of the underlying saltpan/saline mudflat evaporites was occurring (Holt and Powers, 1988). The lagoonal environment was persistent for all of Culebra deposition with only episodic shoaling contributing minor amounts of lateral and vertical variability, so lateral and vertical interfingering of facies did not affect the hydrologic properties of the Culebra. Slumping of Culebra sediments occurred in response to compaction of algal laminae, dewatering, and dissolution within and compaction of the underlying sediments. This deformation provided a vertical to subvertical fabric for later fracture reactivation.

The majority of the Culebra sediment was of uniform size, fine-grained carbonate mud, which upon lithification produced finely crystalline dolomite of low permeability. Poorly sorted, often very fine-grained, dolomitic and possibly organic-rich sediment was interbedded with and locally interspersed by bioturbation and sediment slumping throughout the fine-grained carbonate mud. This material provided a pathway of higher permeability for circulating waters containing solutes for syndepositional growth of displacive sulfate, both anhydrite and gypsum, within the soft Culebra sediment. Sulfate nodules and crystals grew more often within this poorly sorted material than the uniformly sized carbonate mud. Following and during the development of displacive sulfate nodules and crystals, most of the interparticle porosity within this poorly sorted material was filled with sulfate cement. During early diagenesis, much if not all, of the gypsum in the Culebra was replaced by anhydrite.

Post-depositional alteration enhanced the hydraulic properties of the Culebra by the dissolution of diagenetic pore-filling materials and the creation of new fracture porosity. Many of these processes occurred synchronously.

Sulfate pore filling materials are common with the Culebra in the vicinity of the WIPP site. Sulfate (usually gypsum) occurs as cements, passive void-fillings, nodules, and incremental fracture-fillings. These sulfate pore-filling materials generally become less common within the Culebra from east to west as they have been subject to dissolution. A clear pattern of alteration progressively occurs within the Culebra from east to west. Anhydrite vugs and crystals are replaced by gypsum, and gypsum occurs as incremental fracture fillings within the Culebra dolomite. Further west, all sulfate consists of gypsum, and gypsum fracture-fillings, cements, and vug-fillings are partly to completely dissolved. Continuing west, gypsum is almost totally removed, and many of the vugs and vug complexes are collapsed, increasing local fracture porosity. In the westernmost part of the region, no gypsum occurs. The areal distribution of this relationship is best shown in Figure 4.4-11, a contour map of the percentage of natural fractures filled with gypsum. This map, when compared with a contour map of Culebra transmissivity values (Figure 4.4-7), shows a clear inverse relationship between the presence of gypsum pore-fillings and transmissivity.

The majority of effective porosity within the Culebra is related to fractures, and the transmissivity values at various locations can be considered as an indicator of degree of fracturing. This allows the degree of fracturing to be compared with other geologic information on a regional scale. Significant fracturing, with respect to fracture flow, within the Culebra occurred in response to alterations of local stress-fields in response to differential unloading, dissolution of evaporites from above or below the Culebra, and dissolution of large vug-fillings or fillings within zones of vugs in the Culebra. Stress-fields associated with regional or local tectonic activity do not cause significant fracturing within the Culebra.

Detailed systematic analysis of fracturing within Culebra cores has yielded little information concerning the degree of fracturing at the cored location due to variable core recovery and zones of poor recovery. Culebra descriptions from three shafts at the WIPP show that the majority of the fractures at the WIPP site are subvertical and occur within a very vuggy zone near the base of the Culebra (Holt and Powers, 1984, 1986, 1989). These fractures usually extend from vug to vug (Holt and Powers, 1989). This zone

can be recognized within Culebra cores as a zone of poor or no recovery. Horizontal fractures, parallel to bedding planes, occur throughout the Culebra in core and the WIPP shafts (Holt and Powers, 1984, 1986, 1988). High-angle subvertical fractures are commonly intersected in core near the upper part of the Culebra and may be vertically persistent for several feet. As these nearly vertical fractures are common, the density of these fractures must be relatively high, at least locally.

Much of the fracturing within the Culebra in the vicinity of the WIPP site can be attributed to unloading. An isopach map of the Culebra overburden is presented in Figure 4.4-12. It shows a general decrease of overburden from east to west, with the overburden north and south of the WIPP site slightly less than that across the WIPP site. Culebra transmissivity (Figure 4.4-7) is generally higher where there is less overburden. As the transmissivity contours do not correlate precisely with the amount of overburden present, other mechanisms must contribute to the variations of transmissivity and degree of fracturing in the Culebra across the WIPP area.

Aside from unloading, the most significant control on fracturing within the Culebra is the dissolution of evaporites from strata above and below the Culebra. Dissolution of evaporites causes collapse of the overlying strata and stress relief of the underlying strata. Both collapse and stress relief can cause or enhance the fracturing within a brittle unit such as the Culebra. Holt et al. (1989) evaluate the extent of dissolution from the Salado and Rustler on the basis of core, shaft, and geophysical log data. The results are shown on Figure 4.4-13. Salado dissolution affects the area south and west of the WIPP site, while Rustler dissolution is concentrated along the depositional margins of halite within the Rustler.

The zone of Salado dissolution occupies the area in and around Nash Draw and a region south of the WIPP site. The dissolution occurs at the uppermost halite within the Salado. Salado dissolution parallels the course of the Ancestral Pecos River and its major tributaries, like Nash Draw. Salado dissolution was hydrologically driven by the ground water system associated with the Ancestral Pecos River and its major tributaries. This system was most active during the Cenozoic, although dissolution of Salado halite continues to occur within Nash Draw. Culebra core from the areas where Salado dissolution occurs often shows evidence of fracturing due to downward collapse. Transmissivity values from these areas are high and reflect increased fracturing due to settling in response to collapse.

Where Salado dissolution occurs close to a halite depositional margin within the Rustler, the potential for dissolution of halite within the Rustler is high. This increased Rustler dissolution potential is because collapse associated with Salado dissolution tends to increase the vertical hydraulic connection between Rustler water-bearing zones and the Rustler interval containing halite. One such zone penetrates the southern part of the WIPP site. Features attributable to dissolution of halite and attendant collapse are found within the interval M-3/H-3 (Holt and Powers, 1988). This zone, although not well defined, corresponds with the highly transmissive zone within the Culebra in the southern part of the WIPP site. As dissolution has not occurred below the Culebra at this location, fracturing was increased in response to stress-relief following dissolution.

A potential zone of Rustler dissolution is located at the northwest corner of the WIPP site. Holt and Powers (1988) observed collapse features within the M-3/H-3 interval at WIPP-13. The collapse features at WIPP-13 may be due to late-stage dissolution of a thin outlying M-3/H-3 halite pan with little or no direct connection to the main M-3/H-3 halite pan (east of the WIPP site). This zone corresponds with high Culebra transmissivity values.

The easternmost zone of potential dissolution within the upper Rustler lies along the depositional margin of the H-3 and H-4 and represents the area in which the halite disappears from the M-3/H-3 and M-4/H-4 intervals. East of the zone halite is present, while west of the zone halite does not occur. In the vicinity of the WIPP site, halite within the M-3/H-3 and M-4/H-4 intervals did not survive deposition and was not

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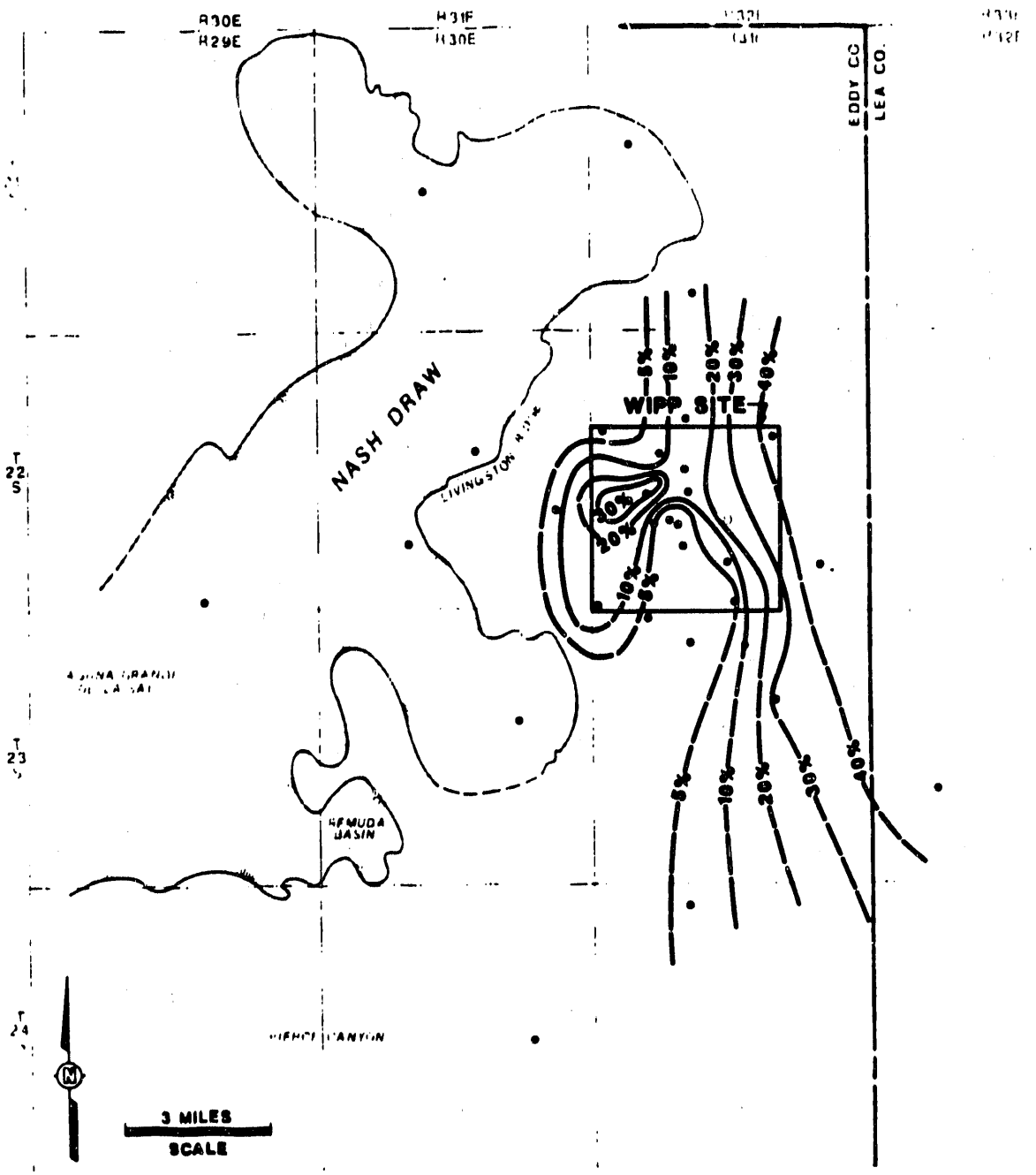

Source: Holt et al., 1989

EXPLANATION

• WELLS EXAMINED CONTOUR INTERVAL = 10% 5% LINE SHOWN FOR CLARITY

FIGURE 4.4-11 PERCENTAGE OF NATURAL FRACTURES IN THE CULEBRA FILLED WITH GYPSUM

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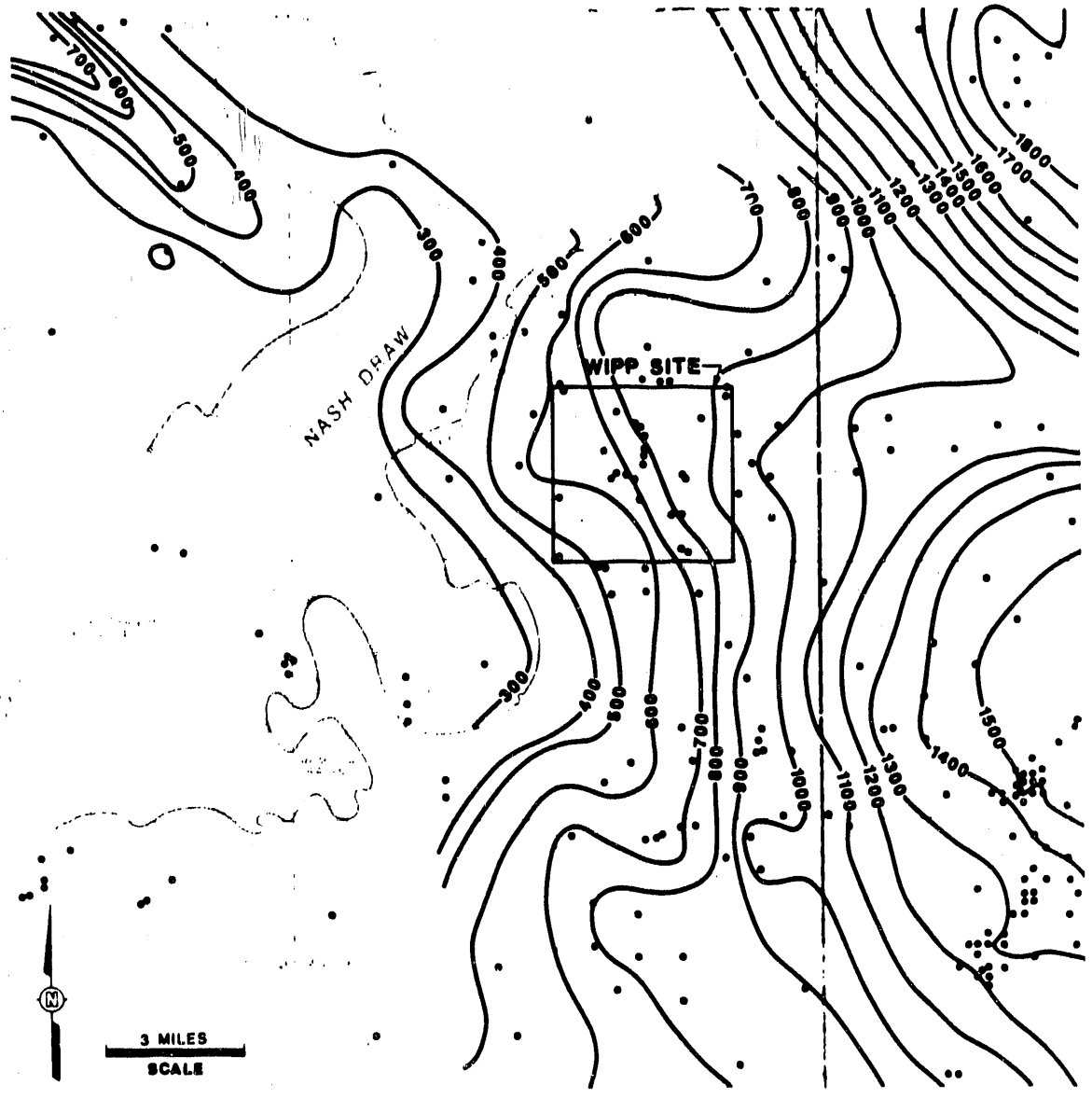

Source: Holt et al., 1989

EXPLANATION

• DRILL HOLES

CONTOUR INTERVAL = 100 FEET

FIGURE 4.4-12 ISOPACH OF CULEBRA OVERBURDEN

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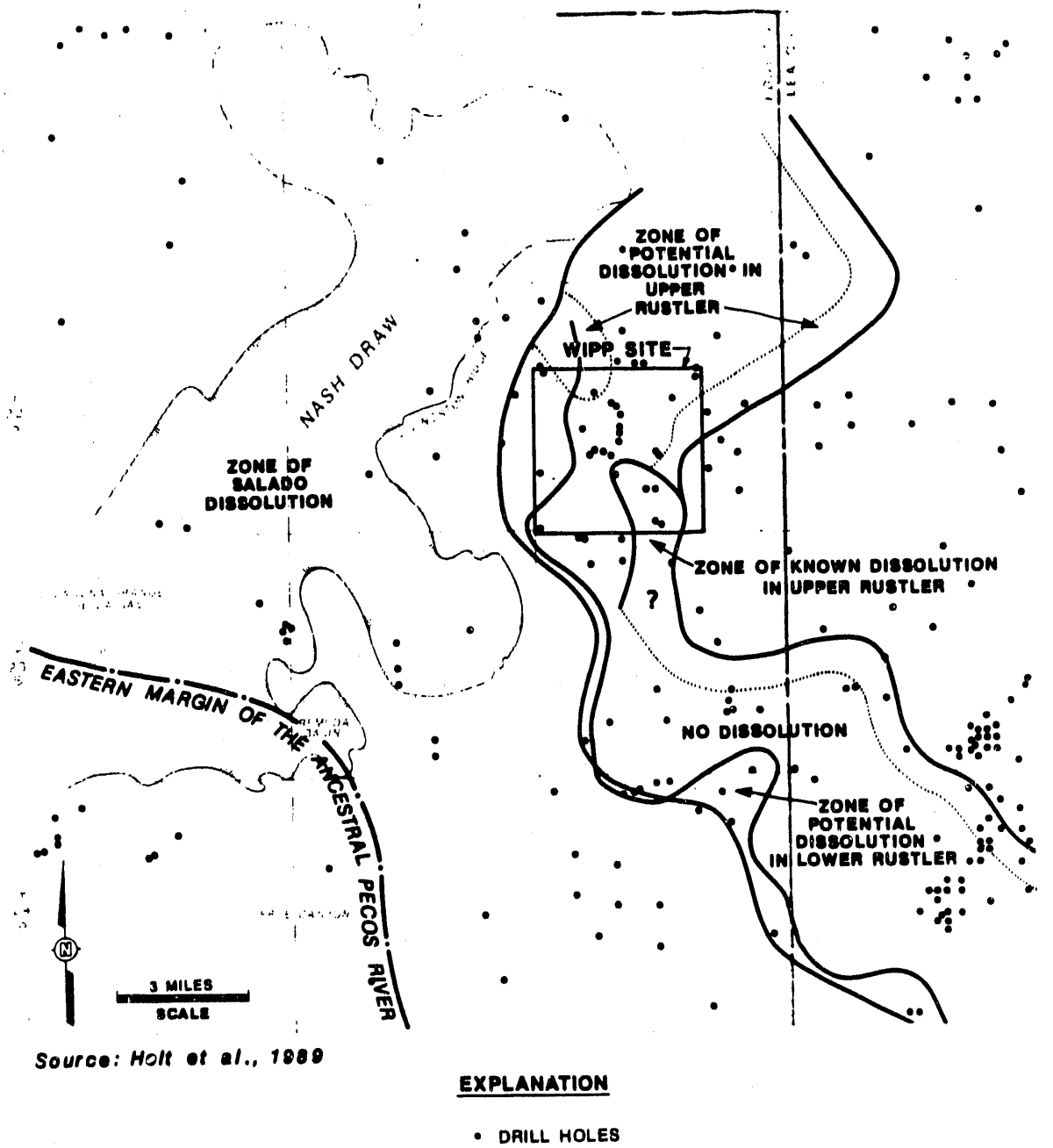

FIGURE 4.4-13 DISTRIBUTION OF RUSTLER AND SALADO DISSOLUTION NEAR THE WIPP SITE

present after the deposition of the overlying anhydrites (Holt and Powers, 1988). As no evidence of dissolution has been found within this zone, this zone of potential dissolution represents the location where dissolution would be found if it were present. Although limited, data from hydrologic testing near this zone of potential dissolution do not show the high transmissivity values expected from an area where dissolution has occurred.

Most of the deep-seated dissolution of Rustler and Salado evaporites in the vicinity of the WIPP site occurred in response to the hydrologic regime of the Ancestral Pecos River. Outcrops of Ancestral Pecos River gravels indicate that the Cenozoic stream level was at least 650 feet higher than the present Pecos River and over 200 feet higher than the equivalent freshwater head within the Culebra east of the WIPP site, where the lowest measured transmissivities are found. The Ancestral Pecos hydrologic system was more than capable of providing recharge to the Rustler and underlying Salado. The dissolution pattern within the Salado and Rustler near the WIPP site originated in response to this hydrologic system. Dissolution prograded northward from the Ancestral Pecos system.

The modern Pecos River is not hydrologically capable of providing recharge to the Rustler or Salado Formations so the development of this dissolution pattern is not continuing. Flow directions within Nash Draw are to the south toward the modern Pecos River (Mercer, 1983), and it is suspected that flow within the Rustler/Salado residuum in the region of Salado dissolution south of the WIPP site is to the south or southeast. Modern dissolution of Salado halite is occurring within Nash Draw and, possibly, continuing in the region of Salado dissolution south of the WIPP site in response to modern recharge in and around Nash Draw. Northward progradation of Salado dissolution cannot continue without recharge from the south.

The primary controls on Culebra transmissivity variations are unloading, Salado halite dissolution, and Rustler halite dissolution. The areal distribution of these controls is depicted in Figure 4.4-14. East of and across most of the WIPP site area, unloading is the primary cause of fracturing within the Culebra. As overburden decreases to the west, the amount of fractures increase. Within zones which penetrate the northern and southern margins of the WIPP site, Rustler dissolution increases the degree of fracturing within the Culebra. Minor amounts of collapse and stress-relief due to Rustler dissolution enhance the fracturing locally. West and south of the WIPP site, Salado dissolution caused more extensive fracturing within the Culebra and is the dominant cause of fracturing. Unloading causes some fractures and the degree of fracturing is related to the amount of unloading. Fracturing generated by Salado dissolution strongly overprints fracturing of different origin.

4.4.2.4 Culebra Conceptual Hydrogeological Model

Holt et al. (1989) synthesized hydrologic, geochemical, and geologic data into a conceptual hydrogeological model of the Culebra. The following discussion is a summary of their model.

The present hydrologic conditions within the Culebra are a relic of a previous hydrologic system. Modern flow directions are not consistent with the distribution of solutes within Culebra ground water (Ramey, 1985), and the Culebra is not actively being recharged across the WIPP site area (Lambert and Harvey, 1987). Isotope studies of the Culebra ground water near the WIPP site indicate that the water is intrinsically old (Lambert, 1987; Lambert and Carter, 1987). Culebra transmissivity varies six orders of magnitude across the WIPP site area (Mercer and Orr, 1979). This variation can be attributed to the interaction of several processes including unloading, Salado dissolution, and localized dissolution within the Rustler. These processes, particularly dissolution of Salado and possibly Rustler halite, were driven by the hydrologic regime of the Cenozoic Ancestral Pecos River. As dissolution and unloading progressed, the higher Rustler transmissivities shifted to the north and east.

In summary, ground water from the Ancestral Pecos River hydrologic system accessed, dissolved, and recharged the Permian evaporites near the WIPP site. Flow through the evaporite section was dominantly north and east across the WIPP site area. Surface runoff increased, and westerly-draining tributaries progressively removed overburden from the evaporite section, including the Culebra. Strain associated with differential unloading provided pathways for ground water into existing gypsum-filled fracture networks and generated new fractures. Along the margins of the river, dissolution of Salado halite and subsequent collapse of the overlying rocks generated additional fractures and permeability in the Culebra. Where halite was dissolved from the Rustler, fractures were more abundant and contributed to a higher transmissivity. As the regional base-level dropped, flow directions in the Culebra reversed and the system began to drain back out toward its original recharge areas. Although permeability continues to develop within the Culebra, because Culebra ground water is nearly all undersaturated with respect to gypsum, it is not likely that the hydrologic system will change rapidly across the WIPP area without a significant increase in regional base-level.

Six hydrogeologic zones are present within the Culebra in the vicinity of the WIPP site. Table 4.4-1 summarizes the characteristics of each zone. The zones were delineated on the basis of transmissivity, amount of overburden, degree of hydraulic confinement, presence or absence of gypsum pore-fillings, and dissolution of underlying Salado halite. The distribution of these zones in the vicinity of the WIPP site is shown in Figure 4.4-15, and they are conceptually presented in cross-section form in Figure 4.4-16. These zones prograded east in response to progressive unloading and dissolution driven by the Ancestral Pecos hydrologic system. The hydrologic conditions which allowed this process to occur in the Cenozoic are no longer active.

4.4.3 Tamarisk Member

The Tamarisk Member of the Rustler Formation (Figure 4.4-1) consists of a mudstone (M-3/H-3), laterally equivalent to halite, sandwiched between two anhydrites (A-2 and A-3) (Holt and Powers, 1988). The anhydrite units act as confining beds (Confining Beds 3 and 4 of Holt et al., 1989), while the mudstone [Water Producing Unit 3 (WPU-3) of Holt et al., 1989] is the least productive of the Rustler water-producing units. Halite (H-3) is laterally equivalent to the mudstone and becomes the dominant rock type in this stratigraphic position along the central and southern portions of the eastern boundary of the WIPP site and farther east (Holt and Powers, 1988).

Less is known about the hydraulic properties of the Tamarisk than about those of the other Rustler members. No hydraulic tests of the Tamarisk anhydrites (A-2 and A-3) have ever been performed because of apparent low transmissivity (Holt et al., 1989). Hydraulic tests of the Tamarisk claystone have been attempted at only four locations: H-3b3 (1984 unpublished field notes), DOE-2 (Beauheim, 1986), H-14 (Beauheim, 1987a), and H-16 (Beauheim, 1987a). Drillstem and/or pulse tests failed at all four locations, as the transmissivities were apparently too low to measure over a period of several days (Holt et al., 1989). Based on the interpretation of similar tests performed successfully on the unnamed lower member at H-16, Beauheim (1987a) concluded that the transmissivity of the Tamarisk claystone is likely 10^{-7} square meters/day (10^{-5} square foot/day) or less. The transmissivity of the Tamarisk claystone might be expected to be greater west of the WIPP site in Nash Draw where dissolution of the upper Salado and Rustler has occurred, but no direct measurements have been made in this area (Holt et al., 1989). The transmissivities of the Tamarisk anhydrites in Nash Draw have probably been increased by dissolution and subsidence-induced fracturing (Holt et al., 1989).

No measurements of the undisturbed hydraulic head within the Tamarisk claystone have ever been made (Holt et al., 1989). The same low transmissivity that prevented successful hydraulic testing of the Tamarisk at H-3b3, DOE-2, H-14, and H-16 also prevented measurements of hydraulic heads at those locations (Holt et al., 1989). Fluid pressures have been measured within the Tamarisk interval of H-16

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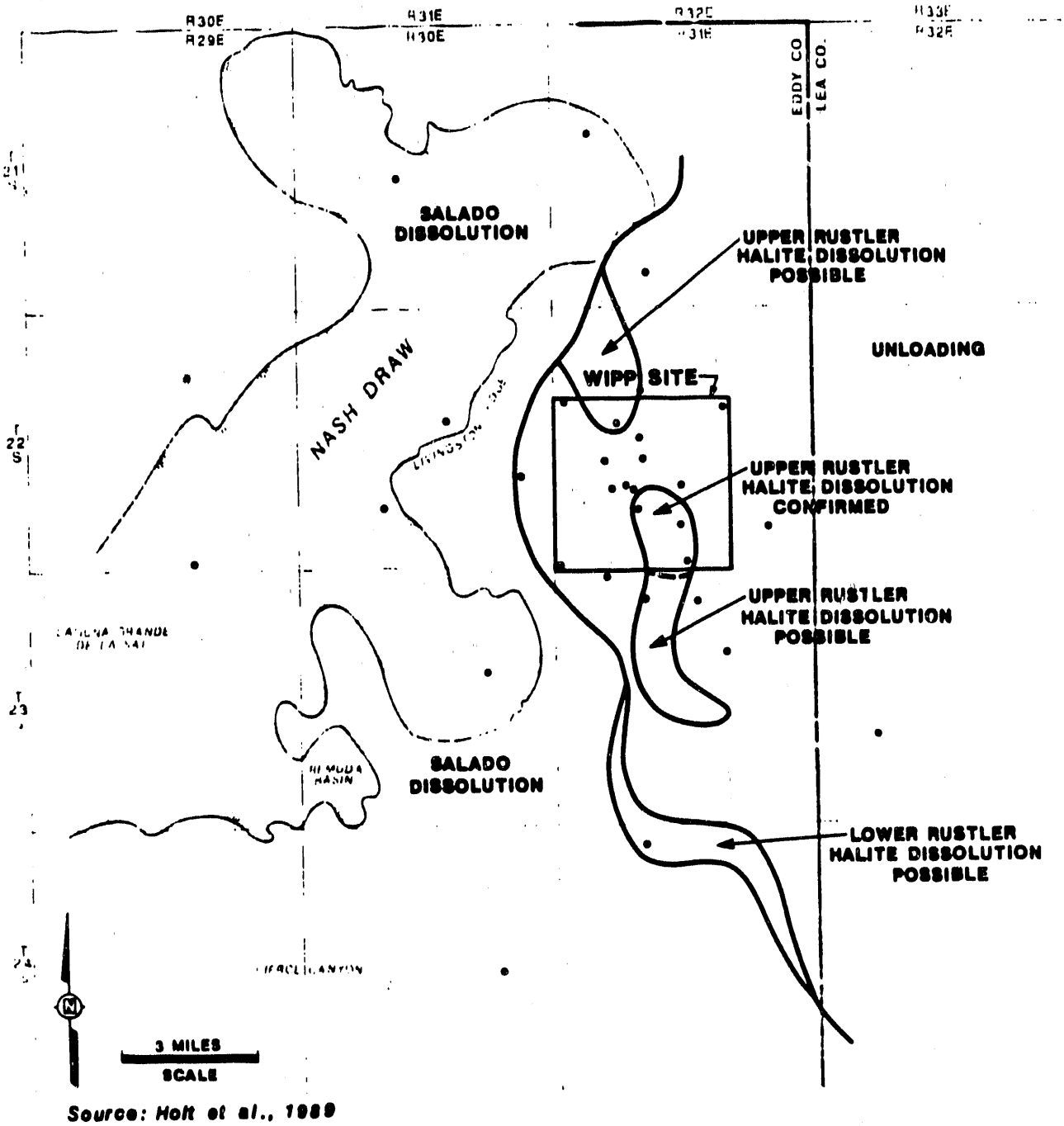

Source: Holt et al., 1989

EXPLANATION

- DRILL HOLES

FIGURE 4.4-14 PRIMARY CONTROLS ON CULEBRA TRANSMISSIVITY

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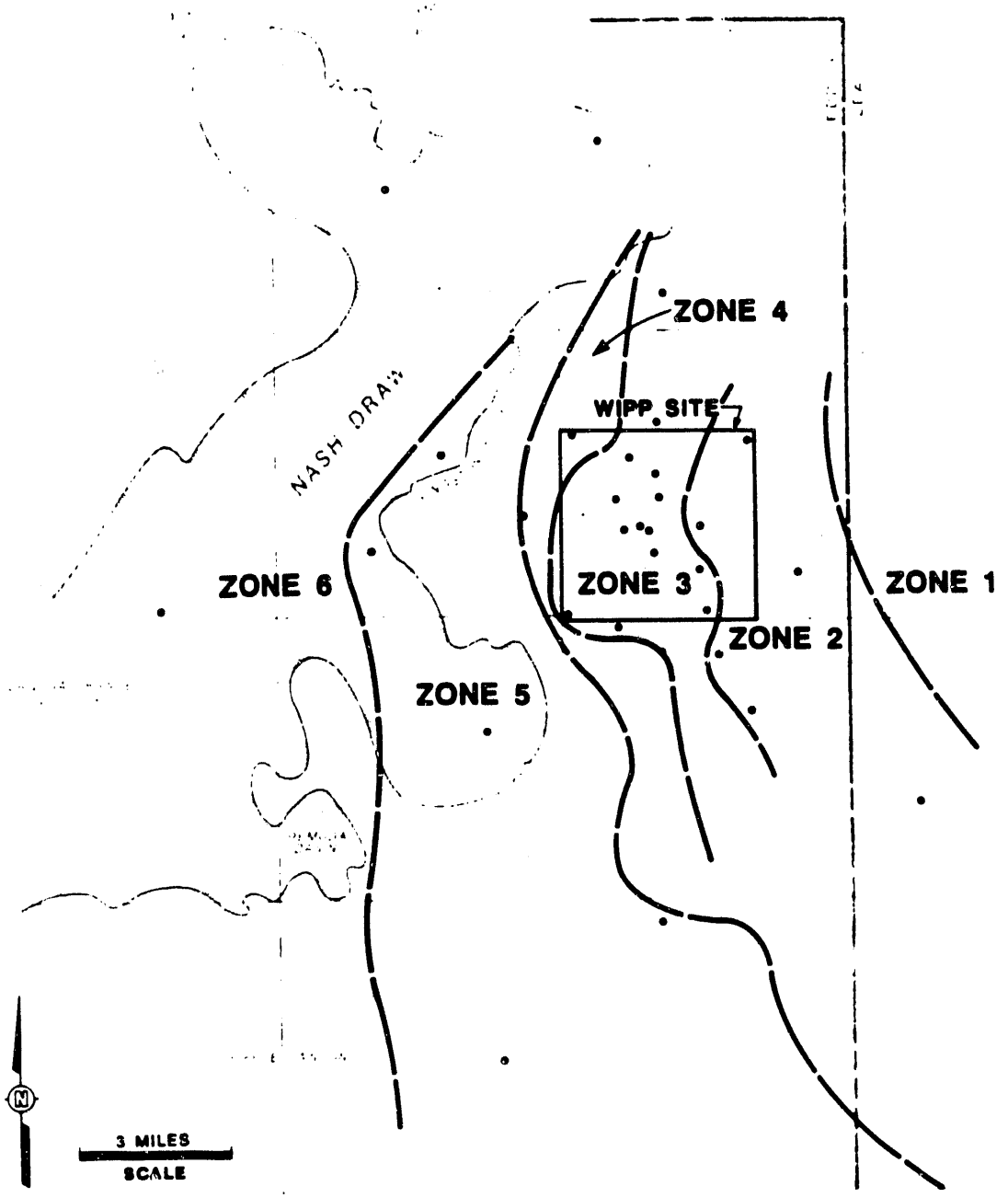

Source: Holt et al., 1989

EXPLANATION

• DRILL HOLES

FIGURE 4.4-15 EXTENT OF CULEBRA HYDROGEOLOGIC ZONES

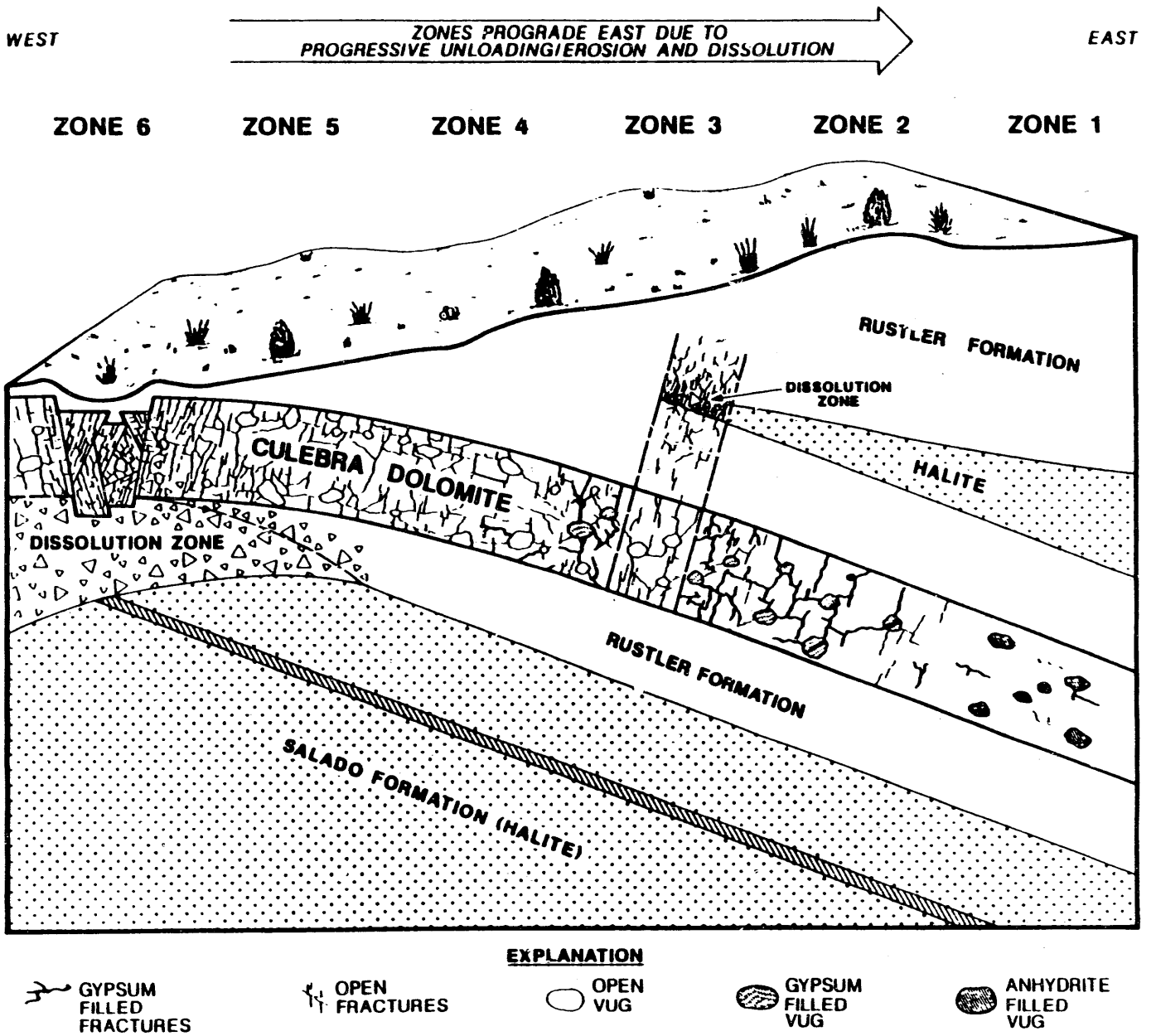

FIGURE 4.4-16 CONCEPTUAL CROSS-SECTION OF THE CULEBRA HYDROGEOLOGIC ZONES SHOWING DISTRIBUTION OF FEATURES

since August 1987 (Stensrud et al., 1988a, 1988b), but pressure stabilization was not achieved before the pressure began responding to the construction of the nearby air intake shaft.

The Tamarisk claystone consists of mostly mudstone and claystone with minor amounts of siltstone (Holt and Powers, 1988). Gypsum occurs as fibrous fracture fillings, nodules, and displacive crystals (Holt and Powers, 1988). The nodules and displacive crystals of gypsum are primary and attest to the lack of circulating ground waters since the Permian (Holt et al., 1989). The fibrous fracture-filling gypsum may have developed without an external source of fluid as the dewatering of the clays within the unit could provide sufficient fluid for the relocation of sulfate (Holt et al., 1989). Holt and Powers (1988) report collapse of A-3 in core from boreholes H-11 and H-3 and attribute this collapse to dissolution of small amounts of halite from this interval. This suggests at least a temporary vertical hydraulic connection between the M-3/H-3 interval and other water-bearing units in the Rustler (Holt et al., 1989). The timing and nature of this possible connection cannot be determined with the limited data available (Holt et al., 1989).

4.4.4 Magenta Dolomite Member

The Magenta Dolomite Member of the Rustler Formation is the uppermost of two regionally persistent dolomite units within the Rustler (Figure 4.4-1). Holt et al. (1989) include the Magenta within their hydrostratigraphic subdivision of the Rustler as Water Producing Unit 4 (WPU-4). The Magenta is confined by A-3 and A-4 of Holt and Powers (1988) which are equivalent to Confining Beds 4 and 5 of Holt et al. (1989). The Magenta is a fine-grained, gypsiferous, arenaceous dolomite (Holt and Powers, 1988).

Hydraulic tests have been performed on the Magenta dolomite at 16 locations (Mercer, 1983; Beauheim, 1986, 1987a). The transmissivity values obtained from these tests are shown on Figure 4.4-17. Most of the transmissivity values are less than or equal to 0.1 ft^2/day. Higher values of transmissivity, 0.3 and 1.0 ft^2/day, are found at H-6a and H-9a, respectively. The two highest values of Magenta transmissivity, 375 and 53 ft^2/day, are found in Nash Draw at WIPP-25 and WIPP-27, respectively, where dissolution of the upper Salado has caused collapse and fracturing of the overlying Rustler.

Between 1979 and 1981, stabilized water levels were measured in 13 wells completed to the Magenta (Richey, 1987b). Figure 4.4-18 shows the elevations of these stabilized water levels, along with estimated freshwater-head elevations calculated using borehole-fluid-density (or specific-gravity) data presented in Mercer et al. (1981), Dennehy and Mercer (1982), Mercer (1983), Lambert and Robinson (1984), Richey (1986, 1987a). The contours of the freshwater heads indicate a southwesterly flow direction within the Magenta in the northern portion of Nash Draw, and a generally westward flow direction toward Nash Draw over the rest of the region. Included on Figure 4.4-18 are freshwater heads estimated from pressure measurements made at DOE-2, H-14, and H-16. The pressure measurements at DOE-2 and H-14 were reported by Beauheim (1986, 1987a) to represent upper bounds on the stabilized formation pressures, while the pressure measurement at H-16 reflects drainage from the Magenta into the nearby WIPP shafts since 1981 (Beauheim, 1987a). With these caveats, the estimated freshwater heads at DOE-2, H-14, and H-16 are in qualitative agreement with the pattern of freshwater heads derived from the water-level data (Holt et al., 1989).

The Magenta was originally deposited as clastic gypsum and carbonate grains and is characterized by its well developed stratification (Holt and Powers, 1988). Upon shallow burial, the gypsum clastic component was at least partly replaced by anhydrite and sulfate cements developed between clastic grains, probably as overgrowths on existing sulfate (Holt and Powers, 1988). The anhydrite has since been replaced by gypsum, and most of the clastic texture within the sulfate component of the Magenta has been erased (Holt and Powers, 1988). Porosity within the Magenta is primarily intergranular and formed by the dissolution of gypsum (Holt et al., 1989). In those areas which originally contained abundant clastic gypsum, small open vugs have developed (Holt et al., 1989). Fracture porosity is less

common and the fractures are often filled with gypsum (Holt et al., 1989). Disruption and fracturing from unloading and dissolution have apparently been less effective in the Magenta than the Culebra (Holt et al., 1989).

4.4.5 Forty-Niner Member

The Forty-Niner Member of the Rustler Formation (Figure 4.4-1) is composed of two anhydrite and/or gypsum units (A-4 and A-5 of Holt and Powers, 1988) separated by a siltstone, mudstone, and claystone interbed (M-4). The anhydrite/gypsum units act as confining beds (Confining Beds 5 and 6 of Holt et al., 1989), while the claystone is a water-producing unit (Water Producing Unit 5 of Holt et al., 1989). Halite (H-4) is stratigraphically equivalent to M-4 east of the WIPP site (Figure 4.4-1).

The claystone water-producing unit (M-4) of the Forty-niner has been hydraulically tested at only four locations: DOE-2 (Beauheim, 1986), H-3d (Holt et al., 1989), H-14 (Beauheim, 1987a), and H-16 (Beauheim, 1987a). Transmissivities reported for the claystone are 2.5×10^{-3} to 1.1×10^{-2} ft^2/day at DOE-2, 3.0×10^{-2} to 7.1×10^{-2} ft^2/day at H-14, and 5.0×10^{-3} to 5.6×10^{-3} ft^2/day at H-16 (Holt et al., 1989). As is the case with the other Rustler members, the transmissivity of the Forty-niner claystone might be assumed to be higher west of the WIPP site in Nash Draw as a result of subsidence and fracturing, but no direct measurements have been made in that area (Holt et al., 1989). Where the H-4 halite unit is found with the M-4 claystone east of the WIPP site, the transmissivity of the claystone is probably less than where the halite is absent (Holt et al., 1989).

The transmissivities of the anhydrites are very low and not measurable (Holt et al., 1989). Where present in Nash Draw, the Forty-Niner anhydrites may have very high transmissivities as a result of dissolution and subsidence-induced fracturing (Holt et al., 1989).

Measurements of the hydraulic head of the Forty-niner claystone have been made at wells H-3d, H-14, H-16, and DOE-2. Beauheim (1987a) summarizes these observations and presents estimates of static fluid pressures at the midpoint of the claystone. The measurement from DOE-2 had the greatest uncertainty. Re-examination of the original data from DOE-2 (Beauheim, 1986) indicates that a "static" pressure 12 psi lower than that reported by Beauheim (1987a) probably provides a more accurate upper bound on the hydraulic head in the Forty-niner member at that location. Figure 4.4-19 shows the static fluid-pressure estimates for the Forty-niner claystone at H-3d, H-14, H-16, and DOE-2 converted to freshwater heads. Firm conclusions cannot be drawn from so few data, but the data are not inconsistent with an assumption of southwesterly to westerly flow towards Nash Draw (Holt et al., 1989). The relatively low head at H-16 may, as suggested by Beauheim (1987a), be related more to localized drainage into the WIPP shafts than to the undisturbed regional head distribution.

The M-4 unit (WPU-5) consists of siltstone, claystone, and locally some sandstone (Holt and Powers, 1988). These clastic materials are cemented with halite (Holt and Powers, 1988; Holt et al., 1989). Porosity within M-4 is principally intergranular, resulting from the dissolution of halite cements (Holt et al., 1989).

4.4.6 Summary of Hydraulic-Head Relationships

The hydraulic-head distributions shown for the unnamed lower member/upper Salado, Magenta, and Forty-niner claystone in Figures 4.4-4, 4.4-18 and 4.4-19 all indicate westerly to southwesterly components to the ground water flow in those units. In contrast, flow within the more transmissive Culebra appears to be largely southerly (Figure 4.4-6). These data are consistent with the paleorecharge/modern discharge hypothesis of Lambert and Harvey (1987).

Vertical gradients within the Rustler reflect a recharge discharge cycle and are consistent with Lambert and Harvey's (1987) hypothesis of late-Pleistocene recharge and current discharge (Holt et al., 1989).

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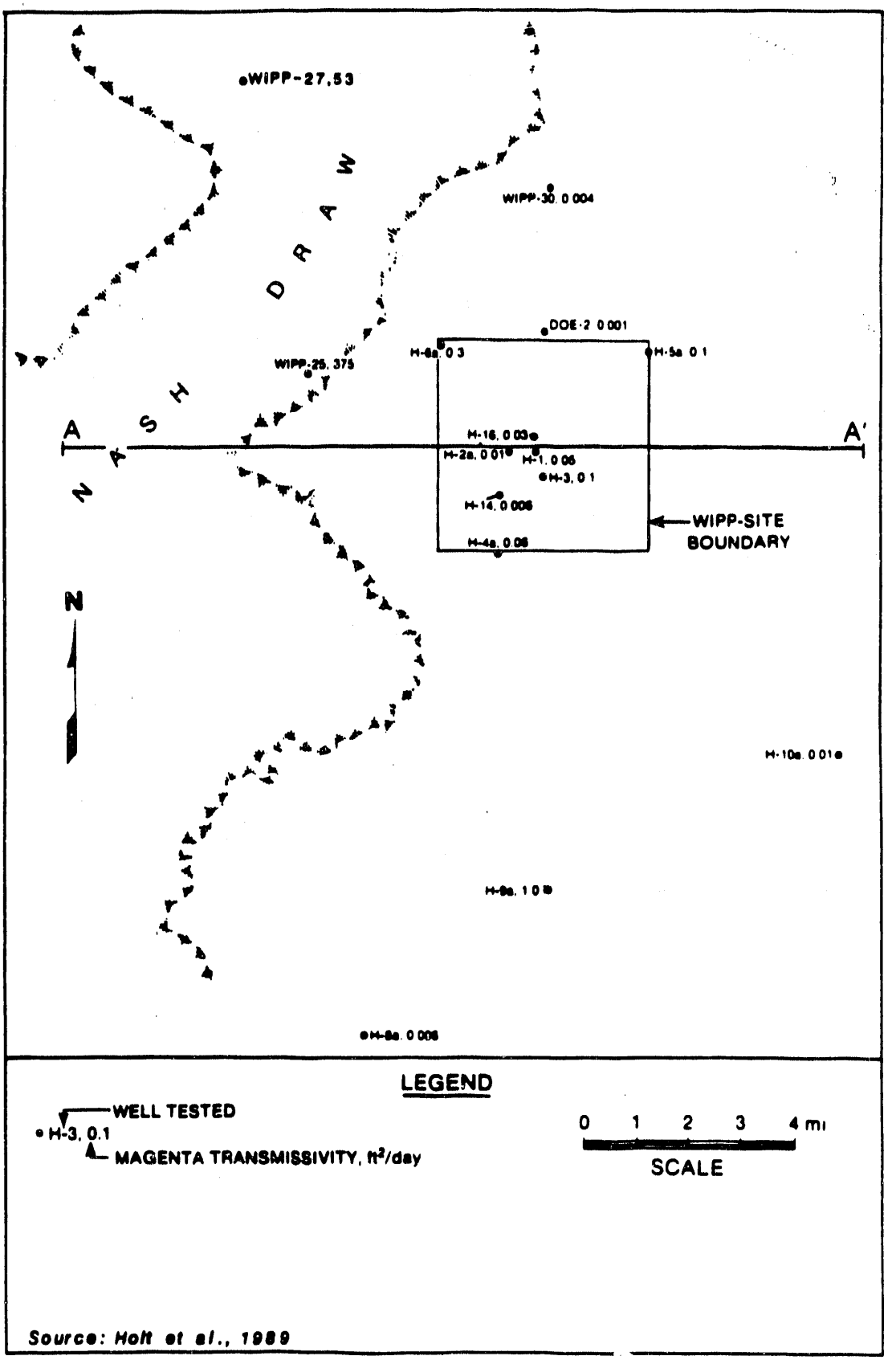

FIGURE 4.4-17 MAGENTA TRANSMISSIVITY

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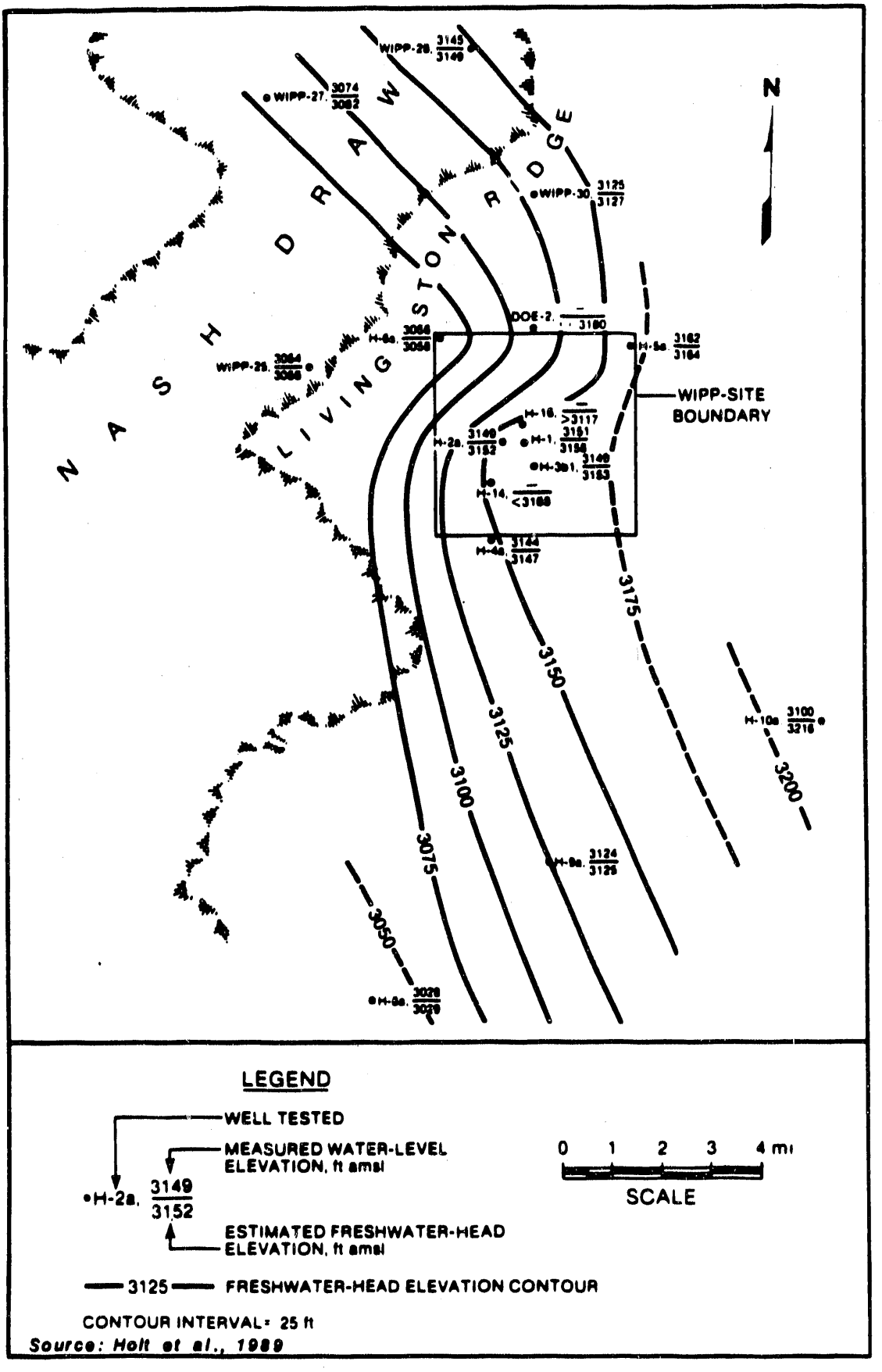


FIGURE 4.4-18 MEASURED WATER LEVEL AND ESTIMATED FRESHWATER-HEAD ELEVATION, MAGENTA DOLOMITE MEMBER

301001 89 04 06 A45

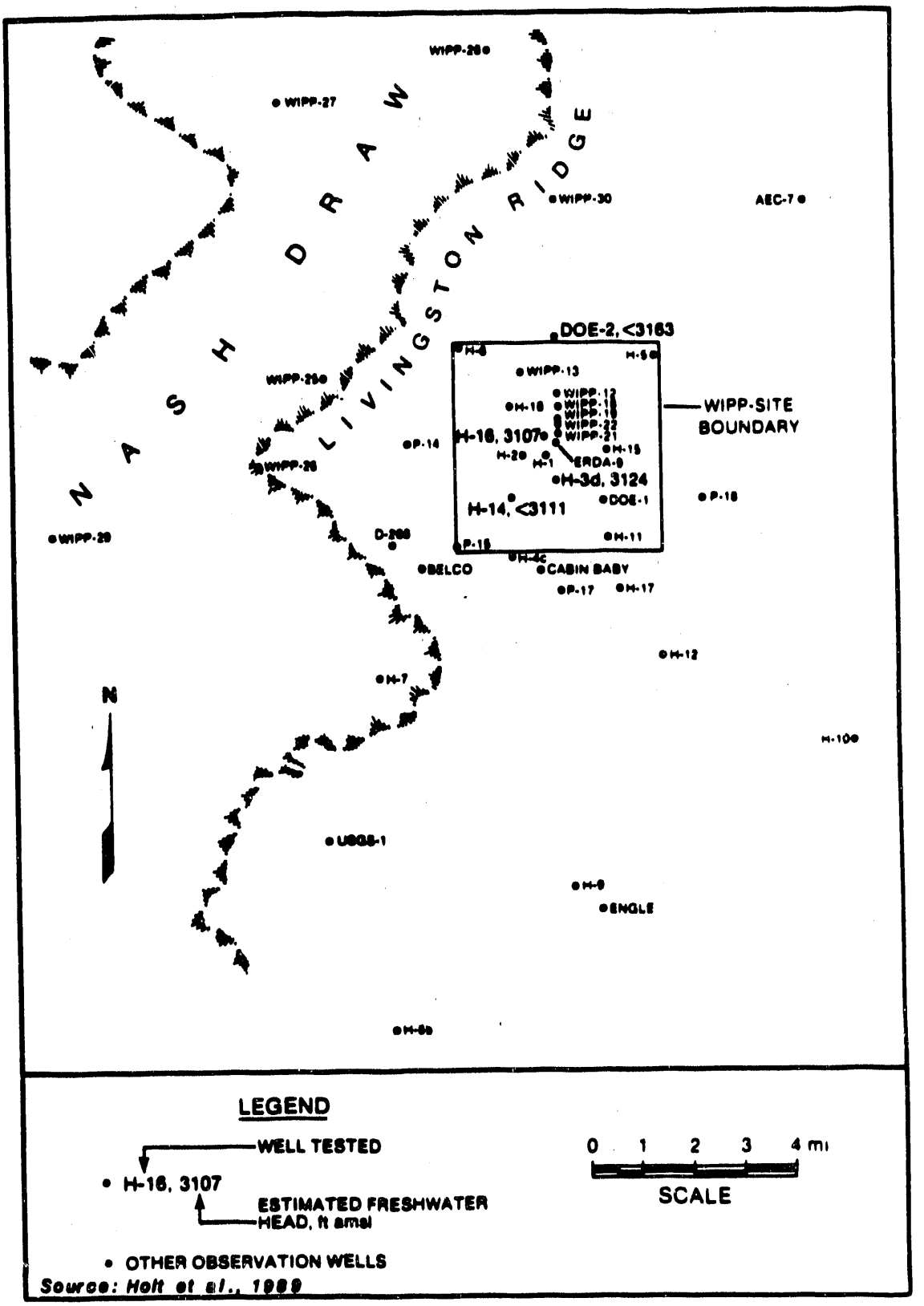


FIGURE 4.4-19 ESTIMATED FRESHWATER HEADS FOR THE FORTY-NINER CLAYSTONE

Figure 4.4-20 is a vertical east-west cross-section through the center of the WIPP site, showing the directions of the vertical hydraulic gradients between members of the Rustler. Where no dissolution of either upper Salado or unnamed lower member halite has occurred, from about the west-central portion of the WIPP site to the east, hydraulic gradients from the unnamed member and Magenta indicate potential fluid flow from both above and below into the Culebra (Holt et al., 1989). The Culebra, being the most transmissive part of the Rustler in this vicinity, drains internally (i.e., towards Nash Draw) faster than the other water- producing units, and probably also acts as a drain on the overall system (Holt et al., 1989). The gradients toward the Culebra do not imply, however, that significant amounts of vertical leakage between units are occurring (Holt et al., 1989). Rather, the preservation of high hydraulic heads in the low-permeability Magenta and unnamed member demonstrate the effectiveness of the confining beds separating them from the Culebra (Holt et al., 1989). Davies (1989) reached similar conclusions based on numerical simulations of various hypothetical scenarios involving drainage of high heads in the Rustler.

The western portion of the WIPP site appears to be a transition region in which vertical hydraulic gradients change (Holt et al., 1989). In the region west of the WIPP site, where dissolution of the upper Salado has occurred, the Magenta head decreases until the unit dewaters, and gradients are downward from the Culebra to the unnamed member/upper Salado (Holt et al., 1989). The increases in the transmissivities of the unnamed member/upper Salado, Culebra, and Magenta caused by the dissolution west of the WIPP site appear to allow increased internal drainage from each of the members to the west and southwest (Holt et al., 1989). The combination of dissolution of the upper Salado and associated Rustler subsidence may also have fractured the Rustler confining beds, allowing increased flow between Rustler members (Holt et al., 1989).

Vertical hydraulic gradients between the Magenta and Forty-niner claystone are upward in the central portion of the WIPP site, based on measurements made in holes DOE-2, H-3d, H-14, and H-16 (Holt et al., 1989). The two water-producing units are separated by an effective confining bed (A-4) in this region, which likely prevents significant leakage (Holt et al., 1989). The origin of the head difference between the Magenta and Forty-niner claystone is unclear, but the relative heads serve to prevent overlying units from recharging the Magenta at the present time (Holt et al., 1989). No data are available to evaluate hydraulic gradients between the Magenta and Forty-niner claystone in the region surrounding the WIPP site, such as at the J. C. Mills Ranch to the south, where portions of the Dewey Lake Red Beds are saturated (Mercer, 1983).

Both the hydraulic gradients within and between the individual water-producing units of the Rustler are consistent with Lambert and Harvey's (1987) hypothesis that the Rustler flow systems are not at steady-state, but are instead draining following a late-Pleistocene recharge event (Holt et al., 1989). The most transmissive unit, the Culebra, has drained faster than the other units, leaving it relatively underpressurized at and east of the WIPP site (Holt et al., 1989). The other Rustler units exhibit hydraulic gradients towards the drainage region represented by Nash Draw (Holt et al., 1989). West of the WIPP site, where dissolution of the upper Salado has caused Rustler subsidence and fracturing, hydraulic communication between all of the Rustler members is likely (Holt et al., 1989).

4.4.7 Conceptual Hydrogeological Model of the Rustler

Holt et al. (1989) proposed the following conceptual model for the development of the hydrologic zones within the Rustler. In the WIPP region, the hydrogeologic conditions in the Rustler developed concurrently with the Ancestral Pecos hydrologic regime. The erosional pattern generated by the Ancestral Pecos River and its tributaries was superimposed over the existing erosional surface. This erosion brought the evaporites of the Rustler and Salado close to the surface allowing recharge from the Ancestral Pecos and meteoric waters to dissolve the evaporites. Ground water circulation and evaporite

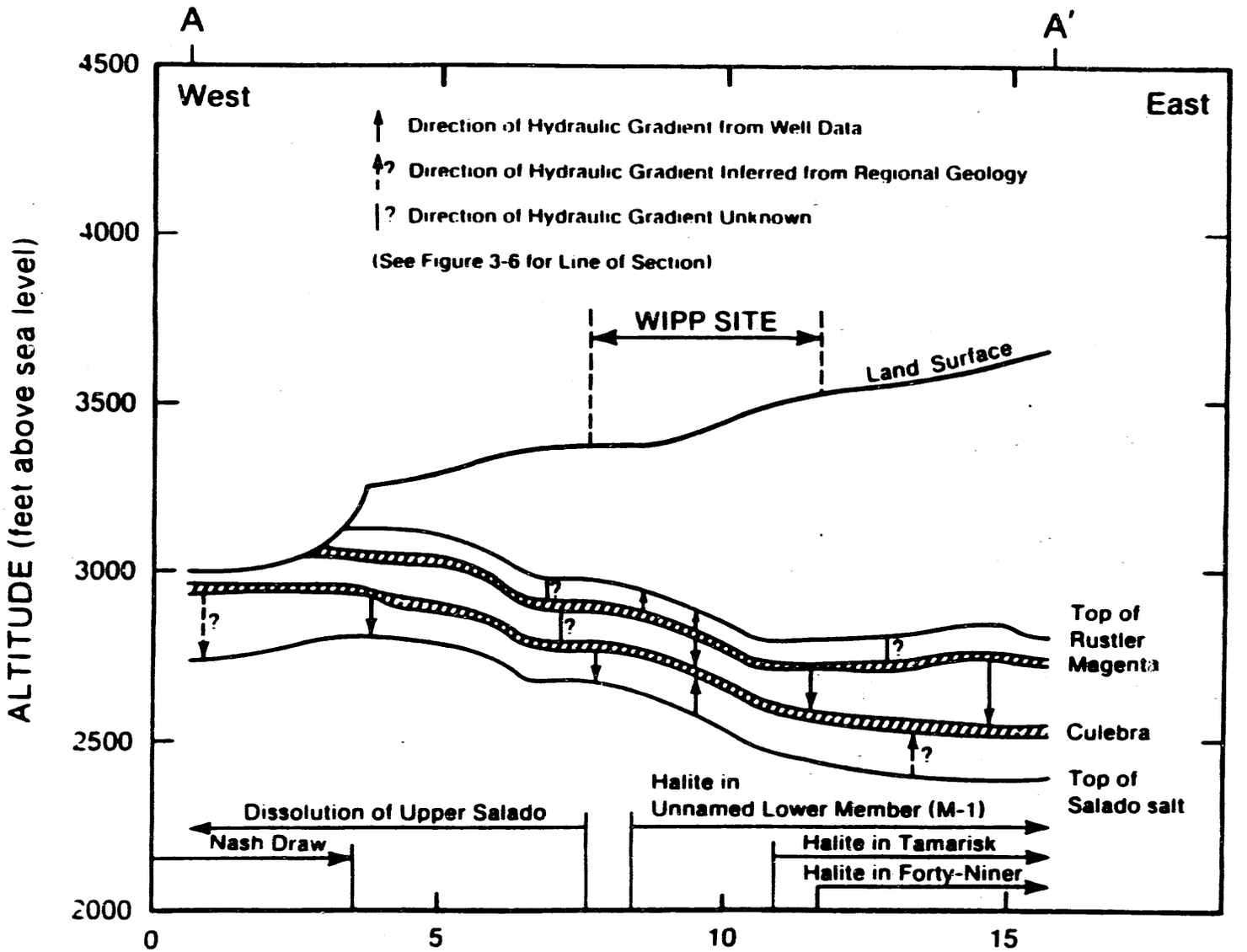
dissolution were most active in those areas adjacent to the Ancestral Pecos River and its tributaries. Collapse enhanced transmissivity within the Rustler.

Major tributaries to the Ancestral Pecos River were also the site of dissolution of evaporites as erosion and later dissolution preferentially exposed the Rustler and Salado to circulating ground water. Local collapse features occurred along these drainages, and later, these features coalesced into karst valleys. The hydrologic regime within the evaporite section around each of these tributaries was dominated by these karst processes. Nash Draw is the closest such tributary. During the Cenozoic, it acted as a recharge and, as the climatic conditions varied with time, a possible discharge point for fluids moving within the Rustler.

Ancestral Pecos River deposits can be considered a record of paleohydraulic head levels. These deposits in the vicinity of the WIPP are higher than the modern head levels within any of the Rustler units when the effect of subsidence due to dissolution is removed. This relationship suggests that the Ancestral Pecos River and its tributaries within karst valleys were capable of recharging Rustler hydrologic units during the Cenozoic.

The hydrologic systems within the Rustler across the site area were mostly passive as no active discharge point existed. Additional recharge to the low permeability parts of the Rustler across the WIPP area only occurred when new porosity was generated. New porosity developed in response to fracturing caused by unloading and dissolution of evaporite cements, fracture fillings, and sedimentary features. The Rustler hydrologic units were most active near the Ancestral Pecos River and tributary hydrologic system, where dissolution and collapse of underlying and overlying evaporite beds enhanced the porosity and permeability within the Rustler. Passive conditions existed further away from the recharge areas, where conditions within the Rustler remained at or near steady-state and discharge was not possible or very slow. The hydrologic conditions in the area between those clearly active and passive hydrologic zones varied with permeability, porosity, recharge rates, and discharge rates decreasing away from the active zones. The active hydrologic zones encroached upon the passive hydrologic zones as unloading, erosion, and dissolution migrated laterally from recharge areas. Variations in climate, the location of the Ancestral Pecos River and tributary channels, and local geologic conditions controlled the rate of advancement and the locations of the active zones. This variability caused the hydraulic head potentials within the Rustler hydrologic units to vary such that flow direction reversals were possible. Paleoflow reversals would allow the removal of dissolved evaporite minerals from those passive areas of the Rustler and an increase in transmissivity and potential for further discharge. As modern transmissivity variations within the hydrologic units reflect the extent of active Cenozoic zones, paleoflow directions within active Cenozoic hydrologic zones must have been parallel to the modern transmissivity distribution. Although it was certainly variable, the principal direction of flow has not been precisely identified.

The hydrologic units within the Rustler across the WIPP site are not being recharged and the flow directions indicate that Rustler hydrologic units are now draining. Therefore, modern transmissivities of these units are interpreted to reflect the maximum encroachment of Cenozoic active areas into passive areas. The modern transmissivities within Rustler hydrologic units in the vicinity of the WIPP site generally decrease away from Nash Draw, a probable Cenozoic recharge area. Modern transmissivities appear to increase where Cenozoic dissolution and collapse occurred within the Rustler and Salado. In those hydrologic units subject to fracturing during unloading (principally the Culebra, WPU-2), modern transmissivity generally is related to the amount of overburden removed by erosion. This is true in the highly transmissive zone south of the WIPP site and east of Nash Draw. Modern transmissivities may be lower than predicted by the preceding relationships in those areas where late-stage secondary pore fillings are present. At the present time, only one such location has been tentatively identified in the Rustler. It occurs within the Culebra Dolomite Member (WPU-2) west of the WIPP site.



Source: Holt et al., 1989

FIGURE 4.4-20 VERTICAL FLOW POTENTIAL IN THE RUSTLER FORMATION

4.4.8 SEIS Modeling of Culebra

Numerical modeling of a hypothetical human breach scenario was performed by Sandia National Laboratories for the SEIS, and the results are summarized by Lappin et al. (1989). The scenario involves the breach of the repository by a drillhole which penetrates a hypothetical pressurized brine reservoir beneath the repository. With time, the borehole plug degrades and brine-reservoir fluids migrate up the borehole and interact with the waste in the repository. The degree of interaction with the waste was varied for different model cases. These fluids were assumed to continue migrating up the borehole, where they are released into the Culebra Dolomite Member of the Rustler Formation and are transported to a hypothetical stock-well at the edge of the WIPP site area. Estimates of ground water travel-times for undisturbed Culebra flow from above the waste emplacement panels to the southern boundary of the site range from 5,100 to 13,000 years.

4.5 DEWEY LAKE RED BEDS

The Dewey Lake Red Beds are the uppermost of the four Ochoan formations (Figure 4.0-1). The Dewey Lake consists almost entirely of mudstone, claystone, siltstone, and interbedded sandstone. With the exception of the upper portion, the Dewey Lake is characterized by locally abundant gypsum-filled fractures. The majority of the fractures are filled with fibrous gypsum, although granular gypsum fracture fillings do occur in the upper portion of the Dewey Lake. The upper portion of the Dewey Lake is cemented with carbonate and is moist within the air intake shaft at the WIPP (Holt and Powers, 1989). Fractures in this zone are unfilled or filled with carbonate, and carbonate-filled fractures become more abundant downward (Holt and Powers, 1989). An abrupt change of cement type was noted by Holt and Powers (1989) from carbonate to a much harder, unidentified material. Coincident with the change in cement, fractures became filled with fibrous gypsum and the Dewey Lake was no longer moist (Holt and Powers, 1989). Moisture has been encountered within the Dewey Lake at several of the WIPP drillholes, and several stock wells south of the WIPP site are possibly completed in the upper Dewey Lake (Mercer, 1983).

4.6 SANTA ROSA FORMATION

The Santa Rosa Formation is part of the Late Triassic Dockum Group (Figure 4.0-1). The Santa Rosa occurs as an erosional wedge that pinches out west and south of the WIPP site (Powers, et al., 1978). At the WIPP site, the Santa Rosa is 8 meters (25 feet) thick (Holt and Powers, 1989). The Santa Rosa consists of calcareous interbedded sandstone, siltstone, and claystone. It is moderately well indurated to soft. It is not a hydrologically significant unit in the vicinity of the WIPP site (Mercer, 1983). It is recharged by precipitation along the eastern margin of the WIPP site, and this recharge probably moves downward into the Dewey Lake Red Beds (Mercer, 1983).

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APPENDIX D11

TYPICAL CARBON SORPTION BED EFFICIENCY

APPENDIX D11
TYPICAL CARBON SORPTION BED EFFICIENCY

Purpose

To determine design concentrations for VOCs and establish the amount of carbon necessary for VOC adsorption as well as bed exchange frequency.

Modeling Requirements

This model is designed to theoretically allow no migration of five targeted VOCs past the carbon bed adsorption system. The target VOCs are:

1. Trichloroethane
2. Trichloroethylene
3. Carbon Tetrachloride
4. Freon 113
5. Methylene Chloride

All calculations done @ STP

Methodology

The methodology used is as follows:

1. Establish target VOC percent contribution to headspace gas by waste type (Table 1)
2. Calculate average target VOC composition in headspace gas (Table 2)
3. Calculate partial pressure of each of the five target VOCs
4. Calculate carbon efficiencies from Calgon-BPL isotherms (Figures D11-1 through D11-5)
5. Determine total VOC loading
4. Calculate carbon required

Assumptions

1. Manifold system is pressure balanced and the average pressure is 14.7 psia.

2. Total gas release rate is 5 moles/drum/year.

3. Six drums will be placed in each bin.

4. There are 116 bins with waste per room.

5. All gases are ideal (22.4 ℓ/mole @ STP).

6. System volume and temperature remain constant, therefore compound partial pressure is a function of percent total compound contribution to overall ambient pressure (atmospheric) of 14.7 psia.

VOC Partial Pressure Calculation: Fraction of Total Contribution of a Given VOC Compound x STP at Average Atmospheric Pressure

$$\text{Compound Partial Pressure} = \frac{\%\text{ of Total Contribution of a given VOC compound (Table 2)}}{100} \text{ (14.7 psia)}$$

$$\text{1,1,1,Trichloroethane} = \frac{.2103}{100}(14.7) = 0.031 \text{ psi}$$

$$\text{Trichloroethylene} = \frac{.0069}{100}(14.7) = 0.0010 \text{ psi}$$

$$\text{Carbon Tetrachloride} = \frac{.0182}{100}(14.7) = 0.0027 \text{ psi}$$

$$\text{Methylene Chloride} = \frac{.0158}{100}(14.7) = 0.0023 \text{ psi}$$

$$\text{Freon 113} = \frac{.0443}{100}(14.7) = 0.0065 \text{ psi}$$

The calculated partial pressures for each compound were plotted on sorption isotherms that were specific to each VOC. The isotherms are plots of VOC partial pressure versus the specific sorption capacity, by weight, of the activated carbon for the particular VOC at various equilibrium temperatures. The sorption capacity is represented as an efficiency of grams of sorbed VOC per gram of activated carbon. The sorption efficiency values are shown below (see attached isotherms in Figures D11-1 through D11-5).

TABLE 1

HEADSPACE COMPOSITION CALCULATION

WASTE TYPE	WASTE TYPE % OF TOTAL		PERCENT OF COMPOUND IN WASTE TYPES								
		NO_x	TRICHL	IPROP	TRCETHY	CCL4	DCM	DCETHA	1.2 FREON	CYCHEX	DCETHY
(1)	12%	I-MAX	0.94	0	0.04	0.04	0.22	0	0	0	0
		I-MIN	0	0	0	0	0	0	0	0	0
		I-AVG	0.1978	0	0.005	0.0025	0.0203	0	0	0	0
		I-COUNT	32	32	32	32	32	32	32	32	32
(2)	37%	II-MAX	2.84	0	0.17	0.09	0.42	0.4	0.81	0.17	0.03
		II-MIN	0	0	0	0	0	0	0	0	0
		II-AVG	0.2669	0	0.0043	0.0029	0.0203	0.0106	0.0103	0.0021	0.0003
		II-COUNT	78	78	78	78	78	78	78	78	78
(3)	49%	III-MAX	1.06	0.62	0.14	0.29	0.25	0	2.87	0	0
		III-MIN	0	0	0	0	0	0	0	0	0
		III-AVG	0.1238	0.0201	0.0087	0.0068	0.0089	0	0.0389	0	0
		III-COUNT	77	77	77	77	77	77	77	77	77
(4)	2%	IV-MAX	7.48	0	0.14	4.09	0.71	0	10.4	0	0
		IV-MIN	0	0	0	0	0	0	0	0	0
		IV-AVG	1.3582	0	0.0213	0.6734	0.0726	0	1.0717	0	0
		IV-COUNT	23	23	23	23	23	23	23	23	23

$$\%\ \text{TOTAL CONTRIBUTION FOR EACH VOC SPECIES} = \sum_{1}^{4} (\text{WASTE TYPE \% OF TOTAL WASTE}) \times (\text{PERCENT OF COMPOUND IN WASTE TYPE})$$

(EXAMPLE) % TOTAL CONTRIBUTION FOR 1,1,1,TRICHLOROETHANE = (.12)(.1978) + (.37)(.2669) + (.49)(.1238) + (.02)(1.3582) = 0.2103%

TABLE 2
CARBON SORPTION BED SPECIFICATIONS

	% TOTAL CONTRIBUTION	CALCULATED PARTIAL PRESSURES OF THE TARGET[a] VOCs	MOLE/BIN/YR[b]	MW (g/mole)	g/BIN/YEAR[c]	CAPACITY FACTOR g CARBON/g VOC[d]	g CARBON/BIN/YEAR[e]
1,1,1,Trichloroethane	0.2103	0.0310	0.0621	133	8.39	1.56	13.09
Trichloroethylene	0.0069	0.0010	0.0021	131	0.27	3.03	0.82
Carbon Tetrachloride	0.0182	0.0027	0.0055	154	0.85	2.5	2.12
Methylene Chloride	0.0168	0.0025	0.0050	85	0.42	1.30	0.55
Freon 113	0.0443	0.0065	0.0133	187	2.49	1.92	4.78
					12.42 grams/BIN/YR TOTAL VOCs		21.36 grams TOTAL/REQUIRED/BIN/YEAR

(a) $\frac{\text{Percent Total Contribution}}{100}$ (14.7 psi) = Compound Partial Pressure

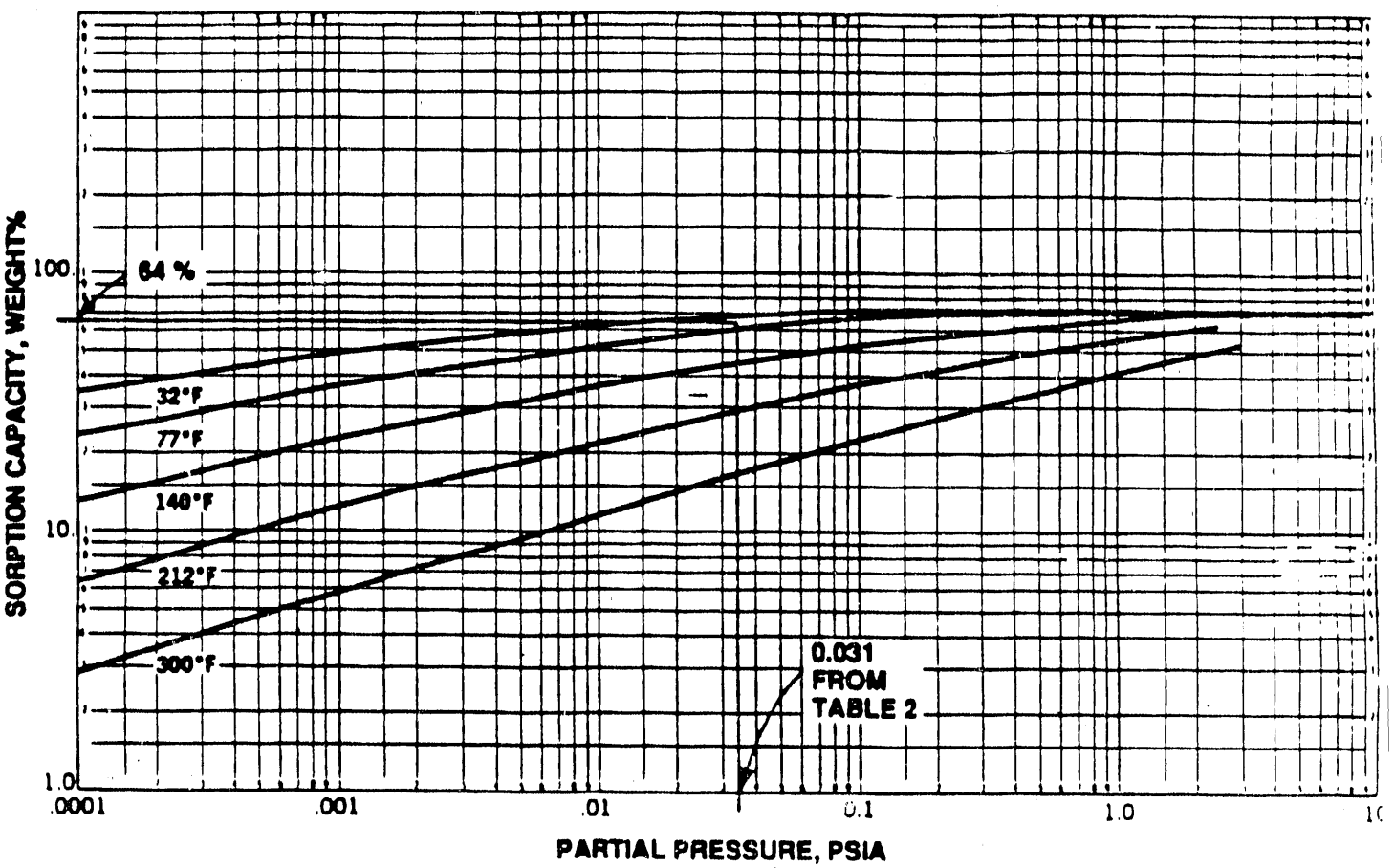
(b) Mole/Bin/Yr = $\frac{\text{(\% Total Contribution)}}{100}$ (30 Mole/Bin/Yr)

(c) g/Bin/Yr = (Mole/Bin/Yr) (g/Mole)

(d) Capacity Factor = $\frac{(100)}{\text{Sorption Capacity (Percent)}}$ from Calgon Isotherms @65°F

(e) g Carbon/Bin/Year = (g/Bin/Yr) (Capacity Factor)

TRICHLOROETHANE ADSORPTION ON BPL ACTIVATED CARBON



For additional information, contact Calgon Carbon Corporation, Box 717, Pittsburgh, PA 15230-0717 Phone: (412) 787-6700

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FIGURE D11-1 SORPTION ISOTHERM FOR CALGON TYPE BPL ACTIVATED CARBON FOR TRICHLOROETHANE

TRICHLOROETHYLENE ADSORPTION ON BPL ACTIVATED CARBON

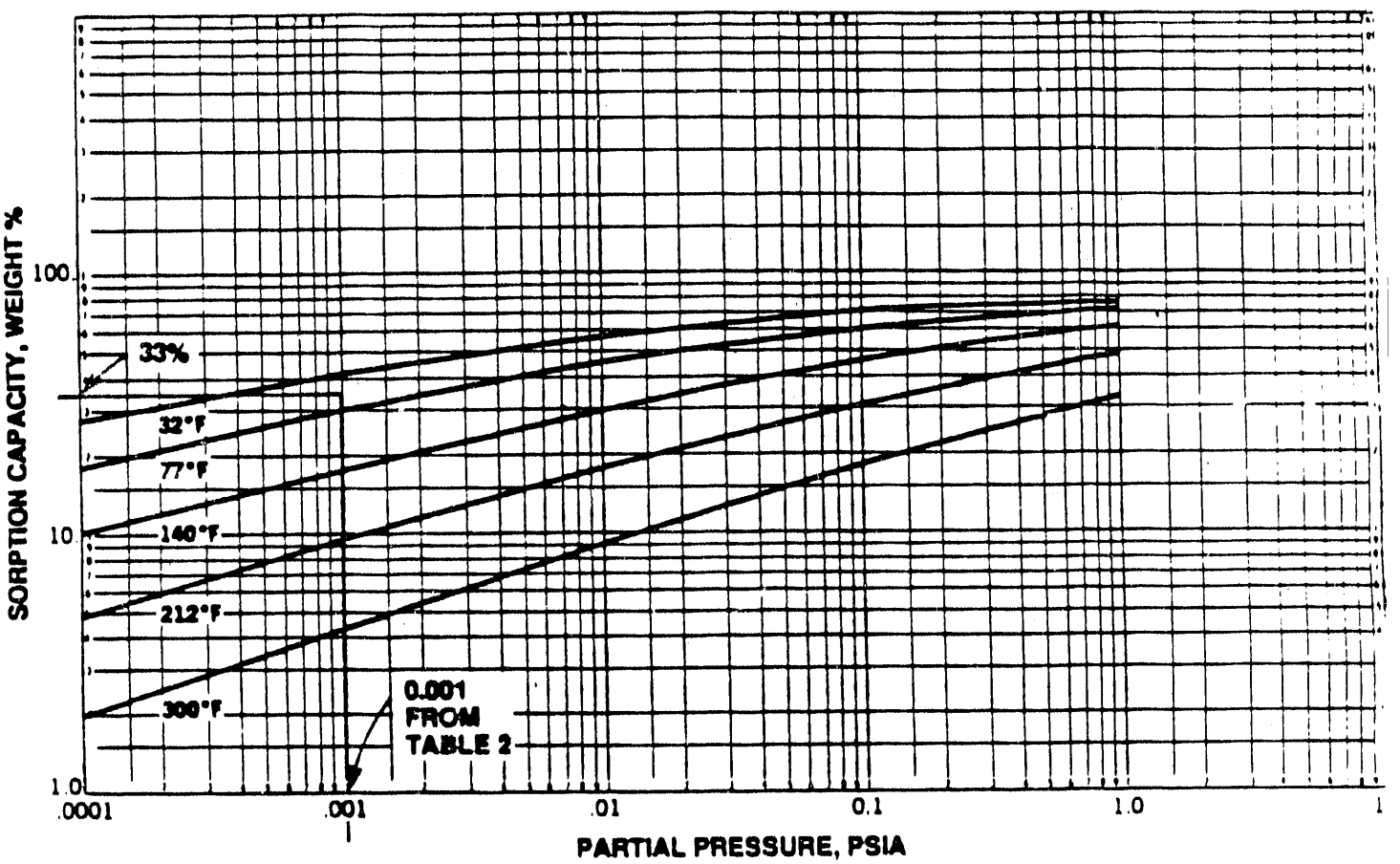

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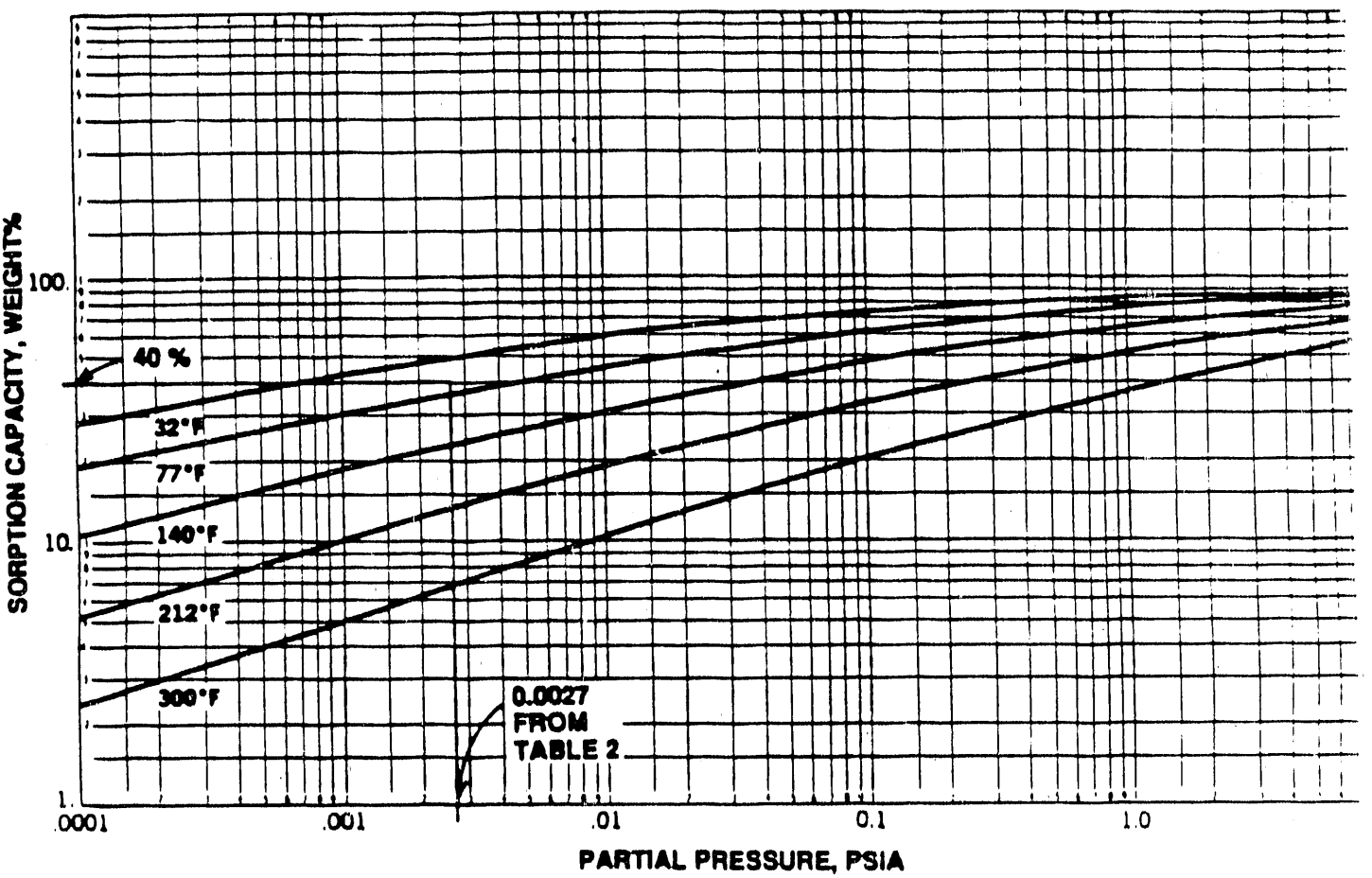
FIGURE D11-2 SORPTION ISOTHERM FOR CALGON TYPE BPL ACTIVATED CARBON FOR TRICHLOROETHYLENE

CARBON TETRACHLORIDE ADSORPTION ON BPL ACTIVATED CARBON



For additional information, contact the Activated Carbon Division, Calgon Corporation, Calgon Center, Box 1346, Pittsburgh, PA 15230. Phone: (412) 923-2345.

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FIGURE D11-3 SORPTION ISOTHERM FOR CALGON TYPE BPL ACTIVATED CARBON FOR CARBON TETRACHLORIDE

METHYLENE CHLORIDE ADSORPTION ON TYPE BPL CARBON

(COMPUTER ESTIMATE)

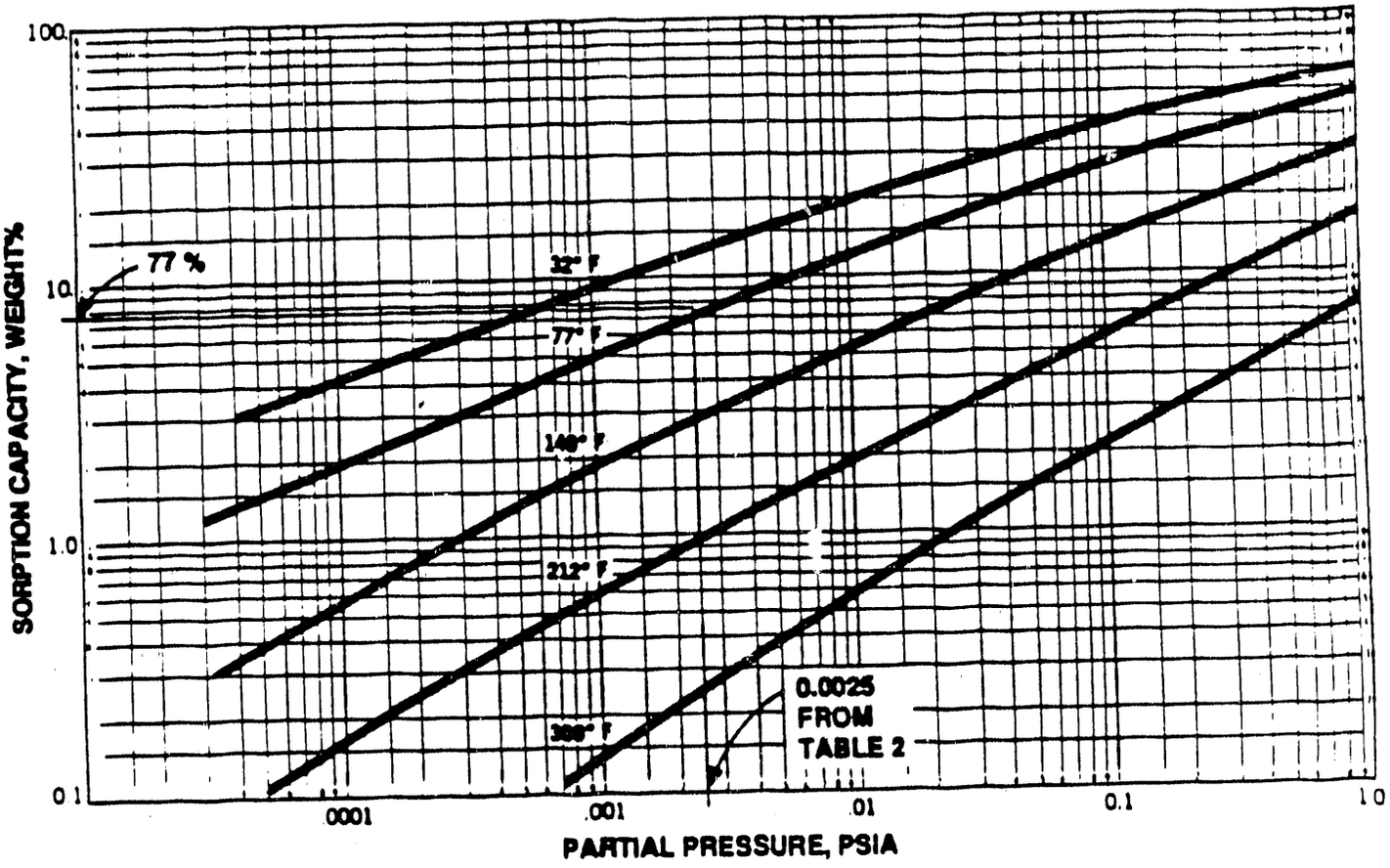

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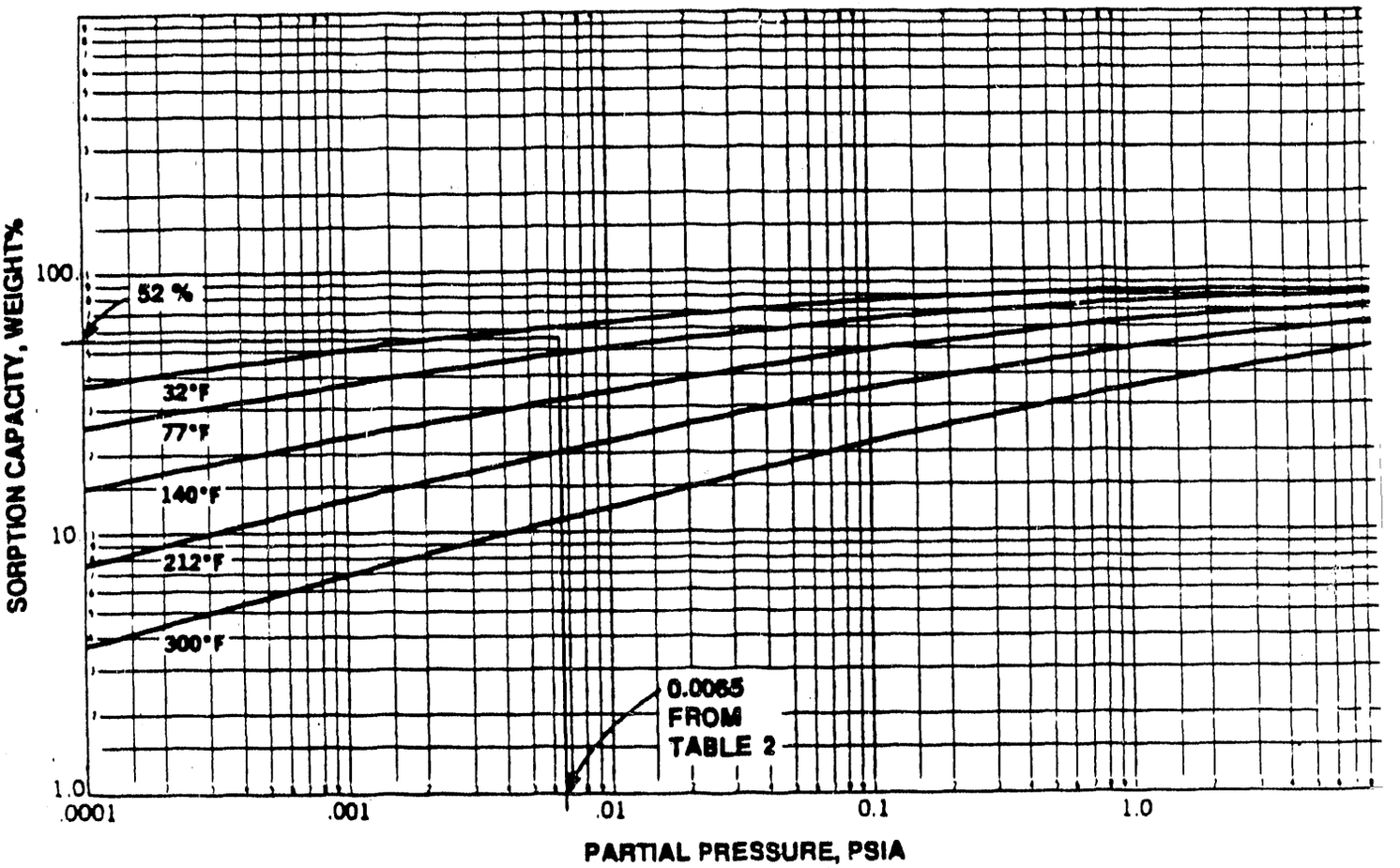
FIGURE D11-4 SORPTION ISOTHERM FOR CALGON TYPE BPL ACTIVATED CARBON FOR METHYLENE CHLORIDE

FREON 113 ADSORPTION ON BPL ACTIVATED CARBON



For additional information, contact the
Activated Carbon Division, Calgon Corporation,
Calgon Center, Box 1346, Pittsburgh, PA 15230.
Phone: (412) 923-2345.

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FIGURE D11-5 SORPTION ISOTHERM FOR CALGON TYPE BPL ACTIVATED CARBON FOR CARBON FREON 113

- 1,1,1,Trichloroethane 64%
- Trichloroethylene 33%
- Methylene Chloride 77%
- Freon 113 52%
- Carbon Tetrachloride 40%

The capacity factor is calculated to determine the number of grams of carbon required to sorb 1 gram of a particular VOC. The formula for calculation of the capacity factor is shown on Table 3, along with capacity factor values. The total carbon requirements for sorbing 100 percent of all five target VOCs per bin per year is also shown in Table 2. The total carbon requirements value of 23.70 grams of carbon/bin/year is the sum of the individual carbon requirement for each of the five target compounds.

The calculated carbon requirements for sorbing all VOCs for all of the bins in each room is:

(Total Carbon/bin/year)(116 bins) = Total carbon/room/year
(21.36g/bin/year)(116 bins) = 2,478 grams/room/year

As has been previously stated in the VOC Monitoring Plan, Calgon recommends a 100 percent overdesign criteria, therefore:

(2,478) + 2,478 = 4,956 grams/carbon/room/year

WIPP Project personnel are designing for an additional 140 percent overdesign specification which yields a carbon bed capacity of approximately 12 Kg/room/year. This value (12 Kg/room/year) represents a 4.80 overdesign factor based on the calculated total requirement. The system design will be more than 95 percent efficient.

APPENDIX D12

VOC MONITORING PLAN FOR BIN-ROOM TESTS

VOC Monitoring Plan for Bin-Room Tests

Cognizant Department: ENVIRONMENT, SAFETY AND HEALTH

Approved By: Leslie L. Reed

VOC MONITORING PLAN FOR BIN-ROOM TESTS

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VOC MONITORING PLAN FOR BIN-ROOM TESTS

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Change History

None

01977

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List of Acronyms

BFB - 4-Bromofluorobenzene
CH - Contact Handled
CMS - Central Monitoring System
DOE - Department of Energy
EPA - Environmental Protection Agency
GC/MS - Gas Chromatograph/Mass Spectrometer
NIST - National Institute of Standards and Technology
NMEID - New Mexico Environmental Improvement Division
PLC - Programmable Logic Controller
ppbv - Parts Per Billion by Volume
ppmv - Parts Per Million by Volume
psig - Pounds Per Square Inch Gauge
QA - Quality Assurance
QAPjP - Quality Assurance Program Plan
QAPM - Quality Assurance Program Manual
QAPP - Quality Assurance Project Plan
QC - Quality Control
RCRA - Resource Conservation and Recovery Act
RH - Remote Handled
RSD - Relative Standard Deviation
SNL - Sandia National Laboratories
SOP - Standard Operating Procedure
SWB - Standard Waste Box
TRU - Transuranic
VOC - Volatile Organic Compound
VOST - Volatile Organic Sampling Train
WID - Waste Isolation Division
WIPP - Waste Isolation Pilot Plant
WP - WIPP Procedure

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1.0 INTRODUCTION

The DOE's plan for monitoring VOCs emitted from the WIPP during the test phase is described in this document.

The monitoring program is designed to demonstrate that there will be no migration of hazardous chemicals from the WIPP in concentrations exceeding health-based criteria. The monitoring plan includes an overview of the WIPP test program, a description of waste sources, the monitoring design, and justification of the design. The plan also includes a description of sampling and analysis procedures, QA objectives, and reporting activities.

1.1 BACKGROUND

The WIPP facility is constructed in a massive salt bed formation, with its design characterized as a "room and pillar" arrangement, allowing containerized solid or solidified waste to be placed in the excavations. Waste, equipment, and personnel enter the underground through designated shafts.

Initially, waste will be placed underground only for the purpose of conducting tests to determine more precisely the impacts of the waste on the long-term performance of the repository. During the test phase, the gas generation rate and changes in the gas composition in bins will be examined, as will simulation of the interactions between the waste and the surrounding salt. The results of these and other tests will determine what additional measures, if any, are needed to meet the long-term performance objectives of the facility. These objectives are derived from 40 CFR Parts 191 and 268 and are directed at permanently isolating the waste from the biosphere.

The WIPP No-Migration Variance Petition (DOE, 1990a) is intended to fulfill the requirements of 40 CFR 268.6, which allows the disposal of wastes prohibited from land disposal only if a demonstration can be made that, to a reasonable degree of certainty, there will be no migration of hazardous constituents from the disposal unit for as long as the wastes remain hazardous. To verify continued compliance with this requirement, a monitoring program must be implemented which is capable of detecting gaseous releases of hazardous constituents beyond the unit boundary at the earliest practicable time.

This monitoring plan describes the sampling and analysis program that will be implemented during the initial test phase and is aimed at quantifying VOC emissions in air that may potentially enter the exhaust shaft. Other media are not considered viable contaminant transport pathways during the test phase and will not be specifically monitored under this program.

This conclusion is based on the following factors. The low annual precipitation in the region and the lack of any significant surface water drainage features within the vicinity of the WIPP site preclude the need for surface water monitoring. Surrounding soils will not be impacted by releases, because all waste handling activities will occur within the Waste Handling Building and underground; further, air emissions will be filtered to remove particulates, which eliminates the potential for their deposition upon the soil. With regard to groundwater, the salt of the Salado Formation, in which the excavations are located, is highly impermeable, contains virtually no circulating fluids, and is itself situated between two confining formations. Thus, no mechanism exists for wastes to migrate via groundwater, and monitoring would be infeasible. It

should be noted, however, that the DOE has and will continue to conduct other environmental monitoring at and around the WIPP site.

This plan addresses the following information requirements, set forth by the EPA in both the final No-Migration Determination (EPA, 1990) and the associated notice of proposed decision:

a. Rationale for the design of the monitoring program, based on:

- Mobility and persistence of hazardous constituents managed at the unit
- Possible migration pathways from the unit, both during the active life of the facility and through the postclosure phase
- Operations at the unit
- Strength of engineered and natural material components of the unit and any weak points in the unit design
- Optimum location of the monitoring stations to detect any migration of hazardous constituents at the earliest practicable time

b. Descriptions of specific elements of the monitoring program, including:

- The type of monitoring conducted
- The location of the monitoring stations
- The monitoring interval
- The specific hazardous constituents monitored
- The implementation schedule for the monitoring program
- The equipment used at the monitoring stations
- Sampling and analytical techniques employed
- Data recording/reporting procedures

The results of the experiments conducted during the test phase will be used, in part, to refine the monitoring programs that will be established for the planned operational phase, during which full-scale waste emplacement activities will occur. Environmental monitoring currently anticipated during both the operational and postclosure phase is described in Volume 1 of the petition (DOE, 1990a).

1.2 TEST PROGRAM

The WIPP project was authorized by Congress to provide a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from national defense activities and programs. To meet this objective, the WIPP facility initially will serve as an experimental pilot plant, and tests will be performed during this phase to collect, interpret, and refine data necessary for the performance assessment required for radioactive waste disposal by the EPA in 40 CFR Part 191. The data will also be evaluated to determine if any additional measures are necessary to ensure that no migration of hazardous constituents will occur beyond the unit boundary. The test program is described in DOE/WIPP 89-011, Waste Isolation Pilot Plan Test Phase Plan: Performance Assessment.

During the test phase, all waste emplaced in the repository will be readily retrievable. If the results of evaluations indicate that the WIPP facility is

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not the appropriate location for the permanent isolation of these wastes, they can be retrieved with minimal risk. The DOE has submitted plans to the EPA that describe the requirements for retrieval of waste from the underground and the activities that will be undertaken during the test program (Section 8.0 of the Addendum to the petition provides a summary of the est program). The WIPP facility will enter full-scale operations upon successful completion of the test phase, the EPA and NMEID approval, and demonstration of compliance with 40 CFR 191 and other regulatory requirements.

Bin-scale tests will be performed underground. The bin-scale tests are designed to provide information concerning gas production, gas composition, and gas depletion rates from actual CH TRU wastes. Some of the CH TRU waste may be mixed with salt, backfill, brine, and backfill additives to simulate conditions to which the waste will be exposed within the repository during the operational phase and/or in the long term. The waste used will be representative of the general CH TRU waste inventory. All CH TRU waste can be divided into four groups based on gas-generation potential: newly generated high organic, retrievably stored ("old") high organic, low organic, and processed sludges. The low organic waste and processed sludges can be either newly generated or old waste.

The waste will be tested under a variety of conditions, including aerobic and anaerobic environments that simulate potential scenario conditions anticipated during the operational and postoperational phases. The interactions of the waste with various compositions of brines will be examined, as well as waste interactions with salt, backfill additives that absorb gases, and steel. Finally, experiments will be conducted to provide information about the production of gas by wastes in various modes (including saturation, compaction, bacterial actions, and degradation product contamination).

The WIPP bin-scale tests involve testing of repackaged CH TRU waste in specially designed, transportable sealed bins after a series of detailed characterization and examination steps. The bin is a metal box with sampling ports and instrumentation. Each bin accommodates the equivalent of four to six 55-gallon drums of CH TRU waste. Each bin will be prepared and filled at the generator facility with CH TRU waste mixed with backfill and/or salt. The test bin will fit within a TRUPACT-II SWB for transportation to the WIPP.

All test bins will have a carefully sealed internal environment that will be accessed by gas sampling ports, pressure gauges, and control systems, as well as temperature monitors. Some bins will also have ports for brine injection and sampling. Additional detail is provided in Molecke (1990) and Molecke and Lappin (1991).

At the conclusion of the test phase, the DOE will decide whether, based upon a performance assessment, the WIPP facility has complied with 40 CFR Part 191, Subpart B. If there is a determination of compliance, the DOE will initiate full-scale operations with EPA and EID approval. If there is a determination of noncompliance, a number of alternatives will be considered, including engineered modifications to the facility or the waste itself. Full-scale disposal operations will not commence until compliance with all regulatory requirements is demonstrated.

1.3 OBJECTIVES OF THE VOC MONITORING PLAN

VOCs could potentially be released from waste containers located in the WIPP underground during the test phase of the project. This plan describes how VOCs

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will be monitored to demonstrate that the concentrations of emissions at the WIPP unit boundary will not exceed health-based criteria. This plan is responsive to requirements of 40 CFR 268.6 and addresses waste management activities during the WIPP test phase only. Prior to the initiation of the WIPP operational phase, a second plan will be developed.

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2.0 WASTE DESCRIPTIONS

The wastes proposed to be emplaced in the WIPP are described in both Section 3.0 and Appendix B (Waste Analysis Plan) of DOE/WIPP 89-003, No-Migration Variance Petition; they are also described in Section 2.0 of the Addendum to the petition. Approximately 60 percent of the waste proposed to be emplaced in the WIPP during the entire lifetime of the facility is classified as mixed waste, which consists of waste that contains both radioactive and RCRA-regulated hazardous chemical components.

Generator knowledge of the wastes and the processes by which they are generated, in addition to available analytical data (Clements and Kudera, 1985), indicate that the VOCs most commonly present in the wastes are:

- 1,1,1-Trichloroethane
- Carbon tetrachloride
- 1,1,2-Trichloro-1,2,2-trifluoroethane
- Methylene chloride
- Trichloroethylene

2.1 SOURCES OF VOC EMISSIONS

During the test phase, VOCs potentially may be emitted from several sources, including test bins. Other activities not related to waste management may also lead to VOC emissions.

Bins. Test bins will be emplaced in the WIPP underground during the test phase in Rooms 1 and 2 of Panel 1 (Figure 2-1).

Each bin will be equipped with a one-way pressure-relief valve which will allow the escape of gases when bins become pressurized. Thus, each bin represents a potential source for the release of VOCs to the atmosphere in the WIPP underground.

Any emissions of gases from test bins will be controlled by a specially designed manifold ducting system which will direct emitted gases from the bins to the sampling system. Gases in the ducting system will be directed through a carbon sorption system designed to remove VOCs from the gas stream prior to discharge to the underground atmosphere. The manifold will discharge gases from a single point (for each room) into the panel accessway. The design characteristics of the bin-room ducting system and the carbon sorption system are given in Engineering Design Specification D-0077 (Westinghouse, 1991).

Other Sources. The bin manifold system will include a carbon sorption system designed to mitigate the release of VOCs from the manifold into the underground atmosphere. The sorption system will be periodically replaced; any used carbon sorption beds will be capped and emplaced in the derived waste storage area. In addition, the sampling and analyses of bins will generate some wastes, such as potentially contaminated equipment and protective clothing. These materials will be drummed and emplaced in the derived waste storage area.

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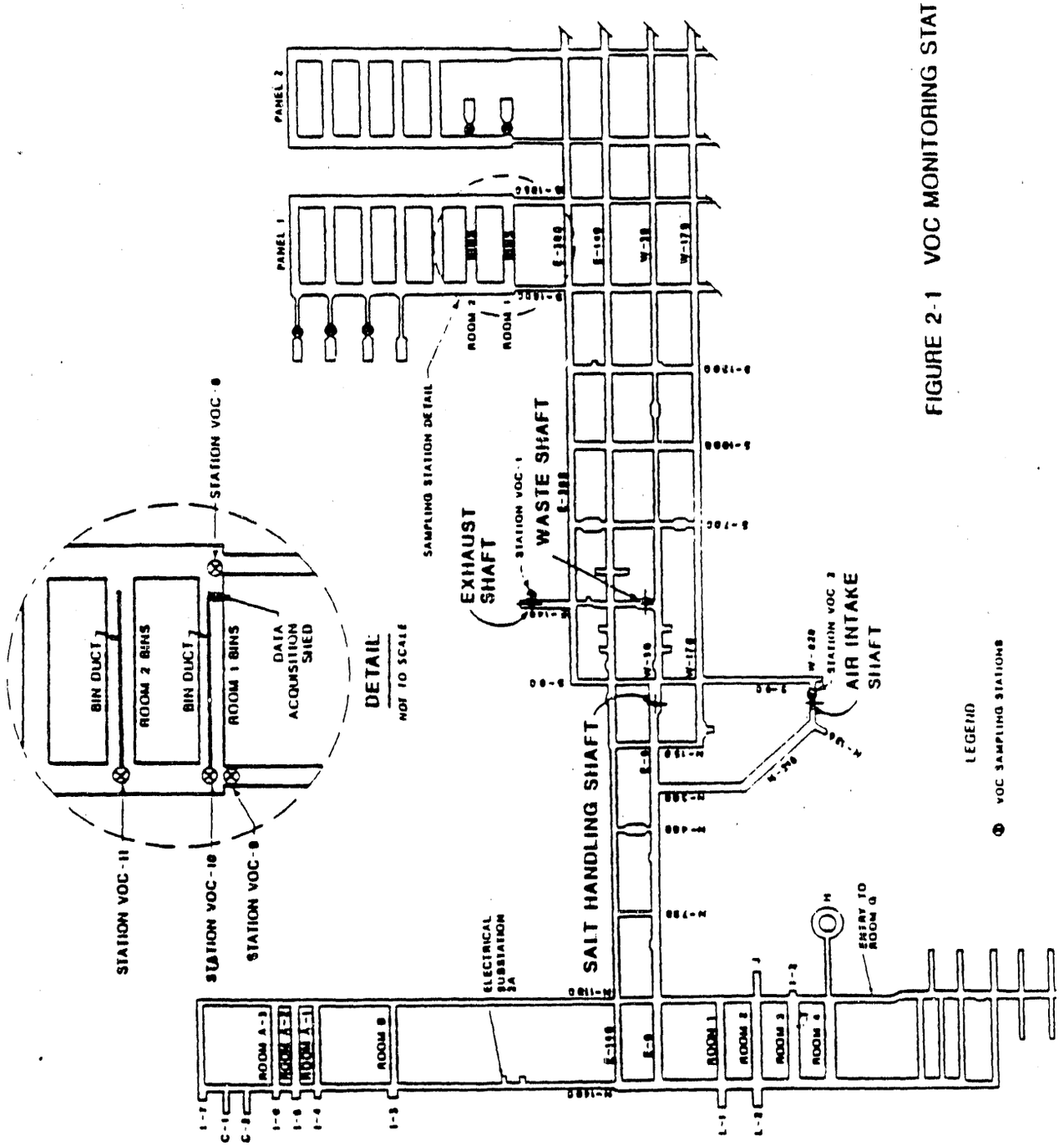

FIGURE 2-1. VOC Monitoring Station Locations

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Nonwaste-related sources of VOCs include background concentrations found in the ambient air drawn into the underground. Also, lubricants, solvents, paints, and other materials not related to wastes are used in the WIPP underground and may also donate VOCs to the repository atmosphere. An additional potential source is the exhaust emissions from the operation of diesel-powered equipment, such as forklifts and haul trucks, in the WIPP underground.

2.2 MIGRATION PATHWAY

The only pathway for migration of hazardous constituents to the unit boundary during the test phase is via airborne transport. Any volatiles released from waste sources in the underground would become entrained in the underground air ventilation flow. The underground ventilation air exits the underground through the exhaust shaft (Figure 2-1). The unit boundary of concern for this pathway is the uppermost extent of the Salado Formation in the exhaust shaft. For monitoring purposes, the top of the exhaust shaft will be considered the facility unit boundary.

3.0 MONITORING DESIGN

The detailed design features of the VOC monitoring program are presented in this section. The monitoring program uses commercially available sampling and analysis techniques to measure VOC concentrations. The bin-room monitoring system (VOC-10) uses a specially-designed sampling system. All other monitoring stations use standard VOC canister sampling equipment. The purposes of this program are:

- To demonstrate that there is no migration of specific VOC target compounds above any health-based criteria in the ventilation exhaust airstream
- To provide data for validation of the proposed monitoring method

3.1 SAMPLING LOCATIONS

VOC samples will be collected at multiple locations at the facility to measure concentrations at both the point of potential release in the underground and at the point of emission into the atmosphere. The most intensive sampling will occur near the bin-scale experimental areas. Sampling locations are shown in Figure 2-1. Additional detail for each location is presented below.

3.1.1 Bin-Scale VOC Sampling

The bin-scale tests will be performed in the Panel 1 rooms. The bins in each room will be vented to a common gas manifold system, equipped with both a HEPA filter and a carbon sorption system to remove radioactive particulates and VOCs from the gas discharge stream. A discussion of the sorption system is provided in Section 5.1. VOC samples will be taken at the downstream side of the gas discharge systems, downstream of the HEPA filters and the sorption system (Stations VOC-10 and VOC-11). Since two bin experimental rooms are proposed during the test program, samples will be collected from the gas discharge system in each room. A conceptual diagram of this sampling configuration is shown in Figure 3-1. A detailed schematic of the VOC monitoring system is shown in Figure 3-2. More detail on the bin-scale tests can be found in Molecke (1990).

3.1.2 Panel Intake and Outlet Sampling

One sampler (Station VOC-8) will be deployed in the Panel 1 ventilation air intake passageway, and an additional VOC sampler (Station VOC-9) will be deployed in the air outlet passageway. All airflow to Panel 1 will be in one direction only. The downstream station (Station VOC-9) will monitor VOC emissions potentially released from any leaks in the bin ducting systems, gases released from the manifold system in the test rooms, and concentrations of VOCs entering Panel 1. The difference in the VOC concentrations, Stations VOC-8 and 9, will represent the amount of VOC emitted from the Panel 1 area.

3.1.3 Unit Boundary and Background Sampling

Two additional sampling stations will be deployed. One sampler (Station VOC-1) will be deployed at existing "Station A," which has been established near the top of the exhaust shaft as part of the radioactive particulate monitoring programming place at the facility. This VOC sampler will be integrated into the existing sampling system to measure detectable levels of the VOC target compounds

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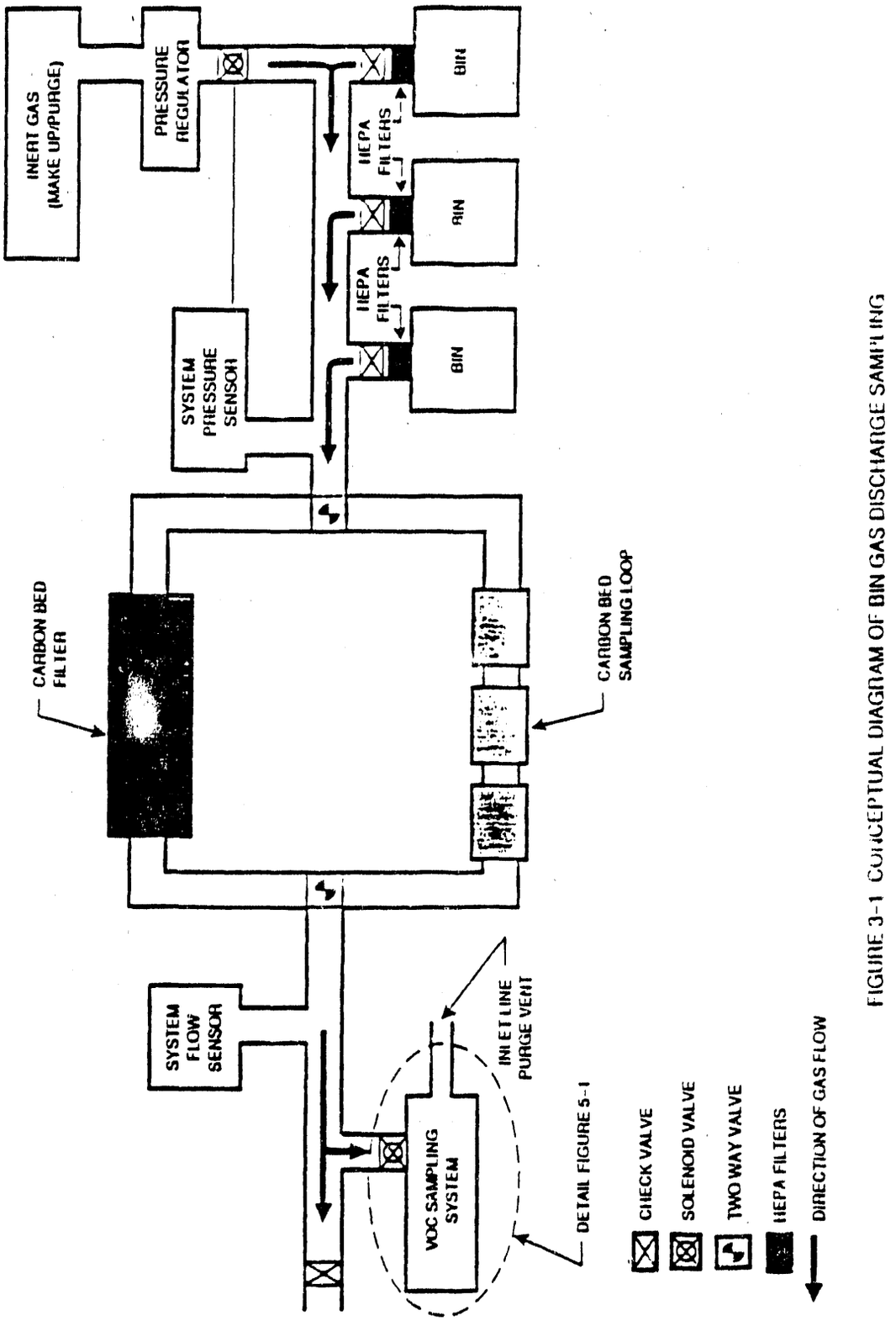

FIGURE 3-1 CONCEPTUAL DIAGRAM OF BIN GAS DISCHARGE SAMPLING

FIGURE 3-1. Conceptual Diagram of Bin Gas Discharge Sampling

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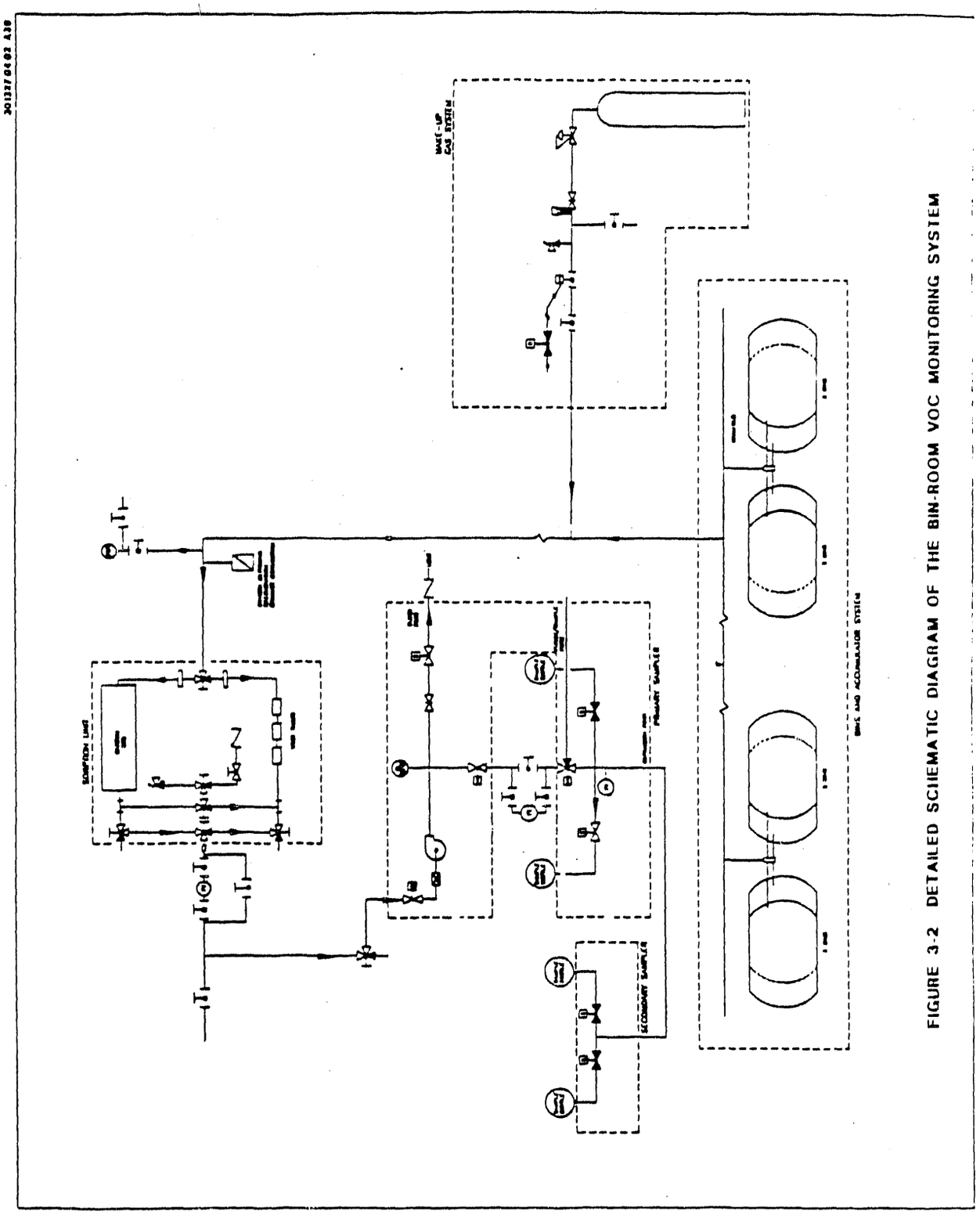

FIGURE 3-2. Detailed Schematic Diagram of the Bin-Room VOC Monitoring System

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in the exhaust airstream. The location of this station is shown in Figure 2-1. For the purposes of this monitoring program, this station represents the unit boundary, since it is not possible to monitor at the top of the Salado Formation in the exhaust shaft.

Another VOC sampling system (Station VOC-2) will be deployed at the air intake shaft as depicted in Figure 2-1. The purpose of this system will be to measure detectable quantities of the target compounds in the ambient air drawn into the underground facility.

3.2 ANALYTES TO BE MONITORED

Concentrations of five target VOC compounds will be routinely quantified. They are: carbon tetrachloride; methylene chloride; trichloroethylene; 1,1,1-trichloroethane; and 1,1,2-trichloro-1,2,2-trifluoroethane. Other compounds may also be present in the wastes; the analytical method selected will allow semi-quantitative evaluation of these compounds. If other compounds are detected on a regular basis at concentrations greater than one ppm, they will be added to the list of target compounds for routine quantitation.

3.3 SAMPLING METHOD AND SCHEDULE

The method selected for sampling and analysis is EPA Compendium Method TO-14 (EPA, 1988a) using 6-liter canisters. SUMMA® passivated stainless-steel canisters will be used to collect an integrated sample at all locations except where grab samples will be obtained. Generally, the samplers will be operated in the pressurized mode. In this mode, air is pumped into an initially evacuated canister by the sampler, which regulates the rate and duration of the sampling. At the end of each sampling period, the canisters will be pressurized to about two atmospheres.

VOC sampling will commence approximately 30 days prior to the beginning of the bin-scale tests at station VOC-1 in the exhaust shaft. Samples will be collected on a frequency at each location as shown in Table 3-1. Not all samplers will be operated on the same schedule, nor will sampling begin at each location at the same time. Initial samples will be taken at the Panel 1 air intake (Station VOC-8), Panel 1 air outlet (Station VOC-9), the exhaust shaft (Station VOC-1), and the air intake shaft (Station VOC-2) prior to the receipt of waste. Sampling at the bin gas discharge systems (Station VOC-10 and Station VOC-11) will begin prior to emplacement of bins within a room.

3.3.1 Provisions for Sampling Frequency Reduction

When data from sampling events at a particular sampling location indicate little variation over a designated time period, sampling frequency will be reduced. These reductions will follow the strategy outlined below and in Table 3-2.

Daily sampling for all stations with the exception of the air intake shaft and the exhaust shaft must be performed for a minimum of 30 days after initiation of a test phase system. If the RSD for any targeted compound is greater than 25 percent, or if the RSD for any compound identified (quantified) in a GC/MS library search is greater than 35 percent, then no reduction in sampling frequency will occur for the next 15 days. After 15 days, the 30-day test will be

Table 3-1

Sampling Schedule

Sampling Location	Station Number	Sampling Frequency[1]	Sampling Duration/Type
Bin Gas Discharge Systems	VOC-10, VOC-11	Daily	24-hr/Integrated
Panel 1 Air Intake	VOC-8	Daily	24-hr/Integrated
Panel 1 Air Outlet	VOC-9	Daily	24-hr/Integrated
Exhaust Shaft	VOC-1	Weekly	24-hr/Integrated
Air Intake Shaft	VOC-2	Weekly	24-hr/Integrated

[1]Frequencies subject to change based on monitoring results.

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performed again, starting 15 days later than the previous evaluation. The pass/fail criteria (RSD of 25 percent and 35 percent, as above) will be applied again. If the data fail the criteria, the system will continue to be evaluated using the same algorithm. If the data pass the criteria, the sampling frequency will be reduced to one sample per week. At no time will the sampling frequency be reduced to less than one sample per week for any sampling station. Also, in no event shall the monitoring frequency be reduced to less than 20 percent of the minimum time required for the consumption of the total working capacity of the carbon sorption system (see Section 5.1).

Sampling frequencies may be increased as well. Increases in frequency require approval of the VOC project management staff only. These increases will follow the strategy outlined below and in Table 3-2. Increases in sampling frequency will be motivated by large excursions from previous data values. These excursions can be in the form of transient excursions or be indicative of trends. In either case, the requirement will be an RSD of greater than 75 percent for the targeted compounds or greater than 100 percent for the compounds identified and quantified during GC/MS library searching functions. If the data evaluated over each contiguous four-month period fail the criteria (greater than 75 percent and greater than 100 percent, as listed above), then the sampling frequency may be increased to once per day.

Sampling frequency may also be increased if the conditions in Panel 1 change, such as the addition of new bins to the test rooms.

3.4 SAMPLE ANALYSES

The analysis system that will be used with the canister samples is GC/MS operating in the SCAN mode. Initially, detailed analysis and definitive quantitation will be obtained for the five target VOC compounds: carbon tetrachloride; methylene chloride; trichloroethylene; 1,1,1-trichloroethane; and 1,1,2-trichloro-1,2.2-trifluoroethane. As part of the routine GC/MS/SCAN analyses for all canister samples, semi-quantitative results will be reported for all identifiable VOC compounds. Additional compounds will be added to the target list if they are detected at average concentrations greater than one ppm over any four-month period.

3.5 MIGRATION CALCULATION AT THE UNIT BOUNDARY

The results of the GC/MS/SCAN analyses will be combined with exhaust ventilation flowrate data, and the gas flow rates in the bin gas discharge systems to calculate the equivalent concentrations of the target compounds passing the facility unit boundary. As described in Section 3.3.2.3.6 of WP 02-9, WIPP Final Safety Analysis Report, the CMS at the facility is designed to continuously monitor the underground exhaust airflow rate.

The equation for these calculations is the same for all compounds. For a given set of analytical results, the calculated concentration of compound "i" at the unit boundary is:

$$X_{ui} = \left(\sum_{b=1}^{N} X_{bi} \cdot Q_b \right) + Q_E$$

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Table 3-2

Criteria for Determining Sampling Frequency Changes

Criteria		Action	Frequency of Verification
Target Compounds	Library Search Compounds		
RSD > 75%	RSD > 100%	Increase sampling frequency one level, where possible	Verify daily if sampling is daily; verify weekly if sampling is weekly.
75% > RSD > 25%	100% > RSD > 35%	No reduction or increase in sampling frequency	Verification by increase and decrease checks.
RSD < 25%	RSD < 35%	Reduce sampling frequency one level, where possible	Verify every 15 days if sampling is daily; verify every six weeks if sampling is weekly.

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where:

X_{ui} = Calculated concentration at the unit boundary for VOC i ($\mu g/m^3$)

X_{bi} = Measured concentration from bin gas discharge system b for VOC i ($\mu g/m^3$)

Q_b = Measured gas flow rate from the bin discharge system b (m^3/min.)

Q_E = Measured ventilation exhaust flow rate (m^3/min.)

This equation will be used to calculate the results for each daily sample collected from the bin gas discharge systems. The determination of migration at the unit boundary and the EPA reporting requirements are discussed in detail in Section 9.4.4 of WP 12-7, VOC Monitoring Quality Assurance Program Plan.

4.0 MONITORING DESIGN JUSTIFICATION

The previous sections present a plan for conducting air monitoring to quantify VOC concentrations related to the bin-scale test activities at WIPP. This section presents the rationale and justification for the selected design.

4.1 SAMPLING LOCATIONS

The proposed sampling locations were selected based on a number of operational and analytical considerations. Operationally, there are a number of different potential sources of release for VOCs: bins, support operations, and the intake air into the underground facility. In addition, due to the ventilation requirements of the underground facility, any VOCs that are released from the waste bins may be difficult to detect with current commercially available analytical techniques. The primary analytical consideration for this plan is the detection limit achievable with current technology as discussed below.

4.1.1 Detection Limits

According to data provided by the EPA, the current health-based standard for carbon tetrachloride, one of the five target compounds, is 0.03 $\mu g/m^3$ (to one significant figure). Values for the other compounds are: methylene chloride, 0.3 $\mu g/m^3$, and trichloroethylene, 0.3 $\mu g/m^3$. The EPA has not specified similar low values for the other target compounds (1,1,1-trichloroethane (10,000 $\mu g/m^3$) and 1,1,2-trichloro-1,2,2-trifluoroethane (30,000 $\mu g/m^3$). At present there are no commercially available sampling and analysis methods that allow for quantitation of multiple VOC compounds at such low levels. Since the health-based standards apply at the unit boundary, it would be desirable to measure the concentrations of these compounds at this point. However, it is unlikely that detectable quantities of the target compounds contributed by the waste and above background can be quantified at this sampling point.

4.1.2 Panel 1 Air Outlet (Station VOC-9)

Initially, all of the waste will be stored underground in Panel 1. Air leakage from bin rooms 1 and 2 and the exhaust from the bin gas discharge systems will all exit into the exhaust drift. A sampling station has been established in the exhaust drift from Panel 1 to determine if detectable quantities of VOCs above background can be found at this point and to verify measurements made further upstream. Initially, this sampler will be operated on a daily basis.

4.1.3 Bin Gas Discharge Systems (Stations VOC-10 and VOC-11)

Because it is anticipated that concentrations of VOCs above background will not be detected in the Panel 1 air outlet, samples will be collected at the next upstream point of potential release, the bin gas discharge systems. The bin gas discharge systems are equipped with carbon sorption systems designed to mitigate any releases from the experimental bins. Initially, samples will be collected daily from each system, starting prior to the day that any bins are connected to the systems. The purpose of the sampling at this point is to demonstrate that no migration of VOCs occurs, not to characterize and quantify VOC releases from the bins. The bin-scale test plan (Molecke, 1990) is designed to do this.

The bin gas discharge system is the point of maximum potential concentration for gas released from the bins (after sorption) and represents the point with the

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greatest likelihood of detecting the target compounds if they are present in the discharges from the bin ducting system. Because two bin experimental rooms are proposed during the test program, samples will be collected from the gas discharge system prior to waste emplacement in each room. If either of the discharge systems were to leak, any potential discharges would be detected by the sampler directly downstream in the Panel 1 air outlet drift (Station VOC-9).

4.1.4 Exhaust Shaft (Station VOC-1)

The EPA has directed that sampling be performed at the facility unit boundary to confirm sampling performed in the underground. From a practical standpoint, it would be difficult to take air samples in the exhaust shaft 850 feet below ground level, at the unit boundary. Consequently, samples will be taken at the top of the exhaust shaft (Station VOC-1). All ventilation air is exhausted at this point, and VOC concentrations in the exhaust air at the surface are expected to be the same as those at the unit boundary (850 feet down this shaft). Weekly samples will be taken at Station VOC-1.

4.1.5 Background Interferences

Sources of the target VOC compounds may not be restricted to the wastes emplaced at WIPP. For example, 1,1,1-trichloroethane is a constituent of some cleaners/lubricants. Also, methylene chloride is found in some paint strippers. Various other sources of VOCs exist in any facility. Consequently, measurements of target VOC compounds in the ventilation air may include a contribution from sources other than the emplaced wastes. These sources may be located either within the facility (above or below ground) or beyond the facility boundaries.

4.1.6 Air Intake Shaft (Station VOC-2)

The WIPP is located in the general vicinity of potash mining and processing facilities and oil and gas wells. Ambient air may contain some or all of the target compounds or other interfering compounds. In addition, the air intake shaft is located immediately adjacent to a parking lot. Automobile emissions include a variety of VOCs.

As part of this monitoring program, it will be important to determine any contribution of VOCs to the samples within the ventilation airstream from aboveground sources. To this end, a sampler will be established in the vicinity of the air intake shaft (Station VOC-2) to quantify detectable levels of VOCs in the intake air. Weekly samples will be taken at this location for a period of time (up to a year). If no detectable quantities of target VOCs are found, sampling at the site may be eliminated.

4.1.7 Panel 1 Air Intake (Station VOC-8)

To quantify detectable levels of VOCs entering Panel 1, another sampler will be established in the air intake drift to Panel 1. This sampler also will be operated on a daily basis. Results from this monitoring station will allow detectable background quantities of target VOCs in the ventilation air entering panel to be distinguished from any target VOCs emanating from the emplaced waste.

4.2 ANALYTES TO BE MONITORED

Based on process knowledge and previous analytical data (Clements and Kudera, 1985), the VOCs that are expected to occur in the waste most commonly are:

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carbon tetrachloride; methylene chloride; trichloroethylene; 1,1,1-trichloroethane; and 1,1,2-trichloro-1,2,2-trifluoethane. Concentrations of these compounds in all of the samples collected will be quantified. Other compounds may also be present in the wastes. These may be identified as part of the bin and experiments. As part of the analytical evaluations, the presence of other compounds will be investigated. The laboratory performing GC/MS/SCAN analyses for this program have implemented SOPs that will provide positive identification of the following compounds if detected during the forward spectral library search as discussed in Section 4.4: perchloroethylene, chloroform, bromoform, dichloroethane, dichloroethylene, toluene, and chlorobenzene.

4.3 SAMPLING METHOD AND SCHEDULES

4.3.1 Sampling Method

Given the need to be able to accurately identify and quantify not only the five target compounds but also other VOCs in the bin rooms, ambient air, and ventilation air, a flexible sampling method is required that is not specific to particular compounds. Another consideration is the desire to use commercially available EPA-approved or recommended methods that are presently in use.

The two methods evaluated were the use of solid adsorbents (e.g., charcoal, Tenax) and canister sampling. Canister sampling provides several advantages over the solid adsorbents: ability to collect all VOCs nonpreferentially; grab-sampling capability; convenient integration of samples over a specific time period (e.g., 24 hours) at adequate flow rates; elimination of the concern of compound breakthrough (eliminating the need for multiple samples); and ease of sample storage and shipping. In addition, this method permits collection of sufficient sample volume to assess measurement precision and to permit analysis of samples by several analytical systems, as required. The method also facilitates multiple dilutions and analyses to define the relative order of magnitude of the concentrations in a gas sample.

EPA Compendium Method TO-14 sampling technique uses 6-liter passivated stainless steel canisters to collect integrated or grab samples. This method will be used to collect all samples. The samples will be analyzed using a GC/MS/SCAN.

The field sampling systems will be operated in the pressurized mode. In this mode, air is drawn through the sampling system with a pump. The air is pumped into an evacuated SUMMA® passivated canister by the sampler, which regulates the rate and duration of sampling.

The passivation process forms a pure chrome-nickel oxide on the interior surfaces of the canisters. This type of container has been used many times in the past and has demonstrated sample storage stability for the target compounds selected for this monitoring program (EPA, 1988a).

During the analysis, the VOCs in the air sample are separated by gas chromatography and measured by mass spectroscopy. It will require some experimentation to define the analytical conditions appropriate for quantitation, since the range of measured concentrations may be very broad. This sampling system lends itself well to this type of process, since a large sample is collected. The limits of detection for the method are less than one ppbv, so extremely low concentrations can be defined. On the other hand, the sample can be diluted many times if high concentrations are encountered.

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Method TO-14 is an EPA-recognized sampling procedure for VOC sampling and speciation. The method can provide 24-hour integrated sampling (or grab samples) and detection limits appropriate for a broad range of concentrations. Laboratory analyses can be expanded to include other compounds if analytical results indicate a need to quantify additional compounds. The sampling system can be operated unattended but requires detailed operator training.

4.3.2 Schedules

Initiation of the monitoring program will occur approximately 30 days prior to receipt of the first waste at WIPP. This will allow a "shakedown" of the entire system and an opportunity to characterize background concentrations. Samplers will be deployed as discussed below.

4.3.3 Exhaust Shaft (Station VOC-1) and Air Intake Shaft (Station VOC-2)

The samplers at the exhaust shaft (Station VOC-1) and the air intake shaft (Station VOC-2) will be installed and operational at the beginning of the program. Samples will be collected on a weekly basis to verify the results of the underground monitoring and to quantify aboveground concentrations of contaminants.

4.3.4 Panel 1 Intake and Outlet (Stations VOC-8 and VOC-9)

The sampler at the Panel 1 intake (Station VOC-8) and outlet (Station VOC-9) will be installed and operational at the beginning of the program. Daily samples collected at these locations will allow any unforeseen problems associated with monitoring in the salt-laden underground environment to be identified and addressed. Data from these two stations will also allow quantification of existing VOC background levels.

4.3.5 Bin Gas Discharge Systems (Stations VOC-10 and VOC-11)

Sampling of bin emissions from any of the gas discharge systems will begin after emplacement of bins within one of the rooms. The waste generation sites will perform an analyses of the waste prior to shipment to WIPP. The WID will not perform analyses until waste shipments are in the underground. At that time stations VOC-10 and 11 will be activated.

4.4 SAMPLE ANALYSES

The analytical strategy for Method TO-14 involves using a GC coupled to a GC detector. The proposed analysis system for the canister sampling involves the use of a specific detector system, GC/MS/SCAN. Since the five target compounds have been specified, the sensitivity of the analysis system can approach that of the multidetector GC, while providing positive compound identification. This system can also resolve coeluting peaks.

For this study, each sample will be analyzed with GC/MS/SCAN to quantify the five target compounds. In addition, the SCAN option coupled with a spectral library search will allow other significant peaks to be evaluated in a semi-quantitative manner. Any significant peaks will be evaluated further and can be included as part of the routine quantification, if necessary. For the purpose of this evaluation, significant peaks will be defined as chromatographic peaks of compounds identified in samples during library search routines at a frequency of at least ten percent of the samples collected. The samples must also have an

average concentration greater than one ppmv during any four-month period, and not be primary or secondary alcohols.

A commercial laboratory has been selected for the analytical effort, and detailed analytical SOPs and QAPjPs have been prepared. As the sampling and analysis systems and SOPs were developed, the recommendations and requirements in Method TO-14 were followed.

In addition, detailed canister and sampling system cleaning and certification SOPs and QAPPs were prepared. These procedures will be consistent with the recommendations and requirements detailed in Method TO-14.

4.5 Unit Boundary Concentration Calculations

As discussed in Section 3.5, VOC concentrations in the exhaust shaft will be calculated based on VOC measurements from the bin room gas discharge systems. There are no commercially available sampling and analysis methods for measuring all of the target VOCs in the facility exhaust airstream at the levels required to confirm compliance with the health-based criteria suggested by EPA. Since monitoring in the exhaust shaft cannot be used for the compliance determination, it is more appropriate to sample at the points of potential VOC release (the bin-manifold systems). The analytical results can then be combined with measured flow rates and mine ventilation rates to calculate equivalent concentrations at the unit boundary. An equation for this calculation is presented in Section 3.5. Example calculation for three of the compounds for which EPA has provided health-based concentration values, carbon tetrachloride (0.03 $\mu g/m^3$), methylene chloride (0.3 $\mu g/m^3$), and trichloroethylene (0.3 $\mu g/m^3$)--are presented below to demonstrate the application of this method.

For the purposes of these calculations, it is assumed that there is no carbon sorption control device installed and that there are two bin rooms containing waste. Further, it is assumed that an approximately equivalent mass of VOCs is released from each location. The concentration values shown below are simply assumed values and may not actually be measured as part of the experiment. Lower concentrations are expected. Inputs to the example equation are as follows:

- Bin gas discharge flow volume: 670 liters/bin/year = .140 m^3/day.

  670 liters/bin/year x 76 bins ÷ 365 days/year = 139.5 liters/day = .140 m^3/day

  The actual volume will be measured and recorded using a calibrated mass-flow meter and strip chart recorder.

- Assumed concentration of VOCs in the bin gas discharge system for <u>each</u> bin room (two total):

  Carbon tetrachloride: 1,850,000 $\mu g/m^3$
  Methylene chloride: 470,000 $\mu g/m^3$
  Trichloroethylene: 699,000 $\mu g/m^3$

  Assumed concentrations are for the purpose of example calculation only and are taken from Table 5-1.

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- Mine ventilation rate: 425,000 ft^3/min. = 17,332,000 m^3/day. The actual ventilation rate is monitored and will be obtained for each sample day.

The resulting concentrations are:

Exhaust shaft concentration of carbon tetrachloride ($\mu g/m^3$) =

[(1,850,000 $\mu g/m^3$ x .140 m^3) x 2] ÷ 17,332,000 m^3 = 0.0299 $\mu g/m^3$

Exhaust shaft concentration of methylene chloride ($\mu g/m^3$) =
[(470,000 $\mu g/m^3$ x .140 m^3) x 2] ÷ 17,332,000 m^3 = 0.0076 $\mu g/m^3$.

The concentration calculation for trichloroethylene is identical to that for methylene chloride.

This example demonstrates that source concentrations well above analytical detection limits would result in concentrations in the exhaust shaft less than the health-based criteria provided by the EPA.

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5.0 SAMPLING AND ANALYSIS PROCEDURES

5.1 SAMPLING EQUIPMENT

The sampling equipment that will be used during the study includes: 6-liter stainless steel canisters, VOC canister samplers, and modified VOST tubes. A discussion of each of these items is presented below. The justification for the design of the carbon sorption bed is also presented.

5.1.1 SUMMA® Canisters

Six-liter, stainless steel canisters with SUMMA® passivated interior surfaces will be used to collect and store all ambient air and gas samples for VOC analyses collected as part of the monitoring processes. These canisters must undergo rigorous cleaning and certification procedures, both prior to their use as required by Compendium Method TO-14. A SOP describing this process in detail has been prepared by the analytical laboratory. Compendium Method TO-14 was used as a guidance document in the preparation of this SOP.

5.1.2 VOC Canister Samplers

A conceptual diagram of a VOC sample collection unit is provided in Figure 5-1.

Initially, 13 VOC sampling systems have been purchased, with the provision for additional systems if required. Two systems will be dedicated to bin testing (Stations VOC-10 and VOC-11), one for monitoring at the Panel 1 intake (Station VOC-8), one for the Panel 1 exhaust (Station VOC-9), one at the exhaust shaft (Station VOC-1), one at the air intake shaft (Station VOC-2), and the last seven will be utilized as back-up systems. Each sampling system includes a gas sample collection unit and sufficient collection canisters so that any delays due to laboratory turnaround time and canister cleaning and certification will not result in canister shortages.

The system consists of a sample pump, flow-controlled sample inlet line, mass flow sensor, vacuum/pressure gauge, electronic timer, inlet purge vent, and two sampling ports. Knowledge of sampler flow rates and duration of sampling will allow calculation of sample volume. The set point flow rate will be verified on a daily basis by monitoring the mass flow sensor. Prior to use and at periodic intervals, the sample collection units including inlet line will be tested and certified to demonstrate that they are free of contamination. Verification of cleanliness will be initiated prior to their use. UHP humidified zero air will be pumped through the sampling unit and collected in previously certified canisters. Prior to the initiation of sampling, an SOP describing in detail the cleaning and certification (certification will include pressure testing and target compound recovery evaluation) procedure for samplers will be prepared.

5.1.3 Carbon Sorption Media

The current design of the VOC air monitoring system for the bin rooms includes a carbon sorption system to ensure no migration of hazardous constituents beyond the unit boundary above health-based limits.

A sampling system for the carbon bed sorption unit utilized in the bin-scale monitoring systems has been installed (see Figure 3-2). The purpose of the

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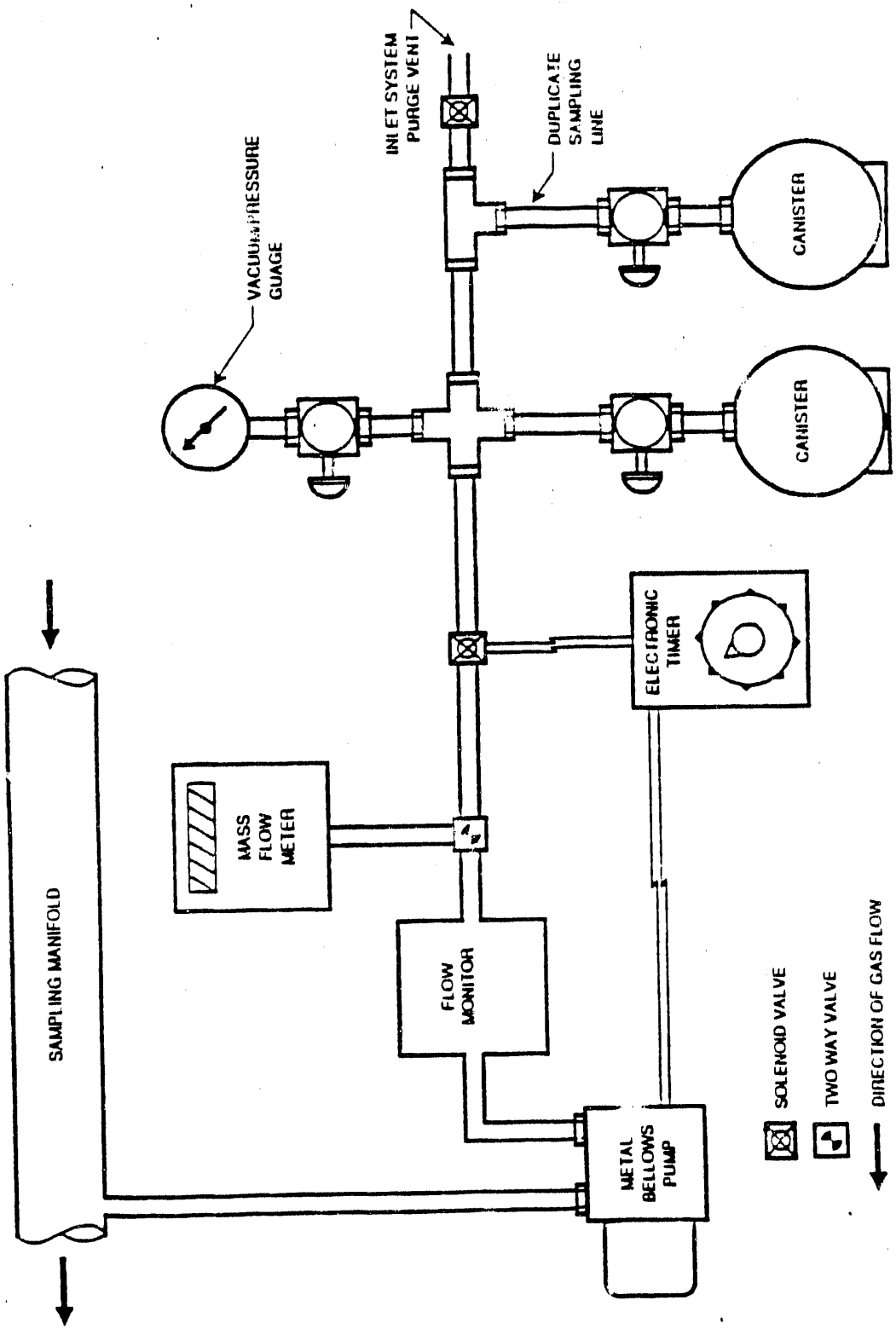

FIGURE 5-1 CONCEPTUAL DIAGRAM OF VOC SAMPLING SYSTEM CONFIGURATION

FIGURE 5-1. Conceptual Diagram of VOC Sampling System Configuration

carbon sorption sampling system is to allow experimental determination of the carbon bed efficiency and lifetime as related to the waste being tested. Gases emitted from bins generally will be directed through the manifold to the main carbon sorption system during routine canister sampling. The conceptual design of the carbon sorption system is provided in Figures 3-1 and 3-2.

The capacity of the main carbon sorption unit has been determined through calculation of the total mass of target VOCs expected to be emitted annually from the experimental bins during the test phase at WIPP. The validity of this calculation is to be confirmed by use of the carbon bed sampling loop (modified VOST tubes) included in the system design.

The sampling loop will include three modified VOST tubes. These tubes will be used and analyzed in a manner based on a modification of the EPA Test Method 0030, as described in SW-846. The VOST tubes will be loosely packed (26 lbs/ft^3) with approximately eight grams of 6x16 mesh calgon type BPL granular carbon or equivalent, the identical carbon to be packed in the main sorption unit. The sorption system has been configured so that flow may be directed through the main carbon unit or through the sampling loop. During operation of the system, flow will be directed through the sampling loop for a specified test period. The duration of the test period will be specified based on the quantity of carbon in the tube and the quantity of gas anticipated to flow through the loop during the test. At the end of the test, flow will be redirected through the main unit. The three VOST tubes will then be removed from the system and sent to the laboratory for analyses of the quantity of VOCs sorbed onto the carbon within each tube.

The analytical data from VOST tube sampling experiments, coupled with the system mass flow data during the test period, will provide a basis for estimating the lifetime of the carbon in the main sorption unit. Once the analytical data are received and evaluated, this test will be repeated, probably at a modified test duration. This iterative process will continue until the lifetime of the main unit can be predicted.

The calculated life of each carbon-filled VOST tube is approximately 12.8 hours at the anticipated full gas discharge rate (139.5 liters/day). Three VOST tubes in series would give an estimated time of 38.4 hours before breakthrough. This anticipated tube life will be used to design the initial sampling experimental program. The sampling system is constructed in a parallel flow path to the main carbon unit (Figure 3-1). Valving will allow manual switching from the main sample flow path to the sampling loop without interruption to the overall system operation.

5.1.4 Carbon Sorption Bed Design Specifications

The maximum quantities of VOCs measured in the headspace of waste drums and potentially released from the bins was used to design the capacity of the carbon sorption system. The concentrations of the five target compounds measured in headspace of the drums (Clements and Kudera, 1985) are summarized in Table 5-1. These data represent the only headspace gas composition data available.

The present design of the bin-scale tests calls for 76 bins in a room. Eight of these bins will be empty and used as controls for the gas generation experiments (Molecke, 1990). The carbon sorption system for each room, which was based on an earlier test plan, was designed to contain any releases of VOCs from 116 bins.

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Table 5-1

Average Concentration of Selected Hydrocarbons in the Headspace of TRU Waste Drums

Hydrocarbon	Average Concentration (grams per liter)
Carbon tetrachloride	1.85×10^{-3}
Methylene chloride	0.47×10^{-3}
Trichloroethylene	6.99×10^{-4}
1,1,1-Trichloroethane	13.2×10^{-3}
1,1,2-Trichloro-1,2,2-trifluoroethane	1.22×10^{-3}

Source: Clements and Kudera, 1985

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A gas generation rate of five moles per drum per year was used to estimate the maximum potential release. Based on experimental data and the fact that the processes that may generate gas (i.e., radiolysis, microbial degradation, and corrosion) will compete for available water and oxygen; this rate is considered a credible maximum rate. The majority of the gas will consist of hydrogen, methane, carbon dioxide, and nitrogen.

Assuming this rate of gas generation, a total of 670 liters of gas per bin per year potentially may be released. To estimate a quantity of VOCs that may be present within this 670 liters of gas, it is assumed that the average concentrations of VOCs found in drums from the Rocky Flats Plant (Clements and Kudera, 1985) are continuously present.

It should be noted that the rate of volatilization of VOCs and the concentrations of VOCs present in the headspace of bins over time cannot be estimated from the rate of generation of hydrogen or other gases. During the bin-scale tests, headspace gas samples will be collected to determine the concentrations of VOCs that are present in the bins over time (Molecke, 1990).

The total grams of each of the five target VOCs in the headspace of the bins (Table 5-2) were calculated using the following equation:

$$\text{Average headspace Gas concentration}^{(g/l)} \times \frac{116 \text{ bins}}{\text{room}} \times \frac{670 \text{ liters}}{\text{bin-year}} = \frac{\text{g VOC}}{\text{room-year}}$$

The volumetric air flow through the underground facility is 12,035 m^3/min. (425,000 ft^3/min.) or 1.73 x 10^7 m^3/day. The estimated maximum concentration of VOCs at the unit boundary assuming a complete failure of the carbon sorption system is provided in Table 5-3.

The total activated carbon requirements were calculated from the partial pressures of each of the five target VOCs, monitoring system air flow velocity, VOC loading, and the carbon efficiencies from Calgon-BPL isotherms. Based on this evaluation, the calculated activated carbon requirement to achieve a VOC sorption efficiency of greater than 95 percent was 24.98 grams of carbon per bin per year. The following calculation was used to define the total carbon requirements for each room per year:

(24.98 g carbon/bin/yr) (116 bin/room) = 2898 g carbon/room yr for 100 percent over design criteria (calgon recommendation)

(2898 g) (1.0) + 2898 g = 5796 g carbon/room/yr.

The specific design for the carbon sorption system uses 12 kg of carbon/room/yr for an additional factor of two conservatism in the design. The design using 12 kg of carbon/room/yr represents an overdesign of 400 percent for an experimental design having 116 test bins.

The following information on the activated carbon was used to determine the volume of the carbon sorption unit:

- 26 lbs/ft^3
- 6 x 16 mesh
- Calgon type BPL

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Table 5-2

Total Quantity of Volatile Organic Compounds Available for Release from the Bin-Scale Experiments

Chemical	Total Quantity (grams/room/year)
Carbon tetrachloride	144
1,1,1-Trichloroethane	1,026
Methylene chloride	37
1,1,2-Trichloro-1,2,2-trifluoroethane	95
Trichloroethylene	54
Total	1356

Table 5-3

Maximum Daily Concentration of Volatile Organic Compounds at the Unit Boundary Assuming No Carbon Sorption System

Chemical	Concentration ($\mu g/m^3$)
Carbon tetrachloride	0.023
1,1,1-Trichloroethane	0.162
Methylene chloride	0.006
1,1,2-Trichloro-1,2,2-trifluoroethane	0.015
Trichloroethylene	0.009

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26 lb/ft^3 ---- > 416.48 kg/m^3

$\frac{(12 \text{ kg carbon})}{(416.48 \text{ kg/m}^3)}$ = 0.0288 m^3 = 28,813.00 cm^3 = 28.81 liters (size of sorption unit)

All spent carbon material from the VOC sorption system will either be stored underground or be regenerated or reactivated by a process that minimizes the release of organics to the atmosphere or is disposed of in full compliance with federal and state regulations. If the carbon is regenerated or reactivated, a signed certification demonstrating compliance with these requirements will be maintained in the facility operating record and will be available for review by EPA.

5.2 SAMPLE COLLECTION PROCEDURES

Sample collection procedures are described in the following sections.

5.2.1 Bin Manifold Sampling

Gas will be directed from the bins through stainless steel riser tubing connected to a common manifold. The manifold system is a pressure-balanced system, maintained at atmospheric pressure, consisting of a positive pressure inert gas supply and a canister sampler. An air-actuated ball valve is controlled by a PLC, which will open the valve to allow the inert gas to fill the manifold in the event of an underpressurized system. The effluent line is fitted with a sampler controlled by the PLC that operates and samples in the event of an overpressurized system. In this way, bin room pressure and manifold pressure can be maintained at approximately the same level, and no large pressure gradient will exist across the system (Figure 3-2). As an added precaution, prior to the installation of the bins, the system has undergone a static pressure test at 20 psig.

After pressure testing is successfully completed and prior to the installation of the bins, a 24-hour composite sample will be collected to determine background levels in the manifold system. This sample will be collected down-flow from the carbon bed filtration unit.

The VOC canister sampler will sample the manifold gas on a schedule programmed into a PLC. The PLC will direct the sample pump to turn on at a frequency of once every 30 minutes and run for one minute. The unit will sample at a flow rate of 250 milliliters per minute for the 24-hour sample period. This will yield a final sample volume of approximately 12 liters. Flow rates may be modified as necessary to meet the data quality objectives.

Twenty-four-hour composite samples will be taken on a daily basis. This sampling process will continue until sufficient data are available to determine average VOC concentrations. When average concentrations are known, sampling frequency may be reduced. Any large excursions from average rates will, however, require a subsequent increase in sampling frequency (see Section 3.3.1).

Samplers are now dedicated to sampling the entire flow stream. A system flow meter, up-flow of the sampling station and down-flow of the carbon sorption unit, will record total system flow rates. As the sampler flow rate becomes known, the percentage of the entire flow monitored will be known as well. Analytical results and system flow measurements will allow the calculation of the total target VOCs in the effluent.

Flow controllers on the sampling equipment will be checked daily by monitoring with an in-line mass flow meter dedicated to the sampler. These meters are initially factory-calibrated and specify a typical accuracy of better than 4 percent full scale. Additionally, the bin mass flow meters and the system mass flow meter will be calibrated using a NIST primary flow standard on a quarterly basis, either by the manufacturer or by the on-site WIPP Calibration Laboratory. The WIPP Calibration Laboratory currently performs routine calibration of mass flow meters. Existing SOPs will be revised to address the specific calibration requirements of the VOC monitoring equipment.

Duplicate field samples will be taken at a frequency of ten percent. Original and duplicate samples will be taken concurrently (see Section 6.1). This design will require the doubling of the sampling frequency for the duplicate sampling period (every 15 minutes).

5.2.2 Shaft and Panel Sampling

Samples taken at the Panel 1 intake and outlet (Stations VOC-8 and VOC-9) can potentially represent transient environments; therefore, 24-hour integrated samples will be collected. Prior to the installation of any waste in the Panel, background samples will be collected and characterized. Samples taken at the Air Intake and exhaust shafts may represent transient environments as well, and 24-hour composite samples will be collected at these two locations to characterize the background concentrations. Due to the potential for airborne particulate contamination at the Panel 1 intake and outlet and the exhaust shaft sampling stations, the collection of background samples at these locations can be utilized as a "shakedown" test for sampler performance. The results of these tests may require modifications to the filtration capabilities of the samplers

Initially, Panel 1 samples (Stations VOC-8 and VOC-9) will be taken daily, with the potential for sampling reduction to weekly based on analytical results (see Section 3.3). Air Intake shaft (Station VOC-2) and exhaust shaft (Station VOC-1) samples will be taken on a weekly basis.

Samples taken at the exhaust shaft and panel locations should represent the same matrix type, that is, elevated levels of salt aerosols. To verify the matrix similarity, duplicate samples will initially be collected from the panel and shaft sampling station (Station VOC-8, -9, -1, and -2) at a frequency of ten percent (see Section 6.1). The duplicate sampling at these locations will continue until at least three duplicate data sets are reported for each sampling station. The duplicate sampling at these stations may be eliminated if the duplicate precision values for the samples differ by no more than ten percent. If compounds cannot be identified in the samples collected at these stations, making calculations of precision unattainable, the duplicate sampling at these stations will be eliminated.

5.2.3 Method Relative Accuracy Sampling

Method relative accuracy will be evaluated by spiking canister samples with a known volume of a gaseous standard. As a first step in this process, concurrent duplicate samples of the matrix gas (i.e., mine air or gas from the bin manifold) will be collected in standard sample canisters through the sampling system. The sampling duration for these samples will be approximately 24 hours, and approximately 11 liters of matrix gas will be collected in each of the two sample canisters.

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The second step will be to connect the gaseous standard cylinder to the sampling system and purge the entire flow path with the gaseous standard to remove all of the matrix air. The gaseous standard will be injected into the inlet of the sampling system. Only the gaseous standard will be injected. No matrix air will be introduced with the standard.

The third step will be to spike one of the duplicate canisters with one liter of the gaseous standard. The sampling system will be used to add this additional volume to the canister designated as the matrix spike sample. The final sample volume of the matrix spike will be approximately 12 liters. The final volume of the duplicate sample will be approximately 11 liters.

After removing the matrix spike and matrix duplicate samples from the samplers, the fourth step of the process will be to disconnect the gaseous standard from the inlet to the sampling system and to purge the system with either matrix gas or zero air. This purge cycle will remove all of the gaseous standard from the sampling system. Finally, both the matrix spike and the matrix sample will be sent to the laboratory for analysis.

The gaseous standard may be prepared by the analytical laboratory, obtained from the EPA, or purchased from a commercial supplier. The standard will contain known concentrations of the five target compounds in a pressurized cylinder. The concentration of the target compounds in the cylinder will be evaluated before use and on a regular basis thereafter. Using a standard sample canister, an initial sample of the gaseous standard will be obtained directly from the cylinder and analyzed by the laboratory. Samples will be collected from each cylinder prior to use and on a semiannual basis thereafter.

This procedure will be conducted on a rotational basis at each sampling location. Method relative accuracy will be tracked at each location through the use of control charts. The matrix spike and concurrent matrix duplicate will be collected and analyzed on a frequency of ten percent. After data are received for ten method relative accuracy samples at each sampling location, accuracy windows and outlier criteria will be determined. Additional information is provided in WP 12-7. Data quality objectives for the measurement of method relative accuracy are presented in Section 6.

5.2.4 VOST Tube Sampling

Accurate VOC concentrations and bin off-gas flow rates and frequencies are presently unknown. For these reasons, carbon bed absorption efficiency and lifetime must be determined experimentally. The proposed design of the bin-scale sampling manifold provides for a carbon bed sampling loop (Figure 3-2). By changing the gas flow direction to the sampling loop, VOCs off-gassing from the bins may be trapped in staged, carbon-filled VOST tubes and analyzed in the laboratory by thermal desorption GC/MS. These tubes may be changed out and analyzed periodically without any interruption to the effluent monitoring effort. A separate SOP for carbon sorption sampling will be completed after the finalization of the manifold design specifications.

After carbon bed lifetime has been determined, additional VOST tube sampling will not be necessary unless there is an increase in gas flow rates or the quantity of VOCs determined through canister sampling, or wastes from new sources/processes are added to the experiments.

5.3 SAMPLE MANAGEMENT

Field sampling data sheets will be used to document the conditions under which each sample is collected. These data sheets have been developed specifically for this study. The individuals assigned to collect the specific samples will be required to fill in all of the appropriate sample data and to maintain this record in field notebooks. The program supervisor will review these forms on a weekly basis.

All samples will be maintained and shipped at ambient temperatures. Completed samples will be shipped in individual shipping containers biweekly. Prior to leaving the unit boundary, all sample containers/tubes must undergo radiological screening. The results of the screening must be submitted to the receiving laboratory prior to or with the samples.

Additional QA requirements for sample management contained in WP-13 will be followed as appropriate. Chain-of-custody procedures required by WP-13 will be followed closely, and additional requirements imposed by the laboratory for sample analysis will be included as necessary.

Individuals collecting samples will be responsible for the initiation of custody procedures. The chain of custody will include documentation as to the canister certification, location of sampling event, time, date, and duration of sampling. Samples will be collected in accordance with written sampling SOPs; deviations from a SOP will be considered a variance. Variances must be preapproved by the project manager and recorded in the project files. Unintentional deviations, sampler malfunctions, and other problems are nonconformances. Nonconformances must be documented and recorded in the project files. All field logs/data sheets must be incorporated into WIPP's document control process.

More detailed documentation of sample management is presented in WP 12-7.

5.4 SAMPLER MAINTENANCE

Routine sampler maintenance will be the responsibility of the sampling personnel. This maintenance will include but not be limited to replacement of damaged or malfunctioning parts, filter changes, leak testing, and minor cleaning. Major cleaning and sampler cleanliness certification will be the responsibility of the contracted laboratory. Additionally, complete spare units will be maintained on the site to minimize downtime due to sampler malfunction. A spare parts inventory will be maintained at the site as well. A sampler preventative maintenance schedule will be developed and included in the QAPP. At a minimum, samplers will be certified for cleanliness on a quarterly basis, after any parts that are included in the sample flow path are replaced, or any time analytical results indicate potential contamination. All sample canisters will be certified prior to each usage.

5.5 ANALYTICAL PROCEDURES

Analytical procedures used in the analysis of VOC samples from canisters are based on recommendation in Compendium Method TO-14. Analysis of carbon sorption media will be performed using a modification to the analytical procedure for the analysis of VOST tubes (EPA, 1986). Analytical SOPs will be in place prior to the analysis of any samples.

5.5.1 Analysis of Samples from SUMMA® Canisters

Sample Preparation

As canisters will be pressurized during the sampling procedure, laboratory pressurization will not be necessary for analyses. Pressures of canisters will be verified when they are received, however, to confirm that losses did not take place during shipping and storage.

Analytical System Requirements

The analytical system will consist of three major components: the sample introduction system, analyte separation system, and the analyte detector system.

- Sample Introduction System for Canisters: The sample introduction system will include a thermostated unit (oven) to allow canisters (samples and standards) to be evacuated at a constant temperature. It will include a Nafion™ drying tube to remove moisture from the gas stream. One or more cryogenic traps may be used to focus and desorb trapped material. Transfer lines within the introduction unit must be heated so that volatile compounds are not actively absorbed. Valves and solenoids should be heated and be of a low dead volume type. The introduction system will have an in-line mass flow controller. The introduction unit will be capable of introducing internal standards directly into the sample flow path.

- Some modifications may have to be made to the introduction system if relatively large amounts of salt aerosols are present in the samples. Problems of this type will be investigated during the analysis of background samples.

- Analyte Separation: Analyte separation will be achieved by gas chromatography. The GC will be capable of subambient temperature programming. The capillary column used will be a 30 meter x 0.53 millimeter I.D., J&W DB-624 with a 3-micron film thickness, or equivalent.

- Detection System: Analyte detection will be accomplished by full scanning quadruple mass spectrometry. The mass spectrometer must be capable of scanning from 40-260 m/z in one second or less, be fitted with a gas jet separator, a data system capable of storing all raw data, and a computer algorithm for analyte quantitation and forward library searching. All raw and processed GC/MS data must be stored on magnetic tape or disk and kept for the duration of this project.

Standard Preparation

Primary standards will be prepared for the five target compounds as well as the internal standards. Secondary standards will be prepared from dilution of the primary standards. Analytes that are gases at STP will be prepared in a static gas dilution bottle. For analytes that are liquids or solids at STP, a mixture will be made and loaded directly into a standard preparation cylinder. These standards will be checked against EPA audit cylinders to verify the accuracy of their concentrations.

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Calibration Procedures

Prior to the analysis of a standard curve, the GC/MS system must undergo a mass calibration check. This check is performed by injecting 50 ng of BFB directly onto the capillary column. The requirements (criteria) for relative ion abundances, listed in Table 5-4, must be met before analyses may proceed. BFB requirements must be met for each 12 hours of operation.

Quantitative standards for the five target analytes, to be determined in the canisters, will be analyzed at five concentration levels. These levels should define the linear range of the instrument for these five compounds; however, if some nonlinearity exists, concentration may be determined through curve fitting or physical plotting of data. One standard concentration level should be at or near a concentration corresponding to the detection limit for the method. Relative response factors will be generated for each target compound. These response factors must meet the requirements listed in the QA objectives section. As discussed above, if low concentration standards do not meet the linearity requirement, then a curve-fitting routine may be used. The method used for quantification of the data must be reported with the analytical results.

Library Searches

In every sample analyzed, a forward search of the NIST library of mass spectra must be performed for all chromatographic peaks greater than ten percent of the nearest internal standard.

Data Reporting

Sample target analyte concentrations will be quantified using the mid-range calibration standards and will be reported in ppbv. Other sample contaminants identified by NIST library searches will be reported as tentatively identified compounds, and concentration calculations will be based on response factors of the nearest internal standard. The relative response factor used for quantitation as well as copies of spectra, with the library search results (purity and fit), will be submitted with the results. A table listing the run sequence with the corresponding internal standard area counts must be reported with the analytical results. A narrative describing any problems with sample analysis must be included. Any nonconformances must be included with the reporting of the data.

5.5.2 Analysis of VOST Tubes

The objective of the analysis of the VOST tubes is not to determine the nature of the waste stream, although library searching may aid in this function, but to determine the effective lifetime of the carbon bed absorbent. As over-design criteria were applied to the carbon bed absorbent, extremely accurate quantitative results are not required. For this reason, the analytical effort and the level of quality control will be somewhat lower than the level that is applied to the emissions monitoring program.

Sample Preparation

VOST tubes do not require any special sample preparation.

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Table 5-4

4-Bromofluorobenzene Key Ions and Ion Abundance Criteria

Mass	Ion Abundance Criteria
50	15 to 40% of mass 95
75	30 to 60% of mass 95
95	Base Peak, 100% Relative Abundance
96	5 to 9% of mass 95
173	<2% of mass 174
174	>50% of mass 95
175	5 to 9% of mass 174
176	>95% but <101% of mass 174
177	5 to 9% of mass 176

Analytical System Requirements

- Sample Introduction System for VOST Tubes: The sample introduction system for the VOST tubes will consist of a thermal desorption oven, heated transfer lines, and mixed sorbent focusing trap; it will be capable of introducing internal standards directly into the flow path. All valving should be heated and be of a low dead volume type.

- Analyte Separation: Analyte separation will be achieved by gas chromotagraphy. The GC will be capable of subambient temperature programming. The capillary column used will be a 30 m x 0.53 mm I.D., J&W DB-624, with a 3-μm film thickness, or equivalent.

- Detection System: Analyte detection will be accomplished by full-scanning quadruple mass spectrometry. The mass spectrometer must be capable of scanning from 40-260 m/z in one second or less, be fitted with a gas jet separator, a data system capable of storing all raw data, and a computer algorithm for analyte quantitation and forward library searching.

Calibration Procedures

Prior to the analysis of a standard curve, the GC/MS system must undergo a mass calibration check. This check is performed by injecting 50 ng of BFB directly onto the capillary column. The requirements (criteria) for relative ion abundances, listed in Table 5-4, must be met before analyses may proceed. BFB requirements must be met for each 12 hours of operation.

Three liquid instrument calibration standards will be used for the analysis of VOST tubes. Thermal desorption efficiencies will be determined once for all compounds on the EPA Contract Laboratory Program, Target Compound List for Volatile Organic Compounds (EPA, 1988b) and Freon-113. After this determination is complete, standard curves will be prepared by a direct injection technique. Relative response factors will be generated based on the total nanograms of analyte and internal standard injected.

Library Searches

In every sample analyzed, a forward search of the NIST library of mass spectra will be performed for all chromatographic peaks greater than 20 percent of the nearest internal standard.

Data Reporting

Sample target analyte concentrations will be quantified using the mid-range calibration standard and will be reported as total nanograms. Other sample contaminants determined by NIST library searches will be reported as tentatively identified compounds and concentration calculations will be based on a response factor for the nearest internal standard. Copies of spectra, with the library search results (purity and fit), will be submitted with the results. A table listing the run sequence with the corresponding internal standard area counts must be reported with the analytical results. A narrative describing any problems with sample analysis must be included. Any nonconformances must be included with the reporting of the data.

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5.6 LABORATORY SELECTION

Measures shall be taken, in accordance with the current Westinghouse Waste Isolation Division (WID) procurement policies and procedures, to ensure that procured services conform to specified requirements. These measures will generally include one or more of the following: evaluation of the supplier's capability to provide services in accordance with requirements, including a history of providing similar services; evaluation of objective evidence of conformance, such as submittals; and examination of delivered services.

5.7 LABORATORY PROCEDURES

The contracted laboratory is required to develop and prepare the following SOPs:

- Canister cleaning and certification procedures
- Sampler cleaning and certification procedures
- Analysis of VOCs from SUMMA® canisters
- Analysis of carbon tubes by thermal desorption GC/MS
- Project-specific data verification procedures.

The contracted laboratory is also required to develop and prepare QAPjP for cleaning and certification of samplers and for laboratory analysis of canister and VOST tube samples. The laboratory will also be required to review and approve WP 12-7.

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6.0 QUALITY ASSURANCE OBJECTIVES

Many quality objectives for the VOC monitoring plan have been addressed in Sections 4.0 and 5.0. For example, sample collection procedures are discussed, including justification of sampling location selection. Additional topics include discussions of sampling program operations, preparation of sampling equipment and sample containers, redundancy in sampling equipment and sample containers (including canister certification), a general sample management/ ontrol scheme, and the selection of analytical procedures. More detailed descriptions of these functions, as well as additional quality-related objectives, are addressed in WP 12-7. This QAPP has been prepared in accordance with the Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans (EPA, 1983) and the criteria listed in Table 6-1. This section addresses the methods to be used to evaluate the components of the measurement system and how this evaluation will be used to establish data quality objectives. In addition, project activities will be performed in conformance with quality assurance requirements described in WP 12-7.

6.1 QA OBJECTIVES FOR THE MEASUREMENT OF PRECISION, ACCURACY, SENSITIVITY, AND COMPLETENESS

- Precision: For the duration of this project, precision will be defined and evaluated by the RPD between field, as well as laboratory duplicate samples.

$$RPD = \frac{A - B}{[(A + B)/2]} \times 100$$

where:

A = Original sample result
B = Duplicate sample result.

- Accuracy: Analytical accuracy will be defined and evaluated through the use of analytical standards. Because recovery standards cannot reliably be added to the sampling stream, overall system accuracy must be based on analytical instrument performance evaluation criteria and sampler accuracy. This will include performance verification criteria for daily quantitation standard evaluation, internal standard area evaluation, and the percent relative accuracy as defined in Method TO-14. These criteria will constitute the verification of accuracy for the quantitative effort. Evaluation of standard ion abundance criteria for BFB will be used to evaluate the accuracy of the analytical system in the determination of targeted analytes, as well as the evaluation of unknown contaminants (qualitative accuracy).

- Sensitivity: Sensitivity will be defined by the Limit of Quantitation (LOQ). The LOQ represents the lowest analytical value that can reliably be quantified.

- Completeness: Completeness will be defined as the percentage of the ratio of the number of valid sample results received versus the total requested. Completeness may be affected, for example, by sample loss or destruction during shipping and laboratory sample handling errors.

Table 6-1

Data Quality Objectives for Accuracy, Precision, Sensitivity, and Completeness for the VOC Monitoring Program

Compound	Relative Accuracy (Percent)	Precision (RPD)	Sensitivity (ppbv)	Completeness (Percent)
Carbon tetrachloride	± 10	15	0.5	>90
Methylene chloride	± 10	15	0.5	>90
Trichloroethylene	± 10	15	0.5	>90
1,1,1-Trichloroethane	± 10	15	0.5	>90
1,1,1-Trichloro-1,2,2-trifluoroethane	± 10	15	0.5	>90

These data quality objectives have been prescribed for this program by EPA and are formally presented in the Final No-Migration Determination (EPA, 1990).

6.1.1 Evaluation of Laboratory Precision

Laboratory duplicates will be used for the evaluation of laboratory precision. Typical values of laboratory precision are listed in Table 6-1. These values will be appropriate for the evaluation of samples with little or no matrix effects. Due to the potentially high level of salt-type aerosols in the WIPP underground environment, analytical precision may be quite different. Laboratory duplicate values will be tracked through the use of control charts, specific to a type of sampling area (e.g., bin-scale). After 20 laboratory duplicate data points have been collected, control values will be established for each sampling area type. These control values will be reevaluated after every ten additional laboratory duplicate analyses. Laboratory duplicates will be analyzed at a frequency of ten percent. Precision windows and outlier criteria will be addressed in WP 12-7.

6.1.2 Evaluation of Field Precision

Duplicate field samples will be taken at a frequency of ten percent for all monitoring locations. Field duplicate values will be tracked through the use of control charts specific to the type of sampling area. After 20 field duplicate data points have been collected, control values will be established for that type of sampling area. Control values will be reevaluated after every ten field duplicate analyses. The difference between the laboratory duplicate and the field duplicate results represents the precision of the sampling event. Precision windows and outlier criteria will be addressed in the QAPP. Data quality objectives for the measurement of duplicate field sample precision are presented in Table 6-1.

6.1.3 Evaluation of Laboratory Accuracy

Quantitative analytical accuracy will be evaluated through performance criteria based on relative response factors generated during instrument calibration and recovery of compounds from audit cylinders. The criteria for the initial calibration (5-point calibration) is that any single relative response factor for a particular target compound can differ by no more than 25 percent from the average of the five. After the successful completion of the 5-point calibration, it is sufficient to analyze only a midpoint standard for every 12 hours of operation. The midpoint standard must pass the 25 percent difference acceptance criteria before sample analysis may begin. Internal standard areas will be monitored as a verification of stable instrument performance. In the absence of any unusual interferences, areas should not change by more than 25 percent over a 12-hour period. Deviations larger than 25 percent are an indication of a potential instrument malfunction. If the internal standard areas in a sample change by more than 25 percent, the sample must be reanalyzed. If the 25 percent criterion is not achieved during the reanalysis, the instrument must undergo a performance check and the midpoint standard reanalyzed to verify proper operation.

6.1.4 Evaluation of Method Accuracy

Percent relative accuracy (as defined in Method TO-14) will be evaluated by sampling standard mixtures from a cylinder containing known concentrations of the target compounds through the sampling system and into a standard sample canister (matrix spike). This procedure will be conducted on a rotational basis, so that the measurement of percent relative accuracy will reflect all of the sampling stations. An EPA audit cylinder is not available that contains the five project-specific target compounds. Laboratory-prepared audit cylinders may be used.

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These audit cylinders will be verified against the EPA audit cylinders (group 5 and group 3) and may not be prepared with the same standards used to manufacture calibration solutions. Verification must be documented and the original submitted to the project file. Alternatively, cylinders may be obtained from a commercial supplier. Percent relative accuracy is expressed as:

Method relative accuracy will be determined for each target compound based on the relative difference between the concentration of the target compound in the gaseous standard cylinder and the concentration of the target compound recovered from the matrix spike sample. The computation of the concentration recovered from the sampler will be adjusted for the actual background concentration measured in the matrix duplicate sample at the time the matrix spike was collected. The sample volumes of matrix air and gaseous standard also must be considered in the calculation. Method relative accuracy is calculated as follows:

$$A = \frac{Cs - Ct}{Cs} * 100$$

$$Ct = \frac{[Cr(Vs + Vm) - (Cd * Vm)]}{Vs}$$

where,

A = Relative accuracy, percent

Cs = Concentration of the target VOC in the gaseous standard, ppb

Cr = Concentration of the target VOC recovered from the matrix spike, ppb

Cd = Concentration of the target VOC recovered from the matrix duplicate, ppb

Ct = Calculated true concentration of the target VOC in the matrix spike, ppb

Vm = Sample volume of matrix gas collected, liters

Vs = Sample volume of the gaseous standard collected, liters.

To correct for potential effects from matrix or background concentrations of the target compounds, matrix duplicate samples will be collected concurrently with the collection of a matrix spike sample.

Percent relative accuracy will be tracked through the use of control charts. After data are received for ten accuracy samples, accuracy windows and outlier criteria will be determined. These control values will be reevaluated after every ten additional accuracy sample analyses. Gas from standard cylinders will be sampled through the systems at a frequency of ten percent. Additional information is provided in WP 12-7. Data quality objectives for the measurement of percent relative accuracy are presented in Table 6-1.

6.1.5 Evaluation of Qualitative Accuracy

Qualitative accuracy will be evaluated by the relative ion abundance criteria established for BFB. For each 12 hours of sample analysis, a 50 ng injection of

BFB must be made, and the requirements listed in Table 6-1 must be met before the instrument may be used to analyze samples.

6.1.6 Evaluation of Sensitivity

Typical values for sensitivity (LOQ) are listed in Table 6-1. These values are based on the evaluation of samples with little or no matrix effects. There is the potential at the exhaust shaft and background locations in the drift for sampling and analytical interferences, due to airborne salt in the form of an aerosol. The sampling manifold for the bin-scale test is sufficiently protected from the underground environment, and this type of interference should not occur during the bin-scale tests. Prior to the initiation of bin, exhaust shaft, and Panel 1 intake/outlet testing, it will be necessary to determine if these airborne aerosols will affect method sensitivity. Partially filled standard cylinders of known concentration will be diluted with a metered volume from a bin-scale monitoring system, a location near the Panel 1 outlet, and from the exhaust shaft. These cylinders will be analyzed to determine if target concentration can be achieved in the presence of the aerosol. Salt aerosol impact on method sensitivity will be reevaluated annually.

6.1.7 Completeness

The expected completeness for this project is greater than 90 percent. Data completeness will be tracked and will be evaluated after every ten quality control analyses.

6.2 SAMPLE HANDLING AND CUSTODY PROCEDURES

Sample packaging, shipping, and custody procedures are addressed in the QAPP (see Section 5.3).

6.3 CALIBRATION PROCEDURES AND FREQUENCY

Calibration procedures and frequencies for analytical instrumentation are listed in Section 5.5. When samplers are in operation, flow rates will be verified on a daily basis.

6.4 ANALYTICAL PROCEDURES

Analytical procedures are outlined in Section 5.5.

6.5 DATA REDUCTION, VALIDATION, AND REPORTING

Data reduction and validation are addressed in the WP 12-7. A brief description of data reporting is given in Section 5.5; more detail on data reporting is provided in WP 12-7.

A dedicated log book will be maintained by the operators. This log will contain documentation of all pertinent data for the sampling. Sample collection conditions, maintenance, and calibration activities will be included in this log. Additional data collected by other groups at WIPP, such as temperature, pressure, etc., will also be obtained to document the sampling conditions, as necessary.

Data validation procedures will be specified in the monitoring program QA protocols. As a minimum, all field data forms and the sampling log book will be

checked for completeness and other relevant information. Sample custody and analysis records will be routinely reviewed by the laboratory supervisor.

Data will be reported to the EPA annually within 60 days of the end of the calendar year. Data summaries will include daily results for each sample for the target compounds as well as overall statistical summaries. Graphical summaries will be included to aid in the evaluation of trends.

In addition, in accordance with the requirements of 40 CFR 268.6(e)(f)(2), if the data indicate average target VOC concentrations in the exhaust shaft above EPA-specified criteria during any three-month period, the DOE will notify the EPA within ten days.

6.6 PERFORMANCE AND SYSTEM AUDITS

System audits will initially address start-up functions for each phase of the project. These audits will consist of on-site evaluation of materials and equipment, review of canister and sampler certification, review of laboratory qualification and history, and may, at the request of the contracting officer, include an on-site audit of the laboratory facilities. The function of the system audit is to verify that the requirements for project initiation, as discussed in this Monitoring Plan and the QAPP, have been met. System audits will be performed prior to the initiation of the monitoring program and semiannually thereafter.

Performance audits will be accomplished through the evaluation of analytical quality control data in the form of control charts and reports by performing periodic site audits throughout the duration of the project and the introduction of audit cylinders (laboratory blinds) into the analytical sampling stream. Control charts for precision and percent relative accuracy are maintained for the duration of the project. Performance audits will also include a bimonthly surveillance/review of all data associated with canister and sampler certification, a semiannual project-specific technical audit of field operations, and an annual laboratory performance audit. Field logs, notebooks, and data sheets will be reviewed weekly. Blind-audit cylinders will be introduced at a frequency of 1 in every 100 samples (initially this will be about twice a month). Details concerning scheduling, personnel, and data quality evaluation are addressed in WP 12-7.

6.7 PREVENTATIVE MAINTENANCE

A brief description of sampler maintenance is described in Section 5.4. Maintenance of analytical equipment will be addressed in the analytical SOPs.

6.8 CORRECTIVE ACTIONS

Corrective actions may be responses to variances or nonconformances. A variance is an intentional modification to an established protocol or procedure. A variance may include technical modifications to field/laboratory procedures, a change in administrative details (for example, a change in personnel or a specified reporting format), or may constitute a change in the scope of work. Nonconformances are unintentional errors that can result from faulty or broken equipment or operational errors. In the case of a variance, corrective actions must be reviewed and approved by project management personnel including appropriate government agencies. Corrections to nonconformances may be initiated in

the field or laboratory. Documentation of variances/nonconformances and the associated corrective actions must be integrated into the project file.

6.9 QUALITY ASSURANCE REPORTS TO MANAGEMENT

As part of the quality assurance function, a semiannual QA report will be submitted to project management. This report will include semiannual control charts for relative percent accuracy, field/analytical precision and completeness, system audit results, and identification of QA problems and recommended solutions. Individual(s) responsible for this function will be identified in the WP 12-7. All monitoring data will be kept on file at the WIPP site.

7.0 REFERENCES

40 CFR 191, Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High Level and Transuranic Radioactive Waste

40 CFR 268, Land Disposal Restrictions

Clements, T.L., Jr., and D.E. Kudera. TRU-Waste Sampling Program. Volume I: Waste Characterization, and Volume II: Gas Generation Studies. 1985. EEG-WM-6503, Idaho National Engineering Laboratory.

DOE/WIPP 89-003, Waste Isolation Pilot Plant No-Migration Variance Petition

DOE/WIPP 89-011, WIPP Test Phase Plan: Performance Assessment

EPA, 1983. QAMS-005/80, EPA-600/4-83-004, Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans. Washington, D.C.

EPA, 1986. SW-846, Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. Third Edition. Office of Solid Waste and Emergency Response, Washington, D.C.

EPA, 1988a. "Compendium Method TO-14: The Determination of Volatile Organic Compounds (VOCs) in ambient Air Using SUMMA Passivated Canister Sampling and Gas Chromatographic Analysis." Quality Assurance Division, Environmental Monitoring Systems Laboratory, Research Triangle Park, North Carolina.

EPA, 1988b. "Contract Laboratory Program Statement of Work, Organic Analysis, Multimedia, Multiconcentration," Washington, D.C.

EPA, 1990, "Conditional No-Migration Determination for the Department of Energy Waste Isolation Pilot Plant (WIPP)." Federal Register. Vol. 55, No. 220. pp. 47700-472221

Molecke, M.A. Test Plan: WIPP Bin-Scale CH TRU Waste Tests. Sandia National Laboratories, Albuquerque, New Mexico.

Westinghouse Electric Corporation, 1991. D-0077, Engineering Design Specification, for Volatile Organic Compound Sampling System for the Bin-Scale Experiment (VOC-10)

WP 02-9, WIPP Final Safety Analysis Report

WP 12-7, VOC Monitoring Quality Assurance Program Plan

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FOR INFORMATION ONLY

APPENDIX D13

CHEMICAL COMPATIBILITY ANALYSIS OF WASTE FORMS AND CONTAINER MATERIALS

APPENDIX D13
CHEMICAL COMPATIBILITY ANALYSIS
OF WASTE FORMS AND CONTAINER MATERIALS

All information for the chemical lists and compatibility study is maintained in data bases on a personal computer. The chemicals reported by the generator sites are classified into reaction groups as defined by the U.S. Environmental Protection Agency (EPA) document, A Method for Determining the Compatibility of Hazardous Wastes (EPA, 1980). The chemical lists are printed directly from the TRUPACT-II data bases using a print program.

A data base program was developed to evaluate the chemical compatibility of the waste. Potential incompatibilities are those defined in the EPA document (Hatayama et al., 1980), which identifies combinations of chemical groups that are incompatible. All such combinations have been entered into a refere..ce data base to be used in assessing the chemical compatibility of a given list of chemicals. The logic of the program used in evaluating the chemical compatibility by content code is described in detail below.

As an initial step, the program indexes the entire data base according to content codes. The program then locates the first reaction group within the first content code and picks the highest concentration of any chemical in that group. The group is then paired with every other group in the data base to check for incompatibility. If a potential incompatibility is found, it is printed out along with the corresponding content codes. After finding all potential incompatibilities for that content code, the program moves on to the next content code until all content codes have been processed.

To ensure accuracy, the reference data base was printed and checked against the EPA document for chemical compatibility, and the TRUPACT-II data base was printed and checked against the original submittal forms from the generator sites. The list of potential chemical incompatibilities reported by the program was hand checked using the EPA document as a reference to assure proper functioning of the program. All potential chemical incompatibilities were then evaluated on a case-by-case basis to identify which, if any, of the reactions could occur, given the nature of the waste and the chemical constituents.

Content codes are classified as "incompatible" if the potential exists for any of the following reactions:

- corrosion
- explosion
- heat generation
- gas generation (flammable gases)

- pressure build-up (nonflammable gases)
- toxic by-product generation

Each generator and storage site has produced a comprehensive list of all possible chemicals present in its waste. The chemical components found in each waste generation process are determined by examination of the process technology, by chemical analysis, or by process flow analysis. Under this system, all chemical inputs into the system are accounted for, even though all of these components may not be a part of the waste. For example, generator sites might include both acids and bases in their lists, even though the two groups have been neutralized prior to placement in a waste container. In addition to the chemical components reported by the generator the following components were added to the data base for each content code in dominant (>10 weight %) quantities:

Group 23 Metals, other Elemental and Alloys as Sheets, Rods, Etc.
Low Carbon Steel

Group 101 Combustible Materials
Polyethylene

Low carbon steel and polyethylene were added to evaluate chemical compatibility between the waste materials and the container materials.

The components that exhibit toxicity characteristics defined under 40 CFR §261.24 were also added to the chemical list in trace (<1 weight percent) quantities:

Group 3 Acids, Organic
2,4-D
2,4,5-TP (Silvex)

Group 7 Amines, Aliphatic and Aromatic
Pyridine

Group 16 Hydrocarbons, Aromatic
Benzene

Group 17 Halogenated Organics
Endrin
Lindane
Methoxyclor
Toxaphene
2,4-D
Carbon Tetrachloride

Chlordane
Chlorobenzene
Chloroform
1,4-Dichlorobenzene
1,2-Dichloroethane
1,1-Dichloroethylene
Heptachlor
Hexachlorobenzene
Hexachlorobutadiene
Hexachloroethane
Pentachlorophenol
Tetrachloroethylene
Trichloroethylene
2,4,5-Trichlorophenol
2,4,6-Trichlorophenol
Vinyl Chloride

Group 19 Ketones
MFK

Group 27 Nitro Compounds
1,1-Dinitotoluene
Nitrobenzene

Group 31 Phenols and Creosols
O-creosol
M-creosol
P-creosol
Creosol
Pentachlorophenol
2,4,5-Trichlorophenol
2,4,6-Trichlorophenol

Group 103 Polymerizable Compounds
Vinyl Chloride

The chemical concentration levels are reported as either Trace (T)(<1% by weight), Minor (M)(1-10%), or Dominant (D)(>10%). The list is divided into groups based on chemical properties and structure (e.g., acids, caustics, metals, etc.). If incompatible groups are combined, the possibility exists for the reactions listed above. For example, a reaction between Group 1 (Acids, Mineral, Non-oxidizing) and Group 10 (Caustics) could result in heat generation. Incompatibilities have been defined within each content code.

Possible chemical incompatibilities between compounds present in trace quantities (<1 percent by weight) and compounds present in concentrations $\geq$ 1 percent by weight (i.e., D x T, D x T1, D x T2, D x T3, M x T, M x T1, M x T2, or M x T3) are included in this report. However, interactions between compounds present in trace quantities (<1 percent by weight) and compounds present in concentrations $\geq$ 1 percent by weight do not pose an incompatibility problem for the following reasons:

- The trace chemicals reported by the sites are in concentrations well below the trace limit of 1 weight percent. Sampling programs show that the concentration levels of these compounds are significantly lower than the upper limit of 1 percent.

- The trace chemicals are usually dispersed in the waste, which further dilutes concentrations of these materials.

- Trace chemicals that might be incompatible with major and dominant materials/chemicals would have reacted during the waste treatment process prior to placement in waste containers.

- Because of restrictions imposed by the Environmental Protection Agency (EPA) on reporting of hazardous wastes, some chemicals are listed in trace quantities even if they have already reacted. Hazardous waste regulations as promulgated by the EPA (EPA, 1988) (known as the mixture rule) require that a mixture of any solid waste and a hazardous waste listed in 40 CFR Part 261, Subpart D, be considered a hazardous waste subject to RCRA regulations. However, Subpart D does not list minimum concentrations for these listed wastes, with the result that any such mixtures must be considered hazardous waste even if the Subpart D constituent is at or below detection limits.

- The waste is either solidified and immobilized (solidified materials) or present in bulk form as a solid (solid materials). In almost all cases, any possible reactions take place before the waste is generated in its final form.

- Total trace chemicals within a payload container are limited to less than 5 weight percent.

All potential incompatibilities between trace, minor, and dominant compounds have been analyzed on a case-by-case basis for each content code at the Rocky Flats Plant and Idaho National Engineering Laboratory. Some chemicals listed as being present in the waste have reacted prior to placement in a waste container. For example, a site listing a caustic (Group 10) and an acid (Group 1) in its waste has only the neutralized product present in an immobilized form. Further reactions of this type do not occur once the waste is generated in its final form. An additional

constraint on the chemicals and materials that can be present within each content code is their gas generation potential due to radiolysis.

Unresolved incompatibilities between trace and minor, trace and dominant, minor and dominant, minor and minor, or dominant and dominant waste constituents were identified and segregated. These wastes cannot be transported until the incompatabilities are resolved (NuPac, 1989). Chemical incompatibilities do not exist in content codes listed in TRUCON (DOE, 1989). This has been ensured by a knowledge of the processes generating the wastes, limited chemical analyses, and the chemical compatibility analysis. The following table presents the chemical compatibility analysis for the different content codes at the Rocky Flats Plant and Idaho National Engineering Laboratory. Low carbon steel (Group 23) and polyethylene (Group 101) in dominant quantities were added to each content code to account for the drum, bin, or standard waste box and the rigid polyethylene liner.

The chemical compatibility analysis was performed using a data base management system. The EPA method (Hatayama et al., 1980) was utilized to analyze the chemical compatibility of each content code. These waste container compatibility codes are listed for each waste content code in Table D9-1, after which is a listing of compatibility code analysis explanations.

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIAL

Rocky Flats Plant

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants#	Reaction Code *	Explanation Code Number
RF 111A	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	19
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
	Metal and Compounds, Toxic x Water (24 x 106)	T x D	S	33
RF 111B	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	19
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
	Metal and Compounds, Toxic x Water (24 x 106)	T x D	S	33
RF 112A	Organic Acids x Alcohols and Glycols (3 x 4)	T x M	H P	11
	Amines, Aliphatic and Aromatic x Halogenated Organics (7 x 17)	T x D	H GT	12b
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	D x D	H F	25
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c

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* Reaction Code: H = heat generation, S = solubilization of toxic substances, F = fire, GF = flammable gas generation, G = non-flammable gas generation, GT = toxic gas generation, P = violent polymerization, E = explosive.

\# Concentration of Reactants: T = Trace (<1% by wt.), T1 = Trace (<0.1%), T2 = Trace (low ppm range), T3 = Trace (<1 ppm range), M = Minor (1-10%), and D = Dominant (>10%).

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Rocky Flats Plant

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
RF 112B	Organic Acids x Alcohols and Glycols (3 x 4)	T x M	H P	11	1 2
	Amines, Aliphatic and Aromatic x Halogenated Organics (7 x 17)	T x D	H GT	12b	3 4
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	D x D	H F	25	5 6 7
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	8 9 10
RF 113A	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	11 12 13
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	14 15 16
RF 113B	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	17 18 19
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	20 21 22
RF 114A	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	19	23 24 25

* Reaction Code: H = heat generation, S = solubilization of toxic substances, F = fire, GF = flammable gas generation, G = non-flammable gas generation, GT = toxic gas generation, P = violent polymerization, E = explosive.

\# Concentration of Reactants: T = Trace (<1% by wt.), T1 = Trace (<0.1%), T2 = Trace (low ppm range), T3 = Trace (<1 ppm range), M = Minor (1-10%), and D = Dominant (>10%).

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Rocky Flats Plant

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	1 2 3
RF 114B	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	19	4 5 6
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	7 8 9
RF 115A	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	10 11 12
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	13 14 15
RF 115B	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	16 17 18
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	19 20 21
RF 116A	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	20	22 23 24

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* Reaction Code: H = heat generation, S = solubilization of toxic substances, F = fire, GF = flammable gas generation, G = non-flammable gas generation, GT = toxic gas generation, P = violent polymerization, E = explosive.

\# Concentration of Reactants: T = Trace (<1% by wt.), T1 = Trace (<0.1%), T2 = Trace (low ppm range), T3 = Trace (<1 ppm range), M = Minor (1-10%), and D = Dominant (>10%).

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Rocky Flats Plant

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	1 2 3
RF 116B	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	20	4 5 6
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	7 8 9
RF 117A	Acids, Organic x Metals and Metal Compounds, Toxic (3 x 24)	T x D	S	12	10 11
	Amines, Aliphatic and Aromatic x Metals and Metal Compounds, Toxic (7 x 24)	T x D	S	12c	12 13 14
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	15 16 17
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	18 19 20
	Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a	21 22

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* Reaction Code: H = heat generation, S = solubilization of toxic substances, F = fire, GF = flammable gas generation, G = non-flammable gas generation, GT = toxic gas generation, P = violent polymerization, E = explosive.

\# Concentration of Reactants: T = Trace (<1% by wt.), T1 = Trace (<0.1%), T2 = Trace (low ppm range), T3 = Trace (<1 ppm range), M = Minor (1-10%), and D = Dominant (>10%).

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Rocky Flats Plant

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
RF 117B	Acids, Organic x Metals and Compounds, Toxic (3 x 24)	T x D	S	12	1 2
	Amines, Aliphatic and Aromatic x Metals and Metal Compounds, Toxic (7 x 24)	T x D	S	12c	3 4 5
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	6 7 8
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	9 10 11
	Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a	12 13
RF 118A	Organic Acids x Metal and Compounds, Toxic (3 x 24)	T x D	S	12	14 15
	Amines, Aliphatic and Aromatic x Metals and Metal Compounds, Toxic (7 x 24)	T x D	S	12c	16 17 18
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	22	19 20 21
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	22 23 24

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* Reaction Code: H = heat generation, S = solubilization of toxic substances, F = fire, GF = flammable gas generation, G = non-flammable gas generation, GT = toxic gas generation, P = violent polymerization, E = explosive.

\# Concentration of Reactants: T = Trace (<1% by wt.), T1 = Trace (<0.1%), T2 = Trace (low ppm range), T3 = Trace (<1 ppm range), M = Minor (1-10%), and D = Dominant (>10%).

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Rocky Flats Plant

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
	Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a	1 2
RF 118B	Organic Acids x Metal and Compounds, Toxic (3 x 24)	T x D	S	12	3 4
	Amines, Aliphatic and Aromatic x Metals and Metal Compounds, Toxic (7 x 24)	T x D	S	12c	5 6 7
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	22	8 9 10
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	11 12 13
	Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a	14 15
RF 119A	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	16 17 18
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	19 20 21

* Reaction Code: H = heat generation, S = solubilization of toxic substances, F = fire, GF = flammable gas generation, G = non-flammable gas generation, GT = toxic gas generation, P = violent polymerization, E = explosive.

\# Concentration of Reactants: T = Trace (<1% by wt.), T1 = Trace (<0.1%), T2 = Trace (low ppm range), T3 = Trace (<1 ppm range), M = Minor (1-10%), and D = Dominant (>10%).

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Rocky Flats Plant

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
RF 119B	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	1 2 3
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	4 5 6
RF 121A	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	23	7 8 9
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	10 11 12
RF 121B	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	23	13 14 15
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	16 17 18
RF 122A	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	24	19 20 21
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	22 23 24

* Reaction Code: H = heat generation, S = solubilization of toxic substances, F = fire, GF = flammable gas generation, G = non-flammable gas generation, GT = toxic gas generation, P = violent polymerization, E = explosive.

\# Concentration of Reactants: T = Trace (<1% by wt.), T1 = Trace (<0.1%), T2 = Trace (low ppm range), T3 = Trace (<1 ppm range), M = Minor (1-10%), and D = Dominant (>10%).

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Rocky Flats Plant

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
RF 122B	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	24	1 2 3
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	4 5 6
RF 123A	Organic Acids x Metal and Compounds, Toxic (3 x 24)	T x D	S	12	7 8
	Amines, Aliphatic and Aromatic x Metals and Metal Compounds, Toxic (7 x 24)	T x D	S	12c	9 10 11
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	12 13 14
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	15 16 17
	Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a	18 19
RF 123B	Organic Acids x Metal and Compounds, Toxic (3 x 24)	T x D	S	12	20 21
	Amines, Aliphatic and Aromatic x Metals and Metal Compounds, Toxic (7 x 24)	T x D	S	12c	22 23 24

* Reaction Code: H = heat generation, S = solubilization of toxic substances, F = fire, GF = flammable gas generation, G = non-flammable gas generation, GT = toxic gas generation, P = violent polymerization, E = explosive.

\# Concentration of Reactants: T = Trace (<1% by wt.), T1 = Trace (<0.1%), T2 = Trace (low ppm range), T3 = Trace (<1 ppm range), M = Minor (1-10%), and D = Dominant (>10%).

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Rocky Flats Plant

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	1 2 3
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	4 5 6
	Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a	7 8
RF 124A	Organic Acids x Caustics (3 x 10)	T x M	H	11b	9
	Caustics x Halogenated Organics (10 x 17)	M x T	H GF	13	10 11
	Caustics x Ketones (10 x 19)	M x T	H	13a	12
	Caustics x Metals and other elemental and alloys as sheets, rods, etc. (10 x 23)	M x D	H GF	14	13 14 15
	Caustics x Metal and Compounds, Toxic (10 x 24)	M x T1	S	16	16 17
	Caustics x Nitro Compounds (10 x 27)	M x T	E	16b	18 19
	Caustics x Polymerizable Compounds (10 x 103)	M x T	P H	16c	20 21
	Caustics x Water Reactive Substances (10 x 107)	M x M	Not Valid	17	22 23

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* Reaction Code: H = heat generation, S = solubilization of toxic substances, F = fire, GF = flammable gas generation, G = non-flammable gas generation, GT = toxic gas generation, P = violent polymerization, E = explosive.

\# Concentration of Reactants: T = Trace (<1% by wt.), T1 = Trace (<0.1%), T2 = Trace (low ppm range), T3 = Trace (<1 ppm range), M = Minor (1-10%), and D = Dominant (>10%).

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Rocky Flats Plant

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	1 2 3
	Halogenated Organics x Water Reactive Substances (17 x 107)	T x M	Potentially Reactive	28	4 5
	Ketones x Water Reactive Substances (19 x 107)	T x M	Potentially Reactive	28b	6 7
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	8 9 10
	Metals and other elemental and alloys as sheets, rods, etc. x Water Reactive Substances (23 x 107)	D x M	Potentially Reactive	31	11 12 13
	Metal and Compounds, Toxic x Water Reactive Substances (24 x 107)	T1 x M	Potentially Reactive	35	14 15
	Nitro Compounds x Water Reactive Substances (27 x 107)	T x M	Potentially Reactive	36a	16 17
	Phenols and Creosols x Water Reactive Substances (31 x 107)	T x M	Potentially Reactive	36c	18 19
	Combustible and Flammable Materials x Water Reactive Substances (101 x 107)	D x M	Potentially Reactive	39	20 21
	Polymerizable Compounds x Water Reactive Substances (103 x 107)	T x M	Potentially Reactive	40	22 23

* Reaction Code: H = heat generation, S = solubilization of toxic substances, F = fire, GF = flammable gas generation, G = non-flammable gas generation, GT = toxic gas generation, P = violent polymerization, E = explosive.

\# Concentration of Reactants: T = Trace (<1% by wt.), T1 = Trace (<0.1%), T2 = Trace (low ppm range), T3 = Trace (<1 ppm range), M = Minor (1-10%), and D = Dominant (>10%).

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Rocky Flats Plant

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
RF 124B	Organic Acids x Caustics (3 x 10)	T x M	H	11b	1
	Caustics x Halogenated Organics (10 x 17)	M x T	H GF	13	2 3
	Caustics x Ketones (10 x 19)	M x T	H	13a	4
	Caustics x Metals and other elemental and alloys as, sheets rods, etc. (10 x 23)	M x D	H GF	14	5 6 7
	Caustics x Metal and Compounds, Toxic (10 x 24)	M x T1	S	16	8 9
	Caustics x Nitro Compounds (10 x 27)	M x T	E	16b	10 11
	Caustics x Polymerizable Compounds (10 x 103)	M x T	P H	16c	12 13
	Caustics x Water Reactive Substances (10 x 107)	M x M	Not Valid	17	14 15
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	16 17 18
	Halogenated Organics x Water Reactive Substances (17 x 107)	T x M	Potentially Reactive	28	19 20
	Ketones x Water Reactive Substances (19 x 107)	T x M	Potentially Reactive	28b	21 22

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* Reaction Code: H = heat generation, S = solubilization of toxic substances, F = fire, GF = flammable gas generation, G = non-flammable gas generation, GT = toxic gas generation, P = violent polymerization, E = explosive.

\# Concentration of Reactants: T = Trace (<1% by wt.), T1 = Trace (<0.1%), T2 = Trace (low ppm range), T3 = Trace (<1 ppm range), M = Minor (1-10%), and D = Dominant (>10%).

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Rocky Flats Plant

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	1 2 3
	Metals and other elemental and alloys as sheets, rods, etc. x Water Reactive Substances (23 x 107)	D x M	Potentially Reactive	32	4 5 6 7
	Metal and Compounds, Toxic x Water Reactive Substances (24 x 107)	T1 x M	Potentially Reactive	35	8 9 10
	Nitro Compounds x Water Reactive Substances (27 x 107)	T x M	Potentially Reactive	36a	11 12
	Phenols and Creosols x Water Reactive Substances (31 x 107)	T x M	Potentially Reactive	36c	13 14
	Combustible and Flammable Materials x Water Reactive Substances (101 x 107)	D x M	Potentially Reactive	39	15 16 17
	Polymerizable Compounds x Water Reactive Substances (103 x 107)	T x M	Potentially Reactive	40	18 19
RF 126A	Halogenated Organics x Metals and other elemental and alloys as sheets rods, etc. (17 x 23)	T x D	H F	26	20 21 22
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	23 24 25

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* Reaction Code: H = heat generation, S = solubilization of toxic substances, F = fire, GF = flammable gas generation, G = non-flammable gas generation, GT = toxic gas generation, P = violent polymerization, E = explosive.

\# Concentration of Reactants: T = Trace (<1% by wt.), T1 = Trace (<0.1%), T2 = Trace (low ppm range), T3 = Trace (<1 ppm range), M = Minor (1-10%), and D = Dominant (>10%).

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Rocky Flats Plant

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
RF 126B	Halogenated Organics x Metals and other elemental and alloys as sheets rods, etc. (17 x 23)	T x D	H F	26	1 2 3
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	4 5 6
RF 127A	Organic Acids x Metal and Compounds, Toxic (3 x 24)	T x D	S	12	7 8
	Amines, Aliphatic and Aromatic x Metals and Metal Compounds, Toxic (7 x 24)	T x D	S	12c	9 10 11
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	12 13 14
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	15 16 17
	Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a	18 19
	Metal and Compounds, Toxic x Water (24 x 106)	D x D	S	34	20 21
RF 128A	Organic Acids x Caustics (3 x 10)	T x M	H	11b	22
	Organic Acids x Metal and Compounds, Toxic (3 x 24)	T x D	S	12	23 24

* Reaction Code: H = heat generation, S = solubilization of toxic substances, F = fire, GF = flammable gas generation, G = non-flammable gas generation, GT = toxic gas generation, P = violent polymerization, E = explosive.

\# Concentration of Reactants: T = Trace (<1% by wt.), T1 = Trace (<0.1%), T2 = Trace (low ppm range), T3 = Trace (<1 ppm range), M = Minor (1-10%), and D = Dominant (>10%).

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Rocky Flats Plant

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
	Amines, Aliphatic and Aromatic x Halogenated Organics (7 x 24)	T x D	S	12c	1 2
	Caustics x Halogenated Organics (10 x 17)	M x T	H GF	13	3 4
	Caustics x Ketones (10 x 19)	M x T	H	13a	5
	Caustics x Metals and other elemental and alloys as sheets,rods, etc. (10 x 23)	M x D	H GF	14	6 7 8
	Caustics x Metal and Compounds, Toxic (10 x 24)	M x D	S	16	9 10
	Caustics x Nitro Compounds (10 x 27)	M x T	E	16b	11 12
	Caustics x Polymerizable Compounds (10 x 103)	M x T	P H	16c	13 14
	Caustics x Water Reactive Substances (10 x 107)	M x M	Not Valid	17	15 16
	Fluorides x Water Reactive Substances (15 x 107)	T x M	Potentially Reactive	18	17 18
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	24	19 20 21
	Halogenated Organics x Water Reactive Substances (17 x 107)	T x M	Potentially Reactive	28	22 23

* Reaction Code: H = heat generation, S = solubilization of toxic substances, F = fire, GF = flammable gas generation, G = non-flammable gas generation, GT = toxic gas generation, P = violent polymerization, E = explosive.

\# Concentration of Reactants: T = Trace (<1% by wt.), T1 = Trace (<0.1%), T2 = Trace (low ppm range), T3 = Trace (<1 ppm range), M = Minor (1-10%), and D = Dominant (>10%).

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Rocky Flats Plant

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
	Ketones x Water Reactive Substances (19 x 107)	T x M	Potentially Reactive	28b	1 2
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	3 4 5
	Metals and other elemental and alloys as sheets, rods, etc. x Water Reactive Substances (23 x 107)	D x M	Potentially Reactive	31	6 7 8 9
	Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a	10 11
	Metal and Compounds, Toxic x Water Reactive Substances (24 x 107)	D x M	Potentially Reactive	36	12 13 14
	Nitro Compounds x Water Reactive Substances (27 x 107)	T x M	Potentially Reactive	36a	15 16
	Phenols and Creosols x Water Reactive Substances (31 x 107)	T x M	Potentially Reactive	36c	17 18
	Combustible and Flammable Materials x Water Reactive Substances (101 x 107)	D x M	Potentially Reactive	39	19 20 21
	Polymerizable Compounds x Water Reactive Substances (103 x 107)	T x M	Potentially Reactive	40	22 23
RF 129A	Organic Acids x Alcohols and Glycols (3 x 4)	T x M	H P	11	24 25

* Reaction Code: H = heat generation, S = solubilization of toxic substances, F = fire, GF = flammable gas generation, G = non-flammable gas generation, GT = toxic gas generation, P = violent polymerization, E = explosive.

\# Concentration of Reactants: T = Trace (<1% by wt.), T1 = Trace (<0.1%), T2 = Trace (low ppm range), T3 = Trace (<1 ppm range), M = Minor (1-10%), and D = Dominant (>10%).

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Rocky Flats Plant

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
	Amines, Aliphatic and Aromatic x Halogenated Organics (7 x 17)	T x D	H GT	12b	1 2
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	D x D	H F	26	3 4 5
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	6 7 8

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* Reaction Code: H = heat generation, S = solubilization of toxic substances, F = fire, GF = flammable gas generation, G = non-flammable gas generation, GT = toxic gas generation, P = violent polymerization, E = explosive.

\# Concentration of Reactants: T = Trace (<1% by wt.), T1 = Trace (<0.1%), T2 = Trace (low ppm range), T3 = Trace (<1 ppm range), M = Minor (1-10%), and D = Dominant (>10%).

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIAL

Idaho National Engineering Laboratory

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants	Reaction Code *	Explanation Code Number
ID 111A	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	19
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
	Metal and Compounds, Toxic x Water (24 x 106)	T x D	S	33
ID 111B	Oxidizing Mineral Acids x Metals and other elemental and alloys as sheets, rods, etc. (2 x 23)	T x D	H GF F	4
	Oxidizing Mineral Acids x Combustible and Flammable Materials (2 x 101)	T x D	H F GT	9
	Oxidizing Mineral Acids x Water (2 x 106)	T x D	H	10
	Caustics x Metals and other elemental and alloys as sheets, rods, etc. (10 x 23)	T x D	H GF	15
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	19
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
	Metal and Compounds, Toxic x Water (24 x 106)	T x D	S	33

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
ID 111C	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	19	1 2 3
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	4 5 6
	Metal and Compounds, Toxic x Water (24 x 106)	T x D	S	33	7 8
ID 112A	Organic Acids x Alcohols and Glycols (3 x 4)	T x M	H P	11	9 10
	Amines, Aliphatic and Aromatic x Halogenated Organics (7 x 17)	T x D	H GT	12b	11 12
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	D x D	H F	26	13 14 15
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	16 17 18
ID 112B	Amines, Aliphatic and Aromatic x Halogenated Organics (7 x 17)	T x D	H GT	12b	19 20
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	D x D	H F	26	21 22 23

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

	Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number
1 2 3		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
4 5	ID 112C	Organic Acids x Alcohols and Glycols (3 x 4)	T x M	H P	11
6 7		Amines, Aliphatic and Aromatic x Halogenated Organics (7 x 17)	T x D	H GT	12b
8 9 10		Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	D x D	H F	26
11 12 13		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
14 15 16	ID 113A	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21
17 18 19		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
20 21	ID 113B	Organic Acids x Alcohols and Glycols (3 x 4)	M x T	H P	11
22 23		Organic Acids x Amines, Aliphatic and Aromatic (3 x 7)	M x T	H	11a
24 25		Organic Acids x Metal and Compounds, Toxic (3 x 24)	M x T	S	12

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
	Organic Acids x Polymerizable Compounds (3 x 103)	M x T	P H	12a	1 2
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	3 4 5
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	6 7 8
	Metal and Compounds, Toxic x Water (24 x 106)	T x D	S	34	9 10
ID 113C	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	11 12 13
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	14 15 16
ID 114A	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	19	17 18 19
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	20 21 22
ID 114B	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	19	23 24 25

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

	Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number
1 2 3		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
4 5 6	ID 115A	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21
7 8 9		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
10 11 12	ID 115B	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21
13 14 15		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
16 17 18	ID 115C	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21
19 20 21		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
22 23 24	ID 116A	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	20
25 26 27		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
ID 116B	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	20	1 2 3
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	4 5 6
ID 116C	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	20	7 8 9
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	10 11 12
ID 117A	Organic Acids x Metal and Compounds, Toxic (3 x 24)	T x D	S	12	13 14
	Amines, Aliphatic and Aromatic x Metals and Metal Compounds, Toxic (7 x 24)	T x D	S	12c	15 16 17
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	18 19 20
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	21 22 23
	Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a	24 25

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

	Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number
1 2	ID 117B	Organic Acids x Metal and Compounds, Toxic (3 x 24)	T x D	S	12
3 4 5		Amines, Aliphatic and Aromatic x Metals and Metal Compounds, Toxic (7 x 24)	T x D	S	12c
6 7 8		Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21
9 10 11		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
12 13		Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a
14 15	ID 117C	Organic Acids x Metal and Compounds, Toxic (3 x 24)	T x D	S	12
16 17 18		Amines, Aliphatic and Aromatic x Metals and Metal Compounds, Toxic (7 x 24)	T x D	S	12c
19 20 21		Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21
22 23 24		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
25 26		Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
ID 118A	Organic Acids x Metal and Compounds, Toxic (3 x 24)	T x D	S	12	1 2
	Amines, Aliphatic and Aromatic x Metals and Metal Compounds, Toxic (7 x 24)	T x D	S	12c	3 4 5
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	22	6 7 8
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	9 10 11
	Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a	12 13
ID 118B	Oxidizing Mineral Acids x Metals and other elemental alloys as sheets, rods, etc. (2 x 23)	T x D	H GF F	5	14 15 16 17
	Oxidizing Mineral Acids x Combustible Materials (2 x 101)	T x D	H F GT	9	18 19
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	22	20 21 22
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	23 24 25

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

	Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number
1 2	ID 118C	Organic Acids x Metal and Compounds, Toxic (3 x 24)	T x D	S	12
3 4 5		Amines, Aliphatic and Aromatic x Metals and Metal Compounds, Toxic (7 x 24)	T x D	S	12c
6 7 8		Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	22
9 10 11		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
12 13		Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a
14 15 16	ID 119A	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21
17 18 19		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
20 21 22	ID 119B	Oxidizing Mineral Acids x Metals and other elemental and alloys as sheets, rods, etc. (2 x 23)	T x D	H GF F	4
23 24 25		Oxidizing Mineral Acids x Combustible and Flammable Materials (2 x 101)	T x D	H F GT	9

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
	Caustics x Metals and other elemental and alloys as sheets, rods, etc. (10 x 23)	T x D	H GF	15	1 2 3
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	4 5 6
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	7 8 9
	Metal and other elemental and alloys as sheets, rods, etc. x Oxidizing Agents (23 x 104)	D x T	H F	29	10 11 12
	Combustibles and Flammable Materials x Oxidizing Agents (101 x 104)	D x T	H F G	37	13 14
ID 119C	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	15 16 17
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	18 19 20
ID 121A	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	23	21 22 23
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	24 25 26

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

	Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number
1 2	ID 121B	Organic Acids x Metal and Compounds, Toxic (3 x 24)	T x D	S	12
3 4 5		Amines, Aliphatic and Aromatic x Metals and Metal Compounds, Toxic (7 x 24)	T x D	S	12c
6 7 8		Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21
9 10 11		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
12 13		Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a
14 15 16	ID 121C	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	23
17 18 19		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
20 21 22	ID 122A	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	24
23 24 25		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
ID 122B	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	1 2 3
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	4 5 6
ID 122C	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	24	7 8 9
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	10 11 12
ID 123A	Organic Acids x Metal and Compounds, Toxic (3 x 24)	T x D	S	12	13 14
	Amines, Aliphatic and Aromatic x Metals and Metal Compounds, Toxic (7 x 24)	T x D	S	12c	15 16 17
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	18 19 20
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	21 22 23
	Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a	24 25

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

	Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number
1 2	ID 123B	Organic Acids x Metal and Compounds, Toxic (3 x 24)	T x D	S	12
3 4 5		Amines, Aliphatic and Aromatic x Metals and Metal Compoundsm, Toxic (7 x 24)	T x D	S	12c
6 7 8		Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21
9 10 11		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
12 13		Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a
14 15	ID 123C	Organic Acids x Metal and Compounds, Toxic (3 x 24)	T x D	S	12
16 17 18		Amines, Aliphatic and Aromatic x Metals and Metal Compounds, Toxic (7 x 24)	T x D	S	12c
19 20 21		Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21
22 23 24		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
25 26		Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
ID 124A	Organic Acids x Caustics (3 x 10)	T x M	H	11b	1
	Caustics x Halogenated Organics (10 x 17)	M x T	H GF	13	2 3
	Caustics x Ketones (10 x 19)	M x T	H	13a	4
	Caustics x Metals and other elemental and alloys as sheets, rods, etc. (10 x 23)	M x D	H GF	14	5 6 7
	Caustics x Metal and Compounds, Toxic (10 x 24)	M x T1	S	16	8 9
	Caustics x Nitro Compounds (10 x 27)	M x T	E	16b	10 11
	Caustics x Polymerizable Compounds (10 x 103)	M x T	P H	16c	12 13
	Caustics x Water Reactive Substances (10 x 107)	M x M	Not Valid	17	14 15
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	16 17 18
	Halogenated Organics x Water Reactive Substances (17 x 107)	T x M	Potentially Reactive	28	19 20
	Ketones x Water Reactive Substances (19 x 107)	T x M	Potentially Reactive	28b	21 22

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

	Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number
1 2 3		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
4 5 6 7		Metals and other elemental and alloys as sheets, rods, etc. x Water Reactive Substances (23 x 107)	D x M	Potentially Reactive	31
8 9 10		Metal and Compounds, Toxic x Water Reactive Substances (24 x 107)	T1 x M	Potentially Reactive	35
11 12		Nitro Compounds x Water Reactive Substances (27 x 107)	T x M	Potentially Reactive	36a
13 14		Phenols and Creosols x Water Reactive Substances (31 x 107)	T x M	Potentially Reactive	36c
15 16 17		Combustible and Flammable Materials x Water Reactive Substances (101 x 107)	D x M	Potentially Reactive	39
18 19		Polymerizable Compounds x Water Reactive Substances (103 x 107)	T x M	Potentially Reactive	40
20 21 22	ID 124B	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21
23 24 25		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
ID 124C	Organic Acids x Caustics (3 x 10)	T x M	H	11b	1
	Caustics x Halogenated Organics (10 x 17)	M x T	H GF	13	2 3
	Caustics x Ketones (10 x 19)	M x T	H	13a	4
	Caustics x Metals and other elemental and alloys as sheets, rods, etc. (10 x 23)	M x D	H GF	14	5 6 7
	Caustics x Metal and Compounds, Toxic (10 x 24)	M x T1	S	16	8 9
	Caustics x Nitro Compounds (10 x 27)	M x T	E	16b	10 11
	Caustics x Polymerizable Compounds (10 x 103)	M x T	P H	16c	12 13
	Caustics x Water Reactive Substances (10 x 107)	M x M	Not Valid	17	14 15
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	16 17 18
	Halogenated Organics x Water Reactive Substances (17 x 107)	T x M	Potentially Reactive	28	19 20
	Ketones x Water Reactive Substances (19 x 107)	T x M	Potentially Reactive	28b	21 22

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

	Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number
1 2 3		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
4 5 6 7		Metals and other elemental and alloys as sheets, rods, etc. x Water Reactive Substances (23 x 107)	D x M	Potentially Reactive	32
8 9 10		Metal and Compounds, Toxic x Water Reactive Substances (24 x 107)	T1 x M	Potentially Reactive	35
11 12		Nitro Compounds x Water Reactive Substances (27 x 107)	T x M	Potentially Reactive	36a
13 14		Phenols and Creosols x Water Reactive Substances (31 x 107)	T x M	Potentially Reactive	36c
15 16 17		Combustible and Flammable Materials x Water Reactive Substances (101 x 107)	D x M	Potentially Reactive	39
18 19		Polymerizable Compounds x Water Reactive Substances (103 x 107)		T x M Reactive	Potentially40
20 21 22	ID 125A	Mineral Acids x Metal and other elemental and alloys as sheets, rods, etc. (1 x 23)	T x D	GF H F	1
23 24		Mineral Acids x Metal and Compounds, Toxic (1 x 24)	T x M	S	2
25 26		Mineral Acids x Combustible and Flammable Materials (1 x 101)	T x D	H G	3

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
	Oxidizing Mineral Acids x Metal and other elemental and alloys as sheets, rods, etc. (2 x 23)	T x D	H GF F	4	1 2 3
	Oxidizing Mineral Acids x Metal and Compounds, Toxic (2 x 24)	T x M	S	6	4 5
	Oxidizing Mineral Acids x Combustible and Flammable Materials (2 x 101)	T x D	H F GT	9	6 7 8
	Organic Acids x Metals and Metal Compounds, Toxic (3 x 24)	T x M	S	12	9 10
	Amines, Aliphatic and Aromatic x Metals and Metal Compounds, Toxic (7 x 24)	T x M	S	12c	11 12 13
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	27	14 15 16
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	17 18 19
	Metals and other elemental and and alloys as sheets, rods, etc. x Oxidizing Agents (23 x 104)	D x T	H F	29	20 21 22
	Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	M x T	P H	32a	23 24

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

	Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number
1 2		Combustible and Flammable Materials x Oxidizing Agents (101 x 104)	D x T	H F G	37
3 4 5	ID 126A	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	26
6 7 8		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
9 10 11	ID 126B	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21
12 13 14		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
15 16 17	ID 126C	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	26
18 19 20		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
21 22 23	ID 127A	Mineral Acids x Metal and other elemental and alloys as sheets, rods, etc. (1 x 23)	T x D	GF H F	1

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
	Mineral Acids x Metal and Compounds, Toxic (1 x 24)	T x D	S	2	1 2
	Mineral Acids x Combustible and Flammable Materials (1 x 101)	T x D	H G	3	3 4
	Mineral Acids x Water (1 x 106)	T x D	H	3a	5 6
	Oxidizing Mineral Acids x Metals and other elemental and alloys as sheets, rods, etc. (2 x 23)	T x D	H GF F	4	7 8 9
	Oxidizing Mineral Acids x Metal and Compounds, Toxic (2 x 24)	T x D	S	6	10 11
	Oxidizing Mineral Acids x Combustible and Flammable Materials (2 x 101)	T x D	H F GT	9	12 13 14
	Oxidizing Mineral Acids x Water (2 x 106)	T x D	H	10	15 16
	Organic Acids x Metal and Compounds, Toxic (3 x 24)	T x D	S	12	17 18
	Amines, Aliphatic and Aromatic x Metals and Metal Compounds, Toxic (7 x 24)	T x D	S	12c	19 20 21
	Caustics x Metal and other elemental and alloys as sheets, rods, etc. (10 x 23)	T x D	H GF	15	22 23 24

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

	Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number
1 2		Caustics x Metal and Compounds, Toxic (10 x 24)	T x D	S	16a
3 4 5		Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21
6		Isocyanates x Water (18 x 106)	T x D	H G	28a
7 8 9		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
10 11 12		Metals and other elemental and alloys as sheets, rods, etc. x Oxidizing Agents (23 x 104)	D x T	H F	30
13 14		Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a
15 16		Metal and Compounds, Toxic x Water (24 x 106)	D x D	S	34
17 18		Combustible and Flammable Materials x Oxidizing Agents (101 x 104)	D x T	H F G	38
19 20	ID 127B	Organic Acids x Metal and Compounds, Toxic (3 x 24)	T x D	S	12
21 22 23		Amines, Aliphatic and Aromatic x Metals and Metal Compounds, Toxic (7 x 24)	T x D	S	12c
24 25		Halogenated Organics x Metals and other elemental and alloys	T x D	H F	21

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
	as sheets, rods, etc. (17 x 23)				1
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	2 3 4
	Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a	5 6
	Metal and Compounds, Toxic x Water (24 x 106)	D x D	S	34	7 8
ID 128A	Organic Acids x Caustics (3 x 10)	T x M	H	11b	9
	Organic Acids x Metal and Compounds, Toxic (3 x 24)	T x D	S	12	10 11
	Amines, Aliphatic and Aromatic x Metals and Metal Compounds, Toxic (7 x 24)	T x D	S	12c	12 13 14
	Caustics x Halogenated Organics (10 x 17)	M x T	H GF	13	15 16
	Caustics x Ketones (10 x 19)	M x T	H	13a	17
	Caustics x Metals and other elemental and alloys as sheets, rods, etc. (10 x 23)	M x D	H GF	14	18 19 20
	Caustics x Metal and Compounds, Toxic (10 x 24)	M x D	S	16	21 22

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

	Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number
1 2		Caustics x Nitro Compounds (10 x 27)	M x T	E	16b
3 4		Caustics x Polymerizable Compounds (10 x 103)	M x T	P H	16c
5 6		Caustics x Water Reactive Substances (10 x 107)	M x M	Not Valid	17
7 8		Fluorides x Water Reactive Substances (15 x 107)	T x M	Potentially Reactive	18
9 10 11		Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	24
12 13		Halogenated Organics x Water Reactive Substances (17 x 107)	T x M	Potentially Reactive	28
14 15		Ketones x Water Reactive Substances (19 x 107)	T x M	Potentially Reactive	28b
16 17 18		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
19 20 21 22		Metals and other elemental and alloys as sheets, rods, etc. x Water Reactive Substances (23 x 107)	D x M	Potentially Reactive	31
23 24		Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
	Metal and Compounds, Toxic x Water Reactive Substances (24 x 107)	D x M	Potentially Reactive	36	1 2
	Nitro Compounds x Water Reactive Substances (27 x 107)	T x M	Potentially Reactive	36a	3 4
	Phenols and Creosols x Water Reactive Substances (31 x 107)	T x M	Potentially Reactive	36c	5 6
	Combustible and Flammable Materials x Water Reactive Substances (101 x 107)	D x M	Potentially Reactive	39	7 8 9
	Polymerizable Compounds x Water Reactive Substances (103 x 107)	T x M	Potentially Reactive	40	10 11
ID 128B	Oxidizing Mineral Acids x Metals and other elemental and alloys as sheets, rods, etc. (2 x 23)	T x D	H GF F	5	12 13 14
	Oxidizing Mineral Acids x Metal and Compounds, Toxic (2 x 24)	T x D	S	7	15 16
	Oxidizing Mineral Acids x Combustible and Flammable Materials (2 x 101)	T x D	H F GT	8	17 18 19
	Organic Acids x Metal and Compounds, Toxic (3 x 24)	T x D	S	12	20 21
	Amines, Aliphatic and Aromatic x Metals and Metal Compounds, Toxic (7 x 24)	T x D	S	12c	22 23 24

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

	Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number
1 2 3		Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	24
4 5 6		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
7 8		Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a
9 10	ID 129A	Organic Acids x Alcohols and Glycols (3 x 4)	T x M	H P	11
11 12		Amines, Aliphatic and Aromatic x Halogenated Organics (7 x 17)	T x D	H GT	12b
13 14 15		Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	D x D	H F	26
16 17 18		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
19 20	ID 129B	Organic Acids x Alcohols and Glycols (3 x 4)	M x T	H P	11
21 22		Organic Acids x Amines, Aliphatic and Aromatic (3 x 7)	M x T	H	11a
23 24		Organic Acids x Metal and Compounds, Toxic (3 x 24)	M x T	S	12
25		Organic Acids x Polymerizable	M x T	P H	12a

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
	Compounds (3 x 103)				1
	Amines, Aliphatic and Aromatic x Halogenated Organics (7 x 17)	T x D	H GT	12b	2 3
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	D x D	H F	26	4 5 6
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	7 8 9
	Metals and Compounds, Toxic x Water (24 x 106)	T x D	S	34	10 11
ID 211A	Oxidizing Mineral Acids x Metals and other elemental and alloys as sheets, rods, etc. (2 x 23)	T x D	H GF F	4	12 13 14
	Oxidizing Mineral Acids x Combustible and Flammable Materials (2 x 101)	T x D	H F GT	9	15 16 17
	Oxidizing Mineral Acids x Water (2 x 106)	T x D	H	10	18 19
	Caustics x Metals and other elemental and alloys as sheets, rods, etc. (10 x 23)	T x D	H GF	15	20 21 22
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	19	23 24 25

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

	Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number
1 2 3		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
4 5		Metal and Compounds, Toxic x Water (24 x 106)	T x D	S	33
6 7	ID 212A	Amines, Aliphatic and Aromatic x Halogenated Organics (7 x 17)	T x D	H GT	12b
8 9 10		Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	D x D	H F	26
11 12 13		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
14 15	ID 213A	Organic Acids x Alcohols and Glycols (3 x 4)	M x T	H P	11
16 17		Organic Acids x Amines, Aliphatic and Aromatic (3 x 7)	M x T	H	11a
18 19		Organic Acids x Metal and Compounds, Toxic (3 x 24)	M x T	S	12
20 21		Organic Acids x Polymerizable Compounds (3 x 103)	M x T	P H	12a
22 23		Amines, Aliphatic and Aromatic x Halogenated Organics (7 x 17)	T x D	H GT	12b
24 25		Halogenated Organics x Metals and other elemental and alloys	T x D	H F	26

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
	as sheets, rods, etc. (17 x 23)				1
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	2 3 4
	Metals and Compounds, Toxic x Water (24 x 106)	T x D	S	34	5 6
ID 215A	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	26	7 8 9
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	10 11 12
ID 216A	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	20	13 14 15
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	16 17 18
ID 216B	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	20	19 20 21
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	22 23 24

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

	Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number
1	ID 217A	Halogenated Organics x Metals	T x D	H F	21
2		and other elemental and alloys			
3		as sheets, rods, etc. (17 x 23)			
4		Metals and other elemental and alloys	D x T	P H	28c
5		such as sheets, rods, etc. x			
6		Polymerizable Compounds (23 x 103)			
7	ID 217B	Organic Acids x Metal and Compounds,	T x D	S	12
8		Toxic (3 x 24)			
9		Amines, Aliphatic and Aromatic x	T x D	S	12c
10		Metals and Metal Compounds, Toxic			
11		(7 x 24)			
12		Halogenated Organics x Metals	T x D	H F	21
13		and other elemental and alloys			
14		as sheets, rods, etc. (17 x 23)			
15		Metals and other elemental and alloys	D x T	P H	28c
16		such as sheets, rods, etc. x			
17		Polymerizable Compounds (23 x 103)			
18		Metal and Compounds, Toxic x	D x T	P H	32a
19		Polymerizable Compounds (24 x 103)			
20	ID 217C	Organic Acids x Metal and Compounds,	T x D	S	12
21		Toxic (3 x 24)			
22		Amines, Aliphatic and Aromatic x	T x D	S	12c
23		Metals and Metal Compounds, Toxic			
24		(7 x 24)			

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21	1 2 3
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	4 5 6
	Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a	7 8
ID 218A	Oxidizing Mineral Acids x Metals and other elemental and alloys as sheets, rods, etc. (2 x 23)	T x D	H GF F	5	9 10 11
	Oxidizing Mineral Acids x Combustible and Flammable Materials (2 x 101)	T x D	H F GT	9	12 13 14
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	22	15 16 17
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	18 19 20
ID 218B	Oxidizing Mineral Acids x Metals and other elemental and alloys as sheets, rods, etc. (2 x 23)	T x D	H GF F	5	21 22 23
	Oxidizing Mineral Acids x Combustible and Flammable Materials (2 x 101)	T x D	H F GT	8	24 25 26

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

	Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number
1 2 3		Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	22
4 5 6		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
7 8 9	ID 219A	Oxidizing Mineral Acids x Metals and other elemental and alloys as sheets, rods, etc. (2 x 23)	T x D	H GF F	4
10 11 12		Oxidizing Mineral Acids x Combustible and Flammable Materials (2 x 101)	T x D	H F GT	9
13 14 15		Caustics x Metals and other elemental and alloys as sheets, rods, etc. (10 x 23)	T x D	H GF	15
16 17 18		Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	21
19 20 21		Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c
22 23 24		Metals and other elemental and and alloys as sheets, rods, etc. x Oxidizing Agents (23 x 104)	D x T	H F	29
25 26 27		Combustible and Flammable Materials x Oxidizing Agents (101 x 104)	D x T	H F G	37

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
ID 221A	Organic Acids x Metal and Compounds, Toxic (3 x 24)	T x D	S	12	1 2
	Amines, Aliphatic and Aromatic x Metals and Metal Comounds, Toxic (7 x 24)	T x D	S	12c	3 4 5
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	26	6 7 8
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	9 10 11
	Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	D x T	P H	32a	12 13
ID 222A	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	26	14 15 16
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	17 18 19
ID 222B	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	26	20 21 22
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	23 24 25

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

	Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number
1	ID 223A	Organic Acids x Metal and Compounds,	T x D	S	12
2		Toxic (3 x 24)			
3		Amines, Aliphatic and Aromatic x	T x D	S	12c
4		Metals and Metal Compounds, Toxic			
5		(7 x 24)			
6		Halogenated Organics x Metals	T x D	H F	26
7		and other elemental and alloys			
8		as sheets, rods, etc. (17 x 23)			
9		Metals and other elemental and alloys	D x T	P H	28c
10		such as sheets, rods, etc. x			
11		Polymerizable Compounds (23 x 103)			
12		Metal and Compounds, Toxic x	D x T	P H	32a
13		Polymerizable Compounds (24 x 103)			
14	ID 224A	Halogenated Organics x Metals	T x D	H F	26
15		and other elemental and alloys			
16		as sheets, rods, etc. (17 x 23)			
17		Metals and other elemental and alloys	D x T	P H	28c
18		such as sheets, rods, etc. x			
19		Polymerizable Compounds (23 x 103)			
20	ID 225A	Mineral Acids x Metal and	T x D	GF H F	1
21		other elemental and alloys as			
22		sheets, rods, etc. (1 x 23)			
23		Mineral Acids x Metal and	T x M	S	2
24		Compounds, Toxic (1 x 24)			
25		Mineral Acids x Combustible	T x D	H G	3
26		and Flammable Materials (1 x 101)			

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number	
	Oxidizing Mineral Acids x Metals and other elemental and alloys as sheets, rods, etc. (2 x 23)	T x D	H GF F	4	1 2 3
	Oxidizing Mineral Acids x Metal and Compounds, Toxic (2 x 24)	T x M	S	6	4 5
	Oxidizing Mineral Acids x Combustible and Flammable Materials (2 x 101)	T x D	H F GT	9	6 7 8
	Organic Acids x Metal and Compounds, Toxic (3 x 24)	T x M	S	12	9 10
	Amines, Aliphatic and Aromatic x Metals and Metal Compounds, Toxic (7 x 24)	T x M	S	12c	11 12 13
	Halogenated Organics x Metals and other elemental and alloys as sheets, rods, etc. (17 x 23)	T x D	H F	27	14 15 16
	Metals and other elemental and alloys such as sheets, rods, etc. x Polymerizable Compounds (23 x 103)	D x T	P H	28c	17 18 19
	Metals and other elemental and alloys as sheets, rods, etc. x Oxidizing Agents (23 x 104)	D x T	H F	29	20 21 22
	Metal and Compounds, Toxic x Polymerizable Compounds (24 x 103)	M x T	P H	32a	23 24
	Combustible and Flammable Materials x Oxidizing Agents (101 x 104)	D x T	H F G	37	25 26

TABLE D13-1
SUMMARY OF POTENTIAL INCOMPATIBILITIES FOR WASTE FORMS AND CONTAINER MATERIALS (CONTINUED)

Idaho National Engineering Laboratory

	Content Code	Potential Chemical Compatibility Reaction	Concentration of Reactants #	Reaction Code *	Explanation Code Number
1	ID 225B	Oxidizing Mineral Acids x Metals	T x D	H GF F	4
2		and other elemental and alloys			
3		as sheets, rods, etc. (2 x 23)			
4		Oxidizing Mineral Acids x	T x D	H F GT	9
5		Combustible and Flammable			
6		Materials (2 x 101)			
7		Halogenated Organics x Metals	T x D	H F	27
8		and other elemental and alloys			
9		as sheets, rods, etc. (17 x 23)			
10		Metals and other elemental and alloys	D x T	P H	28c
11		such as sheets, rods, etc. x			
12		Polymerizable Compounds (23 x 103)			
13	ID 226A	Halogenated Organics x Metals	T x D	H F	26
14		and other elemental and alloys			
15		as sheets, rods, etc. (17 x 23)			
16		Metals and other elemental and alloys	D x T	P H	28c
17		such as sheets, rods, etc. x			
18		Polymerizable Compounds (23 x 103)			

Summary of Potential Incompatibilities for Waste Forms and Container Material

The following is a listing and explanation of compatibility code numbers used to identify potential incompatibilities in Table D9-1.

Explanation Code Number Descriptions

1. (1 x 23) The potential chemical incompatibility is the possible reaction between non-oxidizing mineral acids (Group 1) and metals and other elemental and alloys as sheets, rods, etc. (Group 23). The non-oxidizing mineral acids are present only in trace quantities (T<1%) and are neutralized and bound in the cemented waste form. Due to the immobilization and prior reaction of the acids, the materials in this content code are considered chemically compatible.

2. (1 x 24) The potential chemical incompatibility is the tendency of non-oxidizing mineral acids (Group 1) to solubilize metals and metal compounds, toxic (Group 24). The mineral acids are present only in trace quantities (T<1%) and are neutralized and bound in the cemented waste form. Due to the immobilization and prior reaction of the non-oxidizing acids, the materials in this content code are considered chemically compatible.

3. (1 x 101) The potential chemical incompatibility is the possible reaction between non-oxidizing mineral acids (Group 1) and combustible materials (Group 101). The mineral acids are present only in trace quantities (T<1%) and are neutralized and bound in the cemented waste form. An absorbent has been added to immobilize free liquids. Due to the immobilization and prior reaction of the non-oxidizing acids, the materials in this content code are considered chemically compatible.

3a. (1 x 106) The potential chemical incompatibility is the possible reaction between mineral acids (Group 1) and water (Group 106). The mineral acids are present only in trace quantities (T<1%) and are reacted prior to loading in waste containers. In addition, the free liquids are immobilized in an absorbent and would not be available for reaction.

4. (2 x 23) The potential chemical incompatibility is the possible reaction between oxidizing mineral acids (Group 2) and metals and other elemental and alloys as sheets, rods, etc. (Group 23). The oxidizing mineral acids are present only in trace quantities (T<1%) and are reacted prior to loading in waste containers. In addition, the oxidizing mineral acids are fixed in the solidified product and would not be available to react with the metal.

5. (2 x 23) The potential chemical incompatibility is the possible reaction between oxidizing mineral acids (Group 2) and metals and other elemental and alloys as sheets, rods, etc. (Group 23). The oxidizing mineral acids are present only in trace quantities (T<1%) as residues on glass after allowing the waste to drain. The oxidizing mineral acids are present only as residual films on the glass and not as free liquids that could react with metals.

6. (2 x 24) The potential chemical incompatibility is the solubilization of metals and metal compounds, toxic (Group 24) in oxidizing mineral acids (Group 2). The oxidizing mineral acids are present only in trace quantities (T<1%) and are reacted prior to loading in waste containers. In addition, the oxidizing mineral acids are fixed in the solidified product and would not be available to react with the metal.

7. (2 x 24) The potential chemical incompatibility is the possible reaction between oxidizing mineral acids (Group 2) and metals and compounds, toxic (Group 24). The oxidizing mineral acids are present only in trace quantities (T<1%) as residues on glass after allowing the waste to drain. The oxidizing mineral acids are present only as residual films on the glass and not as free liquids that could react with metals.

8. (2 x 101) The potential chemical incompatibility is the possible reaction between oxidizing mineral acids (Group 2) and combustible materials (Group 101). The oxidizing mineral acids are present only in trace quantities (T<1%) as residues on glass after allowing the waste to drain. The oxidizing mineral acids are present only as residual films on the glass and not as free liquids that could react with the combustible materials.

9. (2 x 101) The potential chemical incompatibility is the possible decomposition of combustible materials (Group 101) by the oxidizing mineral acids (Group 2). The oxidizing mineral acids are present only in trace quantities (T<1%) and are reacted prior to loading in waste containers. In addition, the oxidizing mineral acids are fixed in the solidified product and would not be available to react with the combustible materials.

10. (2 x 106) The potential chemical incompatibility is the possible dissolution of oxidizing mineral acids (Group 2) by water (Group 106). The oxidizing mineral acids are present only in trace quantities (T<1%) and reacted prior to loading in waste containers. Both the water and the oxidizing mineral acids are fixed in the solidified product and would not be available for reaction.

11. (3 x 4) The potential chemical incompatibility is the possible reaction between organic acids (Group 3) and alcohols and glycols (Group 4). The organic acids are immobilized in a cement matrix and not available to react with the alcohols and glycols. The alcohols and glycols are also immobilized in the solidified product.

11a. (3 x 7) The potential chemical incompatibility is the possible reaction between organic acids (Group 3) and amines, aliphatic and aromatic (Group 7). The organic acids are immobilized in a cement matrix and would not be available for reaction.

11b. (3 x 10) The potential chemical incompatibility is the possibility of acid-base reactions. The organic acids (Group 3) are immobilized in a cement matrix and are not available to react with the Caustics (Group 10). Thus, this potential chemical incompatibility would not occur.

12. (3 x 24) The potential chemical incompatibility is the possible reaction between organic acids (Group 3) and metals and compounds, toxic (Group 24). The organics acids are basified prior to cementation and do not exist as free acids in the resulting product. Based on the immobilization of the acids, reactions are considered highly unlikely. In this case, solubilization is not possible.

12a. (3 x 103) The potential chemical incompatibility is the initiation of cationic polymerization by organic acids. The organic acids (Group 3) are cemented and do not exist as free acids in the resulting product. Due to the immobilization of the acids, reactions are considered highly unlikely.

12b. (7 x 17) The potential chemical incompatibility between amines (Group 7) and halogenated organics (Group 17) would not occur because the halogenated organics are solidified and are not available for reaction.

12c. (7 x 24) The potential chemical incompatibility is the possible increase in the solubility of toxic metal compounds in water due to amines acting as potential surfactants. The amines are present only in trace (T<1%) and are immobilized through absorption on sorbent materials. Also, these solid waste forms usually contain very little water and excess sorbents are added to waste containers to sorb any fluids.

13. (10 x 17) The potential chemical incompatibility is the possible reaction between caustics (Group 10) and halogenated organics (Group 17). The caustic in this content code is calcium oxide, a solid, which is dispersed in the chloride salts. The

halogenated organics are present in only trace quantities (T<1%) and are absorbed, immobilized, or solidified. Due to the immobilization of the calcium oxide in the salt, reactions are considered highly unlikely.

13a. (10 x 19) The potential chemical incompatibility is the possible self-condensation of ketones (Group 19) catalyzed by caustics (Group 10). The caustic in this content code is calcium oxide, a solid, which is dispersed in the chloride salts. Due to the immobilization of the calcium oxide in salt, reactions are considered highly unlikely.

14. (10 x 23) The potential incompatibility is the possible reaction between caustics (Group 10) metals and other elemental and alloys as sheets, rods, etc. (Group 23). The caustic in this content code is calcium oxide, a solid, which is dispersed in the chloride salts. Due to the immobilization of the calcium oxide in salt, dissolution of metals is caustics is not possible.

15. (10 x 23) The potential incompatibility is the possible dissolution of metals and other elemental and alloys as sheets, rods, etc. (Group 23) in caustics (Group 10). The caustics are present only in trace quantities (T<1%) and are reacted prior to loading in waste containers. In addition, the caustics are fixed in the cemented sludge and would not be available to react with the metals.

16. (10 x 24) The potential chemical incompatibility is the possible solubilization of toxic metals (Group 24) in caustics (Group 10). The caustic in this content code is calcium oxide, a solid, which is dispersed in the chloride salts. In this case, solubilization is not possible.

16a. (10 x 24) The potential incompatibility is the possible solubility of toxic metals (Group 24) in caustics (Group 10). The caustics are present only in trace (T<1% quantities and are reacted prior to loading in waste containers. In addition, the caustics are fixed in the cemented sludge and would not be available to react with the metals.

16b. (10 x 27) The potential chemical incompatibility is the formation of salts from nitro alkanes (Group 27) and caustics (Group 10) in the presence of water. The only caustic in this content code is calcium oxide, a solid, which is dispersed in the chloride salts. In addition, liquids are immobilized through absorption on sorbent materials. Due to the immobilization of the caustic in the fused salt, this reaction would not occur.

16c. (10 x 103) The potential chemical incompatibility is the possible initiation of anionic polymerization of Group 103 chemicals by caustics (Group 10). The only caustic in this content code is calcium oxide, a solid, which is dispersed in the chloride salts. In addition, liquids are immobilized through absorption on sorbent materials. Due to the immobilization of the caustic in the fused salt, this reaction is highly unlikely.

17. (10 x 107) This potential incompatibility is an artifact of the EPA method. Calcium oxide appears in Groups 10 and 107, and is compatible within itself.

18. (15 x 107) This potential chemical incompatibility is the reaction of fluorides (Group 15) and water reactive substances (Group 107). The solid fluorides are present in only trace quantities (T<1%) and form part of the pyrochemical salt matrix. Calcium oxide, the only water reactive substance present, is a solid dispersed in the pyrochemical salt matrix. These salts always occur with each other and are compatible.

19. (17 x 23) The potential chemical incompatibility is the reaction of halogenated organics (Group 17) with metals and other elemental alloys as sheets, rods, etc. (Group 23). The halogenated organics are present in only trace quantities (T1<1%) and are fixed in cemented sludge and would not be available to react with the metals.

20. (17 x 23) The potential chemical incompatibility is the reaction of halogenated organics (Group 17) with metals and other elemental and alloys as sheets, rods, etc. (Group 23). The halogenated organics are present in only trace quantities (T<1%) and are absorbed on combustibles. The halogenated organics are not present as free liquids to react with the metals.

21. (17 x 23) The potential chemical incompatibility is the potential reaction between halogenated organics (Group 17) and metals, other elemental and alloys as sheets, rods, drops, moldings, etc (Group 23). Aluminum and magnesium in bulk forms are especially reactive with halogenated hydrocarbons releasing much heat. Although this is a potential incompatibility, the potential effects are considered minimal for the following reasons. First, the halogenated hydrocarbons are only present in trace quantities (<1 percent by weight) and are immobilized through absorption on sorbent materials or solidification with calcium silicates or gypsum-base processes. Second, although the metals of concern may occur in dominant quantities in the content code, the metals only occur as large pieces and not in powder form, which is more reactive with the halogenated hydrocarbons. Due to the trace quantities of immobilized

halogenated organics and the non-powder size of the metal pieces, any reaction that may occur will produce minimal heat.

22. (17 x 23) The potential chemical incompatibility is the reaction of halogenated organics (Group 17) with metals and other elemental and alloys as sheets, rods, etc. (Group 23). The halogenated organics are present in only very small trace quantities (T3 < 1 ppm) as residual films on the glass and not as free liquids that could react with metals.

23. (17 x 23) The potential chemical incompatibility is the reaction of halogenated organics (Group 17) with metals and other elemental and alloys as sheets, rods, etc. (Group 23). The halogenated organics are present in only trace quantities (T<1%) as coatings on solid organics materials and are not present as free liquids that could react with metals.

24. (17 x 23) The potential chemical incompatibility is the reaction of halogenated organics (Group 17) with metals and other elemental and alloys as sheets, rods, etc. (Group 23). The halogenated organics are present in only trace quantities (T<1%) as coating on the inorganic solid materials and are not present as free liquids that could react with metals.

25. (17 x 23) The potential chemical incompatibility is the reaction of halogenated organics (Group 17) with metals and other elemental and alloys as sheets, rods, etc. (Group 23). The halogenated organics are fixed in the cemented product and would not be available for reaction.

26. (17 x 23) The potential chemical incompatibility is the reaction of halogenated organics (Group 17) with metals and other elemental and alloys as sheets, rods, etc. (Group 23). The halogenated organics are fixed in the solidified product and are not available for reaction with the metals.

27. (17 x 23) The potential chemical incompatibility is the reaction of halogenated organics (Group 17) with metals and other elemental and alloys as sheets, rods, etc. (Group 23). An absorbent has been added to immobilize any free liquids that may exist. Due to the trace quantities and immobilization of the halogenated organics, reactions are highly unlikely.

28. (17 x 107) The potential chemical incompatibility is the reaction of halogenated organics (Group 17) with water reactive substances (Group 107). The halogenated

organics are present in only trace quantities (T<1%) and are not in the form of free liquids. Calcium oxide, the only water reactive substance present, is dispersed in chloride salts. Based on the immobilization of the calcium oxide in the salt and the absence of halogenated organics as free liquids, reactions are considered highly unlikely.

28a. (18 x 106) The potential incompatibility is the possible reaction between isocyanates (Group 18) with water (Group 106). The isocyanates are present only in trace quantities (T<1%). The water is usually fixed in the solidified product and would not be available for reaction.

28b. (19 x 107) The potential chemical incompatibility is the reaction between ketones (Group 19) and water reactive substances (Group 107). The ketones are present in only trace quantities (T<1%) and are not in the form of free liquids. Calcium oxide, the only water reactive substance present, is dispersed in chloride salts. Based on the immobilization of the calcium oxide in the salt and the absence of ketones as free liquids, reactions are considered highly unlikely.

28c. (23 x 103) The potential chemical incompatibility is that polymerization may be catalyzed by these metal surfaces. The polymerizable compounds are present only in trace (T<1%) quantities and would be immobilized through absorption on sorbent materials or solidification. Second, although the metals of concern may occur in dominant quantities in the content code, the metals only occur as large pieces and not in powder form, which is more reactive with the polymerizable compounds. Due to the trace quantities of immobilized polymerizable compounds and the non-powder size of the metal pieces, any reaction that may occur will produce minimal heat.

29. (23 x 104) The potential incompatibility is the possible reaction between metals and other elemental and alloys as sheets, rods, etc. (Group 23) and oxidizing agents (Group 104). The oxidizing agents are present only in trace quantities (T<1%) and reacted prior to loading in waste containers. The waste is mixed with cement to absorb any residual liquid. Due to the immobilization and prior reaction of the oxidizing agents, reactions are highly unlikely.

30. (23 x 104) The potential incompatibility is the possible reaction between metals and other elemental and alloys as sheets, rods, etc. (Group 23) and oxidizing agents (Group 104). The oxidizing agents are present only in trace quantities (T<1%) and dissolved in aqueous solutions that were cemented into a solid monolith-type

structure. Due to the immobilization and prior reaction of the oxidizing agents, reactions will not occur.

31. (23 x 107) The potential incompatibility is the possible reaction between metals and other elemental alloys as sheets, rods, etc. (Group 23) and water reactive substances (Group 107). The outer low carbon steel drum is the only Group 23 metal found in this content code. Calcium oxide, the only water reactive substance present, is a solid dispersed in the chloride salts. Based on the immobilization of the calcium oxide in the salt, reactions are considered highly unlikely.

32. (23 x 107) The potential incompatibility is the possible reaction between metals and other elemental alloys as sheets, rods, etc. (Group 23) and water reactive substances (Group 107). Calcium oxide, the only water reactive substance present, is a solid dispersed in the chloride salts. Based on the immobilization of the calcium oxide in the salt, reactions are considered highly unlikely.

32a. (24 x 103) The potential incompatibility is the possible reaction between metals and compounds, toxic (Group 24) and polymerizable compounds (Group 103). The polymerizable compounds are present only in trace (T<1%) quantities and would be immobilized through absorption on sorbent materials or solidification. Second, although the metals of concern may occur in dominant quantities in the content code, the metals only occur as large pieces and not in powder form, which is more reactive with the polymerizable compounds. Due to the trace quantities of immobilized polymerizable compounds and the non-powder size of the metal pieces, any reaction that may occur will produce minimal heat.

33. (24 x 106) The potential chemical incompatibility is the possible solubilization of toxic metals (Group 24), which is not a concern since the water (Group 106) from the sludge is fixed in the cemented product and would not be available for reaction.

34. (24 x 106) The potential incompatibility is the possible solubilization of toxic metals (Group 24). The water (Group 106) is fixed the in the cemented product and would not be available for reaction.

35. (24 x 107) The potential incompatibility is the possible reaction between metals and metal compounds, toxic (Group 24) and water reactive substances (Group 107). The metals are present only in trace quantities (<1% by weight). Calcium oxide, the only water reactive substance present, is a solid dispersed in the chloride salts. Based on

the immobilization of the calcium oxide in the salt, reactions are considered highly unlikely.

36. (24 x 107) The potential incompatibility is the possible reaction between metals and metal compounds, toxic (Group 24) and water reactive substances (Group 107). Calcium oxide, the only water reactive substance present, is dispersed in chloride salts. Based on the immobilization of the calcium oxide in the salts, reactions are considered highly unlikely.

36a. (27 x 107) The potential incompatibility is the possible reaction between nitro compounds (Group 27) and water reactive substances (Group 107). Calcium oxide, the only water reactive substance present, is dispersed in chloride salts. Based on the immobilization of the calcium oxide in the salts, reactions are considered highly unlikely.

36c. (31 x 107) The potential incompatibility is the possible reaction between phenols and cresols (Group 31) and water reactive substances (Group 107). Calcium oxide, the only water reactive substance present, is dispersed in chloride salts. Based on the immobilization of the calcium oxide in the salts, reactions are considered highly unlikely.

37. (101 x 104) The potential incompatibility is the possible reaction between combustible materials (Group 101) and oxidizing agents (Group 104). The oxidizing agents are present only in trace quantities (T<1%) and are reacted prior to loading in waste containers. In addition, cement is added to absorb any residual liquid. Due to the immobilization and prior reaction of the oxidizing agents, this content code is considered to be chemically compatible.

38. (101 x 104) The potential incompatibility is the possible reaction between combustible materials (Group 101) and oxidizing agents (Group 104). The oxidizing agents are present only in trace quantities (T<1%) and are fixed in the solidified product. Due to the immobilization and prior reaction of the oxidizing agents, this content code is considered to be chemically compatible.

39. (101 x 107) The potential incompatibility is the possible reaction between combustible and flammable materials (Group 101) and water reactive substances (Group 107). The dominant combustible material in Group 101 is the polyethylene rigid drum liner. Calcium oxide, the only water reactive substance present, is a solid dispersed in the chloride salts. Based on the immobilization of the calcium oxide in the salt, reactions are considered highly unlikely.

40. (103 x 107) The potential incompatibility is the possible reaction between polymerizable compounds (Group 103) and water reactive substances (Group 107). Calcium oxide, the only water reactive substance present, is a solid dispersed in the chloride salts. Based on the immobilization of the calcium oxide in the salt, reactions are considered highly unlikely.

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Waste Isolation Pilot Plant

Carlsbad, New Mexico

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APPENDIX E1

RCRA GROUNDWATER PROTECTION INFORMATION
WASTE ISOLATION PILOT PLANT

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APPENDIX E1
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APPENDIX E1
RCRA GROUNDWATER PROTECTION INFORMATION
WASTE ISOLATION PILOT PLANT

1.0 Introduction

The Waste Isolation Pilot Plant (WIPP) Project was authorized by the U.S. Department of Energy (DOE) National Security and Military Applications of the Nuclear Energy Authorization Act of 1980 (Public Law 96-164). Its legislative mandate is to provide a research and development facility to demonstrate the safe disposal of radioactive waste resulting from national defense programs and activities. To fulfill this mandate, the WIPP facility has been designed to perform scientific investigations of the behavior of bedded salt as a repository medium and the interactions between the salt and radioactive wastes.

In 1991, DOE proposed to initiate a multi-year experimental Test Phase designed to demonstrate the performance of the repository (Molecke, 1990; Molecke and Lappin, 1991). The Test Phase activities involve experiments using transuranic (TRU) waste typical of the waste planned for future disposal at the WIPP facility.

Experimental waste will be received from the DOE Rocky Flats Plant and the Idaho National Engineering Laboratory. Although the WIPP facility is designed to receive wastes over a 25-year period, the full design capacity will not be utilized until scientific data and analysis obtained during the Test Phase indicate that disposal of radioactive and radioactive mixed waste at the WIPP facility is protective of human health and the environment. Near the end of the Test Phase, DOE will make a determination as to whether the WIPP facility will ultimately become the nation's first permanent TRU waste repository for DOE facilities.

Substantial quantities of the TRU waste proposed for shipment to the WIPP facility will contain hazardous chemical components that qualify as "hazardous waste" under the Resource Conservation and Recovery Act (RCRA). Therefore, the WIPP facility is a "mixed waste" miscellaneous unit, subject to regulation by the New Mexico Environment Department (NMED) under New Mexico Hazardous Waste Management Regulations (HWMR-6), Part V, Subpart X. The NMED was granted authority by the U.S. Environmental Protection Agency (EPA) to regulate radioactive mixed waste facilities in New Mexico effective July 25, 1990. Part A of a RCRA permit application was submitted by DOE to the NMED's predecessor to meet part of the requirements for interim status under RCRA.

Because geologic repositories, such as the WIPP facility, are defined under RCRA as land disposal facilities, the groundwater monitoring requirements of HWMR-6, Pt. V, Subpart X, must

be addressed. HWMR-6, Pt. V, Subpart F, applies to miscellaneous unit treatment, storage, and disposal facilities (TSDF) only if groundwater monitoring is needed to satisfy HWMR-6, Pt. V, sections 264.601 through 264.603, performance standards. This appendix demonstrates that groundwater monitoring is not needed in order to demonstrate compliance with the performance standards; therefore, HWMR-6, Pt. V, Subpart F, will not apply to the WIPP facility.

DOE is seeking to demonstrate to a reasonable degree of certainty that there will be no migration of hazardous waste or hazardous constituents via groundwater during the Test Phase. In March 1989, DOE submitted a No-Migration Variance Petition (DOE, 1990a) under 40 CFR 268.6 to the EPA demonstrating that there will be no migration of hazardous waste or hazardous constituents from the WIPP facility during the Test Phase. On November 14, 1990, EPA granted the WIPP Project a Conditional No-Migration Variance under 40 CFR 268.6. The EPA concluded that hazardous constituents will not migrate to groundwater from the repository during the Test Phase (EPA, 1990).

To fulfill environmental performance standards for groundwater requirements as described in HWMR-6, Pt. V, secs. 264.601(a) and 264.602, the following points are addressed in this appendix:

1. The potential for migration of hazardous waste or hazardous constituents from the facility to the uppermost aquifer by an evaluation of:

   a. A water balance of precipitation, evapotranspiration, runoff, and infiltration.

   b. Unsaturated zone characteristics (e.g., geologic materials, physical properties, and depth to groundwater).

   c. The existing quality of groundwater, including other sources of contamination and other cumulative impact on the groundwater.

2. The potential for hazardous waste or hazardous constituents that enter the uppermost aquifer to migrate to a water supply well or surface water by evaluation of:

   a. Saturated zone characteristics (i.e., geologic materials, physical properties, and rate and direction of groundwater flow).

   b. The proximity of the facility to water supply wells or surface water.

   c. The proximity to and withdrawal rates of current and potential groundwater users.

This document provides the data necessary to demonstrate that the migration of hazardous waste or hazardous constituents from the WIPP underground facility by way of the most likely water-bearing unit to water supply wells (domestic, industrial, or agricultural) or to surface water is unlikely. To make this demonstration, DOE considered formation permeability and fractures, the location and relationship of water-bearing units to the repository horizon, and the potential for flooding. Also considered were the characteristics of the waste, integrity of the waste containers, and the chemical composition of groundwater in the repository area, as recommended in the EPA's permit guidance for hazardous waste storage and disposal in geologic repositories. The facility design (Section 7.0) and waste containment (Section 8.0) are key factors related to the ability of the WIPP site to isolate waste from groundwater with a high degree of certainty.

The demonstration provided in this appendix is formatted as follows:

- Section 2.0 is a groundwater protection summary.
- Section 3.0 describes the geographical setting and land use at the WIPP site.
- Section 4.0 provides a general summary of the geologic characteristics of the WIPP site that pertain directly to the ability of the WIPP site to contain waste.
- Section 5.0 presents local climatological data and describes the water balance at the WIPP site.
- Section 6.0 describes the hydrologic conditions and groundwater quality at the WIPP site.
- Section 7.0 describes facility design related to waste containment.
- Section 8.0 presents waste containment characteristics that ensure isolation of wastes in the WIPP facility.
- Section 9.0 presents a general summary that demonstrates that the WIPP facility meets groundwater performance standards and the requirements for groundwater protection, as required in HWMR-6, Pt. V, secs. 264.601 and 264.602.

2.0 Groundwater Protection Summary

Since 1975, an extensive program of site characterization and validation has been conducted at the WIPP site. The results of these studies have been summarized in numerous publications, including the following documents: (1) Geological Characterization Report (Powers et al., 1978); (2) the WIPP Design Validation Final Report (DOE, 1986); (3) Summary of Site-Characterization

Studies Conducted from 1983 Through 1987 at the Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico (Lappin, 1988); (4) the WIPP Final Safety Analysis Report (FSAR) (DOE, 1990b); and (5) the WIPP No-Migration Variance Petition (DOE, 1990a). These studies provided information that was used to substantiate the conclusion that there is no possibility of migration of hazardous waste or hazardous constituents from the WIPP facility by groundwater. This section summarizes the factors (discussed in detail in Chapter D, Facility and Process Information, and the appendices to Chapter D) that justify the determination that the groundwater monitoring requirements in HWMR-6, Pt. V, Subpart F, and HWMR-6, Pt. V, sec. 264.602, are not applicable to the WIPP site.

The WIPP site geologic and hydrologic investigations indicate there will be little groundwater available to mobilize and transport waste. The groundwater protection information provided will demonstrate that during the Test Phase: (1) groundwater will not come in contact with the waste, and (2) there is no potential for any possible contaminated groundwater to migrate from the disposal horizon to the accessible environment, due to the existence of natural hydrologic gradients toward the facility level from all surrounding water-bearing zones.

Because the WIPP site is a unique land disposal unit constructed far below the surface, the water-bearing unit most likely to be affected by releases from the repository is the Culebra Dolomite Member of the Rustler Formation which lies 1400 feet above the repository horizon. The Culebra Dolomite is the most likely pathway to transport contaminated groundwater to the accessible environment or to surface water. The possibility of transport of hazardous waste or hazardous constituents to the Culebra Dolomite Member will be discussed later in this section.

The WIPP facility horizon is located 2,150 feet below the land surface in the Salado Formation, a bedded salt formation. The thick sequences of predominantly very low to low permeability sediments and evaporites isolate the waste disposal horizon from any infiltration from the surface as well as from the overlying water-bearing units (Sections 5.0, 6.0, and 7.0). The facility disposal horizon is isolated from the underlying water-bearing formations by about 2,000 feet of very low permeability sediments and evaporites. It is separated from the overlying Culebra Dolomite Member by about 1,400 feet of evaporites and other sedimentary rocks. All shafts extending to the facility horizon have been designed and constructed to minimize the infiltration of water from the overlying water-bearing units into the facility during the operational life of the facility (DOE, 1990b). All groundwater seepage into the shafts is collected and routed for disposal by water collection rings built into the shaft liners.

Very small amounts of brine are trapped in the host rock salt (Deal and Case, 1987; Deal et al., 1987, 1989). The quantity of brine available is insufficient to consider it a potential transport medium during the Test Phase. Additionally, evaporation of the brine due to the normal mine ventilation prevents the accumulation of brine in quantities sufficient to come in contact with the

√ waste itself. Also the natural hydrologic gradient during the Test Phase is from the surrounding
√ rock to the repository horizon, making transport away from the facility unlikely.

√ During the Test Phase, brine compositionally similar to the brine that occurs naturally in the WIPP
√ vicinity will be added to some of the waste containers for experimental purposes. Containers will
√ be inspected and monitored during these tests. In the unlikely event that the test bins should
√ develop leaks, the brine added for experimental purposes will not migrate from the test bins and
will be controlled by the Radiological Control Boundary (RCB), which will serve as a secondary
containment system installed around the bins. The secondary containment around the bins, and
√ the limited amount of added brine will preclude the migration of hazardous waste or hazardous
constituents from the disposal area to any water-bearing unit or to the accessible environment
√ during the Test Phase at the WIPP facility (Section 8.0).

The WIPP site is located in a very sparsely populated region in which the major land uses are
cattle grazing, oil and gas production, and potash mining (DOE, 1990b). The facility is remote
from significant surface water resources, and the poor quality and small quantity of groundwater
in the area limit its possible uses. Water in the water-bearing strata overlying and underlying the
facility horizon is high in dissolved solids and is not potable. The only potable groundwater in the
√ general area is found in isolated and discontinuous perched or semiperched water tables in the
√ Dewey Lake Redbeds or the Santa Rosa Formation. The nearest wells that produce potable
√ water used for domestic and livestock purposes are located 3 miles south of the WIPP facility
(DOE, 1990b). There is no connection between the confined groundwater systems at the WIPP
√ facility and nearby surface water bodies. There is, therefore, no potential for waste placed in the
√ WIPP facility to affect water resources by entering water supply wells or surface water systems.

To summarize, for waste to migrate to groundwater-bearing units, there must first be a transport
medium (in this case, water or brine). There must also be a pathway, such as a shaft, a drill
hole, or fracture, that would connect the contaminated brine with overlying water-bearing units,
that would be the most likely routes to the accessible environment. In addition, there must be a
driving force or gradient to transport contaminants from the waste disposal area. None of these
√ factors is considered to be significant at the WIPP facility during the Test Phase, because of the
√ physical characteristics of the site and test and facility designs. No feasible transport medium or
√ hydraulic gradient will exist during the Test Phase period at the WIPP facility, and no natural
√ pathway exists to allow migration of hazardous waste or hazardous constituents from the waste
√ disposal area to any water-bearing unit. If, after the Test Phase, the WIPP facility is determined
to be an unsuitable repository for permanent disposal of TRU waste, the waste emplaced during
√ the Test Phase will be removed from the underground storage facility. Migration of hazardous
√ waste or hazardous constituents in groundwater during the Test Phase is highly unlikely.

3.0 Geographical Setting and Land Use

3.1 Geographical Setting

The WIPP site is located in the Pecos River Valley section of the Great Plains physiographic province in the north-central part of the Delaware Basin. The land surface in the region surrounding the WIPP site slopes gently to the west and southwest at approximately 45 feet per mile. The surface elevations range from 3,550 feet above mean sea level (MSL) along the eastern border of the site to 3,300 feet MSL in the west. Eolian sand, which occurs as partially stabilized or active sand dunes, covers much of the site. The sand, of Holocene age, is very erratic in distribution and thickness (DOE, 1990b). Appendices D6 and D7 of Chapter D, Facility and Process Information, provide more detail on the geographical setting of the WIPP site.

The WIPP site is located in Eddy County 26 miles east of Carlsbad, New Mexico, in an area known as Los Medanos (The Dunes) (Figure E1-1). This area is relatively flat and sparsely inhabited with little water and limited land uses. Most of the land is federally or state owned and is used principally for grazing. Other uses of land in the area include potash mining and oil and gas exploration and development.

Livingston Ridge, located about 4 miles northwest of the WIPP facility, is the most prominent physiographic feature in the area. This northeast-trending escarpment is about 12 miles long and 75 feet high and marks the eastern edge of Nash Draw. Late Permian Dewey Lake Redbeds and the Pleistocene age Gatuna Formation and Mescalero caliche crop out along the ridge (Figure E1-2).

Nash Draw is northwest of Livingston Ridge and is a shallow northeast-trending depression 3 to 9 miles wide. It is the nearest drainage course to the west of the WIPP facility. Elevations within Nash Draw range from 3,300 feet MSL at its head in the northeast to 2,945 feet MSL at Salt Lake near the Pecos River and are generally 200 to 300 feet lower than the surrounding terrain. Nash Draw is believed to have developed as a result of the subsurface dissolution of salt from the Rustler and upper Salado Formations and gypsum and anhydrite from the Rustler, followed by subsidence of overlying materials (DOE, 1990b).

East of the WIPP facility, the nearest major drainage course is the San Simon Swale (Figure E1-2). The swale is a southeast-trending depression about 25 miles long and from 2 to 6 miles wide that overlies the southern extent of the Capitan Reef. Elevations within the depression range from 3,650 feet MSL in the northwest to 3,270 feet MSL in the collapse feature called San Simon Sink at the southeastern end of the swale, about 18 miles east of the WIPP facility. The sink is filled with fine sand and calcareous silt, and the surface of the swale is covered by eolian sand, which masks the relief (DOE, 1990b).

San Simon Swale probably originated from a combination of surface stream erosion and solution subsidence because the area of collapse seems to be confined to the sink areas and is not pervasive over the entire swale. Rather, collapse in the sink areas steepened the local drainage gradient, resulting in headward cutting and widening of the swale.

Between San Simon Swale and the WIPP facility is a broad, low mesa named "the Divide." About 7 miles east of the WIPP facility, the Divide rises about 100 feet above the surrounding terrain and has an elevation of about 3,800 feet MSL. It marks the local boundary between the southwest drainage toward Nash Draw and the southeast drainage toward San Simon Swale. The Divide is capped by the Ogallala Formation of late Tertiary age and an overlying caliche layer (DOE, 1990b).

3.2 Land Use

The WIPP site consists of 16 sections of federal land located in Township 22 South, Range 31 East (Figure E1-3). Lands were withdrawn from settlement, sale, location, or entry under the general land laws by Public Land Order 6403, which authorized the land to be used for the construction of the WIPP facility. Surface land uses in this area remain largely unchanged with the exception of the one square mile area encompassing the facility. Surface entry for mining, drilling, and resource exploration is restricted in the 16 sections from purposes other than support of the WIPP Project.

The WIPP site is divided into three zones (Figure E1-3). Zone I, covering about 35 acres, encompasses all major surface facilities and is surrounded by a chain-link fence (Figure E1-3). Zone II indicates the maximum extent of present and future underground development (Figure E1-3). The Zone III boundary extends a minimum of 1 mile beyond any underground development and provides a functional barrier between the underground region defined by Zone II and the accessible environment.

The major use of land within 10 miles of the center of the site is cattle ranching. There are about 500 head of cattle within 5 miles of the site and approximately 1,500 head between 5 and 10 miles from the site. At present, none of the ranches within a 3-mile radius of the WIPP facility uses well water for livestock. The Smith Ranch used well water for domestic consumption and grazing until 1978, but the quality was poor and they now use water supplied by pipeline. Drinking water at the Smith Ranch and the WIPP facility is supplied by the International Mineral and Chemical Corporation (IMCC), which has a well system in the Capitan Aquifer. Stock water comes from IMCC and the New Mexico Potash Corporation, whose well systems tap the Ogallala Formation (DOE, 1990b).

The WIPP site lies in a sparsely populated area. Eight people reside at the Mill's Ranch, the residence nearest the WIPP facility, located about 3.5 miles south-southwest of the site. The

nearest town, Loving, New Mexico, has a population of about 1,700. Loving lies about 18 miles southwest of the site. There are several active potash mines within 15 miles of the WIPP site. The closest is the Western Ag-Mineral Company potash mine located approximately 5 miles west-southwest of the WIPP site.

4.0 Site Geology

4.1 Site-Specific Exploration Techniques

Detailed site-specific exploration techniques have been and are being utilized at the WIPP site. Among these are geophysical surveys, including seismic reflection, resistivity, gravity, electromagnetic, and magnetic techniques; borehole exploration, including coring, geophysical logging, and hydrologic testing; and geologic mapping. Many publications describe the geology at the WIPP site, including the Geologic Characterization Report, Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico (Powers et al., 1978); the Final Safety Analysis Report (FSAR) (DOE, 1990b); Regional Geology of Ochoan Evaporites, Northern Part of the Delaware Basin (Bachman, 1984); Summary of Site-Characterization Studies Conducted from 1983 through 1987 at the Waste Isolation Pilot Plant (WIPP) Site, Southeastern New Mexico (Lappin, 1988); and Facies Variability and Post Depositional Alteration Within the Rustler Formation in the Vicinity of the Waste Isolation Pilot Plant, Southeastern New Mexico (Holt and Powers, 1991).

4.2 Site Stratigraphy

The WIPP facility is constructed near the middle of a sequence of evaporite beds about 3,600 feet thick that consist primarily of halite and anhydrite (Figures E1-4, E1-5). This chapter summarizes the stratigraphic units from the surface down to the Castile Formation, including the Salado Formation. Special emphasis is placed on the water-bearing units and the Salado Formation whose properties eliminate the potential for migration of hazardous waste or hazardous constituents from the WIPP site during the Test Phase. Detailed descriptions of local stratigraphy are provided in the reports named above and in Appendices D6 and D7 of Chapter D, Facility and Process Information.

4.2.1 Permian System

The nearly 13,000 feet of Permian strata that were deposited within the Delaware Basin area constitute the most complete Permian sequence in North America (Brokaw et al., 1972). At the WIPP site, the average thickness of the Permian sequence is about 12,800 feet. The upper part of the sequence, in which the facility is located, is composed of approximately 3,600 feet of thick evaporite beds (primarily halite and anhydrite) with only minor amounts of clastic material (DOE, 1990b). The Permian System is divided into four series which are, in ascending order, the

Wolfcampian, Leonardian, Guadalupian, and Ochoan. The Permian-age rocks of interest here are part of the Ochoan Series.

Ochoan Series

The Ochoan sediments are of marine origin and are separable into two distinct sections: (1) a thick lower section of evaporites, and (2) a thinner upper layer of redbeds. The lower section includes, in ascending order, the Castile, Salado, and Rustler Formations. The upper section consists of the Dewey Lake Redbeds. A summary of the Ochoan evaporites in the northern Delaware Basin is provided in Bachman (1984).

Castile Formation

The Castile Formation underlies the Salado Formation. The thickness of the Castile at and near the WIPP site is approximately 1,250 feet. Lithologically, the Castile contains a sequence of three thick anhydrite beds, separated by two thick halite sequences. These low-permeability evaporite units lie between the rocks of the Bell Canyon Formation and the overlying Salado Formation. The evaporites of the Castile Formation were deposited in the Delaware Basin on the basinal side of the Permian Capitan Reef. These evaporite deposits almost completely filled the basin prior to deposition of the Salado Formation.

Salado Formation

The WIPP underground structures are being excavated in the Salado Formation. A core hole, ERDA-9, was drilled at the center of the WIPP site through the Salado and into the Castile Formation. At ERDA-9, the top of the Salado is 848 feet below ground surface (BGS), and the base is at 2,824 feet BGS for a total thickness of 1,976 feet. The waste disposal horizon is located approximately 2,150 feet BGS. Schematic sections and detailed lithologic logs for ERDA-9 and additional core holes surrounding the site, as well as information obtained from shaft mapping, may be found in the WIPP FSAR (DOE, 1990b) and Holt and Powers (1984, 1986, 1990).

The Salado Formation is composed predominantly of halite, which constitutes about 85 to 90 percent of this formation at the WIPP facility. The next most abundant rock type in the formation is anhydrite. The remainder of the formation is polyhalite and other potassium-rich rocks with subordinate amounts of glauberite, magnesite, sandstone, siltstone, and claystone (DOE, 1990b).

The Salado Formation is divided informally into three members: an unnamed lower member, the McNutt potash zone, and an unnamed upper member. The WIPP underground facility is in the lower member, which is 1,094 feet thick and is composed of alternating thick layers of halite and

thinner interbeds of anhydrite and polyhalite. Thin bands of magnesite form a carbonate-rich zone in the lower part of most of the polyhalite and anhydrite seams. Seams of claystone underlie the anhydrite and polyhalite seams. The clay seams, in turn, are underlain by dark to medium-gray argillaceous halite, which grades downwards into polyhalite or clear halite (DOE, 1990b).

The McNutt potash zone is 380 feet thick at the center of the WIPP site and differs from the other members of the Salado in that it is rich in potassium-bearing minerals. In addition to potassic rocks, the McNutt contains thin seams of anhydrite and polyhalite within the dominant halite (DOE, 1990b).

The upper unnamed member is 502 feet thick at the center of the WIPP site and is composed predominately of halite with minor amounts of anhydrite and polyhalite. It also contains two persistent beds of very fine-grained sandstone, the Vaca Triste sandstone and Marker Bed 101. These halite-cemented sandstones are found throughout the Delaware Basin. These relatively thin sandstone beds occur, respectively, 30 to 40 feet and 112 to 120 feet below the top of the member (DOE, 1990b). A detailed discussion of the stratigraphy of the Salado Formation at the underground facility level is given in Appendices D6 and D7 of Chapter D, Facility and Process Information.

Rustler Formation

In the WIPP site area, the Salado Formation is overlain conformably by the Rustler Formation. The Rustler Formation is approximately 310 feet thick at the center of the site. Overall, the lithology of the Rustler is quite variable, containing carbonates, sulfates (gypsum, anhydrite, polyhalite), clastic materials, and halite (Holt and Powers, 1991). The Rustler Formation is the youngest unit in the Ochoan evaporite sequence and is a key marker bed of the upper Permian in Texas and New Mexico. The Rustler Formation is divided into five members in the WIPP site area. The division includes: (1) at the base, an unnamed unit of clayey siltstone and very fine-grained sandstone with thin interbeds of anhydrite and halite; (2) the Culebra Dolomite Member, a unit of thin bedded, finely crystalline dolomite; (3) the Tamarisk Member, mostly anhydrite and some unconsolidated clayey silt; (4) the Magenta Dolomite Member, a cross-laminated, fine-grained dolomite; and (5) the Forty-niner Member, anhydrite with a single interbed of clayey silt. The unnamed lower member is approximately 120 feet thick and is dominated by siltstone and claystone with lesser amounts of anhydrite and halite. The anhydritic upper Forty-Niner Member of the formation is approximately 50 to 60 feet thick (Powers et al., 1978). The Culebra and Magenta Dolomite Members of the Rustler Formation are water-bearing in the vicinity of the WIPP site. These two dolomite members are discussed below. Additional detail on Rustler Formation stratigraphy is given in Appendices D6 and D7 of Chapter D, Facility and Process Information.

Culebra Dolomite Member

The Culebra Dolomite Member occurs in the Rustler Formation between 704 and 727 feet BGS near the center of the WIPP site (Winstanley and Carrasco, 1986). It is a thinly-bedded microcrystalline dolomite that contains many small spherical cavities ranging 2 to 20 millimeters in diameter. These cavities may be partially filled with secondary anhydrite, gypsum, or calcite. Although many cavities are open, they do not appear to be interconnected except along fractures (Mercer, 1983).

The Culebra Dolomite has been examined extensively during mapping of the Waste Handling Shaft (Holt and Powers, 1984), the Exhaust Shaft (Holt and Powers, 1986), and in the Air Intake Shaft (Holt and Powers, 1990). These observations, along with the results of the evaluation of numerous core samples, have indicated that most zones of interconnected porosity and formation permeability is along fractures. Both open-and sulfate-filled vugs and fractures are locally abundant across the site area. The majority of the Culebra sediment is of uniform size, fine-grained carbonate mud, which upon lithification produced finely crystalline dolomite.

Magenta Dolomite Member

The Magenta Dolomite Member occurs in the Rustler Formation between 596 and 620 feet BGS near the center of the WIPP site (Winstanley and Carrasco, 1986). It is characterized by alternating wavy laminae of silty dolomite and anhydrite altered locally to gypsum. The dolomite is bounded above and below by anhydrite (Mercer, 1983) of the Forty-niner and Tamarisk Members of the Rustler Formation, respectively.

Dewey Lake Redbeds

The Dewey Lake Redbeds are the uppermost unit of the Late Permian Ochoan Series at the WIPP site and represents the top of the Paleozoic section in the Delaware Basin. At the center of the WIPP site, the Dewey Lake Redbeds are 474 feet thick. The Dewey Lake Redbeds consist of mudstone, siltstone, and interbedded thin lenticular beds of sandstone.

4.2.2 Triassic System

Late Triassic rocks in the northern part of the Delaware Basin belong to the Dockum Group which unconformably overlies the Dewey Lake Redbeds. The Dockum Group occurs in the vicinity of the WIPP site as an erosional wedge pinching out near the center of the site. It consists of fine-to-coarse-grained sandstone with interbeds of siltstone and mudstone. Throughout most of the area, the Dockum Group sandstone is covered by surficial Cenozoic deposits.

4.2.3 Tertiary and Quaternary Systems

Cenozoic and more recent rocks found at the WIPP site consist of the Pleistocene- and Holocene-age Gatuna Formation, the Mescalero caliche, and recent windblown sand and playa lake deposits. Although not occurring at the site, the late Cenozoic Ogallala Formation occurs in the WIPP site area.

Recent (Holocene age) deposits in the vicinity of the WIPP site include windblown sand, alluvium, and playa lake deposits (Powers et al., 1978). The most prevalent recent deposits consist of the windblown sand that covers most of the WIPP area (Figure E1-6). The sand occurs as either tracts of conspicuous dune fields or as sheet deposits. The dune deposits can be up to 100 feet thick, whereas the sheet deposits are typically no more than 10 to 15 feet thick.

Alluvial deposits occur in ¼- to ¾-mile-wide belts along declivities into Nash Draw, for example, along the base of Livingston Ridge and locally in small depressions (Figure E1-6). These deposits are similar to small alluvial fans or sheet deposits.

Playa deposits consist of eolian sand, alluvium, and gypsum and halite. The nearest playas are about 5 miles west of the WIPP site within Nash Draw (Figure E1-6).

Twenty-seven feet of the Gatuna Formation were encountered at the center of the site. This formation consists of reddish-brown, poorly consolidated sand, gravel, and silty clay. Beneath a cover of windblown sand, much of the site area is covered by a hard, resistant petrocalcic horizon informally known as the Mescalero caliche, which is about 4.3 feet thick in the site area (DOE, 1990b).

The Ogallala Formation, of Miocene age, is a major water-bearing unit supplying groundwater for a large area of the Permian Basin east of the WIPP site. This unit does not occur west of San Simon Swale, except for thin exposures about 7 miles east of the WIPP facility. Therefore, activities at the WIPP facility will not impact the Ogallala aquifer.

5.0 Climatology and Water Balance

5.1 Climatology

The regional and local climate is semiarid. The mean annual rainfall is approximately 12 inches, about half of which is received from thunderstorms during June through September. Daytime summer temperatures consistently exceed 90°F and occasionally rise above 100°F. Winter afternoon temperatures often rise as high as 70°F. Nighttime lows during the winter average near 23°F, occasionally dipping below 14°F. Prevailing winds are from the southeast; however, strong winds are frequent (especially in the spring) and can blow from any direction, creating potentially

violent windstorms which can carry large volumes of dust and sand. Detailed compilations of climatic data for the WIPP site appear in the WIPP Ecological Monitoring Reports (Fischer, 1985, 1987, 1988; DOE, 1990c). Climatic data are currently being collected approximately 2,000 feet northwest of the Zone I boundary of the WIPP site. Additional climatic information appears in the Final Environmental Impact Statement (FEIS) (DOE, 1980) and the WIPP FSAR (DOE, 1990b). Additional discussion of the local climate of the WIPP site is given in Appendices D4, D5, and D6 of Chapter D.

5.2 Local Water Balance

The infiltration and percolation rates of meteoric water into the sediments overlying the facility horizon have been investigated for the U.S. Bureau of Land Management (Geohydrology Associates, Inc., 1978). At least 96 percent of precipitation was lost due to evapotranspiration. On the average, therefore, the annual amount of infiltration would be less than 0.5 inch per year and may, for many years, be essentially nonexistent.

The widespread presence of the Mescalero caliche, which has existed several feet below the surface for approximately 500,000 years, provides an additional barrier to infiltration (Bachman, 1985). Its existence indicates that, on a regional scale, not enough infiltration has taken place to result in its complete dissolution. The upper surface of the hard caliche typically is covered with a mat of plant roots which indicate that most of the moisture that reaches that surface is taken up by plants and transpired. It is difficult to arrive at a precise figure for the amount of water that infiltrates downward into the formations overlying the WIPP site. Infiltration is apparently negligible as evidenced by the absence of a near-surface groundwater body or regional water table above the Rustler Formation at the WIPP site (DOE, 1990b).

A regional water-balance study has been conducted covering approximately 2,000 square miles in Eddy County east of the Pecos River (Figures E1-7 and E1-8) (Hunter, 1985). The study encompassed all local stratigraphic units above the Salado Formation and below the Ogallala Formation. The results of that study showed that recharge to the Rustler Formation water-bearing units was not occurring at or in the vicinity of the WIPP site. Hunter (1985) showed that the uncertainties in local and regional precipitation, infiltration, evapotranspiration, and groundwater discharge from the Rustler Formation are so large that water-budget techniques cannot be used either to determine the amount of recharge or to determine that recharge is actually occurring. As reported in Lappin (1988), the water budget described by Hunter (1985) is, in fact, consistent with the conclusion that no recharge is now occurring at or near the WIPP site. The hydrologic and isotopic studies presented in Sections 4.1, 4.3, and 4.4.2 of Lappin (1988) place tight constraints on the possibility of recharge to the Rustler Formation presently being active at the WIPP site.

A recent, detailed hydrogeologic study (Holt et al., 1989) presents additional evidence that the Rustler Formation and its water-bearing units are not now receiving recharge. The results of this study support the concept that the Rustler Formation in the WIPP site area has not been recharged for at least 10,000 years. This conclusion is supported by the results of isotopic studies presented by Lambert (1983, 1987) and Lambert and Harvey (1987).

Recharge to the waste disposal horizon would require the infiltration and percolation of precipitation from the surface and through the overlying sedimentary sequence. The hydrologic investigations discussed above demonstrate that this is not occurring at the WIPP facility.

It is concluded from these investigations that infiltration of precipitation and recharge to either the facility disposal horizon or the water-bearing units of the overlying Rustler Formation is not sufficient to cause the future migration of hazardous constituents to the accessible environment during the Test Phase. It is also concluded that the waste will not come into contact with infiltrating precipitation and groundwater recharge during the Test Phase.

6.0 Site Hydrology and Water Quality

6.1 Surface Hydrology

Surface water is generally absent at the WIPP site. The nearest large surface water body, Laguna Grande de la Sal, is located about 8 miles west-southwest of the WIPP site in Nash Draw where shallow brine ponds occur. The only other surface water is the Pecos River, which is 14 miles southwest of the WIPP site at its closest point. Small man-made livestock water holes ("tanks") occur several miles from the WIPP site, but are not hydrologically connected to the formations overlying the WIPP facility. The source of water in these tanks is runoff from precipitation (Hunter, 1985). Additional detail on the surface water hydrology of the WIPP site area is presented in Appendices D6 and D7 of Chapter D, Facility and Process Information.

6.2 Subsurface Hydrology

Several water-bearing zones have been identified and extensively studied near the WIPP facility. Limited amounts of potable water are found in the Dewey Lake Redbeds and the overlying Triassic Dockum Group several miles south and east of the WIPP facility. Two water-bearing units, the Culebra and Magenta Dolomites, occur in the Rustler Formation and produce brackish to saline water in the vicinity of the site. Another saline water-bearing zone that occurs west of the site beneath Nash Draw is the so-called "Brine Aquifer" at the Rustler-Salado contact. These water-bearing horizons, which occur above the Salado Formation, are described below, but do not represent useable aquifers at the site due to their very poor water quality and low yields. Brine and gas occurrences in the Salado and Castile Formations are also described.

6.2.1 Hydrology of the Castile Formation

The Castile Formation is composed of a sequence of three thick anhydrites separated by two thick halites. This formation acts as an aquitard, separating the Salado Formation from the underlying water-bearing sandstones of the Bell Canyon Formation (DOE, 1990b). Except for the isolated brine reservoirs locally found in the fractured anhydrites, very little hydrologic data are available from the Castile Formation (Mercer, 1987). In the halite zones, the occurrence of circulating groundwater is restricted because halite at these depths does not readily maintain porosity, open fractures, or solution channels. Drill stem tests conducted in the Castile Formation show the permeability of the anhydrite and salt beds underlying the WIPP facility to be negligible, and in most tests, values for permeabilities were too low to be determined accurately with conventional methods. Based on the limitations of the instrumentation used to measure these very low permeabilities, a conservative estimate for permeability would be less than 0.1 microdarcy (Mercer, 1987).

No regional groundwater flow system is present in the Castile Formation. The only significant water present in the formation occurs in isolated brine reservoirs in fractured anhydrite. The brine occurrences are described in several reports (Popielak et al., 1983; Mercer, 1983; Griswold, 1980; DOE, 1990a, 1990b). Geochemical data (Lappin, 1988) support the hypothesis that the brines represent trapped Permian seawater that is now halite saturated and in equilibrium with the host rock. Therefore, these brine reservoirs are not increasing in volume or pressure, are unconnected with other aquifers or the surface, and have little potential to dissolve the host rocks or move through them. The regional and local hydrogeology of the Castile Formation is presented in Appendix D7. The structural and dissolution characteristic of the Castile are discussed in detail in Appendix D9.

6.2.2 Hydrology of the Salado Formation

The massive halite beds within the Salado Formation host the WIPP facility emplacement horizon at a depth of 2,150 feet BGS. The Salado Formation represents a regional aquiclude due to the hydraulic properties of the bedded halite that forms most of the formation. In the halites, the presence of circulating groundwater is restricted because halite does not readily maintain primary porosity, solution channels, or open fractures. During the mapping that was conducted as part of the construction of the Waste Handling, Exhaust, and Air Intake Shafts, the halites of the Salado Formation did not produce any observable fluid inflow (Holt and Powers, 1984, 1986, 1990). In addition, significant brine flows have not been encountered in hydrologic testing from the surface (Lappin, 1988).

Limited hydrologic testing has been conducted in the past within the Salado Formation, but hydrologic characterization investigations are currently in progress. The results of the permeability testing, within the underground facility, are generally consistent with a permeability

of the undisturbed salt mass that is approximately 0.001 to 0.01 microdarcy, with no distinguishable strata variability (Lappin, 1988). Published results of "successful" hydrologic tests of the Salado from the surface indicate permeabilities from approximately 0.01 microdarcy to a high of 25 microdarcies. Later evaluation of the tests indicated that the data from the Salado in Well DOE-2 are the most reliable, indicating a maximum permeability of 0.3 microdarcy (Mercer, 1987). Field testing of the Salado from the surface has had only limited success. The apparent causes of this are (1) the formation permeability appears to be below the testable minimum for the equipment used (approximately 0.01 to 0.1 microdarcy), and (2) hole aging during the time between hole completion and attempted testing of the Salado caused great difficulty in finding locations in the borehole that allowed successful setting of packers to isolate test intervals. Evaluation of all existing hydrologic test data from the Salado indicate that data from testing of undisturbed halite at the underground facility level is the most representative permeability data available. Hydrologic data from testing in the WIPP underground were used in hydrologic modeling presented in the WIPP No-Migration Variance Petition (DOE, 1990a). Such very low permeability values indicate that any fluid flow within the competent salt is extremely slow and would result in an imperceptible rate of fluid movement in conventional hydrologic considerations. The only significant variation to these extremely low permeabilities stated above occurs in the disturbed rock zone in the immediate vicinity of the underground excavation. Gas-flow permeability tests indicate a marked increase in the permeabilities within approximately 6 to 7 feet of the underground excavation (Stormont et al., 1987). This apparent increase in permeability is restricted to the disturbed zone immediately surrounding the excavation and is believed to be a result of near-field fracturing and possible matrix dilatancy due to stress relief associated with excavation. Stormont et al., (1987) also indicated that interpretation of their gas-flow permeability tests was complicated by uncertainties in the degree of saturation of the Salado, pressure threshold effects inherent in the testing techniques, and local inhomogeneities due to fracturing in the disturbed rock zone near the underground facility openings.

Marker Bed 139, an anhydrite unit which lies approximately 1 meter (approximately 3.28 feet) below the facility floor, exhibits increased permeability due to fracturing in the disturbed rock zone. Separation along these fractures in the floor of WIPP facility rooms and drifts may be quite large (several centimeters). Hydrologic testing in Marker Bed 139 at one location of the facility suggested that separate fracture systems existed and yielded transmissivity values of 10×10^{-6} to 2.2×10^{-6} square meters per second (approximately 6×10^{-4} to 1×10^{-3} square feet per day). Geotechnical evaluations have shown that Marker Bed 139 may be connected to the floors of rooms and areas excavated through fractures. However, pathways for brine and gas migration in the floor and in Marker Bed 139 are limited to zones directly below the excavations. In the pillars and away from the excavation outside of the disturbed rock zone, the anhydrite bed will not exhibit open fractures due to compressive loading and migration of fluid away from the excavation through marker Bed 139 is not expected. Should a spill reach Marker Bed 139, migration to overlying or underlying water-bearing units will not occur.

Salado Formation Brine and Gas Inflow

Minor quantities of gas and brine have been encountered in the salt beds of the WIPP facility excavation, as described in Deal and Case (1987) and Deal et al. (1987, 1989). The inflows of brine occur as "weeps" on the exposed surfaces of the underground workings and as accumulations in some of the boreholes drilled outward from the workings, most noticeably in the downholes. Gas (mostly nitrogen) is usually associated with the brine inflow and can be observed as gas bubbles in the brine occurrences. Moisture content measurements of the Salado host rock salt have been made as part of the Brine Sampling and Analysis Program (BSEP) (Morse and Hassinger, 1985). These measurements are based on the easily moved fluid content in the low range of temperatures (25° to 250°C or 77° to 482°F) as described in Deal et al. (1987, 1989). The BSEP has measured moisture content of more than 500 core samples representing different lithologies and different areas of the underground facility. The results of these measurements indicate that moisture content ranges from 0.01 to 6.67 percent (for one isolated clayey sample), with most samples less than 1 percent. Stratigraphic variations in moisture content were shown by Deal et al. (1987, 1989) to be related to the clay content of the units. Based upon the thickness of the various stratigraphic units, a weighted-average amount of brine that occurs naturally in the rock and is not bound crystallographically or sealed in fluid inclusions, is in the order of 0.1 to 0.6 percent by weight (up to 1.6 percent by volume) of the surrounding rocks (Deal et al., 1989). Most of the measured brine inflows in boreholes have ranged between a few tenths to a few hundredths of a liter per day. The liquid and gas movement observed in the walls, floors, and roofs of the excavated surfaces is believed to be the result of the pressure gradient caused by the excavation. Geochemical studies on the origin of the brines indicate that they originate as intergranular fluids with residence times within the Salado Formation of at least several million years (Stein and Krumhansl, 1986) and may have been resident since Permian time (Abitz et al., 1990; Deal et al., 1989). In addition, the variability found by Stein and Krumhansl (1986) of the compositions of fluid inclusions in salt near the WIPP facility workings is consistent with there being little or no vertical fluid movement. During the five-year Test Phase, the majority of the moisture entering the facility from the host rock will evaporate and be removed in the air circulated by the underground ventilation system (Deal and Case, 1987). Additional detail of the hydrogeology of the Salado Formation is presented in Appendices D7 and D10 of Chapter D, Facility and Process Information.

6.2.3 Hydrology of the Rustler-Salado Contact

The contact zone between the Rustler and Salado Formations at the WIPP site was tested in 20 cased and open drill holes (DOE, 1990b). In Nash Draw and areas immediately west of the site, the contact exists as a dissolution residue capable of transmitting water. Moving eastward from Nash Draw toward the WIPP site, the amount of dissolution decreases and the transmissivity of this interval decreases. All tests within the boundary of the WIPP site showed very low transmissivities, ranging from 3×10^{-5} to 3×10^{-3} square feet per day (Mercer, 1983).

6.2.4 Hydrology of the Culebra Dolomite

The Culebra Dolomite Member of the Rustler Formation has been studied extensively during the site characterization program. Because it is the most transmissive hydrologic unit in the WIPP site area, it is considered the most likely hydrologic pathway to the accessible environment for any potential contamination.

Mercer (1983) and Mercer and Orr (1977) provided detailed test results for a number of wells completed in the Culebra prior to 1983. Results for both single and multiwell hydrologic tests were presented by Beauheim (1986, 1987a, 1987b) and Lambert and Robinson (1983). These tests show that the Culebra Dolomite is a fractured, heterogeneous system with varying local anisotropic characteristics. Calculated transmissivities for the Culebra Dolomite within the WIPP site boundary have a wide range with values between 9×10^{-2} to approximately 69 square feet per day, with the majority of the values being less than 1 square foot per day (Beauheim, 1987b). Transmissivities generally decrease from west to east across the site area. A summary of Culebra hydrologic characteristics is presented in Lappin (1988), and detailed discussions are given in Appendices D6, D7, and D10 of Chapter D, Facility and Process Information.

Potentiometric surface maps have been constructed using water-level data (see Appendices D7 and D10). The Culebra Dolomite Member is heterogeneous and anisotropic, and the flow path of water moving through the Culebra Member is affected by fractures and variable water densities caused by compositional variability. Consequently, the regional direction of flow may have little or no relationship to local flow paths. An interpretation of flow direction in the Culebra Member is depicted in Figure E1-9. This map shows the most likely regional flow direction of groundwater in the Culebra Dolomite Member to be predominately to the south (LaVenue et al., 1988; Crawley, 1988). The flow directions were computed from variable density corrected potentiometric surfaces. The average linear velocity between the WIPP facility and the southern boundary of the WIPP site is 1.77×10^{-3} feet per day. The average linear velocity is based on the 15 wells that are within the WIPP site boundary.

6.2.5 Hydrology of the Magenta Dolomite

Because the Magenta Dolomite is generally much less permeable than the Culebra Dolomite at and near the WIPP site, less testing of the Magenta has been performed at the WIPP site. The hydrologic characteristics of the Magenta Dolomite Member were determined in 15 test holes in the area of the WIPP site. Transmissivities within the WIPP site boundary calculated from the results of these tests range from 1×10^{-2} to 3×10^{-1} square feet per day (Mercer, 1983). The results of recent testing of the Magenta Dolomite in wells H-14, H-16, and DOE-2 (Beauheim 1986, 1987b) indicated that transmissivities were 5.6×10^{-3} square feet per day for well H-14, 2.8×10^{-2} square feet per day for well H-16, and 1.0×10^{-3} square feet per day for well DOE-2 (see Figure E1-10 for well locations).

Water-level data have been collected and potentiometric surface maps constructed. The direction of groundwater flow at the WIPP site, as estimated from the potentiometric surface map, is west-southwest toward Nash Draw (Mercer, 1983). Potentiometric surface maps and additional detail on the hydrogeology of the Magenta Dolomite are provided in Appendices D6 and D7 of Chapter D, Facility and Process Information. The average hydraulic conductivity in the Magenta Dolomite at the WIPP facility was calculated from transmissivity and aquifer thickness values as 1.18×10^{-3} feet per day. The calculated hydraulic conductivity values and potentiometric contours were used to calculate average linear groundwater-flow velocity of the Magenta aquifer at the WIPP facility. The average linear velocity in the Magenta aquifer at the WIPP site is 3.18×10^{-5} feet per day.

6.2.6 Hydrology of the Dewey Lake Redbeds

Hydrologic investigations at and near the WIPP site have not identified a continuous zone of saturation within the Dewey Lake Redbeds. Where water is present in the formation, it is generally in small perched or semiperched water tables, and its occurrence is localized (Mercer, 1983). Several wells believed to be completed in the Dewey Lake Redbeds are located within several miles of the WIPP facility. These wells include Ranch Well, Barn Well, Twin Wells, Fairview Well, and Unger Well. Of these wells, one is used occasionally by a ranch house for drinking water (Barn Well) and the remainder supply water for livestock (Figure E1-10).

Four intervals of the Dewey Lake Redbeds were tested in drill holes at the WIPP site. Although no saturation was encountered during drilling, ten wells were completed as observation wells (Ward and Walter, 1983). The data obtained showed that there was no evidence of a zone of saturation in any of these wells. Additional data concerning the hydrogeologic characteristics of the Dewey Lake Redbeds are given in Lappin (1988) and Appendix D7 of Chapter D, Facility and Process Information.

6.2.7 Hydrology of the Dockum Group

At the WIPP site, exploratory holes were drilled through the Gatuna Formation and the Dockum Group. The Gatuna Formation and Dockum Group occur within 50 feet of the surface and little or no water was encountered in these formations. Only one hole reported a small zone of moisture in the Dockum Group, but observation wells completed in the Dockum Group were dry (Mercer, 1983). Two private wells (Comanche and Clifton Wells) located approximately 10 miles east of the WIPP site produce potable water from the Dockum Group, and they are used for livestock watering.

6.3 Water Quality

In addition to the study of site hydrology, surface and groundwater quality have been characterized for two major reasons: (1) to establish baseline levels of naturally occurring inorganic solutes, radionuclides, and potential organic contaminants in water prior to waste emplacement; and (2) to define the existing use in the area for ground and surface water as a supply for domestic, industrial, and livestock consumption. Evaluation of the WIPP site area hydrology and water quality data indicates that the existing and potential future use of groundwater is extremely limited due to nonsaturated conditions and very poor water quality. Table E1-1 lists the wells that have been sampled as part of the WIPP Water Quality Sampling Program (WQSP) and the formation sampled by each well. The well locations are shown in Figure E1-10. The subsections below describe the general quality of the groundwater that occurs in the WIPP site area. Groundwater quality data from the WQSP have been reported annually in water-quality data reports. These data are now included as part of the Annual Environmental Monitoring Report. The results of the WQSP can be found in Uhland and Randall (1986), Uhland et al. (1987), Randall et al. (1988), and Lyon (1989). Detailed discussions of water chemistry for the water-bearing units at the WIPP are given in Appendix D7 of Chapter D, Facility and Process Information.

Rustler-Salado Contact

Mercer (1983) provided data from 20 wells sampled in the WIPP vicinity from the Rustler-Salado contact. The highest concentrations of total dissolved solids (TDS) in the WIPP water-bearing formations were contained in the Rustler-Salado contact. TDS values ranged from 79,800 milligrams per liter (mg/ℓ) (approximately 2.6 ounces per quart) in well H-07b1 to 480,000 mg/ℓ (approximately 15.9 ounces per quart) in well H-01. Sulfates and chlorides of calcium, magnesium, sodium, and potassium made up the primary dissolved mineral constituents of this brine.

Culebra Dolomite

The water quality of the Culebra varies greatly. The TDS values range from 2,900 mg/ℓ (approximately 9.6×10^{-2} ounces per quart) at well H-08b to about 291,000 mg/ℓ (approximately 9.6 ounces per quart) at well WIPP-29. These two wells are fairly remote from the site, but even closer to the WIPP facility, a marked variation in water quality is observed. Well H-02a is located ½ mile west of the site and has a TDS of 13,500 mg/ℓ (approximately 4.5×10^{-1} ounces per quart), whereas Well H-15, which lies 2 miles east of the site, has a TDS of 231,000 mg/ℓ (approximately 7.6 ounces per quart). The chemical constituents consist predominantly of chlorides and sulfates of sodium, calcium, magnesium, and potassium.

Magenta Dolomite

The water-quality data for the Magenta Dolomite indicate that the water is saline to briney, with TDS values ranging between 5,460 to 270,000 mg/ℓ (approximately 1.8×10^{-1} to 8.9 ounces per quart). The predominant dissolved species are sodium, calcium, magnesium, chloride, and sulfate.

Surface Water

No surface water occurs in the immediate area of the WIPP site. Several surface-water bodies located within an approximate 25-mile radius of the site, such as the Pecos River, the Laguna Grande de la Sal, and livestock tanks which are fed from surface runoff, are sampled and monitored for water quality. Data were collected and reported as part of the WIPP Radiological Baseline Program, the Water Quality Sampling Program, and the Ecological Monitoring Program. Surface-water sampling is now conducted and reported as part of the WIPP Operational Environmental Monitoring Program (Mercer et al., 1989).

Surface-water samples have been collected at four surface-water bodies near the WIPP site. These sampling locations are: Hill Tank, Red Tank, Indian Tank, and Laguna Grande de la Sal-Laguna Tres (Figure E1-11). The water chemistry of the three tanks is similar and is a calcium bicarbonate type, having TDS less than 240 mg/ℓ. Laguna Grande de la Sal, a saline lake, contains water that is a sodium chloride type with a TDS concentration of 320,000 to 350,000 mg/ℓ (approximately 10.6 to 11.6 ounces per quart). Surface water quality data for these sampling locations are presented in Appendix D7 of Chapter D, Facility and Process Information.

7.0 WIPP Facility Design

The WIPP facility consists of surface and subsurface installations designed to receive, handle, and safely dispose of radioactive mixed waste underground. Several design features, particularly in the shafts connecting the surface and subsurface operations, are utilized to assure that groundwater and precipitation do not enter the facility and that no wastes will enter the local groundwater system during the five-year Test Phase. This section summarizes these design features of the WIPP facility.

7.1 Shaft Designs

The WIPP facility design includes four shafts. These are the Waste Shaft, the Salt Handling Shaft, the Exhaust Shaft, and the Air Intake Shaft (AIS). Each shaft includes a shaft collar, a shaft lining, and a shaft key section (DOE, 1990b).

The reinforced concrete shaft collars extend from the surface to the top of the underlying consolidated sediments. Each collar serves both to retain adjacent unconsolidated sands and soils and to prevent surface runoff from entering the shaft. The shaft linings extend from the base of the collar to the top of the salt beds approximately 850 feet below the surface. The shaft lining serves to inhibit water seepage into the shafts from water-bearing formations, such as the Magenta and Culebra Dolomite Members of the Rustler Formation. The liners are also designed to retain loose rock. The shaft liners are concrete except in the Salt Handling Shaft, in which a steel shaft liner has been grouted in place.

The shaft key is a circular reinforced concrete section emplaced in each shaft below the liner in the base of the Rustler Formation and extending about 100 feet below and into the Salado Formation. The key functions to resist lateral pressures and to support the shaft liner. The key ensures the liner will not separate from the host rocks or fail under tension. This prevents the shaft from becoming a conduit for groundwater flow into the underground facility.

Two water-seal rings are incorporated in each key. The rings are separated by an 11-foot interval into which eight 2-inch-diameter pipes are inserted to monitor any water that may penetrate the upper ring. If groundwater is detected flowing past the upper ring, this condition is corrected by injecting chemical sealants or cement grouts to stop the leakage.

On the inside surface of each shaft, excluding the Salt Handling Shaft, there are three water-collection rings. The first is located just below the Magenta Dolomite interval, the second just below the Culebra Dolomite interval, and the last at the lowermost part of the key section. These collection rings function to collect any groundwater that may seep into the shaft through the liner. The groundwater would then be piped to the storage tanks located at the station. The water could either be used underground for dust control or would be transported to the surface in portable tanks for disposal (DOE, 1990b). At the present time, the AIS liner has not been grouted in place. Groundwater seepage from the Rustler Formation is collected by water rings and routed to mobile water holding tanks. These tanks are inspected and emptied periodically to ensure that they do not overflow. Therefore, overfilling and leakage from these tanks is not a source of water underground which could come into contact with the waste. Recent inflow measurements from the AIS indicate that total seepage is approximately 1.24 gallons per minute. On January 17, 1992, the NMED issued an approved Discharge Plan to expand the WIPP sewage facility. The discharge plan allows for the disposal of AIS brine waters in the evaporation lagoon and the expanded sewage facility.

7.2 Repository Seals

Upon closure of the WIPP facility, sections of the shaft liners may be removed and replaced by permanent shaft seals. Seals may also be placed in boreholes at the WIPP site, as well as in tunnels throughout the facility. These seals will function primarily to limit any seepage into the

facility from overlying water-bearing units or from infiltration from the surface. In addition, seals will help prevent any contaminated water in the facility from reaching the accessible environment.

√ The approaches to preliminary seal design and performance goals for the WIPP facility are described in detail by Stormont (1988). The general approach taken in the preliminary design
√ concepts for shaft and borehole seals at the WIPP facility is to limit the inflow of groundwater from formations above the facility level until the host rock and the backfill encapsulate the waste because of salt consolidation. Water from other sources, such as saturated interbeds near the facility horizon or from the host salt itself, may also enter the repository following decommissioning. Although these water sources are volumetrically less significant, the seal system will be designed to limit inflows and to inhibit the expulsion of contaminated brines through the shafts upon pressurization due to host formation consolidation. Seals will be emplaced throughout the facility to separate areas of the facility should human intrusion, (e.g., drilling) occur at some time greater than 100 years following decommissioning. Existing boreholes will be sealed, thus, they are unlikely to become significant flow paths. Therefore, borehole seals provide some additional assurance that dissolution will be minimized.

8.0 Waste Containment

√ The Test Phase of the WIPP Project is scheduled to take several years to complete. During the Test Phase, the sealed bin-scale test waste containers will be emplaced in the storage rooms of Panel 1. Waste containers will be fully retrievable in case it is determined that removal or
√ relocation of the waste is necessary. The WIPP Project bin-scale contact-handled TRU waste tests are to be performed over the duration of the Test Phase to gain a better understanding of waste interactions due to differing degradation modes, waste forms, and repository conditions. The experiments are intended to obtain data under various controlled conditions such as different material classifications and compositions, age, compaction ratios, backfill and gettering materials, added brine type and amount, temperature, and atmospheric conditions. The data to be collected during these tests relate to both single and combined effects of gas generation phenomena with
√ respect to short-term and long-term waste isolation at the WIPP facility. Gas generation is anticipated under differing conditions to be produced by corrosive, bacteriological, and radiolytic reactions with the waste components. The data will be used to better define the nature of long-term and short-term gas composition, production, transport, and consumption in the WIPP facility. Additional tests will be performed to define more precisely the rate of natural brine inflow from the host rock to the underground facility.

The sealed test bins will isolate the waste from contact with any available brine and will preclude the possibility of any hazardous constituent migrating into a water-bearing unit either above or below the repository horizon. Shipment of the test bins to the WIPP facility will be in a Standard Waste Box (SWBs) inside of the U.S. Nuclear Regulatory Commission-certified Transuranic Package Transporter (also called a TRUPACT-II) shipping container. Upon arrival at the WIPP

facility, additional preparation activities for the test bins will be performed. These activities include modification of the SWB to create an RCB, connection of test-bin instrumentation, and modification of the test-bin internal environment (e.g., argon purge, oxygen gettering, etc.). The RCB will act as a secondary containment structure surrounding each test bin. Proper sealing of the bin lid will be assured by reviewing the records associated with bolt tightening to verify that the proper torque was applied.

Verification of proper bin assembly and secondary containment by the RCB will add an extra margin of safety to ensure that migration of hazardous waste or hazardous constituents from the test rooms is unlikely. The brine added to test bins will neither be capable of dissolving the host salt, nor will it be added to any container in sufficiently large quantities to reach and contaminate the Culebra Dolomite Member or other water-bearing units, should it leak from the containers (Molecke, 1990a; Molecke and Lappin, 1991).

The Waste Acceptance Criteria (WAC) for TRU waste (Westinghouse, 1989) destined for disposal at the WIPP site specifically control the inclusion of constituents that are chemically incompatible. Strict control of explosives, pyrophorics, gas generators, heat generators, and corrosives is covered in the WAC and reduces the potential for waste releases due to accidents or container breaches in the facility subsequent to placement. Limits on respirable particulates in the waste (less than 1 percent by weight) reduces the quantities of harmful materials that could be released due to accidents. All materials shipped and emplaced in the WIPP facility must meet these stringent requirements for stability, compatibility, and physical form to ensure the safety of the repository even in the unlikely event that waste comes into contact with the Salado Formation during the Test Phase.

9.0 Summary and Conclusions

Release of hazardous waste or hazardous constituents from the WIPP site to the accessible environment via groundwater during the Test Phase is unlikely. The most transmissive hydrologic unit in the WIPP area, and the most likely groundwater transport pathway, would be the Culebra Dolomite Member, a water-bearing stratum in the Rustler Formation overlying the underground facility. The natural characteristics of the site and the design of the WIPP facility ensure that there is no potential of hazardous waste or hazardous constituents reaching the Culebra Dolomite and subsequently affecting the accessible environment during the Test Phase. These characteristics include site geology, site hydrology, climate, and groundwater utilization in the WIPP area, as well as the WIPP shaft designs and the waste container configuration used during the Test Phase.

The inapplicability of RCRA groundwater monitoring requirements during the Test Phase at the WIPP facility is determined based on the information provided in the previous sections of this document. The major points used in this determination are:

- The facility horizon is located 2,150 feet below the land surface in the Salado Formation which is composed mainly of bedded salt. The salt acts as a very low permeability regional barrier isolating the facility from water-bearing units above and below. The Castile Formation underlying the Salado Formation is also a very thick, low-permeability evaporite unit that further isolates the facility from underlying water-saturated units.

- There appears to be little or no infiltration of precipitation deeper than the most shallow
✓ surface soils at the WIPP site, and no shallow perched saturated zones have been detected at the site.

- The possibility of groundwater reaching the underground facility in quantities capable of transporting waste up the shafts to the Culebra Dolomite or other water-bearing units is unlikely. During the Test Phase, small brine seeps from the Salado Formation will evaporate in circulating air in the facility. The shafts do penetrate water-bearing units
✓ but the shaft design incorporates features designed to minimize and control groundwater inflow to the facility and to divert any inflow for collection and disposal.
✓ Tests with brine added to the waste containers will not contaminate groundwater should
✓ any leaks occur. The volumes of brine to be added to test bins will be too small to flow to the Culebra Dolomite Member, and test designs that include secondary containment features will prevent any leakage of brine from the test bins.

✓ • The waste container design and the open rooms will ensure complete control and containment of the waste throughout the Test Phase.

- No migration pathways or hydraulic gradients exist for the transport of contaminants from the disposal facility level via groundwater to the accessible environment during the
✓ Test Phase. During the Test Phase, the natural hydraulic gradients of all surrounding
✓ water-bearing units are toward the facility, making migration of contaminants from the
✓ facility horizon to the nearest aquifer impossible.

✓ • Groundwater quality in the vicinity of the WIPP facility, particularly in the Rustler and Rustler-Salado Formations contact water-bearing zones, is generally poor. Thus, groundwater from these water-bearing zones is not a resource for domestic, irrigation, or livestock use. The major groundwater resources in the area, the Capitan and Ogallala aquifers and surface water, are not hydrologically connected with the WIPP
✓ underground facility or water-bearing units overlying the WIPP facility.

This document serves as a demonstration that the RCRA groundwater monitoring requirements
✓ are not applicable to the WIPP facility because they are unnecessary to meet or demonstrate
✓ compliance with environmental performance standards, as described in HWMR-6, Pt. V,
✓ sec. 264.601. The groundwater protection information provided demonstrates that, to the best

of DOE's knowledge, migration via groundwater of hazardous waste or hazardous constituents emplaced in the WIPP facility during the Test Phase to pose a threat to the environment is unlikely. The facility provides effective isolation of hazardous waste or hazardous constituents from groundwater sources that would be the most likely pathways to the accessible environment. Because DOE is seeking to demonstrate that migration of hazardous waste or hazardous constituents to any water-bearing formations at the WIPP site is unlikely, there can be little potential for hazardous waste or hazardous constituents to move via these water-bearing formations to water supply wells (domestic, industrial, or agricultural) or to surface water. Groundwater monitoring, as mandated by RCRA, is not required at this time.

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TABLES

TABLE E1-1

WELLS SAMPLED AS PART OF THE WATER QUALITY SAMPLING PROGRAM

WELL NAME	WATER-BEARING UNIT	WELL NAME	WATER-BEARING UNIT
DOE-1	Culebra	H-14	Culebra
DOE-2	Culebra	H-17	Culebra
H-02a	Culebra	H-18	Culebra
H-03b1	Magenta	P-14	Culebra
H-03b3	Culebra	P-17	Culebra
H-04c	Magenta	Barn Well	Dewey Lake
H-04b	Culebra	Clifton Well	Santa Rosa
H-05c	Magenta	Comanche Wells	Santa Rosa
H-05b	Culebra	Engle Well	Culebra
H-06c	Magenta	Fairview Well	Dewey Lake
H-06b	Culebra	Mobley Ranch Well	Culebra
H-07b1	Culebra	Poker Trap	Culebra
H-08b	Culebra	Ranch Well	Dewey Lake
H-09b	Culebra	Unger Well	Dewey Lake
H-11b3	Culebra	USGS-1	Culebra
H-12	Culebra		

FIGURES

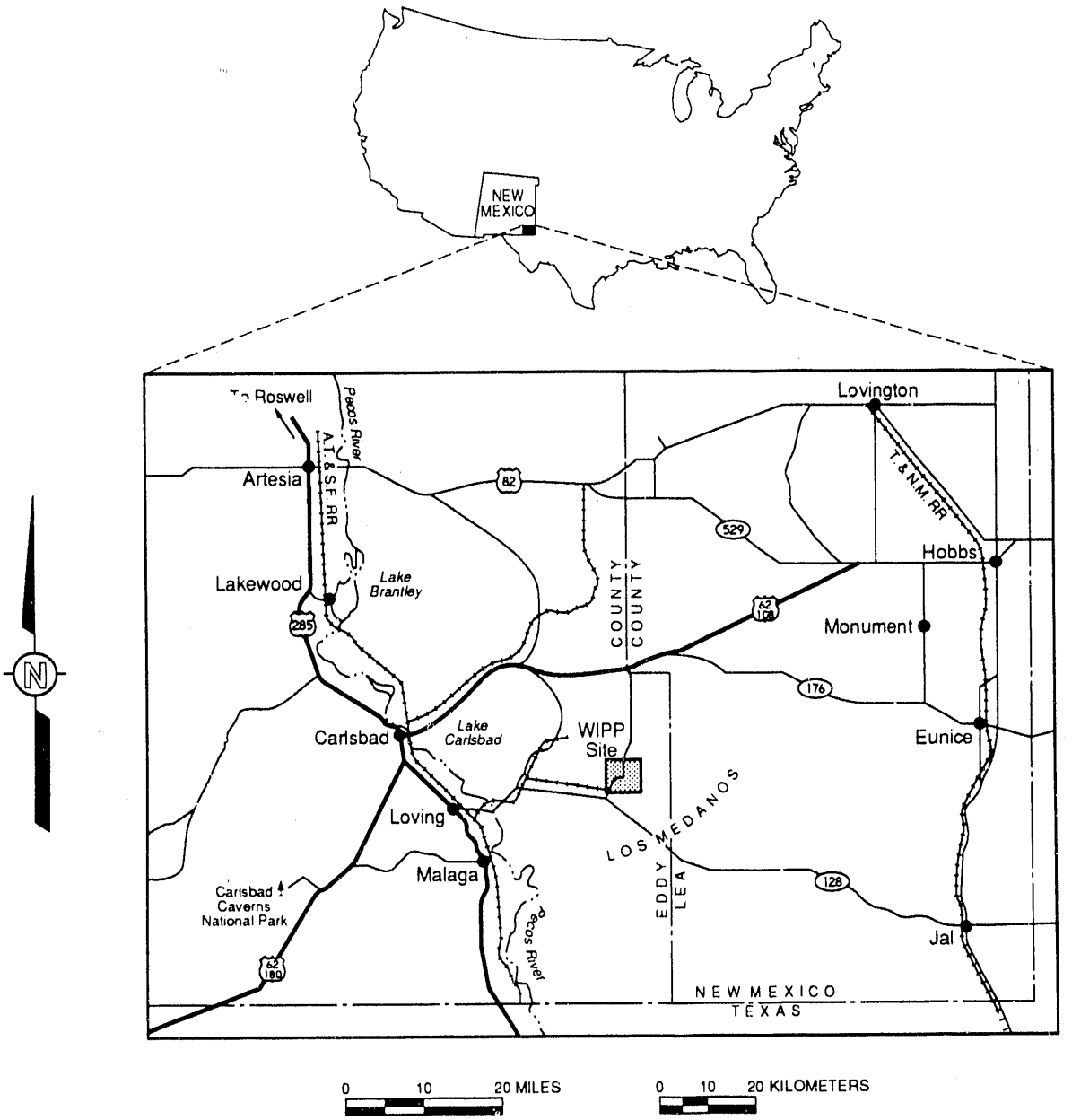
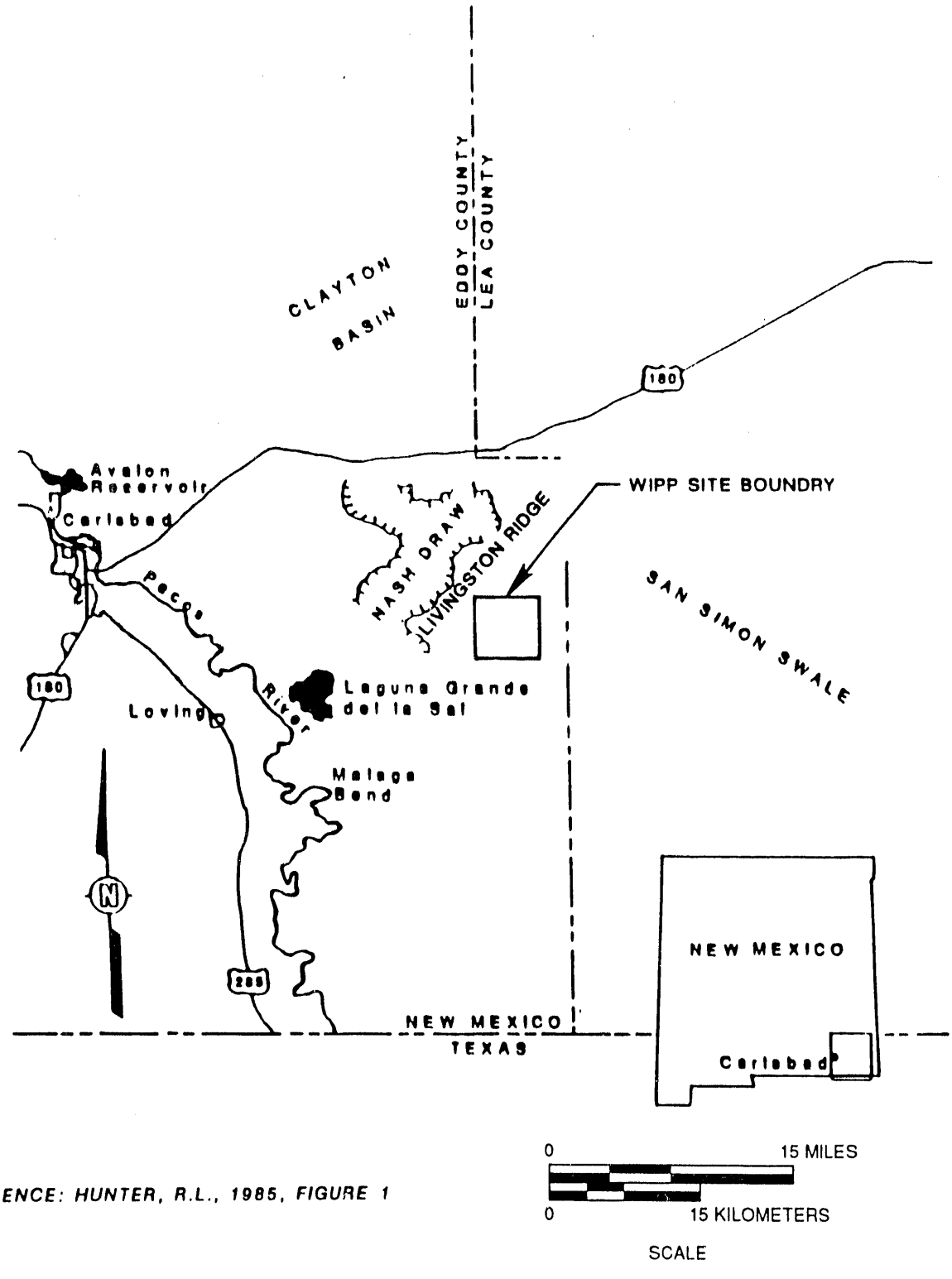


FIGURE E1-1 LOCATION OF THE WIPP SITE



REFERENCE: HUNTER, R.L., 1985, FIGURE 1

FIGURE E1-2 GENERALIZED PHYSIOGRAPHIC SETTING OF THE WIPP FACILITY

301404 96 A9

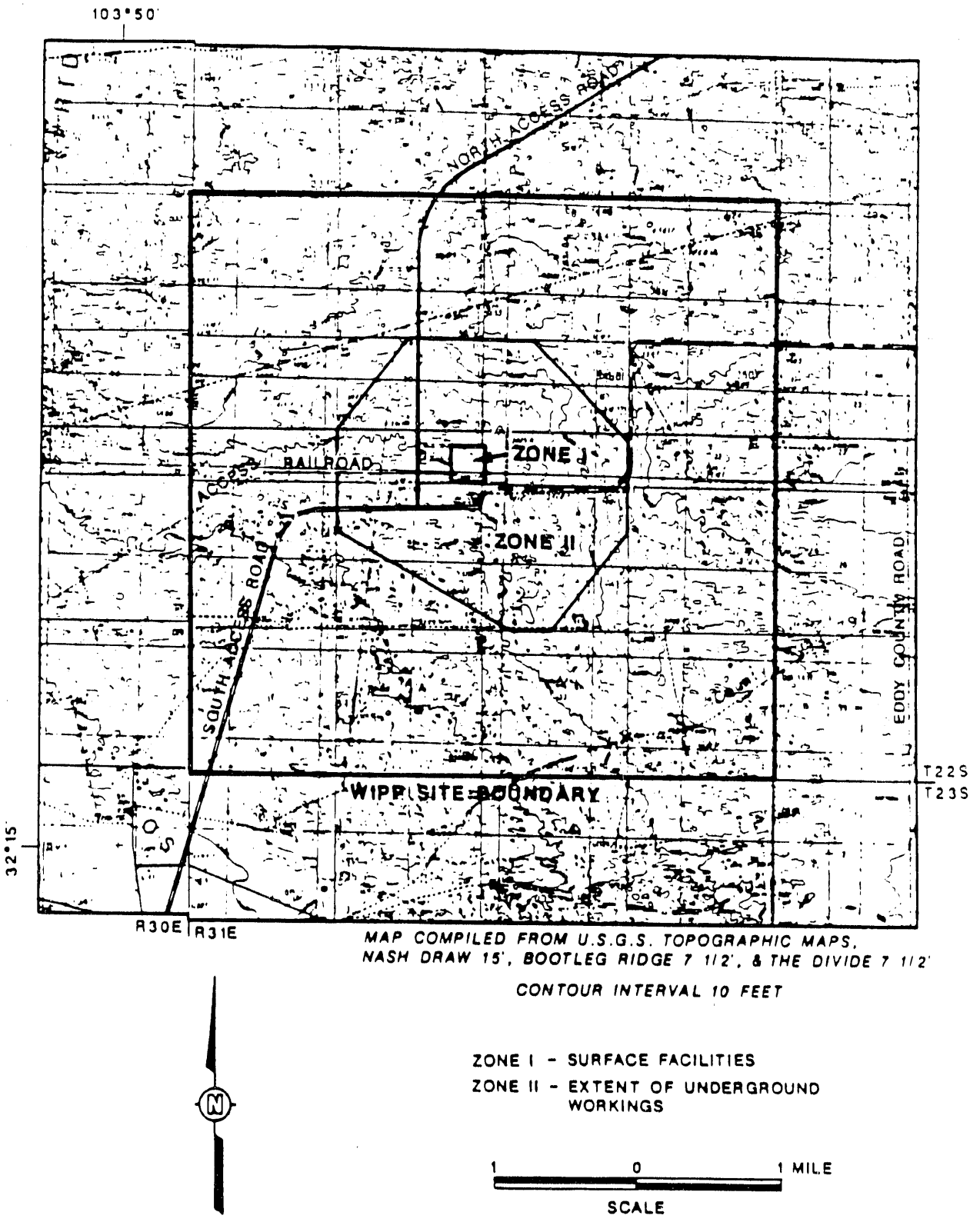


FIGURE E1-3 WIPP LOCATION AND BOUNDARIES

5014040606 A10

SYSTEM	SERIES	GROUP	FORMATION	MEMBER
RECENT	RECENT		SURFICIAL DEPOSITS	
QUATER-NARY	PLEIST-OCENE		MESCALERO CALICHE	
			GATUNA	
TRIASSIC		DOCKUM	UNDIVIDED	
PERMIAN	OCHOAN		DEWEY LAKE RED BEDS	
			RUSTLER	Forty-Niner
				Magenta
				Tamarisk
				Culebra
				Unnamed
			SALADO	Upper
				McNutt
				Lower
			CASTILE	
	GUADALUPIAN	DELAWARE MOUNTAIN	BELL CANYON	
			CHERRY CANYON	
			BRUSHY CANYON	

Geologic Column Representative of WIPP Facility Area

REFERENCE: POWERS et al., 1978. COOPER AND GLANZMAN, 1971

FIGURE E1-4 STRATIGRAPHIC COLUMN AT THE WIPP SITE

301404 06 A11

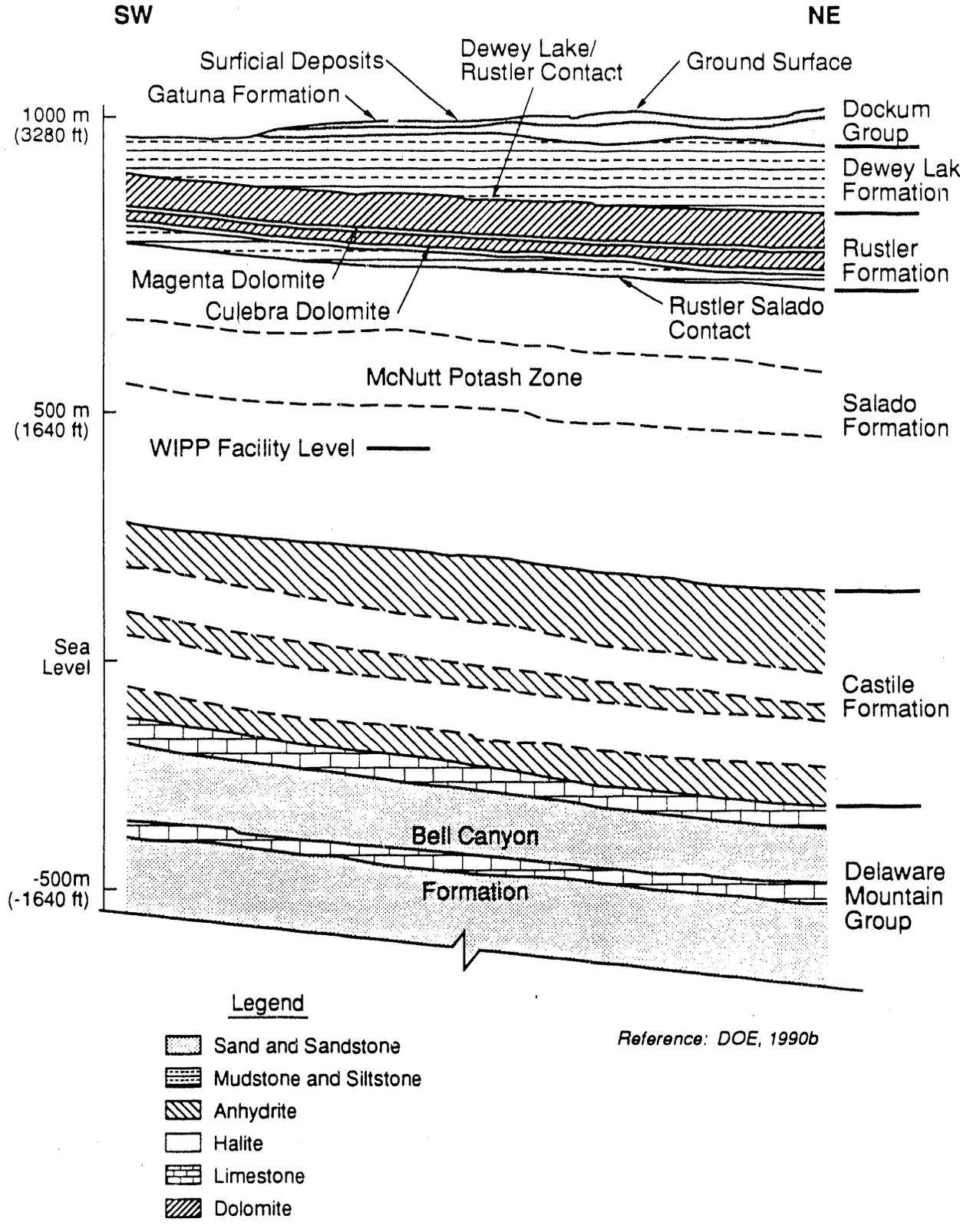


FIGURE E1-5 GENERALIZED STRATIGRAPHIC CROSS SECTION

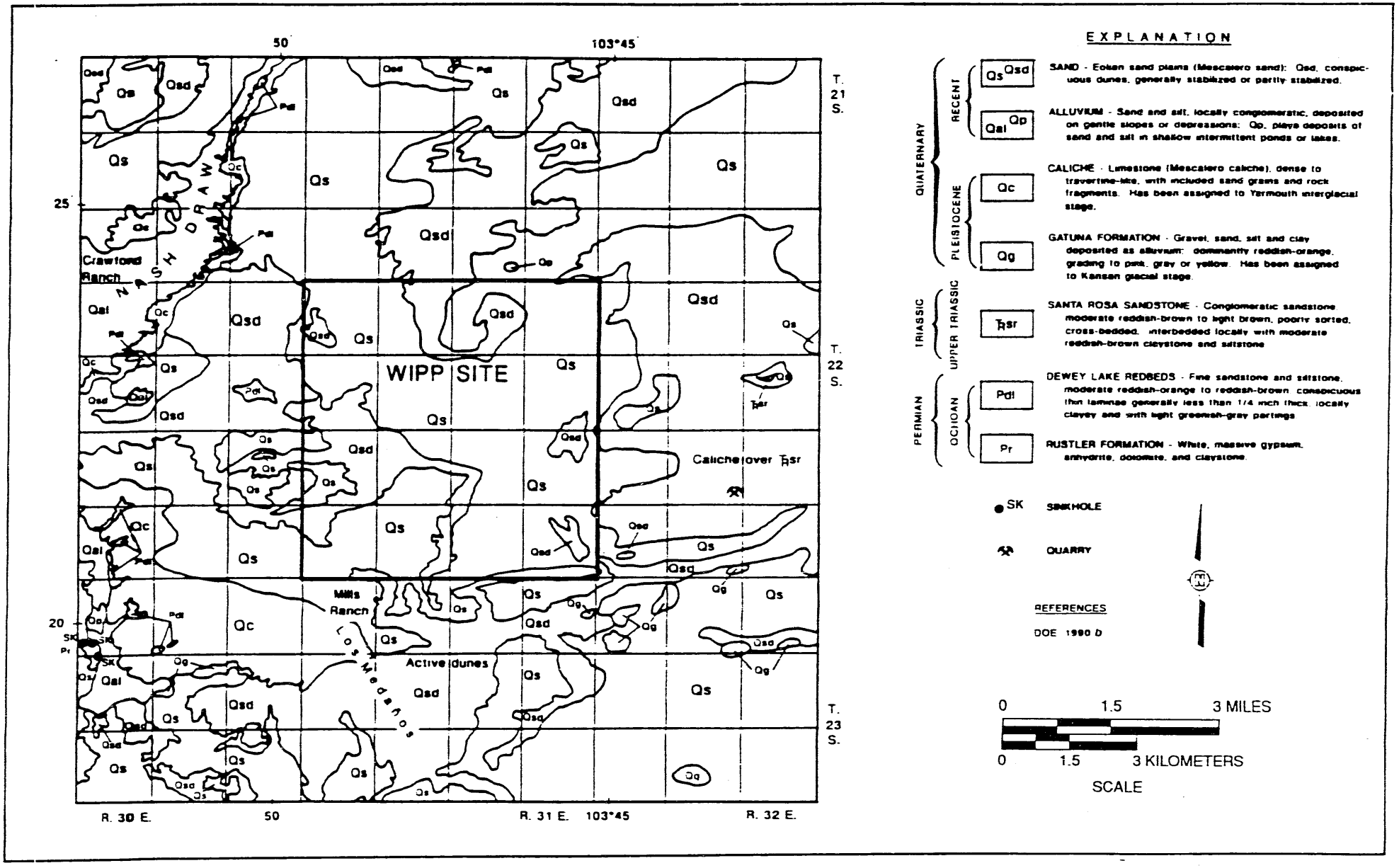
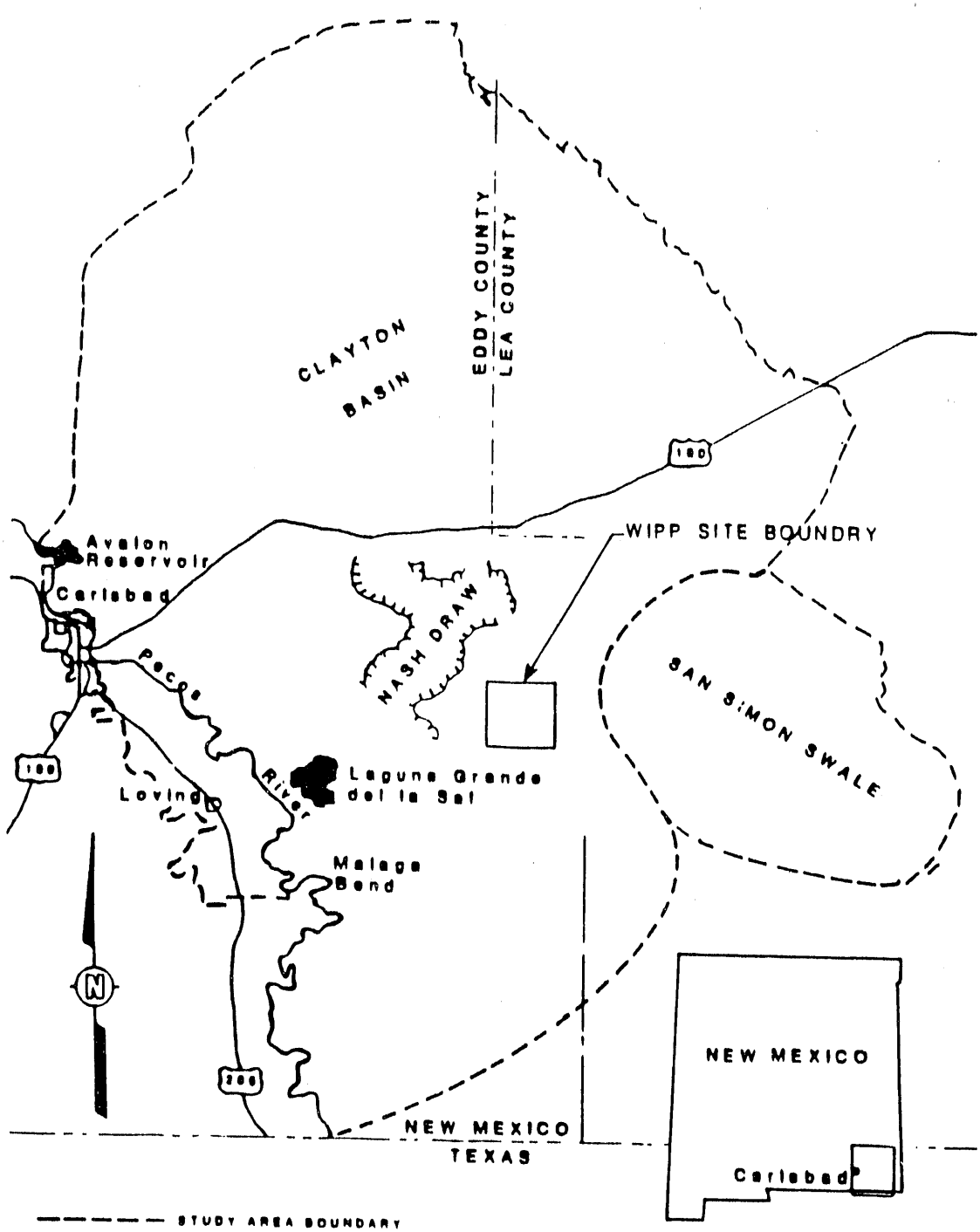


FIGURE E1-6 MAP OF SURFICIAL GEOLOGY



REFERENCE: HUNTER, R.L., 1985, FIGURE 1

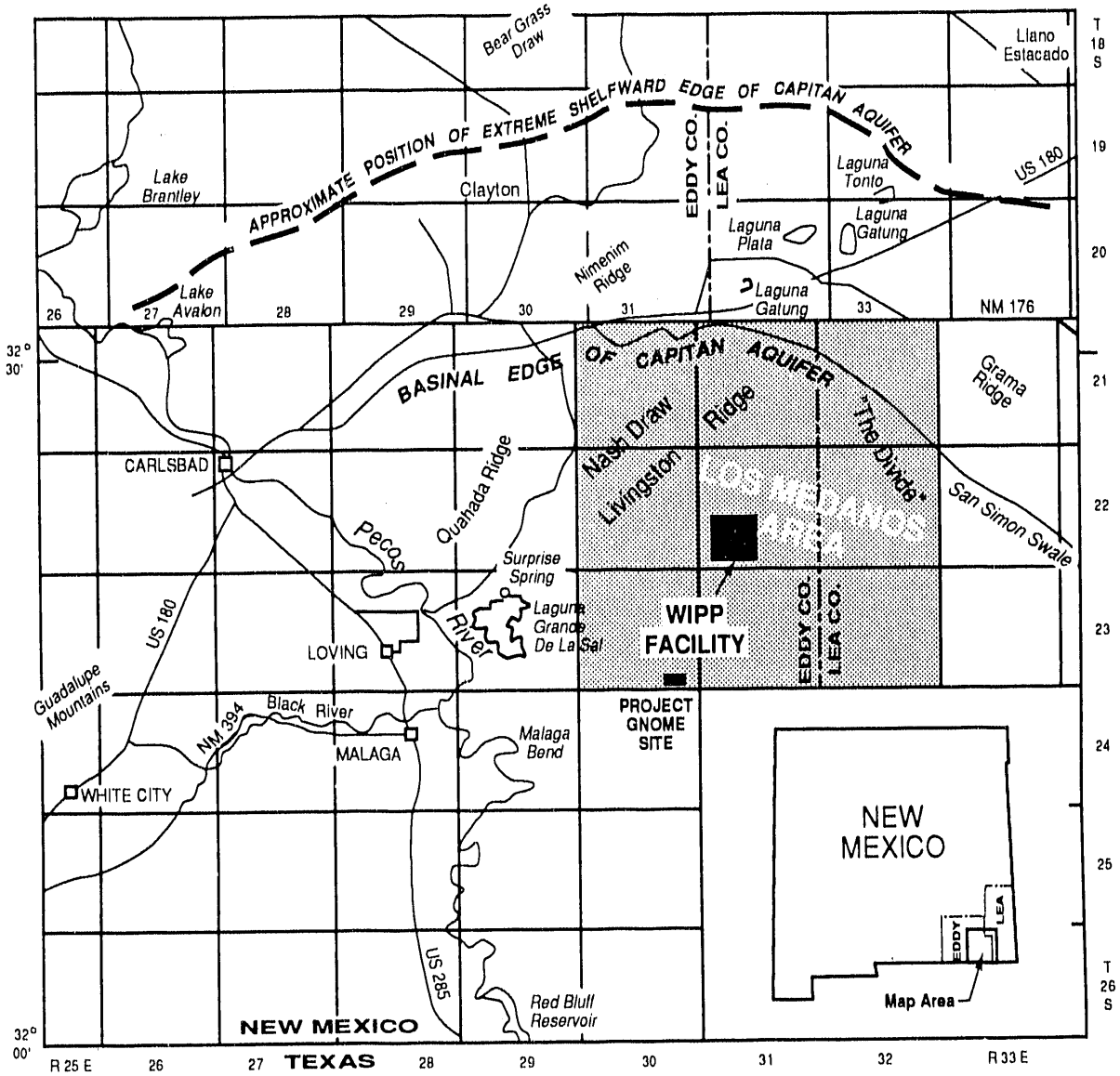
0 15 MILES

0 15 KILOMETERS

SCALE

FIGURE E1-7 STUDY AREA FOR THE WIPP WATER-BALANCE STUDY

301486.01 A27



REFERENCE DOE, 1990 b

FIGURE E1-8 WIPP LOCATION AND SURROUNDING FEATURES CONTRIBUTING TO WIPP WATER BALANCE

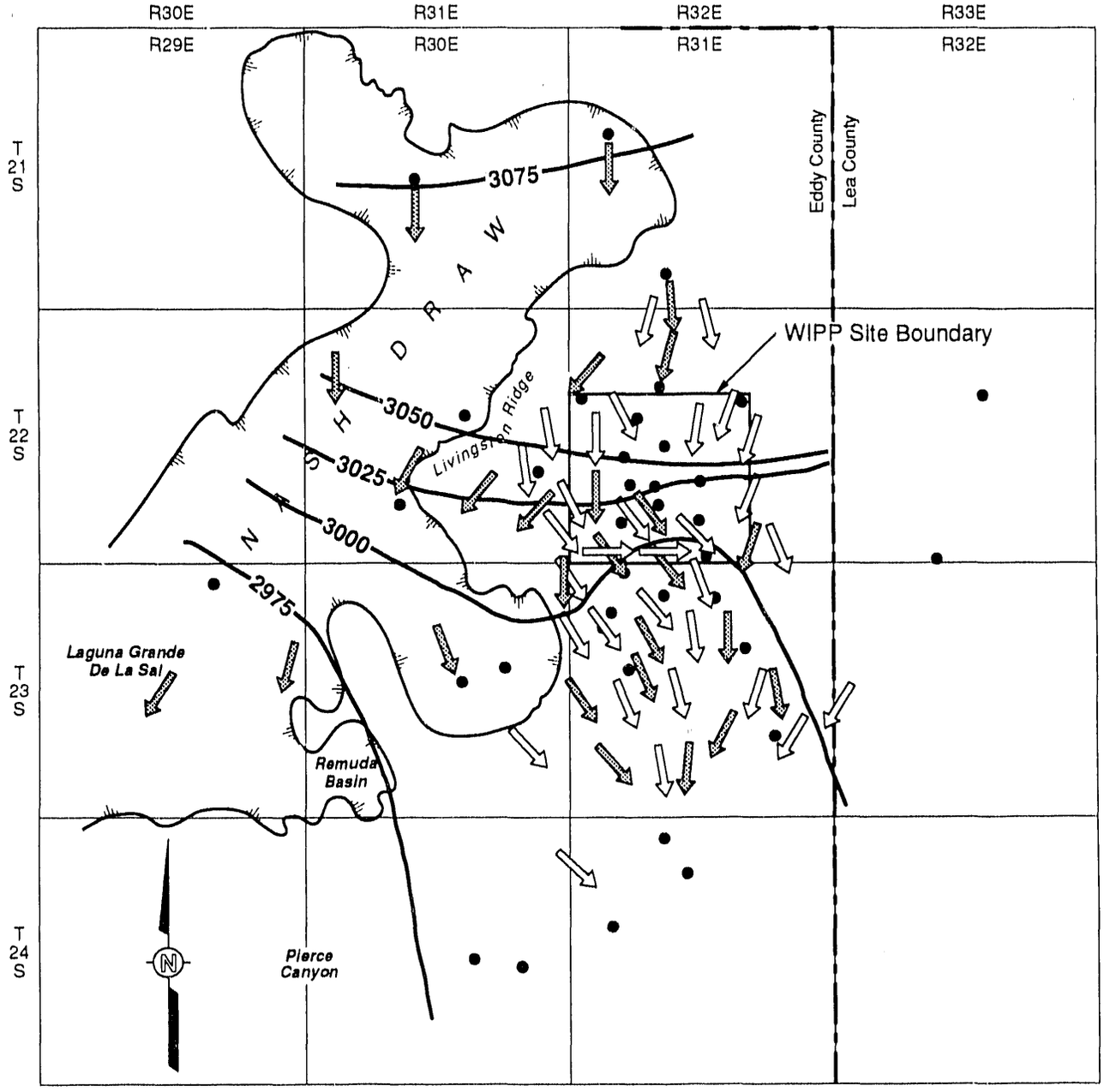
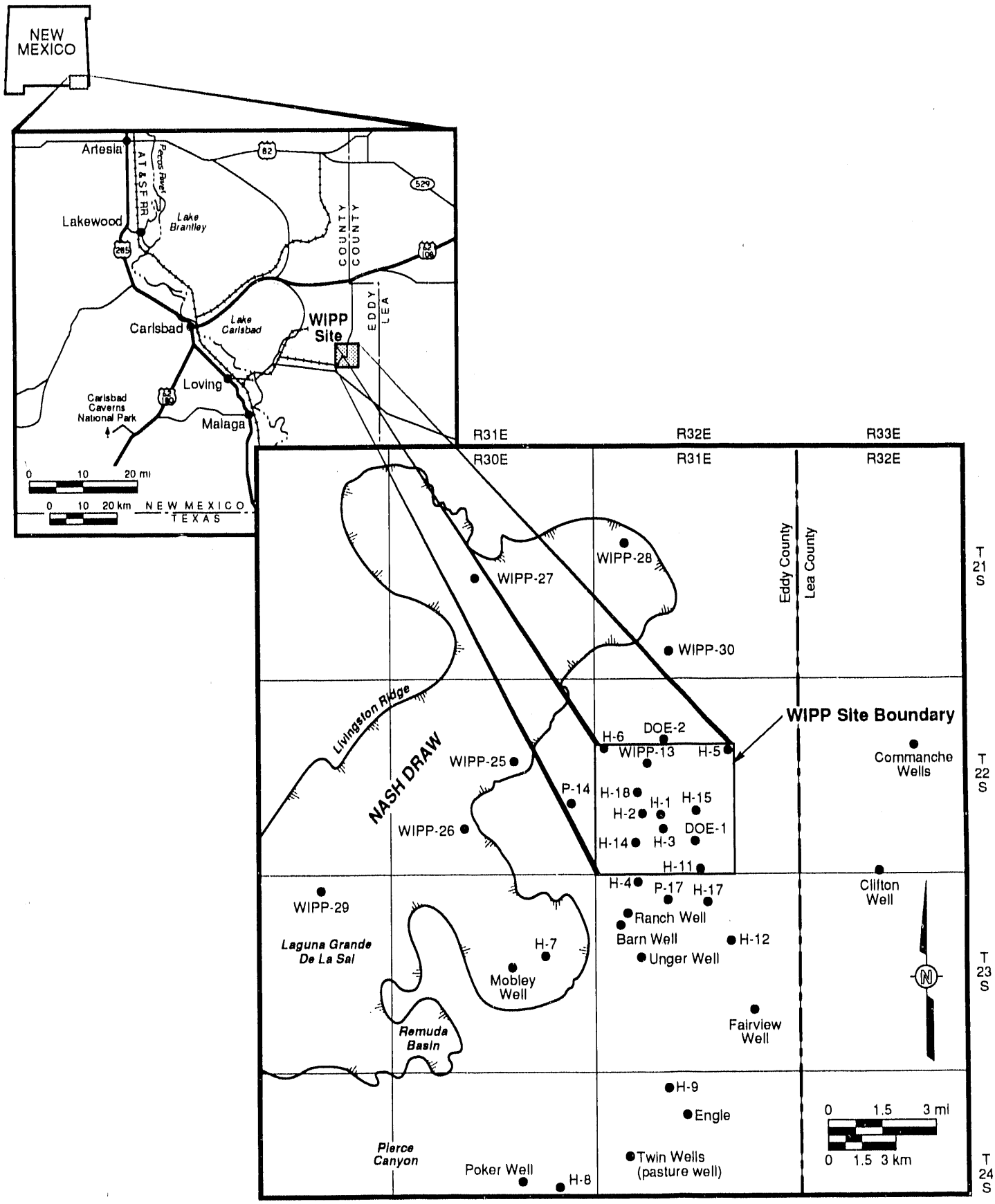
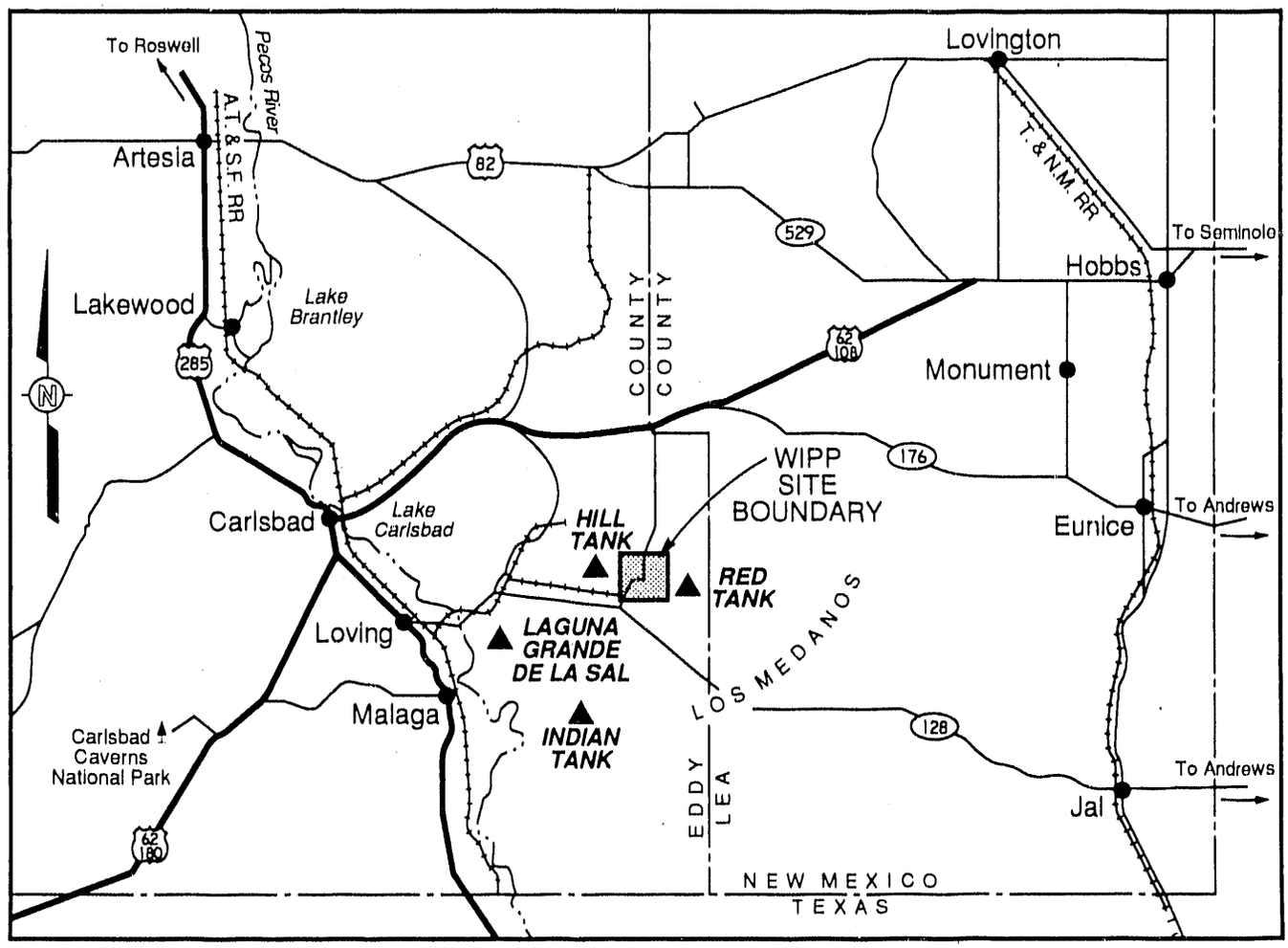


FIGURE E1-9 CALCULATED GROUND WATER FLOW DIRECTIONS
CULEBRA DOLOMITE MEMBER OF THE RUSTLER FORMATION



Reference: Randall et al., 1988

FIGURE E1-10 GROUND WATER SAMPLING AND PRIVATE WELL LOCATIONS



Reference: Fischer, 1988

0 10 20 MILES 0 10 20 KILOMETERS

▲ SURFACE WATER AND SEDIMENT LOCATIONS

FIGURE E1-11 SURFACE WATER AND SEDIMENT SAMPLING LOCATIONS

APPENDIX H1

LIST OF JOB TITLES

APPENDIX H1
LIST OF JOB TITLES

RCRA Position Title	WIPP Section
Shaft Tender	Hoisting Operations
Senior Shaft Tender	Hoisting Operations
Hoisting Operation Specialist	Hoisting Operations
Supervisor, Hoisting Operations	Hoisting Operations
Manager, Hoisting Operations	Hoisting Operations
Senior Engineer	Hoisting Operations
Senior Operations Engineer "B"	Facility Operations
Senior Engineer	Facility Operations
Shift Supervisor	Facility Operations
Manager, Facility Operations	Facility Operations
Waste Handling Technician	Waste Handling Operations
Senior Waste Handling Technician	Waste Handling Operations
Waste Handling Specialist	Waste Handling Operations
Senior Waste Handling Specialist	Waste Handling Operations
Senior Operations Engineer "B"	Waste Handling Operations
Associate Operations Engineer	Waste Handling Operations
Manager, Waste Handling	Waste Handling Operations
Health Physics Technician	Operational Health Physics
Senior Health Physics Technician	Operational Health Physics
Health Physics Specialist	Operational Health Physics
Senior Health Physics Specialist	Operational Health Physics
Manager, Operational Health Physics	Operational Health Physics
Quality Assurance Specialist	Inspection Services and QA Records
Senior Quality Assurance Technician	Inspection Services and QA Records
Quality Assurance Technician	Inspection Services and QA Records
Manager, Inspection Services and QA Records	Inspection Services and QA Records
Quality Assurance Analyst	Inspection Services and QA Records
Technical Assistant	Inspection Services and QA Records
Manager, Quality Assurance Engineering	Quality Assurance Engineering
Quality Assurance Engineer	Quality Assurance Engineering
Senior Quality Assurance Engineer	Quality Assurance Engineering
Senior Engineer	Quality Assurance Engineering
Senior Engineer "B"	Quality Assurance Engineering

APPENDIX H1
LIST OF JOB TITLES
(CONTINUED)

	RCRA Position Title	WIPP Section
1	Emergency Services Technician	Safety and Plant Protection
2	Manager, Safety and Plant Protection	Safety and Plant Protection
3	Emergency Services Coordinator	Safety and Plant Protection
4	Scientist, Environmental Permits and Programs	Environmental Permits and Programs
5	Principal Engineer	Environmental Strategic Planning
6	Senior Engineer	Environmental Strategic Planning
7	Technical Assistant	Environmental Analysis and Compliance
8	Engineering Technician	Environmental Analysis and Compliance
9	Experimental Technician	Environmental Analysis & Compliance
10	Senior Engineer	Environmental Analysis & Compliance
11	Senior Engineer "B"	Environmental Analysis & Compliance
12	Associate Scientist	Environmental Analysis & Compliance
13	Senior Scientist "B"	Environmental Analysis & Compliance
14	Utility Technician	Maintenance Operations
15	Maintenance Technician	Maintenance Operations
16	Supervisor, Maintenance Operations	Maintenance Operations
17	Manager, Maintenance Operations	Maintenance Operations
18	Maintenance Specialist	Maintenance Operations
19	Senior Maintenance Specialist	Maintenance Operations
20	Assistant Engineer	Environmental Monitoring
21	Training Coordinator	Technical Training
22	Manager, Technical Training	Technical Training
23	Associate Engineer	Quality Assurance Programs
24	Senior Quality Assurance Engineer	Quality Assurance Programs
25	Quality Assurance Specialist	Quality Assurance Programs
26	Senior Engineer "B"	Radiological Engineering
27	Senior Engineer	Radiological Engineering
28	Health Physics Specialist	Radiological Engineering
29	Associate Operations Engineer	Transportation & Hazardous Materials Handling
30	Senior Engineer "B"	Transportation & Hazardous Materials Handling
31	Senior Operations Engineer	Transportation & Hazardous Materials Handling
32	Utility Technician	Transportation & Hazardous Materials Handling
33	Manager, Transportation and Hazardous	Transportation & Hazardous Materials Handling
34	Maintenance Technician	Transportation & Hazardous Materials Handling

APPENDIX I1

MEMORANDUM OF UNDERSTANDING BETWEEN THE UNITED STATES DEPARTMENT OF ENERGY, WIPP PROJECT OFFICE, AND THE UNITED STATES DEPARTMENT OF THE INTERIOR, NEW MEXICO STATE OFFICE, BUREAU OF LAND MANAGEMENT, 1983

MEMORANDUM OF UNDERSTANDING

BETWEEN

UNITED STATES
DEPARTMENT OF ENERGY
WIPP PROJECT OFFICE

AND

UNITED STATES
DEPARTMENT OF THE INTERIOR
NEW MEXICO STATE OFFICE, BUREAU OF LAND MANAGEMENT

This Memorandum is effective the 29th day of June, 1983, between the U.S. Department of Energy (hereinafter called "DOE"), represented by the Project Manager, Waste Isolation Pilot Plant (WIPP) Project Office and the Bureau of Land Management, U.S. Department of the Interior (hereinafter called "BLM"), represented by the State Director, New Mexico BLM and concurrence by the Secretary of the Interior.

WITNESSETH THAT:

WHEREAS, DOE desires to develop the Waste Isolation Pilot Plant (WIPP), research and development facility to demonstrate the safe disposal of radioactive waste materials generated in defense programs; and

WHEREAS, this activity is authorized by Public Law 96-164, "Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980," Project 77-13-f; and

WHEREAS, public lands, as described in Appendix 1, "Legal Description" of lands withdrawn, identified for the development of the WIPP facility are lands administered by the BLM except for the 640 acres in the DOE Exclusive Use Area which are reserved for the exclusive use of the DOE; and

WHEREAS, the BLM Resource Management Plan (Appendix 2) concerning these public lands calls for the management of these lands in a manner consistent with protection of the site for development of the WIPP facility; and

WHEREAS, this Agreement is consistent with the policies set forth in the Federal Land Policy and Management Act of 1976, 43 U.S.C.-1701 et seq.; and

WHEREAS, this agreement is consistent with the administrative land withdrawal application filed by the DOE for construction of the WIPP facility and protection of the WIPP site;

NOW THEREFORE, the parties hereto agree as follows:

1. Facility Development

a. DOE is authorized to proceed with the development of the Waste Isolation Pilot Plant (WIPP) as described in the Final Environmental Impact Statement on the project (DOE/EIS-0026) and WIPP Safety Analysis Report during the period preceding enactment of a legislative land withdrawal for the herein described public domain lands. However, approval to conduct any action on lands administered by the BLM will be obtained by the DOE from BLM prior to initiation of that action.

b. The environmental impact of this action and the mitigation measures to be employed as part of the action authorized under this Memorandum of Understanding are reported in the documents cited in Section 1a, above.

c. State and Federal permits and approvals required to conduct the actions authorized under this Memorandum shall be obtained by the DOE. Copies of the applications and permits shall be transmitted to the BLM.

d. The Roswell District Manager, BLM, shall be provided with Waste Isolation Pilot Plant (WIPP) summary schedules and shall be notified as in 2f below.

e. No radioactive materials other than radiological instruments normally used for non-destructive testing and geophysical logging will be transported to or used on the site during the term of the administrative withdrawal unless specifically authorized by the Secretary of the Interior.

2. Site Protection

a. The withdrawal will close the lands to applications and proposals for land use that could result in the transfer of title to the surface and subsurface estate. Such applications and proposals will not be accepted by the BLM.

b. The BLM shall immediately notify the DOE of any request for permits to drill on existing mineral leases within the withdrawal area in order that DOE may initiate condemnation actions.

c. The DOE withdraws any objection to leasing, drilling and mining outside the withdrawal area; however, the BLM will notify the DOE of any requests for permits for resource recovery activities within one mile of the WIPP site boundary.

d. The BLM shall not allow any habitation within one mile of the outer edge of the withdrawal area and will place a "no-habitation" (no permanent inhabitants) stipulation on all leases within this one-mile buffer zone.

e. The BLM shall authorize DOE to enter BLM administered lands adjacent to the withdrawal area for emergency decontamination purposes.

f. The Roswell District Manager shall be provided with a draft copy of all project specifications and/or Request for Bid packages involving surface disturbing activities outside the exclusive use area not less than 30 days prior to finalization of the specification and/or Request for Bid packages. This is necessary so that resource protection stipulations can be included in each authorization for DOE use of BLM administered lands. Modification of a BLM approved DOE action will not be made by DOE or its subcontractor(s) without BLM concurrence if the modification involves a surface disturbing activity.

g. BLM shall submit comments relative to the approval for land use to the Project Manager, DOE, within 15 days of BLM's request receipt of DOE's request for approval or modification as identified under 2f above.

h. Allowance of applications and proposals for land use other than those described in part 2a above, that are subject to the discretion of the Secretary of the Interior shall be subject to comments by the DOE. Notification of the DOE as to the consideration of such applications and proposals shall be made by the Roswell District Manager, BLM.

i. DOE shall submit comments relative to the allowance of applications and proposals for land use to the Roswell District Manager, BLM, within 15 working days of DOE's receipt of notification by the BLM under part 2h above.

3. Stipulations

a. DOE will comply with the BLM stipulations contained in Appendix 3.

4. Administration

a. This Memorandum of Understanding will be administered on behalf of DOE by the Project Manager, WIPP Project Office, DOE/ALO, P.O. Box 5400, Albuquerque, NM.

b. This Memorandum of Understanding will be administered on behalf of the BLM by the State Director, BLM, New Mexico State Office, P.O. Box 1449, Santa Fe, NM.

5. Term

a. The parties to this Memorandum of Understanding may negotiate revisions after a 30-day written notice by either party. This Memorandum supercedes all existing agreements and shall continue in effect unless and until it is terminated by agreement of the parties hereto or is terminated by either party upon 30 days written notice to the other.

IN WITNESS WHEREOF, the parties hereto have executed this Memorandum of Understanding on the respective dates indicated.

BUREAU OF LAND MANAGEMENT
U.S. DEPARTMENT OF THE INTERIOR

By _____

Date June 14, 1983

U.S. DEPARTMENT OF ENERGY

By _____
J. D McGough, Project Manager

Date June 10, 1983

Concurrence:

Assistant Secretary of the Interior

/s/ Garrey E. Carruthers

By _____

JUN 17 1983

Date _____

APPENDIX 1

LEGAL DESCRIPTION

Lands Withdrawn

Federal Lands (Public Domain)

T22S - R31E		Acres
DOE Exclusive Use Area		
Section 20	SE 1/4	160
Section 21	SW 1/4	160
Section 28	NW 1/4	160
Section 29	NE 1/4	160
BLM Managed Surface Area		
Section 15	All	640
Section 17	All	640
Section 18	All	640
Section 19	All	640
Section 20	W 1/2 and NE 1/4	480
Section 21	NW 1/4 and E 1/2	480
Section 22	All	640
Section 27	All	640
Section 28	E 1/2 and SW 1/4	480
Section 29	SE 1/4 and W 1/2	480
Section 30	All	640
Section 31	All	640
Section 33	All	640
Section 34	All	640
Total		8960

State lands within withdrawal area

T22S - R31E		Acres
Section 16	All	640
Section 32	All	640
Total		1280

Total acreage within withdrawal area boundary 10240

APPENDIX 2

RESOURCE MANAGEMENT PLAN FOR LANDS UNDER THE BLM/DOE MEMORANDUM OF UNDERSTANDING FOR THE WASTE ISOLATION PILOT PLANT

This Resource Management Plan summarizes actions and activities which will be authorized by BLM to take place on the public lands administered by BLM within the withdrawal area, and except for those actions and activities that are mutually determined to be inconsistent with the mission of WIPP, this RMP also applies to the DOE exclusive use area which will be administered by DOE. This plan takes into account any recommendations for management of these lands as outlined in the BLM's East Eddy/Lea Management Framework Plan (MFP) and the Rangeland Management Program of April 1980, as revised in January 1981.

Minerals

Oil and Gas--One 80 acre tract of the public lands within the BLM Managed Surface Area is leased for oil and gas development. DOE will be notified in the event that an application to drill is submitted by the lessee. BLM concurrence will be withheld until comments are received from DOE.

Potash--The MFP decision was to continue to process all potash leases within the Economic Reserve Areas. The exception was to hold lease applications within the WIPP withdrawal until such time as the provisions of the withdrawal are accepted or rejected. Therefore, the leases in this zone will not be processed.

Sand, Gravel and Caliche--There are saleable deposits of caliche and sand and gravel within this area. Sales or free use permits will be made on an "as needed" basis to support the WIPP, road building, adjacent oil and gas development.

Realty and Lands

Applications and proposals for land uses, that could result in the transfer of title to the surface and subsurface estate, will not be accepted by the BLM.

Allowance of applications and proposals for land uses, other than those described above that are subject to the discretion of the Secretary of the Interior, will be subject to comments by the DOE. Notification of the DOE as to the consideration of such applications and proposals shall be made by the BLM authorized officer.

All proposals for land uses shall be submitted to the Roswell District Manager, BLM, for review, comment and authorization. In order for resource protection activities to be carried out as an integral part of each action, BLM "standard stipulations" and/or "Special Stipulations" shall be made a part of all land use authorizations, as applicable.

Range Management

Grazing will continue as recommended in the MFP outside the DOE fenced area. Range management will attempt to improve forage production on the allotments in order to attain maximum productivity of the range.

This area is located on two grazing allotments, the J. C. Mills allotment, No. 7032, and the Kenneth Smith allotment, No. 7027. The Mills allotment is currently being run under a management plan whereas the Smith allotment has no formal mangement plan. A plan will be formalized in the future for the Smith allotment. Grazing will be administered as outlined in the Rangeland Management Program of April 1980 as revised in January 1981.

Several range monitoring studies are located on the two grazing allotments within the boundaries of this area. These studies will continue.

Future projects will be implemented as needed, including possible chemical brush control. DOE will be allowed to review the proposed range improvements and submit comments.

Wildlife

This area will be managed to protect existing wildlife resources. In particular, this is an area of heavier-than-usual raptor nesting. The Harris hawk, a species which is declining nationwide, is a common nester here. Raptor nests and broadleaf trees are to be protected primarily because of this, as recommended by the MFP.

In certain locations, wildlife water is nonexistent or available only to certain species. Methods such as bird ramps, pipeline waters and dirt tank enclosures may be implemented in the future to improve habitat.

Threatened or Endangered Species

This area is not considered to be habitat for any Federally listed threatened or endangered plant or animal species.

Cultural Resources/Paleontology

The BLM will retain all management responsibilities for cultural resources and paleontological resources in this area. All potential impacts to these resources, which are attributable to the WIPP Project in general, will be assessed by the BLM. The BLM will then develop appropriate mitigation plans for these resources in consultation with the State Historic Preservation Officer and the Advisory Council on Historic Preservation. Mitigation plans will be implemented by the DOE under the direction of the BLM.

Recreation

Except as set forth in the physical access sub-section of this plan, the lands will continue to be designated as "open" to recreational use by the public. Hunting, sightseeing and off-road vehicle use will continue to be the major recreational uses of the area.

No developed recreation sites are planned for the area.

Off-Road Vehicles

Except as set forth in the physical access sub-section of this plan, the area will continue to be designated as "open" to off-road vehicle use.

Physical Access

Physical protection of the DOE exclusive use area is deemed necessary. The DOE is responsible for controlling the entry of unauthorized personnel and the transport of unauthorized personal property into the DOE exclusive use area.

Wilderness

No land within this area is suitable for wilderness designation as defined by the 1964 Wilderness Act.

Visual Resources Management (VRM)

This area is managed as a Class IV VRM area.

Fire

The BLM will continue to be responsible for wildland fire suppression efforts on public lands in this area. DOE is assigned the responsibility to take initial attack effort on any fire within this area until BLM can relieve them.

Watershed

The BLM does not expect to engage in any major watershed management projects in the area. Watershed management will be limited to brush control, rehabilitation areas, etc.

Air Quality

Air quality for this area will be managed consistent with existing laws and regulations.

Prime and Unique Farmlands

No prime and unique farmlands exist within this area.

General

Upon request, DOE or their contractors will supply BLM with a copy of any studies or reports done in connection with the WIPP Project.

The Resource Management Plan for lands under the BLM/DOE Memorandum of Understanding for the WIPP Project withdrawal is hereby approved by the two agencies.

Department of the Interior
Bureau of Land Management
Roswell District

Richard Gaskin
Associate District Manager

Date 6/13/1983

Department of Energy
Albuquerque Operations Office
WIPP Project Office

Roger Dutcher for
J. H. McGough, Project Manager

Date June 10, 1983

APPENDIX 3

BLM STIPULATIONS FOR WIPP ADMINISTRATIVE WITHDRAWAL

DOE agrees to comply with the following stipulations to the satisfaction of the BLM Roswell District Manager or his authorized representative.

1. All projects and/or facilities authorized by previous Cooperative Agreements and/or Memorandum of Understanding shall be either maintained to acceptable BLM standards and/or design standards or will be removed. If removed, rehabilitation of the sites will be prescribed by BLM.

2. DOE will remove caliche and/or other mineral material only from BLM approved sites. DOE will submit a pit development and rehabilitation plan to BLM and receive BLM approval prior to the removal of any caliche. The pit plan will include estimated depth, lateral extent of mining, estimated quantity of material to be removed, and restoration/rehabilitation methods.

3. DOE will sign applications for Bureau of Land Management Free Use Permits for the borrowing of caliche, sand, gravel and other construction materials in such quantities as may be reasonably required for this project. WIPP Site contractors shall be responsible for locating the source, obtaining and completing applications, processing applications and complying with all Bureau of Land Management requirements. The DOE's sole responsibility will be limited to signing properly compiled applications for Free Use Permits.

4. To protect livestock DOE will either maintain the barbed wire fence surrounding the area previously identified as the Drilling Fluid Disposal Area or, if necessary remove the old fence and reconstruct a new barbed wire fence surrounding the same Fluid Disposal Area now identified as a Sanitary Landfill Area. Fence will be constructed to BLM's standard Type A-11 special 4-strand barbed-wire fence specifications.

5. DOE will provide BLM, Roswell Office, with WIPP technical specifications and drawings.

6. DOE will dispose of vegetation in accordance with the design specifications.

7. Unless BLM approval to close a road is given, DOE will keep all roads open to public access outside the DOE fenced area.

8. The DOE plan for mitigation of all adverse impacts to cultural resources generated by this project will be reviewed and approved by the BLM Roswell District Manager or his authorized representative.

9. Upon completion of SPDV surface disturbing operations, DOE will comply with the following rehabilitation measures:

a. Restoration of caliche pits and their access roads; i.e., ripping, leveling, and reseeding with seed mixture #2 (sandy sites). If pit is required for future use, restoration may be waived by the BLM.

b. All roads and pads constructed in conjunction with SPDV that are no longer needed for SPDV or WIPP require ripping, leveling, and reseeding with seed mixture #2 (sandy sites). Specific roads and/or pads to be rehabilitated will be identified by the Roswell District Manager or his authorized representative in consultation with DOE. Rehabilitation will be initiated by January 1, 1985.

10. If the WIPP site is abandoned for any reason, DOE will comply with the following rehabilitation measures:

a. Restoration of caliche and/or other mineral material pits and their access roads, i.e., ripping, leveling and reseeding with seed mixture #2 (sandy sites). If pits are required for future use, restoration may be waived by BLM.

b. All salt from the stockpile shall be removed from the site surface.

c. The salt stockpile base shall be ripped, leveled, mixed with soil and reseeded with seed mixture #2 (sandy sites). DOE shall make provisions to return this soil to basically original conditions.

d. The stripping stockpile areas shall be ripped, leveled, mixed with soil, and reseeded with seed mixture #2 (sandy sites).

e. All roads and pads constructed in conjunction with WIPP may require ripping, leveling, and reseeding with seed mixture #2 (sandy sites). Specific roads and pads to be rehabilitated will be identified by the Roswell District Manager or his authorized representative during project phase-out.

f. All fences constructed in conjunction with the project may require removal.

g. Abandonment of the surface facilities, including support facilities such as power lines, etc. and underground facilities shall be done by DOE in accordance with all applicable laws, rules, and regulations in effect at the time. BLM recommended procedures for underground work derived from similar abandonments in the known potash area will be considered. In the areas where surface facilities are removed, the areas shall be ripped, leveled, mixed with soil and reseeded with seed mixture #2 (sand sites).

11. Physical access will be controlled in accordance with the DOE site physical access plan which has been approved by the BLM.

APPENDIX J1

SOLID WASTE MANAGEMENT UNIT (SWMU) CHARACTERIZATION SHEETS

001 MUD PITS

Unit Type:	Mud Pits
Unit Use:	Storage/Settling
Operational Status:	Decommissioned
Use Period:	1970s-1980s
Materials Managed:	Solid Waste
Hazardous Release:	None
Radioactive Release:	None
Information source(s):	Seward, 1982 USGS, 1978 Winstanley and Carrasco, 1986

Unit Description

Refer to Figure J-1 for location. Approximately 46 decommissioned mud pits are located on 28 drill pads at the WIPP facility. They were used for settling drill cuttings out of the drilling fluids being used in drilling holes to support hydrologic testing and monitoring, potash evaluation, and drilling for hydrocarbons. Each mud pit was approximately 100 feet by 50 feet by 5 feet. Diesel fuel was added to the drilling mud to reduce dissolution of the water soluble rocks and to help lubricate the drill rods. It is not known how many of the wells were drilled using diesel in the drilling mud. Each mud pit was lined with a plastic sheet and used for one to two months during drilling, then allowed to dry out. To facilitate drying, holes were cut in the bottom of the liner. Once a pit was dry, it was covered with the soil that had been removed to make the berms and then graded to the original contours. The individual mud pits in SWMU No. 001 are listed on Table J1-1. It is difficult to determine the exact location of most of the mud pits because of the grading and revegetation that has taken place.

Many of these mud pits were the result of exploration activity that was conducted prior to the selection of the area for the WIPP facility and, therefore, were not created by DOE in support of the WIPP Project. All such locations are indicated in Table J1-1

Waste Description

Materials in the mud pits consisted of sodium- and potassium chloride-saturated brine to which starch, bentonite gel, and diesel fuel were added; drill cuttings; metal cuttings; trace amounts of hydraulic fluid, grease, and motor oil; and the plastic liner.

Release Information

Potential releases from each of the drill sites occurred when the mud pits were drained by cutting holes in the liner. The materials released consisted of saturated brines, which are not considered hazardous under RCRA. All of the solids confined in the plastic liner of the mud pits were buried when the pits were covered with soil and graded.

TABLE J1-1
SWMU DATA - MUD PITS

SWMU	LOCATION[1]	HOLE #	# OF PITS[2]	PERIOD OF USE	WELL STATUS	SIZE OF DRILL PAD (ACRES)
001-a	SW, NE, NE, 29	H-1	1	5/76 - 6/76	Open	8
001-b	SW, NE, NW, 29	H-2a H-2b1 H-2b2 H-2c	3	2/77 & 5/84 2/77 7/83 & 5/84 2/77 & 8/83	Sampled once/yr. Sampled once/yr. Open Open	3
001-c	NE, NE, SE, 29	H-3b1 H-3b2 H-3b3	3	8/76 & 4/86 11/83 1/84	Sampled once/yr. Open Sampled once/yr.	3
001-d	SE, NE, NE, 15	H-5a H-5b H-5c P-21	2	6/78 6/78 6/78 10/76	Open Sampled once/yr. Sampled once/yr. Plugged	3
001-e	NW, NW, NW, 18	H-6a H-6b H-6c P-13	2	7/78 7/78 6/78 9/76	Open Sampled once/yr. Sampled once/yr. Plugged	6
001-f	SE, NE, SE, 33	H-11b1 H-11b2 H-11b3 P-9	2	8/83 11/83 1/84 9/76	Open Open Sampled once/yr. Plugged	1
001-g	SW, SW, SW, 29	H-14 P-1	2	9/86 8/76	Sampled once/3 yrs. Plugged	1
001-h	NE, NE, NE, 28	H-15	1	10/86-11/86	Sampled once/3 yrs.	1
001-i	NE, NW, NW, 20	H-18	1	11/87	Sampled once/3 yrs.	1
001-j	SE, SE, SW, 20	P-3	1	8/76-9/76	Plugged	1/2
001-k	SE, SW, SE, 28	P-4	1	8/76-9/76	Plugged	3/4
001-l	SE, SE, SE, 17	P-5 WIPP-12	3	9/76 11/78 & 10/85	Plugged Open	6
001-m	SW, SW, NW, 30	P-6	1	9/76	Plugged	1
001-n	SW, SW, SW, 31	P-15	1	10/76	Plugged	1
001-o [3]	NW, NE, SW, 15	Badger Unit	1	1974	Plugged	2
001-p [3]	SW, NE, SW, 34	Cotton Baby	1	1973-1974	Plugged	3
001-q	SE, SE, SE, 28	DOE-1	2	1982	Open	3

TABLE J1-1
SWMU DATA - MUD PITS
(CONTINUED)

SWMU	LOCATION[1]	HOLE #	# OF PITS[2]	PERIOD OF USE	WELL STATUS	SIZE OF DRILL PAD (ACRES)
001-r [3]	NE, NE, SE, 34	D-123	1	Unknown (pre-1975)	Plugged	1/2
001-s	SE, SE, SE, 20	ERDA-9	1	4/76 - 6/76	Open	2
001-t [3]	SE, SE, SW, 30	IMC-374	1	Unknown (pre-1975)	Plugged	1
001-u [3]	NW, NW, NW, 20	IMC-376	1	Unknown (pre-1975)	Plugged	1
001-v [3]	SE, SE, SW, 22	IMC-456	1	Unknown (pre-1975)	Plugged	1
001-w [3]	SE, SW, SW, 27	IMC-457	1	Unknown (pre-1975)	Plugged	1
001-x	NW, NE, SW, 17	WIPP-13	2	8/78 & 10/85	Open	4
001-y	NW, NW, NW, 21	WIPP-18	2	4/78 & 10/85	Open	1
001-z	SW, SW, NW, 21	WIPP-19	2	5/78 & 10/85	Sampled once/yr.	1
001-aa	SW, NW, SW, 21	WIPP-21	2	5/78 & 10/85	Open	3
001-ab	NW, NW, SW, 21	WIPP-22	2	5/78 & 10/85	Open	1

1 All of the mud pits are in T22S, R31E. The location column gives the 1/4 of the 1/4 of the 1/4 of the section.
2 Probable number of mud pits. Many of the drill pads were used to drill several holes, requiring the use of more than one mud pit.
3 These are wells that were not drilled at the request of DOE; they were drilled for hydrocarbon and potash exploration.

002 SALT AND TOP SOIL STORAGE AREAS

Unit Type:	Storage Areas
Unit Use:	Storage
Operational Status:	Active
Use Period:	1981-present
Materials Managed:	Solid Waste
Hazardous Release:	None
Radioactive Release:	None
Information source(s):	Process knowledge Annual aerial photos Westinghouse, 1984

Unit Description

Refer to Figure J-1 for location. Two areas have been used for salt storage at the WIPP facility. The older area (002-a), located due east of Zone I, was active during the early excavation phases of the underground, starting in 1981. This area holds about 155,000 cubic yards of salt and covers about 7 acres. It was used until the main salt storage area (002-b) became active in April, 1984. This salt storage area, located north of Zone I, is still active, contains about 402,000 cubic yards of salt, and covers about 15 acres. Berms and a holding pond are used to control run-off from the main salt storage area, but just a berm is used for the older area.

Two other areas have been used to store top soil from the WIPP facility. The first area (002-c), first used in 1981, was located 470 feet due east of the Salt Handling Shaft and covered approximately three acres. Most of this stockpile has been covered by the expansion of Zone I; the east end of it is still visible at the eastern boundary of Zone I. A second area (002-d), located on the east side of SWMU No. 002-a, has been used since 1981 to store the top soil removed to clear the salt pile location. It covers about 3.1 acres.

Waste Description

Based on process knowledge, material stored at the salt storage sites is primarily salt with trace amounts of hydraulic oil, motor oil, diesel, and scrap steel. The impurities in the salt are from the heavy equipment used for excavation of the repository and transport of the salt to the salt pile. Material stored at the top soil storage areas is only top soil.

Release Information

Releases of RCRA hazardous waste or hazardous constituents have not occurred at these sites. There is an area of vegetation kill along the outer edge of the berm near the older salt storage area that appears to have been caused by the salt. The maximum extent of the vegetation kill was an area of approximately 50 feet by 100 feet. The vegetation kill area is decreasing in size as it recovers.

003 LANDFILLS

Unit type:	Landfill
Unit use:	Disposal
Operational status:	Active
Use period:	1976-present
Materials managed:	Solid Waste
Hazardous release:	None
Radioactive release:	None
Information source(s):	Annual aerial photos DOE, 1988 Flynn, 1989 Westinghouse, 1991a

Unit Description

Refer to Figure J-1 for location. Two areas have been used as landfills at the WIPP facility. The older location, called the Brinderson Landfill (003-a), is located 1 mile due south of Zone I. Prior to use as a landfill, the area was used as a quarry for road bed materials. It was an active landfill from 1976 to January 1988 and covers about 4 acres. The closure of the Brinderson Landfill was approved by the U.S. Department of Interior, Bureau of Land Management (BLM). Since it was closed, the Brinderson Landfill has been covered over and reseeded. The new landfill (003-b) is located 1/2 mile south of Zone I. The new construction landfill is actually two landfills. One, to the south of the current one, was excavated on BLM land and operated under a BLM permit until 1989. It was closed at the request of the BLM and a new landfill was opened on land designated by the BLM as part of the DOE Exclusive Use Area in Public Land Order 6403. Ground was first broken for the new landfill area in November, 1982; it is still active and covers about 15 acres. All necessary permits were obtained from the BLM for both landfills.

Waste Description

Both of the landfills have been used to bury construction debris consisting of foundation excavation soils, waste concrete, scrap wood, and metal. In addition, it has been reported that small amounts of non-construction debris (most likely office wastes) were dumped in the Brinderson Landfill. No asbestos materials are known to have been disposed of in the landfills. Administrative controls in WP 02-5, Nonradioactive Hazardous Materials Environmental Compliance Manual, prohibit the disposal of RCRA hazardous waste or hazardous constituents in the construction landfill (Westinghouse, 1991a).

Release Information

Releases of RCRA hazardous waste or hazardous constituents have not occurred at these sites.

004 STORAGE YARDS

Unit type:	Storage Areas
Unit use:	Storage
Operational status:	Active
Use period:	1976-present
Materials managed:	Solid Waste
	Hazardous Waste
	Oils
Hazardous release:	Potential
Radioactive release:	None
Information source(s):	Process knowledge
	Annual aerial photos
	Sampling/laboratory analysis data
	Westinghouse, 1992a

Unit Description

Refer to Figure J-1 for location. Two areas outside of Zone I are presently used for storage. One storage yard, the portacamp (004-a), is located about 1,000 feet southeast of Zone I. The yard is used to store construction and maintenance materials, including approximately 100 drums of virgin petroleum products, and as temporary storage for wastewater and waste oils awaiting laboratory analysis. The waste oils are recycled if free of hazardous contamination. The area is approximately 2 acres in extent and has been active since 1976. The other area, the reclaimables yard (004-b), is located 1/2 mile due south of Zone I, just east of the new landfill (SWMU No. 003-b). The yard is about 1/2 acre in extent and is used as temporary storage for materials that can be recycled or reclaimed. It has been in use since February, 1987.

Waste Description

The wastes stored at the portacamp are water contaminated with motor oil, hydraulic oil, and diesel fuel from the vehicle wash bays; used hydraulic oil; used motor oil; glycol-based oils; used antifreeze; and discontinued oils. In 1987, the excess chemical grout from grouting the Exhaust Shaft and the Waste Handling Shaft was stored in this yard prior to being shipped off site for disposal as hazardous waste.

The materials in the reclaimables yard consist of used batteries, empty 55-gallon drums, and scrap metal. Some of the 55-gallon drums are used for fork-truck practice and are filled with caliche or lead pellets.

Release Information

There have been no releases of RCRA hazardous waste or hazardous constituents from either area; however, small areas of stained soil under the pallets where the virgin petroleum products are stored indicate there have been minor releases of oil and petroleum products (non-RCRA regulated materials) from the drums. Any releases from the area used for staging wastewater and waste oils are remediated as per the applicable WIPP facility procedure. Materials collected from the remediation activities are managed in accordance with procedures in WP 02-6 and 02-7 (Westinghouse, 1992a).

005 CONCRETE BATCH PLANTS

Unit type:	Concrete Batch Plants
Unit use:	Storage/Production
Operational status:	Decomissioned
Use period:	1984-1989
Materials managed:	Solid Waste
Hazardous release:	None
Radioactive release:	None
Information source(s):	Process knowledge Annual aerial photos

Unit Description

Refer to Figure J-1 for location. Three areas at the WIPP facility have been used as temporary locations for cement batch plants. The first area (005-a) was located in the southeast corner of Zone I where the Waste Handling Building is now located. It was active from early 1984 to December, 1984. The second area (005-b) was located just west of Zone I and the main salt storage area (SWMU No. 002-b) and the evaporation pond (SWMU No. 007-c). It covers about 2 acres and was active from late 1988 to early 1989. Since the plant has been removed from this location the area has been reclaimed. The south of Zone I, next to the drill pad for well H-1 (SWMU No. 001-a). It covers about 5 acres, was active from January, 1985 to early 1987, and is currently used as an aggregate storage area.

Waste Description

Releases of RCRA hazardous waste or hazardous constituents have not occured at these sites. The waste consists of small amounts of spilled concrete and possibly trace amounts of motor oil and grease that leaked from the trucks and equipment.

Release Information

The only releases from these sites consist of spillage that occurred during filling of the trucks and stockpiling materials. The material released was water mixed with concrete, sand, and gravel and is considered nonhazardous. In addition, trace amounts of non-RCRA regulated motor oil, grease, and diesel may have leaked from the trucks during loading.

006 HOLDING PONDS

Unit type:	Holding Ponds
Unit use:	Storage/Settling
Operational status:	Decommissioned
Use period:	1981-1984
Materials managed:	Solid Waste
Hazardous release:	None
Radioactive release:	None
Information source(s):	Process knowledge Annual aerial photos Westinghouse, 1984

Unit Description

Refer to Figure J-2 for location. During the drilling of the first two shafts at the WIPP facility, brine was used as a drilling fluid and each shaft had a separate holding pond for the brine. The holding pond for the Exploratory Shaft (006-a), now called the Salt Handling Shaft, covered 1-1/2 acres, was about 10 feet deep, and was located 75 feet east of the current Salt Handling Shaft. This pond was active from June 1981 to April 1983. The holding pond for the Ventilation Shaft (006-b), the current Waste Handling Shaft, covered 1/2 acre and was 10 feet deep. It was located 115 feet west of the current Waste Handling Shaft. It was active from December 1981 until late 1984. Both ponds were allowed to dry and were then covered with soil. Both areas were later excavated for construction purposes. The Engineering Building was constructed on top of 006-a and the Waste Handling Building was constructed on top of 006-b.

Waste Description

Based on process knowledge, material stored in the holding ponds consisted of saturated brine with bentonite added, drill cuttings, and trace amounts of hydraulic oil and grease that may have leaked from the drilling equipment. The solid material left in the mud pits after drilling still contained a high percentage of water at the time they were covered. This resulted in a gelatinous material consisting of the drill cuttings, bentonite, and water being encountered during excavation for the Engineering Building foundation. The gelatinous material was excavated and disposed of in the construction landfill.

Release Information

Releases of RCRA hazardous waste or hazardous constituents have not occurred at these sites. Potential releases from these ponds may have occurred because holes were cut in the lining after the water had evaporated. The holes were cut to prevent the ponds from holding water after they were covered over. The solids confined in the plastic liner of the holding ponds were buried when the ponds were covered with soil and graded. The material released was sodium-and potassium-saturated brine, which is considered nonhazardous.

007 EVAPORATION PONDS

Unit type:	Evaporation Ponds
Unit use:	Storage/Disposal
Operational status:	Active
Use period:	1981-present
Materials managed:	Solid Waste
Hazardous release:	None
Radioactive release:	None
Information source(s):	Annual aerial photos Westinghouse, 1984

Unit Description

Refer to Figure J-1 for location. Three ponds have been used for evaporation of water. The oldest pond (007-a) was located in the southwest corner of Zone I. It covered about 1/2 acre and was about 4 feet deep. It received water from the employee showers in temporary buildings and was active from 1981 to 1983. The area is presently covered by the Waste Handling Building and the paved area southwest of the Waste Handling Building. Another pond (007-b), which also received water from the showers, was located about 770 feet due west of the Waste Handling Shaft. This pond was present from late 1983 to early 1984. The third pond (007-c) is used to collect run-off from the main salt storage area. It is located on the west side of the main salt storage area (SWMU No. 002-b), covers 3 acres, and is 5 feet deep. It has been active since May 1984.

Waste Description

Based on process knowledge, the waste in the inactive ponds (007-a and 007-b) consisted of water containing soap, nonhazardous cleaning solutions, and trace amounts of oil. The third pond (007-c) receives runoff from the main salt storage area, consisting primarily of unsaturated salt brine.

Release Information

Releases of RCRA hazardous waste or hazardous constituents have not occurred at this site.

008 SURFACE SATELLITE ACCUMULATION AREAS

Unit type:	Storage Areas
Unit use:	Storage
Operational status:	Active
Use period:	1988-present
Materials managed:	Hazardous Waste
	Solid Waste
Hazardous release:	None
Radioactive release:	None
Information source(s):	Process knowledge
	Westinghouse, 1992a
	Westinghouse, 1992b
	Westinghouse, 1991b

Unit Description

Refer to Figure J-2 for location. The satellite accumulation areas on the surface all use DOT-approved containers for storing all hazardous waste. Specifics of the satellite accumulation areas are listed on Table J1-2.

Waste Description

The wastes collected in surface satellite accumulation areas consist of chlorinated solvents, motor oil, hydraulic oil, oily rags, aerosol cans, antifreeze, and developing fluid. Satellite accumulation areas are managed (e.g., inspected, sample collection and analysis) in accordance with procedures in WP 02-6 and 02-7, Resource Conservation and Recovery Act (RCRA) Compliance Manual (Westinghouse, 1992a). Corrective actions for potential releases are described in WP 02-8, WIPP Spill Prevention, Control, and Countermeasures Plan (Westinghouse, 1991b) (for nonhazardous releases) and WP 02-12, WIPP Contingency Plan (Westinghouse, 1992b) (for hazardous releases).

Release Information

Releases of RCRA hazardous waste or hazardous constituents have not occurred aat these sites.

TABLE J1-2
SWMU DATA - SURFACE SATELLITE ACCUMULATION AREAS

SWMU	Date Started	Location	Status	Material Stored
008-a	1988	Maintenance Warehouse Bldg. 455	Active	Chlorinated solvents, oily rags, aerosol cans
008-b	1988	Outside Bldg. 455, east side	Active	Spent oils, solvents, oily rags, aerosols
008-c	1988	Sandia Calibration Lab Bldg. 993	Active	Aerosols and solvents
008-d	1989	Sandia Cable Shop Bldg. 911G	Active	Aerosols and solvents
008-e	1988	Security Armory Bldg. 473	Active	Powder solvents, gun oil, oily rags
008-f	1987	Drafting Area Engineering Bldg. 486	Active	Solvent concentrates, developing fluid, aerosols
008-g	April 1989	Emergency Services Bldg. vehicle wash bay	Active	Water with solvents and minor amounts of motor oil, grease, and hydraulic oil
008-h	Unknown	Overpack Repair Room Bldg. 411	Active	Derived waste

009 UNDERGROUND SATELLITE ACCUMULATION AREAS

Unit type:	Storage Areas
Unit use:	Storage
Operational status:	Active
Use period:	1983-present
Materials managed:	Hazardous Materials Hazardous Waste Solid Waste
Hazardous release:	None
Radioactive release:	None
Information source(s):	Process knowledge Westinghouse, 1992a Westinghouse, 1992b Westinghouse, 1991b

Unit Description

Refer to Figure J-3 for location. The underground satellite accumulation areas are located at various locations in the waste repository. The satellite accumulation areas in the underground all use DOT-approved containers for storing all hazardous waste. Unit information for these areas is provided in Table J1-3.

Waste Description

The materials stored in the underground satellite accumulation areas are nonradioactive, site-generated wastes that include new and used storage batteries; waste motor oil; waste hydraulic oil; naphtha-based solvents; oily rags; aerosols; wastewater contaminated with motor oil; grease; diesel; hydraulic oil and salt; and silicon grout. Satellite accumulation areas are managed (e.g., inspected, sample collection and analysis) in accordance with procedures in WP 02-6 and 02-7, Resource Conservation and Recovery Act (RCRA) Compliance Manual (Westinghouse, 1992a). Corrective actions for potential releases are described in WP 02-8, WIPP Spill Prevention, Control, and Countermeasures Plan (Westinghouse, 1991b) (for nonhazardous releases) and WP 02-12, WIPP Contingency Plan (Westinghouse, 1992b) (for hazardous releases).

Release Information

Releases of RCRA hazardous waste or hazardous consituents have not occurred at these sites.

TABLE J1-3
SWMU DATA - UNDERGROUND SATELLITE ACCUMULATION AREAS

SWMU	Dates	Location	Status	Material Stored
009-a	1988-present	S1300/W30 Maintenance Shop	Active	Naphtha-based solvents, oily rags, aerosols
009-b	1990-present	E300 Experimental Programs Shop	Active	Aerosols
009-c	1989-present	S1300/W170 Intersection	Active	Storage batteries, waste oil
009-d	1989-present	West End of S1300	Active	Petroleum, oil, lubricants storage and 1 drum of waste oil
009-e	1988-present	S1000 Tool Room	Active	Storage batteries
009-f	1990-present	S1950 Storage area	Active	Silicon grout, purple K (fire extinguishing agent), rockbolts
009-g	1990-present	S1600/W30 Underground Wash Rack	Active	Water contaminated with salt, grease, hydraulic oil, motor oil, and diesel
009-h	1990-present	S1000/E140	Active	Oily rags, naphtha-based solvents, aerosols
009-i	1989-present	N780 Shop	Active	Aerosols, oily rags
009-j	1983-1988	SPDV Rm. 1 Old Maintenance Shop	Inactive	Oily rags, naphtha-based solvents, aerosols, used oil
009-k	1983-1988	SPDV Rm. 2 Storage Area	Inactive	Scrap metal, portable brine sump
009-l	1983-1988	SPDV Rm. 4 Storage Area	Inactive	Drill core, rock cutting oil (for rock saw), scrap metal, grout, solvent, cement
009-m	1983-1988	West End N1420	Inactive	Scrap metal, waste oil, solvents, grout, cement, blasting powder
009-n	---	Panel 1 undesignated	Inactive	Derived waste

010 SHAFT SUMPS

Unit type:	Shaft Sumps
Unit use:	Collection/Storage
Operational status:	Active
Use period:	1981-present
Materials managed:	Solid Waste Hazardous Waste
Hazardous release:	None
Radioactive release:	None
Information source(s):	Process knowledge Westinghouse, 1984 DOE, 1987

Unit Description

Refer to Figure J-3 for location. Four shafts have been completed to the WIPP acility underground. The Salt Handling and the Waste Handling Shafts have sumps (010-a and 010-b) that extend below the facility horizon (148 feet and 119 feet, respectively). The sumps have been cut into the salt of the repository and have not been lined. The other two shafts, the Exhaust Shaft and the Air Intake Shaft, end at the facility horizon and do not have sumps. The bottoms of these shafts are 010-c and 010-d, respectively. The bottoms of all four shafts have received construction debris. The Salt Handling and Waste Handling Shafts have been grouted and there is no wastewater accumulation. The solid material cleaned up from the bottom of the shafts without sumps is disposed of on the main salt storage area. The Air Intake Shaft currently receives brine from the Rustler Formation. On January 17, 1992, the New Mexico Environment Department issued an approved Discharge Plan to expand the WIPP sewage facility. The discharge plan allows for the disposal of Air Intake Shaft brine waters in the evaporation lagoon and the expanded sewage facility. Until the new sewage lagoon expansion is complete, the discharge plan permits the disposal of wastewater generated by observation well pumping at the site in the evaporation basin (SWMU No. 007-c), west of the main salt storage area (SWMU No. 002-b). Unit information for these SWMUs is listed on Table J1-4. Engineering drawings of the Waste Handling and Exhaust Shafts are included in Appendix D3 of this permit application.

Waste Description

The wastes consist of welding debris, scrap steel, concrete from the shaft lining, cement grout, chem grout, grease, wash water, brine from the Rustler Formation, and salt.

Release Information

Releases of RCRA hazardous waste or hazardous constituents have not occurred at these sites.

TABLE J1-4
SWMU DATA - SHAFT SUMPS

SWMU	Dates	*Location and Description	Status	Material Stored
010-a Salt Handling Shaft	1981	0/0 Sump extends 148 feet below the facility horizon.	Active	Welding residue, scrap wood and metal, salt, class C cement, chem-seal, bentonite, grease, oil
010-b Waste Handling Shaft	1982	S400/E30 Sump extends 119 feet below the facility horizon.	Active	Concrete, salt, cement grout, chem grout, brine from Rustler Formation, wash water, grease, oil
010-c Exhaust Shaft	1985	S400/E480 The shaft ends at the facility horizon.	Active	Salt, concrete, cement grout, chem grout, brine from Rustler Formation, grease, oil
010-d Air Intake Shaft	1989	0/W620 The shaft ends at the facility horizon.	Active	Salt, brine from Rustler Formation, concrete, grease, oil

*All locations given by underground coordinates.

011 SEWAGE TREATMENT FACILITY

Unit type:	Sewage Treatent Facility
Unit use:	Treatment
Operational status:	Active
Use period:	May 1985-present
Materials managed:	Sanitary Waste Suspected Solid Waste
Hazardous release:	None
Radioactive release:	None
Information source(s):	Process knowledge Westinghouse, 1992a

Unit Description

Refer to Figure J-1 for location. The sewage treatment facility consists of five ponds, primary cells 1A and 2A, polishing cells 1B and 2B, and the effluent pond. The primary and polishing cells are lined with Dynaloy and each has a capacity of 9,250 gallons. The facility is located about 1/4 mile southwest of Zone I and covers an area of about 4 acres. No chemicals are added to the effluent for treatment. The effluent pond is unlined and has a capacity of 18,500 gallons. A discharge plan for the WIPP facility was submitted to the New Mexico Environment Department on January 7, 1992. The discharge plan identifies all WIPP facility discharge streams. The New Mexico Environment Department approved the plan on January 17, 1992.

Waste Description

The sewage treatment facility treats sanitary waste. Neutralized film developer, solvents, and oils are reported to have been disposed of through this system in the past.

Release Information

Releases of RCRA hazardous waste or hazardous constituents have not occurred at this site. The releases from this unit are part of the treatment process and consist of infiltration of the water from the unlined effluent pond. The water is considered nonhazardous. The water undergoes routine sampling and analysis as described in WP 02-6 and 02-7. If hazardous constituents are detected, the water will be handled as site-generated hazardous waste in accordance with procedures in WP 02-6 and 02-7 (Westinghouse, 1992a).

012 NONHAZARDOUS SOLID WASTE COLLECTION BINS

Unit type:	Collection Bins
Unit use:	Storage
Operational status:	Active
Use period:	Jan. 1985-present
Materials managed:	Nonhazardous Waste
Hazardous release:	None
Radioactive release:	None
Information source(s):	Process knowledge

Unit Description

Not shown on figure. There are two 30-cubic-yard rolloff bins and eighteen 6-cubic-yard end dump bins located at various locations around the WIPP facility. These units are portable and their locations vary. After it is collected, the waste is disposed of at the Dark Canyon Landfill located south of the city of Carlsbad. These solid wastes do not contain RCRA-regulated hazardous waste or hazardous constituents.

Waste Description

Nonhazardous solid waste is collected in the bins at the WIPP facility.

Release Information

Releases of RCRA hazardous waste or hazardous constituents have not occurred at these sites.

List of References for Appendix J1

DOE, see U.S. Department of Energy.

Flynn, D. T., (ed.), 1989, "Annual Site Environmental Report for the Waste Isolation Pilot Plant, 1988," DOE/WIPP 89-005, U.S. Department of Energy, Carlsbad, New Mexico.

Seward, P. D., 1982, "Abridged Borehole Histories for the Waste Isolation Pilot Plant Studies," SAND82-0080, Sandia National Laboratories, Albuquerque, New Mexico.

U.S. Department of Energy (DOE), 1988, "Annual Site Environmental Report for the Waste Isolation Pilot Plant, CY 1987," DOE/WIPP 88-009, U.S. Department of Energy, Carlsbad, New Mexico.

U.S. Department of Energy (DOE), 1987, "Geotechnical Field Data and Analysis Report, July 1986 - June 1987," DOE/WIPP 87-017, U.S. Department of Energy, Carlsbad, New Mexico.

U.S. Geological Survey (USGS), 1978, "Test Drilling for Potash Resources: Waste Isolation Pilot Plant, Eddy County, New Mexico," Open File Report 78-592, U.S. Geological Survey.

USGS, see U.S. Geological Survey.

Westinghouse, see Westinghouse Electric Corporation.

Westinghouse Electric Corporation (Westinghouse), 1992a, "Resource Conservation and Recovery Act (RCRA) Compliance Manual," WP 02-6 and 02-7, Westinghouse Waste Isolation Division, Carlsbad, New Mexico.

Westinghouse Electric Corporation (Westinghouse), 1992b, "WIPP Contingency Plan," WP 02-12, Westinghouse Waste Isolation Division, Carlsbad, New Mexico.

Westinghouse Electric Corporation (Westinghouse), 1991a, "Nonradioactive Hazardous Materials Environmental Compliance Manual," WP 02-5, Westinghouse Waste Isolation Division, Carlsbad, New Mexico.

Westinghouse Electric Corporation (Westinghouse), 1991b, "WIPP Spill Prevention, Control, and Countermeasures Plan," WP 02-8, Westinghouse Waste Isolation Division, Carlsbad, New Mexico.

APPENDIX K1

ENVIRONMENTAL PROTECTION STANDARDS

APPENDIX K1
ENVIRONMENTAL PROTECTION STANDARDS

This appendix, while not all-inclusive, includes major federal Executive Orders, statutes, and implementing regulations. Those that are applicable, or potentially applicable, to the WIPP facility are indicated by an asterisk.

1. Executive Orders (EO)

   a. EO 11987, Exotic Organisms.
   b. EO 11988, Floodplain Management.
   c. EO 11989, Off-Road Vehicles on Public Lands.*
   d. EO 11990, Protection of Wetlands.
   e. EO 11514 and EO 11991, Protection and Enhancement of Environmental Quality.*
   f. EO 11593, Protection and Enhancement of the Cultural Environment.*
   g. EO 12088, Federal Compliance with Pollution Control Standards.*
   h. EO 12146, Management of Federal Legal Resources.*
   i. EO 12342, Environmental Safeguards on Activities for Animal Damage Control on Federal Lands.*
   j. EO 12344, Naval Nuclear Propulsion Program.
   k. EO 12580, Superfund Implementation.

2. The National Historic Preservation Act of 1966, As Amended*

   a. 36 CFR Part 800, Protection of Historic and Cultural Properties.*
   b. 43 CFR Part 7, Protection of Archaeological Resources.*

3. Title 42 U.S.C. secs. 7401 et seq., The Clean Air Act, As Amended*

   a. 40 CFR Part 50, National Primary and Secondary Ambient Air Quality Standards.*
   b. 40 CFR Part 52, Approval and Promulgation of Implementation Plans.
   c. 40 CFR Part 53, Ambient Air Monitoring Reference and Equivalent Methods.*
   d. 40 CFR Part 58, Ambient Air Quality Surveillance.*
   e. 40 CFR Part 60, Standards of Performance for New Stationary Sources.*
   f. 40 CFR Part 61, National Emission Standards for Hazardous Air Pollutants.*
   g. 40 CFR Part 65, Delayed Compliance Orders.
   h. 40 CFR Part 66, Assessment and Collection of Noncompliance Penalties by EPA.

i. 40 CFR Part 69, Special Exemptions from Requirements of the Clean Air Act.
j. 40 CFR Part 81, Designation of Areas for Air Quality Planning Purposes.*

4. Title 33 U.S.C. secs. 1251 et seq., The Clean Water Act, As Amended*

a. 33 CFR Parts 153-157, Control of Pollution by Oil and Hazardous Substances.*
b. 33 CFR Part 159, Marine Sanitation Devices.
c. 33 Parts 320, 322-329, Permit Programs Regulations.*
d. 40 CFR Part 109, Criteria for State, Local, and Regional Oil Removal Contingency Plans.
e. 40 CFR Part 110, Discharge of Oil.
f. 40 CFR Part 112, Oil Pollution Prevention.
g. 40 CFR Part 113, Liability Limits for Small Onshore Storage Facilities.
h. 40 CFR Part 114, Civil Penalties for Violation of Oil Pollution Prevention Regulations.
i. 40 CFR Part 116, Designation of Hazardous Substances.*
j. 40 CFR Part 117, Determination of Reportable Quantities for Hazardous Substances.*
k. 40 CFR Part 121, State Certification of Activities Requiring a Federal License or Permit.
l. 40 CFR Part 122, EPA Administered Permit Programs: The National Pollutant Discharge Elimination System.
m. 40 CFR Part 125, Criteria and Standards for the National Pollutant Discharge Elimination System.
n. 40 CFR Part 129, Toxic Pollutant Effluent Standards.
o. 40 CFR Part 131, Water Quality Standards.
p. 40 CFR Part 133, Secondary Treatment Regulation.
q. 40 CFR Part 136, Guidelines Establishing Test Procedures for the Analysis of Pollutants.
r. 40 CFR Part 140, Marine Sanitation Device Standard.
s. 40 CFR Parts 220-225, 227-229, Ocean Dumping Regulations and Criteria.
t. 40 CFR Part 230 sec. 404(b)(1) Guidelines for Specification of Disposal Sites for Dredged or Fill Material.
u. 40 CFR Part 231 sec. 404(c) Procedures.
v. 40 CFR Part 401, General Provisions for Effluent Guidelines and Standards (Note: 40 CFR sec. 401.14, Cooling Water Intake Structures).
w. 40 CFR Part 403, General Pretreatment Regulations for Existing and New Sources of Pollution.
x. 40 CFR Part 413, Electroplating Point Source Category.
y. 40 CFR Part 423, Steam Electric Power Generating Point Source Category.
z. 40 CFR Part 457, Explosives Manufacturing Point Source Category.
aa. 40 CFR Part 459, Photographic Point Source Category.

5. Title 42 U.S.C. secs. 300 F et seq., The Safe Drinking Water Act, As Amended

   a. 40 CFR Part 141, National [Interim] Primary Drinking Water Regulations.
   b. 40 CFR Part 142, National Primary Drinking Water Regulations Implementation.
   c. 40 CFR Part 143, National Secondary Drinking Water Regulations.
   d. 40 CFR Part 144, Underground Injection Control Program.
   e. 40 CFR Part 146, Underground Injection Control Program: Criteria and Standards.
   f. 40 CFR Part 147, State Underground Injection Control Programs.
   g. 40 CFR Part 149, Sole Source Aquifers.

6. Title 16 U.S.C. secs. 1451 et seq., The Coastal Zone Management Act of 1972, As Amended

   a. 15 CFR Part 921, NOAA (National Oceanographic and Atmospheric Administration) Guidelines on Estuarine Sanctuaries.
   b. 15 CFR Part 923, NOAA Coastal Zone Management Program Approval Regulations.
   c. 15 CFR Part 930, NOAA Regulations on Federal Consistency with Approval Coastal Management Program.
   d. 15 CFR Part 931, NOAA Regulations on Coastal Energy Impact Program.

7. Radiation Protection

   a. 10 CFR Part 712, Grand Junction Remedial Action Criteria.
   b. 40 CFR Part 190, Environmental Radiation Protection Standards for Nuclear Power Operations.
   c. 40 CFR Part 191, Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes.*
   d. 40 CFR Part 192, Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings.

8. Title 42 U.S.C. secs. 9601 [9615] et seq., The Comprehensive Environmental Response, Compensation, and Liability Act of 1980, As Amended*

   a. 40 CFR Part 300, National Oil and Hazardous Substances Pollution Contingency Plan.
   b. 40 CFR Part 302, Designation, Reportable Quantities, and Notification.*
   c. 40 CFR Part 305, Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Arbitration Procedures.

d. 40 CFR Part 306, Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Natural Resources Claims Procedures.
e. 43 CFR Part 11, Natural Resources Damage Assessments.

9. Title 7 U.S.C. secs. 136 et seq., The Federal Insecticide, Fungicide, and Rodenticide Act, As Amended

a. 40 CFR Part 162, Regulations for the Enforcement of the Federal Insecticide, Fungicide, and Rodenticide Act.
b. 40 CFR Part 165, Regulations for the Acceptance of Certain Pesticides and Recommended Procedures for the Disposal and Storage of Pesticides and Pesticides Containers.*
c. 40 CFR Part 166, Exemption of Federal and State Agencies for Use of Pesticides Under Emergency Conditions.*
d. 40 CFR Part 170, Worker Protection Standards for Agricultural Pesticides.
e. 40 CFR Part 171, Certification of Pesticide Applicators.

10. Title 42 U.S.C. secs. 6901 et seq., The Resource Conservation and Recovery Act of 1976, As Amended*

a. 40 CFR Part 240, Guidelines for the Thermal Processing of Solid Wastes.
b. 40 CFR Part 241, Guidelines for the Land Disposal of Solid Wastes.
c. 40 CFR Part 243, Guidelines for the Storage and Collection of Residential, Commercial, and Institutional Solid Waste.*
d. 40 CFR Part 244, Solid Waste Management Guidelines for Beverage Containers.*
e. 40 CFR Part 245, Promulgation Resource Recovery Facilities Guidelines.*
f. 40 CFR Part 246, Source Separation for Materials Recovery Guidelines.*
g. 40 CFR Part 247, Guidelines for Procurement of Products that Contain Recycled Material.
h. 40 CFR Part 256, Guidelines for Development and Implementation of State Solid Waste Management Plans.
i. 40 CFR Part 257, Criteria for Classification of Solid Waste Disposal Facilities and Practices.
j. 40 CFR Part 260, Hazardous Waste Management System: General.*
k. 40 CFR Part 261, Identification and Listing of Hazardous Waste.*
l. 40 CFR Part 262, Standards Applicable to Generators of Hazardous Waste.*
m. 40 CFR Part 263, Standards Applicable to Transporters of Hazardous Waste.*
n. 40 CFR Part 264, Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.*
o. 40 CFR Part 265, Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.*

p. 40 CFR Part 266, Standards for the Management of Specific Hazardous Wastes and Specific Types of Hazardous Waste Management Facilities.

q. 40 CFR Part 267, Interim Standards for Owners and Operators of New Hazardous Waste Land Disposal Facilities.

r. 40 CFR Part 268, Land Disposal Restrictions.*

s. 40 CFR Part 270, EPA Administered Permit Programs: The Hazardous Waste Permit Program.*

t. 40 CFR Part 272, Approved State Hazardous Waste Management Programs.*

u. 40 CFR Part 280, Underground Storage Tanks.*

11. Title 16 U.S.C. secs. 1531 et seq., The Endangered Species Act of 1973, As Amended*

a. 50 CFR Part 17, Fish and Wildlife Service List of Endangered and Threatened Wildlife and Plants.*

12. Title 15 U.S.C. secs. 2601 et seq., The Toxic Substances Control Act, As Amended*

a. 40 CFR Part 761, Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions.*

13. Title 42 U.S.C. secs. 4901 et seq., The Noise Control Act of 1972, As Amended

14. Title 16 U.S.C. secs. 1131 et seq., The Wilderness Act, As Amended

a. 43 CFR Part 19, Wilderness Preservation.

APPENDIX K2

SUMMARY OF AGREEMENTS BETWEEN DOE AND THE STATE OF NEW MEXICO THAT AFFECT THE WIPP ENVIRONMENTAL PROGRAM AND THE JULY 9, 1987, MEMORANDUM OF UNDERSTANDING BETWEEN THE U.S. DEPARTMENT OF ENERGY AND THE U.S. DEPARTMENT OF LABOR

SUMMARY OF AGREEMENTS BETWEEN DOE AND THE STATE OF NEW MEXICO THAT AFFECT THE WIPP ENVIRONMENTAL PROGRAM

APPENDIX K2
SUMMARY OF AGREEMENTS BETWEEN DOE AND THE STATE OF NEW MEXICO THAT AFFECT THE WIPP ENVIRONMENTAL PROGRAM

Stipulated Agreement on Civil Action No. 81-0363 JB -- This agreement, approved by the U.S. District Court when it stayed (held in abeyance) proceedings in the lawsuit against DOE by the State of New Mexico, was executed on July 1, 1981. The eight-page agreement assures that a binding, enforceable "consultation and cooperation" agreement will be entered into by DOE and the state and that DOE will make a "good faith effort" to resolve certain state off-site concerns (which are covered in the Supplemental Stipulated Agreement). The Stipulated Agreement also addresses a number of additional studies and experiments to be conducted by DOE for the Site Preliminary and Design Validation phase of the WIPP facility. It was signed by Jeff Bingaman, Attorney General, State of New Mexico, and Myles Flint, Attorney, U.S. Department of Justice, and issued July 1, 1981, by Juan G. Burciaga, U.S. District Judge, District of New Mexico.

Agreement for Consultation and Cooperation -- Usually referred to as the "C&C Agreement," this agreement is contained in Appendix A to the Stipulated Agreement. It affirms the intent of the Secretary of Energy to consult and cooperate with New Mexico with respect to state public health and safety concerns. It was signed in July 1981 by Bruce King, Governor, State of New Mexico, and James B. Edwards, Secretary, U.S. Department of Energy.

Working Agreement for Consultation and Cooperation, Appendix B, Article IV, Revision I -- This agreement, Appendix B to the Stipulated Agreement, identifies in Article IV over 60 "key events" and "milestones" in the construction and operation of the WIPP facility that must be reviewed by the state before they are commenced. Many environmental items are included. It was signed in March 1983 by Robert McNeill, Chairman, Radioactive Waste Task Force, and R. G. Romotowski, Manager, Albuquerque Operations Office, U.S. Department of Energy. (Article IV of the Working Agreement was revised on April 8, 1983.)

Supplemental Stipulated Agreement Resolving Certain State Off-Site Concerns Over WIPP -- This agreement, dated December 27, 1982, addresses five state concerns including the need for state "verification" of the WIPP Environmental Monitoring Program. The concerns addressed are: state liability (for a nuclear incident), emergency response preparedness, transportation monitoring of the WIPP facility waste, the WIPP facility environmental monitoring by the state, and upgrading of state highways. It was signed in December 1982 by Bruce King, Governor, State of New Mexico, et al., and R. G. Romotowski, Manager, Albuquerque Operations Office, U.S. Department of Energy.

First Modification to the July 1, 1981, Agreement for Consultation and Cooperation on WIPP by the State of New Mexico and the U.S. Department of Energy -- This modification was signed November 30, 1984, wherein DOE and the state agree to address certain concerns of the state regarding: (1) the specific mission of the WIPP Project, (2) a demonstration of retrievability prior to waste emplacement, (3) post-closure control and responsibility, (4) completion of certain additional scientific testing and reports, (5) compliance with applicable federal regulatory standards for waste repositories, and (6) a program for encouraging and reporting on the hiring of New Mexico residents at the WIPP Project. It was signed in November 1984 by Joseph Goldberg, Secretary, Health and Environment Department, State of New Mexico, and R. G. Romotowski, Manager, Albuquerque Operations Office, U.S. Department of Energy.

Second Modification to the July 1, 1981, Agreement for Consultation and Cooperation on WIPP by the State of New Mexico and the U.S. Department of Energy -- Signed August 4, 1987, wherein DOE and the state agree to address certain concerns of the state regarding: (1) surface and subsurface mining and drilling after closure of the WIPP site; (2) the disposal of salt tailings at the WIPP site; and (3) compliance with U.S. Environmental Protection Agency, U.S. Department of Transportation, and U.S. Nuclear Regulatory Commission regulations. It was signed in August 1987 by Garrey Carruthers, Governor, State of New Mexico, et al., and R. G. Romotowski, Manager, Albuquerque Operations Office, U.S. Department of Energy.

1988 Modification to the Working Agreement of the Consultation and Cooperation Agreement Between the U.S. Department of Energy and the State of New Mexico on the Waste Isolation Pilot Plant -- This modification deleted the sorbing tracer test from the list of required reports and substituted additional tests. In addition, the state is allowed to operate a fixed-air sampler in the mine ventilation effluent air stream. It was signed in March 1988 by Kirkland Jones, Deputy Director, New Mexico Environmental Improvement Division, State of New Mexico, et al., and R. G. Romotowski, Manager, Albuquerque Operations Office, U.S. Department of Energy.

Environmental Oversight and Monitoring Agreement -- This agreement states that DOE will provide additional technical and financial support for state activities in environmental oversight, monitoring, access, and emergency response to ensure compliance with applicable federal, state, and local laws at several DOE facilities including the WIPP facility. It was signed in October 1990 by Garrey Carruthers, Governor, State of New Mexico; Dennis Boyd, Secretary, Health and Environment Department; and Bruce G. Twining, Manager, Albuquerque Operations Office, U.S. Department of Energy.

THE JULY 9, 1987, MEMORANDUM OF UNDERSTANDING BETWEEN THE U.S. DEPARTMENT OF ENERGY AND THE U.S. DEPARTMENT OF LABOR

Memorandum of Understanding
Between the
U.S. Department of Energy
and the
U.S. Department of Labor

I. Introduction

A. Background

The Department of Energy (DOE), Albuquerque Operations Office, is responsible for the construction of the Waste Isolation Pilot Plant (WIPP), a research and development facility under construction near Carlsbad, N.M., to demonstrate the safe, geologic disposal of defense-generated radioactive waste. The project will include underground facilities at a depth of 2150 feet.

A major concern of DOE in carrying out these activities is the safety and health protection of all underground workers at the site, both for the personnel involved in extractive processes as well as for the underground operating personnel.

Under the Federal Mine Safety and Health Act of 1977 (the Mine Act), the Mine Safety and Health Administration (MSHA) of the U.S. Department of Labor (DOL) is responsible for conducting mine inspections and investigations and developing and enforcing regulations and standards to protect the safety and health of miners. In the course of carrying out this responsibility, MSHA has developed technical expertise in mine safety and health.

B. Purpose

The purpose of this Memorandum of Understanding (MOU) is to accomplish the following:

1. To formalize a working arrangement whereby MSHA inspects operations at WIPP to determine compliance with MSHA standards. The results of these inspections will be furnished to DOE so that DOE can implement its policy of compliance to MSHA standards (as though the WIPP was a commercial mine) by taking the necessary actions with the DOE contractors to assure the prompt and effective correction of any deficiencies and to otherwise ensure general compliance with MSHA's mining health and safety requirements, and

2. To establish a procedural framework for the furnishing of MSHA technical assistance and consultation services to DOE with respect to mine geology, underground construction techniques, and related matters concerning the protection of life, the promotion of health and safety, and the prevention of accidents in DOE's underground repository operations.

C. Authorities

This MOU is consistent with and is entered into under the following statutory authorities: Section 601 of the Economy Act of 1932, as amended (31 U.S.C. 1535); Section 161 (f) of the Atomic Energy Act of 1954, as amended (42 U.S.C. 2201 (f); Section 646 of the Department of Energy Organization Act (42 U.S.C. 7256); P.L. 96-164, the WIPP authorization; the Federal Mine Safety and Health Act of 1977, as amended (30 USC 801 et. seq.); and Section 100 of the Departments of Labor, Health and Human Services, and Education and Related Agencies Appropriations Act of 1986 (30 USC 962).

II. Inspections, Investigations and Technical Assistance

A. MSHA will conduct periodic, health and safety compliance assistance inspections of WIPP mining operations to assess the conformance of such operations with MSHA standards.

B. The following MSHA standards are relevent to underground operations conducted by the WIPP project:

30 CFR Parts 31, 32, 36, 48, 49 and 57.

In addressing these standards, DOE may encounter situations in which DOE considers that an alternative approach to that specified in the standards is required. In those instances, DOE will consult with MSHA to arrive at a mutually agreeable solution.

C. The results of all compliance assistance inspections will be furnished to the WIPP Project Office in writing at the conclusion of each inspection and DOE will thereafter take the necessary actions to assure the timely correction of any deficiencies. In the results of inspections forwarded to DOE, MSHA will

indicate conditions which would constitute a violation of MSHA standards and also, where appropriate, will include recommendations for remedial actions.

D. DOE's health and safety program encourages its contractors' employees to bring any health or safety complaints to either the employer or to DOE directly. Any such complaint or other information received by MSHA while performing work under this MOU will be transmitted to DOE and DOE will inform MSHA of its disposition of the complaint.

E. When requested by DOE, MSHA will participate in any accident or fatality investigation at the WIPP site.

F. In addition to inspections, MSHA will provide technical assistance as well as review and consultation services regarding mine safety and health matters for the WIPP project when requested by DOE via the WIPP Project Office subject to the availability of MSHA manpower.

G. Property

When available, DOE shall furnish the use of working space and other equipment (e.g., office equipment) required for the performance of this MOU, except such types of equipment as MSHA normally furnishes in connection with its regular mission.

H. Radiological Safety and Health, and Security

MSHA agrees to conform to all radiological safety and health, and security regulations and requirements of DOE while performing services in connection with this agreement.

III. Administration

This MOU will be administered on behalf of DOE by the WIPP Project Office. Normal working contacts with DOE shall be with the Project Manager, or by such other representative(s) as the Project Manager shall designate in written notice to MSHA. Administration on the behalf of MSHA will be by the Administrator for Metal and Nonmetal Mine Safety and Health, or by such other representative(s) as he/she shall designate in written notice to DOE.

IV. Reimbursement

Subject to future specific agreement of the parties, DOE will reimburse MSHA for the cost of services provided under this MOU.

V. Public Release of Information

MSHA and DOE shall consult with each other before release of information under the Freedom of Information Act, 5 U.S.C. 552, regarding activities carried out pursuant to this MOU.

VI. Effective Date, Amendment and Termination

This MOU shall become effective when signed by both parties. It may be modified or amended by written agreement between DOE and MSHA. It shall continue in effect until terminated by either party upon 30 days written notice to the other.

U.S. DEPARTMENT OF LABOR	U.S. DEPARTMENT OF ENERGY
BY: Roy L. Bernard	R. G. Romatowski
Title: Administrator for Metal and Nonmetal Mine Safety and Health	Manager, Albuquerque Operations Office
Date: 6/9/87	July 9, 1987

APPENDIX L1

CONDITIONAL AND PROPOSED NO-MIGRATION DETERMINATIONS FOR THE WASTE ISOLATION PILOT PLANT

FINAL CONDITIONAL DETERMINATION

NOVEMBER 14, 1990

federal register

Wednesday
November 14, 1990

Part VI

Environmental Protection Agency

Department of Energy Waste Isolation Pilot Plant; Notice of Final No-Migration Determination

ENVIRONMENTAL PROTECTION AGENCY

[FRL-3860-1]

Conditional No-Migration Determination for the Department of Energy Waste Isolation Pilot Plant (WIPP)

AGENCY: Environmental Protection Agency.

ACTION: Notice of final no-migration determination.

SUMMARY: In response to a petition from the Department of Energy (DOE), the Environmental Protection Agency (EPA) is today making a determination of no migration for placement of hazardous waste at DOE's Waste Isolation Pilot Plant (WIPP), located near Carlsbad, New Mexico. Today's determination imposes several conditions on such placement and is for a maximum of ten years. As a result of this determination, DOE may place a limited amount of untreated hazardous waste subject to the land disposal restrictions of the Resource Conservation and Recovery Act (RCRA) in the WIPP for the purposes of testing and experimentation. DOE submitted a petition to EPA for a no-migration determination in March 1989; EPA proposed to grant the petition in April 1990. After a careful review of public comments on the proposal, EPA has concluded that DOE has demonstrated, to a reasonable degree of certainty, that hazardous constituents will not migrate from the WIPP disposal unit during the testing period proposed by DOE, and that DOE has otherwise met the requirements of 40 CFR 268.6 for the WIPP. The approved petition requires DOE to remove the hazardous wastes from the underground repository if it cannot demonstrate the long-term acceptability of the disposal site by the end of the test period.

EFFECTIVE DATE: November 14, 1990.

ADDRESSES: The public docket for this determination is available for public inspection in Room M2427, U.S. Environmental Protection Agency, 401 M Street SW, Washington, DC, 20460, Monday through Friday, excluding Federal holidays. Members of the public may make an appointment to review docket materials by calling (202) 475-9327. Copies of docket materials may be made at no cost, with a maximum of 100 pages of material from any one regulatory docket. Additional copies are $0.15 per page.

FOR FURTHER INFORMATION CONTACT: General questions about the regulatory requirements under RCRA should be directed to the RCRA/Superfund Hotline at 800-424-9346 (toll free) or 202-382-3000 (local).

Specific questions about the issues discussed in this notice should be directed to Matthew Hale, Office of Solid Waste (OS-341), U.S. Environmental Protection Agency, 401 M Street SW, Washington, DC 20460, at 202-382-4746.

SUPPLEMENTARY INFORMATION:

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I. Background

A. RCRA Land Disposal Restrictions

The Hazardous and Solid Waste Amendments (HSWA) of 1984, which amend the Resource Conservation and Recovery Act (RCRA), imposed substantial new requirements on the land disposal of hazardous waste. In particular, the amendments prohibit the continued land disposal of hazardous wastes, unless either (1) the wastes meet treatment standards specified by EPA, or (2) the Administrator determines that the prohibition is not required in order to protect human health and the environment. This latter determination must be based on a demonstration by the owner/operator of the facility receiving the waste "that there will be no migration of hazardous constituents from the disposal unit or injection zone as long as the wastes remain hazardous." (RCRA sections 3004(d)(1), (e)(1), and (g)(5).) The Department of Energy (DOE) has chosen to comply with the land disposal restrictions for certain transuranic (TRU) wastes to be shipped for testing and experimentation at its Waste Isolation Pilot Plant (WIPP) by pursuing the second option. Today's notice approves, with conditions, DOE's petition for the WIPP site.

EPA first promulgated standards and procedures for review of no-migration petitions under 40 CFR 268.6 in November 1986. These regulations, which apply to land disposal units other than underground injection wells, codify the statutory standard for no-migration findings, specify the information required in no-migration petitions, and establish EPA's procedures for approving or denying petitions (November 7, 1986, 51 FR 40572). EPA amended these regulations on August 17, 1988 (53 FR 31138) to add further procedural requirements and standards.[1] EPA is now developing additional no-migration standards to clarify or expand on certain parts of the current regulations. The Agency expects to propose these standards in the near future. In conjunction with this proposal, EPA has also developed draft no-migration guidance, a copy of which is available in the docket for this rulemaking.

To date, EPA has received 31 no-migration petitions submitted in accordance with 40 CFR 268.6. Today's notice, which addresses disposal of mixed radioactive and hazardous waste in a mined salt bed, is the Agency's first decision on any of these petitions under § 268.6. The other § 268.6 petitions, which primarily address land treatment operations, are currently under Agency review. In addition, EPA has received approximately 65 no-migration petitions for underground injection wells under 40 CFR part 148. Of these, 30 have been approved, 28 are still under review, and a number of others have been withdrawn.

B. Regulatory Status of Mixed Wastes

The hazardous wastes that are subject to today's notice are "mixed wastes." Mixed wastes are defined as a mixture of hazardous wastes regulated under Subtitle C of RCRA and radioactive wastes regulated under the Atomic Energy Act (AEA). Because section 1004 of RCRA excludes "source," "special nuclear," and "byproduct materials," as defined under the Atomic Energy Act,

[1] On July 26, 1988, EPA also promulgated standards under 40 CFR part 148 for no-migration determinations for underground injection wells (53 FR 28122).

from the definition of RCRA "solid waste," there has been some confusion in the past as to the scope of EPA's authority over mixed waste under RCRA. EPA clarified this question in a **Federal Register** notice on July 3, 1986.

EPA's clarification stated that the section 1004 exclusion applies only to the radioactive portion of mixed waste, not to the hazardous constituents. Therefore, a mixture of "source," "special nuclear," or "byproduct materials" and a RCRA hazardous waste must be managed as a hazardous waste, subject to the requirements of RCRA subtitle C (that is, RCRA standards for the management of hazardous waste). EPA's oversight under RCRA, however, extends only to the hazardous waste components of the mixed waste, not to the source, special nuclear, or byproduct materials themselves. The exempted radionuclides are instead addressed under the AEA.[2] DOE subsequently confirmed and clarified this interpretation in the **Federal Register** on May 1, 1987. Sections I.D and V.A of this notice further discusses the relationship between the AEA standards and the no-migration finding.

EPA's July 3, 1986 interpretation went into effect immediately in states not authorized to administer the RCRA hazardous waste program—that is, in the ten states and territories where EPA directly regulates hazardous waste under the Federal RCRA regulations. At the same time, the July 3, 1986 notice informed authorized states that they were required to apply for and receive authorization from EPA to regulate mixed waste under RCRA. To date, twenty-three states and territories (including New Mexico, where the WIPP is located) have obtained authority to regulate mixed waste under the state RCRA hazardous waste programs. Thus, mixed wastes are currently regulated as hazardous under Federal RCRA requirements in thirty-three states and territories.

C. WIPP Project

Today's notice addresses mixed waste that DOE intends to ship for testing and experimentation to the WIPP site near Carlsbad, New Mexico, during a preliminary test phase. At the site, the waste will be placed in a mined underground repository, located in a salt bed approximately 2,150 feet below the earth's surface. Over an approximately five-year period, DOE plans to test and evaluate the behavior of the waste in the repository, as well as the characteristics of the surrounding formation, to determine the site's acceptability for the long-term disposal of radioactive waste. Today's no-migration determination requires DOE to remove the waste from the repository if the site proves to be unacceptable for long-term disposal.

Over the long-term, the WIPP repository has been designed as a permanent disposal site for transuranic (TRU) radioactive wastes resulting from nuclear weapons production at ten DOE sites around the country.[3] TRU wastes are defined as wastes contaminated with alpha-emitting radionuclides with an atomic number greater than 92 (that is, heavier than uranium) in concentrations of greater than 100 nanocuries per gram of waste. In addition, TRU wastes by definition have half-lives of more than twenty years, although the actual half-lives of radionuclides in waste to be placed in the WIPP are often hundreds or thousands of years. The TRU wastes targeted for the WIPP consist of a variety of materials, including tools, equipment, protective clothing, rags, graphite, glass, and other material contaminated during the production and reprocessing of plutonium; contaminated organic and inorganic sludges; contaminated process and laboratory wastes; and contaminated items from decontamination and decommissioning activities at DOE facilities. As TRU wastes, these wastes are distinguished from high-level radioactive waste, such as used reactor fuel, and low-level radioactive waste. Other disposal strategies are being developed for high-level and low-level radioactive wastes.

The land in the area of the WIPP is owned by the Federal government and administered by the Bureau of Land Management. The four-mile by four-mile plot of land overlying the repository has been temporarily withdrawn from public use by the Department of Interior; it is now under the control of DOE. Before DOE can bring waste to the site, however, either Congress or the Department of Interior must take new land withdrawal action. The repository is designed to hold TRU wastes that are currently stored at the DOE generating facilities, as well as new TRU wastes that will be generated over the next 35 years. The underground waste disposal area of the WIPP, when completed, will cover 100 acres, with a total design capacity of 8.45 million cubic feet (or approximately 850,000 drums of waste). To date, 15 acres of underground disposal rooms have been mined.

Although DOE has conducted extensive studies of the WIPP site and the repository performance, uncertainties still remain. For example, concerns have been raised over the possibility that gas generated underground at the WIPP could, over the long term, build up to unacceptable pressures, leading to possible releases from the repository. To address this and other questions, DOE plans to conduct testing and experimentation over the next several years. This testing will include in-situ experiments with actual TRU wastes underground, as well as other investigations. These in-situ tests would initially involve wastes amounting to approximately 0.5 percent of the total repository capacity. From these tests, DOE hopes to gather data that will allow it to demonstrate compliance with EPA's standards for disposal of radioactive materials (40 CFR part 191 subpart B) and long-term no-migration of RCRA hazardous constituents, as well as in identifying any engineering modifications that may be necessary to meet these standards. DOE is also considering the need for an "operations demonstration" during the test period. The purpose of this demonstration, which might involve up to an additional three to eight percent of the total WIPP capacity, would be to show DOE's operational readiness to ship waste to the WIPP and to place it underground. (Today's approval does not cover placement of wastes for the purposes of the "operations demonstration." DOE would have to submit for EPA's consideration an amendment to its no-migration petition; any EPA decision on such an amendment would be proposed in the **Federal Register**, with opportunity for public comment.)

As a condition to today's approved petition, DOE must remove all hazardous wastes from the repository if it is unable to meet EPA standards for permanent disposal of hazardous and radioactive wastes at the conclusion of the test period.[4] However, if the WIPP

[2] This interpretation, however, does not preclude EPA from requiring data on radionuclide content of wastes where necessary to carry out EPA's authorities under RCRA—for example, to ensure protection of personnel carrying out RCRA inspection or oversight sampling.

[3] The DOE facilities that intend to send TRU waste to the WIPP are Idaho National Engineering Laboratory, Idaho Falls, Idaho; Rocky Flats Plant, Golden, Colorado; Los Alamos National Laboratory, Los Alamos, New Mexico; Argonne National Laboratory, Argonne Illinois; Savannah River Plant, Aiken, South Carolina; Oak Ridge National Laboratory, Oak Ridge, Tennessee; Hanford Reservation, Richland, Washington; Mound Plant, Miamisburg, Ohio; Lawrence Livermore National Laboratory, Livermore, California; and Nevada Test Site, Mercury, Nevada.

[4] Under 40 CFR 268.6(a)(3), petitioners seeking a no-migration demonstration must provide sufficient

Continued

proves acceptable as a permanent repository, and if DOE successfully petitions EPA for a long-term no-migration determination. DOE will then be able to begin full-scale disposal of waste at the site. Drums, metal boxes, and metal canisters of waste will be shipped to the WIPP from the generating sites and placed in underground rooms. Under current plans, the rooms will be backfilled with crushed salt and sealed. After an operating period of approximately 25 years, DOE plans to seal the shafts of the mine with cement-clay plugs and compacted salt and decommission the facility. After decommissioning, the salt of the Salado Formation will creep inward and is expected to encapsulate the waste within 60 to 200 years.

Access to the WIPP site will be restricted. The Department of Interior temporarily withdrew the lands on the WIPP site from public use in 1983, allowing DOE to begin construction of the facility. Before DOE can bring waste to the site, however, either Congress or the Department of Interior must take new land withdrawal action. In addition, DOE and the State of New Mexico have agreed to prohibit in perpetuity all subsurface mining, drilling, and resource exploration unrelated to the WIPP project at the WIPP site. As a further protection, the Federal government has acquired the entire surface and subsurface estate at the WIPP site. Finally, to discourage drilling in the vicinity of the repository in the distant future, DOE intends to place permanent warning markers at the site.

D. Regulatory Status of the WIPP

The WIPP is located in the State of New Mexico, which received authorization for mixed waste on July 25, 1990. (See 55 FR 28397, July 11, 1990.) As an "existing" hazardous waste management facility at the time of New Mexico's authorization for mixed waste, the WIPP is eligible for RCRA interim status. Facilities "in existence" (which include facilities under construction) at the time a waste is identified as hazardous under RCRA can obtain interim status if their owner/operators submit a part A application to EPA or the appropriate state. If DOE submits an application to New Mexico and secures interim status, it will be legally authorized to receive mixed waste at the WIPP—subject of course to the land disposal restrictions. The WIPP must also comply with the RCRA interim status standards, codified at 40 CFR part 265, and eventually obtain a RCRA permit under 40 CFR parts 264 and 270.

The interim status requirements of part 265 establish general facility standards. For example, the WIPP is required under these standards to have a waste analysis plan for its mixed waste, a contingency plan describing procedures that DOE will take in the case of an emergency, and a closure plan describing how the facility will be closed. In addition, the State of New Mexico has recently requested that DOE submit to it the RCRA part B permit application for the WIPP; this application must be submitted no later than six months after the State's request, or by February 28, 1991. The RCRA permit for the WIPP (if granted) will establish detailed operating, closure, and post-closure conditions in accordance with 40 CFR part 264, subpart X. (As a geological repository, the WIPP is regulated under the RCRA category of subpart X "miscellaneous units.") The permit's scope would extend to all facility activities related to mixed waste.

Several commenters on EPA's proposed decision on the WIPP expressed confusion over the relationship between a no-migration decision by EPA and a RCRA permit issued by the State. In explanation, EPA notes that its no-migration determination is relatively narrow in scope, only addressing the question of whether hazardous constituents will or will not migrate from the underground repository. To ensure no-migration, EPA's determination imposes certain conditions (e.g., a volume limitation and retrievability of waste); these conditions will be enforced by EPA. On the other hand, the State RCRA permit is significantly broader than a no-migration finding, since it will impose the full technical and general facility standards of 40 CFR part 264, and it will apply to the above-ground operations as well as operations underground. The permit may include certain requirements already imposed under EPA's no-migration determination, or it may establish more stringent requirements, if the State of New Mexico determines that they are necessary. The State permit will be issued under State procedures, which include public notice, comment, and an opportunity for a public hearing. The conditions of the permit will be enforced by the State.

As discussed earlier, EPA's authority under RCRA over waste destined for the WIPP extends only to mixed hazardous and radioactive waste, and it is further limited to the hazardous components of the mixed waste. The potential release of radioactive material from the WIPP is addressed under the Atomic Energy Act (AEA). EPA has promulgated standards under the AEA limiting releases associated with the disposal of radioactive wastes. These standards, which are codified at 40 CFR part 191, consist of two parts: Subpart A dealing with releases during the operational phase of a permanent disposal facility, and subpart B, dealing with long-term releases after decommissioning. Under these regulations, a facility is not defined as a disposal site until it has been designated as a permanent respository and removal is not contemplated; since this decision will not be made for the WIPP until after the test phase, the WIPP is not legally subject to the part 191 standards. Under an agreement with the State of New Mexico, however, DOE has agreed to comply with the subpart A standards, beginning with the initial receipt of waste at the WIPP—that is, before the facility has been designated as a permanent repository. The subpart standards also do not yet apply to the WIPP because they have been remanded to EPA by the U.S. Court of Appeals at the First Circuit, and therefore are not in effect at this time. DOE, however, has agreed with the State of New Mexico to demonstrate compliance with the remanded standards (if final standards have not been developed) before a final decision is made to dispose of waste permanently in the repository. This decision will be made on the basis of data gathered during the test phase at the WIPP.

Finally, EPA emphasizes that today's finding addresses only the specific question of whether hazardous constituents will or will not migrate from the WIPP as long as the waste remains hazardous. Issues raised by the transportation of waste to the WIPP site, or by handling and possible treatment of waste before it reaches the WIPP, are beyond the scope of EPA's legal authority in evaluating no-migration petitions, and thus are not addressed in this notice.

II. DOE Petition and EPA Proposed Determination

The mixed waste DOE intends to ship to the WIPP for testing includes solvent-contaminated wastes, which became subject to the land disposal restrictions on November 8, 1988, and characteristic wastes (containing heavy metals such as lead), which became subject to the land

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Information to assure the Administrator that the disposal area will comply with other applicable Federal, State, and local laws. Therefore, if the WIPP cannot comply with radioactive disposal standards under 40 CFR part 191, it would not satisfy the conditions for a long-term no-migration determination.

disposal restrictions on August 8, 1990. (However, it should be noted that EPA granted a two-year national capacity variance to mixed characteristic wastes, deferring the effective date of the disposal prohibition until May 8, 1992 (June 1, 1990, 55 FR 22520).) In addition, some mixed wastes are likely to include wastes that are hazardous under EPA's new toxicity characteristics rule (55 FR 11798), although the Agency has not yet promulgated land disposal restrictions for these wastes.

To comply with the land disposal restrictions, DOE has sought to demonstrate to EPA, in a non-migration petition submitted in March 1989, that placement of these wastes untreated in the WIPP repository will not lead to migration of hazardous constituents beyond the disposal unit boundary. In response to EPA concerns, DOE provided additional supporting material after its initial submission, including addenda in October 1989 and January 1990. DOE's final petition was bound into eight volumes in March 1990 (DOE/WIPP 89-003, Revision 1) and is included in the docket for this rulemaking.

After careful review of DOE's petition as well as information from numerous other sources, EPA proposed in the **Federal Register** of April 8, 1990 to grant DOE's petition with certain conditions. (See 55 FR 13068 for a more detailed discussion of the information provided by DOE and of the basis for EPA's proposed decision.) Under EPA's proposal, DOE would be allowed to place untreated mixed waste in the WIPP repository within the scope of the testing and experimentation activities described in the petition. EPA's proposal would not have allowed DOE to conduct its proposed operations demonstration, nor would it have allowed DOE to conduct two pilot-room tests, which had originally been suggested by EPA. If the testing failed to show that the WIPP could meet the no-migration standards for the longterm disposal of mixed waste, DOE would be required to remove the waste from the underground repository. The proposal also included the following conditions: (1) The waste must be placed in the WIPP in a retrievable form; (2) DOE must provide annual written reports on the test phase progress to EPA; (3) a carbon adsorption device capable of achieving a 95 percent efficiency must be installed in the discharge system of the bin experiment rooms; (4) DOE must implement a specific air monitoring plan; (5) DOE must certify that it has secured control of the surface and subsurface estate at the WIPP site before wastes can be placed in the repository;[5] and (6) during the test phase, DOE must provide detailed waste characterization and analyses on the waste emplaced in the WIPP.

EPA provided a 60-day public comment period on its proposed determination and held public hearings in Carlsbad, Albuquerque, and Santa Fe, New Mexico, during the comment period. The Agency received 103 written comments on its proposal from both individuals and organizations, and more than 300 people testified at the three hearings. Today's decision is based on a careful review of the public's comments and clarifying information provided by DOE, as well as EPA's further evaluation of the suitability of the site based on a field visit to the WIPP site on July 28, 1990.

III. Summary of EPA Determination

After a review of DOE's petition, supporting information, and public comment, EPA finds that DOE has demonstrated, to a reasonable degree of certainty, that hazardous constituents will not migrate from the WIPP repository as a result of its planned test activities, as required by the statute and regulations at 40 CFR 268.6. This determination is based on the condition that DOE only place hazardous waste within the scope of the test phase operations described in its no-migration petition and its performance assessment test plan. Consistent with the determination, EPA is approving DOE's no-migration petition for the WIPP for the test phase operations, subject to the conditions laid out in section VI of this notice. It should be noted that the proposed operations demonstration and pilot room tests cannot be conducted under the terms of today's decision. Before these activities could be carried out, DOE would have to submit an amendment to its no-migration petition, which EPA would evaluate. EPA would then propose a decision for comment before a final decision would be made.

EPA's action today allows DOE to place untreated mixed waste subject to the RCRA land disposal restrictions in the WIPP for testing and experimentation to determine whether the site is appropriate for the long-term disposal of mixed waste (that is, whether disposal at the site will conform with standards for the permanent disposal of hazardous wastes). Only the waste specified by DOE in is petition may be placed in the WIPP under this determination.[6] The quantity of waste that may be placed in the WIPP is limited to 8,500 drums, or 1 percent of the facility's final capacity. DOE may not begin permanent disposal of the mixed waste subject to the RCRA land disposal prohibitions at the site and must remove all waste from the underground repository if it cannot demonstrate no migration of hazardous constituents over the long term. (In addition to EPA's requirement that hazardous waste be removed from the respository, DOE has also committed to carry out such a removal in a consent agreement with the State of New Mexico.)

In making its no-migration finding, EPA concentrated on whether releases of non-radioactive hazardous constituents from the repository might occur during the test phase. In doing so, EPA addressed all possible routes of release, but focused in particular on the potential for volatile organic constituents released during testing to migrate out of the WIPP unit through the ventilation exhaust shaft. Because of the nature of the tests that will be conducted in the WIPP and their relatively short duration, EPA has concluded that releases of hazardous constituents from the unit through brine, salt, or other geological media is implausible during the test phase.

The retrievability of waste placed in the WIPP during the test phase is central to EPA's finding. Therefore, EPA has reviewed both the technical feasibility of retrieval and the practicability of DOE's retrieval plan. EPA has concluded that retrieval of wastes from the WIPP can be accomplished safely, and that DOE's commitment to retrieving the wastes and taking it above ground, if it proves necessary, is satisfactory. Finally, EPA considered the general design, construction, and mine maintenance program at the WIPP and has concluded that the mine is well-designed and will remain stable during

[5] DOE recently secured the last outstanding mineral lease at the WIPP site, thereby satisfying this condition. As a result, EPA has eliminated this condition in its final determination.

[6] In its no-migration petition, DOE identified listed solvents and EP (Extraction Procedure) characteristic wastes as hazardous under RCRA. In addition, some of the waste described in DOE's petition may now be hazardous under the EPA's recently promulgated Toxicity Characteristics (TC) rule (55 FR 11798). EPA has not yet promulgated treatment standards for TC wastes; however, it is required to do so under this statute. Once these standards have been promulgated, TC wastes placed in the WIPP will be subject to the land disposal restrictions. Because EPA's review of DOE's petition considered potential migration of hazardous constituents from all of the waste DOE identified as scheduled for the WIPP, today's no-migration determination applies to wastes that are hazardous under the TC rule, as well as solvents and EP characteristic wastes, as long as the wastes were included in the petition.

the test period and well beyond. The specific conditions of today's finding are discussed in the following section and listed in summary form in section VI of this notice.

Although EPA's granting of DOE's petition is specifically based on a finding of no-migration of hazardous constituents from the unit during the test phase, EPA has thoroughly reviewed available information on the expected long-term performance of the WIPP repository. Given the geological stability of the area; the depth, thickness, and very low permeability of the salt formation in which the repository has been mined; and the properties of rock salt as an encapsulating medium, EPA believes that the WIPP is a promising site for the permanent disposal of mixed waste. To be sure, a number of uncertainties related to the long-term performance of the WIPP remain—for example, the extent and effects of gas generation, the effects of brine inflow into the repository, and the influence of a "disturbed rock zone" around the mined repository. DOE will be investigating these uncertainties in the test phase at the WIPP, and it will review whether technical modifications to the repository design or the waste are necessary to ensure compliance with the regulatory standards.

It should be remembered that today's decision is only for the disposal of mixed waste during the test phase for testing and experimentation to determine whether the site is appropriate for the long-term disposal of mixed wastes. Before DOE may move from the test phase to full-scale operations, it must petition EPA again and demonstrate no migration over the long term—that is, it must successfully address current uncertainties about long-term WIPP performance. Information gathered by DOE during the test phase will be central to such a demonstration. Any EPA decision to approve (or deny) a no-migration petition for permanent disposal at the conclusion of the test phase will be made with full opportunity for public comment, as prescribed in 40 CFR 268.6(g).

Further technical details regarding EPA's final decision are provided in a background document. In addition, major issues raised by public commenters are discussed in section V of today's notice, as well as in a response to comments document. Both the background document and the response to comments document are available in the public docket for this action.

IV. Discussion of EPA Determination and Conditions of Determination

A. *No-Migration Finding*

To make a no-migration determination, sections 3004 (d)(1), (e)(1), and (g)(5) of RCRA require EPA to find that "there will be no migration of hazardous constituents from the disposal unit or injection zone as long as the wastes remain hazardous." As EPA explained in the preamble to its proposed decision, it interprets this requirement to mean that constituents listed in appendix VIII of 40 CFR part 261 cannot migrate at hazardous levels from the disposal unit during the time that hazardous waste is present in the unit. If the hazardous waste within the unit becomes non-hazardous or if it is removed from the unit, further migration from the unit ceases to be an issue. In the case of the WIPP, DOE will have to remove all hazardous waste from the underground repository if it cannot demonstrate the long-term acceptability of the site; therefore, the effective period of EPA's finding is the test phase. Thus, EPA's decision today is based on the conclusion that the Appendix VIII constituents will not migrate at hazardous levels from the underground repository during the test phase and that DOE will remove all hazardous waste from the unit if testing cannot show that the site meets long-term no-migration standards.

EPA's no-migration finding for the WIPP test phase falls into several categories: Migration of hazardous constituents under anticipated test conditions in the repository; short-term stability of the repository; feasibility of retrieval; possible effect of accidents and spills; and effectiveness of controls against human intrusion during the test phase. These aspects of EPA's determination are discussed below.

No migration of hazardous constituents beyond the unit boundary. In the proposal, EPA explained in some detail its definition of the unit boundary for the WIPP and its standards for determining whether a constituent migrating from the unit is "hazardous." The proposed unit boundary was the Salado Formation at the WIPP site, bounded by the four-mile by four-mile land withdrawal area, except that, for air emissions during operations, the unit boundary was the point where the air exhaust ventilation shaft met the surface. EPA's definition of the unit boundary in today's decision is largely unchanged from the proposal; however, in response to public comment, it has slightly modified the unit definition as it applies to air emissions. In the final decision, the unit refers to that portion of the Salado Formation that falls within the WIPP land withdrawal area; specifically, any movement of constituents above "hazardous" levels into overlying or underlying formations, or beyond the lateral boundaries of the land withdrawal area would constitute migration. This unit boundary would apply to migration via air emissions during operations as well as via ground water or other routes after closure of the unit. (This issue is discussed in more detail in section V.H of today's notice.) EPA's definition of "hazardous" levels of migration remains unchanged from the proposal. As discussed below in section V.G, EPA is relying on "health-based levels" to define migration—that is, levels that would be hazardous to a person exposed at the unit boundary for an entire lifetime.

The no-migration standard applies to all possible routes of release from the unit. EPA, however, has concluded that migration of hazardous constituents out of the unit during the test period is implausible by any route other than air. Waste will be containerized during the test period, and even if it were released from a container, there is no possibility that waste could migrate from the unit by ground water or directly through the salt rock within the test period. No commenters questioned this conclusion, which EPA discussed in the proposal.

Potential for Migration via Air Emissions. For air emissions during the test period, EPA's finding is based on a careful review of possible releases from the bin-scale and alcove tests DOE is planning to conduct during the test period. For reasons described below, EPA has concluded that any releases from the alcove-scale tests will be negligible. Therefore, it has focused its attention on the bin-scale tests. In these tests, headspace gases will be vented into the bin discharge system whenever the bins become pressurized through a pressure relief valve installed on each bin. The gases will then be passed on to the exhaust shaft. Because the purpose of the experiments is to gather data on the gas generation potential for the various types of wastes intended for disposal at the WIPP, the rate of gas generation and thus the amount of hazardous constituents expected to be released can only be estimated. Because of this uncertainty, DOE has proposed and EPA's decision today requires the inclusion of a carbon canister in the bin gas discharge system to remove any volatile organic constituents released from the bins. This carbon adsorption control device must be designed to achieve a control efficiency of at least 95 percent. As explained in its proposal,

EPA has taken this control device into account in its no-migration finding for air emissions.

For its assessment of releases from the bin-scale tests, EPA used the concentrations of volatile organic compounds measured in the headspace of 200 drums containing waste generated at DOE's Rocky Flats Plant and stored at the Idaho National Engineering Laboratory. As described in the WIPP no-migration proposal, DOE has been able to provide little or no information on sampling plans, sample handling procedures, or quality assurance/quality control measures for these data. Therefore, EPA views the analytical results on these headspace samples as being semiquantitative. Nevertheless, even if these data underestimate the constituent concentrations by as much as an order of magnitude, the concentration of constituents at the unit boundary are still expected to be below health-based levels.

The results of EPA's assessment are shown in Table 1 below along with levels of regulatory concern.

TABLE 1.—TEST PHASE COMPLIANCE POINT CONCENTRATIONS IN AIR

Constituents	Average headspace concentrations (g/m3)	Compliance point concentrations (μg/m3)	Levels of regulatory concern* (μg/m3)
Carbon tetrachloride	1.86	0.0027	0.03
Methylene chloride	0.47	0.00068	0.3
Trichloroethylene	0.70	0.0010	0.3
1,1,1-Trichloroethane	13.2	0.019	10,000
1,1,2-Trichloro-1,2,2-trifluoroethane	1.22	0.0018	30,000

EPA conservatively assumed that both test rooms planned for the bin-scale tests are filled to capacity. The capacity of each room is 120 bins; therefore, the total number of bins is 240. EPA then assumed an average gas generation rate of 5 moles per drum per year, a figure that DOE characterizes as representing the upper bound of the range of credible gas generation rates (Test Plan: WIPP Bin-Scale CH TRU Waste Tests, January 1990; SAND 89-0462). Each bin can hold the equivalent of six drum volumes of waste. Therefore, DOE's upper bound gas generation rate is equivalent to a total gas generation rate from all 240 experimental bins of 0.5 cubic meters per day. DOE has specified the general ventilation rate through the repository as 425,000 cubic feet per minute, which is equivalent to 17 million cubic meters per day. This entire volume of air is exhausted at the exhaust shaft and is available to mix with any gases released from the bin discharge system. The resulting dilution factor at the exhaust shaft is 34 million. EPA applied the dilution factor to the average headspace concentrations, together with the control device efficiency, to calculate the concentration of constituents in the exhaust shaft.

The compliance point concentrations (with the carbon adsorption control device installed in the bin discharge system) are an order of magnitude below the level of regulatory concern for carbon tetrachloride and are two to seven orders of magnitude below any other level of regulatory concern. These figures represent the bin-scale tests alone; however, the contribution of the alcoves is negligible by comparison. Although it would not be allowable under today's decision, DOE has provided data to show that even when 10 percent of the wastes, equivalent to 85,000 drums are emplaced in the repository before sealing of the rooms, the concentrations in the exhaust shaft would be two to eight orders of magnitude below the levels of regulatory concern.

Because the alcove experiments involve only 3,850 drums (more than a factor of 20 lower), the concentrations in the exhaust shaft from the alcove drums would be a factor of at least three to nine orders of magnitude below the level of a regulatory concern. The actual concentrations would be even lower than this once the alcoves are sealed at the start of the experiment.

EPA recognizes that the actual bin gas generation rate may be higher than 5 moles per drum per year. However, even if the rate were significantly higher, concentrations at the unit boundary would still be below health-based levels, given the requirement for a carbon adsorption system designed for 95 percent efficiency. Therefore, EPA finds that DOE has demonstrated, to a reasonable degree of certainty, that hazardous constituents will not migrate beyond the repository boundary during the test phase at greater than health-based levels.

Short-term stability of the site. In the long term, salt creep will be the primary mechanism to seal the WIPP repository. In the short term, however, salt creep—which can lead to localized fracturing and rock fall—must be mitigated to ensure a stable repository environment. Repository stability has been greatly enhanced during the test phase by several design modifications to the experimental area. The most significant alteration is rockbolting, a standard mining technique to ensure stability. The roofs of all test alcoves and bin test rooms will be rockbolted. This practice alone should prevent excessive cracking and rockfall during the entire test phase. The effects of early room closure, however, are of greater significance for the test alcoves because they cannot be inspected while the tests are underway, and because drums must be retrievable after the tests have been completed. For this reason, DOE will be reducing the dimensions of the test alcoves, which will slow down the rate of creep closure. Finally, DOE intends partially to backfill several alcoves with crushed salt to simulte disposal conditions. Backfilled test alcoves will be fitted with "stand-off" walls between the backfill and the mine walls, so that room closure does not impinge on the backfilled drums. These modifications ensure the successful retrieval of the drums from the alcoves at the conclusion of the test phase, if it proves necessary.

Feasibility of retrieval. Several commenters expressed concern that retrieval may not be technically feasible, and that, given this uncertainty, EPA cannot assume removal in its no-migration finding. These commenters pointed out specific instances where retrieval might be difficult or infeasible, such as in the case of fire or explosion. They also suggested that creep closure of the test alcoves would preclude removal—an issue discussed in the previous section. Finally, they argued that retrieval from backfilled alcoves has not been demonstrated and that considerable shuffling of waste underground during retrieval may have inherent risks.

EPA has concluded that DOE's Waste Retrieval Plan, in combination with mock retrievals, demonstrates that retrieval is technically feasible. All major aspects of the retrieval process are addressed in the plan, including radiological and hazardous waste contamination control, drum and bin handling, overpacking procedures for corroded or damaged drums, clean up of contamination, and backfill retrieval. While release or leakage of hazardous constituents from containers within the repository during the test period would certainly complicate retrieval, it would not render retrieval technically infeasible. Such events are adequately addressed by emergency response procedures defined for the WIPP. The specifics of the various emergency response procedures are detailed in several DOE publications referenced in the Waste Retrieval Plan. In addition, while EPA agrees with commenters that a fire or explosion would make retrieval more difficult, the Agency is imposing additional conditions to minimize the potential for such an event. (See section V.I.1 of today's notice for a detailed

description of this point.) Thus, adequate safeguards have been imposed and will be implemented in the event of an accidental release of hazardous constituents.

It should be noted that the Waste Retrieval Plan is backed by successful mock retrieval demonstrations, although EPA recognizes that mock retrieval demonstrations performed thus far at the WIPP did not include removal of waste from the alcoves themselves. Other aspects of the removal process, however, were simulated in the retrieval demonstration. Mock retrieval experiments on backfilled alcoves and on bins will be performed before any waste is placed in the WIPP.

EPA agrees with commenters that shuffling of the waste during the retrieval process could increase the risk of a release; however, safe movement of the waste containers is technically feasible, and EPA has concluded that DOE's routine container-management procedures are adequate. Furthermore, any removal activities will be conducted under the oversight of the State of New Mexico, either during RCRA interim status or under permit conditions, which will ensure an appropriate level of care. Finally, the Environmental Evaluation Group, an independent group established by Congress to provide review of the WIPP project, provides oversight over waste management and safety aspects of WIPP operations, including removal.

A number of commenters raised the possibility of drum corrosion during the test phase, which could lead to spillage and complicate retrieval. EPA has concluded, however, that the potential for significant drum corrosion during the test phase is limited and will not substantially affect the retrieval of wastes. While it is true that salt is very corrosive, the rate of corrosion of the drums being stored in the repository is expected to be low. This is because several key factors affecting the rate of drum corrosion allow for favorable drum storage conditions. In particular, the rate of corrosion is affected by the composition of the brine contacting the drums. That is, corrosion proceeds most rapidly if the brine is unsaturated and contains dissolved oxygen. However, the brine in the WIPP repository is both saturated with salt and contains low levels of dissolved oxygen; therefore, drum corrosion would be inhibited. Moreover, the rate of corrosion is directly affected by the amount of brine contacting the drums. Since the repository is expected to remain dry during the test period and thus there will be minimal drum-brine contact, EPA does not expect the drums to corrode significantly. For these reasons, EPA has concluded that the useful drum life in the WIPP will exceed the period of this determination, including retrieval time, and it sees no reason to question DOE's statement that the drums will maintain integrity for twenty years.

In addition, EPA notes that containers at the WIPP will be subject to monitoring and inspection procedures required under RCRA 40 CFR part 265 (and, once a permit has been issued, under 40 CFR part 264). These requirements will be administered by the New Mexico Environmental Improvements Division, with EPA oversight. If any questionable drums were identified, mitigative measures—such as overpacking—could be undertaken. To be sure, drums that are sealed in the alcoves during the alcove tests cannot be routinely inspected. However, under DOE's test plan, these tests are expected to last approximately five years. Thus, inspection would be possible well within the useful life of the drum.

Finally, as EPA discusses in this and the following section, spillage from drums (however unlikely) can be contained and cleaned up, and corroded drums can be overpacked. Thus, EPA disagrees with commenters that drum corrosion might prevent the safe removal of drums from the WIPP, if removal proves necessary.

Limited effect of accidents and spills. Numerous commenters argued that accidents or spills at the WIPP site would complicate retrieval of wastes or might lead to migration. EPA agrees that accidents or spills might complicate retrieval, but it has nevertheless concluded that the cleanup of spills and the removal of contaminated material from the WIPP is technically feasible. The WIPP Retrieval Plan outlines DOE's planned approach to the removal of contaminated material; in addition, the feasibility of safe removal of such material was demonstrated in DOE's mock retrievals. Moreover, neither EPA nor public commenters identified any spill situations that by themselves would lead to a release from the repository.

EPA has addressed the possibility of fire or explosion in the WIPP by new waste characterization requirements in today's decision. Under these requirements, DOE must test every container shipped to the WIPP for flammable gases. If flammable gases are identified, the waste cannot be placed in the repository. Therefore, under the terms of EPA's determination, explosion or fire in the WIPP is not a credible event. (After DOE has developed a greater body of data on wastes shipped to the WIPP, it is likely that waste characterization requirements addressing flammability can be relaxed. However, this could only take place through a modification of the determination, with opportunity for public comment.)

Effectiveness of controls against human intrusion. During the period covered by today's determination, DOE will maintain active control over the WIPP site, and unauthorized access will be prohibited. Furthermore, the site will be operating under RCRA interim status and permit conditions, administered by the State of New Mexico, and therefore will have to comply with the RCRA security requirements. These requirements include prevention of unknown entry of persons or livestock to the active portion of the facility. Finally, DOE has secured all mineral leases at the WIPP site, eliminating the possibility of the disturbance of the repository as a result of mining or drilling. For these reasons, the Agency has concluded that migration resulting from human intrusion will not occur during the term of the determination.

B. Conditions of Determination

1. Limitation to Testing and Experimentation

In EPA's proposed finding, it limited activities involving mixed waste at the WIPP repository to the testing and experimentation described in DOE's petition and referenced documents. The Agency has retained this condition in its final determination. Consequently, DOE will be restricted to its planned test phase activities, as described in the "WIPP Test Phase Plan: Performance Assessment," Revision 0 (DOE/WIPP 89-011, April 1990). Before DOE could conduct activities beyond the scope of this test plan, it would have to petition EPA to modify its no-migration finding.

Several commenters on the proposal expressed uncertainty about what specific activities would fall under the definition of "testing and experimentation"; in addition, the commenters asked for clarification of when DOE would have to notify EPA of changes from activities described in the performance assessment test plan.

With respect to the first point, DOE could conduct in the repository only those tests or experiments designed to provide data to demonstrate the long-term acceptability of the WIPP. Thus, DOE's planned "operations demonstration" has been explicitly excluded from the allowed activities;

other nontesting activities would similarly be excluded. For clarification, EPA has modified this condition, which originally read "placement of waste for the primary purpose of conducting an operations demonstrated is prohibited under this variance * * *," by dropping the word "primary." Several commenters suggested that the inclusion of the word "primary" amounted to an invitation to DOE to conduct a full-scale operations demonstration with the excuse that some testing was also going on. This was not EPA's intention, and therefore it has modified the condition accordingly. EPA, however, stresses that it does not understand this condition as preventing DOE from incidentally testing some operational aspects of its system when it places waste underground for permissible testing. Such activity, in EPA's view, would not constitute an "operations demonstration" in the sense that DOE as well as DOE critics have used the phrase up to this point. In addition, EPA recognizes that some mixed wastes might be generated underground as a result of legitimate experimentation or air monitoring in the WIPP repository. These wastes, which might no longer have any experimental purposes, could nevertheless be stored in the repository until a final determination on the site was made. Because the materials were originally placed in the WIPP for permissible testing, continued storage of the wastes in the repository would be consistent with the terms of EPA's decision.

With respect to the second point, tests and experiments conducted under today's determination would have to be consistent with the activities described in DOE's performance assessment test plan and its no-migration petition. For example, where substantially different wastes or waste containers are used, where waste volumes were increased above 0.5 percent (but less than one percent), or where tests outside DOE's planned three-phase bin and alcove-scale tests are contemplated, DOE would be required to notify EPA and, if the changes might affect the basis of EPA's finding, seek a modification to that finding. The only exception to this would be those wastes that are described in DOE's no-migration petition that are modified through various treatment technologies; because the composition of these wastes, if changed, would contain fewer toxic constituents, the Agency does not believe it would have to be notified before the wastes could be placed in the repository. EPA does note, however, that the pilot-room tests originally suggested by EPA and now contemplated by DOE, would be excluded under today's decision, because they go substantially beyond the program described in DOE's test plan and furthermore are inconsistent with other conditions of the determination (e.g., the volume limit and retrievability of wastes).

2. Limitation on Volume

In its proposed determination, EPA did not set a specific limit on the amount of mixed waste that DOE could place in the repository during the test phase. Instead, EPA argued that, because of the experimental nature of the test phase, DOE needed a reasonable degree of flexibility in carrying out its experimental program. Although several commenters supported EPA's approach, many opposed it, arguing that it was open-ended and allowed DOE to expand the scope of the test phase indefinitely. Although EPA continues to believe that its no-migration finding, as proposed, significantly restricts the nature of DOE activities during the test phase, the Agency nonetheless understands the concerns of the commenters. Therefore, it has decided to place a volume limitation of 8,500 drums or 1 percent of the total projected WIPP volume on wastes that can be placed in the repository under this determination.

In setting a volume limit, EPA notes that DOE's "WIPP Test Phase Plan" called for bin and alcove-scale testing of waste amounting to 0.5 percent of the projected WIPP capacity, while in Congressional testimony, DOE indicated that bin, alcove, and pilot-room tests might require waste amounting to approximately 2 percent of the WIPP capacity. Because EPA has determined that the pilot-room tests, as currently planned, could not be conducted under the proposed no-migration finding, it believes that the 2 percent volume limit would be inappropriate. At the same time, EPA also believes that limiting DOE to the amounts specified in the current test plan might not provide sufficient flexibility for DOE to modify those plans, particularly in response to comments from reviewing organizations. Consequently, EPA has decided to impose a limit of 1 percent of total WIPP capacity (or 8,500 drums), a figure that provides some flexibility to DOE and at the same time gives the public assurance of an opportunity to comment if significant increases over DOE's proposed waste volumes are needed.

EPA emphasizes that it is not basing the 1 percent limit on any technical determination of how much waste would be necessary for DOE to carry out an adequate testing program. Rather, EPA in effect is defining a limit that it would consider to be a significant departure from the activities described in DOE's no-migration petition and its final test plan. Before DOE could exceed that limit, it would have to repetition EPA, and any EPA approval of an expanded test program would have to undergo public comment. EPA also emphasizes that the 1 percent figure represents an upper limit on the amount of waste that may be placed in the WIPP under today's determination. This limit would not override the condition that waste could be placed in the WIPP only for testing and experimentation within the scope of DOE's test plan. Waste would not be allowed in the repository for purposes other than testing and experimentation, even if the volume of waste involved did not exceed the 1 percent limit.

Many commenters also suggested that EPA shorten the proposed ten-year expiration date for petition approval. EPA has not adopted this suggestion, because, as it discussed in the proposed decision, it believes such a limit might artificially constrain legitimate testing. EPA does not believe the difference between five years (the projected length of DOE's test phase) and ten years is significant in terms of the likelihood of release of hazardous constituents from the repository. Furthermore, it has concluded that this difference in time will not significantly effect retrievability. However, EPA acknowledges that the timing and procedures for removal of waste if DOE is not able to demonstrate the long-term acceptability of the WIPP at the close of the ten-year period was not clear in the proposed finding. Therefore, the Agency has amended the conditions of the finding to address this concern. This issue is discussed below.

3. Waste Retrieval

The requirement that DOE retrieve wastes from the repository if it cannot demonstrate the long-term acceptability of the site remains unchanged from the proposal. As discussed above in section IV.A, EPA has found such retrieval to be feasible within the general parameters of the plans submitted with the petition. In addition, EPA has added a clause spelling out in more detail the timing of retrieval. Under this requirement, DOE must submit to EPA a specific retrieval schedule no later than six months after it is determined that the WIPP cannot meet the long-term disposal standards, or six months before the expiration of the petition approval (*i.e.*, 10 years after petition approval), whichever comes first. This schedule would have to detail

retrieval procedures and include a schedule for the removal of the waste as rapidly as technically feasible. Before retrieval took place, the plan would be subject to public comment and EPA approval.

4. Waste Retrievability

DOE is required to place all waste in the repository in a readily retrievable manner. This condition is unchanged from the proposal. By "readily retrievable," EPA means adoption of the specific measures identified in DOE's petition to maintain room stability (*i.e.*, room sizing, rock bolting), the use of easily retrieved waste containers (*e.g.*, boxes, bins, and drums), and the absence of backfilling—except in alcove tests where standoff walls will be used. (EPA notes that testing in pilot-scale rooms, which the Agency originally suggested and DOE is now considering, would not be allowed under this condition, because—as currently planned—they would involve backfilling of waste in the pilot rooms without standoff walls. DOE would have to seek a modification of the no-migration finding, with opportunity for public comment, before conducting such tests.)

5. Carbon Adsorption Device

Today's decision requires DOE to install a carbon adsorption control device in the bin discharge system of each room designed to achieve a 95 percent control efficiency. The Agency believes a 95 percent control efficiency is readily achievable. (See 55 FR 25454.) The design must be based on a total design gas volume consisting of a design gas generation value of at least 5 moles per drum per year from the bins and the volume of gas used to purge the bin exhaust manifold. EPA also wishes to clarify that the design value for the frequency of carbon replacement must be verified by testing and modified as needed to prevent breakthrough from occurring. The testing must consist of measurements of the adsorption capacity of carbon for the bin exhaust gases, as described in the petition. EPA is also requiring DOE to maintain design records, including any test data, and operating records in the facility operating record, as described in the notice of the proposed decision. (See 55 FR 13068, Section IV.J.) Records must be maintained for the term of today's determination (i.e., ten years from today's date), or three years after the creation of the records, whichever is longer. In addition, the records must be maintained during the course of any enforcement action for which they are relevant.

EPA is not requiring DOE to perform testing to verify the control efficiency of the carbon bed. However, DOE must monitor the bin exhaust manifold to show that no migration above health-based levels occurs at the unit boundary. This must be further confirmed by monitoring at the exhaust shaft. Although the 5 moles per drum per year design value for gas generation is believed to be conservative, the overall average rate of gas generation from TRU wastes is not known with certainty; this is the purpose of the bin and alcove tests. The control efficiency actually achieved will be higher or lower depending on the rate at which gas is generated during the tests. However, even if gas generation rates were to be as high as 25 moles per drum per year, the design would still achieve the no-migration standard.

6. Air Monitoring Plan

EPA is requiring air monitoring for activities conducted under today's no-migration finding to confirm that there is no migration of hazardous constituents above health-based levels beyond the unit boundary. As described in its notice of proposed decision (55 FR 13068), EPA has concluded that the only possible migration pathway during the test phase is through the exhaust shaft. Therefore, in accordance with the requirements of 40 CFR 268.6(c), the Agency is requiring DOE to implement the air monitoring plan submitted with its petition, subject to the clarifications, modifications, and reporting requirements described in the notice of proposed decision, except as noted below.

In its proposed decision, EPA solicited comment on whether additional monitoring should be conducted in the underground repository with portable explosimeters to detect any buildup of methane, hydrogen, or other flammable gases. No comments were received in favor of portable explosimeters. Therefore, EPA has decided not to require their use. At the same time, however, EPA has determined that only by testing individual waste containers to be placed in the WIPP can it be assured that no fire or explosion hazard exists. Thus, EPA is including an additional condition requiring such testing, as described in section IV.B.7.a of today's notice.

EPA also solicited comment on whether to allow a reduction in monitoring frequency from weekly to monthly. EPA received no comments on this question and has decided to retain a weekly minimum monitoring frequency. Furthermore, EPA solicited comment on whether other constituents, in addition to the five constituents proposed, should be targeted for routine quantitation. No comments were received on this question; therefore, EPA has decided to retain the five target constituents listed in the notice of proposed decision, with provisions for targeting additional constituents, as described in the proposal.

In the proposal, EPA spelled out a variety of quality assurance and quality control requirements, making mention of the "Report on Minimum Criteria to Assure Data Quality." Since that time, EPA has revised this report and has retitled it "Quality Assurance and Quality Control" (August 1990), a copy of which has been placed in the docket to this rule. Therefore, EPA is requiring DOE to follow the requirements of the revised report, in addition to adhering to the specific quality control requirements described in the DOE monitoring plan and EPA's notice of proposed decision. EPA wishes to clarify that it intends the "method limit of quantitation," the term used in the notice of its proposed decision, to be synonymous with the term "method detection limit," or MDL, used in the report, "Quality Assurance and Quality Control." In addition, EPA is requiring DOE to maintain documentation of all aspects of quality assurance and quality control, as described in the revised report, in the WIPP facility operating record; this documentation must be available for inspection by the Agency. The records must be maintained for the term of today's determination or three years after they are created, whichever is longer. In addition, the records must be maintained during the course of any enforcement action for which they are relevant.

Initial monitoring results underground at the WIPP have revealed significant background levels of 1,1,1-trichloroethane and carbon tetrachloride.[1] The levels measured can interfere with the evaluation of accuracy if the approach described in the notice of proposed decision is used. Therefore, EPA is changing the method by which relative accuracy is determined. Instead of computing accuracy based on a matrix spike alone (as the relative difference between the concentration recovered from the sampler and the concentration of the targeted analyte as determined from the known concentration in the audit gas cylinder), the computation should be adjusted for

[1] Significant levels of methylene chloride were also detected in background samples. However, laboratory contamination is the most likely explanation for the measured levels of methylene chloride.

the actual background concentration measured in a matrix duplicate at the time the matrix spike is collected. Therefore, DOE must collect and analyze both a matrix spike and a concurrent matrix duplicate.

EPA further solicited comment on what specific quality assurance (QA) objectives it should require for data acceptability. DOE requested that EPA allow less accurate measurements at concentrations near the detection limit. The data provided by DOE, however, gave no basis for establishing an alternative QA objective for accuracy, due to high background levels. Because of this, and because EPA is not requiring data that are below the method detection limit (MDL) to be used in the evaluation of relative accuracy (the MDL is generally considerably higher than the limit of sensitivity of the analytical procedure), EPA has concluded that the plus or minus 10 percent requirement can be achieved. Therefore, no change is being made to the QA objectives established in the notice of proposed decision.

Finally, EPA proposed to require calibration of the ventilation exhaust fans on a quarterly basis. In its comments on the proposal, DOE interpreted this to mean a full dynamic calibration, which it argued is needed only on a yearly basis. EPA means to require only a check on the fan calibration on a quarterly basis, using the methods described in the notice of proposed decision. EPA agrees that a full calibration is needed only on a yearly basis.

Several commenters expressed concern that EPA is allowing monitoring at the top of the exhaust shaft instead of at the entrance to the shaft. They argued that EPA should require DOE to monitor the entrance and exit of the shaft to demonstrate EPA's statement that there will be no difference between measurements. EPA disagrees with these commenters. Even if, as suggested by one commenter, the integrity of the concrete shaft liner were compromised, it is inconceivable that any depletion of concentrations of hazardous constituents could be detected, given the large volume of air that the exhaust shaft is designed to handle during operation. EPA's overriding concern regarding the specific location of the exhaust shaft monitoring station is that it be situated so as to enable ready access for operation and maintenance purposes. Indeed, EPA views ready accessibility as one of a number of important quality assurance objectives. Therefore, EPA continues to accept monitoring at the top of the exhaust shaft.

7. Waste Analysis

a. *Flammability.* EPA received a number of comments that flammable gases could build up in waste containers, creating a fire and explosion hazard. After reviewing these comments and new information made available during the public comment period, EPA has concluded that, while a fire or explosion is unlikely, the possibility of accidental ignition of flammable gases in waste containers cannot be ruled out. Were a fire or explosion to occur as a result of accidental ignition of flammable gases in the void space of a waste container, retrieval could be much more difficult, should retrieval become necessary. Moreover, such an event could itself cause migration above hazardous levels beyond the unboundary.

For these reasons, EPA believes that no waste container should be emplaced in the underground repository if it contains flammable mixtures of gases in any layer of confinement, or mixtures of gases that could become flammable when mixed with air. To assure a sufficient margin of safety, EPA defines any mixture as potentially flammable if it exceeds 50 percent of the lower explosive limit (LEL) of the mixture in air.

To ensure that individual waste containers have met the prohibition on flammable gases, the Agency is requiring that every waste container be tested for hydrogen, methane, and volatile organic compounds (VOCs) as a class. Given the heterogeneity of the waste package, the Agency is also requiring that headspace sampling be representative of the entire void space of the waste container. EPA expects that all layers of confinement in a container will have to be sampled until DOE can demonstrate to the Agency, based on the data collected, that sampling of all layers is either unnecessary or can be safely reduced. The testing of wastes that exhibit high rates of radiolysis should be performed a relatively short time before the container is actually emplaced underground. Otherwise, hydrogen levels could build up to flammable levels following sample collection and analysis. Therefore, DOE must determine, and document, the length of time that headspace gases can be expected to remain below flammable levels (i.e., 50 percent of the mixture LEL) after sampling has been performed, for both newly generated and retrievably stored wastes, and to ensure that the waste containers are emplaced in the WIPP within that time.

If testing reveals the presence of significant levels of flammable VOCs, DOE must perform an explicit flame test to determine if a flammable mixture can be formed with air. Significant levels of flammable VOCs are defined as measured concentrations (excluding methane) of 500 parts per million or greater. If testing shows that VOCs are insignificant, i.e., below 500 parts per million, DOE may determine the lower explosive limit of the mixture from the lower explosive limits of methane and hydrogen using the Le Chatelier formula, as described in Section V.I.a of today's notice.

All testing must satisfy the quality assurance and quality control requirements described in EPA's report "Quality Assurance and Quality Control" (August 1990) and must meet quality assurance objectives of plus or minus 10 percent on precision and accuracy. DOE must also maintain records on all testing performed and other documentation needed to comply with this condition at the generating site or in the WIPP facility operating record. These records must be available for inspection by EPA, and must include documentation of all aspects of quality assurance and quality control, as described in the above-referenced document. Records must be maintained for the term of today's decision, or three years after they are generated, whichever is longer. They also must be retained for the duration or any enforcement action related to this part of today's decision.

b. *RCRA Constituents—Short-term characterization.* In response to comments regarding the accuracy of the waste composition estimates provided by DOE in its no-migration petition, EPA is modifying its proposal to require that DOE analyze headspace gases in containers that are shipped to the WIPP and compare the results of this analysis to the estimated values provided in the no-migration petition. Since it was the values in the petition that EPA evaluated in today's decision, DOE must ensure that the analytical data derived from the actual test-phase wastes are similar to the petition estimates. Wastes that are not compositionally similar may not be placed in the WIPP.

(1) *Bin-scale tests.* DOE must compare actual measurements of headspace concentrations of volatile organics in each of the drums containing wastes to be used in the bin-scale tests to the headspace concentrations reported in DOE's petition. The comparisons must be made in terms of both maximum and mean concentrations. (EPA considers only headspace concentrations to be

necessary because migration through air was determined to be the only viable route of migration during the test phase.)

The comparison of the maximum concentrations is designed to ensure that the wastes to be emplaced in the WIPP are in fact similar to the wastes described in the petition. In its proposed decision, EPA noted concerns with the precision and accuracy of some of the analytical data in the petition and took this uncertainty into account during its evaluation. To address concerns over the quality of its data, DOE will be conducting an extensive characterization program on wastes to be shipped to the WIPP for the bin-scale and alcove tests under greatly improved quality assurance/quality control (QA/QC) procedures. (See e.g., DOE's Pre-Test Waste Characterization Plan, Revision 6, in the docket to today's decision.) Because of improved data quality, EPA expects these new data to differ somewhat from those contained in the petition. However, the Agency believes that the measured maximum concentrations identified in individual drums in DOE's pretest waste characterization program should be generally comparable to the maximum values reported in the petition.

There are no established criteria for quantitatively defining "comparability" in this context. EPA, however, has concluded that, if the measured headspace concentration in a given drum are no more than a factor of two over the maximum reported for the drum in the petition, the wastes are reasonably comparable. In selecting a factor of two, EPA notes that some differences between the new data and that contained in the petition are expected. This is because the new data will represent a larger sample and analytical results may be more accurate. (As noted in EPA's proposal, the precision and accuracy of the analytical data in the petition were not always well documented.) For these reasons, EPA has concluded that it is reasonable to expect some concentrations will be measured that will exceed the maximum values reported in the petition. EPA, however, also believes that the data should not be significantly different and concludes that a factor of two represents a reasonable expectation.

Accordingly, DOE may place the contents of individual drums into bins for the bin-scale tests if the measured headspace concentrations do not exceed the reported maximums by more than a factor of two.[8] Testing and verification must be completed before the waste is shipped to the WIPP. If the measured concentration of any of the pertinent hazardous constituents in a drum headspace exceeds the allowable maximum, the contents of the drum from which the sample was collected cannot be shipped to or emplaced in the WIPP, unless DOE subsequently treats the waste so as to reduce headspace concentrations to below the maximum levels. Alternatively, DOE may petition EPA to modify the conditions of its determination. Any such modification would require public comment. Further, DOE must maintain records of all relevant test data at the generating site or the WIPP for the term of today's determination, or three years after the data are generated, whichever is longer. In addition, records must also be retained for the duration of any enforcement action for which they are relevant.

The maximum allowable concentrations for hazardous constituent by waste type (the maximum reported concentrations multiplied by two) are presented in Table 2.

TABLE 2.—MAXIMUM HEADSPACE CONCENTRATIONS

[In volume percent]

Constituent	Type I	Type II	Type III	Type IV
Carbon tetrachloride	0.08	0.18	0.58	8.18
Methylene chloride	0.44	0.84	0.50	1.42
1,1,1-Trichloroethane	1.88	5.68	2.12	14.96
Trichloroethylene	0.08	0.34	0.28	0.28
1,1,2-Trichloro-1,2,2-trifluoroethane	0.05	1.62	5.74	20.80

EPA's no-migration finding for air releases was based upon the mean headspace concentrations of volatile constituents reported by DOE. Accordingly, EPA has concluded that comparison of the new, pre-test characterization data with the mean concentrations reported in the petition is also necessary to ensure that EPA's estimates of volatile emissions are valid for the actual test-phase wastes. In determining a reasonable factor for this comparison, EPA considered the "safety margin" indicated by the no-migration demonstration. For the constituents of concern, this safety margin ranges from approximately eleven to well over sixteen million, varying by constituent. EPA has no reason to believe that the headspace concentrations for 1,1,1-trichloroethane and 1,1,1-trichloro-1,2,2-trifluoroethane (with safety factors of six and seven orders of magnitude, respectively) could be high enough to alter the no-migration finding. For the other constituents (carbon tetrachloride, methylene chloride, and trichloroethylene), the safety factors are lower (one, two, and two orders of magnitude, respectively). EPA, therefore, has concluded that DOE must compare the new headspace data for these constituents to the mean values reported in the petition.[9] To ensure that the no-migration finding remains valid for these constituents, EPA is requiring that the mean values for the test phase wastes cannot exceed ten times the mean values reported in the petition.

EPA is confident that the factor of ten (back-calculated from the modeling for carbon tetrachloride) is sufficiently conservative for all three of the constituents. Even though no additional safety factor has been added for carbon tetrachloride, EPA notes that the modeling upon which the calculation was based contains several conservative assumptions (e.g., that both test rooms are filled to capacity). EPA also notes that, during the test phase, emissions will be monitored and it will be clear well in advance if emission levels are approaching the no-migration limits, and corrective measures could be taken. Therefore, EPA is comfortable with a safety factor of ten for the comparison of the mean values.

DOE must compare the predicted mean values (multiplied by ten) against the average of the measured concentrations of the headspaces of all drums of a single waste type used to make up each bin. That is, the mean from the population of drums going to each bin (by waste type) must be compared with the reported mean for that waste type. If the calculated mean exceeds the reported mean by more than a factor of ten, that bin cannot be emplaced at the WIPP under today's decision. Testing and verification must be completed before the waste is shipped to or emplaced in the WIPP. As with comparisons of maximum concentrations, DOE must maintain records of all relevant test data at the generating site or at the WIPP facility for the term of today's determination, or for three years after generation, whichever is longer.

The allowable average concentrations for each waste type in drums to be used

[8] As with the condition related to flammability discussed previously, DOE must demonstrate that samples collected for these analyses are representative of the entire headspace within the drum, including the headspace within inner bags.

[9] See footnote 8.

in a single bin are presented in Table 3.[10]

TABLE 3.—MEAN HEADSPACE CONCENTRATIONS

(In volume percent)

Constituent	Type I	Type II	Type III	Type IV
Carbon tetrachloride	0.24	0.25	0.30	6.90
Methylene chloride	0.39	0.42	0.33	0.93
Trichloroethylene	0.25	0.28	0.29	0.38

(2) *Alcove tests.* EPA has found emissions from the alcove tests to be inconsequential in comparison to the bin-scale tests. Accordingly, EPA is not requiring testing of the headspace of drums used in the alcove tests to demonstrate comparability with reported concentrations in DOE's petition.[11] Before any drums can be shipped to the WIPP for alcove tests, however, DOE must verify (by waste type), through results of the bin-scale tests conducted up to that point, that the measured mean concentrations for specific hazardous constituents do not exceed the reported mean values by more than a factor of ten. (See Table 3.) (This condition would not require DOE to conduct all bin-scale tests before the alcove tests could proceed; however, based on discussions with DOE, EPA believes that most of the bin-scale tests will be conducted before the alcove tests begin.) EPA is also not requiring DOE to test the drums to determine maximum concentrations for specific hazardous constituents, because it believes that sufficient data will have been compiled from tests conducted in bin-scale drums to determine if there is a concern. In this regard, EPA notes that the drums for both the bin-scale and the alcove tests will be randomly selected from the population of each appropriate waste type. Therefore, there is no reason to believe that the wastes used in the alcove tests will be any more or less accurately characterized by the data in the petition than will be the wastes used in the bin-scale tests. For this reason, EPA has concluded that the data collected from the drums selected for the bin-scale tests can be appropriately extrapolated to the drums for the alcove tests.

c. *RCRA Constituents—Long-term characterization.* In its proposed decision, EPA expressed some concern over the limited waste characterization data provided by DOE in support of its petition. While EPA concluded that the data were sufficient for the no-migration demonstration for the test phase, it also believed that further characterization was required, before any finding could be made for the operational and post-closure phases. EPA believes that this further characterization will be necessary both to further confirm DOE's estimates of waste composition and to ensure that the wastes are sufficiently similar to allow the results of test-phase experimentation to be extrapolated to the wastes that DOE wishes to emplace at the WIPP in the operational phase. That is, the Agency wished to ensure that the test-phase wastes are accurately represented by the estimates and are representative of the remainder of the wastes.[12] In addition, more accurate source term data may prove necessary, EPA believes, in long-term modeling exercises. Toward these ends, the Agency proposed to require DOE to report all characterization data that will be collected.

After carefully reviewing public comments, EPA continues to believe that the data provided by DOE in its petition are sufficient for its finding with respect to the WIPP test phase, where air emissions are the major concern (especially given the standards on headspace concentrations and flammability imposed in today's decision). The additional waste characterization data under development by DOE during the test phase will be important for any review of a subsequent no-migration petition for operational and post-closure periods, where groundwater migration and other issues may arise; however, the data are not needed for today's decision. Accordingly, EPA has not included detailed requirements for waste characterization of the test-phase wastes (beyond the headspace concentrations and flammability limits) or of wastes generated at the ten DOE sites as a condition for today's final decision. However, DOE is developing waste characterization plans, including sample collection, preservation, and analytical procedures, to demonstrate the extent to which the test phase wastes are representative of the other wastes from the ten sites, and to confirm the actual levels of RCRA constituents in headspace gases and sludges. If certain wastes that are generated at the ten sites are not represented (as defined in footnote 12) by the wastes that were tested during the test phase, they could not be shipped to the WIPP without further Agency evaluation, including the possibility for public comment or treatment of the waste.

Over the past several months, EPA—and the state of New Mexico—has reviewed a number of documents concerning DOE's pre-test waste characterization plans. EPA will continue to provide comments to DOE to assist DOE in evaluating whether the waste characterization data that DOE will be collecting are sufficient to make a long-term finding for the WIPP. If adequate data are not collected, EPA will not be in a position to approve any no-migration petition for the operational and post-closure phases, if DOE submits such a petition. At a minimum, the wastes should be analyzed for the following constituents:

Acetone	Hydrazine
Benzene	Methanol
Bromoform	Methylene chloride
Butanol	4-Methyl-2-pentanone
Nitrobenzene	1,1,1-Trichloroethane
1,1,2,2-Tetrachloroethane	Trichloroethylene
Tetrachloroethylene	1,1,2-Tricholoro-1,2,2-trifluoroethane
Toluene	1,3,5-Trimethylbenzene
2-Butanone	1,2,4-Trimethylbenzene
Carbon tetrachloride	m-Xylene
Chloroform	o-Xylene
Chlorobenzene	p-Xylene
Cyclohexane	Cadmium
1,1-Dichloroethane	Chromium
1,2-Dichloroethane	Lead
1,2-Dichloroethene	Mercury
cis-1,2-Dichloroethene	Selenium
Ethyl benzene	Silver
Ethyl ether	
Formaldehyde	

Testing for these constituents should include headspace analysis of all waste types for the organic compounds, as well as total analysis of the sludges for both the organic compounds and the metals.[13] Since these date are not

[10] The allowable concentrations are the reported mean concentrations for each waste type multiplied by ten. In calculating the mean headspace concentrations, EPA used one-half the detection limit indicated in the no-migration petition to represent concentrations where the constituent was not detected.

[11] Although today's decisions does not require DOE to characterize RCRA constituents in the drums to be used in the alcove tests, DOE has informed EPA that it intends to test some statistical number of drums that are to be used in the alcove test. In addition, as discussed earlier, DOE will be required to test the headspace of drums used in the alcove tests for flammability.

[12] By "representative," EPA is referring to those factors that should contribute to migration of hazardous constituents. The purpose of the test-phase experiments is to evaluate gas-generation processes and provide a database of information that can be used to predict gas generation potential of the wastes that are planned to be emplaced during the operational phase. Thus, the issue of whether the test-phase wastes are "representative" deals with whether the results of the test-phase experiments can be extrapolated to the remaining wastes. To that end, DOE's approach is based upon an "envelope" or "bounding" concept wherein wastes whose characterization (for gas-generation potential) is within that envelope would be considered "represented" by the test-phase wastes.

[13] As indicated in Section I.D of today's notice, the state of New Mexico is responsible for enforcing

Continued

necessary for today's finding, but rather will be evaluated as part of a subsequent review of a petition for the operational and post-closure periods (if DOE chooses to submit such a petition). EPA has concluded that the specifics of this testing should not constitute a condition in today's decision.

d. Reporting Requirements

Reporting requirements associated with EPA's final no-migration determination are unchanged from the proposal—that is, annual written reports are required on the status of DOE's performance assessment during the test phase—except that the final determination requires that DOE send reports to EPA's Region VI office in Dallas, Texas, as well as to the EPA Office of Solid Waste at EPA headquarters. Because Region VI will have direct enforcement authority over the WIPP, EPA believes that it is important for reports to go directly to the regional office as well as to EPA headquarters.

V. Discussion of Major Issues

EPA received more than 400 comments on its proposal, some supporting EPA's proposed decision and others opposing it. Commenters raised a wide variety of issues, including the general scope of EPA's review and its proposed decision; the suitability of the site; the consistency of EPA's proposed approach with the statutory no-migration standards; adequacy of waste characterization; the feasibility and likelihood of retrieval; the impact of possible human intrusion; and many other issues. The major issues raised by the public are discussed below as well as in other sections of this notice. These and the other issues raised by commenters are also discussed in detail in a Response to Comment document prepared by EPA. This document is available in the public docket to this decision.

A. *Appropriateness of "Exemption" for DOE*

A number of commenters criticized EPA for proposing to grant to DOE what they regarded as an "exemption" from the hazardous waste regulations for its WIPP operations. They questioned why EPA would grant an "exemption" or "variance" to DOE for radioactive wastes, given the risks of this material. Numerous commenters also questioned DOE's record at other sites, and argued that DOE should be required to comply with all applicable regulations—without special "exemptions" or "variances"—before it was allowed to place waste in the WIPP repository for any purposes.

EPA stresses that it is not granting an "exemption" to DOE from the hazardous waste regulations. This action, however, is a "variance" only in a very narrow sense. HSWA establishes two routes by which a regulated party may dispose of waste in compliance with the land disposal restrictions: It may pretreat wastes according to specified treatment standards, or it may dispose of the waste in a unit that meets the stringent no-migration standard. DOE has chosen the second route of complying with these restrictions—an option that is in some respects the more stringent of the two. For example, if DOE were to choose treatment as its approach, DOE would no longer be required to demonstrate that no hazardous constituents would migrate from the WIPP before the treated waste (which might still remain hazardous) could be placed underground. In any case, EPA reemphasizes that its action today in no way exempts DOE from the hazardous waste regulations; instead, it is a determination by EPA that the placement of untreated mixed waste in the WIPP during the test phase complies with the statutory and regulatory restrictions on land disposal under RCRA. Furthermore, it should be noted that the WIPP must also comply with the other hazardous wastes standards of RCRA, as well as other applicable standards. Other standards applicable to the WIPP are described in Section I.D of this notice.

EPA recognizes the concerns of many commenters over acknowledged problems at other DOE sites. EPA, however, does not believe that problems at other sites should rule out approval of a no-migration petition for the WIPP. The issue at hand is whether there will be any migration of hazardous constituents from the WIPP disposal unit. EPA has carefully and independently reviewed all the information from other sources. As a consequence of this review, EPA has concluded that DOE has demonstrated, to a reasonable degree of certainty, that hazardous constituents will not migrate from the disposal unit, under the conditions prescribed in Section VI of this notice.

B. *Timing of EPA Decision*

A number of commenters expressed concern about what they considered to be EPA's undue haste in proposing to grant DOE's no-migration petition for the WIPP, and they criticized EPA's tentative schedule for a final decision. They suggested that EPA may have taken undue shortcuts in the regulatory process, or that DOE's petition was given an insufficient level of technical review.

EPA disagrees with these commenters. The Agency deliberated on DOE's original petition for more than a year before its proposed no-migration determination for the WIPP in April 1990, and it spent an additional five months in the review of public comments before reaching a final decision. In the course of this review EPA conducted a complete and thorough evaluation of DOE's petition, material provided by DOE in support of its petition, independent studies of the WIPP, and public comments on the proposed no-migration determination. In addition, EPA staff conducted three investigatory visits to the WIPP site. The results of EPA's review are summarized in today's notice and in the Agency's proposed decision in April 1990. Technical details are provided in EPA's Response to Comments Document and its Background Document, both of which are available in the docket for this rulemaking.

EPA acknowledges that it placed a high priority on the review of DOE's WIPP petition. The Agency disagrees, however, that it took any undue shortcuts in the review or omitted any significant procedural steps. EPA's decision was made in full accord with the procedures for no-migration determinations, codified at 40 CFR 268.6, and with EPA's procedures for site-specific decisions under RCRA. EPA modeled its procedures for handling the WIPP no-migration petition (as well as other no-migration petitions now under review) on its procedures for handling RCRA delisting petitions. These procedures ensure a thorough and complete Agency review, with public notice and full opportunity for public comment.

C. *Scope of Determination*

In its proposed no-migration determination for the WIPP, EPA noted that it did not consider the release and possible risks associated with radioactivity; rather, its review addressed the release of hazardous constituents from the disposal unit. EPA pointed out in its proposal that the statutory language on no-migration referred to the release of hazardous constituents, which do not include radionuclides, and risks of radioactivity from the materials DOE is placing in the WIPP fall within the scope of the Atomic

RCRA interim status standards at the WIPP and for issuing a RCRA permit to the facility. In carrying out these responsibilities, the State may require additional or more stringent waste characterization requirements.

Energy Act rather than RCRA. The Agency further noted that risks associated with transportation lay outside the scope of its no-migration review. Finally, EPA did not seek to determine whether the approach proposed by DOE—that is, deep geologic disposal of TRU wastes at the WIPP site—was the best possible alternative for handling that waste. Despite EPA's explanation of the scope of its no-migration review, numerous commenters raised issues related to radioactivity, transportation, and alternatives to the WIPP. EPA understands that concerns of these commenters; however, its continues to believe these concerns lie outside the scope of its legal authority and are better addressed in other forums.

Radioactivity was a major concern of many commenters. A number, in particular, argued that, since EPA's charge is to protect human health and the environment, it must address the release of radionuclides in any evaluation of the non-migration potential of waste from the WIPP. EPA, however, believes that the potential for radioactive releases from source, special nuclear, and byproduct material is not within the scope of the non-migration determination. First, as EPA explained in its proposed no-migration finding for the WIPP, the Agency's authority over mixed wastes under RCRA extends only to the hazardous components of the waste, not to the radionuclides exempted from RCRA. (EPA explained this position more fully in its mixed waste clarification notice of July 3, 1986, 51 FR 37045. See also Section I.B above). Second, release of radionuclides is not within the specific mandate of the no-migration language in RCRA or the regulatory standards codified at 40 CFR 268.6. Under the statute, EPA may not find a method of disposal protective of human health unless "* * * it has been demonstrated to the Administrator, to a reasonable degree of certainty, that there will be no migration of hazardous constituents from the disposal unit * * * for as long as the waste remains hazardous." Hazardous constituents are a term of art under the statute, referring to compounds listed in 40 CFR part 261, appendix VIII. No type of radionuclide is listed in the appendix. Moreover, EPA regulations at 40 CFR 268.6 do not contemplate evaluation of the radioactive risks of a given unit.

EPA acknowledges that it has a general authority and responsibility under RCRA and other acts to protect human health and the environment, and that this standard is an overriding consideration in any no-migration decision, including a decision regarding the WIPP. The Agency believes, however, that the standards issued by EPA under the Atomic Energy Act and the Clean Air Act are the proper standards for protection of human health and the environment for radiation risks at the WIPP site. Air emissions from the WIPP during the test phase will have to comply with the Clean Air Act standards for radioactive releases in 40 CFR part 61 and (under agreement with the State of New Mexico) with AEA standards issued under 40 CFR part 191 subpart A. In chapter 6 of its Final Safety Analysis Report, DOE calculated radionuclide emissions from the WIPP according to EPA-approved models to document compliance with Clean Air Act and AEA standards. DOE is also preparing a NESHAP notice of anticipated start-up to file with EPA, in accordance with Clean Air Act standards. Finally, long-term releases of radionuclides will be controlled under AEA disposal standards codified at 40 CFR part 191 subpart B. These regulations, which were specifically designed to address potential radioactive releases, are the appropriate authority for addressing any such releases at the WIPP site.

EPA also acknowledges public concerns about transportation safety and agrees that it is important for DOE to take every necessary measure to ensure the safety of shipments to the WIPP. The question of transportation risks, however, lies outside the scope of EPA's no-migration authority, and therefore the Agency has not addressed them in its review. Instead, overall issues of transportation safety for the WIPP project are addressed under the National Environmental Policy Act (NEPA) through the Environmental Impact Statement process and by the Nuclear Regulatory Commission, which by agreement with DOE has oversight over shipping containers and the waste form during transportation.

Finally, EPA has reviewed comments suggesting that alternatives other than the WIPP—for example, long-term storage of TRU wastes at the sites of generation—should be chosen for management of TRU wastes. The Agency continues to believe that deep geological burial is a promising strategy for the disposal of radioactive waste. But, in any case, the question of whether acceptable alternatives to the WIPP exist, or whether other approaches might be preferable, lies outside the scope of EPA's review. Under the statute, DOE may place untreated mixed waste in the WIPP repository if it can meet the statutory standards for no migration. Alternative approaches to deep geological burial are more appropriately addressed under the NEPA process.

D. EPA Oversight Over the Test Phase

Several commenters of EPA's proposed determination argued that EPA should assert direct oversight over the testing and experimentation during the test phase. For example, some commenters argued that, before any waste was placed in the repository, EPA should make a finding that in-situ testing at the repository was both necessary and sufficient. Others identified what they considered to be flaws in DOE's test plans—e.g., sealing the alcoves in the alcove-scale tests—and argued that EPA should not allow waste to be placed in the repository before those flaws were addressed.

Although EPA believes that DOE has generally laid out a reasonable test program for the WIPP, it disagrees with commenters who argue that the Agency must find, as part of today's determination, that DOE's test plans are necessary and sufficient. The question before EPA is whether there will be any migration of hazardous constituents beyond the unit boundary for as long as the waste remains hazardous, not whether alternatives to in-situ testing are available, or whether DOE's testing program has shortcomings. If DOE can demonstrate no migration for the test phase, which EPA concludes it has done, then it has met the statutory standard for placement of untreated hazardous wastes in the WIPP.

At the same time, the results of the test phase will be critical in review of a no-migration petition for long-term disposal at the WIPP, if DOE chooses to submit one. EPA, therefore, has put DOE on notice that data from the bin and alcove tests must be of good quality. For example, if the adequacy of alcove seals cannot be demonstrated, any data derived from the alcove tests will be of questionable value. Similarly, it is essential for the long-term finding that DOE adequately characterize test waste for RCRA constituents. Toward this end, EPA has described in some detail in section IV.B.7 of this notice the types and quality of data on waste characterization it expects to see in any petition for long-term disposal. However, for the reasons discussed above, the Agency has concluded that it is not appropriate to address the scope or details of DOE's test plans in today's decision—except insofar as they involve possible migration of waste from the disposal unit or the retrievability of the waste.

E. Site Suitability

In reaching its proposed determination, EPA reviewed more than 300 studies of the WIPP site, not only by DOE and its contractors, but also by independent researchers and groups such as the U.S. Geological Survey and the Environmental Evaluation Group. The overwhelming conclusion that EPA drew from these studies is that the WIPP has been located in a remarkably stable formation, and that it is a promising site for the permanent disposal of radioactive waste. Although there remain some questions about the site, which DOE will be addressing during the test phase, EPA expressed its conclusion that the site was sufficiently well characterized for the test phase to proceed. Thus, EPA agreed with the National Academy of Sciences and DOE's Blue Ribbon Panel that it makes sense to begin testing in the WIPP repository as soon as regulatory requirements are satisfied.

Several commenters on the petition, however, raised issues associated with the suitability of the WIPP site. Commenters, for example, expressed concern about the possibility of karst formation in the vicinity of the WIPP site and the general role of dissolution processes in the area; the assumed existence of a pressurized brine pool below the repository; and the rate of brine inflow into the repository. These issues are discussed briefly below and are addressed in more detail in EPA's Response to Comment document for this rulemaking.

A number of commenters expressed concern that the WIPP landscape had the characteristics of a karst terrain. A karst terrain is a kind of topography that is typically formed over limestone, dolomite, or gypsum through dissolution processes; it is usually characterized by closed depressions or sinkholes, caves, and underground drainage. The implication for the WIPP, according to commenters, is that contamination from the repository if it reached the overlying Rustler formation, could be transported rapidly to the accessible environment. Commenters also suggested that ground water in overlying karst formations might attack the repository shaft seals, after closure, and enter the Salado Formation—the salt bed in which the WIPP repository has been constructed. This might lead to dissolution of the halite, allowing a potential pathway for migration past the unit boundary.

The commenters argument that the WIPP area is karstic is based primarily on the presence of several acknowledged and alleged dissolution features in the WIPP area. These include sinkholes in Nash Draw, several kilometers from the WIPP site; dissolution features identified in the WIPP 33 drill hole, just outside the site boundary; and "Barrows Bathtub," a depression about one kilometer from the proposed underground disposal area. Such features, according to commenters, demonstrate that the WIPP site is found in a mature karst area and that wastes can be expected to leak from the WIPP shortly after closure.

As a result of commenters' concerns, EPA reevaluated the question of karst in reaching its final decision. This reevaluation included a field investigation of the WIPP site, in the company of one of the commenters. The tour covered the most important features that the commenters believed were karstic in the vicinity of the WIPP. The closest of these was approximately one kilometer from the surface buildings at the facility. On the basis of this review, EPA has concluded that karst is not now an issue at the WIPP, and is unlikely to become one for many thousands of years, if ever.

EPA recognizes the presence of some localized, surface dissolution features in the general area of the WIPP, particularly in Nash Draw. This is not surprising, given that the geologic units within the area are composed of rock that would be susceptible to dissolution under the correct hydrologic and geochemical conditions. However, evidence suggests that these are ancient features and that current rates of dissolution are extremely slow. For example, dissolution rates at the Nash Draw have been estimated at one-third of a foot every one thousand years, rates that would not threaten the WIPP repository for millions of years. In addition, the widespread occurrence of caliche—a surface feature indicating arid conditions and limited surface dissolution—in the WIPP area suggest the stability of the surface landscape over at least the last 10,000 years. At the same time, borings drilled at and near the WIPP site have failed to encounter solution channels indicative of a karst environment. Finally, it should be noted that the Salado Formation lies 260 meters below the surface, shielded by relatively impermeable rocks. Thus, the repository horizon is isolated from any ongoing dissolution process. The fact that the Salado Formation in the area of the WIPP has remained largely unaffected by dissolution processes over its 225-million-year history is evidence of its stability.

Numerous commenters also expressed concern about the presence and possible effects of pressurized brine in the Castile formation underlying the Salado. One bore hole in the immediate vicinity of the repository—WIPP 12—encountered a large brine pocket in the Castile. Geophysical measurements suggest that this pocket extends underneath the repository itself. Commenters expressed the concern that this brine might, in the long run, threaten the WIPP through dissolution processes or, if a bore hole were drilled at some future date through the repository into the brine pocket, pressurized brine might force contamination to the surface.

After reviewing the comments and other data in the record, EPA continues to believe that the brine pockets in the Castile formation—although they contain a substantial amount of fluid—do not offer a significant threat to the repository. Castile deformation, which led to the formation of the brine pockets, was initiated millions of years ago in association with major tectonic tilting of strata in the Delaware Basin. The region is tectonically inactive at present, implying that new development of major Castile features is not occurring. In addition, the brine pool is completely saturated with respect to halite and therefore has no potential to dissolve the surrounding host rock. Since the Castile and Salado Formations are hydrologically distinct, there is no credible hydrologic connection between the two formations. Finally, because of restrictions on access, there is no realistic possibility of a borehole reaching brine pockets below the repository during the test period. Therefore, this issue does not arise for today's determination. DOE's performance assessment, however, is addressing the possible effects of such a borehole after repository closure.

A number of commenters also expressed concern about the effects of brine inflow into the repository and the validity of permeability values used for the Salado Formation. EPA has reviewed the information pertinent to this discussion and believes that, while a good understanding of brine inflow into the repository exists, additional studies must be conducted to understand the true nature of brine inflow and to quantify inflow in a manner more indicative of facility conditions. These tests will be performed during the WIPP test phase. They will be important in any decision on the long-term acceptability of the WIPP site. Brine inflow, however, will not be a problem during the test phase and thus is not an issue for today's decision.

Finally, commenters expressed concern that DOE's petition and EPA's proposed decision did not fully address the long-term closure scenario expected at the repository. Commenters cited data predicting high rates of gas generation and argued that this gas might delay or prevent creep closure of the repository. As a worst case, gas generation exceeding lithostatic pressure might fracture surrounding salt or threaten the seal system of the repository. In fact, DOE, EPA, and other groups have recognized that the issue of gas generation, and its relation to repository performance, must be adequately addressed before permanent disposal of waste takes place at the WIPP. The major purpose of DOE's in-situ tests in the WIPP with actual wastes is to explore the issue of gas generation. Today's decision will allow these tests to proceed. The Agency believes that the end of the test phase is the appropriate time for it to make a determination of whether the repository is or is not suited for long-term disposal, since the results of the experiments performed during the test phase will help quantify gas generation rates, as well as identify different mitigative measures if the rates prove unacceptable.

F. Conditional Determination

Several commenters took issue with EPA's "conditional" approach in its proposed decision. EPA's proposed determination was based on: (1) The finding that hazardous constituents would not migrate from the disposal unit during the test period, and (2) the requirement that DOE remove the waste at the conclusion of the test period unless it could demonstrate that there would be no migration over the long-term. According to commenters, this approach is inconsistent with the statute, which requires a finding that hazardous constituents will not migrate from the unit as long as the waste remains hazardous. The commenters argued that, under the statutory standard, DOE should be required to demonstrate that hazardous waste permanently place in the repository would not migrate from the unit before DOE could place any waste underground, even temporarily. EPA, however, continues to believe that its proposed approach is consistent with the statute and has not amended its finding.

As commenters point out, RCRA specifies that hazardous constituents must not migrate from the unit for as long as the waste remains hazardous. The phrase "from the unit" is a key element of this standard. If the waste is removed from the unit at the end of the test period, migration of hazardous constituents from the unit after that time is clearly impossible, because there are no longer any hazardous constituents in the unit to migrate. Consequently, in the case of temporary placement, for example during the WIPP test phase, the appropriate question is whether hazardous constituents will migrate during the period of temporary placement. (As discussed elsewhere in today's notice, EPA has concluded that hazardous constituents will not migrate from the unit during the test phase.) At the same time, of course, it is important to see that removal at the end of the test period is reasonably assured. EPA judge DOE's no-migration petition for the WIPP on these grounds. (See Section V.G for discussion of this point.)

One group of commenters argued further that, if EPA were to continue with its "conditional" approach, it should review DOE's test plan to ensure that in-situ testing at the WIPP was necessary to demonstrate long-term no migration and that the specific tests to be conducted would be sufficient. Although EPA has commented on DOE's test plan, EPA disagrees with these commenters on the type of EPA review that is necessary. On the basis of its review, EPA has concluded that DOE's test plan is well designed and the testing will yield important information on the long-term performance of the repository. EPA, however, has not and believes that it should not formally analyze DOE's in-situ testing at the WIPP to determine whether it is necessary of sufficient, and it does not believe such an analysis is within the scope of a no-migration review. As long as DOE can demonstrate that hazardous constituents will not migrate from the disposal unit, it is legally entitled to place prohibited waste in the WIPP. There is nothing in the statute that further compels a petitioner to demonstrate that placement in the unit is "necessary."

G. Definition of No Migration

Sections 3004 (d)(1), (e)(1), and (g)(5) of RCRA state that land disposal is prohibited, unless "it has been demonstrated to the Administrator, to a reasonable degree of certainty, that there will be no migration of hazardous constituents from the disposal unit or injection zone as long as the waste remains hazardous." In its proposed no-migration decision on the WIPP, EPA adopted the same interpretation of this standard as it had in its no-migration regulations for underground injection wells; that is, the Agency interpreted the standard to prohibit the migration of hazardous constituents in concentrations high enough to render the waste hazardous. (See 53 FR 28122, July 26, 1988.) Critics of this approach argued that Congress clearly meant that not a single molecule of a hazardous constituent could migrate from the unit, as long as the waste remaining in the unit was hazardous. Under this standard, DOE's WIPP no-migration petition could not have been approved, because at least some molecules of volatile organics listed as hazardous constituents will migrate via the air route during operations—although most likely at several orders of magnitude below levels of detection.

In today's decision, EPA is retaining its proposed definition of "no migration" of hazardous constituents. As explained in detail in the preamble to the proposed decision, EPA believes that this approach is fully consistent with the language of the statute and is protective of human health and the environment. EPA also notes that its interpretation of "no migration" was recently upheld in a decision on the underground injection well rules by the U.S. Court of Appeals for the District of Columbia. (*NRDC* v. *EPA* No. Slip. Op. (D.C. Cir. 1990).) In this decision, the Court accepted EPA's argument that "no migration of hazardous constituents * * * for as long as the waste remains hazardous" may be read to mean no migration of constituents above hazardous (or health-based) levels. As a result, EPA has decided to retain the same standard in its final decision on the WIPP petition.

H. Definition of Unit Boundary

In today's finding, EPA has slightly modified its definition of the disposal unit boundary in response to public comments. In the proposal, EPA defined the unit boundary (or point of compliance) for groundwater migration as the Salado Formation, laterally bounded by the limits of the four-mile by four-mile land withdrawal area. For air emissions during operations of the WIPP, EPA defined the unit boundary as the point where the air shaft met the surface.

Numerous commenters expressed concern about the extent of the unit boundary for groundwater, arguing that it might allow broad areas of contamination underground; they objected to EPA arguing that there would be no migration from the unit even if the hazardous constituents moved up to two miles laterally. Several commenters suggested that the unit boundary in no case should be greater than the mined repository, and should probably be less. One group of

commenters also pointed to what they believed was an inconsistency between the unit boundary for air and for groundwater. They argued that the unit boundary should be the same in both cases and that the unit boundary for air, therefore, should be no farther than the top of the Salado. After reviewing these comments, EPA has decided to retain its definition of the lateral boundary of the unit (i.e., the boundary of the land withdrawal area within the Salado Formation), but to define the boundary for air emissions as the top of the Salado Formation.

EPA has rejected commenters suggestion that the unit boundary be defined as the mined area (or some smaller area). As the Agency explained in detail in its proposed finding, it believes that, in the context of a geological repository, some credit should be given for the surrounding formation in which a waste is placed. The purpose of placing waste in a geologic repository is to isolate it from the general environment; it is not to prevent any movement of waste, however slight, within that formation. In fact, some lateral movement of waste into the surrounding formation can be an inevitable, and desirable, aspect of repository performance—as it is in the case of the WIPP. A no-migration standard that prohibited any lateral movement would run counter to the concept of a geological repository, without providing for any additional environmental protection or protecting against any meaningful release.

In taking this general position, EPA believes that it is being consistent with the intent of Congress, for example as expressed in the Senate Report on the 1984 HSWA amendments: "In determining appropriate confinement from which migration shall not be allowed to occur, the term disposal unit or injection zones should be construed * * * in terms of the overall integrity of the disposal practice, keeping in mind, in particular, the potential for contamination of ground-water or surface water resources" (S. Rep. No. 284 98th Cong. 1st Sess. at 15). Wastes confined to the boundaries of the unit, as defined in EPA's final determination, would remain more than 1,000 feet from the nearest unconfined ground water. EPA also notes that its position is consistent with the recent court decision on its no-migration rules for underground injection wells. (*NRDC* v. *EPA* No. Slip. Op. (D.C. Cir. 1990).) In this decision, the court supported EPA's position that the term injection zone (which for underground injection wells is analogous to the unit) includes confining material surrounding the porous formation into which the waste is actually injected. Similarly, EPA believes it is appropriate to consider at least a portion of the confining salt at the WIPP as part of the unit.

Critics of EPA's proposed definition of the WIPP unit suggested no alternative boundaries, other than somewhere within the furthest extent of the mined area. As discussed above, EPA has rejected this alternative. In the absence of any rationale for an intermediate boundary between the mined area and the proposed boundary, EPA has decided to retain the proposed approach. EPA emphasizes that the WIPP unit, under this definition, is fully isolated from the surrounding environment. If waste remains within the unit boundary, no meaningful movement of waste will have occurred, and no contamination of ground-water resources will result. Further, although there will undoubtedly be some lateral migration of contaminated material along marker beds within the salt formation, all projections indicate that this migration will be very limited, in no way approaching the boundaries of the unit. (The most likely route of migration, instead, would be up the closed shafts to overlying formations.) Therefore, extensive underground movement of waste is not expected, regardless of the definition of unit.

In the case of air migration, EPA recognizes that its proposed definition caused some confusion. To address commenters' concerns, EPA has amended the unit definition for air during operations, placing the boundary at the top of the Salado Formation. The issue of where DOE should monitor to demonstrate compliance at that point, however, is a different question. (See section IV.B.6 for a discussion of this point.)

I. Waste Characterization

1. Flammability

In evaluating the potential for release of hazardous constituents in its proposed decision, EPA considered the potential for fire and explosion at the WIPP. The Agency noted that the Waste Acceptance Criteria (WIPP-WAC) prohibits explosives and compressed gases in TRU Wastes and requires that pyrophoric materials be rendered safe by mixing them with chemically stable materials, such as concrete or glass, or be processed to render them nonhazardous. In addition, the Nuclear Regulatory Commission requires that all waste containers be equipped with one or more carbon composite filters designed to prevent pressure buildup or the accumulation of flammable gases prior to shipment to the WIPP, as specified in "TRUPACT-II Authorized Methods for Payload Control" (TRAMPAC).[14] EPA suggested that these requirements, in conjunction with the maintenance of general ventilation in the underground repository, make the possibility of fire or explosion extremely unlikely.[15]

EPA continues to believe that a fire or explosion is unlikely. It acknowledges, however, the concerns of commenters that flammable gases could build up in waste containers, creating a fire and explosion hazard. The Agency has reanalyzed the available information and has concluded that the accidental ignition of flammable gases in waste containers cannot be ruled out, given the available data on waste characterization. At the same time, EPA has concluded that spontaneous combustion within an individual waste container, i.e., without an ignition source, is not credible.[16]

Were a fire or explosion to occur as a result of accidental ignition of flammable gases in the void space of a waste container, retrieval could become more difficult, should retrieval be necessary. Moreover, such an event could itself cause migration of hazardous constituents above health-based levels beyond the unit boundary. For these reasons, EPA has concluded that no waste container should be emplaced in the underground repository if it contains flammable mixtures of gases in any layer of confinement, or mixtures of gases that could become flammable when mixed with air. To assure a sufficient margin of safety, EPA considers any mixture to be potentially flammable if it exceeds 50 percent of the lower explosive limit (LEL) of the mixture in air.

EPA, consequently, is requiring DOE to ensure that individual waste containers have met the prohibition of flammable gases. DOE must implement this provision by testing each waste drum or individual container for hydrogen, methane, and volatile organic compounds (VOCs) as a class. EPA is

[14] The Agency notes that TRAMPAC also sets limits on the thermal wattage, i.e., decay heat of individual waste containers to control the rate of generation of hydrogen gas by radiolysis (DOE, *Safety Analysis Report for the TRUPACT-II Shipping Package, Appendix 1.3.7 revision 2, June 1989*).

[15] The Agency notes that the WIPP-WAC also place restrictions on the total quantity of fissile material in a waste container to ensure criticality safety.

[16] See the conclusions in the Sandia National Laboratory memorandum from Sieszak and Lappin to Marcer and Fredrickson, January 5, 1990.

establishing this condition because it does not judge available process knowledge to be sufficiently reliable or accurate to allow a determination on the flammability hazard of individual waste packages.

EPA recognizes that headspace testing of every drum or individual container on a continuing basis may pose a significant burden on DOE. Without sufficient data, however, EPA feels compelled to require that DOE conduct testing, given the potential consequences of a fire or explosion. Once sufficient data have been collected, however, EPA will consider the extent to which continued testing is necessary. Test data may well show that flammable gases are only present at levels well below the lower explosive limit, either for certain wastes (e.g., TRUCON content code or item description code) or from particular generating sites. If the test data in fact show that no fire or explosion hazard exists, DOE should submit the data to EPA and request that the testing requirement be modified accordingly. Any change in the terms of this condition will be made under the procedures of 40 CFR 268.6(e), which include public notice and opportunity for comment.

EPA is also requiring that headspace sampling be representative of the entire void space of the waste container. Initially, the Agency believes that each individual layer of confinement within the container will have to be sampled, given the limited data available for inner bags. EPA, however, expects that once DOE accumulates enough data, it may be able to show that for most package configurations in which bags are twisted and taped, similar levels of flammable gases will be found in all layers of confinement.[17] However, it is anticipated that the occurrence of detectable quantities of free liquids, as determined by real-time radiography of visual inspection, will continue to indicate the need to sample the layer in which it occurs, unless DOE can demonstrate otherwise.

EPA also believes that testing of wastes that exhibit high rates of radiolysis should be conducted within a relatively short time period of when the container is actually placed underground. Otherwise, hydrogen levels could build up to flammable levels following sample collection and analysis. DOE has accumulated considerable data on radiolysis rates for various materials in TRU wastes. DOE used such data in its application to the Nuclear Regulatory Commission for a certificate of compliance for the TRUPACT-II shipping package to determine the length of time a waste drum must aspirate (i.e., vent) before it can be shipped after retrieval from storage.[18] Similarly, EPA is requiring DOE to determine, and document, the length of time during which headspace gases can be expected to remain below flammable levels (i.e., 50 percent of the mixture LEL) after sampling has been performed, for both newly generated and retrievably stored wastes, and to ensure that waste containers are emplaced at the WIPP within that time.

If testing reveals the presence of significant levels of flammable VOCs, an explicit flame test must be performed to determine if a flammable mixture can be formed with air. American Society for Testing and Materials (ASTM) Method E 681-85, "Concentration Limits of Flammability of Chemicals," or equivalent, are acceptable test methods. Significant levels of flammable VOCs are indicated by measured concentrations (excluding methane) of 500 parts per million or greater, as propane, as determined by gas chromatography and flame ionization detection (GC/FID) or of 300 parts per million or greater, by volume, as determined by gas chromatography and mass spectrometry (GC/MS.)[19] If testing shows that VOCs are insignificant, i.e., below 500 parts per million, the lower explosive limit of the mixture may be determined from the lower explosive limits of methane and hydrogen using the Le Chatelier formula as follows: If LEL_1 and LEL_2 are the lower explosive limits of hydrogen and methane, respectively, and C_1 and C_2 are the measured concentrations of hydrogen and methane, respectively, expressed as volume percent, then if the fraction, C_1/LEL_1 and C_2/LEL_2 sum to 0.5 or greater, the mixture is considered to be flammable when mixed with air.[20]

2. RCRA Constituents

In its proposal, EPA expressed some concern with the quality of the waste characterization data provided by DOE in support of its petition. However, given the nature of the wastes, the safety margins between predicted emission levels and health-based levels, and required controls on air emissions, EPA concluded that the information provided by DOE (based primarily upon process knowledge) was sufficient to demonstrate, to a reasonable degree of certainty, no migration of hazardous constituents during the test phase. Many commenters, nevertheless, criticized the quality and completeness of DOE's waste characterization information and DOE's approach to waste characterization. Several commenters noted the critical role played by waste characterization in the prediction of no migration and stressed that EPA needed accurate waste descriptions, supported by detailed analysis, to evaluate the potential evironmental impacts of waste disposal. In responding to these comments, EPA has differentiated between short-term issues (relevant to today's decision for the test phase) and long-term issues (relevant to a decision for the operational and post-closure phases, should DOE submit a petition for these phases).

a. *Short-term issues.* Many of the commenters expressed concern with the Agency's acceptance of waste characterization data based primarily upon process knowledge. Commenters stated that, in the case of the WIPP, waste characterization requirements have not been met.

EPA disagrees with the commenters' position that DOE's waste characterization information is insufficent for a no-migration determination for the test phase. DOE's analysis of the wastes incuded an evaluation of the materials and processes from which the wastes were generated as well as actual chemical analysis of the wastes. In the former case, DOE provided flow diagrams and narrative descriptions of the processes that generated all 128 of the identified waste Content Codes as well as an identification of the RCRA hazardous constituents used in the process. DOE also provided estimated concentrations for each of the hazardous constituents expected in the wastes. This was designed to be a conservative characterization, in which it was assumed that any hazardous constituents that were used in a process would be present in the resulting waste stream, regardless of known physical

[17] EPA notes that DOE intends to open up and disassemble the drums selected for the bin-scale tests for visual inspection. Therefore, this requirement should not increase radiation exposure to workers.

[18] DOE, *TRUPACT-II Content Codes (TRUCON)*, DOE-WIPP 88-004, Revision 3, July 1989, and DOE, *Safety Analysis Report for the TRUPACT-II Shipping Package*, Appendix 1.3.7, Revision 2, June 1988.

[19] For purposes of determining concentration levels using GC/MS, only noncombustible compounds may be excluded from the sum total of non-methane VOC, e.g., carbon tetrachloride, tetrachloroethylene, chloroform, and bromoform.

[20] The lower explosive limits of hydrogen and methane are 4.0 and 5.0 percent, respectively, in air (Bureau of Mines, "Flammability Characteristics of Combustible Gases and Vapors," Bulletin 627, 1966).

processes that would reduce the likelihood that the constituents would in fact be present (e.g., volatilization). EPA notes that no comments were received indicating that wastes from the processes described by DOE would be expected to be compositionally different from the DOE-estimated compositions.

The bulk of the analytical data presented by DOE to corroborate the conclusions of the above-described characterization were focused on the only viable route of release during the test phase—namely, through the air. For this characterization, DOE provided results from over 200 headspace analyses, representing all four of the identified waste types; these samples were analyzed for numerous gases, including nine organics. Other analyses for which results were reported included Toxicity Characteristic and Extraction Procedure leaching tests, total volatiles, and total metals. While these analyses were not typically conducted on all four of the waste types, EPA notes that these tests are not directly relevant for characterizing the most likely route of release during the period that is subject to today's decision (i.e., the test phase).

Additionally, EPA in its proposal considered the "safety margin" indicated by calculations of air emissions. That is, even if the concentrations of hazardous constituents were significantly underestimated, the no-migration standard would still be met during the test phase.[21] Additional assurances are provided by the air monitoring systems that will be operated to allow detection of emissions. Based upon the safety margin indicated by these factors, the Agency concludes that the level of waste characterization is acceptable for the test phase. Nevertheless, to ensure that the wastes to be used in the bin-scale tests are similar in composition to those described in the no-migration petition, EPA is requiring that DOE test the headspace of the wastes shipped to the WIPP (as a measure of the waste constituents' propensity to migrate through air) and compare the results to the values provided in DOE's no-migration petition. This comparison must be conducted and the waste must be found to be compositionally similar before the waste can be sent to and emplaced in the WIPP; if the waste is not similar to the estimated concentrations provided in the no-migration petition, the waste cannot be shipped to the WIPP unless it is modified compositionally, such that it is compositionally similar. The details of this comparison are described in section IV.B.7.b of today's notice.

Other commenters stated that, to the extent that DOE has provided any laboratory analysis of wastes intended for the WIPP, it is solely headspace analysis (i.e., analysis of the constituents' concentrations in the air under the lid of the drum) used as a surrogate for the waste in the drum. These commenters maintained that headspace analysis, while extremely useful for homogeneous phases, is limited, at best, for analyzing heterogeneous wastes such as those intended for the WIPP. In the opinion of these commenters, headspace analysis is unreliable as a surrogate for direct analysis of liquids and solids in drums due to uneven partitioning of constituents.

The Agency recognizes that there are limitations on the utility of headspace analysis as a surrogate for analysis of waste composition. Certainly headspace analysis is not appropriate for all evaluations for all waste types. In some cases, however, headspace analysis is the most relevant measurement. For purposes of the test-phase determination, headspace analysis is primarily used in the evaluation of gas generation and explosivity hazards. Since it is the composition of the gas that is of concern, analysis of the headspace (*i.e.*, the actually evolved gas) is the most appropriate parameter to consider. If concentrations in the waste were used for the explosivity evaluation, the composition of the evolved gas would be modeled, or predicted, rather than actually measured.

EPA agrees with the commenters' concerns regarding the validity of a single headspace sample (under the lid) as representative of potentially evolved gases from heterogeneous wastes. This is especially problematic when the drums contain several inner layers of confinement, as do the drums that will be emplaced in the WIPP. Specifically, questions exist as to whether the headspace beneath the lid is compositionally different from the headspace in the inner layers. EPA is addressing this issue in the context of the testing condition related to headspace analysis. In that condition, EPA is requiring that DOE take representative samples of the headspace (which may require, in some cases, for DOE to take samples from inner bags) and analyze them to confirm its assertion that the headspace beneath the lid is, in fact, representative of the total evolved gas within the drums.

EPA also agrees that headspace analysis is not a suitable surrogate for direct analyses of the waste for purposes of evaluations where the total composition is a factor. However, for volatile organic constitutents, EPA believes that headspace analysis can be a useful tool for determining whether the constituents are present. That is, if a volatile constituent is present in the waste, it is reasonable to assume that it will also be present in the headspace. Accordingly, results from headspace analyses were used to confirm the presence of volatile hazardous constituents, not to quantify their concentrations in the wastes.

Several commenters argued that DOE's quality assurance/quality control of waste characterization data was deficient. Others noted that DOE had been unable to provide adequate sampling plans and sample handling procedures for analytical work. EPA raised similar concerns with DOE's procedures, but, for the reasons described in the proposal and further elaborated upon above, the Agency has concluded that the data are sufficient for the test phase demonstration. At the same time, EPA advises DOE that it expects additional analytical data to support a long-term demonstration, where significantly greater quantities of waste are involved and routes of possible migration are not limited to release of volatiles to the air during operations.

b. *Long-term issues.* EPA notes that the "safety margin" for the long-term showing (*i.e.*, the operational and post-closure phases) has not been determined. For that reason, the Agency believes that additional waste characterization data are needed to reduce the uncertainties before a decision on a long-term no-migration determination can be made. EPA, however, has decided not to make such testing a condition of today's decision, because the collection of such data is not relevant to the decision during the test phase; EPA, however, expects DOE to develop and implement waste characterization plans, including appropriate sample collection, preservation, and analytical procedures, that will allow a demonstration of the extent to which the test phase wastes are representative of the other wastes from the ten generating sites and that allows greater precision in estimating potential for long-term migration (*e.g.*, through routes such as ground water). If such data are not collected, EPA will not be in a position to approve a no-

[21] The safety factor assumes that an explosivity hazard is not present. To ensure against such a hazard, EPA placed an additional condition on the decision (see section IV.B.7).

migration petition for the operational and post-closure phases, if DOE submits such a petition. EPA's expectations related to these data are presented in Section IV.B.7.b of today's notice.

Many commenters expressed concerns regarding the extent to which the wastes that will be used for the test phase are representative of the other wastes that DOE wishes to emplace at the WIPP during the operational phase. It was stated by many commenters that, for the test phase, adequate waste characterization is vital to assure that tests will be performed on representative wastes. Commenters pointed out that almost 70 percent of the wastes proposed for storage do not yet exist. They asked what controls and safeguards were in place to ensure that these future wastestreams are adequately represented by existing wastes.

The Agency agrees with commenters' concern that the use of representative wastes in the test phase will be critical to the success of any DOE no-migration petition for the later (operational and post-closure) phases. More specifically, the test-phase wastes must be sufficiently representative of the other wastes that DOE wishes to emplace at the WIPP to allow extrapolation of data from the test-phase experiments to the behavior of the other wastes.[22] This issue is, in fact, the basis for the selection of wastes that will be used in the test phase experiments. The selection process will be based upon those parameters that contribute to gas generation and is designed to identify wastes that represent the spectrum of expected values for those parameters. Since waste selection and characterization, as part of the design of the experiments, is the responsibility of DOE, EPA believes that it is DOE's responsibility to establish and implement procedures to demonstrate that the wastes are, in fact, sufficiently representative.

Many commenters also argued that EPA's proposed decision did not clearly establish whether all waste analysis data would be provided to EPA prior to emplacement of any waste or whether the data would be provided incrementally as waste is being emplaced. These commenters stated that they had serious concerns if the Agency is proposing to allow DOE to provide waste analysis data simultaneously with waste emplacement. They argued that waste analysis should be provided to the Agency not only before the waste is put into the ground, but before EPA can make a decision about a no-migration variance. They believed that this condition would allow EPA independently to asses the quality of the data. In the opinion of some commenters, delivering waste analysis information while the waste was "nding the Carlsbad elevators" would essentially render EPA's independent technical review of the data inconsequential.

EPA is not requiring that DOE submit the analytical data on the test waste for EPA review before the test wastes are emplaced. Much of the analytical work to be conducted by DOE is related to the eventual demonstration of no-migration over the long term. Since EPA will evaluate these data as part of any subsequent petition for the later phases, EPA disagrees with the commenters' statement that this evaluation will be "inconsequential." Rather, it will be a critical element of that evaluation.

EPA, however, is requiring DOE during the test phase to evaluate headspace data before waste is placed in the repository, as described earlier. For example, DOE must evaluate the explosivity-related testing before shipping test wastes to the WIPP. Similarly, DOE must compare the analytical results of newly conducted headspace analyses to the waste characterization data in the no-migration petition before the waste is emplaced in the underground repository. Because the standards for both the flammability and the RCRA constituent analyses are objective and straightforward, EPA does not believe that Agency review of the data before placement is necessary.

The flammability and RCRA constituent requirements, described in detail in section IV.B.7, will address many of the commenters' concerns with the accuracy of the data. These requirements will also ensure that the wastes emplaced during the test phase are, in fact, the wastes characterized by DOE in the petition and evaluated by the Agency and the public.

J. Retrievability

Commenters also raised concerns about whether waste would ever be retrieved from the WIPP if it were placed in the repository, regardless of the technical feasibility of retrieval. Some questioned DOE's commitment to retrieval, even if the WIPP site proved unacceptable. Others argued that, even if DOE were willing to remove the waste, no other site would accept it, and therefore the waste would not be retrieved. Several commenters argued that DOE should identify a permitted site ready to receive retrieved waste before any waste should be allowed underground.

EPA believes that it has placed adequate safeguards in today's determination to ensure that DOE in fact removes the hazardous waste from the repository, if it cannot demonstrate the repository's long-term acceptability. Condition 3 in Section VI of today's determination explicitly requires retrieval of wastes if DOE cannot demonstrate compliance with the standards of 40 CFR Part 268 before the expiration of the petition approval. Failure on the part of DOE to remove wastes under these circumstances would constitute a violation of the terms of EPA's determination, leading to possible enforcement action by EPA. In addition, citizens could sue DOE under section 7002 to enforce retrieval of waste from the repository.

Because of this condition, EPA has not found it necessary to require DOE to identify a specific site where waste retrieved from the WIPP would be stored, or to require that a permit be granted for storage of retrieved waste before any waste is placed underground. Furthermore, EPA questions whether any such condition would be useful, given that wastes would probably not be removed (if removal proved necessary) for a five-to-ten year period. Current predictions on the best storage site for the waste up to ten years in the future would be at best open to question, and valuable permitting resources would be expended on a site that might never receive the waste.

K. Human Intrusion

Commenters generally accepted that DOE could maintain institutional controls over the test period to preclude human intrusion. One group of commenters, however, argued that EPA must consider the possible effects of human intrusion in the distant future before allowing the placement of any waste for testing. These commenters expressed particular concern about potential mineral resources at the WIPP site, and the possibility that knowledge of the site would disappear after decommissioning. Other commenters argued that permanent markers should be erected at the WIPP site once the facility is closed, and information regarding the type and location of the markers should be published.

[22] It should be noted that, if one or more wastes that are generated at any of the DOE sites are not "represented" by the test wastes, these wastes should not be sent to the WIPP without further evaluation. However, this would not invalidate the testing for all other wastes that are generated at the ten DOE sites and are represented by the test wastes.

EPA generally believes that the issue of human intrusion is a long-term question, not relevant to the short-term operation of the WIPP during the test and operational phases. In the short-term, DOE management of the site and RCRA permit controls will ensure limited access. Long-term issues would be addressed at the time a petition is considered for permanent disposal. For this reason, EPA disagrees with commenters who argue that it must consider human intrusion in the distant future before allowing any testing at the WIPP.

More generally, EPA believes that, in the context of RCRA no-migration decisions, it should address the question of human intrusion by considering the likelihood of the intrusion, and imposing controls to make such intrusions unlikely. EPA agrees that permanent markers will be necessary (in fact, they are required under 40 CFR part 191 subpart B) and that information on the markers should be published. These issues will be addressed in any no-migration decision allowing permanent disposal.

In its final determination, EPA has removed one proposed condition related to human intrusion. In the proposal, EPA required that "DOE certify to EPA that it has secured control of the entire surface and subsurface estate at the WIPP site." This condition is now moot, because DOE has now secured control over all oil and gas and mineral leases at the site. EPA has placed documentation of this fact in the record for this rulemaking. Thus, because the condition has been satisfied, EPA has dropped it from its final determination.

VI. Conditions of No-Migration Determination

As a condition of granting DOE's no-migration petition, EPA is requiring that the following conditions by met by DOE:

(1) No wastes subject to this determination may be placed in the WIPP repository for purposes other than testing or experimentation to determine the long-term acceptability of the WIPP. In accordance with 40 CFR 268.6(e), DOE must notify EPA before it conducts any testing or experimentation not within the scope of the "WIPP Test Phase Plan: Performance Assessment," April 1990 (DOE/WIPP 89-011, Revision 0), as further explained in Section IV.B.1 of this notice. Placement of waste for the purpose of conducting an operations demonstration is prohibited.

(2) Wastes placed in the repository may not exceed 8,500 drums or 1 percent of the total capacity of the repository, as currently planned.

(3) All wastes placed in the WIPP must be removed if DOE cannot demonstrate compliance with the standards of 40 CFR 268.6, before the expiration of this petition approval, with respect to permanent disposal of mixed waste in the repository. DOE must submit a detailed schedule for retrieval of the waste, including times for completing retrieval as quickly as reasonably feasible, no later than six months after a determination that the repository cannot meet standards for long-term disposal under 40 CFR 268.6 or six months before the expiration of this petition approval, whichever occurs first.

(4) All wastes placed in the WIPP must be placed in a readily retrievable manner, as described in section IV.B.4 of this notice.

(5) DOE must install and operate a carbon adsorption device designed to achieve a control efficiency of 95 percent in the discharge system of the bin experiment rooms. DOE must monitor the control device outlet airstream in accordance with the monitoring plan described in section IV.K of EPA's proposed decision (55 FR 13089) as amended by section IV.B.7 of today's notice, and it must maintain design and operating records as described in section IV.J of EPA's proposed decision, as amended by section IV.B.6 of today's notice. Records must be maintained at the WIPP facility for the term of this determination or for three years after they are created, whichever is longer. Records must also be maintained during the course of any enforcement actions for which they are relevant.

(6) DOE must implement the air monitoring plan described in section IV.K of EPA's proposed decision (55 FR 13089), as amended in section IV.B.7 of today's notice. Records must be maintained at the WIPP facility for the term of this determination or for three years after they are created, whichever is longer. Records must be maintained during the course of any enforcement action for which they are relevant.

(7) Conditions relating to waste analysis:

(a) DOE must ensure that each waste container emplaced underground at the WIPP has no layer of confinement which contains flammable mixtures of gases *or* mixtures of gases that could become flammable when mixed with air. This prohibition must be implemented by analytical testing of a representative sample of headspace gases from each waste drum or individual container, as described in section IV.B.7.a and V.F.1.a of today's notice.

(b) DOE must analyze representative samples of the headspaces of containers to be used in the bin-scale test and compare these results to the estimated compositions provided in its petition for each waste type, as detailed in IV.B.7.b of today's notice. If the waste is not compositionally similar, as defined in Tables 2 and 3 in IV.B.7.b, that waste cannot be shipped to the WIPP until the waste has been treated or modified such that it is compositionally similar to the estimates provided in the no-migration petition. In addition, as prescribed in IV.B.7.b, DOE must demonstrate the comparability of bin-scale wastes to wastes described in DOE's petition before placing waste in the WIPP for the alcove tests.

(c) Waste analysis records must be maintained for the term of this determination or for three years after generation, whichever is longer. Records must also be maintained during the course of any enforcement action for which they are relevant. The records may be maintained at the generating site or at the WIPP facility.

(8) DOE must provide to the EPA Office of Solid Waste and EPA Region VI annual written reports on the status of DOE's performance assessment during the test phase. These reports must include: A description of the tests to date and their results, modifications to the test plan, a summary of DOE's current understanding of the repository's performance, waste characterization data from pre-test waste characterization, and an annual summary of air monitoring data required in Item 6 above.

Beyond these specific conditions, the wastes placed by DOE in the WIPP and DOE's activities under this variance must be consistent with those described in the petition. Under § 268.6(e), DOE must notify EPA of "any changes in conditions at the unit and/or environment that significantly depart from the conditions described in the variance and affect the potential for migration of hazardous constituents from the unit * * *." If the change is planned, EPA must be notified in writing 30 days in advance of the change; if it is unplanned, EPA must be notified within ten days.

Under § 268.6(f), if DOE determines that there has been migration of hazardous constituents from the repository in violation of part 268, it must suspend receipt of prohibited wastes at the unit and notify EPA within ten days of the determination. Within 60 days, EPA is required to determined whether DOE may continue to receive prohibited waste in the unit

and whether the variance should be revoked.

Finally, under § 268.6(h), the term of today's petition approval runs for ten years, that is until November 14, 2000.

Dated: October 31, 1990.

Don R. Clay,

Assistant Administrator for Solid Waste and Emergency Response.

[FR Doc. 90-26836 Filed 11-13-90; 8:45 am]

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PROPOSED DETERMINATION

APRIL 6, 1990

federal register

Friday
April 6, 1990

Part VII

Environmental Protection Agency

Hazardous and Solid Waste; Conditional Variance to Department of Energy Waste Isolation Pilot Plant; Notice of Proposed Decision

ENVIRONMENTAL PROTECTION AGENCY

[FRL-3753-3]

Notice Proposing To Grant a Conditional Variance to the Department of Energy Waste Isolation Pilot Plant (WIPP) From Land Disposal Restrictions

AGENCY: Environmental Protection Agency.

ACTION: Notice of proposed decision.

SUMMARY: The Environmental Protection Agency (EPA) is today proposing to grant a conditional no-migration variance to the U.S. Department of Energy (DOE). This variance would allow DOE to place hazardous waste subject to the land disposal restrictions of the Resource Conservation and Recovery Act (RCRA) in DOE's Waste Isolation Pilot Plant (WIPP) near Carlsbad, NM, for the limited purposes of testing and experimentation. DOE submitted a petition to EPA under 40 CFR 268.6 requesting a no-migration variance from the RCRA land disposal treatment standards on the grounds that treatment was unnecessary to protect human health and the environment because there would be no migration of hazardous constituents from the disposal unit. After a review of DOE's petition and supporting information, EPA has tentatively concluded that DOE has demonstrated, to a reasonable degree of certainty, that hazardous constituents will not migrate out of the WIPP disposal unit during the testing period proposed by DOE.

DATES: Comments on this proposed decision should be submitted on or before June 5, 1990.

EPA notes that it is providing the public a 60-day comment period on this proposed decision, which is longer than it generally provides for site-specific actions. For example, the Agency allows 30 days for comments on proposed no-migration variance decisions for underground injection wells, and 45 days for comments on RCRA permits. The Agency has provided extended time for comment on today's proposal because of the scope of the record, and because it is the Agency's first proposed decision on a variance request under 40 CFR 268.6. EPA, however, considers the extended comment period sufficient, and does not intend to grant any further extensions to the period.

Comments on today's proposal should be addressed to the docket clerk at the following address: U.S. Environmental Protection Agency, RCRA Docket (OS-305), 401 M Street, SW., Washington, DC 20460. One original and two copies should be sent and identified by regulatory docket reference number F-90-NMWP-FFFFF. The docket is open from 9 a.m. to 4 p.m., Monday through Friday, excluding Federal holidays. Docket materials may be reviewed by appointment by calling (202) 475-9327. Copies of docket materials may be made at no cost, with a maximum of 100 pages of material from any one regulatory docket. Additional copies are $0.15 per page.

A copy of the record supporting this proposal is also available to the public in Albuquerque, New Mexico, at the National Atomic Museum Library, Building 20358, Wyoming Boulevard, Kirkland Air Force Base, from 9 a.m. to 5 p.m., Monday through Friday; and in Carlsbad, New Mexico, at the WIPP Office and Information Center, 101 W. Greene Street, from 7:30 a.m. to 4:30 p.m.

Public hearings on this proposed decision have been scheduled for May 22, 1990, in Carlsbad, New Mexico, at the Park Inn International, 3706 National Parks Highway, beginning at 9:00 a.m., and for May 23 to 26, 1990, in Albuquerque, New Mexico, at the Albuquerque Convention Center, 401 Second St. NW. The hearing on May 23 in Albuquerque will begin at 1:00 p.m.; the hearing on subsequent days will begin at 9 a.m. Persons interested in testifying at either hearing should telephone 1-800-955-9477 to register. Requests to testify must be received by May 11, 1990.

FOR FURTHER INFORMATION CONTACT: General questions about the regulatory requirements under RCRA should be directed to the RCRA/Superfund Hotline, Office of Solid Waste (OS-305), U.S. Environmental Protection Agency, Washington, DC 20460, 800-424-9346 (toll free) or 202-382-3000 (local).

Specific questions about the issues discussed in this notice should be directed to Matthew Hale, Office of Solid Waste (OS-341), U.S. Environmental Protection Agency, 401 M Street, SW., Washington, DC 20460, at 202-382-4746.

SUPPLEMENTARY INFORMATION:

I. Background

A. RCRA Land Disposal Restrictions: No-Migration Variances

The Hazardous and Solid Waste Amendments (HSWA) of 1984, which amend the Resource Conservation and Recovery Act (RCRA), imposed substantial new requirements on the land disposal of hazardous waste. In particular, the amendments prohibit the continued land disposal of hazardous wastes, unless the wastes meet the treatment standards specified by EPA. "Land disposal" is defined to include placement "in a landfill, surface impoundment, waste pile, injection well, land treatment facility, salt dome formation, salt bed formation, or underground mine or cave" (RCRA section 3004(k)).

The statute requires EPA to establish treatment standards for wastes subject to the land disposal restrictions; these standards define when a hazardous waste may be land disposed. In its implementing regulations, EPA has established these standards based on the best demonstrated available technology (BDAT). The HSWA amendments also lay out specific dates by which the land disposal restrictions become effective, beginning with November 8, 1986, for solvents and dioxins. By May 8, 1990, restrictions will be in effect for all wastes that were listed or identified as hazardous before November 8, 1984, although EPA may extend the land disposal prohibition dates for up to two years if it finds a lack of national treatment capacity. EPA may also grant a 1-year case-by-case capacity extension, which can be extended once, in certain circumstances. Once the land disposal prohibition date for a specific waste has passed, that waste cannot be placed in a land disposal unit, unless it has been treated to meet or otherwise meets BDAT standards, or "unless the Administrator determines that the prohibition * * * is not required in order to protect human health and the environment for as long as the waste remains hazardous * * *" (RCRA sections 3004 (d)(1), (e)(1), and (g)(5).) This determination must be based on a demonstration by the facility owner/operator "that there will be no migration of hazardous constituents from the disposal unit or injection zone for as long as the wastes remain hazardous." (RCRA sections 3004 (d)(1), (e)(1), and (g)(5).) A determination under this authority is referred to as a "no-migration" variance; a request from a facility owner/operator for such a variance is called a "no-migration" variance petition.

The Agency first promulgated no-migration standards under 40 CFR 268.6 on November 7, 1986. These regulations, which apply to land disposal units other than underground injection wells, codify the statutory standard for no-migration variances, specify information to be included in variance petitions, and establish procedures for the granting or denying of a variance (November 7,

1986, 51 FR 40572).[1] EPA amended the regulations on August 17, 1988 (53 FR 31138), to add further procedural requirements and standards. EPA is now developing additional no-migration standards, including a generic definition of "no-migration," for land disposal units other than underground injection wells. The Agency expects to propose these standards in the near future. In conjunction with this proposal, EPA has also developed draft no-migration variance petition guidance, a copy of which is available in the docket for this rulemaking.

The current standards and procedures for no-migration variances (for units other than injection wells) are laid out in 40 CFR 268.6. Under this section, persons seeking a no-migration variance must submit a petition to the EPA Administrator "demonstrating, to a reasonable degree of certainty, that there will be no migration of hazardous constituents from the disposal unit or injection zone for as long as the wastes remain hazardous." Petitions must identify the waste and the specific unit that is the subject of the petition; provide waste analysis; characterize the unit, including background conditions; provide monitoring to confirm that no migration has occurred after the disposal has begun; and demonstrate compliance with other federal, state, and local laws.

Under 40 CFR 268.6, the Administrator must publish a tentative decision to grant or deny a no-migration variance for public comment in the Federal Register. EPA is required to publish final decisions in the Federal Register, after considering and responding to public comments. Variances may be valid for up to 10 years, but for no longer than the term of the facility permit. (Variances, however, may be reissued after their term has expired.) If petitions are granted, facility owners/operators must report changes in operating conditions from those described in the petition and notify EPA if hazardous constituents are detected migrating from the unit. If migration is detected, further disposal of wastes subject to the petition is suspended.

To date, EPA has received 24 no-migration variance petitions submitted in accordance with 40 CFR 268.6. Today's notice, which addresses disposal of mixed radioactive and hazardous waste in a mined salt bed, is the Agency's first proposed decision on any of these petitions. The other petitions submitted under § 268.6 primarily address land treatment operations. They are currently under Agency review. In addition, EPA has received approximately 65 no-migration petitions under 40 CFR part 148 for underground injection wells. Of these petitions, one has been granted final approval, several have been granted preliminary approval, and certain others have been withdrawn.

B. Regulatory Status of Mixed Wastes

The hazardous wastes that are subject to today's notice are "mixed wastes." Mixed wastes are defined as a mixture of hazardous wastes regulated under Subtitle C of RCRA and radioactive wastes regulated under the Atomic Energy Act (AEA). Because section 1004 of RCRA excludes "source," "special nuclear," or "byproduct material," as defined by the Atomic Energy Act from the definition of RCRA "solid waste," there has been some confusion in the past as to the scope of EPA's authority over mixed wastes under RCRA. EPA clarified this question in a Federal Register notice on July 3, 1986. EPA's clarification stated that the Section 1004 exclusion applies only to the radioactive portion of mixed waste, not to the hazardous constituents. Therefore, a mixture of "source," "special nuclear," or "byproduct materials," and a RCRA hazardous waste must be managed as a hazardous waste, subject to the requirements of RCRA subtitle C (that is, RCRA standards for management of hazardous waste). EPA's oversight under RCRA, however, extends only to the hazardous components of the mixed waste, not to the radionuclides themselves; the radionuclides (and any risks they may pose) are instead addressed under the AEA. DOE subsequently confirmed and clarified this interpretation in an interpretive rule, published in the Federal Register on May 1, 1987.

EPA's July 3, 1986 interpretation went into effect immediately in states not authorized to administer the RCRA hazardous waste program—that is, in the ten states and territories where EPA directly regulates hazardous wastes under federal RCRA regulations. At the same time, the July 3, 1986 notice informed authorized states that they are required to apply for and receive authorization from EPA to regulate mixed waste under RCRA. Until an authorized state has received mixed waste authorization, mixed waste is not considered to be hazardous under federal RCRA regulations in that state. To date, fourteen states or territories have obtained authority to regulate mixed waste under the state RCRA hazardous waste program, bringing the total to twenty-four states and territories where mixed wastes are subject to the RCRA hazardous waste requirements.

Mixed wastes, like other hazardous wastes, are subject to the land disposal restrictions. Treatment standards for mixed wastes containing solvents and dioxins—which are generally based on levels achieved through incineration—went into effect on November 8, 1986, and November 8, 1988. Disposal prohibitions for mixed wastes containing "California list" wastes went into effect on July 8, 1987. The remaining mixed wastes (for example, mixed wastes exhibiting a toxicity characteristic) are included in the "third thirds" category; the effective date of the land disposal restrictions for wastes in this category is May 8, 1990. In a recent proposal, however, EPA proposed a two-year national capacity variance for mixed wastes falling into the third thirds (54 FR 48492, November 22, 1989). If this variance is retained in the final regulation, the effective date of land disposal restrictions for these wastes would be extended until May 8, 1992.

It should be noted that the facility addressed in today's proposal is located in New Mexico, a state that has not yet been authorized for mixed waste. EPA recently proposed to grant the state mixed waste authorization (55 FR 10076, March 19, 1990), and expects a final decision on this question in the near future. Until the state has been authorized for mixed waste, however, mixed waste is not a RCRA hazardous waste in the State of New Mexico and the Federal land disposal restrictions do not apply to it.

C. WIPP Project

1. Introduction

In March 1989, the Department of Energy (DOE) submitted a no-migration variance petition for its Waste Isolation Pilot Plant (WIPP), a program to dispose of mixed transuranic (TRU) radioactive and hazardous waste in a mined salt bed near Carlsbad, New Mexico. DOE has designed the WIPP as a permanent repository for TRU wastes that are generated and stored at ten DOE sites around the country.[2] These wastes,

[1] On July 28, 1988, the Agency also promulgated standards under 40 CFR 148 for no-migration variances for underground injection wells (53 FR 28122).

[2] The DOE facilities that would send wastes to the WIPP are Idaho National Engineering Laboratory, Idaho Falls, Idaho; Rocky Flats Plant, Golden, Colorado; Los Alamos National Laboratory, Los Alamos, New Mexico; Argonne National Laboratory, Argonne, Illinois; Savannah River Plant, Aiken, South Carolina; Oak Ridge National Laboratory, Oak Ridge, Tennessee; Hanford Reservation, Richland, Washington; Mound Plant,

Continued

which result from the production of nuclear weapons, consist of a variety of materials, including tools, equipment, protective clothing, and other material contaminated during the production and reprocessing of plutonium; contaminated organic and inorganic sludges; contaminated process and laboratory wastes; and contaminated items from decontamination and decommissioning activities at DOE installations.

Wastes emplaced in the WIPP will be limited to transuranic (TRU) wastes, a specific category of radioactive wastes. TRU wastes are defined as wastes contaminated with alpha-emitting radionuclides with atomic numbers greater than 92 (that is, heavier than uranium) in concentrations of greater than 100 nanocuries per gram of waste. In addition, TRU wastes by definition have half-lives of greater than 20 years, although the actual half-lives of radionuclides in waste to be placed in the WIPP are often hundreds or thousands of years. Two types of TRU wastes are targeted for the WIPP: (1) Contact-handled (CH) wastes, which have a measured radiation dose rate at the container surface of 200 millirems per hour and can be safely handled without special equipment when drummed; and (2) remote-handled (RH) wastes, which have a measured radiation dose rate at the container surface of above 200 millirems per hour and must be heavily shielded with lead for safe handling. The upper limit for radiation dose rate of RH wastes to be placed in the WIPP is 1,000 rems per hour. The great majority (97%) of the wastes that will be shipped to the WIPP will be contact-handled. TRU wastes are distinguished from high-level radioactive waste, such as used reactor fuel, and low-level radioactive waste. Other treatment and disposal strategies are being developed for high-level and low-level wastes.

A significant portion of the waste destined for the WIPP (up to 60%, according to current DOE estimates) is contaminated with RCRA hazardous waste, making this waste a "mixed waste" potentially subject to RCRA jurisdiction, although the concentration of hazardous constituents in these wastes is generally very low. The hazardous wastes in question are primarily solvents and EP toxic metals, especially lead. Of these wastes, the solvents are currently subject to treatment standards under the land disposal restrictions, and the EP toxic metals will be subject by May 1990 (or May 1992 at the latest). DOE intends, at this time, to dispose of these wastes in the WIPP without treating them in conformance with BDAT standards.[3] As a result, DOE has applied for a no-migration variance for the mixed wastes to be emplaced in the WIPP.

2. History of the WIPP Project

The effort to locate a permanent disposal site for TRU waste began over 30 years ago, when the National Academy of Sciences recommended that radioactive waste be permanently disposed of in salt beds. After a decade of experimentation, and the rejection of one site for technical reasons, the Atomic Energy Commission, the Oak Ridge National Laboratory (ORNL), and the U.S. Geological Survey (USGS) began a formal selection process for a site in 1973. A set of selection criteria addressing factors such as stratigraphy, hydrogeology, seismicity, population density, and land ownership, were defined, and the USGS reviewed most of the larger rock-salt deposits in the United States against these criteria. On the basis of this review, USGS selected eastern New Mexico as the area best satisfying the site-selection criteria. After further review against detailed, site-specific criteria (e.g., minimum distances were set from the Capitan reef aquifer, existing boreholes, and dissolution fronts), the WIPP site was chosen in 1975.

The WIPP project was authorized by Congress in the Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1980. DOE began construction of the repository in the early 1980s. Construction of the surface buildings, the underground experimental rooms, and the first underground disposal rooms is now essentially complete.

3. Description of WIPP

The WIPP repository is an underground mine, located approximately 2,150 feet below the surface in the Salado Formation—a 2,000-foot-thick salt bed that extends laterally for approximately 36,000 square miles. The land in the area of the WIPP is owned by the Federal government and administered by the Bureau of Land Management. The four-mile by four-mile plot of land overlying the repository has been temporarily withdrawn from public use by the Department of Interior; it is now under the control of DOE. The repository is designed to hold TRU wastes that are currently stored at the ten DOE generating facilities, as well as new TRU wastes that will be generated over the next 25 years. If the WIPP site is eventually determined to be a permanent repository, the underground waste disposal area of the WIPP will cover 100 acres, with a total design capacity of 6.45 million cubic feet (or approximately 850,000 barrels of waste). To date, 15 acres of underground disposal rooms have been mined.

Although DOE has conducted extensive studies of the WIPP site and the repository's performance, uncertainties remain. For example, concerns have been raised over the possibility that gas generated underground at the WIPP will, over the long term, build up to unacceptable pressures, leading to possible releases from the repository. To address this and other questions, DOE plans to conduct testing over a 5-year period. This period will involve in-situ tests with actual TRU wastes underground, as well as other investigations. Under DOE's current plans, the in-situ tests would initially involve wastes amounting to approximately 0.5% of the total repository capacity. From these tests, DOE expects to demonstrate compliance with EPA's standards for disposal of radioactive materials (40 CFR part 191 subpart B) and long-term no-migration of RCRA hazardous constituents, as well as to identify any engineering modifications that may be necessary to meet these standards.

DOE is also considering the need for an "operations demonstration" during the 5-year test period. The purpose of this demonstration, which might involve up to an additional 3 to 8% of the total WIPP capacity, would be to show DOE's operational readiness to ship waste to the WIPP and to place it underground.

If DOE is unable to meet EPA hazardous and radioactive waste disposal standards at the conclusion of the test period, it has committed to remove all wastes from the WIPP.

If the WIPP proves acceptable as a permanent repository, DOE will then begin full-scale disposal of waste at the site. Drums, metal boxes, and canisters of waste will be shipped to the WIPP from the generating sites and placed in the underground rooms. Under current plans, the wastes will be backfilled with crushed salt and the rooms sealed. After an operating period of approximately 25 years, DOE plans to seal the shafts of the mine with cement and clay plugs and compacted salt, and decommission

Miamisburg, Ohio; Lawrence Livermore National Laboratory, Livermore, California; and Nevada Test Site, Mercury, Nevada.

[3] Since the no-migration petition was first submitted, DOE has formed an Engineering Alternatives Task Force that, among other things, will consider treatment alternatives for TRU wastes before they are disposed of at the WIPP.

the facility. After decommissioning, the salt of the Salado Formation will creep inward on the waste and is expected to encapsulate the waste within 60 to 200 years.

Access to the WIPP site will be restricted during operations and decommissioning, and possibly for longer periods. The Department of Interior temporarily withdrew the lands on the WIPP site from public use in 1983, allowing DOE to begin construction of the facility. Before DOE can place waste at the site, however, either Congress or the Department of Interior must take new land withdrawal action. In addition, DOE and the State of New Mexico have agreed to prohibit in perpetuity all subsurface mining, drilling, and resource exploration unrelated to the WIPP project at the WIPP site. The Federal government has acquired, or is in the process of acquiring, the entire surface and subsurface estate at the WIPP site, including leasehold interests in subsurface resources. Finally, to prevent drilling in the vicinity of the repository in the distant future, DOE intends to place permanent warning markers at the site.

D. Regulatory Status of the WIPP

The WIPP is located in the State of New Mexico, which is expected to receive authorization for mixed waste in the near future. (See 55 FR 10078, March 19, 1990.) Once mixed waste becomes subject to the RCRA hazardous waste regulations in New Mexico, the WIPP will be eligible for RCRA interim status. Facilities "in existence" (which includes those under construction) at the time a waste is identified as hazardous may obtain interim status by submitting a Part A permit application to EPA or the appropriate state. If DOE submits the appropriate application to New Mexico and secures interim status, it will be legally authorized to receive mixed waste—subject, of course, to the land disposal restrictions. The WIPP must also comply with interim status standards, codified at 40 CFR part 265, and obtain a RCRA permit under 40 CFR parts 264 and 270.

The interim status requirements of part 265 establish general facility standards. For example, the WIPP will be required under these standards to have a waste analysis plan for its mixed waste, a contingency plan describing procedures that DOE will take in the case of an emergency, and a closure plan describing how the facility will be closed. At the same time, DOE will be required to submit a RCRA Part B permit application to the State of New Mexico no later than six months after a request by the state.

The RCRA permit for the WIPP, which would be issued by New Mexico, would establish detailed operating, closure, and post-closure conditions for the facility in accordance with 40 CFR subpart X. (As a geological repository, the WIPP is regulated under the RCRA category of subpart X "miscellaneous units.") The permit's scope would potentially extend to all facility activities related to mixed waste. In this respect, the permit is significantly broader than the no-migration variance, which addresses the specific issue of whether hazardous constituents will migrate from the WIPP disposal unit. At the same time, the permit provides an opportunity to ensure that DOE manages the facility in a way that ensures that migration will not occur.

As discussed earlier, EPA's authority under RCRA over waste destined for the WIPP extends only to mixed hazardous and radioactive waste, and it is further limited to the hazardous components of the mixed waste. The potential release of radioactive material from the WIPP is addressed under the Atomic Energy Act (AEA). EPA has promulgated standards under the AEA limiting releases associated with the disposal of radioactive wastes. These standards, which are codified at 40 CFR part 191, consist of two parts: Subpart A dealing with releases during the operational phase of a permanent disposal facility, and subpart B, dealing with long-term releases after decommissioning. Under an agreement with the State of New Mexico, DOE will comply with the Subpart A standards, beginning with the initial receipt of waste at the WIPP, before the facility has been designated as a permanent repository. The Subpart B standards have been remanded to EPA by the U.S. Court of Appeals for the First Circuit, and therefore are not in effect at this time. DOE, however, has agreed with the State of New Mexico to demonstrate compliance with the remanded standards before a final decision is made to dispose of waste permanently in the repository. This decision will be made on the basis of data gathered during the test phase at the WIPP.

Finally, EPA emphasizes that today's proposal addresses only the specific question of whether hazardous constituents will or will not migrate from the WIPP for the purposes of the RCRA no-migration variance. Issues raised by the transportation of waste to the WIPP site, or by the handling and possible treatment of waste before it reaches the WIPP, are beyond the scope of this notice.

II. Summary of DOE Petition

DOE initially submitted its no-migration petition for the WIPP in early March 1989, with two addendums submitted on October 1, 1989, and January 22, 1990. For the convenience of commenters, DOE has consolidated the various parts of the petition and reprinted them as a single document, dated March 1990. This consolidated document has been placed in the public docket for today's proposal as DOE's complete no-migration variance petition. This petition, which consists of six volumes, provides the information required by 40 CFR 268.6, including facility description, site characterization, waste characterization, description of anticipated repository performance, modeling of potential environmental releases, air monitoring plan, seal designs, demonstration of compliance with other federal, state, and local requirements, and other items. EPA has carefully reviewed this document and concluded that, together with other materials submitted by DOE in support of the petition, it constitutes a complete submission, providing sufficient information for EPA to propose a tentative decision on the variance request.

Beyond the petition itself, several documents have been critical to EPA's review and its proposed decision. Two documents, in particular, are important adjuncts to DOE's petition: DOE's "Draft Final Plan for the Waste Isolation Pilot Plant Test Phase: Performance Assessment" (December 1989, DOE/WIPP 89-011) and its "Draft Waste Retrieval Plan" (January 1990, DOE/WIPP 89-022). The first document provides important details on DOE's planned activities during the test phase; the second describes the procedures by which DOE will retrieve waste from the repository if it cannot demonstrate the long-term acceptability of the facility. DOE's test plans and the retrievability of any waste placed in the WIPP are central considerations in the approach EPA is proposing today.

In addition, EPA has paid particular attention to DOE's Draft and Final Supplemental Environmental Impact Statements (April 1989 and January 1990, DOE/EIS-0026-FS), which discuss in detail many aspects of facility performance; the Design Validation Report (October 1986, DOE/WIPP 86-010), which discusses the validation of the design for underground openings; and DOE's draft "Final Safety Analysis

Report" (June 1989, WP-02-9). Also particularly important has been DOE's "Safety Analysis Report for the TRUPACT-II Shipping Package" (June 27, 1989), which provides information on waste compatibility, gas release, and other questions developed by DOE to support the Nuclear Regulatory Commission's approval of waste shipment. Beyond these sources, DOE provided EPA with several hundred additional reports, studies, and other documents, as background support to the no-migration petition.

These, and all other documents considered by EPA in reaching its proposed decision, have been included in the public docket for this rulemaking. The docket also contains a complete list of items considered.

III. Summary of Proposed Decision

EPA is proposing today to grant a "conditional" no-migration variance to the DOE for the WIPP. This variance would allow DOE to place mixed waste subject to the RCRA land disposal restrictions in the WIPP for testing and experimentation to determine whether the site is appropriate for the long-term disposal of mixed waste. The proposed variance would be restricted to mixed wastes emplaced in the WIPP repository for the purpose of testing and experimentation designed to show the long-term acceptability of the WIPP (that is, its conformance with standards for permanent disposal of radioactive and hazardous wastes). DOE would not be allowed to conduct an "operations demonstration," involving the placement of waste underground for the purposes of demonstrating that the facility is operationally ready to receive waste. Furthermore, DOE would not be allowed to begin the permanent disposal of waste subject to RCRA land disposal prohibitions at the site under today's proposal. Finally, DOE would be required to remove all wastes subject to the variance from the repository if it could not demonstrate no migration of hazardous wastes over the long term. (It should be noted that DOE has committed to conducting such a removal in its no-migration variance petition, as well as in a consent agreement with the State of New Mexico.)

In support of today's proposal, EPA has tentatively determined that there is a reasonable degree of certainty that hazardous constituents will not migrate from the WIPP disposal unit during the test period. In making this tentative determination, EPA has considered all possible routes of release, but has focused in particular on the release of volatile constituents in the course of testing and the potential for these constituents to migrate out of the WIPP unit through the ventilation shaft. Because of the nature of the tests that will be conducted, and their relatively short duration, EPA believes that release of hazardous constituents from the unit through brine, salt, or other geologic media is implausible during the test phase.

The retrievability of waste placed in the WIPP during the test phase is central to the conditional variance EPA is proposing today; therefore, EPA also reviewed both the technical feasibility of retrieval and the practicability of DOE's retrieval plan. EPA has tentatively concluded that retrieval of wastes from the WIPP can be accomplished safely, and that DOE's commitment to retrieval, if it proves necessary, is satisfactory. Finally, EPA has considered the general design, construction and mine maintenance program at the WIPP, and has concluded that the mine is well-designed and will remain stable (with proper maintenance) during the test period and well beyond.

Although today's proposed variance is specifically based on a finding of no migration of hazardous constituents from the unit during the test phase, EPA has thoroughly reviewed available information on the expected long-term performance of the WIPP repository. Given the geologic stability of the area; the depth, thickness, and the very low permeability of the salt formation in which the repository has been mined; and the properties of rock salt as an encapsulating medium, EPA believes that the WIPP is a promising site for a permanent mixed-waste repository. Nevertheless, a number of uncertainties related to the long-term performance of the WIPP remain—for example, the extent and effects of gas generation, the effect of brine inflow into the repository, and the influence of a "disturbed rock zone" around the mined repository. DOE will be investigating these uncertainties in the test phase at the WIPP, and it will review whether technical modifications to the repository design or the waste are necessary to ensure compliance with the regulatory standards.

Before DOE can permanently dispose of untreated mixed wastes in the WIPP, it must demonstrate no migration over the long term—that is, it must successfully address current uncertainties about long-term WIPP performance. Information gathered by DOE during the test phase will be central to such a demonstration. Any EPA decision to grant (or deny) a variance for permanent disposal will be made with full opportunity for public comment, as prescribed in 40 CFR 268.6(g).

The specific conditions of today's proposed variance for the test phase are listed in Section V of this notice. The basis for EPA's tentative decision and the major issues addressed in the course of EPA's review are discussed in the following section. EPA has also developed a background document, which discusses in more detail the geology of the site, repository performance, waste characterization, and air monitoring. This document is available in the public docket for this proposed action.

IV. Discussion of Issues and Basis of Proposed Finding

A. Definition of No Migration for as Long as the Waste Remains Hazardous

Section 268.6(a) of 40 CFR states that petitioners for a no-migration variance must demonstrate, to a reasonable degree of certainty, that hazardous constituents will not migrate from the disposal unit or injection zone for as long as the waste remains hazardous. EPA proposes to interpret this standard to mean that hazardous constituents cannot migrate from the unit at hazardous levels. In other words, to show "no migration," the petitioner must demonstrate that constituents released from the unit do not exceed health-based standards at the point where they exit from the unit.

EPA adopted this interpretation of "no migration" in its final standards for underground injection wells under 40 CFR part 148 (53 FR 28122, July 26, 1988), and it is taking the same approach in its review of other no-migration petitions submitted under section 268.6. EPA believes that this interpretation of the no-migration standard is a permissible reading of the statute, because the logical focus of the statutory language is whether what escapes from the unit is hazardous. The ultimate judgment required by the statute is whether the prohibition on land disposal "is required in order to protect human health and the environment," a determination that will depend on the concentration levels of constituents. Similarly, in making this determination, the Agency must take the toxicity of waste constituents into account, which necessarily involves consideration of the concentration of the constituents.

The legislative history of the statute likewise indicates that the no-migration demonstration should focus on whether what migrates is hazardous. The Senate Report states that "the Administrator is required to find that the nature of the

facility and the waste will assure that migration of the waste will not occur while the wastes still retain their hazardous characteristics in such a way that would present any threat to human health and the environment." S. Rep. No. 284, 98th Cong., 1st Sess., 15. Waste constituents migrating from a unit at allowable risk to human health and the environment satisfy this standard, as negligible harm to human health and the environment would result.

The statute refers to migration of "hazardous constituents" without defining the term. In other EPA regulations, the term "hazardous constituents" normally has regulatory consequence only if the concentrations of hazardous constituents are significant enough to pose a risk above allowable levels. (See 52 FR 32453, August 27, 1987, which describes the Agency's use of the term in the listing, delisting, closure, and groundwater protection standard regulations.) It is a reasonable construction of the statute that Congress intended the same approach here. It is possible that Congress was equating wastes and hazardous constituents, so that when Congress stated that there shall be "no migration of hazardous constituents * * * for as long as the wastes remain hazardous," it was referring to waste constituents whose migration is prohibited for as long as they remain hazardous, i.e., are at hazardous levels. The passage from the Senate Report cited above appears to support this reading, since its uses the terms "waste" and "constituent" interchangeably.

EPA acknowledges that the statute could also be interpreted as requiring that a single molecule of any hazardous constituent (i.e., substances listed in Apendix VIII of 40 CFR part 261) may not migrate for as long as the waste in the unit remains hazardous. EPA believes that this is not a preferred reading of the statute, given that the health and environmental concerns focus on whether hazardous levels of constituents leave the unit, and not whether hazardous levels remain in the unit. The alternative reading is not compelled by the statutory language nor the legislative history, and is not necessary to protect human health and the environment. A zero molecule standard would be impossible to meet, both because it is impossible to monitor or realistically model the fate of individual molecules (or atoms) of waste constituents and because certain waste constituents are substances that persist indefinitely. Congress simply would have forbidden all land disposal of untreated hazardous waste if this were its intent. Congress, however, expected that some individual land disposal units might be able to satisfy the standard. S. Rep. No. 284 at 14; H. Rep. No. 198, 98th Cong., 1st Sess. at 34; S. 9153. In addition, even under this latter reading, nonhazardous levels of constituents would be allowed to migrate once wastes in the unit were no longer hazardous. Thus, EPA believes the appropriate focus is on whether constituents ever migrate at hazardous levels. The Natural Resources Defense Council has challenged this Agency construction of RCRA in the context of EPA's regulations for underground injection at 40 CFR part 148, *NRDC* v. *EPA* No. 88-1657 (D.C. Cir.). The court decision is pending.

In establishing hazardous levels of hazardous constituents—that is, the levels of a compound that would fail the no-migration standard—EPA proposes to rely on peer-reviewed health and environmental effects data, where available. These data are based for the most part on the drinking water Maximum Contaminant Levels (MCLs), surface water quality criteria (Ambient Water Quality Criteria, 45 FR 79318, November 18, 1980; 49 FR 5831, February 15, 1984; 50 FR 30784, July 29, 1985), verified Reference Doses (RfDs) for systemic toxicants developed by the Agency's Risk Assessment Forum (Verified Reference Doses of USEPA, ECAO-CIN-475, January 1986), and Risk-Specific Doses (RSDs) for carcinogens developed by the Agency's Carcinogen Assessment Group. EPA typically combines these dose levels with standard exposure numbers for each medium (e.g., groundwater and air) to obtain allowable health and environmental exposure levels. The standard exposure numbers assume direct human exposure at the point of compliance or, to be specific, the unit boundary. This is consistent with the approach EPA promulgated in the 40 CFR part 148 regulations for no-migration petitions for underground injection wells.

Finally, the statute requires the petitioner to demonstrate no-migration for "as long as the waste remains hazardous." Typically, EPA would judge this demonstration on the basis of an understanding of the waste transformation process and of the long-term performance of the disposal site, in combination with predictive modeling. In many cases, hazardous wastes can be expected to degrade over time, limiting the scope of predictive modeling required. For example, in the case of land treatment facilities—which are specifically designed to degrade organic wastes through microbial action—degradation of hazardous constituents might take place over a 90-day time period. In other cases, degradation will take significantly longer. In the context of underground injections, EPA provides that, if petitioners can demonstrate no-migration over a 10,000-year period, they will have met the statutory standards (40 CFR 148.20). Petitioners may also demonstrate that their wastes would be nonhazardous or otherwise immobilized on the basis of a showing of chemical transformation or fate. (Id.)

In the case of the WIPP, heavy metals such as lead will not degrade, and therefore will remain hazardous virtually indefinitely—certainly far beyond the predictive capabilities of any models. For this reason, EPA believes that its final determination concerning the WIPP's conformance with the no-migration standard over the long term must rest on the Agency's professional judgment regarding the containment properties of the Salado formation within the vicinity of the WIPP, and on any transformation or immobilization of wastes within the unit. The Agency's views on the long-term acceptability of the WIPP are discussed in Section IV.F of this notice.

At the same time, predictive modeling can act as a check and provide insight into the long-term performance of the site. In its no-migration petition, DOE has modeled possible waste migration out of the WIPP through brine flow along the sealed shafts over a 10,000-year period. Under this model, hazardous constituents would not come anywhere near the upper edge of the Salado formation within the modeling period. (DOE's modeling exercise is discussed in more detail in section IV.F of this notice.) Because of the uncertainties of long-term modeling, EPA believes that, for the purposes of determining compliance with RCRA no-migration standards, it is not particularly useful to extend this model beyond 10,000 years into the future. While modeling over longer periods had certain uses—for example, in comparing the performance of different repositories—EPA questions whether models have the precision to be used in making a meaningful prediction of whether a specific unit will or will not meet no-migration standards after many thousands or millions of years. The Agency, however, does believe that modeling over a 10,000-year period provides a useful tool in assessing the long-term stability of the repository and the potential for migration of hazardous constituents. In summary, the Agency is not proposing a specific limit on the time

over which no-migration must be demonstrated. Instead, it believes that the final determination should be based primarily on a knowledge of the geologic conditions at the site, supported by modeling.

B. Unit Definition

The definition of the disposal unit's boundary is critical to any decision on a no-migration variance. The boundary of the unit will define the point of compliance; that is, the point at which potential migration would be measured. If waste constituents migrated beyond this point at hazardous levels, a variance could not be granted, while movement of wastes within the unit boundary would be acceptable. In the case of the WIPP, the question of the unit boundary is of particular importance, because there is limited regulatory precedent for defining the boundary of geologic repositories, and because of the general absence of clear engineered barriers designed to contain the waste.

Under current regulations, a "hazardous waste management unit" is defined as a "contiguous area of land on or in which hazardous waste is placed, or the largest area in which there is significant likelihood of mixing hazardous waste constituents in the same area" (40 CFR 260.10). This definition on its face allows considerable flexibility when it is applied to underground repositories. Clearly, the salt bed formation in the vicinity of the repository represents a contiguous "area" of land in which the waste is placed. The regulatory definition does not preclude the inclusion of at least a portion of the surrounding formation in the "disposal unit." It provides little guidance, however, on where the exact points of compliance should be drawn.

EPA has discussed the issue of unit definition in a draft guidance on no-migration petition variances for land disposal units other than underground injection wells. In this guidance, EPA explained that, for units with engineered barriers, the unit boundary should be considered the outermost extent of the engineered barrier. Thus, for a landfill, the outer boundary of the unit would be the outside of the berms and engineered liners (either clay or synthetic). In the case of units without such barriers, other rules would have to apply. For example, the boundary of an unlined land treatment unit would be set at the base of the maximum treatment zone (which cannot exceed a depth of 5 feet from the soil surface). In this case, EPA has recognized that the purpose of a land treatment unit is to allow some movement of a waste down into the soil, as it is being treated, absorbed, or transformed. However, if constituents move out of the treatment zone at hazardous levels, migration from the unit has occurred. In its draft guidance, EPA also recognizes that defining the unit boundary of a geological repository raises special issues. Although the guidance does not discuss the specific issues raised by these units, it states that their boundaries should be defined on a site-specific basis.

One final precedent should be mentioned. RCRA 3004 (d), (e), and (g) require that a no-migration variance be based on no migration of hazardous constituents from the disposal unit or the injection zone. EPA discussed the meaning of the term "injection zone" in its recent regulations establishing standards for no-migration variances for underground injection wells. In the preamble to those regulations, EPA explained that an injection zone is defined in 40 CFR 146.3 as "a geologic formation, group of formations, or part of a formation receiving fluids through a well." The Agency went on to clarify that the injection zone includes confining material as well as the more permeable material into which the waste is injected (53 FR 28122, July 26, 1988). EPA emphasizes that, for the purposes of RCRA compliance, it considers the WIPP to be a miscellaneous land disposal unit rather than an injection well. Therefore, the relevant standard for the WIPP is the "unit boundary," rather than the "injection zone." The underground-injection rule, nevertheless, does define the concept of no-migration in the context of somewhat similar underground disposal and, thus, has some relevance to the WIPP.

The boundaries of the WIPP must be defined in light of these general precedents, as well as the specific circumstances of the facility. As described earlier, the WIPP is an underground geologic repository mined within a relatively homogeneous salt bed. After waste has been placed in the WIPP and the shafts have been sealed, the salt bed will creep and encapsulate the waste. If the WIPP works as intended, the encapsulating salt will act as a barrier and prevent the migration of the waste out of the immediate vicinity of the mined area. Clearly, migration of hazardous constituents at hazardous levels from out of the sealed repository into unconfined aquifers lying above or below the salt bed would constitute migration from the unit; similarly, movement of constituents at such levels via air to the surface atmosphere during the operations of the facility would also constitute migration.[4] Beyond these general limits, however, there is no immediately obvious point where the boundaries of the underground repository must be drawn. In today's notice, the Agency discusses alternatives for defining the WIPP boundary and proposes an approach that, it believes, fully protects human health and the environment, meets the statutory and regulatory standards, and accurately reflects the particular situation of an underground salt-bed repository.

To begin with, the immediate underground disposal area and the shafts of the WIPP are clearly within the disposal unit. The shafts, however, are a hypothetical route of migration out of the salt bed as a result of brine flow. The Agency proposes that the point of compliance, for the purpose of assessing migration out of the unit by way of the shafts, be defined as the point where the Salado formation (i.e., the salt bed) meets the overlying Rustler formation. This is the point at which migrating constituents could be expected to escape from the long-term engineered barrier designed to contain the waste—that is, the compacted salt shaft seal ending at the top of the Salado formation—and potentially move into an overlying aquifer. Although the possibility of human or significant environmental exposure is virtually nonexistent at this point, EPA belives that compliance with the no-migration standard should nevertheless be measured there. The appropriate standard is whether hazardous constituents have migrated from the unit at hazardous levels, not whether exposure is likely or whether the concentration of hazardous constituents will be significantly reduced in the course of migration outside the unit boundary.

The point of compliance for the WIPP is more difficult to define if hazardous constituents move through the salt bed itself, rather than along sealed shafts. Theoretically, hazardous constituents may migrate laterally or horizontally in the salt bed—for example, along

[4] The Agency believes that it must consider the air exposure pathway in assessing the no-migration standard. The statute does not limit the environmental pathways to be considered in making the no-migration demonstration. Moreover, given the policy goal of the land disposal prohibition provisions to end land disposal of wastes that have not been treated to satisfy the section 3004(m) standards, except for wastes disposed of in units that meet the rigorous no-migration standard, it is not appropriate to ignore a major environmental pathway in assessing whether the no-migration standard is met.

fractures or anhydrite marker beds. The Agency believes that, considering the purpose and design of the WIPP, a certain amount of movement within the confining salt bed should be considered movement within the unit. The underground repository has been designed so that the salt bed will creep, encapsulate the waste, and contain it. If the WIPP works as planned, there will be limited movement of contaminants into the salt bed, but the constituents will be effectively blocked from potential routes of release. In this respect, movement within the salt bed is analogous to movement within the treatment zone of a land treatment facility, the engineered clay liner of a landfill or surface impoundment, or the confinement material of an injection zone. EPA therefore proposes that the disposal unit include at least part of the surrounding Salado formation, bounded on top by the Rustler formation and underneath by the Castile formation.

The Salado formation, it should be noted, extends horizontally for approximately 36,000 square miles. While EPA believes, for the reasons stated above, that some movement from the original repository through this bed should not constitute "migration from the unit," it also believes that unlimited lateral movement would be inconsistent with the overall integrity of the disposal practice. The Salado formation surrounding the WIPP (unlike an underground injection zone) is very low in permeability and is intended to encapsulate and confine the waste. If the waste disposed of at the WIPP moved laterally for significant distances into the encapsulating formation, the repository clearly would not be operating as intended, and the integrity of the disposal practice would be called into question. It would be hard in this case to argue that migration was not occurring.

Extensive lateral migration might also be problematic because there are a number of potential routes of waste migration in the Salado formation outside of the immediate vicinity of the WIPP. These include numerous boreholes and mines, both old and currently operating, and localized areas of salt dissolution. If wastes moving laterally from the WIPP reached these possible routes of migration, hazardous constituents could conceivably be released to overlying aquifers. To address this concern, EPA believes that it is appropriate and necessary to set lateral boundaries on the movement of waste within the Salado formation, beyond which "migration" from the unit would be considered to occur.

After reviewing the specifics of the WIPP site, the Agency has tentatively concluded that the 4-mile by 4-mile WIPP land withdrawal area represents the most appropriate lateral boundary of the disposal unit. This area is clearly defined, relatively limited in size (compared to the Salado formation), and coincident with the land under DOE control. The Agency has carefully reviewed the geology of this specific area, and has tentatively concluded that no realistic routes of migration lie within it—other than the hypothetical route of escape up the shaft seals. Defining the unit boundary at the edge of the WIPP site, therefore, would effectively isolate the wastes from possible routes of migration beyond the immediate limits of the WIPP site and confine it to an area whose geology EPA has examined in detail. At the same time, this boundary will allow some relatively limited movement of hazardous constituents through the encapsulating salt, which as discussed above is consistent with the design of the WIPP. In addition, as discussed below, the possibility of human intrusion resulting from future drilling operations would be minimized because of federal control of the land area and mineral rights in perpetuity, as well as other institutional controls that will be required at the site.

EPA believes that this approach is not only consistent with current practice, but also reflects Congressional intent. The legislative history of the 1984 amendments states that "in determining appropriate confinement from which migration should not be allowed to occur the terms disposal unit or injection zone should be construed • • • in terms of overall integrity of the disposal practice, keeping in mind, in particular the potential for contamination of groundwater or surface water resources" (S. Rep. No. 284 98th Cong., 1st Sess. at 15). If hazardous constituents disposed of at the WIPP remain within the Salado formation and within the WIPP land withdrawal area, the overall integrity of the disposal practice will clearly be intact, and any potential for contamination of groundwater, surface water, or other resources will be eliminated.

Another option considered by EPA was to define the unit boundary as the walls of the salt mine, or alternatively as the furthest extent of the disturbed rock zone surrounding the excavated area. (The rock surrounding the open repository has been found to fracture as a result of salt creep. The disturbed rock zone is believed to extend one to five meters beyond the mine walls.) The Agency has rejected this approach in today's proposal because defining the unit boundary at this point would run contrary to the intended performance of the WIPP. The WIPP is designed to confine wastes within the salt bed, not to prevent any movement of constituents into the surrounding salt formation as the formation encroaches on the waste and encapsulates it. For example, it is possible that waste would migrate limited distances laterally along horizontal marker beds within the Salado formation. Yet this migration, as long as it remained within the immediate vicinity of the original repository, would in no way threaten the "overall integrity of the disposal practice." Drawing the unit boundary right at the repository walls or at the furthest extent of the disturbed rock zone therefore would be inappropriately limiting, and would not accurately reflect the intended performance of the WIPP. For these reasons, EPA has not proposed the mine walls or the disturbed rock zone as the WIPP unit boundary. (It should be noted that the proposed unit boundary at the WIPP is based on site- and unit-specific considerations, which may not apply to other types of units.)

The preceding discussion focuses on long-term migration of hazardous constituents, once the repository has been sealed. It is also possible that hazardous constituents will migrate from the unit via air during the operation of the WIPP. It is clearly a permissible, if not mandated, construction of the RCRA no-migration provisions to consider an air pathway as part of the no-migration demonstration. The statute requires the demonstration of encompass "no migration of hazardous constituents for as long as the waste remains hazardous," and consequently includes all potential migration pathways. In addition, there is no logical reason to ignore the air migration pathway in assessing no-migration petitions. For this reason, EPA is proposing to consider migration via air at the WIPP.

Air migration at the WIPP would be a potential concern during both testing and oeprations at the facility. During these activities, bins and drums underground will be vented to prevent buildup of gas pressure within the containers. To ensure mine safety, the repository will be ventilated, with exhaust air flowing up an air shaft and out into the general atmosphere. This shaft, therefore, represents a possible route of escape for hazardous constituents from the disposal unit.

The Agency proposes that the point of compliance for the air route during

operations be defined as the point where vented repository air exits from the exhaust shaft and enters into the general atmosphere. During its operational period, the WIPP is in effect an enclosed or "covered" unit, with a single point of air release. Once hazardous constituents have exited from the point of release and entered the general atmosphere, EPA believes that migration from the enclosed unit has occurred. Up until that point, however, air emissions are contained within the repository, and should not be considered to have migrated from the unit. This proposed approach is consistent with the approach EPA is considering for covered surface impoundments or waste piles. In its draft guidance for no-migration petitions, EPA has defined "the outer limit of any engineered barrier over the unit (roof, dome, etc.)" as the air point of compliance for covered units. For the WIPP, the outer limit of the engineered barrier over the unit is the point of release from the shaft. (In the case of the WIPP, the question of where in the air exhaust migration is measured is in fact moot. Because the shaft is nothing more than a vent, concentrations of hazardous constituents will be the same at all points in the shaft. Therefore, for all practical purposes, the unit boundary for air releases could be defined as anywhere in the shaft.)

In summary, the Agency is proposing the following points of compliance for determining no migration from the WIPP:

1. For upward movement out of the repository (e.g., along shaft seals): The point of contact between the Salado and the Rustler formation.

2. For downward movement: The point of contact between the Salado and the Castile formation.

3. For lateral movement: The boundary of the 4 × 4 mile WIPP land withdrawal area within the Salado formation.

4. For air migration: The point where the air exhaust shaft releases to the ambient environment.

The Agency solicits comments on these proposed points of compliance as well as on other alternatives.

C. Conditional Variance

As described earlier, DOE intends to begin WIPP operations with a 5-year test program. The purpose of this program is to demonstrate the long-term acceptability of the WIPP and to show compliance with EPA's disposal standards for TRU wastes. Although substantial information on the long-term performance of the WIPP has been gained over the last fifteen years, important issues remain, particularly in relation to gas generation. DOE plans to investigate these and other issues during the test period. The results of this investigation may confirm the acceptability of the WIPP as currently planned, or may identify necessary engineering or other modification to the waste or the facility. It is also possible that, at the conclusion of the test period, the WIPP will fail to meet AEA or RCRA standards for permanent disposal. In this case, DOE will be required, and has committed, to remove the waste from the underground repository and seek another disposal strategy.

The no-migration variance EPA is proposing today would allow DOE to place waste in the WIPP for the purpose of conducting tests or experiments to demonstrate the long-term acceptability of the facility. The variance would be granted on the condition that DOE remove waste placed underground for testing if its performance assessment fails to show that the WIPP meets the no-migration standard over the long term. Testing and experimentation would include the bin and alcove tests outlined in DOE's draft test plan for the WIPP, but would not include the "operations demonstration." This demonstration is aimed at showing the readiness of the WIPP to receive waste, but not to show its long-term acceptability. The variance would have to be modified, or a revised variance issued, before untreated mixed waste subject to the RCRA land disposal procedures could be placed in the WIPP for purposes other than testing or experimentation. Modification or reissuance of the variance, in this case, would take place according to the full variance approval procedures of 40 CFR 268.6(g). For example, the operations demonstration would not be allowed under the variance proposed today without public notice in the Federal Register, opportunity for public comment, and EPA approval.

EPA believes that a conditional variance, limited to testing and experimentation, is appropriate for the WIPP because the Agency has tentatively concluded that migration will not occur during the test phase. In addition, WIPP shows promise as a permanent disposal site. Because of the possible consequences of gas generation as well as other uncertainties, however, DOE cannot at this time demonstrate no-migration of hazardous constituents over the long term. The conditional variance proposed today would provide DOE with the opportunity to conduct this in-situ testing on gas generation with actual mixed waste, while ensuring that no migration occurs during the test period itself, and that wastes will be removed from the WIPP if the demonstration ultimately cannot be made.

EPA notes that the concept of a conditional no-migration variance for the WIPP is consistent with the approach it intends to propose in other cases as well. For example, EPA is now considering "conditional" no-migration variances for a number of land treatment demonstrations involving petroleum refinery wastes. The purpose of these demonstrations is to provide data necessary to show no-migration during full commercial operation, as well as to allow EPA or an authorized state to collect data to set specific permit conditions. Under a "conditional" variance, a demonstration could proceed, as long as the facility operator could show that no migration would occur during the demonstration, and that the long-term demonstration for a permanent disposal had a reasonable chance of succeeding. If the demonstration succeeded, permanent disposal could then begin. If it failed, the operator would be required to remove the waste placed during the demonstration and dispose of it according to RCRA Subtitle C requirements. Similarly, EPA is also reviewing a no-migration variance petition for the temporary storage of untreated hazardous waste in a pile before incineration. In this case, the facility owner would be required to demonstrate that no migration would occur during the storage period; the owner would also be required to remove the pile completely at the end of the storage period. EPA believes that the approach it is proposing today for the WIPP is similar to the approach it is considering for land treatment demonstrations and temporary storage in waste piles. Today's proposal would allow placement of untreated hazardous waste in the WIPP for the limited purpose of testing, as long as migration did not occur during the test period, and the waste would be removed if long-term no-migration could not be demonstrated. See also 51 FR 40605 (November 7, 1986), where the Agency indicated that a potential no-migration situation would be one involving storage in a land disposal unit where wastes would be removed at the end of the storage period.

Section V of this notice describes in detail the specific conditions of the proposed variance. The key condition is the restriction of the variance to the placement of wastes in the WIPP for purposes of testing and experimentation. This condition would allow DOE to

conduct the testing outlined in its petition and other sources—specifically, the bin and alcove-scale tests described in DOE's "Draft Final Plan for the Waste Isolation Pilot Plant Test Phase: Performance Assessment" (December 1989, DOE/WIPP 89-011). (EPA recognizes that DOE's test plan is currently in draft form, and that a final version is not expected until May 1990. If the activities described in the final document differ substantially from those in the draft, EPA will provide the public with an opportunity to comment on how the changes might affect the proposed variance.)

As an alternative to the approach proposed today, EPA considered the possibility of setting a specific limit on the amount of waste that might be placed in the WIPP. The Agency, however, has tentatively rejected this approach. It is difficult at this time to estimate exactly how much waste may have to be placed in the WIPP to satisfy testing needs. DOE currently estimates that the initial phases of the test period will require waste amounting to 0.5% of the total capacity of the WIPP, but the actual amount finally needed is likely to depend on the results of early tests, as well as the extent to which it is necessary for DOE to explore different engineering modifications. EPA thus believes that any specific quantity limit would be difficult to justify, and might artificially constrain legitimate and necessary testing. The Agency solicits comments on the appropriateness of its proposed approach and on the advisability of a volume limit on the waste that may be placed in the WIPP under the variance. It also solicits comments on the specific limit that might be imposed, as well as the justification for setting such a limit.

EPA also considered, but is not proposing, a time limit on the conditional variance, other than the regulatory limit of ten years, which applies to any no-migration variance (40 CFR 268.6(h)). DOE's current plans, as outlined in the December 1989 draft Final Plan for the Waste Isolation Pilot Plant Test Phase (DOE/WIPP 89-011), call for the development of a "final EPA compliance report" four years after first placement of waste in the WIPP, and a final "disposal phase decision" after five years. One option, therefore, would be for EPA to limit any conditional variance to five years. EPA, however, has tentatively rejected this approach because it believes that, like limits on volume of waste placed, specific time limits could artificially constrain legitimate testing. Instead, EPA believes that restricting placement to wastes used in testing and experimentation will sufficiently limit activities under the conditional exemption.

EPA also notes that today's variance applies only to the activities and conditions described in DOE's no-migration variance petition and in the supporting material provided by DOE. These were the activities and conditions that EPA reviewed in proposing to grant the variance, and therefore they define the limits and scope of that variance. This requirement is enforced through 40 CFR 268.6(e), which requires that facility owners/operators subject to a variance report to EPA "any changes in conditions at the unit and/or the environment that significantly depart from the conditions described in the variance and affect the potential for migration of hazardous constituents from the unit * * *" If a significant change from the petition is planned—for example, a significant change in testing plans or the addition of a test—the owner/operator must notify EPA 30 days in advance, and the change cannot take place without Agency approval. Where the change affects the basis of the no-migration finding, it could not occur before EPA modified the variance through the variance issuance procedures of 40 CFR 268.6. In the case of unplanned changes (e.g., significant new information related to repository performance is discovered), EPA must be notified within 10 days of learning of the unplanned change. If the information warrants such a step, EPA may require that the variance be modified, or it may revoke the variance.

D. Retrievability

As a condition of granting the no-migration petition during the test phase, the Agency is proposing to require that DOE remove all TRU waste subject to this variance from the underground repository if the no-migration demonstration cannot be made for permanent disposal. EPA believes that DOE has reasonably demonstrated that the waste can be retrieved by: (1) Successfully performing mock retrieval demonstrations, (2) providing technical information to show that waste can be removed from the underground repository, (3) demonstrating mine stability during the test phase, and (4) storing the waste in retrievable containers. DOE has committed to removing the waste, if it cannot demonstrate compliance with the no-migration standards for permanent disposal or the disposal standards of 40 CFR 191 for radioactive waste.

DOE's commitment to retrieve test-phase waste has been clearly delineated in several documents, including the "Working Agreement for Consultation and Cooperation" with the State of New Mexico (Article IV).[4] This document establishes, under Public Law 96-164, eight milestones that must be met before the retrievability decision can be made. Key milestones outlined in that agreement include development of a waste retrieval plan and conduct of mock retrieval demonstrations of CH and RH TRU waste. Successful mock retrieval demonstrations have been conducted at the site, and no unsafe conditions occurred during the demonstrations. These demonstrations have been described in two DOE documents, "Report of the Remote-Handled Transuranic Waste Mock Retrieval Demonstration" (May 1987) and "Final Report for the Contact-Handled Transuranic Waste Mock Retrieval Demonstration" (January 1988), which have been included in the docket for this proposed decision. DOE has also developed a draft retrieval plan; under the retrieval plan, an additional alcove retrieval simulation will be conducted. The final waste retrieval plan is expected to be published in April 1990. If there are significant changes in the final plan affecting the no-migration decision, EPA will reopen the comment period to allow comment on those changes.

The stability of rooms during the test period has at times been raised as an issue. The repository rooms have experienced a creep closure rate, at least initially, that is three times what was originally predicted. (The closure rate has been measured at a few inches per year, although the rate depends somewhat on room size.) As a result, early room closure and fracturing of walls or ceilings have been a concern. DOE will address this concern in the alcove test rooms by reducing their size (and thus increasing stability), rock bolting the backs (roofs), and constructing standoff walls in those alcoves to be backfilled with salt. (Standoff walls are walls placed between the drums and the repository walls to ensure that room closure does not impinge on the backfilled drums.) The bin-scale test rooms will be rock bolted to insure stability, and will not be sealed. The Agency has reviewed the design of the test rooms, including the use of rock bolts, and believes that the rooms will be stable during and after the test phase. The petition also indicates

[4] In addition, DOE has committed to removing test-phase waste in the Final Supplemental Environmental Impact Statement for WIPP (Volume 1, page 2-15) and in its no-migration variance petition.

that during the test phase all waste will be placed in the repository in a readily retrievable manner, i.e., all wastes will be in retrievable containers, and wastes will not be backfilled (except in the case of two alcoves, where "standoff" walls will be used). After reviewing the material DOE provided with its petition, EPA has tentatively concluded that the measures to be taken will allow for the safe removal of the waste within the time-frame required for the test phase.

Since room stability and waste containment are critical to the assurance of waste retrieval at the end of the test phase, EPA is proposing to require that all waste emplaced in the repository during that period be placed in a readily-retrievable manner. By "readily-retrievable," EPA means adoption of the specific measures identified in DOE's petition to maintain room stability (i.e., room size, rock bolting, and standoff walls) and the use of easily-retrieved waste containers (boxes, bins, drums). Significant changes to these conditions would require a modification to the variance.

The draft retrieval plan identifies several options for alternative storage of the TRU waste if it is retrieved. While a specific storage and disposal alternative or site was not selected, the Agency believes that DOE has made a satisfactory commitment to remove the waste, if considered necessary. To ensure that any mixed waste removed from the repository is handled appropriately, EPA has included as a condition the requirement that removed waste be managed in accordance with RCRA subtitle C requirements.

E. Post-Closure Controls

Although today's proposed variance for the WIPP is based on a finding of no-migration during the test period, EPA has extensively reviewed a significant body of information related to the long-term performance of the WIPP. In this review, EPA has focused on the "undisturbed" performance of the repository. In other words, the Agency has not specifically reviewed or assessed possible releases from the WIPP that might occur if the facility were disturbed as a result of human intrusion—for example, in the course of oil and gas exploration at some point in the future. EPA believes that, in the context of RCRA no-migration variance decisions, the question of human intrusion, either during operations or after closure, is best addressed through a consideration of the likelihood of intrusion, and the imposition of controls to make such intrusions unlikely events.

EPA emphasizes that this approach to human intrusion is consistent with its general approach under RCRA, both in permitting and variances. Under RCRA, EPA typically relies on institutional controls (both active and passive) imposed through general regulatory standards and site-specific conditions (e.g., in RCRA permits) to ensure that access to a hazardous waste disposal site is appropriately restricted. EPA believes that any permanent no-migration variance for the WIPP will have to impose long-term passive institutional controls, such as land withdrawal, records, and markers—to ensure that the likelihood of human intrusion is appropriately reduced, even after active control of the facility has ceased and any permits at the site may have terminated.

The specific conditions that EPA might impose in a no-migration variance for the WIPP to reduce the possibility of human intrusion in the future would be addressed in the context of any decision that EPA might make on a variance for permanent disposal. Thus, for today's proposal, which applies solely to the test period, the issue of human intrusion in the distant future is not relevant. Nevertheless, EPA notes that DOE has taken, or has committed to taking, several important steps to reduce the possibility of human intrusion after closure of the facility. The most important of these steps, which would likely be conditions for a no-migration variance for permanent disposal, are described below.

First, DOE states that the site will remain under federal jurisdiction in perpetuity, and therefore it or successor agencies will be in a position to restrict access. Furethermore, in August 1987, DOE and the State of New Mexico agreed to prohibit in perpetuity all subsurface mining, drilling, or resource exploration on the WIPP site unrelated to the WIPP project. Finally, the Federal government owns the entire surface and subsurface estate at the WIPP site, with the exception of a single potash leasehold interest; DOE states it is now negotiating with the owner of that leasehold interest. DOE also states that, at WIPP closure, it will notify all state and county planning, deed and record offices, oil and gas commissions, and other agencies, to prevent access by unknowing parties. It will also place permanent warning markers at the site, as required by 40 CFR part 191 standards.

These specific controls, and perhaps others, would constitute assurances against human intrusion for the variance for permanent disposal. But in one area EPA believes a specific condition may be appropriate for today's proposed variance. As mentioned above, DOE is now attempting to secure a potash leasehold interest at the site; it has indicated that it will resolve this issue by mid-May 1990. EPA, however, is concerned about the possibility that this interest might not be secured before mixed waste is placed in the WIPP. Therefore, it is proposing to require, as a condition of a variance for the test phase, that DOE must certify to EPA that it has secured control of the entire surface and subsurface estate at the WIPP (including the potash leasehold), before waste is placed in the WIPP. At the same time, EPA notes that the current land withdrawal at the WIPP site prohibits mining, and any future land withdrawal is likely to include a similar prohibition. Therefore, EPA solicits comment on the appropriateness and the need for this proposed condition.

F. Site Geology and Hydrology

40 CFR 268.6(a) requires that a petitioner seeking a no-migration variance provide a comprehensive characterization of the disposal unit site. For a facility such as the WIPP, this characterization must address the regional and site-specific geologic and hydrologic characteristics in the vicinity at the site. This section of the preamble describes the general site geology and hydrology of the WIPP.

EPA believes that DOE has provided sufficient information to demonstrate that hazardous constituents will not migrate from the unit by any geologic pathway during the WIPP test period. (For a discussion of this issue, see sections IV.J and IV.K of this notice.) Furthermore, the general area of the site has been shown to be geologically stable, and the confining unit (that is, the Salado Formation) appears to be a good medium for disposal, given its thickness, general homogeneity, and low permeability. In addition, the relative remoteness of the site and the limited ground water in the area, while not relevant to a no-migration finding under RCRA, were an important consideration in site selection. While several uncertainties remain concerning the long-term performance of the repository, the Agency believes that the site will not present a problem during the test phase. These uncertainties are being investigated by DOE as part of the test program. Data from this assessment will be essential in any EPA finding of no-migration with respect to the permanent disposal of waste at the WIPP.

1. Site Overview

The WIPP site is located in southeastern New Mexico, in the Pecos

Valley section of the southern Great Plains physiographic province, a broad highlands that slopes gently eastward from the Basin and Range physiographic province. The site is located in the northern section of the Delaware Basin, which is a portion of the larger Permian Basin of the Texas/New Mexico area. The Delaware Basin is a broad, oval north-south trending trough, in which there are over 6,100 meters of structural relief on top of the Precambrian basement. The basin rocks show little deformation, and have undergone only minor tectonic activity since the end of Permian time, approximately 225 million years ago. In ascending order, the Permian units at the site are the Delaware Mountain Group of the Guadalupian Series (Brushy Canyon, Cherry Canyon, and Bell Canyon Formations), followed by the Ochoan Group (the Castile, Salado, and Rustler Formations, and the Dewey Lake Red Beds). Above these formations is the Triassic Dockum Group (undivided), followed by Quaternary deposits of the Pleistocene Epoch (Gatuna Formation and Mescalero Caliche). The rocks described above represent approximately 4,000 meters of the stratigraphic column at the site. The repository is located in the Salado Formation, approximately 655 meters (or 2,150 feet) below the surface.

2. Castile Formation Hydrogeology

The Castile Formation is the rock formation directly underlying the Salado. At the WIPP site it is approximately 400 meters thick and is a major halite-bearing unit. The halites, which are of varying purity and thickness, are separated by three relatively thick anhydrite and carbonate beds. Significant volumes of fluid are usually not encountered in the formation. However, reservoirs of pressurized gas and brine have been found in the Castile.

Borehole ERDA-6, drilled in 1975, encountered a reservoir of pressurized brine in the Castile Formation, about 8 kilometers from the current WIPP site. More recently, Borehole WIPP-12, located about 1.5 kilometers from the site center, encountered another brine reservoir in the Castile. Data from recent geophysical studies have led DOE to assume that the WIPP-12 reservoir may extend underneath a portion of the waste emplacement section of the repository. However, the brines are 250 meters or more stratigraphically below the repository horizon, and there appears to be no natural mechanism that would cause the movement of these brines to the repository. Uranium disequilibrium studies performed on the brine in both the ERDA-6 and the WIPP-12 reservoirs indicate that the fluids are between 360,000 and 800,000 years old; there is also no evidence to show contributions from present precipitation. Furthermore, the brines are saturated with respect to halite, so there is no mechanism for halite dissolution from the fluids. Consequently, after reviewing the data, the Agency has concluded that these brine reservoirs do not present a threat to the integrity of the repository under undisturbed conditions. (DOE is assessing the possible effects of a borehole penetrating through the repository and into an underlying Castile brine pocket, leading to the upward flow of brine into the repository. The issue of possible human intrusion is discussed in section IV.E of this notice.)

3. Rustler Formation Hydrogeology

The Rustler Formation is the rock unit that overlies the Salado Formation. It is composed of five members, in ascending order: The unnamed member at the Rustler/Salado contact, the Culebra Dolomite, the Tamarisk Member, the Magenta Dolomite, and the Forty-Niner Member. Two of the members will be discussed in this notice, because one is in contact with the proposed unit boundary of the disposal unit (unnamed member), and the other member overlying it is the most significant water-bearing stratum (Culebra Dolomite).

The unnamed lower member of the Rustler Formation is a layered sequence of siltstone, gypsum/anhydrite, and halite. Near the WIPP site the average thickness of this member is approximately 35 meters. It contains a siltstone water-producing portion, which may be hydraulically continuous with the upper Salado residuum and any dissolution member of the upper Salado. However, since the Rustler-Salado contact contains water that is saturated with respect to halite, it is not capable of dissolving pure halite.

The member directly above the unnamed lower member is the Culebra Dolomite. If migration from the repository were to occur, this formation is considered the most important potential pathway for release to the environment. The Culebra is a finely crystalline, locally argillaceous and arenaceous, vuggy dolomite, with an average thickness at the site of approximately 10 meters. As a result of fracturing, Culebra transmissivities (which are very low) have been found to range over six orders of magnitude near the WIPP site.

Approximately 60 wells have been completed in the Culebra since WIPP studies began; water-level measurements have been taken for most of these wells over the life of the project. In these measurements, a good correlation was found to exist between water-level measurements from well to well at the site. However, limited quantities of the water in the formation drained into the shafts of the facility with the drilling of the construction and salt handling shaft. This, coupled with wide variations in fluid density within the formation and very low hydraulic gradients, have made flow directions difficult to define, particularly in the southern area of the site. The freshwater head contours at wells in the area indicate a southwestern flow direction across Nash Draw, a southern flow direction across the WIPP site, and an area of apparent western flow south of the site (apparent because of low hydraulic gradients). In this instance, it is noteworthy to remember that the Culebra Formation is approximately 400 meters above the respository level, meaning that, under undisturbed conditions, the potential for hydrologic interference by the Culebra into the Salado or the possibility of the Culebra being a sink for contaminants from the respository is very low.

As mentioned above, the geochemistry of the Culebra formation waters is highly variable. The total dissolved solids (TDS) concentration of the Culebra in the area of the WIPP varies from 10,000 to greater than 200,000 mg/L. These values render the waters of the Culebra at the site considerably saline and not a source of drinking water. It has been noted that the variability of the salinity of the Culebra waters is such that modern flow directions within the Culebra do not appear consistent with modern salinity distribution. This provides evidence that there is no modern contribution of recharge water into the Culebra at the WIPP site. Evidence suggests that the Culebra has been hydrologically isolated for several thousand years.

The Agency believes that the DOE has adequately described the general hydrologic and geologic conditions for the Rustler Formation for the purposes of this petition. In addition, during the performance assessment, DOE will continue to measure the hydrologic responses of the Rustler with respect to flow direction. This assessment should serve to confirm and refine the current understanding of the uppermost water-bearing stratum in the area.[6]

[6] It should be reiterated that these studies, while pertinent to an understanding of hydrology in the

Continued

4. Salado Formation Hydrogeology

Because the repository has been constructed in the Salado Formation, the Salado is the formation of the most interest at the WIPP site. It is located between the Castile and Rustler Formations. The Salado is informally divided into three members: An unnamed upper member, the McNutt potash zone (the informal regional name for the unnamed middle member), and an unnamed lower member. The rationale for this division is the type and composition of laterally-consistent beds of halite, polyhalite, and anhydrite, with varying amounts of other potassium-bearing minerals. The beds of anhydrite and polyhalite alternate with the thicker beds of halite within the Salado. Indeed, approximately 85 to 90 percent of the Salado is pure halite. The composition of the Salado and the Castile Formations are similar, but the lateral extent of the two formations differ. Unlike the Castile, the Salado is not confined to the Delaware Basin, but extends well beyond the Capitan Reef complex onto the Northwestern Shelf and Central Basin Complex.

The porosity of the Salado is extremely low. While the near-field permeability (immediately surrounding the mined repository) is estimated to range from 1 x 10 E-14 to 2.5 x 10 E-11 m2 (0.01 to 25 microdarcies, where one darcy = 10 E-4 m2), with an average of approximately 0.3 microdarcy, the far-field permeability has been measured at approximately 10 E-20 m2 (one nanodarcy). The Salado Formation was initially thought to contain only very small amounts of water (brine). This liquid was postulated to be held only within the small pockets of the salt crystals themselves (intragranular). Later research, however, showed that the brine was also situated in the interstices of the individual crystals (intergranular), or it saturated very thin and discontinuous pockets and layers of clay.

This is the fluid that has been seen at the WIPP in the form of brine seeps. These studies showed that the brine content of the Salado may be approximately 2 percent by volume. The question of brine inflow and formation permeability is discussed in more detail in the next section.

5. Geologic Stability

The geologic stability of the WIPP site is a key element in any no-migration finding for long-term disposal at the repository. In the course of its review of DOE's petition, EPA addressed a number of questions related to site stability, the most important of which are brine inflow into the facility, potential for dissolution of the Salado Formation, seismicity, and the occurrence of maker beds in the Salado Formation. These questions are discussed below.

a. *Brine inflow.* There are two main potential sources for brine infiltration into the repository: Leakage from the Rustler formation above the WIPP and brine inflow from the Salado Formation into the WIPP.

While there has been some leakage from the Rustler Formation down each of the four WIPP shafts into the repository, the leakage rate does not exceed 0.06 liters per second, even when the shaft is unlined and no effort is made to correct the situation. This is not considered a problem with respect to the overall integrity of the Salado, but did lead to inflow of water into the facility. As a result, the WIPP shafts have been concrete-lined and grouted through the Rustler Formation, successfully eliminating the inflow into the shafts. This will be adequate (with proper maintenance) to control leakage from the Rustler over the operating life of the facility, at which time the shaft seals will be constructed. Therefore, the shafts do not contribute fluid to the repository, and thus do not threaten the unit through dissolution or provide a driving force for the transport of hazardous constituents from the underground.

Underground experience with the WIPP has also allowed more information to be gathered on the occurrence and movement of brine within the Salado. The movement of brine in the area immediately surrounding the repository (the disturbed rock zone) has consisted of small, low flow "weeps" that commonly develop on the walls and ceiling of an excavation shortly after the mining of an area. It has been observed that the weeps generally occur at random intervals along planes of heterogeneity within the repository, which means along clay and anhydrite seams found within the Salado. Only rarely does the inflow from a particular weep exceed the evaporation rate of the mine ventilation. In this case, the small amounts of brine will accumulate on the salt surface (usually at a rate of a few tenths of a milliliter per day) until the flow from the weep diminishes, which usually occurs within a few months. The current view, accepted by EPA, is that brine movement into the repository is from the disturbed rock zone, and may be the result of stress-driven flow, with little or no contribution of flow from the far-field (which is the area beyond the zone affected by the underground workings). The fluid inflow question is an important one because brine is a key factor in gas generation, which is partially caused by the corrosion of the waste containers. Gas generation may affect the amount of time required for creep closure of the facility, and, if gas pressure is sufficient, it could also fracture surrounding walls or seals. Gas may also generate enough pressure to drive liquid out of the repository. (The question of gas generation is discussed later in this section.)

Because of these uncertainties, DOE has developed several conceptual models to predict brine movement within the Salado Formation. One model is based on far-field Darcy flow. It assumes that the Salado is hydraulically saturated in the far-field, that fluid flow is the controlling or limiting factor in the long term, and that fluid flow can be modeled effectively through the Darcy equation. (Darcy flow means that fluid flow is directly proportional to the pressure gradient, even when these gradients are very low.) The other concept for modeling the Salado assumes that Darcy permeability is valid only in those regions that have been significantly distrubed. In this approach, the far-field Salado permeability would be essentially zero under any pressure gradient, and brine would flow into or out of the WIPP (along with any hazardous constituents) only in response to the formation of a disturbed rock zone in which deformation of the halite produced interconnected porosity. A third model, which falls between these two approaches, assumes that there is some interconnected porosity within the Salado even under undisturbed conditions, and that fluid flow would take place in the near field in the absence of mechanical disturbance, but there would be no far-field fluid flow due to the absence of sufficient gradients.

Currently it is not certain that the different models of fluid flow within the Salado have significantly different impacts to the long-term behavior of the repository. In general, interpretations assuming Darcy flow in the far-field are conservative in that they do not result in a zero far-field flow rate and do not indicate maximum amounts of brine

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area, are not directly relevant to the Agency's decision on a no-migration variance, even for permanent disposal. If contaminants pass beyond the Salado at greater than health-based levels, migration has occurred regardless of the fate of the contaminants in the Rustler formation.

inflow. Based on the models, however, DOE estimates that the brine inflow might total 40.6 m3 in 200 years, the estimated date by which the repository will be closed. This is a relatively small volume of liquid, representing 1.2 percent of the initial room volume. DOE believes that this amount of brine would be absorbed by salt backfill that will be placed around the waste.

To verify these results, DOE has scheduled Salado Formation fluid flow behavior studies for the test period at the WIPP; during these studies, DOE will validate the models against in-situ data, and will evaluate the fluid flow characteristics of the Salado in the shafts and in the salt surrounding the disposal rooms.

During the test phase, DOE will also refine the current understanding of the hydraulic characteristics of the Salado Formation, including: (1) The state of the hydraulic saturation in the far-field; (2) the driving forces for fluid flow; and (3) the relevant flow paths. As a result of these studies, DOE will obtain a better understanding of the long-term rates of brine inflow, and the long-term fate of wastes placed in the repository.

b. *Seismicity.* The WIPP site is located in an area of low seismic risk. The possibility is extremely low that faulting at the site is of a magnitued that could significantly affect site integrity. Geophysical investigations performed at the site show that no major faults occur in the area, and that those minor faults that are present do not appear physically to displace repository-horizon strata. The Agency agrees with the conclusion presented by the petitioner that regional tectonic activity is not an issue in terms of maintaining repository integrity.

c. *Dissolution features.* Because halite of the Salado formation is soluble in waters that are undersaturated with respect to the minerals in halite, removal of salt surrounding the repository by dissolution could affect repository performance and provide a route of migration out of the facility. In reviewing the potential for dissolution at the WIPP, EPA considered: (1) The influence of a dissolution front at nearby Nash Draw; (2) the possibility of shallow dissolution at the WIPP; (3) the likelihood of climatic changes affecting the hydrologic system, including the dissolution rate; and (4) the effect of deep-seated dissolution on repository performance and the origin of "breccia pipes" found near WIPP.

The nearest major geomorphic feature to the WIPP is Nash Draw, which is approximately eight kilometers northwest of the site. Nash Draw is an undrained physiographic depression which probably developed as a result of differential dissolution of the anhydrite, gypsum, and halite beds of the Rustler and Upper Salado Formations. It is believed that dissolution on top of the massive Salado Formation produced a uniform lowering of the land surface within Nash Draw, while surficial features were produced and modified by dissolution of the Rustler Formation. The dissolution process also produced individual sink holes within Nash Draw, which vary in size from a few tens of meters to approximately two kilometers across. There are also very small sinkholes elsewhere in the area.

The shallow dissolution features in the WIPP area where formed during wetter climatic periods, primarily during the formation of the Pleistocene Gatuna Formation. Even during the period of greatest dissolution, only units within approximately 75 meters of the surface were affected. Shallow dissolution can only become a major process in the Salado, which is over 250 meters from the ground surface, if large quantities of halite-unsaturated water gain access to the Rustler Formation. Several factors will inhibit this process. The geologic units above the Salado are confining layers with transmissivities so low as to prevent recharge of surface water. Since the Rustler/Salado contact contains water that is staturated with respect to halite, it is not capable of dissolving additional halite. Lastly, the head-gradient from the Rustler/Salado contact is upward through the Rustler, which means that if water did exist and flow through this area, it would flow away from the Salado.

Significant increases in precipitation in the area of the WIPP could in theory increase the likelihood of surface dissolution. Data, however, indicate that the Quaternary climate of the past 500,000 years has for the most part remained semi-arid, with limited periods of increased precipitation. For example, the Mescalero Caliche, a type of formation characteristics of warm, semi-arid climates, has remained intact since its formation approximately 500,000 years ago; its continued presence is evidence that the climate has been relatively dry since its formation. As part of the performance assessment, DOE is studying further the possible effects of significant climatic changes on the WIPP.

Another type of dissolution feature found in the region is breccia pipes, or dome-like features of fractured rock. Four of these domal features occur in the immediate vicinity of the WIPP area. Two of these have been drilled and tested. These features appear to be the result of localized, deep-seated dissolution wherein a void is created and overlying material collapses into the void. In the Delaware Basin, these breccia pipes form where soluble units overlie the Capitan Reef aquifer system. The pipes are formed by dissolution of the rock and the subsequent collapse of overlying beds, followed by differential solution of upper units, producing subsidence of ground around the collapsed pipe and creating a brecciated "domal" structure. There are two proposed scenarios for collapse: formation of a cavern inside the Capitan and dissolution and collapse of overlying units, or influx of water to the Salado from an outside source through fractures, resulting in Salado dissolution and collapse. EPA agrees with DOE in its conclusion that formation of these features will not affect the WIPP site because the Capitan Formation, necessary as a fluid source for dissolution, does not underlie the WIPP site.

d. *Occurrence and significance of marker beds.* The occurrence of 48 correlatable marker beds throughout the Salado indicates that the formation exhibits lateral continuity. Geologic mapping within the repository and shafts further supports this contention.

The WIPP repository is bounded by two markers beds (MB), an upper MB 138 and an underlying MB 139. Marker Bed 139 is located approximately 1.5 meters below the floor of the repository, and is composed by anhydrite, polyhalite, and halite. It varies in thickness from 0.3 to 1.3 meters, with an average thickness of 0.8 meter. The bed is fractured in the area below the repository as a result of the excavation of the repository. This marker bed is a potential contaminant migration pathway if fluids/gases were to exist in sufficient quantities to allow a driving force. DOE will review the possible role of Marker Bed 139 during the test phase, and will evaluate the need for specific approaches designed to control migration through the bed, including grouting and excavation of the fractured portions.

Marker Bed 138 lies approximately 9 to 10 meters above the repository and is composed of microcrystalline, partly laminated anhydrite that contains scattered halite growths. This bed is typically 0.25 meters thick, and has a very thin clay seam at the base.

Detailed assessment of marker beds surrounding the repository is important because these beds may act as parting surfaces during repository closure and may also serve as fluid migration pathways. DOE is conducting a number of studies to provide a full

understanding of the significance of these marker beds with respect to repository performance. The role of these beds and how the performance assessment will address outstanding issues such as fluid migration pathways are discussed later in this notice.

e. Ground-water modeling. In its no-migration variance petition, DOE provided the results of ground-water modeling that address the possible migration of hazardous constituents in the Salado Formation. The modeled pathway was one in which wastes moved downward from the waste storage panels, through the underlying salt, and into Marker Bed 139. Waste then moved laterally through this bed to the vertical shafts and upward through the seals and salt backfill within the shaft. DOE modeled this scenario using the SWIFT III code, a widely accepted code used to assess contaminant transport underground, and made very conservative assumptions—for example, one-dimensional flow, constant concentration source of 100 percent solubility, high longitudinal dispersivities, and no retardation or attenuation of wastes.

Results of the SWIFT III modeling indicate that the maximum distance from the source of a 10 ppt (part per trillion) concentration level is 350 meters after 10,000 years, assuming a dispersivity value of 10. This is significant, because the 10 ppt "front" would not have reached the sealed shafts by 10,000 years, and would still be over 400 meters from the top of the Salado Formation. Even with an unrealistic dispersivity value of 100, and 10 ppt contaminant front would still be 240 meters from the top of the Salado.

These results indicate that if the enhanced permeability of the marker bed is limited to the area around the disturbed rock zone, and the permeabilities of the constructed seals are low, contaminants will not migrate vertically up the shaft beyond the unit boundary under the modeled scenario and within the period of the model. If significant fracturing of rock were to occur or the seals were to fail, however, more extensive migration might occur. Although DOE considers these conditions unlikely, it will evaluate them during the test phase.

C. Repository Performance

1. Construction and Maintenance of the Repository

The WIPP repository was excavated according to accepted industry techniques, and has been under Mine Safety and Health Administration (MSHA) oversight and inspection since 1987. The basic mine design is "room and pillar," in which large rooms are excavated from the salt bed and the structural support is provided by the intact pillars of salt that remain. The width of the pillars is determined by the structural properties of the in-situ material. During and after construction, some fracturing of the repository walls has been observed. As a result, rock bolts have been used extensively throughout the underground openings. These bolts retard fracturing and are used in areas of the mine that will remain open for extended periods of time, such as the waste unloading areas and the main access drifts. Roofs of many high traffic areas are pattern bolted for extra safety. Both resin and mechanical bolts are used in most areas. The bolts are tested to meet MSHA standards by MSHA-qualified personnel.

The room and pillar type of excavation is used in various mining activities, such as anthracite and potash mining. In fact, much structural information for the WIPP repository was derived from the potash industry experience from mining the Salado Formation. As a result, the Agency is satisfied with the procedures used by DOE with respect to the basic construction of the WIPP underground. The Agency believes that DOE has demonstrated, with reasonable certainty, the stability of the WIPP repository during the period of the proposed variance.

2. Closure Mechanisms

One of the most attractive characteristics of bedded salt is its plasticity, which enables it over time to flow or "creep," a process that enables fractures in the salt to heal at feasible repository depths. The National Academy of Sciences' original recommendation of salt as a repository medium was based in part on the assumption that the salt would creep to closure and that the salt pillars (or the room and pillar concept) would provide sufficient support to prevent premature collapse and failure of the repository.

These are four major elements of the closure mechanism for the WIPP underground: (1) Brine inflow (discussed earlier); (2) rate of closure of the repository; (3) the disturbed rock zone and Marker Bed 139; and (4) gas generation (which is discussed in the next section).

The observed closure behavior of the openings at the facility is more rapid and more complex than originally anticipated. The total macroscopic wall-to-wall and ceiling-to-floor closure to date have proved, at least initially, to be approximately three times the predicted value. Under the most favorable conditions, the more rapid closures would result in time estimates of 60 to 200 years for closure to a near final state, depending on the initial waste and backfill density, brine influx rate, gas generation rate, and creep closure rate. One of the tasks of the performance assessment is to ascertain in more detail the specific mechanisms and timing of repository closure.

EPA believes that the creep closure process will be a step-functioned phenomena, in which slabs of halite, or variable size, will break along fractures and fall into the remaining open space of the mine, or will be involved in floor heave. These fractures will occur mainly along pre-existing microfractures, incipient joints, and bedding planes, following the excavation of underground openings at the WIPP facility. These are the fractures that make up the disturbed rock zone, which is a zone of rock in which mechanical properties have changed in response to the excavation. The term "near-field" describes the rock within the disturbed rock zone, and "far-field" describes the rock outside the zone. The disturbed rock zone extends approximately 1 to 5 meters from the excavation.

Underground observations of the disturbed rock zone indicate that coherent creep of the Salado Formation outside of the disturbed rock zone is the dominant structural process involved in the closure of the repository. The disturbed rock zone, however, may serve as a sink for some or all of the brine that seeps into the rooms and shafts. It may also enlarge the effective room dimensions by moving the area at or near atmospheric pressure to its outer limits. This would increase the time required for complete closure of the repository openings, allowing the potential for increased brine accumulation. It has also been suggested that, if the fractures in the disturbed rock zone or Marker Bed 139 in particular do not heal, they might serve as a route for migration for hazardous waste or radionuclides. A major portion of the test phase will be devoted to exploring the extent and behavior of the disturbed rock zone.

3. Gas Generation in Waste Disposal Rooms

Microbial and radiolytic decomposition of the waste and corrosion of containers will generate a large quantity of gas. This may result in the pressurization of the waste disposal rooms, particularly if the rate of gas production exceeds the rate at which

gas could be consumed in chemical reactions or be diffused into the host rock. This pressurization could become a driving force for the migration of radionuclides and/or hazardous constituents. If gas pressure exceeds lithostatic pressure, it may result in near-field fracturing of the Salado Formation, impede the structural closing of the repository, or result in gases or brines escaping around the shaft and panel seals. (Seal design will be discussed in section IV.H.) While this is a question that DOE is addressing as part of the performance assessment, it will not be a concern during the test phase.

From the viewpoint of long-term performance of the WIPP, the fundamental questions are whether brine inflow will be sufficient to saturate backfill, waste, and the disturbed rock zone, either before or after compaction of the repository to the final mechanical state, and whether the far-field permeability will be sufficient to dissipate brine and/or gas pressures at or near the final repository state at some fluid pressure below lithostatic pressure.

The impacts of potential gas generation cannot be fully assessed at this time. The most important factor with regard to impacts at the site is the rate at which gases will be produced. To some extent, gases may be absorbed into the Salado Formation. The results of experiments performed during the test phase will help quantify the rate of gas generation within the repository, and will determine if any additional engineering modifications or safeguards are needed to meet the long-term performance goals.

4. Evaluation of Engineered Alternatives

The potential for releases as a result of the interactions among wastes, brine, and gas at the WIPP has led DOE to consider whether some type of waste treatment process or some other system modification may be required. Several engineered components might be added to the system to mitigate the effects of gas generation, wastes might be treated before placement to reduce the amount of gas generated, or other measures taken. DOE formed a task force to review and evaluate the technical effectiveness of waste, backfill, and facility design modifications in mitigating problems associated with gas generation. Engineered alternatives that might provide improved performance will be included in the WIPP experimental programs.

H. Seal Design

The WIPP repository is connected to the ground surface by four mine shafts ranging in diameter from 3.7 meters to 6.1 meters. These shafts are used to remove excavated salt, provide fresh air intake, provide for exhaust air outflow, and handle waste, personnel and construction equipment. At site closure, these shafts must be filled and plugged to prevent the escape of hazardous constituents. In addition, each panel and drift of the repository itself must eventually be sealed to prevent migration of wastes to the shaft seals and minimize release in the event of a penetration. Since DOE will not be installing permanent seals during the test phase, the variance proposed today does not require an approved final design. However, for the Agency to be assured that an implementable design will be available at the end of the test phase, it has required DOE to provide in its petition a reference design and a plan for development of a detailed design.

The primary function of the seal system is to limit the release of hazardous constituents (and radionuclides) through the shafts and past the unit boundary. For the purpose of the no-migration petition, hazardous constituents must not escape from the seal system in excess of health-based levels, and the seals must be capable of limiting the inflow of ground water from overlying water-bearing zones. Furthermore, the seals must function effectively for as long as the waste remains hazardous.

In its petition, DOE has developed a two-phase reference seal design. The first phase provides a "short-term" barrier to fluid flow and is designed to function for at least 100 years. The purpose of this "short-term" barrier is to provide containment until the long-term barrier of compressed salt consolidates. The second phase provides the long-term barrier to fluid flow and is expected to become effective at approximately the 100-year time frame.

DOE has chosen salt as the principal long-term barrier to fluid flow from the repository. Salt has been selected because: (1) It is compatible with the surrounding host rock, providing long-term mechanical and chemical stability unmatched by any other material considered; (2) it is emplacable with conventional techniques; and (3) emplaced crushed salt is expected to reconsolidate as a result of creep closure of the mine and shaft openings, resulting in a fluid conductivity approaching that of the host rock salt.

Laboratory testing and numerical modeling have demonstrated the feasibility of rock salt as the long-term seal; however, complete consolidation of the salt columns within the shafts and mine drifts is expected to take up to 100 years. Therefore, DOE has proposed a short-term seal system to provide waste containment during the period of salt seal consolidation.

The materials chosen for the short-term seals must satisfy the following criteria: (1) They must provide an effective fluid barrier; (2) they must be emplacable in the mine environment; (3) they must provide mechanical and chemical stability for at least 100 years; and (4) they must be compatible with and capable of containing the hazardous waste constituents found in the TRU wastes. (Although the Senate legislative history indicates that the no-migration applicant must "sustain the burden of meeting this standard without the use of artificial barriers such as liners" (S. Rep. No. 284 at 15), EPA does not read this language as precluding assessment of artificial barriers for temporary containment. The concern expressed in the legislative history is that artificial barriers do not provide indefinite containment. Since the artificial seals at the WIPP would only provide a barrier to migration during the temporary period (i.e., 100 years) between closure and consolidation of the permanent salt seal, the concern expressed in the legislative history does not appear to be presented.)

DOE's ongoing seal development program has evaluated a number of seal materials for use in short-term seals, including clays, grouts, concretes, and asphalt. After substantial investigation, including laboratory and small-scale field testing, literature review, and modeling, DOE has proposed a multicomponent reference or conceptual design for the short-term seals. The reference seal materials chosen were concrete and sodium bentonite (a type of clay). They are expected to satisfy the above criteria, although their effectiveness will be the subject of further study during the test phase.

Within the repository shafts there will be three major seal subsystems—the water-bearing zone seal system, the upper shaft seal system, and the lower shaft seal system. The water-bearing zone and upper shaft seal systems are located in the Rustler Formation, while the lower shaft seal system is in the Salado Formation. The water-bearing zone seal system is composed of a 4-meter-thick compacted sodium bentonite seal sandwiched between massive 10-meter-thick concrete bulkheads. The upper shaft seal system is composed of three 4-meter-thick sodium bentonite

seals, each sandwiched between massive concrete bulkheads 10 meters in thickness. The redundant nature of the approximately 60-meter-long shaft system in the Salado Formation can be expected to assure that water-bearing zones are isolated from the shafts.

The lower shaft seal system, which will be in the Salado formation, is expected to function for the long term. This seal system will be composed primarily of compacted crushed salt, ultimately returning the shaft area to a state of permeability to fluids comparable to that of intact host rock salt. The expected height of the final column of reconsolidated salt in each of the four shafts is approximately 200 meters.

A short-term seal will be installed at the top of the Salado formation, above the compacted crushed salt column. The seal will be composed, from top to bottom, of (1) a 10-meter-thick concrete bulkhead, (2) a 4-meter-thick compacted sodium bentonite seal, (3) a 5-meter-thick preconsolidated crushed salt core, (4) a 4-meter-thick compacted sodium bentonite seal, and (5) a 10-meter-thick concrete bulkhead. This upper component will provide redundant protection of the preconsolidated salt from infiltration by water from strata above the Salado formation. The concrete used in this seal, and all other seals within the Salado formation, will be salt saturated to increase compatibility with the host rock. At the bottom of each shaft another short-term seal similar to the one emplaced at the top of the Salado formation will provide a base for the shaft's preconsolidated salt seal, and will limit the movement of fluids between the salt column and the repository itself. A redundant seal similar to the two mentioned above is also proposed to be located within the Salado formation just below the Vaca Triste marker bed, which is a halitic siltstone approximately 240 meters above the repository horizon.

DOE also intends to place a series of horizontal seals within the drifts and panels of the repository itself, and along the four long North-South access drifts leading to the panels. The purpose of these seals is to provide an interval within each panel that has a permeability to fluids comparable to the permeability of undisturbed host rock salt. These seals will be composed of a preconsolidated salt core (either tamped salt or salt block) with 10-meter concrete bulkheads at each end. Considerable overexcavation is anticipated within the drift and panel seal areas just prior to placement of the seals to reduce the disturbed rock zone and remove areas of Marker Bed 139, which might permit migration of the waste constituents. Swelling clays are not now included in the panel and drift seal design.[7]

In its petition, DOE provided a reference design for this seal system. A significant portion of test phase activities is devoted to seal system development based on the reference design. To characterize seal system behavior and performance more fully, DOE is conducting an in-situ and laboratory testing, analysis, and design program. The primary activities or issues addressed by the program are:

1. *Geochemical stability.* Additional laboratory work is necessary to confirm that short-term components will perform adequately throughout their design life. During the test phase, DOE will evaluate the potential for chemical degradation for the seal materials as a result of interaction with the hazardous waste (and other waste) to be disposed of in the repository.

2. *Crushed salt consolidation.* The effect of consolidation on crushed salt properties requires verification with further laboratory tests, including an expansion of the testing program to include brine-saturated crushed salt. Consolidation rates of crushed salt under deviatoric loading will be determined. Measurements will then be made on samples saturated with brine to determine how fluid-filled pores inhibit compaction. The extent to which reconsolidation is accelerated by moisture will be measured in tests on samples containing controlled quantities of added brine. The relationship between reconsolidation, density, and permeability will also be determined.

3. *Cementitious materials development.* DOE will also investigate anhydrite bonding concrete, principally to support the development of material to seal Marker Bed 139 as well as anhydrite markerbeds of less importance. Testing of previously-developed concretes will continue.

4. *Crushed-salt consolidation modeling.* DOE will update the numerical crushed salt consolidation model to include the latest data from laboratory tests. Calculations will be made of crushed salt consolidation in proposed seal excavation shapes to guide the choice of seal shapes for rapid consolidation to high density and low permeability.

5. *Seal system design integration.* An architectural/engineering contractor will prepare a design for the WIPP sealing system after evaluating the results of the testing and model development activities. The design will provide the basis for preparing a WIPP construction design.

6. *Small- and large-scale seal tests.* DOE has placed a number of vertical and horizontal bore holes in the experimental area of the repository. Various candidate seal materials have been placed in these boreholes to provide in-situ data on their efficacy. To more fully simulate the effects of the disturbed rock zone and to test emplacement techniques, DOE will emplace large-scale seals during the test phase. These seals will simulate typical panel seals, and will be composed of crushed salt or salt blocks and concrete.[8]

The Agency believes that DOE's seals development program, as outlined in the no-migration variance, is appropriate. The reference materials currently selected exhibit key properties of mechanical and chemical stability, emplaceability, and hydraulic impermeability. The overall seal design is redundant and calls for seals in critical portions of the repository and shafts. The test phase will address outstanding data needs, verify existing data, and develop new models, as well as improve models developed previously. Information developed during the test phase will be used to develop a preliminary seal design suitable for a construction design.

The Agency solicits comments on DOE's current reference design as well as DOE's program for developing a preliminary seal design during the test phase.

I. Waste Characterization

1. Waste Sources and Types

The TRU wastes intended for emplacement in the WIPP are generated at the ten DOE facilities involved in production operations and research and development activities related to national defense. Many of the processes conducted at the DOE generating facilities are typical manufacturing operations—machining, degreasing, foundry operations, assembly, laboratory operations, etc.; the major difference is the use of radioactive

[7] In addition to isolating each panel from the rest of the repository, the panel seals will also function as a barrier for backfilled salt placed in each panel. The backfilled salt and other absorbent or getter material will aid in the encapsulation of the waste material, absorb brine infiltrating individual rooms, and reduce the time necessary for final closure.

[8] DOE is also continuing to participate in international salt seal development programs. Advanced programs with salt, bentonite, and concrete are being conducted concurrent to the DOE program in Sweden, Canada, Germany, and the Netherlands.

materials to produce defense-related materials. The wastes that are generated from these processes include: (1) Laboratory hardware such as glassware, ring stands, piping, and other metal structures, (2) cellulosic materials such as towels, tissues, and wiping cloths, (3) protective gloves and clothing; (4) inorganic process sludges, many of which are stabilized, (5) various plastic, rubbers, and resins, (6) stabilized organic wastes, and (7) worn out or contaminated equipment and tools. The specific DOE facilities that generate these wastes are:

Rocky Flats Plant, Golden, CO
Idaho National Engineering Laboratory, Idaho Falls, ID
Los Alamos National Laboratory, Los Alamos, NM
Argonne National Laboratory-East, Argonne, IL
Savannah River Plant, Aiken, SC
Oak Ridge National Laboratory, Oak Ridge, TN
Hanford Reservation, Richland, WA
Mound Plant, Miamisburg, OH
Lawrence Livermore National Laboratory, Livermore, CA
Nevada Test Site, Mercury, NV

While the wastes originate from numerous sources within each facility, they have been categorized into four general waste types based upon their physical form and primary chemical content (i.e., organic or inorganic). These types, an example of each, and the approximate volumes of waste they represent, are depicted in Table 1.

TABLE 1—VOLUMES OF WASTE BY WASTE TYPE

Waste type	Examples	Volumes (ft^3) [1]
Solidified aqueous or homogeneous inorganic solids (Waste Type I).	Wastewater Treatment Sludges; Cemented inorganic process solids; Solidified aqueous wastes.	800,000
Solid inorganics (Waste Type II)	Graphite waste; Metal waste—tools, equipment; Glass waste; Pyrochemical salt waste	850,000
Solid organics (Waste Type III)	Combustible waste—paper, rags, soft plastics, cloth coveralls; Filter wastes; Leaded rubber; Exchange resins.	1,750,000
Solidified organics (Waste Type IV)	Solidified lab waste; Solidified solvents	100,000
Total		3,500,000

[1] The volumes reflect previously generated wastes plus the expected volumes that will be generated during the operating life of the WIPP facility.

As can be seen, the largest percentage (approximately 75%) of waste is solid organic- and inorganic-types wastes—paper, protective clothing, tools, equipment, etc.—while solidified organics (the waste that is expected to contain the highest amount of toxicants) will comprise a relatively small percentage of waste (approximately 3 percent).

All wastes to be sent to the WIPP must comply with the Waste Acceptance Criteria (WAC) established by the DOE WIPP Project Office. (These criteria are normally referred to as the WIPP-WAC.) These criteria specify requirements regarding the physical, chemical, and radiological characteristics of the wastes, as well as package labeling requirements. For example, the WIPP-WAC prohibits wastes containing free liquids except in residual amounts.[9] Therefore, wastes destined for emplacement at the WIPP must be in a solid or solidified form. Similarly, corrosive materials and nonradioactive pyrophorics are also prohibited by the WIPP-WAC. Therefore, all corrosive materials must be neutralized or processed to render them noncorrosive, and all nonnuclide pyrophorics must be stabilized or processed to render them nonhazardous. The WIPP-WAC also place limits on the radionuclide levels allowed in individual waste packages. Compliance with the WAC is verified by a combination of process controls: visual inspection during waste packaging, real-time radiography, nondestructive radiological assay, and waste sampling. DOE requires that each waste generator or storage site certify that all wastes meet the WIPP-WAC requirements prior to being sent to the WIPP.

[9] One of the concerns expressed by EPA over the long-term fate of the wastes is the potential for liquids contained in the wastes to be released due to increased pressure after the closure of the repository and, thus, creating the potential for movement of hazardous constituents. As a result of this concern, DOE provided information which indicates that the potential for liquids to be released from the solidified inorganic process sludges (Waste Type I) during the closure period is minimal. Similar assurance needs to be provided for the solidified organic sludges and the wastes that are stabilized by the addition of absorbent. Since the repository will remain open during the testing period, the potentials for liquid release is not a concern during the testing period. However, additional data will be necessary before the Agency can reach a decision on the operational and post-operational periods.

2. Waste Characterization Data

DOE's characterization of the RCRA hazardous constituents in the TRU wastes to be emplaced at the WIPP facility is primarily based upon best engineering judgment, considering the processes from which the wastestreams originate, the materials used in each process, and the technologies used in treating the wastes. In compiling these data, DOE grouped wastes together into Content Codes which comprise wastes of similar types (e.g., combustibles, metals, etc.). Each Content Code indicates where the waste is stored or generated and consists of one or more Item Description Codes (IDCs). These IDCs are site-assigned codes for wastes: they represent more detailed waste descriptions than are contained in the Content Codes. For example, Content Code RF 116 represents combustible wastes currently being generated at Rocky Flats. This Content Code is composed of IDC 831 (dry combustibles), IDC 832 (wet combustibles), and IDC 833 (plastics). (The Content Code 116 wastes previously generated at Rocky Flats and currently stored at the Idaho National Engineering Laboratory are designated as ID 116.)

In support of its petition, DOE provided information on each of 138 Content Codes. For the various codes, the information was provided in two parts. The first part contains a description of the waste in the Content Code and its corresponding IDCs. This description includes flow diagrams and narrative descriptions of the processes which generate the waste, as well as identification of the RCRA hazardous constituents that are used in the process and estimated concentrations for each of the hazardous constituents expected in the waste.

In using process knowledge to establish the identity and concentration of RCRA hazardous constituents in particular wastestreams, DOE assumed that, if a constituent was used in a process contributing to a wastestream, then the constituent would be present in the treated waste. DOE notes that this is a conservative approach since many of

the identified constituents (i.e., the solvents) are very volatile and are likely not to be present in the wastestreams, or are present at very low levels.

The second part of the Content-Code-specific information references available analytical data; these data, DOE argues, support its conclusions on waste composition based upon process knowledge. These data include results from total volatile organic analysis, total metals analysis, Toxicity Characteristic Leaching Procedure (TCLP) tests for organics and metals, Extraction Procedure (EP) tests for metals, and headspace gas analysis for organics. Except in a few cases, all the analytical results represent wastes that were generated at the Rocky Flats Plant, the Idaho National Engineering Laboratory, or the Los Alamos National Laboratory.

Total volatile analysis data were reported for 15 samples. Thirteen of the samples represented Waste Type I and two represented Waste Type IV. Total metals analysis data were reported for six samples. These samples represented Waste Type I and were also tested for the RCRA hazardous waste characteristics of ignitability, corrosivity, and reactivity.

TCLP results were reported for ten samples, all representing Waste Type I. Nine of the samples were analyzed for organics and metals while one was analyzed for organics only. EP toxicity test results were reported for fifteen samples. All these samples represented Waste Type I.

Two sets of gas headspace analysis results were provided. In the first set, results were reported for 22 samples. Ten samples represented Waste Type I; five samples represented Waste Type II; three samples represented Waste Type III; and four samples represented Waste Type IV. In the second set, headspace analysis results were reported for 209 samples.[10] Thirty-two samples represented Waste Type I; 78 samples represented Waste Type II; 77 samples represented Waste Type III; and 23 samples represented Waste Type IV. In both sets of headspace data, the samples were analyzed for numerous gases, including nine organics.

It should be noted that one of the goals of DOE's waste characterization program is to ensure that the wastes used in the experimental or test phase are representative of all of the wastes that will be placed in the WIPP facility during its operational period. DOE believes that wastes from Rocky Flats (newly generated) and the Idaho National Engineering Laboratory (stored and newly generated) will be representative of wastes from the other facilities because Rocky Flats will generate 46% of the newly generated waste over the next 26 years and INEL contains 62% of the stored waste that will be shipped to the WIPP facility, much of which was generated at Rocky Flats. DOE further notes that Rocky Flats produces wastes described by most of the Content Codes.

[10] Forty-one gas headspace samples were also analyzed for wastes generated at the Los Alamos National Laboratory. These analyses indicate that no RCRA VOCs were detected in the headspace.

3. Summary of Waste Characterization Data

The RCRA hazardous constituents in the wastes destined for the WIPP are certain toxic metals and both halogenated and nonhalogenated solvents. Based upon the process information and analytical data, DOE compiled a table (Table 2-1 of the Waste Analysis Plan) which identifies the RCRA hazardous constituents and estimated concentrations expected to be present in each Content Code. The maximum estimated concentrations of the predominant hazardous constituents are presented in Table 2.

The toxic metals cadmium, chromium, lead, mercury, selenium, and silver are predominantly present in discarded tools and equipment, solidified inorganic sludges, and cemented laboratory liquids. Lead is the most prevalent EP metal and is present mostly in lead-lined gloves, aprons, and gloveboxes; lead bricks; and piping.

TABLE 2—MAXIMUM ESTIMATED CONCENTRATION VALUES

Hazardous Constituent [1]	Waste Type I	Waste Type II	Waste Type III	Waste Type IV
Acetone			T	
Butanol	T		T2	T
Carbon tetrachloride	T	T	T	D
Methanol	T		T2	T
Methylene chloride	T	T	T	M
Tetrachloroethylene	T			T
1,1,1-Trichloroethane	T	T	T	D
Trichloroethylene	T		T	M
1,1,2-Trichloro-1,2,2-trifluoroethane	T	T	T	M
Xylene	T		T	M
Cadmium	T	T2	D	T
Chromium	T	T	T	T3
Lead	T	D	D	T
Mercury	T	T1	T	
Selenium	T2	T2		
Silver	T2	T2	T	

[1] The following chemicals in this table are defined in the hazardous waste regulations solely for their ignitability characteristics: (1) Acetone, (2) butanol, (3) methanol, and (4) xylene. The other chemicals identified in the table are defined as toxic in the hazardous waste regulations.

Key: T3 = < 1 ppm; T2 = Few ppm; T = < 0.1%; T = < 1%; M = 1-10%; D = > 10%.

The primary halogenated organic compounds identified as being present in the wastes are tetrachloroethylene, trichloroethylene, methylene chloride, 1,1,1-trichloroethane, carbon tetrachloride, and 1,1,2-trichloro-1,2,2-trifluoroethane. These constituents are regulated as hazardous under RCRA due to their toxicity. The compounds are commonly used as degreasing solvents to clean metal surfaces and to solubilize other compounds. As indicated in table 2, DOE estimates that halogenated organics are not present in any of the Type I, II, or III wastestreams at greater than 1%.

The primary nonhalogenated organic compounds identified as being present in the wastes are xylene, acetone, methanol, and butanol. These constituents are regulated as hazardous

under RCRA due to their ignitability only. Like the halogenated compounds, these compounds are used as degreasers and solubilizers. As indicated in Table 2, DOE estimates that these constituents also are not present in any of the Type I, II, or III wastestream at greater than 1%.

4. DOE's Analysis of Waste Compatibility

DOE used the compositional data described above to perform analyses to demonstrate the compatibility of the various wastes to be emplaced in the WIPP. DOE first identified potential incompatibilities; it then analyzed the potential incompatibilities to determine whether or not they would actually occur. In performing these analyses, DOE considered wastes to be incompatible if the potential existed for any of the folowing reactions: Corrosion, explosion, heat generation, gas generation (flammable gases), pressure build-up (nonflammable gases), and toxic by-product generation.

To identify incompatibilities, DOE listed the materials and chemicals (with their estimated concentrations) contained in each Content Code according to 41 reaction groups (e.g., metals and compounds, caustics, *etc.*). That is, for each Content Code, all pertinent reaction groups were identified. DOE then identified all of the reaction group combinations that could occur within the same Content Code and between different Content Codes (assuming that wastes with different Content Codes are mixed).

DOE performed compatibility analyses for Rocky Flats wastes (both within each Content Code and across Content Codes) and for wastes across all sites. In analyzing compatibilities within each Rocky Flats Content Code, 19 potential incompatibilities were identified. DOE evaluated each of the 19 cases and concluded that the required processing (prior to placing the waste into the containers) would eliminate the potential incompatibility.

DOE's analysis of potential incompatibilities across Rocky Flats Content Codes were designed to simulate a scenario in which individual waste containers within TRUPACT-II containers were breached and the contents mixed. DOE identified six potential reactions due to incompatibilities. DOE discussed each of the potential incompabilities and concluded that, based upon a more detailed analysis of the identity and concentration of constituents within the reaction groups, the reactions would not occur.

In its analysis of compatibility of wastes across all sites, DOE considered reaction of wastes with brine as well as with wastes from other Content Codes. DOE identified 59 potential incompatibilities. After further evaluation, however, DOE concluded that the wastes would not result in a reaction.

5. Agency Analysis of Data

In comparing the process descriptions with DOE's judgments as to the identification of RCRA hazardous constituents in the wastes, the Agency believes that DOE's estimates to be reasonable in most instances. The Agency agrees with DOE's assertion that assuming all hazardous constituents associated with a process to be present in the resultant wastestreams provides for a conservative approach. Further, the process descriptions suggest that the hazardous solvent constituents are not expected to be present in the wastes in high concentrations,[1] except for Waste Type IV—Solidified Organics. (The Agency notes that Waste Type IV will account for only 3 percent of the wastes that are to be emplaced in the WIPP facility.) With respect to those wastes that contain toxic heavy metals, while these wastes may contain significant concentrations of certain metals (e.g., lead), the Agency believes that the potential for these constituents to leach from the waste (and escape into the environment) is minimal, considering the form of the waste.

While this information is an important basis for the Agency's conclusions, it should be noted that in certain instances DOE's judgments were not always correct. In particular, in a number of cases, DOE predicted that hazardous constituents would not be present in certain wastes; however, the analytical results for these wastes indicated that hazardous constituents were present, albeit in low concentrations. Therefore, the engineering judgments must be viewed in concert with other information (i.e., analytical data).

With respect to the analytical results, the Agency is concerned with the quality of DOE's analytical data. For most of the data, DOE has been able to provide little or no information as to sampling plans and sample handling procedures. Thus, the Agency is unable to evaluate the extent to which the samples are representative of the wastes, although the Agency recognizes that analytical data was provided for all the various wastes generated at Rocky Flats and the Idaho National Engineering Laboratory. In addition, much of the data contain no indication as to whether appropriate quality assurance/quality control measures were employed. As a result of these shortcomings, the Agency believes that additional analytical data will be required before the Agency can consider DOE's petition for the operational and post-operational period. Nevertheless, the Agency believes that sufficient information was provided for DOE to proceed with testing during the five-year test phase. In particular, as is described later in today's notice, the concentrations at the unit boundaries (using DOE's waste characterization estimates) are expected to be well below health-based levels. Therefore, even if the characterization data underestimate the hazardous constituent concentrations by an order of magnitude, the boundary concentrations would still be expected to be below hazardous levels. In addition, during the test phase, the monitoring described in Section IV.K of today's notice will confirm that no migration of hazardous constituents occurs during this period. Should problems develop, the wastes will be retrievable.

The Agency has also evaluated DOE's analysis of waste compatibility. The Agency agrees with DOE that no incompatible reactions should occur as a result of possible waste mixing. The Agency reached this determination for Rocky Flats wastes (both within each Content Code and across Content Codes) and for waste across all DOE generator sites.

Finally, it should be noted that for DOE to demonstrate no migration for the operational and post-operational periods, it will be necessary for it to extrapolate information gained during the test phase to behavior of the wastes during the later phases. Thus, the Agency is proposing to require that DOE provide to the Agency the results of detailed waste characterization and analyses performed on the waste to be emplaced in the WIPP during the test phase (see Section V of today's notice); in addition, as already indicated, the Agency believes that during the test phase additional waste characterization data will need to be developed for those wastes to be emplaced during the operational phase. While DOE believes that the wastes to be used in the test phase (from Rocky Flats and Idaho National Engineering Laboratory, as

[1] While the data indicate that Waste Types I, II, and III may contain up to 1% of certain volatile organics, the Agency would expect that most of the wastes that contained these constituents (not every Content Code contained each of the hazardous constituents identified in Table 2) would contain them at much lower levels based on waste type, the volatility of these solvents, and the manner in which these wastes are generated. This point is in some extent confirmed by the analytical data.

described in section IV.I.3, above) are representative of the wastes to be emplaced in the WIPP, the Agency recognizes that variations in the composition of wastes from different facilities—even though the processes are similar—are not uncommon. The Agency therefore believes that additional waste analysis will be necessary to demonstrate more clearly that the wastes from Rocky Flats and Idaho National Engineering Laboratory that are to be emplaced in the WIPP during the test phase are, in fact, representative of all of the wastes scheduled for emplacement in the WIPP facility.

J. No-Migration Demonstration

During the test phase, DOE intends to conduct two types of in-situ tests involving mixed wastes: bin-scale and alcove tests. In the bin-scale experiments, waste will be placed in specially designed bins with various combinations of brine, backfill, and gas getter materials. In the alcove tests, drummed wastes will be placed in sealed alcoves. (These tests are described in more detail in section IV.L of this notice.) The Agency assessed the possible levels of hazardous volatile organic constituents at the unit boundary during these experiments for the organic solvents most commonly present in TRU mixed wastes. The proposed unit boundary for the air pathway is the point where the air exhaust shaft releases to the ambient environment at the WIPP. As discussed in section IV.K, air is the only plausible pathway during the test phase for migration from the land disposal unit.

In the bin-scale experiments, headspace gases will be vented into the bin discharge system whenever the bins become pressurized through a pressure relief valve installed on each bin. The gases will then be passed on to the exhaust shaft. Since the purpose of the experiments is to gather data on the gas generation potential for the various types of wastes intended for disposal at the WIPP, the rate of gas generation can only be estimated from data gathered in previous laboratory studies. In its review of the gas generation data, the Agency concluded that the possibility that health-based levels might be exceeded in the exhaust shaft could not be eliminated. Therefore, the DOE has provided for the inclusion of a carbon canister in the bin gas discharge system to remove any volatile organic constituents released from the bins. Given the uncertainty inherent in conducting the experiments, the Agency agrees that such a control device is appropriate. (Although this part of the no-migration demonstration depends on the integrity of artificial containment mechanisms, EPA does not believe the use of air control devices for a temporary period (i.e., the operational period) precludes an approval of the no-migration petition. As noted earlier in the discussion of the temporary seals, EPA does not read the legislative history (S. Rep No. 284 at 15) as precluding EPA from considering the integrity of artificial barriers during a limited period.)

To be assured that there is no migration above health-based levels, the Agency is proposing to require the carbon adsorption control device to be installed in the bin discharge system of each room be designed to achieve a control efficiency of at least 95 percent.[18] The Agency believes a 95 percent control efficiency is readily achievable by carbon adsorption systems (see 52 FR 3748, February 5, 1987). In addition, the Agency is proposing to require that certain records be maintained in the facility operating record to ensure that the above requirement is met and that the spent carbon (which will contain the hazardous constituents) will not be improperly regenerated or disposed. In particular, the following records would have to be kept in the facility operating record: (1) The date and time when the carbon in the control device is replaced with fresh carbon and when samples are collected for monitoring carbon breakthrough, along with records of the monitoring results; (2) engineering design analyses used to size the control device and to determine the frequency of carbon replacement; and (3) a signed certification that all carbon removed from the control device is regenerated or reactivated by a process that minimizes the release of organics to the atmosphere by means of a condenser, thermal vapor incinerator, catalytic incinerator, or similar emission control system; is incinerated in a device that meets the performance standards of 40 CFR part 264, subpart O; or is disposed in compliance with Federal and State regulations.

The Agency used for its assessment the concentrations of volatile organic compounds measured in the headspace of 209 drums and standard waste boxes sampled at random from waste form categories generated at the Rocky Flats Plant and stored at Idaho National Engineering Laboratory. The waste form categories when sampled were expected to comply with the requirements of the WIPP-WAC, although upon subsequent visual examination and radionuclide reassay DOE found only 179 of the original 209 to be WAC certifiable (after modifying the initial WAC assessment to allow a free liquid residual of up to 1 percent by volume). The Agency views the analytical results from these headspace samples as being semi-quantitative, for the reasons previously described in section IV.I of this notice.

The results of the Agency's assessment are shown in Table 3 below along with levels of regulatory concerns. The Agency conservatively assumed that both rooms reserved for the bin-scale experiments are filled to capacity. The capacity of each room is 120 bins; therefore, the total number of bins is 240. The Agency then assumed an average gas generation rate of 5 moles per drum per year, a figure the DOE characterizes as representing the upper bound of the range of credible gas generation rates (Test Plan: WIPP Bin-Scale CH TRU Waste Tests, January 1990; SAND89-0462). Each bin can hold the equivalent of 6 drum volumes of waste. Therefore, DOE's upper bound gas generation rate is equivalent to a total gas generation rate from all 240 experimental bins of 0.5 cubic meters per day.[19] The DOE has specified the general ventilation rate through the repository as 425,000 cubic feet per minute which is equivalent to 17,000,000 cubic meters per day. This entire volume of air is exhausted at the exhaust shaft and is available to mix with any gases released from the bin discharge system. The resulting dilution factor at the exhaust shaft if 34,000,000. The dilution factor is applied to the average headspace concentrations, together with the control device efficiency, to calculate the concentration of constituents in the exhaust shaft.

[18] While DOE has submitted a preliminary design of the carbon adsorption control device, the Agency has not been able to determine with the information provided what control efficiency the device will achieve. Therefore, EPA is proposing to require that the carbon adsorption control device be designed to achieve at least a level of 95 percent efficiency.

[19] The Agency notes that even if the gas generation rate is higher (e.g., 25 moles per drum per year), the concentrations at the unit boundary would still be below health-based levels, given the requirement for a carbon adsorption system with a 95 percent control efficiency.

TABLE 3—TEST PHASE COMPLIANCE POINT CONCENTRATIONS IN AIR

Constituents	Average headspace concentrations (g/m^3)	Compliance point concentrations ($\mu g/m^3$)	Levels of regulatory concern [1] ($\mu g/m^3$)
Carbon tetrachloride	1.85	0.0027	0.03
Methylene chloride	0.47	0.00069	0.3
Trichloroethylene	0.70	0.0010	0.3
1,1,1-Trichloroethane	13.2	0.019	10,000
1,1,2-Trichloro-1,2,2-trifluoroethane	1.22	0.0018	30,000

[1] See "Docket Report on Health-based Regulatory Levels for Volatile Organic Compounds in TRU Mixed Wastes."

The compliance point concentrations (with the carbon adsorption control devices installed in the bin discharge system) are an order of magnitude below the level of regulatory concern for carbon tetrachloride and are two to seven orders of magnitude below any other level of regulatory concern. These represent the bin-scale experiments alone; however, the contribution of the alcoves is negligible by comparison. Although it would not be allowable under today's proposed action, DOE has provided data to show that even when 10 percent of the wastes, equivalent to 85,000 drums, are emplaced in the repository prior to sealing of the rooms, the concentrations in the exhaust shaft would be two to eight orders of magnitude below the levels of regulatory concern. Since the alcove experiments involve only 3,850 drums (more than a factor of 20 fewer drums), the concentrations in the exhaust shaft from the alcove drums would be a factor of at least three to nine orders of magnitude below the levels of regulatory concern. The actual concentrations would be even lower than this once the alcoves are sealed at the start of the experiments.[14]

The agency recognizes that the actual bin gas generation rate may be higher or lower than 5 moles per drum per year. However, the Agency agrees with DOE that this figure likely overestimates the average gas generation rate from wastes representative of the entire range of TRU wastes. Therefore, the Agency believes that the DOE has demonstrated, to a reasonable degree of certainty, that during the test phase hazardous constituents will not migrate beyond the land disposal unit above health-based levels.

[14] The Agency notes that for the carbon composite filter volatile organic compound diffusion experiments, QA/QC data on accuracy and precision for the sampling and analysis procedures were not submitted with DOE's petition. However, the diffusion coefficient was determined for three different filters for most experimental conditions. Comparison of the diffusion coefficients between filters generally indicate consistent results, although the comparisons are not favorable in every case.

K. Monitoring

As described in the previous section, the Agency believes that DOE has demonstrated, to a reasonable degree of certainty, that there will be no migration of hazardous constituents from the WIPP disposal unit above health-based levels during the test phase. Nevertheless, regulations at 40 CFR 268.6(c) require that monitoring of all environmental media be conducted to confirm that no migration of hazardous constituents beyond the unit boundary occurs, unless the Agency determines that monitoring of one or more media are unnecessary or infeasible.

In evaluating the possible pathways for migration of hazardous constituents, the Agency has concluded that hazardous constituents will not migrate to ground water or surface water during the test phase. Therefore, the Agency does not believe that ground water or surface water monitoring is necessary. In reaching its conclusion, the Agency notes that all waste emplaced at the WIPP during the test phase will be contained within steel drums or standard waste boxes which serve as the primary containment barrier. The waste itself is in an immobile form. Although the salt bed formation in which the repository is located contains small amounts of trapped brine, the permeability of the salt formation is exceedingly low, creating a natural barrier to transport. Furthermore, full retrievability of the waste will be maintained during the test phase; retrieval will be accomplished by means of the removal of the waste containers and any salt which has become contaminated. (See section IV.D in today's notice for a discussion of retrievability.) Upon completion of the test phase, the Agency will reconsider whether ground water or surface water monitoring will be necessary before waste disposal operations are initiated.

The Agency believes that the only credible pathway for transport beyond the unit boundary during the test phase is through the underground exhaust shaft. The exhaust shaft is the discharge point for all ventilation air from the underground facility. Because the waste containers and experimental bins are vented to prevent the buildup of gases generated by the wastes, some gases and vapors will be released into the underground environment. It should be noted that all waste containers are vented through high efficiency particulate filters that prevent the release of any airborne particulate material during routine waste handling operations. In the event that one or more waste containers are accidentally breached causing radiation to be detected by the WIPP radiation monitoring system, all underground ventilation air will be automatically routed through high capacity HEPA filter assemblies. Therefore, any particulate matter contaminated with RCRA hazardous constituents, e.g., EP metals, will be prevented from being released from the exhaust shaft. Thus, only those constituents that are in the gas phase, e.g., organic solvent vapors, could be released to the environment during the test phase.

The Agency considered the potential for fire and explosion hazard in evaluating the potential for release of hazardous constituents as part of its review of the no-migration petition. The Agency notes that the WIPP-WAC prohibits explosives and compressed gases in TRU waste and requires that pyrophoric materials be rendered safe by mixing with chemically stable materials, such as concrete or glass, or be processed to render them nonhazardous. In addition, the Nuclear Regulatory Commission requires that all waste containers be equipped with one or more carbon composite filters designed to prevent pressure buildup or the accumulation of flammable gases prior to shipment to the WIPP, as described in the TRUPACT-II Methods for Payload Control. The performance of these filters has been specifically tested with respect to hydrogen gas diffusivity. The Agency believes that these requirements, in conjunction with the maintenance of general ventilation in

the underground repository, make the possibility of fire or explosion extremely unlikely. The Agency notes that, while DOE is planning to monitor the repository for explosive or flammable gases, monitoring is limited to three fixed locations within the repository. The Agency, therefore, is soliciting comment on whether routine monitoring should be conducted with portable explosimeters to detect any localized buildup of methane, hydrogen, or other flammable gases underground.

In accordance with the requirements of 40 CFR 268.6(c), the petition includes an air monitoring plan which describes DOE's plan to monitor for the presence of organic solvent vapors and other volatile organic compounds at the unit boundary during the test phase. The monitoring plan involves localized monitoring of gases released during the course of experimental activities with TRU mixed wastes, confirmatory monitoring at the underground repository exhaust shaft, and background monitoring at the main air intake shaft. The Agency is proposing to require that DOE implement the air monitoring plan submitted with the petition, subject to the clarifications and modifications discussed below.

The Agency is proposing to require that the monitoring in the exhaust shaft begin 30 days prior to the emplacement of any experimental wastes underground. Monitoring of the bin-scale experiment rooms under today's proposal would have to commence prior to emplacement of any bins containing TRU wastes in the rooms. Monitoring of the alcoves would have to commence prior to the initiation of experiments in the alcoves, after the alcoves are sealed and prior to any purging of the alcove atmosphere. The Agency does not believe that monitoring of the alcoves should be required to begin with emplacement of the first drum of waste. The DOE has demonstrated that migration above health-based levels will not occur if as many as 85,000 waste drums are emplaced in the repository prior to sealing the rooms. By comparison, only 3,850 drums of experimental waste are to be emplaced in the alcoves. Given the small number of drums and given that monitoring will be conducted in the exhaust shaft during the emplacement of waste drums in the alcoves, the Agency has concluded that monitoring of the alcoves may begin when the alcove experiments are initiated.

1. Location and Frequency

The monitoring plan provides for air monitoring at the following underground locations: (1) The gas discharge system for each of two rooms containing the experimental bins; (2) the ventilation air intake and outlet passageways serving the two rooms containing the bins; (3) the atmospheres within the five alcoves containing wastes; (4) the exhaust shaft; and (5) the main air intake shaft. (See the Background Document for a diagram that indicates the specific monitoring points.) Flow rates will be monitored at the downstream end of the gas discharge system for the bins and at the exhaust shaft. The Agency is also proposing to require that the leakage rate of the sealed alcoves be measured by means of the injection of tracer gases into the atmosphere within each alcove and monitoring of the tracer gas levels. The Agency believes this is necessary to ensure the validity of the data collected from the alcoves. As provided for in the monitoring plan, air concentrations in the exhaust shaft will be calculated from the analytical results from the bin and alcove samples and the measured air flow and alcove leakage rates. Monitoring of the exhaust shaft and the main air intake shaft will provide additional measurements for comparison with the calculated concentrations.

To obtain representative samples, DOE will collect integrated 24-hour samples at all locations with the exception of the alcoves, where the gas composition is expected to remain relatively stable over time. Grab samples are judged to be sufficient for monitoring the alcoves.

Initially, samples will be collected daily at all locations except for the exhaust shaft and the main air intake shaft. After 30 days of daily sampling at a monitoring location, the frequency of sampling at that location may be reduced from daily to weekly if the monitoring results are relatively constant over time, as indicated by a relative standard deviation (RSD) of not more than 25 percent over the last 30-day period for any targeted constituent. DOE requested in its petition that the monitoring frequency be allowed to be reduced further, from weekly to monthly, if after 12 weeks the RSD of any targeted constituent was not more than 25 percent. The Agency is concerned that monitoring on a monthly schedule may not adequately detect or characterize changes in air releases that may occur with the inclusion of new waste forms in experimental bins and alcoves as the testing program progresses. Therefore, the Agency is proposing that, at a minimum, samples be collected weekly. The Agency is also proposing that the exhaust shaft and air intake locations be monitored weekly for the same reasons. However, the Agency is soliciting comment on whether to allow a further reduction in monitoring frequency. In addressing this point, commenters should specify a sampling frequency and the rationale for selecting a particular frequency.

EPA believes, however, that in no event should the monitoring frequency for the bin discharge system be reduced to less than 20 percent of the minimum time required for the consumption of the total working capacity of the carbon adsorption system. The Agency believes this requirement is necessary to ensure that, should the total working capacity of the carbon bed be exceeded prematurely and breakthrough occur, the event will be detected in sufficient time to take corrective action and replace the carbon charge.

In the event that weekly monitoring results exhibit increased variability, the Agency believes that daily sampling should be reinstituted. Therefore, the Agency is proposing to require that daily sampling be resumed if the calculated RSD for the preceding 4-week period at a monitoring location exceeds 75 percent for any targeted constituent. Daily sampling would have to continue until such time as the criteria for a reduction in frequency to weekly sampling are met again.

2. Hazardous Constituents

Air monitoring will be conducted for the organic solvents most commonly present in the wastes destined for the WIPP facility. The constituents specifically targeted for routine quantitation in the monitoring plan are carbon tetrachloride, methylene chloride, trichloroethylene, 1,1,1-trichloroethane, and 1,1,2-trichloro-1,2,2-trifluoroethane. In addition to these five compounds, the presence of other volatile organics will be investigated and evaluated for possible inclusion in the monitoring program. Specifically, the Agency is proposing to require that any volatile organic compound be targeted for routine quantitation if the average estimated concentration at the point of sampling is 1 ppm or more during any 4-month period and the compound is detected in at least 10 percent of the samples collected from the gas discharge system from either room containing bins or 50 percent of the samples collected from any alcove. The Agency believes that identification and semiquantitative analysis of other compounds is reasonable and necessary as a precautionary requirement, given the limited waste sampling and analysis data available at DOE's waste-

generating sites and the limitations on those data.

To carry out this requirement most effectively, EPA is proposing to require that DOE implement standard operating procedures that will provide positive identification of the following compounds: Perchloroethylene; chloroform; bromoform; dichloroethane; dichloroethylene; toluene; and chlorobenzene. These hazardous constituents have been identified by DOE as being present in TRU mixed wastes at low concentrations and can be determined quantitatively with the TO-14 method. Therefore, the Agency believes these constituents are good candidates for inclusion in the monitoring program as targeted constituents if detected in significant amounts.[16]

As a criterion for inclusion of a constituent as one targeted for routine quantitation, the Agency is proposing to allow a higher frequency of detection for the alcoves than for the bins because once an alcove is filled with experimental wastes and sealed and the experiment begins, the composition of the alcove gases is expected to change only slowly. In contrast, because each bin represents a separate experiment, a highly heterogeneous and time-varying composition of gases is expected in the bin discharge system.

Although the Agency believes that monitoring for the five target constituents listed above in conjuction with specific criteria for inclusion of additional constituents is sufficient, the Agency is soliciting comment on whether other constituents should be targeted for routine quantitation.

3. Sampling and Analysis

The monitoring plan provides for sampling and analysis to be performed using EPA Compendium Method TO-14. The Agency believes the method is well suited for routine monitoring of the more toxic and most prevalent organic solvents found in TRU mixed wastes. The method is capable of detecting the hazardous constituents targeted for quantitation with a sensitivity below 1 part per billion. Samples will be collected in pressurized six liter SUMMA® passivated stainless steel canisters. Sample storage stability has been demonstrated for a variety of volatile organic compounds with this type of container. Individual canisters are required to be certified clean and free of leaks prior to each usage. The method requires that all samplers, including pumps and valves, also be certified to ensure cleanliness and reliable sample recovery.

Samples will be analyzed by high-resolution gas chromatography, followed by full scanning mass spectrometry (GC/MS/SCAN) to provide the capability to identify a wide variety of volatile organic compounds. Cryogenic focusing can be used to concentrate samples as needed to meet analytical detection limits. The GC/MS analytical system is required to be certified clean with humidified zero air prior to sample analysis. Consistent with "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods" Method 8240 "Gas Chromatography/Mass Spectrometry for Volatile Organics" (EPA Publication SW-846, Third Edition), the Agency is proposing to require that an average response factor for each target analyte, as determined by a five-point instrument calibration, be used for quantitation. (Target analytes are the five constituents initially targeted plus any other constituents subsequently targeted for routine quantitation based on the criteria described previously.) In addition, the initial calibration and any subsequent recalibrations would be required to satisfy the criterion that any single response factor differ by no more than 25 percent from the average of the five. However, if it can be demonstrated that the instrument response is nonlinear, the initial calibration and any subsequent recalibrations would have to satisfy the criterion that any single response factor differ by no more than 25 percent from the expected value derived from regression analysis. For the purpose of investigating the presence of other volatile organic compounds, EPA proposes that a forward search of the National Bureau of Standards library of mass spectra be performed on each sample analyzed.

4. Quality Assurance and Quality Control

The Agency is proposing to require that standard operating procedures be adopted to ensure the validity of the monitoring data. These would cover a range of activities, including sampling and analysis certification procedures, instrument calibration checks, duplicate sampling, audit cylinder sampling, technical systems audits, and data quality audits.

All flow measurement instrumentation used in the calculation of exhaust shaft concentrations would have to be calibrated in accordance with EPA Reference Method 2 "Determination of Stack Velocity and Volumetric Flow Rate (Type S Pitot Tube)," Method 2A "Direct Measurements of Gas Volume Through Pipes and Small Ducts" (40 CFR part 60 appendix A), or an equivalent method approved by EPA. EPA is also proposing to require that the calibrations be performed quarterly due to the possible effect of salt aerosols in the repository environment on flow measurement instrumentation.

To ensure sample integrity, Method TO-14 requires that all sample canisters be cleaned, pressure tested, and certified with humidified zero air initially and following each sampling event prior to reuse. Method TO-14 also requires that all samplers (which includes pumps, valves, and peripheral equipment used for sampling) be removed from service for routine maintenance and be leak tested and certified with humidified zero air and humidified gas calibration standards. The monitoring plan submitted by DOE indicates that all samplers will be certified on a quarterly schedule.

Method TO-14 requires that GC/MS tuning be performed daily with 4-bromofluorobenzene to verify proper analytical system functioning, that instrument calibration be checked daily with a one point midrange humidified calibration gas standard for each targeted analyte, and that the GC/MS analytical system be certified clean with humidified zero air daily prior to sample analysis. Consistent with SW-846 Method 8240, the Agency is proposing to require that the instrument be recalibrated by a full five point calibration if the response factor from the calibration check differs by greater than 25 percent of the average or expected response factor. All gas calibration standards must be traceable to a National Bureau of Standards standard reference material or an EPA-approved certified reference material.

To ensure that constituents are capable of being detected with the necessary degree of sensitivity, the Agency is proposing to require that the method limit of quantitation be established for each target analyte prior to the initiation of the monitoring program and that it be reevaluated annually thereafter in accordance with the specifications in "Report on Minimum Criteria to Assure Data Quality" (EPA/530-SW-90-021, December 12, 1989). The Agency is further proposing to require that the method limit of quantitation be determined separately for the bin, alcove, and exhaust shaft monitoring locations due to the possible occurrence of differential matrix effects associated

[16] The Agency notes that most other volatile organic constituents found in TRU mixed wastes are listed as hazardous in 40 CFR part 261 because of their exhibiting the characteristic of ignitability rather than their being toxic. Such constituents are generally only hazardous when present at high concentrations.

with the presence of salt aerosols in the repository environment.

In addition to the implementation of canister and sampler certification and analytical calibration procedures, routine quality control procedures must be implemented to evaluate data accuracy, precision, and completeness. In order to evaluate the accuracy of the monitoring data, the Agency is proposing to require that recovery samples be collected from audit cylinders and analyzed at a frequency of 10 percent at each monitoring location. In order to evaluate the precision of the monitoring data, the Agency is also proposing to require that duplicate samples be collected and analyzed at a frequency of 10 percent at each monitoring location, including the exhaust shaft. In addition, the Agency is proposing to require that data completeness be evaluated by data validation audits at a frequency of not less than 5 percent. The Agency believes that data validation is an essential part of the monitoring program and that the proposed audit frequency represents an adequate but not burdensome level of quality control. To ensure that any sampling and analysis problems which may occur are detected and corrected, accuracy, precision, and completeness would have to be tracked and evaluated after every 20 quality control analyses.

DOE's monitoring plan indicates that a systems audit will be conducted at the start of the monitoring program. The Agency is proposing to require that systems audits be performed not only prior to the initiation of the monitoring program but also semi-annually thereafter to be consistent with good operating practice. In addition, corrective action must be taken whenever a condition or practice is found which is outside system specifications or standard operating procedures, or which could reasonably be expected to compromise the ability of the monitoring program to meet established quality assurance objectives for data acceptability.

The Agency is also proposing to establish specific quality assurance objectives for data acceptability for the WIPP air monitoring program consistent with method capability and good operating practice. DOE has raised concerns regarding the establishment of specific quality assurance objectives due to the presence of salt aerosols in the underground repository environment. EPA believes that regular maintenance of sampling equipment will adequately address sampling and analysis difficulties imposed by the repository environment. The Agency believes the following quality assurance objectives are achievable: plus or minus 10 percent for relative accuracy as indicated by the relative difference between the measured concentration recovered from a sampler and the known concentration of the targeted analyte in the audit gas cylinder; 15 percent for precision as indicated by the relative difference between field duplicate samples; 90 percent for data completeness as adjusted statistically to account for the results of data validation audits; and 0.5 part per billion by volume for method limit of quantitation or one fifth of any established health-based level for a targeted constituent, whichever is greater. The Agency is therefore proposing to require these as quality assurance objectives for data acceptability and to require that corrective action be taken whenever these objectives are not being met.[16]

5. Reporting

If during the course of the monitoring program migration above health-based levels of any hazardous constituent is detected, DOE is required under 40 CFR 268.6(f)(2) to notify the Administrator in writing within 10 days. To determine whether migration has occurred (i.e., any of the targeted constituents exceed health-based levels at the unit boundary), the Agency is proposing that concentrations be averaged over an annual time period. This is consistent with the approach the Agency is taking in providing guidance to other parties submitting no-migration petitions to the Agency. The Agency believes that concentrations should be averaged over an annual time period because the health-based levels are derived by assuming chronic or lifetime exposures. The Agency is further proposing that the incremental contribution from the land disposal unit, over and above measured background levels at the site, be used in making the determination. The Agency does not believe that background levels should be a reason for the Agency to deny or revoke the variance proposed in today's notice.[17]

In order that the Agency be notified at the earliest possible time of any likelihood that migration is occurring, the Agency is proposing to require that DOE notify the Administrator in writing within 10 days if during any three-month period the average concentration of any hazardous constituent measured or calculated in the exhaust shaft over and above background levels exceeds a health-based level established by the Agency. In addition, the Agency is proposing to require the submittal of annual data summaries and summaries of data accuracy, precision, and completeness at each monitoring location, together with calculated concentrations at the exhaust shaft and documentation of the actual method limit of detection achieved for each targeted analyte. These data would have to be submitted to the Chief, Technical Assessment Branch, Characterization and Assessment Division, Office of Solid Waste, U.S. Environmental Protection Agency. In addition, documentation on all aspects of quality assurance and quality control as described in "Report on Minimum Criteria to Assure Data Quality" [EPA/530-SW-90-021, December 12, 1989] must be maintained in the WIPP facility operating record and be available for inspection by the Agency.

L. Performance Assessment

A primary objective of the test phase is to demonstrate compliance with the applicable standards that would govern long-term disposal of TRU wastes in the WIPP. These standards will include 40 CFR part 191 for disposal of the radioactive wastes and 40 CFR 268.6 to demonstrate no migration of the chemical hazardous constituents of the TRU mixed waste. The process through which DOE will investigate compliance with these standards is called performance assessment. This will consist of an analysis of all aspects of repository performance under all conditions of interest as well as experiments to collect data and verify models used in the analyses. The analytical and experimental processes will be coordinated to arrive at predictions of repository performance.

During the test phase, DOE has an extensive and varied series of experiments planned. For example, the test plan contains 66 different categories of supporting activities for the

[16] DOE has recently submitted data from an experimental study designed to address the question of what quality assurance objectives can be achieved in the underground repository environment (see Research Triangle Institute, Analysis of Very Volatile Organic Compounds in Canisters from the Waste Isolation Pilot Plant, March 20, 1990). Because the experimental data were submitted very recently, the Agency has not had the time to evaluate it. However, EPA will evaluate these data in comparison to the proposed quality assurance objectives in today's notice. The Agency solicits public comment on DOE's experimental study results, and on what specific quality assurance objectives EPA should require DOE to meet.

[17] As described previously, DOE plans to perform monitoring of background levels in the main air intake shaft.

performance assessment, of which 30 involve in-situ experiments of different types. These experiments will include measurements to better define the characteristics of the surrounding geology, as well as studies of the performance of each component of the repository system (e.g., seals, backfill, etc.). Most of these activities involve experiments that do not use radioactive wastes.

One of the major areas of uncertainty to be addressed during the test phase, however, is the amount of gas that may be generated from the waste proposed for disposal at the WIPP. Gas will primarily be generated by corrosion of the waste containers, microbial decomposition of the waste and radiolysis of the waste. Gas generation is important because the amount of gas generated could affect the way in which the repository reconsolidates over time, and the amount of brine that may flow into the repository. Too much gas generation could even lead to extra fracturing in the surrounding geologic media and could create pathways for waste migration.

DOE plans to conduct several types of gas-generation experiments in the underground repository. One series of tests would use instrumented metal bins containing specially-prepared transuranic wastes and various combinations of backfill, brine, and gas getter materials. These bin-scale experiments are to be conducted in three phases. Phase 1 will involve approximately 48 waste-filled bins of different waste compositions and backfills. Phase 2 will incorporate another 68 bins with more moisture conditions, gas-getter materials and supercompacted high-organic and low-organic wastes. The details of Phase 3 of the bin-scale tests will be defined later. DOE, however, anticipates that these tests will be based on new developments, the results of Phases 1 and 2, and future data needs.

In addition to underground bin-scale tests, the DOE test plan proposes underground alcove tests with TRU wastes. A test alcove is a room mined in the salt with one blind end and one open end sealed with a leak-tight closure plug. Each of the six planned alcoves is approximately 100 feet long, 25 feet wide, and 13 feet high. A total of 3,650 drums of TRU wastes will be emplaced in five of the six alcoves; one alcove will be left empty to provide gas reference baseline data. These tests will continue until the data acquired are sufficient to provide confidence in the reliability of the information being obtained.

DOE will also study modifications to the backfill material, repository design, and the wastes that may reduce the gas generation problem. Types of modifications to be considered will include waste compaction, waste processing (e.g., incineration or immobilization), modifying the storage room or panel configuration, and other changes in the WIPP design, such as modified seals. DOE has established an Engineered Alternatives Task Force to evaluate such potential modifications. Whenever feasible, modifications that appear beneficial will be included in the test program so that their effects on gas generation and repository performance can be measured. (Some of these modifications will not have a direct bearing on gas generation, but will affect other aspects of repository performance, such as brine inflow, that may affect potential releases of waste from the respository).

At the end of the test phase, DOE expects to be in a position to predict the amounts of gas generated by different combinations of waste forms, container materials, and repository design steps such as gas getters, backfill modifications, etc. The effects of gas generation on long-term repository performance will then be predicted by analytical models, with validation of certain aspects of these models by in-situ testing. The net result of all of these activities will be recommendations about the appropriate waste forms and repository design to use for the WIPP, or even whether the WIPP is appropriate to use for permanent disposal of transuranic wastes. These recommendations will be based in part upon comparisons with the various EPA standards for radioactive and hazardous wastes.

The Agency believes that gas generation and its effects are significant questions that need to be better understood before a decision can be made as to the use of WIPP as a permanent repository. The Agency believes that DOE has laid out a reasonable approach for defining the amount of gas that should be generated by different combinations of waste and engineering controls. Perhaps the most difficult part of the problem is predicting the effects of different levels of gas generation on long-term repository performance. In its comments on DOE's test plan, the Agency has requested that DOE publish, as soon as possible, a summary of its models, describing the effects of gas generation, and more information about its plans to validate these models. DOE has agreed to develop a summary of the current status of its performance assessment, scheduled for June 1990.

In addition, DOE plans to develop annual "consequence analysis reports" throughout the test program to document the project's progress, and it has agreed to give periodic briefings on the project to EPA, the National Academy of Sciences WIPP Panel, the State of New Mexico, and the Environmental Evaluation Group (EEG) (an organization established by act of Congress to provide an independent technical evaluation of the WIPP). To ensure that EPA is adequately informed of the progress of the test phase, EPA is proposing to require that DOE provide annual reports describing tests conducted to date (including results), modifications to the test plan, and a summary of DOE's understanding of the repository performance.

V. Conditions of Proposed Variance

As a condition of granting this proposed variance from the land disposal restriction requirements, EPA is proposing that the following conditions be met by DOE:

(1) No wastes subject to this variance may be placed in the WIPP repository for purposes other than testing or experimentation to determine the long-term viability of the WIPP. In accordance with 40 CFR 268.6(e), EPA must be notified before DOE conducts any testing or experimentation not within the scope of the "Draft Final Plan For the Waste Isolation Pilot Plant Test Phase: Performance Assessment" (December 1989, DOE WIPP 89-011). Placement of waste for the primary purpose of conducting an operations demonstration is prohibited under this variance.

(2) All wastes placed in the WIPP under this variance must be removed if DOE's Performance Assessment cannot demonstrate compliance with the standards of 40 CFR 268.6 with respect to permanent disposal of mixed waste in the repository. Hazardous wastes removed from the WIPP must be handled in accordance with RCRA subtitle C requirements. (A condition of 40 CFR 268.6(a)(5) is in compliance with other applicable Federal, State and local laws. Therefore, removal will also be required under this variance if DOE cannot comply with 40 CFR part 191 standards for the disposal of radioactive materials.)

(3) All wastes placed in the WIPP under this variance must be placed in a readily retrievable manner, as described in section IV.D of this notice.

(4) DOE must provide to the EPA Office of Solid Waste annual written reports on the status of DOE's performance assessment during the test

phase. These reports must include: a description of the tests to date and their results, modifications to the test plan, a summary of DOE's current understanding of the repository's performance, and an annual summary of air monitoring data required in item 6 below.

(5) DOE must install and operate a carbon adsorption control device designed to achieve a control efficiency of 95 percent in the discharge system of the bin experiment rooms. DOE must monitor the control device outlet airstream in accordance with the monitoring plan described in section IV.K of today's notice, and it must maintain design and operating records as described in section IV.J.

(6) DOE must implement the air monitoring plan described in section IV.K.

(7) Before placing waste in the repository, DOE must certify to EPA that it has secured control of the entire surface and subsurface estate at the WIPP site.

(8) DOE must provide to EPA the results of detailed waste characterization and analyses performed on the waste to be emplaced in the WIPP during the test phase.

Beyond these specific conditions, the wastes placed by DOE in the WIPP and DOE's activities under this variance must be consistent with those described in the petition. Under § 268.6(e), DOE must notify EPA of "any changes in conditions at the unit and/or environment that significantly depart from the conditions described in the variance and affect the potential for migration of hazardous constituents from the unit * * *." If the change is planned, EPA must be notified in writing 30 days in advance of the change; if it is unplanned, EPA must be notified with in ten days.

Under § 268.6(f), if DOE determines that there has been migration of hazardous constituents from the repository in violation of part 268, it must suspend receipt of restricted wastes at the unit and notify EPA within ten days of the determination. Within 60 days, EPA is required to determine whether DOE can continue to receive prohibited waste in the unit and whether the variance should be revoked.

Finally, under § 268.6(h), the term of today's proposed variance would run for ten years from the date of approval.

Dated: April 2, 1990.

Don R. Clay,

Assistant Administrator for Solid Waste and Emergency Response.

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